Co-Located Many-Player Gaming on Large High-Resolution Displays

David A. Machaj

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Dr. Chris L. North, Chair
Dr. Doug A. Bowman
Dr. Yong Cao

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David A. Machaj

Abstract

Two primary types of multiplayer gaming have emerged over the years. The first type involves co-located players on a shared display, and typically caps at four players. The second type of gaming provides a single display for each player. This type scales well beyond four players, but places no requirement on co-location. This paper will attempt to combine the best of both worlds via high-resolution, highly-multiplayer gaming.

Over the past few years, there has been a rise in the number of extremely high-resolution, tiled displays. These displays provide an enormous amount of screen space to work with. This space was used to allow twelve co-located players to play a game together.

This study accomplishes three things: we designed and built PyBomber, a high-resolution and highly multiplayer game for up to twelve players; secondly, user trials were conducted to see whether this type of gaming is enjoyable as well as to learn what sorts of social interactions take place amongst so many players; lastly, the lessons learned were generalized into design criteria for future high-resolution games.

Results show that with more people, much more of the time during a game was filled with vocal interactions between players. There were also more physical movements in the larger games.

Over the course of this study, we learned that good high-resolution games will: decide between a singular gameplay area and split views, use the physical space in front of the display, provide feedback that is localized to each player, and utilize input devices appropriately.

Dedication

I would like to dedicate this thesis to the late Vincent R. Machaj. You may be gone, but you will never be forgotten.

Acknowledgements

I would like to begin by thanking Dr. Chris North, my graduate advisor. He has been guiding me since I began doing research. His input and recommendations have been invaluable towards my progress both in my research and in my studies overall. Without him, I would have lost sight of the big picture long ago.

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Chapter 1: Introduction

1.1 Motivation

Multiplayer gaming has evolved considerably over the years. However, two primary types of multiplayer gaming have emerged. The first type involves co-located players and a single, shared display. This type of gaming has historically had a cap of four players. The second type of gaming provides a single display for each player. This type of gaming scales well beyond four players, but places no requirement on co-location. This paper discusses work that attempts to combine the best of both worlds, in the process creating many-player gaming. A many-player game is one in which more than four co-located players share a single display.

The catalyst enabling this new type of gaming is the rise of large, high-resolution displays. While still far from mainstream, the use of multiple high-resolution displays is becoming increasingly common. The reason why older co-located games have stuck to four players is one of space. A television provides only so much screen space to work with. However, when the GigaPixel is considered, that is no longer a concern.

This larger space allows for the expansion of the gameplay area, not just in the virtual sense but also in a physical one. There are two dimensions to the increased physical space. The first of these is the large dimensions of the screen, allowing many more players and game objects to coexist with full fidelity. The second dimension is the large open space that is typically present in front of such a large display to allow physical navigation.

This open space creates numerous possibilities for both game design and for the interaction amongst players in a game. They are now able to move around both in the game sense as well as in a physical one. Players will also get in each others' way, either by accident or on purpose. How they react to this stimulus, if at all, is something that this thesis attempts to study.

This space also opens the door to incorporating physical actions into the game itself, similar to the trend that has begun with the Nintendo Wii. Rather than using physical actions to manipulate the game state directly, these actions would complement the game. The physical actions would be a distinct part of the game.

The final motivation behind this is to study what sorts of group dynamics evolve when such a large number of players are playing together on a large display. A side-effect of scaling beyond the typical four-player, co-located games of the past is that larger groups may have different interactions and dynamics than smaller groups. This thesis hopes to find some evidence one way or the other.

Overall, this thesis is an exploratory study for a new area of research. It attempts to answer some of the fundamental questions about games on large, high-resolution displays with many players. These questions involve both the design of such games as well as player response to them.

1.2 Research Questions

There are three primary research questions that this thesis is based upon:

1. Is game design on a large display different from design on traditional displays?
    a. If so, what new types of gaming are possible?
    b. Are there any special design principles for high-resolution games?
2. Is co-located gaming on such a large scale enjoyable to players?
    a. If so is it superior to four-player games in any way?
3. What kinds of social interactions occur among so many players?
    a. Are they any different from those that take place with four players?
    b. Does team-based gameplay have an effect?

c. What types of verbal interactions take place between the players?

d. How do players move and physically interact in the physical space in front of the display?

1.3 Hypotheses

The corresponding hypotheses are as follows:

- Players will find that gaming on a high-resolution display is enjoyable. This will hold true both for the small condition (4-player) and the large condition (12-player). Due to the increase in social interaction, players will find the large game more enjoyable.
- A larger number of social interactions will take place between participants in the twelve-player version of the game. This will be true both for the total number of interactions and for the per capita number of interactions. The reason for this change will be the larger number of person-to-person avenues for communication, which scale far faster than the number of participants.
- In the team-based version of the game, more interactions will take place as players try to coordinate their actions.
- Players will make use of the physical space in front of the display to move around and physically interact with other players, since they are not able to do this with a normal video game.
- Game design on a large display has many commonalities with tradition game design. However, there will be new factors that need to be taken into account for success.

1.4 Summary

This thesis aims to describe a new type of multiplayer gaming. Chapter 2 will cover the literature that was reviewed prior to conducting the study. These papers served both as a guide for the design, but also as a base for the study itself. Chapter 3 will cover the design of the game in greater detail, providing rationale for many of the decisions that were made in the course of development. Chapter 4 serves to provide details on the experiment that was conducted in high-resolution gaming as well as the results from said experiment. Finally, Chapter 5 will wrap up the thesis by providing conclusions, lessons learned, and future work. The appendices contain statistical information as well as the forms that were used in the study itself.

Chapter 2: Literature Review

There is a limited amount of relevant literature on the specific topic of high-resolution multiplayer gaming. Therefore, the related literature was used more as a guide than a foundation.

2.1 High-Resolution Displays

Previous research in the field of high-resolution displays, especially of the tiled variety, has shown that performance on basic tasks is increased by a large amount when compared to ordinary display [1-4]. The larger volume of information on display is indeed taken advantage of by users. Also, by studying the way that people utilize such displays [5], it has been shown that physical navigation is much preferred over virtual navigation.

This knowledge is helpful to this study since one aspect that is being looked at is how people move and interact in the physical space. The indication from previous studies is that users will prefer to move around the display to gain better insight into a particular location. Due to the nature of the shared display and game area, virtual navigation is not present. However, physical navigation will be required to see the entire display at full detail. It has been shown in previous studies that when forced to navigate, 100% of users preferred physical navigation to virtual for several general types of tasks [6].

This is promising in the context of gaming since gameplay requires analysis of large amounts of information in some way. The high-resolution display provides a large gameplay area complete with a large amount of information to process. The implication taken from this study is that the increase in analysis ability will counteract the increase in complexity from having more players and more information present on the display.

Another interesting aspect of large high-resolution displays is that they become what are known as a "public artifacts" [7]. The takeaway from this is that the same information can be taken from a small screen, displayed on a large one, and it becomes public. Once the information is public, it is far more open to interactions since the barrier-to-entry of seeing its contents has been lowered drastically. This has indeed been the case with the GigaPixel display, where uninvolved people will see games on it and come over to watch and ask questions about what is going on.

An important area of research involving high-resolution displays concerns the interface to the machine. The traditional interaction techniques and feedback mechanisms do not always scale well to high resolution displays [8], for a variety of reasons. Researchers have implemented several different methods of interaction in an attempt to counteract this [9, 10].

2.2 CSCW

In collaborative systems, there is a broad split based on place and time, providing a 2x2 matrix [11]. The place is either the same for the users, or distributed. The collaboration either occurs at the same time, or at different times. In the context of this study, the same-time (synchronous) and same-place (co-located) collaborations are of greatest interest.

Previous work has explored both tabletop [12, 13] and wall [14, 15] displays, which are both co-located and synchronous. Some of this work has seen a tradeoff between the power of an individual and the awareness of the group as a whole [16]. In many ways this plays into the single, shared gameplay area that is explored in this study. This shared gameplay area trades some individual power, the ability of a player to virtually navigate, for maximized group awareness, since everyone can see everything.

2.3 Collaborative Games

Since a focus of this paper is on the interactions amongst the players of the game, existing literature on collaborative games was explored. These games may actually force players to work together. In one case, a shared virtual space was what forced the players to interact [17]. Several games were created using different design patterns to create the shared virtual space and make it meaningful to the game.

Collaborative games also exist wherein the shared resource is the computer itself [13]. In this study, multiple users collaborated on a game using a tabletop computer with speech- and gesture-based inputs. This paper shows a trend that the players were more engaged and entertained as opposed to when they played the games on a traditional computer.

The theories of aesthetic interaction [18] provide some evidence to support the importance of movement in social games. As an example, iGameFloor uses a high-resolution floor display as part of a co-located collaborative game [19]. In that study, both the social and physical interactions were vital to the success of the game as a whole. These physical-social interactions were regarded as enjoyable by the participants.

2.4 Game Development There is much that has been written on the topic of game design. One of the most widely-cited books was written in the 1980's by Chris Crawford [20]. Within this series of chapters, some of the fundamental aspects of game design are covered in considerable depth. The lessons are fundamental enough that they have not become dated with time. Other interesting and relevant literature covers the design of games in general [21], evaluation of video games [22], and the framework of pertinent courses that have been taught on this topic [23].

The frame rate of a game is vital to its playability. It has been shown that the frame rate of a game has a larger effect on user performance than even resolution [24]. A high frame rate is vital for a compelling and enjoyable experience, since any hiccups will increase user frustration and detract from their enjoyment.

In light of this information, the literature review for this paper extended to the topic of game engines [25]. This study greatly influenced the design of the game from a coding perspective. Another piece of the puzzle from the standpoint of game programming was looking into a framework to provide high-resolution graphics. It was decided, as described in greater detail later in this thesis, to use Chromium to display such high-resolution graphics on the GigaPixel [26].

2.5 High-Resolution Gaming

High-resolution games have been explored in a limited fashion at several universities. However, all of these studies have used preexisting games that were modified to run at higher resolutions. None of them were created explicitly for the high-resolution display, or tailored towards taking advantage of these displays in any meaningful way. Nonetheless, they provide useful information for the creation of such games.

One such example was a study that allowed several users to split up a large display and then use gestures to interact with it [27]. The games were used to help test the latency of their gesture-based input system. This paper provided insight into the latency problems associated with such a system and provided some good information on how they were able to modify open-source games to scale up to use such a large display.

The most relevant study to this thesis was conducted here at Virginia Tech [28]. This study involved high-resolution gaming compared to normal desktop computers, as can be seen in Figure 1. Matches were conducted between normal computers running a strategy game and the same game played across a high-resolution display. The findings were that players on the high-resolution display performed significantly better than those on the normal desktop computer.

Figure 1: One Monitor (640x480), four-monitor (1600x1200), and nine-monitor (2400x1800) variations.

A corollary to this finding was that users on the high-resolution display spent much less time navigating the world, since much more of it was visible at a time. There was a statistically significant link between the amount of time spent navigating and the win percentage of that player. This indirectly reinforces the earlier literature which demonstrated that users preferred, and performed better with, physical navigation.

2.6 Measuring "fun"

A fun experience can mean many things to many different people. Since fun is inherently a subjective experience, the measurement of it can be quite difficult.

Read et al [29] have attempted to objectively measure fun in children. Over the course of their work, they have created the "fun toolkit". The premise for their work breaks fun down into three parts: expectation, engagement, and endurability. Expectation can be measured by asking the players' how much fun they expect the game to be. They are then asked after the game how much fun they actually did have. The difference between these two values can be used to measure whether the experience lived up to their expectations. These values are measured using the "smileyometer" that was developed along with the fun toolkit, as seen in Figure 2.

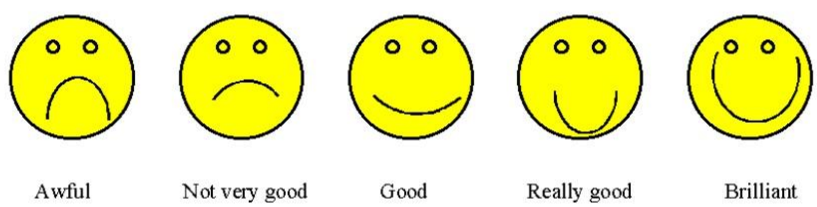


Figure 2: The "smilyometer" from the fun toolkit

The second measure is engagement. Read et al have described "instantiations" as verbal or nonverbal actions that reflect a person's true feelings while experiencing something. At least in children, these have been shown to be more accurate than actually asking them. An instantiation can be either positive or negative. An example of positive instantiations would be smiling, laughing, or explicitly stating enjoyment. Examples of negative would be a yawn or looking around the room. The final measure, endurability, is based on the principle that the more enjoyable an event is, the more likely someone is to remember it. This metric was measured in the fun toolkit using the "Again-again" table, which asks the participants whether they would like to repeat each of the measured events. A desire to repeat an event implies that the event was enjoyable.

The concept of Flow can also be applied to the measuring of enjoyment in a game since “most flow experiences occur with activities that are goal-directed, bounded by rules, and require mental energy and appropriate skills” [30, 31]. That description is a very good match for most types of video games. The metrics associated with GameFlow are based around expert review, in some ways limiting their applicability to many-player gaming.

To provide a continuous measure of enjoyment, it is possible to use physiological measures to model the emotional state of players [32]. This approach provides the ability to observe specific emotions, such as frustration, while the game is being played. Unfortunately, the physiological measures are impractical for many-player gaming due to the large amount of equipment required per player.

In the gaming industry, it is common to use focus groups to evaluate different aspects of a game [33]. However, focus groups are not the best instrument in many cases-- there are several alternatives that provide a different set of strengths and weaknesses [34]. User studies, in particular, are a good way to measure some of the factors that are being looked at in this study.

2.7 Summary

This thesis draws on several unrelated fields of research to study something new. The benefits of high-resolution displays have been known for some time now; it is simply a matter of testing whether they extend to the gaming world. Gaming has been studied as well, and some of this knowledge has been drawn upon to help create a more entertaining experience for the players. Lastly, the measurement of fun is a difficult area that virtually requires building upon previous work to create a good series of metrics. When combined, these pieces of knowledge have laid a solid foundation for the research that follows.

Chapter 3: Design

3.1 Design Space

Due to the exploratory nature of this study, no pre-existing game existed that would fulfill all of the requirements imposed upon it. These requirements include: good performance on high-resolution displays, support for many (12+) players, optional team-based gameplay, and ease of modification. A new game, PyBomber, was created to fit this mold.

3.2 High-Level Design

3.2.1 High-Resolution Displays and Gameplay Area

One of the first questions that need to be asked when designing a game is whether it should be two-dimensional (2D) or three-dimensional (3D) in nature. This is true for any game, high-resolution or not. However, in high-resolution and multiplayer situations, there are specific benefits to choosing a 2D game.

3D games typically involve a player controlling a camera with a viewing frustum. The issue with a frustum is that it is exclusive to a particular player. This greatly inhibits the maximum number of players that can be supported on a display. Since a frustum is tied to a player's field of view, the addition of more pixels will not provide any additional information without altering the frustum itself. This was demonstrated when Quake 3 Arena was modified to run on the GigaPixel Display in a previous study. As can be seen in Figure 3, there is no more information or gameplay area as compared to playing on a single monitor.

To counteract this, it is possible to split up a high-resolution display into multiple viewing frustums, allowing multiple views simultaneously. This could allow multiple players to participate in a 3D game on a high-resolution display. However, each player would be fixed to a particular frustum and would only be viewing a small portion of the display. This would negate some of the benefits of the large high-resolution display since each participant would only be using a subsection.

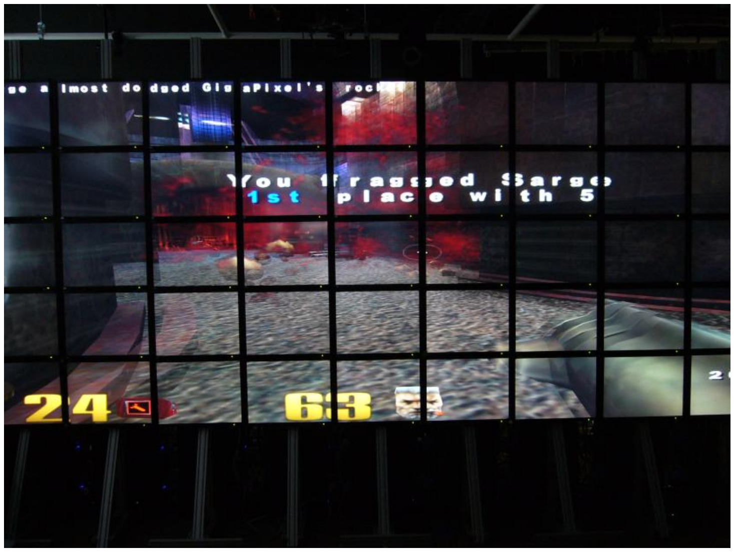


Figure 3: Quake 3 being played on the GigaPixel display

These issues segue into 2D game design. Since current computer screens are inherently two-dimensional in nature, adding more resolution has a direct effect on the gameplay area. Utilization of this increased play area provides the ability to attempt a previously un-attempted type of game: highly-multiplayer.

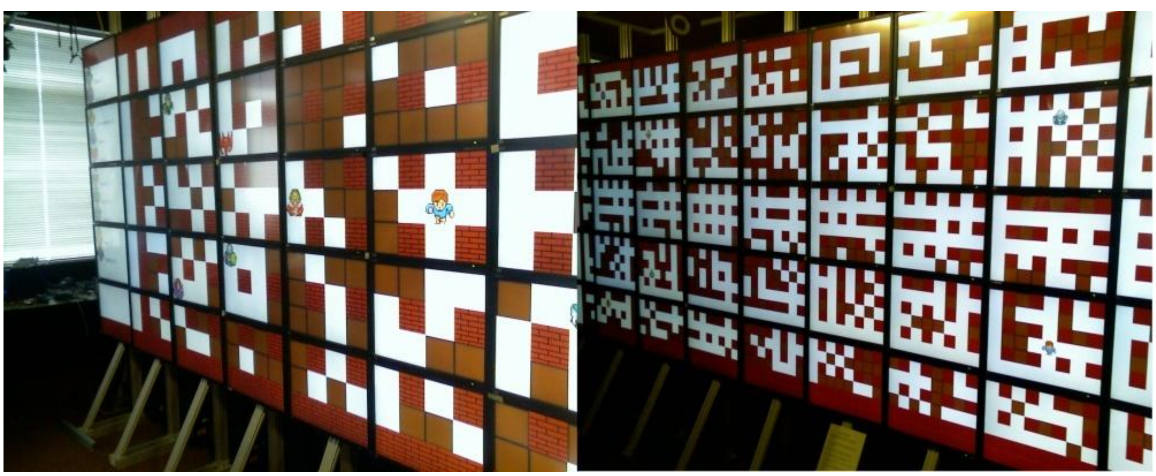


Figure 4: lower-resolution (4000x1500) and higher-resolution (8000x3000) versions

A secondary benefit from a uniform 2D play area is that it is also shared amongst all the players. This sidesteps all of the problems with virtual navigation and turns the large display into a public artifact [7].

3.2.2 Cluster Rendering

The GigaPixel display is a computing cluster based around twenty-five computers, each of which output to two monitors. This provides a total of fifty monitors, each of which runs at a resolution of 1600x1200. When combined, the total resolution of the display is 16000x6000 or 96 megapixels. Each of the machines in the rendering cluster runs Fedora Core 5.

In order to render graphics for such a large display, it is necessary to split the workload and render as a cluster. There are several broad approaches to this problem, each with its own strengths and weaknesses. Some previous work on high-resolution gaming has used other methods [27]. However, in this case Chromium was used to provide distributed rendering [26].

The primary benefit of Chromium is its simplicity. Applications require no knowledge of the distributed rendering. All cluster rendering is handled transparently. The drawbacks associated with Chromium are its incomplete implementation of OpenGL and fairly low performance. Neither of these issues posed a significant problem for PyBomber.

3.2.3 Player Input

A fundamental issue in any game is how to get input from the players. This is even truer in high resolution and highly-multiplayer environments. Nintendo Wii Remotes were used with PyBomber for several reasons. These reasons include: wireless, low cost, familiarity, and having pre-existing software libraries.

The wireless nature of Wii Remotes is critical in highly-multiplayer situations. This is because cords are typically too short to be used across such a large physical space. Also, with so many players the tripping hazard associated with the cords would be large.

Wii Remotes also have the secondary benefit of being low cost. This is important since a dozen of them are required to play a full multiplayer session. The form factor of a Wii Remote is useful in that it is similar to most other controllers and should provide a fair degree of familiarity to players. The final benefit of Wii Remotes is that they already have numerous open-source libraries that facilitate their inclusion into games on a normal computer.

The pre-existing CWiid library for Linux is the interface between PyBomber and the Wii Remotes. CWiid operates by mapping button presses on a Wii Remote to key presses on the machine that it is connected to. Each player in the game needs six buttons in order to play (up, down, left, right, plant bomb, and detonate). A typical keyboard has enough keys to support about ten players.

A client/server architecture was developed to distribute input events over TCP/IP. This architecture allowed the use of multiple machines to overcome the limitation many Bluetooth receivers have on how many devices they can connect to simultaneously. This allowed PyBomber to scale up to the point where it could support input for twelve players at the same time.

3.2.4 The Game Mechanics

PyBomber is based, in part, on a previously successful game franchise: Bomberman. This franchise has spawned numerous and sequels throughout the years. This implies that the fundamental game mechanics of it are enjoyable. These mechanics were used as a guide to create the rich gameplay of PyBomber. This was done to minimize the risk of creating a game around flawed and non-fun game mechanics.

3.3 Construction

PyBomber was created using an iterative design process. It ended up taking several phases of iteration to transform from a basic game with limited logic to the final product with twelve players on the GigaPixel display. The phases are outlined below.

3.3.1 The Beginning Phase

The first stage involved the creation of the basic game on a single, traditional computer. The code for the game was written in Python. This language was chosen for several reasons. The first of which is that it is known for its ease of use and rapid prototyping. The second reason was the PyGame library, which was used extensively in the early prototypes. Lastly, Python is known to be functional on the existing GigaPixel display setup.

The result of this phase is a game that had all of the basic logic and ran well on a single Linux desktop. All rendering was done in software, and many debugging hooks were still present in the code. However, at this point in time the gameplay was tweaked to provide a compelling experience on a traditional computer. A good sign of progress was several graduate students and a professor playing a four-player variant on a laptop and losing track of two hours without realizing it.

3.3.2 High-Resolution and Performance

The second phase of game development involved getting the game running with acceptable performance on the GigaPixel display. 96,000,000 pixels require a lot of data, and the code underwent some serious changes in the name of performance – the python profiler was an invaluable tool in this stage. As seen in the literature, frame rate has an enormous effect on player experience [24].

An example of the significant change that took place was the switch from software rendering to hardware accelerated rendering via OpenGL. This change alone increased the frame rate from less than one to roughly twenty frames per second.

This example highlights one of the best qualities of Python code: the ability to quickly write correct code and then switch in compiled code for performance. Several key bottlenecks in PyBomber were reworked to take advantage of the speed of compiled code. These areas saw enormous performance improvements without impacting the rest of the game code. The result of this phase was a version of PyBomber that ran equally well on large and small displays.

3.4 User Testing

A series of informal demos and trials were run to garner some feedback that was used to improve the game further. The basis for most of the shortcomings involved the cognitive distance being too large, especially the gulf of evaluation [35]. This large gulf led to an excessive cognitive requirement for players of the game. The following section contains some of the more significant changes that were made to address player feedback.

3.4.1 "Who is that?"

One of the most obvious issues in early versions of the game was the use of generic sprites to represent the players. Since no artists were involved in the creation of PyBomber, public domain sprites were used as the game art. This decision came with a drawback: nobody knew who anyone else was in the game. This issue came to the forefront due to the co-located nature of the game.

As the number of players present in a game expands, each player needs to remember a larger number of image-to-person mappings in their head. This represents an expanded gulf of evaluation. However, it was quickly discovered that with ten players or more players, the gulf was just too large.

The change to the game that addressed this issue was the inclusion of player photos. Before each trial, every participant's face was photographed in front of a green background. A script was then run to turn the green background invisible and then save the resulting image in a format that PyBomber understood. The difference can easily be seen in Figure 5.

Figure 5: The difference between a player photo and a public domain sprite

The result of this change was that everyone played the game as themselves, in more than one sense. It became instantly obvious which person was taking which action, since their face was visible in the game. The gulf of evaluation was reduced drastically, largely solving the problem of image-to-person mappings.

3.4.2 Sounds

One shortcoming of the initial game that not many people realized, but everyone experienced, was the lack of sound in the initial version of PyBomber. Sounds in a game are not something that typically gets the players' full attention. However, that does not make them any less important than other aspects of the game.

The change to the game based on this feedback was the addition of explosion sounds when a bomb is detonated. As basic a change as it is, more people commented on this addition than any other change. Instantly, the participants reported that the game felt more fun. The takeaway from this is that sound really is that important.

3.4.3 Previews

A common request throughout the early life of PyBomber was the ability to tell how large of an explosion each bomb would have. Players often struggled with the power-up that increased the size of the explosions generated by their bombs (described in greater detail in chapter 4). The reason for this is that they would need to use their head keep track of how many power-ups they had picked up. On the occasions where they forgot or were not paying attention, they could easily kill themselves with an unexpectedly large explosion.

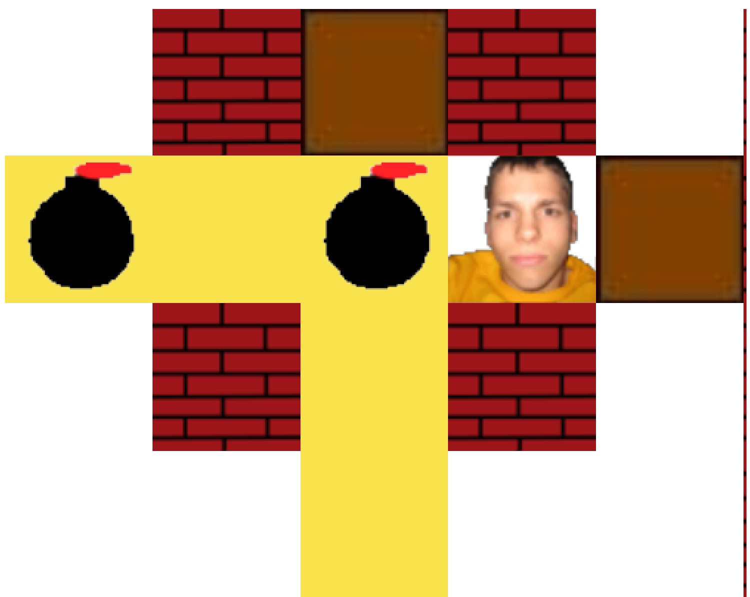


Figure 6: The bomb previews clearly indicate the radius of an explosion

The modification that was made to address this issue was the inclusion of previews when a bomb was planted, as seen in Figure 6. These previews were a light yellow background that filled the entire area that would be covered by that bomb when detonated. Once this change was made, it became obvious to the players how powerful their bombs really were. This change feeds back into the common theme of increasing feedback for the players by increasing the amount of information presented to them in an easy-to-understand fashion, thereby reducing the gulf of evaluation.

3.4.4 Respawning

A critical issue that was wrestled with throughout the life of PyBomber is that of respawns. This seemingly minor issue in fact has an enormous effect on how the game is played. The original version of the game was structured as last man standing. In this mode, every player has a single life and once they died they would stay dead. The last player who was alive at the end of the round was the victor.

However, there is a critical flaw with last man standing. Players who die early in the round are stuck waiting until the next round begins. A common side effect of this waiting is that players will lose interest in the game. Also, the frustration level from mistakes is significantly higher when the penalty for failure is so high.

Several approaches to solving this problem were attempted. All approaches were based on the ability of players to respawn. This shifted the endgame condition from last-man-standing to a time-based one. The goal changed from just staying alive to getting the highest score. The primary differences between the approaches involved the location where a player would respawn.

The first approach to respawns was to have players come back at target sites that were randomly generated and then checked for viability. If a site was rejected then another one was created and the process continued. A site would be rejected if it was too close to another player, bombs, or was completely boxed in. .The drawback to this approach was that the gulf of evaluation was far too large. Players had no idea where they respawned, or even when it happened.

A second approach was to remember where each player began the round and then respawn them in that spot every single time. This largely solved the problem of a player not knowing where they respawned. However, it indirectly discouraged players from moving around the gameplay area. This was because every time that they died, they would start over in the same place, negating their movement.

The third approach, as seen in the final version of PyBomber, was to keep track of where a player died and to respawn them there. This allowed players to keep active throughout the duration of the game, and encouraged them to move around the gameplay area. Any progress they made towards a certain place or person was maintained even after death.

3.4.5 Invincibility

The issue of player invincibility was not something that was based on direct player feedback. Rather, it was based on observation of gameplay. An issue was noticed that detracted from the game for some players. This issue was "spawn camping". Spawn camping is when a player plants bombs in a location knowing that a player will respawn within the radius of said bomb. This abuse prevents the respawning player from taking any action before being killed again.

To counteract the problem of spawn camping, invincibility was added to the game. The way it works is that when a player respawns, they are invincible for several seconds or until they plant a bomb, whichever comes first. This prevents a player from being victimized while preventing the more aggressive players from using invincibility for an unfair advantage against others.

Figure 7: A player is invincible (red) after respawning

An important consideration is whether a player even realizes that they are invincible. Early versions of invincibility provided no feedback as to their status. The approach used to solve this problem is the tinting of the background behind a player to a bright shade of red, as can be seen in Figure 7.

3.4.6 Sudden Death

The original version of PyBomber provided no warning of the impending end of a given round. Players would be actively playing and suddenly the game would finish. At this point "Game Over" would appear in giant letters across the screen.

After numerous piece of feedback from players, it was deemed necessary to provide some sort of warning that a round was about to end. Again, this reinforces the point that players of a game need to be informed about what is happening. The alteration made to PyBomber was the addition of "Sudden Death" mode. This is triggered in the final twenty seconds of a round. Once it is triggered, the background color is changed from the typical white to an aggressive shade of red (Figure 8). This makes it obvious to everyone involved that something important is happening – the end of the game.

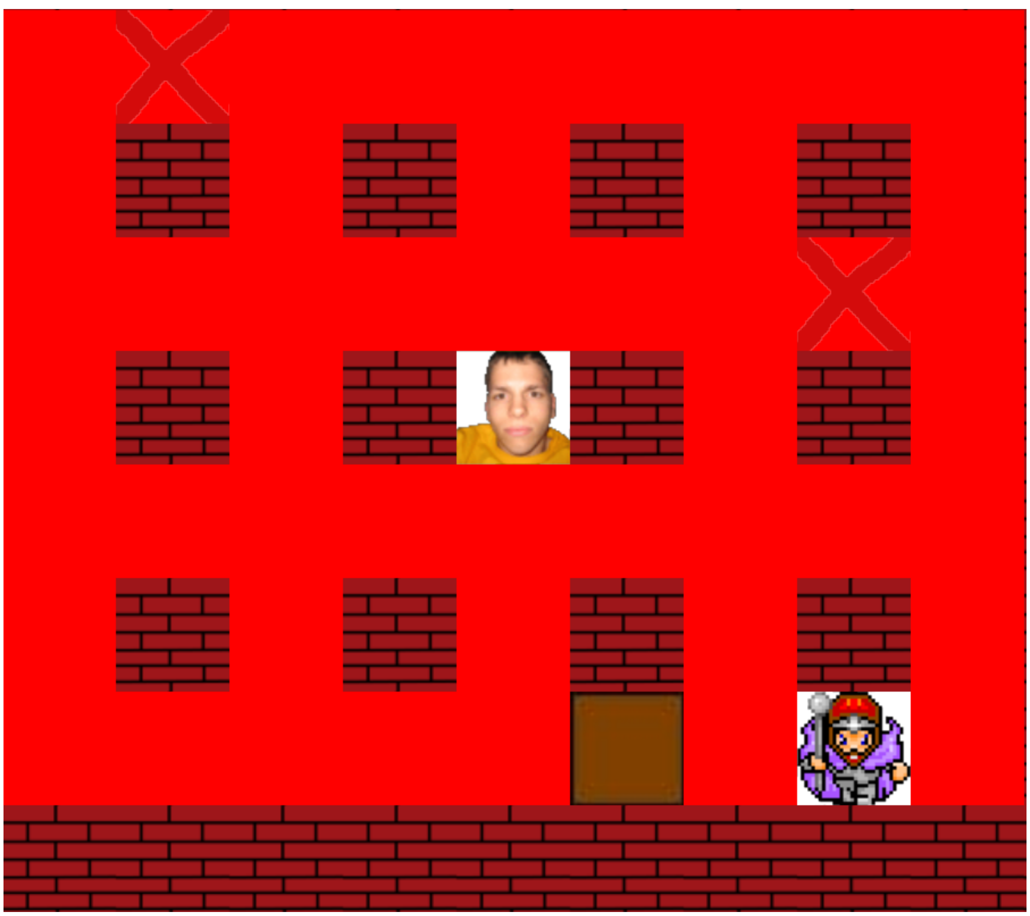


Figure 8: Sudden death has been triggered as a round nears its end

3.4.7 Early Endings

A round of play in PyBomber is limited to five minutes in duration. However, it was discovered early in play-testing that it was possible for rounds to become boring as the round continued on. The reason for this boredom was that all of the exhaustible game objects would have been used up. At this point, the unpredictability of gameplay would decrease significantly, and with it went the player's interest.

In order to combat this issue, the concept of early endings was introduced. This concept allows a round to end before the five minute timeout if a certain condition is met. Every round plays out differently, so a dynamic measure was needed to provide the most reasonable early ending. The early ending condition in PyBomber is when 90% of the combustible blocks (described in chapter 4) have been destroyed.

3.5 Summary

The lessons learned throughout the design process fall into two categories of relevance: those for all games, and those for high-resolution games. The lessons learned in the context of all games typically revolved around a large cognitive distance [35]. The problem was usually an excessively large gulf of evaluation. The solutions to these problems were simply to provide better feedback, although exactly how to do that is non-trivial.

The lessons learned for high-resolution games are more interesting. The typical pattern for these lessons was that some of the assumptions made in traditional games do not hold true for high-resolution games. An example of this would be the player images in the game. In a typical four-player game, it is trivial to keep track of which player corresponds to which image. However, with a dozen players this becomes very difficult and very frustrating.

Chapter 4: The Game

4.1 Basic Gameplay

The goal of PyBomber is for a player to blow up as many other players as possible, while minimizing the number of times he or she is blown up. The basic mechanic of the game is that a player can press a button to plant a bomb. A second button detonates that bomb. Anyone caught in the explosion, including the player who planted the bomb, will be killed. Players are able to move in the four cardinal directions. There are walls that create an even grid and funnel the explosions of bombs along straight lines.

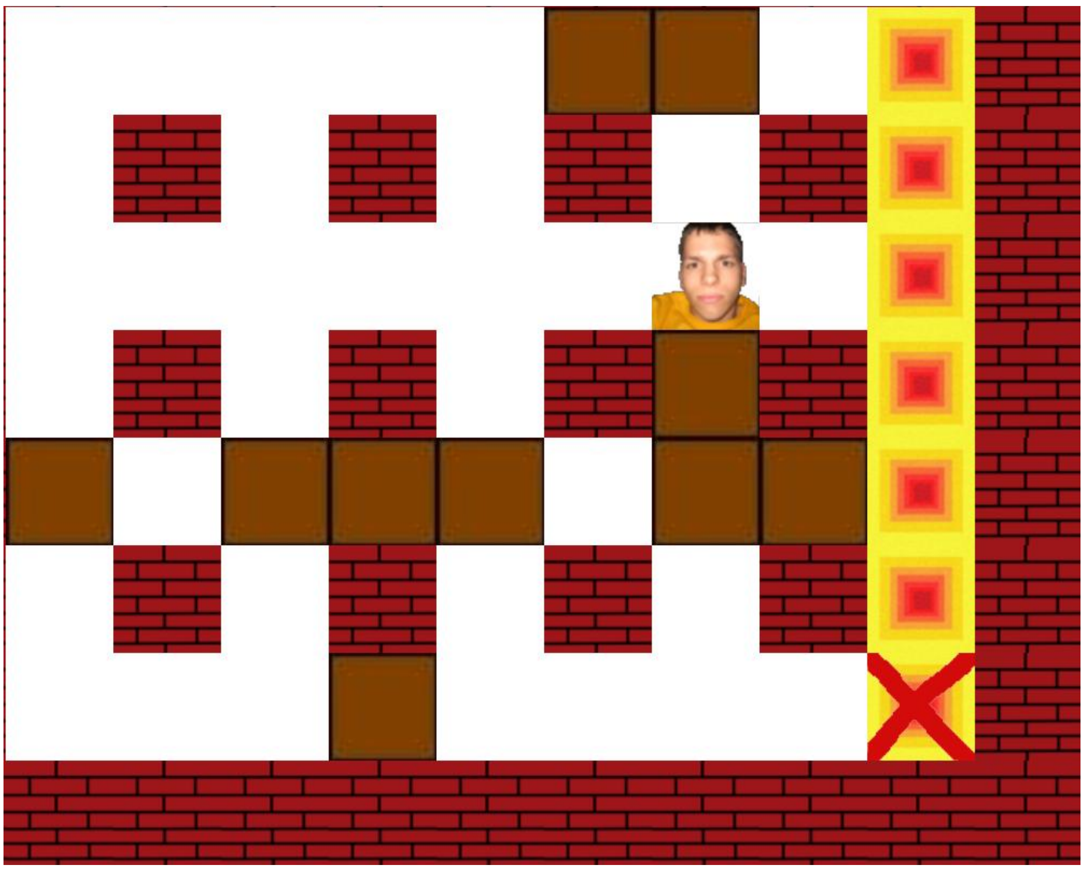


Figure 9: A player has used a bomb to kill another player. The explosion has been funneled by the walls into a line.

Players score one point each time that they kill another player. Players lose a single point every time they kill themselves. When the game is being played in team mode, killing a teammate also costs a player a single point. All scores are displayed along the sides of the screen, sorted from highest to lowest.

At the start of the game, a significant portion of the gameplay area is filled with brown blocks. These blocks serve two purposes. The first purpose is to create an unpredictable gameplay area. The second purpose of the blocks is to provide powerups. When hit by an explosion, a block is destroyed, stops the explosion, and sometimes provides a powerup to the player.

Whenever a player is killed, they leave behind a gravestone. This is represented in the game as a bright red X. The graves stay in place until the round ends, providing a high-level overview of where the majority of the action is taking place.

4.2 Powerups

There are two types of powerups: the ability to plant an extra bomb (Figure 10) and increased radius (Figure 11). The radius powerup increases the explosion radius of all bombs planted by that player by one tile. The starting radius is one tile in each direction.

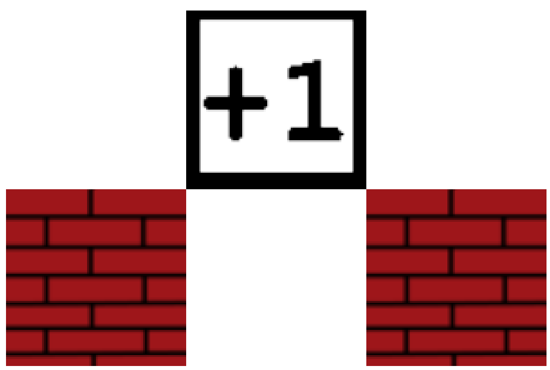


Figure 10: The extra bomb powerup

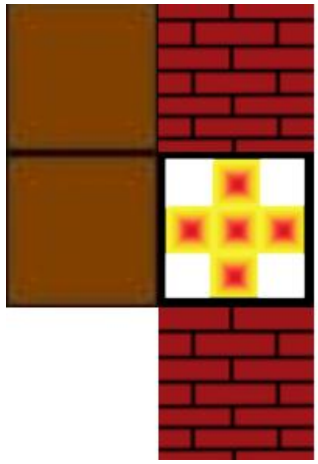


Figure 11: The increased radius powerup

At the beginning of a round, all players have a single bomb that they can plant. Once they plant that bomb, they cannot plant another until it is detonated somehow. The extra bomb powerup allows a player to deploy a second bomb concurrently.

There is no limit to the number of each powerup that a player can pick up. However, every time that a player dies, they lose half of their powerups.

4.3 Teams

PyBomber can be played in two different configurations: team and non-team. The non-team variant of the game pits every player against every other player. In this version of the game each player is displayed with no tinting of any kind. All scores are kept individually.

In the team variant of PyBomber, the players are split up into two equally-sized teams: blue and green. All of the players on a given team have their player image tinted to reflect their team color (Figure 12). As noted earlier, players lose points for killing teammates. The total of all scores on a team is computed and displayed at all times along both sides of the screen.

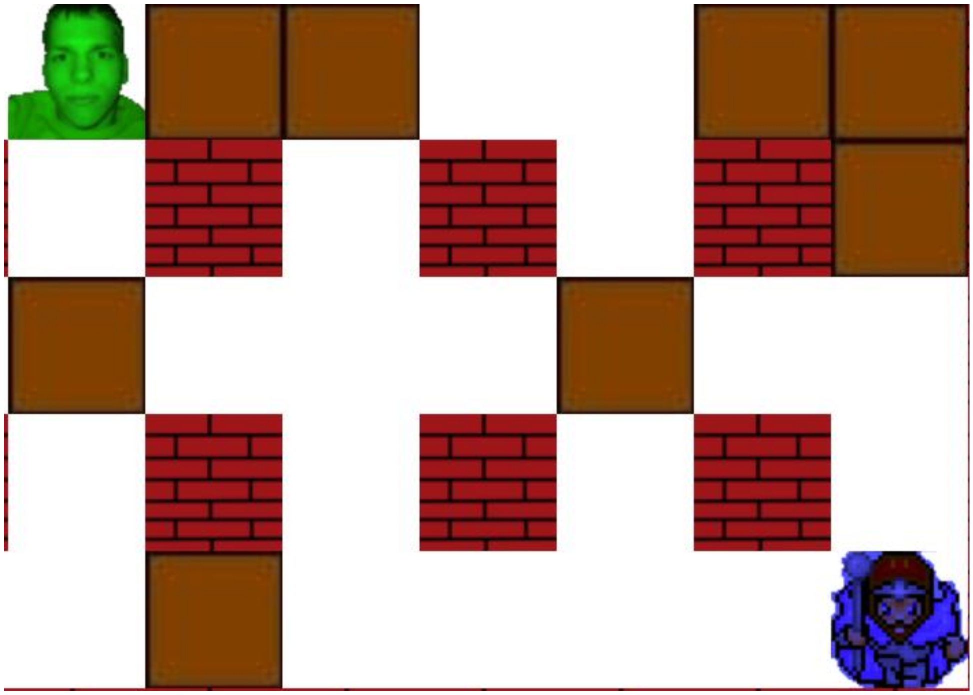


Figure 12: The blue team and green team battle for supremacy

4.4 Software Architecture

PyBomber is architected to take full advantage of object oriented design principles. A single game class, PyBomber, handles the game loop. The game loop is used to update all game objects exactly thirty-three times per second. The loop also forces the game to redraw itself whenever it is not updating the game objects. The decoupling of game updates and rendering is critical to good game design.

The game logic takes place inside individual classes that represent objects in the game world. An example of such an object would be a player. All of these game objects are derived from two parent classes that handle most of the low-level details. These classes are PyGame.Sprite and Image.

Deriving from PyGame provides numerous features that are relevant to game logic, such as collision detection. Image is a class that was created specifically for PyBomber. It provides hardware accelerated drawing of 2D sprites. Deriving from Image allows a game object to be drawn without the object having to manage anything itself.

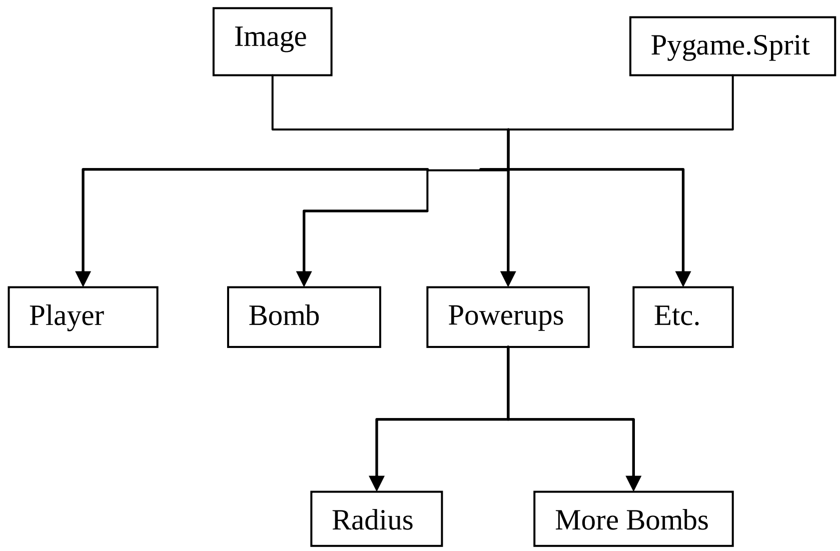


Figure 13: A class diagram containing many of the important game objects

4.5 Software Used

- Python – The programming language used for PyBomber.
    - Twisted – Asynchronous TCP library, used to receive input from players over the network.
    - PyQt – Python version of the QT Framework. This was used to provide an OpenGL context for rendering as well as for the callbacks used by the game loop.
    - PyGame – A library containing numerous constructs that are useful for programming games. This library was used for collision detection, rendering groups, and other miscellaneous tasks.
    - CTypes – This library was used to interface native C++ code into Python for performance-critical regions.
- CWiid – A library providing connections to Nintendo Wii Remotes under Linux.

Chapter 5: Experiment

5.1 Motivation

Since high-resolution, highly-multiplayer gaming is a new field, this study is exploratory in nature. The goal of this study is to provide evidence supporting the research questions outlined above. Namely, that high-resolution, highly-multiplayer gaming is enjoyable. It is also investigating the social interactions that take place between such large numbers of players.

The independent variables in this study are the number of players and the type of gameplay. The study includes both four- and twelve-player variants of PyBomber. The two types of gameplay are team and non-team.

5.2 Method

5.2.1 Hardware Used

All trials were run on the GigaPixel display. An ordinary laptop computer with Bluetooth was used as a second receiver to forward input over the network to the head node. Players interact with the game using a Nintendo Wii Remote. Each player is provided with his or her own Wii Remote to use. Video footage of the user trials was recorded digitally from cameras mounted on the roof of the lab space. This footage was passed via Firewire to nNovia boxes that encoded and stored the video.

Figure 14: The physical space in front of the GigaPixel display

The space in front of the GigaPixel display is approximately 9ftx18ft in size. This space is completely open for movement by players, with no chairs or other obstacles. The space in front of the display is bordered in the rear by a tabletop display.

5.2.2 Software Used

The primary piece of software that was used in the user trials is PyBomber. The game was run at a resolution of 4000x1500 in the four-player condition. In the twelve-player condition, the resolution was 8000x3000.

The resolution was scaled with the number of players in order to provide a similar amount of game space per player across conditions. While running PyBomber with the same resolution regardless of the number of players would provide a greater degree of control in the study, the ecological validity would suffer. The reason for this is that most, if not all, games scale the game space to suit the number of players. The purpose of the scaling is to avoid very sparse or very congested gameplay areas.

5.2.3 Experimental Design

Both of the independent variables, the number of players and team or non-team gameplay, were run within-subjects. The conditions were applied to groups of four, rather than the specific participants within said group. The number of players could either be four and then twelve, or twelve and then four. The gameplay could either be free-for-all then team, or team then free-for-all. To balance these conditions, the ordering varied amongst them. Every fourth group of participants would be exposed to a particular ordering.

The gameplay condition was always varied within the player count condition. For example, a group is to play the four-player, non-team variant first. They would begin with this condition and then play the team variant without altering the player count. Once that condition is finished, they would move on to play the twelve-player variant, again starting with non-team.

4 player first, non-team then team	4 player first, team then non-team
12 player first, non-team then team	12 player first, team then non-team

Table 1: A Latin square of the two independent variables

A full trial involved two groups of four participants. The first group of four would arrive and play the four-player variant of PyBomber. Within the four-player variant, they would have three rounds of team-based gameplay. They would then play three rounds of the non-team gameplay variant.

At this point, the second set of four participants would arrive. Also, a group of four "filler" players would arrive. The filler players' purpose was to pad out the game to the full twelve players without requiring twelve actual participants. The primary difference between filler players and participants was that the fillers were not being studied. Since they were not being studied, they were able to play in multiple sessions. This reduced the number of participants needed for the full set of user trials by a third. It is important to note that the important factor is having twelve players involved in the game, not that all twelve players are experiencing PyBomber for the first time.

The twelve-player trial would then commence, following the same team/non-team ordering as the four-player trial that just concluded. Three rounds of each condition would still be played. After finishing all six rounds of PyBomber, the first group of four participants and the four filler players would depart.

At this point in time the second group of four participants would stay around and play the four-player variant of the game. Again, the ordering for team/non-team would remain the same. It would also involve three rounds of each condition. After the six rounds were concluded, the four participants would depart.

This layout of user trials provides an equal number of participants experiencing four- and twelve-player games first. However, every one of these participants would have experienced team-based gameplay first. In order to balance this out, the next trial would have everyone experience non-team gameplay first. Together, this experimental design would balance both of the independent variables' ordering effects.

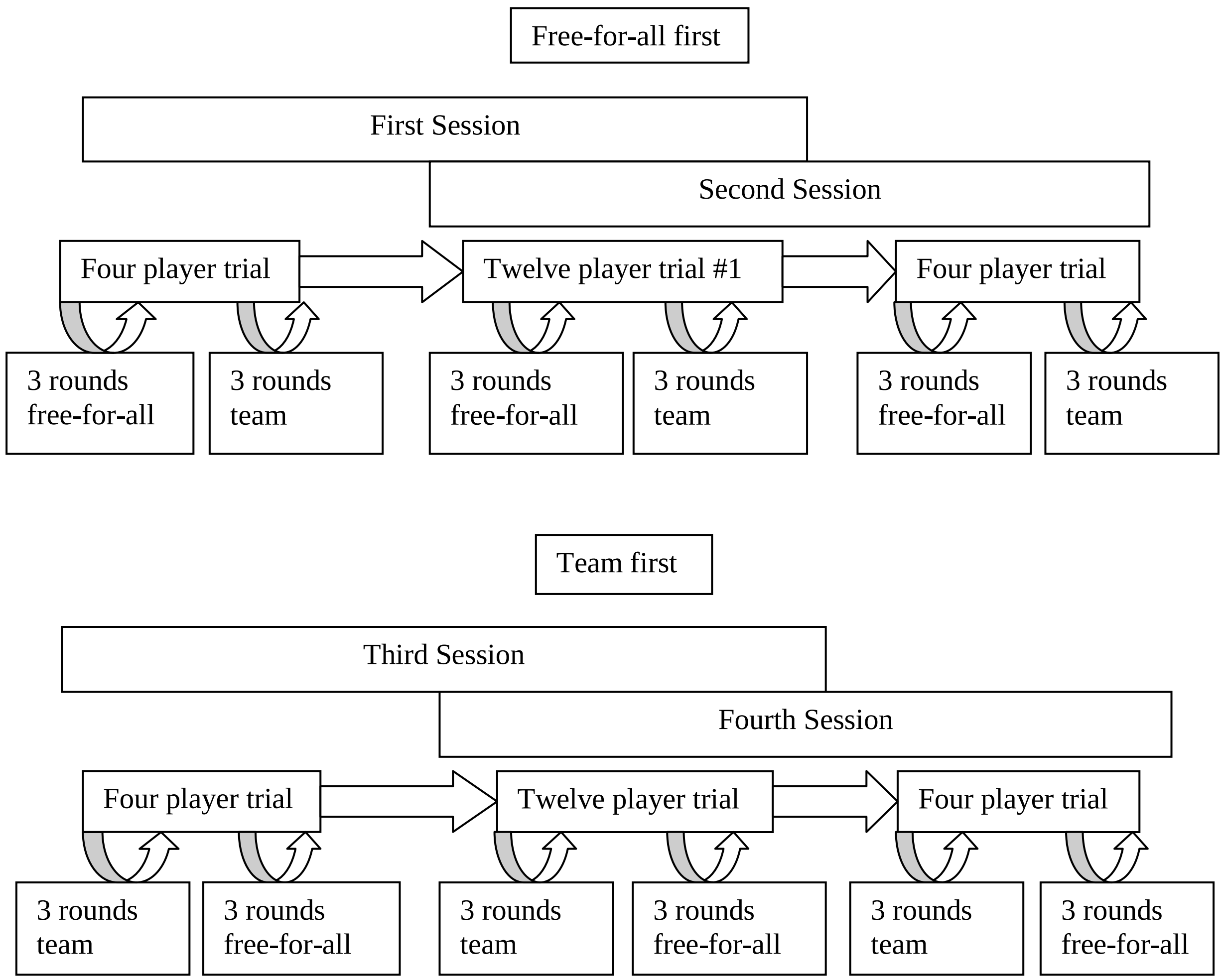


Figure 15: This chart helps to demonstrate the ordering of the conditions

5.2.4 Demographic Information

A total of thirty-two participants participated in user trials for PyBomber. Twenty-eight of the participants were male, while the remaining four were female. The average age was twenty-four years old, with a minimum of nineteen and a maximum of thirty-three. A majority of participants were students, nine undergrads and thirteen graduate students. When asked to rate their skill with video games, twenty-six of the participants rated themselves as intermediate or advanced.

The four-person groups of participants were recruited as a whole, meaning that all recruiting documentation specifically mentioned the need for groups. This was an attempt to maximize the players' familiarity with each other. It was hoped that the players knowing each other prior to playing the game would increase the potential for social interaction.

5.2.5 Procedure

Prior to the arrival of the first participant, several preparations were made. The video cameras that were used to record the experiment were powered on and connected to their storage medium. All of the Wii Remotes were powered on and connected to a computer. The conditions for the first game were entered into the configuration files.

As the participants arrived, they were given informed consent documents and asked to sign them. After each participant signed the informed consent, they were assigned a participant ID number made up of a letter and a number (e.g. C3). The letter identified what group of four that they belonged to, and the number identified them within that group.

After being given an ID number, the participants filled out a background questionnaire. They also had their photo taken in front of a green background for incorporation into the game. At this stage they were also given the instructions for PyBomber and a necklace to wear. This necklace had four colors on it: red, orange, yellow, and green.

The necklace was used to provide a rating system. The scale for this rating ranged from red (worst) to green (best). After each round of gameplay, all of the participants were asked to rate their enjoyment of the previous round, and only the previous round, using the same scale.

Players completed two types of post-game surveys. The first one was given twice, after the four- and twelve-player conditions. This survey asked them to rate their enjoyment of the game overall as well as for the team and non-team conditions. The second type of survey was given after all of the trials were complete. This survey asked players how much fun they had overall, as well as how much they enjoyed the four- and twelve-player conditions.

5.2.6 Data Collection

Every trial of the game was recorded both on video and in the game itself, as a replay. The replay enables researchers to re-watch any individual round in its entirety. It is also possible to go back and as a batch re-run all of the trials to gather specific information. The specific information that was harvested from the replays was the number of kills, deaths, suicides, and team-kills for each and every participant in each and every round.

The video was also processed in a similar fashion. Every trial was run through VCode [36], a video tagging program, with the purpose of tagging specific actions within the video. The tagged actions are: utterances, physical reactions, conversations, movements, trash talk, and view adjustment. Conversations, movements, and trash talk were tagged with duration. Everything else was simply a point in time.

Utterances, in the context of this study, are defined as any vocalization by a participant. A single utterance could be as simple as saying "yes" or as complex as a sentence. During a conversation, each new response was counted as an utterance.

Physical reactions are when a player reacts to the game in a very flagrant way. An example of such a reaction would be a participant throwing their hands up in the air after dying in the game.

Conversations are defined as any dialog between two or more participants. A single person speaking does not count as one. The beginning of a conversation was tagged when the first person begins speaking, and ends when the last response finishes being spoken. A similar tagging system was used for trash talk. Any speech by a player that was interpreted as a taunt by the analyst was tagged as trash talk.

Movements were tagged whenever a participant was changing location by more than two feet. Any small motion, such as shifting weight around or taking a single step, was not counted as movement. Movement tags remained active as long as one or more participant was in motion. The movement tag was begun when a participant started moving, and ended when the last participant stopped moving again.

The final metric for video analysis was view adjustment. This point tag was given whenever a player made some sort of visible motion, involving more than just their head, to get a better view of the game. Simply looking around did not count. A common example of view adjustment was a person craning their neck to see around someone standing in front of them.

The analysis of a video began when the game first appeared on the display. Analysis stopped when the "Game Over" text was displayed across the screen. Anything falling outside of these bounds was disregarded.

5.3 Subjective Results

5.3.1 Survey Questions

After participants finished a set of four- or twelve-player games, they were provided with a survey (Appendix D) asking them to rate, on a scale of one to ten, several factors related to the previous game. These included their enjoyment of the team and non-team variants, as well as enjoyment of the game overall. The results of these survey questions can be seen on Table 2. None of these results carried statistical significance, as determined by a linear regression model, either between the numbers of players or between team and non-team gameplay. There was a weak trend that four-player was rated higher than twelve-player.

The participants were also asked to give a preference between team and non-team gameplay. The results of this question can be seen in Table 3. Preference was split roughly down the middle, with no statistical significance.

Condition (N=32)	4 player	12 player
Non-team	7.47 (std-dev: 1.46)	7.06 (std-dev: 1.70)
Team	7.28 (std-dev: 1.53)	7.09 (std-dev: 1.44)

Table 2: Post-Game Survey Results. There is no statistical significance between any of the variables.

Condition (N=32)	4 player	12 player
Prefer non-team	14	16
Prefer team	12	13
No Preference	6	3

Table 3: Post-game preference on gameplay type. There is no statistical significance.

After an entire set of trials was concluded, the participants were asked to fill out a second survey (Appendix E), on the experience as a whole. They were again asked to rate, on a scale of one to ten, their enjoyment on the four- and twelve-player variants of the game. These results can be seen in Table 4. No statistically significant results were generated by these questions. Again, there was a weak trend favoring the twelve-player version of the game.

The participants were also asked to give their preference between the two game sizes. Again, this elicited a fairly even split amongst the participants. The exact numbers can be seen in Table 5.

Condition	Average Rating (N=31)	Std Deviation
4 player	7.55	1.48
12 player	7.19	1.60

Table 4: Post-Experiment Survey Results. There is no statistical significance.

Prefer 4-player	Prefer 12-player	No preference	N
15	14	2	31

Table 5: Post-Experiment preferences on game size. There is no statistical significance.

Participants were also asked to write open-ended comments at the end of the post-game surveys. The responses varied quite a bit, but several things were hit upon multiple times. The comments were typically either positive or negative in nature.

Most of the positive responses praised PyBomber in some way, noting enjoyment. Many of these responses also included feedback on ways to improve the game, such as adding more types of powerups. Other common targets for praise were the bomb previews and the use of faces for player images.

The most common target of criticism was the control of the game. The Wii Remotes (or the library interacting with them) have a certain amount of latency associated with them. Many players commented on the latency in the controls. Other criticisms involved the bezels between the screens, the slowdowns in the game caused by an overheated router, and respawn times that were too long.

Several players commented on the number of players involved in the game. A common theme was that the twelve-player version of the game was more hectic and harder to maintain a good situational awareness. The difference was that some of the players enjoyed this challenge, while others did not.

Sometimes the comments were very similar, but one person listed it as a like and another as a dislike. For example, one participant noted that "four-player had less to concentrate on, which I liked". However, another mentioned that "twelve-player is a lot more frantic, and harder as well as more enjoyable".

Some of the comments also stated that the social aspect of the game had an effect on enjoyment. One in particular mentioned that "I didn't know anyone in the experiment very well so the twelve-player was a little intimidating and the four-player less so. I think if I knew all/more participants I would like twelve-player as much as four-player". Another mentioned that "team play is fun, interacting with players I know during the game is fun".

5.3.2 Necklace Ratings

As noted in the procedure section above, after each round the players were asked to rate their enjoyment of the previous round using a necklace. The necklace provided a scale ranging from red (worst) to green (best) with orange and yellow in between. Due to time and procedural constraints, it was not possible to tie each participant's rating to their participant ID. Rather, the ratings were recorded for the group as a whole.

The ratings across the four conditions were compared as a group. The colored responses were converted to a number on a scale from one (red, worst) to four (green, best).

Linear regression was used to test for results based on the player count and team variables. The effects test showed that the number of players had a significant effect ($p<0.001$) while the gameplay type did not ($p=0.60$).

Condition (N=96)	4 player	12 player
Non-team	3.44 (std-dev: 0.629)	3.19 (std-dev: 0.758)
Team	3.42 (std-dev: 0.644)	3.21 (std-dev: 0.631)

Table 6: The average necklace ratings across conditions. Results are significant across rows, but not down columns

A linear regression model was used to test for ordering effects between the team size and number of players in the game and their effect on the sum of all necklace ratings in a round. There was a significant ordering effect based on whether team or non-team gameplay was experienced first ($p=0.01$). The order of game size had no statistically significant effect ($p=0.17$). The averages can be seen in Table 7.

Condition (N=48)	Average Rating	p-value
4 player first	13.42	p = 0.16
12 player first	14.00	
Non-team first	14.17	p = 0.01
Team first	13.25	

Table 7: The average ratings for various ordering effects.

5.3.3 Survey Results and Background Information

When analyzed in tandem, a link emerged between how often a participant plays video games and their preference between the four- and twelve-player versions of PyBomber. A one-way ANOVA (F=13.5, p=0.0003) shows that when grouped by preference, the twelve player group reported themselves as playing video games more. This link can be seen in Figure 16.

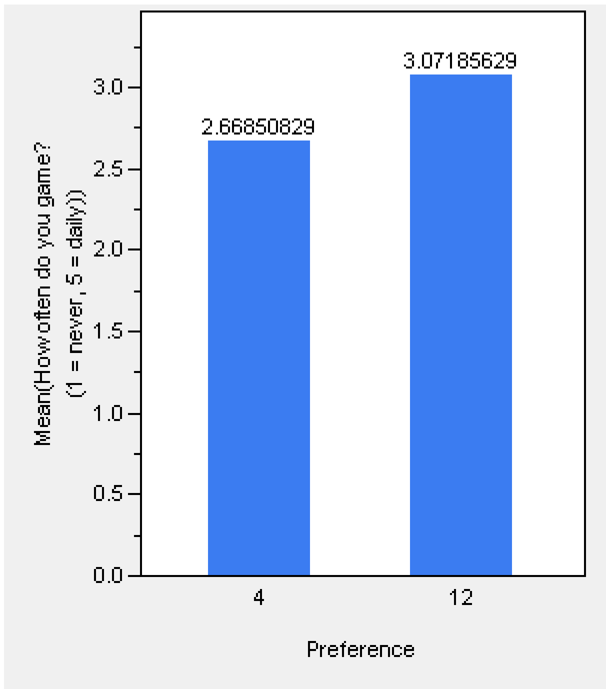


Figure 16: Player skill and preference of game size

5.4 Quantitative Results

5.4.1 Game Data

Every single round of every single game was recorded for later analysis. This recording took place within the game itself. Later, this data was analyzed to provide performance data for every single participant. This information included the number of times in a round that each participant killed, died, committed suicide, or killed a teammate.

This information was then compared across both the survey results for enjoyment as well as the necklace ratings that were taken after each round. Unfortunately, no clear trends emerged between any of these factors. It is not known whether a contributing factor to this is the fact that the necklace ratings were not tied to a particular participant, and were taken for the group as a whole.

A two-way ANOVA was run with this data, and no statistically significant results were found. The implication from this is that there was no measurable difference in a player's performance between different conditions.

Variable	Average – 4 player	Average – 12 player
Kills	2.24	2.15
Deaths	4.32	4.24
Team-Kills	0.14	0.16
Suicides	1.24	1.23

Table 8: The game data, split by player count. Values are per player. There were no statistically significant differences

Variable	Average – Team	Average – Non-Team
Kills	2.13	2.26
Deaths	4.41	4.15
Team-Kills	0.3	n/a
Suicides	1.44	1.34

Table 9: The game data, split by team condition. Values are per player. There were no statistically significant differences

5.4.2 Video Analysis

The complete video of each round was analyzed according to the methodology described above in the data collection section. The first analysis for the video data was determining whether there were any differences between the conditions as a whole. When looking at the game size, every single statistic that was measured had a significant result. This can be seen in the number of occurrences in each metric in

Figure 17. It can also be seen in the duration of the metrics in Figure 18. The exact numbers can be seen in Table 10 and Table 11.

No significant differences were ever found between team and non-team gameplay. Therefore, all of the following analysis will disregard team or non-team as a variable, since it made no statistical difference in any of the results.

These results alone come as no surprise. It is in many ways obvious that when there are three times as many people involved in a trial, more social interactions will take place. However, they serve to show just how large the differences are, in absolute terms. They also allow the dropping of team and non-team gameplay as a variable in further analysis.

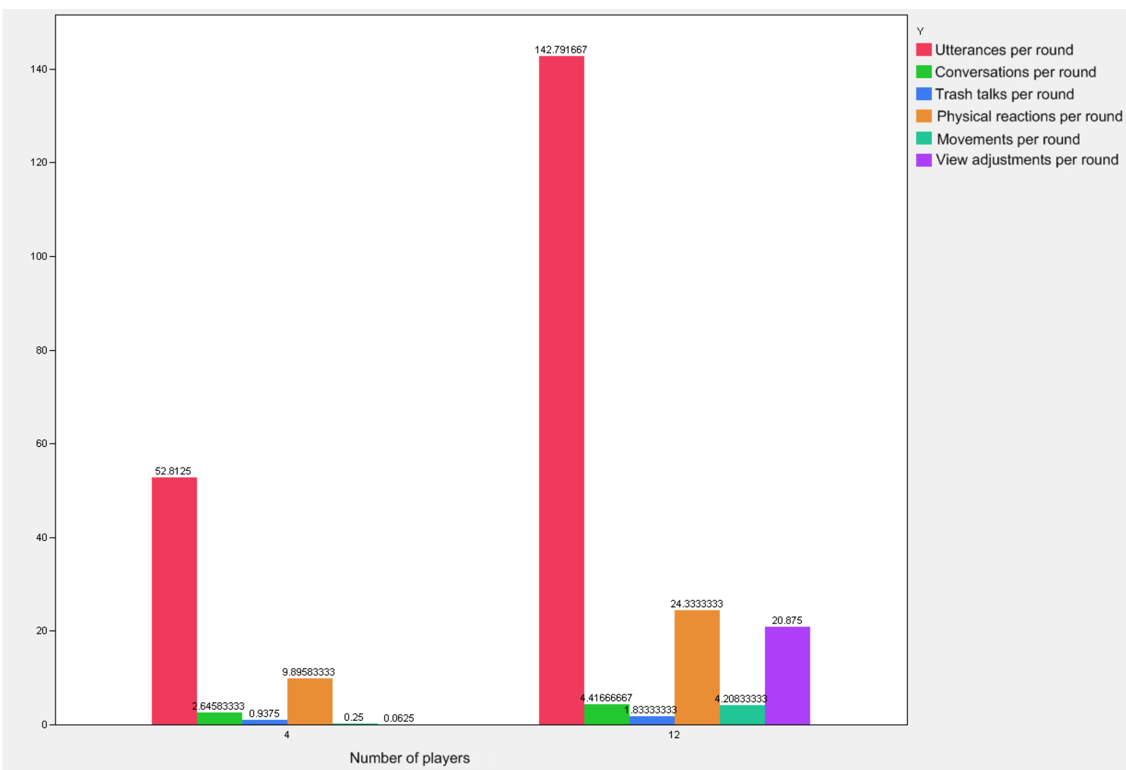


Figure 17: The average number of occurrences of each metric in a given round

Metric	4 player average	12 player average	p-value
Utterances	52.8	142.8	<0.0001
Physical Reactions	9.90	24.3	<0.0001
Conversations	2.65	4.42	0.0012
Movements	0.25	4.21	<0.0001
Trash Talk	0.94	1.83	0.0009
View Adjustments	0.06	20.88	<0.0001

Table 10: The average number of occurrences of each metric in a given round

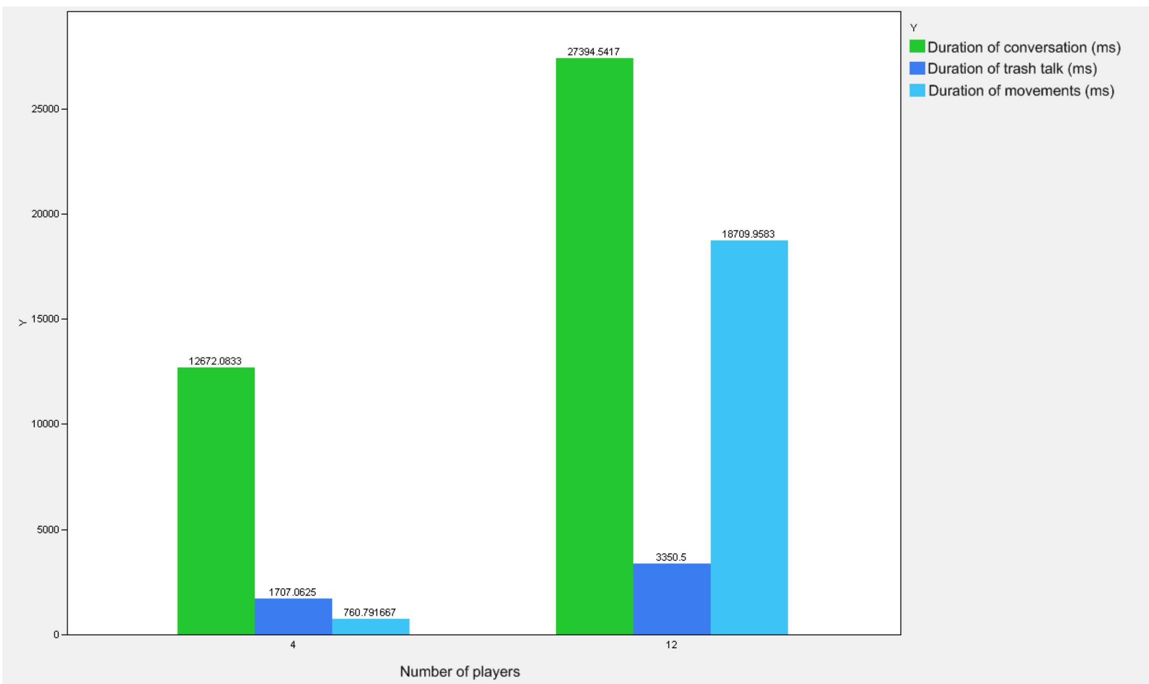


Figure 18: The average duration of each metric, in milliseconds

Metric	4 player average	12 player average	p-value
Length of conversation	12,672ms	27,394ms	<0.0001
Length of movement	760ms	18,710ms	<0.0001
Length of trash talk	1,707ms	3,350ms	0.0018
Round duration	151,948ms	201,278ms	<0.0001

Table 11: The mean duration for each metric, in milliseconds

Since the differences between the four- and twelve-player variants are so large in absolute terms, it makes sense to normalize the results by the number of players and then compare them again. This normalization allows a more direct comparison of how many times the average player would perform each of the measured actions. The normalized values can be seen in Figure 19.

Every one of these results was statistically significant save one: the number of utterances per person. The exact numbers can be seen in Table 12. The number of physical reactions, conversations, and trash talks per person all declined when moving from the four-person variant to the twelve-person version. However, the number of movements and view adjustments increased significantly.

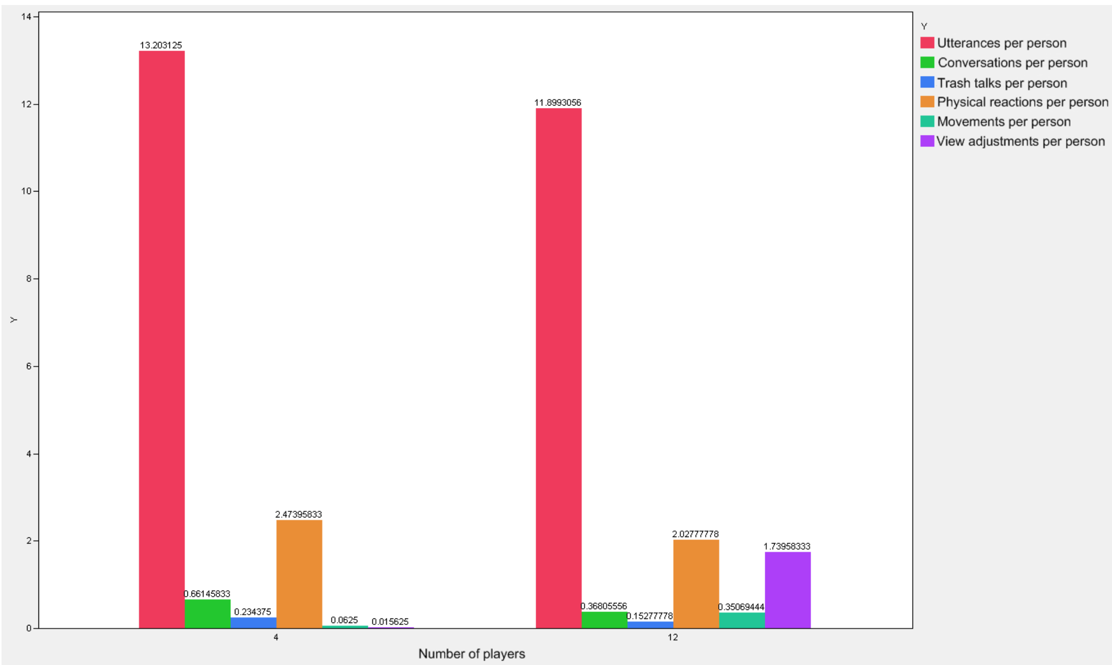


Figure 19: The differences in various metrics between four and twelve player, normalized by the number of players in the game.

Metric	4 player average	12 player average	p-value
Utterances/person	13.20	11.99	0.18
Physical reactions/person	2.47	2.03	0.043
Conversations/person	0.66	0.37	0.0024
Movements/person	0.063	0.35	<0.0001
Trash talks/person	0.23	0.15	0.032
View Adjustments/person	0.016	1.74	<0.0001

Table 12: The metrics normalized by the number of players

A different way of looking at these results would be to see how the social interactions fill the time that is available. In order to help find this out, all of the metrics recorded during a round were divided by the duration of that particular round (in seconds). This provides an idea of how many instances of each metric could be expected per second. These results were then inverted, to provide the average number of seconds that could be expected to pass between occurrences of that metric. The differences can be clearly seen in Figure 20. All of the values, as well as their significance, can be seen in Table 13.

Across all of the metrics, the amount of time between occurrences was significantly lower in the twelve-player variant of the game. This is most pronounced in movements and view adjustments.

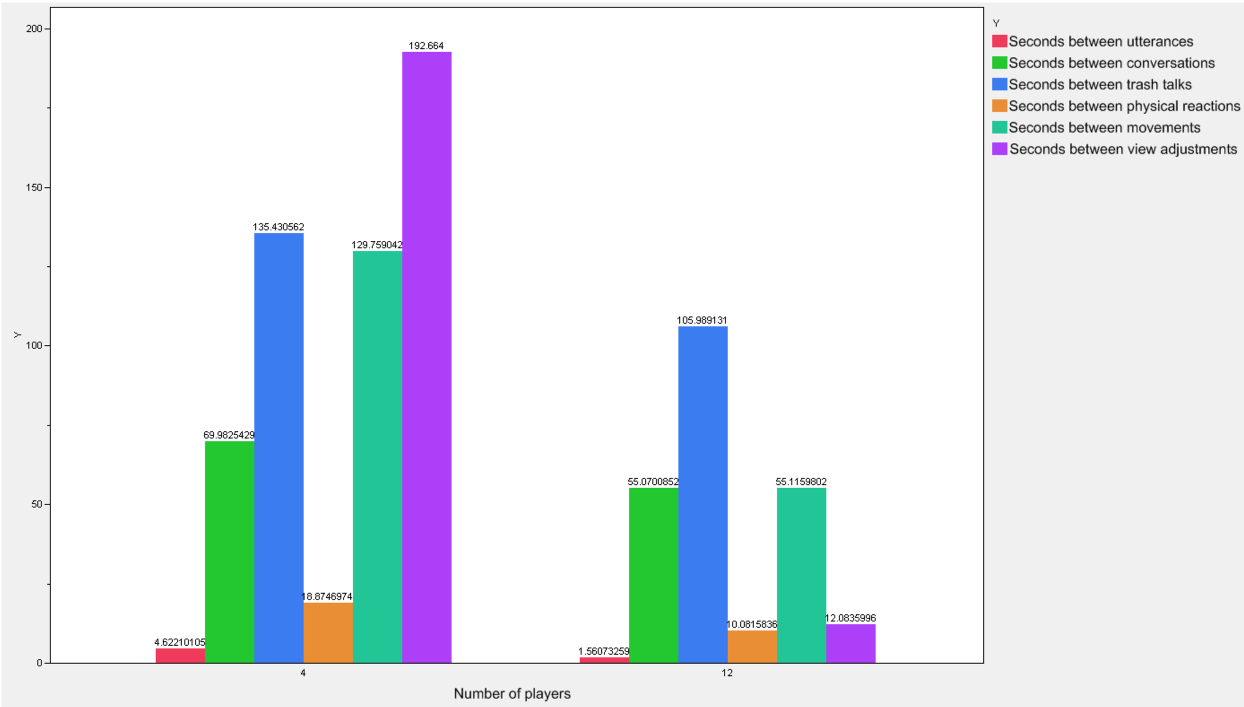


Figure 20: The differences in each metric, normalized by round duration

Metric	4 player average	12 player average	p-value
Seconds between utterances	4.62	1.56	<0.0001
Seconds between conversations	69.98	55.07	0.03
Seconds between trash talks	135.43	106.00	0.02
Seconds between physical reactions	18.87	10.08	<0.0001
Seconds between movements	129.76	55.16	<0.0001
Seconds between view adjustments	192.664	12.08	<0.0001

Table 13: The mean values of each metric, normalized by round duration

Another interesting analysis to perform is to look at the percentage of a given round that is filled by these metrics. For example, it can be seen in Figure 21 that in the four-player variant of the game, almost no time is spent moving. However, in the twelve-player version of the game, about 9% of any given round was spent with one or more players physically moving around the play area. Every single one of these metrics proved to be statistically significant, as noted in Table 14.

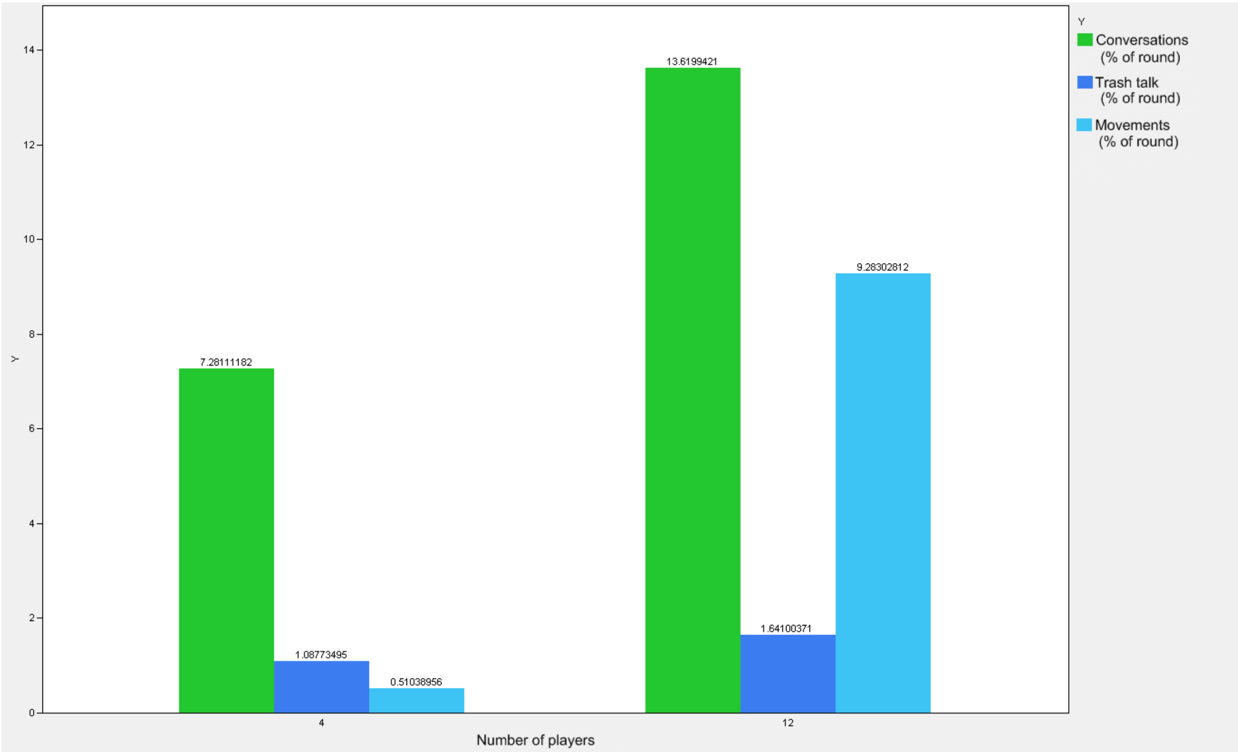


Figure 21: The percentage of a given round that was filled by various activities

Metric	4 player average	12 player average	p-value
Conversation	7.28%	13.62%	<0.0001
Trash Talk	1.08%	1.64%	0.04
Movement	0.51%	9.28%	<0.0001

Table 14: The mean value for various metrics, as well as their significance

In order to gain further insight into how a round is comprised, the utterances that make up a round were mapped to a timeline. These timelines can be seen as Figure 23 and Figure 22. All of these timelines involve the same people. The same four-person group was a part of the twelve-person group that is also shown.

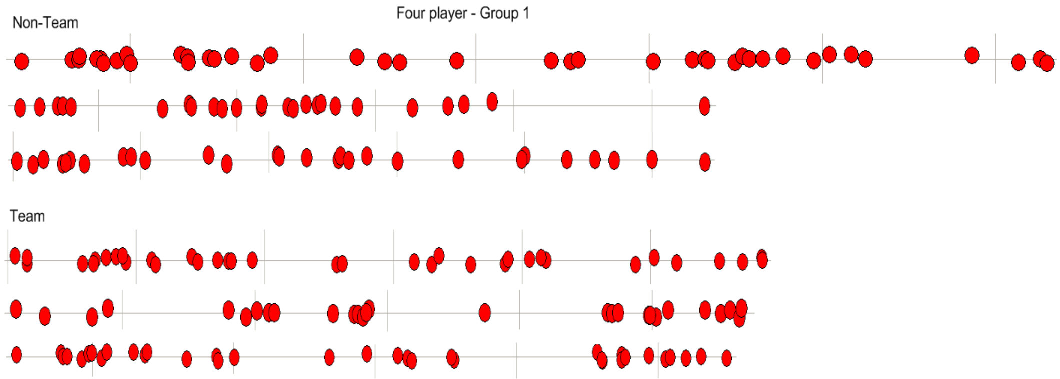


Figure 22: Timelines giving every utterance in the four-player matches for a given group.

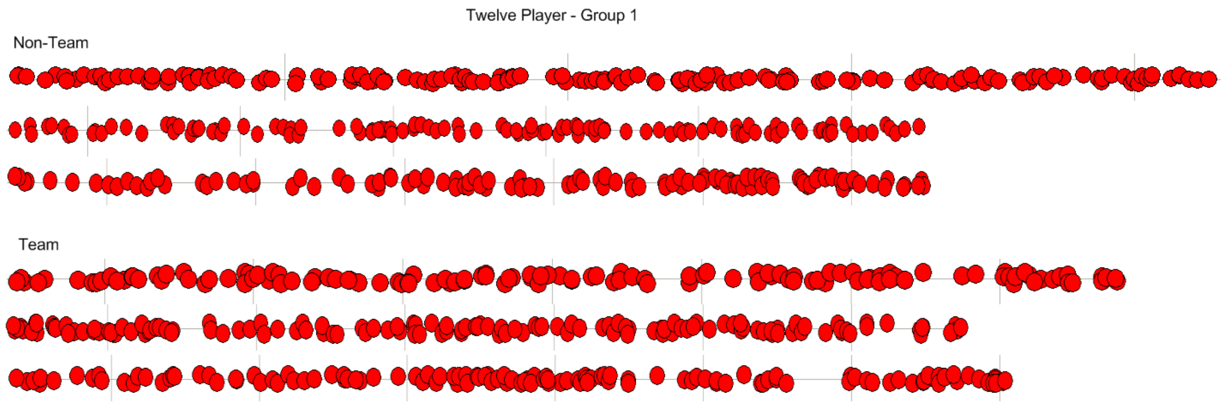


Figure 23: Timelines containing every utterance in the twelve-player matches for a given group.

An interesting result that can be gleaned from these timelines is that the utterances are bursty in nature. This is especially obvious in the four-player version of the game. In the twelve-player version, many of the bursts of utterances overlap, leading to a consistently high level of speech.

It can be seen from these timelines that the four-player rounds were fairly sparse in terms of communication. Large gaps in speech were commonplace. The twelve-player variant differs from this in that a sizeable portion of any given round is filled with utterances.

5.4.3 Observations

Throughout the course of the user trials, the utterances that came out of players' mouths usually fell into several broad categories. These categories are outlined below in Table 15. This list is not exhaustive.

Expletives	It was extremely common for players to let off some kind of expletive while playing the game. These most frequently occurred after dying.
Conversations	Many of the utterances throughout the user trials were part of conversation between multiple players.
Laughs	Players frequently laughed throughout the user trials for PyBomber. Most commonly these laughs were targeted at another player dying.
Taunts	Various taunts and the trash talk they comprise were not unusual. Most players did not engage in taunting, but those that decided to taunted with some regularity.
Questions to the researcher	When a participant was unsure about a game concept, they frequently asked the researcher a question. Questions about the technical details of the game were also common. It should be noted that the researcher's responses were not counted in the video analysis.

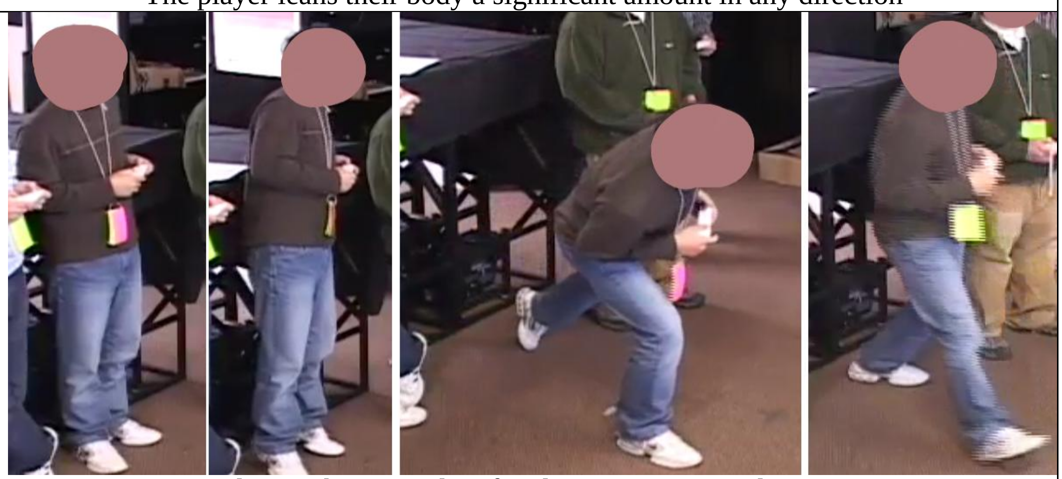
Table 15: The most common types of utterances

While physically moving in the space in front of the display, player actions often fell into several patterns of movement. These patterns are outlined in Table 16. This list is not exhaustive. It is worth noting that players rarely, if ever, moved in order to improve the view of another player. The likely reason for this is that they are too focused on playing the game to realize that they are in someone else's way.

To get a better view	This is covered in more detail below.
Jumping around	This type of movement was limited to a few choice participants. Due to various in-game events, the player would spontaneously begin jumping and/or running around the physical space in front of the display
The beginning of a round	Between rounds, despite the typically short wait, players often clustered somewhat to converse. As the following round began, they would scramble to get a clear view of the display.

Table 16: The common types of physical movements

Participants in the twelve-player games frequently needed to adjust their position. The ways in which they moved varied. However, several clear trends emerged in their reactions. These trends are outlined in Table 17.

Strong lean	 The player leans their body a significant amount in any direction
The big step	 A player takes a single, often large, step in any direction
The squat	 A player squats down right in front to get a good view of the game

Relocation	 Two players relocate from one side of the display to the other

Table 17: The common reactions to a player having their view blocked

A final observation from watching the video of every user trial is that when a round ends, there is almost always a huge uproar from the players. The impending end of the round that is signaled by sudden death seems to up the intensity for the last couple seconds in a round. When it finally ends, there is a large release of tension from most of the players.

5.5 Discussion

5.5.1 Discussion – Enjoyment

As noted in the results above, only a single statistically significant result was present in the area of enjoyment. This result involved the number of players and its effect on necklace ratings. When looking instead at player preference another link emerges. The players who preferred the twelve-player variant were also the players who reported playing video games more often. The likely reason for this trend is that the more serious gamers enjoy the greater challenge that is posed by the larger games.

The game data, consisting of kills, deaths, team-kills, and suicides was also inconclusive. When these metrics were compared across the independent variables, no statistically significant links were found.

It is an unproven hypothesis that there is a link between a player's performance and his or her enjoyment of a game. The expectation is that players who perform better will enjoy the game more. This expectation is based on the idea that, in general, people seem to draw more enjoyment from an activity in which they perform well. Due to a procedural oversight, this hypothesis could not be tested accurately.

The necklace ratings were accurately recorded for the groups that played PyBomber. However, the ratings were recorded without identifying the participant who made each rating. This happened in the interest of minimizing the downtime between rounds. Unfortunately, this made it impossible to link the individual performance data for a participant to that person's exact rating of that same round.

It was noted by several players in the survey questions that the twelve-player version of the game was much more “intense”, “frantic”, or “hectic”. However, there was no statistically significant difference in player performance (as measured in the game data of kills, deaths, suicides, and team-kills) between the four- and twelve-player versions of the game. Also, due to the change in resolution between the conditions, the number of game objects was similar on a per-player basis.

There are several possible explanations for why this happened. The first is that the players clustered in the game space, leading to a higher density of action in a localized area without changing the overall density. Another possible explanation is that the players attempted to keep track of everything that was going on and in doing so overwhelmed their ability to process data in the twelve-player condition, but not the four-player one.

5.5.2 Discussion – Movement

The amount of movement in the twelve-player condition proved to be much higher than in the four-player condition, even when normalized by the number of participants. A small number of movements can be explained by direct physical interaction between players. For example, after being killed by a teammate one participant moved to the player who had just killed him and shook the other participant to make it clear that he did not enjoy being killed by his own teammate. However, the amount of physical interaction between players was much lower than hypothesized.

Nonetheless, another type of movement happened with some regularity. This type of movement was a participant moving a significant distance in order to improve their view of the game. It almost never happened in the four-player variant of the game, but did occur throughout the twelve-player trials of PyBomber.

This probably happened since the large number of players got in each others' way. They also occurred due to the fact that objects in the twelve-player version of the game were smaller, requiring them to more closely follow the progress of themselves on the display. The combination of these factors led to many interruptions in a player's view of the game.

A common side-effect of this movement would be that another participant's view would be blocked by the movement, causing that person to also move for a better view. This sometimes triggered a chain reaction. In one extreme case a participant moving across the front of the display caused almost every single player to frantically shuffle around to regain a clear view of the screen. This shuffle lasted until the end of that particular round.

For the most part, these view blockages were unintentional. Players did not seem to put any consideration into whether they were blocking someone else's view when they moved. When reacting to a view blockage, a player rarely said anything. The reason for this silence and the non-caring of blocking another player's view is most likely the game itself.

Since everyone was focused on the game, the level of concern they expressed over this normally socially-discouraged action was minimal. Players reacted to a view blockage without much complaint: they just wanted to be able to see again.

On rare occasions, the view blockages were intentionally perpetrated by another player. These blockages were short-lived in duration. Usually, the blocking player would quickly lose interest in blocking the other player and cease his or her actions.

On the other end of the spectrum, many smaller movements occurred in the interest of a participant's vision. These movements were recorded in the video analysis as view adjustments. The larger movements discussed above highlight the extreme side of this spectrum. However, there were numerous small motions, such as craning a neck, that were performed in the interest of getting a better view of the screen.

As seen in the results above, view adjustments almost never occurred in the four-player version of the game. However, in the twelve-player variant, they happened approximately twenty times per round. View adjustments serve as an example of players moving as part of playing PyBomber.

5.5.3 Discussion – Verbal Interactions

As can be seen in the numbers from the previous section, there were statistically significant differences between four- and twelve-player games in every measured category. However, when normalized by the number of players, there are still significant differences but the picture is murkier.

The number of social interactions increased in every measurable way as the number of players increased. This held true even when normalized for the duration of a round. This normalization is important because the length of a round varied significantly with the number of players just like all of the other factors.

The fact that more social interactions took place in larger games is not wholly surprising. Nonetheless, the volume of time filled by said interactions is much higher. This is evidenced by the significantly lower amount of time between each type of interaction. . It is also demonstrated in the timeline of utterances provided in the results.

It was noticed while analyzing the video of the user trials that the social interactions were bursty in nature. This means that something of note would happen in the game, triggering a brief period filled with utterances, physical reactions, and possibly full conversations. The crucial difference, though, was that these bursts occurred much more frequently in the larger games. The most likely reason for this is that the larger number of players involved in the game led to a larger number of interesting events, which in turn triggered a larger stream of outbursts.

Four-player games of PyBomber had frequent and lengthy periods of quiet. The bursts of activity were still present, but they occurred much less often, leading to these long periods of quiet. In contrast, the twelve-player version of the game had almost nothing in the way of quiet periods. Between so many players, something interesting would happen often enough to trigger a burst of activity such that the social interactions were often a constant throughout a given round.

This phenomenon is backed up by the significantly lower number of seconds between utterances and conversations in the twelve-player games. Further evidence of this is the percentage of a round that is filled with conversation or trash talk. Both of these events comprised significantly larger portions of the time. In the case of conversation, the percentage of a round made up from this type of interaction jumped from about 7% to over 13%.

An interesting occurrence in the user trials is the huge disparity between the number of utterances and the number of conversations. It is to be expected that the number of utterances is higher, since a conversation is by definition made up of at least two utterances. However, the vast majority of utterances provoked no response. Very few statements by one player solicited a response from another. In some of the trials, this became so severe that it was like seeing twelve people have conversations with themselves. Players would constantly be talking, but none of the talking was ever directed at another player. This proved to be unexpected.

A notable link can be drawn between physical reactions and utterances. In a very large number of cases, a physical reaction was accompanied by an utterance. Physical reactions were very strongly associated with dying in the game. After being killed, on many occasions the player would shout some kind of expletive and then react physically. Common reactions would be throwing their hands up, turning around and walking a few steps away, punching the air, etc.

5.6 Summary

The purpose of this experiment was to seek out evidence supporting the hypothesis' that were made prior to the study. In many ways it was a success. In some ways, it was not. The video tagging provided a wealth of useful (and statistically significant) evidence. From this evidence several conclusions can be drawn. The logging of game data also provided reliable information.

Unfortunately, the subjective ratings proved to be too unreliable. The surveys provided little useful data, at least numerically. The necklace ratings were somewhat useful. However, they were crippled by the anonymous nature of the data recording. Overall, the user trials did well in their task of providing evidence one way or another.

The key finding in this experiment involved the social interactions of the players and their movement in physical space. A much greater number of social interactions took place in the twelve-player version of the game, and a correspondingly larger portion of the time was filled with them. In the larger games, the amount of movement was significantly higher. This movement was primarily concerned with a player's view of the game.

Chapter 6: High-Resolution Games

6.1 Opportunities

High-resolution gaming is a new field and as such is full of possibility. The large, high-resolution screens involved in this field create new opportunities for new types of games and interactions.

6.1.1 More information

High-resolution displays have their roots in information visualization and related fields. The tasks in these fields take well to high-resolution displays due to the volume of information that can be displayed concurrently. The large amount of information on display is something that can be taken advantage of by games. A secondary benefit is that the number of people capable of viewing this information simultaneously is increased.

The primary benefit of the increased information capacity is the ability to increase the size of the view into the gameplay area without adding virtual navigation. This increase in viewable game space can be put to two primary uses. One use is to improve the view of an already-large game space. The other use is to increase the size of a fully-visible game space.

In the context of PyBomber, this increase in viewable space was used to increase the gameplay area accordingly. This was one of the enabling factors in the ability to support a dozen co-located players. Without this increase, there would not be enough gameplay area for so many players to play at the same time.

The other possible use for this improved viewing ability is to improve the view of an already-large space. This approached was used by a previous study in a strategy game to improve a player's situational awareness of a very large map as compared to a smaller display [28]. This increase in screen space had a positive effect on game performance.

6.1.2 More physical space

By their very nature, large high-resolution displays are large in a physical sense. As a consequence of the large physical size of the display, there is typically a large physical space in front of the display. An important facet of this large physical space is that it is also usable due to the large size of the display itself. Open space in front of the display allows for some new possibilities in game design.

The space could be used to allow physical interaction on a larger scale. For example, the Nintendo Wii also allows for 3D interaction; however, the scale is much smaller. A major limitation on the Wii is the often-small displays that it connects to. It is only possible to move so far away from a television before the degraded view of the screen becomes a major problem.

That problem is not present to the same extent on a large high-resolution display. Since the screen is so large, the area in which a player can move without sacrificing a good overview is much larger as well. This movement provides an interesting tradeoff between space, an overview of the display, and the details provided by the high-resolution nature of the display.

Nonetheless, the potential physical interactions on a large high-resolution display are countless, especially when combined with motion tracking. Players have the potential ability to utilize a large amount of physical space to run around, jump, dodge, and to move in any other way that they deem necessary or fun. This space also opens the door to a greater use of props, such as a fake cockpit.

A different possible use for the large space in front of a high-resolution display is to allow for more co-located players. This is what PyBomber used the space for. The space in front of the GigaPixel display was filled with players.

These two approaches are at the opposite ends of a spectrum. It is also possible to fall somewhere in between. For example, a high-resolution game may have several co-located players interacting in physical space as part of the game. In this case, the space would be put to use allowing more physically interacting players than a traditional setup.

6.2 Design of a good high-resolution game

The design, construction, prototyping, and user trials of PyBomber have provided a sizeable amount of insight into the characteristics of a good high-resolution game. The following points are broad design criteria that should be considered as part of the design in any enjoyable high-resolution game.

6.2.1 Shared gameplay area or split gameplay area

The primary strength of high-resolution displays is their ability to display large volumes of data at the same time. There are two broad methods of utilizing this ability: a single, shared gameplay area or the use of split views.

Split views on a large high-resolution display allow multiple players to have their own unique views of the game space. Due to this, the size of the gameplay area can be larger than any of the views would be capable of displaying without loss. However, the use of unique views may limit players to a single portion of the display.

As a consequence of unique views, there is the possibility of non-global data. In the case of a shared gameplay area, all information can be seen by all players. When the view is split up, there is a possibility of displaying different information in different views. However, the co-location aspect of the game would still allow "screen watching" by other players.

The use of a single shared gameplay area has several benefits associated with it. The first of which is that the size of the game area scales directly with the resolution of the display. Because of this, increasingly large displays will get an increasingly large gameplay area free of virtual navigation. This area can also support a larger number of game objects simultaneously.

Another benefit of a single shared gameplay area is that a player will be able to utilize the entire display, rather than being limited to a specific portion like they would be with split views. In addition, the single, shared view of the game space will provide a common focus amongst all of the players. This singular focus is expected to provide a greater level of collaboration [16] and allow for richer social interactions.

As a tradeoff, the use of a single shared gameplay area does not support the ability to show different data to different players. Since the entire view into the game space is global, so is all of the information that it displays. Also, problems may arise if and when players cluster in the game space. This clustering may lead to a clustering in the physical space close to that specific part of the display, leading to an uncomfortably crowded portion of space.

Both types of gameplay areas have their tradeoffs. It is important for the designer of a high-resolution game to weigh the benefits and negatives of each approach and choose the method that is best suited to the game in question.

6.2.2 Use of physical space

As mentioned in the previous section, there are several new paths opened up by the physical space that comes with a large high-resolution display. It is important for high-resolution games to take advantage of this space one way or another.

One way to use this space is to increase the number of players. The large dimensions of the display itself allow more people to see it concurrently. Also, the physical space in front of the display provides the space needed for more people to coexist without becoming overly crowded. The physical space could also be used with physical navigation to provide a modified version of the overview plus detail design pattern [37]. This approach would be well-suited to strategy games. It would allow a player to move further from the screen to gain an overview of the game world, or to move closer to the screen for detailed information on a localized portion of the world.

Physical interactions with the game, or with other players, are another good use for the physical space in front of a large high-resolution display. This space provides enough of an area for players to physically interact while minimizing the possibility of collisions– either with each other or with the display itself.

The design of the game itself may be able to encourage these physical interactions become social in nature. Physical-social interactions would involve players physically interacting with other people. These interactions could be encouraged in several ways, such as by allowing players to tag each other or to create special regions of space in front of the display that provide in-game benefits while limiting occupancy to a single player. It is expected that these physical-social interactions would lead to a richer set of social dynamics.

6.2.3 Localized feedback

Due to the large size of these displays, in terms of both physical size and resolution, normal feedback mechanisms will not always work. It is typical for a video game to put feedback on the periphery of the display. This design pattern scales poorly to large high-resolution displays, since the periphery becomes on average much further away from players.

It is imperative that games provide localized feedback to the players. This type of feedback "follows" each player around in the game space. Because of this, the players will not have to look far away from their position to gain feedback.

There are several notable examples of localized feedback being added to PyBomber to address player issues. These changes include the faces, bomb previews, and sudden death. The picture of a player's face represents them in the game world. This feedback allows players to more easily find themselves in the game space. The more useful aspect of this feedback is that it aides the identification of nearby players by localizing their identity to their in-game representation.

Bomb previews are also localized feedback. Rather than expressing the radius of a bomb's explosion in numeric terms, they provide an obvious visual indication without needing to look anywhere else on the screen. Another example is the sudden death indicator. This feedback to the players turns the entire background bright red. No matter where the players are looking, they cannot miss this change. Therefore, it can be considered local to wherever they happen to be looking.

These examples all highlight the point that players will not bother to look around for feedback. Further evidence of this is the scoreboards on both sides of the screen in PyBomber. These display each player's score in gigantic letters that can be read from far away, yet many players never even noticed their existence. The problem was that they were not localized, and because of that they were simply ignored.

It is important for high-resolution game designers to consider what information should be localized and what information can be pushed to the periphery. The amount of feedback that can be localized has limits, so it is important that only the most important information is localized.

6.2.4 Appropriate use of input devices

As with many other constructs, input devices do not necessarily scale up to high-resolution displays with any kind of grace [10]. It is vital to evaluate the possible input devices in the context of the game that is being designed. In the case of PyBomber, this was as simple as choosing commodity wireless controllers.

Other games may need to take this consideration a step further. The previously mentioned high-resolution gaming study involving strategy games spent a significant amount of time modifying the user interface to retain its usability when scaled up to a large display [28].

This characteristic also includes any physical interactions that are incorporated into the high-resolution game, since the actual players become another input device. Whether through motion tracking or another method, it is important for the game to design the physical interactions in such a way that they are appropriate to the game at hand.

6.3 Improvements

PyBomber serves as a starting point in high-resolution gaming. Along the way, lessons have been learned that can be applied to future games in this field.

6.3.1 More physical interactions

A goal for PyBomber was to have a significant volume of physical interactions between players. Unfortunately that did not happen naturally. In the future, any game desiring a high level of physical interaction amongst players will need to design the game in such a way that physical interactions are required.

There are several possible ways to encourage and/or require physical interactions between players. The first method would tie player input to the physical space in some way. Output in PyBomber was in some ways linked to physical space in the sense that players blocked each other's view. This concept could be extended to input devices.

This could happen with tracked input devices or touch screens. The screens or tracking could be interrupted by other players in physical space. This could happen inadvertently or on purpose by blocking out.

The second way to encourage physical interactions between players would be to include knowledge of the physical space into the game itself. This would require some kind of tracking for each player. It would also provide a much higher level of richness in the interactions. An example of this kind of interaction would be tapping another player to trigger some kind of in-game action. As a result, the player to be tapped could physically move to avoid being tapped.

The incorporation of physical interactions into the game itself could also be achieved using some sort of game board in the physical space in front of the display. This board would define areas of space that trigger or modify in-game states. For example, there could be a certain region that provides a useful power to whoever is standing there. Different strategies could then emerge to handle who gets to stand in the space or how an opponent's access to this space could be limited.

6.3.2 Collaborative gaming

The level of collaboration between players in PyBomber was fairly low. The primary reason for this is that the game did not do much to encourage collaboration. Future high-resolution games have much room to improve upon this.

Collaborative gaming has been explored extensively in traditional computer games. The difference is that high-resolution games increase the number of co-located players significantly. This change should allow the extension of collaborative gaming principles into a larger environment, providing richer interactions due to the larger number of participants.

These collaborations could take place in two primary contexts. The first context is in multiplayer games such as PyBomber. The players on a team will be working together to defeat the other team. The interesting difference from normal games would be the shared nature of the physical space as well as the virtual space.

The physical space will be shared not just in terms of who stands where, but in the sense that people can overhear each other. This simple change could provide many different and interesting strategies. Similarly, the virtual game space is shared amongst every single player, so that everyone has a complete view of the game.

The other context for collaborations could be in single-input games that are in fact being played by several collaborating members. An example of this would be a puzzle game that is displayed across a large high-resolution display, allowing several people to view it together and work on different approaches as a team.

6.3.3 Reduced game complexity and social interactions

Observations made throughout the user trials for PyBomber have shown that players become fixated on the in-game action to the detriment of social interactions. This is evidenced by the large number of utterances and the relatively low volume of conversation. It was observed throughout the user trials that conversations could trail off as the players' focus shifted from speaking to playing the game.

To offset this, it may be necessary to reduce the complexity of the game somewhat. This reduction is expected to allow players to put a greater amount of focus into the social interactions occurring around them and less into the game itself.

6.4 Open-ended questions on high-resolution gaming

As an exploratory study, this paper has generated more questions than it has answered.

- How does the resolution, and by extension the size of the gameplay area, affect the way in which the game is played?
- In what ways, if any, is the twelve-player version of the game more intense?
    - Why does this happen despite the density of game objects remaining constant regardless of the number of players?
    - Is it because the larger number of players cluster, leading to a higher local density of game objects while not affecting the global average?
    - Is it because players attempted to keep track of everything in their head, leading to a cognitive overload?
    - Is it related to the physical space and the social interactions happening within it?
- What are all of the factors that could affect a player's enjoyment of the game?
    - Is game performance a factor? If so, how large of a factor is it?
    - How do the social dynamics factor in to a player's enjoyment of the game?
    - Is movement enjoyable to players? What if the movement is not directly related to the gameplay (like in PyBomber)?
- How does a split view compare to a single shared view?
    - Does a shared focus affect the social dynamics?

- Do all types of games benefit from a shared gameplay area? If not, which genres do and which do not?

- How does the intensity of the game affect the richness of the social dynamics?

6.5 Future High-Resolution Games

There are several possible routes for high-resolution gaming to take from here, none of which are mutually exclusive.

6.5.1 Highly Multiplayer

This route would continue the trend started by PyBomber. This type of game will be fairly simple on a per-player basis. However, when a dozen (or more) players are all going at the same time, the complexity and entertainment value will increase drastically. Highly multiplayer games will be fairly competitive in nature.

6.5.2 Strategy Games

Strategy games should take well to high-resolution displays due to their large, shared maps. This type of game will likely be single-player in nature, with the possibility of collaboration in the context of strategy. The huge volume of information on the display will be an enormous advantage for the high-resolution players if they are up against people on normal displays.

6.5.3 Puzzle Games

Puzzle games stand to take good advantage of high-resolution displays in their ability to scale. A good example of this would be a giant crossword puzzle game. This game would allow several people to work together on a very large overarching goal. It is possible that the massive play area would inspire a completely new type of puzzle game that cannot be accomplished on a smaller scale. The collaboration potential for this type of game would be very large.

6.5.4 Highly-physical games

The physical space in front of a large high-resolution display has enormous potential in terms of physical interactions. Especially when combined with motion tracking, this space will allow for the creation of games that involve very large amounts of physical interaction.

These interactions could involve a single player with a sizeable area to move around in. With a minimized possibility of collisions, a single player could run, jump, or move around in any way that they see fit. The game itself could enforce certain interactions, or leave it open to the player to be creative.

The large space for physical interactions could also be used to facilitate several players interacting physically. These interactions could be between the players, between the players and the game, or a combination of the two. Player-to-player interactions would not directly affect the game while player-to-game interactions would not directly involve other players.

6.6 Summary

High-resolution gaming is a minimally-explored area of gaming that has enormous potential. Through the studies associated with building and play-testing PyBomber, several characteristics have been identified that are present in a good high-resolution game.

It is important that a high-resolution game provides a single, shared screen space in order to maximize the usefulness of the display. The physical space in front of the display should also be incorporated into the game in some fashion. Feedback from the game to the players needs to be localized or else the players will usually ignore it. Lastly, the input devices need to be incorporated into the game in a way that is appropriate to large high-resolution displays.

Chapter 7: Conclusions

7.1 Conclusions

7.1.1 Research Question 1: Is game design on a large display different?

As hypothesized, many of the facets of game design were shared with traditional games. However, it was also true that some things needed to change in order to support higher resolution and more players. PyBomber was based on an already successful game franchise. Therefore, it is implied that the basic game mechanics are solid.

The difficulty in taking advantage of such a large display is putting all of those pixels to good use. It would be simple to use them to make a higher-quality image to show. But to use them to improve gameplay is another matter. One such way to achieve that is to increase the number of players in the game.

Adding more players complicates the design process in other ways, though. It is possible for most people to keep track of three other players, as would be seen in a four-player game. However, no-one is capable of keeping track of twelve-players concurrently. This increases the cognitive distance markedly [35]. This introduces a need to reduce the gulf of evaluation somehow.

A prime example of a design change with the goal of a reduction in cognitive distance was the use of faces in the game itself. This removed the need for players to mentally keep track of the mapping between each sprite and the person controlling it.

A second example of such a design change is the inclusion of bomb previews. It proved overly difficult for most players to keep track of the radius for their own bombs. In light of that, expecting them to also keep track of the radius of all the other players is not possible, especially on a high-resolution display with so many other players. That is where previews come into play. They provide an obvious visual indicator as to the radius of a particular bomb. This proved especially critical when a player had enough powerups to make their explosions span several screens.

One aspect of game design that did not change between normal and high-resolution games is the need to play test. Playing the game with real people is invaluable in the progression from a prototype to a real, enjoyable game.

7.1.2 Research Question 2: Is co-located gaming on a large scale enjoyable?

The results regarding player enjoyment in PyBomber were promising, if not fully conclusive. The necklace ratings showed that in the context of PyBomber, the four-person condition was more enjoyed than the twelve-player condition. Unfortunately, this contradicts the hypothesis for this research question. Regardless, both versions of the game seemed to have been enjoyed by the participants.

The most likely explanation for greater enjoyment in the four-player variant of PyBomber is that many of the players became overwhelmed in the twelve-player version, as noted on their survey responses. With so many players, there is simply too much going on at the same time for some players to keep up. This leads to those players losing confidence and becoming frustrated with the game.

There are two possibilities stemming from this theory. The first possibility is that high-resolution gaming is suited to a more experienced and competitive demographic. This possibility is reinforced by the link between preferring the twelve-player variant and reporting more frequent playing of video games. In this case, it would be beneficial for PyBomber to tailor itself more towards the "hardcore" game market.

The other possibility is that the design of the game needs to be altered to reduce the in-game interactions between players somewhat. This happened to a limited extent in the team-based variant of the game. One participant noted on their post-experiment survey that "four players in teams has too few enemies, twelve players in teams is a good mix of interaction/strategy/skill". This type of change would allow high-resolution gaming to appeal to a wider audience, while sacrificing some amount of in-game interactions.

It is unfortunate that particular necklace ratings were not associated with a particular participant. This would have allowed the game data to be analyzed alongside the ratings.

No conclusions can be drawn regarding the enjoyment of team or non-team gameplay, at least in PyBomber. Most likely the reason for this is the limited impact of team play. The difference in gameplay modes is who a player can target. No overall team goals were provided besides a team-wide score.

In order to maximize the potential of team gameplay, it is ideal to design for teams from an early stage in the game design process. Team-based gameplay in PyBomber is admittedly a later addition to the game. This is evidenced by its limited richness. A more compelling team experience would force players to work together and punish them for not doing so.

These conclusions on high-resolution gaming apply only within the context of PyBomber. It is possible, even likely, that it would be possible for another game, or genre of games, to be more enjoyable on a high-resolution display with many players. PyBomber serves as a minimum. It has been shown that high-resolution, highly-multiplayer gaming has the potential to be as enjoyable as PyBomber.

7.1.3 Research Question 3A: What kind of social interactions occur?

As seen in the results above, the social dynamics in a co-located high-resolution game shift when the number of players increases. The time in a large game was filled to a much greater extent with social interactions. Most of these social interactions took the form of utterances. Interestingly, few of the utterances were part of an actual conversation.

These utterances, along with many of the social interactions, were triggered by the game itself. Because of this, they were bursty in nature. The triggering events, such as several people killing each simultaneously, occurred more frequently in the larger games.

It is interesting that we observed the virtual aspects of the game to be too involved in some ways. This tended to lead to people being completely focused on the game while neglecting the social interactions around them. This was evidenced by the large volume of talk contrasted with the limited amount of true conversation.

The exception to this occurred between rounds, where players would gather and talk. We were able to see some initial aspects of rich social dynamics, such as people moving around each other and talking often. There is an opportunity to reduce the intensity of the virtual game and bringing more physical-social interactions into the fold. These interactions would involve both a social and a physical component, such as blocking another player's view, tagging another player, or moving to a special physical location to trigger an in-game effect.

In this study, a small number of physical-social interactions took place. These were mainly limited to occasions where a player purposely blocked the view of another, or when someone pushed someone else. There was a high level of variation between the groups. In the future, it may be possible to study why that is, and if there are any ways to encourage it.

There were no measurable differences in the social interactions between the team and free-for-all versions of the game. The reason for this is likely that PyBomber's team-based mode had no over-arching team goals that encouraged collaboration.

7.1.4 Research Question 3B: How do players move in the physical space?

The hypothesis that the physical space in front of the display would be used was only supported in a limited fashion. The examples of players using physical interactions were limited to one or two occasions where a player purposely blocked the view of another. However, the space in front of the display was frequently used for movement to get a better view of the game.

Some players seemed comfortable to settle into a single location and remain fixed. However, many players moved in the physical space in front of the display to improve their view of the playing area. This virtually never occurred in the four-player variant of the game, since the players were able to space out and stay out of each other's view.

In the twelve-player variant of the game, players frequently had their view blocked by other players, often by accident. Regardless of the cause, these players had to react in some way. In some cases the reaction was to physically relocate to a different region of the space in front of the display. Overall, about 10% of a twelve-player round involved at least one player actively moving around.

This hypothesis is partially supported by evidence. The expectation was that the game itself would extend to the physical sense in some way. This did not occur. However, the physical space was put to good use when players attempted to establish a clear view of the display.

7.2 Contributions

This study has served to provide a base upon which other high-resolution and/or highly-multiplayer games can build. A primary goal was to demonstrate the feasibility and enjoyability of this new type of gaming. In many ways it was a success.

This study has also shown that when so many people are playing together in the same space, they will move around and interact verbally. The amount of speech and movement is promising. As it stands, there is room for improvement in both of these.

Also, the user study conducted as part of this paper has served to reinforce some of the general ideas about both high-resolution displays and in HCI as a whole. For example, the user interfaces on a high-resolution display have different requirements from those on a normal display, as seen in previous studies [10, 28].

As an exploratory study, numerous questions were also generated over the course of the development and user trials. These questions are useful in that they will serve to guide future research in this field towards some of the more pertinent and interesting questions.

7.3 Lessons Learned

The first lesson learned while conducting the user trials was to always have a contingency plan for finding participants. The initial response to recruiting was muted. Further perseverance proved fruitful, and a total of thirty-two participants were run, not counting the “filler” players. Unfortunately, participants can and do fail to show up with no warning.

Another lesson that was learned throughout the course of this thesis was to always gather as much data as possible. The idiom to “gather more data than you think you will need, and it still will not be enough” is true as ever. The anonymous nature of the necklace ratings single-handedly killed any chance of showing a link between performance and enjoyment.

A similar issue was the video footage. In a previous study footage was taken from both sides as well as from the rear. The analysis of this video made the second side camera seem redundant. While analyzing the video for the final user trials, a second angle on some moments would have been very useful. For most sessions, this extra video would have been wasted time and effort. However, in these few situations having the extra view would have been valuable indeed.

7.4 Future Work

There are three primary directions in which future work could head. The first direction would be to focus on one or more of the open-ended questions regarding high-resolution gaming. Each of these questions is interesting and relevant in its own way.

The second direction would focus high-resolution and highly-multiplayer games. This work would involve creating (or modifying) a game to take even greater advantage of the large gameplay area. A corollary to this would be to create a higher level of support for team-based gameplay. This work would segue into running more user trials on high-resolution, highly-multiplayer gaming. The goal for these trials would be to provide even greater evidence towards the enjoyability of the medium.

The third possible direction would be to put more focus into the social interactions. This work would still involve multiplayer gaming, but it could work on a smaller scale than twelve players. A focus would be placed on forcing interactions in the physical sense, in addition to the already-present game interactions. This could be accomplished through any number of methods. The physical space in front of the display, along with the tracking system installed above it, could be incorporated into the game in a more pervasive manner.

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Appendix A: User Instructions

Bomberman Instructions

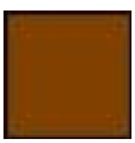
Object of the game:

To eliminate as many enemies as possible with your bombs, while dying as little as possible.

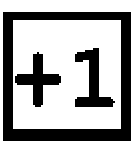
Controls:

D-Pad	Movement
“1 Button”	Plant Bomb
“2 Button”	Detonate Bomb

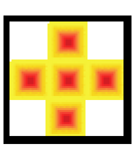
Game Objects:



Blocks – Destroy these with bombs to unveil powerups



More Bombs – For each of these that you walk over, you gain the ability to have one more bomb deployed at any given time.



Larger Explosions – For each of these that you walk over, your bombs will explode with a larger radius.

Note: When you die, you lose half of the powerups that you have.

Status:

- A red background behind your character represents invincibility. This means that explosions will not kill you. This status lasts for several seconds, or until you plant a bomb.
- A red background for the whole level means that the game has entered “sudden death”. This means that time is about to run out.

Appendix B: Informed Consent

Informed Consent for Participant of Investigative Project

Virginia Polytechnic Institute and State University

Title of Project: High-Resolution, Highly Multiplayer Gaming
Principal Investigator: Dr. Christopher L. North

I. THE PURPOSE OF THIS RESEARCH/PROJECT

You are invited to participate in a study of gaming involving a large, high-resolution display. This research studies the feasibility, worthiness, and enjoyment of gaming on a large high-resolution screen. This study involves experimentation for the purpose of evaluating and improving gaming on large high-resolution displays.

II. PROCEDURES

You will be asked to play a game for a specified period of time. The gameplay involves navigating a character throughout a two-dimensional world and planting bombs to destroy other players. Your role in this is simply to play the game. You are helping to evaluate this particular game. All information that you help us attain will remain anonymous. The scores in the game will be stored and video records will be recorded. You may be asked questions during and after the evaluation, in order to clarify our understanding.

You may also be asked to fill out a questionnaire relating to your background with computer games.

The session will last less than an hour and a half. The game is typically played while standing, but you may ask for a seat at any time. You may also terminate your participation at any time, for any reason.

You will be given full instructions before play begins. If anything is unclear, be sure to ask us questions.

III. RISKS

The proposed experiment is a straightforward game, involving a large high-resolution display and a Nintendo Wii Remote for input. Participation involves standing in front of the display, along with several other people, and playing a game. The physical components of this task are not stressful. All light and sound intensities are well within normal ranges. There are no known mental risks. The risks associated with participation in this study are minimal.

IV. BENEFITS OF THIS PROJECT

Your participation in this study will provide information that may be used to judge the feasibility and worthiness of gaming on large high-resolution displays. No guarantee of benefits has been made to encourage you to participate.

You are requested to refrain from discussing the evaluation with other people who might be in the candidate pool from which other participants might be drawn.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. Your written consent is required for the researchers to release any data identified with you as an individual to anyone other than personnel working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

The experiment may be videotaped. If it is taped, the tapes will be stored securely, viewed by only the experimenters (Christopher L. North, David A. Machaj), and will be erased after 6 months. If the experimenters wish to use a portion of your videotape for any other purpose, they will get your written permission before using it.

VI. COMPENSATION

Your participation is voluntary and unpaid.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science.

IX. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project

________________________________ ____________
Signature Date

________________________________ _______________________
Name (please print) Contact: phone or address or

____
email address (OPTIONAL)

Should I have any questions about this research or its conduct, I may contact:

Investigator: Dr. Christopher L. North Phone (540)231-2458
Professor, Computer Science Department (231-6931)
email: north@vt.edu

Review Board: David M. Moore Phone (540) 231-4991
Office 2000 Kraft Drive, Suite 2000 (0497),
cc: the participant, Dr. North

Appendix C: Background Questionnaire

Participant #:
Date:

Background Questionnaire

Please help us to categorize our user population by completing the following items.

Gender (circle one): Male Female

Age: ______________

Occupation (if student, indicate graduate or undergraduate):
____

How often do you play computer games...

a) not at all
b) once a month
c) once a week
d) several times a week
e) daily

Rate your expertise with computer games: (circle one)

•-----------------------•-----------------------•-----------------------•

beginner amateur intermediate advanced

Please rank how familiar you are with the other players of this gaming session.

1 2 3 4 5 6 7 8 9 10

Complete Strangers Longtime Friends

Have you ever used a large display system? If so, please describe it (what type of display was used, what kind of application (e.g. game, virtual environments, geospatial) was running, how did you interact with the system, etc.).

Appendix D: Post-Game Survey

Participant #:
Date:

Post-Game Questionnaire

Please complete the following questions.

1. Please rank how much you liked the game overall.

1	2	3	4	5	6	7	8	9	10
Hated									Loved

2. Please rank how much you liked the free-for-all variant of the game.

1	2	3	4	5	6	7	8	9	10
Hated									Loved

3. Please rank how much you liked the team variant of the game.

1	2	3	4	5	6	7	8	9	10
Hated									Loved

4. Which version of the game did you prefer?

Free-for-all Teams Equal Preference

5. How important to this game is the **social** interaction?

1	2	3	4	5	6	7	8	9	10
Not very									Very

6. How important to the game was your familiarity with the other players?

1	2	3	4	5	6	7	8	9	10
Not very									Very

7. How much would you like to come back and play this game again?

1	2	3	4	5	6	7	8	9	10
Not much									Very much

8. If you had access to a high-resolution screen, would you consider purchasing this game or something similar?

Yes No

9. What aspects of this game did you like/dislike?

10. Please feel free to add any comments, suggestions, and concerns.

Appendix E: Post-Experiment Survey

Participant #:
Date:

Post-Experiment Questionnaire

Please complete the following questions:

1. Please rank how much you liked the game with four players.

1	2	3	4	5	6	7	8	9	10
Hated									Loved

2. Please rank how much you liked the game with twelve players.

1	2	3	4	5	6	7	8	9	10
Hated									Loved

3. Which version of the game did you prefer?

Four players   Twelve players   Equal Preference

4. Please write any miscellaneous comments that you may have.

Appendix F: Miscellaneous Snapshots

Figure 24: Trial 1

Figure 25: Trial 2

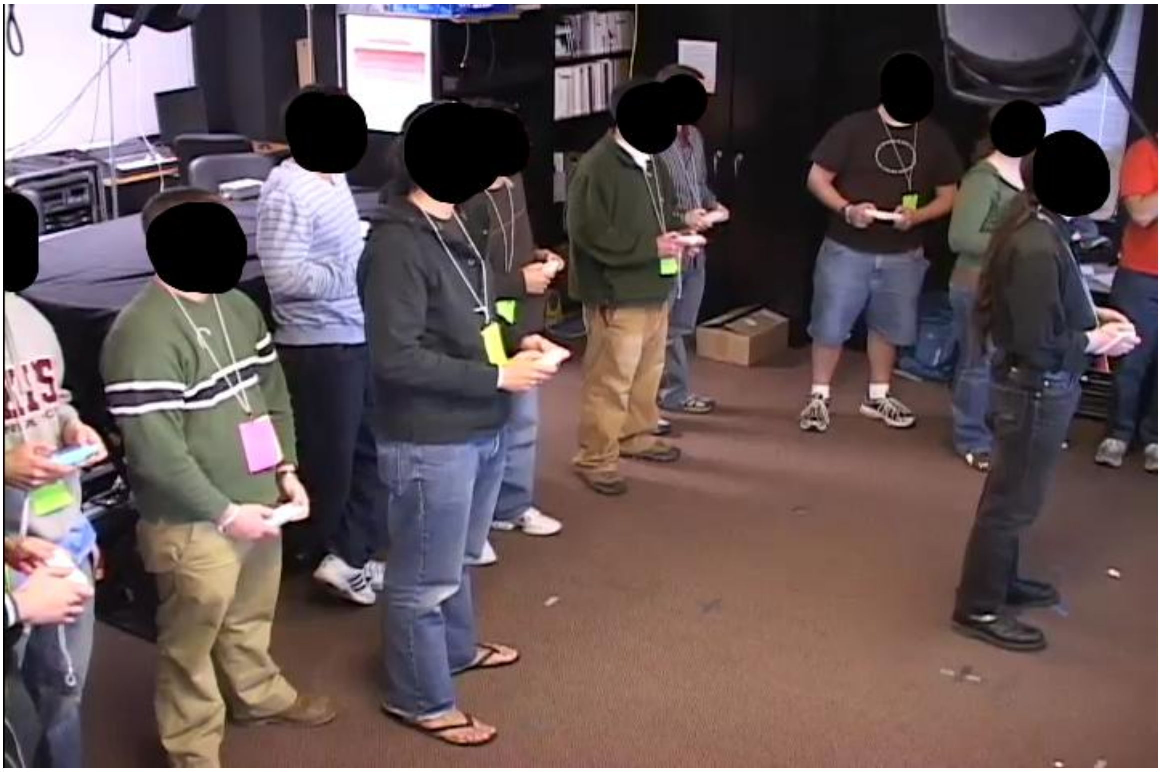


Figure 26: Trial 3

Figure 27: Trial 4