Discussing the Effects of Visual Scaling on Games

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Abstract. We are interested in a systematic understanding the effect of *visual scaling* — changing the size of the screen, while holding other factors constants — on gameplay. Through examples, we illustrate the effects that arise. We investigate scaling up as well as down, and find that the effects are quite different. We give a first classification of the underlying causes that give rise to these effects. We hereby hope to start a scientific analysis of visual scaling and its relation to gameplay.

1 Introduction

In recent years, we have seen an explosion in the variety of displays: cell phones, tablets, 19" to 30" PC displays[1], ever larger televisions, and even fully immersive 3D virtual environments. Game developers have attempted to deal with this variety using different means while retaining the essential character of their game. While small changes in visual scale (say from a 19" monitor to a 21" monitor) are usually barely noticed, changes in scale reach a point where a game is fundamentally altered from its intended design. One can only imagine the horror of playing *StarCraft II* [5] on an iPhone 6, or Piano Tiles [9] on a 70" wall mounted touch screen! Thus two research questions arise: 1) Can a game be scaled to different display sizes such that players subjectively feel that they are still playing the *same game*? 2) What are the factors that would prevent a game from delivering the "same game" experience at different *visual scales*?

Usability of large displays for productivity [11, 4, 8] has been studied, but many of these issues do not apply to games [25]. For example, in a game, it is difficult to lose the cursor as the cursor is often exaggerated or the player's avatar **is** the cursor. Similarly, responsive interfaces [18] also worry about visual scale by adjusting with respect to browser width to make the "best" use of the available space. However web sites can scroll, which is not feasible for most

[1] It is unfortunately standard to measure of displays in inches, even if that pains us greatly.

Fig. 1: A Protoss army (gold; green on mini-map) attacking a Zerg army (brown; purple). Left: uniform scaling, right: non-uniform scaling

games. A variant, adaptive interfaces, achieves similar aims by pre-formatting a web site for 6 different screen size configurations.

But what exactly is *visual scale*[2]? Three factors control the (perceived) size of an image: the physical size of the screen (typically given as the diagonal measurement of the screen in inches), the resolution of the display (the number of pixels in the horizontal and vertical dimensions), and the pixel density (how many pixels there are in a square inch of the display) [27]. By "scaling", we mean changing the *effective size* of a game's display. Usually this is because the physical size of the screen itself has changed, but scaling also happens when a game uses pixel-based measurements and the resolution of the display changes.

We distinguish two kinds of scaling: uniform and non-uniform (see Fig. 1 for an example). Uniform scaling is when the size of game elements is proportional to the screen size. This is done automatically by graphics hardware on displays that have the same resolution. When the display resolution changes, game elements are stretched to keep the same relative number of pixels. In non-uniform scaling, each game element can be scaled differently (by programming this explicitly into the game). One can give size limits to game elements; or fix the size of game assets and change the size of the play area — the Field of View (FoV). Movement speed appears the same because the same relative distance in the play area is traversed per second. However gameplay can be seriously affected by the change in FoV.

We consider how the gameplay experience is affected by changing screen size (up or down) and scaling method, assuming all other factors (e.g. controller, platform, viewing distance, etc.) are held constant. To show the variety of effects,

[2] As we are only concerned about *visual* scaling in this paper, we will henceforth just use 'scaling'.

we will use three games (*StarCraft II*, *Duck Hunt*, and *Fruit Ninja*) chosen as they are both well known and serve well to illustrate each of our observations. We hypothesize that experiential changes will be the result of unintentional shifts in the *perceivable amount of information*. Changes in perceivable information affect underlying gameplay mechanics such as *selection tasks* and *perception tasks*. This triggers issues with the human perception, memory, and motor systems [13, 10, 21]. This may seem obvious at an intuitive level – but a solid understanding crucially depends on the details, and is a precursor to any future mitigation strategy. In this discussion paper, we will mix observed effects (either directly observable or obtained through the literature) with speculation of the effects we would likely observe. Our aim is to come up with the *effects on gameplay* that comes with scaling, and classify their root causes.

2 Assumptions and Setup

Our scenarios share some assumptions — most importantly that design choices must reflect an attempt to preserve the game designer's "intended player experience". This is particularly important for non-uniform scaling, where we will only consider design changes that *might* preserve the experience. For example, when scaling down non-uniformly, we consistently choose to decrease the gameplay area, but maintain the HUD and game objects at their original size.

As we aim to isolate visual scale, for each scenario we fix the controller and the viewing distance such that individual pixels are indistinguishable. Individual configurations of display type or mouse speed scaling (and other input methods) may vary between examples, but stay fixed within each scenario.

For uniform scaling — due to the fixed viewing distance — the relative distances between objects, and absolute speed of objects remains constant. However individual objects will subjectively appear larger when scaling up (and smaller when scaling down).

We also assume an *average* player — neither a novice nor an expert, and certainly not a professional. For example, we assume that the player uses keyboard shortcuts often (when available) and has memorized the HUD. We consider players to conform to the *Model Human Processor* framework, where they act as a set of perceptual, memory, and motor subsystems [7]. The average player should not experience *unintentional* overloading of any individual subsystem during play, as that would "break" the designed experience.

3 StarCraft

StarCraft II: Wings of Liberty (SC2) [5] is a real-time strategy game for Windows and macOS. One mode of play is "1v1" where players engage an opponent — usually another player — with the goal of destroying the opponent's bases and army. Gameplay tasks involve: delegating units to collect resource, constructing bases, as well as building and commanding an army of units in real time. This requires attention to detail, multitasking, and rapid input.

We assume keyboard and mouse input, with the screen being a 24” LCD with a 16:9 aspect ratio. Figure 1 shows scaling (left: uniform ’down’, right: non-uniform ’down’), showing changes to the FoV.

3.1 Scaling up

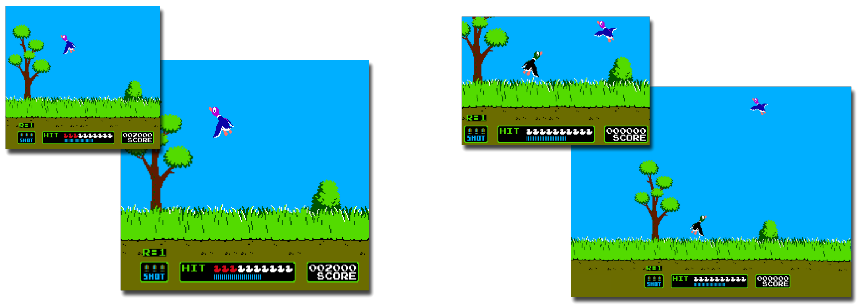
Uniform. For large displays (e.g. 60”) viewed at a fixed distance (and the same distance as for ‘normal’ play), the player loses the ability to maintain the entire play area in their FoV. Therefore they must move their heads to gather information, which is tiring and slower than eye saccades, creating a significant disadvantage. The player might not perceive that they are being attacked in a timely manner. Because SC2 requires players to quickly ascertain their status through the information immediately available to them, the lack of *information locality*[3] hampers their performance.

Non-Uniform. The visible play area is expanded to fill the display and the HUD takes less room. Thus the player may be able to observe more of their army — even if only peripherally — without panning. As the play area increases, the mini-map may prove progressively less useful. A small-to-moderate increase in play area is likely quite beneficial, by allowing them to see danger sooner; but for very large screens, the challenges discussed above become an issue. Changing the mouse speed will also hamper performance. At some point information overload may be a problem (information overload occurs when there is more relevant information to be processed than can be comfortably achieved at the games’ pace). A variety of underlying factors are at play. The advantage of information locality morphs into information overload as the player begins to see too many units and can’t track and process the available information. Selection precision decays for moving units as the target sizes have effectively become smaller (as per Fitts’ Law). Thus scaling changes the experience dramatically, as what may be advantageous in small amounts becomes detrimental at larger sizes. Controlled experiments are needed to understand the impact on the gameplay experience.

3.2 Scaling down

Uniform. The main effect of uniform down scaling comes from smaller icons, which are harder to differentiate and select, causing the player to slow down – a serious disadvantage in a time-sensitive game. While an advanced SC2 player may be able to play on a screen as small as 10”, the strain would likely be considerable. A cellphone seems to be totally out of the question without implementing serious changes to the game.

[3] We define *information locality* to be when all the required information for effective gameplay is within a player’s current visual focus.



(a) Uniform (b) Non-uniform

Fig. 2: Visually scaling *Duck Hunt*

Non-Uniform. Non-uniformly scaling down restricts the player's FoV which is further reduced by a comparatively larger HUD (to maintain text legibility and distinguishable icons). Enemies become harder to see, and the player requires more activity (panning) to observe what is readily visible on a larger display. Success in SC2 depends on perceiving and processing a lot of information, having to constantly pan would seriously slow down the players' perceive-reason-act cycle, putting them at a significant disadvantage. The *perceive-reason-act cycle* is the simplified decision cycle for cognitive agents described by Russell and Norvig [24]. It is based on the perception-action cycle in cognitive psychology [14] which describes how human information processing works. Conducting experiments to understand the quantitative effect on the perceive-reason-act cycle and player performance would be quite interesting.

4 Duck Hunt

Duck Hunt [20] for the Nintendo Entertainment System (NES), is a single player, light gun shooter game, where the player "shoots" ducks that fly across the screen. Gameplay consists of three rounds with ten ducks to shoot in each. One or two ducks are released at a time, depending on options chosen, and for every released duck the player gets three shots to hit them. The ducks follow a zig-zag path, turning three times before escaping. The goal of the game is to get a high score by shooting as many ducks as possible. The original game is played with the *Zapper light gun*, a controller that only worked with CRT TVs.

We analyze a modern versions of the game, using a keyboard and mouse, and a 24" LCD monitor. Figure 2 illustrates both kinds of scaling. The challenge of *Duck Hunt* is to accurately aim and shoot at moving targets in a limited amount of time — a time-limited selection task. Despite target movement, the best model for such tasks is Fitts' Law [10].

4.1 Scaling up

Uniform. The ducks get (relatively) larger, and thus selecting and tracking targets becomes easier, which is consistent with Fitts' Law — further supported by Browning et al. [6]'s experiments for moving targets. Selection difficulty may be affected by mouse speed — if it is kept constant while the size of the screen increases, movement time will increase. For an extremely large screen, if mouse speed scales uniformly, the game should become very easy — even with head movement taken into consideration.

Non-Uniform. This increases the play area, and thus the distance that the ducks can travel. Though the screen size is increased, the duck's movement speed is fixed to the original speed to keep with the designer's original intent for the game's player experience. As well, since the duck size is unchanged, they appear to be smaller (see Figure 2b), making them more difficult to hit. However, the difficulty is mitigated by the larger travel distance, i.e. the ducks remain on screen longer. Thus the selection (aiming) task becomes easier. Proportionally scaling the duck's speed to the larger gameplay area will make the ducks appear to move faster. However, their time on screen would match that of the original game. If duck movement speed is proportional to the size of the gameplay area, then continuing to scale up would make the targets smaller and faster than originally intended, thus making the game increasingly difficult. With a sufficiently large screen, fatigue from large movements to aim at the ducks would be a problem too. Modern VR interpretations of *Duck Hunt*, such as *Duck Hunter VR* [15] and *Duck Season* [26], have a (large) fixed duck size and almost infinite gameplay area. The repetitive stress of moving your head and neck to search and aim wears the player down. On an extremely large screen, tiny ducks moving extremely quickly would create an almost impossible to play game — incredibly fatiguing on both perceptual and motor senses. In other words, the lack of information locality can also lead to physical fatigue.

4.2 Scaling down

Uniform. The left-top image of Figure 2a shows the game uniformly scaled down. The game becomes more difficult as each target is significantly smaller, making selection of moving targets harder. This is consistent with Browning et al. [6], where it was found that moving target selection performance was significantly worse on small displays than on medium-sized displays.

Non-Uniform. As the left-top image of Figure 2b shows, the distance over which the ducks can travel is much smaller, with larger ducks. Again, as per Fitts' Law, larger ducks make the game very easy. Varying the speed of the ducks could rebalance the game back to its original difficulty, though the pace becomes faster than the original. The game would also shift from a tracking task to almost a pure reaction-time selection task, forcing the player to shoot the ducks as soon as they appear on the screen — at least until the screen is so small that the ducks fill the whole play area!

5 Fruit Ninja

Fruit Ninja [17] is a single-player mobile game where players “slice” fruits by swiping their finger over them on the screen. We focus on the game’s *ARCADE* mode where fruits and bombs move in from multiple sides of the screen and the player has one minute to get a high score. The player gains points by slicing fruit, but slicing bombs ends the game.

We fix the hardware to an iPhone 3GS (the original platform — and thus the intended gameplay experience) in landscape mode and laid flat on a tabletop. Landscape is forced by the game, while having the phone flat on a table is to mitigate potential fatigue from holding the device. As the original game was for very small screens (3.5”), we do not discuss scaling down.

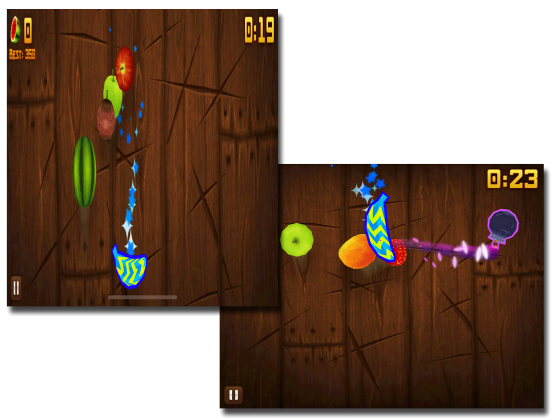


Fig. 3: Uniform scaling *Fruit Ninja* for different aspect ratios

Effectively, *Fruit Ninja* is a modern derivative of *Duck Hunt*, as both involve targeting tasks, with the principle differences being the interaction method (touchscreen vs. mouse) and the number of targets on screen at a time. As such, we will only cover aspects not already covered in the previous section.

5.1 Scaling up

Uniform. As with *Duck Hunt*, the selection task part of the game gets easier; however, the added complexity of bombs (targets that should not be hit), which have been similarly scaled up, means that the overall difficulty actually remains the same. However, as screen size increases, the interactions with the touchscreen become more energy consuming. At 3.5”, “swiping” is a movement of the fingers, while at the size of a tablet like a Cintiq (some as large as 24”) movements begin to involve the shoulder and forearm. Exaggerating the size further would result in a full body experience, where players need to move quickly, making gameplay significantly more tiring.

There is another facet of mobile that affects games like *Fruit Ninja*: aspect ratio. Uniformly scaling the game to fit the screen, there may be odd stretching or skewing of the fruits and other icons (e.g. Figure 3). Other than changing the aesthetics of the game, for reasonable aspect ratios, there is little difference in gameplay. Of course, extreme changes would have an effect on selection (aiming at targets), and can be computed using Fitts' Law.

Non-uniform. We choose to consider non-uniform scaling where the play area changes and the size of the fruit and bomb are unchanged. Scaling up increases the relative distance between the moving targets. While this may make it easier to navigate around bombs, it would increase the difficulty in "slicing" all the fruit in on motion — therefore resulting in lower score.

6 Discussion

Varying the visual scale in our examples "broke" the designer's intended player experience in various ways. The take-away from this exploration is that, while games don't all break in the same way, why they break seems consistent with our original assumption (unintentional overloading of a player's subsystems, cognitive or motor). We found that there are two aspects of games that correlate to specific subsystem breaks: *information density* and *information distance*.

Information density is the *amount of information* on the part of the screen that is in focus. Information density correlates to break downs in the perceptual subsystem, and is affected by scaling. Increasing the information density increases the difficulty of perceiving individual pieces of information, eventually overloading the player's perceptual subsystem, resulting in decreased performance in games involving selection tasks. Decreasing information density makes the perception of information easier until the issue becomes one of information distance.

Information distance is the distance between *relevant information for effective gameplay* and the player's FoV. *Information locality* is when **all** relevant information is in the FoV. As visual scale changes the FoV, the amount of information that players have access to at a given time changes. A restricted FoV increases the information distance as information is relatively further apart (eventually requiring panning), while an increased FoV decreases information distance as information is relatively closer together.

Increased information distance changes the gameplay experience by making the player exert more effort to gather information for effective play. This correlates to an increased strain on the motor subsystem by increasing the amount of physical energy the player must expend to effectively play the game (panning, scrolling, etc). All actions require energy and, with repetition, will fatigue the player. Fatigue decreases the engagement of the player with the game and may decrease their performance [16]. As screens increase in size, and VR becomes increasingly popular, player fatigue will become a major design consideration.

Increased information distance may also overload the memory subsystem, specifically the working memory [1–3]. We know that there are limits to short term memory, which differ based on information type [19]. By increasing information distance, the player must attempt to remember information that was previously in their FoV. This becomes particularly salient in games where availability of information is a key element to developing and executing strategies, like SC2 and *Civilization V* [12], or where the entire playable area needs to be seen to infer information, like *Nonograms* [23].

Decreasing information distance has two kinds of effects. A small decrease can improve overall performance, as was seen in a variety of experiments [22] that showed that diegetic versus non-diegetic is not quite as important (for performance) than information distance. Peacocke et al. [22] performed controlled experiments to measure the perception efficiency of various kinds of information displays for HUDs; generally speaking, it is indeed information distance and density which matters more than diegesis. However, a drastic decrease in information distance may cause overloading of the perceptual and memory subsystems. This was seen in *StarCraft II* where at a sufficiently large size there is too much information available to effectively track it all; furthermore, filtering between relevant and irrelevant information becomes quite stressful.

7 Future Work

Our findings identify how the human motor, memory, and perceptional subsystems are affected by changes in visual scale. Other subsystems may be affected as well, but our work as not yet uncovered such effects. Further aspects might emerge through a systematic exploration of visual scale via controlled experiments. Finding them is important as it improves our understanding of what contributes to experience at different scales. We also encourage more research into finding the limits of experience — accurately defining the boundaries of screen size that preserve a specific experience. By understanding these boundaries for different types of games, we will be able to better inform design decisions for scalable games.

8 Conclusion

By systematically analyzing some of the effects of uniform and non-uniform visual scaling on the gameplay experience of three specific games (*StarCraft 2*, *Duck Hunt*, and *Fruit Ninja*), we have seen that these effects all seem related to *information density* and *information locality.* The actual details of the effect on the player experience and/or the player's performance vary quite a bit between scenarios, but it does seem that, abstractly, there are indeed very few causes for those effects. We may then speculate why this is: as we have examined a single change to a game — the size of the visual display used for the gameplay — and this change is in the *physical realm*, it is unsurprising that the induced experiential effect is on the player's motor and lower-level cognitive skills. We also find that while some work has considered scaling down, very few seem to have seriously examined the problems of scaling up — probably because scaling up to even "large" monitors (24 to 30 inches) does not induce very large effects; only when one goes much larger do scale effects become quite obvious.

Our observations are supported by empirical research from a variety of fields, but we still find a dearth of systematic work studying such effects. We are hopeful that our work here might encourage others to systematically study the effect of visual scale on gameplay.

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