Esports and the Broader Need for More Interactive Displays

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ABSTRACT

Displays are being used for increasingly interactive applications including gaming, video conferencing, and perhaps most demanding, esports. We review the display needs of esports, and describe how current displays fail to meet them by using a high-latency I/O pipeline. We conclude with research directions that move away from this pipeline and better meet interactive user needs.

1 Introduction

For nearly a century, uses of modern display technology were largely passive, providing viewers with a largely identical linear experience that did not depend on their response. Today, with the growth of personal computing and gaming, display use is predominantly active, with every user receiving a highly individualized experience — part of a constant interactive dialog only they are having with their computer.

In this paper, we argue that:

- Esports is only the harbinger of a much broader demand for low-latency interactivity.
- Serving this interactive demand is much more challenging than many realize.
- To meet this demand, we must question fundamental assumptions about display design.

2 Interactive Display Uses Are Already Dominant

Esports — intensely competitive interactive computer gaming — is currently an industry with $2 billion in annual revenue [1], and is projected to triple in size by 2030. It is part of a much larger gaming industry with $350 billion in annual revenue [2], which is roughly twice the revenues of the film industry [3]. To meet the interactive needs of gamers, the display industry has recently begun producing displays with low latencies and high refresh rates.

Other display applications demanding low latency interaction are also emerging, including video conferencing [8], drones and virtual reality [9].

Yet the large majority of the displays the industry makes have long been serving the broader needs of interactive computer users. While the industry sells about 200 million televisions per year serving traditional passive viewers [4] (many showing content from 40 million gaming consoles [5]), it also sells 130 million computer monitors annually [6] — and more importantly, it makes the displays for about 1.5 billion smartphones sold each year [7].

3 Interaction Needs Much Lower Latency

The needs of esports for low-latency interaction are well-known, but more demanding than many realize. Moreover, the same low latencies would benefit all computer users, particularly those in the emerging applications we discussed above.

3.1 The Latency Requirements of Esports

Esports players and gamers need extremely low levels of latency to excel. Spjut et al. [10] found that shooting performance continued to improve even as latencies dropped to 25ms. Riahi and Watson [11] showed that even the subtle effects of adaptive display synchronization at 60Hz frame rates improve gameplay. Latency “floors” below which gaming performance no longer improves have not yet been established.

To meet these needs, the display industry has released increasingly high refresh and low-latency monitors, with many boasting single-digit input delays [12].

3.2 The Needs of Other Low-Latency Applications

Many other emerging applications likely have similar latency needs. Among display uses requiring head- and eye-tracking, virtual reality’s dependence on low latency is well known. For example, Caserman et al. [9] found that latencies below 70ms caused nausea, while Ellis et al. [13] report that latencies lower than 17ms are perceivable. Two other applications relying on similar tracking and likely with similar low-latency needs include current autostereoscopic displays [14,15], which must limit delay while presenting multiple views on panels with very high pixel counts; and very large, wall-spanning displays [16,17,18], which will demand bandwidths that also require tracking for foveation. Video conferencing is sensitive to latency [8], but latencies below 100ms have not yet been examined. Studies of the effects of latency on drone control are limited as well [e.g., 19], and have also not yet researched latencies below 100ms.

3.3 Regular Users Also Need Low Latency

But even regular computer users benefit from low latencies. Jota et al. [20] found that touchscreen user performance continued to improve as latency dropped to 10ms, and perhaps even further. Moreover, relative improvements in latency could have broad benefits to all users. Taylor [21] found that the average office worker makes nearly 25,000 mouse clicks per week. A 10ms improvement in latency per click has the potential of saving these users hours per year, quickly reaching days with greater improvements.

4 Displays Must Evolve to Deliver Lower Latency

Despite the recent progress made by the industry in meeting the low-latency needs of esports players and gamers, improvements are still needed, both in lowering latency itself, and in disseminating current innovations. Achieving these improvements will require questioning fundamental assumptions about display design.

4.1 Latency in Current Displays

As we have described, latency in current displays is reaching very low levels, with some displays having delays amounting to only a few milliseconds. However, these displays are part of larger PC systems. Carefully and laboriously tuned systems can reach latencies measured in a few tens of milliseconds [22,23]. Standard, “out of the box” systems have latencies ranging between 40 and 70ms [24]. The range of latencies in smartphones is similar, from about 20ms for gaming phones [25], to roughly 70ms for standard phones [26].

While these latencies may at first seem low, the lower-latency systems we report here are difficult for regular users to access, either because they are expensive and niche products, or because they require “hot-rodding” expertise: careful custom selection, assembly and tuning. Moreover, even the lower latencies may not be low enough, with touch interaction requiring latencies of 10ms or lower, and latency floors as yet unknown for gaming and other emerging applications.

4.2 Problematic Assumptions in Display Design

Two historical artifacts have significantly impacted display design. First, when modern displays were first developed, the dominant applications were non-interactive, naturally leading to the adoption of design solutions well-adapted to those needs. Second, during the advent of personal computing, the overarching goal was reducing cost, driving the industry toward modular design to open up the market and increase competition. Both of these impacts can still be seen in display designs today. Below, we offer only a few examples.

4.2.1 The Top-to-Bottom Scan

Since the 1930s, nearly all displays have refreshed pixels from the top row to the bottom. In those early days, there were sound engineering reasons for doing so, and since interactive uses of displays were very limited, it came at little cost to users. Today however, one has to wonder why the top-most pixels should be those with the lowest latency.

4.2.2 Buffering and Synchronization

To enable “plug-and-play” modularity in PC systems, computers were organized into separate subsystems (including the display) along the path between user input and user output. Ensuring this modularity often meant introducing buffering and synchronization delays, but these were insignificant when compute speeds were slow, and throughput (input sampling and frame rates) remained high. Yet today’s low-latency interaction demands have made these delays very problematic.

4.2.3 The Uniform User

To simplify design, displays have assumed that all users have the same needs, and even more, that each user’s needs do not change over time. No pixel was more important than another, no matter who the user was, or what they were doing. Today however, the needs of highly interactive, large-format, and stereoscopic displays are calling this assumption into question.

4.3 New Alternatives in Display Design

In today’s highly interactive application environment, displays — and the computing systems in which they are embedded — can no longer afford these assumptions. In this section we revisit each of the assumptions in Section 4.2, describe how they are beginning to break, and suggest how they should be broken.

4.3.1 The Top-to-Bottom Scan

Bishop et al. [27] came close to suggesting a random scan, advocating for a random pattern in computer graphics rendering, across both space and time. Dayal et al. [28] later proposed an adaptive random pattern biased toward spatiotemporal contrast. Regan and Pose [29] proposed a scanning pattern for VR that supported variation in both spatial and temporal sampling rates. Park et al. [30] described a true alternative display scan that exploited the viewer’s gaze with foveation.

We believe many other alternative display scans have promise. We are developing a uniform random scan that distributes latency equally across the display [31], rather than making the top of the display low-latency, and the bottom high-latency. Alternative distributions are possible, redistributing latency to adjust to the user’s gaze or interaction.

4.3.2 Buffering and Synchronization

The latency introduced by synchronization between the GPU (or indeed the CPU) and display are well known to gamers, who regularly turn it off [32], despite the tearing artifacts it introduces. Adaptive synchronization [11] is only a partial solution to this problem, redistributing the synchronization delay from the GPU to the display. Nevertheless the communication it requires is a first step toward tighter integration of the display into the larger computing system.

Our work on random scanning [31] hides the tearing that appears without synchronization by distributing samples evenly across the display. Going even further, Bishop et al. [27] also proposed reducing latency by eliminating double buffering, used to avoid display of incompletely rendered imagery. Such a scheme would only work if GPU renderers were changed to build images pixel by pixel, rather than triangle by triangle (with occluded triangles never being sent to the display). Today this is becoming feasible, with hardware support for ray tracing in modern GPUs [33]. We believe such deeper integration of the display into the computing system is crucial if we are to achieve further significant reductions in latency. As a first step, recent anti-lag technology [34,35] does not remove buffers, but improves synchronization between them. Broader system integration of this sort should make it possible for non-expert computer users to gain access to low-latency systems.

4.3.3 The Uniform User

Current autostereoscopic displays have already begun breaking the assumption of the uniform user by adjusting to users’ inter-pupillary distances, and indeed to their changing eye positions [14,15]. Similarly, some head-mounted displays adjust to the user’s gaze direction, and their focal length.

This trend of specializing to the user should continue. In an example of both specialization and tighter display-computer integration, we are working on computer graphics rendering that dynamically adjusts to the user's current view of an autostereoscopic display's optics [36], improving latency, resolution and image quality. Our random scanning design [31] can also bias scanning to reduce latency to match the user's gaze, or around their mouse cursor. To support wall-spanning displays, Whitted [16] also advocates not only for user-specific foveation [e.g., 37], but also tighter display-computer integration, and perhaps even alternatives to the pixel [e.g., 38, 39].

5 Conclusions

In this paper, we have described the low-latency requirements of esports, and sketched how low-latency interaction would in fact benefit a much broader set of computer users. As a contribution toward realizing this sort of interaction, we described a few fundamental display assumptions that should be reassessed, and outlined how those assumptions are already beginning to become questionable, and could be exploited if fully discarded. We look forward to continued work in realizing low-latency interactive computing systems, moving toward tighter integration of displays into their surrounding computer systems, and questioning not only these but other long-standing assumptions about display design.

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