Stochastic Scanning for Unsynchronized, Low-Latency Display Without Tearing

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Figure 1. The proposed stochastic scan with synchronization disabled

Abstract

Since their creation, displays have used the top-to-bottom raster scan. In today's interactive applications, this scan is a liability, forcing users to choose between complete frames with synchronization delay; or "torn" frames without this delay. We propose a stochastic scan that enables low-latency, unsynchronized display without tearing. We also discuss an interactive display simulator that allows us to investigate the effects of stochastic and other scans on interaction and imagery.

Author Keywords

refresh; raster scan; alternative scan; shuffle; tearing; VSYNC; delay; latency; synchronization

1. Raster Scanning can Harm Interaction

Television was developed in the late 1920s and early 1930s. Since then, television and indeed all types of displays have used the top-to-bottom raster scan to refresh and change pixel color. Over the following decades, display applications changed significantly, with passively viewed, recorded content giving way to interactively used, real-time content. Games, video conferencing, and word processing are just a few examples of these new applications, which require prompt feedback to user action, answering questions such as "Did I hit my target?", "Is this a good time to speak?", and "Did I click on the right word?"

In this new interactive context, the raster scan can be a liability. Because the rates at which computers generate images and displays refresh them are different, computers and displays are typically synchronized, delaying user feedback and slowing user interaction.[5] Without synchronization, screen tearing results (see Figure 2): a visual artifact that occurs when the computer delivers a new frame while the display is still scanning out the previous frame. It is often seen as a clear break in vertical edges when the objects in the image are moving relative to the camera. Despite this, gamers often turn off synchronization, tolerating tearing to reduce delay.[1] Research indicates that gamers may be justified in their actions, with even 30 ms harming interaction and 10 ms being visible. [2,]

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Figure 2. A typical screen tear using a raster scan

Moreover, the raster scan also distributes latency vertically across the screen. On the display itself the region of least refresh latency is at the top of the screen, where the first portions of the frame appear, with latency increasing downward to the display bottom. In addition, with synchronization disabled, there are also vertical differences in frame latency caused by partial frames made at different times appearing on the display. These are distributed vertically as well, but in the reverse direction: older partial frames appear at the display's top, while newer partial frames appear at the display's bottom.

This vertical distribution of latency and up-to-date information has no relationship to the interactive needs of users. For example, there is no reason that gamers might need to know if they hit their target more quickly at the bottom of the scene than the top, nor for writers to know more quickly if they've highlighted the correct word at the bottom of their document than at the top.

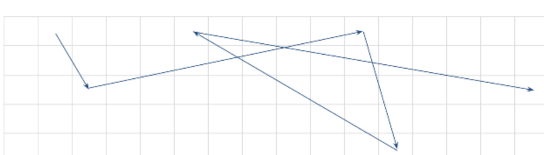

Figure 3. A partial stochastic scan.

2. An Alternative Stochastic Scan

We suggest that modifying the display scan pattern can avoid synchronization delay without introducing distracting tears, and without any sort of vertical bias in the distribution of new information.

We propose a stochastic scan. The next pixel to be displayed is chosen randomly, with each pixel equally likely to be next. No pixel is revisited again until all pixels in the frame have already been displayed. This stochastic order is pre-computed and well-known to both computer and display. Figure 3 diagrams a partial stochastic scan on a small display, while Figure 1 shows an example image during stochastic scanning when synchronization is off.

A stochastic scan has three primary benefits. First, on the display itself, stochastic scanning distributes refresh latency and new information evenly across the panel — a reasonable distribution since multipurpose displays cannot know which display regions are most important. Thus whether gaming, conferencing, or writing, users will find low-latency information to assist them.

Next, when the computer and display are unsynchronized to reduce latency, stochastic scanning achieves a similar distribution of frame latency, with new frame information again appearing evenly across the image, providing some low-latency support for any user interaction.

Finally, temporal artifacts are less distracting. Rather than displaying a localized, horizontal screen tear akin to spatial aliasing, stochastic scanning displays a "distributed tear" closer to visual noise (see again Figure 1), which our visual system tolerates better.[7] In addition, the more the computer's frame generation rate exceeds the display's refresh rate (sending more partial frames to the display), the better the stochastic scan's artifacts approximate motion blur, a natural

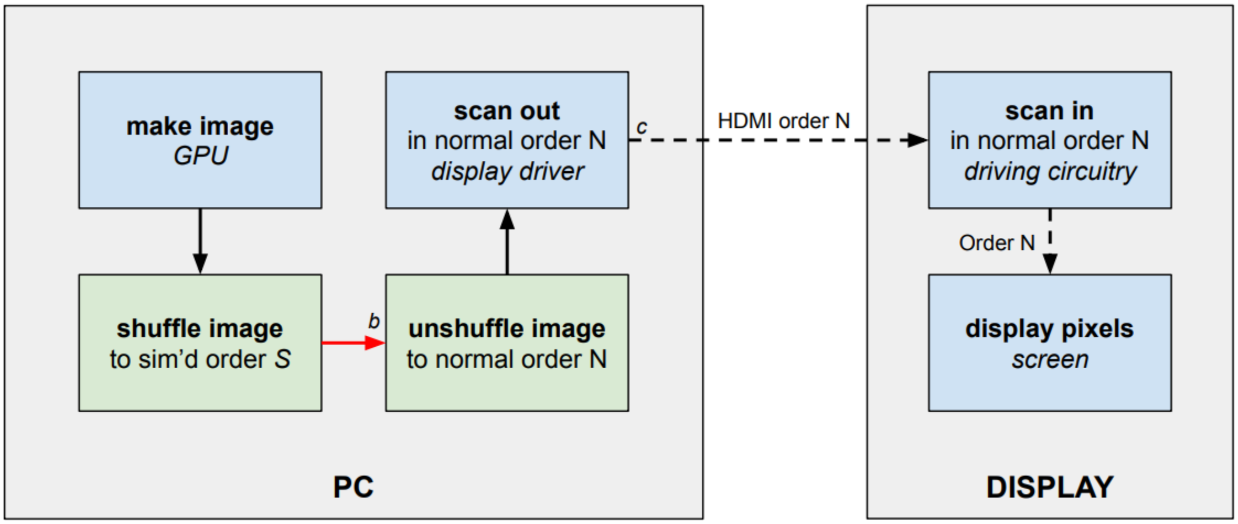

Figure 4. Our software simulator runs on a PC. It uses the novel scan order S before synchronization and HDMI scan out, redistributing the tear. The physical display scan is still in normal top-to-bottom order N.

component of human visual experience.[3] Of course, as with the raster scan, when the scene becomes static, the displayed image stabilizes and has no visible temporal artifacts.

3. A Display-Scanning Prototype

Unfortunately, current display driving components, which sequentially update pixel rows, cannot support a stochastic scan. However, we have been able to build a software-based prototype to demonstrate the effect of stochastic (and indeed any) order on scanning without synchronization, which allows us to evaluate human task performance with novel scans. It does not, however, simulate the effect of novel scans on the order in which pixels are illuminated on the display itself. To ease development and support evaluation, we built our prototype with FirstPersonScience, Nvidia's open source esports and gaming research software.[6]

Our prototype has two primary components: the *PC* and the *display* (see Figure 4). First, the GPU in the PC makes the current frame. Next, a custom shader within FPSci shuffles the pixels of the frame to a precomputed, novel order. The shuffled frame is then sent to another shader often unsynchronized with the first, which unshuffles the pixels in the received frame back to their original top-to-bottom raster order. When the shuffle and unshuffle processes are unsynchronized, this can mix the pixels from two or more frames together. Lastly, we send the resulting frames to a standard physical display using a top-to-bottom scan, so that users can see the final image.

Our prototype is able to display unsynchronized frames with novel scanning orders at frame rates over 60 Hz, using an NVIDIA RTX 4080 GPU. This is fast enough to support interactive viewing and use, enabling human evaluation. However, the shuffling and unshuffling steps would not be necessary in a fully implemented hardware hardware system, increasing delay slightly — in our prototype this added latency is 35ms, measured using NVIDIA's LDAT tool. Note however that we could use our software prototype to simulate any other scanning order for comparison (including the raster top-to-bottom scan), adding the same latency to any scans we compare with novel scans of interest.

To evaluate our prototype, we captured its imagery using a high-speed camera while it simulated synchronized and unsynchronized top-to-bottom. Our test video showed solid red being replaced by green in a right-to-left wipe. Figure 5 shows the results. At the left (a), synchronization avoids any tearing; at the right (b), a top-to-bottom scan shows tearing at the red-green boundary. These results indicate that our prototype is working, producing the variation in tearing we expect.

4. Limitations

As our prototype scanning simulator is purely software-based, it does not implement the scan on the display itself. So, while the generated images correctly model the visual and latency interactions between synchronization and the various scan orders, they do not reproduce the temporal effects on the physical scanout itself. We are working on updates to our simulator to better approximate the temporal aspect of the display scans.

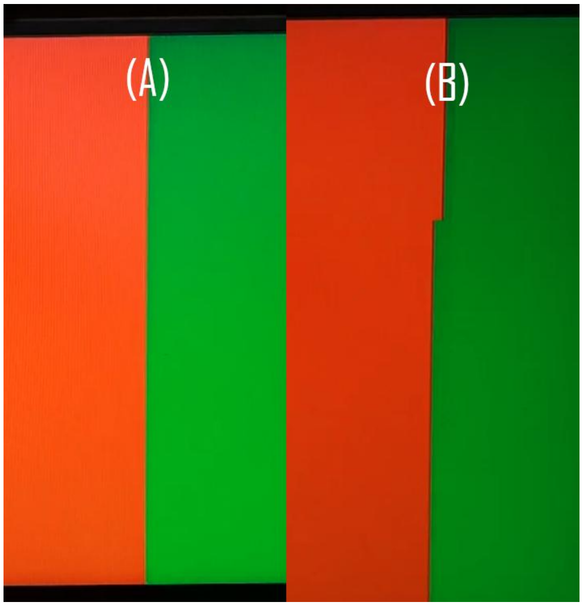

Figure 5. Images of our prototype simulating two different scans during a right-to-left wipe: synchronized (A) and unsynchronized with top-to-bottom scan (B).

5. Future Work

In the near future, we will assess the value of our stochastic scan in targeting performance during gaming. Participants will shoot targets in a typical first-person shooter setting, with the conventional raster scan in both synchronized and unsynchronized configurations, and with our proposed stochastic scans. We will assess both objective task performance, and subjective preference.

In the longer term, we will study additional alternative scanning patterns. The design of our software prototype makes it easy to generate and apply such patterns. We can easily generate pseudo-random sampling distributions to bias the sampling to update certain regions of the screen more quickly than others, for example the edge display before the center, the center before the edge, or even work in conjunction with an eye-tracking device to bias the sampling towards the eye's fixation point.

6. Conclusion

In this paper, we advocate for a stochastic over a conventional raster scan, to better support user interaction. This enables low-latency, unsynchronized display updates, without the distracting tearing caused by the raster scan. Moreover, recent, low-latency image updates are distributed across the display, rather than focused at the bottom of the display where they are often unuseful.

We also discuss our prototype that demonstrates this concept in real-time, enabling assessment of human performance differences using the proposed scan as compared to a raster scan. Additionally, using this prototype, it will be a simple matter to apply several new types of scan patterns to evaluate human performance and how it compares to using both the current standard and the proposed stochastic scan.

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