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[INTRODUCTION]

The use of pixels underpins almost all forms of contemporary digital imaging. Pixels are used throughout digital animation processes for capture, manipulation and presentation of images and animation, including within camera sensors, software applications and output or display technologies. As such, we often consider pixels to be the fundamental 'building blocks' of digital imaging across all stages and modes of the digital image. This is not to suggest the pixel is completely indivisible as a unit of imaging - the pixel itself is constituted by carefully modulated electrical signals, but from the perspective of the animator or digital artist, the pixel is usually the smallest practical constituent unit. In terms of digital materiality, both time and space in animation are similarly structured; timeline-based animation is comprised of frames, but perceptually we might say that it is constituted of *motion*, recalling Norman MacLaren's suggestion that animation is not so much 'drawings that move', but rather '*movements* that are *drawn'* (Ronald & Halas, 1974). Likewise, digital images are spatially constituted of an array of pixels that exist beneath the threshold of awareness. However, the use of pixels in animation and digital art has aesthetic and historical importance beyond the mere utility of the technology.

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In this entry, we introduce the reader to the evolution of bitmapped pixels in digital animation, and some of the concepts of producing and perceiving down-sampled images. Though the use of pixels is ubiquitous in the production and display of animation, they are often unseen due to increases in display resolution. The use of discernible pixels as an aesthetic choice often deliberately evokes our awareness of the process of perceptual interpolation from the limited picture elements available. It also evokes an awareness and nostalgia towards the period in technological history when pixelated images were prominent and hinted at the future of digital imaging. As such, the pixel can be a retro-futurist visual device, with connotations of both utopian and dystopian techno-futures and pasts.

[HISTORY]

The principle of creating images by encoding color information in sub-components is not unique to digital images. The Jacquard Loom, invented in 1803, uses a system of punch cards to store and control the warp and weft of tapestry strings, allowing for complex patterns to be stored, transported and reproduced. The thread sized patches of color revealed at each position in the final tapestry combine perceptually to create highly detailed patterns and images. Classical mosaics use non-uniform 'pixels' – such as stones or pieces of colored tile to create larger images in a similar way. Printing presses use a system of 'dot grids' which print tiny dots of color in various quantities, to create the impression of a full color spectrum while using a very limited palette (typically just four colors), similar to digital image pixels.

The earliest electronic broadcasting technology used entire lines, rather than individual pixels, whereby strips of luminance information were stacked on top of each other. Horizontally, the information varied across its span by modulation of an electrical signal. By separating images into reproducible components, images could be transmitted in wave form, and reconstructed at their destination. The deconstruction, transmission, and reconstruction of images in this way is fundamental to broadcast media, and to the digital image. In the 1940's and 50s, broadcast technology allowed audiences to experience animation in the home and not just in the cinema. Information transmitted by analog wave signals were reproduced on home television sets that used cathode ray tubes in conjunction with pixel matrices (though always imperfectly, with unplanned visual artefacts and imperfections potentially entering the technology stream at each stage). Media artists in the mid 20th century identified these technologies as constituting a new materiality of artistic expression, with artists such as Nam Jun Paik (Fig 1.), Andy Warhol and Dara Birnbaum experimenting with the reproducibility of the image and interventions with the transmission and reproduction technologies, deliberately exposing the relationship between the electronic signal and its reproduction on screen.

Fig 1. Nam June Paik's innovative media sculpture work reveals the functions and materiality of broadcast technology (Nam June Paik, 1965)

In 1968, the short animation *Kitty (ref),* which is often cited as the first computer character animation demonstrated the potential of this digital materiality of the pixel for creating a new type of animation. The film was produced on BESM-4 computer system and arranged for display by printing the frames using a dot matrix printer - another version of the pixel/bitmap paradigm, which allows the screen matrix to map to the physical world via the pin matrix of the printer. In this case, the pixels have only two modes – on or off. In terms of image quality, this represents a reduction in image complexity from equivalent so called black and white television images of the era, which could display a range of grey tones. But the ability to specifically manipulate each pixel intentionally represents a shift in process that brought artists closer to the material of the digital image.

Fig x. Kitty, animated the first pixel character animation (ref)

In the 1970s and 80s video game environments necessitated the creation of on-demand artwork and animation frames that encoded images as pixel values, rather than recorded electronic signal. This period also saw the rise of graphical user interfaces in digital artwork pipelines, allowing artists to use pixels directly during production, not merely relying on it for transmission and display of images. Pixel-native environments required efficiencies such as low resolution, limited color palettes, color dithering and animation shortcuts such as color cycling and sprite loops, for optimizing the limited memory and processing available at the time. These optimizations often became part of the language of digital animation from the period. Artists were able to extend the limited vocabulary of the pixels by utilizing the inherent imperfection of the screen display technologies. For example, television screens would tend to exhibit 'light bleed', so that the light emitted from a single pixel might merge with that of its neighbors, which when carefully controlled could extend both the apparent resolution and also the apparent color palette of the image. In this way, pixel art and animation became a material, unbound from its pure abstraction of encoded physical space and color space.

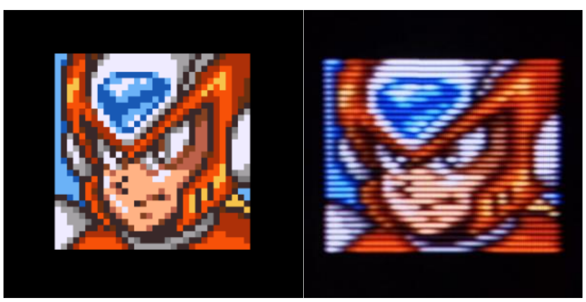

Fig 2. A comparison of the original pixel artwork for the Super Nintendo game *Megaman,* and their appearance when displayed on a CRT Television (Jordan Starkweather [@CRTpixels], 2021)

[PIXELS, PERCEPTION AND ANIMATION PRACTICES]

It is not quite accurate to completely equate pixels with the small squares of color in a grid, that constitute larger images; pixels are in fact the numerical sample values themselves, which are then subsequently represented by squares of color or value (Smith, 2021)[i]. These sample points are always perceived with some perception of spreading into adjacent areas, whether due to display technologies (as above) or as a function of the optical and perception system. The use of pixels for image display relies on the human visual perceptual ability to re-merge the individual color blocks into a coherent image. The compression, or 'down sampling' process of expressing an image as an array of pixels is akin to calculus; discreet samples or local approximations of color are used to encode a limited amount of image information. Our visual perception is able to 'decompress' the elements back into the intended image. This process relies on the principle of 'resolution' – the size and number of the picture elements must provide sufficient information to perceive the image.

For practitioners, techniques for animating at the level of pixels involves using software that is specifically designed to manipulate *raster* graphics (images composed of rows and columns of pixels). These various software applications offer a multitude of tools for interacting with the two-dimensional array of pixels that make up each animation frame. Essentially, the artist or animator uses the interface features of the software to set the RGB value of each pixel for each frame in a sequence, and each frame of animation is akin to a very finely detailed pointillist painting. These values may be defined on each frame (the digital equivalent of drawing frame by frame), or by using time tools which infer the values for pixels between keyframes. The notable characteristic of this type of animation is that the pixels values are defined directly on the raster grid – they are not inferred from other computational abstractions (such as the rendering of three-dimensional geometry and lighting) or the interpretation of other encoded information (such as vector graphics). Typically, each color channel (red, green and blue) has 256 potential levels of intensity within each pixel. The mixture of each of the combinations of pixel levels yields a standard color palette of around 16.7 million possible colors[ii]. However, importantly for pixel animation, this color palette is often deliberately restricted. Originally, this was to increase processing speed and file size. For example, an 8-bit image has only 256 total colors (compared to the 16.7 million of a 24 bit image), and hence was stored, recalled and displayed using far lower resources (somewhat akin to the restricted color palette of the printing press). As storage space and processing speed increased, and with the advent of compression algorithms, resolution, frame rates and bit depth of digital images have also increased.

The nature of the software and the different tools it affords the user for setting the pixel values typically follows conventions or analogies that pre-date digital imaging. These may mimic natural media or photographic tools, including brushes and paint buckets, scissors and global color adjustments such as contrast, or saturation. The various metaphors and abstractions of the software interface, and the workflows and processes that they support amount to what Ian Bogost (2010) describes as the 'procedural rhetoric' of the software, through which the artist becomes attuned to, and learns to interact with the creative workspace. In a sense, the artist learns to think *through* the software tools, working on images and movements, rather than thinking directly about the pixels that comprise the image. The compression and decompression is persistent. But ultimately, these tools simply provide a means of selecting and adjusting the RGB values per pixel, and per frame.

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Over time, the evolution of raster graphics applications, display technologies, and increasingly efficient compression algorithms have supported the tendency to increase digital image and video resolution to the level where we typically no longer notice the pixels comprising the images. Consumer-driven advances in technology have intensified the relentless pursuit to eliminate the pixel. Each advance in technology seeks to reduce the prominence of pixels and deliver images with exceptional clarity and realism. From the early days of low-resolution screens, the mission has been to erase the visibility of pixels from the viewer's perception. Augmented reality (AR) and virtual reality (VR) technologies have flourished, creating immersive experiences that blur the line between the digital and physical/spatial worlds. Advances in display technologies in these realms include efforts at minimizing the screen door effect (the visible grid of pixels) and enhancing realism to the point where users are completely engrossed in virtual environments.

[PIXEL ANIMATION AS RETROFUTURISM]

With digital imaging technologies having largely achieved this elimination of pixel visibility, why would artists utilize pixel art aesthetics in production and display environments that no longer demand it? One reason for this is that the history of limitations and the digital material practices that emerged within those constraints engender production cultures that persist beyond the technical constrictions which caused them. Pixel art and pixel animation has grown its own aesthetic branch, which persists on its own aesthetic terms.

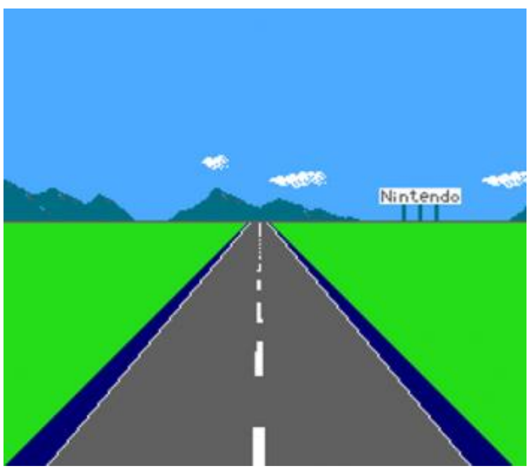

Figure 3 Cory Arcangel's F1 Racer Mod (aka Japanese Driving Game) (2004)

Many forms of animation utilize nostalgia to evoke emotions from an audience. Operating on both individual and cultural levels, nostalgic images, icons or objects refer the viewer back to previous experiences, but more importantly to previously felt emotions. For example, Svankmajer's use of children's toys in Alice (1988)(and other related examples) use nostalgic objects and scenarios set against uncanny motion and life to create a unique surreal experience. Pixar's *The Incredibles* (Brad Bird,

2004) reminds us of the history of superhero moral narratives, and their film and comic book tropes. The film uses these tropes and design cues (such as the modernist architecture of the Parr's house) to evoke a meta-temporality that underpins the direct events and narrative of the film. The aesthetics of pixel art also create a meta-temporal sensibility by evoking techno-nostalgia for the period from which it emerges. The early days of digital media were revolutionary in the realms of entertainment, work, and the early internet. Emerging near the end of the 20th Century, pixel aesthetics evoke a time focused on the future, a time which imagined a technological landscape that was full of potential. This is not to say that the visions of the future of the time were utopian, as dystopic visions were just as thematically present. This period of history hinted at a new experience of truly global connection based on technology. Digital art and media offered new ways to distribute and consume international content and international ideals. Street Fighter 2 (1991)presents a global competition and ironic harmonization of East and West, albeit set within a future, or alternate present characterized by ultra-violence.

Revisiting this time period reminds us of dreams of a computational future much like the interest in Sci-fi, robots and space travel of the mid 20th Century, but this time appearing within the early forms of the media on which it comments. The aesthetics of the pixel is more than mere nostalgia – it is a deliberate re-activation of history and its technologies, *through* those technologies. It recalls a period of history that was characterized by looking forward to a future that may never have occurred, and sits askew of our own present reality. Philosopher Elie During proposes that we take these alternate futures seriously - even radically. By engaging in this process of 'retrospective anticipation', During invites us to recognize that the present has no particular virtue over other futures that did not come to pass, and that virtual futures of the past still have effect, especially as they remain unbound by the inconveniences of concrete reality (Bublex & During, 2014).

The retro-futurist aesthetics of pixel animation invite the viewer to see the world as constituting an imagined future of the past – a potential branch of history which may or may not be the one which we inhabit. The pixels, referencing a common past (perhaps for example, the period of 8-bit video games from the 1980's and 90's) incite diachronic mobility, inviting the viewer to travel back to that period, but also to travel *forward, from* that period to a potential future. This involves retracing both technological and personal timelines, as well as global, collective potentials. As such, the pixel art aesthetic evokes a holistic temporal and perspective shift.

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[i] For a more thorough reading on the history and technical development of pixels and the digital image, the authors refer readers to Alvy Ray Smith's outstanding *A Biography of the Pixel*

[ii] It should be noted that a contribution of this length cannot explore the enormous range of technical aspects and variations in formats, specifications, and types of digital image. While the descriptions given represent a typical technical case, they should be taken as examples only.