Planetariums as 21st Century Digital Dioramas

By Ryan Wyatt

For more than a century, natural history museums have used dioramas to allow visitors to experience a sense of travel in the confines of an exhibit gallery. With fulldome video projection technology, modern planetariums can recreate virtual environments that extend the concept of travel to celestial realms—and connect the human scale to global and even cosmological scales.

This paper explores how planetariums and natural history museums share objectives around creating a sense of travel (in both space and time), around maintaining visual and scientific authenticity, and around providing larger context for individual objects, specimens, and discoveries.

The Experience of Space and Time

Since their origins as "cabinets of curiosity" in the 16th Century, museums have collected objects from widely-dispersed locales and, in the very act of bringing items together for display, have constructed physical travelogues. And as they evolved into curators of life's evolutionary heritage, natural history museums also began to communicate a temporal context to their collections. Thus, visitors to natural history museums are invited to experience travel in both space (the locations from which specimens have been collected) and time (the periods from which fossils date or the evolutionary relationships which exhibits depict).

Planetariums have long attempted something similar; indeed, the most thorough history of planetariums bears the title *Theaters of Time and Space* (Marché, 2005). As planetariums have evolved from the opto-mechanical reproductions of the night sky (nonetheless addressing many contemporary astronomy topics in their programming) into fulldome immersive environments, the deepening of astrophysical data representation and the broadening of science topics have collectively tightened the focus on spatio-temporal voyages.

As fulldome planetariums begin to encroach on disciplines more traditionally addressed in natural history museums, I believe that we are extending the work of the last century's museum professionals. In particular, we have an opportunity to wed traditional representations of the natural world seamlessly with 21st-century data visualizations: by integrating these tools across spatio-temporal scales, we can establish meaningful context for modern discoveries and allow audiences to make profound connections to critical global trends.

Natural History Habitat Dioramas

When Charles Willson Peale opened his museum of natural sciences in Philadelphia in 1786, he brought together the relatively new art of taxidermy with his training as a painter. Painting skies and landscapes behind his specimens, he pioneered what we today think of as a museum diorama (Quinn, 2006). Recognizing this seminal contribution, it nonetheless makes more sense to situate our modern conception of habitat dioramas within the larger context of immersive art in the 19th Century.

Panoramas (also called cycloramas) made their debut in London just a year after Peale's museum opened across the Atlantic, and they skyrocketed in popularity over the next century. Typically site-specific, these cylindrical paintings in rotundas a few stories tall and tens of meters in diameter cropped up all over Europe and the United States, depicting ancient cities, exotic locales, and bloody battles. Accessed in a manner (via corridors and staircases) intended to disorient visitors, panoramas created the illusion of travelling to a distant place and/or time. And in many such works, three-dimensional figures, mannequins, and foreground objects integrated seamlessly with the background. In short, "panoramas had to be so true to life that they could be confused with reality" (Comment, 1999).

In 1822, Louis Daguerre coined the term "diorama," from the Greek words *dia* (meaning "through") and *horao* ("that which is seen") in reference to his invention that differed considerably from most current implementations. Daguerre's dioramas used painted scrims in front of a changing light source to create the illusion of depth in a confined space. Conceived as commercial ventures, these dioramas initially competed with panoramas for public attention and admission fees, but in the face of waning enthusiasm and a destructive fire in 1839, Daguerre prepared only one final diorama and then focussed his attention on perfecting his photographic technique, the daguerreotype.

And in the latter part of the 19th Century, the wax museums Madame Tussauds in London and Musée Grévin in Paris began staging historical reconstructions in their galleries. At Musée Grévin, one could encounter the latest grisly murder or international intrigue displayed in meticulous detail, in a constantly-changing series of tableaus designed to grab the public's attention—and admission fees (Levingston, 2014).

These various immersive experiences certainly influenced the development of the habitat diorama in natural history museums. (Indeed, these influences reverberated well into the 20th Century: the panorama, for example, spawned the moving-image Cinéorama, a film-based immersive experience that appeared briefly at the 1900 World's Fair, and eventually culminated in Disney's Circle-Vision 360° experience much later in the century. More on that later.)

Credit for creating the earliest habitat diorama usually goes to Carl Akeley, a taxidermist, sculptor, and painter who combined his varied skills in his work. In 1889, at the Milwaukee Public Museum, Akeley assembled "a diorama that featured mounted specimens in a re-created foreground habitat that merged with a realistic background habitat painting. This example of a new genre measured three feet tall, four feet wide, and two feet deep, and depicted muskrats in a re-created marsh against a mural of a wetland. It is still on display today" (Quinn, 2006). Thus, taxidermied specimens appeared in context with the environments in which they lived, engaged in activities characteristic of the species—in the case of the muskrats, feeding, burrowing, and even swimming.

Akeley's subsequent work at the Field Museum, along with the efforts of Frank M. Chapman at the American Museum of Natural History (AMNH), refined the concept of the habitat diorama, and the design spread to other institutions. In 1916, the California Academy of Sciences (the Academy) opened its North American Hall of Birds and Mammals, which featured numerous innovative dioramas. "Illuminated by natural light, they treated the viewer to a dynamic that varied with the seasons and the time of day, a concept new to the museum genre" (Wellck et al, 2003).

Simson African Hall opened in 1934 in the original California Academy of Sciences building complex. Image courtesy of the California Academy of Sciences Archives.

It's worth noting that "most dioramas in the museum depict an actual location somewhere in the natural world." And very early on, AMNH designed the work with significant conservation messages. "The museum's habitat dioramas were intended not just to be popular. They evolved in response to the public's growing awareness of wildlife and wilderness as finite and fragile ecosystems as well as a resource for human exploitation. They were created to promote the love of and concern for nature and its wise stewardship. Their goal was its protection and preservation, both within the diorama and in the real world" (Quinn, 2006).

California Academy of Sciences exhibit preparators Cecil Tose and Toshio Asaeda working on Water Buffalo exhibit in 1958. Image courtesy of the California Academy of Sciences Archives.

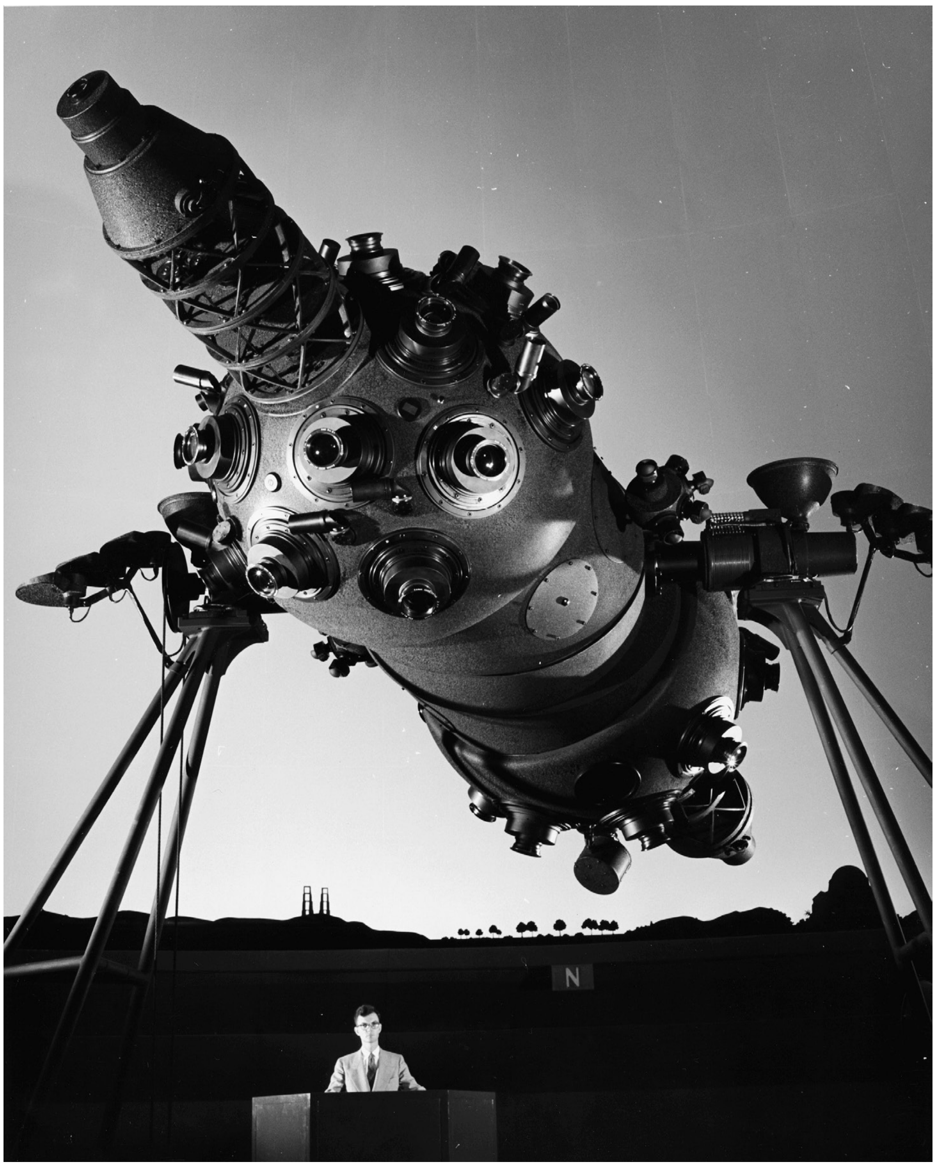
The habitat diorama arguably reached its apotheosis in AMNH's Akeley Hall of African Mammals, which opened in 1936. "In the center of the hall, Akeley's massive elephant group stands out on an elevated platform. The elephants are depicted in a state of alarm: the old bull faces the entrance, ears extended, trunk testing the air; a younger bull has wheeled around to guard the rear of the herd. All around the elephants, embedded in walls of black polished marble, are Akeley's habitat groups. They stand out in the darkened hall in a blaze of internal sunlight, as if one were looking through bright windows into another world at another time—the Africa that Carl Akeley wanted so to save" (Preston, 1986).

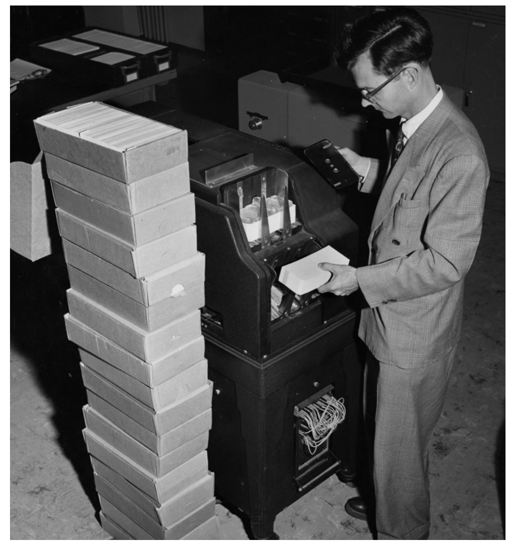
Opto-Mechanical Planetariums and the Night Sky

Much like dioramas, early planetarium experiences were valued for their verisimilitude and accuracy: "one of the amazing triumphs of science and engineering" (Luyten, 1927), "optical effects that correspond precisely with those of nature" (Kaempffert, 1928), and a "realistic experience… beyond belief" (Fisher, 1934), to quote selected contemporary sources.

Each successive generation of planetarium projectors refined the accuracy with which they addressed the mechanical challenges of simulating diurnal (daily) motion, the movement of the planets, and the precession of the equinoxes. Luckily, the “mechanical universe” proved amenable to analog solutions involving mostly gears and motors. But in addition, there were thousands of stars to position accurately in the simulated sky. From a modern perspective, we can see this as a data visualization challenge—albeit one focused purely on a single dataset, namely the stars as observed from Earth.

Leon Salanave painstakingly described one solution in an article written for the Academy’s *Pacific Discovery* magazine at the time, detailing how the team used digital techniques to address the challenges of accurately positioning 3,800 stars on the physical projection mechanism. “One of the big jobs in the building of our star projector involved sorting out the stars to be assigned to each of the 32 fields, and then computing the stars’ positions thereon. The vast amount of labor involved in this work was carried out on International Business Machines sorting and calculating devices in the Computing Laboratory, University of California, Berkeley” (Salanave, 1952). Modern planetariums have become increasingly dependent on computers (see below), so this article makes for intriguing historical reading.





Left: *Star projector with Leon Salanave at console of the original Morrison Planetarium. Image courtesy of the California Academy of Sciences Archives;* ***Top right:*** *Leon Salanave putting IBM cards in sorting machine to help calculate star positions for the original Morrison Planetarium. Image courtesy of the California Academy of Sciences Archives;* ***Bottom Right:*** *Leon Salanave stands at one end of a 58-foot-long printout of complete data on over 6,000 star locations. Image courtesy of the California Academy of Sciences Archives.*

What motivated the drive for accuracy? Marché draws parallels between planetariums and museum dioramas in terms of preservation, arguing that conservation-minded museums may have driven “museum directors, curators, and educators to unite astronomy with other exhibits and programs” in order to protect the vanishing night sky. “When viewed from the confines of an urbanized, industrial landscape, the innate starry sky had become another of those elements that had vanished from the natural world.” (Marché, 2005) Indeed, a *New York Times* article about the opening of Adler Planetarium in Chicago (the first planetarium in the Western Hemisphere) addressed this concern in the second paragraph: “The crowding of hundreds of thousands into large industrial centers is chiefly responsible for the decline of popular interest in the noblest of sciences” (Kaempffert, 1928). The planetarium community took this charge very much to heart, viewing preservation of the night sky as a core function—indeed, a definitional aspect, for some—of the planetarium.

Perhaps this is also reflected in the grandiloquent, quasi-mystical language that planetarium professionals could often employ in describing the medium…

“There is something about a planetarium environment that is unique, save for the real out-of-doors under nature’s sky. It is this uniqueness that makes the planetarium experience potentially superior to the documentary Film. What is this mysterious quality? From the physical point of view, it is the dimension of space. Under the realistic stars, one soon forgets that he is looking at a projection on a curved surface, for the planetarium sky adds the impression of the third dimension. On a more inspirational level, the planetarium setting, with stars gliding slowly overhead, affords the viewer an opportunity to contemplate the mysteries of creation, to consider the vastness of space, and at the same time to gain some insight into his own relation to time, space, and eternity” (Hagar, 1980).

“The lights are turned down gradually, just as in a theatre before the curtain rises on a play. Gradually, your eyes accustom themselves to the darkness. You lose all sense of confinement. In some incomprehensible optical way you have been transported out into the open on a marvelously pellucid night. What was once a naked white vault is now the deep blue nocturnal sky, but strangely orbless. A miracle happens. A switch has been thrown, and that cerulean vault suddenly becomes a firmament of twinkling stars. Even trained astronomers who know exactly what to expect cannot suppress a long-drawn ‘Ah-h-h!’ of astonishment and pleasure when they behold this dramatically presented counterfeit of the heavens for the first time” (Kaempffert, 1928).

Or, as Clyde Fisher, director of AMNH’s astronomical department, expressed the role of astronomy in his 1927 plea for establishing a planetarium in New York City: “What field of science offers so great an opportunity to enjoy majestic beauty? What subject helps us more in our natural struggle to comprehend the infinite? What science does most to lift one out of the petty things of everyday life, thus allowing the soul to expand?” (Fisher, 1927).

Fulldome Planetariums and the Digital Universe

The most recent advance in planetarium technology, fulldome video, allows the planetarium dome to showcase a wider range of content than simply the night sky. Fisheye lenses or seamlessly blended video projectors fill an entire hemisphere with visuals, allowing for the recreation of diverse environments, whether through computer-generated imagery or real-world videography. The primary emphasis has remained astronomical, but the toolkit has widened to include visualization of three-dimensional data and accurate depiction of astrophysical phenomena well beyond an earthbound perspective (Wyatt, 2004, 2005).

Although fulldome video entered the planetarium field in the late 1990s, the re-opening of AMNH’s Hayden Planetarium in February 2000 registered as a signal change within the profession. Aside from igniting debate among long-time planetarians (often related to the moral imperative to focus on naked-eye astronomy), it helped redefine expectations for planetariums in general.

As *New York Times* reviewer Malcolm W. Browne described the new Rose Center for Earth and Space at the time of its opening: “The domed Space Theater, which is the centerpiece of the Rose Center, the latest branch of the American Museum of Natural History, offers synthetic views of the cosmos far more detailed than the most elaborate Hollywood productions. With the help of a supercomputer, a state-of-the-art Zeiss star projector, an advanced laser system, a gigantic data base (in which the motions and distances of thousands of stars are catalogued) and, of course, the hemispheric Space Theater itself, the builders have created a marvelous celestial playhouse” (Browne, 2000).

In my six years as science visualizer at AMNH, I worked with dozens of scientists (mostly astrophysicists and the occasional geologist) to interpret their data for the highly-produced “space shows” that engage the majority of visitors to Hayden Planetarium. However, the backbone of the shows also had a real-time instantiation: the Digital Universe data that Browne mentions parenthetically and incompletely could be loaded onto the aforementioned supercomputer and piloted through in a live presentation.

Director of Astrovisualization Carter Emmart hosted informal after-hours gatherings, "tours of the Universe" that eventually evolved into public programs sponsored by the institution.

In a 2004 article cowritten with my AMNH colleagues, we described the advances in technology as follows: "When the Hayden Planetarium reopened in 2000, after its extensive renovation, a virtual trip through the universe required a supercomputer. Navigating databases of thousands of celestial objects and displaying them in a series of still images at the standard video rate of thirty times a second posed a tremendous computational challenge. Fortunately, the phenomenal growth and popularity of flight simulators and electronic video games spurred the field of data visualization to grow up almost overnight. Thanks in part to the video-game industry, personal computers today incorporate graphics processors that surpass the capabilities of the supercomputer the planetarium purchased only five years ago. The new technology arrived practically ready-made for transfer into industry and academia" (Abbott et al, 2004).

AMNH's leadership in these efforts, bridging the divide between planetariums and astrophysics researchers, helped elevate the medium and establish visualization as a core function of modern digital theaters. In particular, the real-time tools and data have since spread to literally thousands of planetariums around the globe, and their application extends to terrestrial and even microscopic topics as well as the more typical cosmic purview of planetariums.

Connecting to the Human Scale

Whatever the focus of the programming, fulldome video has developed clear parallels with immersive filmmaking such as the aforementioned Circle-Vision 360° or IMAX formats. As we look to tap into the true power of the medium, we cannot design our content like typical television or film productions. Instead, we need to explore immersive-appropriate techniques for science storytelling.

I think of a successful immersive experience as an embodied experience, ideally connecting with the whole person—intellectually, emotionally, and viscerally. (If you like, you can think of these as imprecisely mirroring Bloom's taxonomy of cognitive, affective, and psychomotor domains, respectively.) My intended meaning of an intellectually and emotionally engaging program probably makes sense to an uninitiated reader, but I want to emphasize the visceral aspect of an immersive experience: a planetarium provides an ideal environment for inducing the sensations of flying, of changing scale, of moving through space, of *travelling* in a way that affects the individual in a physical, visceral manner—preferably without causing discomfort or motion sickness.

Filmmaker Ben Shedd describes this as "frameless film," in contrast to the long history of framed cinema, with its well-developed vocabulary of camera moves, shots, and cuts. "In accounting for the sensation of movement, the filmic experience has moved from passive, from being held in a frame, to active, to becoming the engulfing reality with the audience present within the filmic events. In frameless film the audience becomes the main character in the film" (Shedd, 1989).

I refer to this as a "narrative journey," an audience-centered approach to filmmaking that integrates storytelling and virtual travel (Wyatt, 2005). Insofar as we can incorporate this mindset into our productions, I believe that we are poised to create content that can connect powerfully with our audiences—and effect the kind of change that Akeley and others attempted with their work more than a century ago.

These stylistic considerations have critical didactic implications as well. I maintain that transitions in scale are particularly amenable to the immersive environment, allowing viewers to experience continuous changes in size relationships that helps in constructing mental models of the phenomena. Thus, when we depict human-scaled phenomena in a fulldome planetarium—and then continuously transition to larger or smaller scales—we have an opportunity to connect spatial relationships that include our own human, embodied experience.

California Academy of Sciences Fulldome Productions

Although the planetarium community has embraced non-astronomical content rather slowly, an increasing number of shows and programs address terrestrial topics. Aside from the Academy shows I will describe below, the programs *Natural Selection* (2011), *Dynamic Earth* (2012), and *Dream to Fly* (2013) have made significant inroads into distribution and/or garnered awards at various fulldome festivals.

Since its reopening, the Academy has committed to producing planetarium programming that addresses a variety of science content, especially that which reinforces the institutional mission to "explore, explain, and sustain life."

The Academy's opening show, *Fragile Planet* (2008), begins in a virtual model of the planetarium itself, before fading away the screen and the dome, then lifting up to reveal the exterior of the building. The 23-minute film includes no cuts ("frameless film" taken to an extreme), so the audience experiences a seamless journey from their seats to the Virgo Cluster (some 60 million light years distant) and back home to Earth. About two-thirds of the show addresses astronomy topics (in particular, the possibility of life elsewhere), but a significant portion of the remaining time addresses biodiversity loss, remote sensing, and climate.

In the Academy's subsequent productions, digital artists have worked in close collaboration with researchers to recreate specific locations for display in Morrison Planetarium. In this sense, we have continued the work of diorama artists into the digital realm.

Life: A Cosmic Story (2010) opens in a redwood forest, recreating Bohemian Grove in Muir Woods, about 25 kilometers north of San Francisco. Within the computer-generated reconstruction of the forest based on photography of the site, butterflies (western tiger swallowtail, Papilio rutulus) and birds (Junco), animated in Maya, flutter overhead. From the familiar perspective of standing in the grove, we follow a twisting path toward the underside of a redwood leaf, photo-textured from microscopic images from the Academy's botany department. En route, we pass by computer-generated ants (of an appropriate species, Stenamma diecki) based on observations of living specimens supplied by Academy entomologist Brian Fisher. Reference diagrams and micrographs drove the design of the leaf's interior as well as the cell structures—from the major organelles to the interior of the chloroplast—based on a combination of reference diagrams and micrographs. Finally, having traversed twelve orders of magnitude in scale, we arrive at the surface of a thylakoid, showing four molecules involved with photosynthesis (ATP Synthase,

The California Academy of Sciences Visualization Studio production team previews the opening shot of Life: A Cosmic Story *(2010). Image courtesy of the California Academy of Sciences Visualization Studio.*

Photosystem I, Photosystem II, and Cytochrome) based on models from the Protein Data Bank (PDB) archive, with the animation of ATP Synthase's ratcheting motion based on research by John M. Walker at Cambridge University (Wyatt et al, 2012).

This example takes the core concept of the habitat diorama and extends it meaningfully into the digital realm, not simply re-creating an environment but also allowing audiences to explore it in a different way. Because the scene connects the human scale, the cellular scale, and the molecular scale, it enables viewers to link the objects and the concepts in a coherent, unified fashion. It establishes context for the viewer in a highly visual, intuitive, and visceral manner.

Similarly, in a single scene from *Earthquake: Evidence of a Restless Planet* (2012), we transition seamlessly from a street-level recreation of the 1906 San Francisco Earthquake to a global-scale supercomputer simulation of the event. This unbroken transition allows viewers to place local events in a global context.

Along the same lines, a scene in our upcoming production will take viewers from a human-scaled view of water transport in a Douglas fir forest through the root system and down to the size of mycorrhizal fibers wrapped around the root tips, then follow the movement of water up the height of the tree before being transpired through the needles and into an aerial perspective of the forest… At which point, the show reveals regional, continental, and global phenomena that connect the forest ecosystem to worldwide climate and environmental networks.

In addition to pre-produced shows, we also create live programming that showcases the work of the Academy's researchers, integrating georeferenced data with images and 3D scans of specimens. As collaborators on the NOAA-funded Worldviews Network, we designed immersive virtual environments to help audiences evaluate complex global change issues across multiple scales of space and time. Through live presentations, interactive scientific visualizations, and community resilience dialogues, we are bringing the cosmic and global down to the local and back again.

These very literal, embodied (albeit digital) experiences allow us to give visitors a new perspective on these disparate topics—and to ground that perspective in their own sense of time and space. Creating digital environments and integrating them with data visualization, we can leverage the impact of traditional museum dioramas and planetariums—19th- and 20th-century innovations—in a truly 21st-century medium.

A historically-accurate recreation of 1906 San Francisco moments after a simulated earthquake. Image courtesy of the California Academy of Sciences Visualization Studio.

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