The Concept of the Astronomy Museum: Rethinking the Planetarium of the 21st Century

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The idea of a museum of astronomy has been interpreted across time and cultures, but the early twentieth century invention of the projection planetarium developed a commonality in concept and methods for demonstrating the motions in the sky and a place to show what we know about the heavens. Major enhancement to this medium occurred at the turn of the millennium with full dome video systems capable of immersive data visualization. Similar pioneering efforts at the American Museum of Natural History (AMNH) and the National Astronomical Observatory of Japan (NAOJ) to visualize the charted universe and astrophysical simulations in this new medium have helped move astronomy education forward, along with other efforts now in practice around the world. Live, public presentation with different, yet complementary methods are worth comparing at a time when new software developments allow networking the world of planetariums together to share a common virtual space that can be explored together. Just as light is the common shared artifact of astronomy, a shared 3D data atlas of what we have interpreted from that light becomes a new concept of place, instantly accessible from anywhere as an expanded notion of what a museum of astronomy is.

1. Planetarium in Transition as a Millennium Project

The planetarium before the turn of the millennium, as a projected star field served several generations since its invention by the German optics company, Zeiss in the 1920's. This optical-mechanical system of projecting the starry night sky onto a dome mimicking all the motions of diurnal, seasonal, planetary, lunar and solar, with capability of latitudinal adjustment remains a sensational achievement, yet is restricted to the very confounding nature of the sky itself. With celestial objects very far away, there is no apparent parallax seen to the human eye, and only the moon is seen to occult other bodies and have an obvious phase appearance with respect to the sun, in addition to its eclipse behavior coupled to both sun and earth.

At the International Planetarium Society conference in 1998, in London, high quality full dome video was first shown, while at AMNH, a NASA funded effort was begun to assemble a three dimensional atlas of the universe from published astronomical catalogs with distance information in order to visualize it. A trend in the 1990's academic data visualization community toward immersive displays was central to the AMNH plans to bring this capability into public display. The Evans and Sutherland company had in the 1980's pioneered a vector graphic, monochrome fisheye projection system as their Digistar product line, but high resolution, full-color, raster graphics employed through multiple projector systems was necessary to truly visualize high quality 3D data immersion on a dome.

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In addition, the trends in computing technology both for interaction and movie playback where becoming a reality at the end of the 1990's, enabling for the first time an accurate depiction of the charted universe and its behaviors as far as current understanding.

The planetarium's transition from a depiction of two-dimensional "sky" to a depiction of three-dimensional "space" was a fundamental shift in ability to show the science of astronomy and astrophysics. The same attributes of a dome that mimic our experience of viewing the sky, also mimic our eyes' viewing system, essentially seeing the world hemispherically in front of us. An audience under a dome can be shown an accurate depiction of the night sky, or a three-dimensional world. Theater based "virtual reality" would be used in the modern planetarium to take people into the night sky and into what we have come to know about the universe, fitting with the long-standing tradition in natural history museums to depict our knowledge of the world in three-dimensional displays.

2. The 3D Atlas & Astrophysical Sim-viz/AMNH Hayden & NAOJ

As the millennium approached, studies were conducted in how to modernize the Hayden Planetarium as a concept. AMNH asked the question, "What would be the planetarium of the 21st Century?" For the exhibits, an emphasis on "light as artifact" dominated the decisions as to he overall design around a central "Hayden Sphere" housing the planetarium theater. The centerpiece of this rethinking process was the 430-seat planetarium that would host the grand scientific data visualization of the universe. Considering the effort, the data, and its authoritative understanding required, the museum chose the addition of an academic department of astrophysics to its already existing Earth and Planetary Science research division. The three-dimensional atlas of the observed universe built from academically available catalogs would be a cornerstone for journeying beyond the two-dimensional sky into charted space. This atlas would then be used as the scaffold upon which the greater stories of its process would be illustrated by visualizing astrophysical simulations. "Sky Shows" would become "Space Shows", backed up by this new department lead by noted research astrophysicists as curators.

Concurrently, NAOJ was looking at a similar concept in combination with research partners at other Japanese institutions. Academic contact between AMNH, NAOJ occurred shortly after the rebuilt Hayden Planetarium opened in 2000 as part of the Rose Center for Earth and Space, named for philanthropist Frederick P. Rose. An inaugural conference at AMNH on stellar collisions brought these groups together for research into computational large number gravitational interactions. Exchanges of ideas and collaborations grew into exploration of visualization methods and production techniques.

High traffic figures at AMNH of roughly five million visitors a year served the launch of the new planetarium well generating great interest in the new building, but also the new concept of what was being shown. Backed up by the authority of the science, the new Hayden "Space Shows" where showing the public something it had never seen before. In its first fifteen years of operation, a continued interest in the planetarium has maintained high visitor levels with over a million space show tickets purchased annually. The programming demand generated by this success has dictated over a dozen years of crowd management through simple movie playback of solely AMNH produced content on a half hour rotation schedule, a dozen times daily (two additional shows on Saturday and Sunday).

3. Interaction vs. Production

AMNH anticipated great public interest in its opening show as the main event of the new planetarium, so it placed high priority for production of its debut "space show". Key to building space show production capacity at AMNH was development of interactive visualization of its "Digital Universe 3D Atlas" (DU). During building phase lead-up to the Millennium opening, storage space was expensive and digital movie playback was just beginning in the world of cinema. The mode of delivering a show was much in question, whether it would be scripted, real-time generated graphics, or a more traditional movie playback of high quality rendered visualizations. The situation at AMNH lead to purchasing state of the art, real-time graphics machines from Silicon Graphics (SGI) in use across the world at the top data visualization facilities. Software was initially contracted through SGI to visualize DU interactively on the SGI machine, but partnership with the National Center for Supercomputing Applications (NCSA) lead to use of software they had developed for networked, simultaneous interaction between research partners across the Internet. These interactive applications allowed AMNH to study the datasets that comprised DU in context to one another and get to recognize the universe across scales from planetary, solar system, galactic and extragalactic. Interaction gave familiarity and facility with the data, to understand it in ways not possible if limited to only rendered sequences thought up for study. Interaction also guided learning as to how best present the data, which was then applied to production, as ultimately AMNH settled on movie playback as the mode to deliver its "space show".

Those involved at AMNH in these developments saw the great teaching potential of interactive presentation, which eventually got shown in the form of evening public programs and briefly as a course offering. Ironically, the ability to conduct live demonstrations of DU has never penetrated beyond the daily schedule of the "space show" movie, of which five have been produced in fifteen years of operation.

By comparison at NAOJ, use of live presentation of interactive demonstrations, coupled with detailed movie visualizations of simulations too complex for interactive graphics was developed as the primary method for public demonstrations and programs. Japan's first stereographic dome was built at NAOJ in 2006, and lessons learned there were then imported to the Tokyo Science Museum for their Universe Live Show.

4. Interactive Software Development

A set of basic needs for interactive astronomical visualization was, to some degree simultaneously and independently developed by teams organized through AMNH and NAOJ in the first decade of the new millennium. Ability to continuously traverse across the known scale range of the observable universe had to be constructed. A dynamic solar system, demonstrations of eclipses in 3D and other phenomena, visualization of specific missions, detailed planetary surface depiction, and accurate display of atmospheric properties were needed. AMNH in partnership with Sweden's Linkoping University (LiU) developed "Uniview" in series of master's level thesis internships while NAOJ developed its freely available "4D2U" software called "Mitaka". Decision by the first round of Uniview interns to commercialize the software they authored, by forming the company SCISS enabled serious entry into the planetarium market of this new software to display the AMNH DU, but complicated what started out as an academic collaboration between AMNH and LiU. Inability to negotiate a freely available version of Uniview for academic use lead to the persistence on the DU website of the NCSA open source software called "Partiview", still of use to display DU, albeit without a solar system, and without support of multi-channel rendering or fisheye perspective for dome projection.

Partiview, or "particle viewer" was developed in part as an open source, single screen version of NCSA's "Virtual Director", an immersive, remote conferencing software developed to support multi-site interaction for production previewing of data visualizations. NCSA partnered with AMNH on the first two of its productions allowing Virtual Director to be adapted to the dome and display DU. Successful production work on one show was conducted with Virtual Director by live link-up of the Hayden dome with NCSA's CAVE, or Computer Assisted Virtual Environment. While this method was not repeated, the power of working with simultaneous, remote data immersion in a shared virtual space made a strong impression that led to a networking feature being built into Uniview that became known as "domecasting", or linking of multiple planetariums for distributed, live events.

Having the SGI based Virtual Director was an important step for viewing DU which lead to direction of what Uniview would become. The ability to navigate through DU experimentally in the dome, while not available to the general public, was used to teach an evening course and show occasionally to special visitors. A carpet was rolled out in the center of the theater where navigation was conducted while laying on ones back, which became known at the "magic carpet ride". This sparked interest by both planetarium vendors, Sky Skan and Evans & Sutherland which lead to AMNH developing a leasing structure for commercial use of DU. The basic notions for a DU viewing system were then essentially developed separately but in parallel by SCISS, Sky Skan and E&S for the global planetarium market in the first decade of the millennium.

5. The Promise of Networking and Future Development

The development of live interactive presentation of the virtual 3D universe in planetariums has been a sensation, but adds complexity of content to the demands on staff who traditionally only presented the sky. The planetarium since its inception has been a place for scientists to come and speak to the public. That tradition has been enhanced now by having the universe "at our fingertips", so that demonstrations of the layout and behavior of the universe can be shown, surrounding the audience. The complexity afforded by data now available does need adequate presentation and description, and the ability to network such description across multiple sites and to archive such presentations is a powerful capability to consider in the future. Such "domecasting" is also not restricted to domes and can be shared with non-dome viewers, such as in classrooms, or out to personal virtual reality headsets. Networked interaction with authoritative narrative has been demonstrated within single vendor systems, but fundamental differences across competing vendor systems pose difficulties to conduct such networking between them.

In 2010, the continuing academic partnership between AMNH and LiU began to consider a non-commercial open source model for new software with emphasis, amongst other features, on networking that might be able to be loaded on different vendor systems or augmented to their code that might enable cross vendor domecasting, as well as be freely available for anyone, but most importantly for schools.

6. OpenSpace

This new open source project was named "OpenSpace" and was envisioned primarily to reinvigorate the AMNH–LiU academic collaboration, unfettered by commercial concerns, and develop latest research methods for interactive data visualization applied to astrophysics. Where DU is primarily a group of static data sets, a greater challenge is the handling of dynamic data, either generated in simulations or gathered by increasingly sophisticated methods and vast data storage. Techniques researched at LiU in other fields such as medical imaging can be applied to aid our understanding of processes at work across the cosmos and provide thesis topics worthy of investigation for handling "big data".

OpenSpace is being built on an extensible, modular, plug-in architecture within the OpenGL framework targeting multiple operating systems of Windows, Linux and Mac. Its focus areas include dynamic volumetric rendering, streaming of data from multiple on-line sources such a web map serving, space mission observation targeting and image projection using NASA's NAIF/SPICE navigation system, multiple display environment support, remote multi-user synchronization for domecasting, multi mode rendering of all the above within a single scene, plus record and playback of interactive sessions with audio narrative recording.

While broad in scope, several years' work has already been conducted in collaboration with NASA's Goddard Spaceflight Center and their Community Coordinated Modeling Center (CCMC) for space weather forecasting. This particular field provides a rich challenge for assembling multiple modes of rendering, such as volumetric rendering, spacecraft models, stars, planets, orbits and observation movie playback, within the relatively familiar setting of the solar system.

The New Horizons mission to Pluto, essentially rounding out the reconnaissance of the classical nine planets of our solar system, provided a need for a visualization capability unavailable to planetariums. Vendors had developed ways to read spacecraft positions from NASA's SPICE system, but generally not the orientation information, which is key to visualizing the observation sequence, nor the instrument fields of view. OpenSpace development saw opportunity to develop these features for Pluto encounter because of the expected interest and the fact that during the main phase of the encounter, New Horizons would be on an automated sequence and not even in communication with Earth. A global event was produced, using the network capabilities developed in OpenSpace, by stationing the developer student, Michal Marcincowski at mission control at the Applied Physics Laboratory in Maryland where he could operate the visualization along side of mission scientists who could provide commentary. Geoff Haines-Stiles, a producer of the original Carl Sagan Cosmos TV series hosted the event carried live as a Google Hangouts session which carried video of the commentary to the world and archived it automatically on YouTube as "Breakfast with Pluto" (referring to east coast United States time). The OpenSpace network server was stationed at Linkoping University, which had roughly twenty participants from around the world watching in domes, and in auditoriums, following the action as Michal steered the view around New Horizons as the simulation ran in actual time showing what was expected to be happening at Pluto without the four hours time delay. The main participants spanned every continent except Antarctica as a fitting planetary awareness of our first view of Pluto, fifty years to the day after the first planetary flyby in history when Mariner 4 passed Mars.

In the fall of 2015, OpenSpace received NASA funding to expand its collaborative efforts in the United States. Currently, the rate of data from observation and simulation continues its exponential rise in every field, including astronomy, placing demand on methods to access, visualize and describe relevance to the public. A shared virtual universe as the meeting space between institutions, a new concept of the "astronomy museum", is perhaps the way that many will be able to access demonstration of the layout and behavior of the universe, guided by experts. Ultimately, the awareness of the bigger picture reveals the context of ourselves better and raises appreciation for how special and integrated we are here on earth, and how we need to better manage ourselves as part of our planet in the future ahead.