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Timelapse GigaPan: Capturing, Sharing, and Exploring Timelapse Gigapixel Imagery

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ABSTRACT

Ever wished for a time machine? Capturing a gigapixel-scale image freezes a moment in time for later exploration. It's especially useful in a case where a scientist doesn't know at capture time which location in an environment will be salient later. We present technology to extend gigapixel-scale imagery into the time dimension, capturing many co-located images over time. Explorers of timelapse, gigapixel imagery explore in both space and time. Hop in your time machine and explore!

Keywords

Timelapse, Gigapixel, Panorama, GigaPan

INTRODUCTION

Image-making has long been a compelling tool in the sciences, from geology to paleontology. But what about gigapixel images that capture the entire context of a place, and also capture sub-millimeter features on the objects of interest? What if those extreme-resolution images could be shared, over the internet, with fellow scientists and with the public? Over the past two years we have begun to address both scientific utilization of gigapixel imagery and public engagement with high-resolution science visualization by deploying a curriculum for teaching top internationally recognized scientists how to use the GigaPan robot as a tool for inquiry, documentation and outreach to the public. Three Fine Outreach for Science workshops have been held in 2008 and 2009 with a total of 95 scientists, enrolled by tapping the MacArthur Fellow recipient pool and their peer network from amongst the fields of agriculture, anthropology, archaeology, botany, climate research, ecology, entomology, forestry, geology, linguistics, paleontology, sustainable design, urban planning and others.

These Fine Fellowship recipients have together captured, stitched, uploaded and annotated more than 2,800 publicly viewable gigapixel images on gigapan.org. Peer-reviewed scientific journal articles utilizing gigapixel imagery are now emerging from the Fine Fellows inducted in 2008. In the journal *Rangeland Ecological Management*, Dr. Nichols demonstrates the use of periodic GigaPan imagery of western ranges as a tool for macroscopic analysis of specific plant species changes as well as cattle use patterns, enabling scientists to better model change over time and therefore steer more ecologically conservative use of public lands [Nichols et al. 2009]. In *Critical Inquiry in Language Studies*, Dr. Hanauer describes the ethnographic analysis of a microbiological laboratory by capturing a full panorama of the lab, then explicitly analyzing the lab contents and distribution [Hanauer 2010]. This landscape analysis has deep potential to change the face of linguistic and ethnographic analysis in fields as disparate as educational analysis, rhetoric of science and the study of near-extinct spoken languages.

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As part of the Barcode of Life project, the University of Guelph's Professor Alex Smith endeavors to DNA barcode animal species and quantitatively capture biodiversity and phylogenetic diversity within the context of population ecology and ecological monitoring. The GigaPan unit is used by field biologists as they make specimen collections [Crozier et al. 2010]. In Figure 1, the context of an entomology-focused collection is captured. Insects were barcoded around the perimeter of the sink hole, and the habitat information in the panorama preserves the ecological context for those finds, including a distant beaver dam in the sink hole.



Figure 1. Sink hole taken by Jason Straka; near the Georgian Bay in Canada (left) and a beaver dam within the gigapixel panorama (right)

Brown University archaeologists focused on Petra, the capital of the Nabataean kingdom in present day Jordan, sought to capture the spatial relationships in the city center that stem from the Great Temple, currently under excavation by Brown's Joukowsky Institute. This archival GigaPan panorama (Fig. 2) captures the scale and position of elements in the natural and built environment and shows how the Great Temple relates to the Royal Tombs.



Figure 2. 260 degree view of Petra city center and surroundings (above); Royal Tomb (below)

We are encouraged to see great diversity in how a gigapixel acquisition robot can empower scientists to rethink documentation and sharing both within their communities and beyond their scientific boundaries. Spatial referencing and annotation of microscopic and macroscopic features changes the relationship of both scientist and informal learning to the image itself, making the image a world in which to explore, discover, annotate and share. Fundamentally, a form of opportunistic science is newly surfaced because the broad application of extremal resolution nearly guarantees the unintentional capture of scientifically interesting data that has not yet been discovered even by the photographer-scientist author herself.

Yet temporality contains easily as much meaning in the process of scientific inquiry and discovery as spatiality. The ability to explore a place not only in place, but rather in time and place simultaneously, would yield an exploratory, nonlinear tool akin to a local time machine, enabling the opportunistic capture of events and fluents just as gigapixel photography today affords the capture of scientifically important detail and context. The 2008 Glacier Point rockfall at Yosemite National Park is an illustrative example of a condition that is impossible to predict, yet rich with scientific detail if captured using a Yosemite Valley gigapixel time machine. Fields as diverse as ethnobotany, geology, ecology and urban studies bear compelling examples of new research and discovery strategies that would be possible if only massive-resolution, spatio-temporal recordings of events were practical both in recording, searching, tracking, annotating and sharing.

This paper addresses the extension of the GigaPan gigapixel image capture, stitching and viewing system to such a spatio-temporal data system, or time machine. We begin by describing the time lapse gigapixel capture process, then the alignment and correction strategies that yield the post-processed spatio-temporal content. Then, we describe the viewing process, which proposes unconventional tiled video viewers as an interactive technology for simultaneously searching in time and space to explore and annotate processes and places of interest.

TIMELAPSE GIGAPIXEL IMAGE CAPTURE

An individual GigaPan is captured as a set of camera images by varying camera pan and tilt across a grid. A timelapse GigaPan is captured simply as a sequence over time of individual GigaPans.

The authors have developed two systems to capture timelapse gigapixel-scale imagery:

- Early prototype GigaPan unit, with dedicated PC
- Stand-alone GigaPan Epic Pro unit, with custom firmware

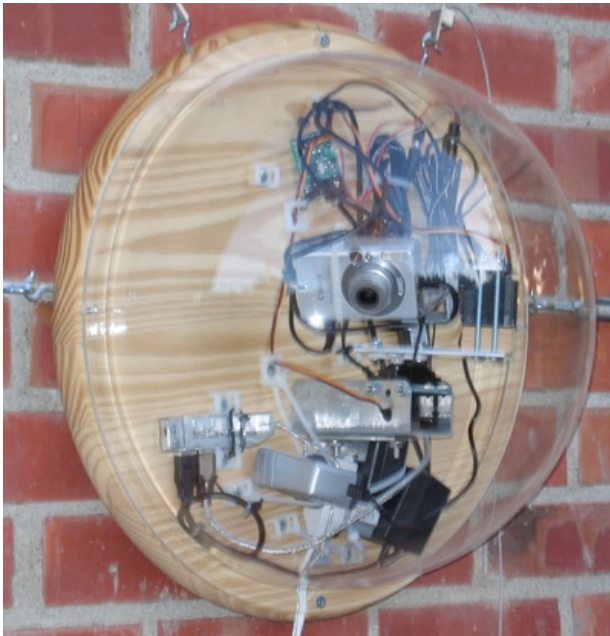


Figure 3. Original prototype timelapse GigaPan capture unit, with outdoor enclosure (2004). Not shown is the dedicated PC (indoors). Interior was later painted black to minimize internal reflections.



Figure 4. GigaPan Epic Pro is a lower-cost and readily available solution for timelapse GigaPan capture (2010). Stand-alone; no dedicated PC.

Timelapse capture with early prototype GigaPan (2004-2005)

In the early prototype GigaPan, a dedicated Windows PC sequenced all actions. Camera pan and tilt were actuated by Hobbico RC model aircraft servos, interfaced to a Windows PC via a mini-SSC controller. The PC controlled the Canon S400 camera over USB by software written by author Sargent, utilizing the Canon SDK library. The USB connection allowed direct download of images from the camera onto the PC's hard drive. While the system successfully captured imagery over a 6-month period, it had some problems:

- The RC model aircraft servos failed several times, requiring replacement. Furthermore, repeatability of servo pointing over time was poor; angles differed by more >10 degrees, possibly correlating with enclosure temperature.

- The Canon S400 plus Canon SDK library combination failed at unpredictable times, locking up the camera. Typically the system would capture 2000-5000 images before failing. We worked around this problem by adding the ability for the PC to power-cycle the camera after detecting the lockup condition. The Windows capture program was restarted at the same time.

Timelapse capture with GigaPan Epic Pro (2010)

The GigaPan Epic Pro became commercially available in 2010. It includes electronic shutter control, and an on-board rechargeable battery with external charger, much like a laptop. The Epic Pro's firmware is reprogrammable over USB. To support timelapse operation, author LeGrand wrote a special version of firmware for the device. Timelapse firmware and directions for use are available at <http://wiki.timelapse.gigapan.org>.

Camera selection, power, and settings

We've used the Canon G10 and G11 cameras for timelapse operation. Both have available external power adapters which allow operation from AC power. We shoot in aperture priority, selecting f/6.3 (the smallest aperture before significant blurring due to diffraction; see <http://pixelpix.com.au/samples/G10LensTest.htm>). Some timelapses were shot with automatic focus, while others were shot with manual focus. Letting the camera select exposure is important when lighting isn't controlled; we compensated for this in the image stitching. The G10 and G11 have an exposure adjustment setting; selecting to underexpose by ½ to 1 stops helps to reduce loss of information due to saturation (the stitcher can't effectively reduce exposure of a saturated pixel).

We saved all camera settings using the "Custom" (C1/C2) shooting mode. While the custom mode can save a manual focus setting, it's worth noting that the Canon G10 and G11 cameras revert to automatic focus when the camera is idle for a certain amount of time. We added a special firmware option to keep the shutter active after the last photo in a panorama, which fortuitously manages to keep the G10 and G11 from becoming idle and losing the focus setting.

Upon loss and regaining of power, the camera unfortunately does not turn back on until its power button is physically pressed. Use of a small uninterruptible power supply (UPS) is recommended.

GigaPan power and settings

The GigaPan Epic Pro can be straightforwardly run from external AC power using its included charger. Once the capture geometry is selected, it can be saved to flash using the "Panorama Memory" menu. Saving the capture geometry includes selection of a reference point from the environment. If the camera is replaced or device mount is disturbed, this same menu will allow you to re-calibrate the system by pointing the camera again at this reference point.

Data management

This setup captures images directly to the camera's SDHC flash card. The maximum size supported by the SDHC standard is 32GB; with camera set to highest quality, this size card holds around 5,000 images for the G10 and around 10,000 images for the G11 (differences due to different CCD pixel count and compression levels). Newer cameras which support the XDHC standard for larger cards are starting to arrive on the market (Fall 2010).

Unfortunately, replacing the card in the camera requires periodic manual intervention. Eye-Fi (<http://eye.fi/>) has created a special SDHC card with built-in Wi-Fi radio link; we're working to integrate this into the system but as of the time of this writing we've found problems with reliability.

Storing and managing several hundred thousand camera images for a timelapse sequence can be a daunting task. Author Dille developed a special application for automatically importing images from cards, dividing them into separate panoramas, and letting the user inspect the grids of images prior to stitching to confirm proper operation of the system.

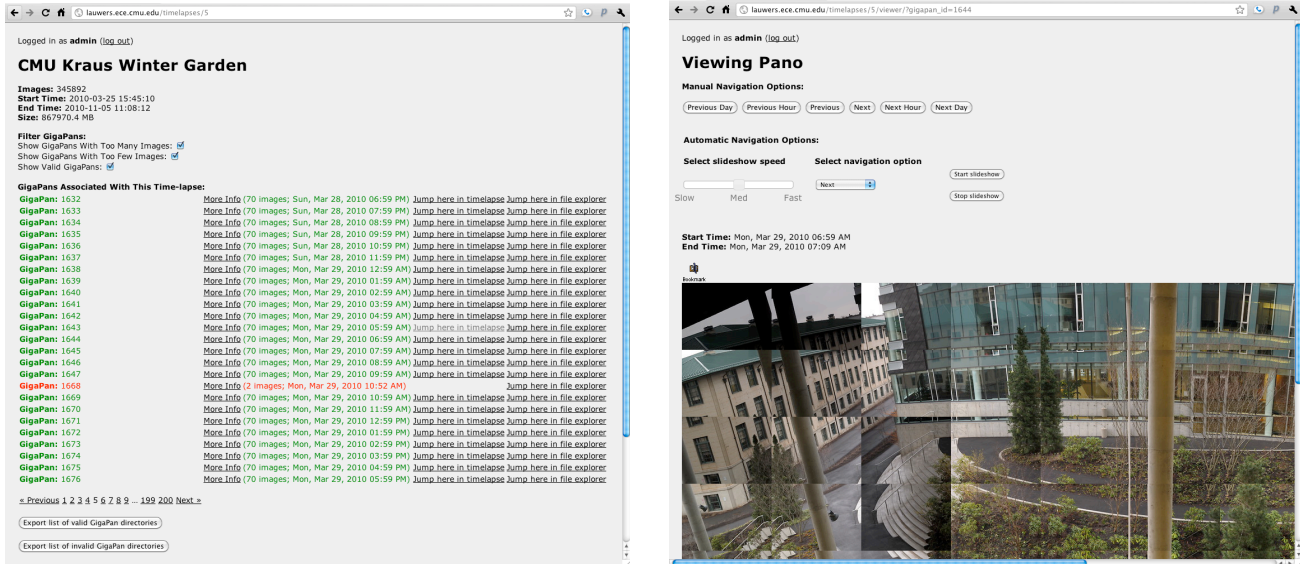


Figure 5. Timelapse GigaPan image manager, showing the Kraus Winter Garden timelapse (as of Fall 2010, 345K images, 870GB of storage)

ALIGNMENT AND STITCHING

To support stitching timelapse GigaPans, authors Keller and Sargent added two capabilities to the standard GigaPan stitching software:

- Capability to align multiple gigapans taken at different times to each other
- Capability to correct for varying exposure

Alignment across time

Standard, single-frame GigaPan images are assembled from a grid of input imagery. Each image overlaps with its neighbors; stitching software uses SIFT optical features [Lowe 2004] from the overlapping areas, as well as the geometry of the GigaPan device, to generate a set mathematical constraints on the alignment of images. These constraints are passed to Levenberg-Marquardt optimization [Levenberg 1944], which finds the optimal set of image locations, orientations, and camera lens parameters (focal length and radial distortion) to most closely align the images with one another. Images are then projected into a common coordinate system, and blended together using a variant of Burt and Adelson's multiresolution spline [Burt and Adelson, 1983].

To align images across time, we added the ability to align a new GigaPan against one or more prototype GigaPans which were previously aligned. SIFT features between the images from the new GigaPan and the prototype GigaPan[s] are found and added to the constraints for the alignment optimization step. After alignment, the projection parameters, including bounding box, are selected from the first prototype GigaPan, ensuring that the stitched GigaPan image has the same coordinates as the first prototype.

Single prototype GigaPan

The simplest way to leverage this new feature is to select a single GigaPan image to be the prototype for all other GigaPan images in the timelapse (Figure 6). This approach requires a number of reliable SIFT features be found between the one prototype and each additional GigaPan in the timelapse.

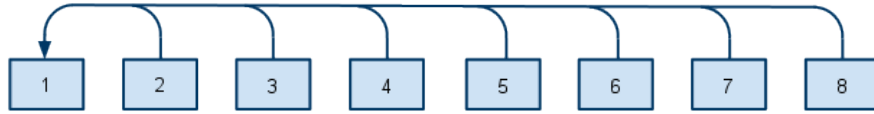


Figure 6. GigaPan 1 is the prototype for all other GigaPans in the timelapse sequence

There are two important ways this might fail:

- The subject of the timelapse GigaPan itself is evolving substantially over time, and there are too few portions of the subject which remain constant over time to serve as landmarks for SIFT.
- The lighting on the subject changes drastically over time (e.g. diurnal lighting variation of outdoor scenes)

Each can be solved by use of the “align to prototypes” feature, but require more than a single prototype GigaPan.

Compensating for subject evolving (insufficient stable SIFT features over time)

After selecting a master prototype, successive GigaPan images are aligned to the prototype as in the single prototype case. But as the subject evolves too much for the initial prototype to be of use, we select a new prototype for successive images (Figure 7). This approach is similar to the selection of keyframes for digital video compression [Le Gall 1991].

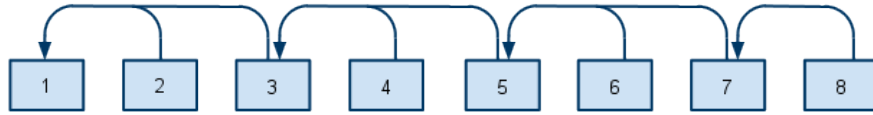


Figure 7. Periodic “keyframe” GigaPan images are selected (1, 3, 5, 7) to be prototypes for following GigaPan images, compensating for an evolving subject with insufficient fixed features over time.

Compensating for diurnal lighting variation

A timelapse of an outdoor scene which includes daytime and nighttime images is subject to substantial differences in SIFT features. It may be impossible to align a GigaPan image taken at noon with another GigaPan image taken at midnight. For this case, we can arrange a tree of alignment prototypes (Figure 8).

After selecting a master prototype, GigaPan images from the same day are aligned in a chain, one to another. Thus the lighting change between each is lessened, and sufficient SIFT features can be found. This chain of GigaPan images then become prototypes for GigaPan images from each successive day; each successive panorama can be aligned to the prototype with the most similar lighting.

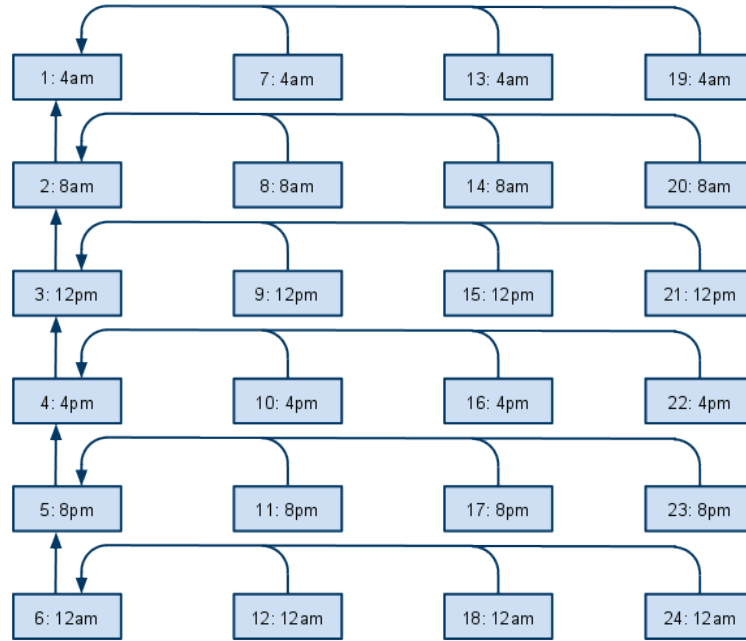


Figure 8. The first day's GigaPan images are aligned in a chain, and then used as prototypes for successive days.

Correcting for varying exposure

Typically, for a single GigaPan, the photographer selects a single exposure setting for all camera images which are stitching into the single GigaPan mosaic. In this way, the transition artifacts between neighboring images is minimized.

However, in many timelapses with lighting that changes over time, it is unrealistic to expect that a photographer be present to find a good exposure for each individual GigaPan capture. Our solution is to let the camera select the exposure itself by shooting in an automatic mode (typically aperture priority). Cameras typically record the exposure selected for each image in the EXIF metainformation that is part of the image file itself.

To compensate for exposure differences between images in a GigaPan, the stitcher reads the shutter speed, aperture, and ISO settings from EXIF tags in each input image. It then computes the average overall exposure of the scene, and computes a per-image exposure correction to bring each image to the average exposure.

Adjusting exposure on a digital photograph requires knowledge of the camera's response curve. We determined the Canon G10's response curve using the open-source utility Qtpfsgui; the same response curve worked for the G11 as well.



Figure 9. Subsection of Carnegie Mellon University carnival setup GigaPan (April 2010), composed of 5 rows and 5 columns, shot with aperture priority. Left mosaic is created from uncorrected images; note especially the dark square around the peak of the tent due to exposure differences. Right mosaic is created from images automatically adjusted in exposure by the stitching software.

VIEWING

Individual gigapixel-scale images are generally too large to be shared in easy ways; they are too large to attach to emails, and may take minutes or longer to transfer in their entirety over typical internet connections. The problem is compounded for gigapixel-scale timelapse imagery, which can easily stretch into multiple terabytes of information for a single timelapse.

GigaPan addresses the problem of sharing and interactive viewing of large single images by streaming in realtime the portions of images actually needed by the viewer of the image, based on the viewers current area of focus inside the image. To support this realtime streaming, the image is divided up and rendered into small tiles of multiple resolutions (Figure 10). The viewer pulls in only the tiles needed for a given view. Many mapping programs (e.g. Google Maps) use the same technique.

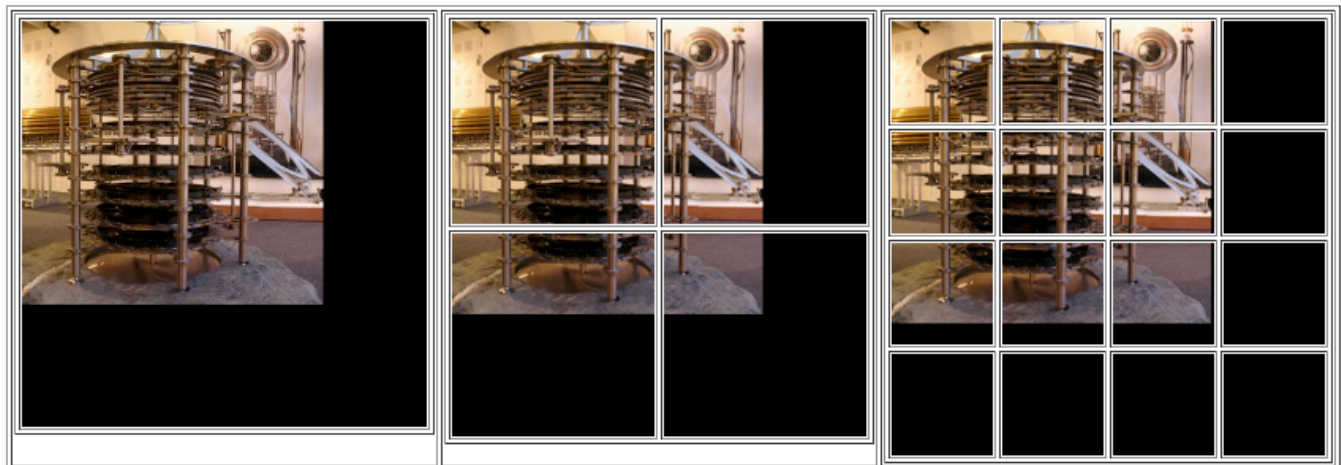


Figure 10. GigaPan divided into multi-resolution tiles of successively higher levels of detail. In the case of the gigapan.org website, each tile is 256x256 pixels in size. Diagram courtesy Rich Gibson

One approach to showing gigapixel imagery over time would be to make a modified viewer that would switch between individual GigaPan tilesets. However, this approach is expensive in bandwidth and CPU, leading to sluggish updates when moving through time.

To solve this problem, we divide each individual GigaPan image in multi-resolution tiles in this standard way. Each individual GigaPan has the same pixel dimensions, so each GigaPan divides into an equivalent set of tiles. We then take all tiles from all GigaPan images in the timelapse, and group them according to tile location and resolution; if one GigaPan is composed of 1000 tiles, we make 1000 groups of tiles, with each group containing the corresponding tile from all GigaPans. For each group of tiles, we sort by time, and then compress this stack of tiles into a video file. As the individual GigaPan image has image tiles, the timelapse GigaPan sequence has *video tiles*. We compress tiles using the standard h264 codec.

Author Bartley has created a prototype GigaPan Timelapse viewer which allows the user to fluidly explore across both space and time. As the user zooms and translates through space, the viewer requests new video tiles from the server and throws away old ones no longer visible, displaying each video tile with an individual video player. As the user plays time forwards and backwards, commands are relayed to the individual video players simultaneously, ensuring all maintain the same time.

As of the time of this writing, Barley's viewer is implemented in Javascript and relies on recent web browsers' built-in support for the HTML5 video tag (Figure 11). The current viewer adapts code from the Seadragon javascript-based viewer, extending it to work with video tiles. As of Fall 2010, browsers supporting HTML5 video and the h264 codec include Apple's Safari browser and Google's Chrome browser. Microsoft has announced support for these for its to-be-released Internet Explorer version 9.

RESULTS

We've successfully captured timelapses from a number of sources:

- Backyard in Palo Alto, CA from 2004-2005 (Figure 12)
- Kraus Winter Garden at CMU, March 2010-present (Figure 11, with timelapse viewer)
- Carnival at CMU, April 2010
- Backyard garden in Pittsburgh, April-September 2010
- Hillside reclamation project at Falk School in Pittsburgh, April-June 2010
- Garden at Pittsburgh Children's Museum, August-September 2010
- Phipps Conservatory production greenhouses, September-October 2010 (captured by Jordyn Melino)
- Brassica plant and caterpillar lifecycle, October-November 2010 (captured by Janet Steven, Sweetbriar College)
- Rangeland grazing test, October 2010 (captured by Mary Nichols, USDA)

Alex Smith from the Biodiversity Institute of Ontario, has also manually captured an excellent weekly set of panoramas from over a year in a wooded area close to his campus, without use of a standard GigaPan device.

As of the time of this writing, we've successfully aligned and stitched all but three with good results; the Pittsburgh backyard has some alignment problems due to close-by trees with swaying branches from frame to frame, and we have not yet collected and imported the 2004-2005 timelapse into our new system. Alex Smith's timelapse has some differences in geometry over time, and we're working to extend the stitching system to correctly align his timelapse.

Additionally, the timelapse stitcher has been used with some success by Justin Borevitz's GigaVision team at the University of Chicago.

Please visit <http://timelapse.gigapan.org/> to find the current status of the viewer, and explore a number of timelapse GigaPans created so far.

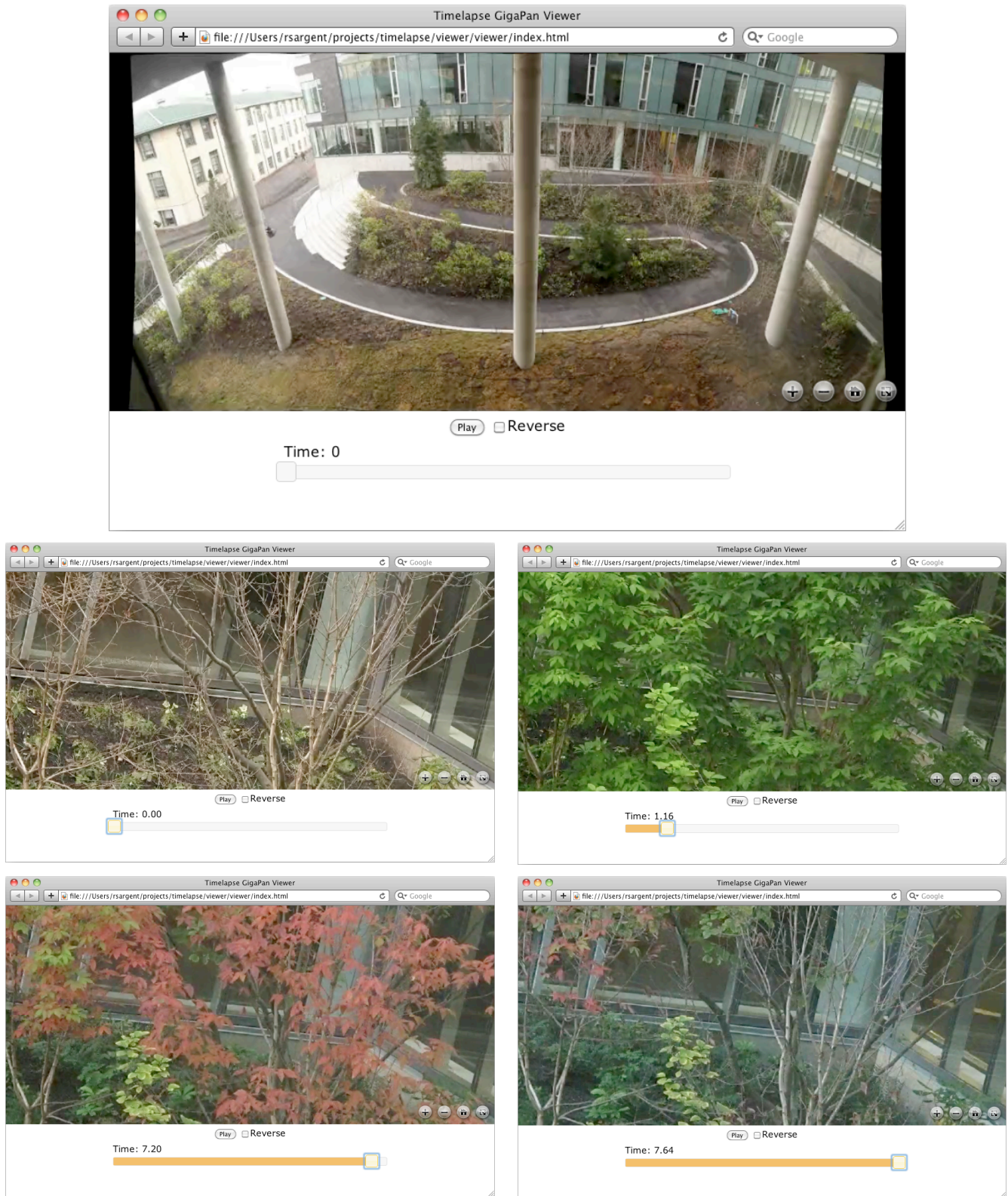


Figure 11. Prototype Timelapse GigaPan viewer, displaying the Kraus Winter Garden at Carnegie Mellon University. Zooming into the upper right of the scene, playing forward in time, the tree grows its leaves and subsequently loses them

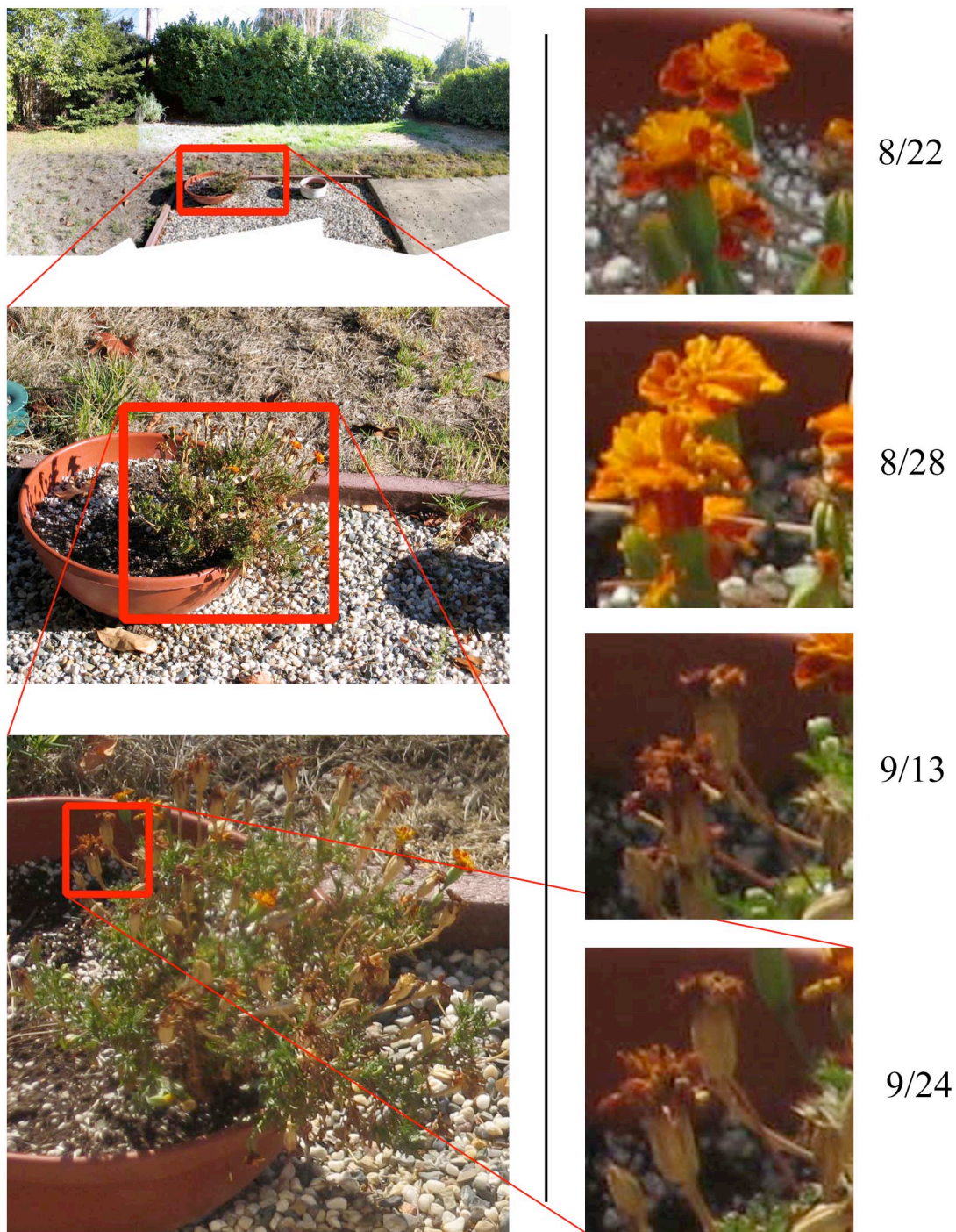


Figure 12: The first 2004-05 “Backyard in Palo Alto” timelapse. Zooming in reveals a marigold; exploring through time shows the marigold bloom and go to seed.

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