The Light Stage: Photorealistically Integrating Real Actors into Virtual Environments

Paul Debevec
USC Institute for Creative Technologies
www.debevec.org

The key to achieving realism in much of visual effects is to successfully combine a variety of different elements - matte paintings, locations, live-action actors, real and digital sets, CG characters and objects - into a single shot that looks like it was all there at the same time. An important, subtle, and frustratingly complex aspect of this problem is to match the lighting amongst these elements. Not only do the objects and environments need to be lit with the same sources of light, they need to properly reflect and shadow each other. In our graphics research, we have explored ways of using advanced lighting simulation techniques and philosophies to integrate CG objects, digital characters, and live-action performances into real and synthetic environments with physically correct and perceptually believable lighting.

In our 1999 film Fiat Lux, we used the Facade photogrammetric modeling system to model and render the interior of St. Peter's Basilica from a set of high-dynamic range digital photographs. The film called for this space to be augmented with numerous animated computer-generated spheres and monoliths. The key to making the computer-generated objects appear to be truly present in the scene was to illuminate the CG objects with the actual illumination from the Basilica. To record the illumination we used a high dynamic photography method we had developed in which a series of pictures taken with differing exposures are combined into a radiance image -- without the technique, cameras do not have nearly the range of brightness values to accurately record the full range of illumination in the real world. We then used image-based lighting to illuminate the CG objects with the images of real light using the RADIANCE global illumination rendering system, also calculating the cast shadows and reflections in the floor. The full animation may be seen at: http://www.debevec.org/FiatLux/

Most movies star people rather than spheres and monoliths, so much of our research since then has focused on the more complex problem of realistically rendering people into real and virtual scenes. In this work we have designed a series of Light Stage devices to make it possible to light real people with light from virtual sets. Version 1 of the Light Stage was designed to move a small spotlight around a person's head (or a small object) so that it is illuminated from all possible directions in about a minute - the amount of time a person can comfortably stay still in a neutral expression. It consisted of a two-bar rotation mechanism which can rotate the light in a spherical spiral about the subject. During this time, a set of stationary digital video cameras record the person or objects' appearance as the light moves around, and for some of our models we precede the lighting run with a geometry capture process using structured light from a video projector. From this data, we can then simulate the object's appearance under any complex lighting condition by taking linear combinations of the color channels of the images in the light stage dataset. In particular, the illumination can be chosen to be measurements of illumination in the real world or the illumination from a virtual environment, allowing the image of a real person to be photorealistically composited into such a scene with correct illumination. Light Stage 1 may be seen at: http://www.debevec.org/Research/LS/

Light Stage 2 was designed to shorten the amount of time needed to acquire a light stage dataset so that a person could be captured in a variety of natural facial expressions. This set of expressions could then be used as morphing targets to produce an animated version of the person. Light Stage 2 consists of a semicircular arm three meters in diameter that rotates about a vertical axis through its endpoints. Attached to the arm are twenty-seven evenly spaced xenon strobe lights, which fire sequentially at up to 200 Hz as the arm rotates around the subject. The arm position and strobe lights are computer-controlled allowing the strobes to synchronize with high-speed video cameras.

In 2001 we applied the Light Stage 2 capture process to capture a number of Native American cultural artifacts including an otter fur headband, a feathered headdress, an animal-skin drum, and several pieces of neckwear and clothing. We were able to show these artifacts illuminated by several real-world natural lighting environments, and designed a software program for interactively re-illuminating artifacts in real time. Images from this project can be seen at: http://www.debevec.org/Research/LS2/

Light Stage 1 and 2 provided the necessary proof-of-concept to build Light Stage 3, which can achieve realistic composites between a actor's live-action performance and a background environment by directly illuminating the actor with a reproduction of the direct and indirect light of the environment into which they will be composited. Light Stage 3 consists of a sphere of one hundred and fifty-six inward-pointing computer-controlled light sources that illuminate an actor standing in the center. Each light source contains red, green, and blue light emitting diodes (LEDs) that produce a wide gamut of colors and intensities of illumination. We drive the device with measurements or simulations of the background environment's illumination, and acquire a color image sequence of the actor as illuminated by the desired environment. To create the composite, we implemented an infrared matting system to form the final moving composite of the actor over the background. When successful, the person appears to actually be within the environment, exhibiting the appropriate colors, highlights, and shadows for their new environment. Images and videos from Light Stage 3 can be seen at: http://www.debevec.org/Research/LS3/

This talk will present joint work with Tim Hawkins, Andreas Wenger, C.J. Taylor, Jitendra Malik, HP Duiker, Westley Sarokin, Dan Maas, Mark Sagar, Jamie Waese, Andrew Gardner, and Chris Tchou.