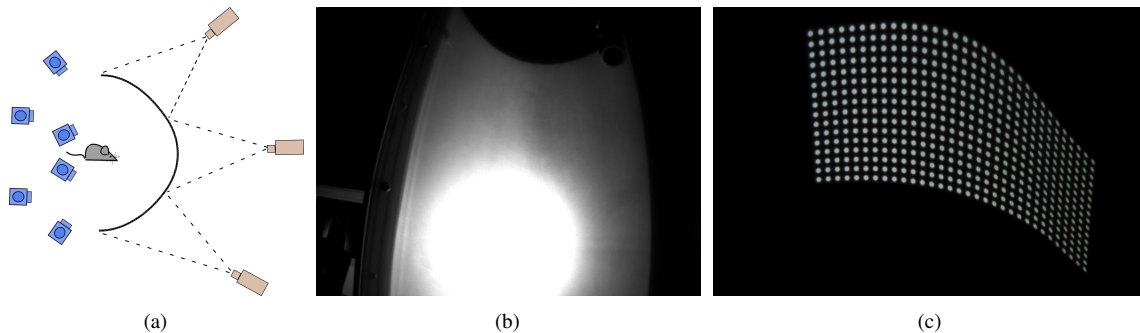


# RatCAVE: Calibration of a Projection Virtual Reality System

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**Figure 1:** (a) RatCAVE overhead schematic, showing calibration cameras (blue), rat viewpoint, screen, and projectors (brown). Our technique reconstructs the screen and projector geometry and compensates for (b) projector hotspots and (c) image warping due to non-flat screen.

## Abstract

We have created a suite of automated tools to calibrate and configure a projection virtual reality system. Test subjects (rats) explore an interactive computer-graphics environment presented on a large curved screen using multiple projectors. The locations and characteristics of the projectors can vary and the shape of the screen may be complex.

We place several cameras around the workspace for redundant coverage. We locate each projector's hotspot as seen by each camera, and produce a brightness profile which tells the projector how much to dim each pixel of its output to achieve uniform output. We reconstruct the 3D geometry of the screen and the location of each projector using shape-from-motion and structured-light multi-camera computer vision techniques. We determine which projected pixel corresponds to a given view direction for the rat. From these, we create a warping profile for each projector, which tells it how to pre-distort its output image to appear undistorted to the rat's viewpoint. We apply both pre-distortion and hotspot correction before displaying to the screen.

**Keywords:** virtual reality, projector calibration, image feature detection, shape reconstruction

**Concepts:** •Computing methodologies → Computer vision; Computer graphics;

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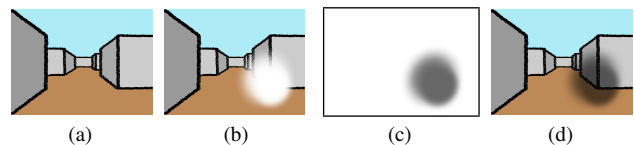
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## 1 Introduction

Neuroscientists at Howard Hughes Medical Institute (HHMI) want to determine whether rats navigate based on what they presently see or by routes they have learned. They have created a virtual reality (VR) maze which changes while the rat explores. The virtual environment is created by projectors shining on a curved screen which partly surrounds the rat, similar to the CAVE [Cruz-Neira et al. 1993]. The rat remains at a fixed location relative to the screen, but the exact shape of the screen and the positions of the projectors is not known. Certain projector characteristics are also not known. Ad-hoc manual tuning is difficult and tedious. We have created a suite of software tools to calibrate and configure the RatCAVE system automatically. Our tools can be used for the current projector/screen system and for future systems already being built.

## 2 Projector Hotspot Calibration



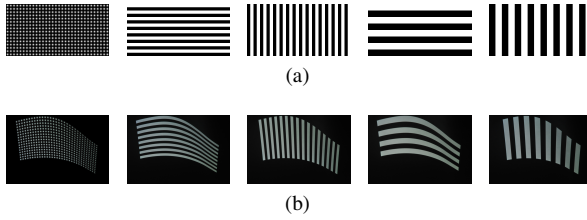
**Figure 2:** Projector brightness calibration and correction. (a) Desired appearance. (b) Uncorrected image as seen by subject. (c) Dimming map tells projector how to adjust image brightness. (d) Corrected image sent by projector.

The projectors have extra-bright view-dependent hotspots which wash out parts of the images as shown in Figure 2(b). We compensate for those hotspots by dimming the corresponding projected pixels as shown in Figure 2(d). To identify the appropriate pixels and determine how much to reduce their brightness, we project a series of images in which small gaussian dots are illuminated at various brightness levels. We determine a brightness multiplier for each dot which gives uniform brightness across the image. We use Radial Basis Function interpolation [Carr et al. 2001] to fill in between the captured pixels and produce a complete map of bright-

ness multiplier values, as shown in Figure 2(c). The appearance of the hotspot is viewpoint-dependent, so we repeat this process for every projector/camera pair. Unlike most hotspot-calibration methods, ours does not require the screen geometry or camera / projector positions.

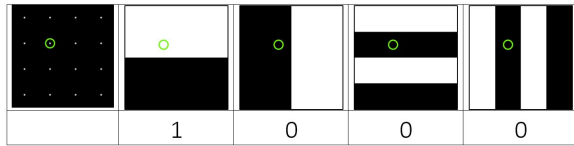
### 3 Screen Reconstruction with Structured Light

To reconstruct the 3D geometry of the screen, we project a sequence of Structured Light images [Posdamer and Altschuler 1982] onto the screen and capture the result from multiple cameras (Figure 3).



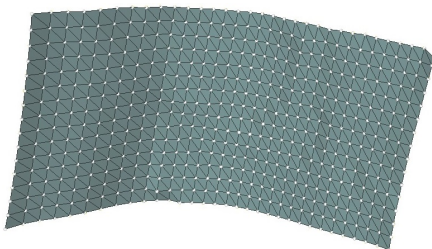
**Figure 3:** Structured light images. Source images in (a) are projected onto the screen and captured by calibration cameras (b).

We detect each dot in each captured dot-grid image and use its image coordinates to extract its unique binary code by observing the same location across the corresponding sequence of striped images. This yields a sequence of black-or-white values which are interpreted as 0's and 1's (Figure 4). When we detect dots with the same binary codes in multiple views, we know they are the same projected dot, and can determine the dot's 3D position. At the same time, we determine the positions of the projectors.[Lowe 2004]



**Figure 4:** A dot in the first image is uniquely identified by a binary code which is derived from the black-white sequence seen at the dot's location in the striped images (green circles).

We infer the 3D points' connectivity from the binary codes, which correspond to the dots' positions in the projected grid. Finally, we create a 3D point mesh tagged with binary labels (Figure 5).

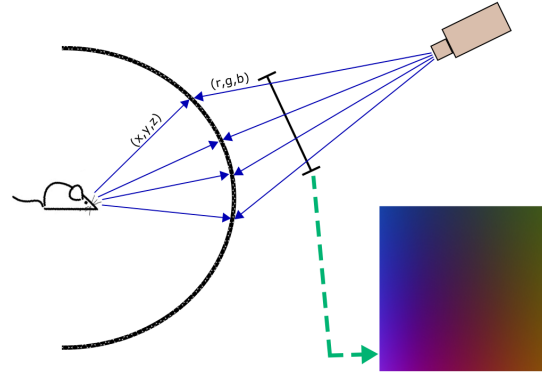


**Figure 5:** Reconstructed 3D mesh approximating screen geometry

### 4 Projector Warp Maps

Images projected onto a curved screen appear distorted. We calibrate the distortion and determine how each projector should warp

its output so the projected image appears undistorted from the rat's point of view. We use the reconstructed 3D screen geometry to develop a distortion map for each projector. The three color channels (r,g,b) of a high-precision image store the three coordinates of the rat's view direction (x,y,z) through the point on the screen where each pixel hits. During RatCAVE operation, the rendering system uses this map to pre-distort its output so it appears undistorted on the screen when seen by the rat.



**Figure 6:** Construction of warp map

### Acknowledgements

Funding support from Howard Hughes Medical Institute. The authors would like to thank Albert Lee, Jeremy Cohen, and Mark Bolstad.

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