A Computer Graphics Perspective on Inverse Light Transport

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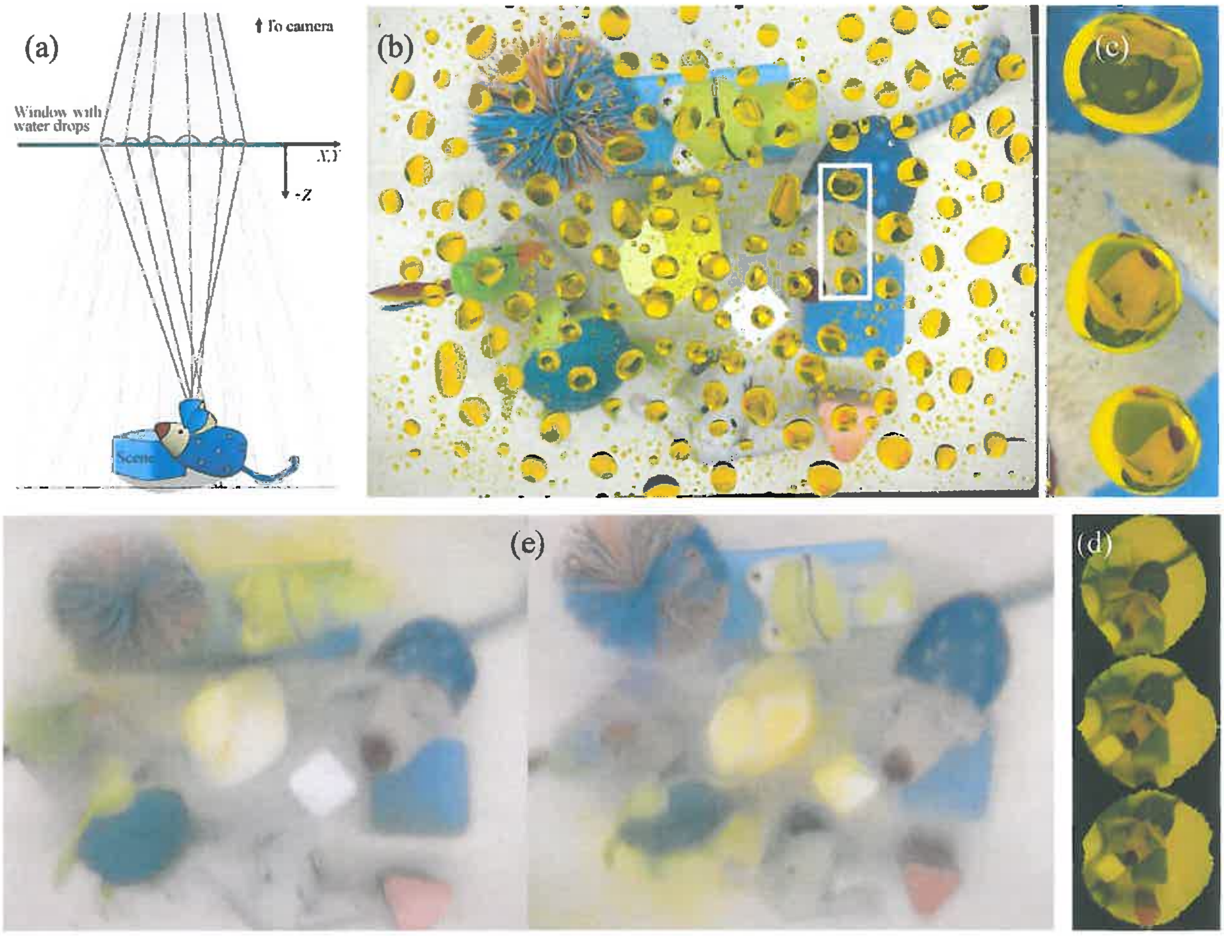
Abstract

A recurring theme in my work is the development of devices and computational methods to measure, simulate, analyse and invert the propagation of light on macroscopic scales. In this talk, I will present a selection of recent research that is linked by the desire to replace specialized and heavyweight optical devices with consumer-grade hardware and computational methods.

The first example addresses optical systems for imaging. To this day, camera lenses are complex devices consisting of up to dozens of individual optical elements on the high end. Historically, this complexity emerged from the need to compensate for geometric and chromatic aberrations of simpler optics when chemical film was the only medium available. In the digital age, however, many aberrations can be corrected post capture. We introduced a computational photography approach to shooting high-quality images through uncompensated, simple optics which are lighter and significantly less expensive. At the center of the method is a detailed characterization of per-channel, spatially-varying point spread functions, which we use to perform non-blind deconvolution with a novel cross-channel term specifically designed to eliminate color fringing.

In a second line of work, we addressed the capture of videos of light itself moving through time and space. So far, this challenge of "transient imaging" required holographic setups or even multi-stage optoelectronic devices like streak sensors. By establishing a relationship between temporally resolved optical impulse responses and measurements of standard time-of-flight sensors, we were able to cast the transient imaging problem as an inverse problem given data from low-end AMCW range imaging systems like the Microsoft Kinect. The resulting system can be used to obtain robust depth maps in the presence of nonlocal illumination, and even to reconstruct geometry and albedo of objects outside the line of sight.

Finally, I will showcase a recent project where we made extensive use of domain knowledge to replace optical design and interpret integral imaging a casual way. Instead of relying on a specially designed lens system, our liquid light field camera uses water drops resting on a transparent window as an ad-hoc optical device. By combining low-level computer vision elements with state-of-the-art drop shape simulation, we crafted an exemplary pipeline that is capable of calibrating the refractive free-form geometry, and capturing a full 4D light field, from a single input image.



Liquid light field imaging. Clockwise from top left: (a) Our capture setting for light fields. The scene is observed by a 2D camera (not in illustration) through a wetted window. Light rays falling through water drops are refracted and sample the scene's light field. (b) Example input image of the scene, as seen by the primary camera. A close-up (c) reveals that each drop produces a different view on the scene. The water has been dyed yellow for easier drop segmentation. By using physical simulation to establish the refractive geometry of our imager, we obtain rectified views of the scene (d). (e) shows renderings of the resulting unstructured light field after re-colorization. Note the parallax and occlusion effects.