Differentiable Transient Rendering

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Rendering includes techniques and theories to simulate light transport effects on 3D scenes such as reflection, refraction, and scattering, to produce 2D images. Inverse rendering, to obtain the inverse of rendering, represents various problems from research fields and industry such as computer vision, optical imaging, and image recognition. As a general approach to solve inverse rendering, the importance of differentiable rendering, which differentiate the rendering problem to let one able to use gradient descent method, has been recently emerging.
Meanwhile, existing differentiable rendering methods assume steady-state light transport, i.e., infinite speed of light. Therefore, we introduced the first differentiable transient rendering method, which takes time-resolved behavior of light transport into account. Our method proposed a potential improvement of imaging transparent object, and can play a key role to lift constraints of existing methods of non-line-of-sight imaging, which is a imaging technology looking around a corner.

1. Background (objectives)

Rendering is a research field to simulate various physical light transport effects from given 3D scenes to draw resulting images. Differentiable rendering is one of most recently emerging field, which computes derivatives of rendered images as functions of scene parameters. Differentiable rendering makes rendering pipelines have roles of inverse models of light transport effects as well as those of forward models, so that one can perform general-purposed inverse rendering using gradient descent computed by differentiable rendering.
Existing models of differentiable rendering, however, assume steady-state light transport, i.e., infinite speed of light and time-independent radiance. While this is a safe assumption for many applications, recent advances in ultrafast imaging, such as femto-photography and non-line-of-sight imaging, leverage the wealth of information that can be extracted from the exact time of flight of light. In this context, physically-based transient rendering allows to efficiently simulate and analyze light transport considering that the speed of light is indeed finite.

2. Contents

The process of rendering can be considered as a function from scene parameters, which represent 3D scenes, to radiometric measurements (or pixel intensities of the resulting image) captured by sensors. Here, the scene parameters consist of any values contained in the scene such as positions of objects, intensity of light source, reflectance of object surface, and positions and sensitivity of sensors. The rendered radiometric measurements are computed by the path integral formula, and differentiable rendering is a process to differentiate the path integral formula with respect to the scene parameters.

We introduced the first method of differentiable transient rendering framework, to help bring the potential of differentiable approaches into the transient regime. In contrast to conventional steady-steady rendering, to differentiate the transient path integral we need to take into account that scattering events at path vertices contribute no longer independently; instead, tracking the time of flight of light requires treating such scattering events at path vertices jointly as a multidimensional, evolving manifold. We thus turned to the generalized transport theorem, which handles derivatives of integrals on domains with general dimensionality, and introduced a novel correlated importance term, which links the time-integrated contribution of a path to its light throughput, and allows us to handle discontinuities in the light and sensor functions. Then our general-purposed differentiable transient renderer can handle complex light transport effects including multiple bounces and transparant media, and provides potential uses of non-line-of-sight imaging and inverse rendering of transparent objects with challenging scenarios which cannot be solved by previous methods.

3. Expected effect

Non-line-of-sight imaging captures information of hidden objects around corners using light source and sensors with pico-femto scales of time resolutions. While existing methods have requirement of using a single planar surface as relay wall, our method allows us to lift these constraint and to capture information of hidden object around a wavy wall or two walls.
Time-of-flight of light captured in transient rendering contains information of refractive indices of transparent media. Our method also provides improvement of capturing transparent objects.

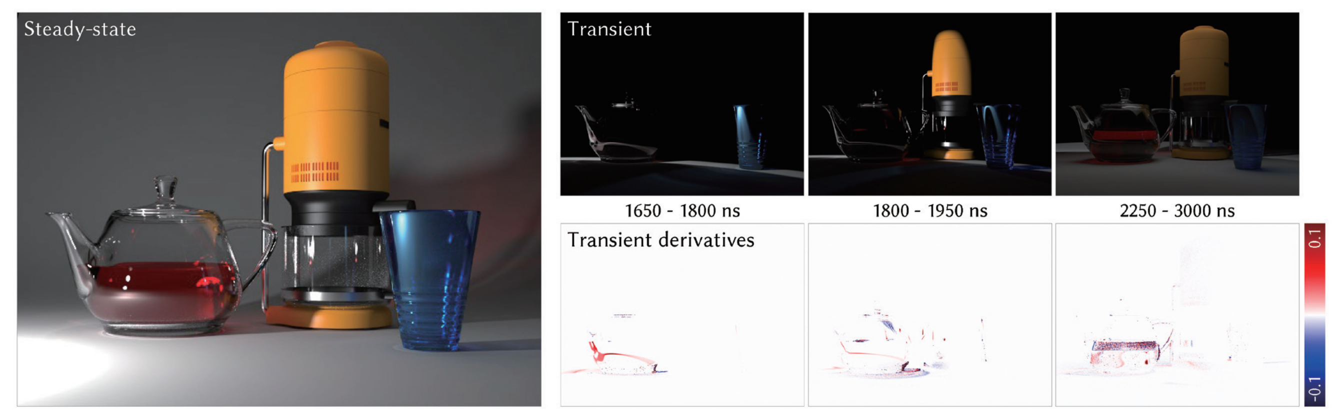

Figure.
Our differentiable transient rendering method for given scene (left) provides the derivatives (right bottom) of the transient images (right top).

Research outcomes

Paper Shinyoung Yi, Donggun Kim, Kiseok Choi, Adrian Jarabo, Diego Gutierrez, and Min H. Kim. "Differentiable transient rendering." ACM Transactions on Graphics (TOG) 40, no. 6 (2021): 1-11, presented at ACM SIGGRAPH Asia 2021.

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