Computational Image Formation Based on Surface Light Fields

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PhD Thesis Proposal

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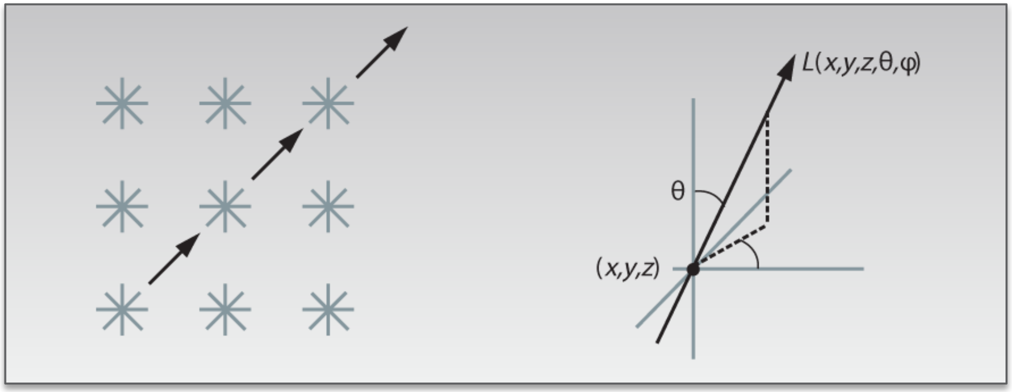
Outline

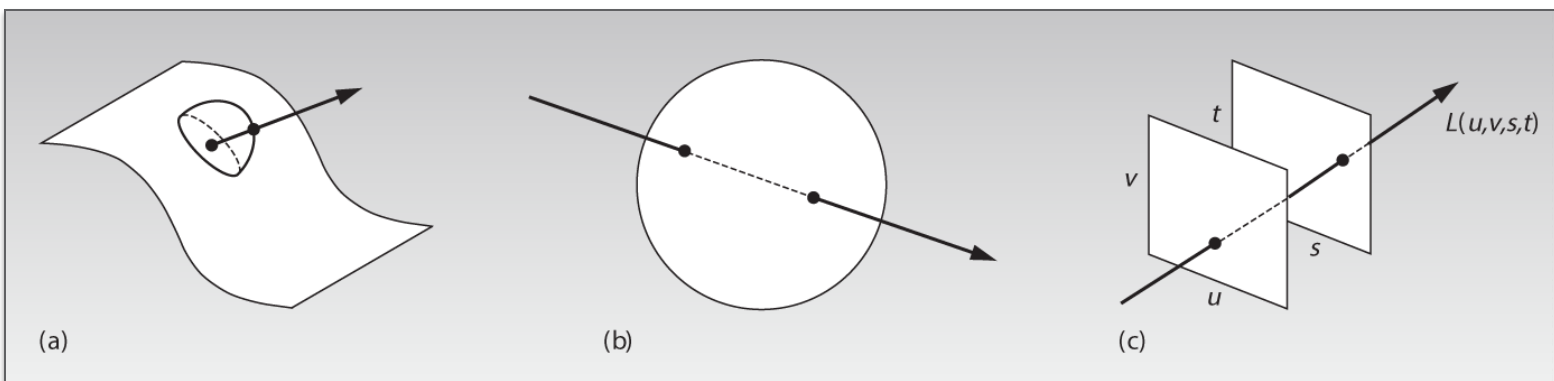
1. Background
2. Related Open Problems
3. Thesis Statement and Backing
4. Proposed Renderers and Case Studies
5. Conclusion

Plenoptic Data

- The 5D plenoptic function represents the flow of light through 3D space:

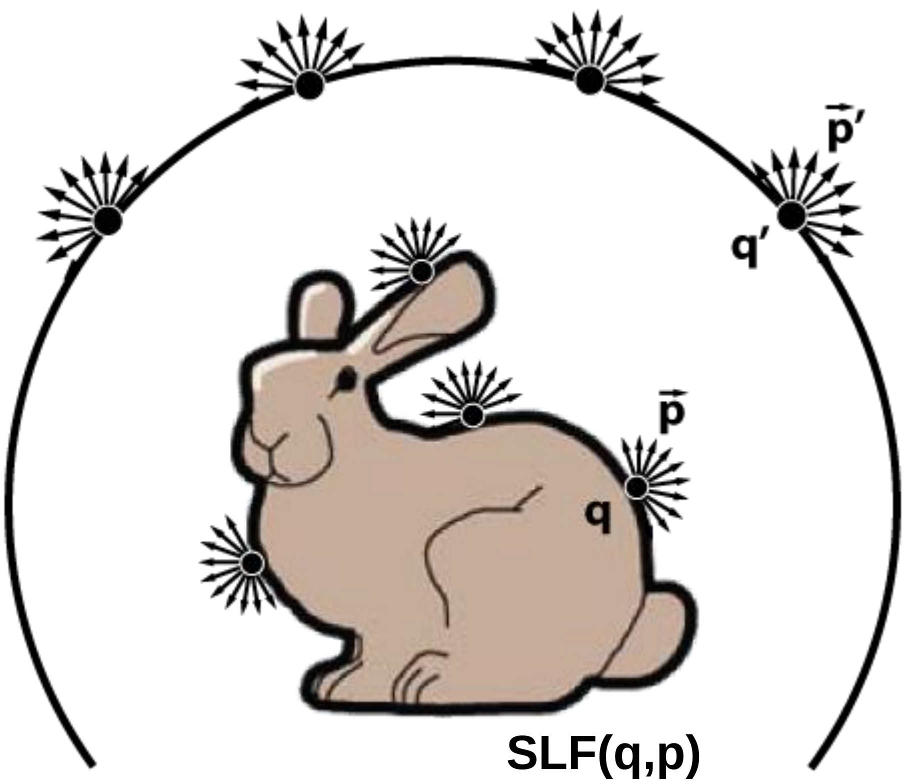


- Light fields are 4D slices from the plenoptic function, which can represent the flow of light in free space, or the radiance/irradiance at a 2D manifold:



Surface Light Fields

- A discontinuous 4D light field can be mapped to the radiance sources in a scene.

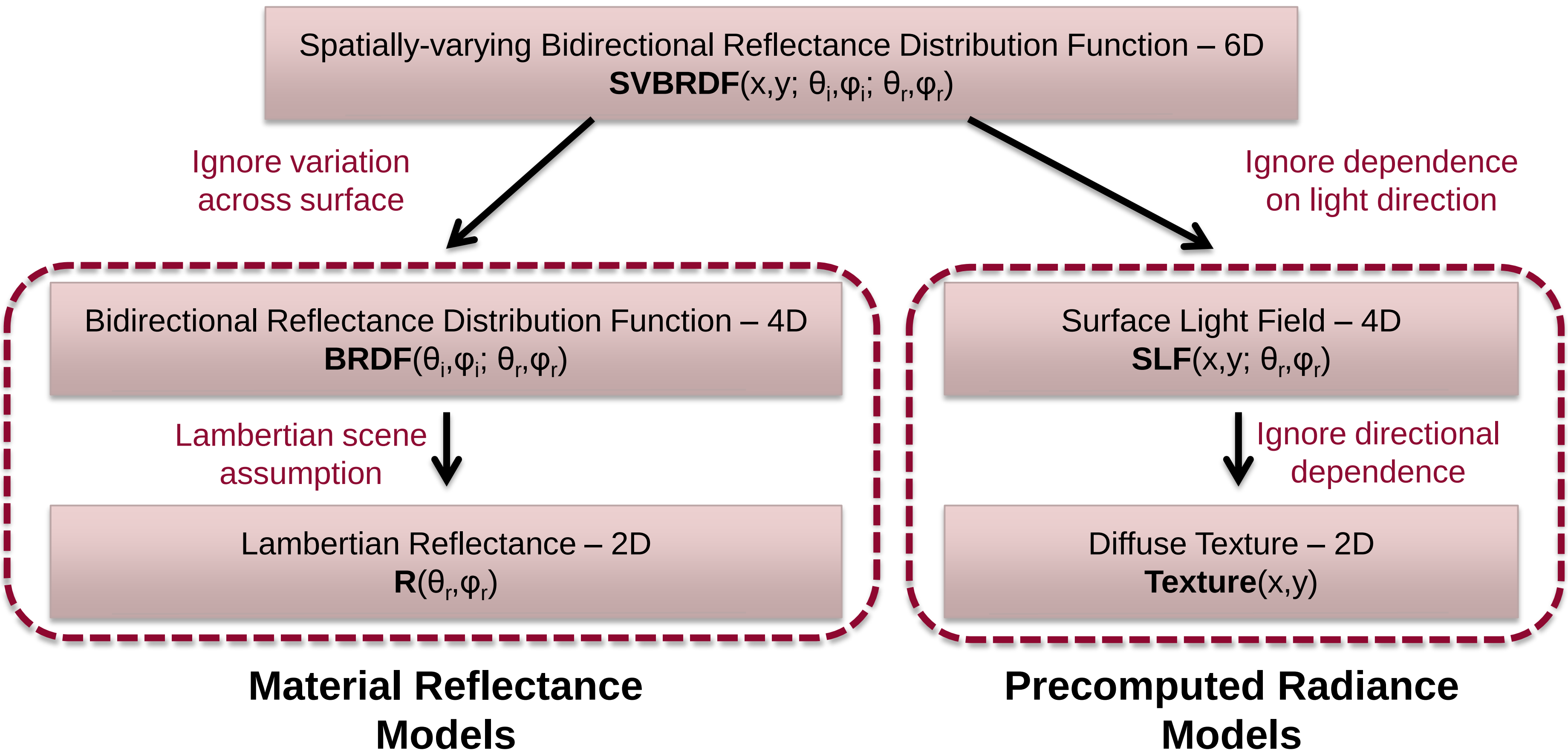


LF(q',p') – light field away from the scene. Can be used to reconstruct the plenoptic function in free space, e.g. inside a camera.

SLF(q,p) – light field on the scene surfaces. Can be used to reconstruct the plenoptic function of the scene. Implicitly stores information about the refocusable radiance sources in the scene.

Surface Light Fields

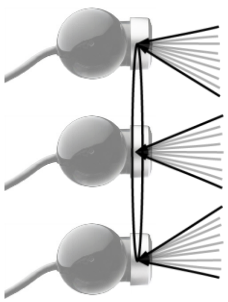
- SLFs are a view-dependent generalization of texturing.



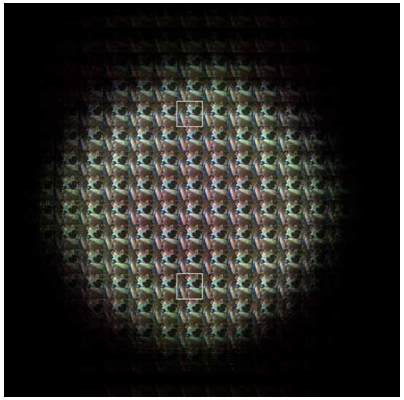
Unmodified Diagram: Szymon Rusinkiewicz

Light Field Capture

- Camera Array

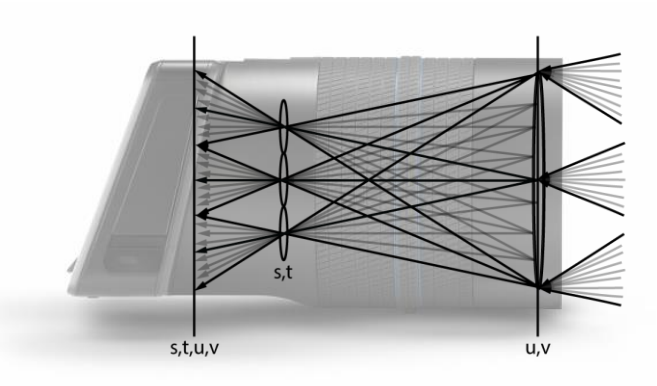


Sub-aperture Mosaic

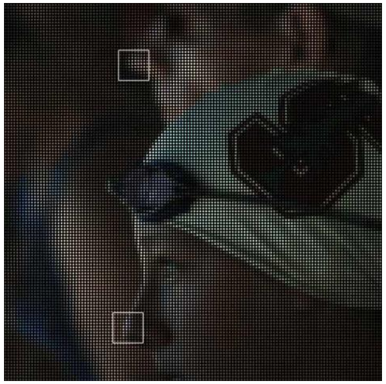


Sub-aperture Image

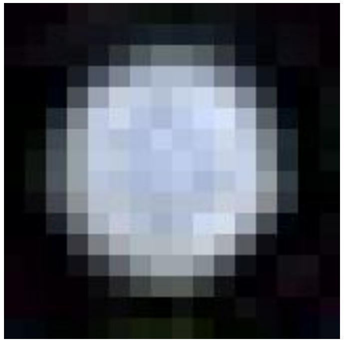
- Microlens Array



Microimage Mosaic

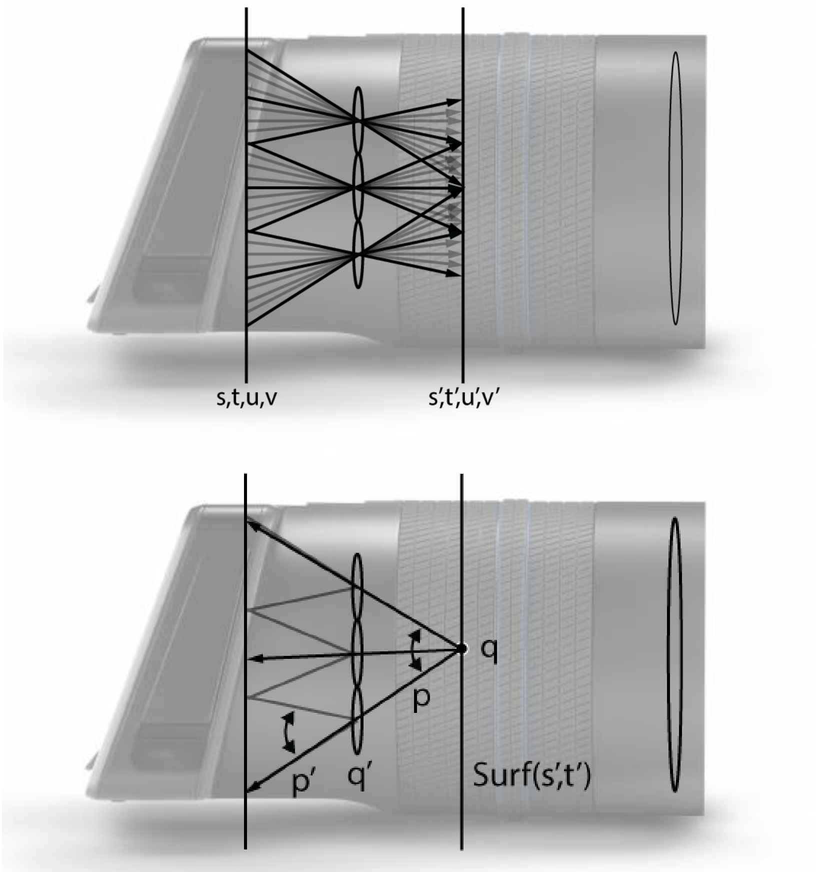


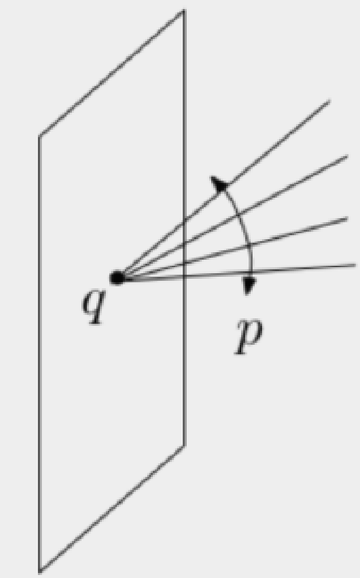
Microimage



Light Field Rendering

- A captured light field can be transformed to any focal surface where it can be integrated to form an image:





$$I(q) = \int_p r(q,p)\,dp$$

Outline

1. Background
2. Related Open Problems
   1. Ghosting Artifacts
   2. Limited Depth of Field Effects
   3. Plenoptic Vignetting
3. Thesis Statement and Backing
4. Proposed Renderers and Case Studies
5. Conclusion

Sparse Light Field Refocusing Artifacts

- Projecting neighboring views results in defocus mismatches, which can produce ghosting artifacts for scene features placed sufficiently out of focus.

Foreground in focus;
Background has ghosting artifacts.

Background in focus;
Foreground has ghosting artifacts.

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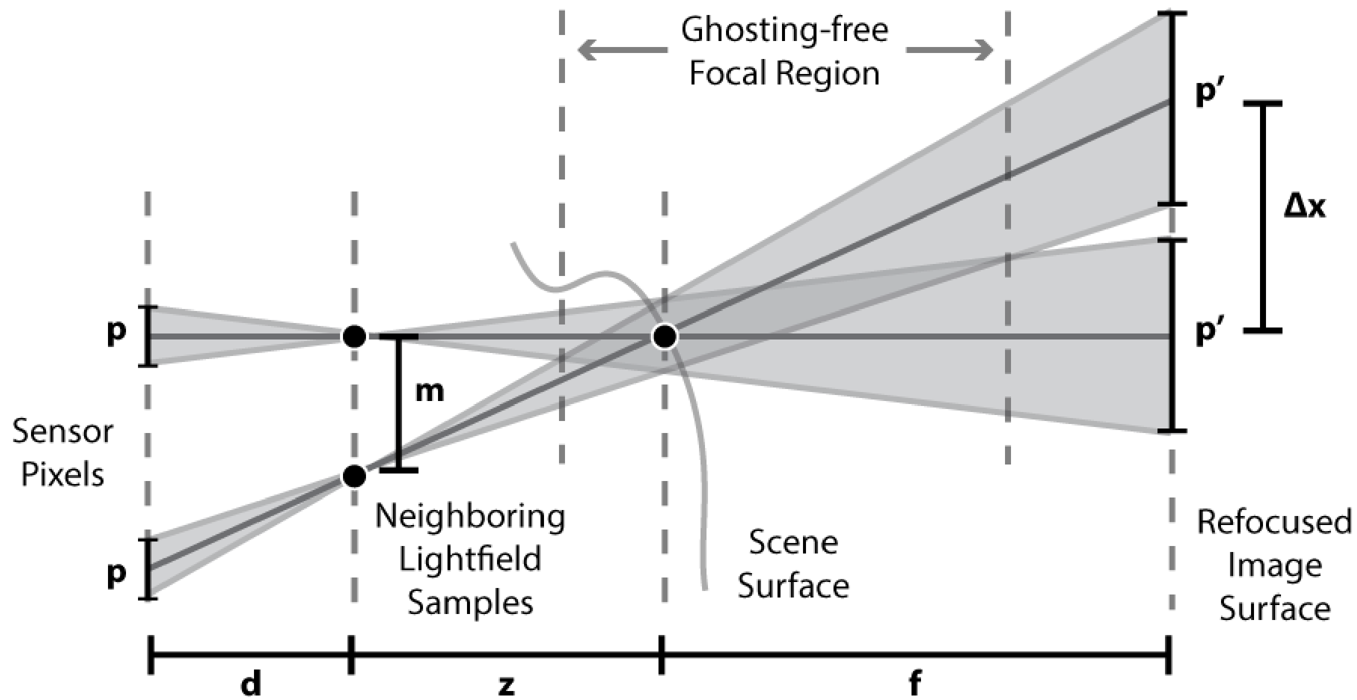


Fixing Ghosting Artifacts

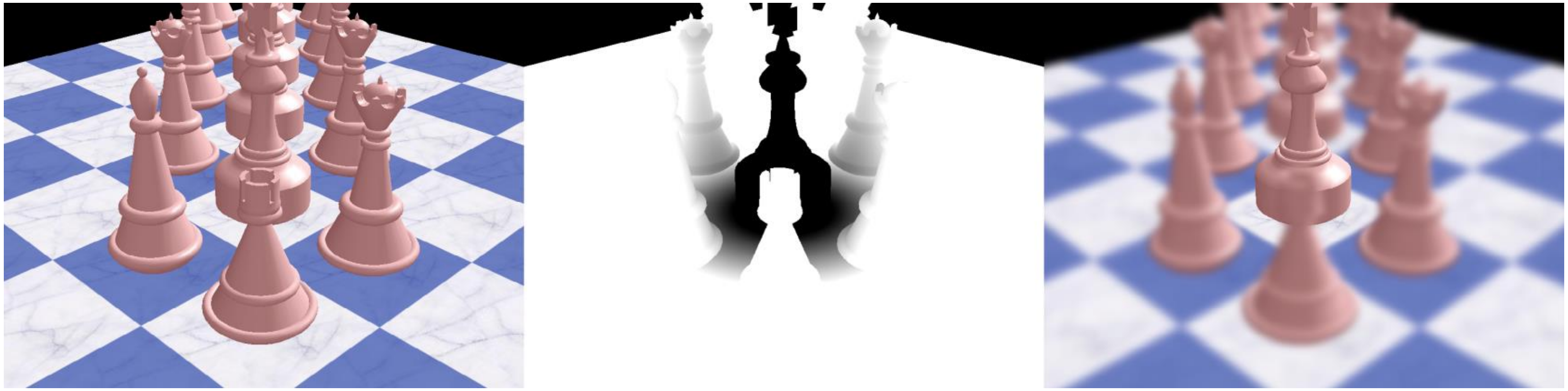
- Wide Aperture Microlens Filtering:
  - Results in over-blurring.

- Depth-dependent Microimage Filtering/Blurring:
  - Focus-dependent;
  - Needs to be precomputed as it is too slow for real-time rendering.
- Rendering from a Scene Model:
  - Prior solutions are based on view interpolation techniques, suitable for all-in-focus novel view synthesis.
  - For wide-aperture renditions, view-independent models could be utilized more directly, e.g., consider rendering from an SLF reconstruction.

Generalized Depth of Field

- Optical systems specify DoF indirectly and coarsely though parameters like focal length, F-stop, aperture, and focal surface;

- The goal of generalized DoF is to allow per-point focusing, which is useful both for esthetic purposes and cognitive cues (e.g., directing attention).

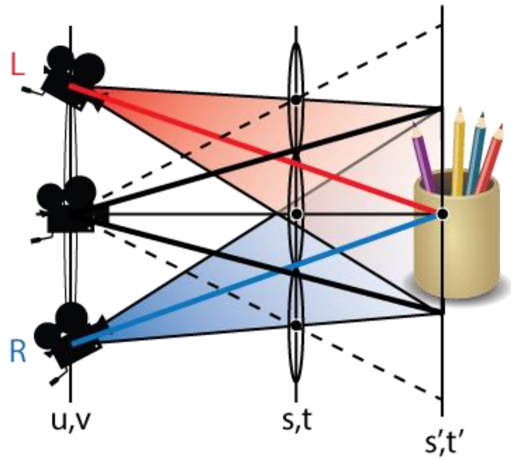


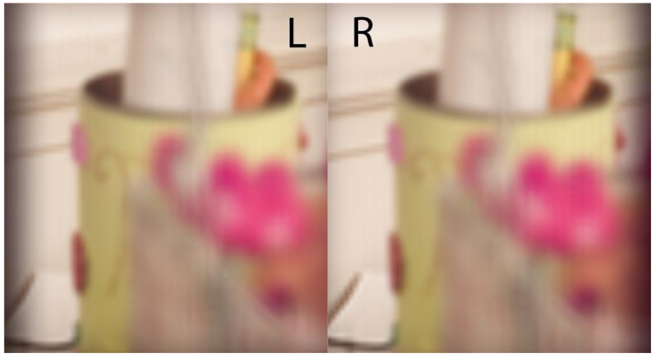
Generalized Depth of Field

- Prior solutions have been non-physically-based and have relied on substituting defocus with depth-dependent blurring, which fails to account for a large number of photographic effects:
  - Light attenuation;
  - Partial occlusions;
  - Shaped bokeh;
  - Positive and negative defocus.
- Prior solutions have targeted static scenes and static cameras. This has left a number of open questions:
  - How to specify focusing at the scene objects themselves;
  - How to specify focusing relative to a changeable view distance.
- Prior solutions have neglected scattered, refracted, and retransmitted light.

Plenoptic Vignetting

- Re-parameterizing a captured light field may result in shrinking the stereo window for neighboring views:





- Fixing Plenoptic Vignetting:
  - Color reweighting does not work, as missing views result in geometric aberrations – warped perspective;
  - Missing views need to be reconstructed, e.g., via SLF extrapolation.

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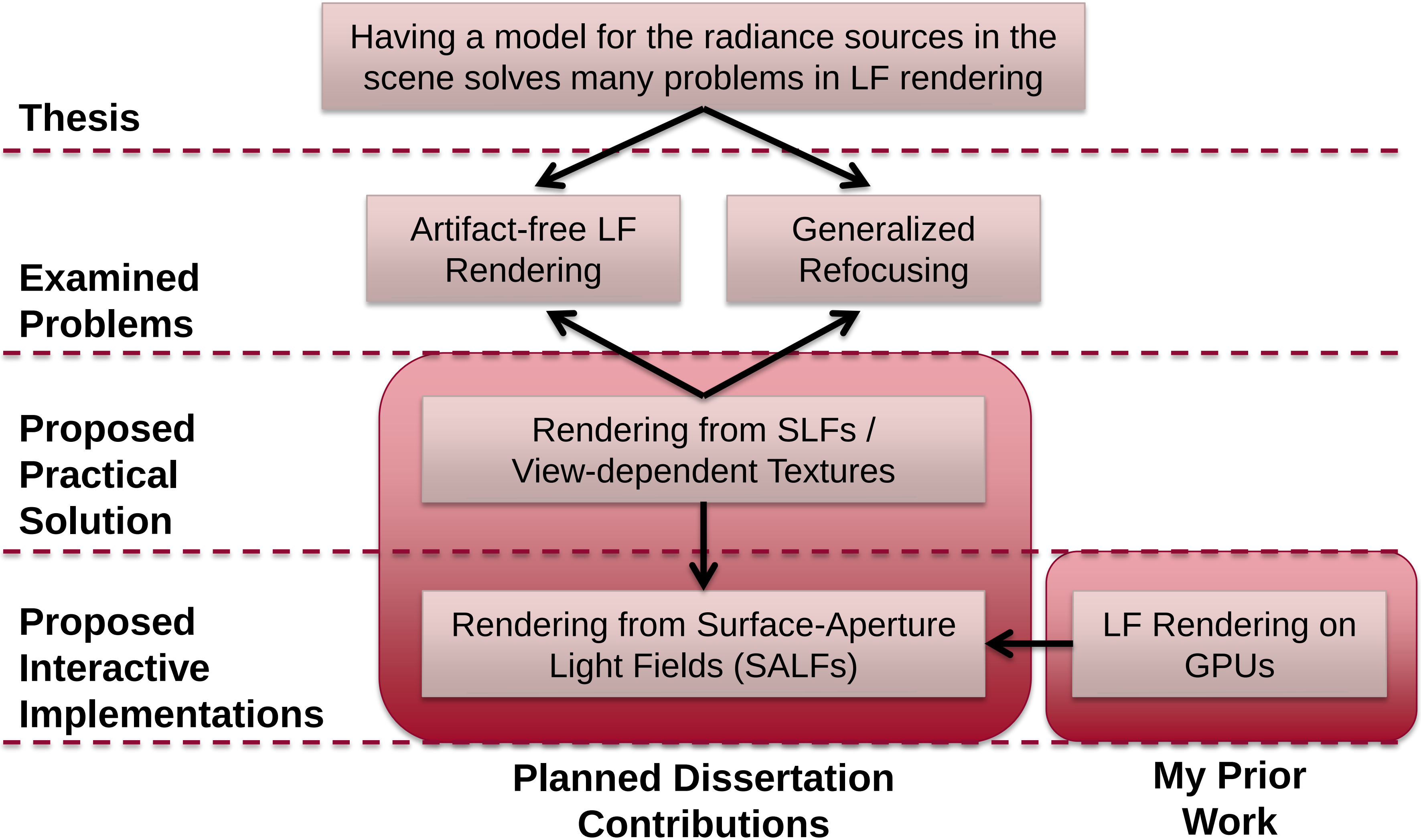
Thesis Statement

“Knowing the positions, from which radiance originates in a scene, allows for the implementation of more general and less artifact-prone refocusing algorithms than what is achievable just with 4D light field data captured away from that scene.”

Thesis Backing

- Surface light field samples can easily be interpolated and extrapolated to *reconstruct missing views*;
- Surface light field propagation can be done with *no aliasing* caused by directional undersampling;
- Surface light field refocusing allows for direct implementation of *physically-based generalized depth of field effects*;
- Going back to the scene surfaces allows us to *undo all camera-specific effects* on the captured light field data.

Outline of Thesis Contributions



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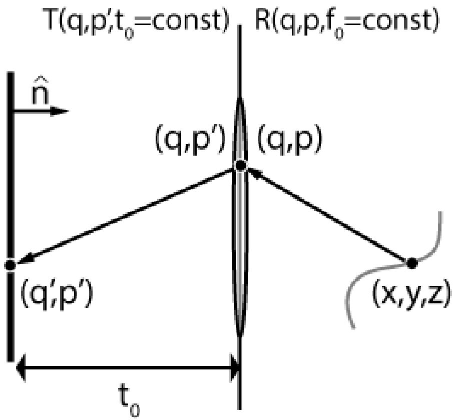
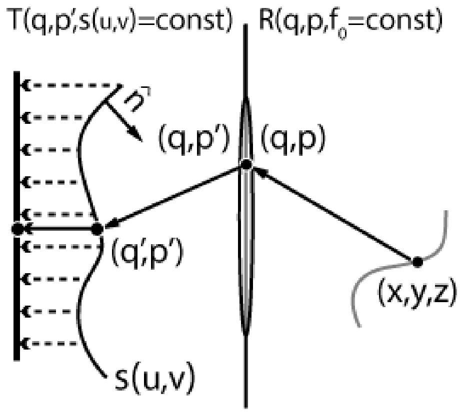
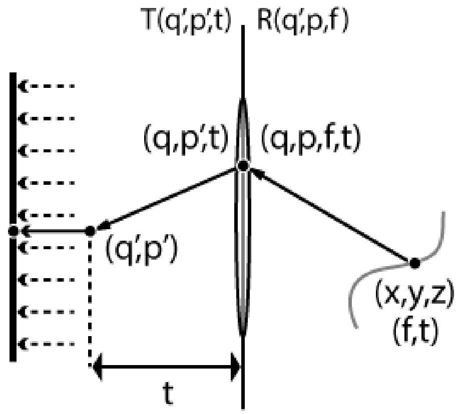
Proposed Focusing Generalization



Standard Camera Focusing



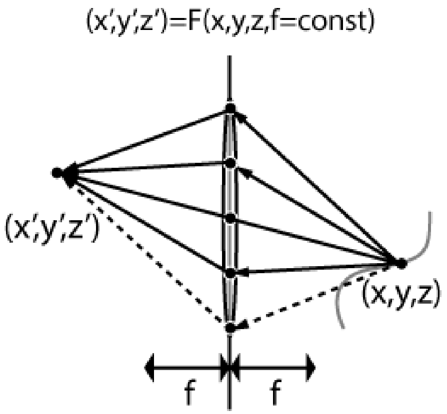
Standard LF Focusing



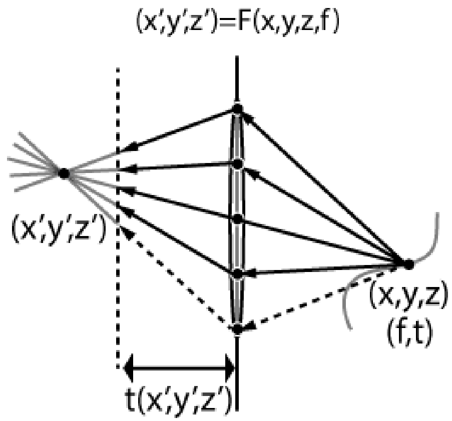
Proposed SLF Focusing

- In standard image formation, focusing is specified indirectly, though a number of parameters (camera distance, f/stop, and main lens focal length) specified globally for the image formation process.
- One way we could generalize image formation could be to consider a per-ray specification of the imaging transformation variables (refraction coefficient, *f*, and transmission distance, *t*).

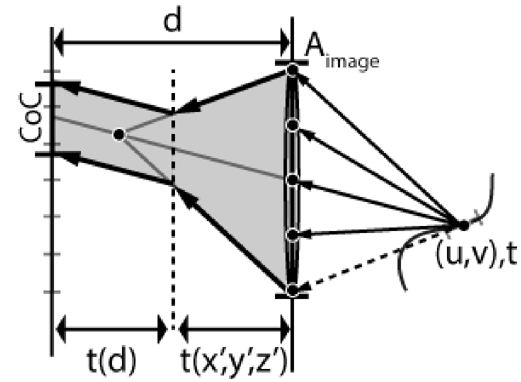
Image Formation with Offset Focusing



Standard Point
Refocusing



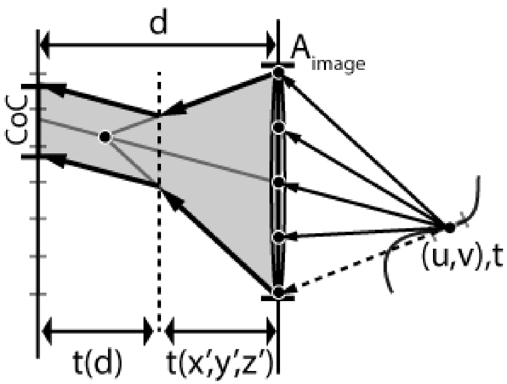
Proposed Offset
Refocusing



Proposed Offset
Image Formation

- Generalized DoF effects can be implemented just by varying the transmission distance, *t*. This parameter can be specified at each scene point and can be interpreted as distance, relative to: the main lens; the true focal conjugate; or any focal surface.
- To form a final image, each ray can be projected to an output image surface according to a desired output image perspective.

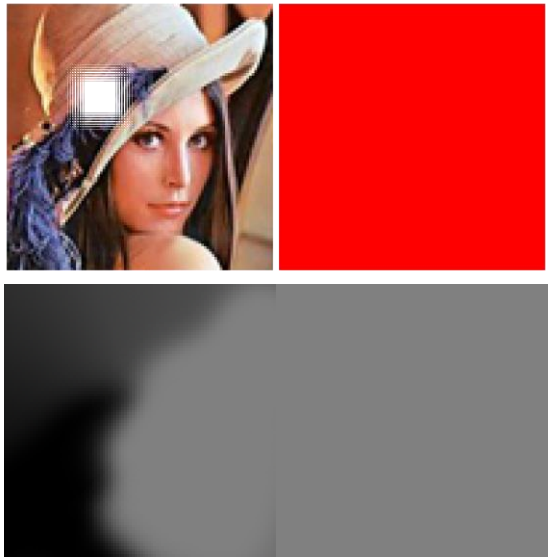
Real-time Offset Refocusing from Surface-Aperture Light Fields (SALFs)



Proposed Offset Image Formation

SALF Atlas

Focus Maps



Example Rendition

- For static cameras, most of the radiance transfer can be precomputed – up to a set of partially occluded aperture images. These images can be stored as super-pixels in an unwrapped texture space and passed onto a GPU for real-time rendering.
- The proposed imaging model is also very well suited for implementing intuitive generalized DoF tools, i.e. a focus brush.

Practical Case Studies

- Virtual Scene Photography
- Photography of Multi-view Reconstructed Scenes
- Plenoptic Camera Photography

Virtual Scene SLF Photography

- Challenges
  - Baking view-dependent radiance onto surfaces is non-standard in PBR;
  - Consider non-refocusable radiance sources (e.g., scattered, refracted, and re-transmitted light);
  - Consider real-time rendering implementations.

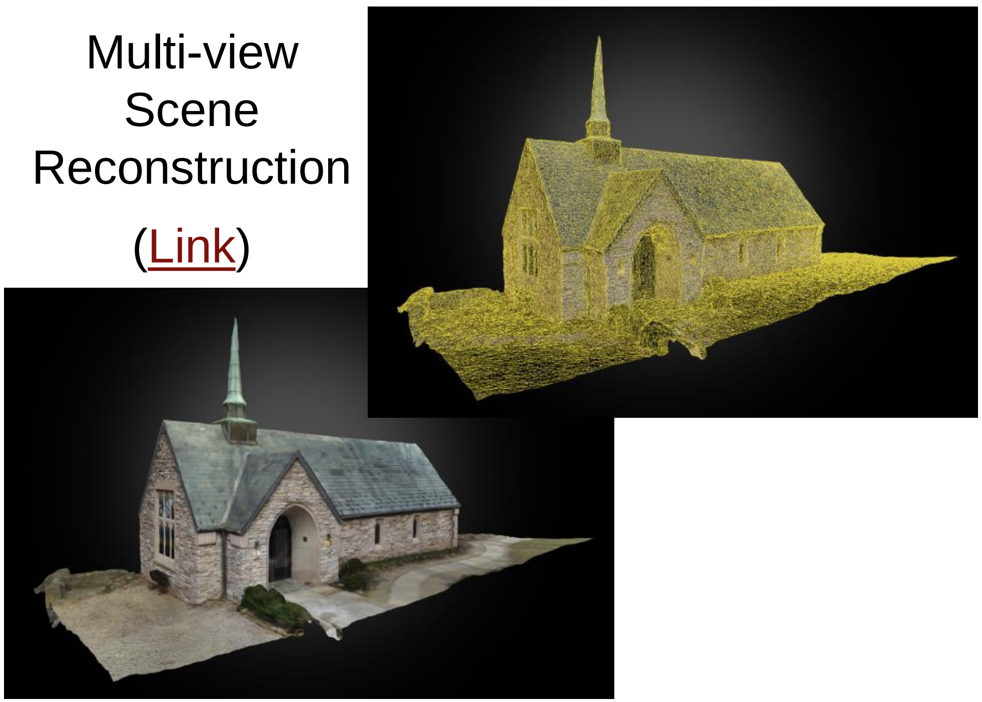
Rendered with V-Ray

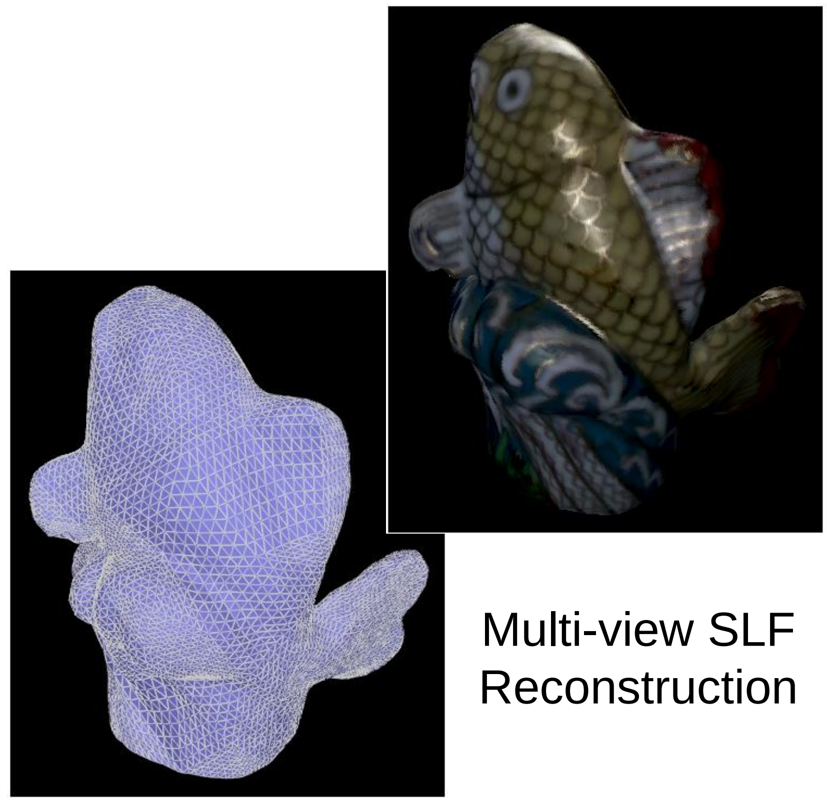
Multi-view Reconstructed SLF Photography

- Challenges
  - Consider how to map directional samples onto scene reconstructions;
  - Consider avoiding light field resampling;
  - The MV acquisition technique is restricted to static objects and scenes;

Multi-view Scene Reconstruction

(Link)





Multi-view SLF Reconstruction

Plenoptic Camera SLF Photography

- Challenges
  - Plenoptic camera calibration;
  - Small parallax scene reconstruction;
  - Consider disparity-space implementations.

For general scenes, layered depth reconstructions are the most suitable choice.

Close-ups of isolated objects can additionally be smoothed though filtering.

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Expected Specific Contributions

- Physically-based generalized refocusing;
- Interactive implementations and interfaces for generalized refocusing – the focus brush.

- Surface light field photography, as artifact-free plenoptic rendering.

Remaining Work

Task	Timeline
Consider a Paper	Fall 2015
Implement Renderers - Lytro Renditions - Blender GE / Focus Brush - Cycles Implementations - 3D Photo-modeling Results	Now – May 2016
Thesis Writing	Fall 2015 – Fall 2016
Thesis Defense	Fall 2016

Conclusion

“Even though, a light field captured away from the scene is sufficient for implementing post-capture photographic effects, starting the image formation process from the surface light fields of the scene allows for a direct implementation of more general and less artifact-prone rendering algorithms.“