# PHYSICALLY-BASED RENDERING OF HIGHLY SCATTERING FLUORESCENT SOLUTIONS USING PATH TRACING

Marwan Abdellah   Ahmet Bilgili   Stefan Eilemann   Henry Markram   Felix Schürmann
Blue Brain Project, Brain Mind Institute, École Polytechnique Fédéral de Lausanne (EPFL), Switzerland

## Context

### Motivation & Goals

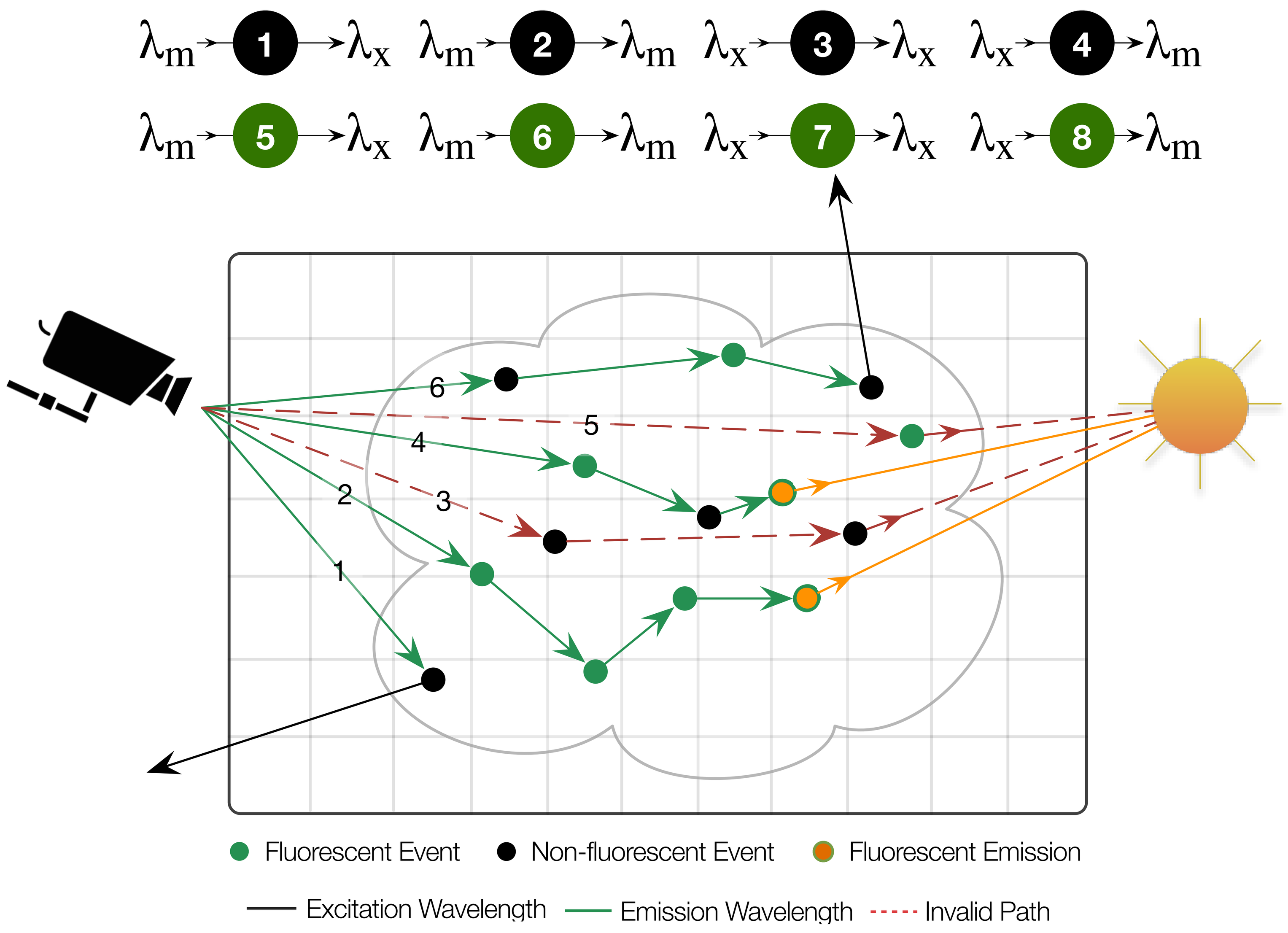
Introducing accurate fluorescence model that can render highly scattering fluorescent participating media. This model is presented to extend previous fluorescence models that ignore the spectroscopic properties of the fluorescent dyes [1, 2, 3] and can only handle low scattering media [4, 5].

### Contribution

1. Development of Monte Carlo estimator that handles highly scattering fluorescent participating media while taking into account the fundamental characteristics of the fluorescent dyes including their emission and excitation spectra, quantum efficiency, molar absorptivity and concentration for a given mixture.
2. Extending the physically-based rendering toolkit (PBRT) [6] to be capable of rendering highly scattering fluorescent media.
3. Qualitative validation of the resulting images by comparing their spectral responses with experimental emission spectra of different fluorescent dyes.

## Our Fluorescence Model

### Possible Events & Paths




### Monte Carlo Estimator

Our fluorescence model evaluates the radiance arriving to the film at certain emission wavelength due to multiple scattering using the following Monte Carlo estimator

$$L_{\mathrm{i}}(\mathbf{x}_0,\omega,\lambda_{\mathrm{m}}) \approx \frac{1}{N_\lambda}\frac{1}{N}\sum_{\lambda=1}^{N_\lambda}\sum_{i=1}^{N}\frac{L_{\mathrm{e}}(\mathbf{x}_l,\lambda_{\mathrm{x}})\hat{V}_i}{p(\mathbf{x}_l)p(\lambda_{\mathrm{x}})}V_{\mathrm{f}_i}\prod_{j=1}^{M}\frac{\hat{V}_j\hat{C}_jG_j}{p(\omega_j)p(t_j)}$$

Path Binary Fluorescence Visibility

$$\hat{V}_i = \tau(\mathbf{x}_l,\mathbf{x}_i,\lambda_{\mathrm{x}})V(\mathbf{x}_l,\mathbf{x}_i)$$

$$\hat{V}_j = \tau(\mathbf{x}_j,\mathbf{x}_{j-1},\lambda_{\mathrm{m}})V(\mathbf{x}_j,\mathbf{x}_{j-1})$$

$$\hat{C}_j = f_p(\mathbf{x}_j,\omega_j,\omega_{j+1},\lambda_{\mathrm{m}})\sigma_s(\mathbf{x}_j,\lambda_{\mathrm{m}})$$

All the symbols are defined in the accompanying paper published in the proceedings

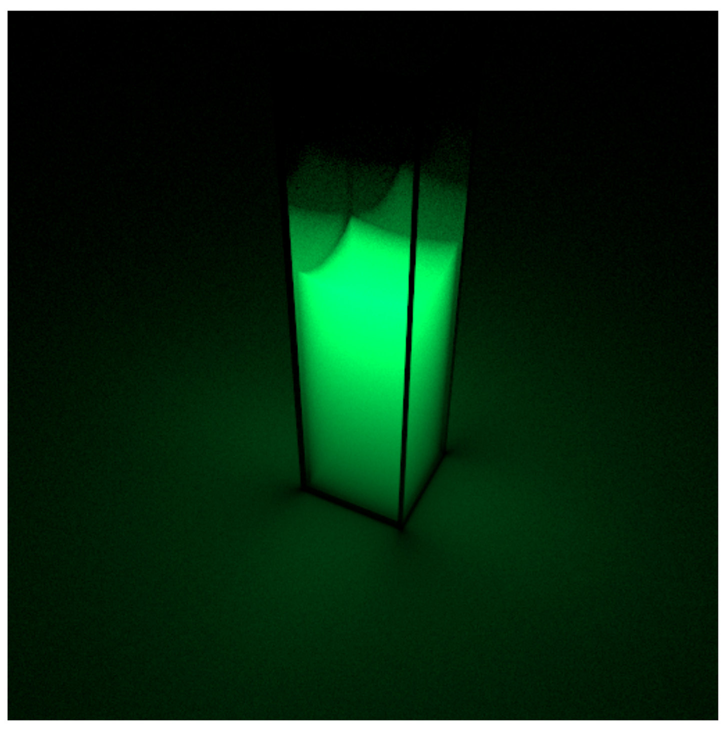
The **path binary fluorescence visibility** term indicates whether a fluorescence event exits on certain path or not. This term is expressed by the optical properties of the medium, the spectroscopic characterises of the fluorescent dye, and the concentration of the fluorescent solvent in a given mixture.

A valid fluorescent path expresses a series of inelastic scattering and a single fluorescence emission.

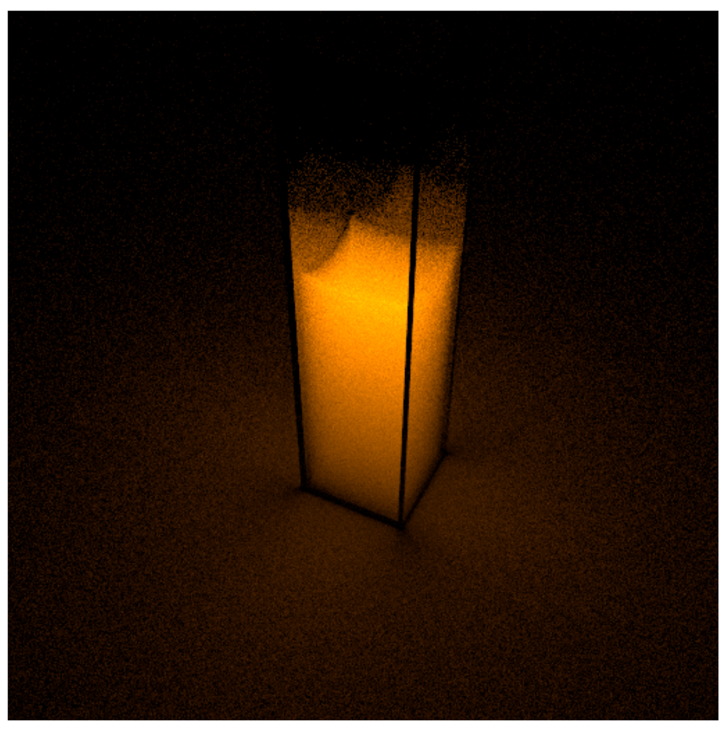
## Results

### Rendering Results

Unbiased rendering of fluorescent cuvettes filled with highly concentrated GFP and RFP dissolved in dense solutions.
The two cuvettes are excited with monochromatic light sources emitting at 460 and 520 for the GFP and RFP solutions respectively.



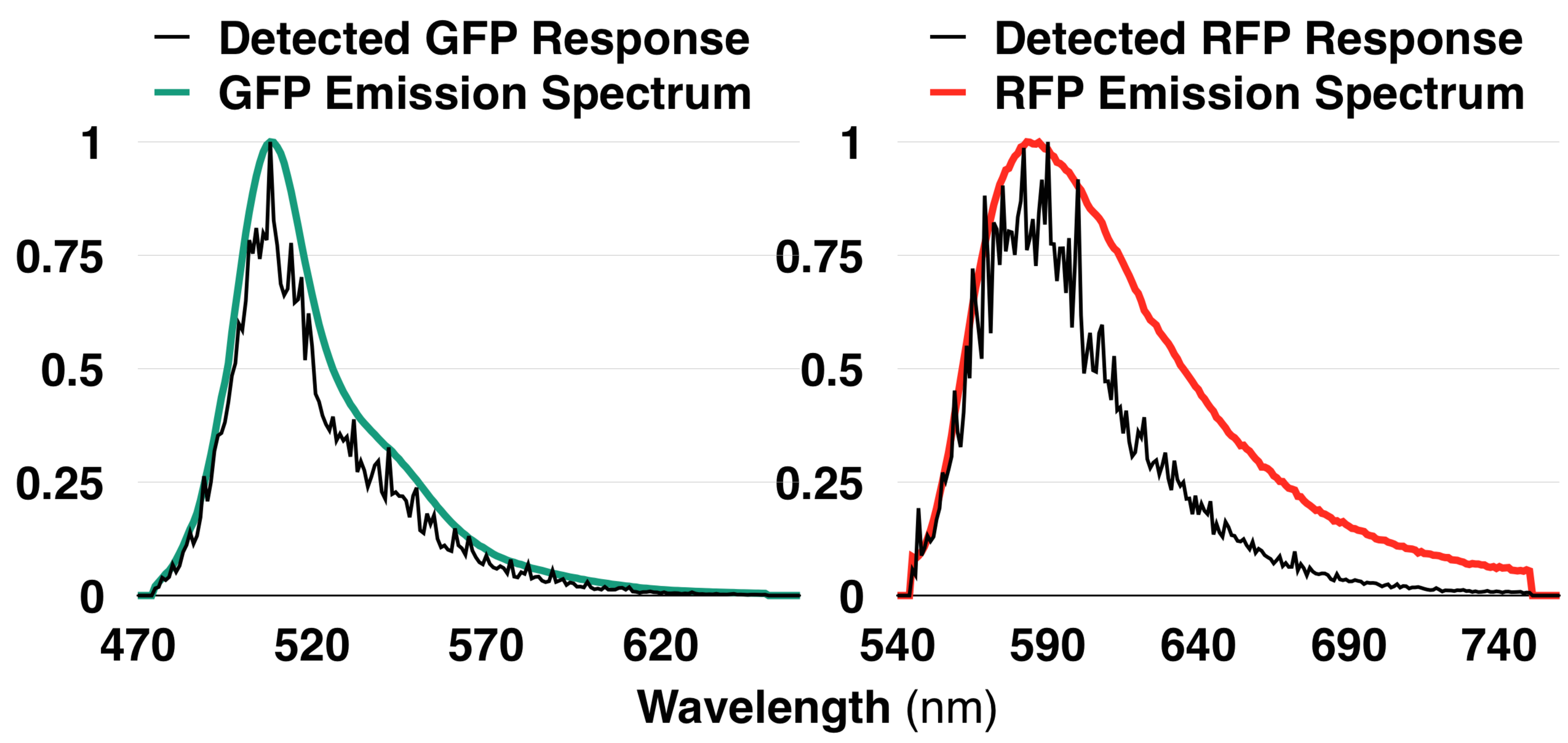
GFP : Green Fluorescent Protein



RFP : Red Fluorescent Protein

### Qualitative Validation

The normalised spectral responses of the GFP and RFP renderings are compared with the spectroscopic emission profiles of GFP and RFP.




## Future Work

1. Using multiple importance sampling to improve the efficiency of the presented estimator.
2. Complete system validation using realistic fluorescent beads and quantitative comparisons against physical fluorescent experiments.
3. Extending this work to bidirectional methods including bidirectional path tracing and virtual point lights.

## References

1. CEREZO B. E., SERON F. J.: Rendering natural waters taking fluorescence into account. Computer Animation and Virtual Worlds 15, 5 (2004), 471–484.
2. GLASSNER A.: A model for fluorescence and phosphorescence. In Photorealistic Rendering Techniques, Sakas G., Müller S., Shirley P., (Eds.), Focus on Computer Graphics. Springer Berlin Heidelberg, 1995, pp. 60–70.
3. GUTIERREZ D., SERON F. J., MUNOZ A., ANSON O.: Visualizing underwater ocean optics. In Computer Graphics Forum (2008), vol. 27, Wiley Online Library, pp. 547–556.
4. ABDELLAH M., BILGILI A., EILEMANN S., MARKRAM H., SCHÜRMANN F.: A computational model of light sheet fluorescence microscopy using physically-based rendering, In Eurographics 2015.
5. ABDELLAH M., BILGILI A., EILEMANN S., MARKRAM H., SCHÜRMANN F.: Physically-based in silico light-sheet fluorescence microscopy for visualising fluorescent brain models, BMC Bioinformatics 16.Suppl 11 (2015): S8.
6. PHARR M., HUMPHREYS G.: Physically Based Render- ing, Second Edition: From Theory To Implementation. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 2010.

## Acknowledgements

The research was supported in part by the Blue Brain Project (BBP), the Swiss National Science Foundation under Grant 200020-129525 and the King Abdullah University of Science and Technology (KAUST) through the KAUST-EPFL Alliance for Neuro-Inspired High Performance Computing. We thank Arne Seitz, Jos´e Artacho, Thierry Laroche, Olivier Burri, Daniel Keller, and Martin Telefont for their support and feedback on the fluorescence model. We also acknowledge the support of Grigori Chevtchenko for the solid voxelization workflow.

Contact { marwan.abdellah | ahmet.bilgili | stefan.eilemann | henry.markram | felix.schuermann } @ epfl.ch
http://bluebrain.epfl.ch

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Blue Brain Project