Multibounce LiDAR for Super Resolution Imaging and Detection

Andreas Velten,

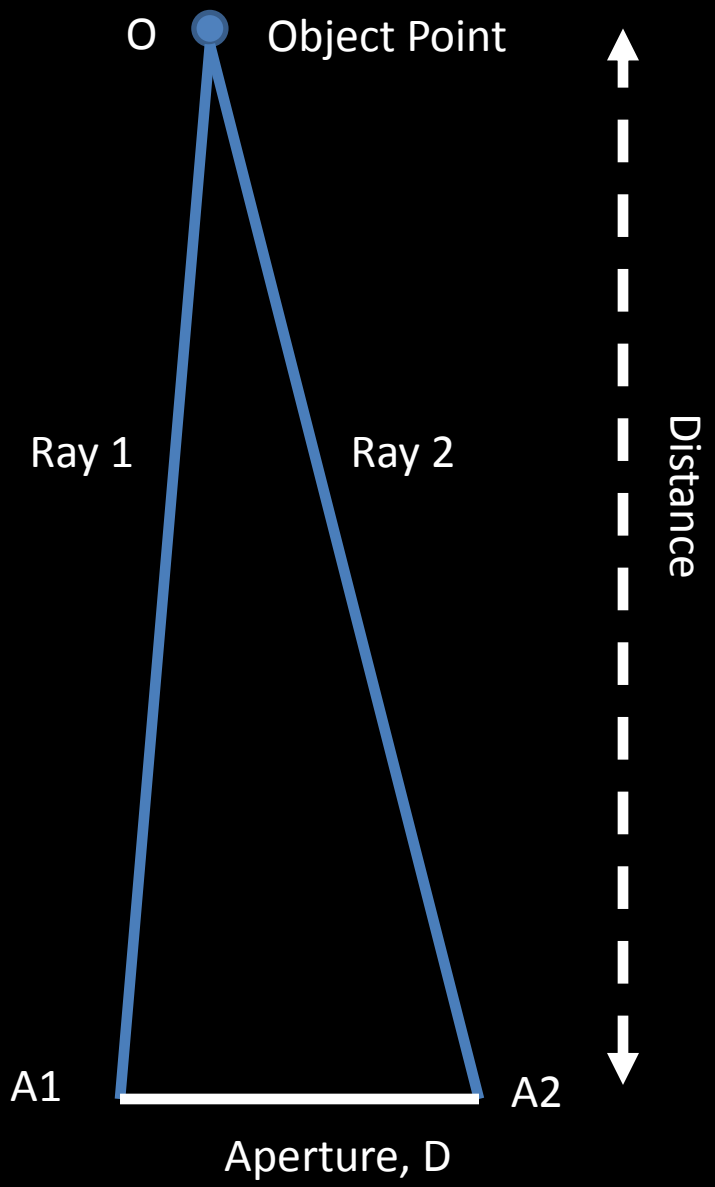
Computational Optics Group

Department of Biostatistics and Medical Informatics,
Department of Electrical and Computer Engineering

Laboratory for Optical and Computational Instrumentation, UW Madison
Affiliate, Living Environments Lab, Morgridge Institute

Fellow, Wisconsin Institute for Discovery

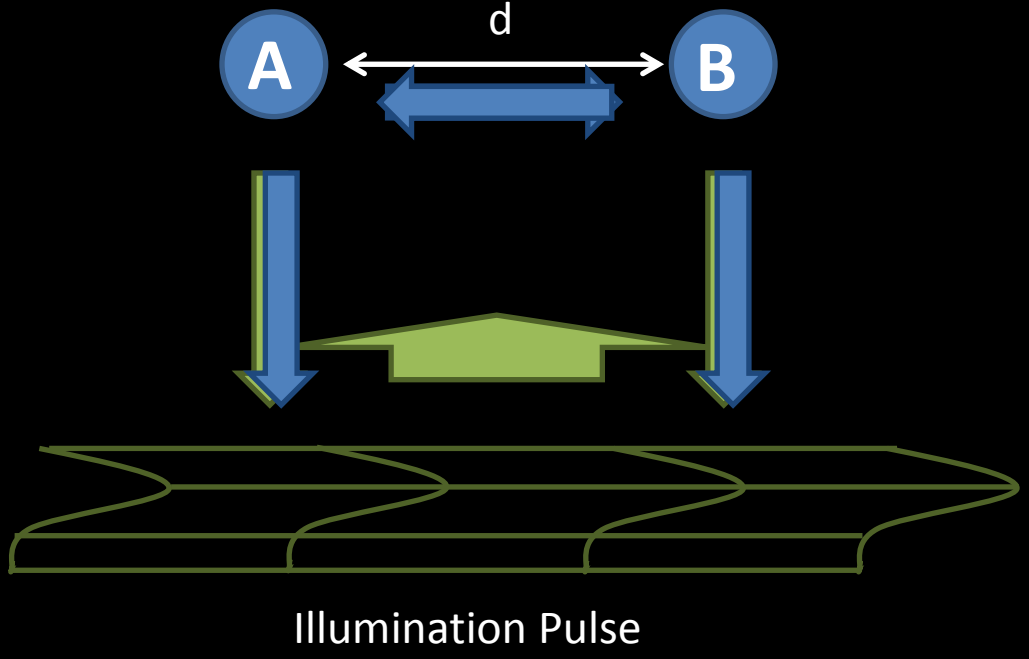
Conventional Imaging

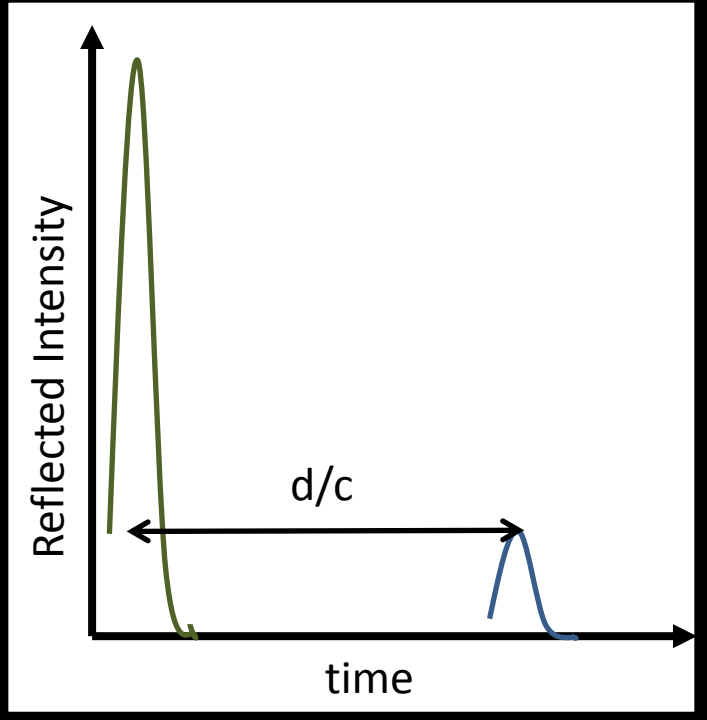


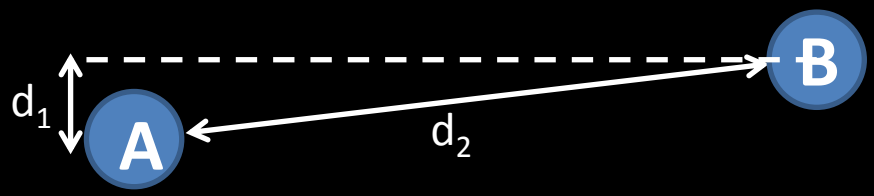
$$\Theta = 1.220\frac{\lambda}{D}$$

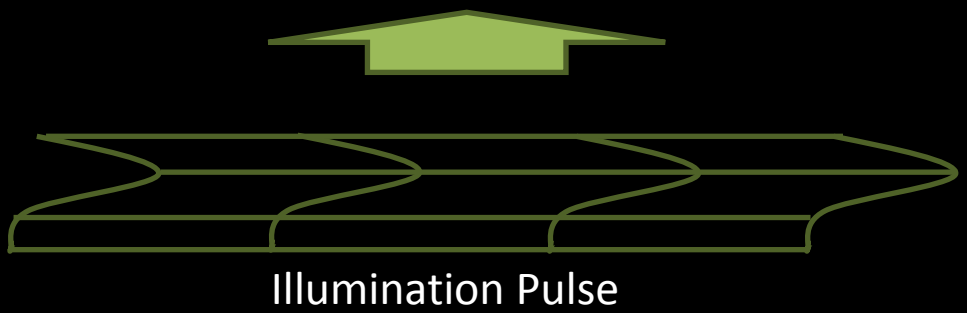
- J. Busck and H. Heiselberg. *Gated viewing and high-accuracy three-dimensional laser radar.*
- Di Wu, et. al. *Frequency Analysis of Transient Light Transport with Applications in Bare Sensor Imaging*
- Ahmed Kirmani, et. al. *Diffuse Imaging: Creating Optical Images with Unfocused Time-Resolved Illumination and Sensing*
- Dongeek Shin, et. al. *Photon-Efficient Computational 3D and Reflectivity Imaging with Single-Photon Detectors*

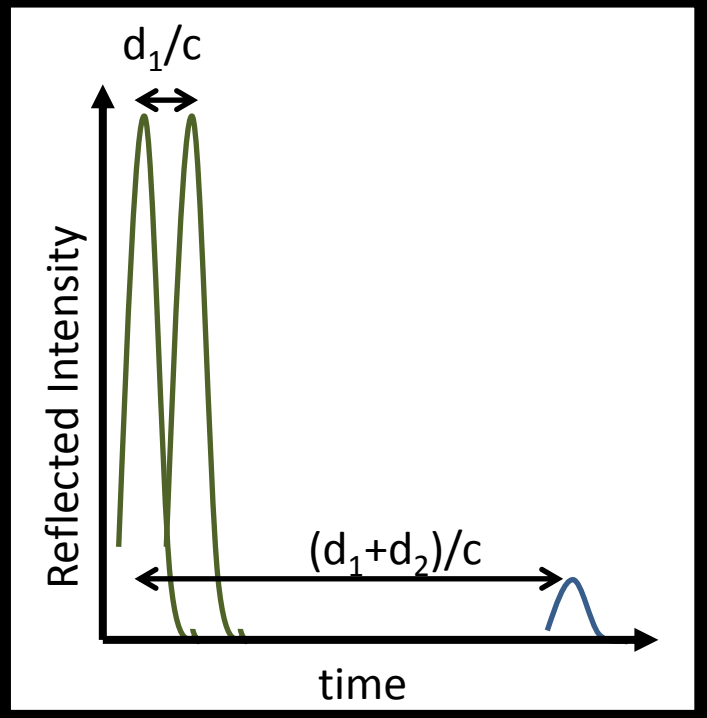
Time Encoded Imaging

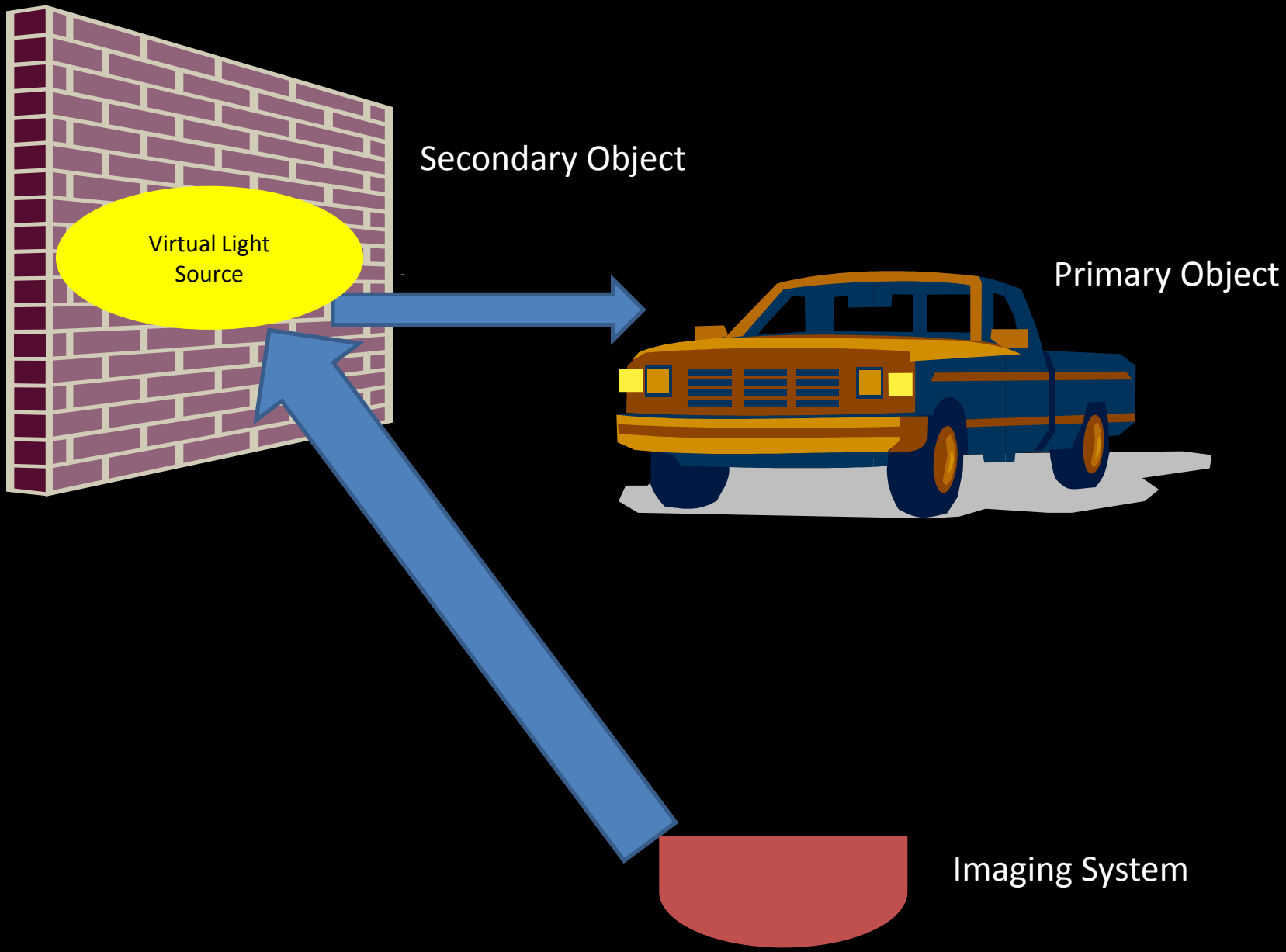


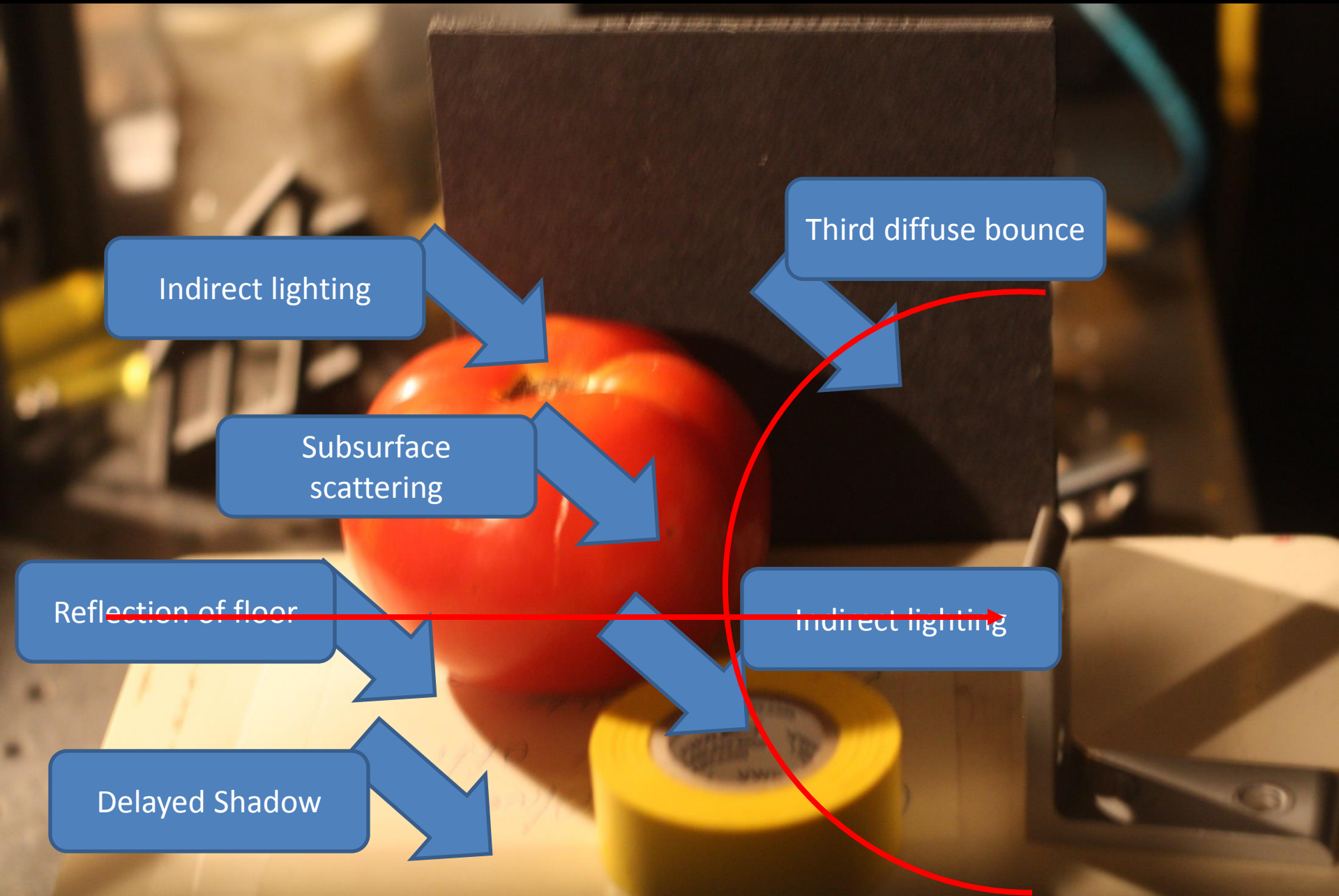






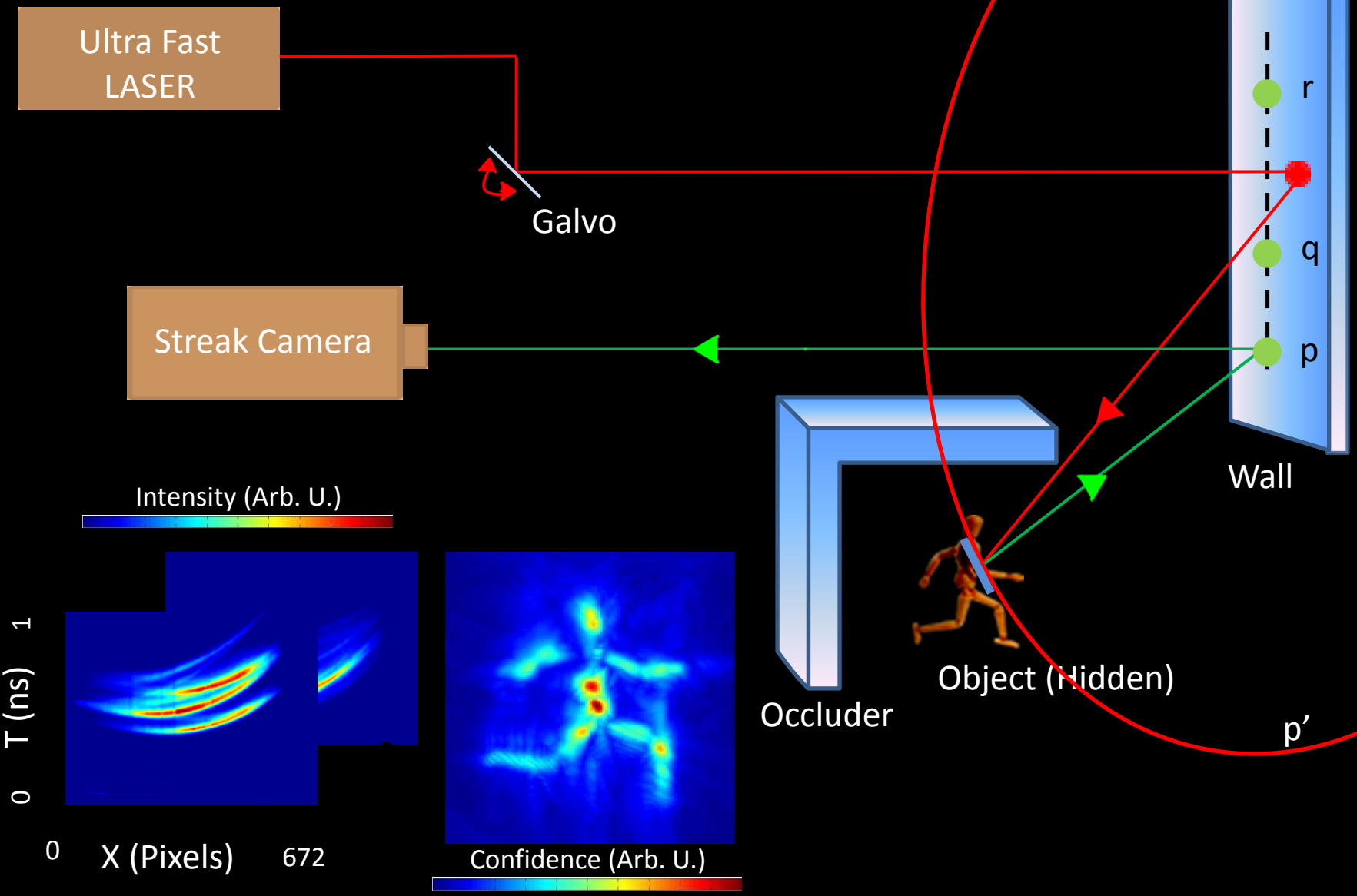



Secondary Object
Virtual Light Source
Primary Object
Imaging System

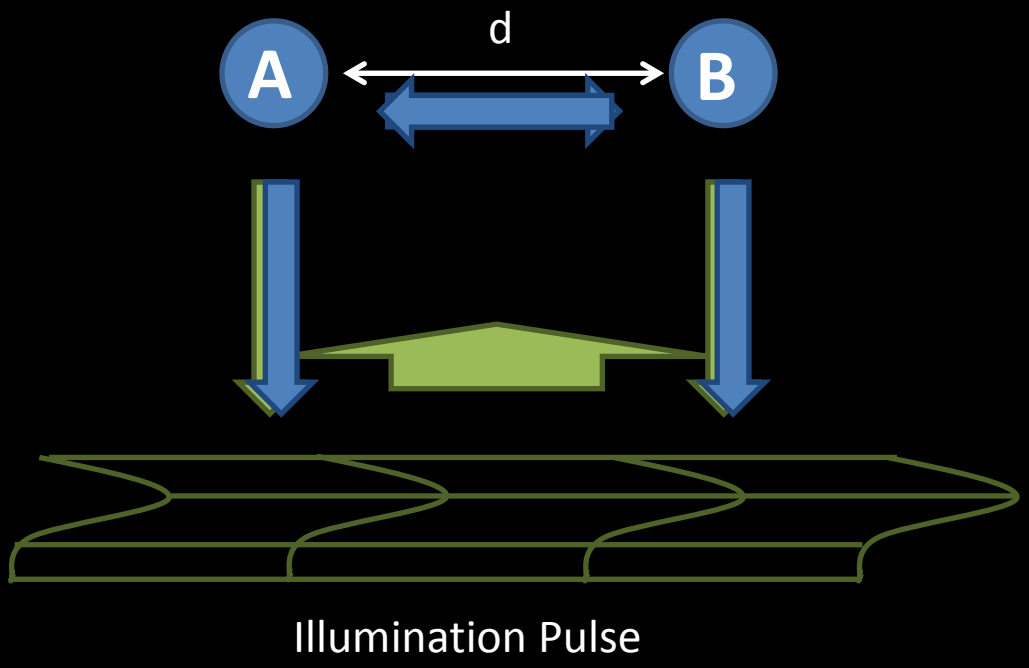

Indirect lighting
Third diffuse bounce
Subsurface scattering
Reflection of floor
Indirect lighting
Delayed Shadow

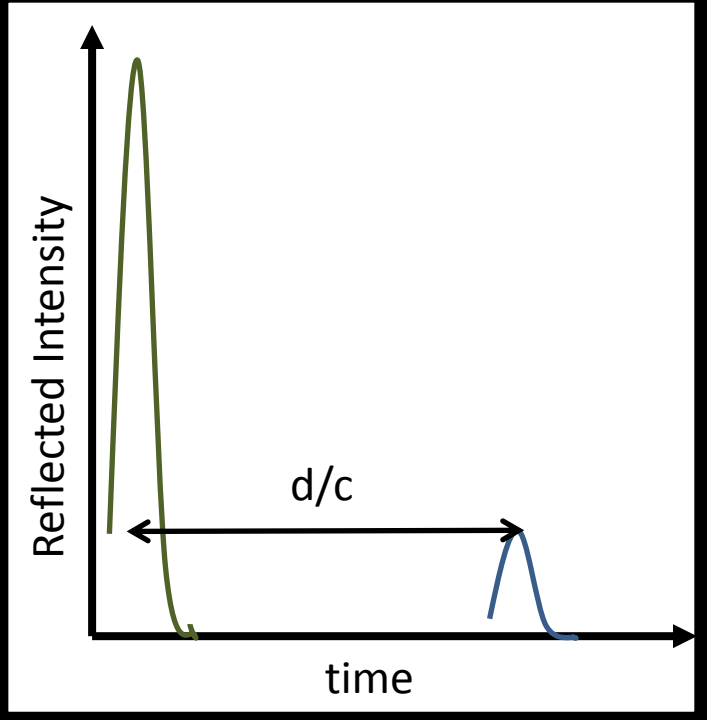
Seeing Around Corners

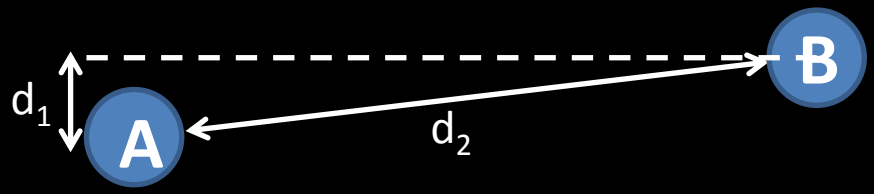
Nature Communications, March 2012

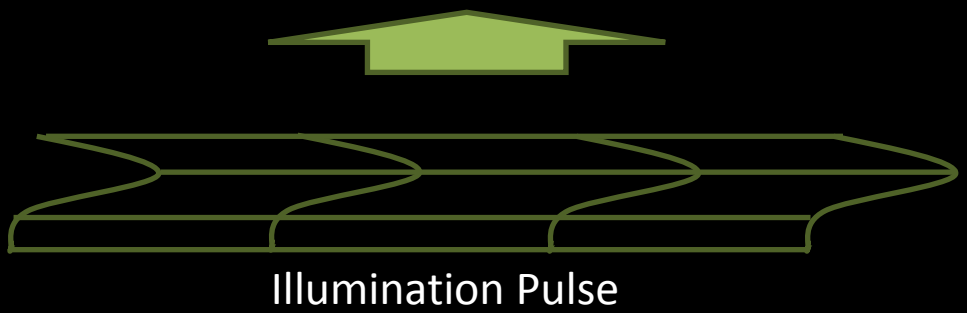


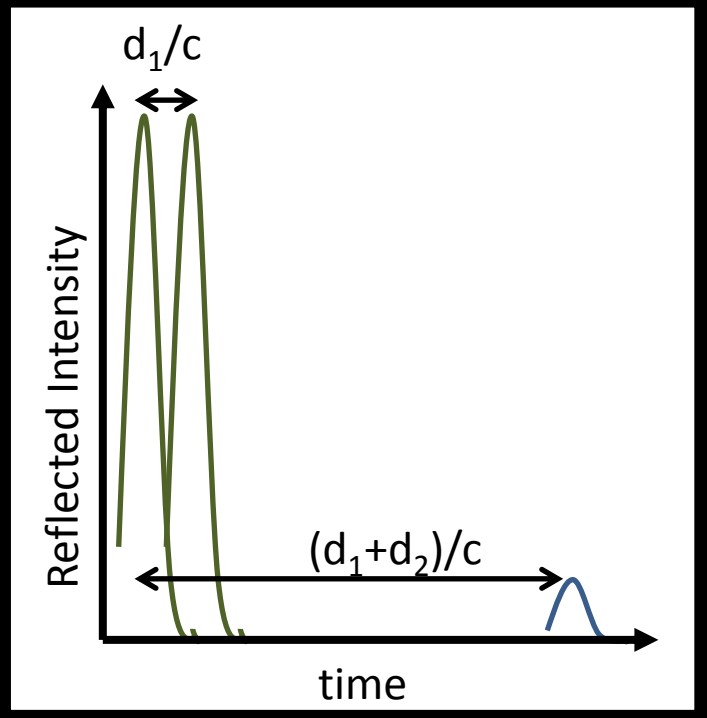
Time Encoded Remote Apertures

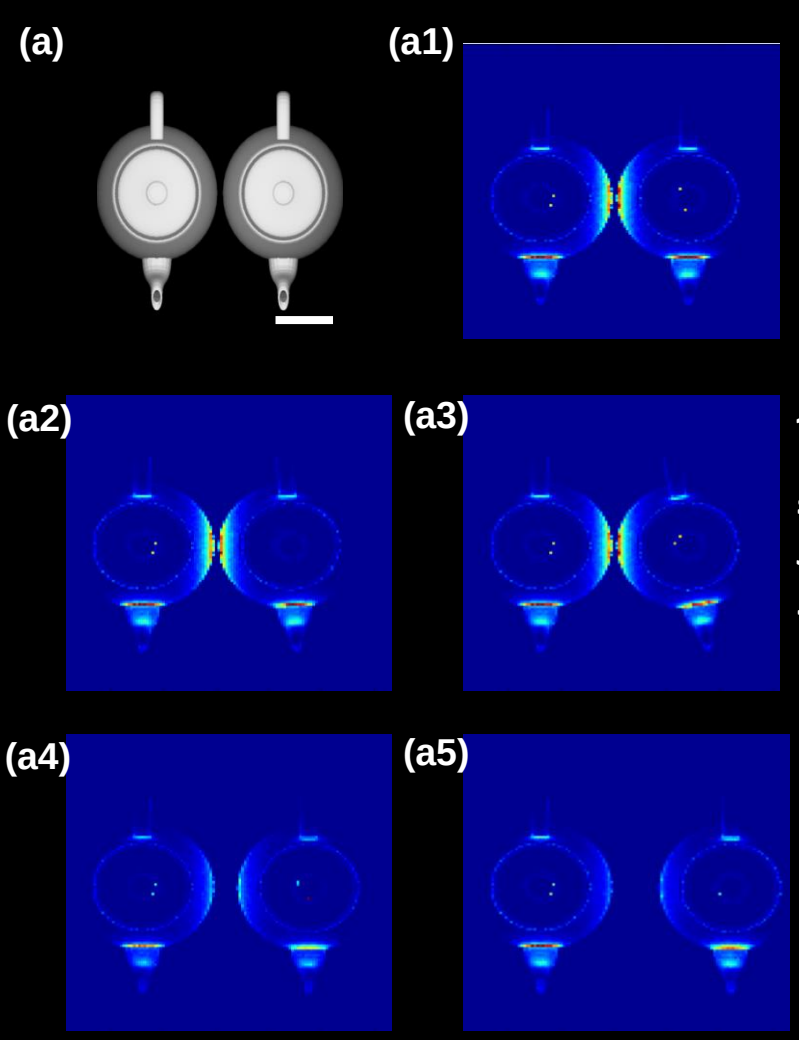

A
d
B
Illumination Pulse

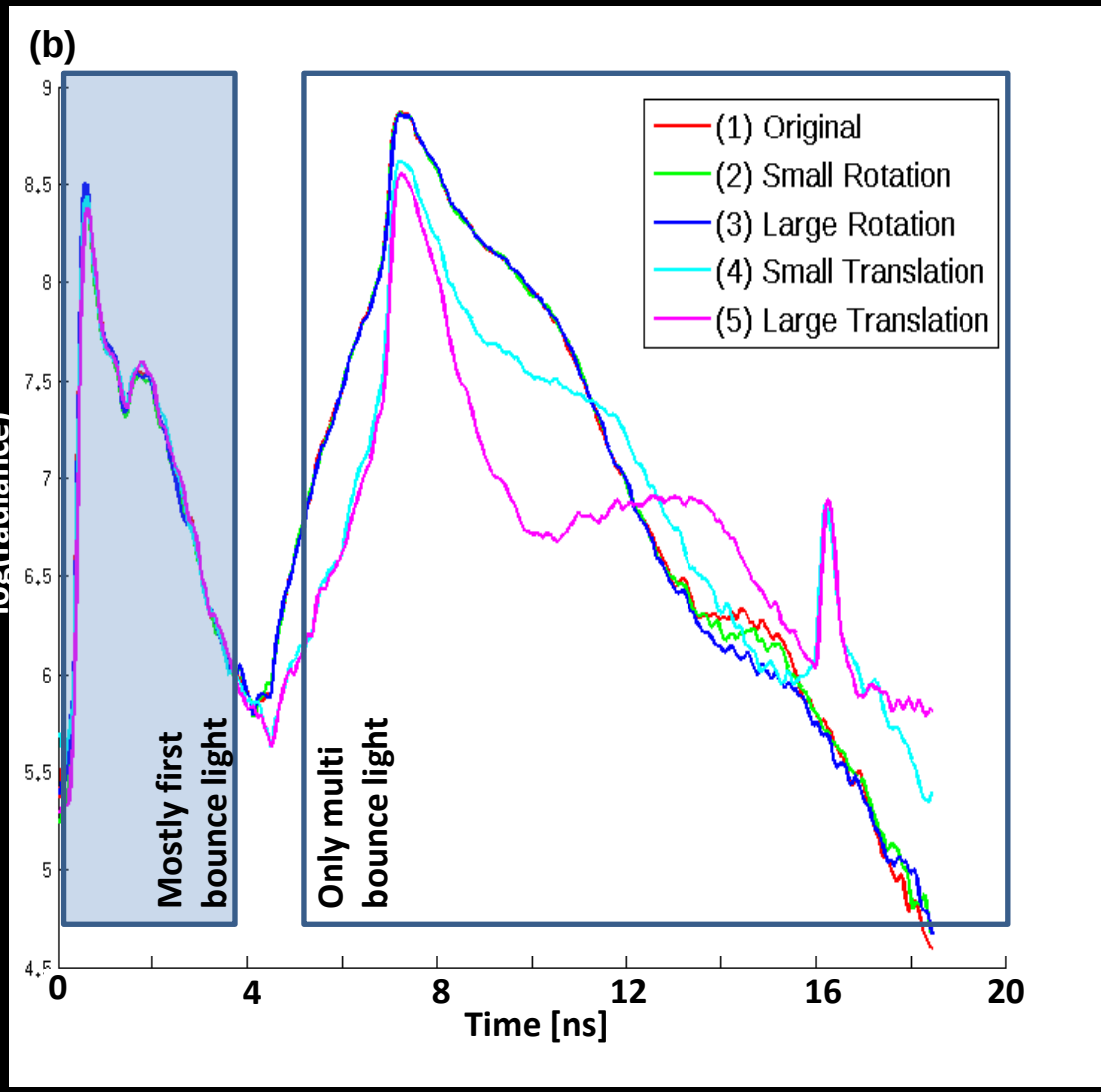

Reflected Intensity
d/c
time


d1
A
B
d2


Illumination Pulse


d1/c
Reflected Intensity
(d1+d2)/c
time

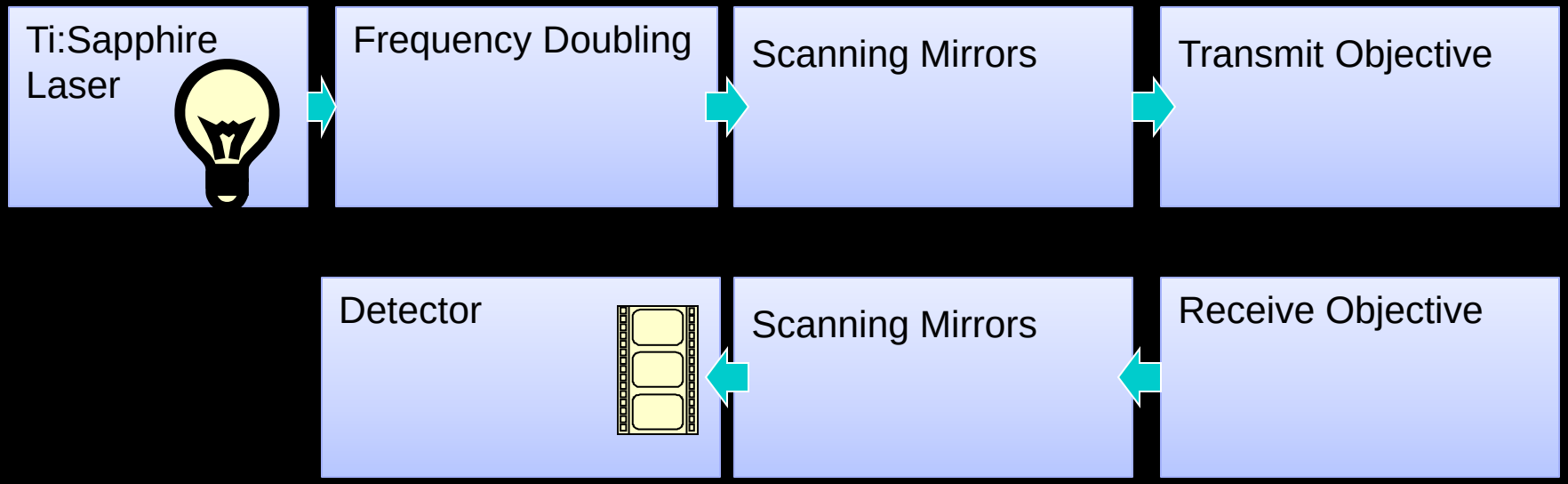

(a)
(a1)
(a2)
(a3)
(a4)
(a5)


(b)
log(radiance)
Time [ns]
Mostly first bounce light
Only multi bounce light
(1) Original
(2) Small Rotation
(3) Large Rotation
(4) Small Translation
(5) Large Translation
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
0
4
8
12
16
20

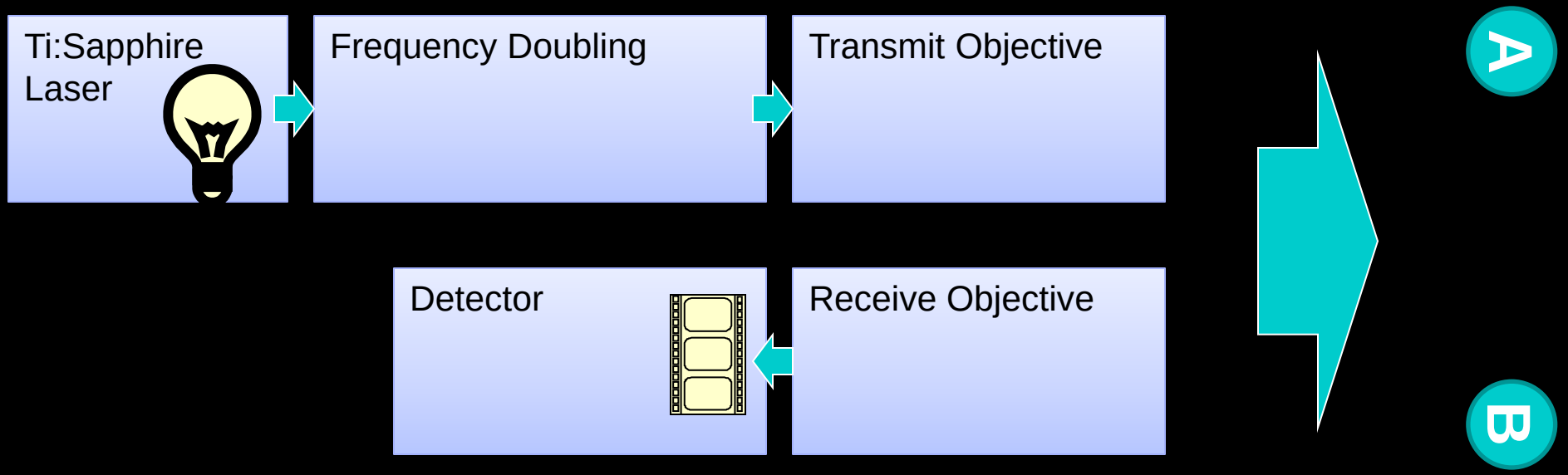
Hardware

- There is a distance regime where TERA provides superior resolution to regular imaging using available hardware
- We need to design new devices
  - High dynamic range
  - High time resolution (10 ns signal, 10 fs res → 1 Mpixel)
- Point scanning system for prototyping and testing technologies

Lab Setup

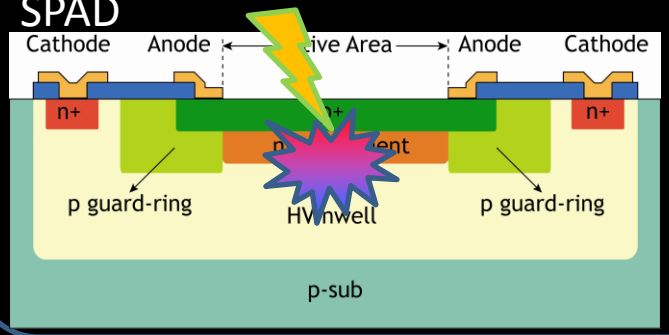

Ti:Sapphire Laser
Frequency Doubling
Scanning Mirrors
Transmit Objective
Receive Objective
Scanning Mirrors
Detector

Lab Setup

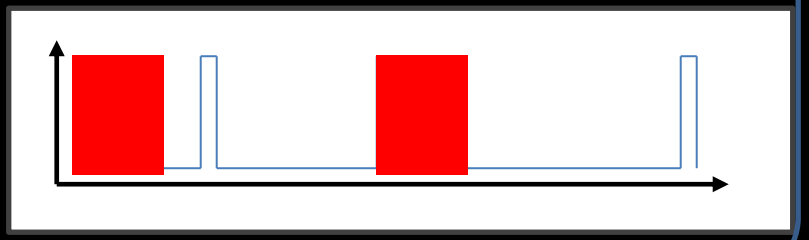

Ti:Sapphire Laser
Frequency Doubling
Transmit Objective
Detector
Receive Objective
A
B

Single Photon Avalanche Diode (SPAD)

SPAD

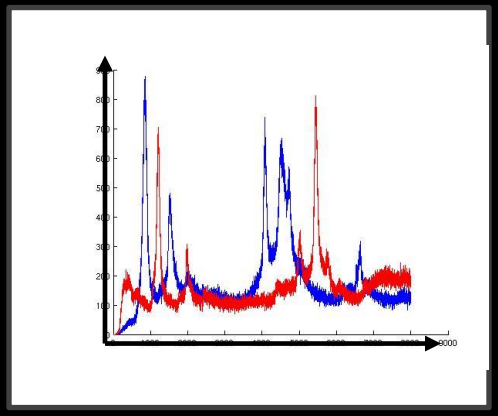


Gate



Laser Pulse Train

Time Correlated Single Photon Counter (TCSPC)



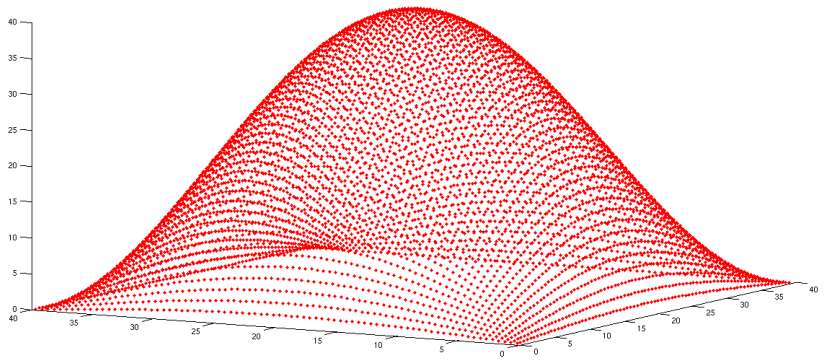
- 20 ps FWHM
- 5 photons / second dark count rate
- ~50% QE
- ~110ps gate

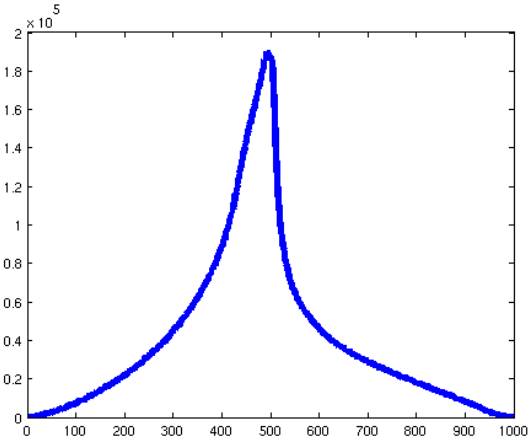
Mauro Buttafava, Alberto Tosi, **Politecnico di Milano, Italy**

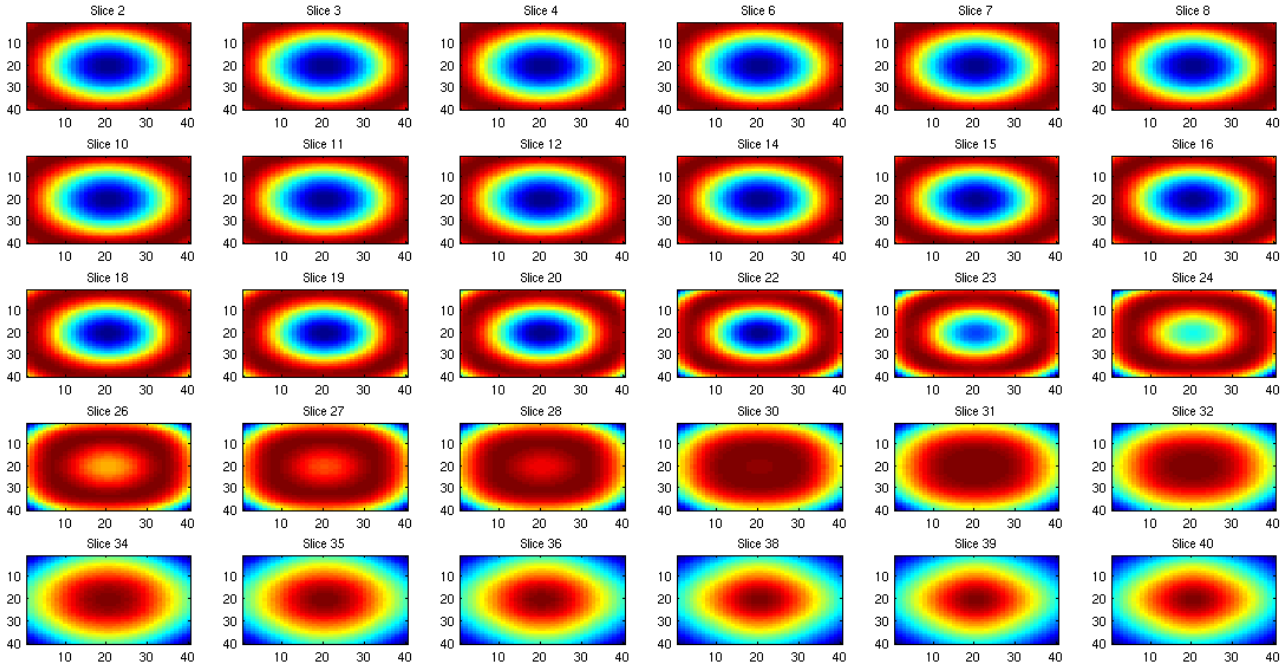
Reconstruction

- When is a reconstruction possible?
  - Do we need spatial information?
- What are good ways to reconstruct the scene?
  - Backprojection
  - Analysis by Synthesis

First Steps - Backprojection

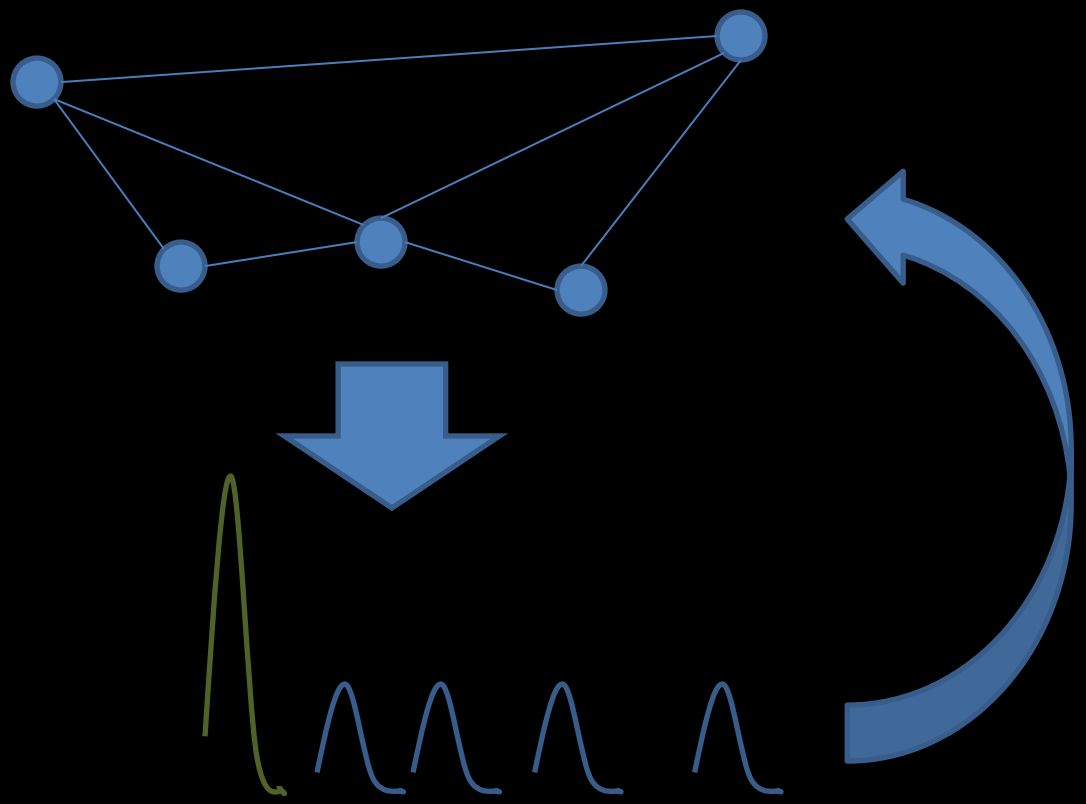




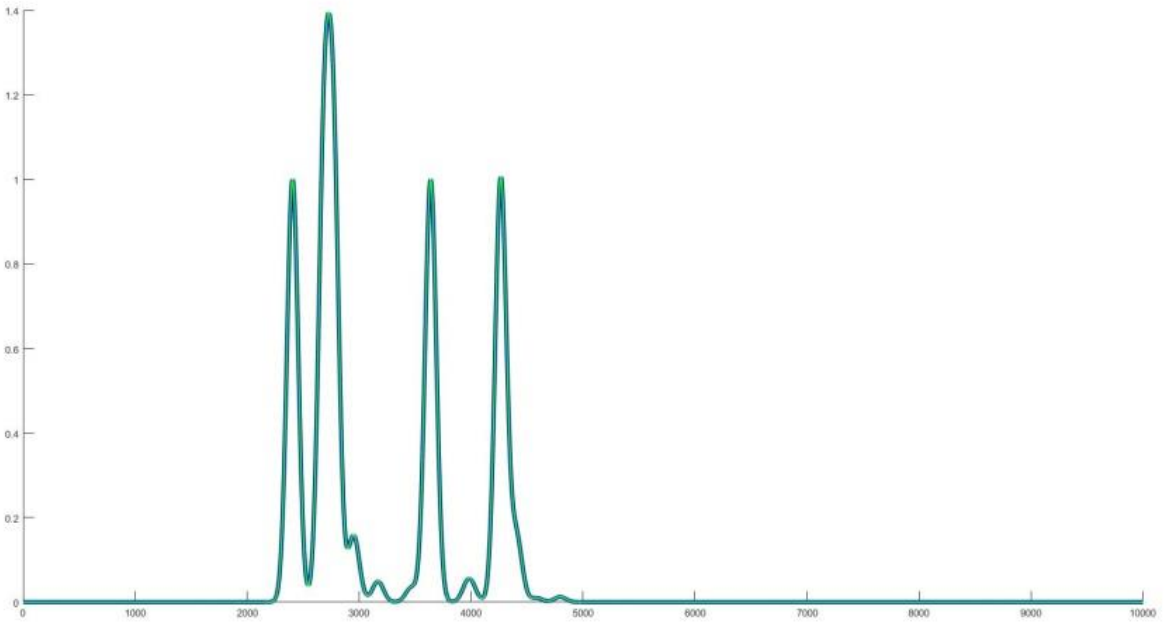


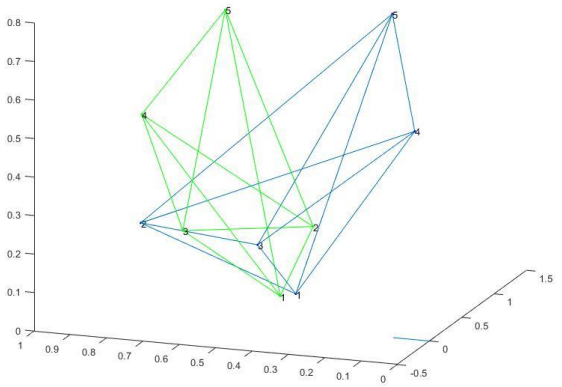
Network Model

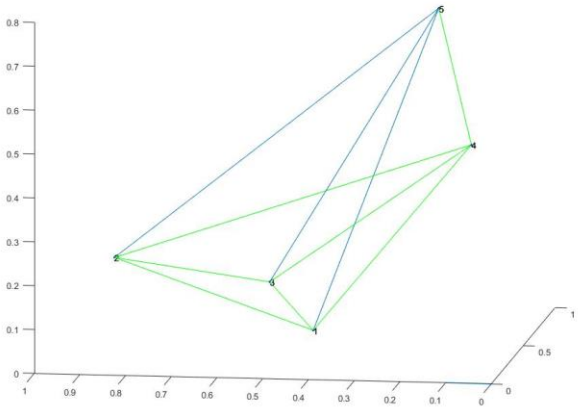
- Proof unique mapping
- Analysis by Synthesis Reconstruction
- (1) Realistic reflectances
- (2) Timing only



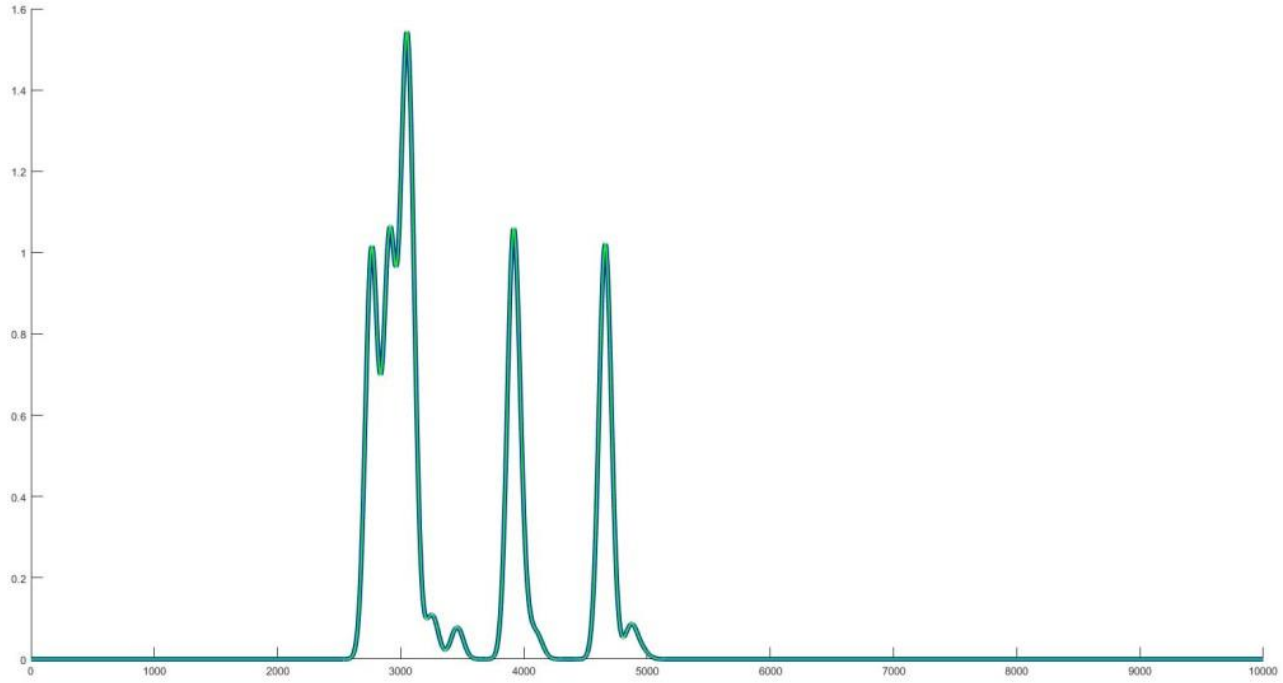
Analysis by Synthesis Reconstruction

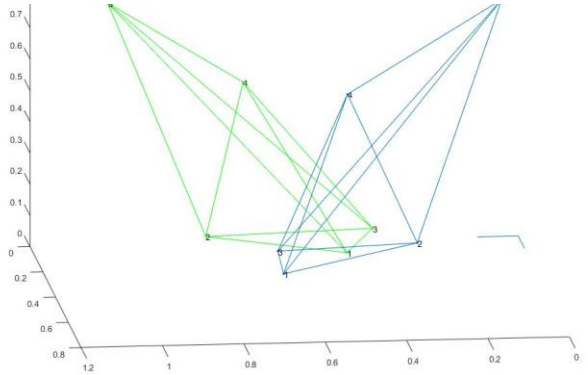


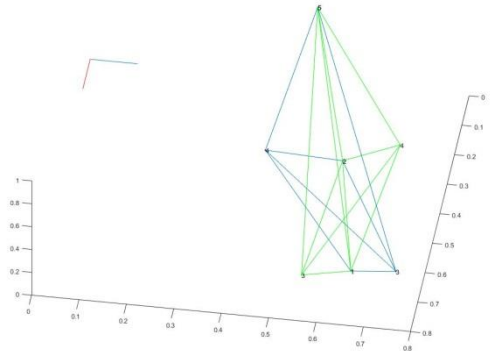




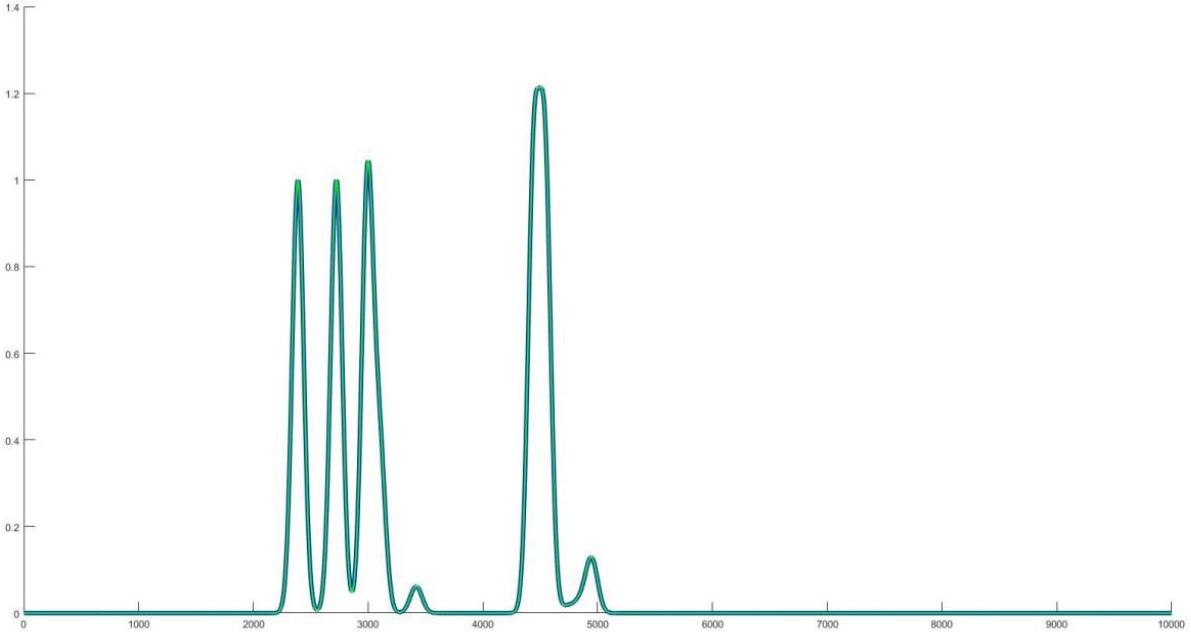
Analysis by Synthesis Reconstruction Degenerate Case

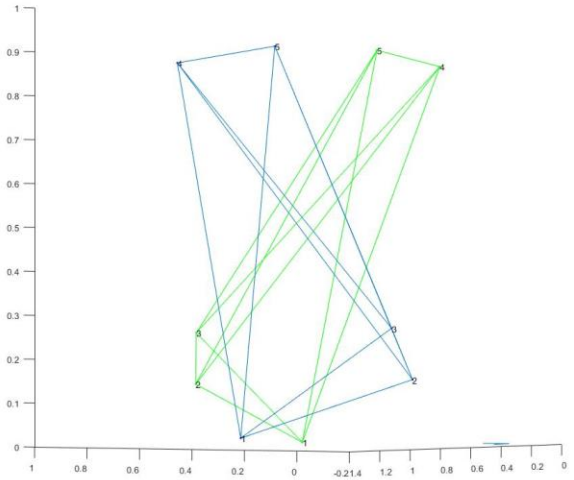


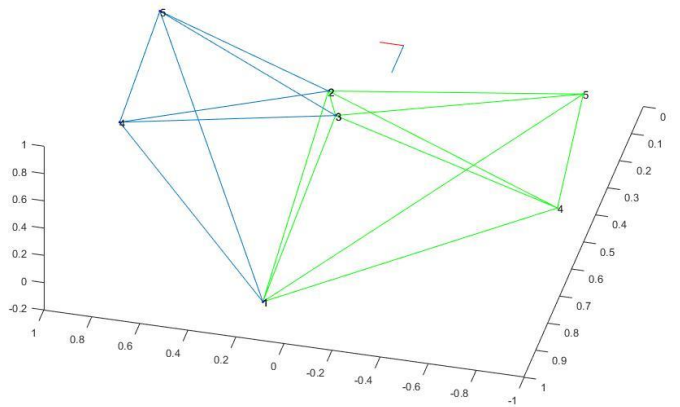




Analysis by Synthesis Reconstruction Degenerate Case





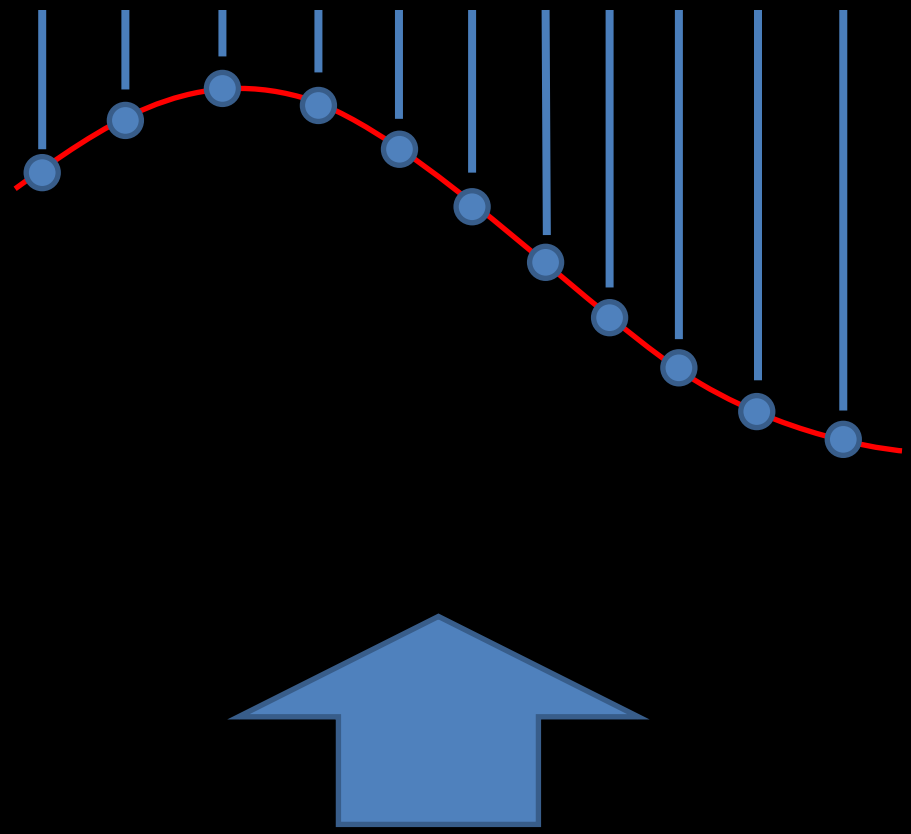


Analysis by Synthesis

- We can show that scenes with 5 objects can be reconstructed using only time information (no intensity)
- Current Analysis by Synthesis approach does not scale to more complex scenes
- Can we construct a proof for more than 5 points?
- Can we reduce scene complexity?

Reconstruction of a surface

- Normal scenes are not volumes, but surfaces
- This constraint reduces complexity and allows the AbS technique to be applied to higher resolution scenes



Next Steps

- High resolution reconstruction of surfaces
- Experimental demonstration
- Hybrid models (i.e. some spatial information is available)
- Coherent methods

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