An evaluation of computational imaging techniques for inverse scattering

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Looking inside stuff

source

sensor
Looking inside stuff

making sense of this
New imaging capabilities
selecting which photons to measure

conventional imaging
structured light

long short
transient imaging
combinations
Problem statement and contributions

heterogeneous inverse scattering by appearance matching

source

material m(x)

sensor

optimization problem

min \| \text{image}(m) \|^2

m(x)

1) Are there ambiguities between the unknowns?

2) How do we solve this optimization problem?
Ambiguities between unknowns?

transient video

- $t = 10$ fs
- $t = 20$ fs
- $t = 30$ fs
- $t = 40$ fs
- $t = 50$ fs

- uniquely determines deepest layer

source + sensor
deepest layer reached after $t = 40$ fs travel time
Ambiguities between unknowns?

**Transient video**
- $t = 10 \text{ fs}$
- $t = 20 \text{ fs}$
- $t = 30 \text{ fs}$
- $t = 40 \text{ fs}$
- $t = 50 \text{ fs}$

- uniquely determines deepest layer
- recursion: uniquely determines entire volume

**Source + sensor**
- deepest layer reached after $t = 40 \text{ fs}$ travel time
Ambiguities between unknowns?

- transient video
  - $t = 10 \text{ fs}$
  - $t = 20 \text{ fs}$ (highlighted)
  - $t = 30 \text{ fs}$
  - $t = 40 \text{ fs}$
  - $t = 50 \text{ fs}$

- source + sensor
  - deepest layer reached after $t = 40 \text{ fs}$ travel time

- uniquely determines deepest layer
- recursion: uniquely determines entire volume
Ambiguities between unknowns?

transient video

$\begin{array}{cc}
\text{t = 10 fs} & \text{t = 20 fs} \\
\text{t = 30 fs} & \text{t = 40 fs} \\
\text{t = 50 fs} & \ldots
\end{array}$

- uniquely determines deepest layer
- recursion: uniquely determines entire volume

source + sensor
deepest layer reached after t = 40 fs travel time
Ambiguities between unknowns?

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  - $t = 10$ fs
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source

material m(x)

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optimization problem
\[
\min_{m(x)} \| \text{image}(m) \|^2
\]

1) Are there ambiguities between the unknowns?
   • provable uniqueness for certain imaging types

2) How do we solve this optimization problem?
How do we do optimization?

$10^4$ unknowns

Material $m(x)$

Optimization problem

$$\min_{m(x)} \| \text{image}(m) \|^2$$

Volumetric density $\sigma(x)$

Scattering albedo $a(x)$

Phase function $f_s(\theta,x)$

Material $m(x)$
How do we do optimization?

10^4 unknowns

source

sensor

very non-linear

optimization problem

\[
\min_{m(x)} \| \text{image}(m) \|^2
\]

volumetric density \( \sigma(x) \)
scattering albedo \( a(x) \)
phase function \( f_s(\theta, x) \)

material \( m(x) \)
How do we do optimization?

- **10^4 unknowns**
- **very non-linear**

**Material** \( m(x) \)

**Optimization Problem**

\[
\min_{m(x)} \| \text{image}(m) \|_2^2
\]

**Stochastic Gradient Descent**

While (not converged)

update \( m \) using \( \frac{\partial \text{loss}(m)}{\partial m} \)

Monte Carlo Rendering
How do we do optimization?

large-scale simulation:
- 20 thousand cores
- 1 million measurements
- 10 thousand unknowns

stochastic gradient descent

while (not converged)

update m using

\[
\frac{\partial \text{loss}(m)}{\partial m}
\]

\[\frac{\partial \text{image}(m)}{\partial m}\]

Monte Carlo rendering

Material m + \(\partial m\)
Problem statement and contributions

heterogeneous inverse scattering by appearance matching

optimization problem

\[
\min_m \| m(x) - \text{image}(m) \|^2
\]

http://tinyurl.com/InvTransient

1) Are there ambiguities between the unknowns?
   • provable uniqueness for certain imaging types

2) How do we solve this optimization problem?
   • scalable, general, physically-accurate algorithm
   • empirical evaluation of imaging configurations