Analyzing Impossible Images

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Computational Photography Symposium
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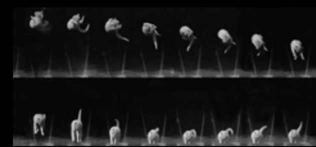
Imaging Breakthroughs



Etienne-Jules Marey, falling cat

- photography, moving pictures
- xray, ultrasound, MRI, etc.

Imaging Desiderata

Analyzing real images is a pain

- occlusions
- clutter
- shading
- focus
- fidelity

Impossible images don't have such problems

- can computational imaging make these problems go away?

Removing Occlusions

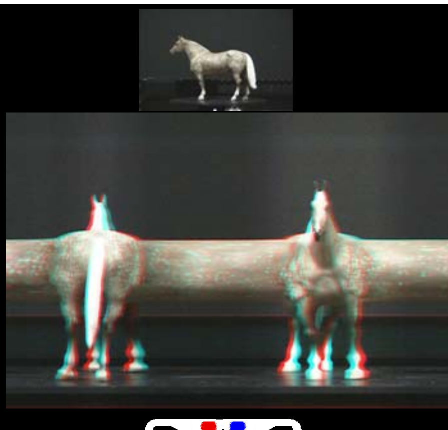
Rollout Photographs © Justin Kerr
http://research.famsi.org/kerrmaya.html

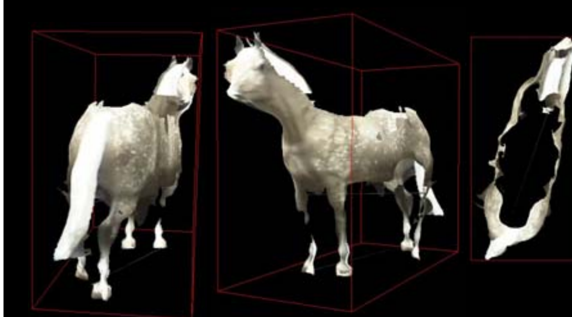
The Blue Marble, NASA satellite image composite

The Blue Marble, NASA satellite image composite

by David Dewey

by Jiwon Kim





Open Questions

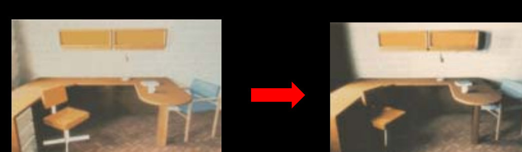
How much visibility can we get?

- sensor design

Many possible projections

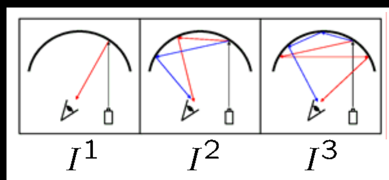
How do we process these images?

Removing Interreflection



Images by Ward et al., SIGGRAPH 88

Bounce Images



$$I = I^1 + I^2 + I^3 + \ldots$$

Main Results

There exists a matrix C^1 that removes all interreflections in a photograph (or lightfield)

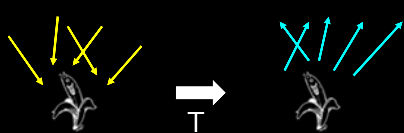
$$I^1 = C^1 I$$

Works for *any* illumination

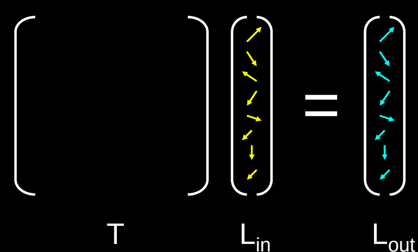
There is a matrix C^k that retains only the k^{th} bounce

$$I^k = C^k I$$

Light transport



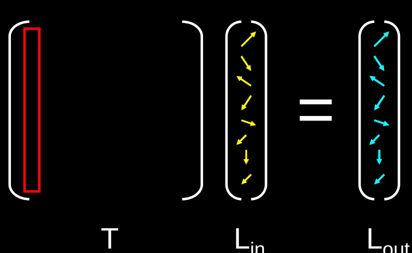
The transport matrix



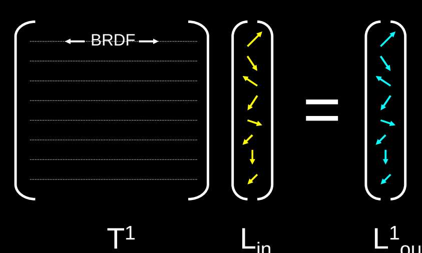
Accounts for

- interreflections, shadows, refraction, subsurface scatter, ...
- [Dorsey 94] [Zongker 99] [Debevec 00] [Peers 03] [Goesele 05] [Sen 05] ...

The transport matrix



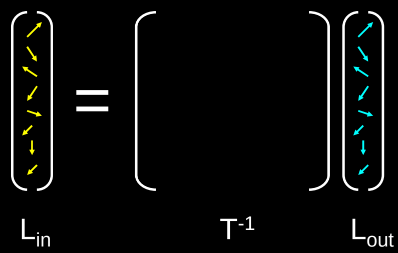
Direct illumination rendering



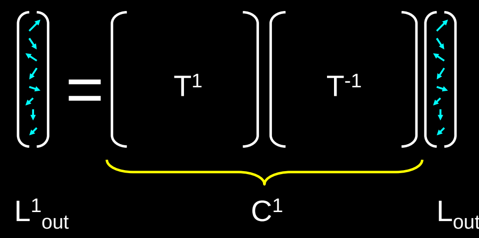
Single bounce from light to eye

- no interreflections

Inverse rendering



Removing Interreflections



Second derivation:

- from the rendering equation [Kajiya 86] [Cohen 86]

Cancellation Operators

Recursively define other operators

$(I - C^1)$
- gives interreflected light

$C^2 = C^1 (I - C^1)$
- gives second bounce of light

$C^k = C^1(I - C^1)^{k-1}$
- gives k^{th} bounce of light

Inverse ray tracing!

How to compute C^1

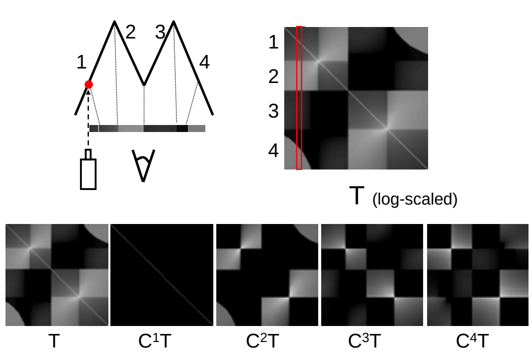
Simplified case

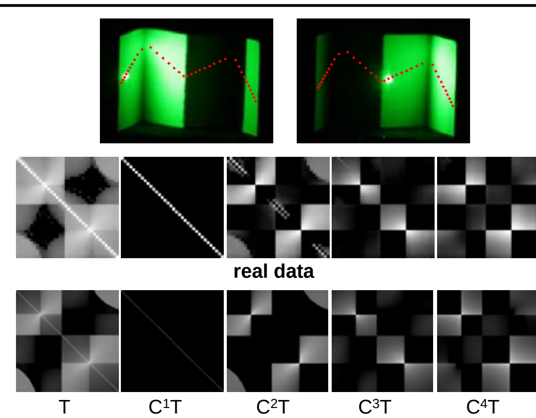
- Lambertian reflectance and fixed viewpoint
- L_{in} and L_{out} are 2D
- Can capture T by scanning a laser

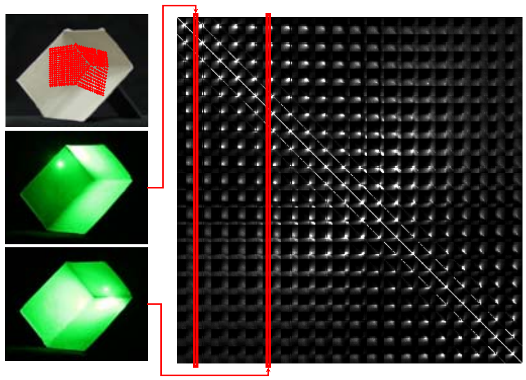
$$\mathbf{C}^1 = \mathbf{T}^1\mathbf{T}^{-1},$$

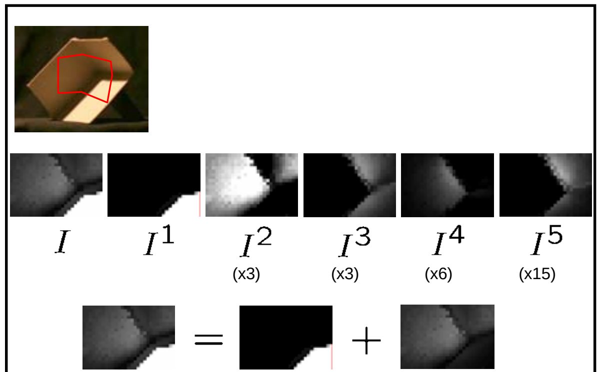
where $\mathbf{T}^1$ is a diagonal $n \times n$ matrix containing the reciprocals of the diagonal elements of $\mathbf{T}^{-1}$.

Synthetic M Scene

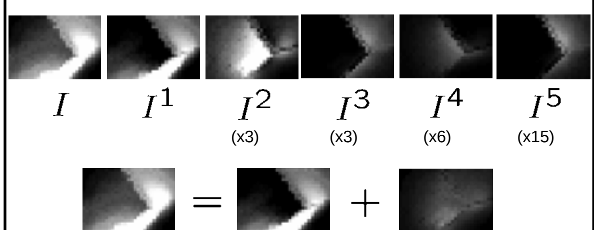




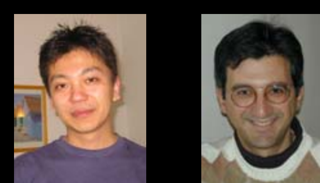




flash light illumination



Collaborators on Interreflections



Yasuyuki Matsushita (MSR Asia) Kyros Kutulakos (U. Toronto)

S. M. Seitz, Y. Matsushita, and K. Kutulakos, "A Theory of Inverse Light Transport," Microsoft Technical Report MSR-TR-2005-66, May 2005.

Conclusions

Impossible images

- no occlusions, no interreflections

Better sensing techniques

- can they solve all analysis problems?
  - shape
  - tracking
  - recognition

What other kinds of "impossible" images do we want?