Shading and Recognition

OR

The first Mrs Rochester

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Structure

• **Argument:**
  • why shading
  • why shading analysis died
  • reasons for hope

• **Some History**
  • Primitives

• **Reconstructions are possible**
  • Variable source shading analysis
Shading offers:
rich cues to short scale detail
cues to long scale structure

From White+Forsyth 07
Reconstruction from shading

• Conventions:
  • Orthography
    • (but. for example, Prados+Faugeras
  • Height field
    • partial derivatives are written $p$, $q$
Reconstruction from shading

\[ R(p, q; S) = I(x, y) \]

- **Local model**
  - Points with the same normal get the same shading value
- **The Image Irradiance Equation (IIE)**
  - Horn, 1970 and lots of later papers by lots of authors
- **This is a PDE**
  - First order, non-linear, actually Hamilton Jacobi

Reflectance Map \( R \)
Image intensity \( I \)
Physical Critiques

- **Real shading is not local**
  - interreflections
    - points with the same normal get different shading values
- **Devastating**
  - because a physically exact formulation is unmanageable
    - (it has been tried, Nayar et al 91)
    - cannot account for distant radiators we can’t see
Forsyth Zisserman ’89, ’91
after Gilchrist, Koenderink, etc.
Existence

- For some boundary conditions, a solution to IIE exists
  - but for relatively few;
    - as geometric constraints grow stronger, existence almost always fails
    - by easy characteristic strip argument

- Characteristic strip
  - FO PDE is ODE, along CS
  - CS given by ODE
  - CS’s don’t intersect
More BC’s -> Existence fails
Existence

• Solutions do not exist for rich boundary conditions
  • current literature says:
    • not a problem - want reconstruction from minimal geometry data
• Options
  • classical fails
  • Lipschitz (too many solutions)
  • Viscosity (one, but no physical justification for choice)
    • RouyTourin 92, Lions et al 93, Prados Faugeras 03
• Real world
  • many rich sources of geometric constraint (identity; stereo; SFM;...)
  • should not impede existence

General Guideline: A formulation which doesn’t have existence for natural problem instances needs to be fixed
Relations to photometric stereo

• Photometric stereo
  • estimate normal (+albedo) locally from multiple shading maps
  • using completely different procedures, reasoning
Pragmatics

- **Shape from shading doesn’t work**
  - ample evidence
    - No comparison between right answer and reconstructions
    - Poor results on synthetic (!) data

From Zhang ea, 99
Pragmatics

From Zhang et al., 99
Pragmatics

Fig. 26. FS on Elk: 0.42 s.

Fig. 27. DD on Elk: 1.25 s.

Durou et al, 2007
Pragmatics

Figure 31: SV $256 \times 256$ images: (a) $\omega = \omega^1$, (b) $\omega = \omega^2$ and (c) $\omega = \omega^3$.

FS on SV ($\omega = \omega^1$): computed shapes with (a) $u = 0$ and (b) $u = g_{SV}$ on the boundary.
Minor critiques

• The world isn’t ideal diffuse
  • True, but so what - if we can’t solve the easiest case...
• There are specularities
  • see above
    • and we can build specularity detectors
• Albedo varies
  • but we have quite good theories of how to infer albedos
Reasons for hope

- Evidence for pragmatic information in shading
  - SF(T+S)
- Evidence that shading cues are compelling to humans
  - Textureshop
  - Retexturing movies
  - Complex, mixed picture from psychophysics
- Evidence that shading is distinctive
  - Face detectors
  - Some others, rather ragged
SF(T+S)  Shading disambiguates texture

White+Forsyth 06
• Hart+Fang, 04
• Retexture illuminated surface by:
  • Obtaining normal estimate from local shape from shading
    • normal estimate is largely meaningless
  • Use this to compute texture normal
  • Shade this texture with original illumination estimate
• Interesting because
  • In a cue conflict between texture and shading, texture loses
Retexturing movies

• White+Forsyth 06
• Retexture moving surfaces by
  • Building non-parametric estimate of illumination from corners
    • assuming silkscreen, known colors, not known texture
  • Rectify texture to very rough geometric (affine distortion) model
  • Shade with illumination estimate
• Get shading right, it looks natural with weak geometry
  • Shading cues beat motion cues? (at short scales?)
  • Quality issues are
    • flicker
    • surfaces look rigid when fold shading is not reproduced.
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Shading Primitives

• Shading patterns on certain structures are stylized
  • We might be able to spot such patterns and use them
• Huge success
  • Frontal face detectors
• But...
  • few examples
    • Pits, etc. (Koenderink ’83)
    • Folds, Grooves, Cylinders (HaddonForsyth, 98a, b)
    • Objects in fixed configuration (Belhumeur+Kriegman ’98)
  • hard to deploy in natural ways
Structure

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  - Classical SFS+Critiques
  - Primitives

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The Irradiance integral

- Obtain radiosity by summing incoming radiance over all directions

\[
B(x, y) = \int_{\Omega} \rho(x, y; \omega_i) L(x, y; \omega_i) \cos \theta_i \, d\omega_i
\]
The Irradiance Integral

- Classical SFS
  - radiance comes only directly from the luminaire
- Rendering
  - radiance comes from luminaire, reflections from other surfaces
Illumination models and formal solns

\[ B(x) = E(x) + \mathcal{K}B(x) \]

Internally generated light

Radiosity

Redistributed light

Internally generated light

One bounce off surfaces

Gathered from sources

Two bounces off surfaces

\[ B(x) = E(x) + \mathcal{K}E(x) + \mathcal{K}^2E(x) + \mathcal{K}^3E(x) \ldots \]

\[ B(x) = E(x) + \mathcal{K}E(x) + \mathcal{K}(B(x) - E(x)) \]
Rendering, Gathering and all that

\[ B(x) = E(x) + \mathcal{K}E(x) + \mathcal{K}(B(x) - E(x)) \]

\[ B(x) = E(x) + \mathcal{K}E(x) + \mathcal{K}(\hat{B}(x) - E(x)) \]

- K smoothes
  - phenomena:
    - don’t need a good estimate of B
    - complex angular patterns of radiance are not resolved
      - (Ramamoorthi Hanrahan, 01)
      - useful in photometric stereo (Basri, Jacobs, Kemelmacher 07)
Gathering - II

Quite large, often fast changing (shadows)

\[ B(x) = E(x) + \mathcal{K}E(x) + \mathcal{K}(\hat{B}(x) - E(x)) \]

- Usually zero
- Typically slowly changing, usually small

- radiance consists of direct term + indirect term
  - indirect term changes slowly over space
    - irradiance cache (Ward, 88, 92)
    - radiance cache (ArikanForsyth, 04)
Illumination changes slowly over space

Radiance Cache Samples

Irradiance Cache Samples

Figure from Arikan Forsyth 05
The effective source

\[ R(p, q; S_e(x, y)) = I(x, y) \]

- A spatially varying source
  - that produces the right answer from the reflectance map
- Properties
  - not very different from ideal source
  - difference changes slowly over space
Variable Source Shading Analysis

Minimize

\[
\begin{align*}
\theta_1 \sum_{i \in \text{Sources}} \int_{\Omega} \| \nabla S_e^{(i)}(x, y) \|^2 \, dA &+ \theta_2 \sum_{i \in \text{Sources}} \int_{\Omega} \| S_e^{(i)}(x, y) - S \|^2 \, dA + \\
\theta_3 \int_{\Omega} (f_{xx} + f_{yy})^2 \, dA &+ \theta_4 (\int_{\Omega} dA - A_0)^2
\end{align*}
\]

subject to:

\[
R(p, q; S_e^{(i)}(x, y)) = I(x, y)
\]

Boundary conditions

Slow change in effective source

Effective sources similar to source

No free creases

Extra area is expensive
Variable source shading analysis

- Solution always exists
  - if boundary conditions are consistent
- Arbitrary (consistent) boundary conditions OK
- Can do 0, 1, 2,... sources
- Area regularizer is very helpful
- Somewhat stabler problem if we substitute:

  \[ S_{ei}^{(i)}(x, y) = g_i(x, y)S^{(i)} \]
Local shading model
Physically realistic shading
No shading (this isn’t unique, but gives some idea of what bc’s do)
1-Source vs 2 Sources

offset as percentage of absolute range
Masked image

Albedo
(inferred from photometric stereo and provided)

Shading image
Without shading
Single source face against reference photometric stereo reconstruction
320x200 representation:
  single source
  256000 variables
  640 depth constraints (32x20 grid) some masked
  Note bump on nose - specularity
Original geometries

Recons with type II, no overall radiometric calibration

Recons with type II, 30% too much area

Recons with type I geometric constraints

Recons with type II geometric constraints

Recons with type II, 30% too little area
Further matters

Fine scale shadows are a cue to projected illumination direction - this is local (Koenderink).

Can this be fused with brightness reasoning?
Further matters

Humans seem to be able to reason about light in volume - how bright would something be if we put it here?

Can we mimic this?
Important points

- There are features which exist over spatial domains
  - at object length scales
- Usable notion of primitive essential
  - to handle unknown objects
- The visual world is very rich
  - cue opportunism is essential for both reconstruction and recognition
- Q: Should we reconstruct for recognition
  - A: ?