Perceptual and Artistic Principles for Effective Computer Depiction

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Computational Vision

and Picture
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Calvin and Hobbes

Wow, honey, you're missing a beautiful sunset out here!

I'll count to 10, and then... Pow!

Pad: How come old photographs are always black and white? Didn't they have color film back then?

Sure, they did. In fact, those old photographs are in color. It's just the world was black and white then.

Réally?

Yep. The world didn't turn color until sometime in the 1930s, and it was pretty grainy color for a while, too.

That's really weird.

Well, truth is stranger than fiction.

But then why are old paintings in color? If the world was black and white, wouldn't artists have painted it that way?

Not necessarily. A lot of great artists were insane.

But... but how could they have painted in color anyway? Wouldn't their paints have been shades of gray back then?

Of course, but they turned colors like everything else did in the '30s.

So why didn't old black and white photos turn color too?

Because they were color pictures of black and white, remember?

The world is a complicated place, Hobbes.

Whenever it seems that way, I take a nap in a tree and wait for dinner.
Perceptual and Artistic Principles for Effective Computer Depiction

Computational Vision and Picture

Fredo Durand
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Plan

- Vision as an cognitive process
- Computational theory of vision
- Complex mapping
Distal vs. proximal stimulus

• Distal stimulus: reality
• Proximal stimulus: retinal image

proximal stimulus (2D)  Distal stimulus (3D)
Vision as an inverse problem

• The distal stimulus is projected into a proximal stimulus
Vision as an inverse problem

• The distal stimulus is projected into a proximal stimulus

• How can we inverse this projection?
Unconscious inference (Helmholtz)

- Our vision system solves a problem
- Under-constrained problem
  - A visible point $A'$ can correspond to an infinity of 3D points ($A_1$, $A_2$, $A$, $A_3$...)

![Diagram of optical system with points A', A1, A, A2, A3](image)
How assumptions help

• Ames chair
  – 3 different scenes
  – Same projection
  – We assume it is a chair
  – Resolves ambiguity
  – Can be wrong
The Ames room

• Invalid assumption
  – Walls perpendicular

• Wrong conclusions
  – Men have different sizes
Positive and hollow face

- Both seen convex because hollow faces are rare!
Constancy & architecture

• Palazzo Spada in Rome (by Boromini)
• Short corridor
• Column size decreases
• Appears longer
The paradox of vision

- Available information: proximal stimulus
- Conscious information: distal stimulus

proximal stimulus (2D)  Distal stimulus (3D)
Brightness vs. lightness

- Brightness: subjective amount of light
- Lightness: how “white”

The white cells in shadow are as dark as the black illuminated cells

Illusion by Ted Adelson
Brightness vs. lightness

- Brightness: subjective amount of light
- Lightness: how “white”

The white cells in shadow are as dark as the black illuminated cells
Brightness vs. lightness

- Brightness: subjective amount of light
- Lightness: how “white”

The white cells in shadow are as dark as the black illuminated cells
Pictures and the inverse problem

• Pictures can
  – Simplify the analysis
  – Be a puzzle, a riddle
Plan

• Vision as an cognitive process
• Computational theory of vision
• Complex mapping
Vision as information processing

• Input: retinal image
• Output: 3D layout, object recognition, etc.
Computational theory of vision

- Marr’s stages (extended by Palmer et al.)
- Human and Computer Vision
- Classification of different kinds of processes
- Has proved fruitful in art studies

View-centered  
Extrinsic  →  Object-centered  
Intrinsic
Retinal image

- Intensity: hard to comprehend
Image-based (primary sketch)

- Contrast, edge detection
- Not so easy

Retinal Image \[\rightarrow\] Image-based processing

Raw edge detection
**Surface-based**

- Visible surfaces, organization
- Distance, orientation

![Diagram showing the process from retinal image to local orientation]

- Retinal Image
- Image-based processing
- Surface-based processing
- Local orientation
Surface-based

- Visible surfaces, organization
- Distance, orientation
Object-based

- 3D properties, structure
- Nature of the description highly discussed
Category-based

- Recognition, category, function
Feedback

• Bottom-up and top-bottom
Scope of the theory

- Computer Vision
- Human Vision
- No direct correspondence in the brain
- Has proved fruitful conceptual tool
Relation to children drawing

- First children draw what they know
  - Object-centered
- Then, what they see
  - View-centered

Age 5

Age 9 (gifted!)
Evolution of children’s drawings

- Asked to draw a table
- First, draw what they know
- Later, what they see

Class of drawing & average age

<table>
<thead>
<tr>
<th>Child’s view</th>
<th>7.4</th>
<th>9.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>d</td>
<td>e</td>
<td>f</td>
</tr>
</tbody>
</table>

Class of drawing & average age

<table>
<thead>
<tr>
<th>11.9</th>
<th>13.6</th>
<th>14.3</th>
<th>13.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td>h</td>
<td>i</td>
<td>j</td>
</tr>
</tbody>
</table>
What about adults?

• Reproduce two drawing with similar angles
• Wheel:
  – Accuracy $\sim 5^\circ$
• Street:
  – Error: $32^\circ$

• Because in the first case, they focus on the 3D (distal) interpretation
Drawing reproduction

- **Drawing on the right side of the brain**, Edwards
- Advises to reproduce drawings upside down
- Distal interpretation does not impede
- Forgers often reproduce paintings upside-down

Original Picasso drawing  Reproduction  Reproduction upside-down
Relation to pictures

- Different classes of pictures for different stages
- Not a strict classification

View-centered
Extrinsic

Object-centered
Intrinsic
Relation to pictures

- Chinese painting refuse extrinsic, only essential
- No shadow

View-centered  
Extrinsic  
Object-centered  
Intrinsic
Retinal image

- Turner
- “My business is to paint not what I know, but what I see”
Retinal image

• Impressionism
Retinal image

- Impressionism
- Photography

Retinal Image → Image-based processing → Surface-based processing → Object-based processing → Category-based processing
Image-based

- Line Drawing
- Rivera
**Intrinsic vs. Extrinsic**

- Visual angle vs. true size
- Caravaggio:
  Wrong geometrically but looks good
Intrinsic vs. Extrinsic

- Visual angle vs. true size
- Vermeer:
  too accurate to be true!
Intermediate

- View-based
- Cues for surface-based feature extraction are enhanced
  - Depth cues
  - Orientation cues
- No subjective feature (e.g. lighting)

Retinal Image → Image-based processing → Surface-based processing → Object-based processing → Category-based processing
Higher level

- Primitive art
- Cubism
- Schema
- “What I know”
Higher level

- Primitive art
- Cubism
- Schema
- “What I know”
Higher level

- Primitive art
- Cubism
- Schema
- “What I know”
Expressionism

• “What I feel”
Relation with 2D/3D emphasis

• Almost the opposite!
• 3D impression corresponds to retinal image
• 2D quality arises from higher-level pictures
• Because of vision paradox
  – Distal is seen when proximal is shown
Relation with 2D/3D qualities

- 3D impression but Retinal image
Relation with 2D/3D qualities

- 2D emphasis but Higher level
Making pictures: inverse of inverse

- Previsualization (Adams)
- Solving the direct problem is a good start, but…
Plan

- Vision as an cognitive process
- Computational theory of vision
- Complex mapping
3D and 2D attributes

- [Willats 97]
- Show coloured or numbered die to children (6-7)
- The still draw a rectangle
- But different colours or many points
- The rectangle stands for the whole dice
- The notion of 3D object with corners is translated as a 2D object with corners
Projection: Topographical

- London underground
- Metric properties are used
Projection: Topological

- Beck’s map of London underground, 1931
- Only the connectedness and organization are preserved
- [Agrawala, in this volume]
Mapping of curvature

• Convex: positive curvature
  – 3D example: Egg
  – 2D: Convex contour

• Concave: negative curvature
  – 3D example: Interior of cup
  – 2D: Nothing, hidden contour

• Saddle: mix of positive and negative curvature
  – 3D example: Saddle (surprising!)
  – 2D: Concave contour
Mapping of curvature

• But some artists map 3D concave objects to 2D concave outlines
• This maps the property of concavity
• The left view of the plate is more “correct” but does not convey the notion of concavity
Mapping of curvature

- Small plate under the cup
Mapping of curvature

- Complex denotation
- See [Durand, page 15]
Further reading
Further reading

- Calvin & Hobbes by Watterson!