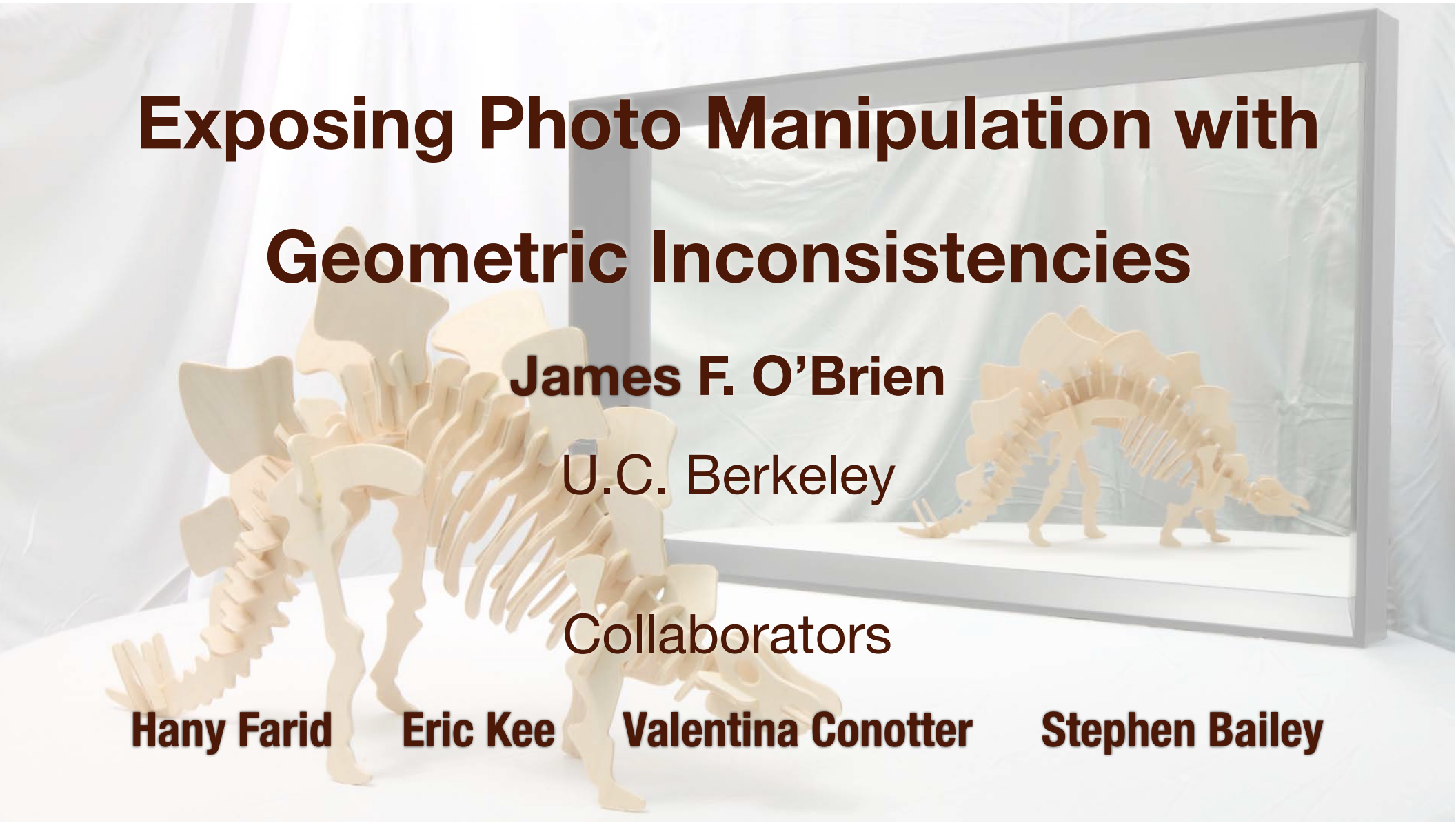


Exposing Photo Manipulation with Geometric Inconsistencies

James F. O'Brien

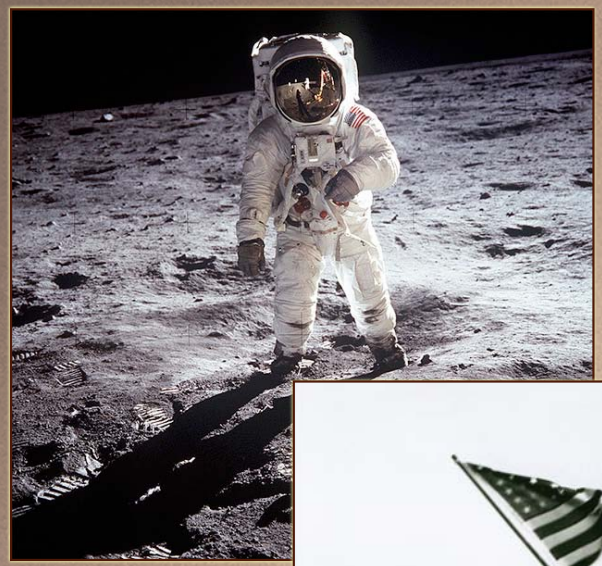
U.C. Berkeley

Collaborators

Hany Farid **Eric Kee** **Valentina Conotter** **Stephen Bailey**

Communication by Images

Communication by Images



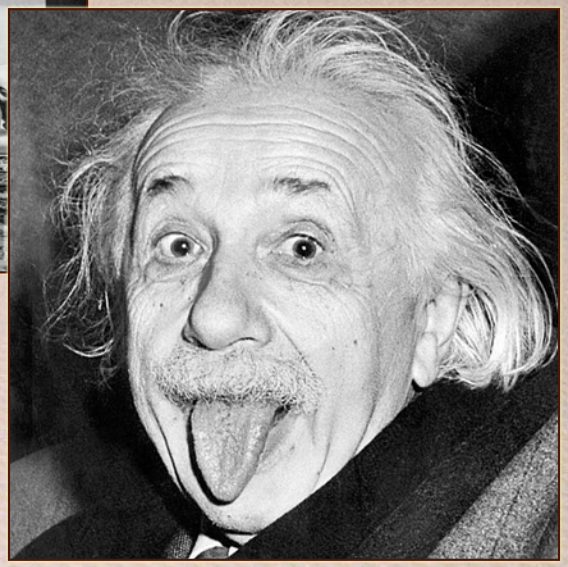


Image Manipulation

Iranian missile test, 2008

Image Manipulation

Iranian missile test, 2008

Image Manipulation

Iranian stealth fighter, 2013

Image Manipulation

Iranian stealth fighter, 2013

Image Manipulation

Economist manipulates image of Obama, 2010

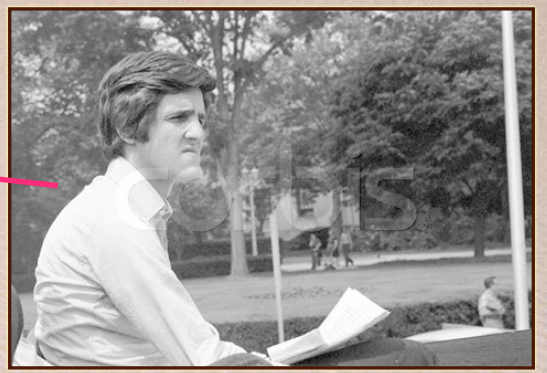
Image Manipulation

Economist manipulates image of Obama, 2010

Image Manipulation

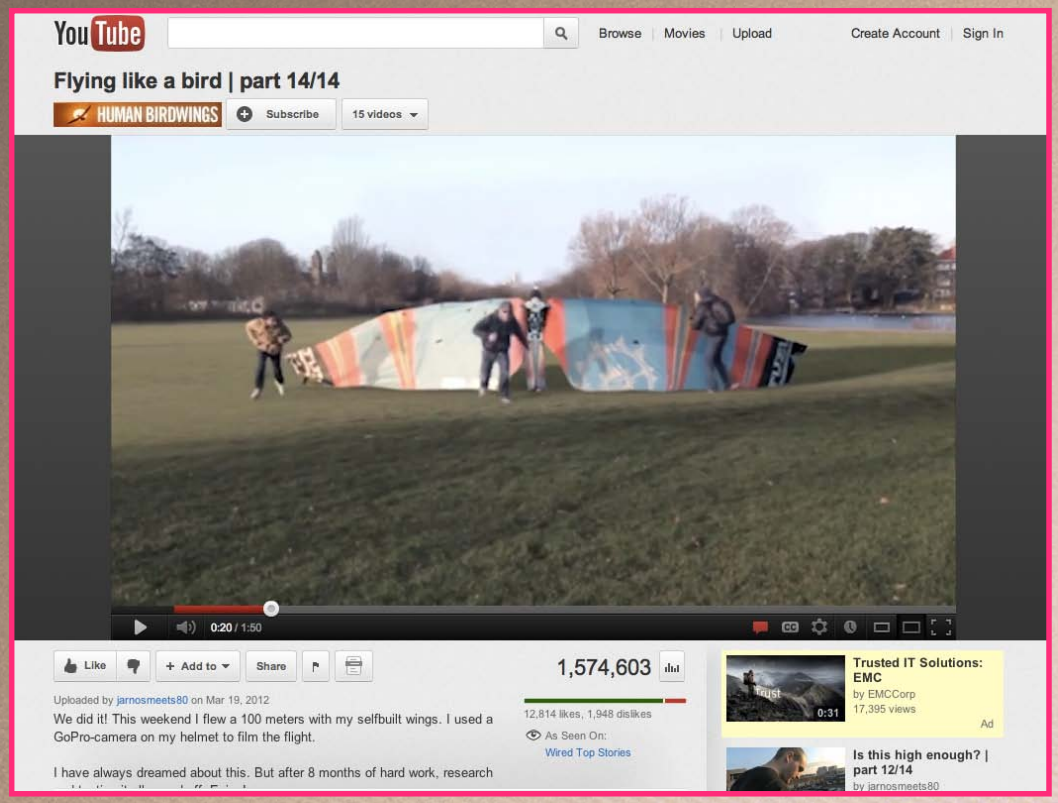
Fabricated image of John Kerry and Jane Fonda, 2004

Image Manipulation



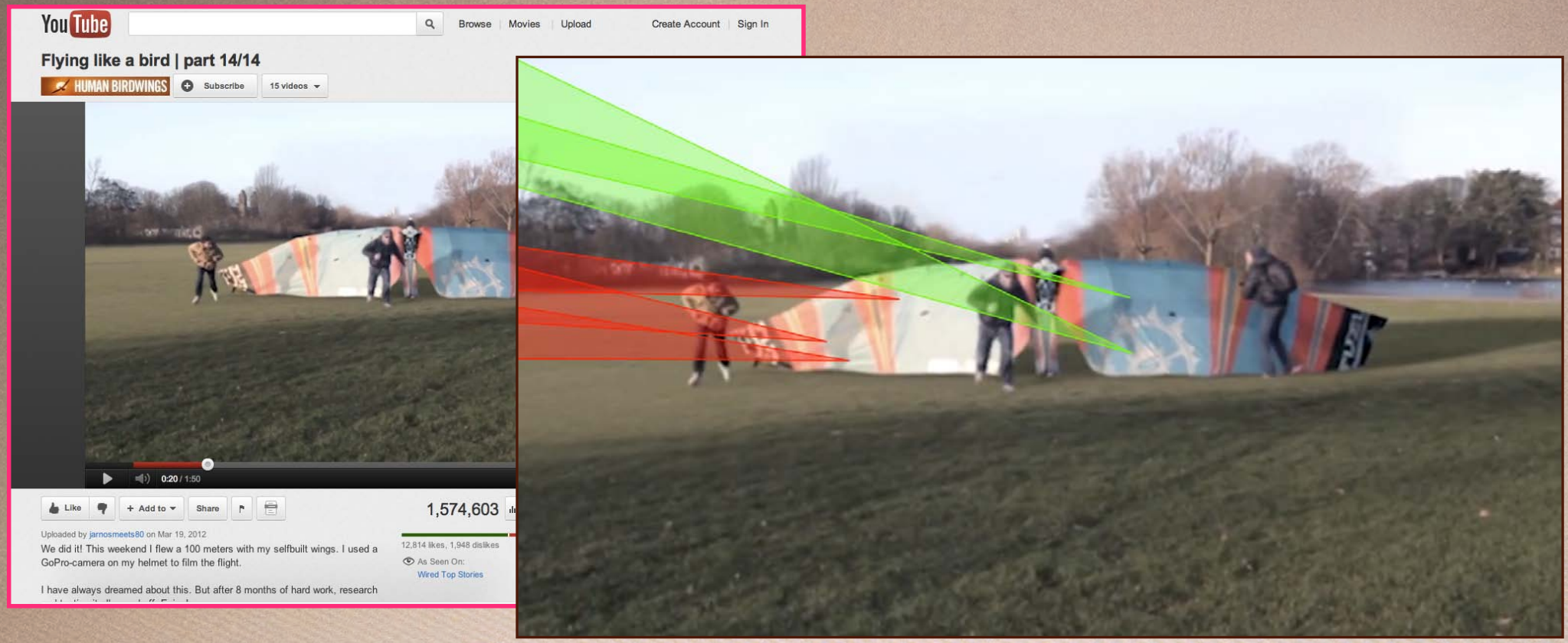
Fabricated image of John Kerry and Jane Fonda, 2004

Video Manipulation



Flying Birdman Hoax, 2012

Video Manipulation



Flying Birdman Hoax, 2012

Historical Image Manipulation

- Image manipulation as old as photography
- Primitive techniques work surprisingly well

Library of Congress archive photo of Abraham Lincoln 1826

Historical Image Manipulation

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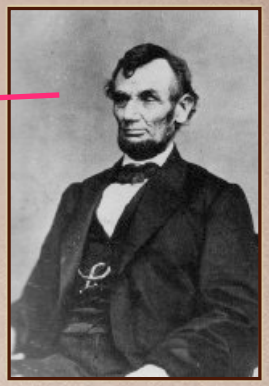
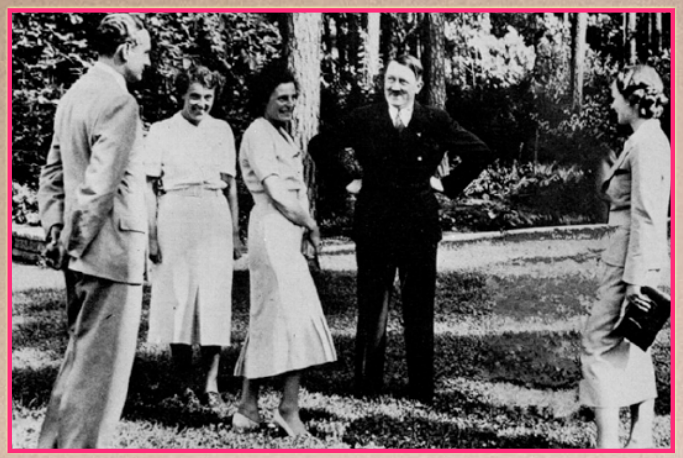


Library of Congress archive photo of Abraham Lincoln 1826

Historical Image Manipulation



Historical Image Manipulation

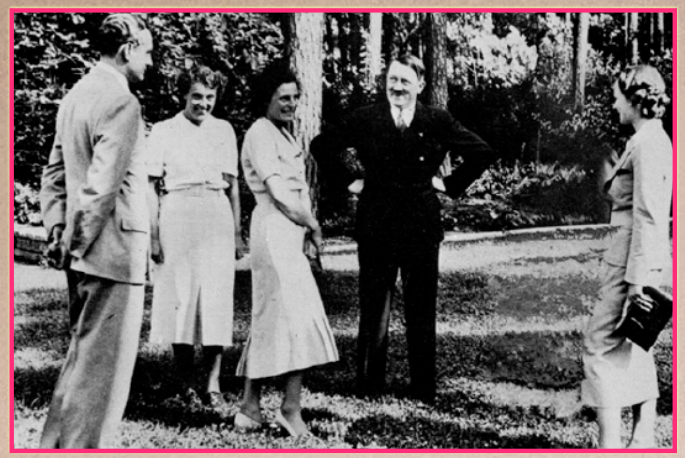


Image Forensics

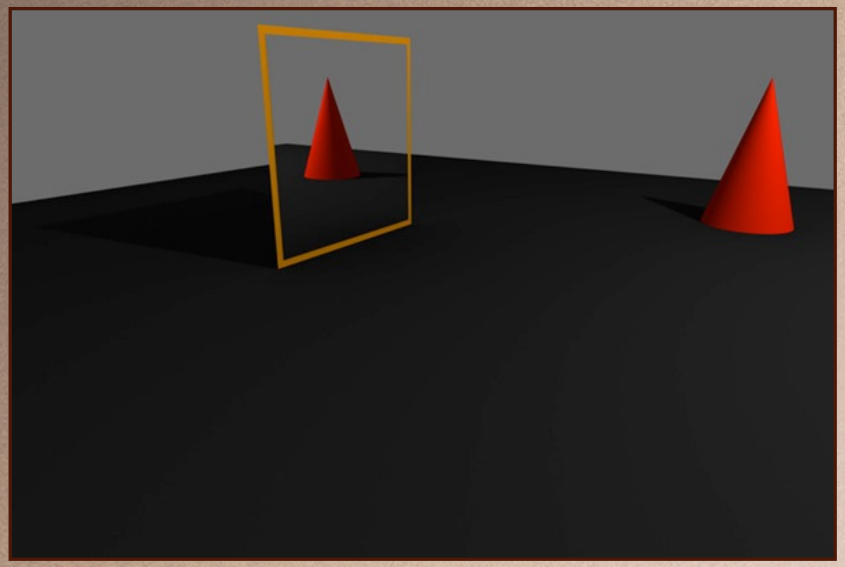
- Detect forgeries
  - Detect signs of manipulation
    - **Prove image was modified in some way**
  - Cannot *prove* an image *unmodified*

- Suite of detection tools
  - Individual methods can be countered by informed attacker
  - Individual tools may not apply in all cases
  - Each additional method makes forgery harder

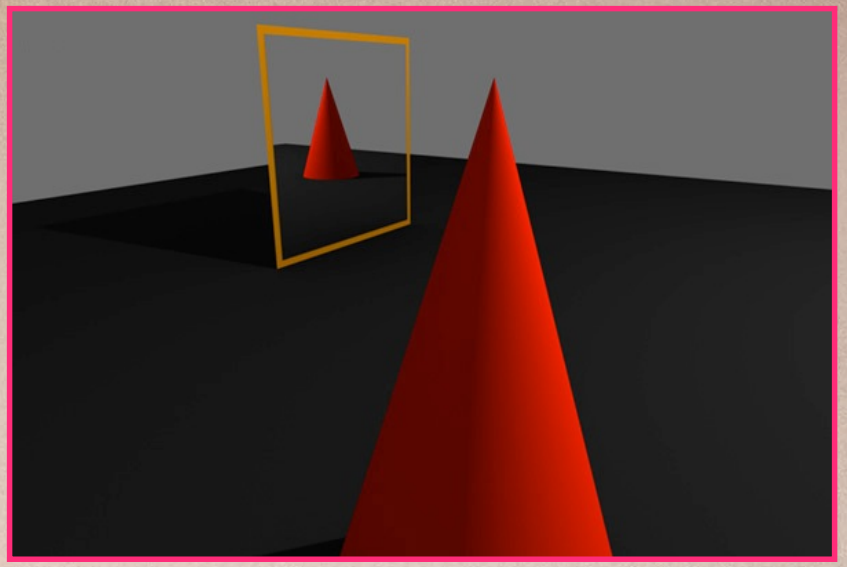
Advantage: Forgers

- People:
  - Good at understanding scene content
  - Poor at noticing many types of inconsistencies
- Simple manipulation methods work well
- New manipulation methods being developed

Example Inconsistency



Selected as correct: 62.1%

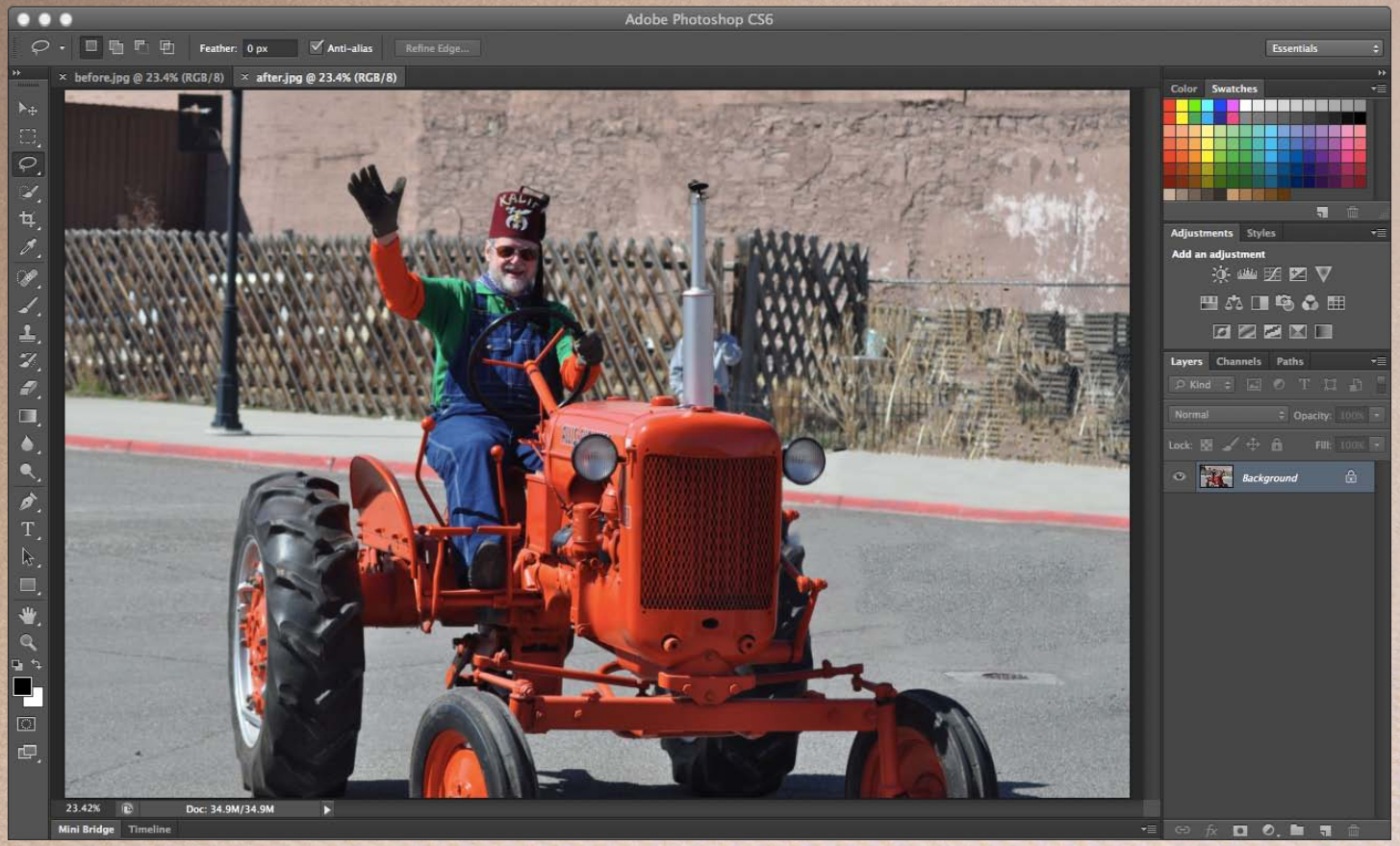


Selected as correct: 50.1%

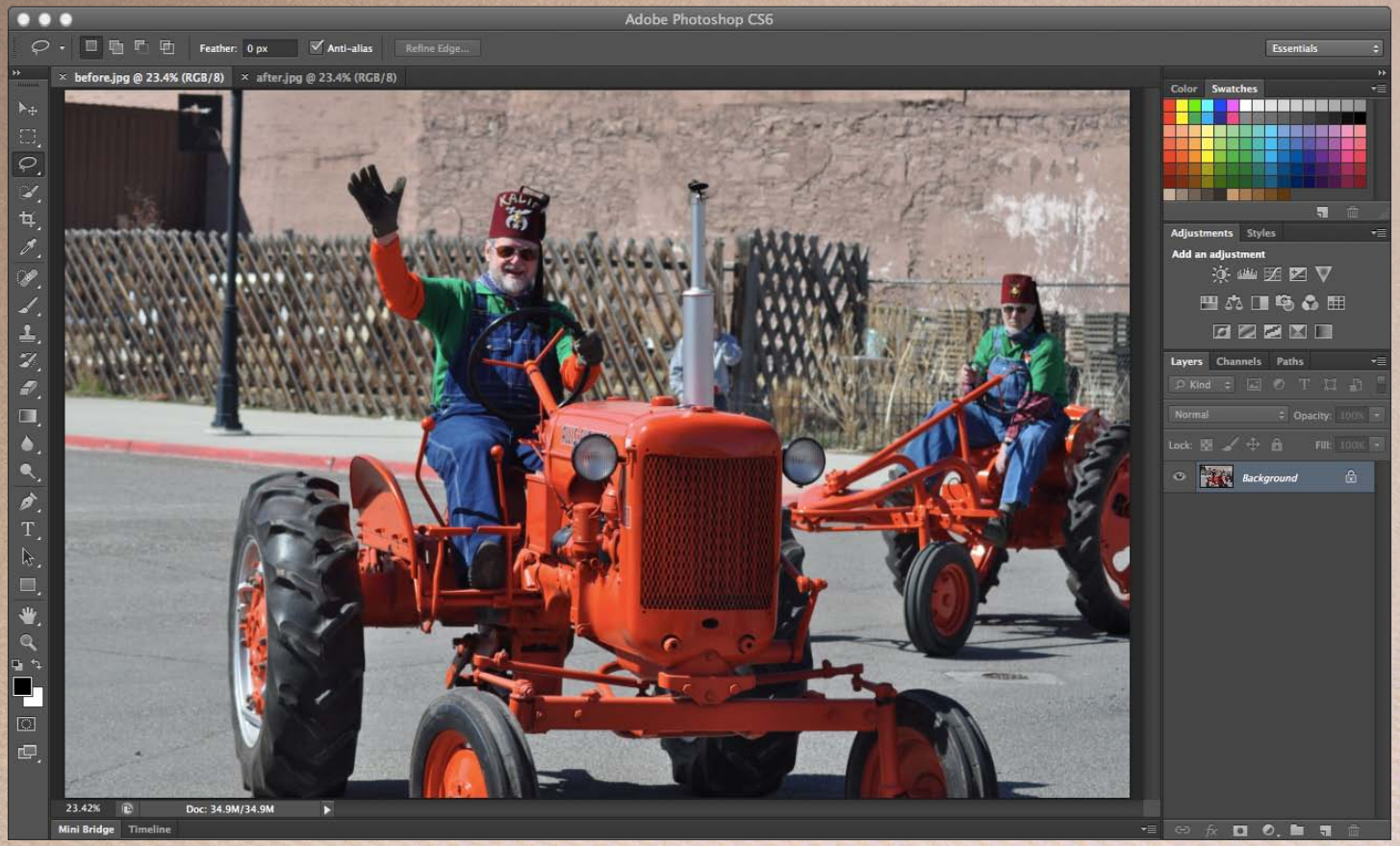
N = 20; RT = 7.6s

Farid and Bravo 2010

Things we don’t see



Things we don’t see



Advantage: Forgers

- People:
  - Good at understanding scene content
  - Poor at noticing many types of inconsistencies
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Image Forensics

- **Format Methods**
  - EXIF meta data
  - Quantization tables
  - Coding decisions
  - Signatures or watermarks
- **Pixel Methods**
  - Linear dependance
  - Bayer pattern artifacts
  - Chromatic aberration
  - Compression artifacts

→

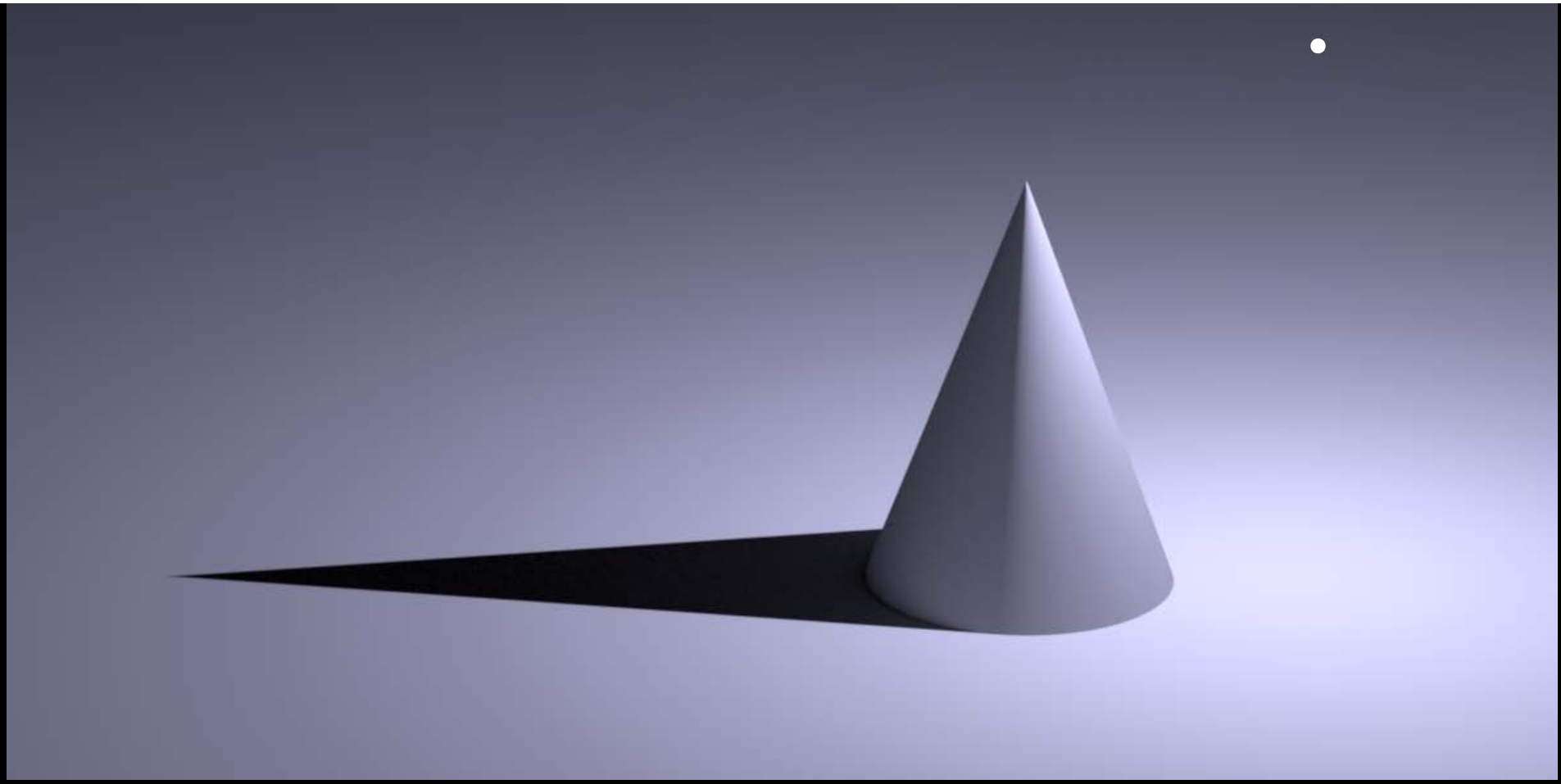
- Not tied to scene content
  - Easy to apply
  - Easy to fool (informed attacker)
  - Not robust to common operations

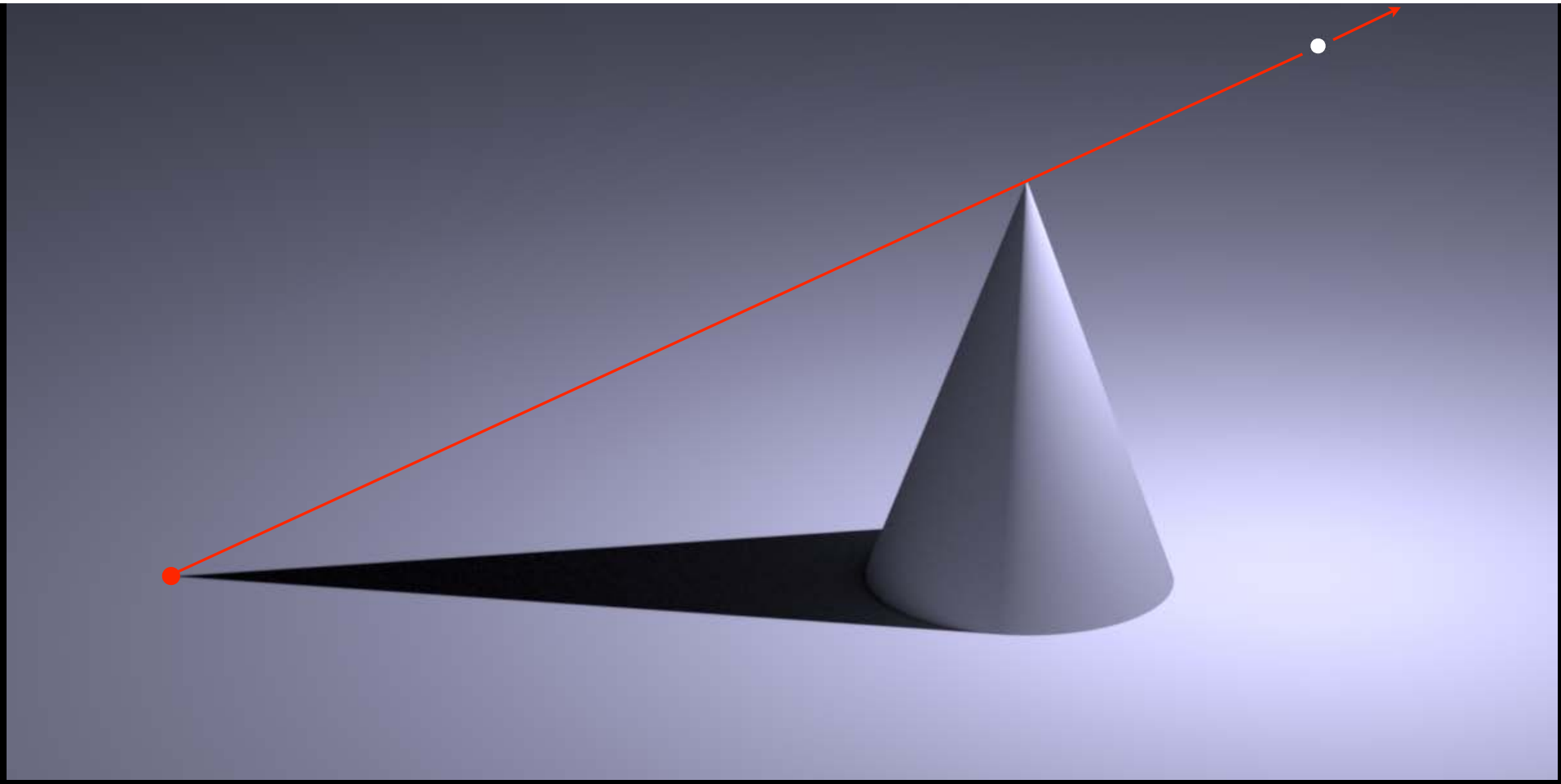
Image Forensics

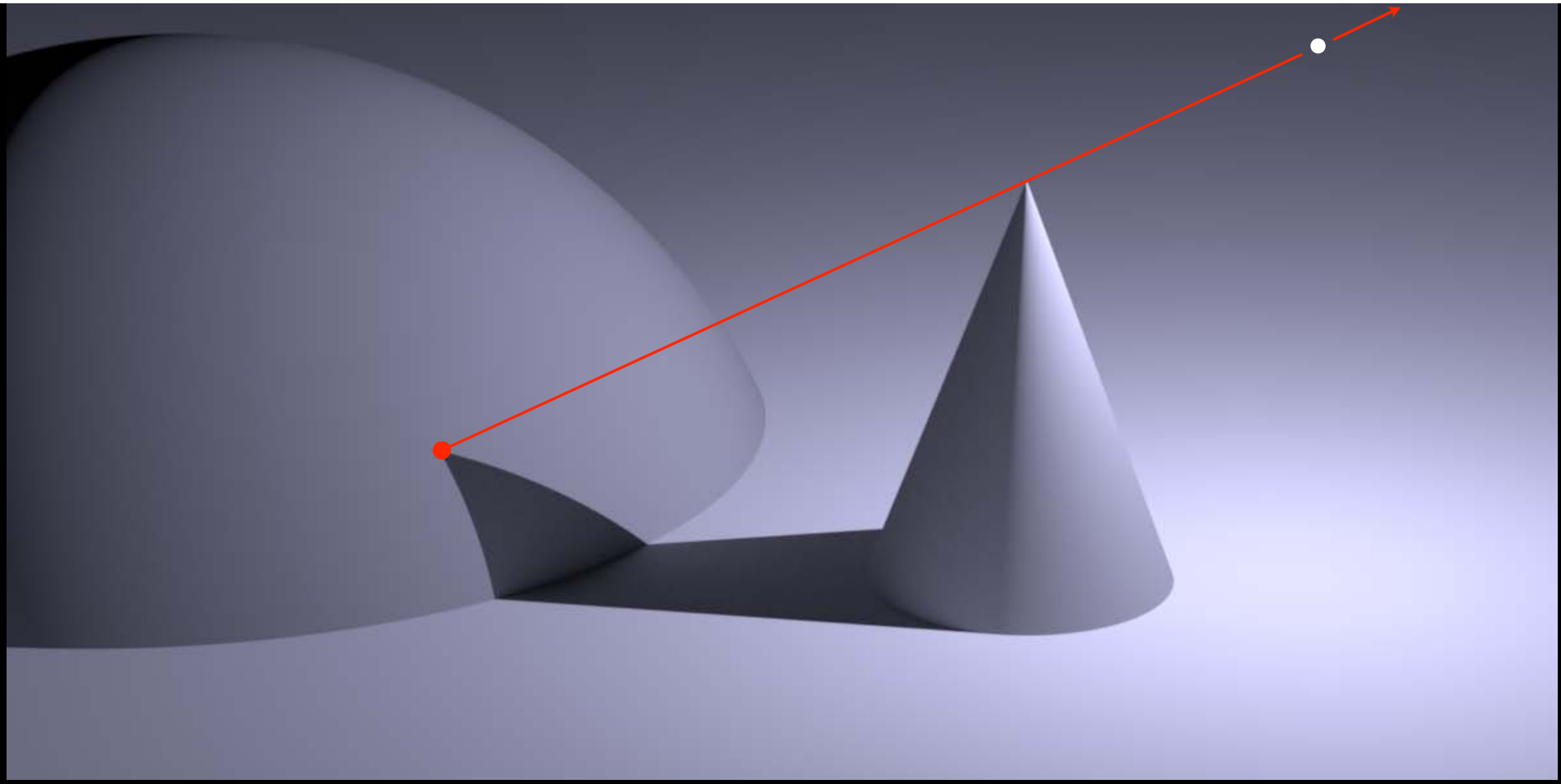
- **Geometric methods**
  - Content inconsistencies
  - Require human annotation
    - Computer analysis
  - Examples:
    - Shadows
    - Lighting
    - Reflections

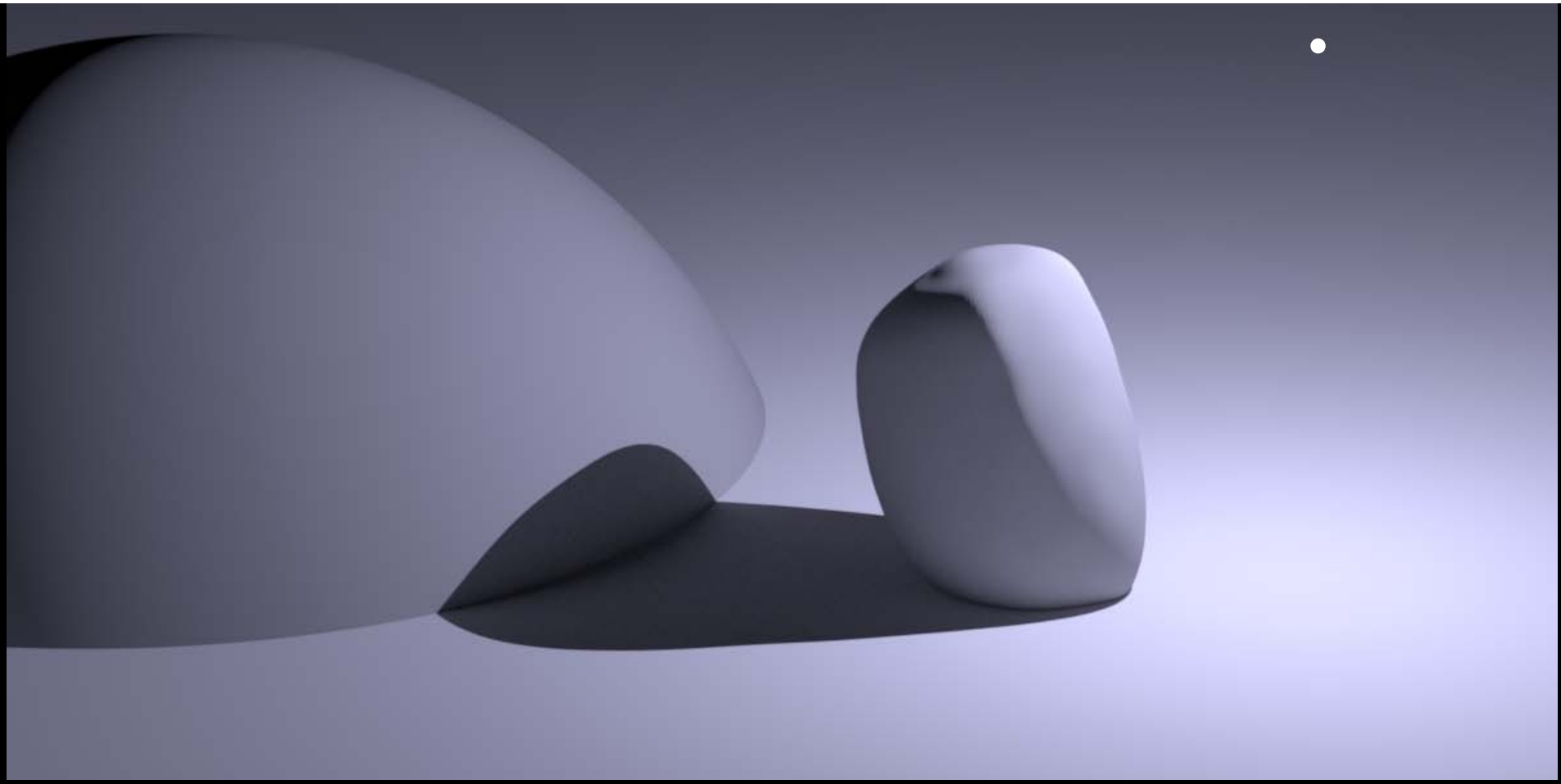
Geometric Image Forensics

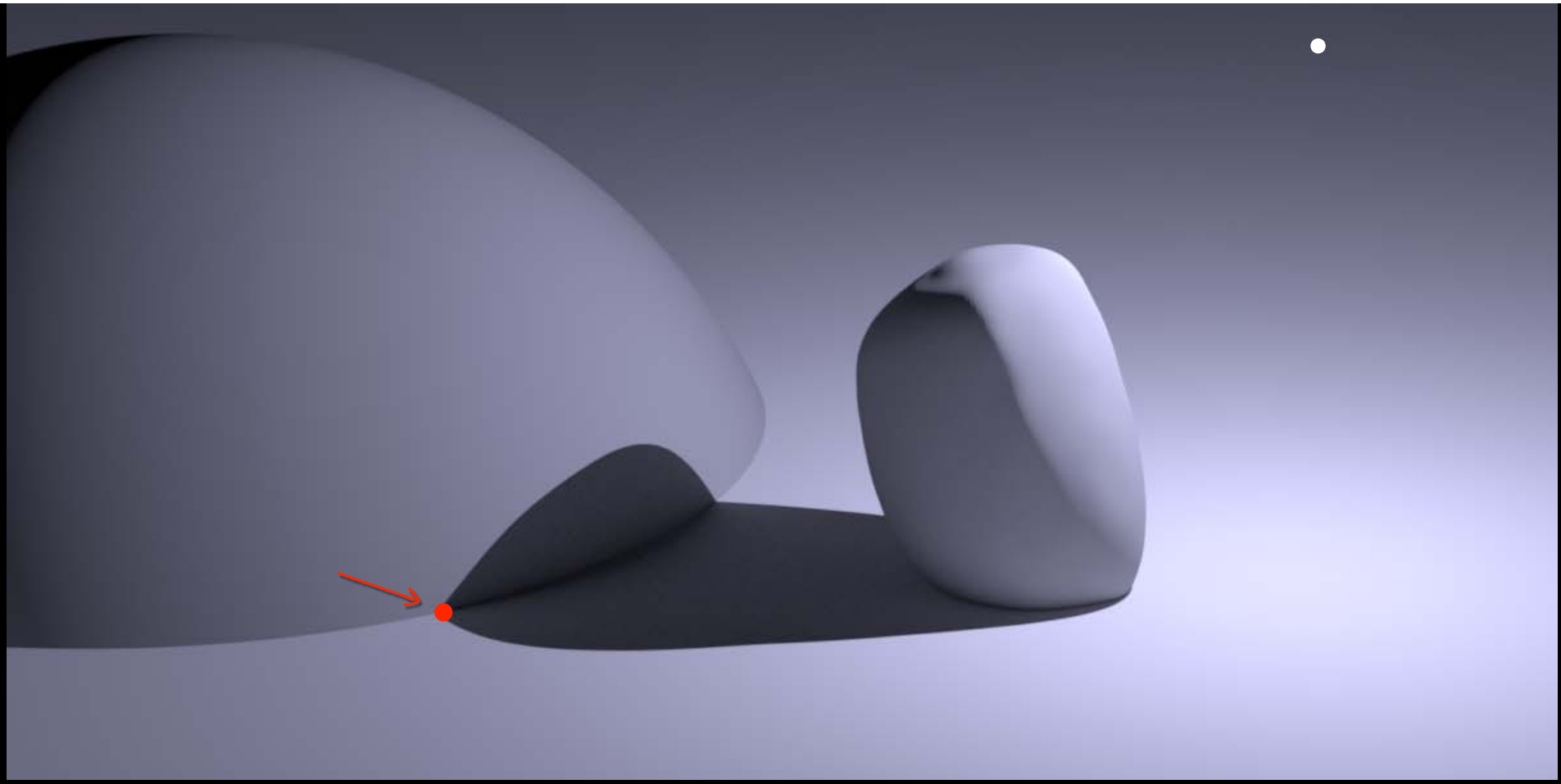
- Not same as Computer Vision
  - Possibly user involved in loop
  - Only looking for inconsistencies only
    - Don’t need to fully extract scene content

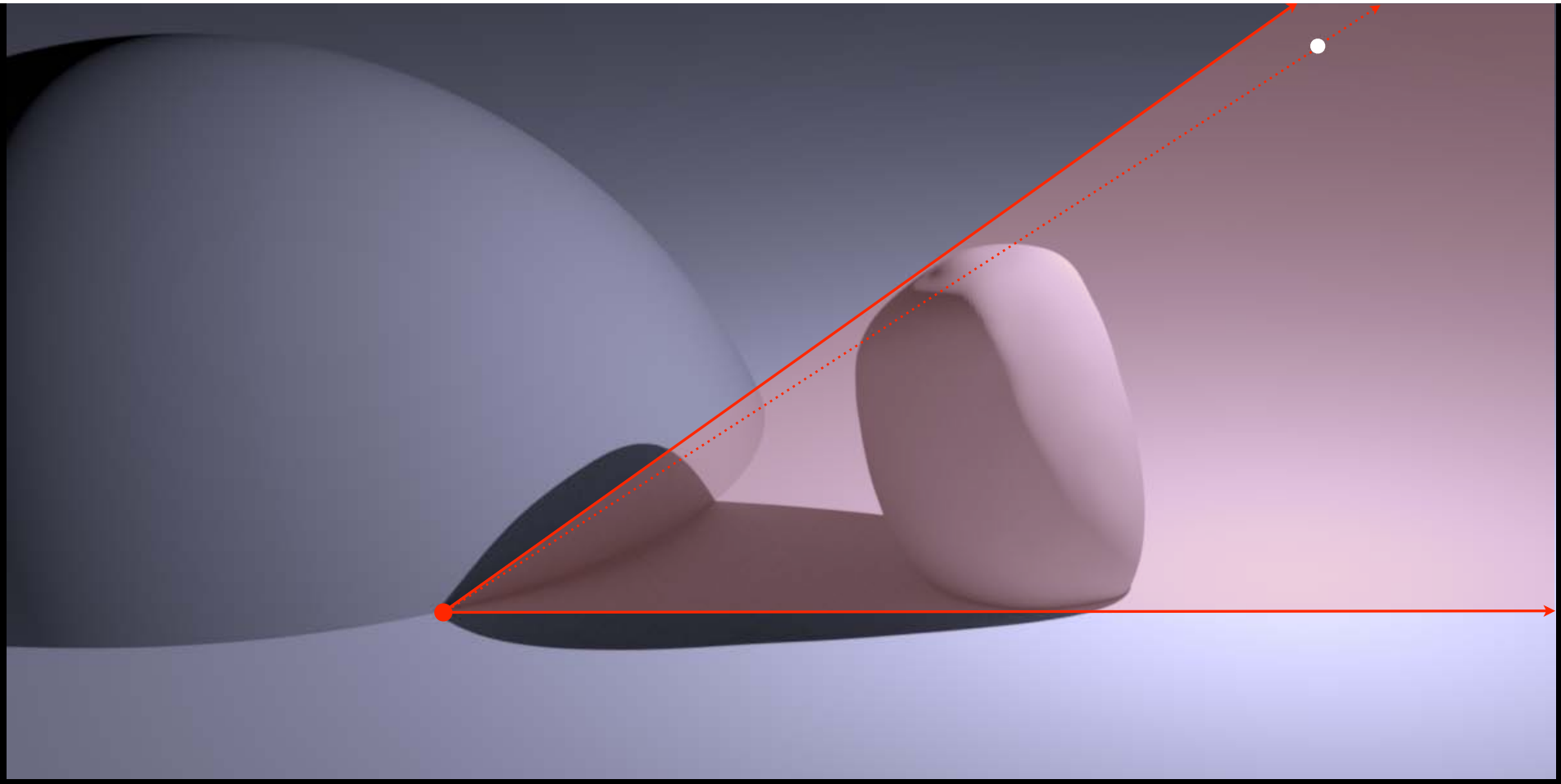


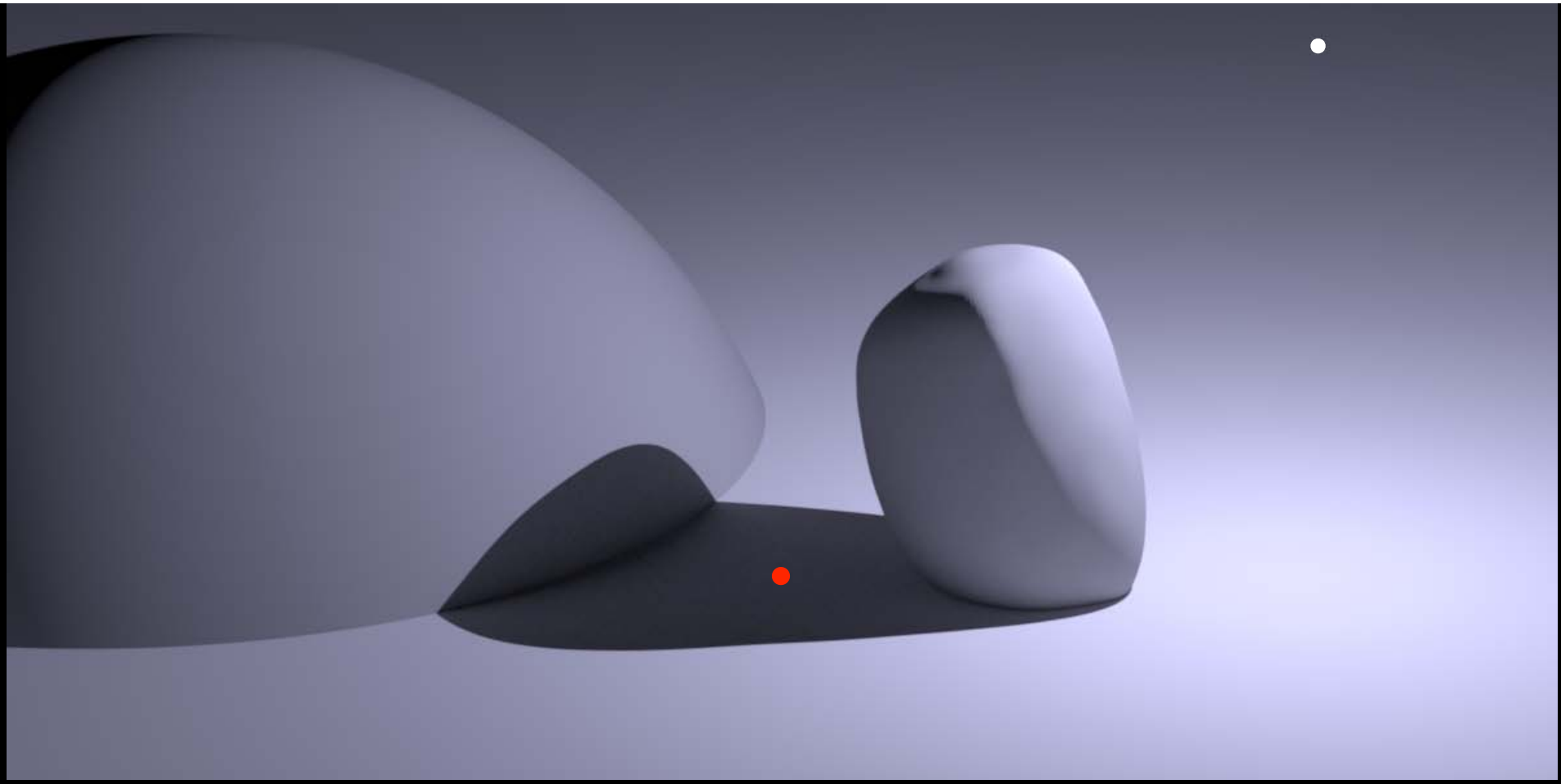


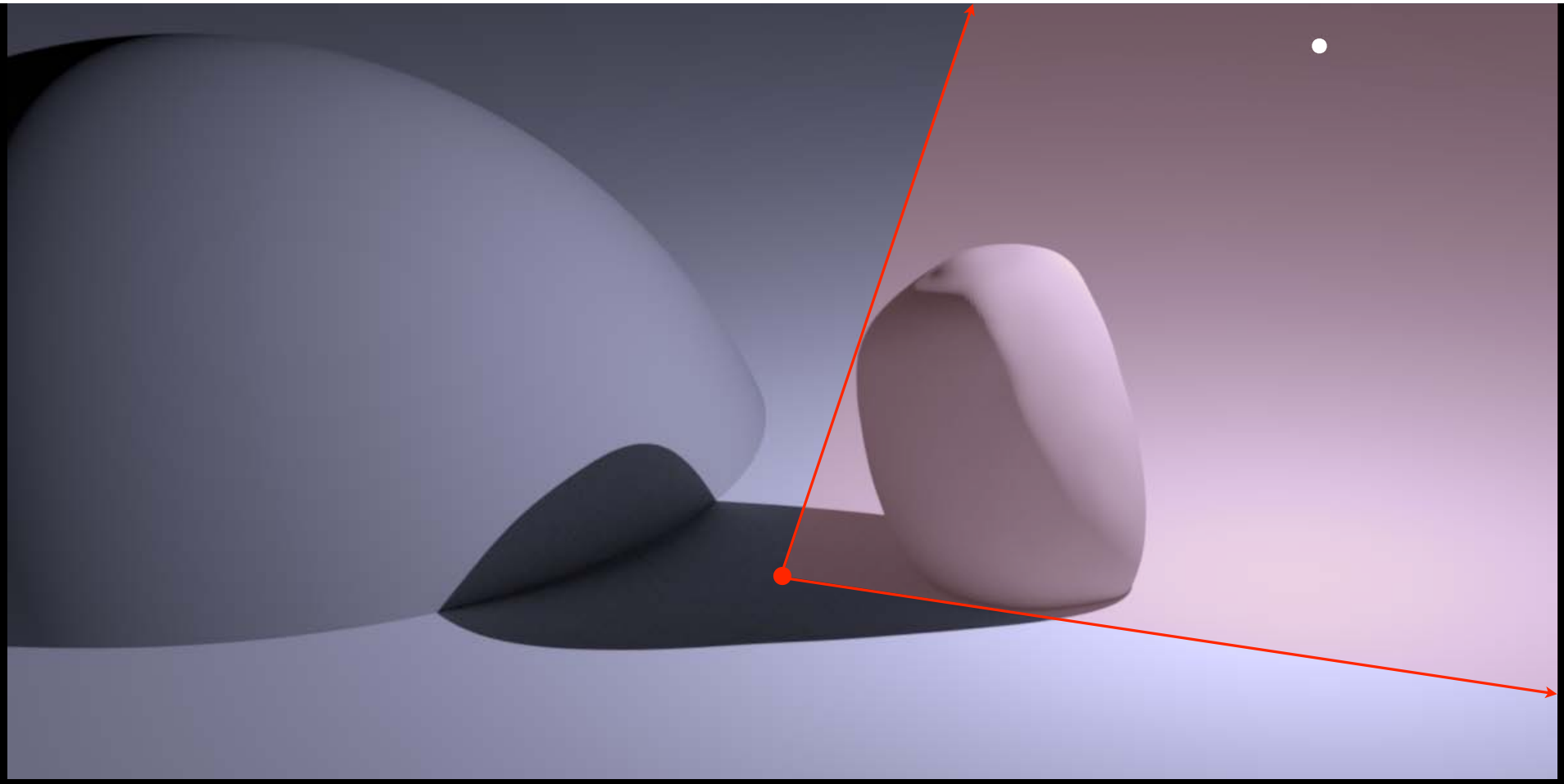


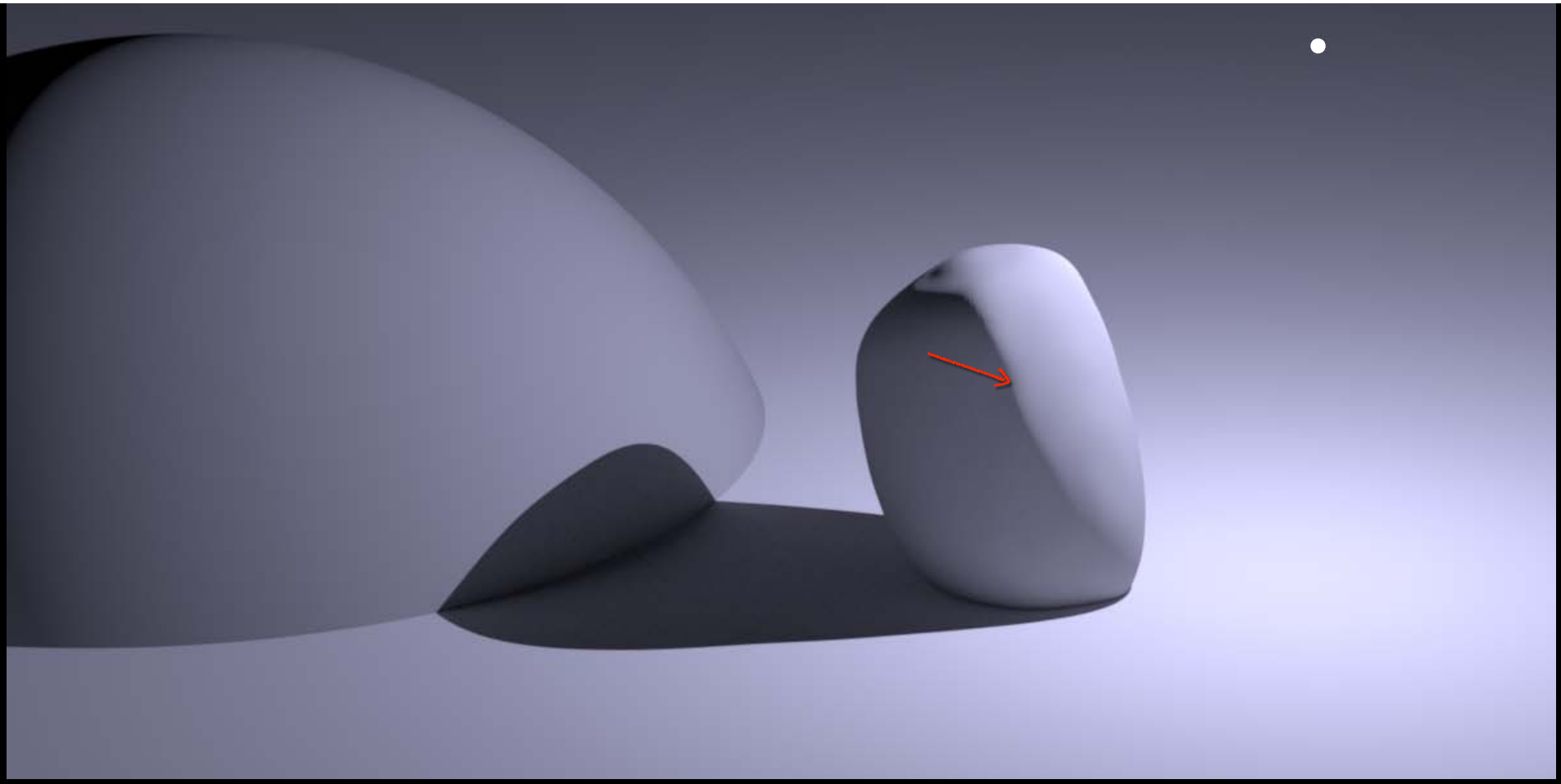


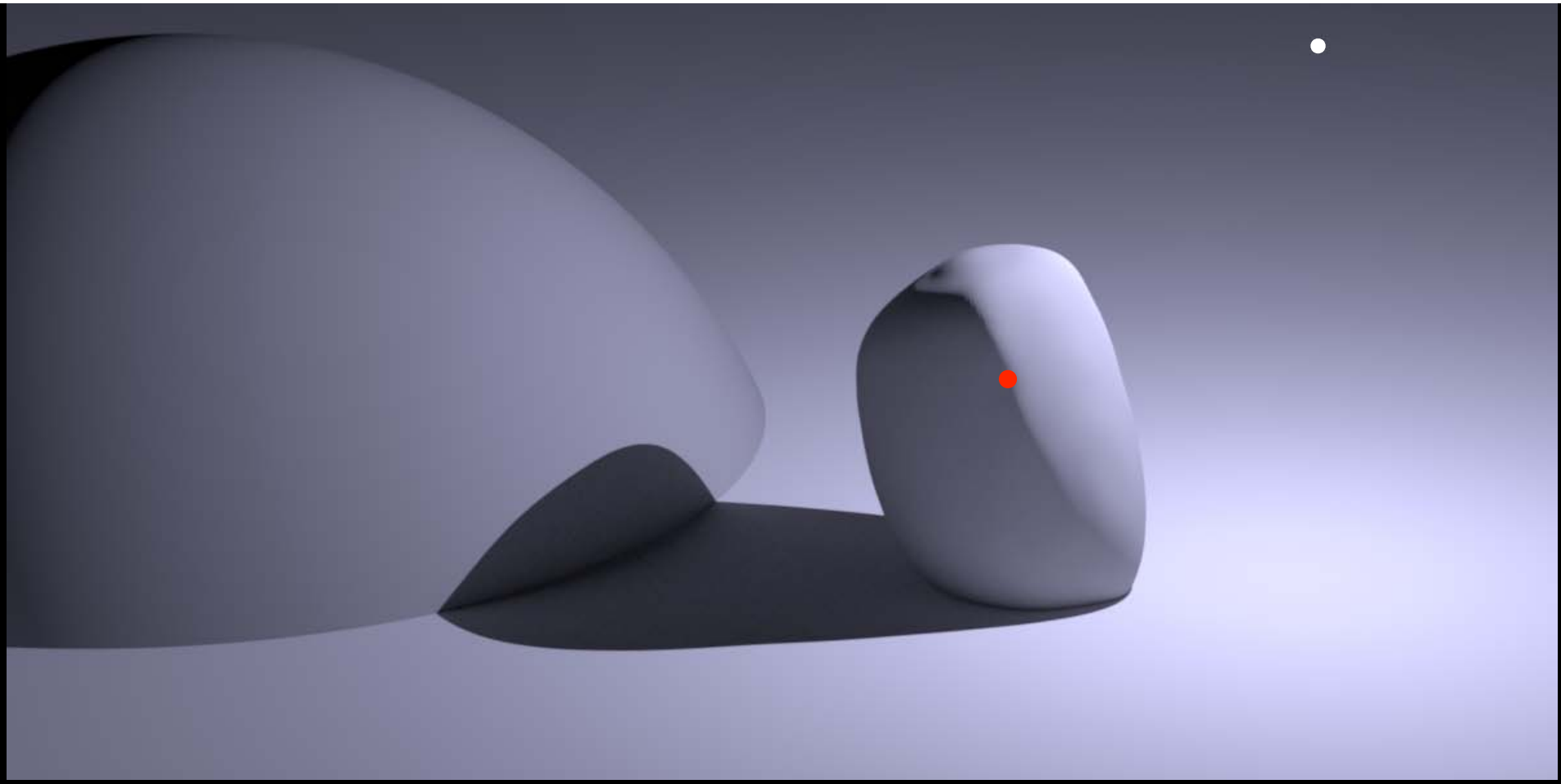


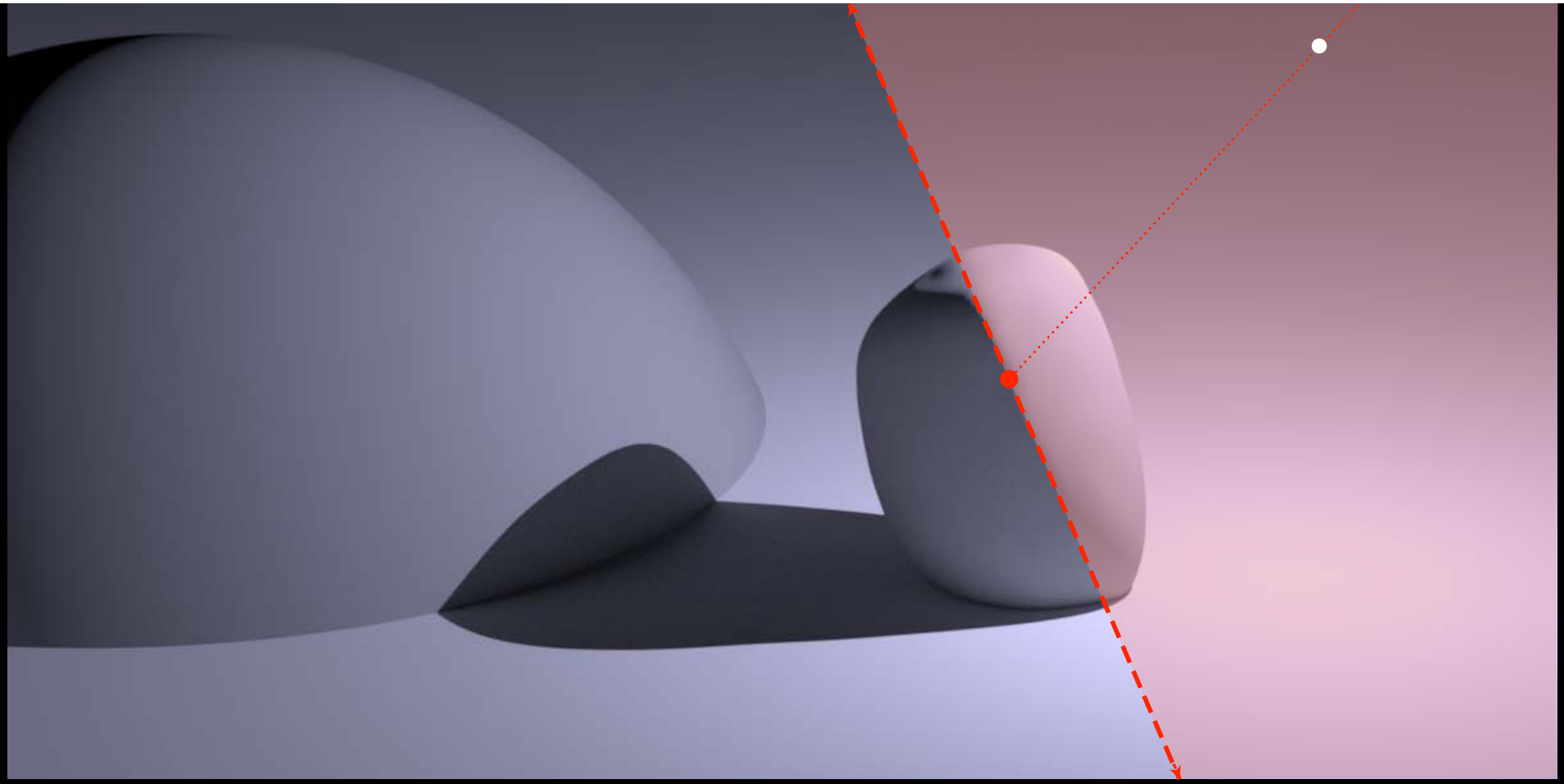


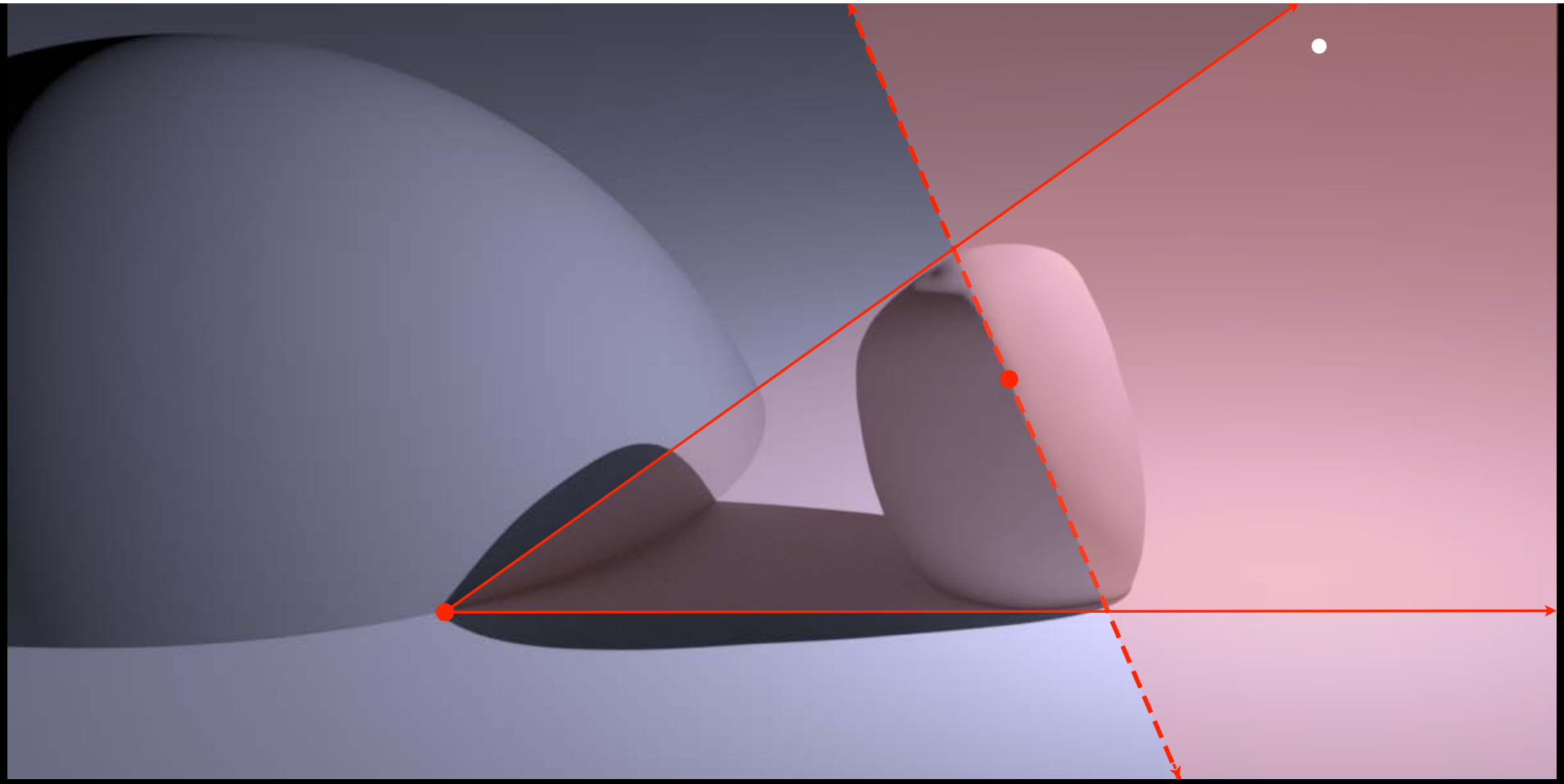


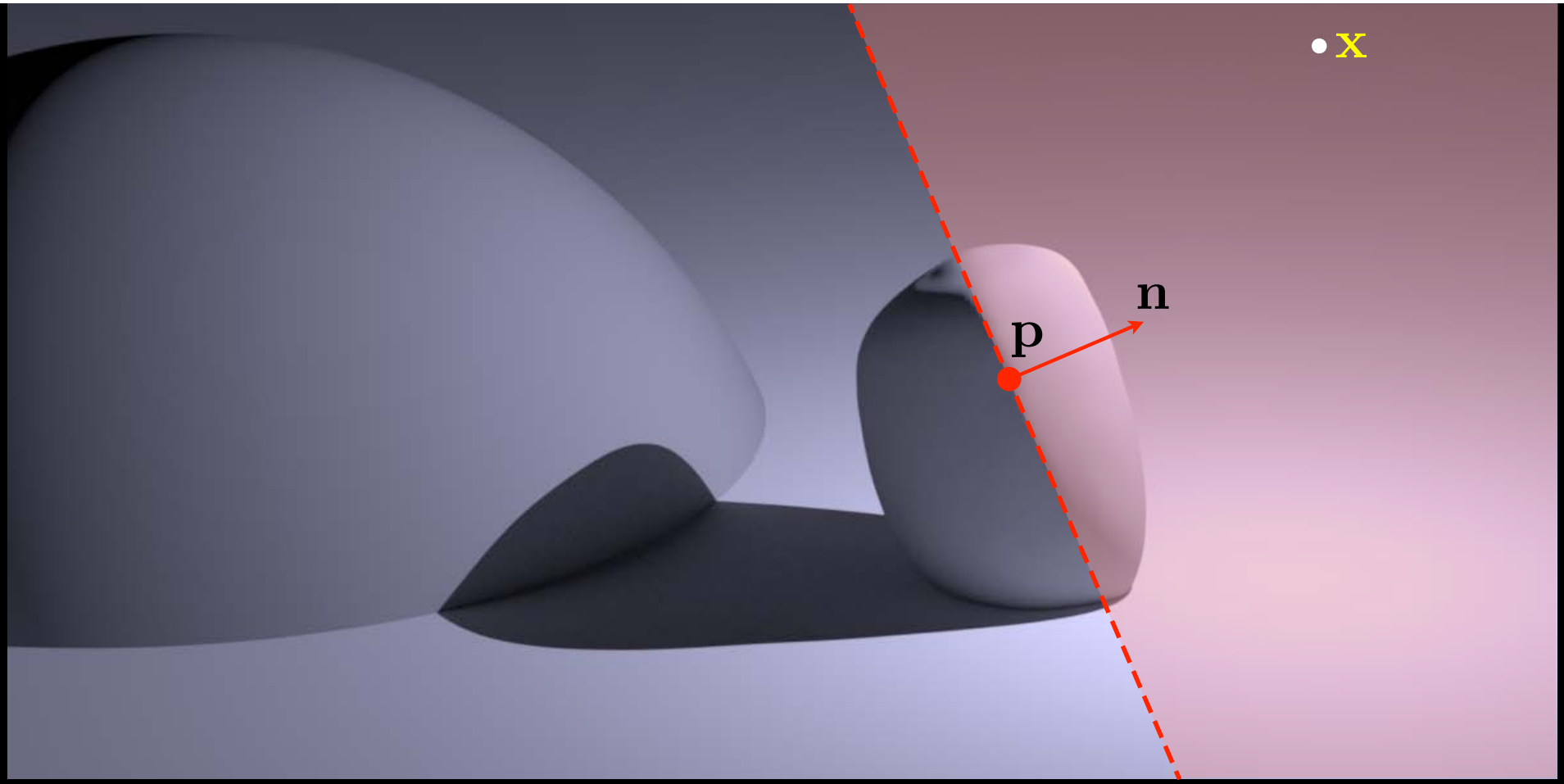


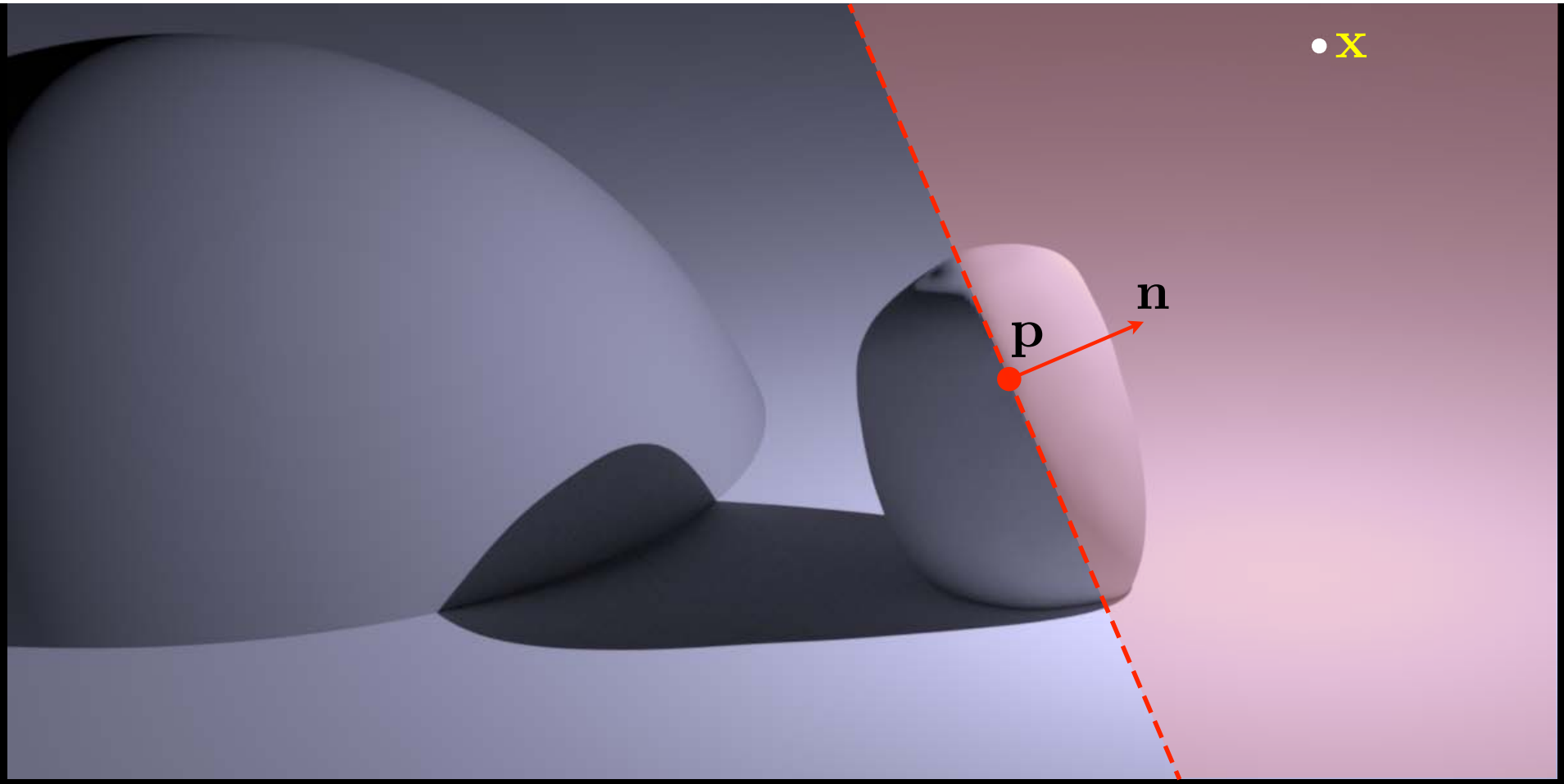




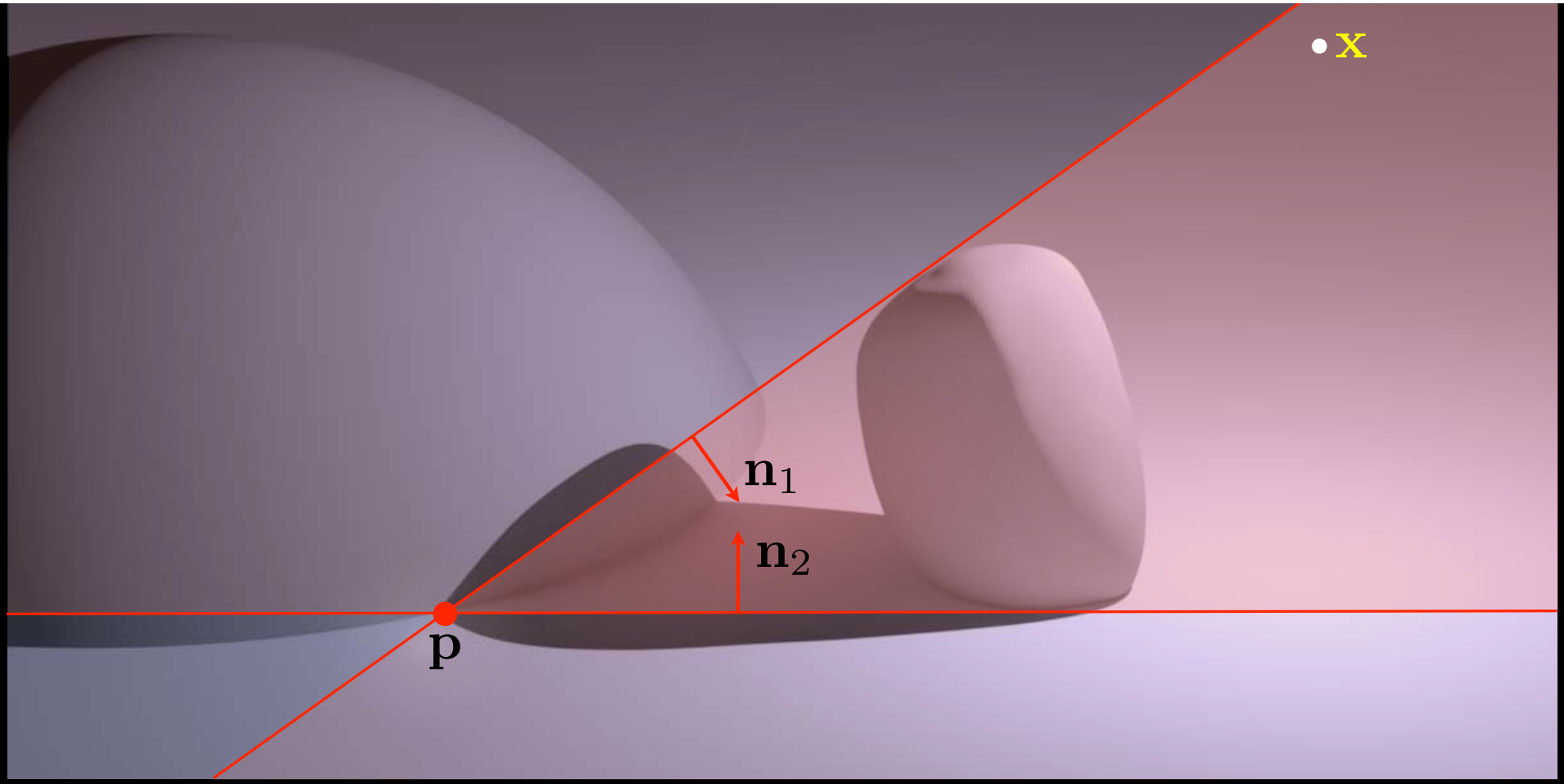


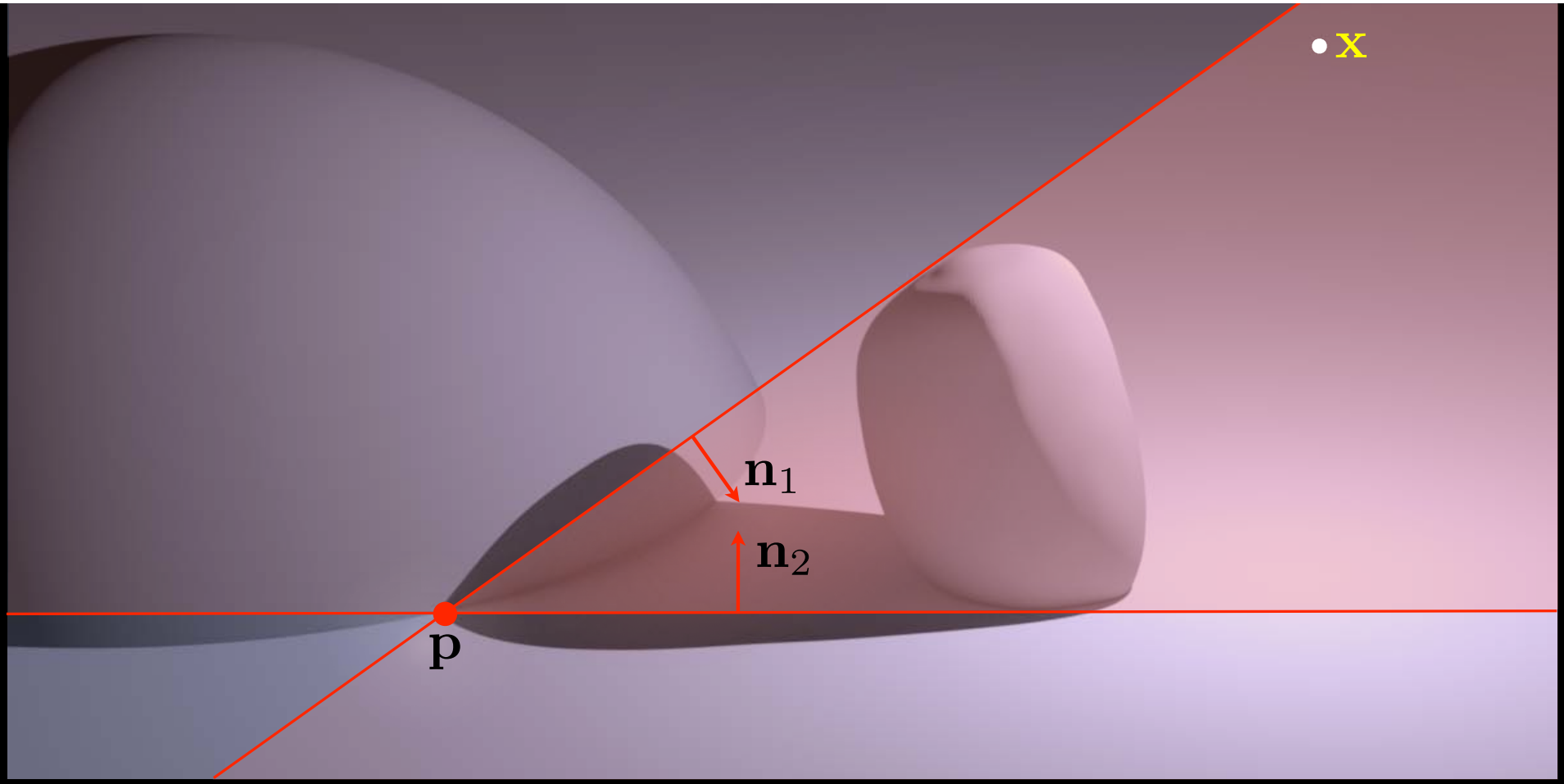



x
n
p

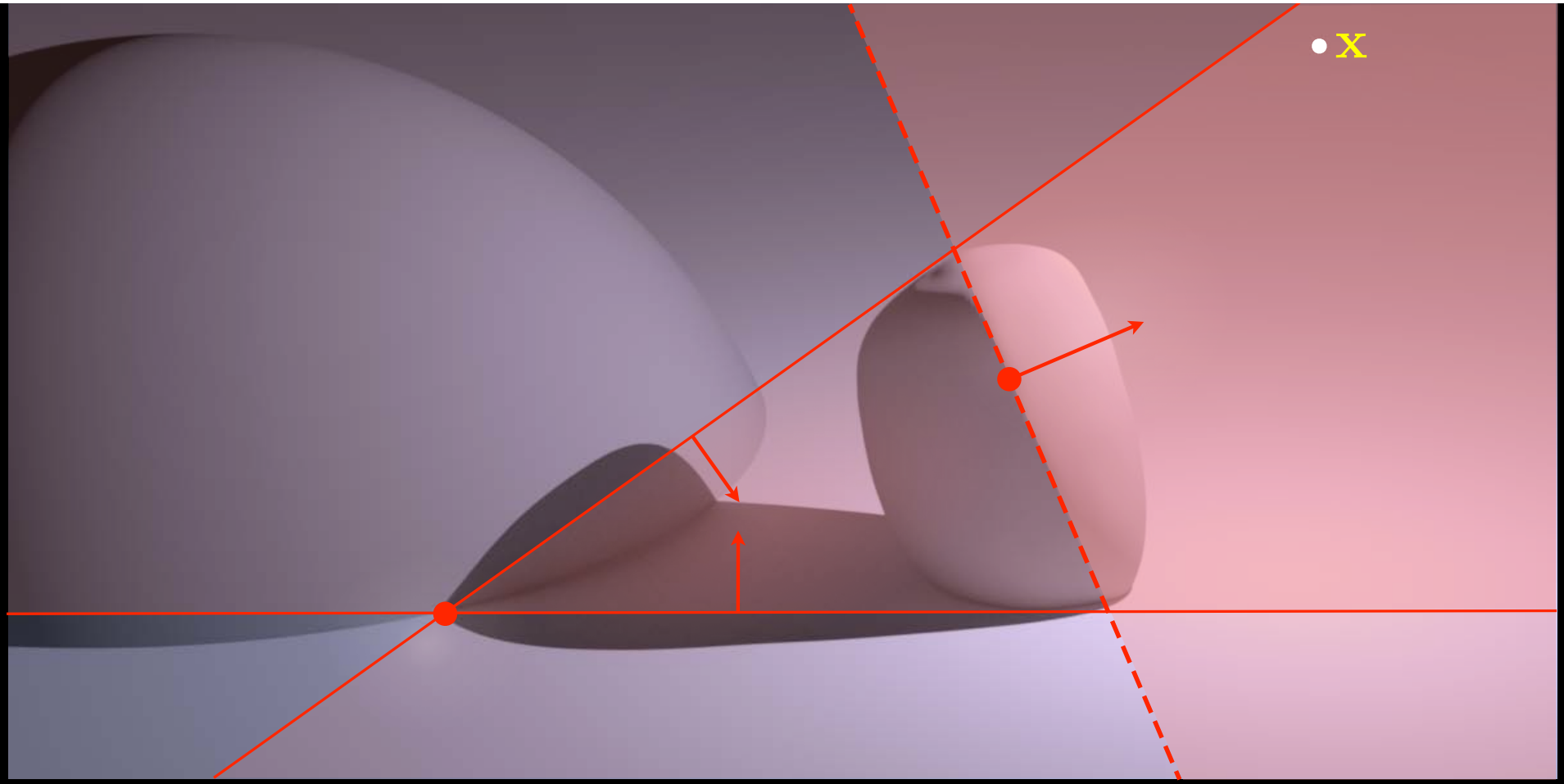


$$\mathbf{n} \cdot \mathbf{x} - \mathbf{n} \cdot \mathbf{p} \geq 0$$

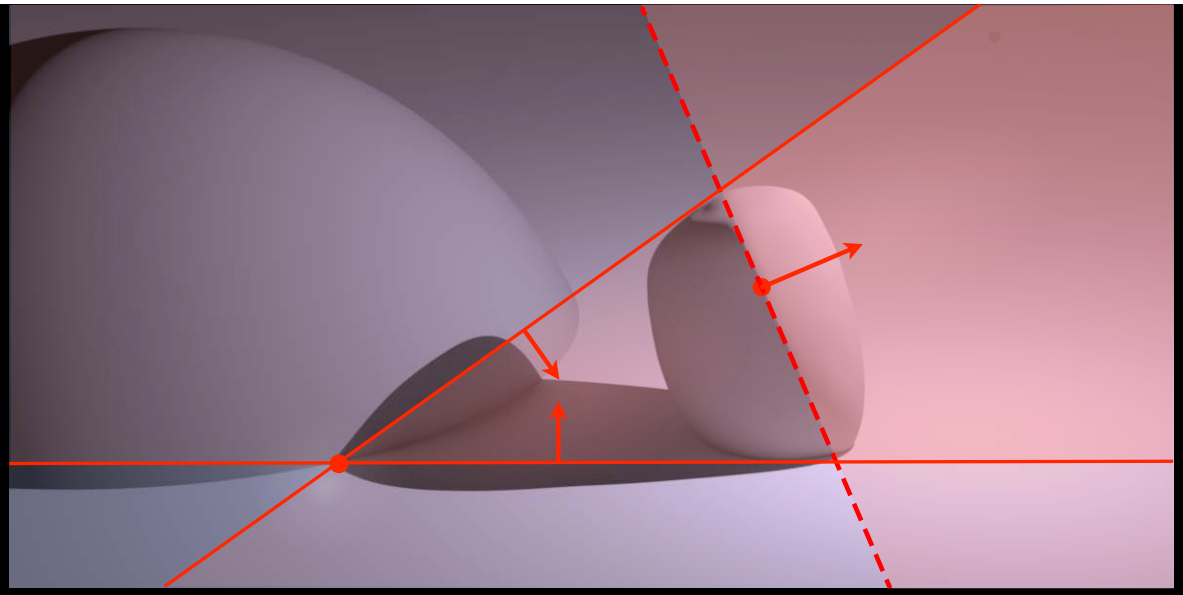

x
$\mathbf{n}_1$
$\mathbf{n}_2$
p



$$\begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \end{bmatrix} \mathbf{x} - \begin{bmatrix} \mathbf{n}_1 \cdot \mathbf{p} \\ \mathbf{n}_2 \cdot \mathbf{p} \end{bmatrix} \succeq \mathbf{0}$$

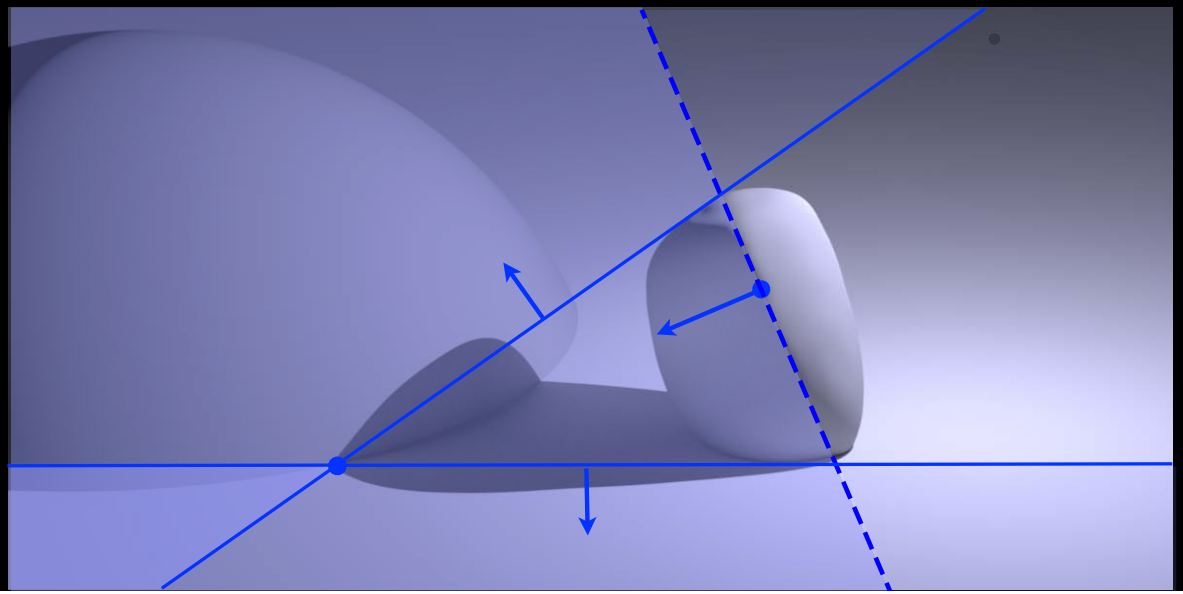


$$\mathbf{N}\mathbf{x} - \mathbf{P} \succeq \mathbf{0}$$



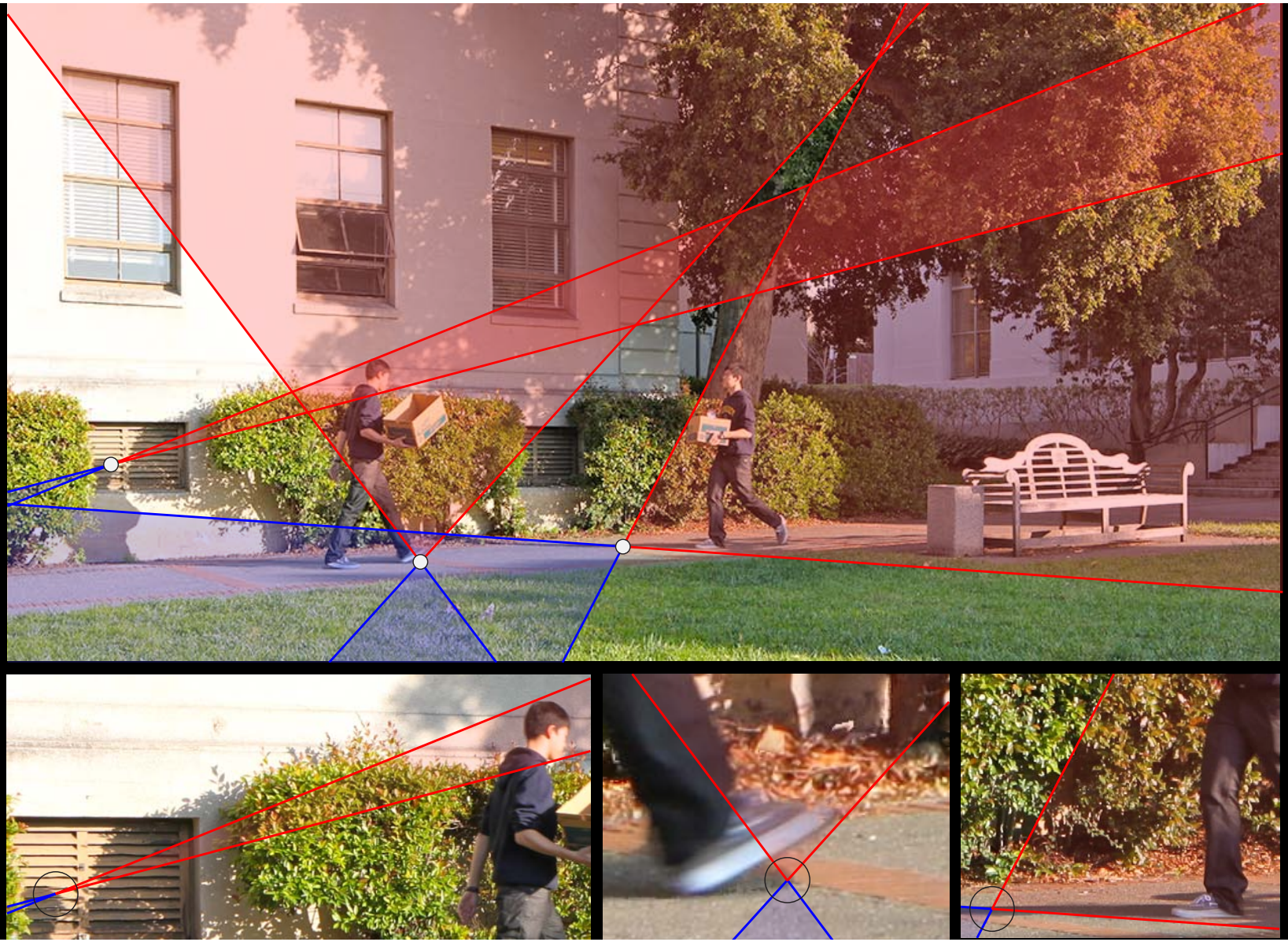
Light *in front* of camera

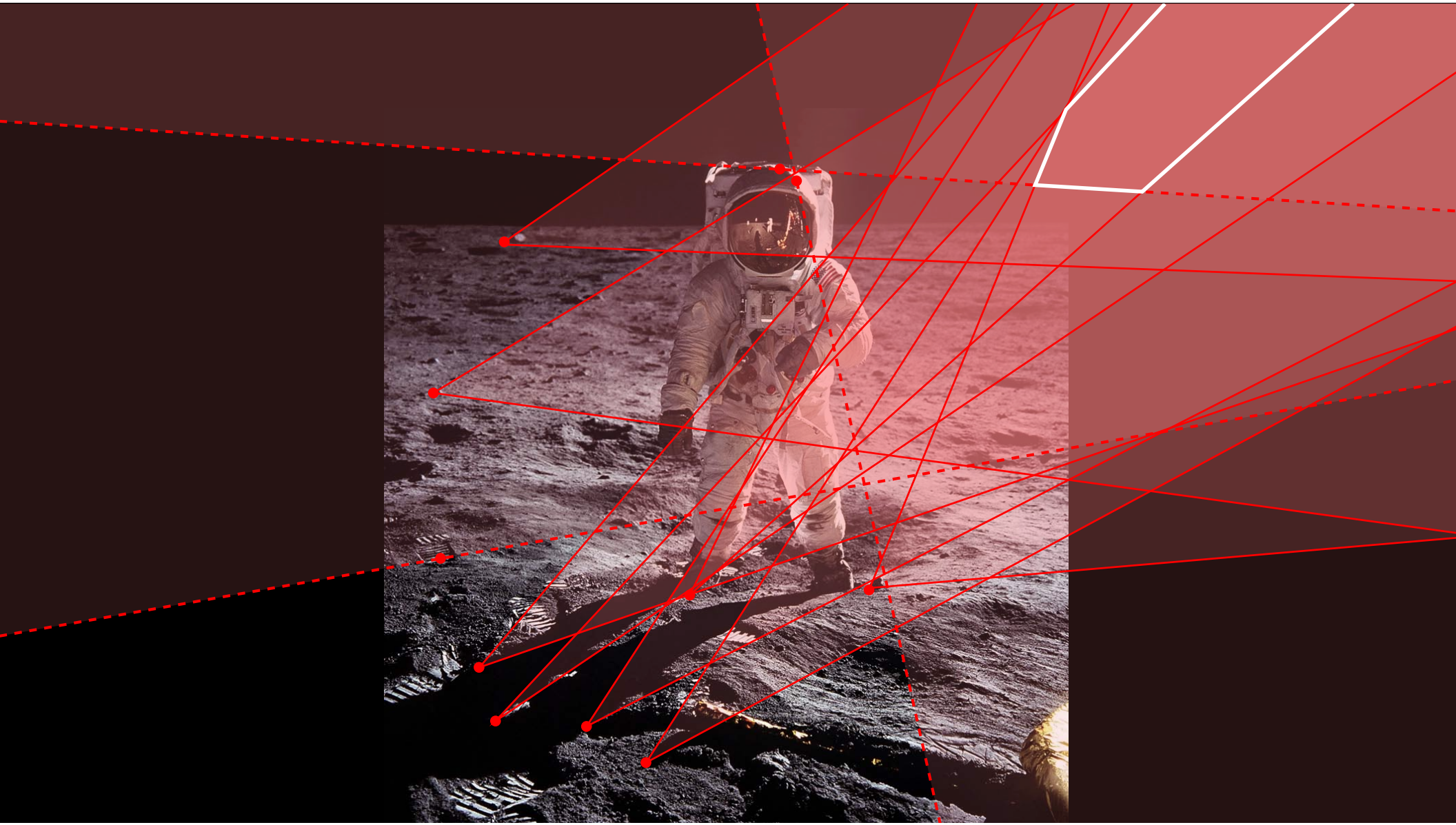
$$\mathbf{N}\mathbf{x} - \mathbf{P} \succeq \mathbf{0}$$



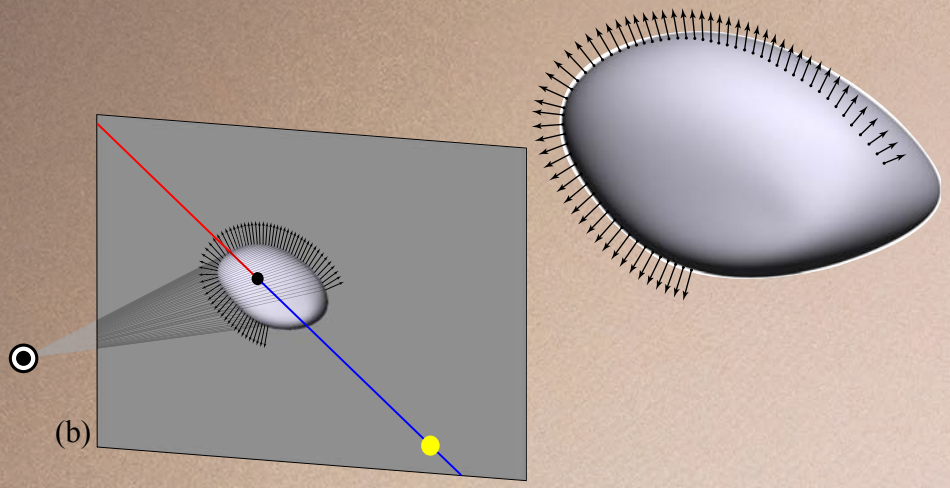
Light *behind* camera

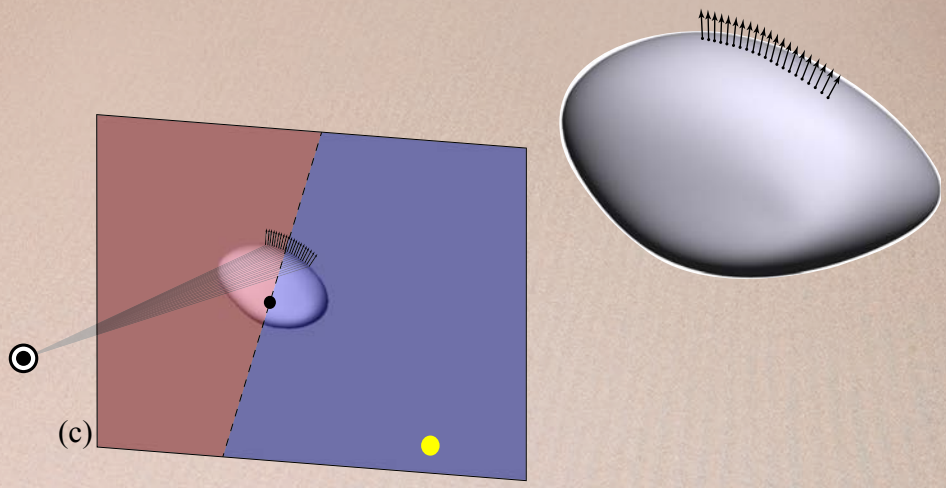
$$-\mathbf{N}\mathbf{x} - \mathbf{P} \succeq \mathbf{0}$$





Shading Constraints





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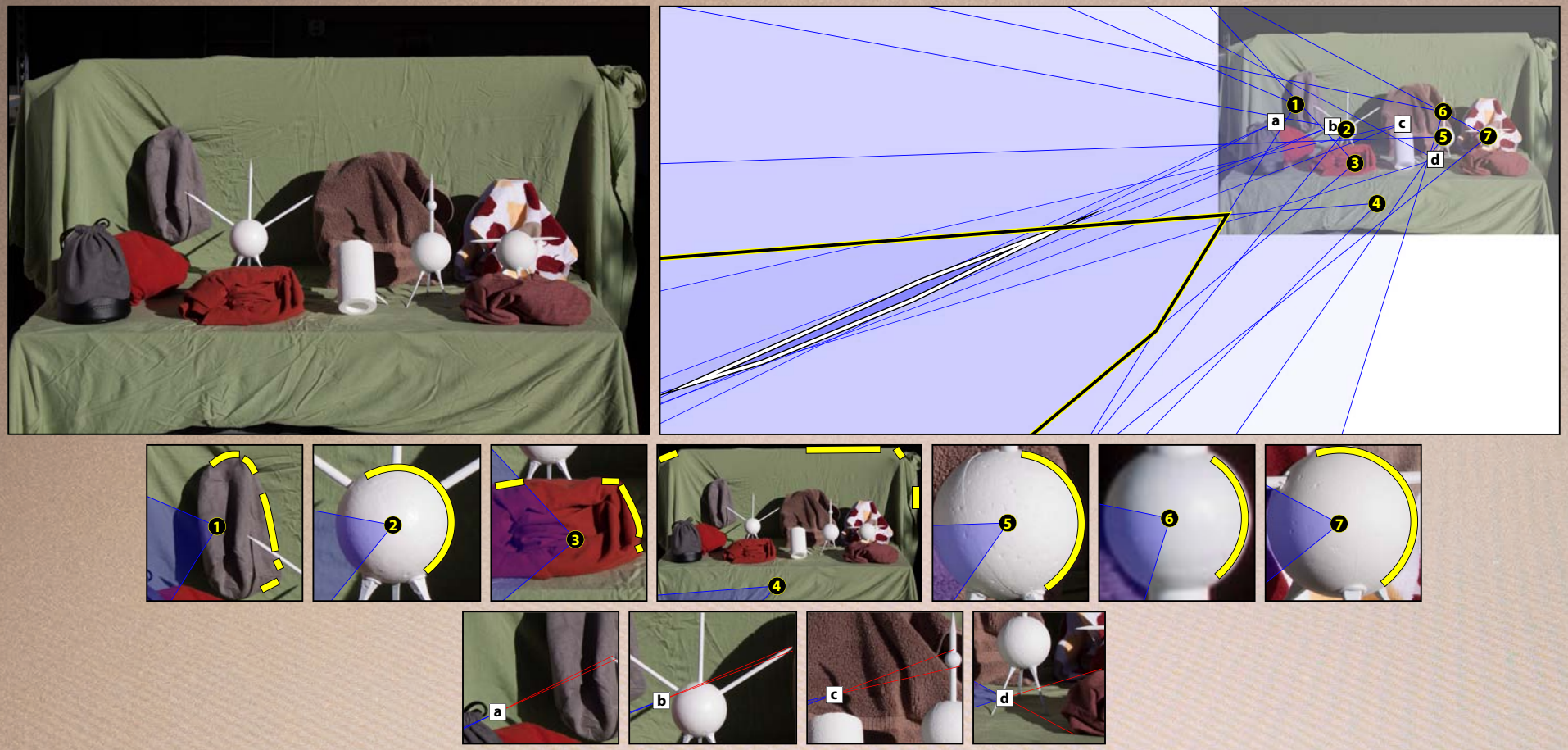

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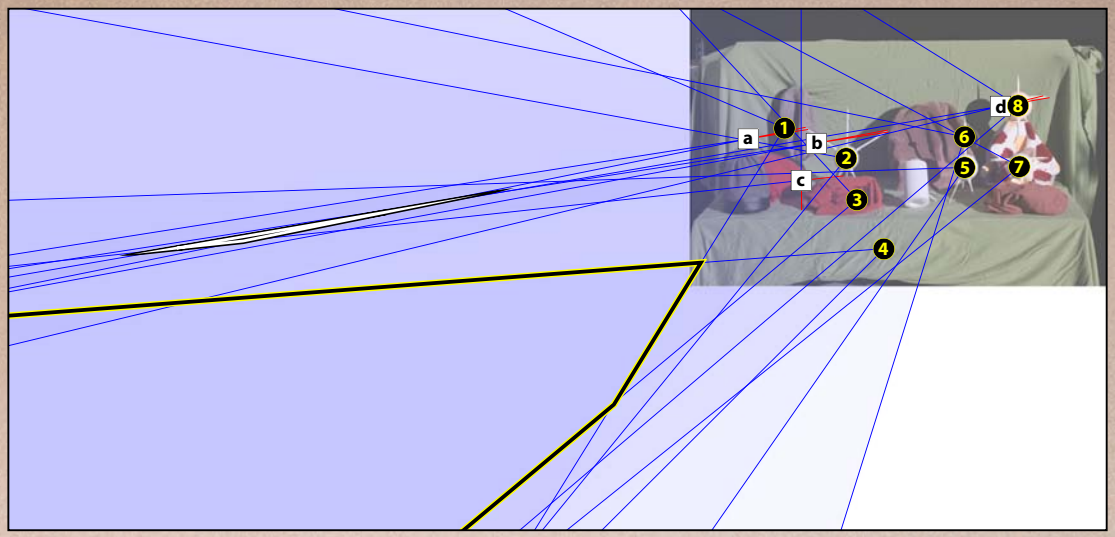
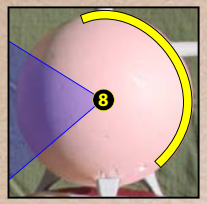
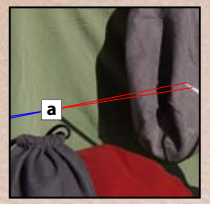
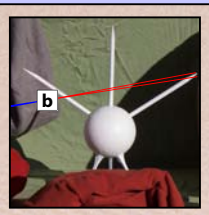
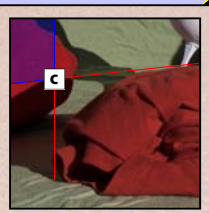
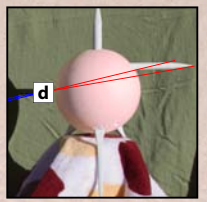




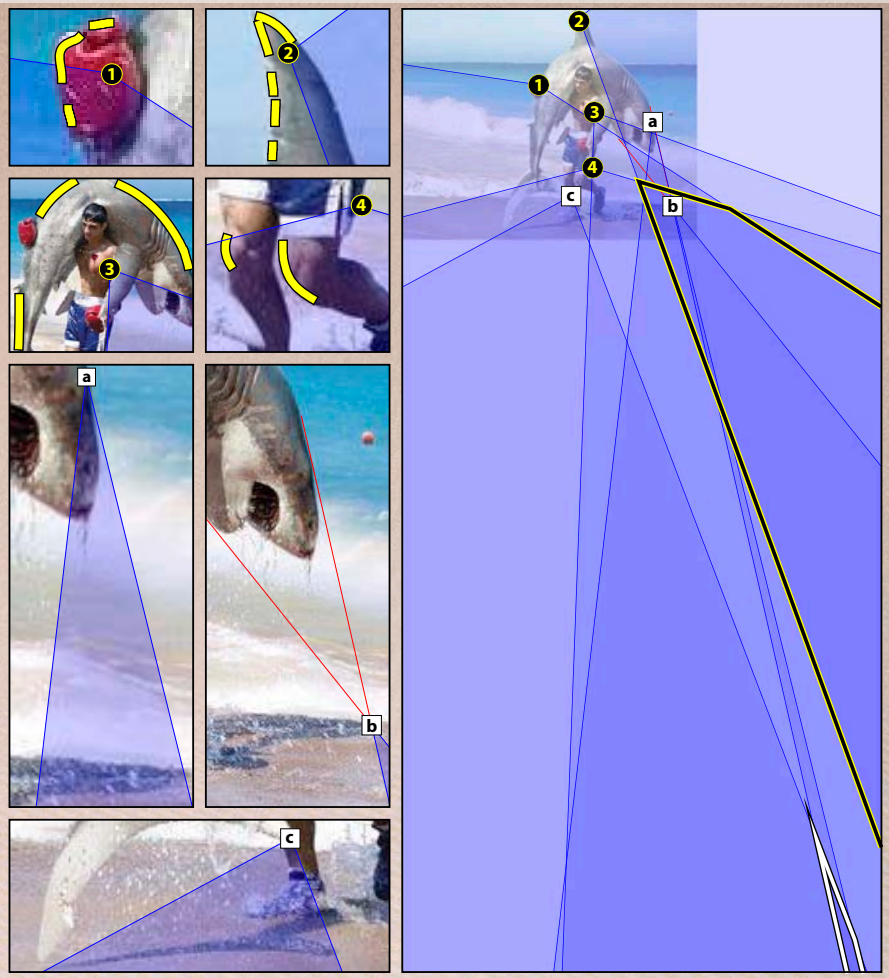








Shading Constraints



Motion in Video

Motion in Video

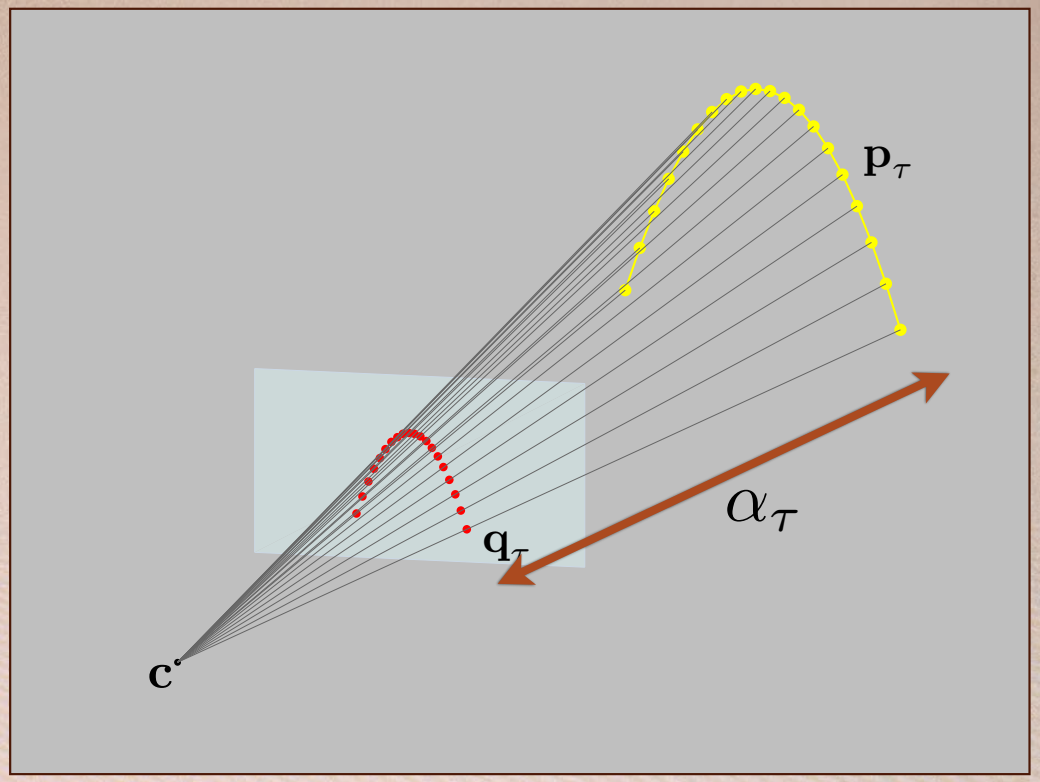
Parabolic Motion in World (Still Camera)

$$\mathbf{p}_\tau = \mathbf{p}_0 + \Delta t\,\tau\,\mathbf{v}_0 + \frac{1}{2}(\Delta t\,\tau)^2\mathbf{g}$$

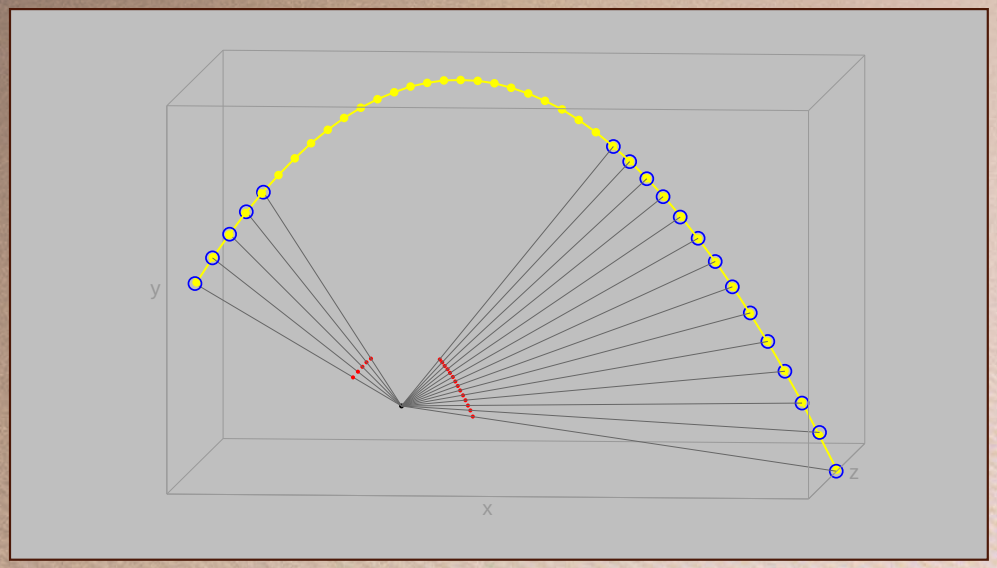
$$\mathbf{p}_\tau = \mathbf{c} + \alpha_\tau(\mathbf{q}_\tau - \mathbf{c})$$

$$\tau \in 1..n$$

Solve for: α_τ $\mathbf{v}_0$ $\mathbf{g}$

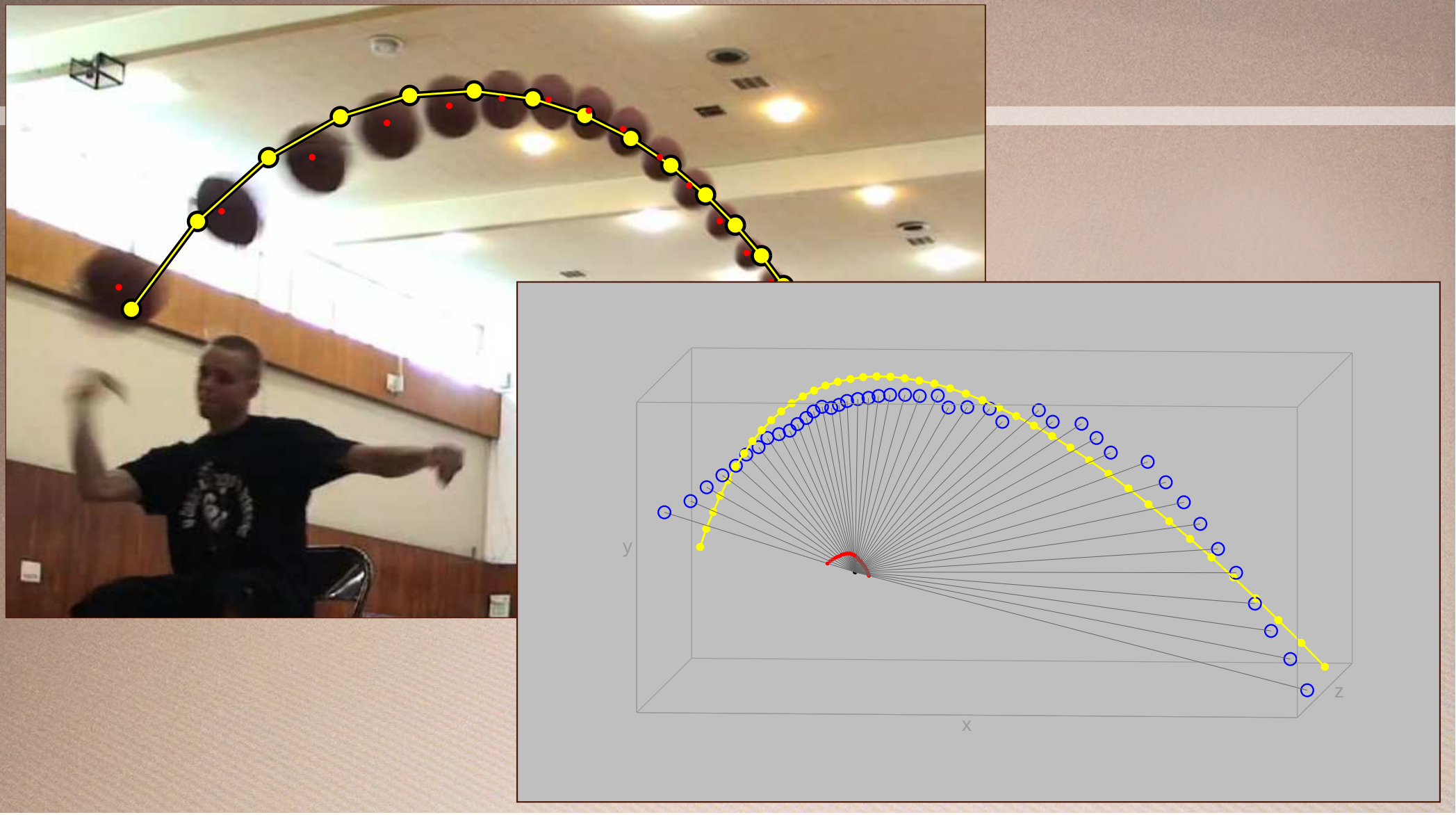


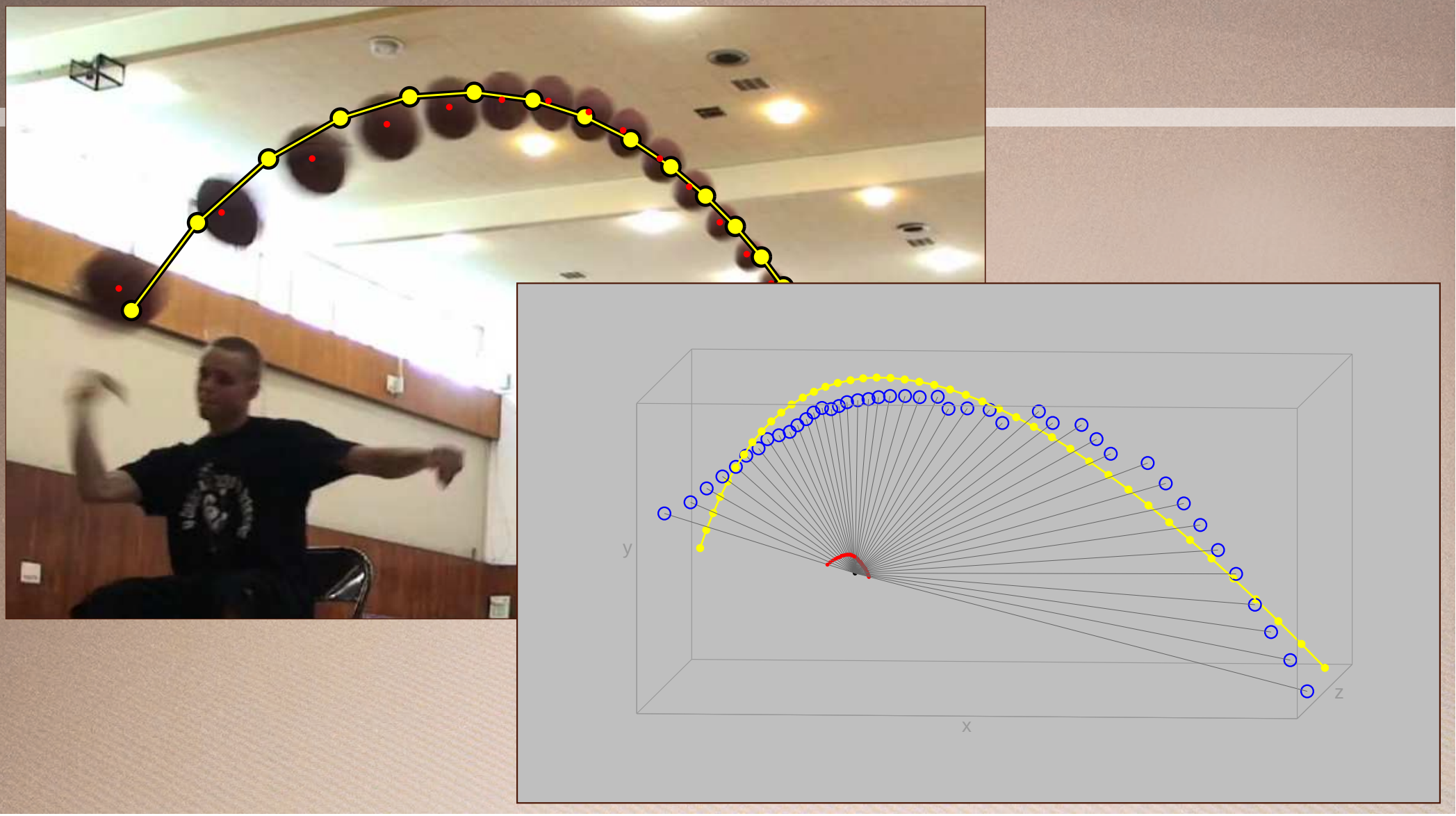
Matching observed motion



http:// www.youtube.com/ watch?v=WbaH52JI3So

http:// www.youtube.com/ watch?v=WbaH52JI3So


y
x
z


y
x
z

Parabolic Motion in World (Moving Camera)

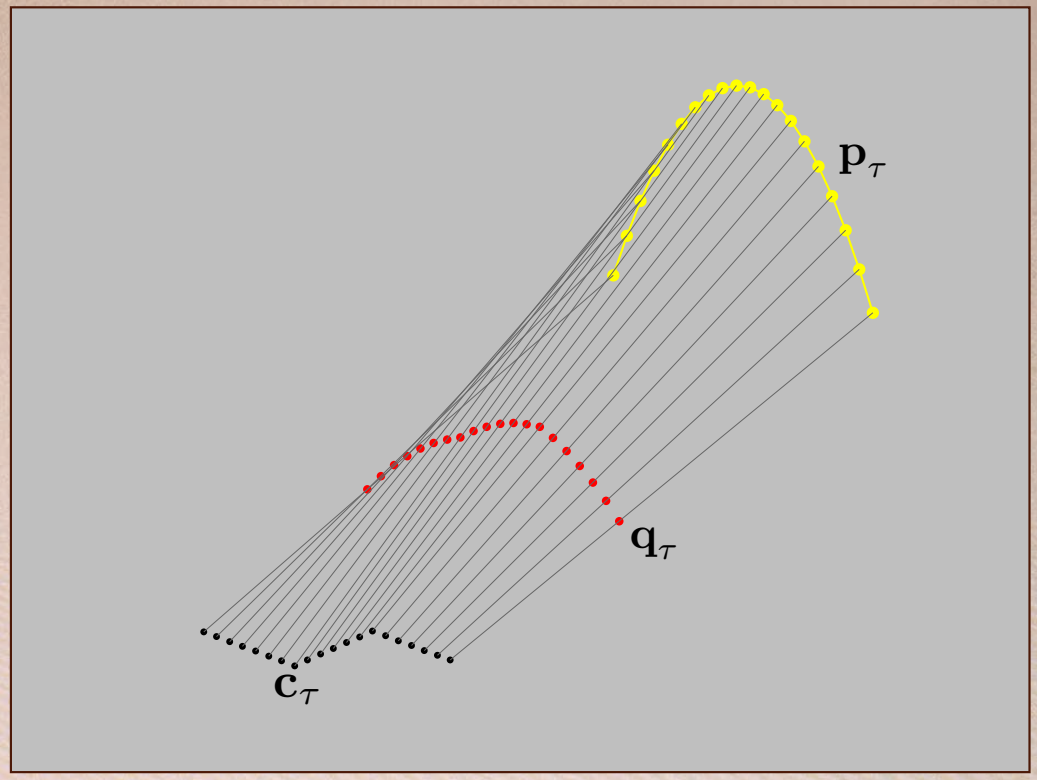
$$\mathbf{p}_\tau = \mathbf{p}_0 + \Delta t\,\tau\,\mathbf{v}_0 + \frac{1}{2}(\Delta t\,\tau)^2\mathbf{g}$$

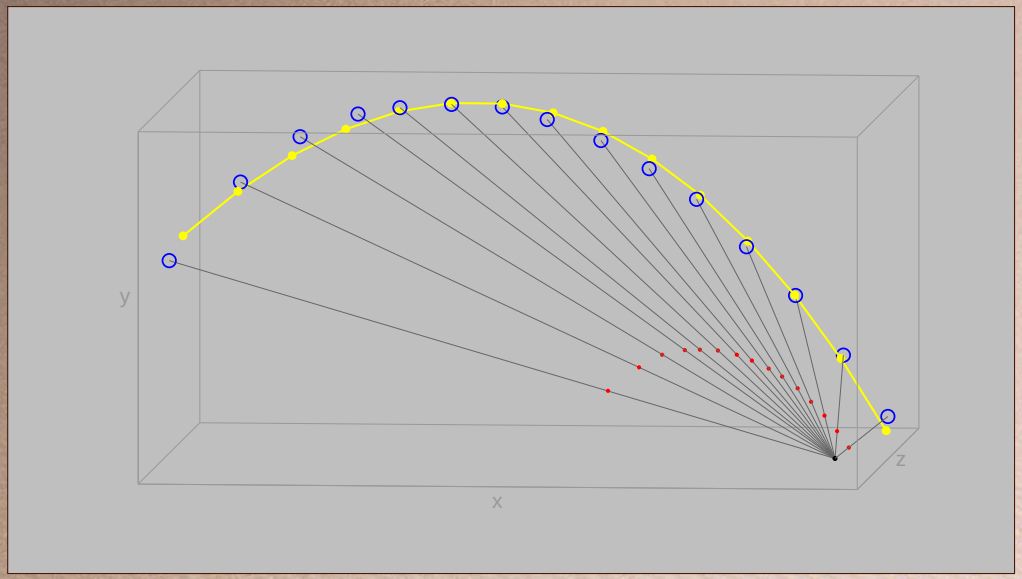
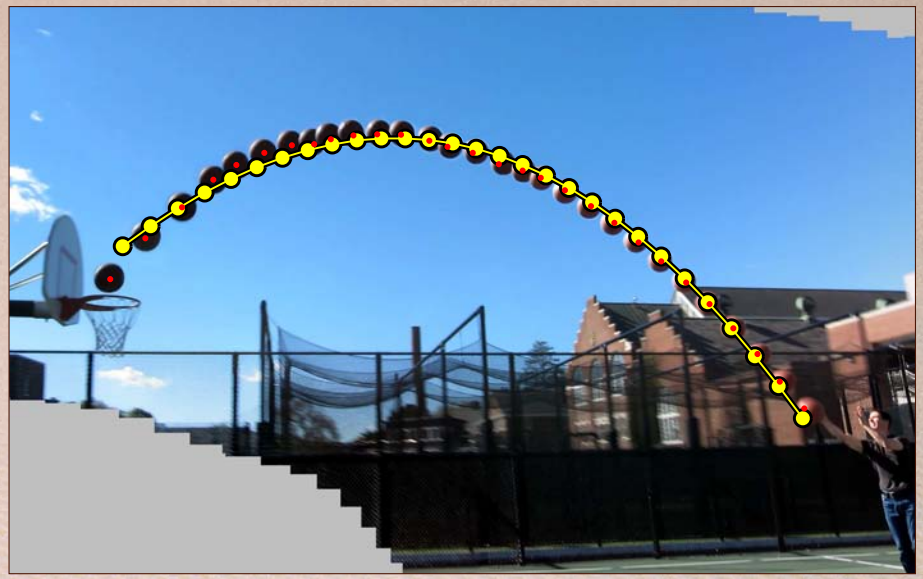
$$\mathbf{p}_\tau = \mathbf{c} + \alpha_\tau(\mathbf{q}_\tau - \mathbf{c})$$

$$\tau \in 1..n$$

Solve for: α_τ $\mathbf{v}_0$ $\mathbf{g}$

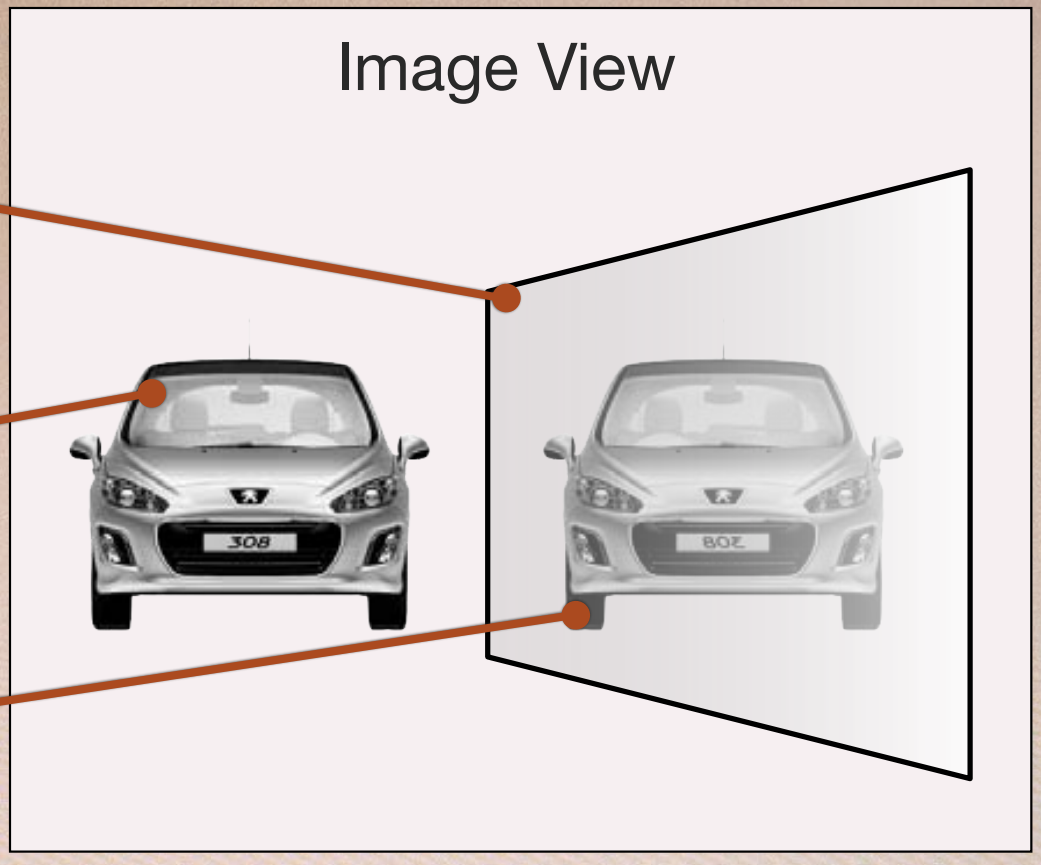
Track camera motion




y
x
z


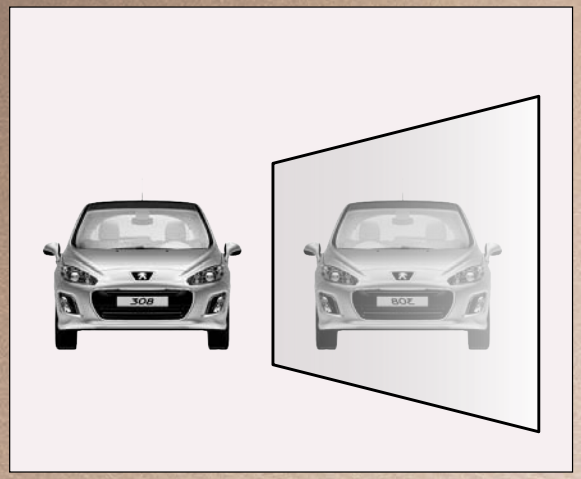
Basic Mirror Geometry

Linear perspective image

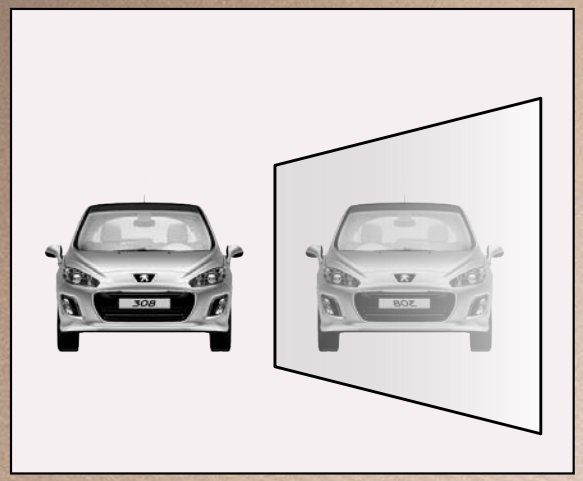


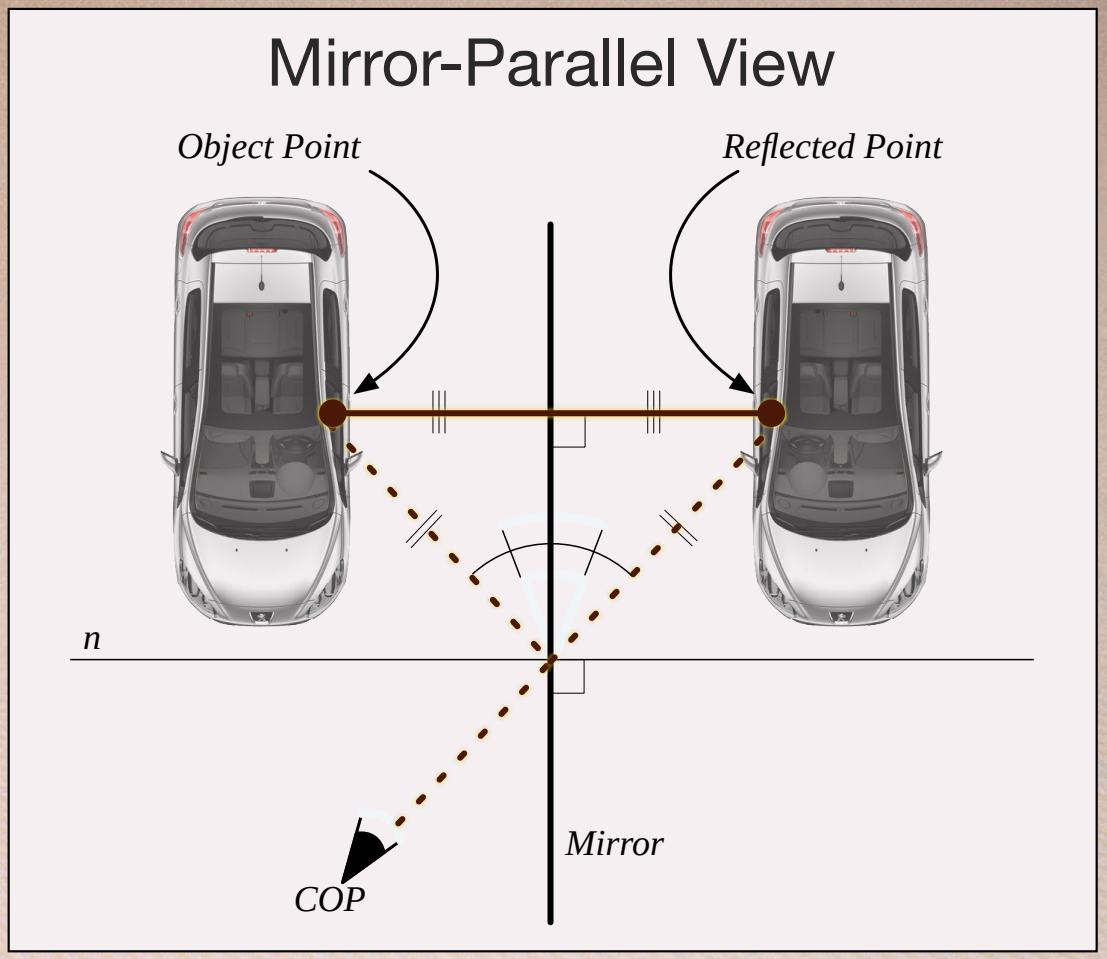
Basic Mirror Geometry

Basic Mirror Geometry

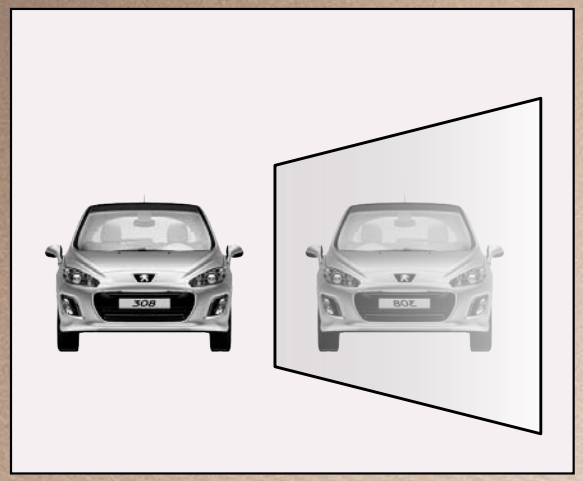


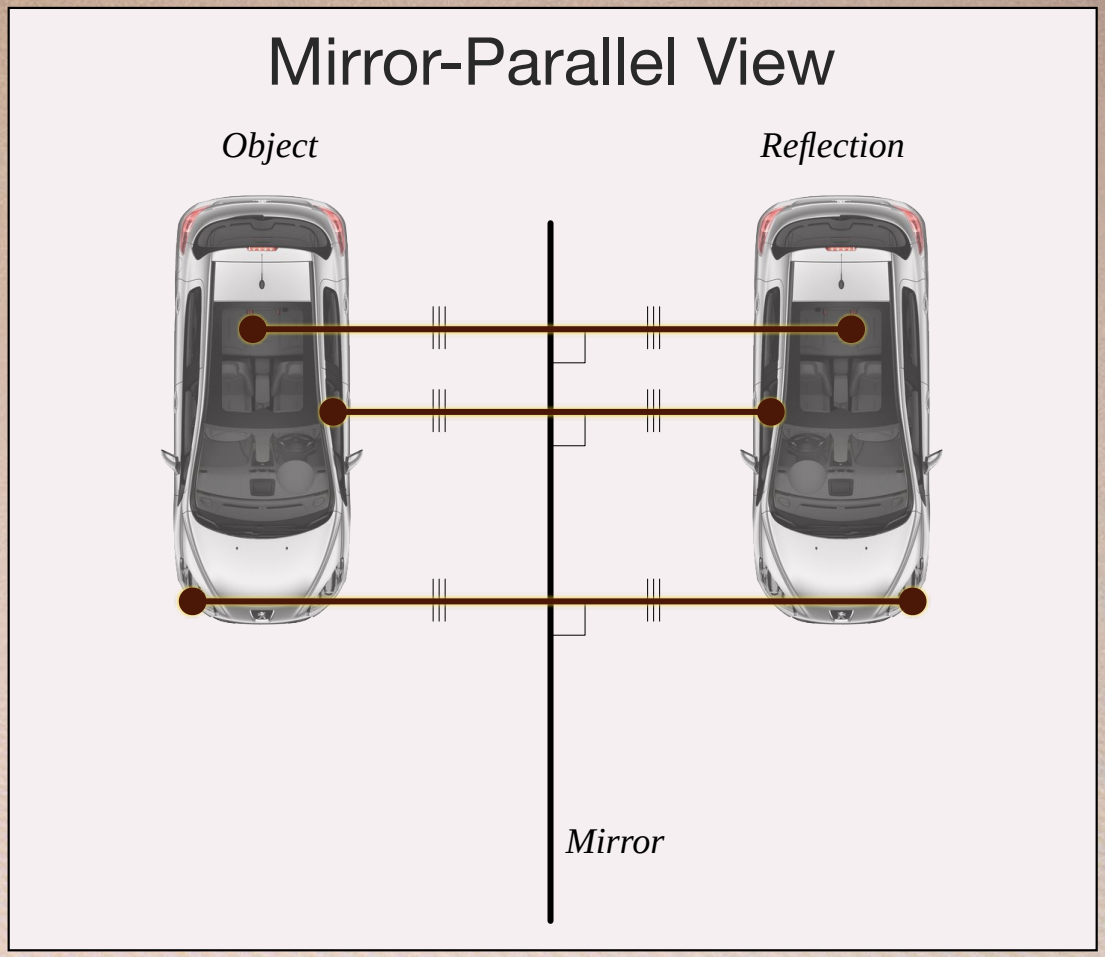
Basic Mirror Geometry





Basic Mirror Geometry



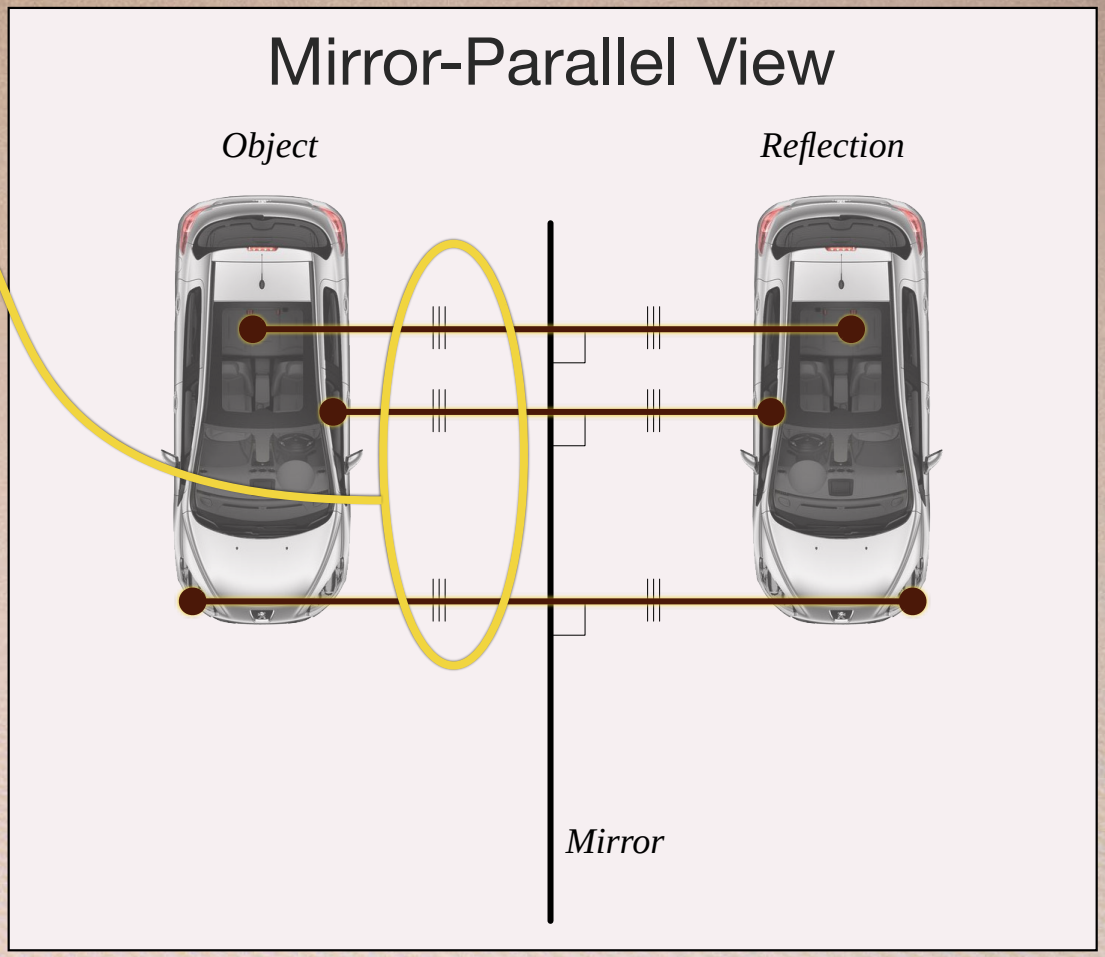


Basic Mirror Geometry

Bundle of parallel lines

In original image they must converge to a common vanishing point.

(Possibly at infinity)

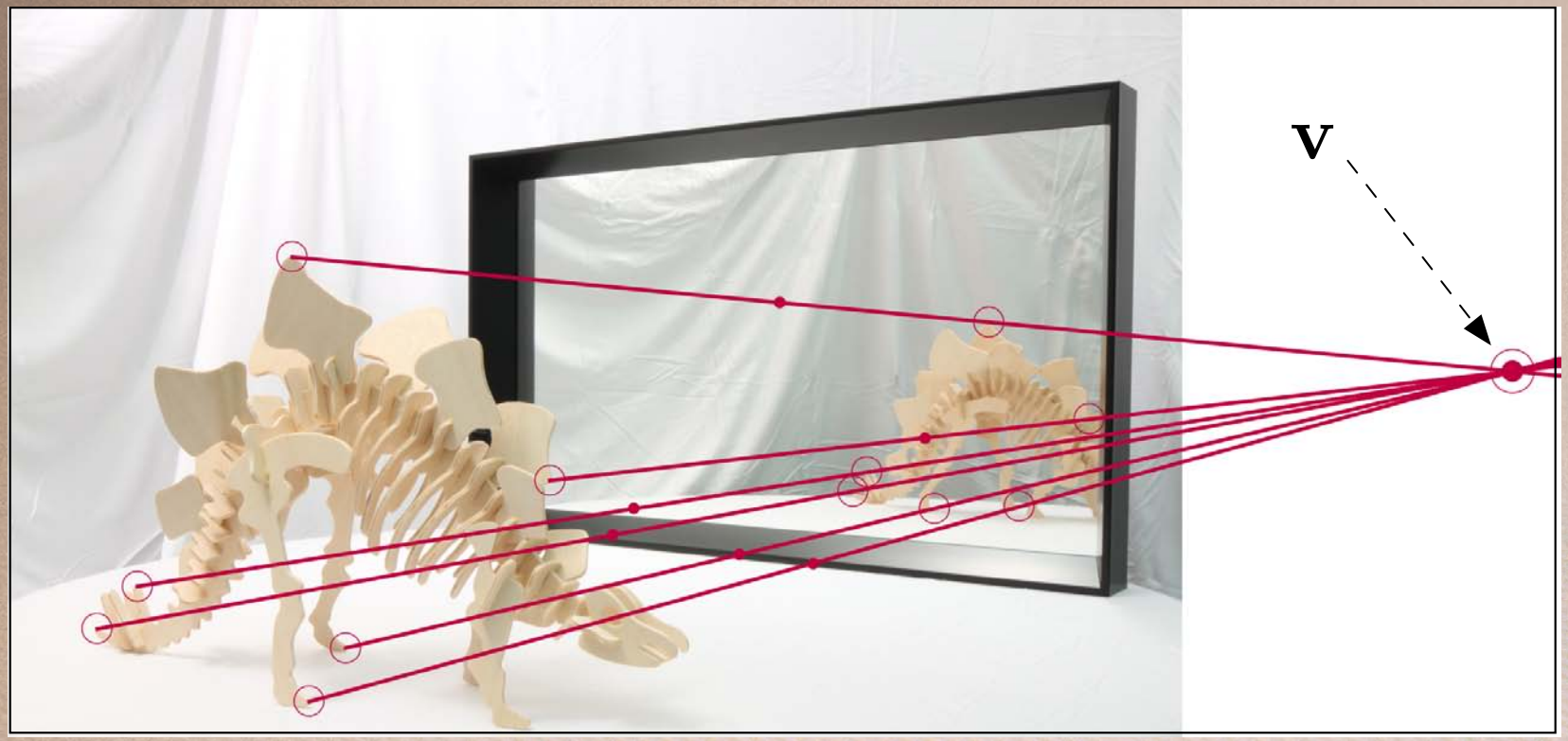


Reflection Vanishing Point

Real Photograph

Reflection Vanishing Point

Real Photograph

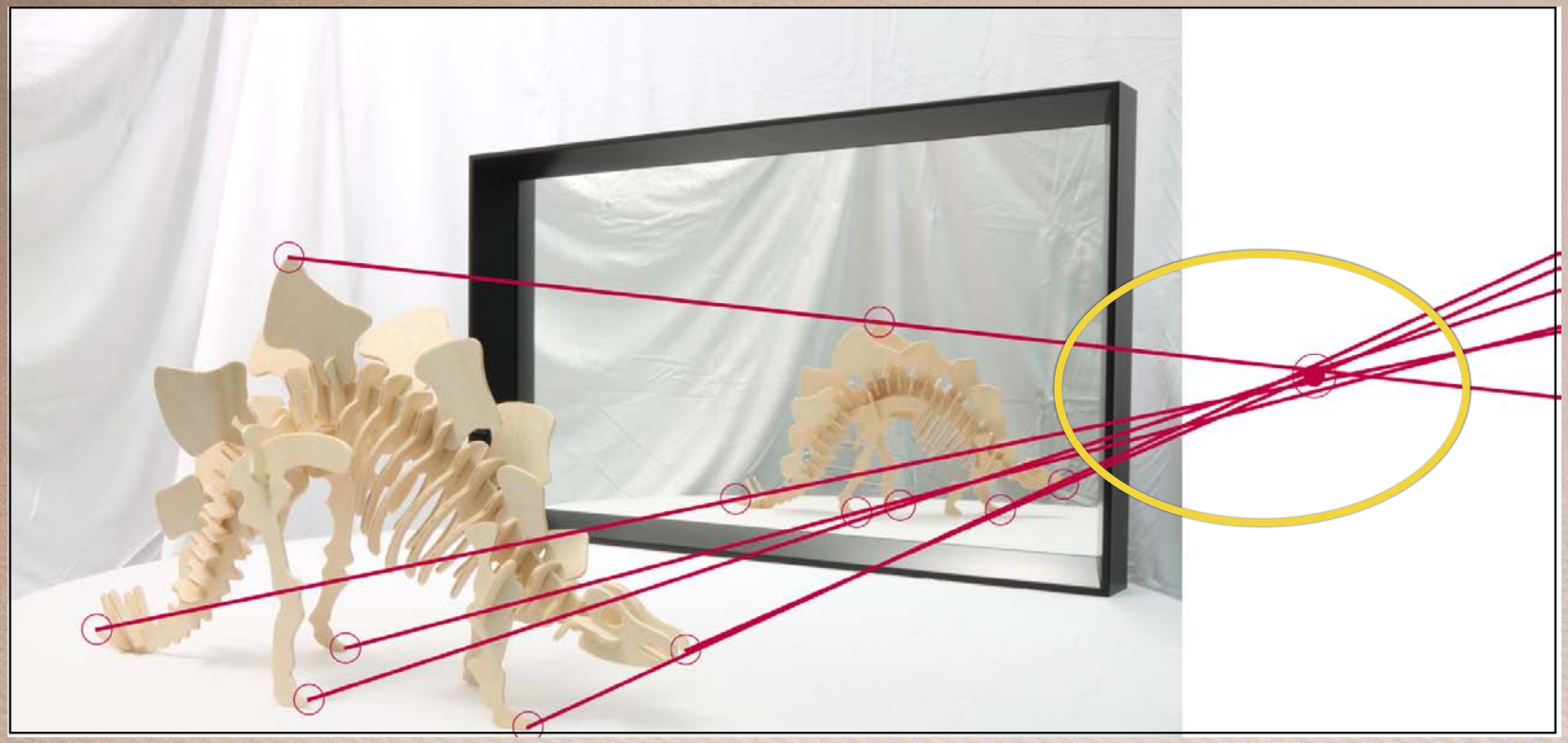


Reflection Vanishing Point

Altered Photograph

Reflection Vanishing Point

Altered Photograph

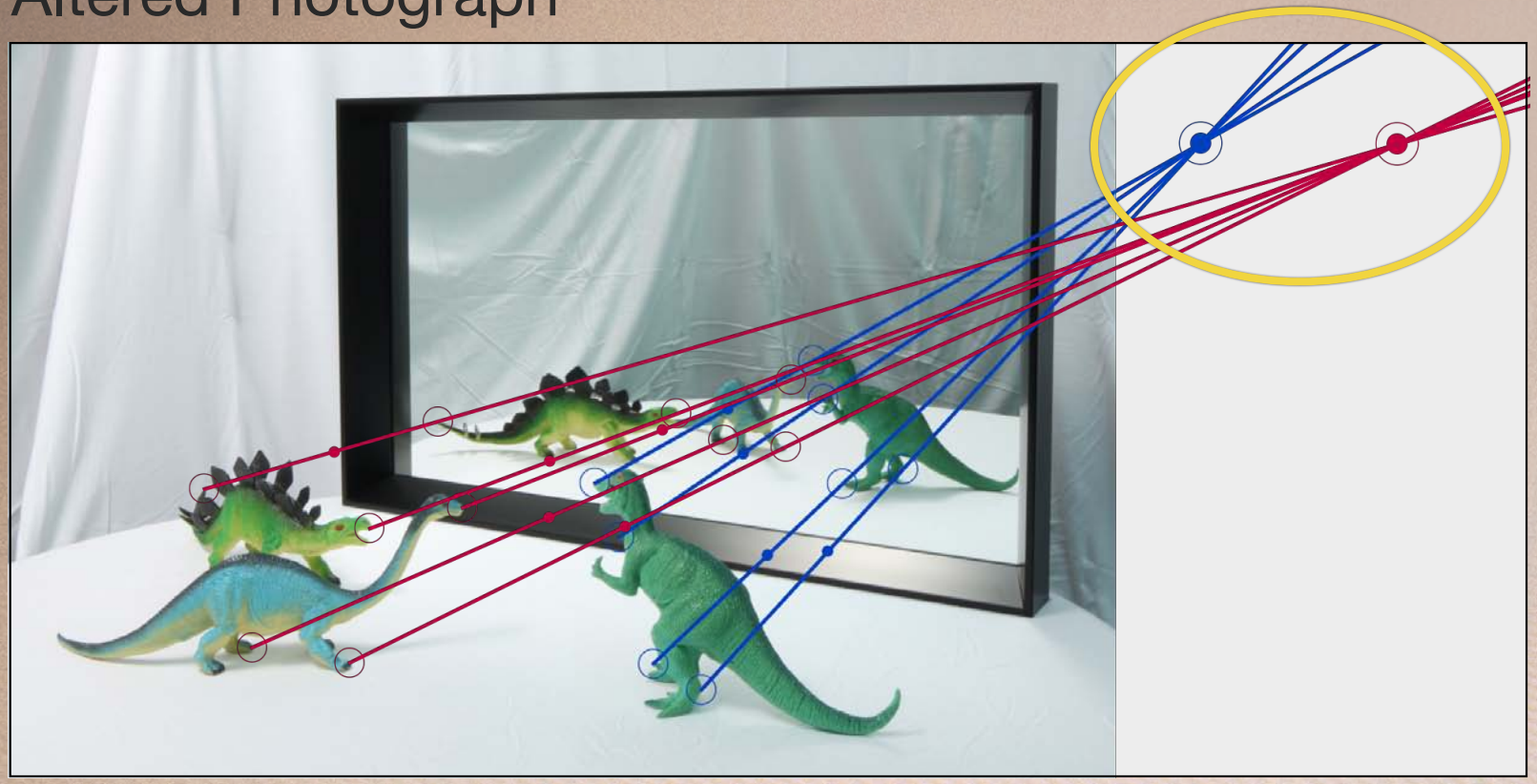


Reflection Vanishing Point

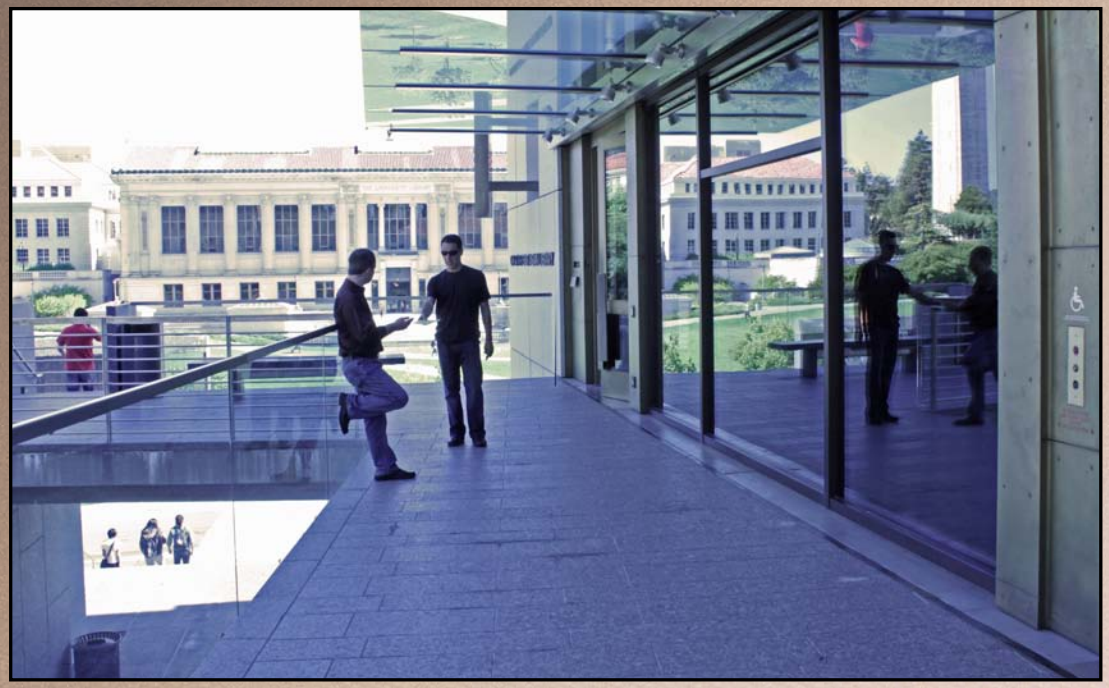
Altered Photograph

Reflection Vanishing Point

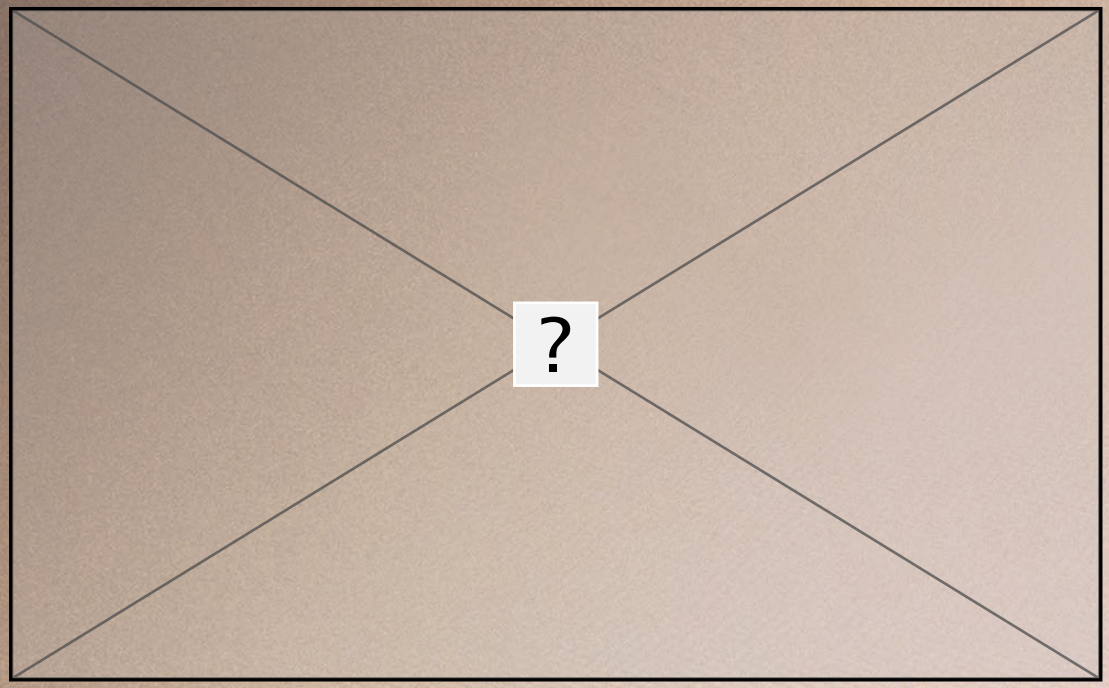
Altered Photograph

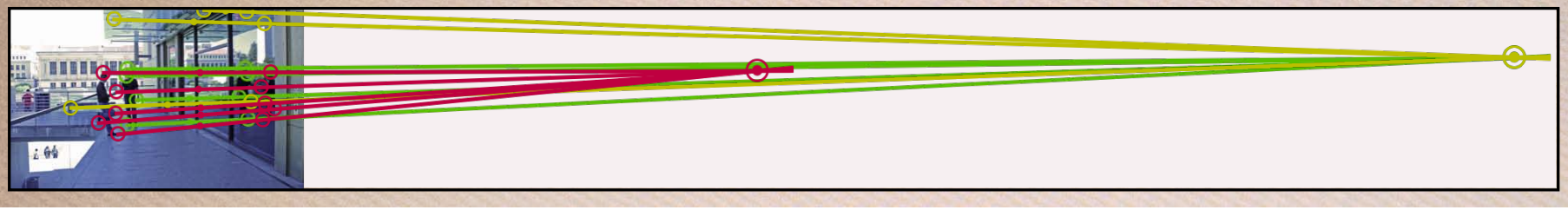


Examples

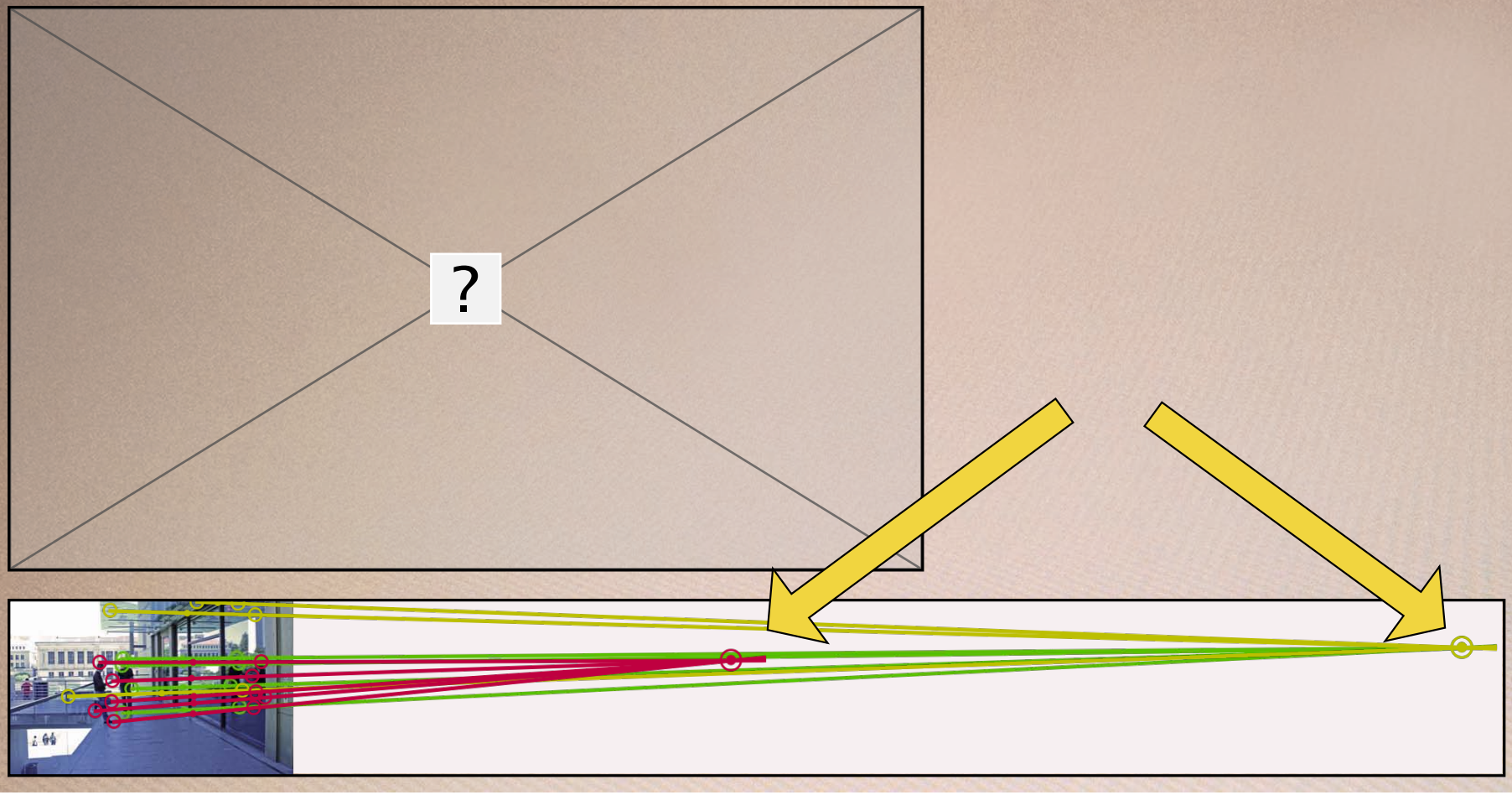


Examples





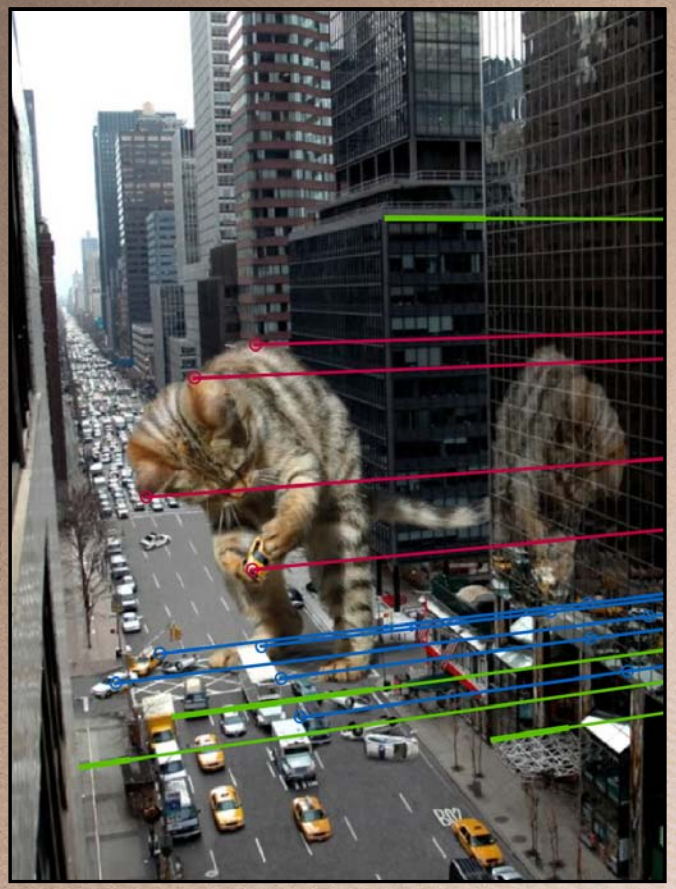
Examples



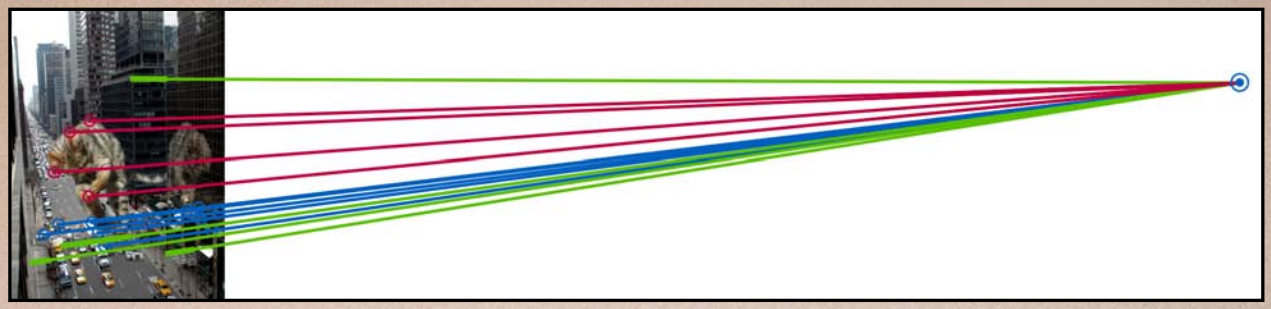
Examples

Composite photo World News, copyright 2006.

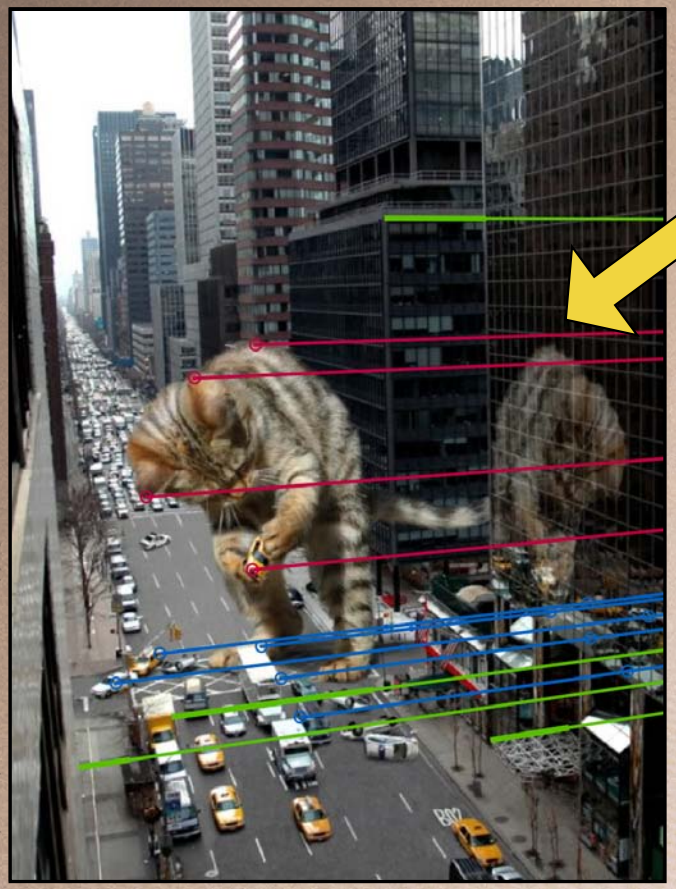
Examples



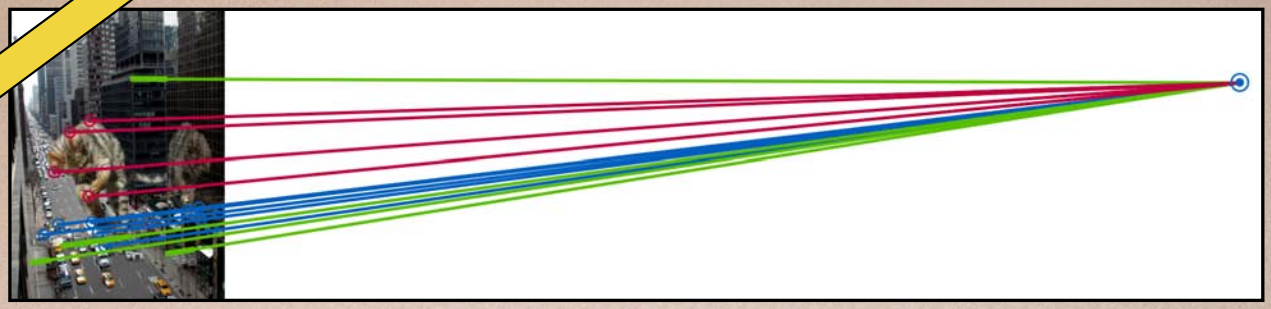
Composite photo World News, copyright 2006.



Examples



Composite photo World News, copyright 2006.



Examples

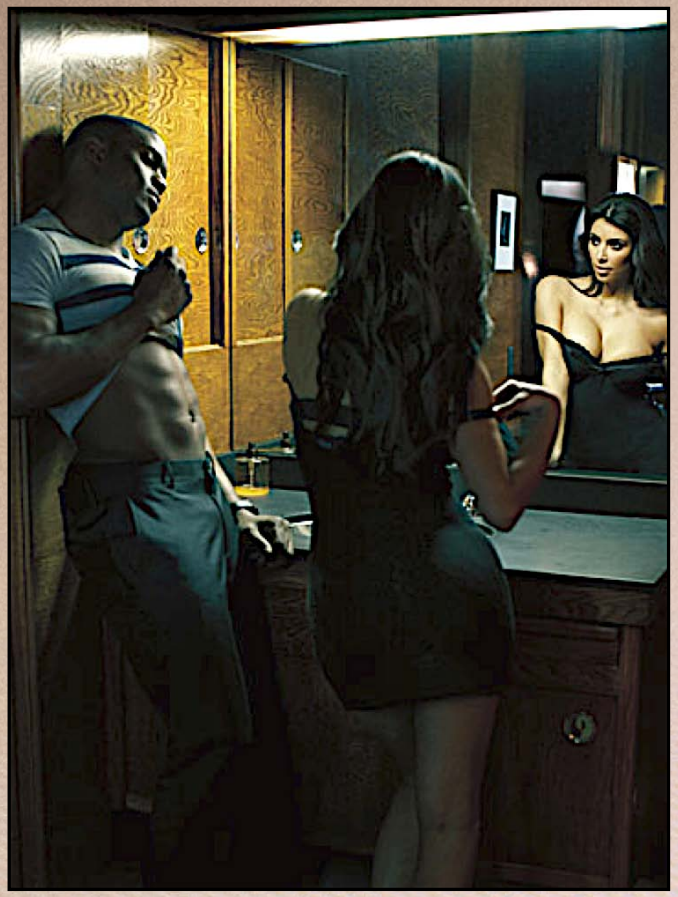


Photo by Alexi Lubomirski, "The Saint and the Sinner," copyright 2009.

Examples

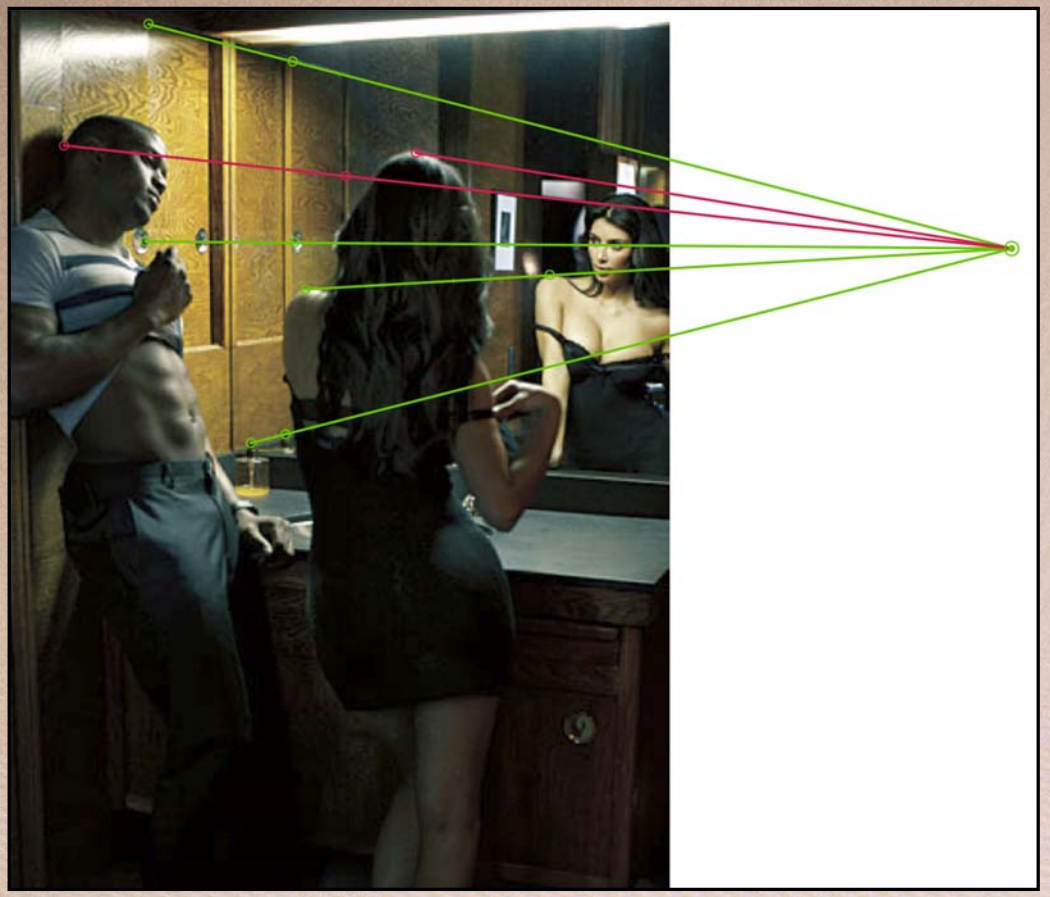


Photo by Alexi Lubomirski, "The Saint and the Sinner," copyright 2009.

Examples

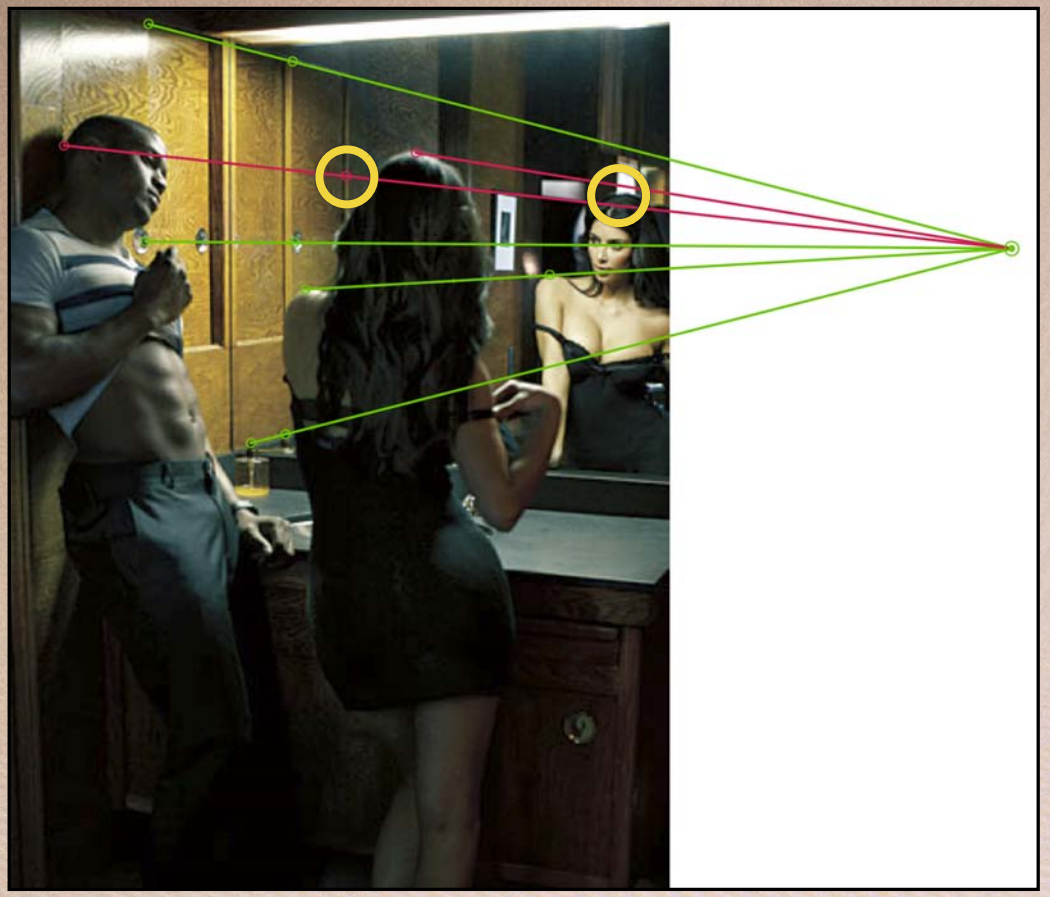
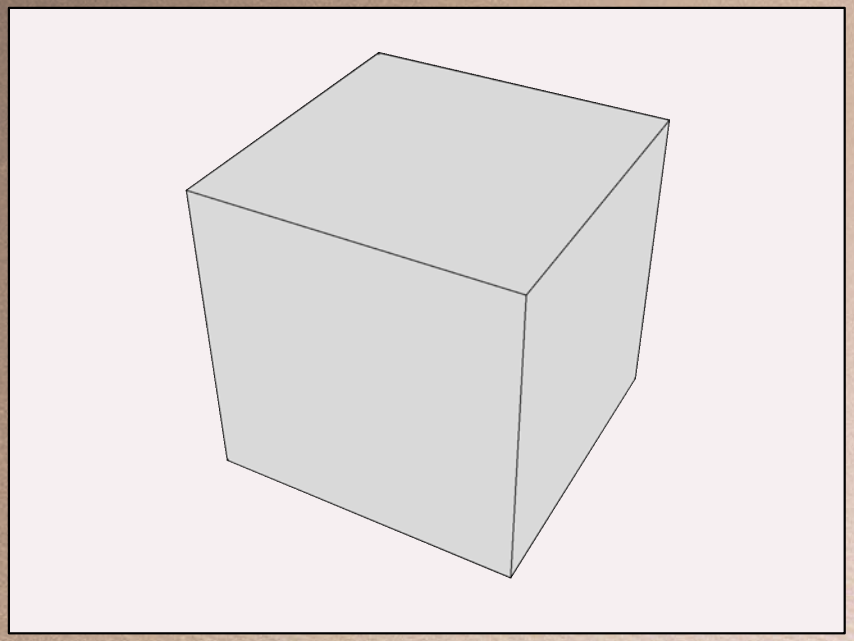


Photo by Alexi Lubomirski, "The Saint and the Sinner," copyright 2009.

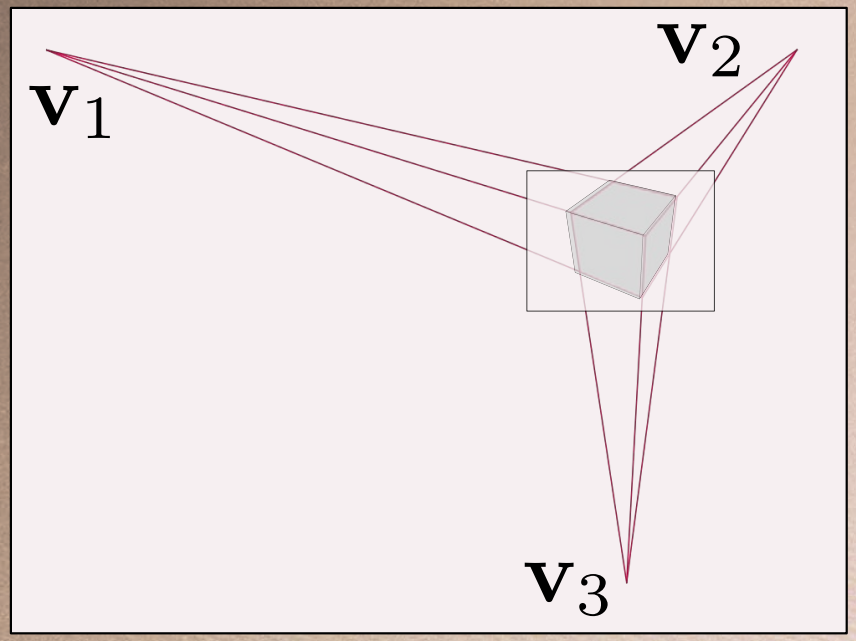
Center of Projection

- COP determined by 3 orthogonal vanishing points



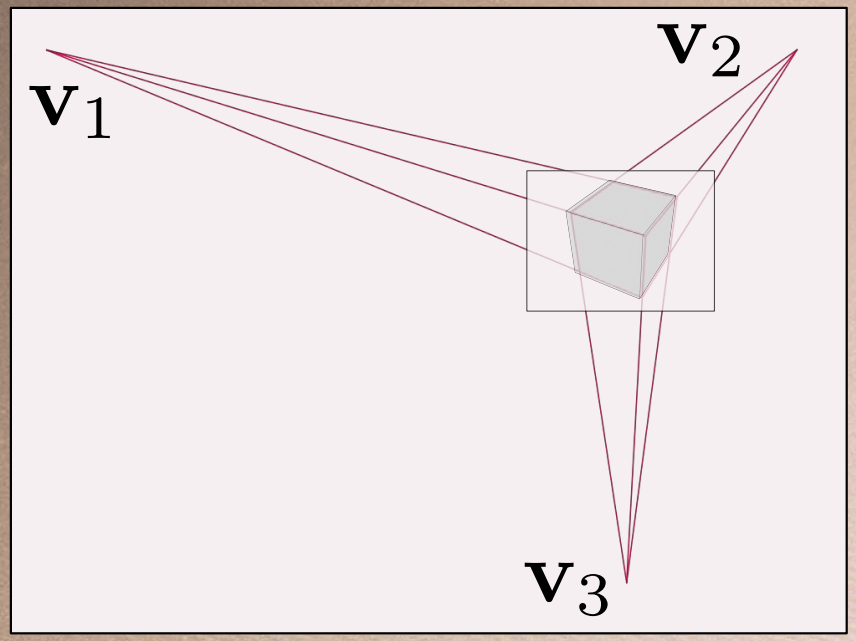
Center of Projection

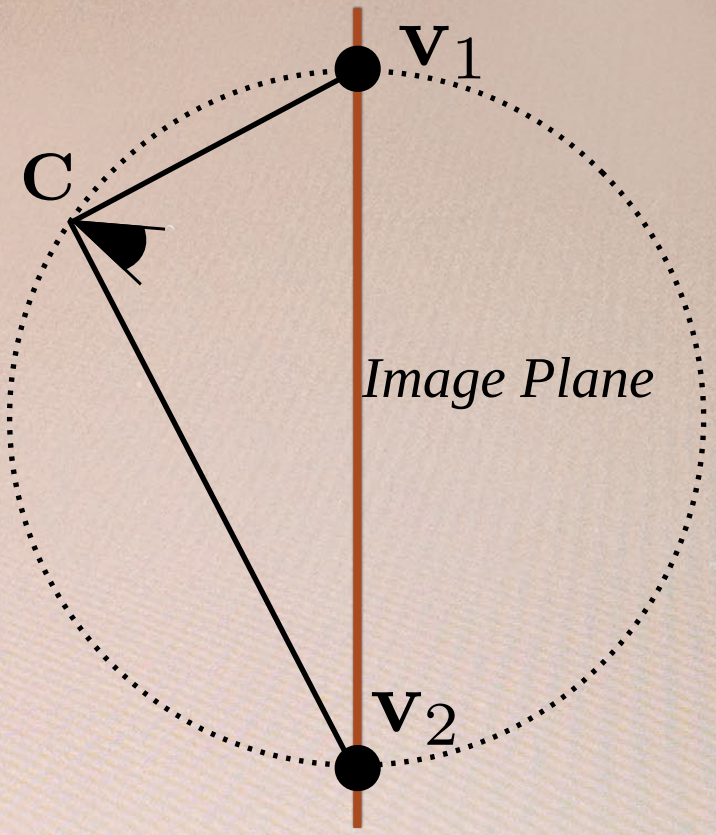
- COP determined by 3 orthogonal vanishing points



Center of Projection

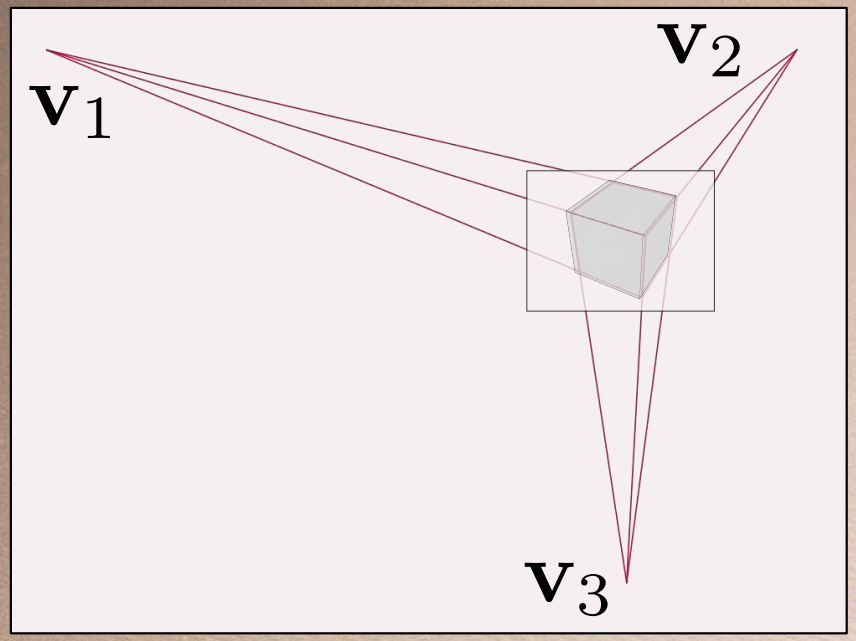
- COP determined by 3 orthogonal vanishing points

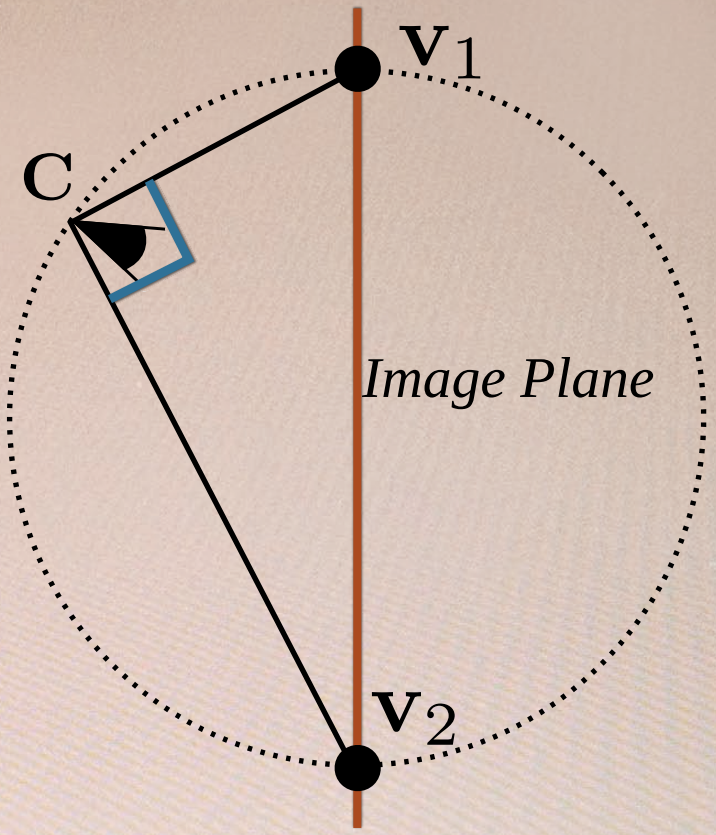




Center of Projection

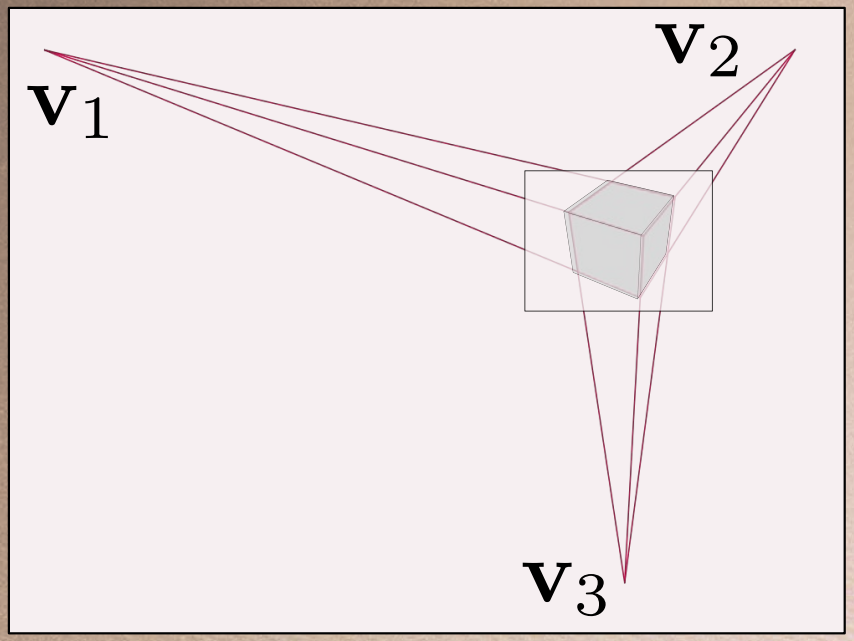
- COP determined by 3 orthogonal vanishing points

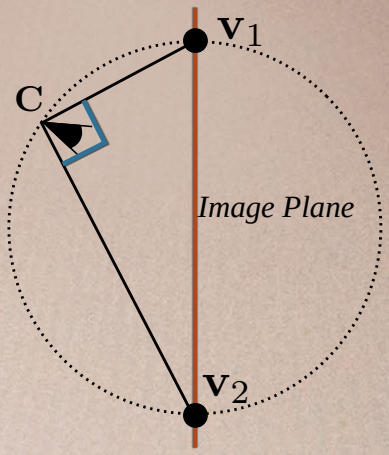




Center of Projection

- COP determined by 3 orthogonal vanishing points

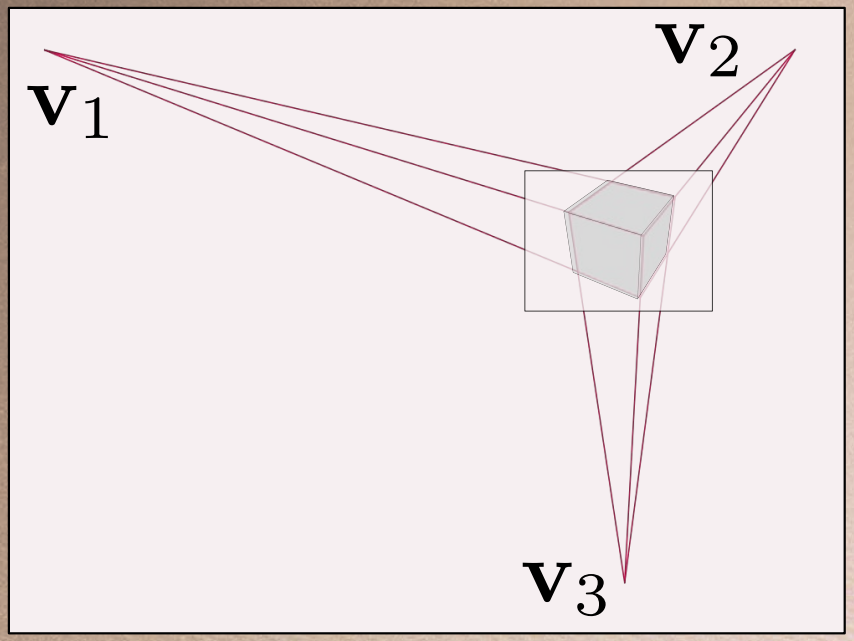


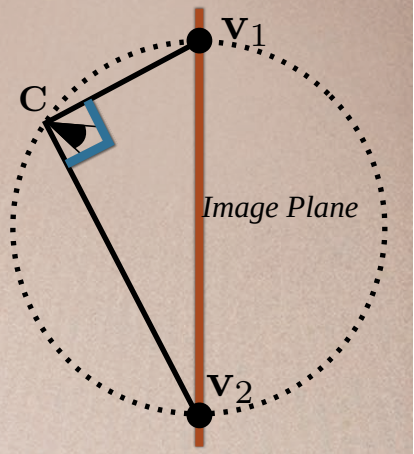


$$(\mathbf{C} - \mathbf{v}_1) \cdot (\mathbf{C} - \mathbf{v}_2) = 0$$

Center of Projection

- COP determined by 3 orthogonal vanishing points

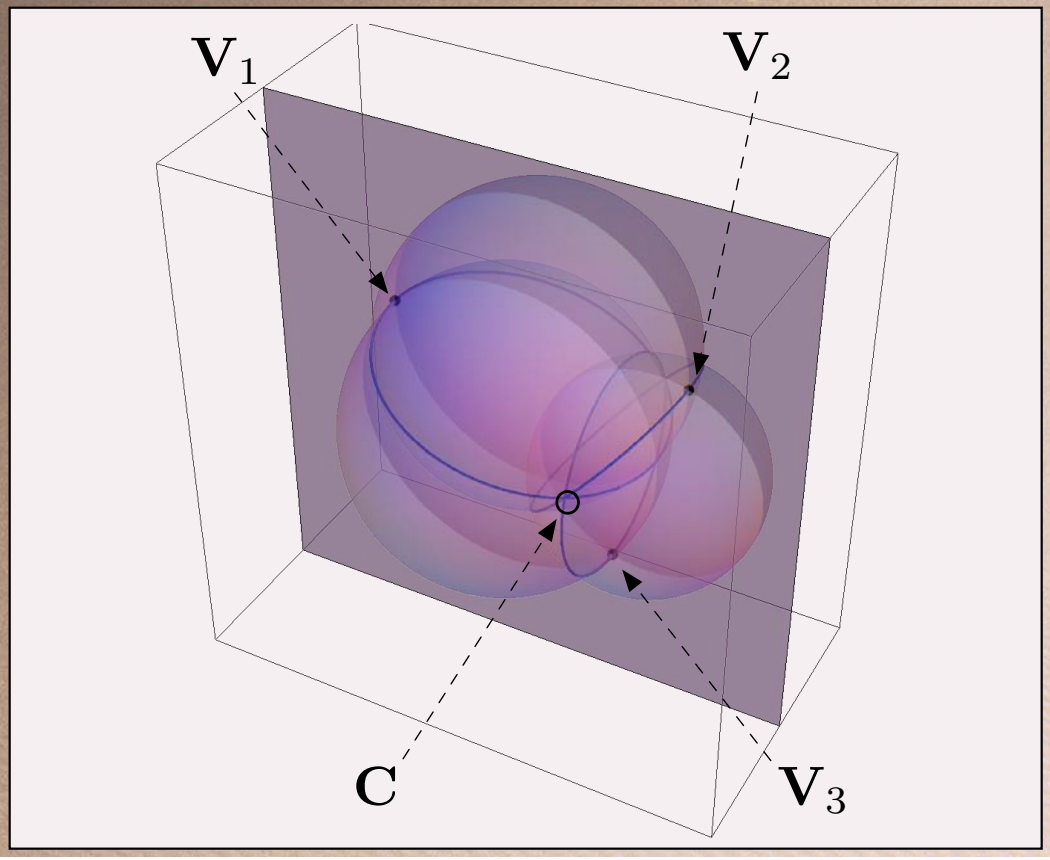


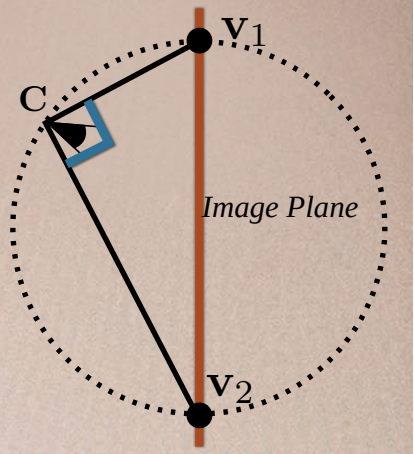


$$(\mathbf{C} - \mathbf{V}_1) \cdot (\mathbf{C} - \mathbf{V}_2) = 0$$
$$(\mathbf{C} - \mathbf{V}_2) \cdot (\mathbf{C} - \mathbf{V}_3) = 0$$
$$(\mathbf{C} - \mathbf{V}_3) \cdot (\mathbf{C} - \mathbf{V}_1) = 0$$

Center of Projection

- COP determined by 3 orthogonal vanishing points





$$(\mathbf{C} - \mathbf{V}_1) \cdot (\mathbf{C} - \mathbf{V}_2) = 0$$
$$(\mathbf{C} - \mathbf{V}_2) \cdot (\mathbf{C} - \mathbf{V}_3) = 0$$
$$(\mathbf{C} - \mathbf{V}_3) \cdot (\mathbf{C} - \mathbf{V}_1) = 0$$

Center of Projection

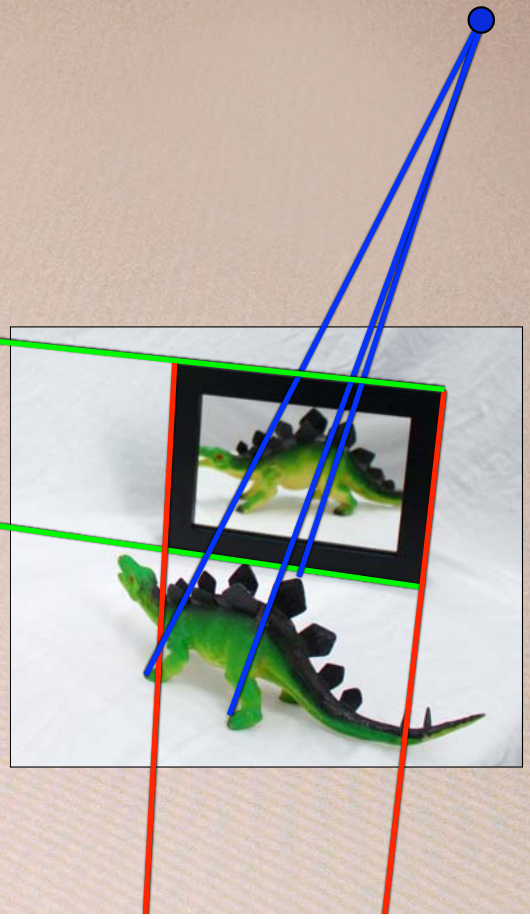
- COP determined by 3 orthogonal vanishing points
- System of quadratic equations

$$(\mathbf{C} - \mathbf{V}_1) \cdot (\mathbf{C} - \mathbf{V}_2) = 0$$
$$(\mathbf{C} - \mathbf{V}_2) \cdot (\mathbf{C} - \mathbf{V}_3) = 0$$
$$(\mathbf{C} - \mathbf{V}_3) \cdot (\mathbf{C} - \mathbf{V}_1) = 0$$

- Easy to solve by change of variables

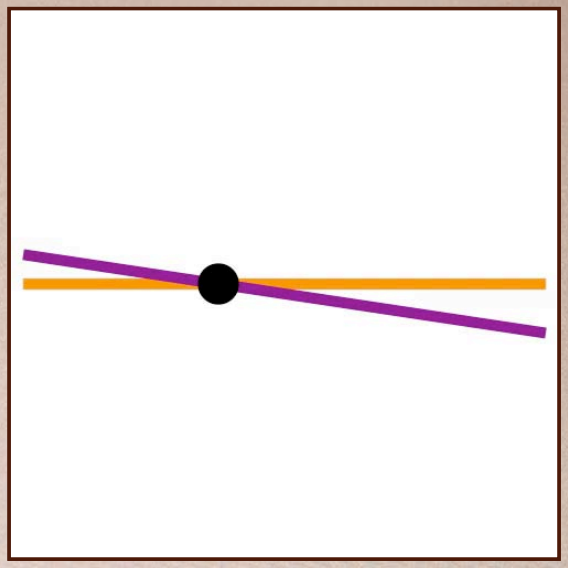
Center of Projection

- Building and other structures
- Reflectors with rectangular frames
  - Frames: two orthogonal vanishing points
  - Reflected features: third vanishing point
- Compare COP from separate elements in the image



Center of Projection

- Computation is unstable
  - Step 1: intersect [nearly parallel] lines
  - Step 2: intersect spheres



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  - Step 1: intersect [nearly parallel] lines
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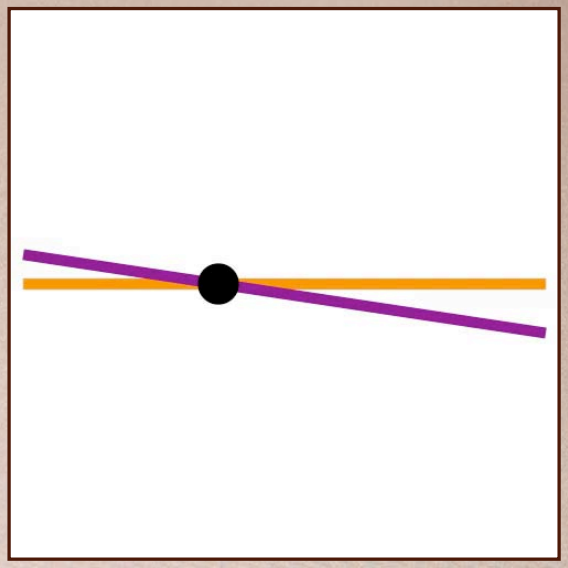

Center of Projection

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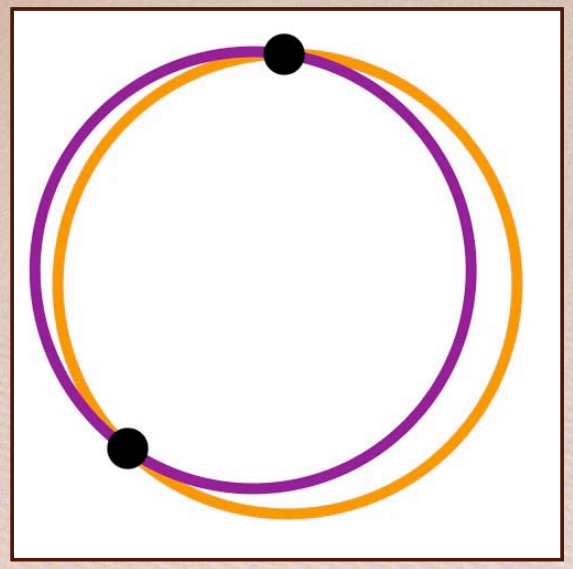
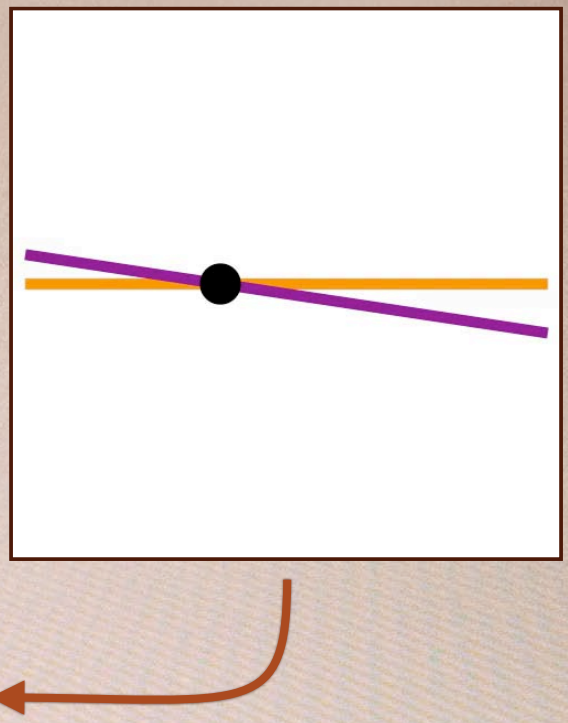
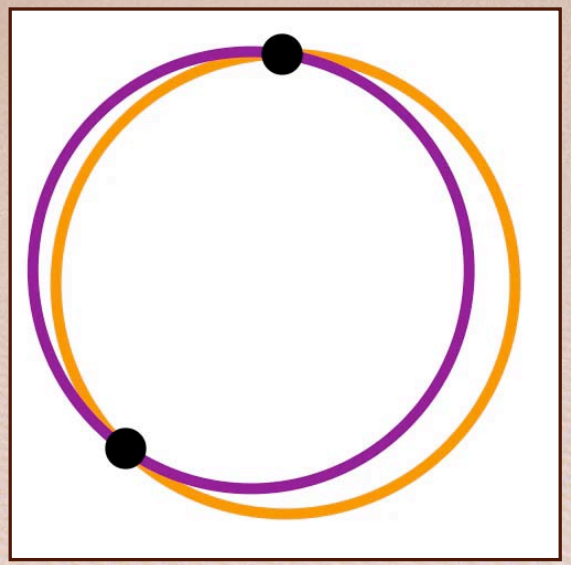
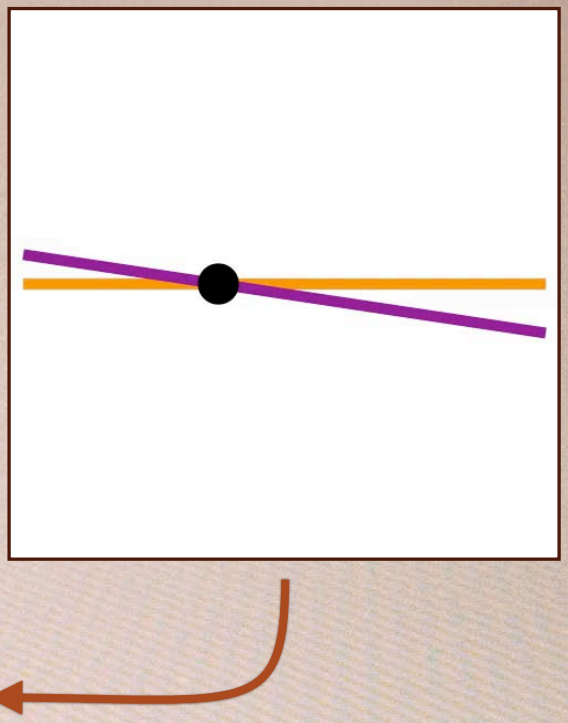




Center of Projection

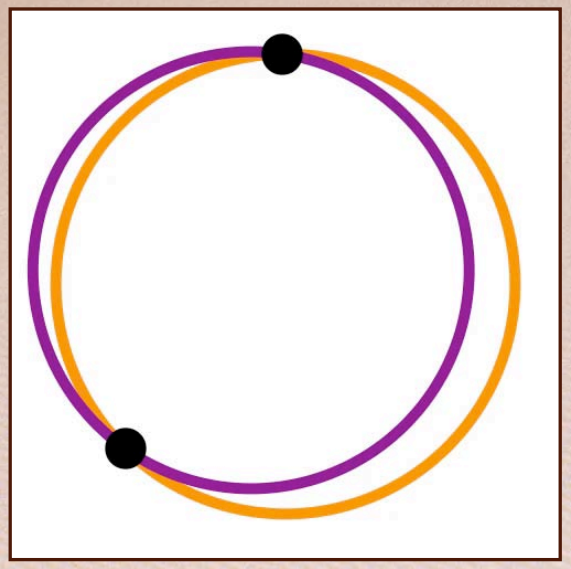
- Computation is unstable
  - Step 1: intersect [nearly parallel] lines
  - Step 2: intersect spheres

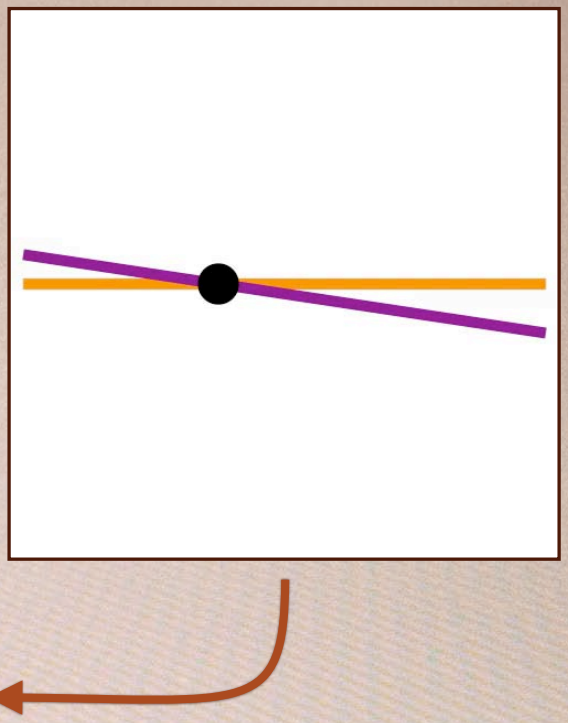




Center of Projection

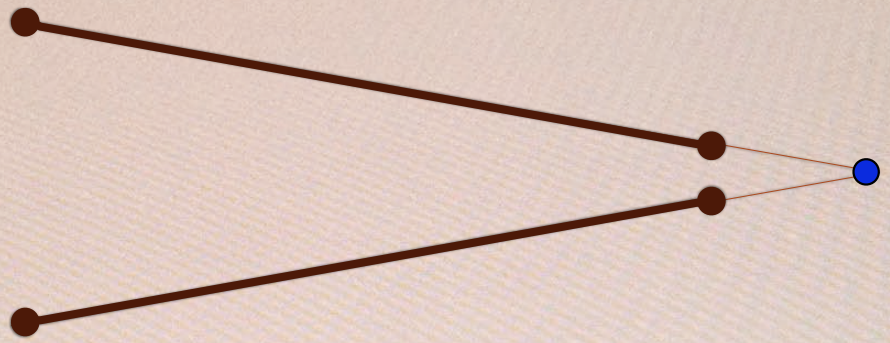
- Computation is unstable
  - Step 1: intersect [nearly parallel] lines
  - Step 2: intersect spheres
- "Instability squared"





Center of Projection

- Error sources:
  - Image resolution
  - User pointing accuracy
  - Features from different perspectives
- COP calculation magnifies error
  - Structure in instability



Center of Projection

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  - Image resolution
  - User pointing accuracy
  - Features from different perspectives
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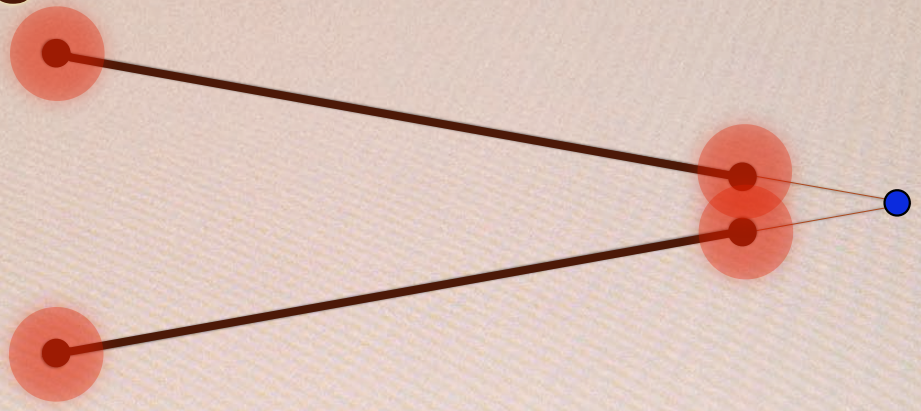
  - Structure in instability

Specify regions, not points



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  - Image resolution
  - User pointing accuracy
  - Features from different perspectives
- COP calculation magnifies error
  - Structure in instability

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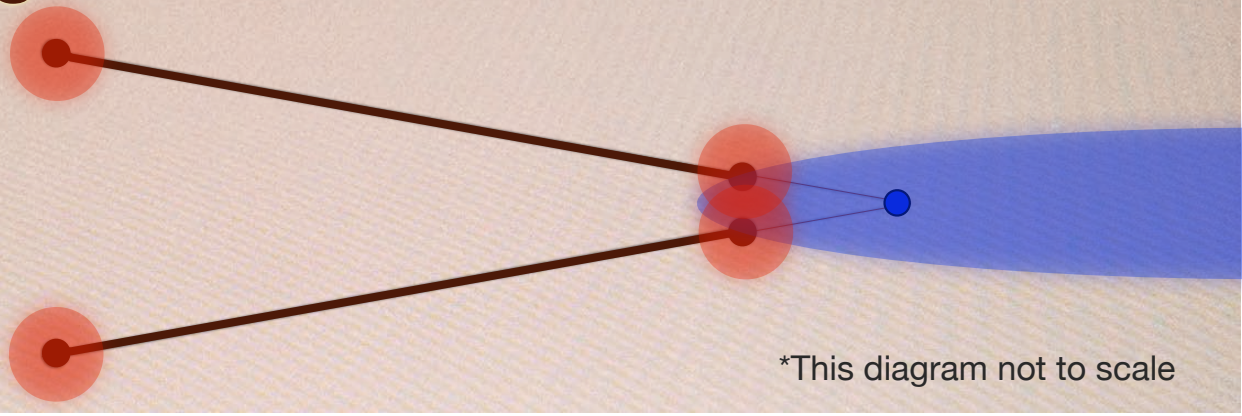


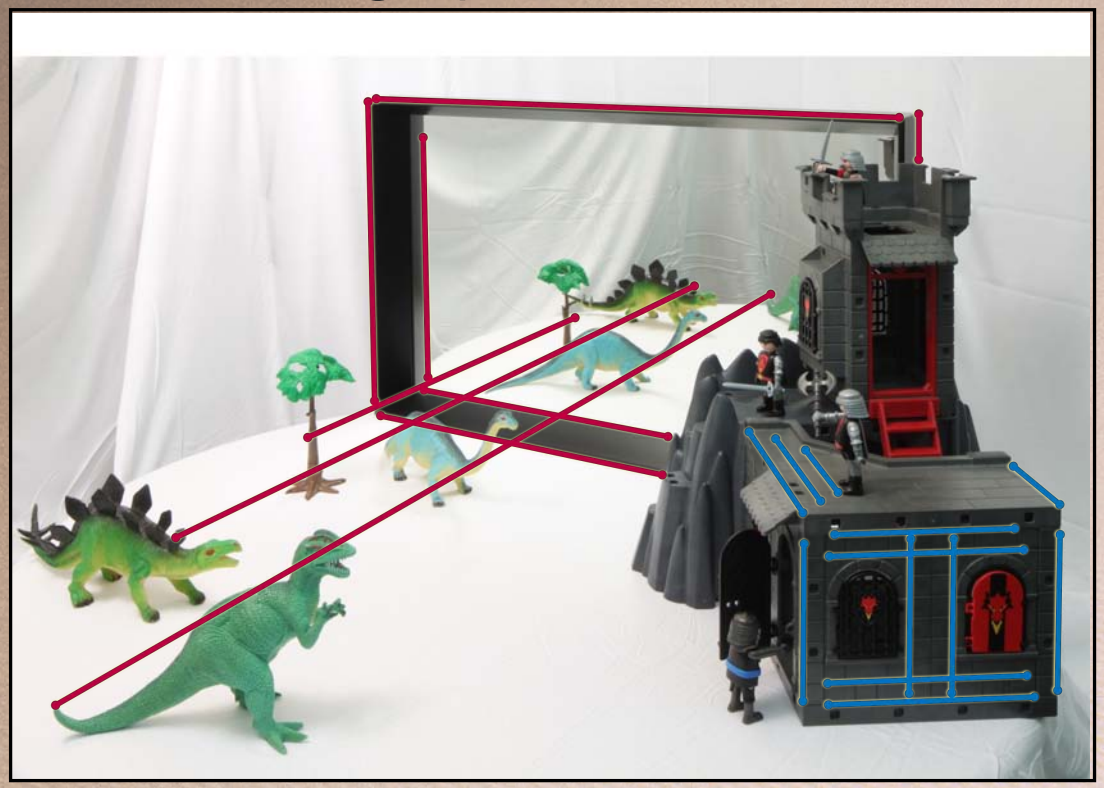
*This diagram not to scale

Center of Projection

Real Photograph

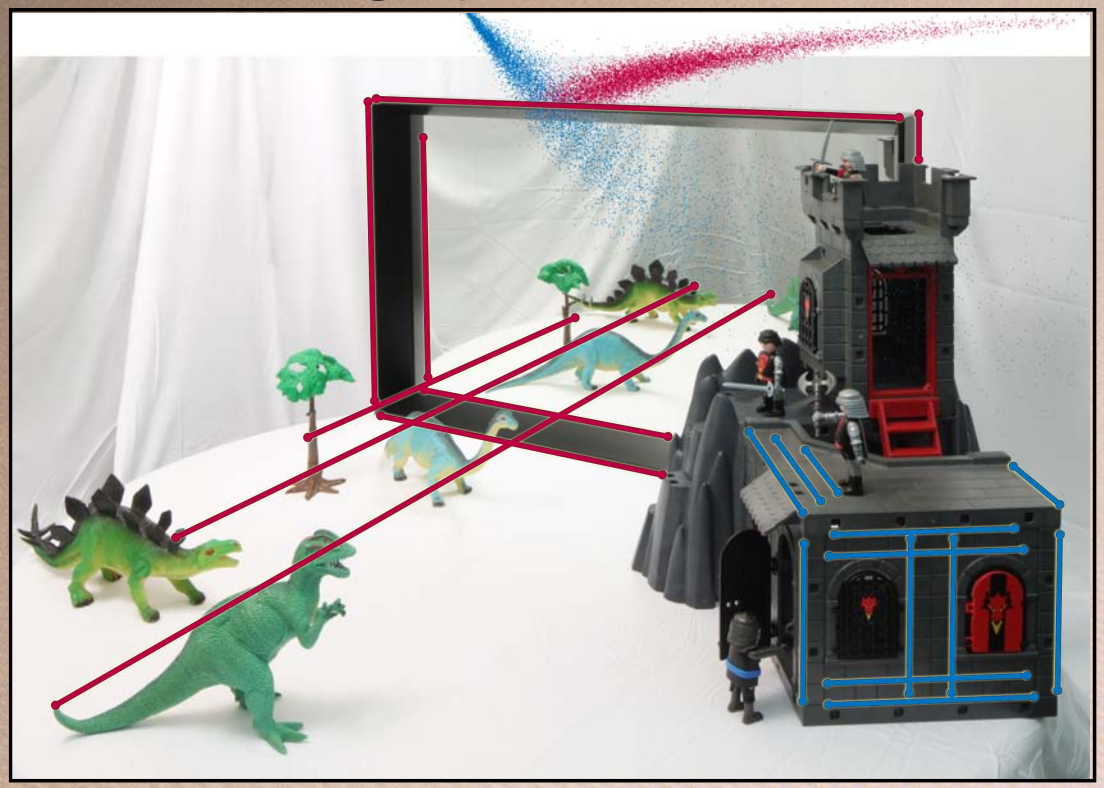
Center of Projection

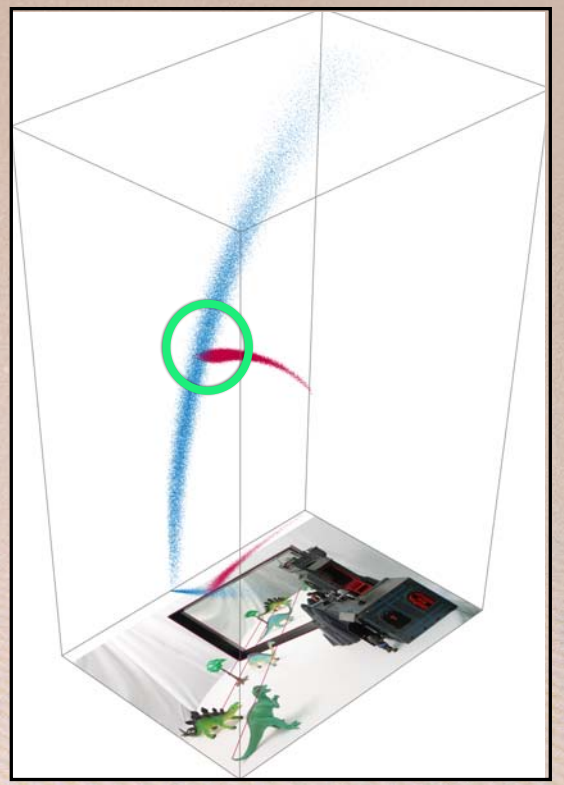
Real Photograph



Center of Projection

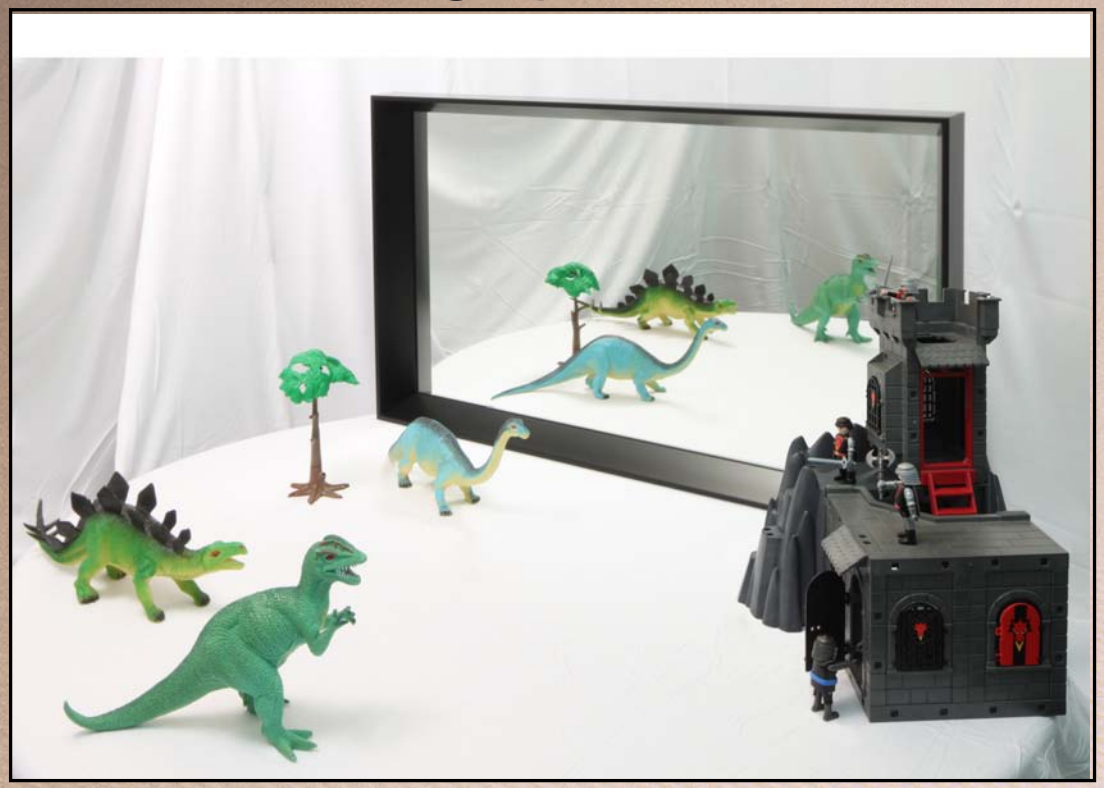
Real Photograph





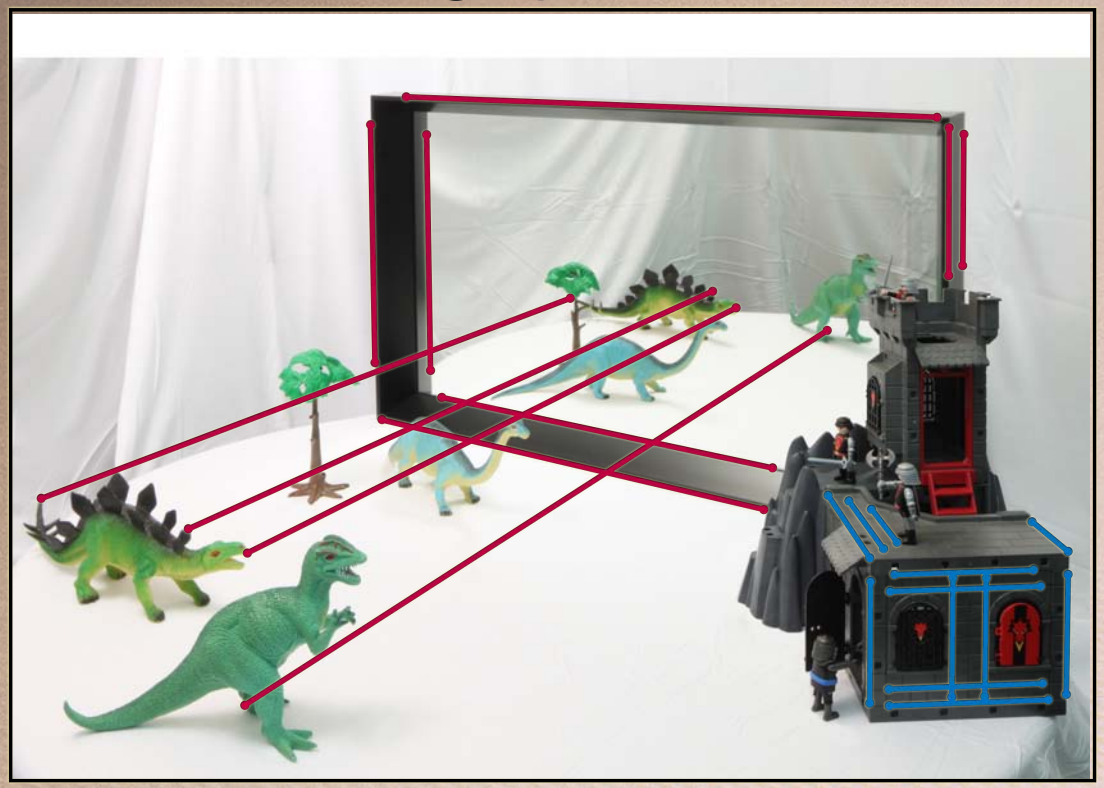
Center of Projection

Altered Photograph



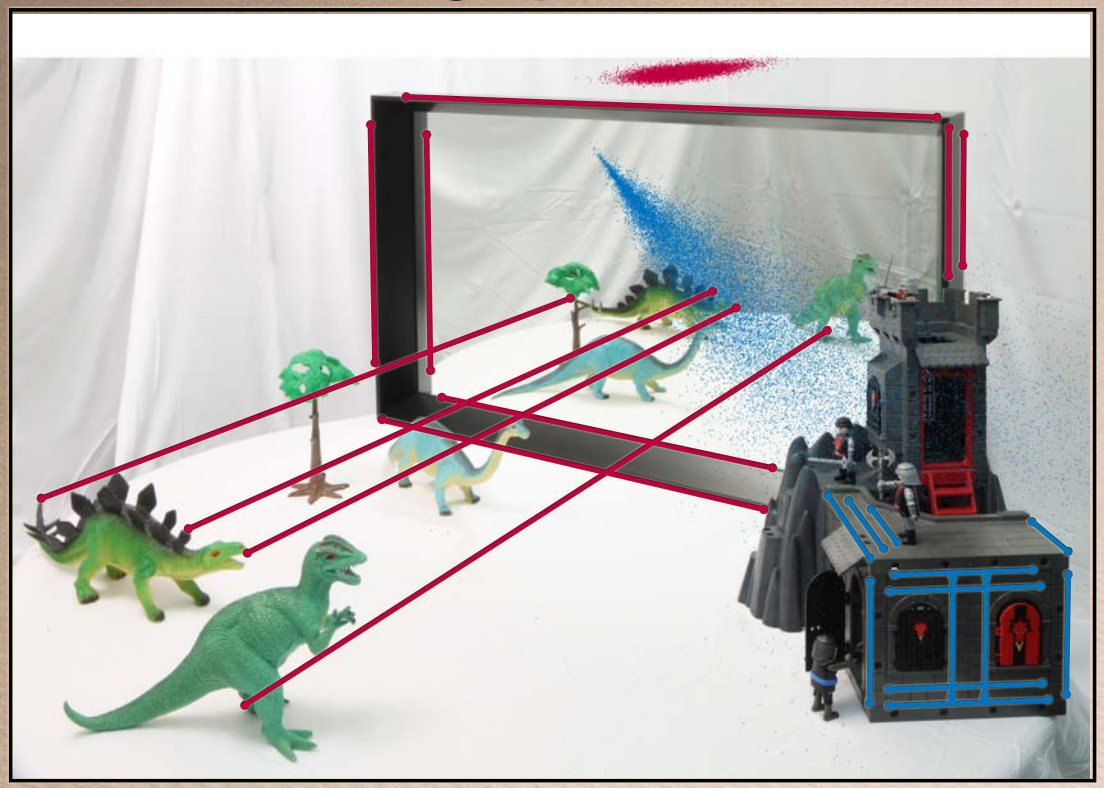
Center of Projection

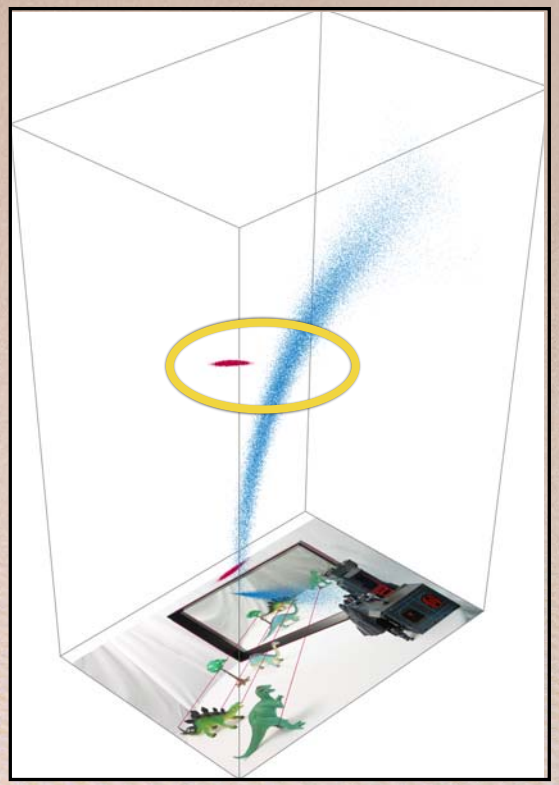
Altered Photograph



Center of Projection

Altered Photograph





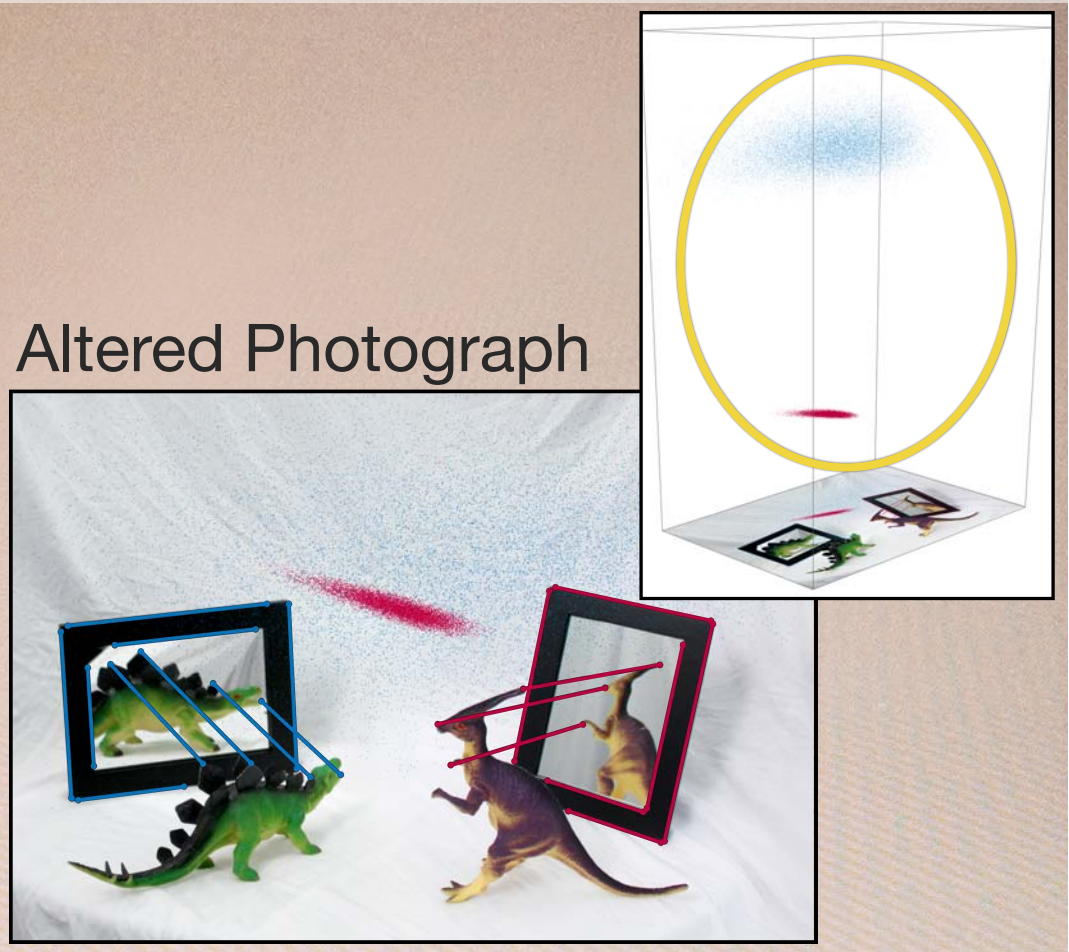
Center of Projection

Center of Projection

Center of Projection

Real Photograph

Altered Photograph



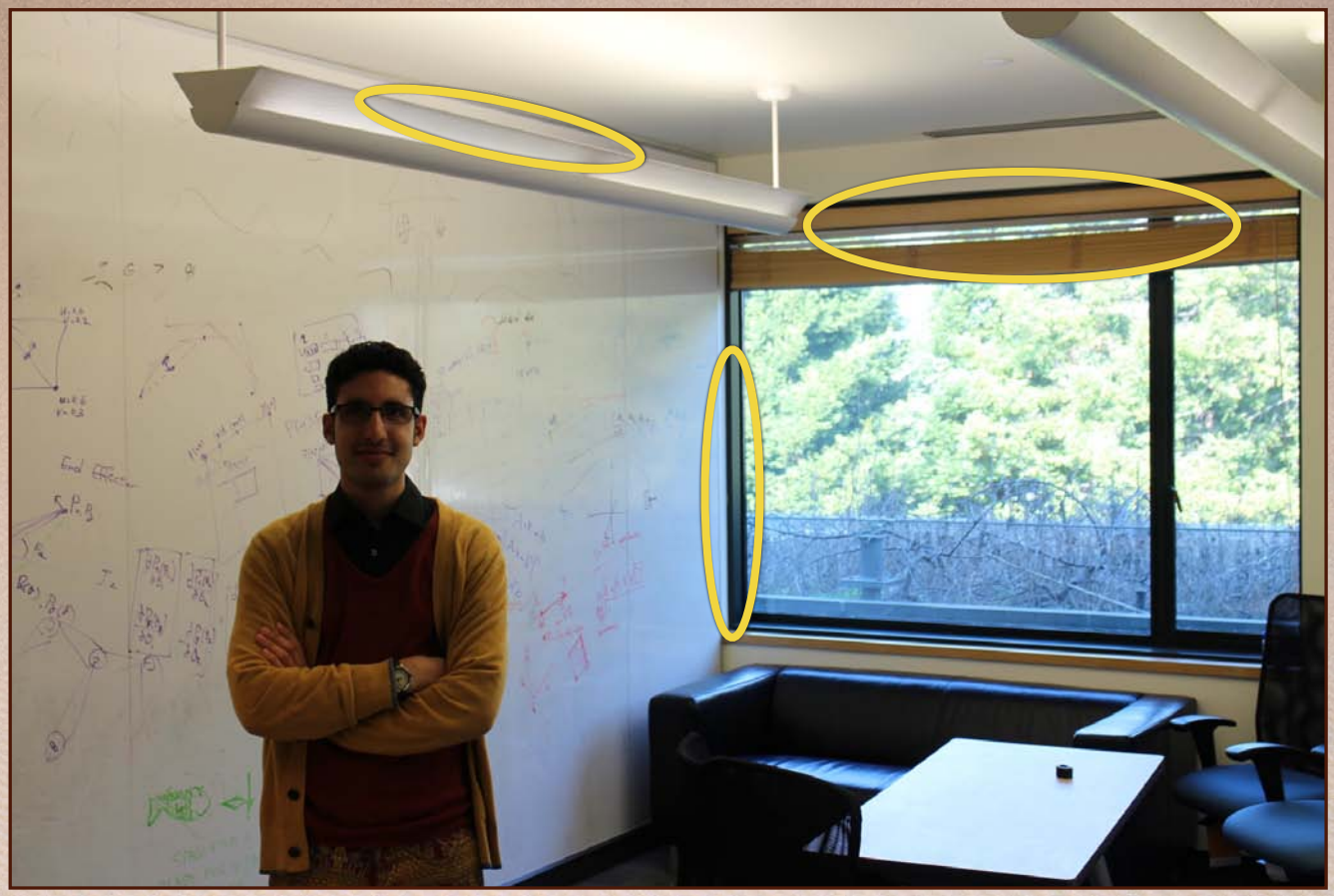
CoP from Faces

Work in progress

CoP from Faces

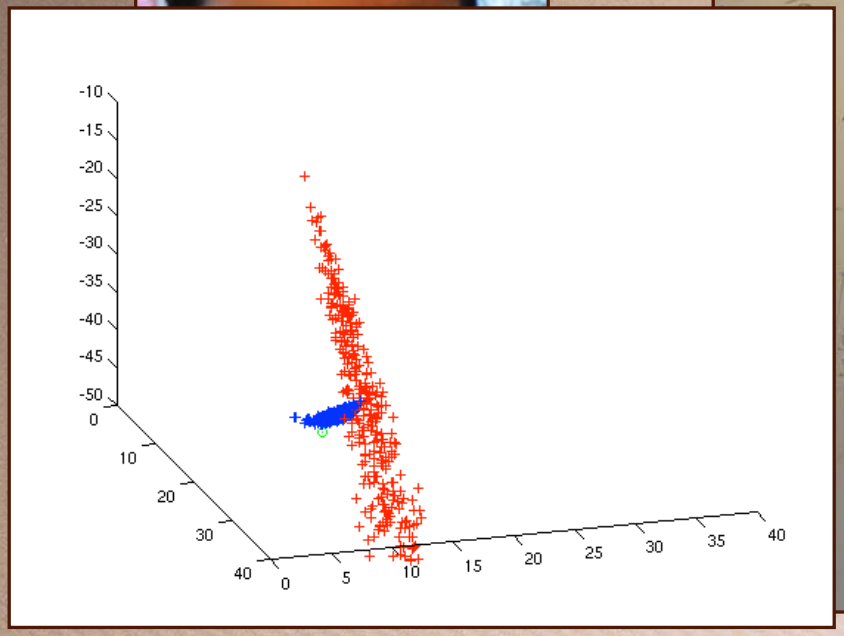
Work in progress

CoP from Faces



Work in progress

CoP from Faces



Summary

- Geometric Image Forensics
  - Human annotation
  - Computer analysis
- Part of “analysis toolbox”
  - Not always applicable
  - Together make forgery more difficult
  - Constrain image content

Relevant Papers

- Eric Kee, James F. O'Brien, and Hany Farid. “Exposing Photo Manipulation from Shadows and Shading”. ACM Transactions on Graphics, too appear. Presented at SIGGRAPH 2014.
http://graphics.berkeley.edu/papers/Kee-EPM-2014-XX

- Eric Kee, James F. O'Brien, and Hany Farid. “Exposing Photo Manipulation with Inconsistent Shadows”. ACM Transactions on Graphics, 32(4):28:1–12, September 2013. Presented at SIGGRAPH 2013.
http://graphics.berkeley.edu/papers/Kee-EPM-2013-09

- Valentina Conotter, James F. O'Brien, and Hany Farid. “Exposing Digital Forgeries in Ballistic Motion”. IEEE Transactions on Information Forensics and Security, 7(1):283 – 296, February 2012.
http://graphics.berkeley.edu/papers/Conotter-EDF-2012-02

- James F. O'Brien and Hany Farid. “Exposing Photo Manipulation with Inconsistent Reflections”. ACM Transactions on Graphics, 31(1):4:1–11, January 2012. Presented at SIGGRAPH 2012.
http://graphics.berkeley.edu/papers/Obrien-EPM-2012-01

Thank You