Recipes for Optical Effect System Design

Real-time Rendering of Physically Based Optical Effect in Theory and Practice
SIGGRAPH 2015 Course

Masaki Kawase
Silicon Studio, Corp.
masa@siliconstudio.co.jp

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  - NOT Based on Optics
  - Based on Optics but NOT based on Photography
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- Optical Animation
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  - Maximum Aperture Varying
- Handling “Law of Reciprocity” in Optics
- Conclusion

Optical Simulation Parameters

Use of Parameters Not Based on Optics

- Advantage
  - Artists are not limited by optical consistency
- Disadvantages
  - Output highly depends on artist
  - A lot of experiences or knowledge is necessary
  - Someone unfamiliar with photography may hardly notice unnatural results
    - Physically implausible results are frequently found
      - e.g. Bokeh in the background is too large compared to near and mid-range
    - Viewers who is familiar with photography may feel something is wrong

Unnatural DOF Handling

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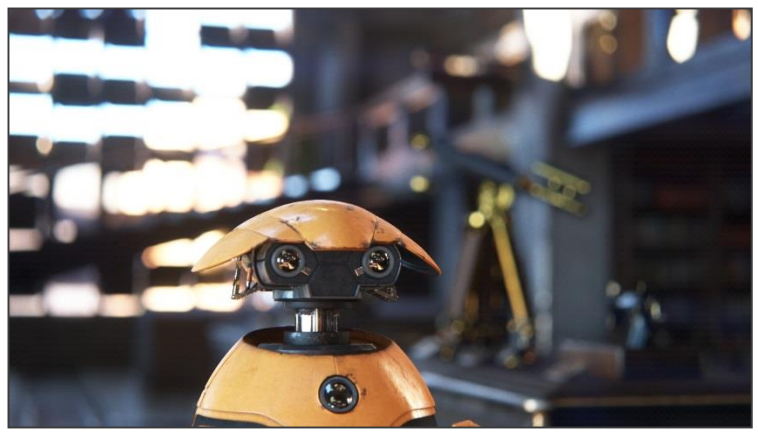
Unnatural DOF Handling

Unnatural DOF Handling

- F-number varies immoderately by focusing or zooming
- Too large bokeh in the background when FOV is wide
  - Miniature-looking scene

f/0.17



f/2.2

f/8.4


Natural DOF Handling

Natural DOF Handling

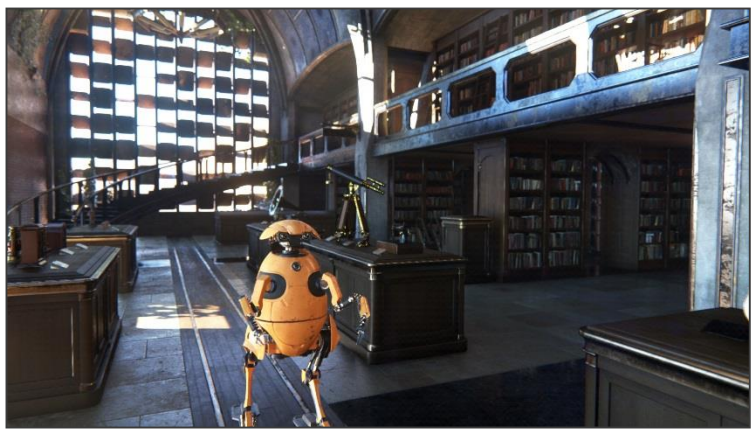
Natural DOF Handling

Natural DOF Handling

Natural DOF Handling

- CoC sizes in the background differ by focus distance and FOV
  - Wide FOV or far focus generates small bokeh
  - Narrow FOV or close focus generates large bokeh

- F-number should not change
  - Keep F-number constant when focusing
  - Minimum F-number may vary by zooming depending on its mechanism



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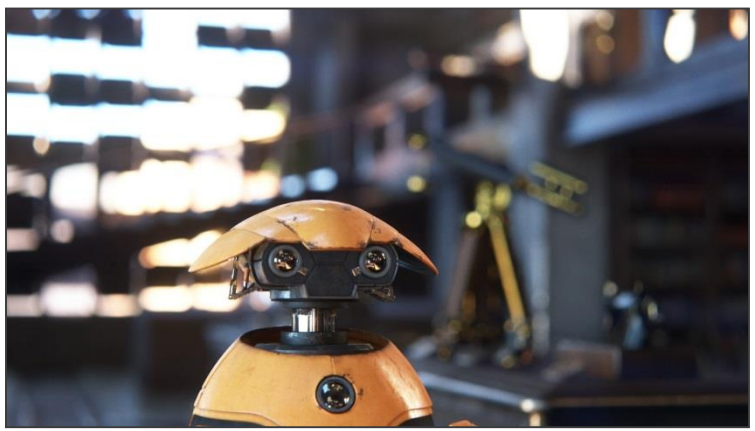

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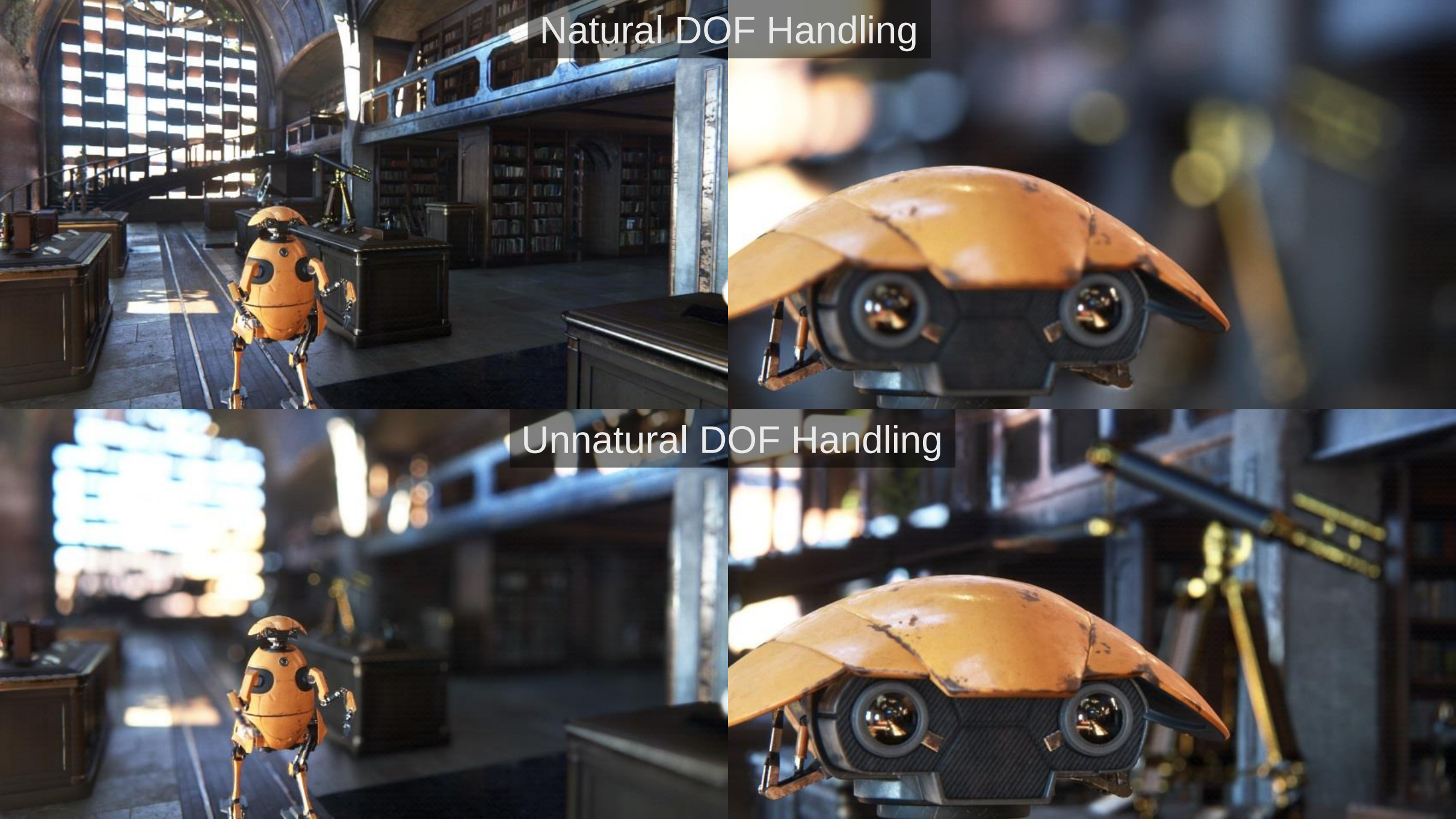

Natural DOF Handling
Unnatural DOF Handling

Use of Parameters Based on Optics

- Calculate the required parameters from artist settings
  - Artist settings:
    - FOV, aperture, focus distance, etc.
- Advantages
  - Can keep optical consistencies
  - Less parameters to set
- Disadvantages
  - Artists are constrained by optical consistency
    - Artists may not control DOF as intended

Parameters NOT based on Photography

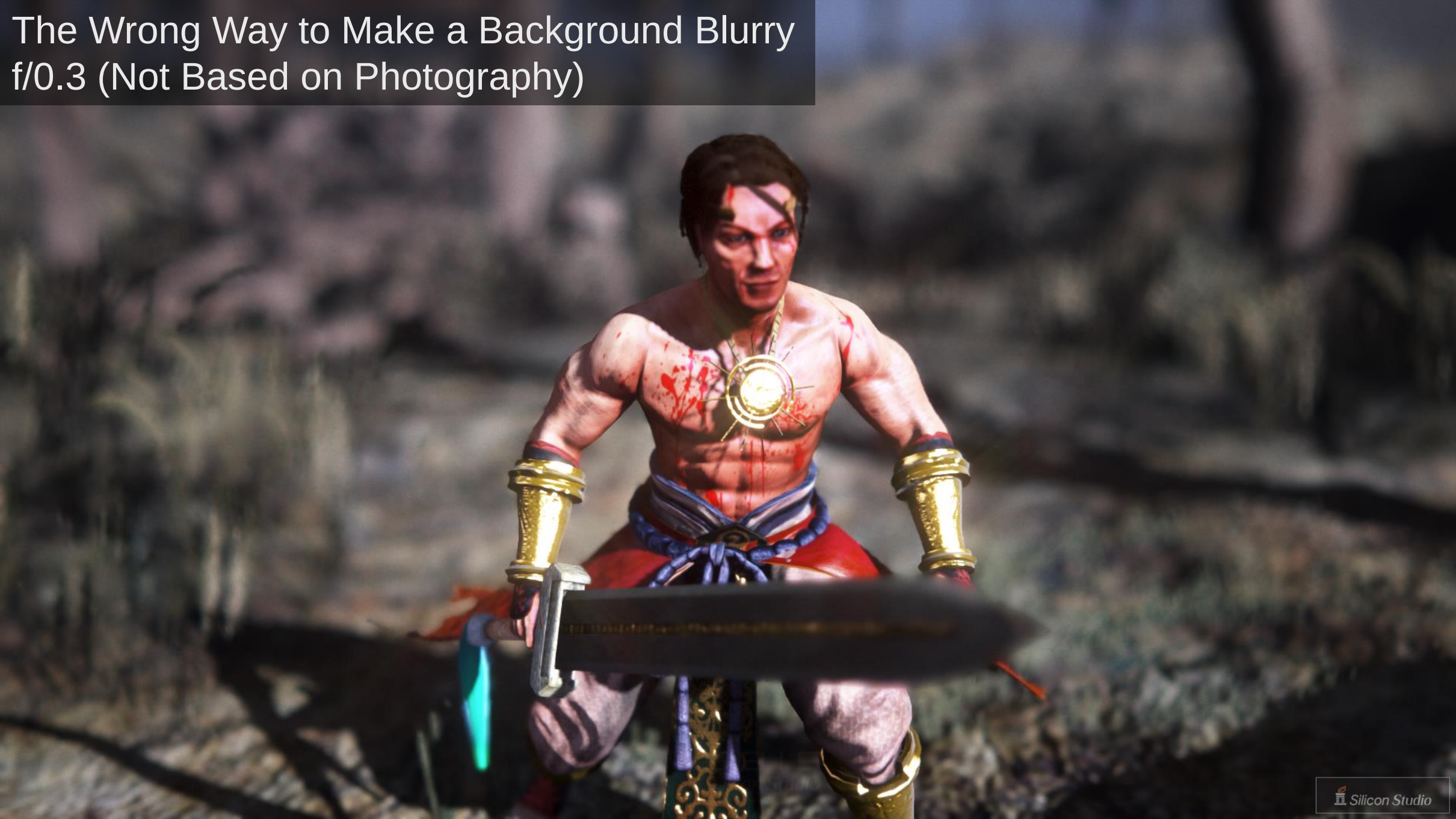
- The optical parameters might be still unnatural
  - 10,000mm of focal length
  - 0.1 of F-number
  - 1cm of focus distance with a telephoto lens
  - And more ...

A Frequently Made Mistake

- When you want to focus on a person and make a blurry background…
  1. Frame the person using a wide angle FOV
  2. Focus on the person
     - Hard to blur the background, so…
  3. Open the aperture until the background becomes blurred
     - F-number might become too small

⇒The scene becomes unnaturally miniaturized

The Wrong Way to Make a Background Blurry f/0.3 (Not Based on Photography)



Parameters Should be Based on Photography

- Not a matter of the aperture setting for the insufficient blur
  - Relationship between camera position and FOV does matter
    - Moving the camera further and zooming-in makes the bokeh larger
- Parameters not based on photography can cause unnatural looking results
  - Limiting optical parameters to a proper range
    - F-number should be from f/1.0 to f/32.0
      - f/2.0 or greater for zoom lenses
    - Lower limit of focus distance should be twice the focal length
      - i.e. Macro 1:1
    - etc.

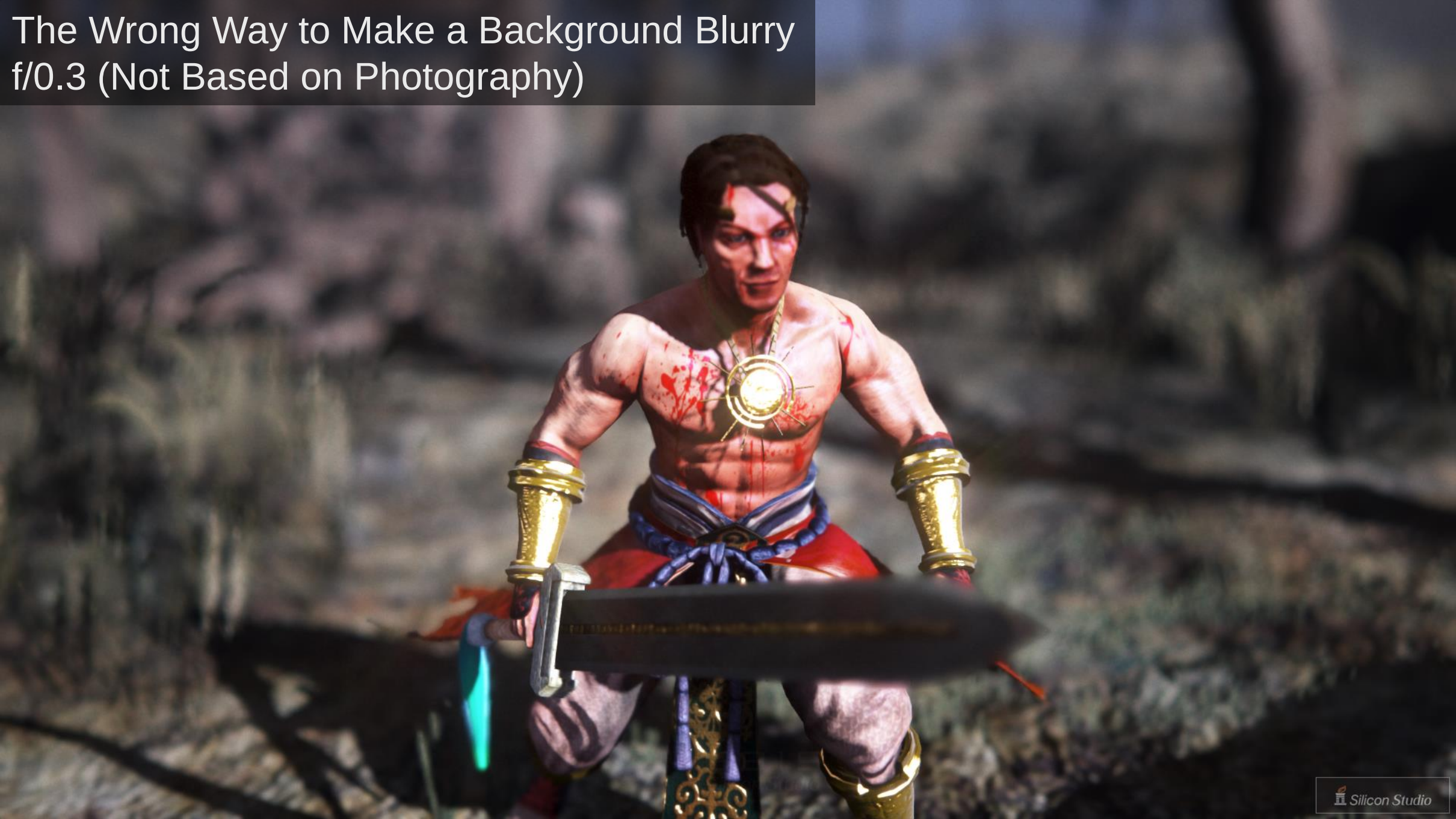
Parameters Based on Photography

- The artist would have to move the camera and zoom-in
  - The result will look natural

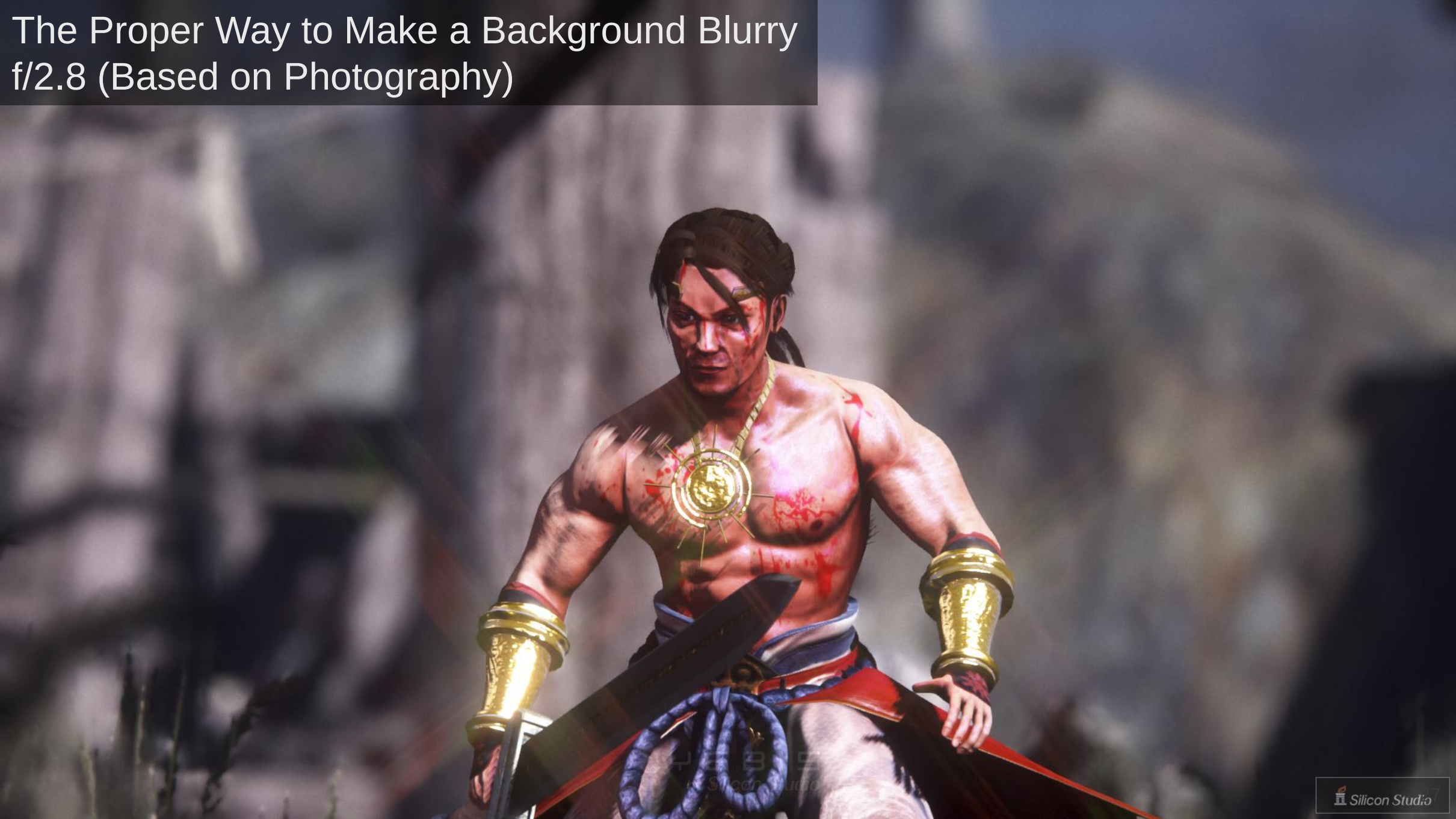
Not based on photography

Based on photography

The Wrong Way to Make a Background Blurry f/0.3 (Not Based on Photography)



The Proper Way to Make a Background Blurry f/2.8 (Based on Photography)



Optical Parameter Animation

Optical Parameter Animation

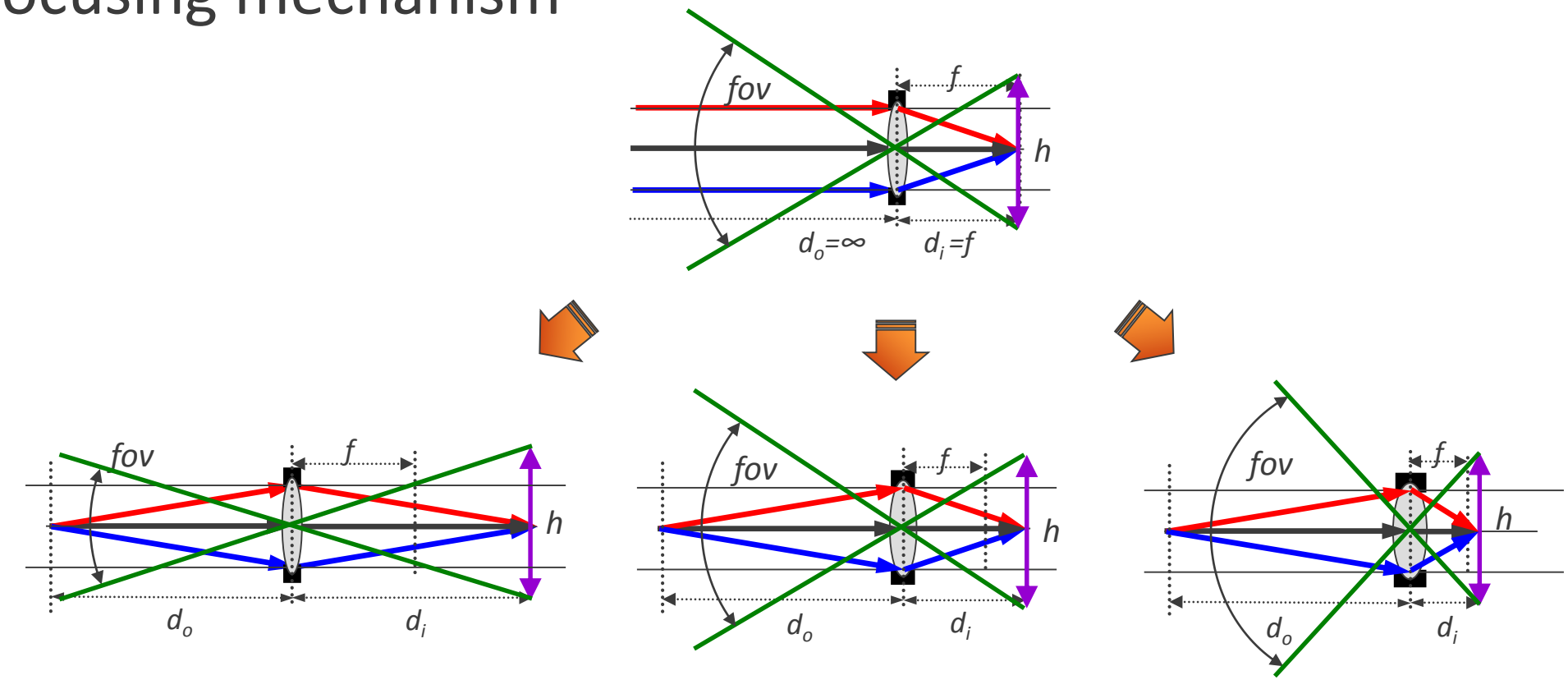
- Focusing animation
- Zooming animation
- Focus breathing
- Maximum aperture varying when zooming
- Vignetting varying
- And more …

Optical Parameter Animation

- Should the artists control all of them?
  - A lot of experience or knowledge is necessary
    - Focusing and breathing are exclusive knowledge
  - Output quality highly depends on artist's experience or knowledge
- Override the settings specified by the artists
  - Make the focusing animation automatic
    - Artists set only the target for focusing
  - Override the FOV by focus breathing
  - Override the minimum F-number depending on FOV
  - And more …

Override FOV by Focus Breathing

- Change the FOV depending on focus distance and focusing mechanism



Approximation of Focus Breathing

- Calculate current finite focus FOV from infinite focus FOV and focus distance

  $f = h / (\tan(fov / 2) * 2)$ — f : Focal length for infinite focus

  $d_i = d_o f / (d_o - f)$ — d_i : Image distance for infinite focus

  $s = d_i / f = d_o / (d_o - f)$

  $sr = \mathrm{pow}(s, r)$

  $d_i' = f * sr$ — d_i' : Image distance for current finite focus (result of breathing)

  $fov' = \mathrm{atan}(h / (d_i' * 2)) * 2$ — fov' : FOV for current finite focus (result of breathing)

  – Optical effective focal length for the result of breathing
    - $f' = d_i / s = f * sr / s = (d_o h / 2) / (\tan(fov' / 2) * d_o + h / 2)$
    - Will be shifted depending on focus distance and r

  – ‘r’ is the degree of the focus breathing
    - You can control breathing by setting r from about -1 to 1

Degree of the Breathing: *r*

- 1.0 means that FOV will be narrow angle according to single lens rule
  - All-group focusing (typical macro lenses)
  - Optical focal length is always constant
- 0.0 means that FOV is constant (with no breathing)
  - The focal length become shorter instead of shifting image distance
  - Some expensive lenses
- -1.0 means that FOV will be wider angle when focus to finite
  - The focal length become much shorter
  - Typical internal focus lenses (less expensive lenses)
- Artists select *r* for each lens
  - Set *'r'* directly
  - Select lens's focus mechanism


Far Focus


Close Focus (All-Group Focusing: r = 1)


Far Focus


Close Focus (with No Breathing: $r = 0$)


Far Focus


Close Focus (Inner Focusing: r = -1)

Upper: Far Focus
Lower: Close Focus

All-group focusing (r = 1) | With no breathing (r = 0) | Internal focusing (r = -1)


Close Focus (All-Group Focusing: r = 1)


Close Focus (with No Breathing: $r = 0$)

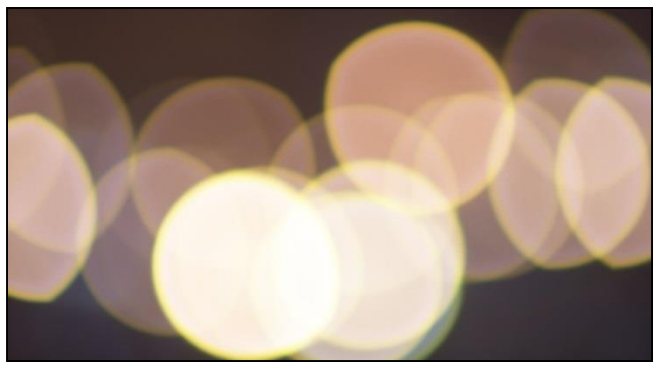

Close Focus (Inner Focusing: r = -1)

Variable Maximum Aperture Zoom Lens

- Change minimum F-number depending on focal length
  - Limit the current F-number to minimum F-number
- Change the aperture shape depending on the ratio of current F-number to minimum F-number
  - From circular aperture to polygonal aperture

Wide

Narrow



Fully opened aperture

4 stops closed aperture

Approximation of Variable Aperture Zoom Lens

- Calculate current minimum F-number from base minimum F-number and FOV and current FOV

$f = h / (\tan(fov / 2) * 2)$ — f : Base focal length

$f' = h / (\tan(fov' / 2) * 2)$ — f' : Current focal length

$F' = F * \mathrm{pow}(f' / f, 1 - q)$ — F' : Current minimum F-number

  - Above parameters are all at infinite focus
    - *fov* is base field of view
    - *f* is base focal length
    - *F* is base minimum F-number (maximum aperture)
    - *fov'* is current field of view
    - *f'* is current focal length
    - *F'* is current minimum F-number
  - *'q'* is the degree of maximum aperture varying
    - You can control maximum aperture shifting by setting *q* from about 0.5 to 1

Degree of the Maximum Aperture Varying: *q*

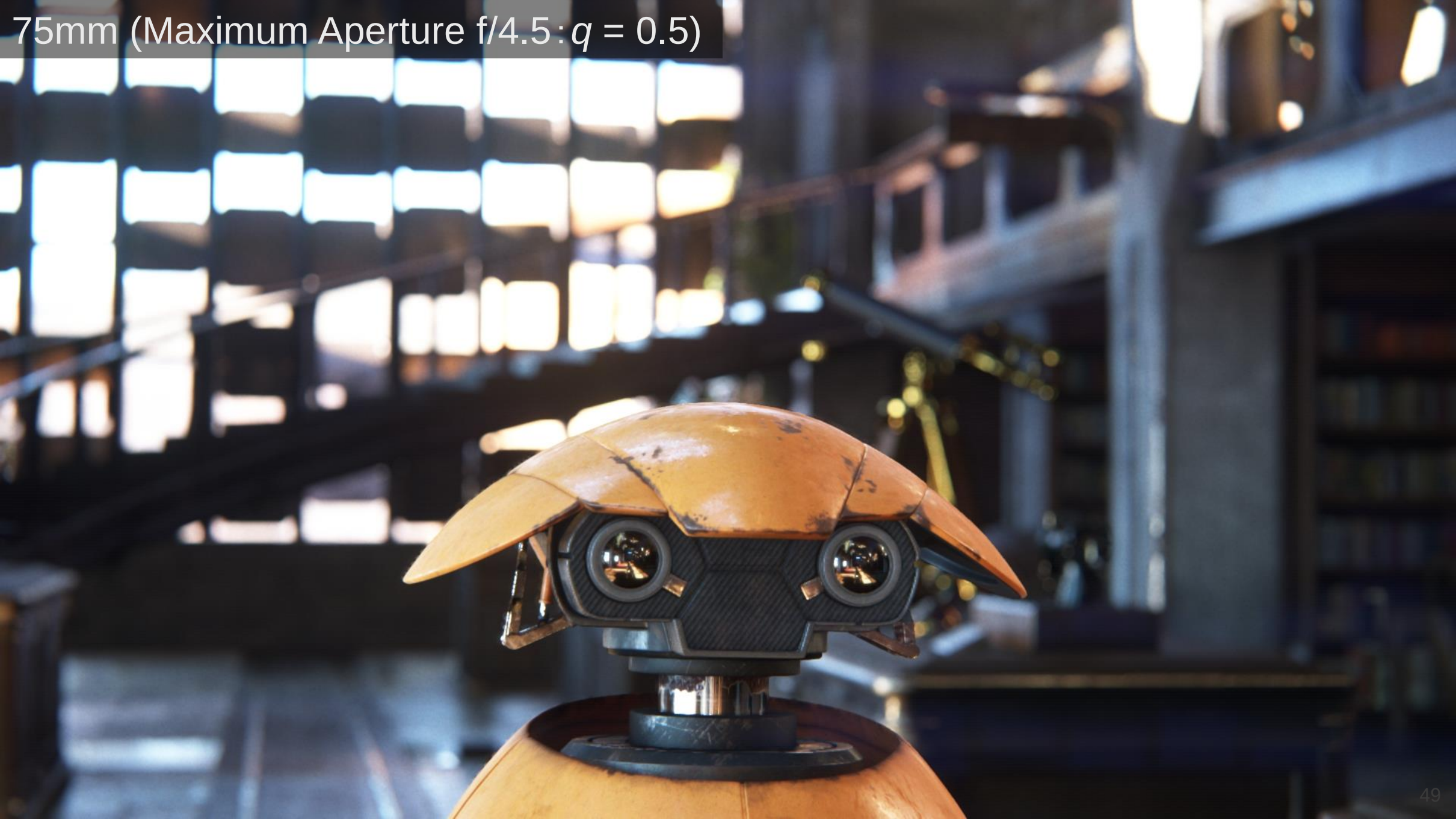
- 1.0 means that minimum F-number is constant
  - Some expensive lenses
- 0.5 means that minimum F-number will shift by focal length
  - If the focal length gets 4 times longer, then minimum F-number becomes 2 times greater
- 0.0 means that minimum F-number is in proportion to focal length
  - If the focal length gets 4 times longer, then minimum F-number becomes 4 times greater
- Most lenses are from 0.7 to 1.0

- Artist select *q* for each lens
  - Set base minimum F-number and *'q'* directly
  - Set a combination of minimum F-numbers
    - From product lens specifications

Approximation of Variable Aperture Zoom Lens

- You can calculate *q* from a combination of apertures
  - $q = 1 - \log(F2 / F1) / \log(f2 / f1)$
- Examples of product lens specifications
  - 9-18mm F4.0-5.6
    - $f1 = 9, f2 = 18, F1 = 4.0, F2 = 5.6$
    - $q = 1 - \log(5.6 / 4.0) / \log(18 / 9)$
    - $q = 0.5$
  - 18-135mm F3.5-5.6
    - $(f1, f2, F1, F2) = (18, 135, 3.5, 5.6)$
    - $q = 1 - \log(5.6 / 3.5) / \log(135 / 18)$
    - $q = 0.7707$
  - 24-70mm F2.8 (the lens that have constant minimum F-number for all range FOV)
    - $(f1, f2, F1, F2) = (24, 70, 2.8, 2.8)$
    - $q = 1 - \log(2.8 / 2.8) / \log(70 / 24)$
    - $q = 1.0$


30mm (Maximum Aperture f/2.8)

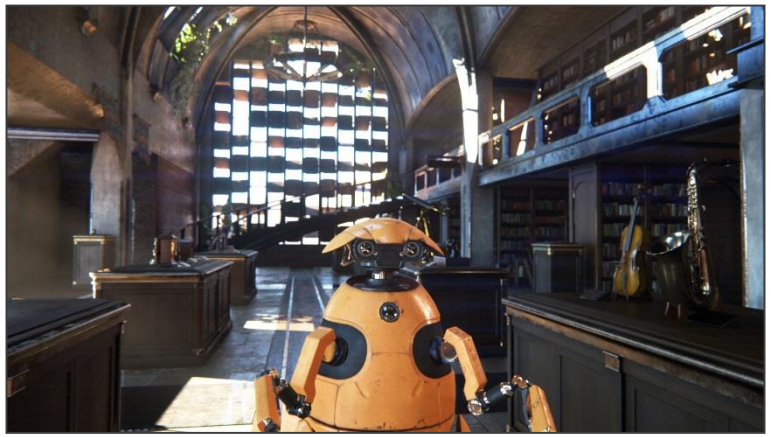

75mm (Maximum Aperture f/4.5 : q = 0.5)

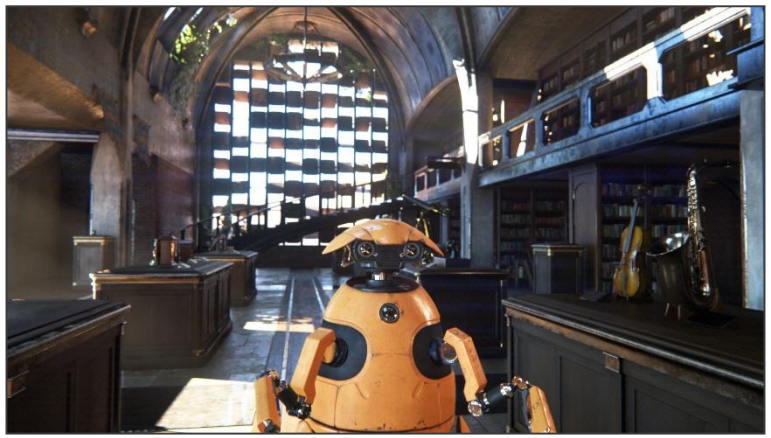

75mm (Maximum Aperture f/2.8 : q = 1.0)


150mm (Maximum Aperture f/6.3 : q = 0.5)


150mm (Maximum Aperture f/2.8 : q = 1.0)

Upper: q = 0.5 (30-150mm F2.8-6.3)
Lower: q = 1.0 (30-150mm F2.8)



Parameters which Should be Controlled Automatically

- Varying without photographer's will in actual lens
  - Due to lens mechanisms

Examples of the Parameters which Should be Controlled Automatically

- Focusing
  - Focusing animation
  - Auto focus confusion
  - Focus breathing
- Zooming
  - Zooming animation
  - Aperture varying
  - Miss focus when zooming
    - Some compact digital cameras
  - Vignetting varying
- Camera nodal point
  - Shift the camera position to NPP (No-Parallax Point)
- Auto-exposure adjustment
- etc.

Handling "Law of Reciprocity" in Optics

Which is Better?

- Handling “Law of Reciprocity” strictly

or

- Exposure is independent of shutter speed and aperture

Handling “Law of Reciprocity” Strictly

- For example
  - If open the aperture, an exposure amount must increase
  - If reduce an exposure amount without varying aperture, shutter speed must be faster
- Optical consistencies are perfectly kept

Handling “Law of Reciprocity” Strictly (cont’d)

- Set scene photometric quantities (luminance, illuminance etc.) and ISO sensitivity properly, or exposure will miscarry
  - In spite of decreasing the exposure, the scene keeps white
  - In spite of increasing the exposure, the scene keeps black
- Hard to control
  - Exposure
  - DOF
  - Motion blur

Exposure is Independent of Shutter Speed and Aperture

- For example
  - F-number is only used for handling “Depth Of Field”
  - Shutter speed is only used for handling “Motion Blur”
  - Independent exposure is only used for handling “Exposure”
- Artists can control optical parameters easily
- Optical consistencies are not perfectly kept
  - Viewers who is familiar with photography might feel unnatural

Handling “Law of Reciprocity” in Optics

- Better approach to handling reciprocity is to do it in a way that fulfills your objectives

Conclusion

Conclusion

- Optics allows us to achieve physically plausible results
  - Parameters not based on photography can cause unnatural results even with optics
  - Limit optical parameters to proper ranges for natural looking results

Conclusion (cont'd)

- You can use derived parameters from camera mechanism
  - Excluding external input from the photographer
- "Law of reciprocity" should be selectively used depending on the purpose

References

- Kawase, M. “Optics knowledge to achieve attractive images.” *Computer Entertainment Developers Conference, 2010.*