































### SLR viewfinder & aperture

• By default, an SLR always shows you the biggest aperture

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- Brighter image
- Shallow depth of field help judge focus
- Depth of field preview button:
  - Stops down to the aperture you have chosen
  - Darker image
  - Larger depth of field













### Depth of field & focal length

- Recall that to get the same image size, • we can double the focal length and the distance
- Recall what happens to physical aperture size when we double the focal length for the same f number? - It is doubled





50mm

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24mm

Depth of field & focal length • Same image size (same magnification) 2NCsame f number d =DoF • Same depth of field Wide-angle lens DoF Telephoto lens (2x f), same aperture



### Important conclusion

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- For a given image size and a given f number, the depth of field (in object space) is the same.
- Might be counter intuitive.
- · Very useful for macro where DoF is critical. You can change your working distance without affecting depth of field
- · Now what happens to the background blur far far away?

### Important conclusion

- For a given image size and a given f number, the depth of field (in object space) is the same.
- The depth of acceptable sharpness is the same • But background far far away looks more blurry
- Because it gets magnified more
- Plus, usually, you don't keep magnification constant



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## **Seeing through** occlusion

### Seeing beyond occlusion

- Photo taken through zoo ba
- Telephoto at full aperture
- The bars are so blurry that they are invisible









V	
•	To make things blurrier
	<ul> <li>Depth of field</li> </ul>
•	To make things sharper
	<ul> <li>Diffraction limit</li> </ul>
	harpness & aperture (e.g. for the Canon 50mm f/1.4)
ht	tp://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/3
	tp://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/3
ht	tp://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/3 f/1.4: soft (geometrical aberrations), super shallow Dof. Lots of
•	tp://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/3 f/1.4: soft (geometrical aberrations), super shallow Dof. Lots of light!



### Soft focus

- Everything is blurry
- Rays do not converge
- Some people like it for portrait





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### Infrared (Active AF)

- Intensity of reflected IR is assumed to be proportional to distance
- There are a number of obvious limitations
- Advantage: works in the dark
- This is different from Flash assistant for AF where the IR only provides enough contrast so that standard passive AF can operate

(Jak)





























### Bokeh

- · Shape of out of focus kernel
- http://www.kenrockwell.com/tech/bokeh.htm ٠



Fig. 1. Poor Bokeh. This is a greatly magnified blur circle showing very poor bokeh. Note how the edge is sharply defined and even emphasized for a point that is supposed to be out-of-focus, and that he center is dim.

the center is dim. Fig 2. Neutral Bokeh. This is a a technically perfect and evenly illuminated blur circle. This isn't good either for bokeh, because the edge is still well defined. Out-of-focus objects, either points of light or lines, can effectively create reasonably sharp lines in the image due to the edges of the sharp blur circle. This is the blur circle from most modern lenses designed to be "perfect." Fig 3. Good Bokeh. Here is what we want. This is great for bokeh since the edge is completely undefined. This also is the result of the same spherical aberration, but in the oposite direction, of the poor example seen in Fig. 1. This is where art and engineering start to diverge, since the better looking image is the result of an imperfection. Perfect bokeh demands a Gaussian blur circle distribution, and lenses are designed for the neutral example shown in 2.) above.

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## Fake Depth of Field



Mask of blurry layer)

Result

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# Tilt/Shift camera movements































### Wavefront coding

- CDM-Optics, U of Colorado, Boulder
- The worst title ever: "A New Paradigm for Imaging Systems", Cathey and Dowski, Appl. Optics, 2002
- Improve depth of field using weird optics & deconvolution



### Wavefront coding

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• Idea: deconvolution to deblur out of focus regions

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- Convolution = filter (e.g. blur, sharpen)
- Sometimes, we can cancel a convolution by another convolution
  - Like apply sharpen after blur (kind of)
  - This is called deconvolution
- Best studied in the Fourier domain (of course!)
  - Convolution = multiplication of spectra
  - Deconvolution = multiplication by inverse spectrum

### Wavefront coding

- Idea: deconvolution to deblur out of focus regions
- **Problem 1: depth of field blur is not shift-invariant** – Depends on depth
  - Blur is not a convolution, hard to use deconvolution
- Problem 2: Depth of field blur "kills information"
  - Fourier transform of blurring kernel has lots of zeros
  - Deconvolution is ill-posed

### Wavefront coding

- Idea: deconvolution to deblur out of focus regions
- Problem 1: depth of field blur is not shift-invariant
- Problem 2: Depth of field blur "kills information"
- Solution: change optical system so that
  - Rays don't converge anymore
  - Image blur is the same for all depth
  - Blur spectrum does not have too many zeros









### **Other application**

- Single-image depth sensing
- Optimize optical system so that blur depends A LOT on depth

### Important take-home idea

#### **Coded imaging**

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• What the sensor records is not the image we want, it's been coded (kind of like in cryptography)

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• Image processing decodes it

## Defocus from focus/defocus



### **Depth from focus**

<u>http://ieeexplore.ieee.org/xpl/freeabs\_all.jsp?isNumber=5032&arNumber=196282&isnumber=5032&arnumber=196282</u>

CSAL CSAL

<u>http://www.ri.cmu.edu/pub\_files/pub1/xiong\_valin\_1</u>
 <u>993\_1/xiong\_valin\_1993\_1.pdf</u>





**Defocus matting** 



Plenoptic camera refocusing



