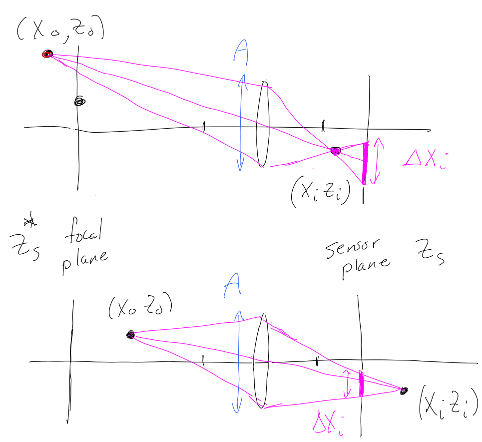
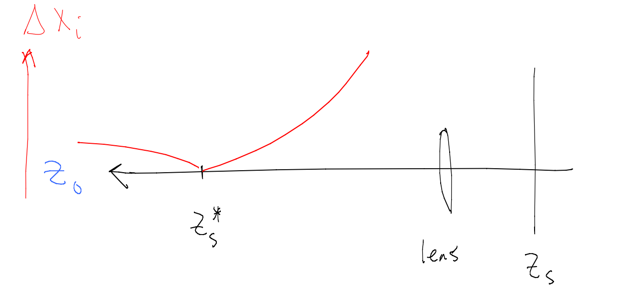
lecture 17 (Part 2)

depth from defocus

RECALL LECTURE 5

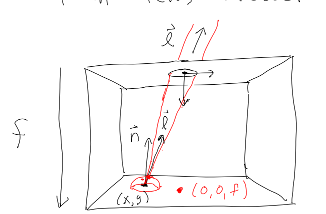


$$\Delta X_i = A \left| Z_s \left(\frac{1}{f} - \frac{1}{Z_0} \right) - 1 \right|$$



RECALL LECTURE 7

Thin lens model (camera)



Let A be the aperture (lens diameter), so lens area is $\frac{\pi A^2}{4}$.

$$E(x,y) = L(\vec{\ell}) \, (\text{area of lens}) \frac{(\vec{n} \cdot \vec{\ell})^4}{f^2}$$

$$= L(\vec{\ell}) \frac{\pi}{4} \left(\frac{A}{f} \right)^2 (\vec{n} \cdot \vec{\ell})^4$$

However, what if image is not in focus at (x,y)?

We can model the resulting blur with a convolution:

$$E(x,y) * G(x,y,\Delta X)$$

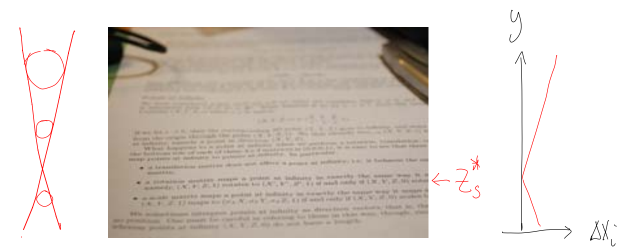
This makes sense in regions where ΔX is approximately constant.

RECALL LECTURE 5

$aX + bY + cZ = 1$

$ax + by + cf = \frac{f}{Z}$

$\Delta X_i = A \left| Z_s \left(\frac{1}{f} - \frac{1}{Z_0} \right) - 1 \right|$



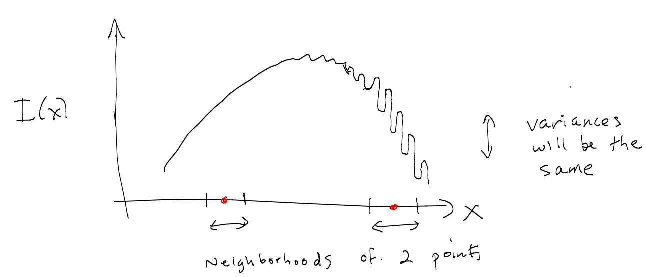
How can we compare blur at different points?

IDEA 1: Heads up – I'm using $I(x,y)$ rather than $E(x,y)$ below.

$$\text{blurMeasure}(x_0, y_0) = \sum_{Ngd(x_0,y_0)} \left(I(x,y) - \bar{I} \right)^2$$

will be smaller in blurred region where $\bar{I}$ is mean intensity in that region. The idea is that blurring is averaging, and averaging reduces variance.

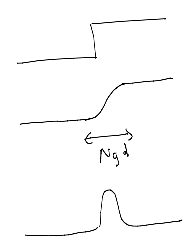
The above method often doesn't work however.



The (intuitively) more blurred Ngd on the left has the same $\sum_{Ngd} (I - \bar{I})^2$ as the Ngd on right.

How can we compare blur at different points?

IDEA 2: Blurred region $\Rightarrow$ smaller $|\nabla I|$



$u(x)$ optical blur i.e. $\Delta X = \sigma_{blur}$

$u(x) * G(x, \sigma_{blur}) = I(x)$ blurred edge

$$\frac{d}{dx} u(x) * G(x, \sigma_{blur}) = \frac{d\, I(x)}{dx}$$

$$= G(x, \sigma_{blur}) \sim \frac{1}{\sigma_{blur}} \text{ @ } x = 0$$

However, be careful. For any edge,

$$\sum_{Ngd} \left|\frac{d}{dx} I\right| = \sum_{Ngd} G(x, \sigma_{blur}) = 1$$

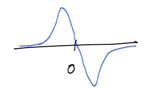
which is independent of the optical blur σ_{blur} if our Ngd covers the whole blurred edge

So we can't just use the average gradient!

[Intuition: a blurred edge covers a larger range of x's.]

IDEA 3 (harder to motivate):

Consider $\frac{d^2}{dx^2} \underbrace{u(x) * G(x, \sigma_{blur})}_{\text{blurred edge}} = \frac{d}{dx} G(x, \sigma_{blur})$



$$\Rightarrow \int_{-\infty}^{\infty} \left\| \frac{d^2}{dx^2} u(x) * G(x, \sigma_{blur}) \right\| dx$$

$$= 2 \int_{-\infty}^{0} \frac{d}{dx} G(x, \sigma_{blur})\, dx = 2\, G(x, \sigma_{blur}) \sim \frac{1}{\sigma_{blur}}$$

The sum of second derivatives are much greater for the neighborhood on the right.

How to compare blur at different points in a 2D image?

$$\sum_{Ngd(x_0, y_0)} \left| \frac{d^2}{dx^2} I(x,y) * G(x,y,\sigma) \right| + \left| \frac{d^2}{dy^2} I(x,y) * G(x,y,\sigma) \right|$$

This convolution is used to reduce noise. Don't confuse it with optical blur (σ_{blur}) within $I(x,y)$.

Depth from defocus using multiple images

① "Accommodation" or "Autofocus"

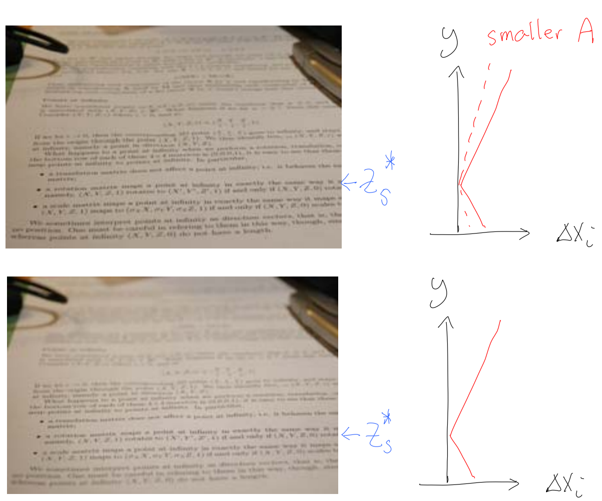
human eye  camera 

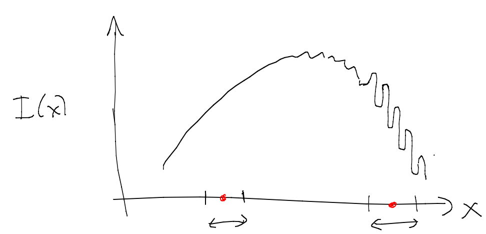
Vary the focal length f (or Z_s) to bring particular pixels into focus, and use thin lens equation to estimate depth at those pixels.

Depth from defocus using multiple images.

② Vary aperture and shutter speed such that (average) exposure is constant

See Assignment 3, Q1.





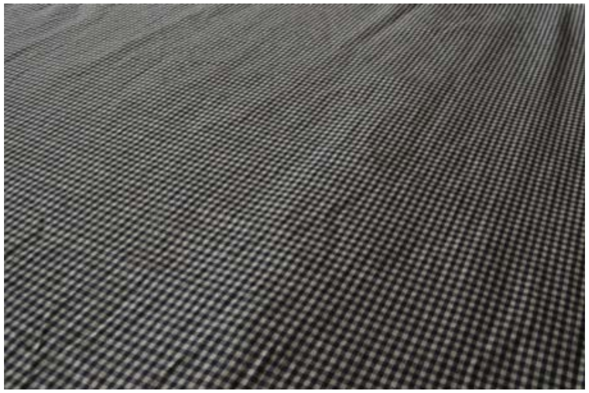
Use two images avoids the problematic situation that the underlying texture has spatially varying statistics. ("non-stationary", "non-homogeneous")

Assignment 3

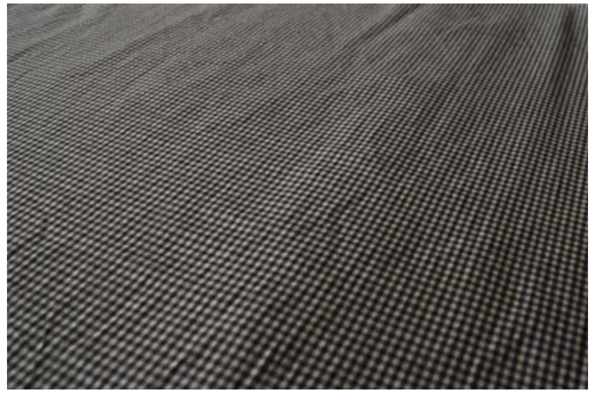
You are given two images,

1) small aperture and long exposure time
2) large aperture and short exposure time.

Estimate the blur at each pixel (in the second image)



small aperture



large aperture

Result