Color

XYZ space

$X+Y+Z = \text{Intensity}$

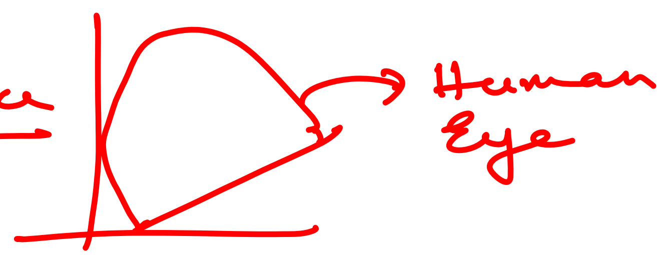
$$(x,y) = \left(\frac{X}{X+Y+Z}, \frac{Y}{X+Y+Z}\right)$$

= Chromaticity (describes chrominance)

$$\text{Dynamic Range} = \frac{\text{Max Intensity}}{\text{Min Intensity}}$$

Color Gamut = Range of chrominance

Can be for a scene or device (capture or display or printer)



Dynamic Range

In nature, very high dynamic range.

Radiance

search light – 10^8

day light – 10^4

office light – 10

moon light – 10^{-2}

Star light - 10^{-6}

$\therefore$ In log units, greater than 10

Dynamic Range

At one time in a scene.

Shadows - 10^{-2}

Highlights - 10^{4}

$\therefore \frac{10^4}{10^{-2}} = 10^6$ $\therefore$ In log units, greater than 4.

But displays - Typically $10^0 - 10^1$

$= 1$ to 100 cd/m^2

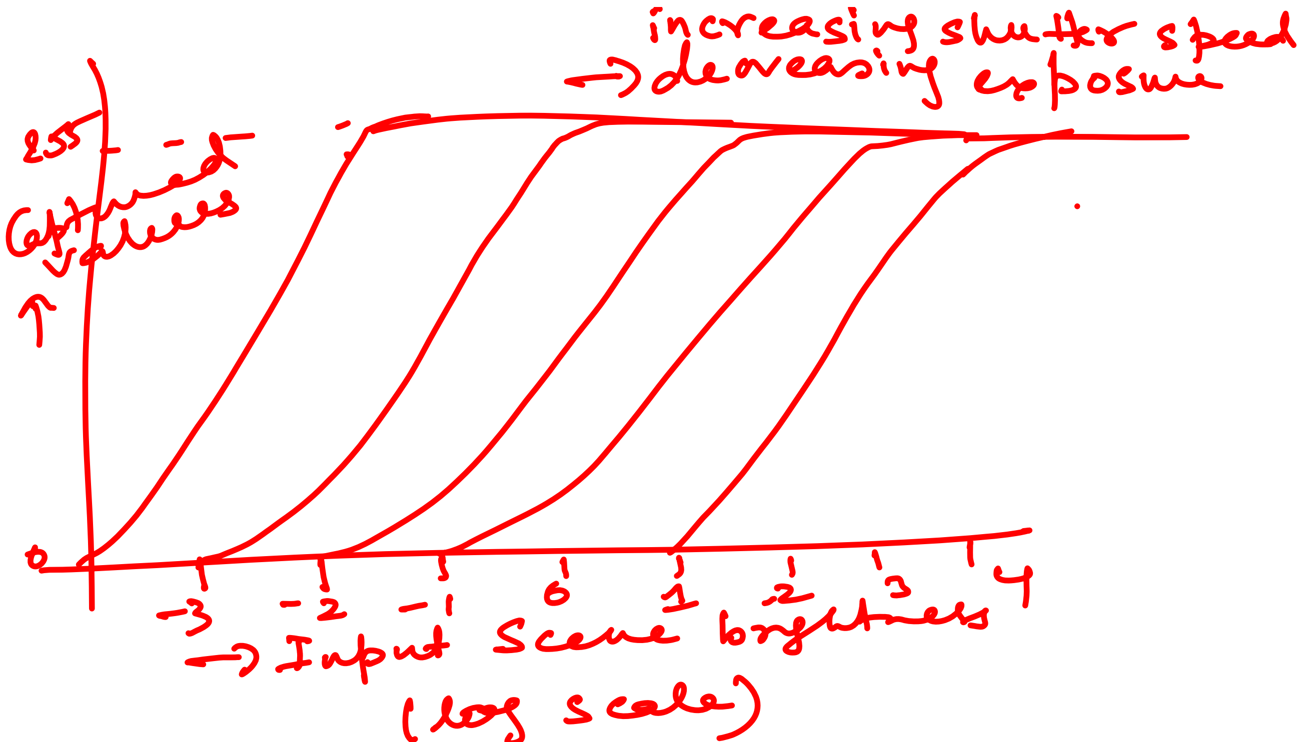
$\therefore$ **Scene Reconstruction**

Even if you consider no view dependency, how do you capture this high dynamic range.

Debevec Siggraph 1997

Capturing High Dynamic Range.

Response of a camera is similar to human eye.



It can only capture a small range of brightness at a time. With changing exposures we will get lower or higher brightness values.

Consider a pixel i. (Assume linear ordering).

$\therefore \; 0 \leq i < N$

for an image of size $m \times n = N$

Let it be taken at different exposures - t_j, $\quad 0 \leq j < P$.

Let the irradiance at pixel i be E_i

$$z_{ij} = f(E_i t_j)$$

$\therefore f^{-1}(z_{ij}) = E_i t_j$

$\therefore \ln f^{-1}(z_{ij}) = \ln E_i + \ln t_j$

or $g(z_{ij}) = \ln E_i + \ln t_j$

$\therefore \underbrace{g(z_{ij})}_{\text{unknown.}} - \underbrace{\ln E_i}_{\text{unknown}} = \underbrace{\ln t_j}_{\text{known}}$

You know z_{ij} but do not know g. $\therefore g_1 \ldots g_{256}$ based on the encoded z_{ij}.

$\therefore$ 256 values for g, $E_1 \ldots E_N$ are unknown.

$\therefore$ Total # of unknowns $= N + 256$

Eqn for P imgs $= NP$.

$NP \geq N + 256$ $\therefore$ Solved by SVD.

Say $N = 10^6$ $P = 10$

$\therefore 10^7$ eqn, 10^6 unknowns,

massive eqn. How do we handle?

Pick a few i, just sufficient to make the system overdetermined.

Let choose $n_1 \leq N$.

$$\therefore n_1 + 256 \leq n_1 P$$

Say $n_1 = 100$

$\therefore$ 356 unknowns, 1000 eqn.

Easier to solve. Once you get g from here note that

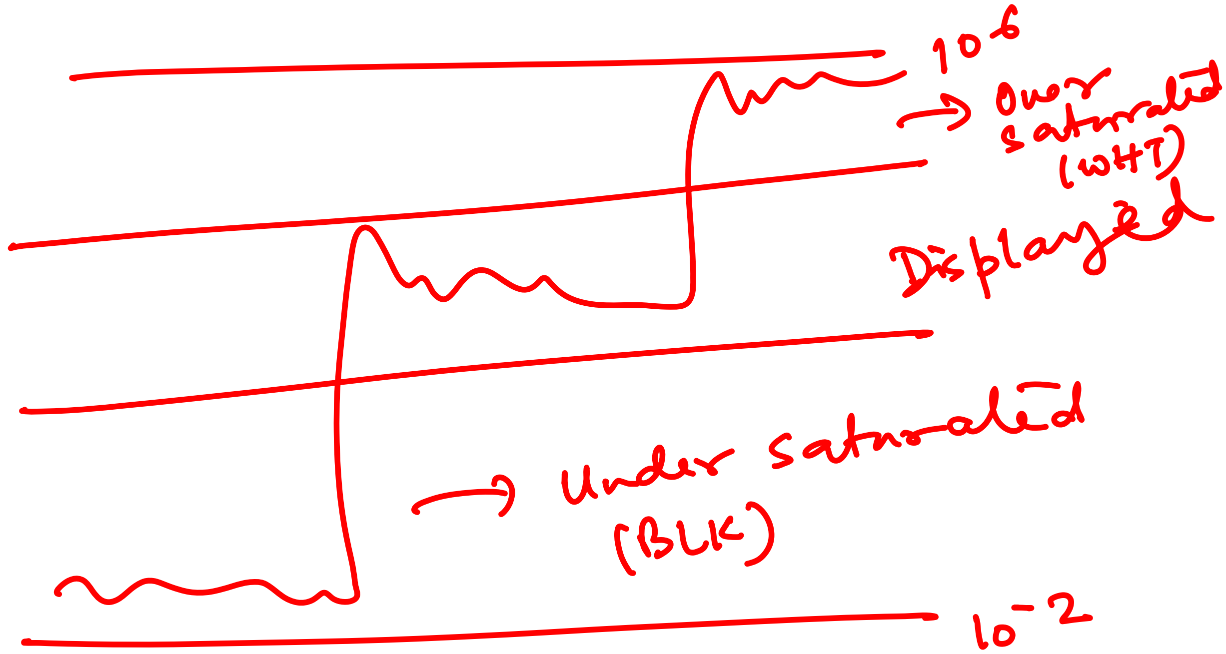
$$g(z_{ij}) = \ln E_i + \ln t_j$$

you can back solve each eqn to get E_i. No need to solve a set of eqn.

Several other optimisations

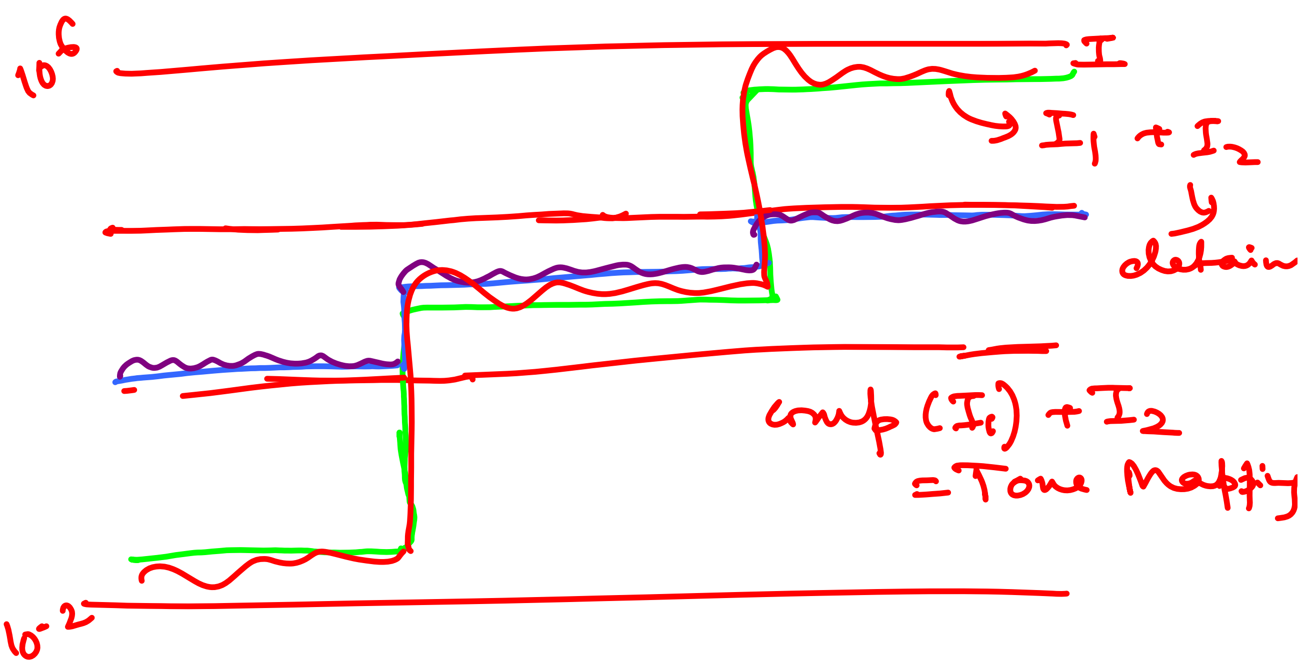
1. Assuming smooth g
2. Extending to color
   (See the reference).
3. How do you combine values? wt. average.

Now we have captured, how to display in LDR displays.



Basic Idea

a) Smooth to remove details.
b) Scale to fit to range
c) Add details back



Many methods to do this, called tone mapping. Basic & common is

Bilateral filtering.

Usually to smooth noise, we use gaussian filter. But that will smudge edges. So how can we preserve edges.

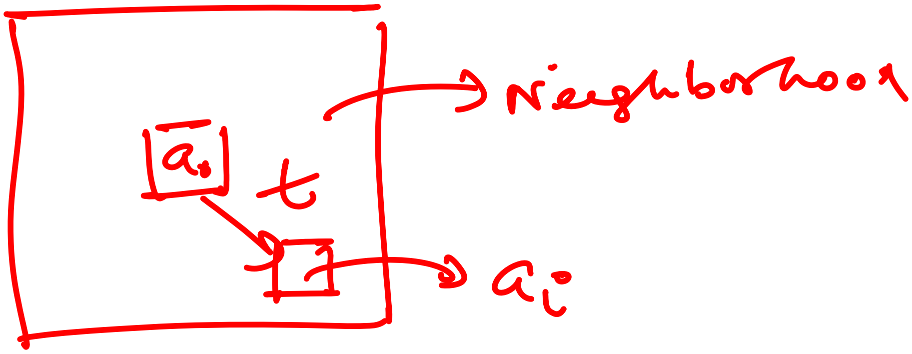
In gaussian filter, neighbors contribute to the pixel based on proximity. Closer pixels have higher wts & vice versa.

Called Domain filter.

No contribution from the values at a pixel. Say a neighbor is very different from the pixel. ∴ This is probably an edge. ∴ This pixel should be given less weights. ∴ Wts. $\propto \frac{1}{\text{int. difference}}$.

Called Range filter

Bilateral filter = f (Domain filter, Range filter)



$$DF = \text{gaussian}(t) = d(a_i)$$

$$RF = \text{gaussian}\big(I(a_i) - I(a_0)\big) = r(a_i)$$

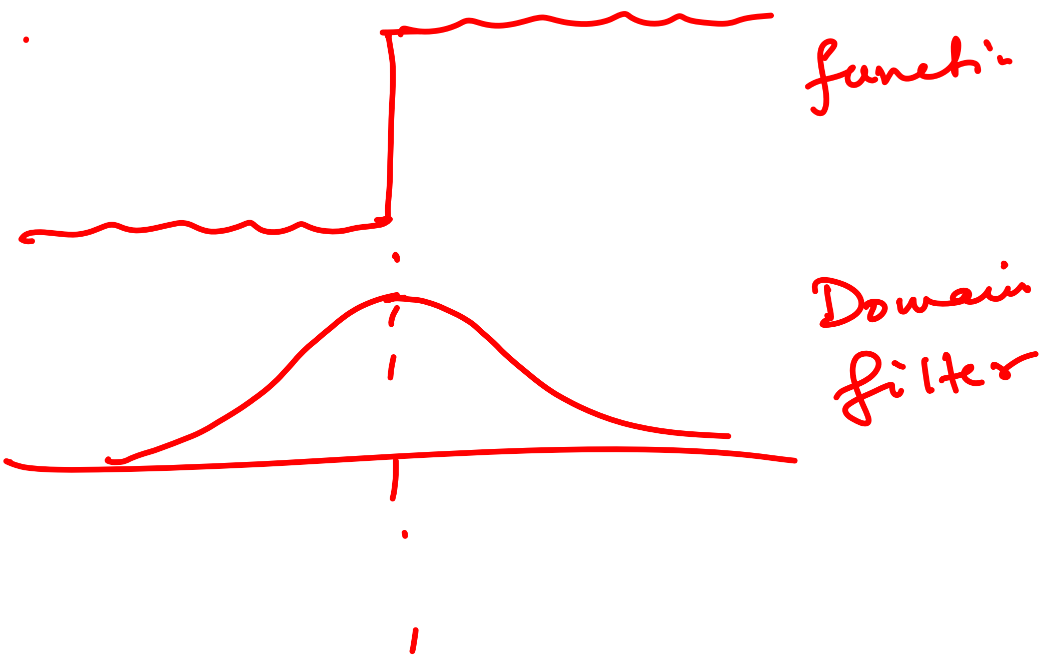
$$BF = DF \times RF$$

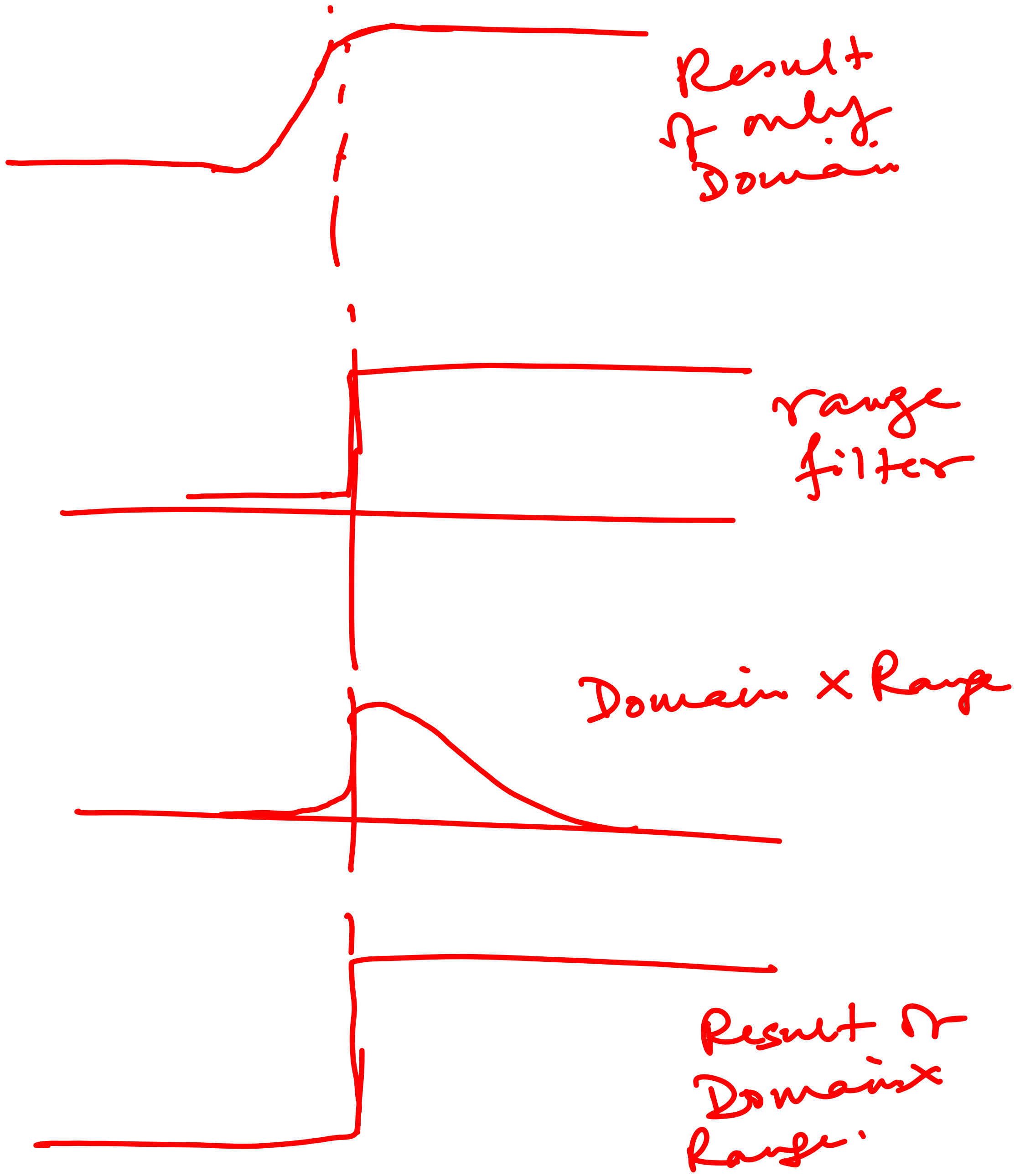
$$h(a_0) = \sum_{k=0}^{n-1} f(a_i) \cdot d(a_i) \cdot r(a_i)$$

For normalizing $\frac{1}{\Delta}$

$$\Delta = \sum_{k=0}^{n-1} d(a_i) \cdot r(a_i)$$

Eg.





Edges can be at different scale & hence has to be done in multi-scale. Laplacian Pyramid.

Display

How much contrast can we get?

Current 1:100 → LDR display.

Displays essentially have filters to attenuate light.
For eg. Proj - white bulb - LCD panel attenuates Red less than others, similarly for g & b.

Consider gray world.

Say $D_1 \rightarrow 1 : c_1$

$D_2 \rightarrow 1 : c_2$

$\therefore$ Say white $= I_1$

After passing through D_1,

black $= I \cdot c_1$

Then passes through D_2,

black $= I \cdot c_1 \cdot c_2$

If no attenuation I_1

$\therefore$ Dynamic Range $= c_1 c_2 : 1$

$\therefore$ Idea is cascade two displays.

Next question is if we have an HDR gray image with I : 1 contrast how do we Drive The two displays.

D_1 — $\sqrt{I}$

D_2 — $\sqrt{I}$

$\therefore D_1 D_2 \rightarrow \sqrt{I}\sqrt{I} = I.$

Usually D_1 & D_2 have gamma fn., g_1 & g_2

$$\therefore D_1 = g_1^{-1}(\sqrt{I})$$

$$D_2 = g_2^{-1}(\sqrt{I})$$

Say D_1 is low resolution Than D_2 and we know The PSF of D_1 as P_1

$$\therefore D_1 = g_1^{-1}(\sqrt{I})$$

$$\text{Effect} = P_1 * (g_1^{-1}\sqrt{I})$$

$$D_2 = \frac{I}{P_1 * (g_1^{-1}\sqrt{I})}$$

honestly LEDs for D1, very bright & low resolution.

This basic idea is extended to color → color calibration is not the greatest.