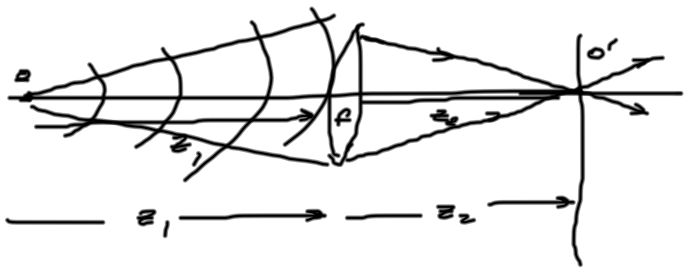
30 November 2009 — Optics — (1)

www.cis.rit.edu/class/simg733

$$\left(+\frac{1}{z_1}\right) + \left(+\frac{1}{z_2}\right) = \frac{1}{f}$$

~~$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$~~



Real Image

Virtual Image

$n = \frac{c}{v}$

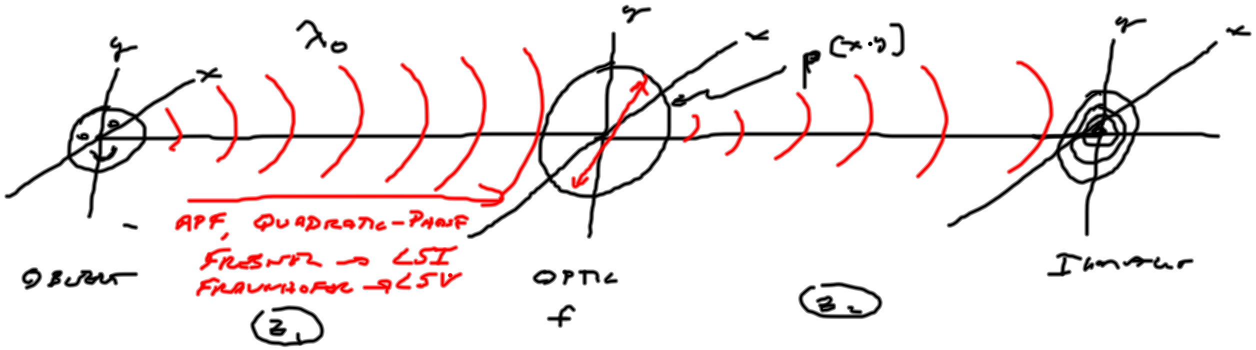
psf

$$f[x,y] * h[x,y] = g[x,y]$$

$$F[\xi,\eta] \cdot H[\xi,\eta] = G[\xi,\eta]$$

OTF

LSI → "Quality" of light
→ monochromatic → coherent
→ incoherent



if $\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$

$$H[\xi,\eta] \propto p[-\lambda_0 f \xi, -\lambda_0 f \eta] \quad ; \quad \mathcal{H}[\xi,\eta] \propto p[-\lambda_0 f \xi, -\lambda f \eta] \circledast p[-\lambda f \xi, -\lambda_0 f \eta]$$

$$h[x,y] \propto P\left[\frac{x}{\lambda_0 f}, \frac{y}{\lambda_0 f}\right] \quad ; \quad \mathscr{h}[x,y] = \left|P\left[\frac{x}{\lambda_0 f}, \frac{y}{\lambda_0 f}\right]\right|^2$$

$$f[x,y] * h[x,y] = g[x,y] \Rightarrow LPF$$

(3) LIGHT AS PHOTONS — QUANTUM OPTICS — SENSORS

"PACKETS" OF ENERGY $E_0 = h\nu_0 = h\frac{c}{\lambda_0}$

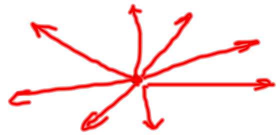
PLANCK'S CONSTANT $\approx 6.626 \cdot 10^{-34}$ J·sec

OPTICS → "MODEL" OF LIGHT TO DO USEFUL STUFF

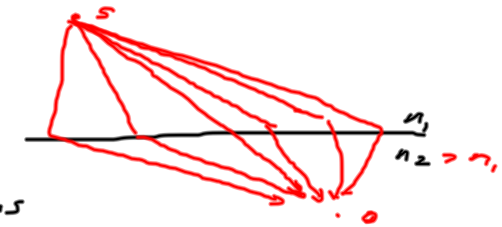
3 MODELS

(1) GEOMETRICAL OPTICS — RAY OPTICS — MACROSCOPIC DESCRIPTION

LIGHT AS RAYS



FERMAT'S PRINCIPLE OF LEAST TIME



DESIGN OPTICAL SYSTEMS

OSLO, CODE V, ZMAX

$\lambda \to 0$; CHROMATICITY

IMAGE "QUALITY" → RESOLVE CLOSELY SPACED POINT SOURCES

11/30 – ②

② PHYSICAL OPTICS – WAVE OPTICS – MICROSCOPIC INTERACTIONS OF LIGHT & MATTER

LIGHT AS WAVES – TRAVELLING OSCILLATION

SINUSOIDAL TRAVELING WAVE

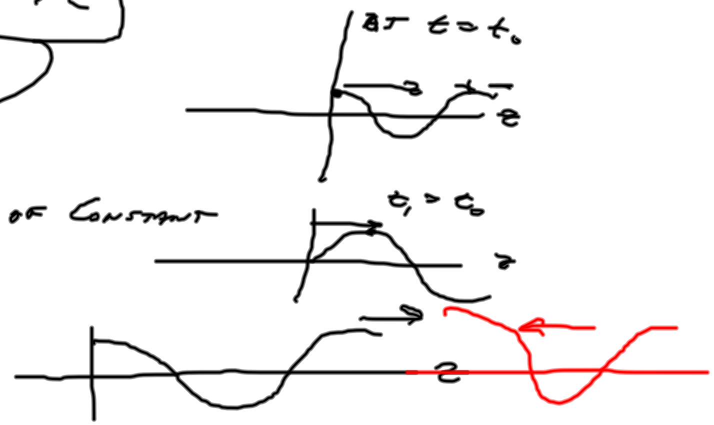
DIRECTION (±)

$$\cos\left(2\pi\left(\frac{z}{\lambda_0} \pm \nu_0 t\right) + \varphi_0\right)$$

$$\boxed{\lambda_0 \nu_0 = V_0 \rightarrow c}$$

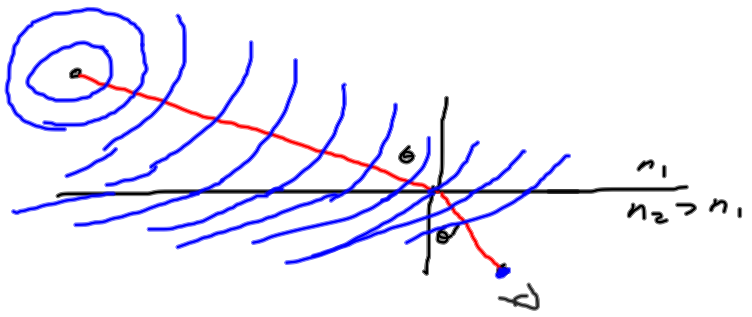
$$2\pi\left(\frac{z}{\lambda_0} - \nu_0 t\right)$$

VELOCITY OF POINT OF CONSTANT PHASE



MAXWELL'S EQUATIONS → WAVE

INTERFERENCE EFFECTS → WAVES



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

INTERFERENCE (FEW SOURCES) ⟶ DIFFRACTION (MANY SOURCES)

INTERFERENCE ⟷ DIFFRACTION

QUALITY METRICS ⟶ RESOLUTION
DEPTH OF FIELD / FOCUS

(A)

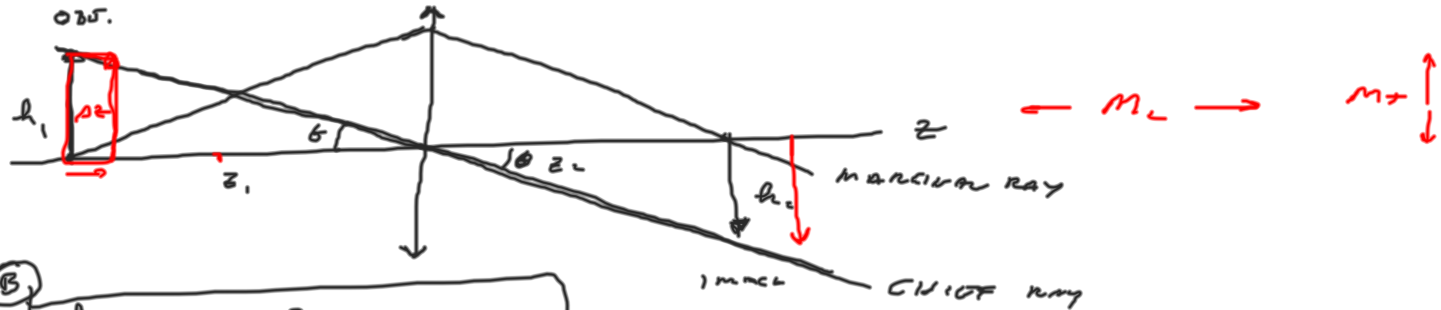
$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

INPUT (z_1) OUTPUT (z_2) SYSTEM (f)

DIRECT (1) $z_2 = \left(\frac{1}{f} - \frac{1}{z_1}\right)^{-1}$

INVERSE (2) $z_1 = \left(\frac{1}{f} - \frac{1}{z_2}\right)^{-1}$

ANALYSIS (3) $f = \left(\frac{1}{z_1} + \frac{1}{z_2}\right)^{-1}$



(B)

$$\frac{h_2}{h_1} = -\frac{z_2}{z_1} = M_T$$

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

$$d\left(\frac{1}{z_1} + \frac{1}{z_2}\right) = d\left(\frac{1}{f}\right) = -\frac{1}{f^2}\,\cancel{df} \rightarrow 0 = 0$$

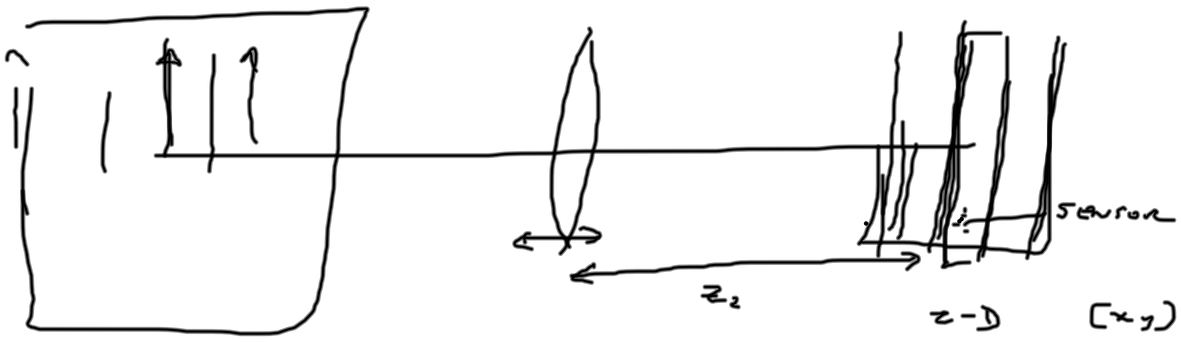
$$-\frac{dz_1}{z_1^2} - \frac{dz_2}{z_2^2} = 0 \implies -\frac{dz_1}{z_1^2} = \frac{dz_2}{z_2^2}$$

$$= \frac{dz_2}{dz_1} = -\frac{z_2^2}{z_1^2} = M_L$$

LONGITUDINAL MAGNIFICATION

$$= -\left(-\frac{z_2}{z_1}\right)^2 = \boxed{-\left(m_T\right)^2 = M_L}$$

$$m_T \equiv \left(-\frac{z_2}{z_1}\right)$$



DEPTH OF FIELD

REAL IMAGES → MEASURE WITH A SENSOR – ACCESSIBLE

$Z_2 > 0$

VIRTUAL IMAGE – NOT ACCESSIBLE

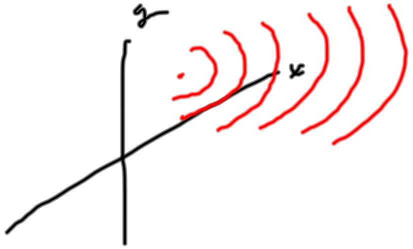
$Z_2 < 0$

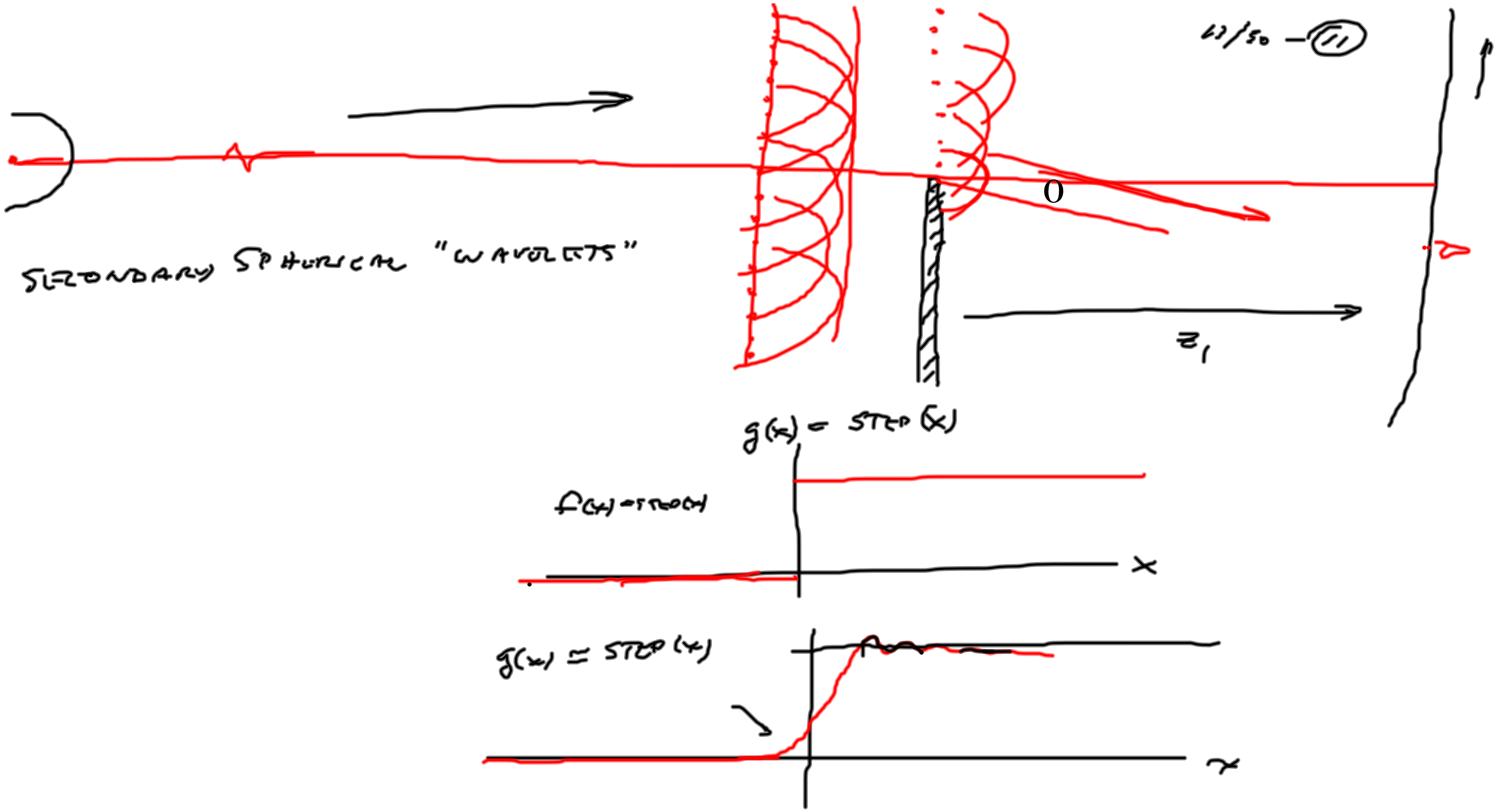
WAVE OPTICS AND IMAGING

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

DESCRIBE PROPAGATION OF LIGHT

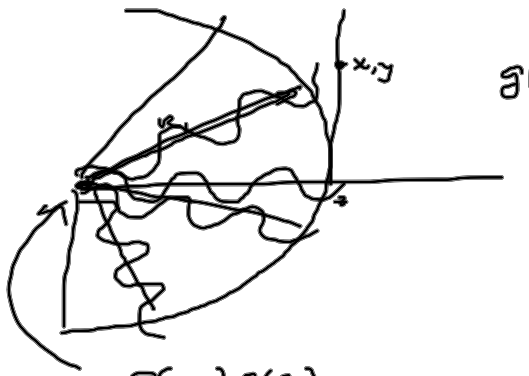
CHRISTIANNE HUYGENS → HUYGENS' PRINCIPLE




SECONDARY SPHERICAL "WAVELETS"
0
z1
g(x) = STEP(x)
x
g(x) ≃ STEP(x)
x

$f[x,y] * \underbrace{h[x,y\,;\,z_1]} = g(x,y;z)$ → FRESNEL DIFFRACTION

$(\ \ )\, e^{+i\pi \frac{x^2+y^2}{\alpha^2}}$



$\delta(x,y)\,\delta(z)$

$g[x,y,z] = \frac{1}{R_1} \underbrace{\cos\left(\frac{2\pi}{\lambda_0} R_1 - 2\pi\nu_0 t + \varphi_0\right)}$

$\frac{1}{R_1}$ ↑ INVERSE SQUARE LAW

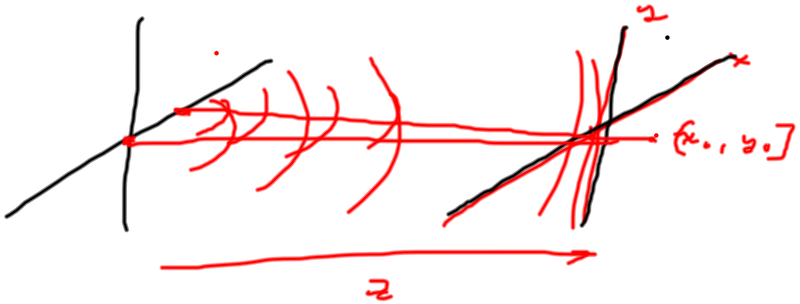
SINUSOID

$R_1 = \sqrt{x^2+y^2+z^2}$ — DISTANCE FROM SOURCE

SPHERICAL WAVES

$\left| g[x,y;z] \right|^2$ → ENERGY

$$g[x,y;z] = \frac{1}{\sqrt{x^2+y^2+z^2}} \cos\left[2\pi\left(\frac{\sqrt{x^2+y^2+z^2}}{\lambda_0} - \nu_0 t\right) + \varphi_0\right]$$



LSV → NO CONVOLUTION

FRESNEL APPROXIMATION TO HUYGENS' PROPAGATION → LSI

$$\frac{1}{z} \cos\left(2\pi\left(\frac{x^2+y^2}{\lambda_0} - \nu_0 t\right)\right) \cos\left(2\pi \frac{z}{\lambda_0}\right) \quad \text{LSI}$$

↑ INVERSE SQUARE

QUADRATIC-PHASE FACTOR