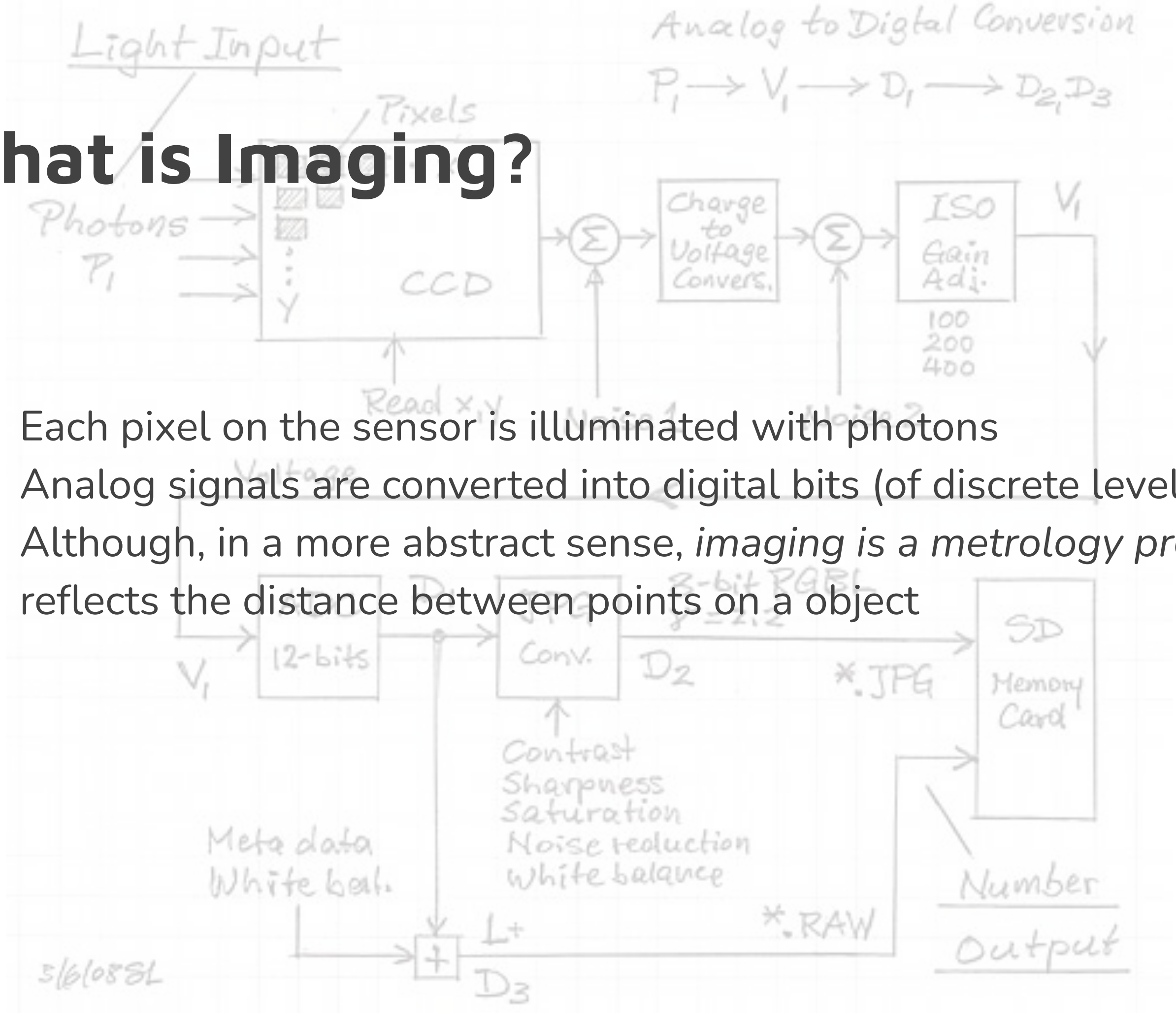
Optimal Imaging of Remote Bodies using Quantum Detectors

Group-7

Introduction

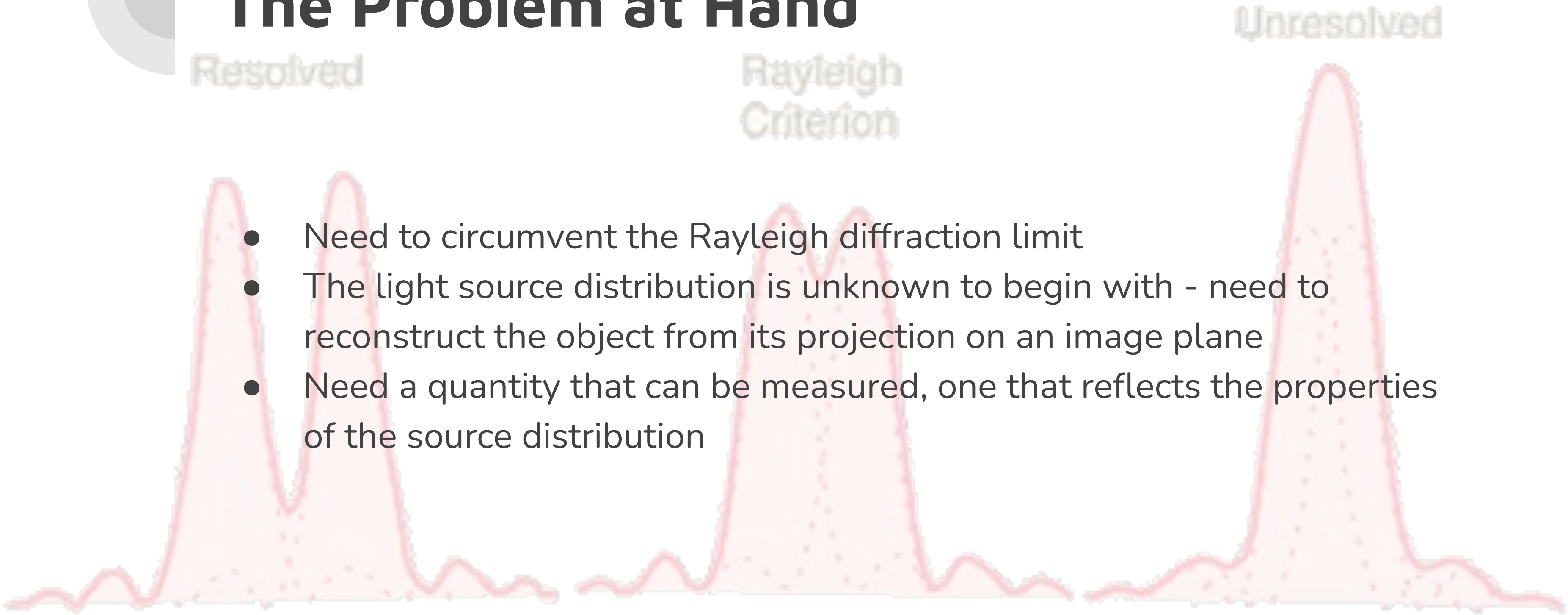
What is Imaging?

- Each pixel on the sensor is illuminated with photons
- Analog signals are converted into digital bits (of discrete levels)
- Although, in a more abstract sense, *imaging is a metrology problem* - reflects the distance between points on a object



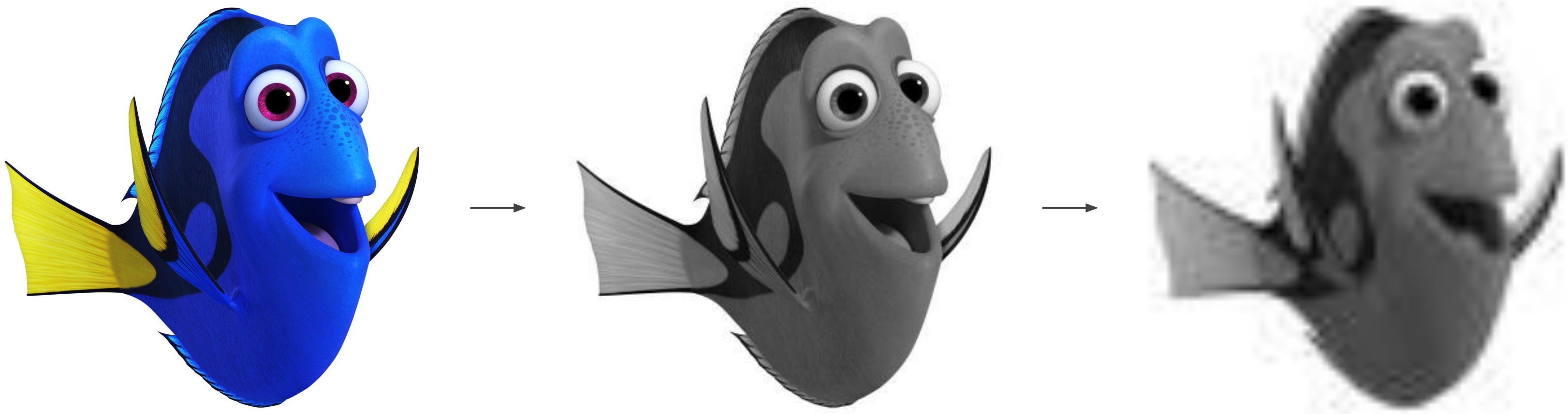
The Problem at Hand

- Need to circumvent the Rayleigh diffraction limit
- The light source distribution is unknown to begin with - need to reconstruct the object from its projection on an image plane
- Need a quantity that can be measured, one that reflects the properties of the source distribution

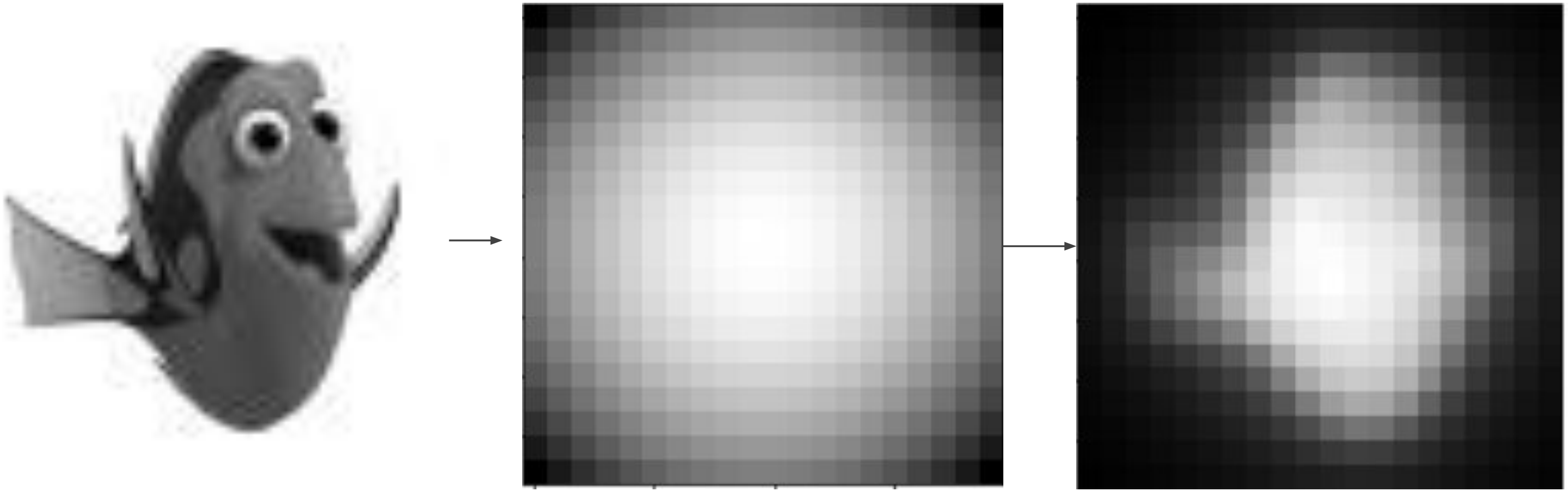


A Classical Simulation

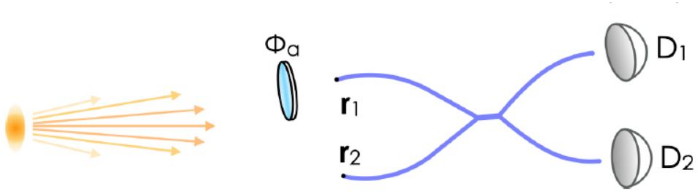
Classical Simulation

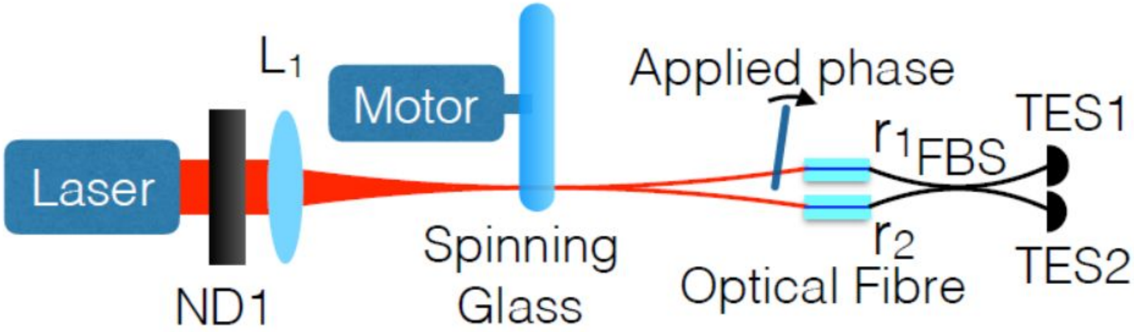


Classical Simulation



Experimental Setup





	Phase Shift	Detectors Used
Count Scheme	Random	Photon Number Resolving
Click Scheme	Random	Not Photon Number Resolving
Traditional Scheme	Fixed	Photon Number Resolving

Complex Degree of Coherence

Mutual Coherence Function:

$$\Gamma_{12} = < V_1(t) V_2^*(t) >_t$$

Complex Degree of Coherence (CDC):

$$\gamma_{12}(\tau) = \frac{\Gamma_{12}(\tau)}{\sqrt{I(x_1) I(x_2)}}$$

Visibility and its relation to magnitude of CDC:

$$\mathcal{V} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2} |\gamma|$$

Van Cittert-Zernike Theorem

The theorem relates the mutual coherence function to the 2 dimensional fourier transform of the intensity distribution of the light source - provided the light source is incoherent.

For the case when the source is far away and the intensity distribution is uniform, this simplifies to

$$\Gamma_{1,2}(u, v) = \iint_{Source} I(l, m) e^{-2\pi i (ul + vm)} dl dm$$

Here u and v are the x and y separation of detector points respectively and (l,m,n) are the direction cosines of a source point as seen from the detectors. Here, n ~ 1.

Quantum Cramér-Rao Bound

$$\Sigma_{\mu\mu} \geq (\mathcal{J}^{-1})_{\mu\mu} \geq (\mathcal{K}^{-1})_{\mu\mu},$$

It relates the Error Covariance matrix (∑) to the quantum Fisher Information Matrix ($\mathscr{K}$)

The quantum Fisher information determines the optimal measurement observables, leading to this setup

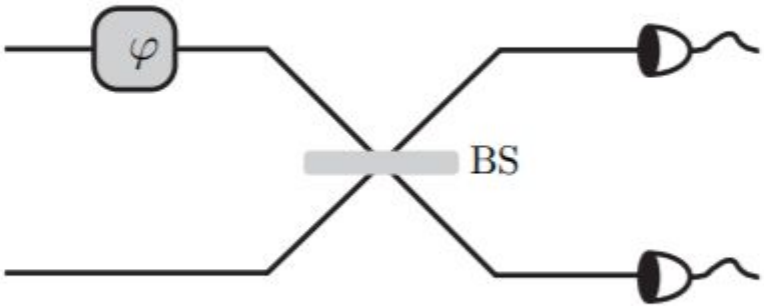


Figure [2]

Estimation of CDC

The paper [1] uses the Maximum Likelihood Estimator to extract the values of $|\gamma|$ and ϕ.

They also reach the following conclusions:

- For an average of dataset sizes from 100 to 10000, the Count and Click scheme perform better than the Traditional scheme.
- For large datasets, the Click scheme performs almost as good as the Count scheme and it's a more economical alternative.