3-Dimensional Imaging

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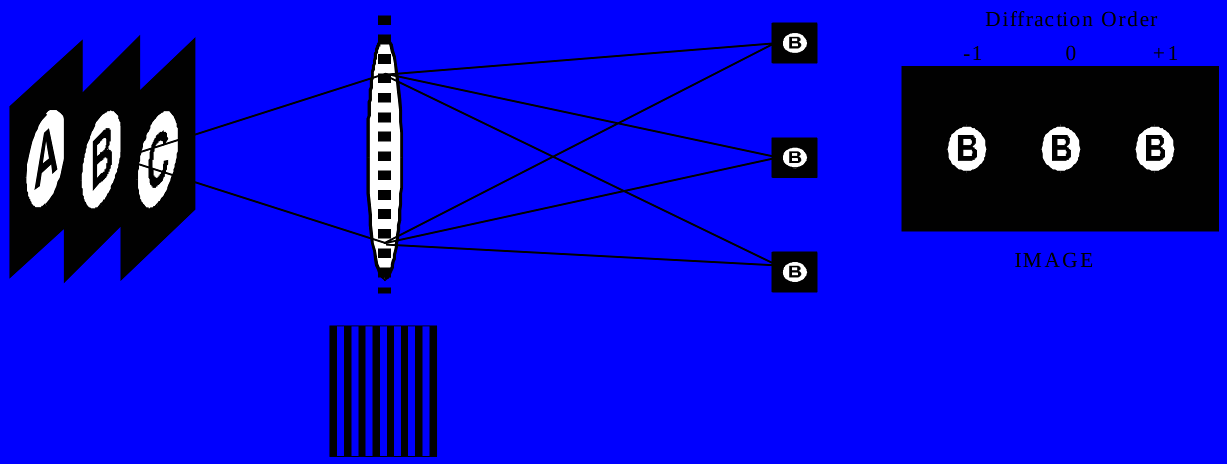
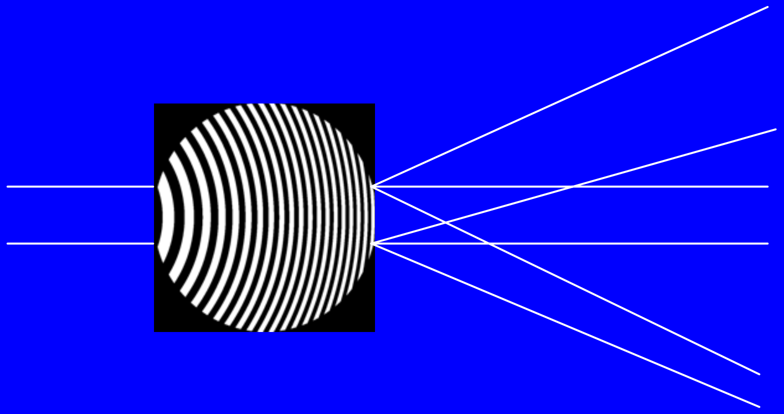
Conventional Imaging

- Conventional imaging system gives in-focus image of a single object plane
- Combined with conventional grating gives multiple images of single object plane



Diffractive Optics

- Distorted grating gives different phase shift in each diffraction order
- Principle of detour phase → holography
- Quadratic distortion → wavefront curvature
- Acts like lens with different focal length in each diffraction order



Grating as a lens

- Grating focal length $${}_m f_g = \frac{R^2}{2mW_{20}}$$

R is the radius of the grating

m is the order of diffraction

W_{20} is the distortion at the edge of the grating

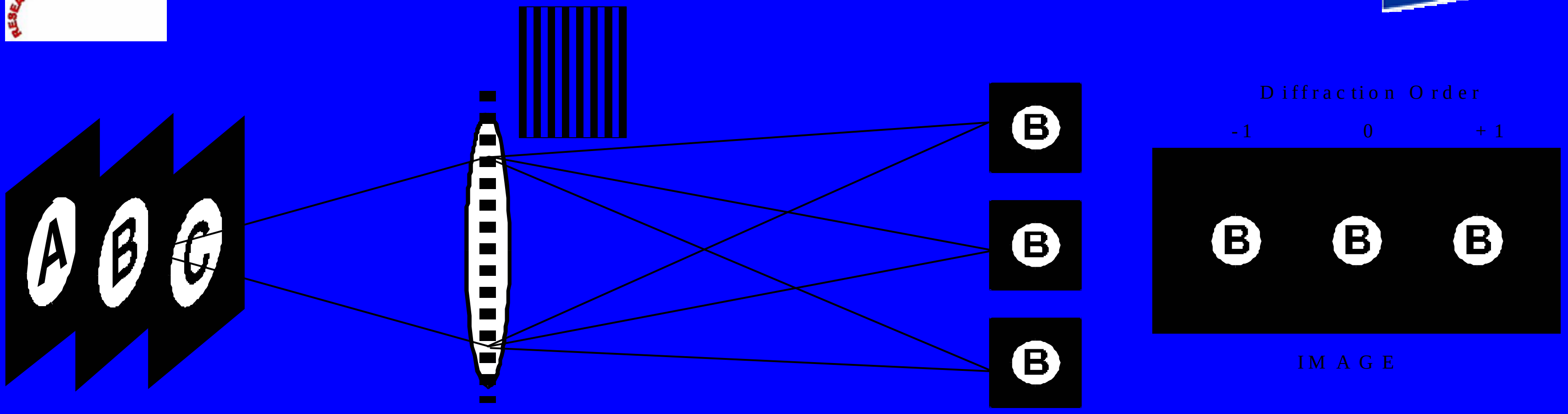
Lens combinations

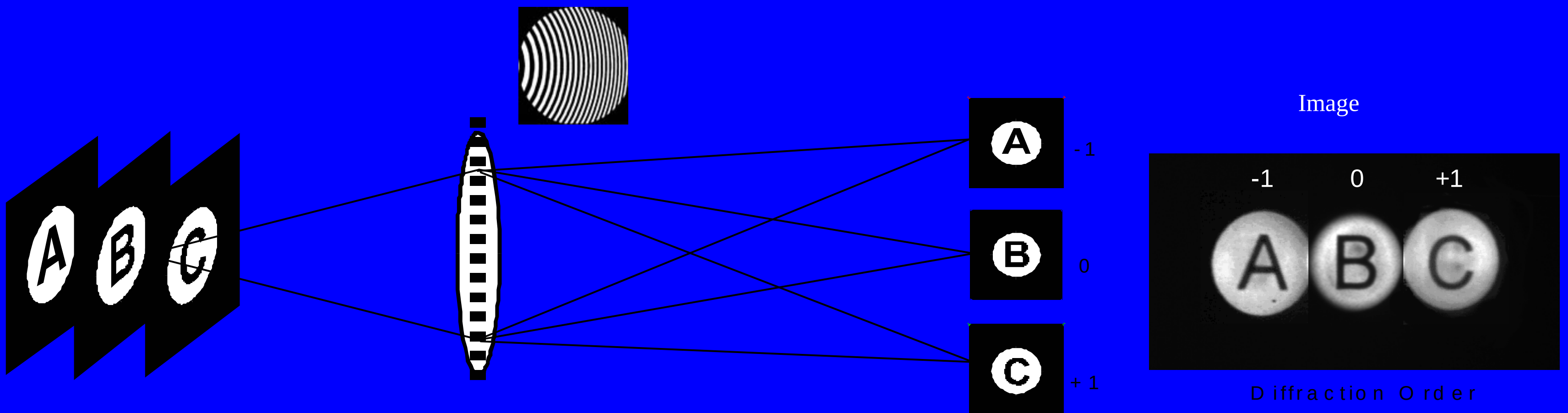
- Standard formulation for lens combination

$$f_c = \frac{f_\ell \, {}_m f_g}{f_\ell + {}_m f_g - s}$$

where	f_ℓ	is the focal length of the lens
	${}_m f_g$	is the focal length of the grating in the m th diffraction order
	s	is the unsigned separation between the lens and grating.

3-dimensional imaging





Telecentric combinations

- Ideally each image slice has same magnification
- If $s = f_\ell$ $$f_c = \frac{f_\ell \, {}_m f_g}{f_\ell + {}_m f_g - s} = f_\ell$$
- i.e. combination focal length is constant $\forall \; {}_m f_g$
- Image magnification is constant in every image

Principal planes

- Primary Principal Plane position

$$p_1 = \frac{s f_\ell}{{}_{m}f_g + f_\ell - s} = \frac{f_\ell^{\,2}}{{}_{m}f_g}$$

- Secondary Principal Plane position

$$p_2 = \frac{s(f_\ell - s)}{{}_{m}f_g + f_\ell - s} = 0$$

wrt objective lens position

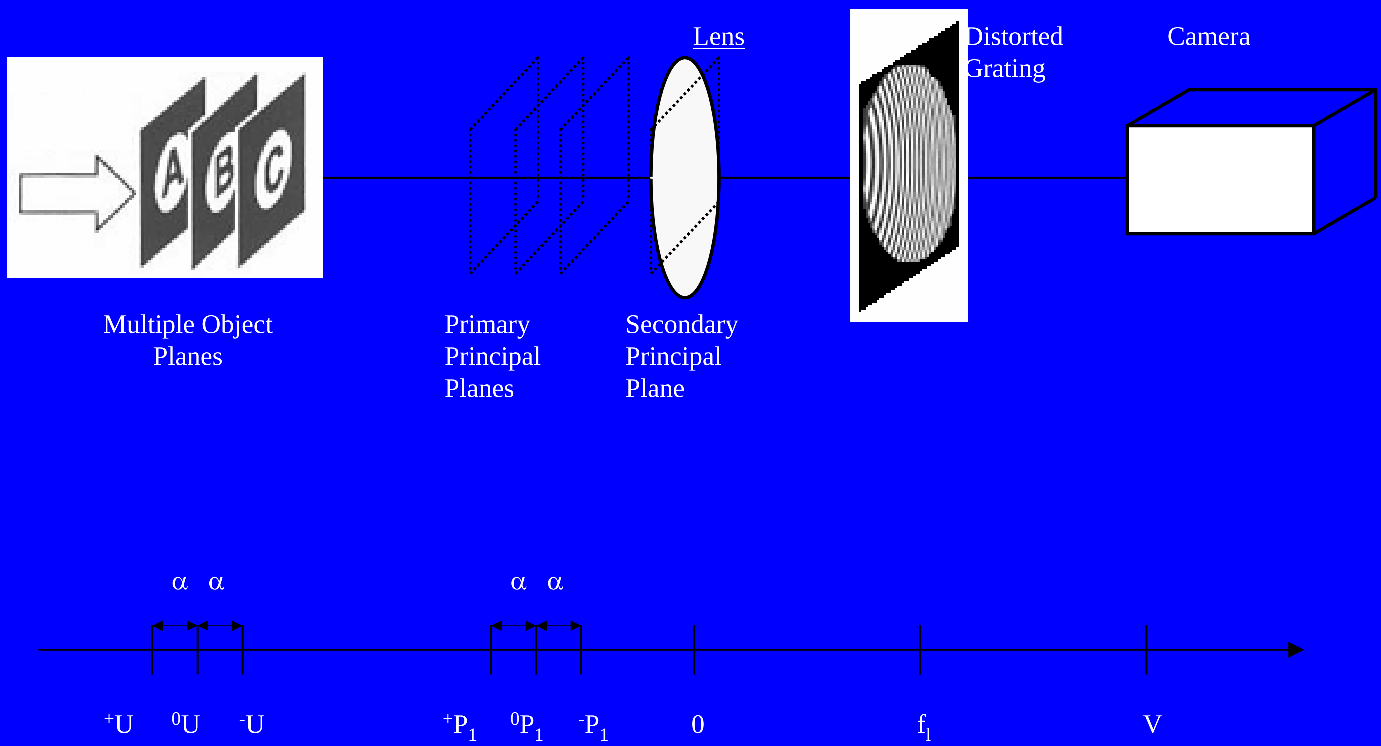
So…

- Primary PP moves by… with respect to lens $\dfrac{f_\ell^2}{m\, f_g}$
- Secondary PP is fixed wrt lens
- Combination focal length is fixed
- Magnification depends on ratio of object dist from PPP to image dist from SPP

Magnification is constant

Object plane in focus varies wrt zero order focus due to movement of Primary PP

System operation



Generalisation

- If original system is modelled as a compound system this analysis is easily generalised
- Spacings of layers in focus in different diffraction orders varies as

$$\frac{f_c^{\,2}}{m\, f_g}$$

with respect to system Primary Principal Plane

Control of depth

- As grating curvature increases
  - ➢ $\dfrac{f_c^2}{{}_m f_g}$ increases
  - ➢ in-focus planes move apart

- No point in using plane separation < depth of focus

Recall $_m f_g = \dfrac{R^2}{2mW_{20}}$ so…
in-focus plane separation increases with m and W_{20}

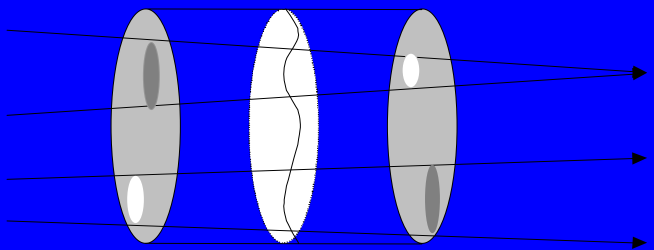
Other possibilities...

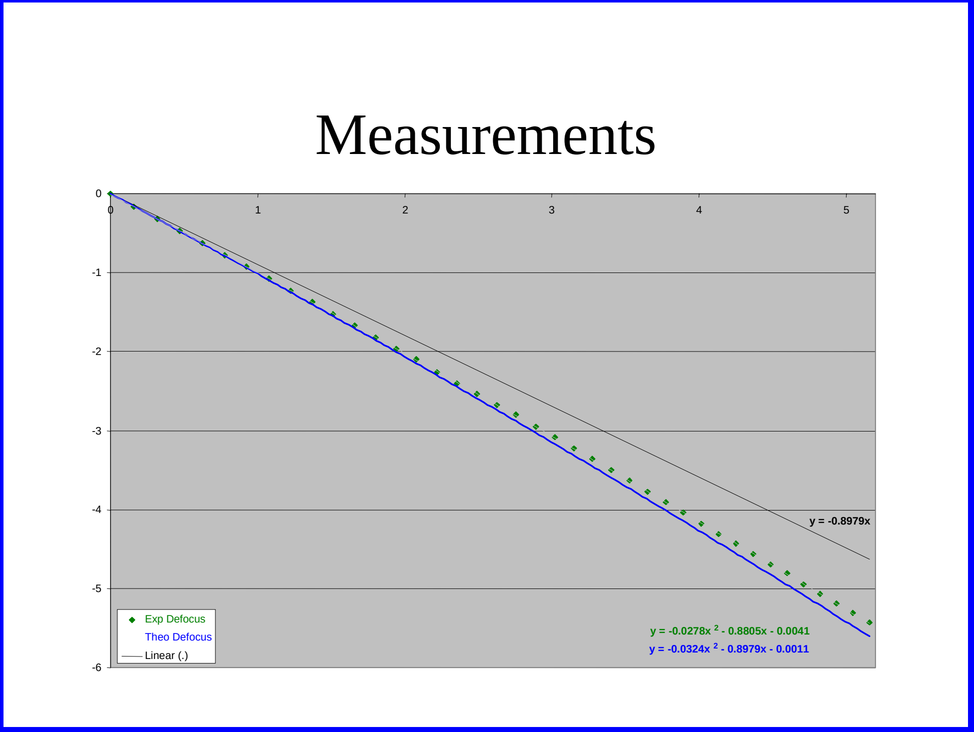
- Instead of grating use programmable lens
- Use wavefront sensing for sub depth of field positioning

- ➢ Wide range of object depths brought to focus electronically at same magnification
- ➢ Thus fast scan with constant magnification is possible
- ➢ Use LC lens

3-D accuracy

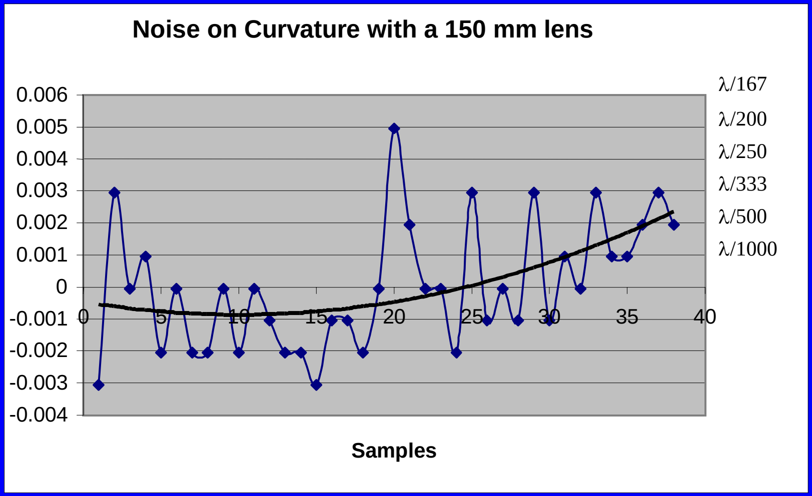
- Determine 3-D position from multiple image





Ranging in dynamic systems

- Current best wavefront measurements ±0.7nm
- Equivalent to ±22.4nm in particle position using f 2 optics
- Scales with $f_{\#}^2$
- Needs aperture to limit field of view
- Complexity of scene to be determined



Ranging depth resolution

$$\Delta d = 8 f_{\#}^2 \Delta s$$

expt data shows focus control 250 x better than usual

Applied for 3-D imaging

- 2 ways to use gratings for 3-D microscopy
- Image in-focus layers with $\Delta d \geq$ depth of focus
  - ➢ Image 2 layers and range to tracer
    - ➢ (x,y) from centroid, *d* from wavefront shape
    - ➢ Density of tracers?
- Other possibility is to scan focus
  - ➢ Programmable or interchangeable lens

Summary

- Some issues (e.g. efficiency, field, flux…) to be resolved - application driven
- 3-dimensional imaging
  - using image slices tiled on single detector
- 3-dimensional imaging
  - tracking small number of particles in 3-D with high accuracy and high speed
- Collaboration with bio-medical groups for whom such techniques are beneficial