

# WORCESTER POLYTECHNIC INSTITUTE MECHANICAL ENGINEERING DEPARTMENT

Optical Metrology and NDT  
ME-593L, B'2011

Introduction: Fringe Skeletonization  
16 November 2011



# Quantitative analysis

## Fringe skeletonization

- Recording of interferograms
- Identification of boundary area (AOI)
- Preprocessing, e.g., filtering
- Identification of fringe centers
- Numbering of interference fringes: fringe ordering
- Reconstruction of phase using interpolation
  - Review papers in handout



# Quantitative analysis

## Fringe skeletonization

Review papers:

- J. Novak, "Techniques for automatic identification and numbering of interference fringes using MATLAB."
- T. Merz, D. Paulus, and H. Niemann, "Line segmentation for interferograms of continuously deforming objects."
- L. Z. Cai, Q. Liu, and X. L. Yang, "A simple method of contrast enhancement and extremum extraction for interference fringes."



# Fringe skeletonization

## Recording of interferograms

- Classic interferometry
  - Michelson
  - Mach-Zehnder
  - Sagnac
- Holographic interferometry
- Digital holographic interferometry
- Speckle pattern interferometry
- White-light interferometry



# Fringe skeletonization

## Identification of boundary area

- Identification of area of interest (AOI)
  - Area of operation
  - Selection of convolution Kernel
  - Minimization of power leakage

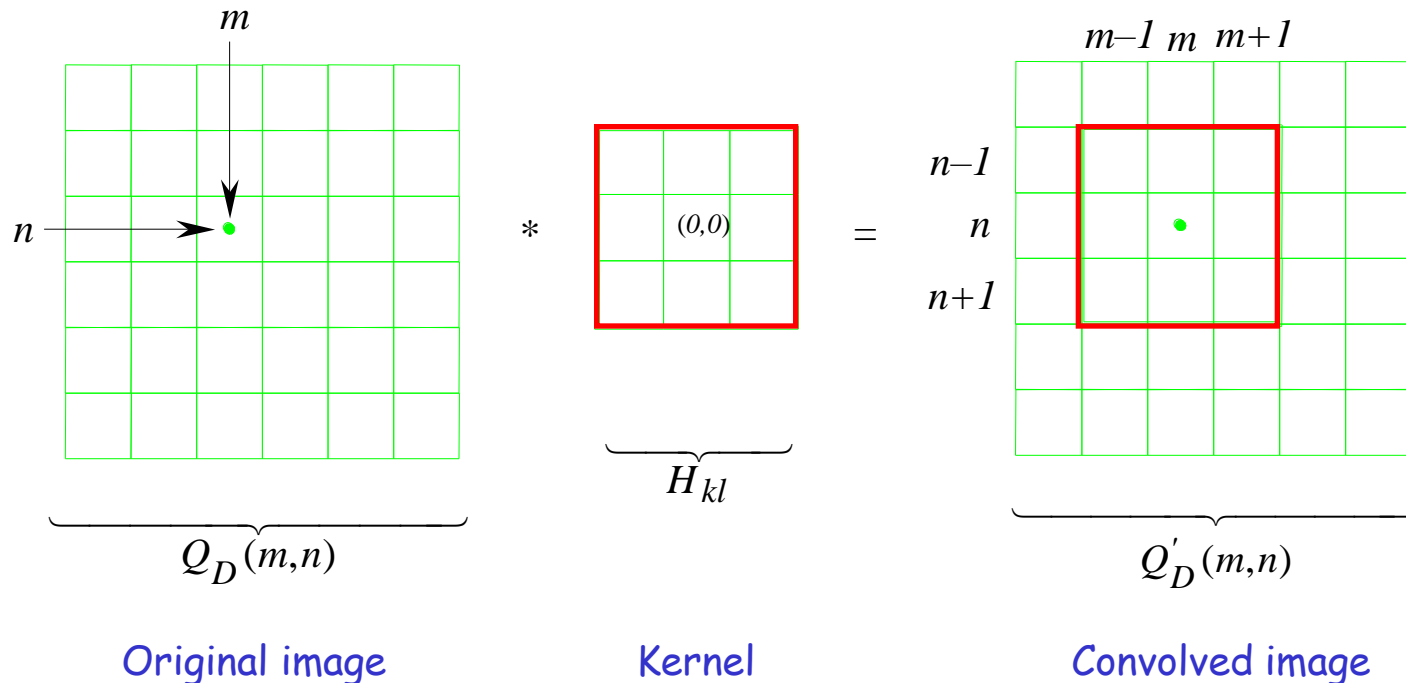


# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

Application of digital spatial convolution to the pixel located at the  $(m,n)$  image plane position

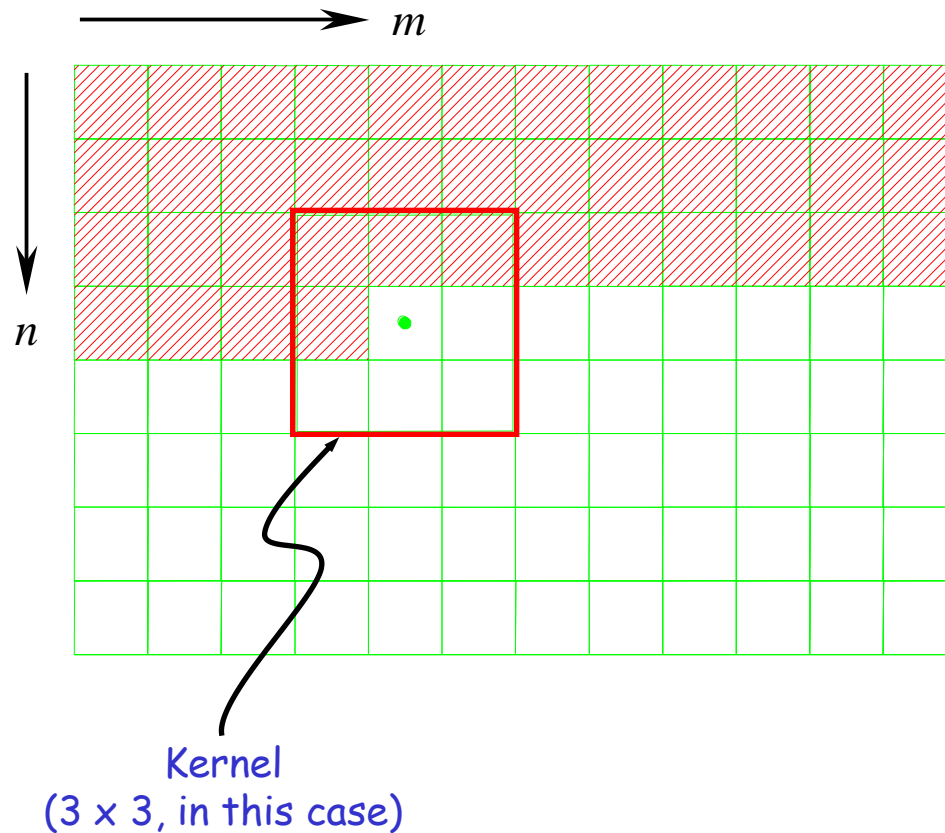
Image convolution:  $Q_D(m,n) * H_{kl} = Q'_D(m,n)$



# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

Digital spatial convolution by scanning the convolution kernel line by line over the entire image plane



# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

Low-pass filtering

Image convolution: 
$$Q'_D(m,n) = \frac{1}{(2r+1) \cdot (2r+1)} \sum_{k=-r}^r \sum_{l=-r}^r Q_D(m+k, n+l)$$

Weighting factors: 
$$H_{kl} = \frac{1}{(2r+1) \cdot (2r+1)}$$

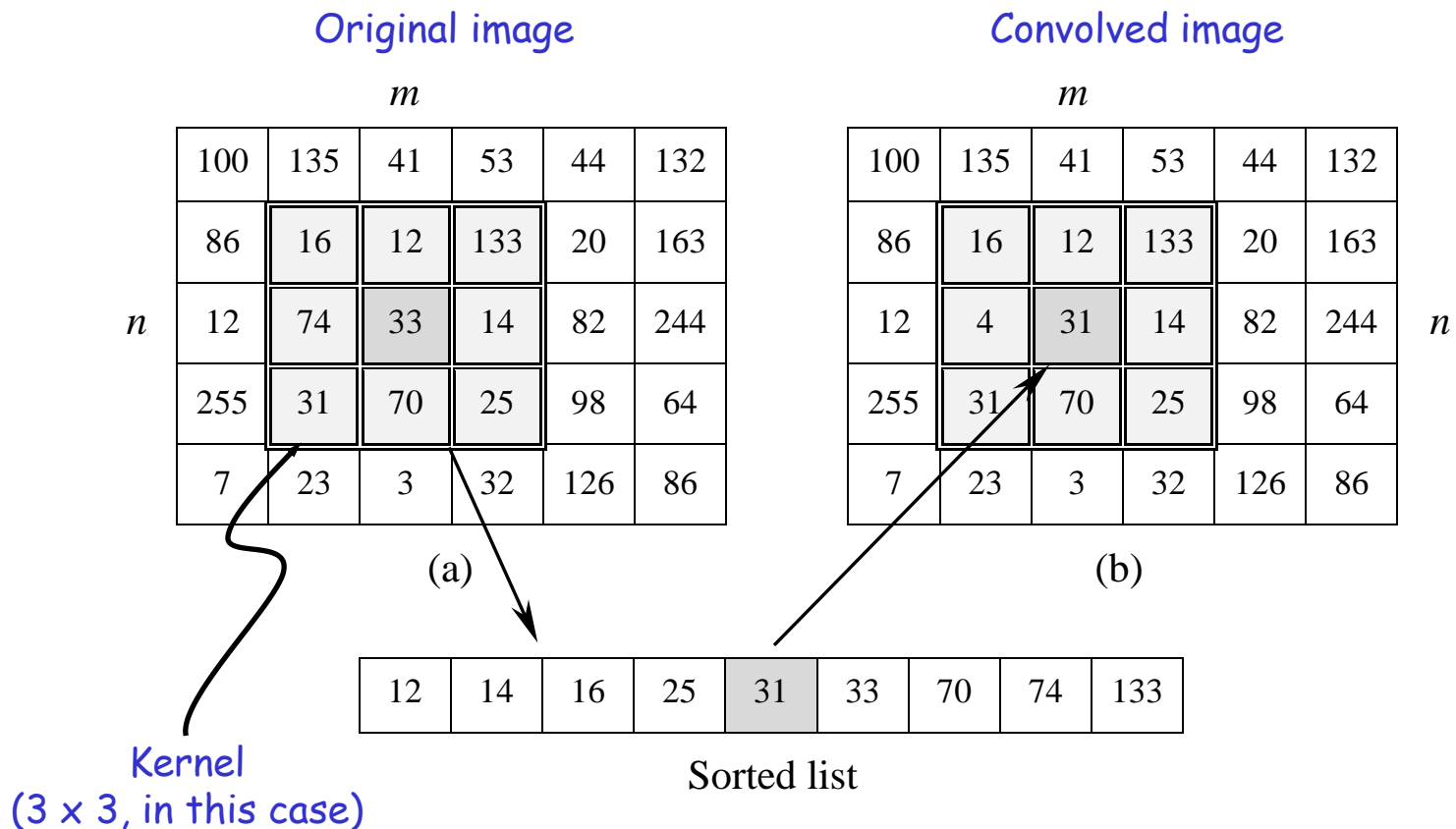


# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

Median filtering

Digital spatial convolution to median filtering the pixel value located at the  $(m,n)$  image plane position



# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

Fourier filtering

Fourier transformation:  $Q_D(f_u, f_v) = \mathcal{F}\{Q_D(m, n)\}$

Convolution in the  
frequency domain:  $Q_D^T(f_u, f_v) = Q_D(f_u, f_v) \cdot W_f(f_u, f_v)$

$W_f(f_u, f_v)$  is the weighting function

Inverse Fourier transformation:  $Q_D'(m, n) = \mathcal{F}^{-1}\{Q_D^T(f_u, f_v)\}$

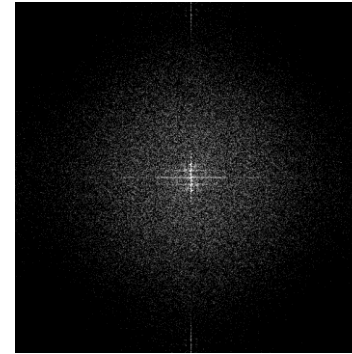
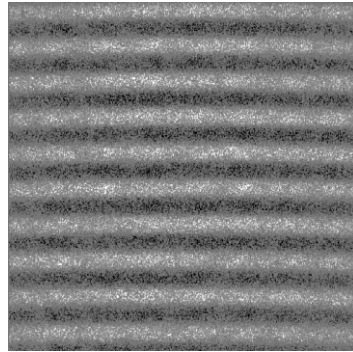
# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

Fourier filtering

Fourier transformation:  $Q_D(f_u, f_v) = \mathcal{F}\{Q_D(m, n)\}$

Original  
interferogram



Original  
interferogram:  
frequency domain

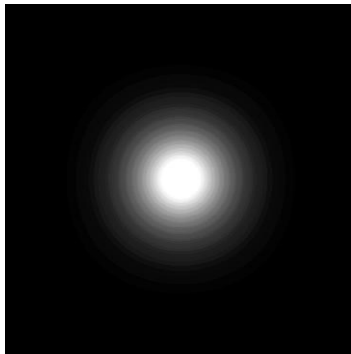
# Fringe skeletonization

Pre-processing, e.g., filtering: convolution

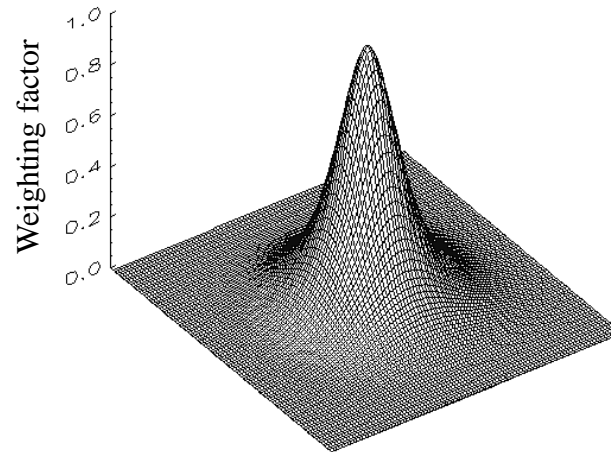
Fourier filtering

$W_f(f_u, f_v)$ , weighting function: Gaussian function

2D representation



3D representation



# Fringe skeletonization

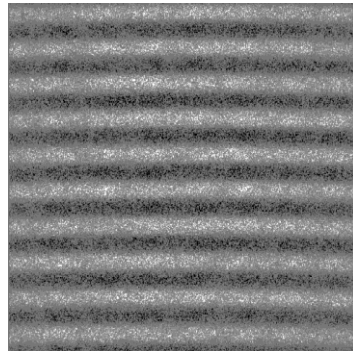
Pre-processing, e.g., filtering: convolution

Fourier filtering

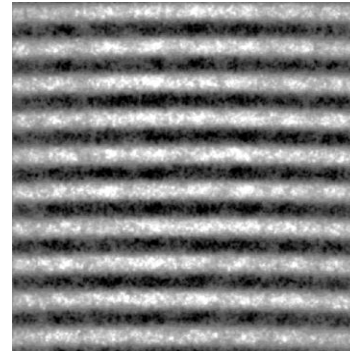
Convolution in the frequency domain:  $Q_D^T(f_u, f_v) = Q_D(f_u, f_v) \cdot W_f(f_u, f_v)$

Inverse Fourier transformation:  $Q_D'(m, n) = \mathcal{F}^{-1}\{Q_D^T(f_u, f_v)\}$

Original  
interferogram



Filtered  
interferogram

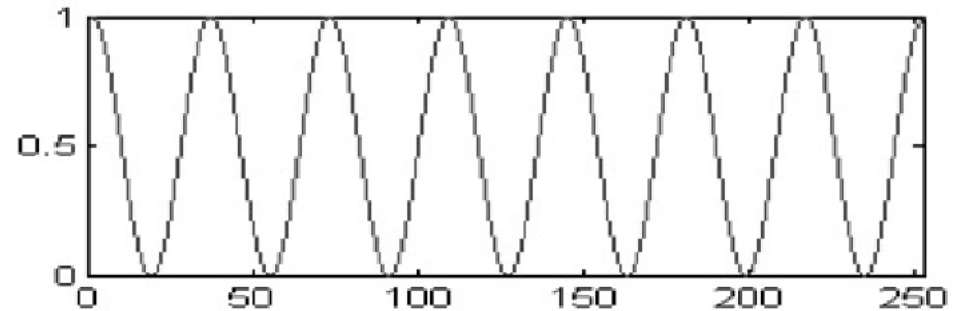
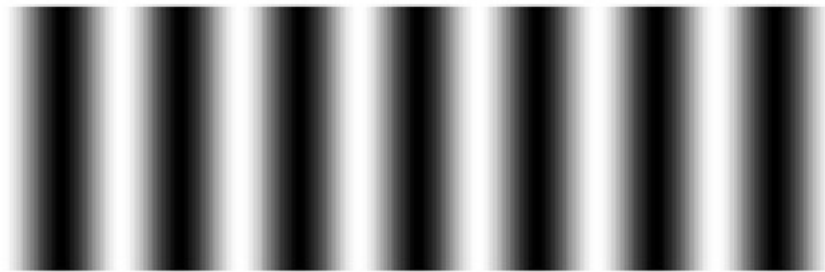


# Fringe skeletonization

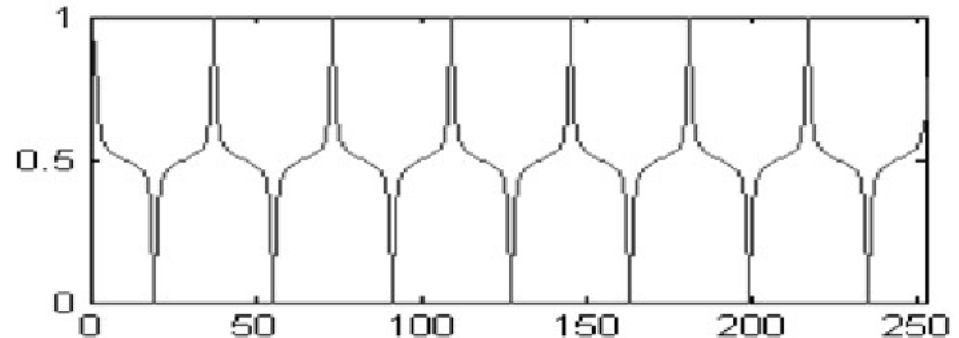
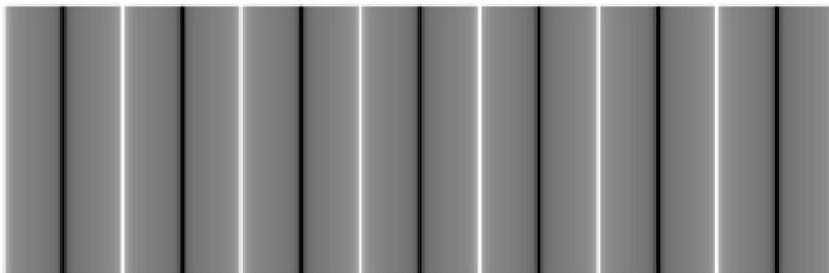
## Pre-processing: thinning

Multiple algorithms exist, e.g., contrast enhancement, edge detection, etc.

Original interferogram

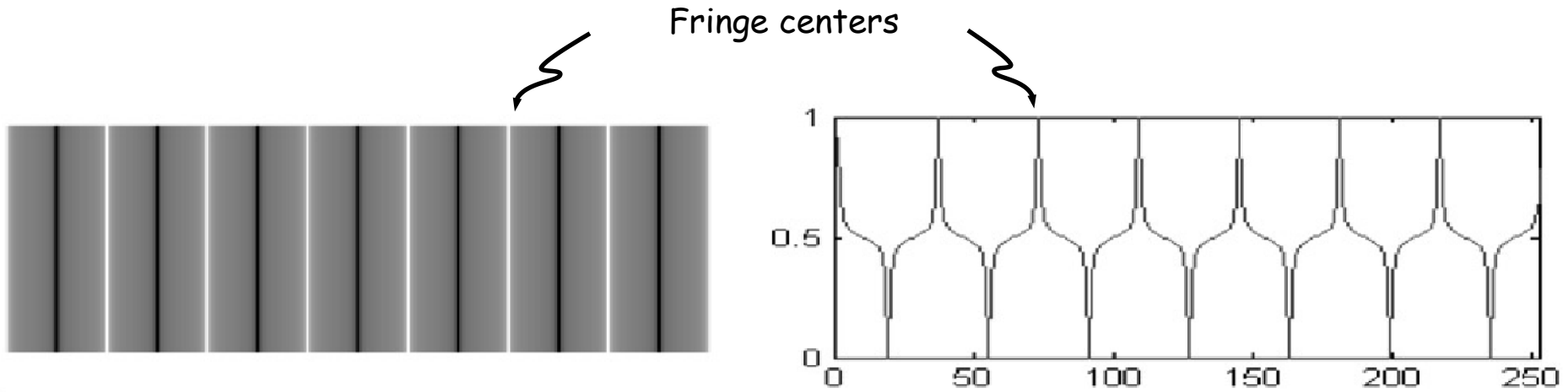


Thinned fringes: contrast enhancement



# Fringe skeletonization

Identification of fringe centers

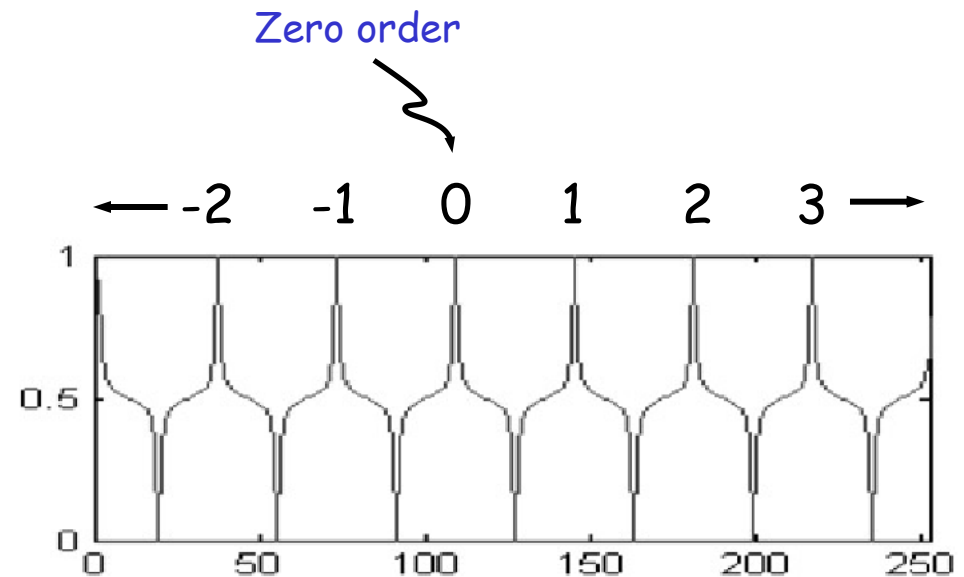
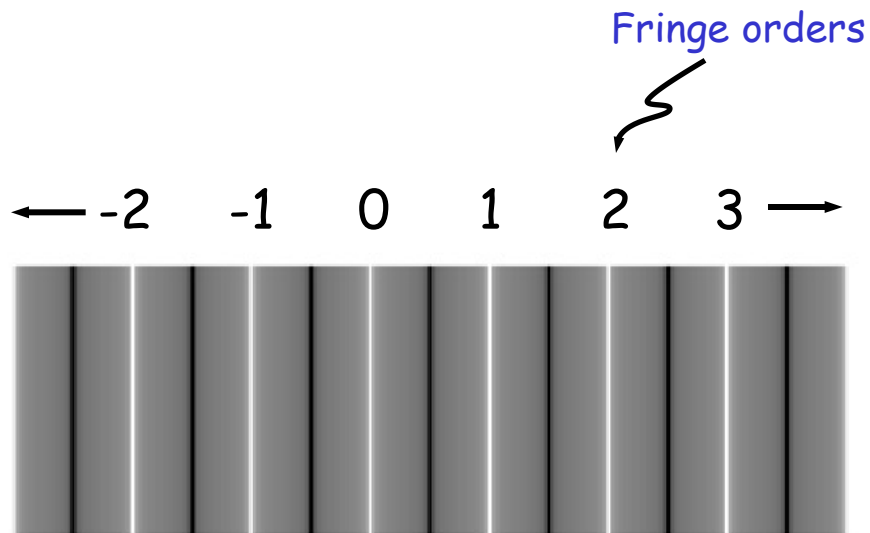


Thinned fringes: contrast enhancement

# Fringe skeletonization

## Fringe ordering

- Identify zero-order: understanding of the physical phenomena
- Use sequential ordering



# Fringe skeletonization

## Phase reconstruction

Fringe interpolation, e.g., Lagrange, Zernike polynomials, etc.

Lagrange polynomials of degree  $n-1$

$$f(x_0) = \sum_{i=1}^n w_i(x_0) f(x_i)$$

$$w_i(x_0) = \frac{\prod_{\substack{j=1 \\ j \neq i}}^{n-1} (x_0 - x_j)}{\prod_{\substack{j=1 \\ j \neq i}}^{n-1} (x_i - x_j)}$$

$$f(x_0) = w_1(x_0)f(x_1) + w_2(x_0)f(x_2) \\ + w_3(x_0)f(x_3) + \dots + w_n(x_0)f(x_n)$$



# Fringe skeletonization

## Phase reconstruction

Fringe interpolation, e.g., Lagrange, Zernike polynomials, etc.

Lagrange polynomials of degree  $n-1$

$n = 2$ :

$$w_1(x_0) = \frac{x_0 - x_2}{x_1 - x_2}$$

$$w_2(x_0) = \frac{x_0 - x_1}{x_2 - x_1}$$

and

$$\begin{aligned} f(x_0) &= w_1(x_0)f(x_1) + w_2(x_0) \cdot f(x_2) \\ &= \frac{x_0 - x_2}{x_1 - x_2} f(x_1) + \frac{x_0 - x_1}{x_2 - x_1} f(x_2) \end{aligned}$$

$$w_i(x_0) = \frac{\prod_{\substack{j=1 \\ j \neq i}}^{n-1} (x_0 - x_j)}{\prod_{\substack{j=1 \\ j \neq i}}^{n-1} (x_i - x_j)}$$
$$f(x_0) = \sum_{i=1}^n w_i(x_0) f(x_i)$$