Enhancement of ultrasound images by linear and non-linear filtering

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Aims and problems

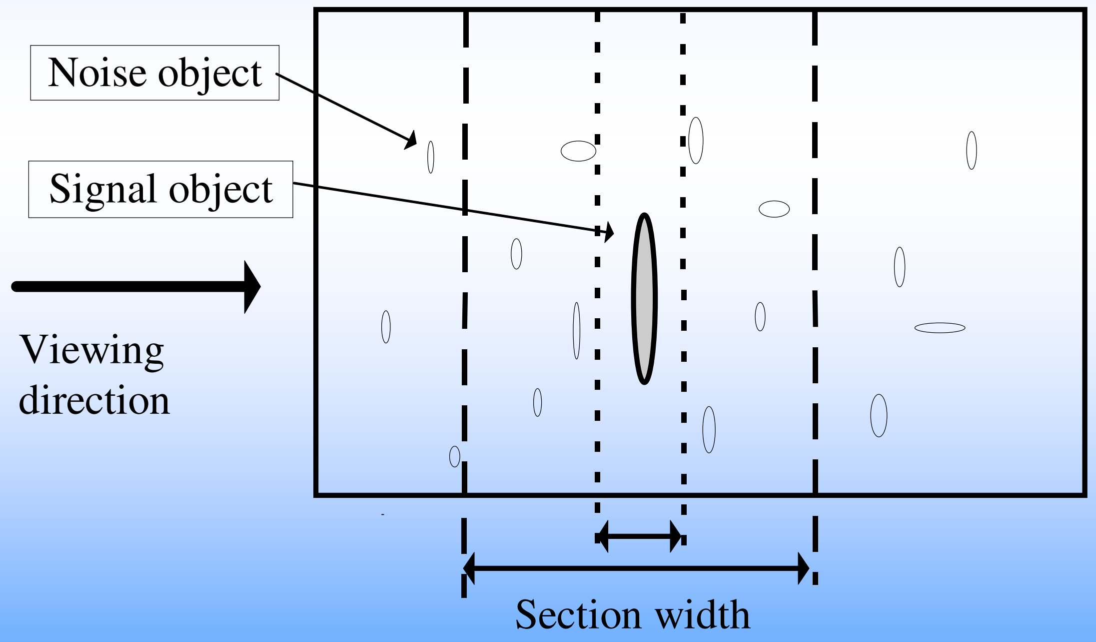
- ***The aim:***

Identification of defects within stainless steel components by manual inspection of images formed by scanning the component with ultrasound.

- ***The problem:***

Energy scattered from individual metal grains is comparable with the energy reflected from defects.

The Physical System



The Approach

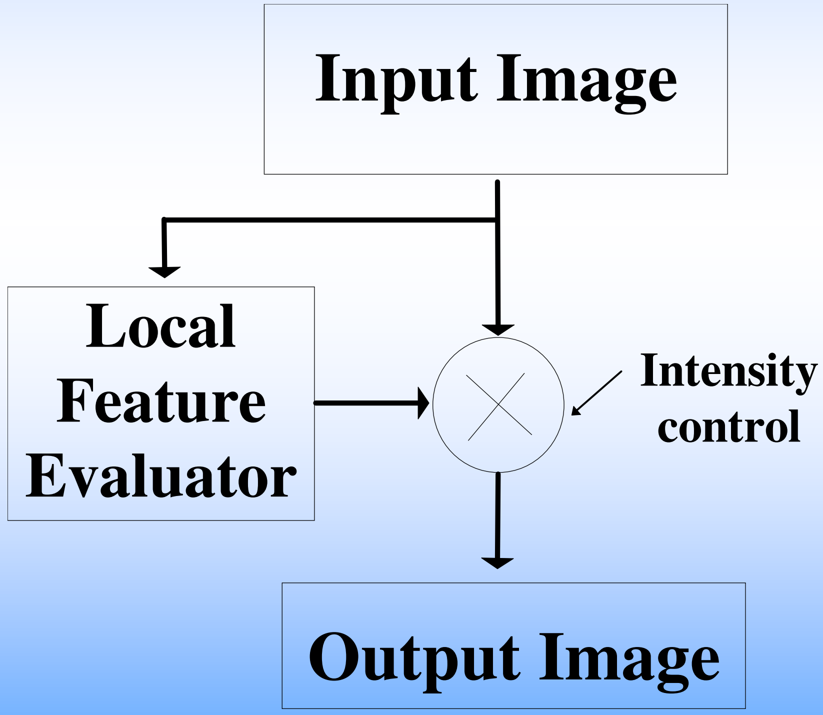
- **Examine same image after filtering in several different ways.**
- **Linear and non-linear spatial digital filtering of the ultrasound images.**

Feature based filtering

- **Position a *window* over each pixel in the image and find the value of a *feature* associated with the set of pixels lying under the window.**

- **Choose a *feature* whose numerical value is large when a defect is present and small when only noise is present. "Filter" the image by scaling each pixel value by its associated local feture value.**

Filtering by Feature



Examples of feature based filtering

- *Class discriminative linear transform* - **Define characteristic eigen vectors for both noise and defect regions. Form feature from ratio of the eigenvalues of the two eigen vectors returned by data under window.**

- ***Linear convolutional filter*** **- If noise and defect objects have non-overlapping local spectral descriptions, then use this as the feature for selection of image components.**

Probability Images

- **Form image whose pixel values are the product -sum of pseudo probability values of the *local image features* given their corresponding *global image feature values:***

  E.g using divergence measures of two different features of the image:

$$P_{l,g} = e^{-D_{\lg}(feature1)} . e^{-D_{\lg}(feature2)}$$

Linear (Convolutional) Spatial Frequency Filters

$$I_{out}(x,y,z)=$$

$$\sum_{i=-w}^{w}\sum_{j=-w}^{w}\sum_{k=-w}^{w} I_{in}(x+i,y+j,z+k).h(i,j,k)$$

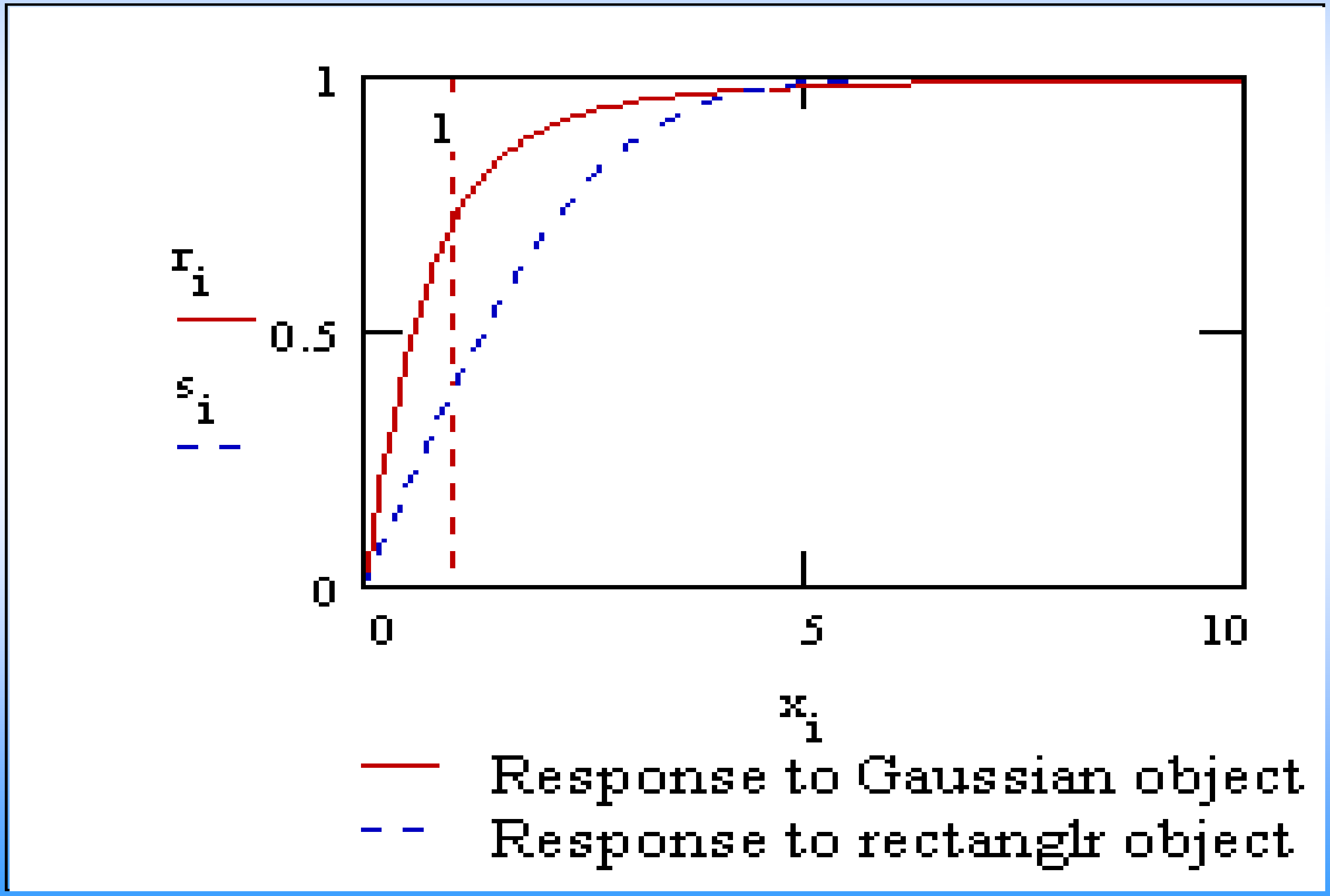
Designing Linear Filters for Specified Frequency Response

- Use FIR zero phase filters
- Translate noise object and wanted object sizes to spatial frequency ranges.
- Specify Magnitude Frequency response
- Use Windowing or Frequency sampling method to find filter coefficients

Using Gaussian filters

- Good approach because step response of filter is well behaved..
- Impulse response: $$h(x) = \frac{1}{\sqrt{2\pi\sigma^2}} . e^{-\frac{x^2}{2\sigma^2}}$$
- Frequency response: $$H(\omega) = \frac{1}{\sqrt{2\pi B^2}} . e^{-\frac{\omega^2}{2B^2}}$$

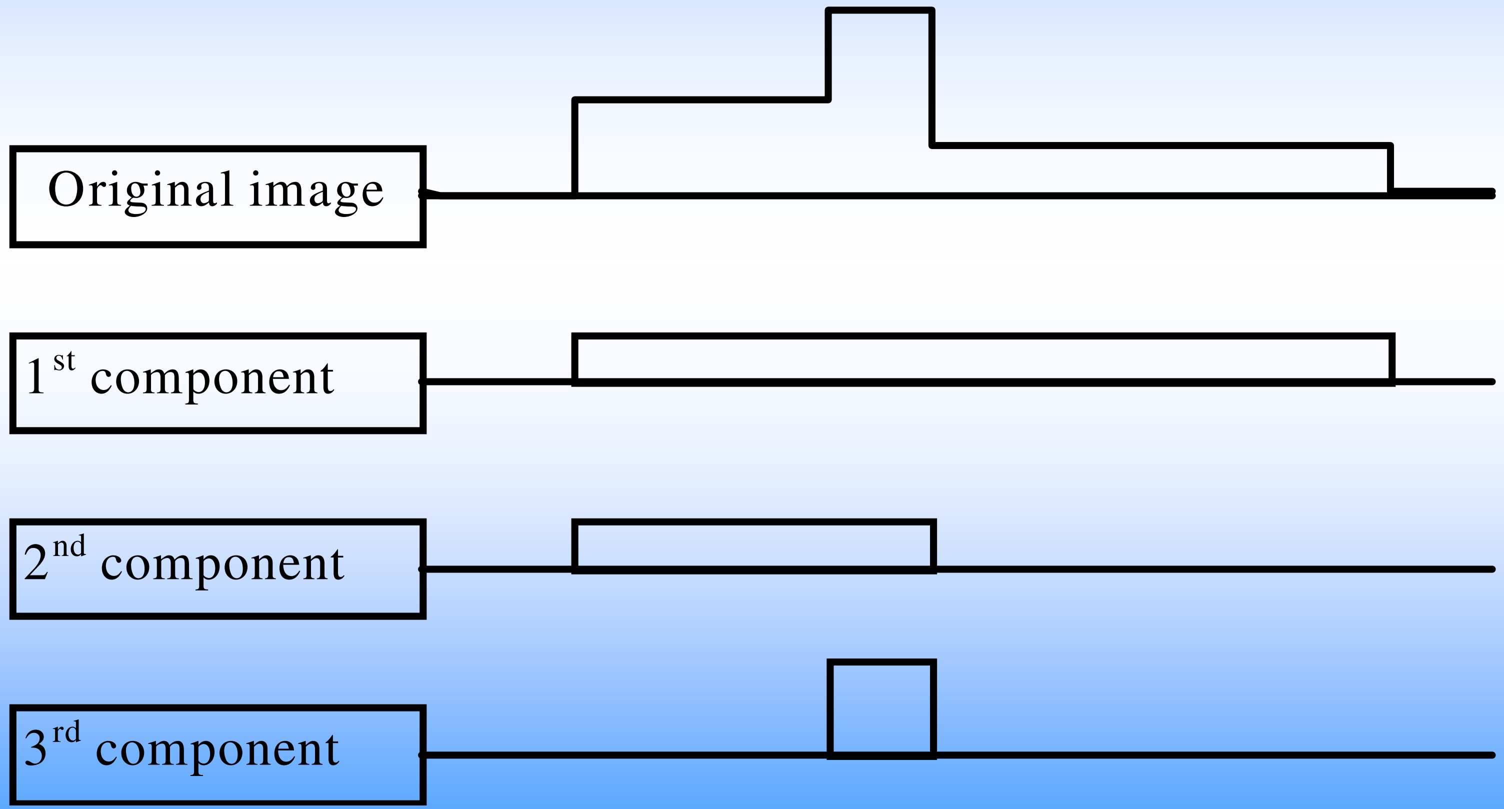
Gaussian object size response



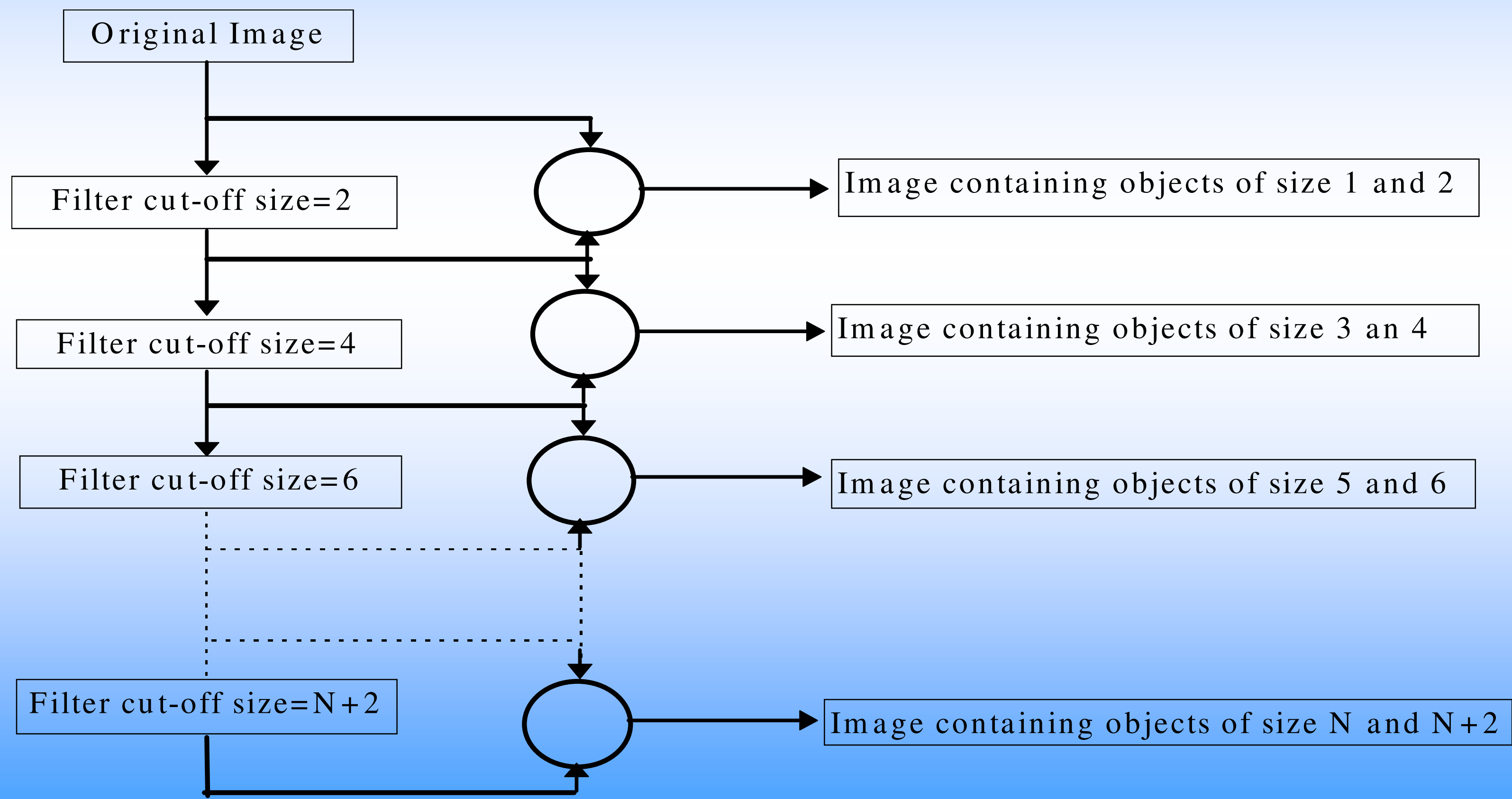
Linear spatial filtering problems:

- **Discrete objects have broadband and continuous spectra. Therefore noise and defect objects can never be completely separated by a *linear* frequency filter.**
- ***Corollary:* Spatial discontinuities such as object edges are destroyed by sharp cut-off frequency filters**
- **A natural descriptor for noise and defects is *object size*, not sinusoidal frequency content.**

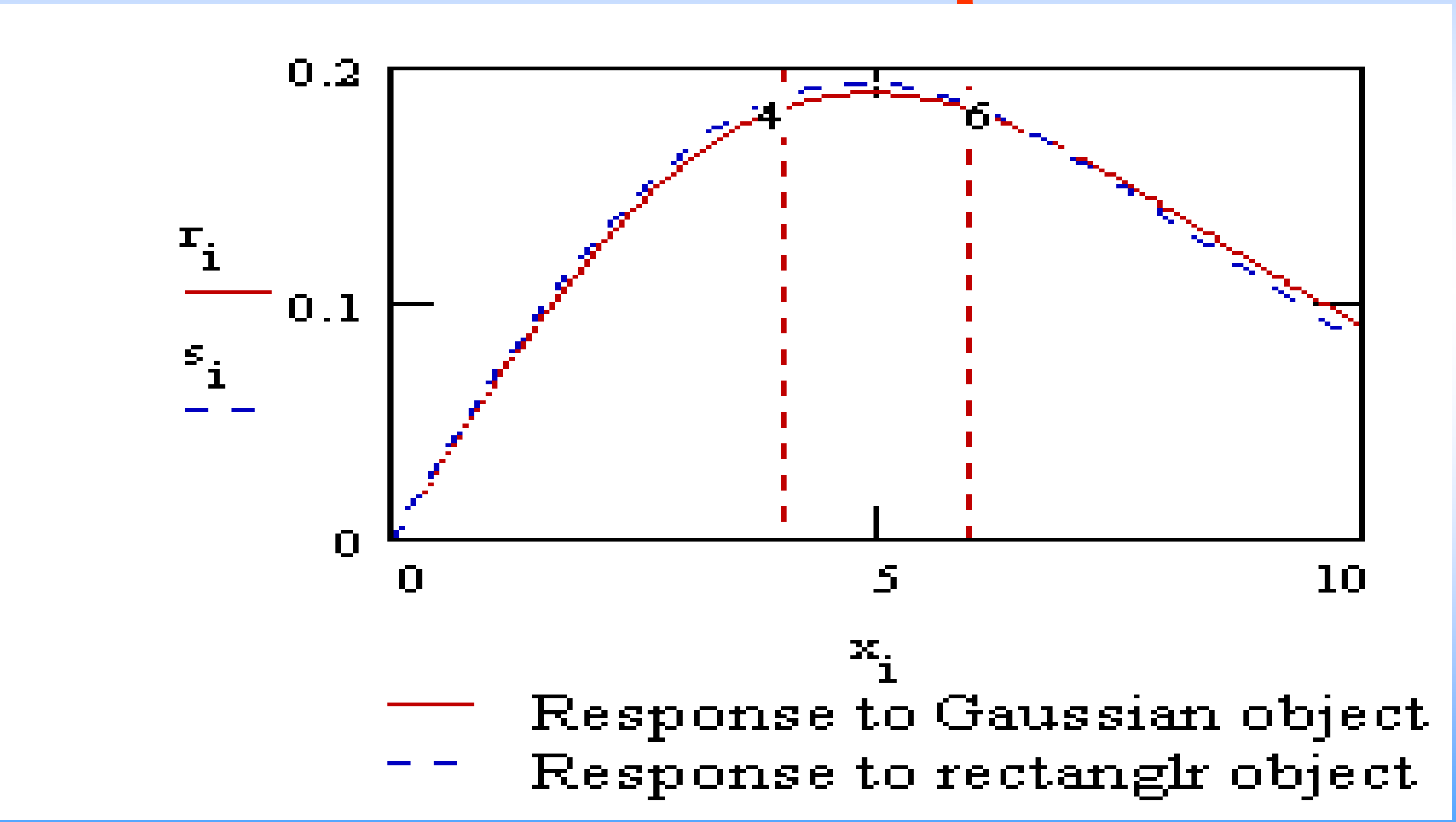
Scale decomposition of image



Scale - space decomposition



Size response of one stage of Gaussian Decomposition

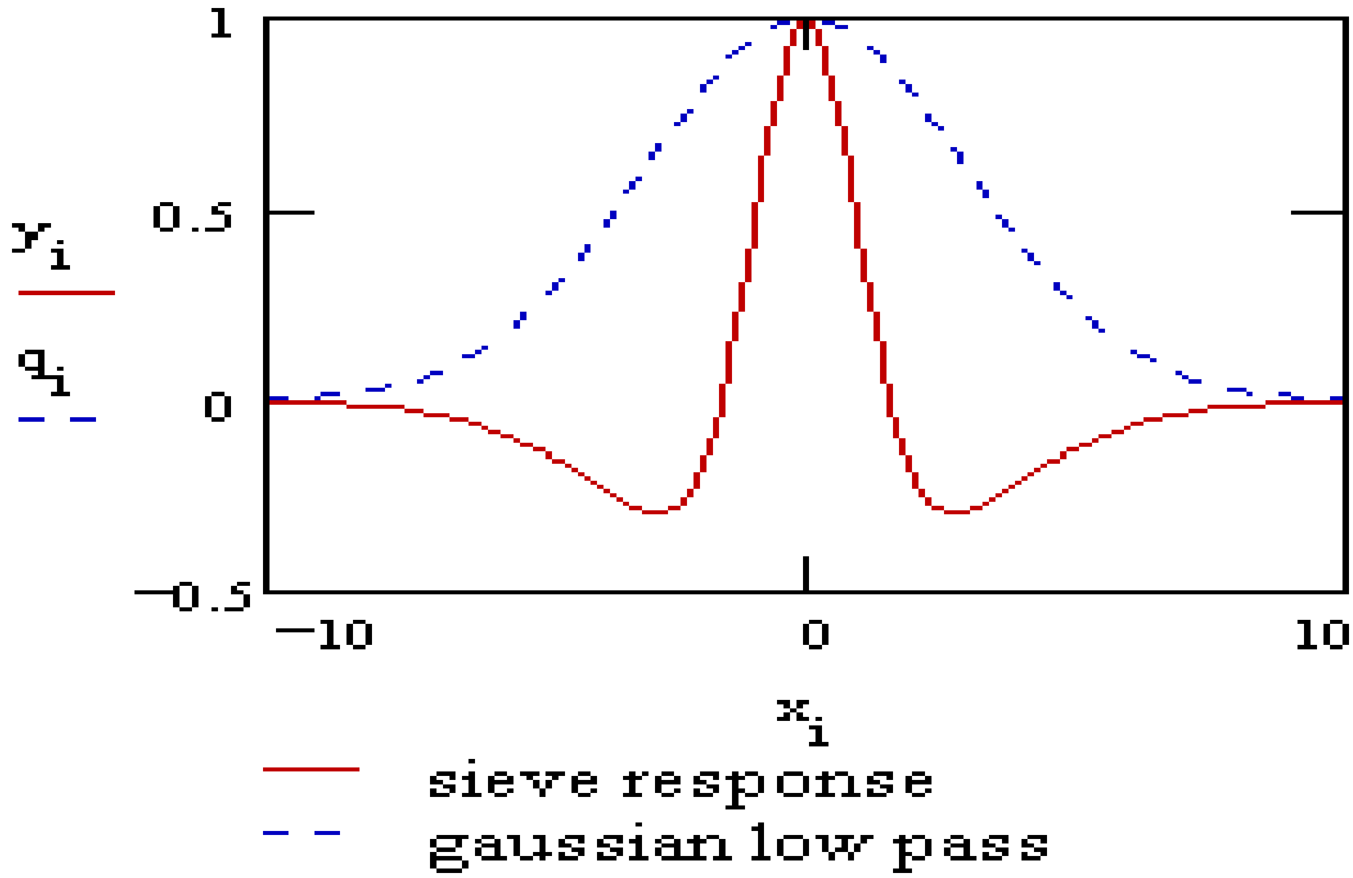


Impulse response of one stage

$$h_n(x) = \frac{1}{\sqrt{2\pi\sigma_n^2}} . e^{-\frac{x^2}{2\sigma_n^2}}$$

$$s_n(x) = \frac{1}{\sqrt{2\pi}} \{ \frac{e^{-\frac{x^2}{2\sigma_n^2}}}{\sigma_n} - \frac{e^{-\frac{x^2}{2\sigma_{n-1}^2}}}{\sigma_{n-1}} \}$$

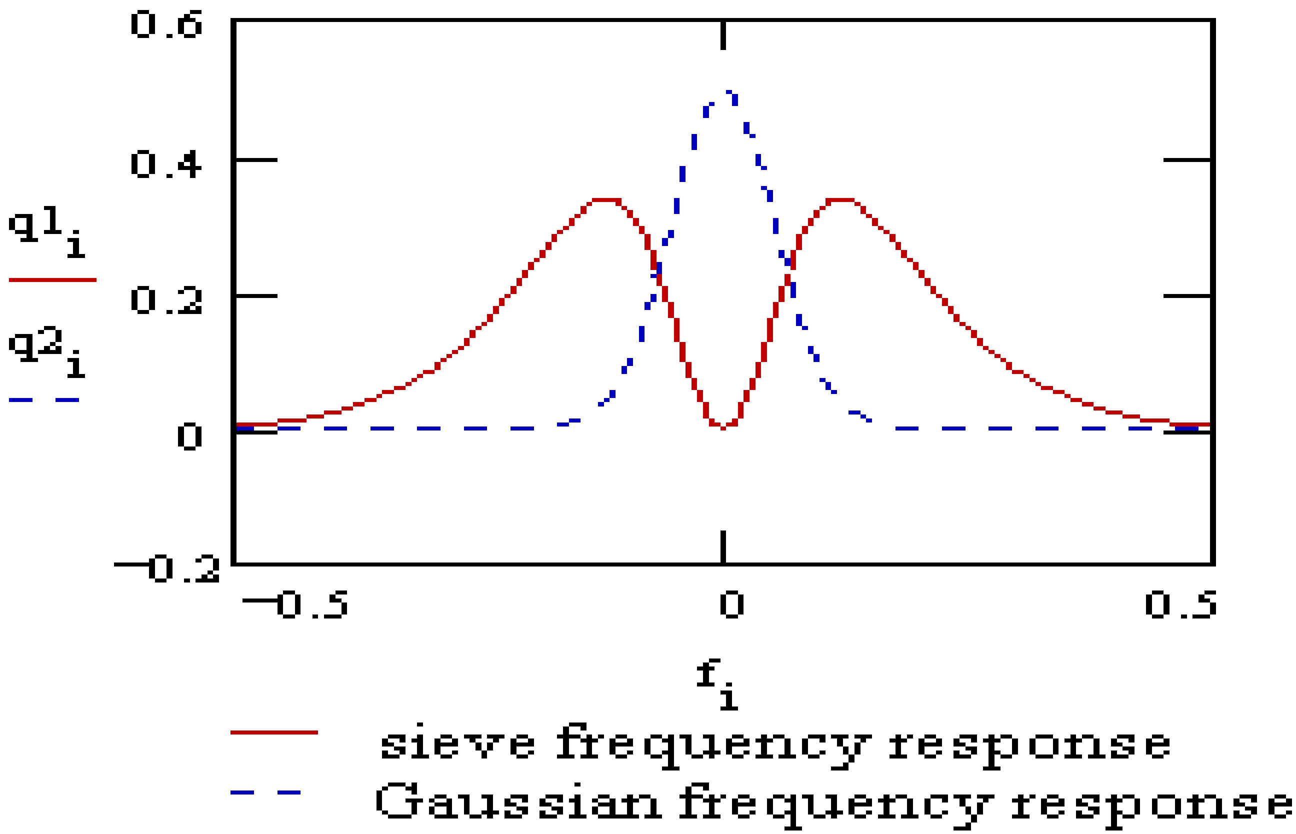
Single stage impulse response



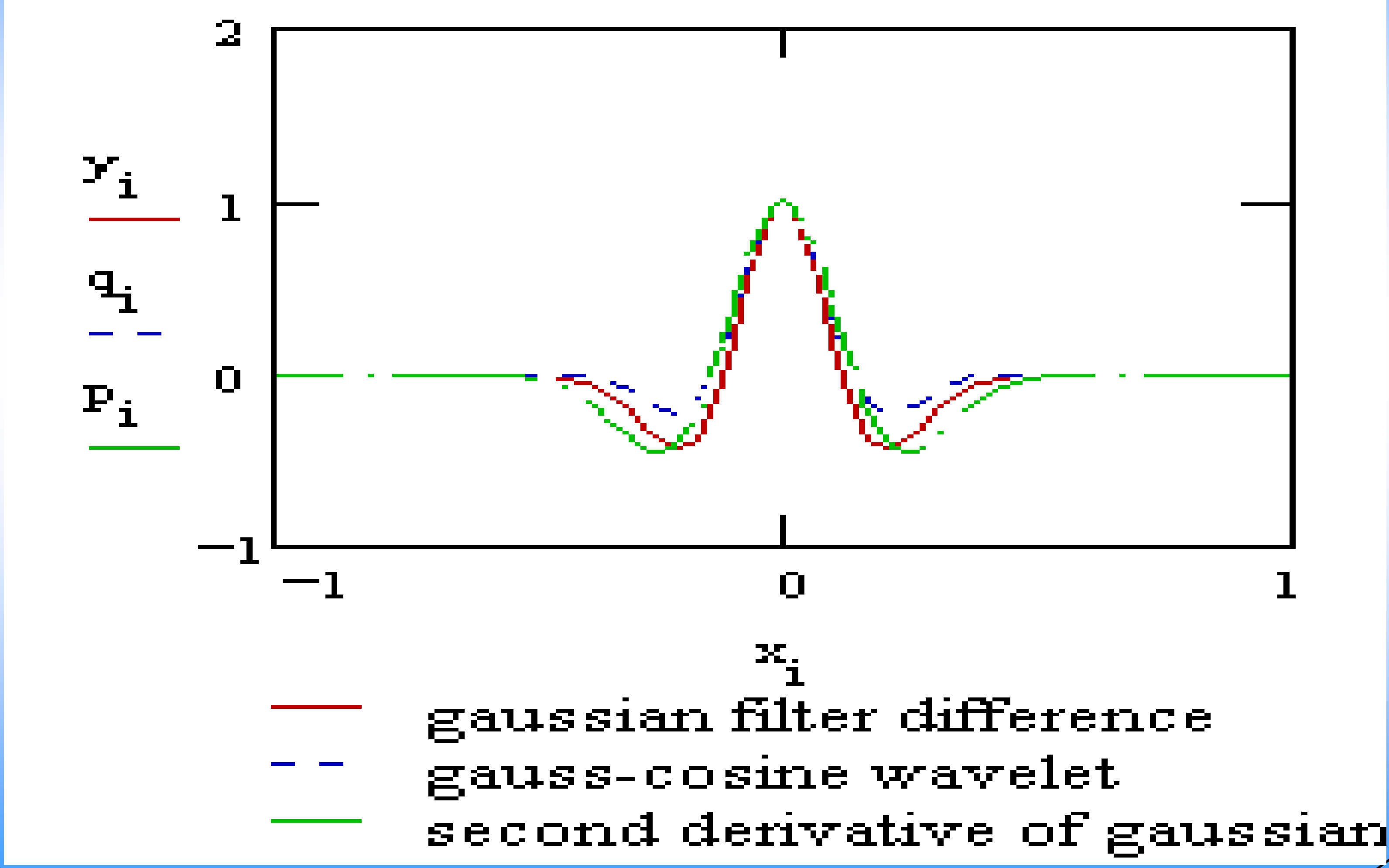
Single stage frequency response

$$H_{sieve,n}(j\omega) = \int_{-\infty}^{\infty} s_n(x).e^{-j\omega x}.dx$$

Single stage frequency response



Relationship to wavelet



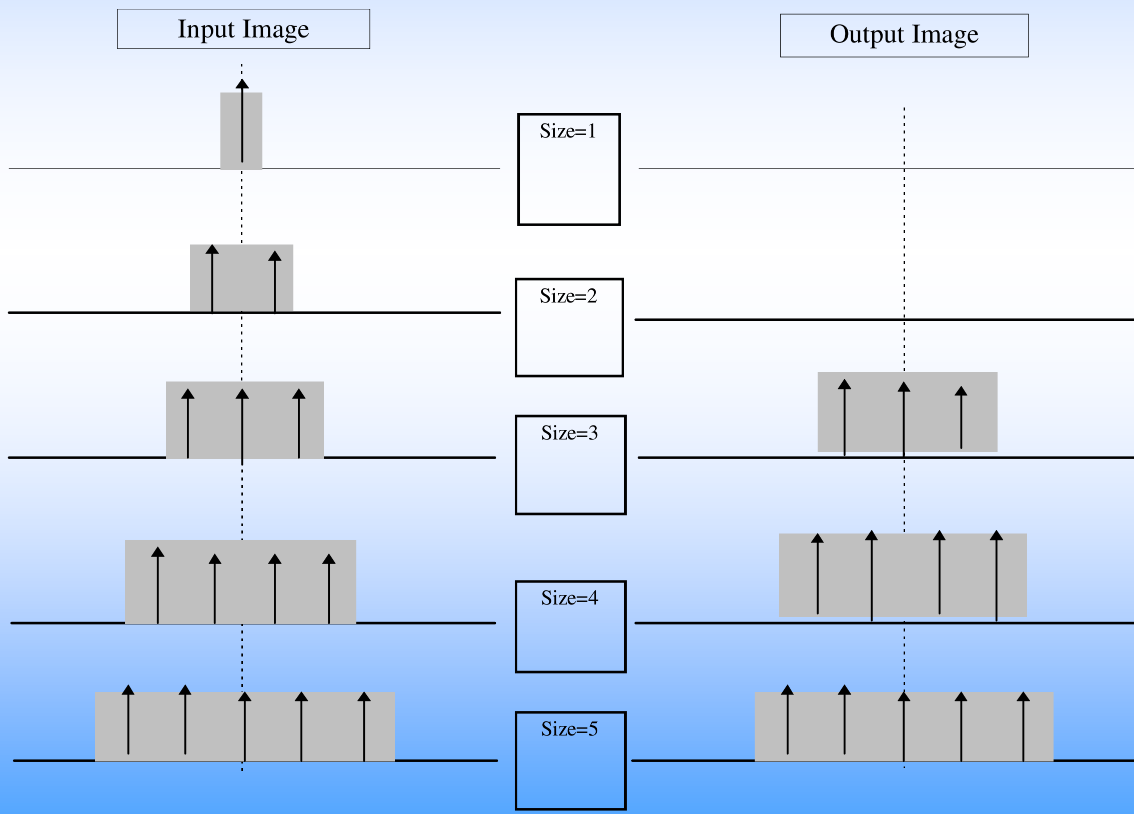
Non-linear spatial filters

- **Median filters**
  - ***Sharp spatial cut off***
  - ***Rejects outlying pixel values***
- **Minimum value filters**
  - ***Can remove noise spikes which are superimposed upon a large wanted object***
- **Other rank order filters**
  - ***Can deal with sparse data***
- **Adaptive percentile filters**
- **Mode filters**

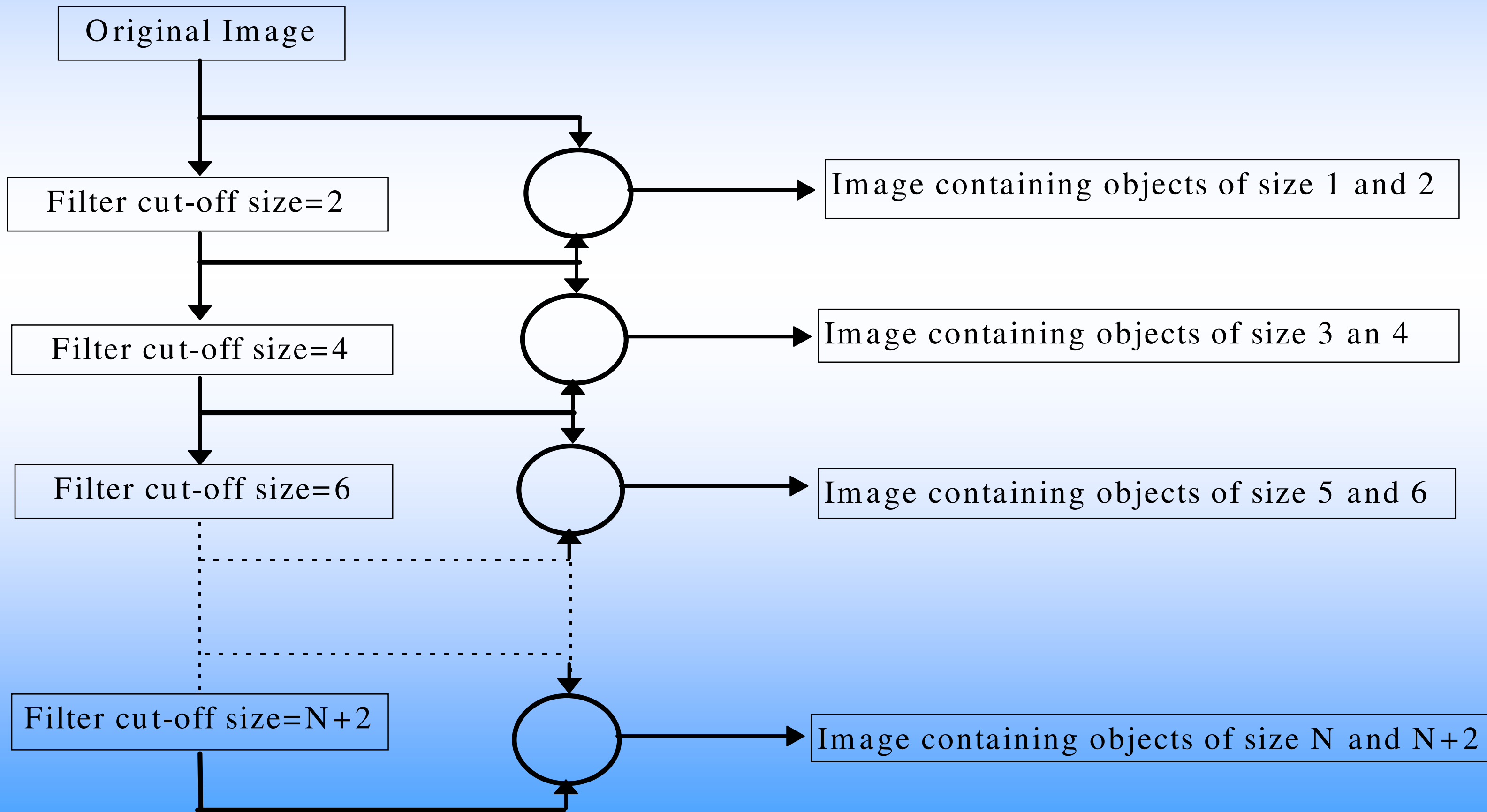
Median filter properties

- **Not effected by outlying pixel values within its window**
- **Has sharp cut off in terms of object size.**

5th order median filter cut off



The Data Sieve (A.Bangham)



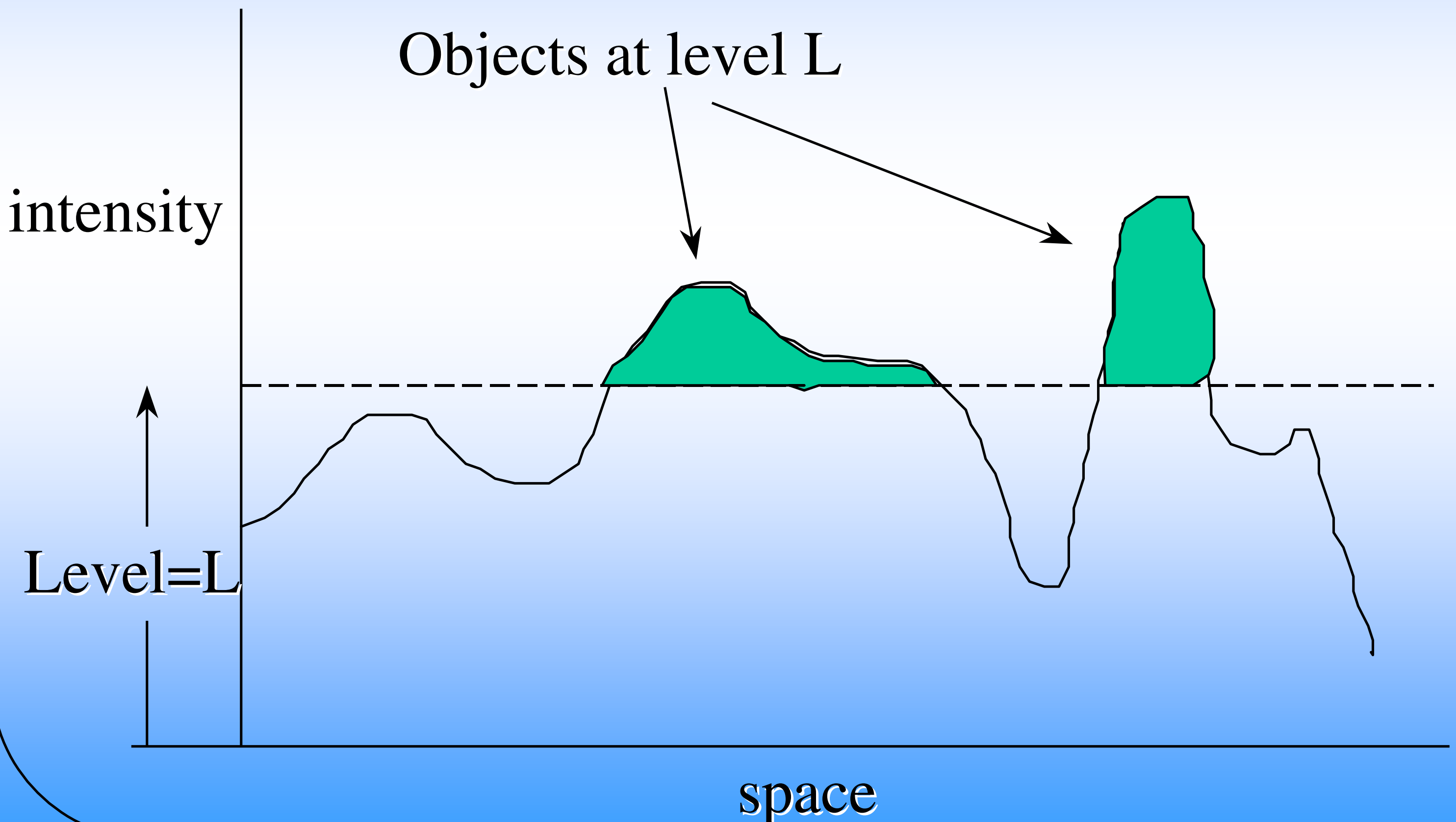
Linear and Non-linear filters: Window problems

- **How to choose the right 3-dimensional window shape when using linear or non-linear filters?**
- **Not very practical when dealing with objects of unknown shape such as cracks and voids in welds.**

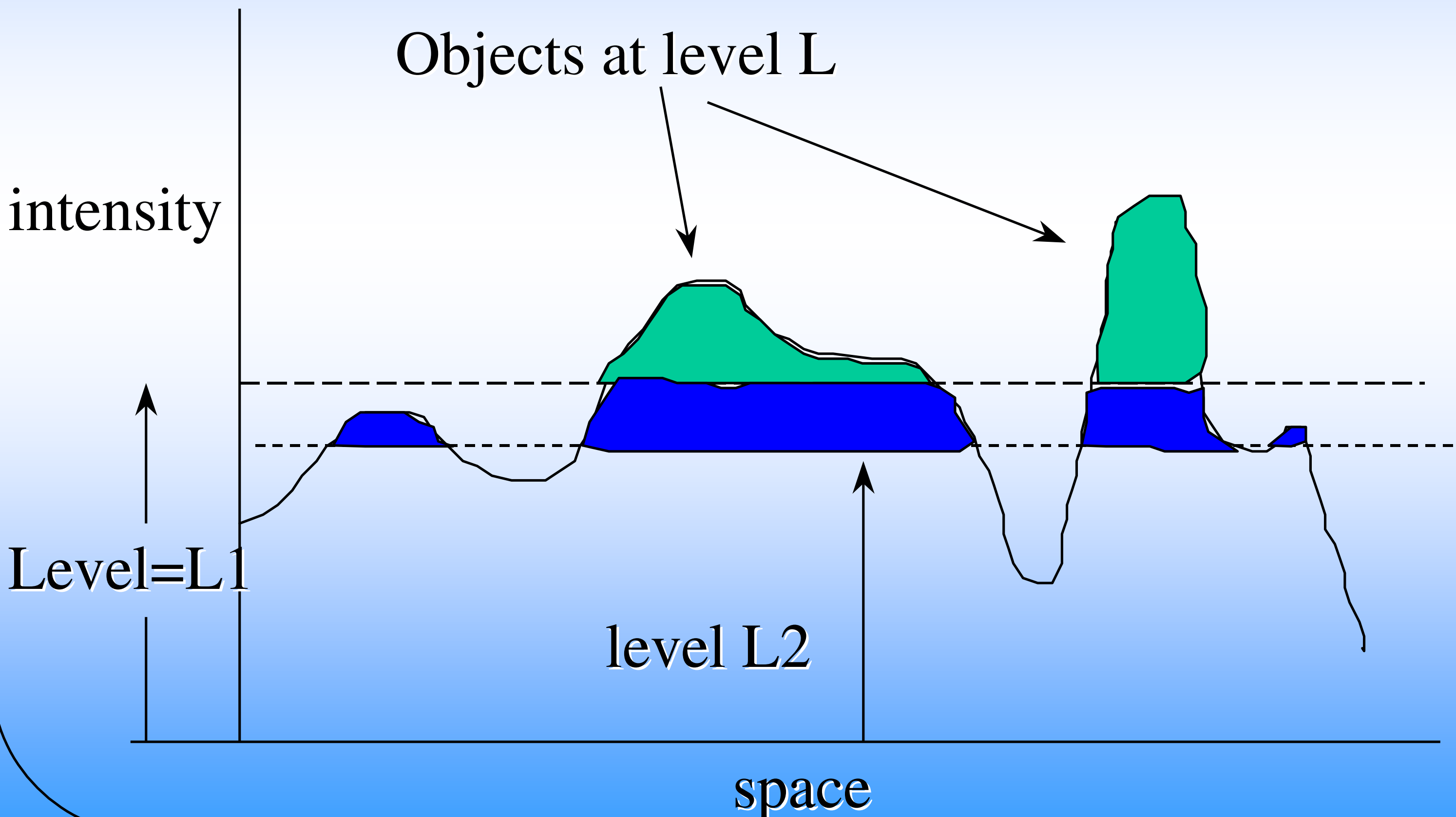
Connectivity filters

- **Abandon shape-size sensitive filters using windows.**
- **Make filters which are sensitive to the number of connected pixels having similar value.**
- **Can be done within context of sieve structure giving Bangham's "volume sieve" or as a single filter. Either approach gives similar results.**

Connectivity filtering in 1-D



Connectivity filtering in 1-D

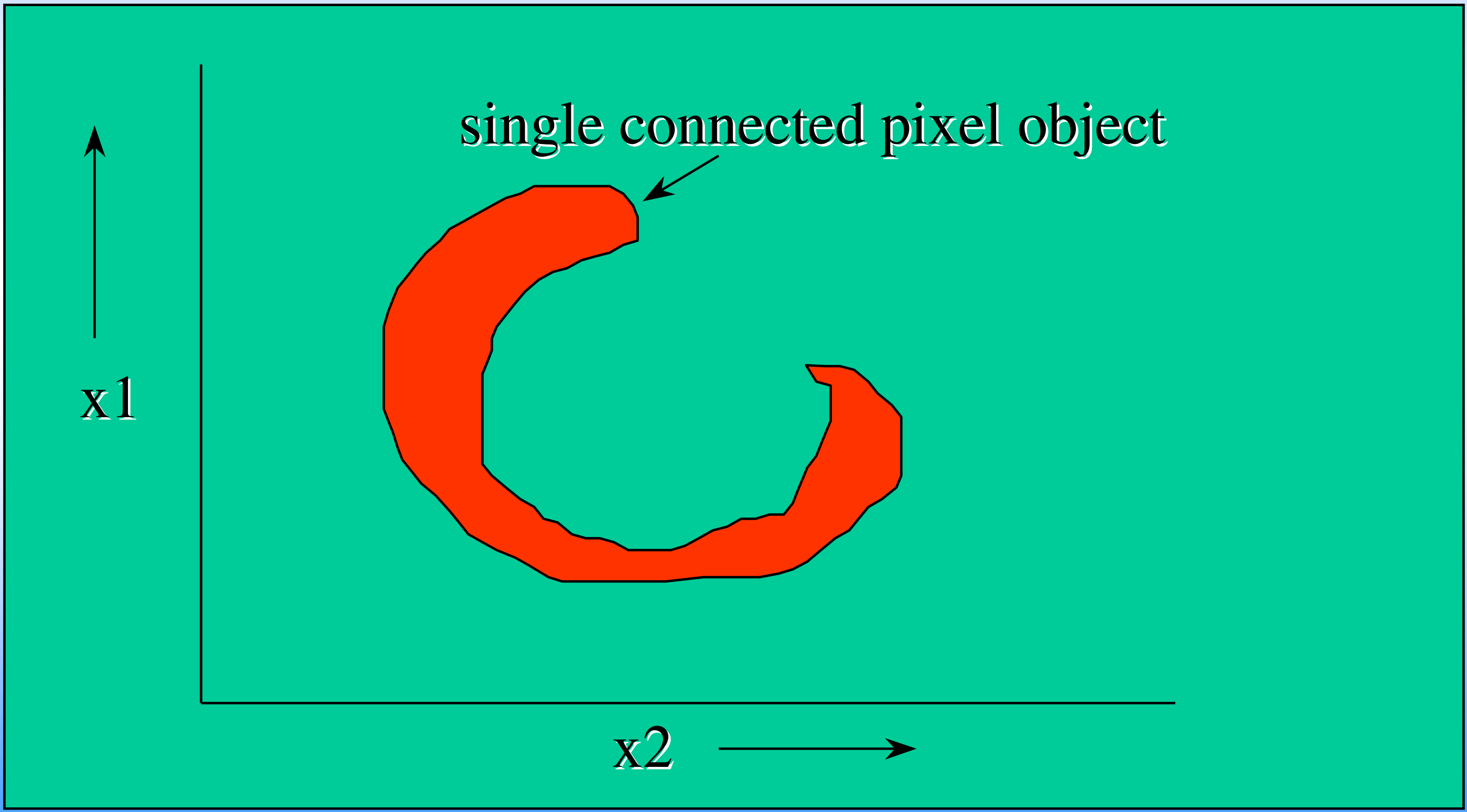


Object Size Decomposition

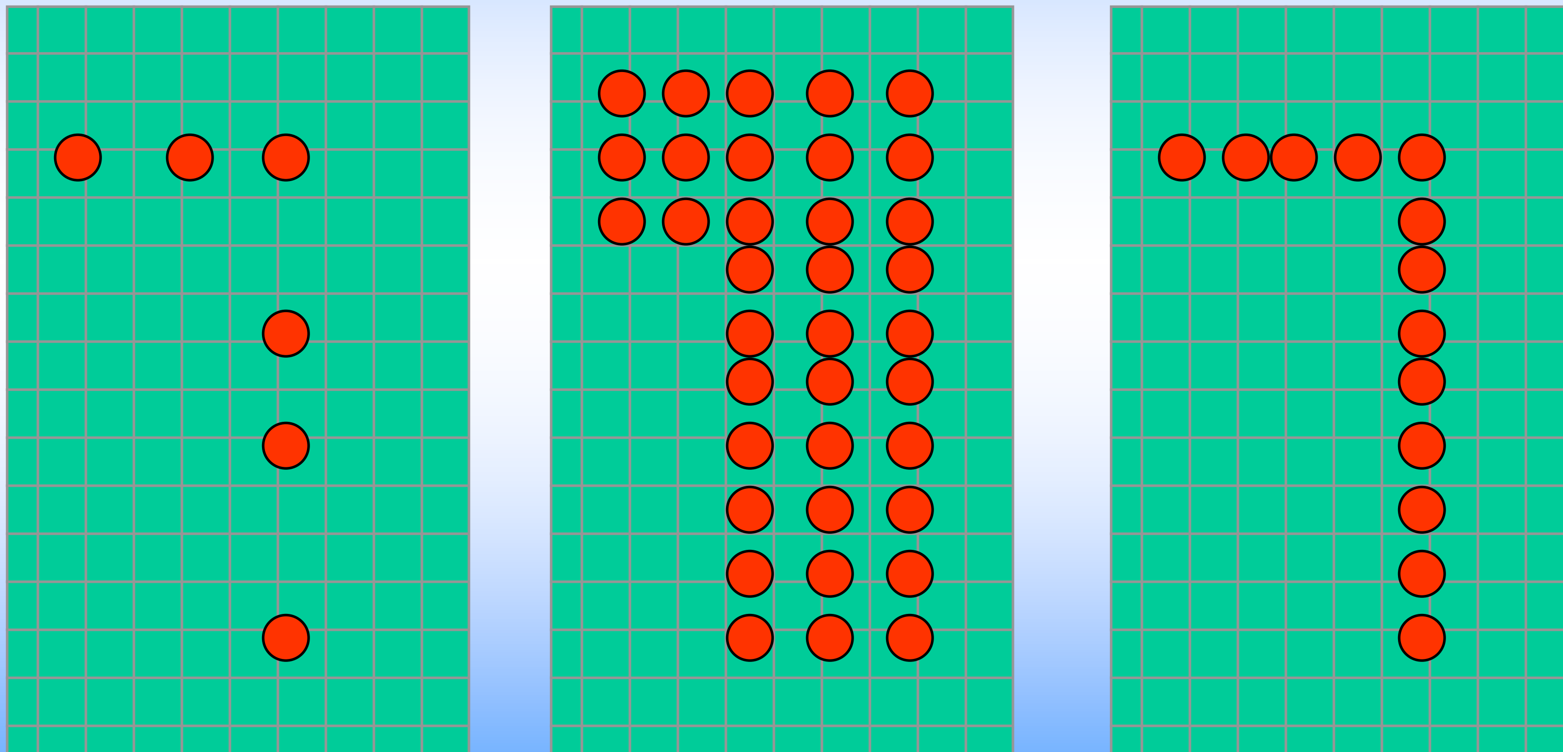
At each chosen level Connectivity Filter gives for example:

Object no. 1	**Size = 136**
Object no. 2	**Size = 1000**
.	
.	
Object no. N	**Size = 56**

Connectivity filtering in 2-D



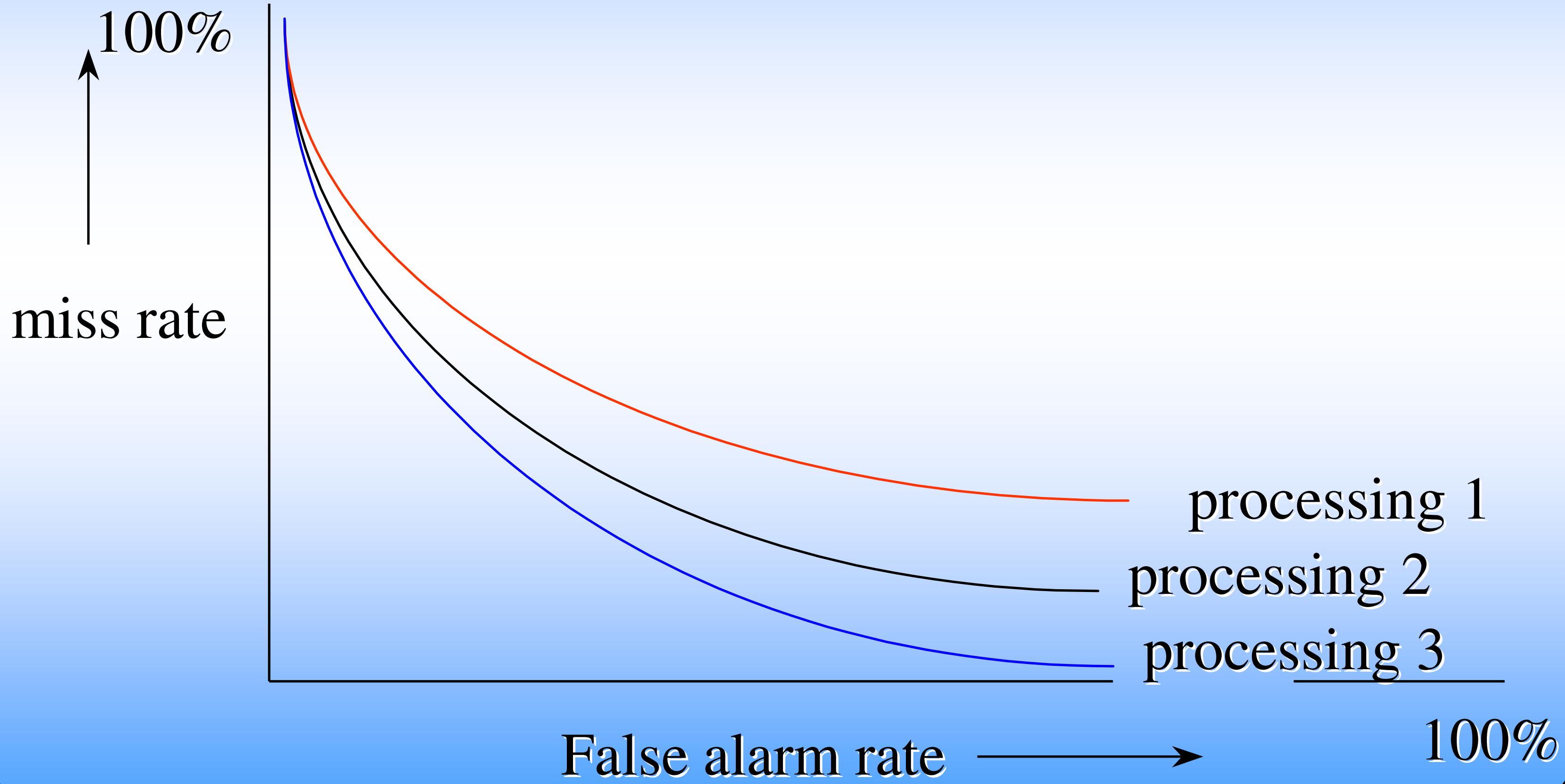
Pixel Dilation and Erosion



Systematic Comparison of Enhancement by Different Filtering Schemes

- **Subjective assessment**
- **Measure *relative* ability of user to find defects**

Receiver Operating Curve



Practical problems in using ROC

- **The position of real defects in test component is only known approximately.**
- **There may be rogue defects in test component.**
- **A single defect may be manifest at more than one position.**

Receiver Operating Curves For Manual Defect Selection