Adaptive Digital Zoom Techniques Based on Hypothesized Boundary

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Outline

- Introduction
- Weighting-Based Digital Zoom Algorithms
- Area-Based Restoration and Resample
- Experimental Results
- Conclusion

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Introduction

- Digital zoom is the process to scale up a digital image to another higher-resolution image by using a computer.
- We can observe details in an image by applying digital zoom algorithms.

Introduction (cont.)

- The major problem of digital zoom technique is that we only have little information to generate a high-resolution image from a low-resolution one.
- Many researches have focused on super-resolution algorithms using multiple images.

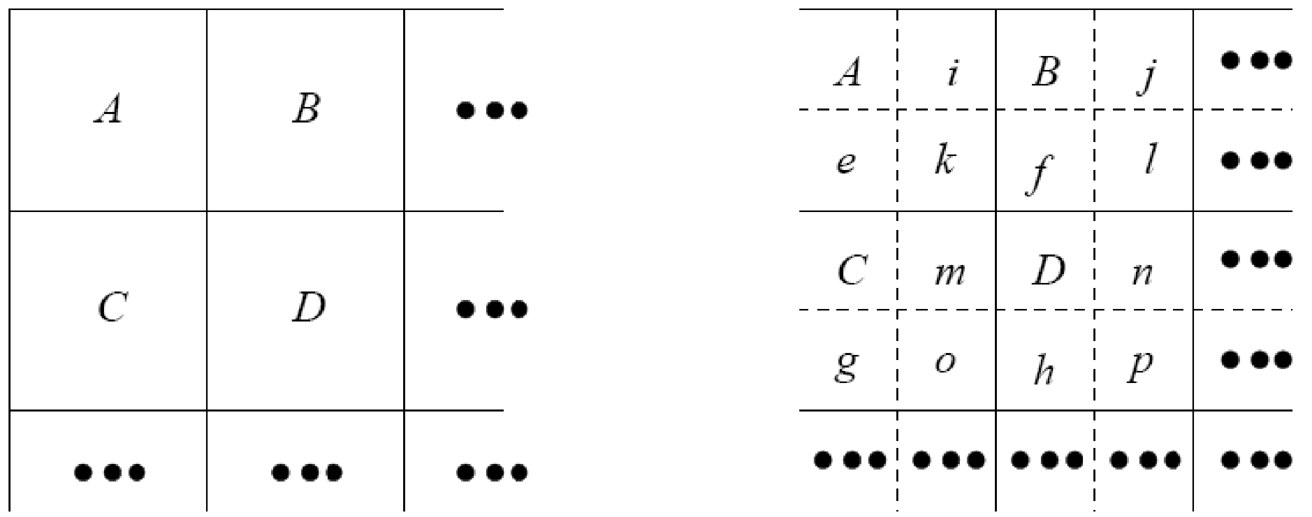
Introduction (cont.)

- The super-resolution technique deals with images containing stationary scene with objects and captured by a moving camera.
- However, we do not always have many images of stationary scene with objects.
- The digital zoom approaches using a single image are developed to solve this difficulty.

Introduction (cont.)

- Because of the lack of information the intensity value of interpolated pixel is guessed or interpolated by its neighboring pixels.
- We can handle the problems in frequency domain or in spatial domain.

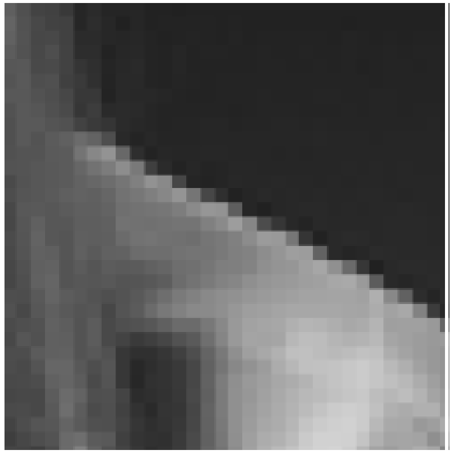
Introduction (cont.)



(a) (b)

Figure 1.1: Observation on bilinear interpolation. (a) The pixels in original image. (b) The pixels in a scale-up image related to (a), where the scale is 2×2.

Introduction (cont.)



Introduction (cont.)

- Left: Original image (Digital zooming in red rectangle)
- Top right: nearest neighbor pixel copy
- Bottom right: bilinear interpolation

Introduction (cont.)

- Because the blurry and blocky effects appear on the edges when applying bilinear interpolation.
- We propose "adaptive digital zoom techniques based on hypothesized boundary" to deal with the effects in this thesis.

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Introduction

- Our motivation is to keep the object edges sharp and to have better results.

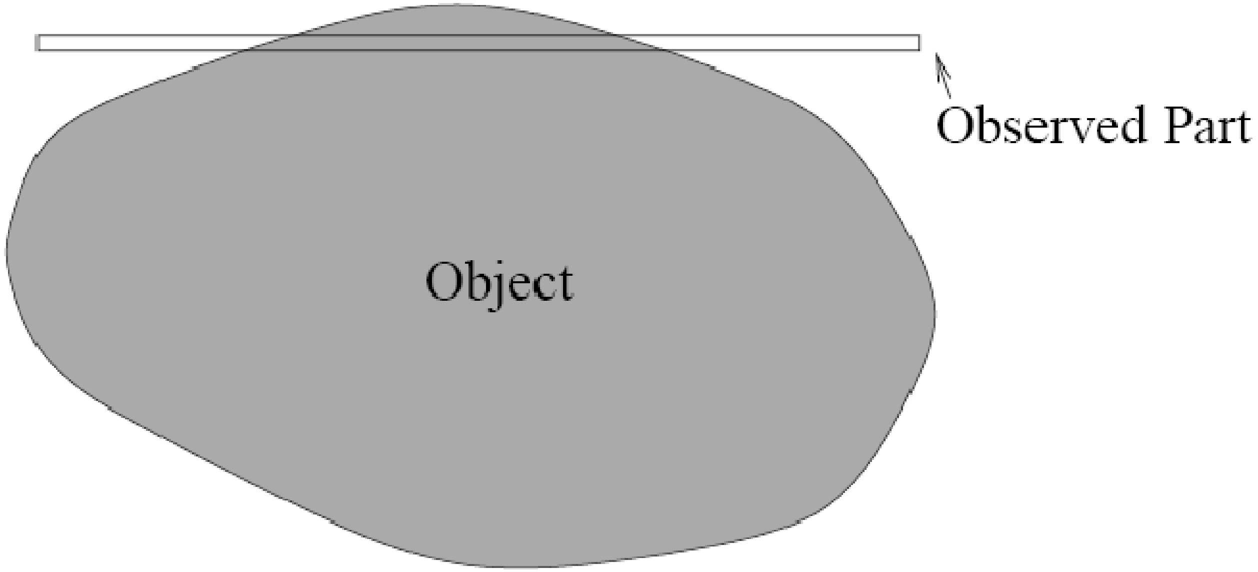


Figure 2.1: An object in an image.

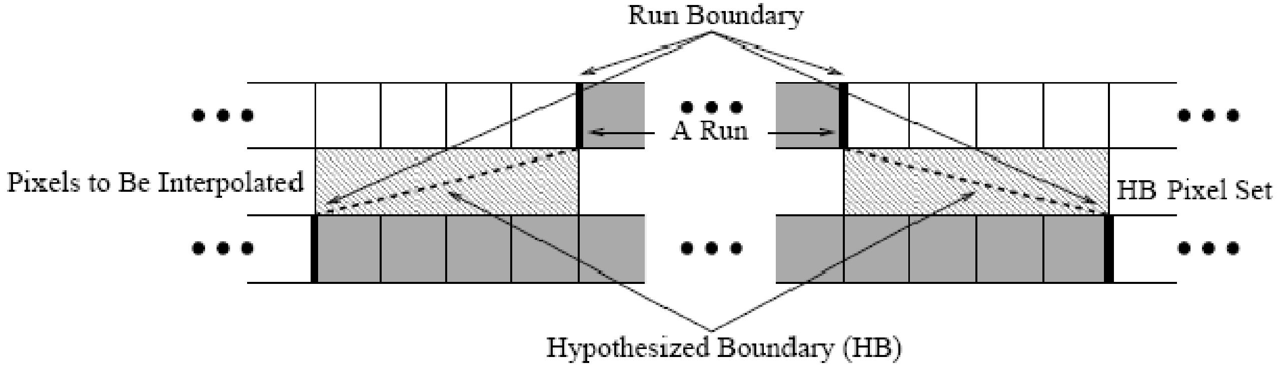


Figure 2.2: Part of the image when scaling up twice the image height.

Terminologies and Algorithm Overview

- **Object**: An image is composed of many objects. An object in an image is defined as a region where the pixels in it have similar property (such as intensity).
- **Run**: A run is defined as a segment of pixels in an image scan line and with similar property.

Terminologies and Algorithm Overview (cont.)

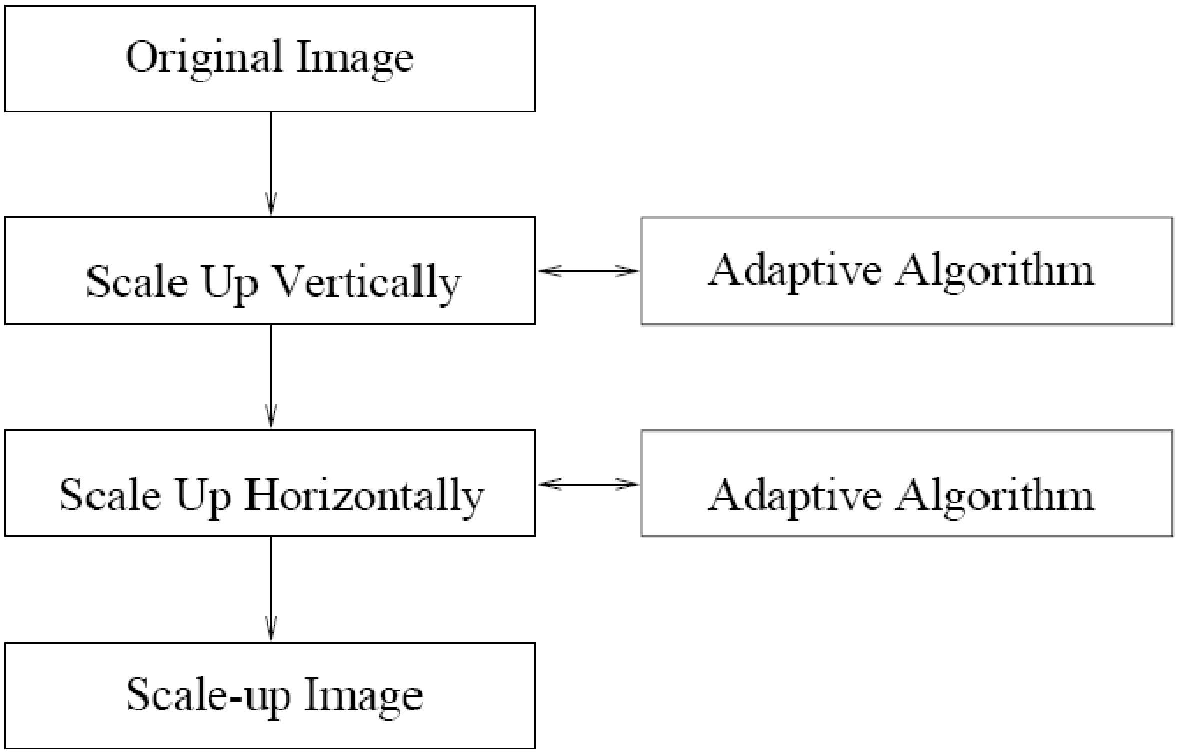
- **Run boundary**: The boundary of two different runs in the same image scan line is called run boundary.
- **Hypothesized boundary (HB)**: The hypothesized boundaries are obviously located from the run boundaries in the nearest scan line to the nearest ones in the third scan line.

Terminologies and Algorithm Overview (cont.)

- **HB pixel set**: A pixel set that hypothesized boundary passes through.

Algorithm Overview

- We divide the scale up process into two sub-processes, one for vertical and the other one for horizontal process



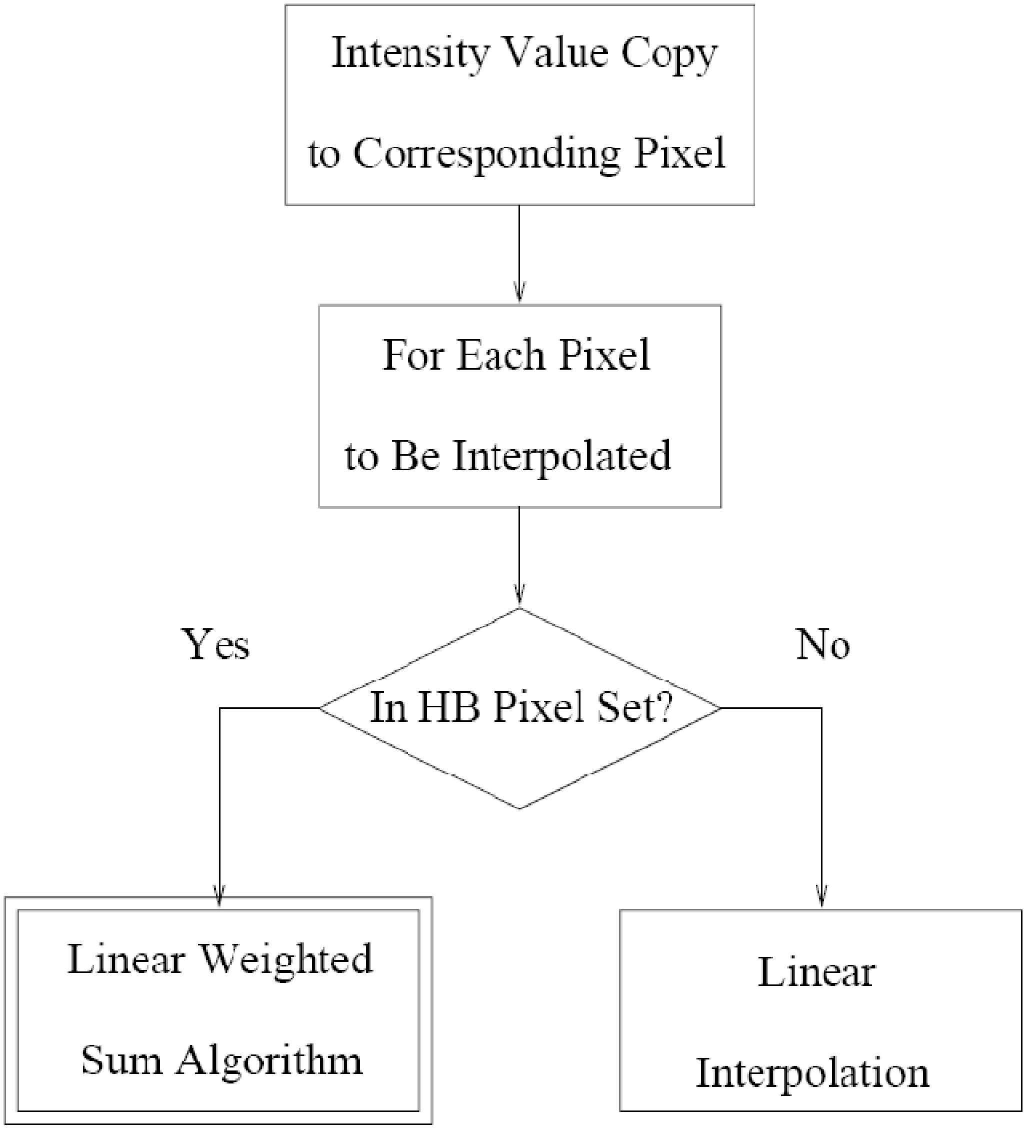
Algorithm Overview (cont.)

- In the beginning of the adaptive algorithm, we copy the intensity values of pixels in the original image to the corresponding pixels in the scale-up image.
- How to generate a pixel to be interpolated in our algorithm depends on whether the pixel is in HB pixel set or not.

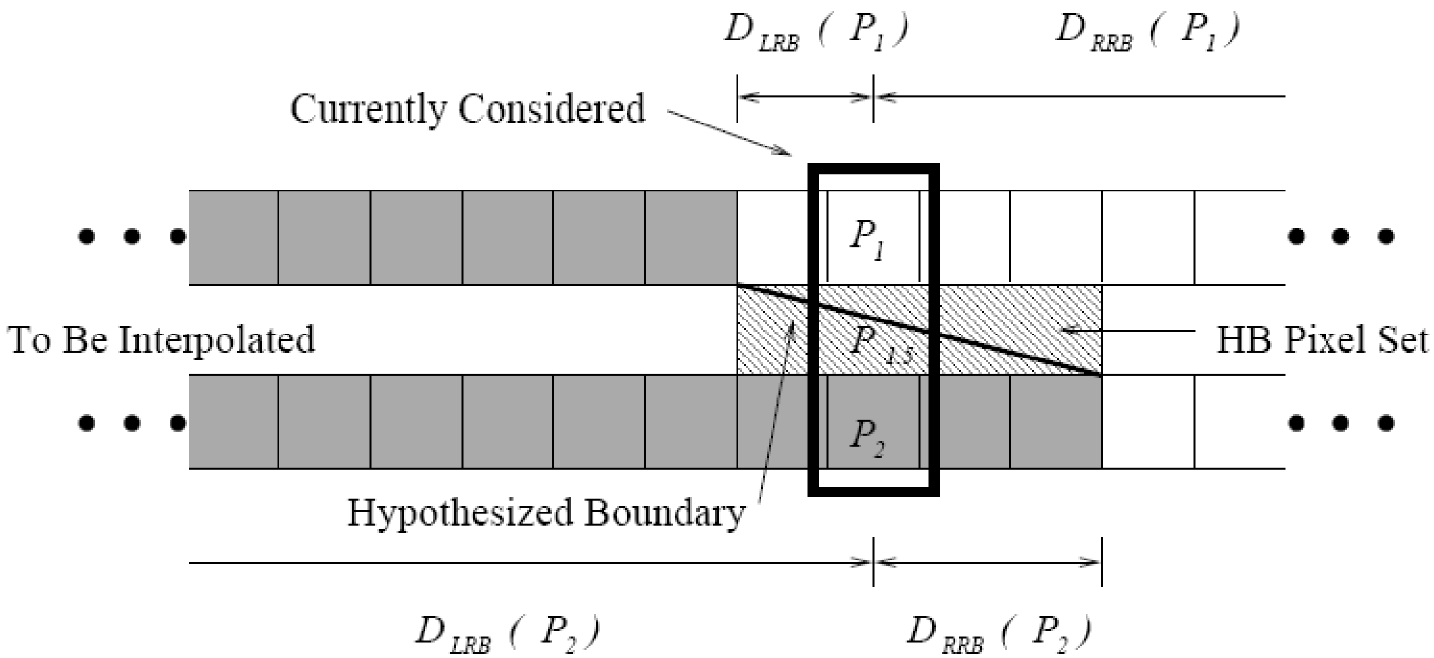
Algorithm Overview (cont.)

- If its gradient values of its interpolating pixels is larger than a user-defined threshold, the pixel falls in an HB pixel set.
- We use our weighting-based algorithm to deal with these kinds of pixels because the hypothesized boundary passes through it.
- If not, we use the linear interpolation.

Algorithm Overview (cont.)



Linear Weighted Sum Algorithm



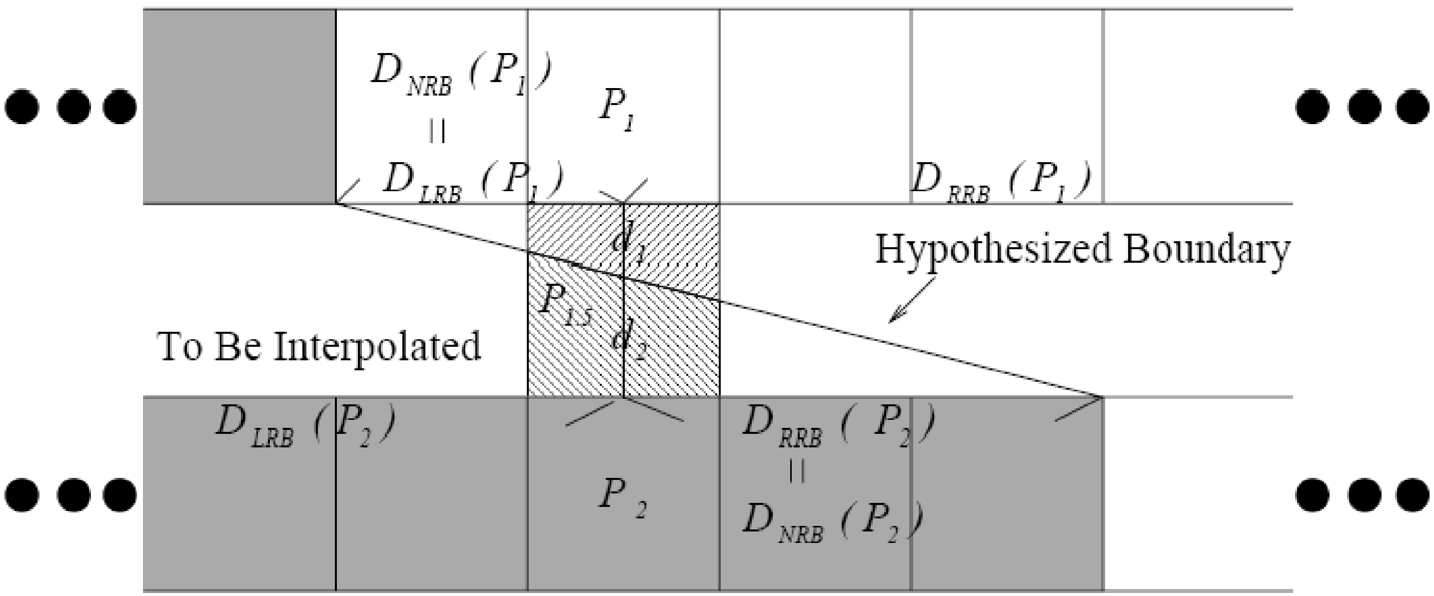
NRB: Nearest Run-Boundary

LRB: Left Run-Boundary

RRB: Right Run-Boundary

D: Distance

Linear Weighted Sum Algorithm (cont.)



Linear Weighted Sum Algorithm (cont.)

$$D_{NRB}(P_1) = \min(D_{LRB}(P_1), D_{RRB}(P_1))$$

$$I(P_{1.5}) = \frac{D_{NRB}(P_1) \times I(P_1) + D_{NRB}(P_2) \times I(P_2)}{D_{NRB}(P_1) + D_{NRB}(P_2)}$$

Nearest neighborhood pixel copy

1x

(a)

(b)

2x

4x

(c)

Bilinear interpolation

1x

(a)

(b)

2x

4x

(c)

Linear weighted sum

1x

(a)

(b)

2x

4x

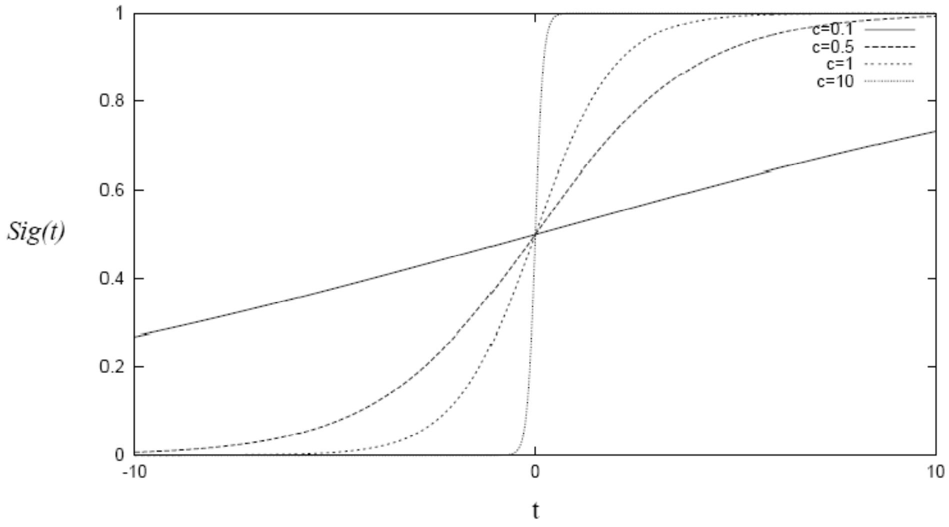
(c)

Sigmoid Weighted Sum Algorithm

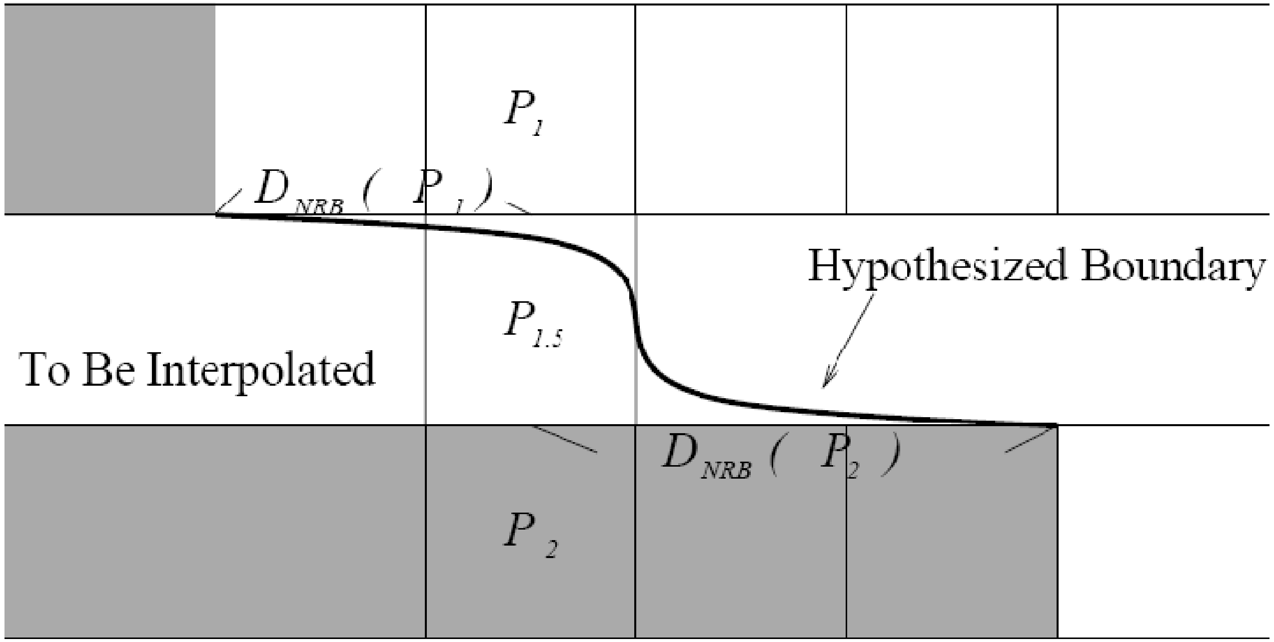
The sigmoid function is defined as

$$SIG(t) = \frac{1}{1 + e^{-ct}},$$

where c is a user-defined parameter.

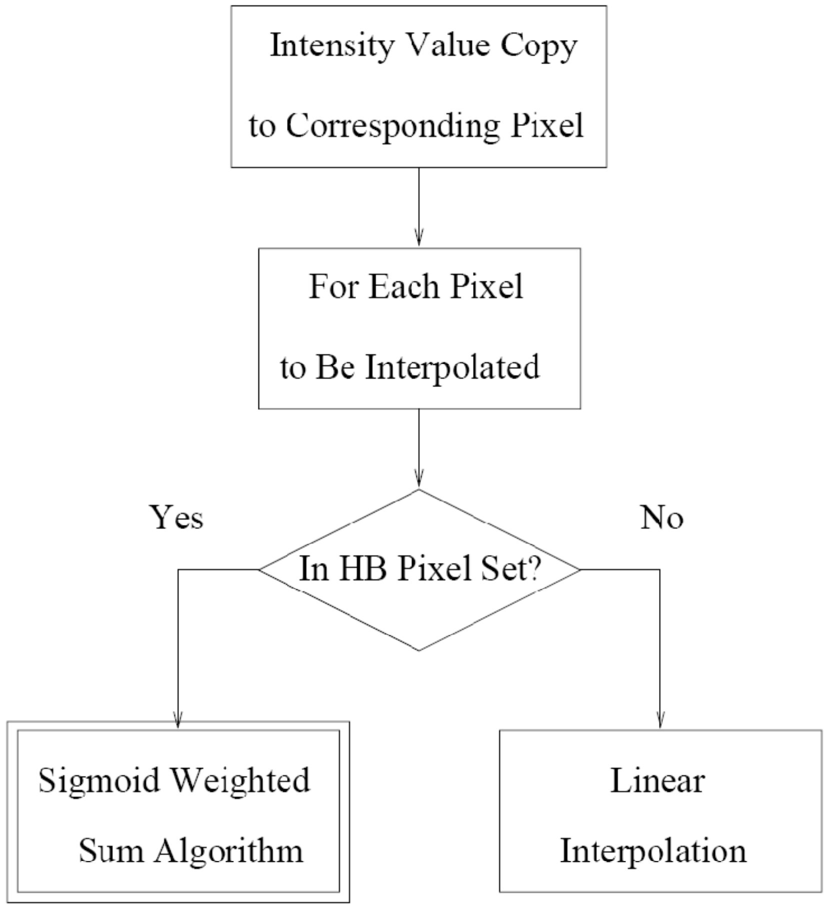


Sigmoid Weighted Sum Algorithm (cont.)



$$I(P_{1.5}) = Sig(D_{NRB}(P_1) - D_{NRB}(P_2)) \times I(P_1) + (1 - Sig(D_{NRB}(P_1) - D_{NRB}(P_2))) \times I(P_2),$$

Sigmoid Weighted Sum Algorithm (cont.)



$C = 0.01$

1x

(a)

(b)

2x

4x

(c)

$C = 1.0$

1x

(a)

(b)

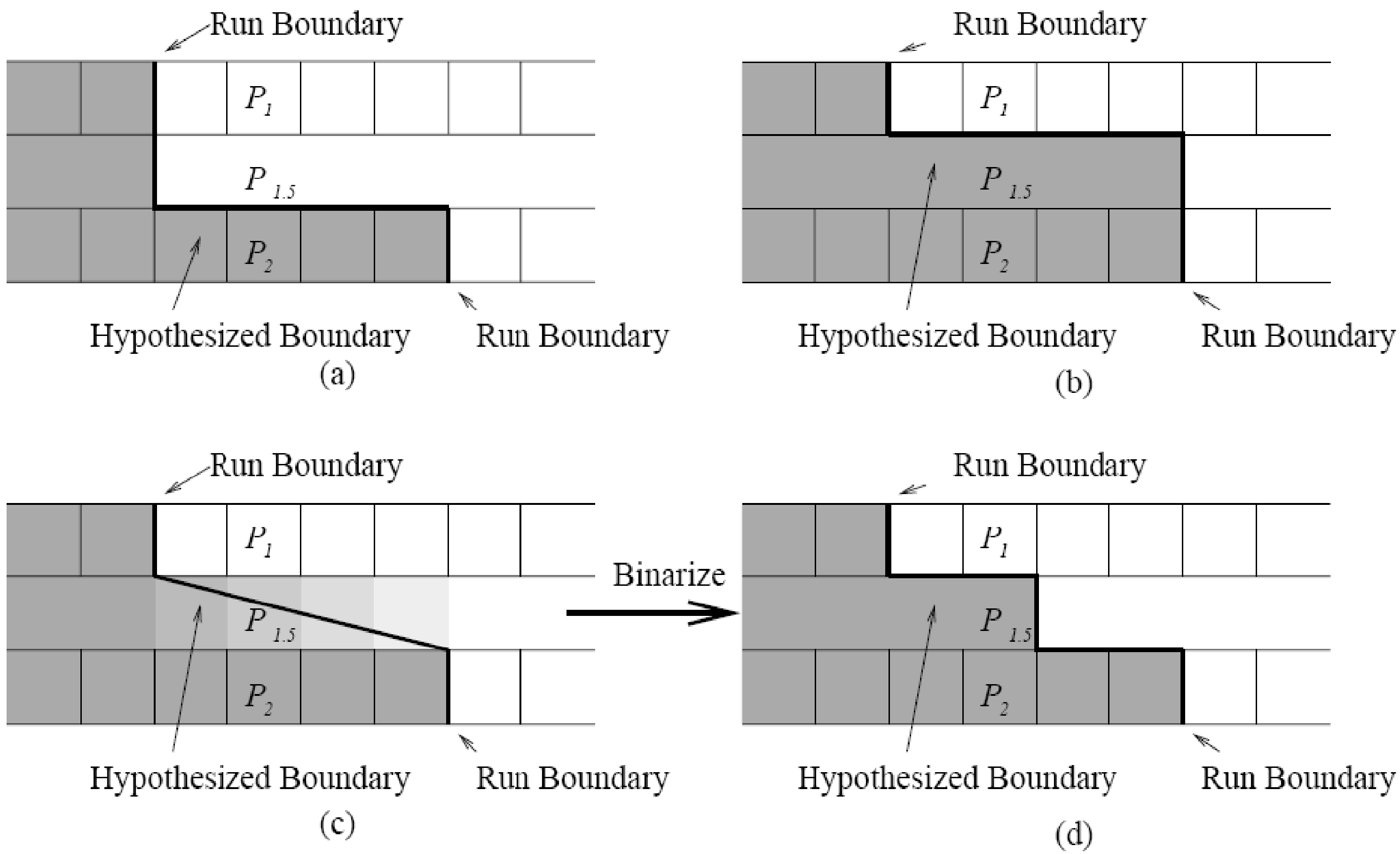
2x

4x

(c)

Realization for a Binary Image: Larger-NRBD Selection

NRBD: Nearest Run Boundary Distance

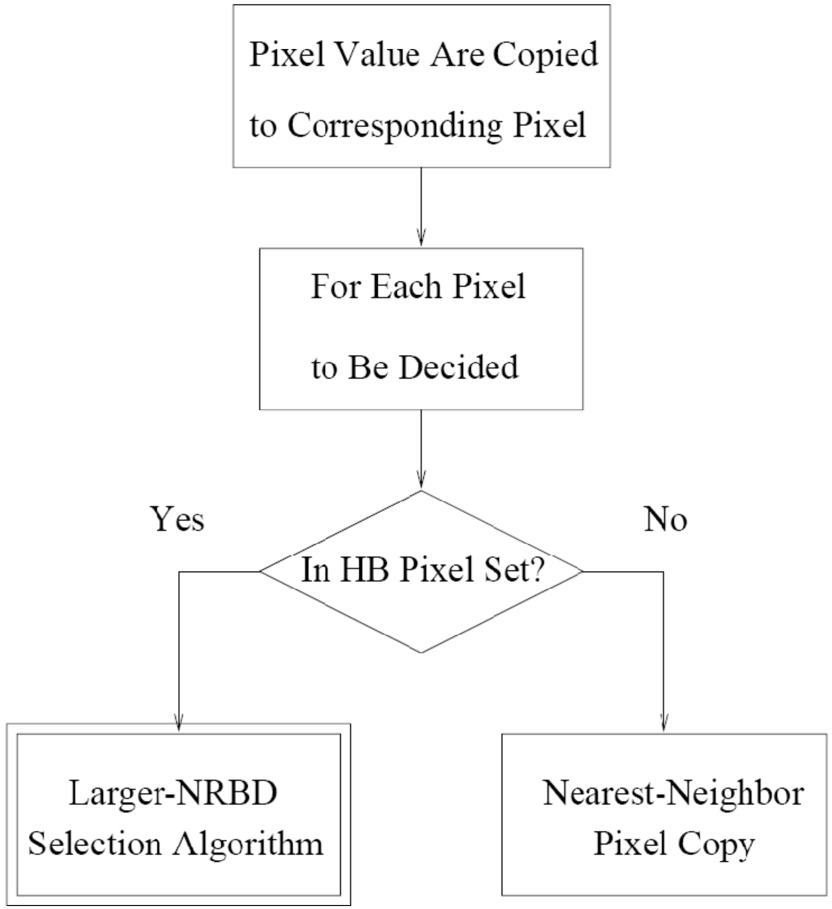


(a) Nearest-neighbor pixel copy
(b) Bilinear interpolation with binarization
(c) Linear weighted sum
(d) Linear weighted sum with binarization

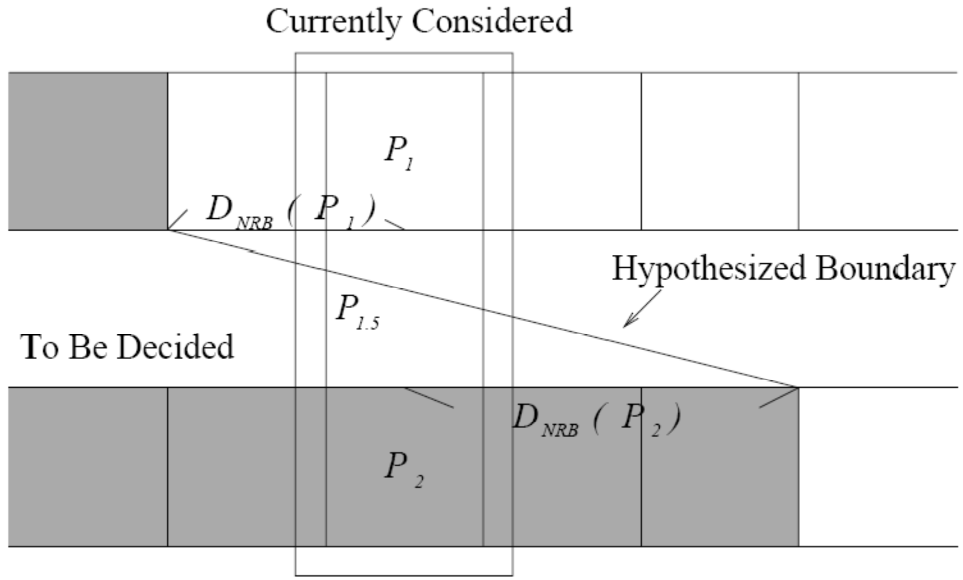
Realization for a Binary Image: Larger-NRBD Selection (cont.)

- We propose a one-pass algorithm to replace the two-pass algorithm linear weighted sum followed by binarization.
- We may call the process as larger-NRBD selection algorithm.

Realization for a Binary Image: Larger-NRBD Selection (cont.)



Realization for a Binary Image: Larger-NRBD Selection (cont.)



$$I(P_{1.5}) = I(\arg\max(D_{NRBD}(P_1), D_{NRBD}(P_2))),$$

Take a Break

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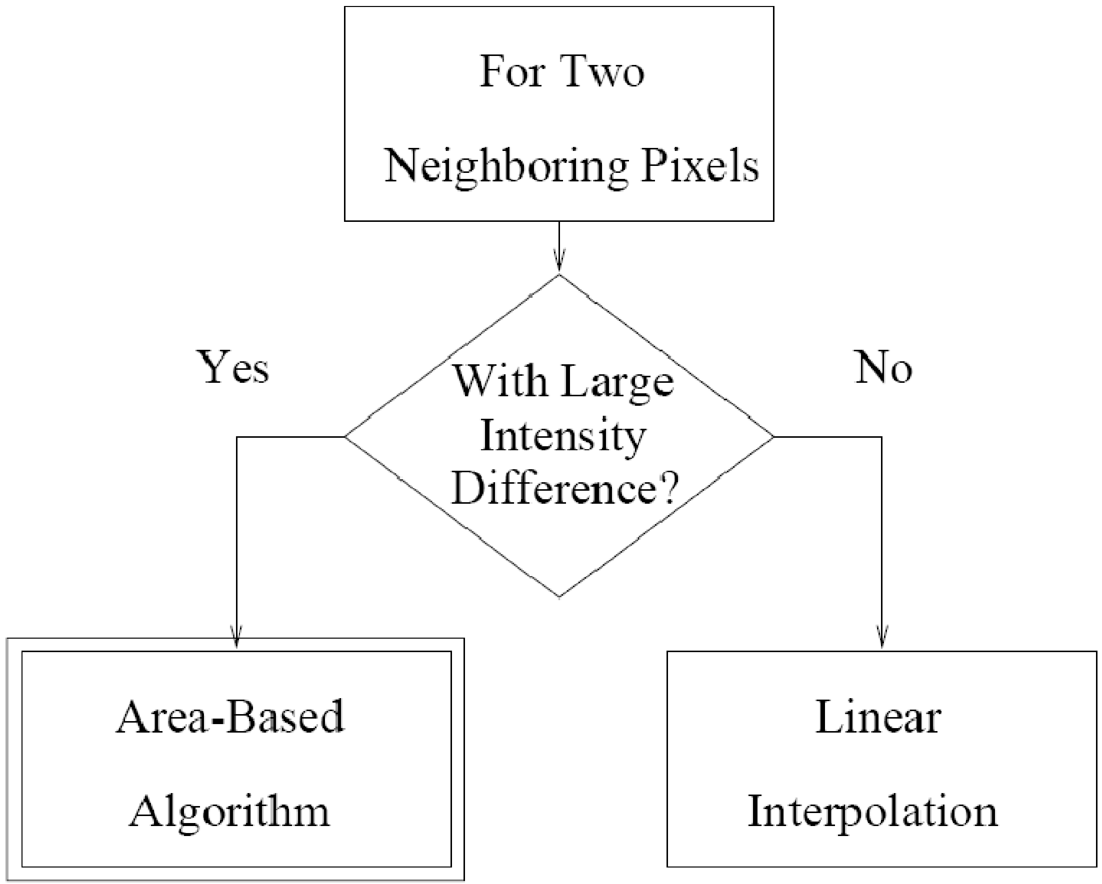
Introduction

- We assume an intensity value of a pixel is the integration of the light energy in a Charge-Coupled Device (CCD) grid.
- Based on the CCD grid mode and the hypothesized boundary concept we can restore the infinite-high-resolution or continuous signal locally.

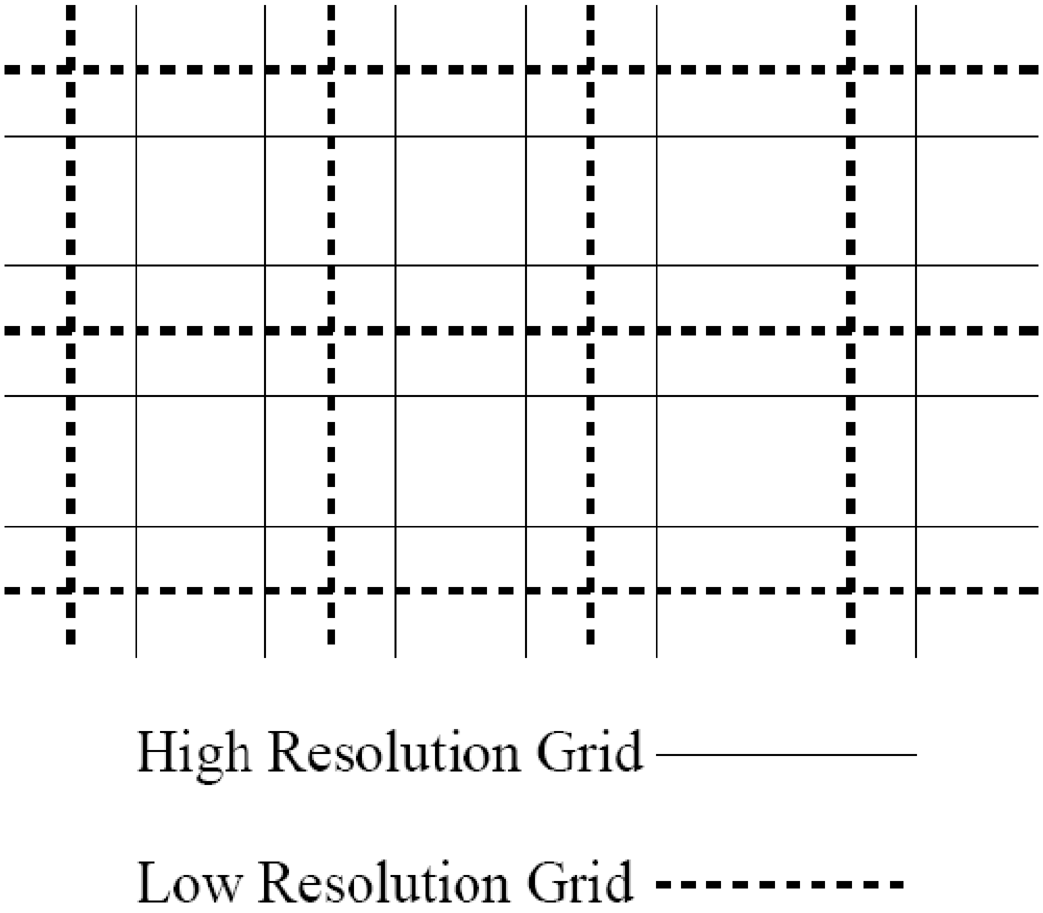
Introduction (cont.)



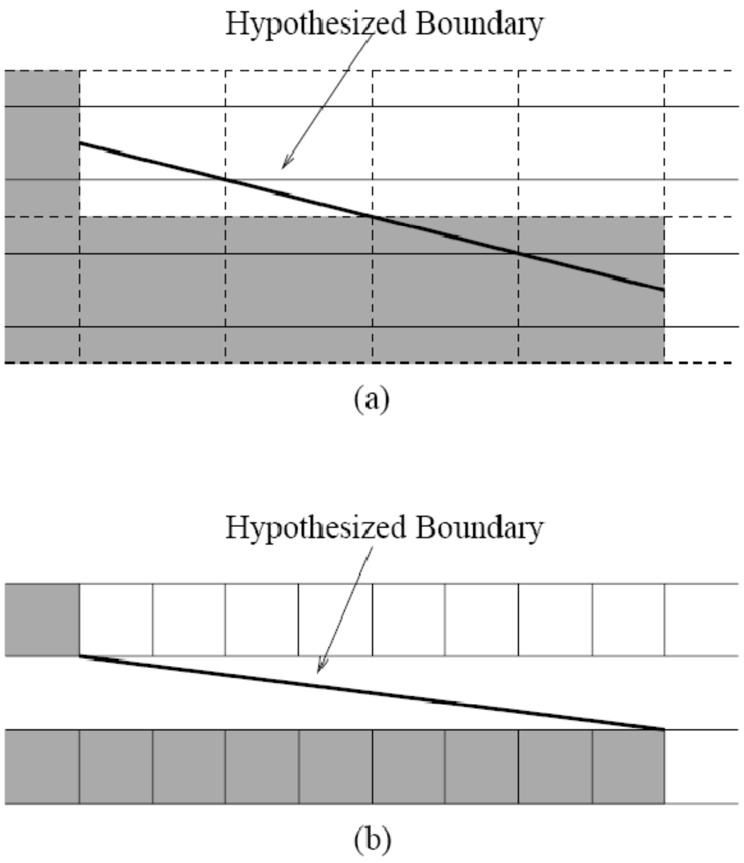
CCD Grid Mode and the Hypothesized Boundary Localization

- We want to scale up the image two-by-two. We may divide a pixel in a low-resolution image into four pixels to get a high-resolution image.
- The pixel center in the low-resolution image locates on one pixel center in the high-resolution image.

CCD Grid Mode and the Hypothesized Boundary Localization



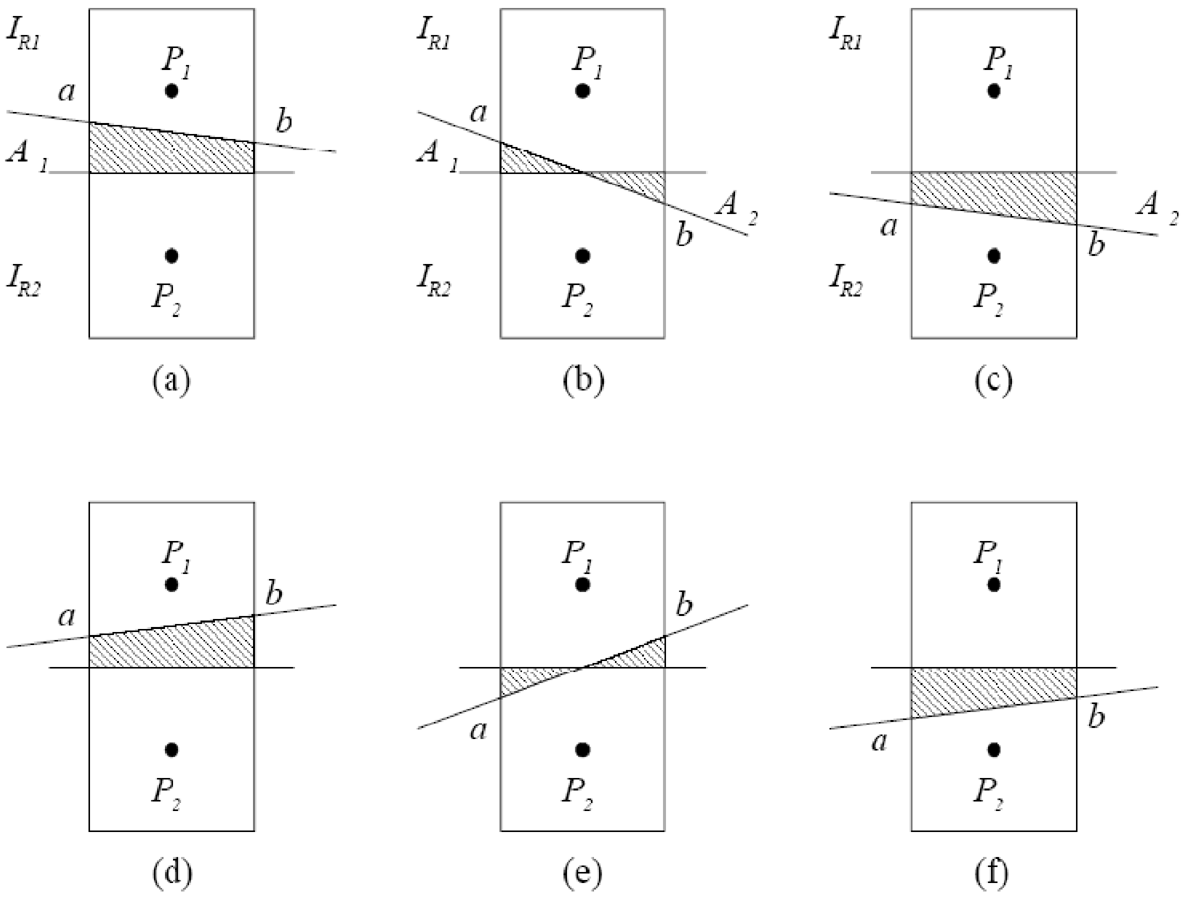
CCD Grid Mode and the Hypothesized Boundary Localization



(a) Area-based algorithm.

(b) Linear weighted sum algorithm.

Local Restoration



(d), (e), (f) : mirrors of (a), (b), (c)

Local Restoration (cont.)

- Use (a) for an example. To count the area of A_1

$$I(P_1) = (1 - A_1) \times I_{R1} + A_1 \times I_{R2}$$
$$I(P_2) = I_{R2}$$

I_{R1}: Original intensity of P_1

I_{R2}: Original intensity of P_2

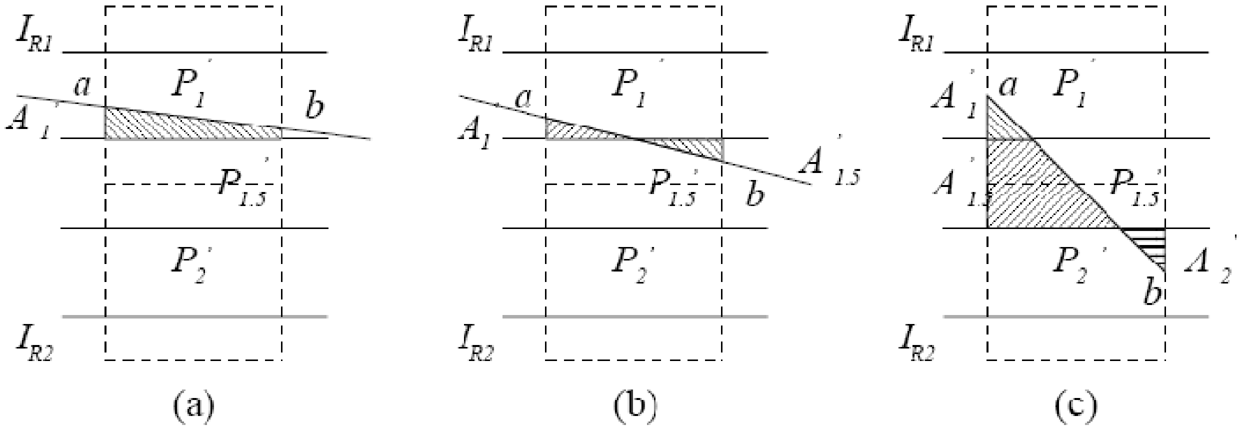
- Let the area of each pixel be 1

$$I_{R1} = \frac{I(P_1) - A_1 \times I_{R2}}{(1 - A_1)}$$
$$I_{R2} = I(P_2)$$

Local Resampling for Scaling up by Two

- Using the high-resolution area divided by the hypothesized boundary to calculate the intensity
- Each high-resolution pixel's area becomes *0.5*
- Take (a) for example

Local Resampling for Scaling up by Two (cont.)



$$I(P_1^{'}) = (0.5 - A_1^{'}) \times I_{R1} + A_1^{'} \times I_{R2}$$

$$I(P_{1.5}^{'}) = I_{R2}$$

$$I(P_2^{'}) = I_{R2}$$

Area-based algorithm

1x

(a)

(b)

2x

4x

(c)

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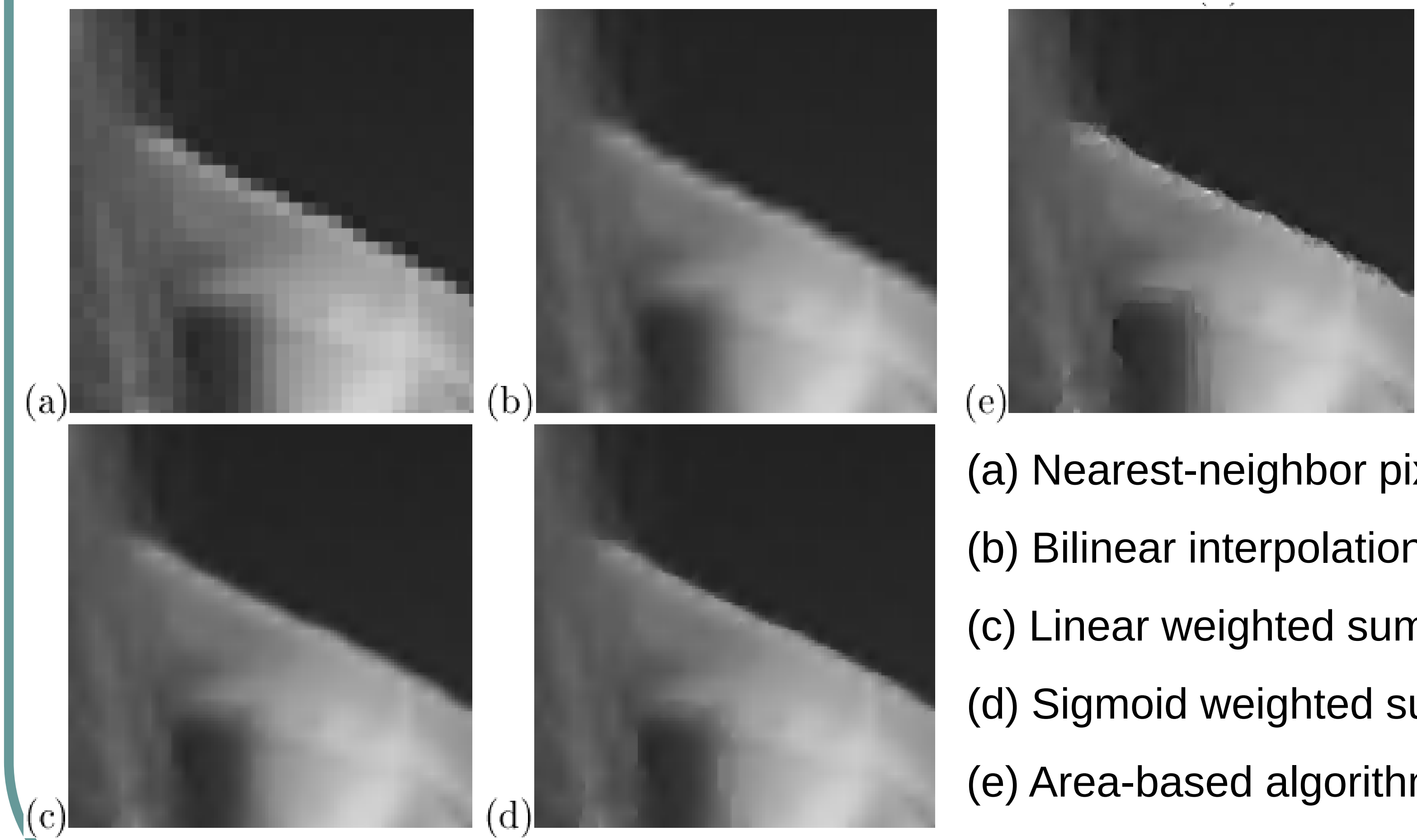
Experimental Results

- Visualization results
- Digital zoom on red rectangle
- Five methods will be compared.

Experimental Results (cont.)



(a) Nearest-neighbor pixel copy

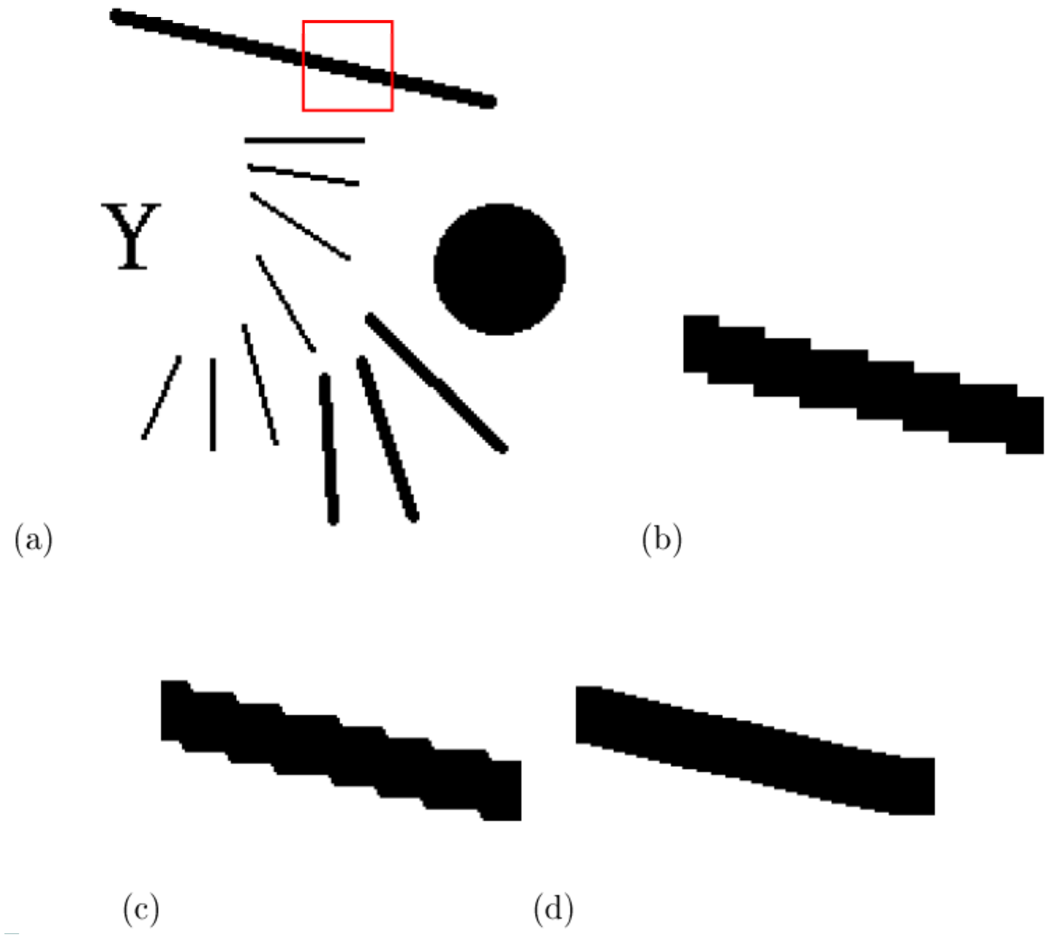
(b) Bilinear interpolation

(c) Linear weighted sum

(d) Sigmoid weighted sum

(e) Area-based algorithm

Experimental Results (cont.)



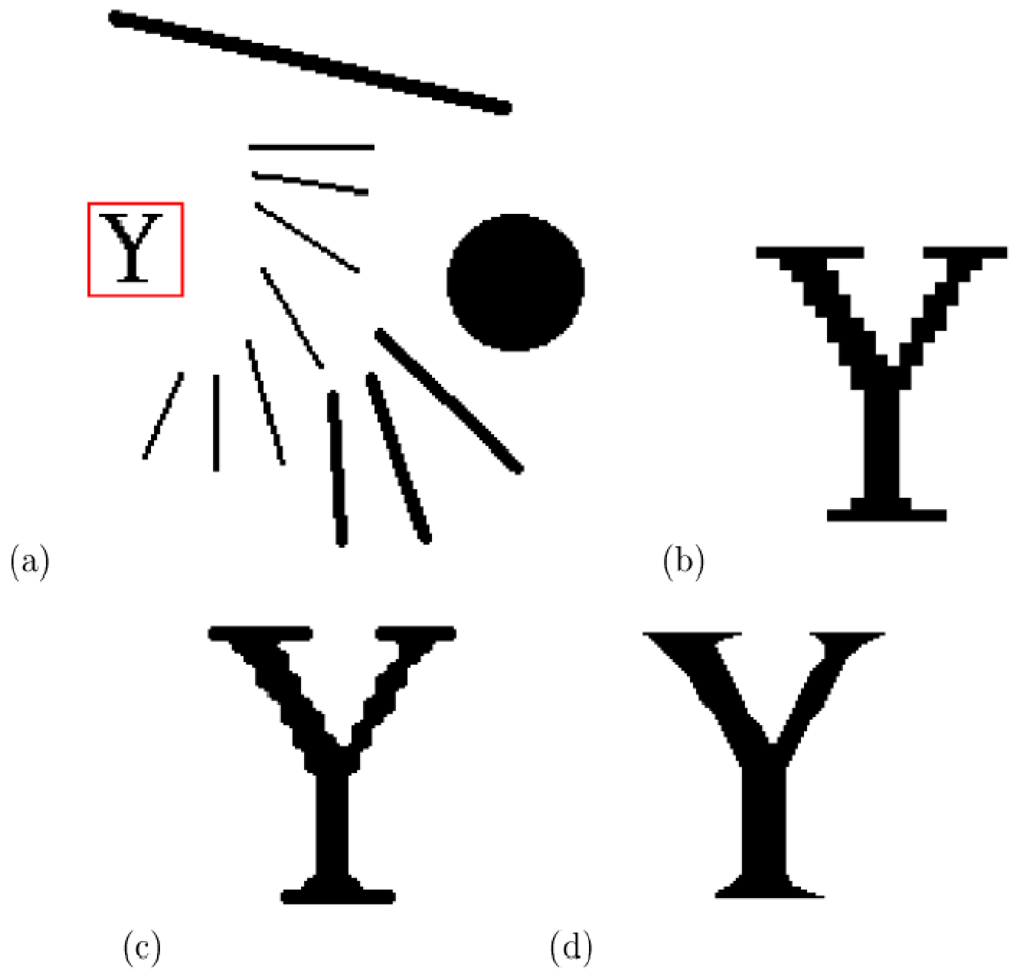
(a) Original image

(b) Nearest-neighbor pixel copy

(c) Bilinear interpolation

(d) Larger-NRBD selection

Experimental Results (cont.)



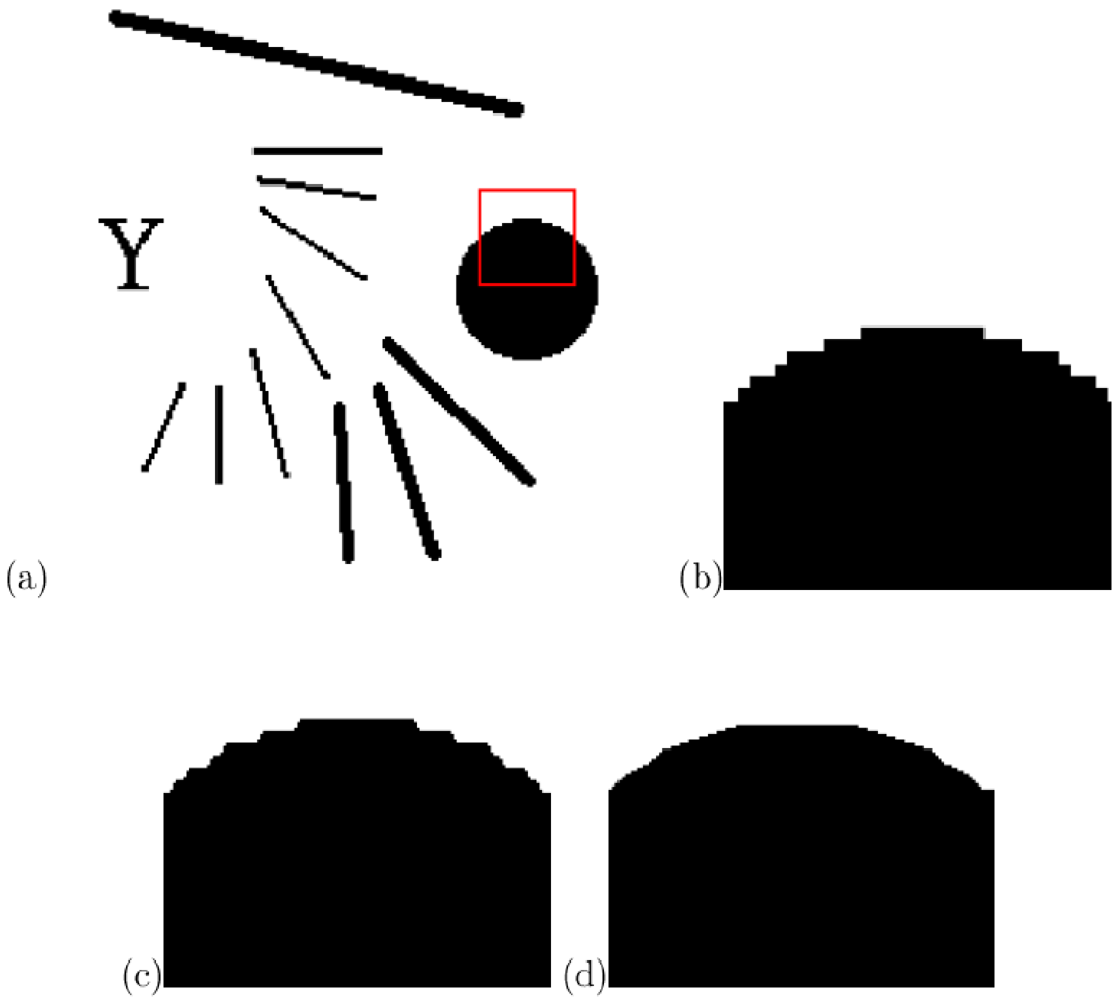
(a) Original image

(b) Nearest-neighbor pixel copy

(c) Bilinear interpolation

(d) Larger-NRBD selection

Experimental Results (cont.)



(a) Original image

(b) Nearest-neighbor pixel copy

(c) Bilinear interpolation

(d) Larger-NRBD selection

SNR and Sharpness Comparison

Original Image

Sharpness: 153,037,221

4x4 nearest neighbor pixel copy

SNR: 9.551811

Sharpness: 99,597,786

SNR: Signal-to-Noise Ratio

SNR and Sharpness Comparison (cont.)

4x4 bilinear interpolation

SNR: 12.807445

Sharpness: 23,033,292

4x4 linear weighted sum

SNR: 12.730128

Sharpness: 26,264,322

SNR and Sharpness Comparison (cont.)

4x4 sigmoid weighted sum

SNR: 12.655672

Sharpness: 23,194,836

4x4 area-based algorithm

SNR: 13.046390

Sharpness: 75,389,265

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Conclusion

- Nearest-neighbor pixel copy
  - Advantage: fast, simple
  - Disadvantage: blocky, useless in scaling up process
- Bilinear interpolation
  - Advantage: fast, simple
  - Disadvantage: blocky and blurry effects on edges

Conclusion (cont.)

- Linear weighted sum
  - Advantage: efficient, fast, no blocky effects on edges, good visualization
  - Disadvantage: not sharp enough on edges
- Sigmoid weighted sum
  - Advantage: a user-defined parameter for tuning, sharpness larger than bilinear interpolation even linear weighted sum
  - Disadvantage: SNR smaller than bilinear interpolation

Conclusion (cont.)

- Larger-NRBD selection
  - Advantage: suitable for binary images
  - Disadvantage: only for binary images
- Area-based algorithm
  - Advantage: good SNR and sharpness values
  - Disadvantage over-enhancement on edges, worse visualization