Computer Vision for HCI

Image Pyramids

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Image Pyramids

- Multi-resolution image representations
- Useful for image coding/compression (and motion analysis – coming later!)

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Image Pyramids Operations: General Theory

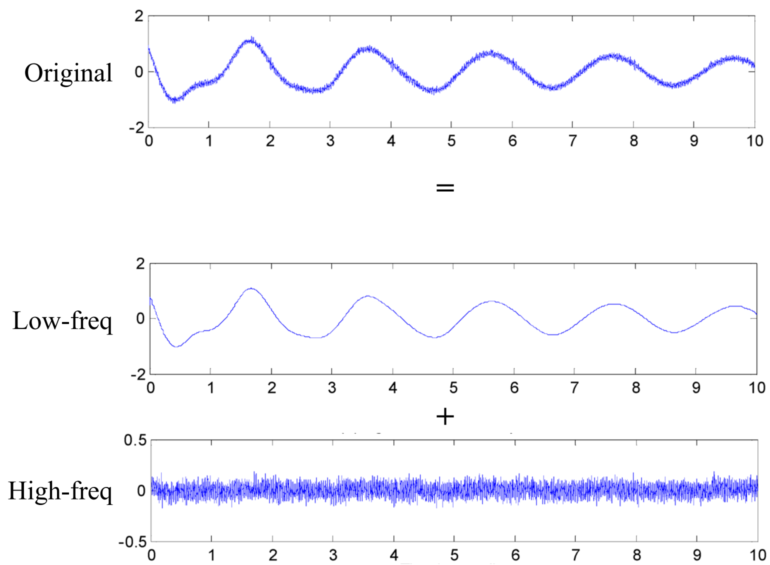
- Two fundamental operations
  - Approximately inverses of one another
  - Linear operations
- First operation blurs and samples the input
- Second "reverse" operation interpolates the blurred and sampled input to estimate the original
- First examine 1-D signal, then move on to 2-D images

Blurring/Sampling Operation

- First operation convolves input signal with a smoothing mask/kernel, then samples the result
  - Blurring and sampling go together
- Blurring creates smoother version of original (reducing aliasing), containing fewer high-frequency components
- Thus can represent blurred data with fewer samples than in original
  - Sample blurred signal at every other value

Original signal = low-frequency + high-frequency info

Visualization

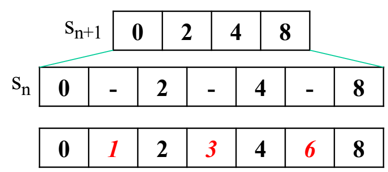


Pyramid Construction

- To create **pyramid**, repeat blurring and sampling on each resulting signal
  - Original signal s_1
  - Blur and sample s_1 to create s_2
  - Blur and sample s_2 to create s_3
  - And so on…
- Each successive level contains half as many sample values as the previous level
  - For an image, sampling every other row and column, each successive level contains one-quarter of the samples as the previous level

Interpolation (Reverse) Operation

- <u>Approximate</u> inverse of blurring/sampling operation
- Make an <u>informed guess</u> of original signal from the reduced signal
  - Approximate s_n from s_{n+1}
- First up-sample s_{n+1} to the size of s_n
  - Place data from s_{n+1} into <u>every other entry</u> of a vector s_n
- Next interpolate new empty values between the given values
  - For example, use the average of the given neighbor values



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Error Signal as Laplacian Pyramid

- Error is difference between estimate (low-frequency) and original
  - Interpolated estimate and original
- Sequence of error signals forms the "error pyramid"
  - This error pyramid is called a "**<u>Laplacian</u>** pyramid"
    - Burt and Adelson 1983
- From Laplacian/error pyramid, can reconstruct original signal s_1 **<u>without any error</u>**
  - Add interpolated s_2 and the error e_1
    - Error e_1 is difference between s_1 and the interpolated s_2 to (s_1)
  - low-frequency (s_2) + high-frequency (e_1)

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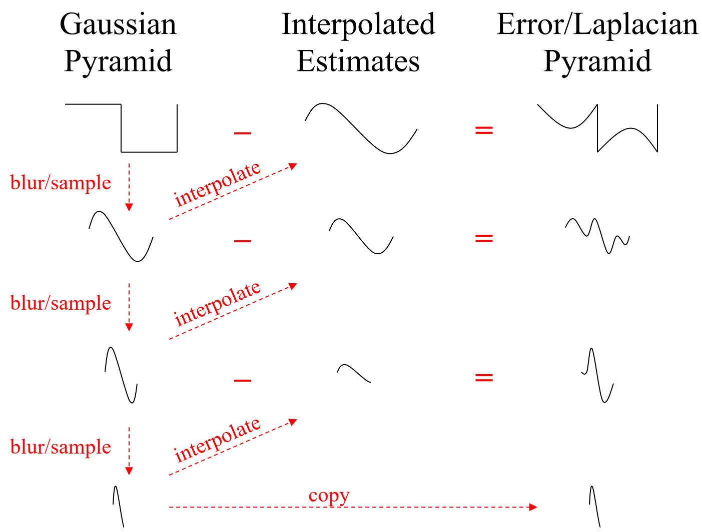
1-D Pyramid Construction



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Reconstruction

- Original signal can be recovered <u>exactly</u> by interpolating, then summing all the levels of the error pyramid
- Hence only the error pyramid is needed to represent the original signal completely
- Why do this?
  - Useful for coding/compression (we'll see soon)

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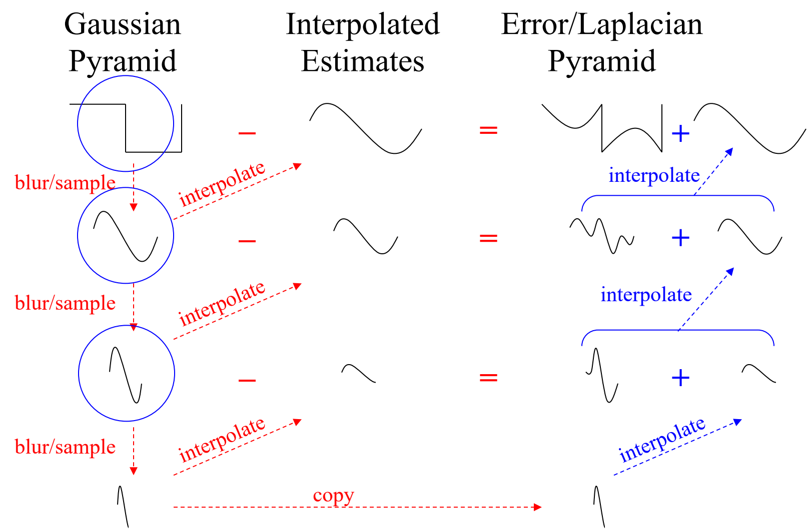
1-D Pyramid Reconstruction



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Images

- None of the previous methods/principles change when dealing with 2-D images
- Use Gaussian blurring
  - $G(m,n) = w(m)w(n)$ **separable!**
  - where $w = [.25\text{-}.5a,\ \ .25,\ \ a,\ \ .25,\ \ .25\text{-}.5a]$
- Sub-sample rows and columns
- Useful for image coding
- Applicable to progressive transmission

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Image Sizes

- From Burt & Adelson:
  The dimensions (R,C) of the original image are *appropriate* for pyramid construction if <u>integers</u> M_C, M_R, and N exist such that

  $$C = M_C 2^N + 1$$
  $$R = M_R 2^N + 1$$

  N is the number of levels desired (original image is level-0)
- Example
  If $M_C = 3$, $M_R = 3$, and $N = 5$ levels,
  then the original image size is 97 x 97 pixels

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Gaussian Pyramid

$a = .4$

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Laplacian "Error" Pyramid

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Reconstruction

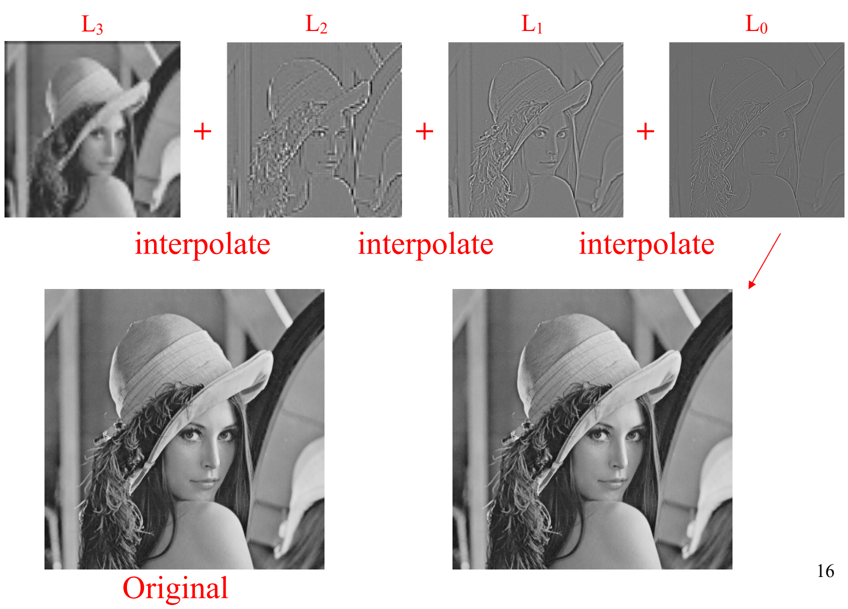

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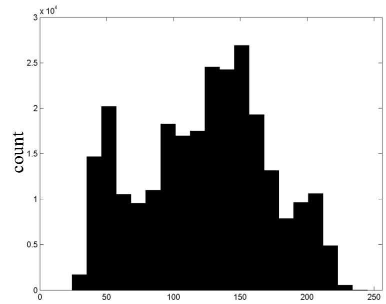
Image Coding/Compression

Original



Is this a good image for high compression without perceptual loss?

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Compression and Coding

- Could just encode the original image
  - But histogram of values is broad (not well suited to compression methods)
- Laplacian pyramid is useful for this
- **Error signals are distributed over smaller range** (around zero) than original image
  - Easier to compress (more compact) in LOSSLESS/LOSSY manner
  - Can be represented very efficiently
- Quantization of error distribution further reduces data without perceptual loss
  - Divide range of pixel values into bins

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Image Coding/Compression

Original

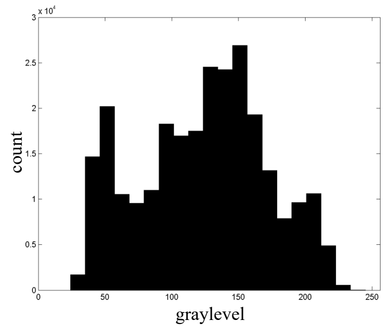
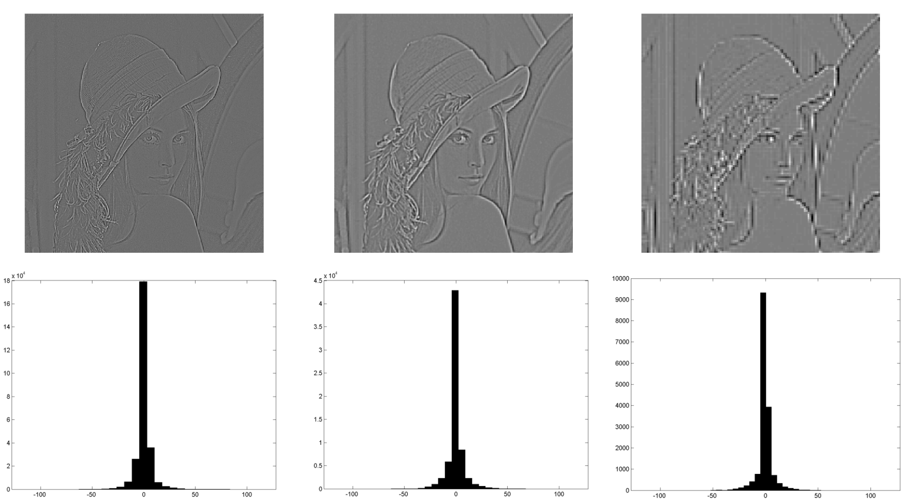


Image Coding/Compression



L_0 L_1 L_2

Progressive Transmission

- Progressive image transmission
  - Coarse rendition of image sent first to give early impression of image content
  - Further transmissions provide image detail of progressively finer resolution
  - Can terminate transmission when user sees enough detail
- Laplacian pyramid well suited for progressive image transmission
  - Topmost level of pyramid sent first (low-res)
  - Next lower level is then transmitted and added to the first, and so on
- On receiving end, see image steadily coming into focus

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Progressive Transmission

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Progressive Transmission

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Progressive Transmission

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Progressive Transmission

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Summary

- Image pyramids as multi-resolution image representations
  - Gaussian pyramid
  - Laplacian pyramid
- Two fundamental operations for pyramids
  - First operation blurs and samples the input
  - Second operation interpolates the blurred and sampled image to estimate the original
- Laplacian error pyramid
  - Error is difference between interpolated estimate and original
  - Original signal can be recovered exactly by interpolating, then summing all the levels of the error pyramid
  - Can be represented very efficiently (easier to compress)
- Useful for image coding/compression and progressive transmission
- Gaussian pyramid useful for other tasks (e.g., motion calculation)

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