Improved Segmentation and Extrapolation for Block-Based Shape-Adaptive Image Coding

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Purpose & Motivation

- Block-based image coding systems (JPEG) produce poor quality images at low bit-rate (<0.5 bpp)
- HVS is sensitive to distortion along object boundary, less sensitive to distortion within the content
- Possible approach proposed: segmentation-based image coding, including
  - Image segmentation system
  - Texture coding system
  - Contour coding system

Morphological-Based Image Segmentation Algorithms

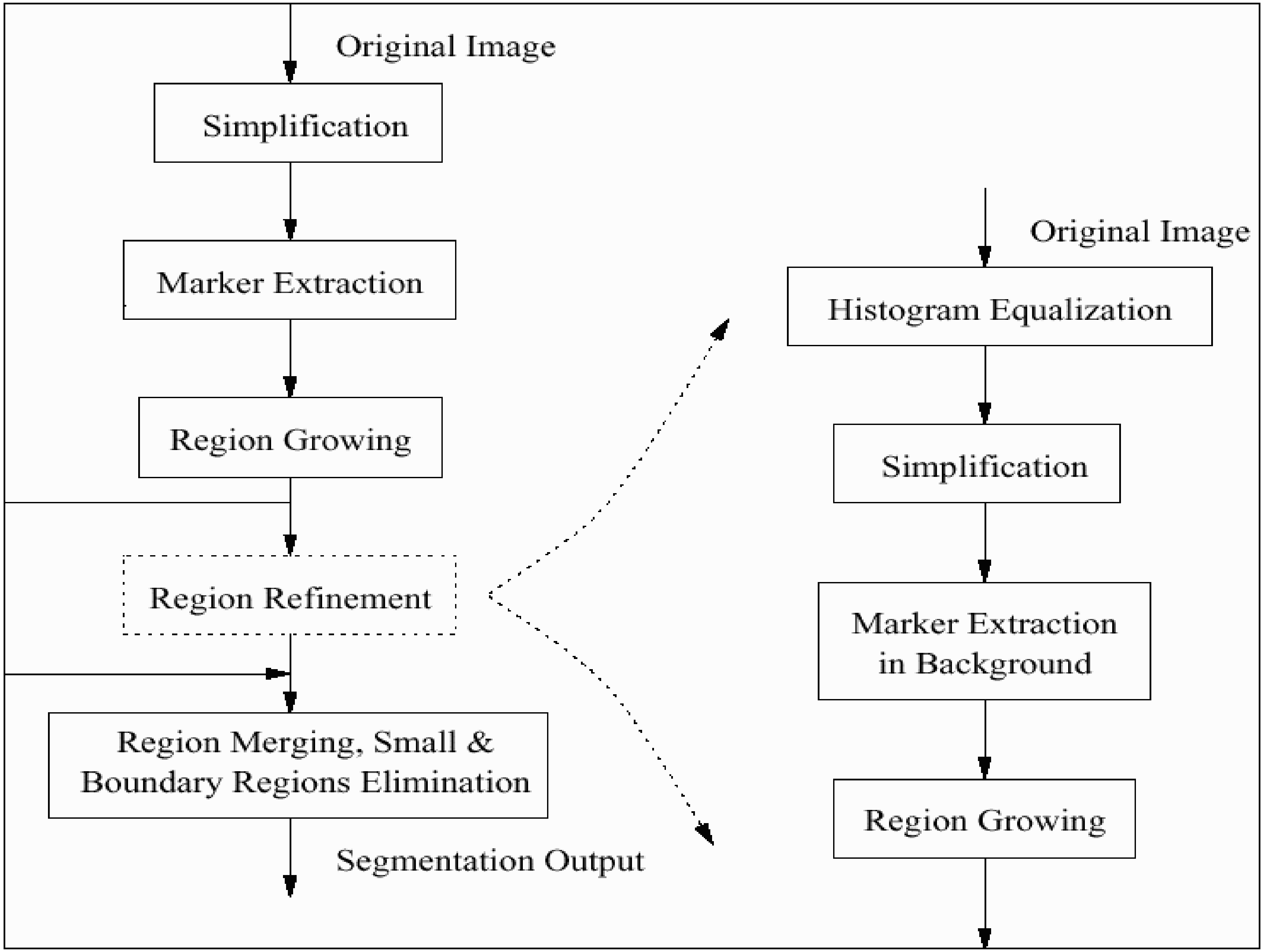
Existing

- Hierarchical Morphological Synthesis-by-Analysis
- Morphological Simplification, Region Splitting & Merging

Proposed

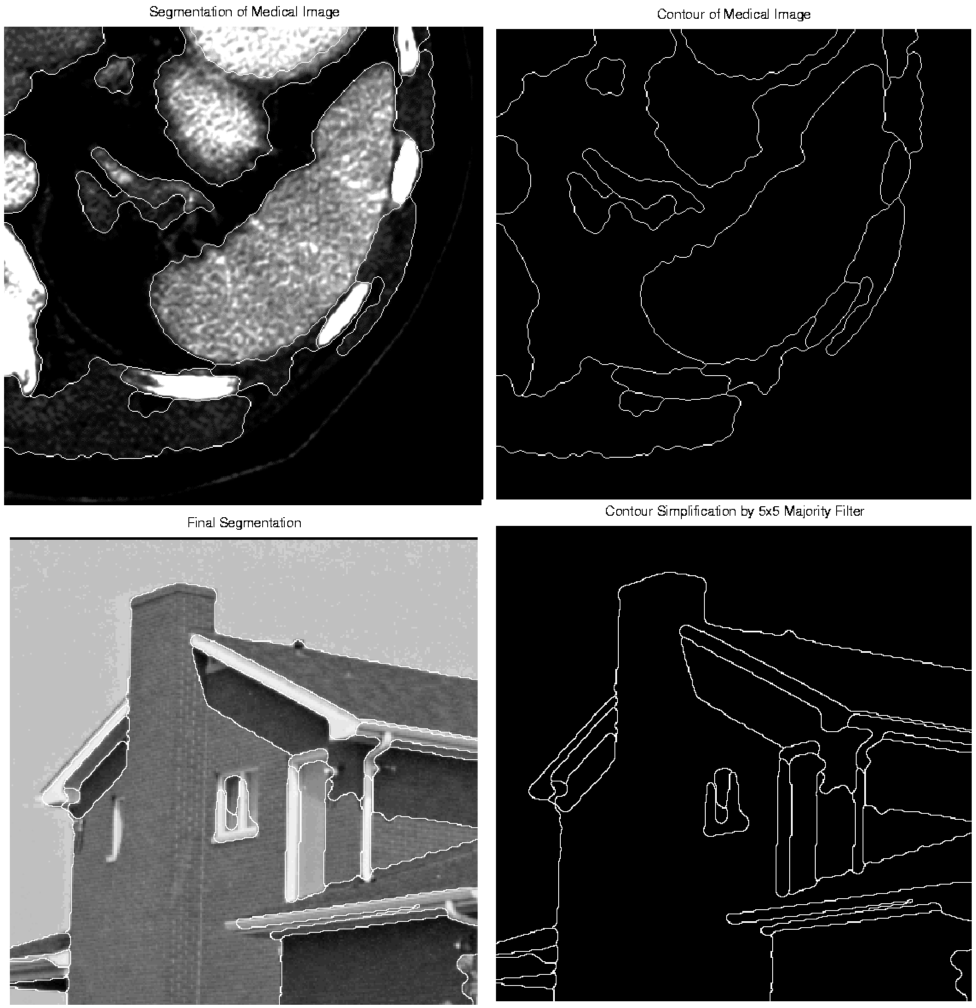
- Edge Detection, Local-Activity Classification

Edge Detection, Local-Activity-Classification Segmentation Algorithm



Edge Detection, Local-Activity-Classification Segmentation Results

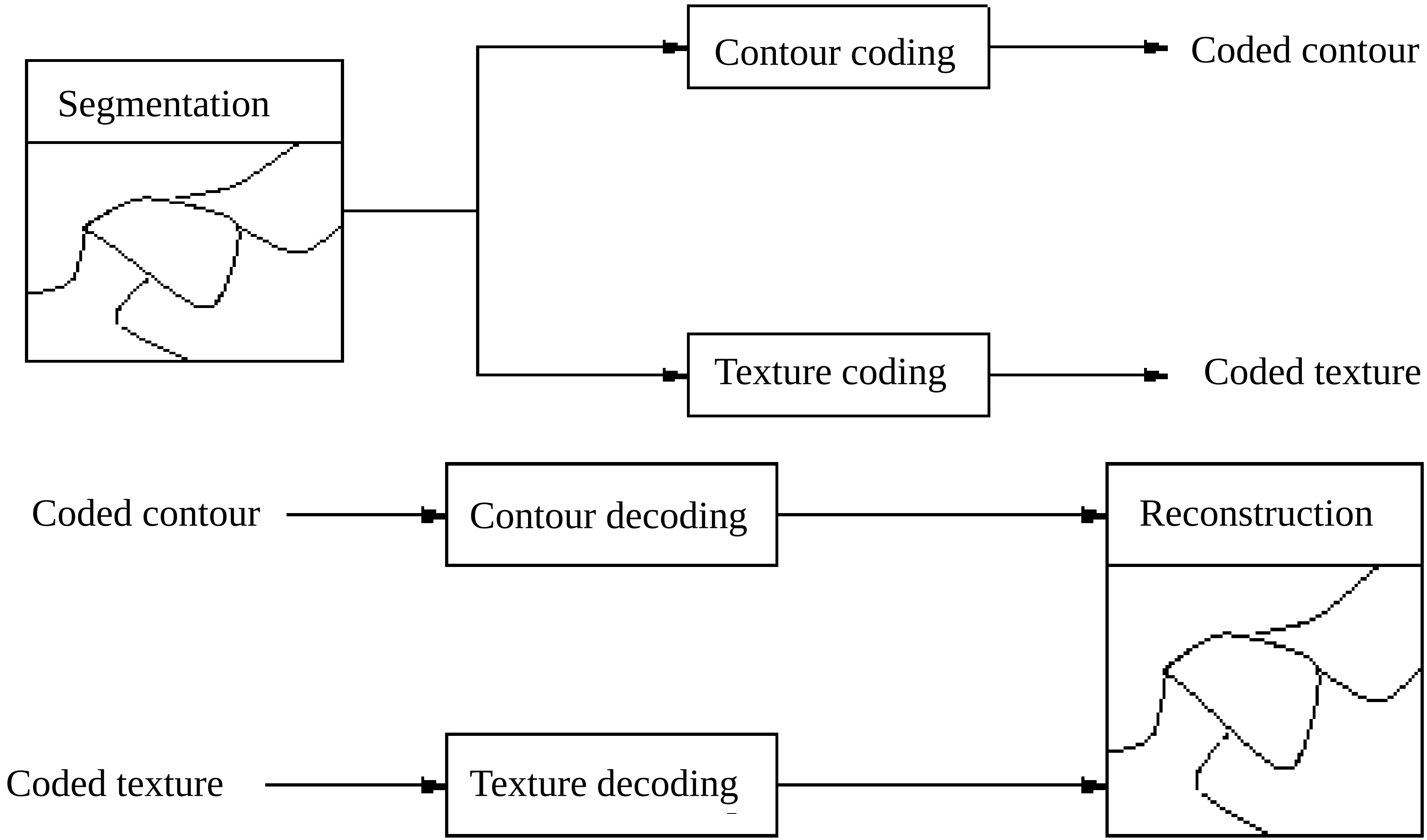
Edge Detection, Local-Activity-Classification Segmentation Results (cont'd)



Advantages of Proposed Segmentation Algorithm

- Segmentation output better matched to coding task
- Moderate computation load
- Possible approach to generic segmentation algorithm

Shape-Adaptive Image Coding System



Block-Based Shape-Adaptive Coding Techniques

- Shape-Adaptive DCT (SADCT)
- Block Extrapolation Methods
  - Low-pass extrapolation (LPE) padding technique
  - Optimal data extrapolation (min. norm sense)

$$\min. \ \|l\|_1 \ \text{(Basis Pursuit)}$$

Optimal Block Extrapolation (min. norm)

- From 2D to 1D

$$C^T A C = S \quad \Leftrightarrow \Phi \underline{a} = \underline{s} = \begin{bmatrix} \underline{\beta}_{m\times 1} \\ \underline{\theta}_{(N-m)\times 1} \end{bmatrix}; \; \Phi = C^T \otimes C$$

- Optimal Approach

$$\min \left\| \underline{a} \right\|_p \quad \text{subject to} \quad \Phi'_{m\times N} \, \underline{a} = \underline{\beta}$$

  - $\min \left\| \underline{a} \right\|_1$ subject to $\Phi' \underline{a} = \underline{\beta}$ (Basis Pursuit)

l_1 Optimal Block Extrapolation

$$\underline{a} = \underline{u} - \underline{v} \quad \underline{u},\ \underline{v} \geq 0$$

$$\min\ 1^T \begin{bmatrix} \underline{u} \\ \underline{v} \end{bmatrix} \quad \text{subject to} \quad \begin{bmatrix} \Phi' & -\Phi' \end{bmatrix} \begin{bmatrix} \underline{u} \\ \underline{v} \end{bmatrix} = \underline{\beta}$$

- Can be solved by Linear Programming
- Only *m* nonzero entries exist in $\underline{a}$, the same number as of known original data
- Positions of nonzero entries are unpredictable

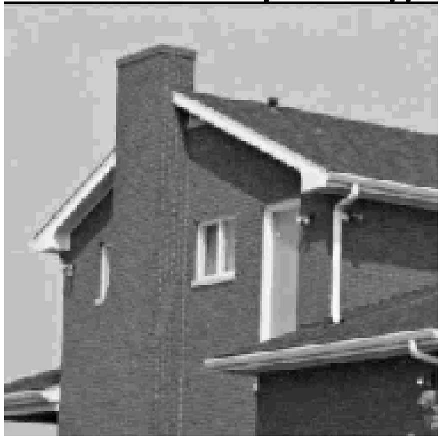
Block-Based Shape-Adaptive Coding Results

Original Image

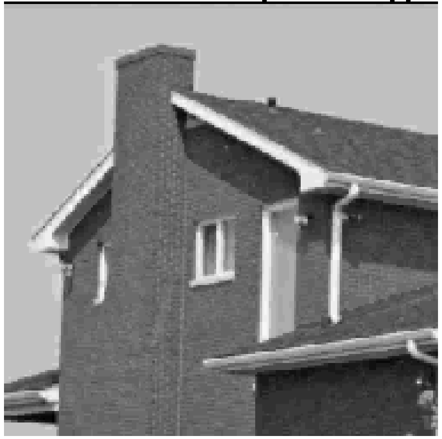
JPEG PSNR=36.134, 0.4154 bpp

JPEG PSNR=33.793, 0.2917 bpp

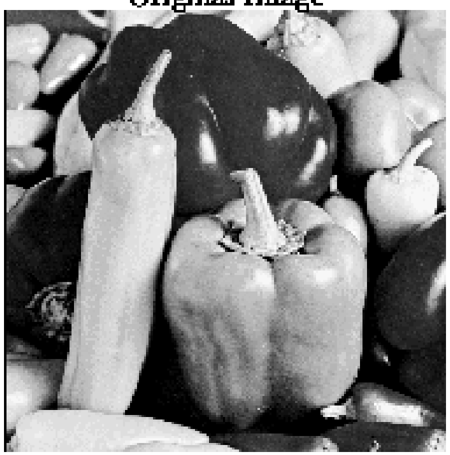
BP PSNR=35.973, 0.3692 bpp

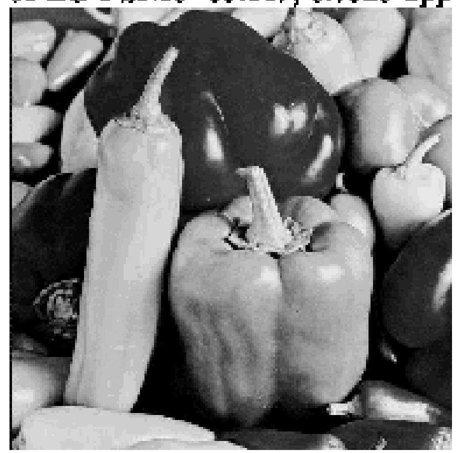


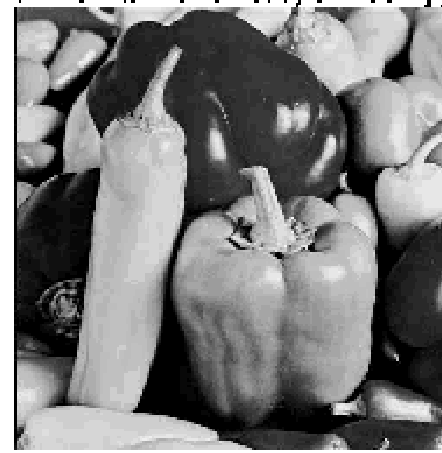
BP PSNR=33.794, 0.2660 bpp

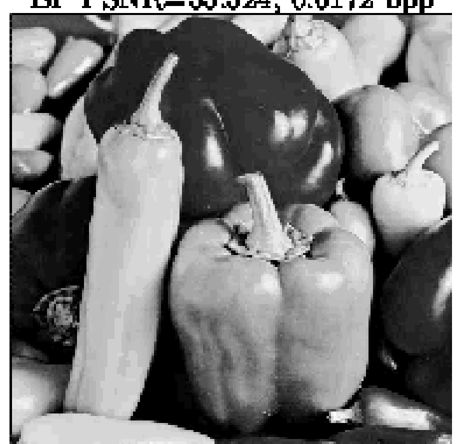


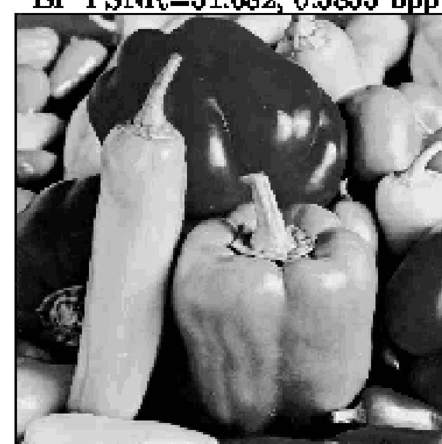
Block-Based Shape-Adaptive Coding Results


Original Image


JPEG PSNR=33.447, 0.7320 bpp


JPEG PSNR=31.879, 0.4488 bpp


BP PSNR=33.324, 0.6172 bpp


BP PSNR=31.682, 0.3835 bpp

Block-Based Shape-Adaptive Coding Results

Method	Texture Bpp	Contours bpp	Total Bpp	PSNR
JPEG	/	/	0.4154	36.134
	/	/	0.2917	33.793
Min. ℓ_1	0.3692	0.0240	0.3932	35.973
	0.2660	0.0240	0.2900	33.794
LPE Padding	0.4609	0.0240	0.4849	36.171
	0.3222	0.0240	0.3462	33.962
SADCT	0.4923	0.0240	0.5163	35.630
	0.3435	0.0240	0.3675	33.831

Table 1:
Comparison of coding Results of the image "House" by block-based techniques.

Method	Texture Bpp	Contours bpp	Total Bpp	PSNR
JPEG	/	/	0.7320	33.448
	/	/	0.4488	31.879
Min. ℓ_1	0.6172	0.0574	0.6746	33.324
	0.3835	0.0574	0.4409	31.682
LPE Padding	0.7282	0.0574	0.7856	33.093
	0.4463	0.0574	0.5037	31.725
SADCT	0.7336	0.0574	0.7910	33.117
	0.4415	0.0574	0.4989	31.309

Table 2:
Comparison of coding Results of the image "Peppers" by block-based techniques.

Conclusions & Future Studies

- **Segmentation**
  - + Proposed algorithm is better matched to the coding task
  - + Proposed algorithm could be the basis for a generic segmentation algorithm, provided that region refinement is further studied
- **Shape-Adaptive Coding**
  - – Region-based approach has practical (numerical) problems concerning the order of basis functions that can be generated

Conclusions & Future Studies (cont'd)

- **Block-based Shape-Adaptive Coding**
  - \+ Block-based approach reduces bit-rate (compared to JPEG) for images with steep edges between segments
  - \+ Compatible with available block-based coding systems
  - – Does not fully exploit the potential provided by segmentation
- **BP Extrapolation**
  - \+ Provides better results than LPE padding & SADCT
  - – High complexity

Optimal Block Extrapolation (min. norm)

- From 2D to 1D

$$C^T A C = S \quad \Leftrightarrow \Phi \underline{a} = \underline{s} = \begin{bmatrix} \underline{\beta}_{m\times 1} \\ \underline{\theta}_{(N-m)\times 1} \end{bmatrix}; \; \Phi = C^T \otimes C$$

- Optimal Approach

$$\min \|\underline{a}\|_p \quad \text{subject to} \quad \Phi'_{m\times N}\, \underline{a} = \underline{\beta}$$

  - $\min \|\underline{a}\|_2$ subject to $\Phi'\underline{a} = \underline{\beta}$ (Method of Frames)
  - $\min \|\underline{a}\|_1$ subject to $\Phi'\underline{a} = \underline{\beta}$ (Basis Pursuit)