Phase-Based Semiautomatic Image Segmentation

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The Problem: Medical image segmentation is the process of labeling each voxel in a medical image dataset to indicate its tissue type or anatomical structure. This is difficult to perform automatically because of anatomical variability, the limited knowledge available to the computer, and inherent limitations of medical image data. These include partial voluming artifacts, noise, and the lack of general correspondence between grayscale and tissue type.

Motivation: The classic method of medical image analysis, inspection of two-dimensional grayscale images on a lightbox, is not sufficient for many applications. When detailed or quantitative information about the appearance, size, or shape of patient anatomy is desired, image segmentation is often the crucial first step. Applications of interest that depend on image segmentation include three-dimensional visualization, volumetric measurement, research into shape representation of anatomy, image-guided surgery, and detection of anatomical changes over time.

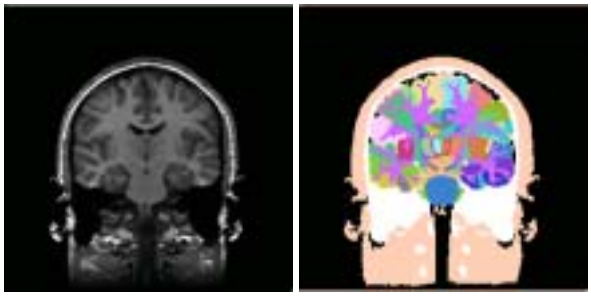


Figure 1: An example of medical image segmentation. The segmentation of a this MRI dataset was created using manual and automatic methods. This image demonstrates the level of complexity of a very complete neural segmentation.

Previous Work: Livewire is an image-feature driven method that finds the optimal path between user-selected image locations, thus reducing the need to manually define the complete boundary. In this way, the user's anatomical knowledge complements the ability of the computer to find boundaries of structures in an image. This intuitive method is driven only by image information, with little geometric constraint, so extracting knowledge from the image is of primary importance. The livewire algorithm has two main parts, first the conversion of image information into a weighted graph, and then the calculation of shortest paths in the graph, which are displayed over the image as "live wires" [4, 1].

Approach: We investigate local phase as the primary source of image information for driving the livewire [5]. The local phase as discussed in this paper is a multidimensional generalization of the concept of instantaneous phase [2, 3].

To motivate the idea of two-dimensional phase, we show the instantaneous phase of a simple one-dimensional signal in Figure 2. This simple signal can be thought of as the intensity along a row of pixels in an image. Note that in this "image" there are two edges, or regions where the signal shape is locally odd, and the phase curve reacts to each, giving phase values of $\pi/2$ and $-\pi/2$. Our system uses these phase values to find desirable boundaries for segmentation in medical images.

To estimate the phase we are using quadrature filters which have a radial frequency function that is Gaussian

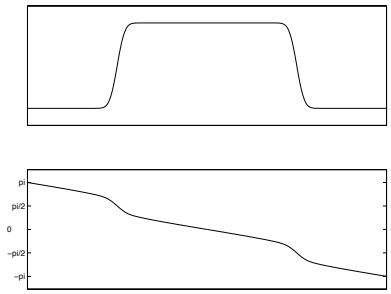


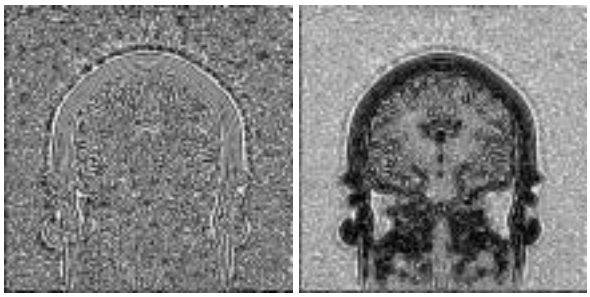
Figure 2: A simple signal (top), and its instantaneous phase (bottom).

on a *logarithmic* scale:

$$\nu(\rho) = \mathrm{e}^{-\frac{4}{\log 2} B^{-2} \log^2(\frac{\rho}{\rho_i})} \tag{12}$$

where ρ_i is the center frequency and B is the 6 dB sensitivity bandwidth in octaves.

Figure 3 shows example input to our phase-based semiautomatic segmentation method. The livewire is attracted to the darker parts of the input image, under guidance from the user. An advantage of using local phase in this way is that the measure is not sensitive to the magnitude of boundaries in the image, so the system allows segmentation along weak or strong boundaries between anatomical structures.



Local Phase Image Combined Image

Figure 3: Local phase images. The left-hand image shows the local phase as calculated for a grayscale MR image of the head. This is the primary feature employed in our phase-based livewire method. The right-hand image displays the weighted combination of phase and our certainty feature, which is proportional to edge strength and can be combined with the phase image to reduce noise. Darker pixels are "attractors" for the livewire.

Future Work: It would be interesting to use local orientation information in addition to local phase information, since both can be obtained using quadrature filters. Also of interest would be a three-dimensional generalization of the method.

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References:

[1] W. A. Barrett and E. N. Mortensen. Interactive live-wire boundary extraction. *Medical Image Analysis*, 1(4):331–341, 1997.

[2] B. Boashash. Estimating and interpreting the instantaneous frequency of a signal - part 1: Fundamentals. *Proceedings of the IEEE*, 80(4):520–538, 1992.

[3] B. Boashash. Estimating and interpreting the instantaneous frequency of a signal - part 2: Algorithms and applications. *Proceedings of the IEEE*, 80(4):540–568, 1992.

[4] A. X. Falcao, J. K. Udupa, and F. K. Miyazawa. An ultra-fast user-steered image segmentation paradigm: Live wire on the fly. *IEEE Transactions on Medical Imaging*, 19(1):55–61, 2000.

[5] L. O'Donnell, Carl-Fredrik Westin, W. Eric L. Grimson, Juan Ruiz-Alzola, Martha E. Shenton, and Ron Kikinis. Phase-based user-steered image segmentation. *accepted for publication in MICCAI*, October 2001.