Chapter II

Optimal Image Segmentation Methods Based on Energy Minimization

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ABSTRACT
In this chapter we present three “case studies” as representative of recent work on solving several segmentation problems (region segmentation, deformable templates matching and grouping) from the energy minimization perspective. Each of the latter problems is solved via an optimization approach, respectively: jump-diffusion, belief propagation and Bayesian inference. Our purpose is to show the connection between the formulation of the corresponding cost function and the optimization algorithm and also to present some useful ideas coming from Bayesian and information theory. This selection of only three problems (and solutions) allows us to present the fundamental elements of optimization in each particular case and to bring the readers to the arena of optimization-based segmentation.

INTRODUCTION
From the energy minimization point of view (see www.emmcvpr.org for a recent series of workshops devoted to propose optimization methods for solving computer vision problems),
vision and pattern recognition problems) segmentation involves both the design of cost functions and the proposal of optimization algorithms for minimizing them. In recent years, approaches in this regard (statistical mechanics methods, Bayesian inference, Markov random fields, belief propagation, PDEs and variational methods, information theory, and so on) have proved to be effective for solving many computer vision problems including region segmentation, clustering, perceptual grouping, contour segmentation and deformable templates fitting. Due to the methodological importance of energy minimization for designing a wide range of segmentation methods, we devote this chapter to describing a selection of optimization methods. We try to present clearly the connection between the models (cost functions) and the algorithms (simulated annealing, jump-diffusion, stochastic gradient descent, optimization via Lagrange multipliers, and so on). Due to space constraints it is impossible to provide here a detailed presentation of all the optimization methods and principles used for solving segmentation problems. However, there are some representative cases in the literature. We have selected three problems (region segmentation, deformable templates fitting and perceptual grouping) and three optimization methods (jump-diffusion, belief propagation and Bayesian A*) which are proved to solve respectively the latter problems with an acceptable computational cost. We present them here as “case studies.”

We begin by introducing a Bayesian inference formulation for the problem region segmentation (where the number of regions is unknown). Here we present existing recent work in solving the latter problem through a jump-diffusion technique. Such a particular approach is particularly interesting because it exploits data coming from bottom-up processes and thus reconciles generative approaches to segmentation with bottom-up ones. The second approach consists of solving a model-based segmentation problem, namely deformable templates fitting. In this latter case it is interesting to introduce recent advances in belief propagation methods for grasping global consistency by propagating local knowledge, in particular the connection between belief propagation rules and minimizing the Bethe free energy. Finally, in the last section of the chapter we will introduce a solution inspired in Bayesian inference to the problem of feature extraction and grouping. The type of cost functions described here for solving path-searching problems (finding contours in images) generalize the cost functions used in contour-based segmentation (snakes models) and allow the researchers to think about existing fundamental limits which constrain the possibility of even solving the problem independently of the algorithm chosen. The presented algorithm (Bayesian A*) is a good example of how to reduce the complexity of a segmentation task by exploiting information theory results.

REGION SEGMENTATION: METROPOLIS AND JUMP-DIFFUSION

Formulation of Bayesian Image Segmentation

Given an image \( f(x) \) defined over a lattice \( S \), the segmentation problem can be posed in terms of “finding a partition” of the lattice into an unknown number of regions \( K \) so that:

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