FAST ACTIVE OBJECT TRACKING IN COLOR VIDEO

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1 Introduction

An important problem in image analysis is object segmentation and tracking in image sequences. It involves the isolation of a single object from the rest of the image that may include other objects and a background. Here, we focus on boundary detection of one or several objects by a dynamic model known as the 'geodesic active contour' introduced in [3–6], see also [11, 17].

Although the geodesic active contour model has many advantages over its predecessors - snake model and geometric flow, its main drawback is its non-linearity that results in inefficient implementations. For example, explicit Euler schemes for the geodesic active contour limit the numerical step for stability.

In this paper we introduce a new method that maintains the numerical consistency and makes the geodesic active contour model computationally efficient. The efficiency is achieved by canceling the limitation on the time step in the numerical scheme, by limiting the computations to a narrow band around the the active contour, and by applying an efficient re-initialization technique.

2 The method

The geodesic active contour model was introduced in [3–6], see also [11, 17], as a geometric alternative for the snakes and is derived from the following geometric functional

$$S[\mathcal{C}] = \int_0^{L(\mathcal{C})} g(\mathcal{C})ds,$$

where the curve $\mathcal{C}(s) = \{x(s), y(s)\}$ is parametrized by Euclidian arclength s and $g()$ is a positive edge indicator function that depends on the image. It gets small values along the edges and higher values elsewhere.

The Euler Lagrange equation as a gradient descent process is given by

$$\frac{d\mathcal{C}}{dt} = (g(\mathcal{C})\kappa - \langle \nabla g, \mathcal{N} \rangle)\mathcal{N}.$$

In order to take care of topological changes of the evolving interface we use the level set method introduced by Osher and Sethian [12] that works on a fixed coordinate system and considers evolving fronts in an implicit form by representing the evolving contour $\mathcal{C}$ using an embedding function $\phi(x, y) : \mathbb{R}^2 \to \mathbb{R}$, such that $\mathcal{C} = \{(x, y) : \phi(x, y) = 0\}$.

The geodesic active contour model written in its level set formulation is given by

$$\frac{d\phi}{dt} = \text{div}\left(g(x, y)\frac{\nabla\phi}{|\nabla\phi|}\right)|\nabla\phi|.$$

Now we have to determine a numerical scheme and an appropriate edge indication function g. An explicit Euler scheme with forward time derivative, introduces a numerical limitation on the time step needed for stability. Moreover, the whole domain needs to be updated each step, which is a time consuming operation for a sequential computer. The narrow band approach [7],[1] overcomes the last difficulty by limiting the computations to a narrow strip around the zero set.

To cope with the time step limitation problem we use the additive operator splitting (AOS) schemes introduced by Weickert et al. [19]. It is an unconditionally stable numerical scheme for the Perona-Malik [14], non-linear image evolution equation of the form $\partial_t u = \text{div}\,(g(|\nabla u|)\nabla u)$, given initial condition as the image $u(0) = u_0$.

The AOS semi-implicit scheme in $2D$ is given by a linear tridiagonal system of equations that can be efficiently solved by Thomas algorithm, and proven to be unconditionally stable, see [19].

Since our interest is only at the zero level set of ϕ, we can reset ϕ to be a distance function every numerical iteration. One nice property of distance maps is its unit gradient magnitude almost everywhere. Thereby, the short term evolution for the geodesic active contour given by a distance map, with $|\nabla\phi| = 1$, is

$$\partial_t \phi = \text{div}\,(g(|\nabla u_0|)\nabla\phi)\,.$$

This can be solved efficiently by the AOS scheme. Yet, we need to keep the ϕ function as a distance map. This is done through re-initialization by Sethian's fast marching method [16, 15] every iteration.

In order to reduce the computational cost we use a multi-scale approach [10]. Moreover, the computations are performed only within a limited narrow band around the zero set. The narrow band automatically modifies its shape as we re-initiate the distance map.

Now the question of proper edge indicator for color images is to be answered. We consider a measure suggested by the Beltrami framework in [18], to construct an edge indicator function. A color image is represented as a two dimensional surface in the five dimensional spatial-spectral space and the magnitude of the metric tensor, that is an area element of the color image surface, is used as the edge indicator function.

We also explore two possibilities to track objects in movies. The first, considers the whole movie volume as a Riemannian space, as done in [6]. In this case the active contour becomes an active surface. The edge indicator function is again derived from the Beltrami framework, by taking a metric for a 3D volume in the 6D $\{x, y, \mathcal{T}, R, G, B\}$ spatial-temporal-spectral space. A different approach uses the contour location in frame n as an initial condition for the 2D solution in frame $n+1$, see e.g. [2, 13]. The above edge indicator is still valid in this case.

The first approach was found to yield accurate results in off line tracking analysis. While the second approach gives up some accuracy, that is achieved by temporal smoothing in the first approach, for efficiency in real time tracking.

3 Experimental Results

As a simple example, the proposed method can be used as a consistent, unconditionally stable, and computationally efficient, numerical approximation for the curvature flow. The curvature flow is proven to bring every simple closed curve into a circular point in finite time [8, 9]. Figure 1 shows an application of the proposed method for a curve evolving by its curvature and vanishing at a point. One can see how the number of iterations needed for the curve to converge to a point decreases as the time step is increased.

We tested several implementations for the curvature flow. Figure 2 shows the CPU time it takes the explicit and implicit schemes to evolve a contour into a circular point. For the explicit scheme we tested both the narrow band and the naive approach in which every grid point is updated every iteration. The tests were performed on an Ultra SPARC $360MHz$ machine for a 256×256 resolution image.

Figures 3 and 4 show segmentation results for color movies with difficult spatial textures. The tracking is performed at two resolutions. At the lower resolution we search for temporal edges and at the higher resolution we search for strong spatial edges. The contour found in the coarse grid is used as the initial contour at the fine grid.

4 Concluding Remarks

It was shown that an integration of advanced numerical techniques yield a computationally efficient algorithm that solves a geometric segmentation model. The numerical algorithm is consistent with the underlying continuous model. The proposed 'fast geodesic active contour' scheme was applied successfully for image segmentation and tracking in movie sequences and color images. It combines the narrow band level set method, with adaptive operator splitting, and the fast marching method.

Figures

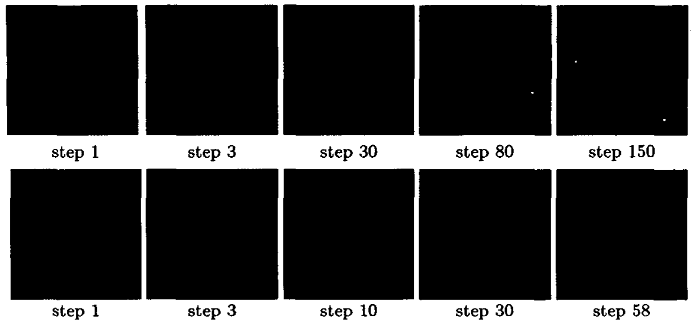

Fig. 1. Curvature flow by the proposed scheme. A non-convex curve vanishes in finite time at a circular point by Grayson's Theorem. The curve evolution is presented for two different time steps. Top: $\tau = 20$; bottom: $\tau = 50$.

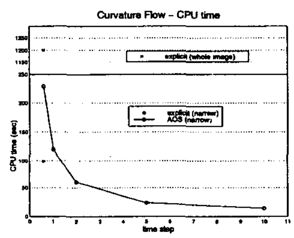

Fig. 2. Curvature flow CPU time for the explicit scheme and the implicit AOS scheme. First, the whole domain is updated, next, the narrow band is used to increase the efficiency, and finally the AOS speeds the whole process. For the explicit scheme the maximal time step that still maintains stability is choosen. For the AOS scheme, CPU times for several time steps are presented.

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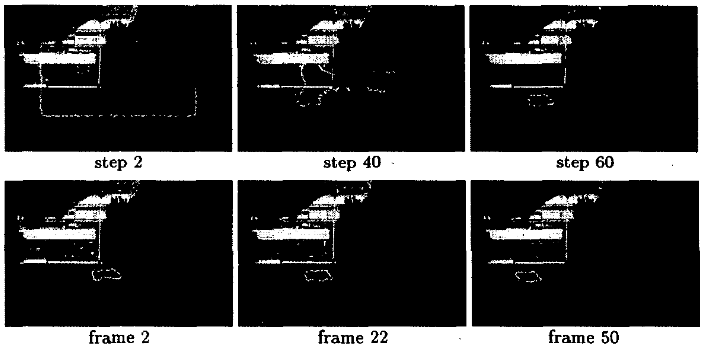

Fig. 3. Tracking a cat in a color movie by the proposed scheme. Top: Segmentation of the cat in a single frame. Bottom: Tracking the walking cat in the 50 frames sequence.

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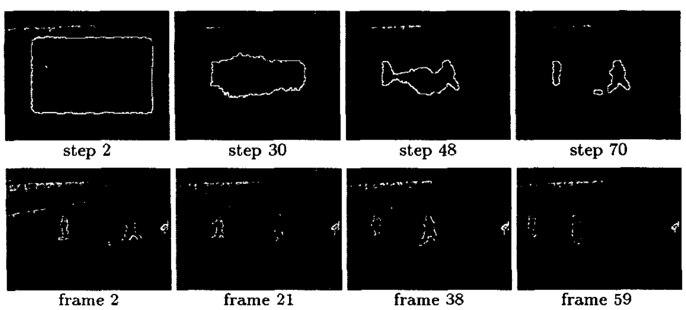

Fig. 4. Tracking two people in a color movie. Top: curve evolution in a single frame. Bottom: tracking two walking people in a 60 frame movie.