Manga Colorization

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Level Set Method

1. Represent a contour as the zero level set of a higher dimensional function, called a level set function (LSF)
2. Formulate the motion of the contour as the evolution of the level set function.
3. Early active contour models are formulated in terms of a dynamic parametric contour $C(s,t):[0,1]\times[0,\infty)\to R^2$ with a spatial parameter s in [0,1], which parameterizes the points in the contour, and a temporal variable $t\in[0,\infty)$. The curve evolution can be expressed as

$$\frac{\partial \mathcal{C}(s,t)}{\partial t} = F/\mathcal{N}$$

3. F is the speed function that controls the motion of the contour,

4. N is the inward normal vector to curve C

How can curve evolution be converted to LSF?

1. By converting the dynamic contour $C(s,t)$ as the zero level set of a time dependent LSF $\phi(x,y,t)$.
2. Embedding LSF ϕ takes negative values inside the zero level contour and positive values outside
3. The inward normal vector can be expressed as $N=-\nabla\phi/|\nabla\phi|$, where ∇ is the gradient operator.
4. The the curve evolution equation, is converted to the following partial differential equation (PDE):

$$\frac{\partial \phi}{\partial t} = F|\nabla \phi|$$

Advantages of LSF

1. They can represent contours of complex topology and are able to handle topological changes, such as splitting and merging, in a natural and efficient way, which is not allowed in parametric active contour models
2. Numerical computations can be performed on a fixed Cartesian grid without having to parameterize the points on a contour as in parametric active contour models

Problems in LSF their remedy

1. Develops irregularities during its evolution, which cause numerical errors and eventually destroy the stability of the level set evolution.
2. To overcome this difficulty, a numerical remedy, commonly known as reinitialization was introduced to restore the regularity of the LSF and maintain stable level set evolution.
3. Reinitialization is performed by periodically stopping the evolution and reshaping the degraded LSF as a signed distance function

Methods of reinitialization

1. A standard method for reinitialization is to solve the following evolution equation to steady state:

$$\frac{\partial \psi}{\partial t} = \mathrm{sign}(\phi)(1 - |\nabla \psi|)$$

2. Fast marching algorithm

Con of using reinitialization

1. The numerical implementation of reinitialization causes errors that may destroy the signed distance property and eventually destabilize the level set evolution

Distance Regularized LSE

1. The distance regularization term is defined with a potential function
2. We provide a double-well potential for the distance regularization term. T
3. The level set evolution is derived as a gradient flow that minimizes this energy functional.
4. The regularity of the LSF is maintained by a forward-and-backward (FAB) diffusion derived from the distance regularization term
5. Thus distance regularization completely eliminates the need for reinitialization in a principled way, and avoids the undesirable side effect introduced by the penalty term

DRLSE for image segmentation

1. Let I be an image on a domain Ω, we define an edge indicator function g by

$$g = \frac{1}{1+|\nabla G_\sigma * I|^2}$$

2. For an LSF $\phi:\Omega\to R$, we define an energy functional $E(\phi)$ by

$$\mathcal{E}(\phi) = \mu\mathcal{R}_p(\phi) + \lambda\mathcal{L}_g(\phi) + \alpha\mathcal{A}_g(\phi)$$