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Elastic Alignment of Microscopic Images Using Parallel Processing on CUDA-Supported Graphics Processor Units

Michálek, J.*, Čapek, M.* **, Janáček, J.*, Kubínová, L.*

* Institute of Physiology, Academy of Sciences of the Czech Republic, v.v.i., Vídeňská 1083, Prague 4 - Krč, 14220 Czech Republic
** Faculty of Biomedical Engineering, Czech Technical University in Prague, nám. Sítná 3105, Kladno 2, 272 01 Czech Republic

Elastic registration or alignment is a task of finding the matching of two images, using geometric and elastic transformations, so that objects in images have the same size, position and orientation. We apply elastic registration in the framework of volume reconstruction [1], where an object acquired from parallel physical sections by a confocal laser scanning microscope is composed and mutual positions of the sections including deformations caused by their cutting have to be found. Our aim was to find a parallelizable algorithm that can be implemented on a graphics card using NVidia CUDA programming environment.

The correspondence between two images to be registered can be found by minimization of a functional penalizing the dissimilarity of corresponding image elements together with roughness of the correspondence function. Let *Pix* be the set of image elements (pixels) and *Edg* the set of edges connecting neighboring pixels. Let u and v be the images of neighboring sections and let $\xi=(\xi^1, \xi^2)$ be a vector image of the correspondence relating element x of the image u and the element $x+\xi_x$ of the image v. As the minimized functional we used

$$F(\xi) = \sum_{e\in Edg}\left|\xi^1_{e_1} - \xi^1_{e_2}\right| + \left|\xi^2_{e_1} - \xi^2_{e_2}\right| + \frac{1}{\lambda}\sum_{x\in Pix}\left|u_x - v_{x+\xi_x}\right|,$$

where the first sum is the *discrete total variation* as a measure of roughness and the second one represents *L1 norm* as a measure of dissimilarity of images. $\lambda>0$ stands for the parameter controlling the trade-off between the smoothness of the correspondence and similarity of corresponding image elements.

The functional F is well-suited to be solved by optimization of *(max,+)-labeling problems*. Nowadays, a very popular optimization of these problems is, for example, the method of *graph-cuts* [2]. Although *graph-cuts* is known as one of the most efficient algorithm, for complex tasks with high number of variables to be solved, like elastic registration is, and when registering large images, *graph-cuts* may become slow. Moreover, *graph-cuts* is difficult to parallelize. Except for finding the suitable functional for elastic registration, our effort was to find and implement an optimization that can work in a parallel way. One such optimization has been described by Schlesinger and Giginyak [3]. This algorithm represents an equivalent transformation of a *(max,+)-labeling problem*.

Let T be a set of pixels in an image. Elements of the set will be denoted as t or t', $t\in T$, $t'\in T$. Let a subset $\mathfrak{I}\subset T\times T$ of object pairs be given, which defines a neighbourhood relation. Designation $tt'\in\mathfrak{I}$ will mean that the objects t and t' are neighbours. It is assumed here and below that the graph of neighbourhood relations $\mathfrak{I}$ is connected. Let K be a set, whose elements will be referred to as labels. For each label k and each object t a number $q_t(k)\in R$ is defined. Similarly, for each pair $tt'\in\mathfrak{I}$ of neighbours and each pair of labels k and k' a number $g_{tt'}(k,k')\in R$ is defined. These numbers will be referred to as local qualities. The weights $q_t(k)$ and $g_{tt'}(k,k')$ are real numbers, none of them being

−∞. A labelling is defined as a function $\mathbb{k}:T \rightarrow K$, which assigns a label $k(t)$ to each object t. A set of all possible functions of such format will be denoted as K^T. A *(max,+)-labelling problem* consists in calculating a quality $G = \max_{\mathbb{k} \in K^T} \left[\sum_{tt' \in \Im} g_{tt'}\big(k(t), k(t')\big) + \sum_{t \in T} q_t\big(k(t)\big) \right]$ and looking for the best labelling $\mathbb{k}^* = \arg\max_{\mathbb{k} \in K^T} G(\mathbb{k})$. An equivalent transformation of a *(max,+)-labelling problem* means here introducing an array of potentials Ψ and transforming the above mentioned quality G into power $Q(\Psi) = \max_{\mathbb{k} \in K^T} G^H(\mathbb{k}, \Psi) + \max_{\mathbb{k} \in K^T} G^V(\mathbb{k}, \Psi)$, where $G^H(\mathbb{k},\Psi)$ and $G^V(\mathbb{k},\Psi)$ are horizontal and vertical qualities of labelling $\mathbb{k}$. Thus, labellings $\mathbb{k}^{*H} = \arg\max_{\mathbb{k} \in K^T} G^H(\mathbb{k}, \Psi)$ and $\mathbb{k}^{*V} = \arg\max_{\mathbb{k} \in K^T} G^V(\mathbb{k}, \Psi)$ can be calculated individually and in a parallel way using horizontal and vertical lines of images only, respectively. For more details see [3].

The proposed elastic registration algorithm, consisting in optimizing the functional F by finding the power Q, was implemented both running on CPU using Matlab and C language and running on a graphics card using Matlab and NVidia CUDA programming environment. We found that CUDA-based implementation of the algorithm is approx. six times faster than CPU-based implementation, depending on the size of images to be registered. CUDA-based implementation of the above described elastic registration algorithm is reasonably fast, requires seconds to minutes of calculations, provides good results and, thus, can be used for practical tasks dealing with alignment of microscopic images.

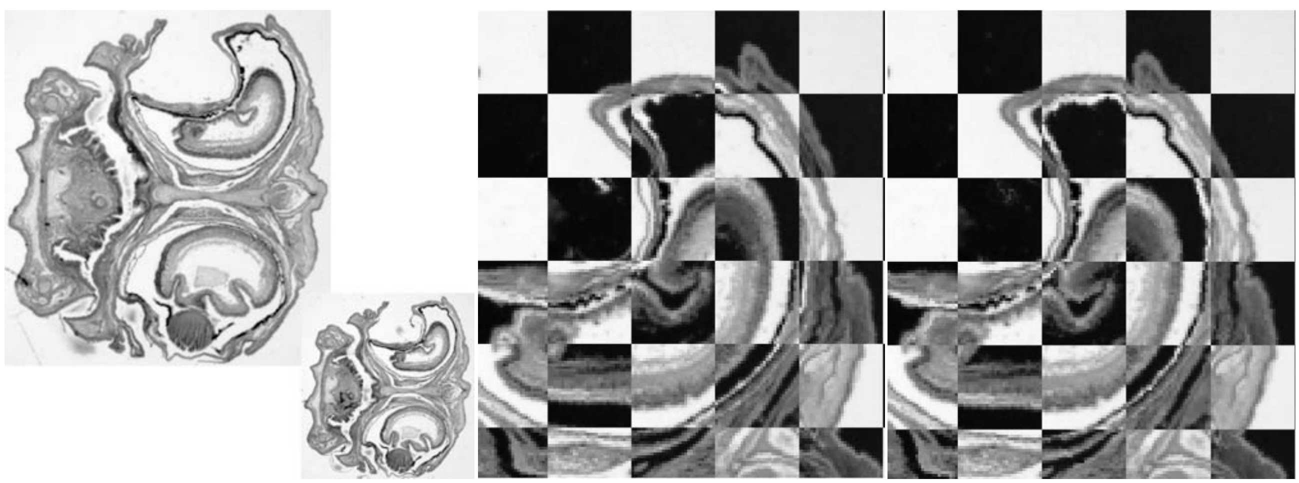

FIG. 1. Example of alignment of successive physical sections of a turtle embryo: left-a reference image (upper) and a floating image (bottom), middle-a right upper corner detail of superimposed pairs of images to be registered, right-after registration.

References

[1] M. Čapek et al., *Microsc. Res. & Tech*. 72 (2009), 110-119.
[2] V. Kolmogorov, R. Zabih, *IEEE Trans. PAMI*. 26 (2004), 147-159.
[3] M.I. Schlesinger, V.V. Giginyak, *Control Systems and Computers*, 2007, Kiev.
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