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Teichmüller Shape Descriptor and Its Application to Alzheimer's Disease Study

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Abstract We propose a novel method to apply Teichmüller space theory to study the signature of a family of nonintersecting closed 3D curves on a general genus zero closed surface. Our algorithm provides an efficient method to encode both global surface and local contour shape information. The signature—Teichmüller shape descriptor—is computed by surface Ricci flow method, which is equivalent to solving an elliptic partial differential equation on surfaces and is numerically stable. We propose to apply the new signature to analyze abnormalities in brain cortical morphometry. Experimental results with 3D MRI data from Alzheimer's disease neuroimaging initiative (ADNI) dataset [152 healthy control subjects versus 169 Alzheimer's disease (AD) patients] demonstrate the effectiveness of our method and illustrate its potential as a novel surface-based cortical morphometry measurement in AD research.

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1 Introduction

Some neurodegenerative diseases, such as Alzheimer's disease (AD), are characterized by progressive cognitive dysfunction. The underlying disease pathology most probably precedes the onset of cognitive symptoms by many years. Efforts are underway to find early diagnostic biomarkers to evaluate neurodegenerative risk presymptomatically in a sufficiently rapid and rigorous way. Among a number of different brain imaging, biological fluid, and other biomarker measurements for use in the early detection and tracking of AD, structural magnetic resonance imaging (MRI) measurements of brain shrinkage are among the best established biomarkers of AD progression and pathology.

In structural MRI studies, early researches (Thompson and Toga 1996; Fischl et al. 1999) have demonstrated that surface-based brain mapping may offer advantages over volume-based brain mapping work (Ashburner et al. 1998) to study structural features of the brain, such as cortical gray matter thickness, complexity, and patterns of brain change over time due to disease or developmental processes. In research studies that analyze brain morphology, many surface-based shape analysis methods have been proposed, such as spherical harmonic analysis (Gerig et al. 2001; Chung et al. 2008), minimum description length approaches Davies et al. 2003, medial representations (M-reps) (Pizer et al. 1999), cortical gyrification index (Tosun et al. 2006), shape space (Liu et al. 2010), metamorphosis (Trouve and Younes 2005), momentum maps (Qiu and Miller 2008), conformal invariants (Wang et al. 2009), and so on; these methods may be applied to analyze shape changes or abnormalities