GIS-based detection of grain boundaries

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Abstract

The recognition of grain boundaries in deformed rocks from images of thin-sections or polished slabs is an essential step in describing and quantifying various fabric elements and strain. However, many of the methods in use today require labor-intensive manual digitization of grain boundary information. Here, we propose an automated, GIS-based method to detect grain boundaries and construct a grain boundary database in which the shape, orientation, and spatial distribution of grains can be quantified and analyzed in a reproducible manner. The proposed method includes a series of operations and functions to identify grain boundaries and construct the grain boundary database. These processes are integrated into a GIS model using ArcGIS ModelBuilder; thus, little or no operator intervention is required to perform the entire analysis. The method was evaluated using thin section images taken from three sandstone samples. The results indicate that the proposed method can correctly identify >70% of grains recognized manually without any intervention and is especially suitable for analyses where large numbers of grains are required.
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1. Introduction

The recognition of grain boundaries is fundamental to any type of analysis where the shape, orientation, and spatial distribution of grains are critical. For example, strain determination methods, such as the Fry (Fry, 1979), enhanced normalized Fry (Erslev, 1988; Erslev and Ge, 1990), and R_f/ϕ (Ramsay, 1967; Lisle, 1985) methods, require the location of specific points along grain boundaries as input. At present, recognition of grain boundaries is most commonly done with thin section images collected with a polarizing microscope (Heilbronner and Pauli, 1993; Starkey and Samantaray, 1993; Ailleres et al., 1995; Lumbreras and Serrat, 1996; Goodchild and Fueten, 1998; Bartozzi et al., 2000; Heilbronner, 2000; Fueten and Goodchild, 2001; Choudhury et al., 2006). Typically, grain boundaries are extracted in two steps: recognition of the boundaries followed by digitization. In polarized light, different grains in a thin section show different interference colors as a function of their mineralogy and optic orientation. If sufficient contrast between adjacent grains exists, the boundaries between them can be easily recognized. If adjacent grains show similar interference colors, the boundaries will be difficult to recognize. In many cases, the contrast can be increased by rotating the thin section relative to the polarizer and analyzer. Thus, full recognition of grain boundaries can be facilitated by using multiple thin section images taken at different angles of rotation (Starkey and Samantaray, 1993; Heilbronner and Pauli, 1993; Goodchild and Fueten, 1998; Heilbronner, 2000; Fueten and Goodchild, 2001). Once the boundaries have been recognized, they must be digitized for additional analysis. Traditionally, manual digitization was used, but due to the labor intensive nature of this process, applications such as strain analysis may not have been used to their full advantage (Choudhury et al., 2006).

To reduce the amount of operator input required, a number of automated grain boundary detection methods have been

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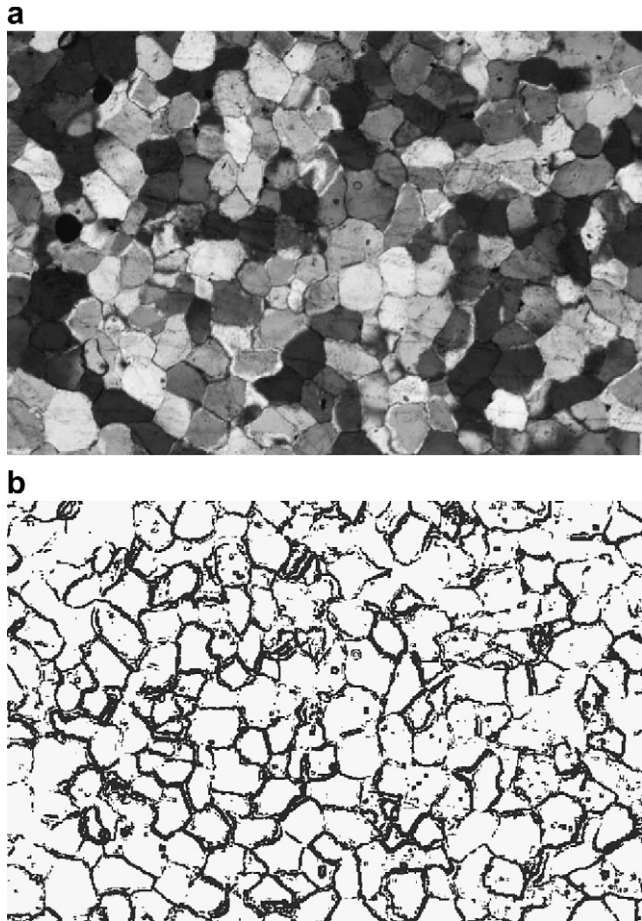*E-mail address:* conasch@bgnet.bgsu.edu (C.M. Onasch).

Fig. 1. Extraction of grain boundaries from a thin section photomicrograph. (a) Original thin section image taken with crossed polarizers and gypsum plate inserted. (b) Raster created by the Focal Range function in ArcGIS.

developed (e.g., Heilbronner, 2000; Bartozzi et al., 2000; Zhou et al., 2004; Choudhury et al., 2006), which can be applied to digital images of thin sections or polished slabs. These methods were developed to recognize grain boundaries through automated edge detection (e.g., Heilbronner, 2000; Bartozzi et al., 2000), region detection (e.g., Choudhury et al., 2006), or a combination of both (e.g., Zhou et al., 2004). In all these methods, various algorithms are applied to digital images, which may or may not have been first manipulated with image analysis software, to yield edges (grain boundaries) or regions (grains). While these approaches can greatly speed up the acquisition of grain boundary data and allow for many more samples to be analyzed, they are still limited in terms of their ability to analyze spatial information associated with the grains themselves. First, most of these methods recognize just the grain boundaries, which while very important, may not allow determination of gain shape information (e.g., area, long axis orientation). Second, as mentioned earlier, full recognition of grain boundaries usually requires multiple images. However, most current methods focus on just one image, which limits the amount of grain boundary information that can be extracted. Third, these methods do not allow other information, such as microstructure abundance and orientation, to be easily integrated with grain shape information.

In the last 15–20 years, geographic information systems (GIS) have been increasingly used to address a wide variety of geoscience problems (e.g., Bonham-Carter, 1994; Bishop and Shroder, 2004). The advantages of GIS include its database manner of data management, its capability to overlay and integrate different spatial information, and its powerful tools and functions for image analysis, spatial analysis, and modelling. Thus, it well suited for extracting, manipulating, and analyzing grain boundary information from deformed rocks (Fernandez et al., 2005).
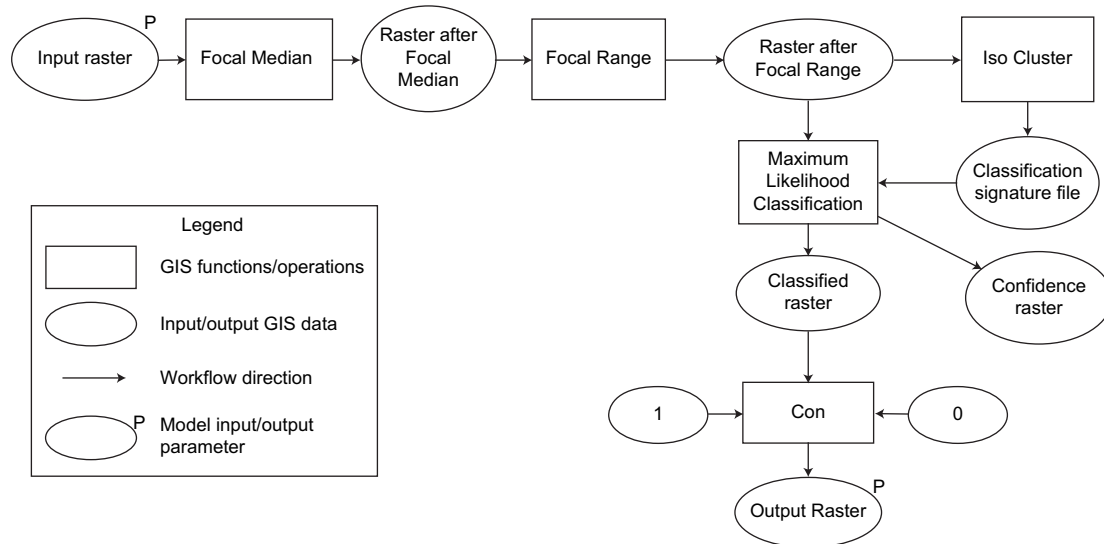

Fig. 2. Model designed using ArcGIS ModelBuilder to extract grain boundaries from a raster image. This model takes a raster as the input and outputs a new raster of 0/1 values representing boundaries (1) and interiors of grains (0). This model also includes a Focal Median operation, discussed in Section 2.3, to reduce noise and increase the contrast of the input raster. Descriptions of different ArcGIS functions used in this model can be found in the Appendix.