Using edge-detection methods and DEMs to identify and characterize craters on Pluto

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Abstract

While sample return presents the only way to directly determine the age of other planetary surfaces, it is infeasible for outer solar system bodies like Triton, Pluto, and Charon. Thus, using crater size frequency distributions complemented with modeled production functions is the only technique to accurately assess the ages of planetary surfaces. However, until recently, images of Pluto and Charon were limited to low-resolution telescopic images. The New Horizons flyby of the Pluto-Charon system in 2015 has dramatically improved our conception of these worlds by providing, among other data, a wealth of high-resolution optical images. Craters are typically identified in optical images manually, but this is a time-intensive endeavor and subject to differences between individuals. Because crater rims produce distinct changes in brightness, I propose to use edge-detection techniques to identify the crater boundaries in Pluto imagery. I also propose to use Pluto digital elevation models to identify craters based on their distinct bowl-shaped topography. Once a crater has been detected, basic parameters such as the crater's diameter, shape, and depth can be extracted. I will test these algorithms on several images of craters, analyze the successes and failures of each, and make any improvements necessary to extend to further data. Once this has been completed, I will apply each method to an image with many craters as well as other surface expressions. Here, I will determine what features lead to false positives and negatives such that the technique could be improved. Furthermore, I will determine the size frequency distribution and the depth-to-diameter relationship for the given region. From previously modeled crater production functions for Pluto, I will determine the age of the study area. I intend for the final algorithms to be easily scalable to identify craters and compute their basic parameters across the entirety of Pluto's surface in order to create an automated database of all craters.

1. Introduction

Craters have routinely been used to estimate the relative ages of planetary surfaces across the solar system. Because any resurfacing event in a given region of a planetary body covers up any previously produced craters, the number of identifiable craters increases with older surfaces. Thus, by comparing the number of craters in different regions, one can assess their relative ages. As plate tectonics has continued to resurface the Earth, there are very few craters across the planet. Mercury, the moon, and Mars, are pockmarked with holes due to the paucity of resurfacing events over the past few billion years. During the Apollo and Luna missions, lunar samples were returned and dated precisely in laboratories, enabling absolute ages of those locations, and thus crater densities, on the moon [1]. From the size-frequency distribution of observed craters, Neukum et al. [2] showed that the size-frequency distribution of the impacting bodies could be determined. Since then, production functions (the density of craters as a function of crater diameter) have been used ubiquitously to estimate surface ages of planetary bodies.

To determine the density of craters of a given region or globally across a planet, craters of all diameters must be identified. Typically, this is done manually using software to locate and measure crater diameters and shapes [3, 4, 5]. This is time-consuming and prone to systematic error. Recently, however, several crater detection algorithms (CDAs) have been developed to recognize craters from optical remote sensing instruments. Two categories of CDAs have emerged — one which uses high resolution imagery and one which uses digital elevation models (DEMs) [6, 7]. High resolution imagery takes advantage of brightness changes across crater walls and the distinct shapes of craters. From these, edge detection can be used to identify craters and fit ellipses (see, for example, [8]). Machine learning algorithms applied to the high-resolution data take advantage of compiled databases. Both of these techniques are resolution limited and dependent on lighting angle. From DEMs, one can use slopes and curvature in elevation data to identify craters by their bowl-shape [6].

Our goal is to identify craters on Pluto's surface. Prior to the recent flyby (July 2015) of the New Horizons spacecraft [9], this would have been impossible. But the cameras onboard have produced a rich data set of high resolution imagery in which craters large and small can be detected. I intend to use the LOng-Range Reconnaissance Orbiter (LORRI) for our edge-detection technique. LORRI is a high-resolution monochromatic imager designed to work under low light conditions (because Pluto receives only 10^{-3} of the sunlight received at Earth) and has a field of view of 0.29° [10]. I will also utilize Ralph - the Multi-spectral Visible Infrared Camera (MVIC). MVIC can produce panchromatic images and has filters for blue, red, and infrared mapping [11]

Below, I propose to adapt CDAs to detect craters on Pluto. I will do this using both high-resolution imagery and DEMs. First, a high-resolution image from LORRI with only a single crater will be used to test an edge-detection technique. Then, I will construct a DEM to test an identification algorithm presented by Li et al. [6]. Each algorithm will also determine basic crater properties. I will then assess the merits of each algorithm, improve them as necessary, and repeat the process for several images with different lighting conditions and craters of different morphologies. Finally, I will apply the methods to an image with many craters of various sizes. I will determine an age of this region based on the size-frequency distribution of craters and compare the results to the manually-derived database of Robbins et al. [5].

2. Proposed Work

Project Goal - Automatically detect craters on Pluto's surface utilizing edge-detection methods, high-resolution imagery, and digital elevation models. Then, use the resulting crater properties to determine the age of the study region.

Project Objectives

1. Identify single crater through edge detection and determine its basic properties
2. Create DEM of region of interest and identify single crater through elevation data
3. Test algorithms on craters with different illumination conditions and morphologies
4. Automate for a large region

2.1. Objective 1: Identify single crater through edge detection and determine its basic properties

First, an image of Pluto's surface from the LORRI instrument aboard the New Horizons spacecraft with favorable lighting conditions (visible crater rim and interior) will be selected. Some of the difficulties with this are displayed in Fig. 1. I will crop the selected image to include only a single clear and fresh crater. The aim is to use an image of a crater from Pluto like that shown in Fig. 2.

I will apply any necessary filters (such as a Gaussian filter) to reduce noise in the image that could preclude an accurate edge detection of the

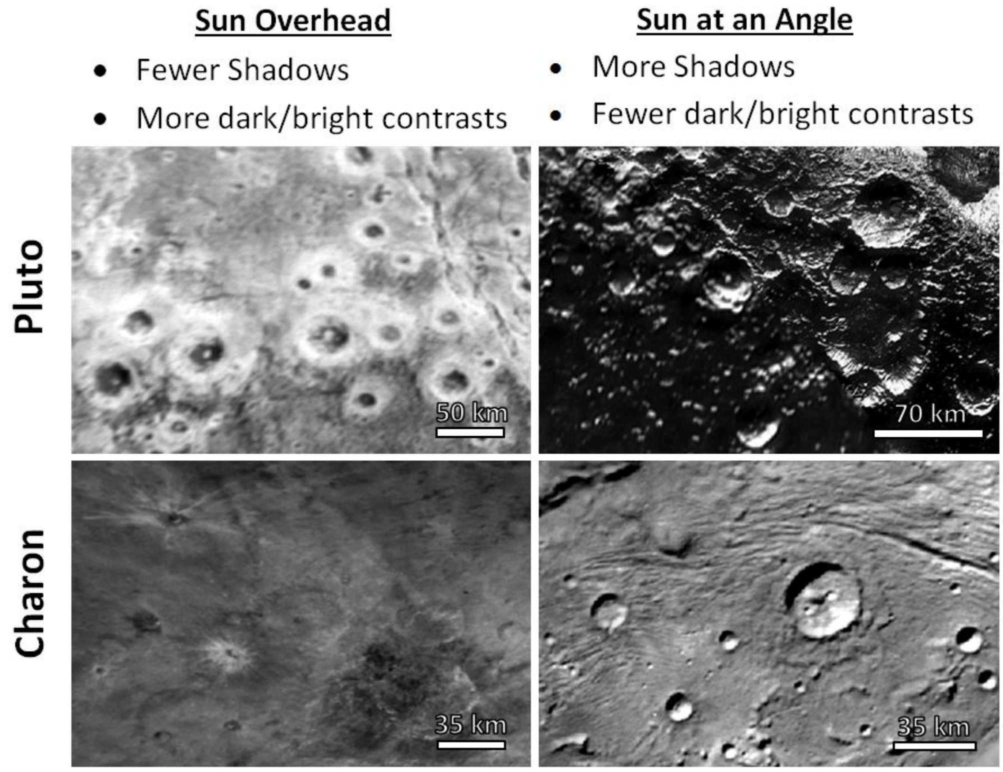

Figure 1: Potential problems resulting from different lighting conditions of LORRI images of Pluto (top row) and Charon (bottom row). (Credit: SwRI/Kelsi Singer https://blogs.nasa.gov/pluto/2015/10/13/the-impact-of-craters/)

crater. From derivatives in the image intensity the edge of the crater can be found. Thresholding the image will remove other edges in the image due to surrounding geologic or topographic boundaries. I will fit an ellipse to the crater boundaries to determine the shape and diameter of the crater.

2.2. Objective 2: Create a DEM and use to identify a single crater

I intend to use images from LORRI and MVIC to produce an original DEM of a region of interest for this project. However, I recognize that time will be limited this semester, so I present this objective as a possible descope because a Pluto DEM is readily available at https://astrogeology.usgs.gov/search/map/Pluto/NewHorizons/Pluto_NewHorizons_Global_DEM_300m_Jul2017 [12].

With the DEM I will follow the procedure outlined by Li et al. [6] to identify a single crater. This is accomplished by locating depressions with large slopes. The concavity of the depression is computed from the second

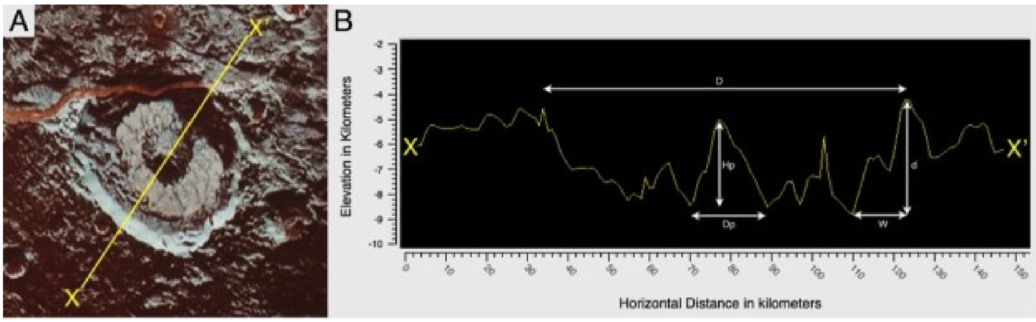

Figure 2: Image of an impact crater on the surface of Pluto from the LORRI instrument. The topography of across the yellow line in (A) is shown in (B). (Credit: Veronica Bray and Paul Schenk, NASA/JHUAPL/SwRI blogs.nasa.gov/pluto/2016/05/06/a-picture-of-pluto-is-worth-a-thousand-words/)

derivative of 4 lines across DEM elevations that have been transformed into a 2D spatial dimensions (A Gaussian filter will be applied to the DEM elevation data). The lines in the pseudo-spatial dimension are 45 degrees apart. Then, the center of a depression is found. This is followed by determining boundary of the depression, which gives the diameter and the shape in addition to the depth from the elevation data. I will compare the results to those obtained in Objective 1.

2.3. Objective 3: Repeat for several images of craters

After developing the CDAs in Objectives 1 and 2, I will apply them to images that will test the robustness of the algorithms. The images will still only cover a small area, but the sizes, shapes, and light conditions will be different. The intention of this objective is to assess problems in identifying craters with the established techniques and amend the algorithms as necessary in order to apply to a broad range of images. I expect problems to arise when an image contains overlapping craters, other circular or bowl-shaped depressions, heavily shadowed craters, etc. This step is crucial to scale the algorithms to larger regions containing a multitude of craters.

2.4. Objective 4: Automate for large region

I will run the proposed CDAs to an image containing 20-50 craters and compare the results to those crater found manually. This will further aid in determining what features lead to false positives and false negatives. What circular or bowl-shaped depressions did the algorithm wrongfully identify as a crater? What craters were missed? This information can be used to construct a decision tree that may help improve detections once scaled up a larger data set.

Also, with craters identified within a large region, I will construct a size-frequency distribution which can be compared to those in the literature for Pluto [5]. I will construct an isochron for the region and estimate its age based on the crater production function.

Our approach outlined above could be automated for all available images to create a database of all craters identifiable with the resolution of the New Horizons cameras. Training data for a machine learning algorithm requires manually identified craters, but to do this globally is an undertaking out of the scope of this project. However, a global "consensus crater database" [5] has very recently been made public (https://astrogeology.usgs.gov/search/map/Pluto/Research/Craters/Craters_PlutoCharon_System_Robbins). This database was constructed by the manual identification of craters and determination of their properties by several individuals. Thus, a global analysis is readily scalable once that data set becomes available.

3. Relevance

Determining accurate ages across the surface of Pluto is necessary to understand the evolution of the planet. The stark contrast between heavily cratered regions and the smooth Sputnik Planum region proves that this evolution contains complex processes. As geologic investigations continue using data from the recent flyby of New Horizons, it will be imperative to have robust methods for detecting craters of all sizes in a fast and consistent manner. Additionally, with a compiled data set of craters, other geologic features in the images or further characterization of the craters (simple vs. complex, layered ejecta, etc.) may be automated. Finally, this endeavor is timely as the release of a crater database has just been made public for Pluto and Charon with which to test our proposed methods against. The techniques I have proposed could be extended to Charon and to other solar system bodies in the future. Specifically, they could be implemented for asteroid Bennu upon the arrival of OSIRIS-Rex next year.

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