CATALOGING THE MOON WITH THE COSMOQUEST MOON MAPPERS CITIZEN SCIENCE PROJECT.

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Introduction: CosmoQuest is a broad astronomy education, public outreach, and science initiative that launched January 1, 2012 [1], with the inclusion of several citizen science projects shortly thereafter. Among these is the lunar-oriented Moon Mappers, launched January 9. Moon Mappers presents users with small slices of *Lunar Reconnaissance Orbiter* Camera (LROC) Narrow Angle Camera (NAC) images (Fig. **1**) and asks users to identify craters and other features of interest. It would be extremely difficult for a single researcher or research group to identify all features across the area at the resolution we ask volunteers to find. However, by crowd-sourcing these basic identifications and measurements, we can generate large datasets of features for targeted science questions and analysis as well as supply them to the community for a broad array of tasks.

Science Objectives: Moon Mappers' objective is to provide a large, scientifically robust, and geographically broad catalog of lunar craters and other features. Specifically, the identification, cataloguing, classification, and analysis of small impact craters (10-1000 m in size), atypical impact formations (*e.g.*, elliptical, exogenic dark-haloed, and concentric craters; bright rays; ejecta exclusion zones), volcanic structures (*e.g.*, vents, endogenic dark-haloed craters, domes, rilles), and other unusual/interesting geologic features can be used to help answer several fundamental questions in lunar science [2]. The founding science objectives for Moon Mappers are:

- Constrain and refine the sub-kilometer production function of craters on the moon and quantify its obliteration on different-aged surfaces.
- Determine the relative ages of units and establish their stratigraphy through crater size-frequency relationships and comparison with published crater isochrons [3].
- Examine the thickness of the lunar regolith through ejected boulders and concentric craters.
- Explore the impact cratering process to better understand the information these craters provide about the lunar surface and subsurface.
- Improve our understanding of lunar volcanic processes along with their distribution, sequence, and timing to better constrain the thermal evolution of the moon.

An additional aspect of the science objectives includes the location of spacecraft hardware. This, while of particular interest to volunteers [4], is also useful in helping to improve lunar cartography. Cartographic accuracy is fundamental for scientific precision, especially at scales afforded by LROC NAC images.

Images and Interface: Moon Mappers launched with ~4800 image slices drawn from five NAC strips; we limited these at launch to verify interface and data fidelity. Image slices are created by:

1. ISIS-processed NAC strips are divided into 450×450 pixel sub-images ("slices") at native resolution.
2. The original NAC strip scale is reduced by a factor of 3×, and 450×450 pixel sub-images are then made from that.
3. The NAC strip is reduced to 450 pixels wide (generally a factor of 8-13×) and again divided into 450×450 pixel sub-images.

Three initial images were selected from the *Apollo 15* landing site, appealing to user interest. The science goal for these is to better refine the crater density correlation with *Apollo 15* samples and study the effects of lighting on crater identification and measurements [5]. Two images were selected from the Mafic Mound area [6] of the South Pole-Aiken (SPA) Basin. These provide users an opportunity to explore the far side of the Moon and allow us to study the compositional character of the area and to search for evidence of crypomare deposits, the SPA impact melt sheet, and lower crustal material. More images from different regions will be added as this project progresses.

Users of the Moon Mappers portal (cosmoquest.org /mappers/moon) are presented with two potential interfaces: "Simply Craters" and "Man vs. Machine." More interfaces with more advanced tasks are being designed and will be deployed in the coming months.

Simply Craters gives users a basic interface (Fig. 1), where they are asked to identify and measure all craters over a certain size. First-time users are guided through a very basic tutorial on how to use the interface. Progress with initial images is then monitored and users are corrected if their marked crater locations and sizes differ too much from a predetermined expert assessment. After this proving stage, users are seamlessly transitioned to marking craters on the science images. Approximately every 15 images (randomized with μ=15), they are unknowingly presented with an-other expert-classified image. They are scored on their accuracy relative to the expert and given feedback on their proficiency (a user-requested feature [4]). If their score is <50%, users are asked to revisit some of the tutorial images. In this way, we are able to quickly train users to a functional level of proficiency, thereby optimizing the users' time, efficiency, and satisfaction, as well as ensuring a reasonable level of science quality. Each user's accuracy score is stored on the server so that it can be monitored. These accuracy scores are also used to weight craters during data reduction.

Man vs. Machine uses the same interface as Simply Craters (Fig. 1). The only difference is the dataset: We have employed an automated crater detection algorithm [7] to mark craters in several NAC frames. Users are presented with an image slice that is already marked by the automated code. They are then asked to correct the machine: adjust incorrectly marked, add missed, and remove falsely identified craters. The main goal is to generate a robust crater catalog potentially faster than fully manual markings. A secondary goal is to study whether people are more likely to remove a falsely identified crater or to add a missed crater. This will be accomplished by using two sets of automated code results for each image where the confidence level the code places on the detected craters has been changed. The set using the lower confidence level has more false positives while the higher has more missed craters.

Data Reduction: User crater classifications are assigned a confidence based on their accuracy score from random tests against experts (described above). The latitude, longitude, diameter, and confidence are then read into a clustering code that groups craters by size and location. The weighted mean and standard deviations are saved for each crater as illustrated graphically in Fig. **2**. We are refining this code as more data are gathered and may develop a more sophisticated one in the future (*e.g.*, a more detailed friends-of-friends or an expectation-maximization algorithm [8] since our data are nominally Gaussian).

User feature classifications are analyzed by consensus: If the majority of users who examined an image flagged a feature, then the weighted average of its location is calculated and the feature location and type is stored to a supplemental database.

The Man vs. Machine data are reduced in two different ways. First, all craters (identified, modified, and confirmed by the user) are reduced as per the above clustering method to determine normal crater counts. The second technique assesses user psychology: The number of craters deleted, added, and altered per image slice are tallied. These are then ranked to determine whether there is a difference in how users behave when presented with the computer-identified craters.

Discussion: We show the results of an early crater analysis in Fig. **2**, but Moon Mappers is still a nascent project as of this writing. By mid-March, it will have been gathering data for over two months. We anticipate it will be possible to demonstrate the validation of user data against expert crater classifications, reduce a statistically significant amount of data, and begin to address several of the science goals.

References: [1] Gay *et al.* (2012) *LPSC XLIII*, this vol. [2] Space Studies Board (2007) *The Scientific Context for Exploration of the Moon: Final Report*, The National Academy Press, Washington, DC, ISBN 978-0-309-10919-2, 107pp. [3] Neukum *et al.* (2001) *Space Sci. Rev.* **96**, 55-87. [4] Gay *et al.* (2011) *LPSC XLII*, Abstract #1701. [5] Ostrach *et al.* (2011) *PCC 2*, Abstract #1107. [6] Pieters C.M. (2001) *LSC XXXII*, Abstract #1810. [7] Burl *et al.* (2001) *Int. Symp. Artif. Intell. Robot. and Autom. Space*. [8] Depster *et al.* (1977) *J. Royal Stat. Soc.* **39**(1):1-38.

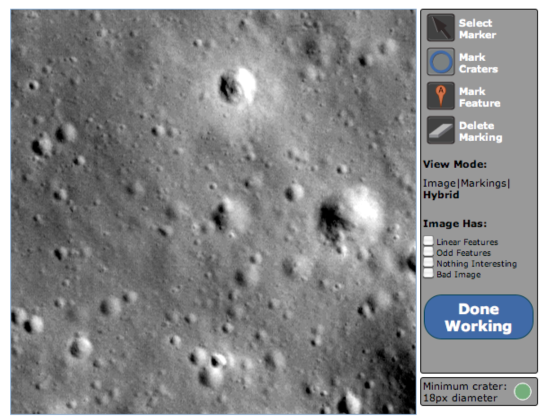

Figure 1: This is the primary Moon Mappers interface. It presents a slice of the moon's surface with a minimalistic toolset. The four upper tools allow users to mark, resize and move, or erase craters and other features. The View Mode allows toggling the image or marked features on/off, and checkboxes let users flag features of the image as a whole.

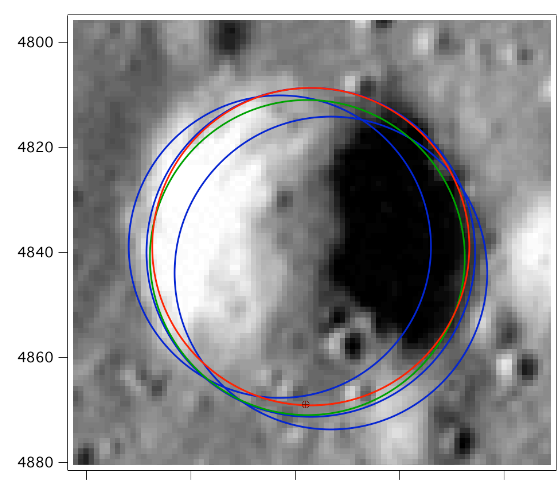

Figure 2: A single crater with user markings illustrated in blue, expert in red, and the clustering code's in green. Agreement is within 2 pixels for location, 1 pixel for diameter between expert and cluster. Units are pixels on NAC image M146959973LE.