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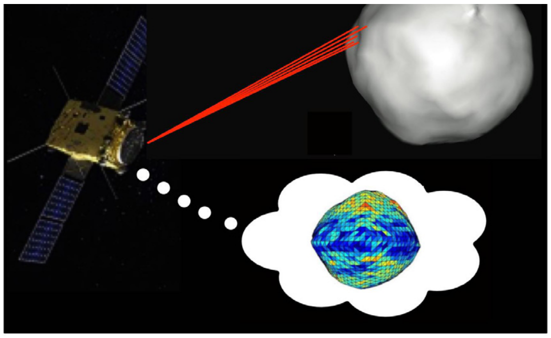
Application of Machine-learning Algorithms for On-board Asteroid Shape Model Determination

Developing an Innovative Autonomous Navigation System

The Application of Machine-learning Algorithms for On-board Asteroid Shape Model Determination project will develop an innovative system for spacecraft navigation to expand the capability of small spacecraft to meet the critical challenges associated with small-body exploration. Such challenges include accurate navigation in a microgravity environment and precision targeting of particular locations on an asteroid surface for sample collection. This on-board system will cut the computational "umbilical" back to Earth – currently necessary for the generation of a global shape model. This requires thousands of images with sufficient resolution and adequate variation of incidence and emission angles, processed manually by a team of experts on Earth for several months. Small satellites have limited bandwidth and are unable to downlink the data volume required for this processing, restricting their ability to perform deep-space asteroid exploration.

Central to this effort is the application of Markov brains (natural cognitive algorithms) to perform on-board image processing and shape model generation. Markov brains represent networks of digital neurons that can make decisions based on a combination of sensory data and internally stored representations. The cognitive algorithm proposed merges two technologies that have already been validated by themselves in different contexts but that have never been put together for autonomous navigation in data-limited environments.

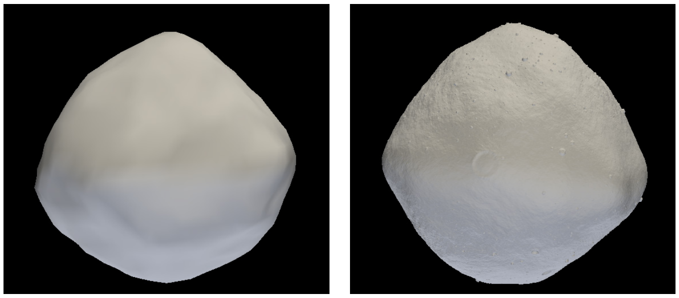
Using NASA Goddard Space Center's state-of-the-art computational infrastructure, thousands of synthetic shape models will be generated informed by the best available physics and observational inputs, rotating at different angular frequencies. These "synthetic asteroids" will be used as the "fitness landscape" within which the artificial Markov brain evolves. Each generation, thousands of brains will direct the acquisition of data from the synthetic asteroids, and will use these data to generate shape models, which will be scored based on the accuracy of the models. The Markov brain will then "know" asteroids because of the representations of asteroids formed within its neurons. It can use this knowledge to generate shapes quickly and effortlessly onboard - just as we generate scenes in our mind's eye using the representations we acquired over our lifetime - allowing spacecraft to navigate and "explore" in real time safely. This approach is in strong contrast to the current state of the art, which requires significant spacecraft data rates to Earth. The Markov brain approach will supplant thousands of hours of human effort related to image-intensive optical navigation, stereophotoclinometry shape model generation, and natural-feature tracking terrain-relative navigation for successful operation about an asteroid.



This effort will enable smart and safe exploration of small bodies throughout the Solar System.

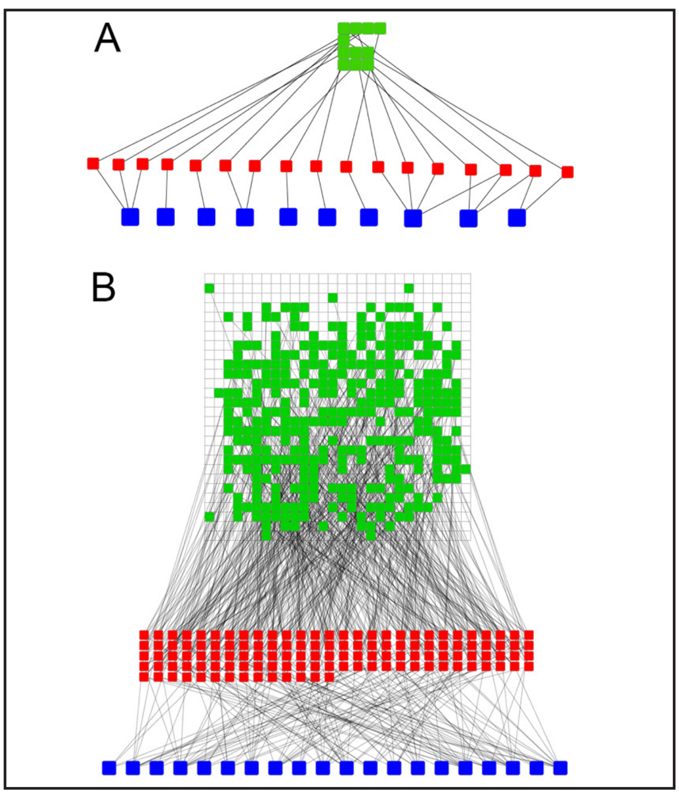
This effort is a collaboration between the University of Arizona, Michigan State University, and NASA Goddard Space Flight Center.

This project is managed and funded by the Small Spacecraft Technology Program (SSTP) within the Space Technology Mission Directorate. The SSTP expands U.S. capability to execute unique missions through rapid development and in space demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space sector. The SSTP will enable new mission architectures through the use of small spacecraft with goals to expand their reach to new destinations, and challenging new environments.

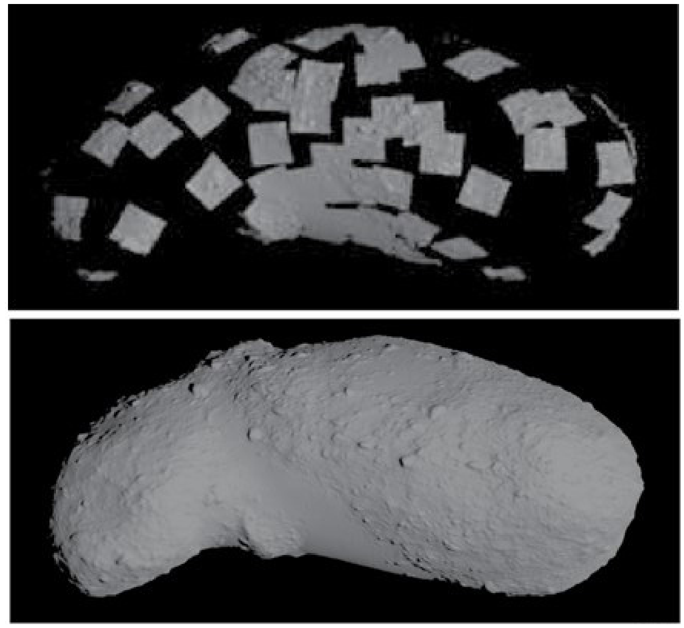


Left: The coarse shape model of asteroid (101955) Bennu from ground-based radar data. Such models are used as input to generate our Asteroid Virtual Realities.

Right: A model of asteroid (101955) Bennu after populating with craters, boulders, and regolith. Such models are the basis of our Asteroid Virtual Realities for artificial intelligence training.



We will create Markov brains that store representations of the asteroid types that spacecraft will encounter.



Equipped with a Markov brain, future small spacecraft will be able to safely navigate around small bodies and gather samples to deliver to Earth.

For more information about the SSTP, visit:

www.nasa.gov/directorates/spacetech/small_spacecraft

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