AstroGen - Procedural Generation of Highly Detailed Asteroid Models

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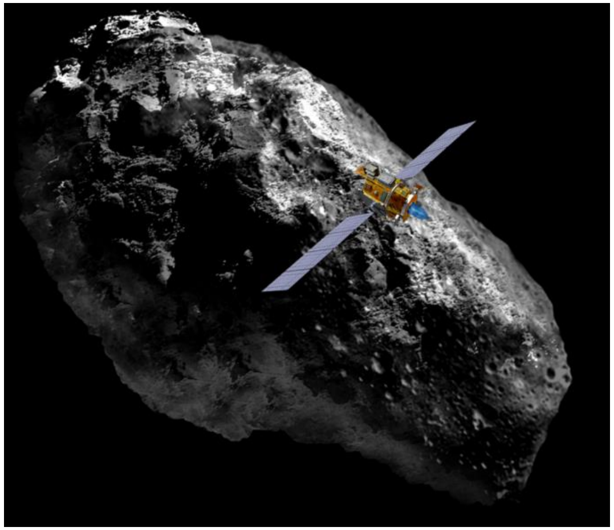
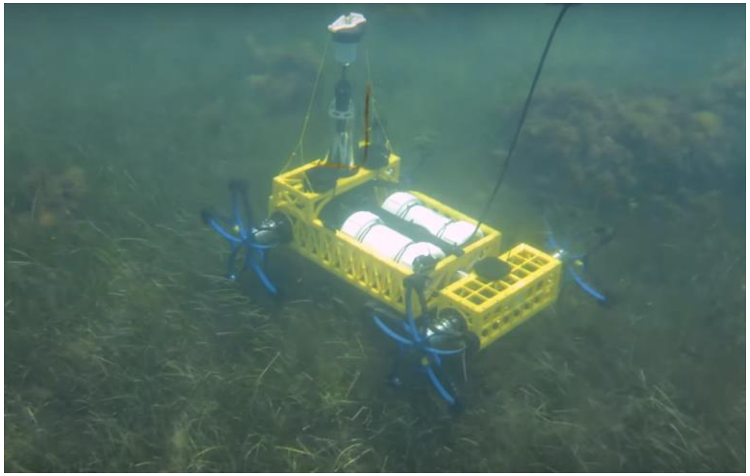
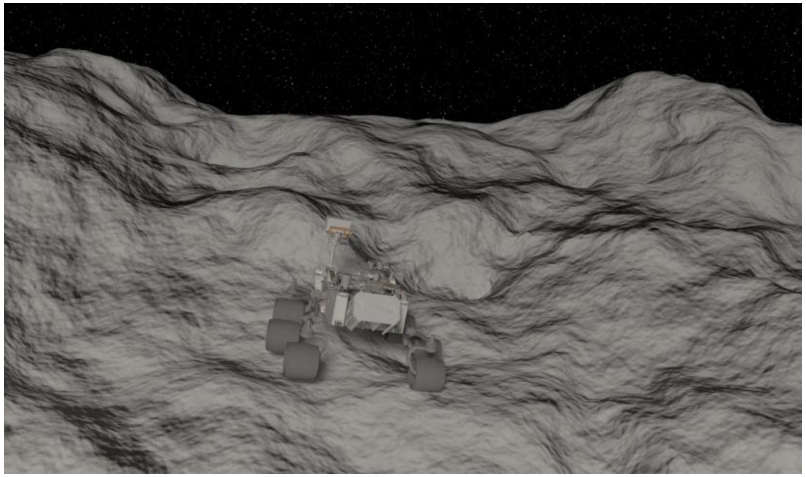
Motivation



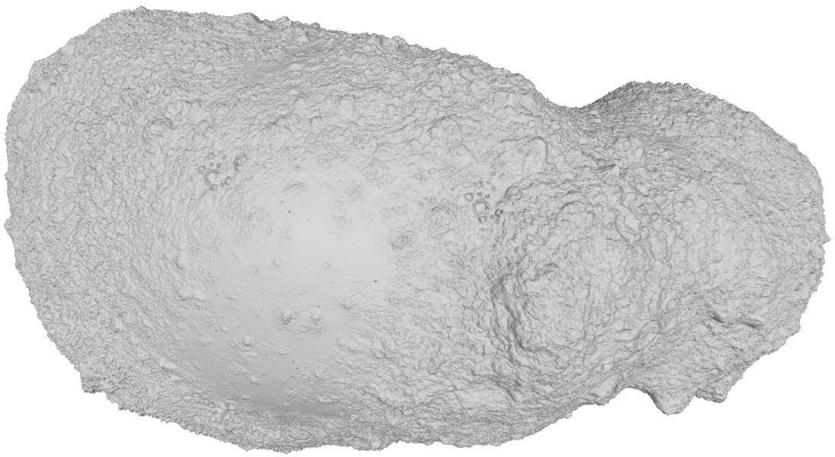
- Low-quality data from earth observation
  - Radar
  - Telescope
- Virtual testbed simulations
  - Time and cost efficient
  - Autonomous operation
    - Long distance scheduling latency





Challenges

- How to generate diverse but similar asteroid surfaces (i.e. virtual testbed) for simulation?
- How to reuse the data from previous space missions?

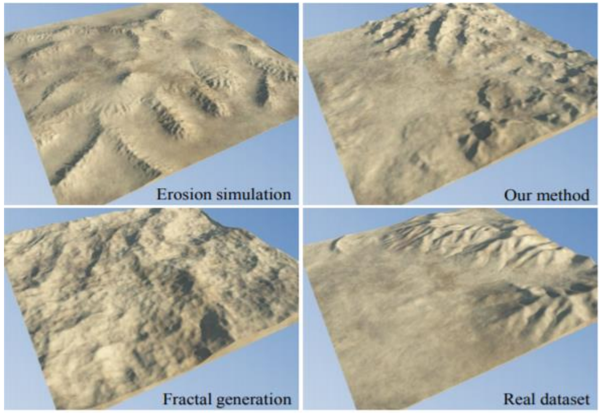


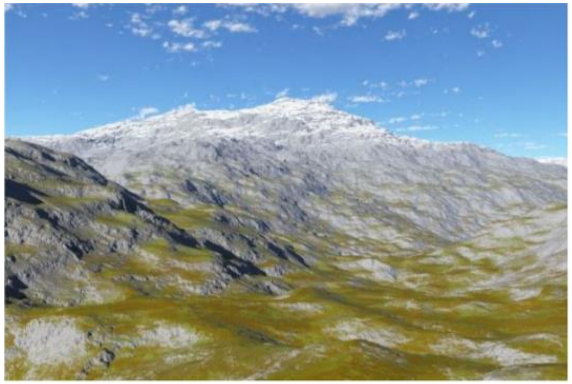
Ground truth model

Low-poly models

Previous Work

- Procedural hydrology terrain [Génevaux 2013]
  - Underlying hydrographic network
  - User defined terrain features (mountain, ...)
- Procedural terrain with real-world data [Parberry 2014]
  - Design terrain with real elevation data
  - Terrain details with value noise
- Sparse representation of terrain [Guérin 2016]
  - Procedural landform features (primitives)
  - Sparse construction tree



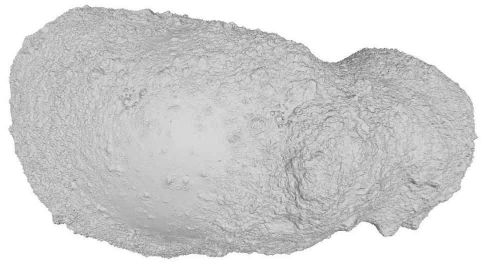


Our Contribution

- Automatic asteroid model generation
  - Given a predefined similarity distance to generate a variety of asteroid models from the given model
  - Add terrain features on the surface easily
- High performance
  - Parallel GPU implementation
- Arbitrary Resolution
  - Implicit representation of a given model

Approach – Overview

- Parameter training



Prototype Mesh

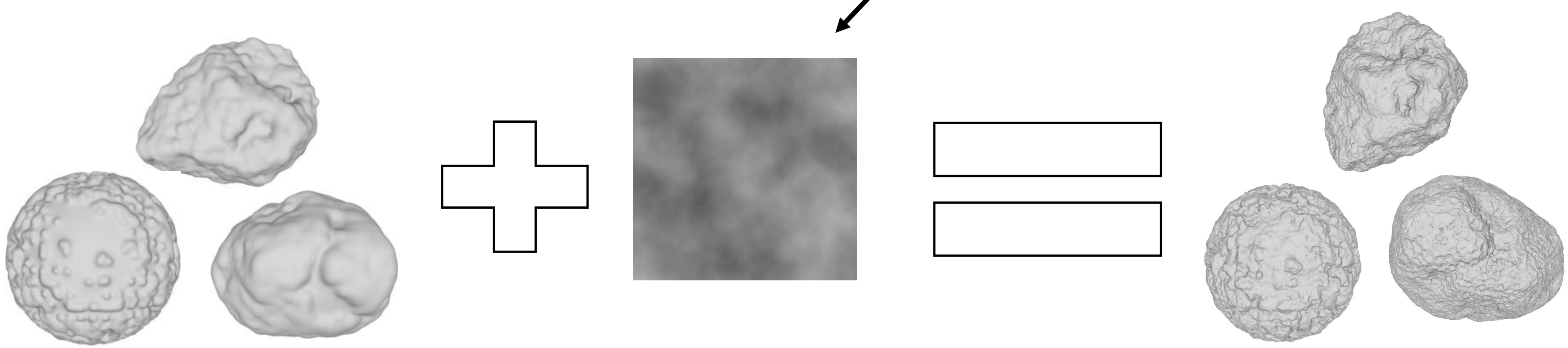
Training Pipeline

Implicit Representation

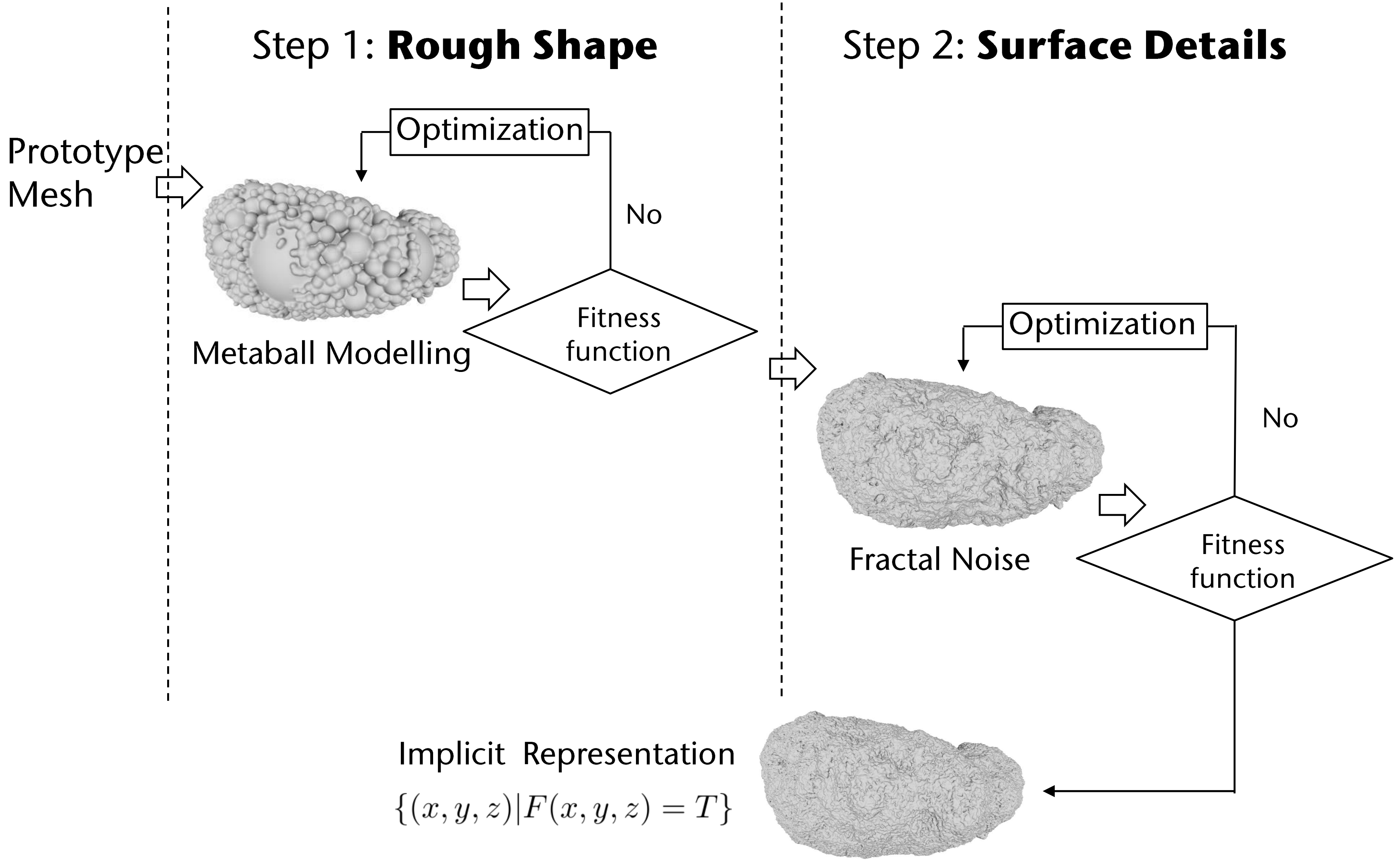
S = $\{(x,y,z)|F(x,y,z)=T\}$

Surface detail parameters

- Surface detail transfer

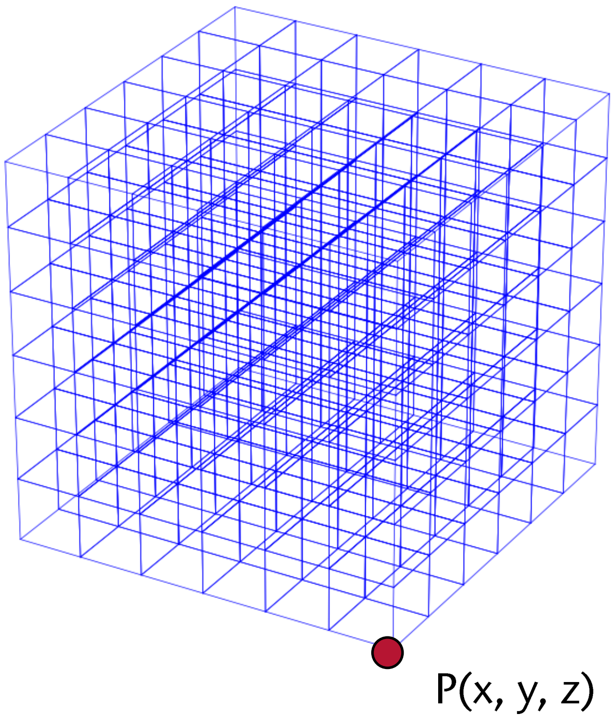


Approach – Training Pipeline



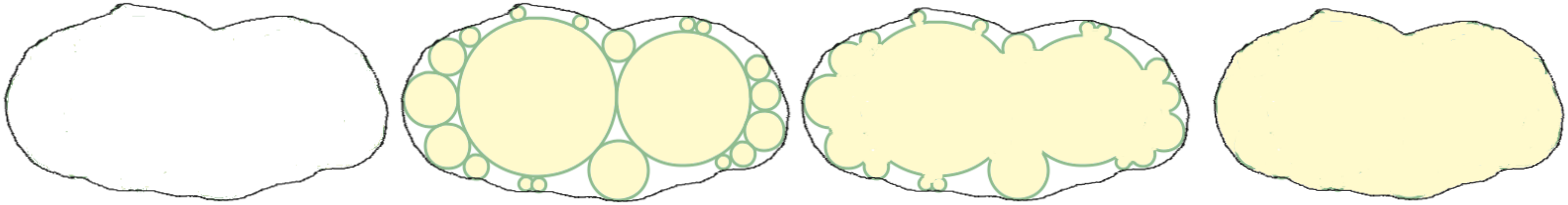
Approach

- Implicit surface
  - Define a series equation F and compute for each grid point P
    - Implicit surface S = $\{(x,y,z)|F(x,y,z)=T\}$
    - T is the isovalue of the implicit surface
- Optimization
  - Change the parameters in F to generate an infinite number of shapes
  - Particle swarm optimization [Samal 2007] with a fitness function leads to target result



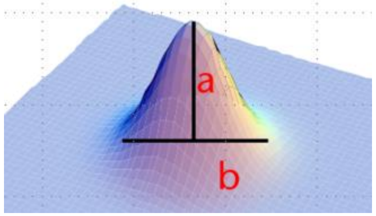
Step 1: Metaball Modelling

- Prototype surface
- Metaballs define the isosurface (implicit surface S with isovalue T_0) to approximate the prototype surface
  - Skeleton of spheres (Sphere Packing [Weller 2010])
  - Potential field
  - Blending



Step 1: Optimization

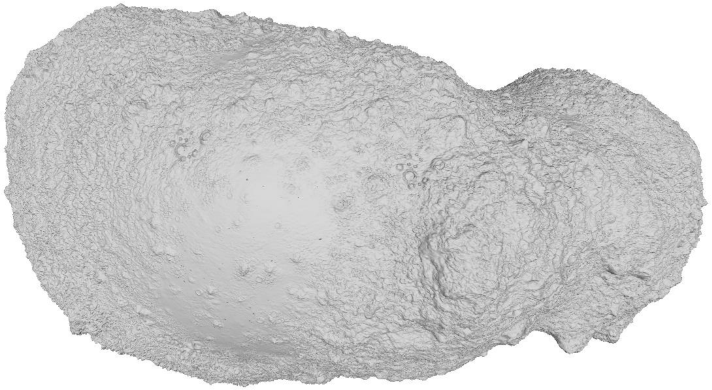
- Protosphere
  - n is the number of spheres in the prototype shape
- Potential function $f(r_p)$



  - a is the tension factor
  - b is the softness factor
- Blend function for each metaball

$$f(r_p) = (f^m(r_{p_A}) + f^m(r_{p_B}))^{\frac{1}{m}}$$

  - m is the overlapping factor

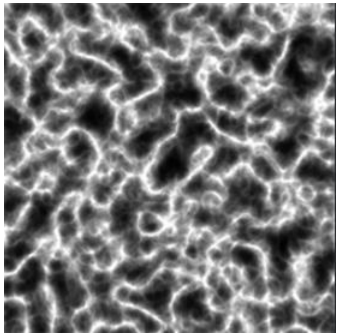


Ground truth shape

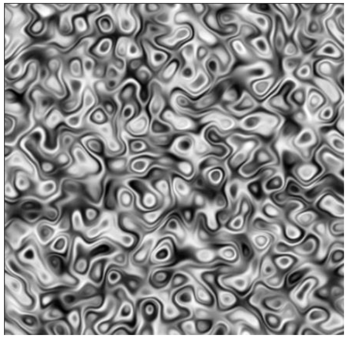
Rough shape

Step 2: Fractal Noise – Perlin & Simplex

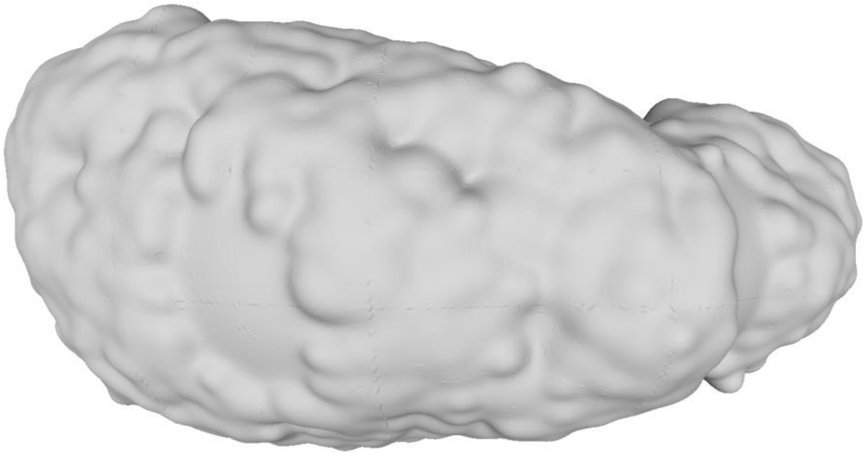
- Fractal terrain
  - 3D Perlin noise
    - Fractal (summation of noises on different octaves)
    - Self-similarity
  - 3D Simplex noise
    - Less directional artifacts

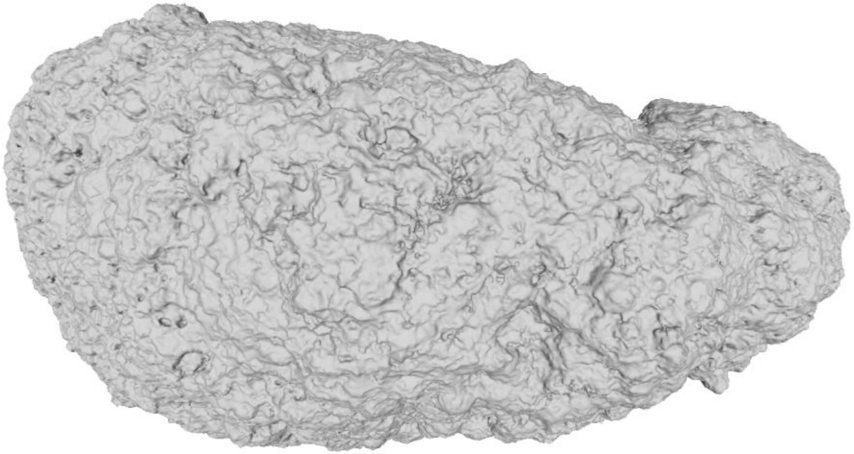


2D Perlin noise



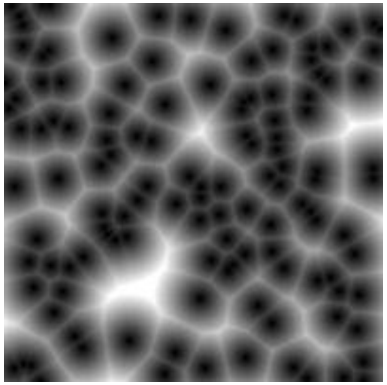
2D Simplex noise



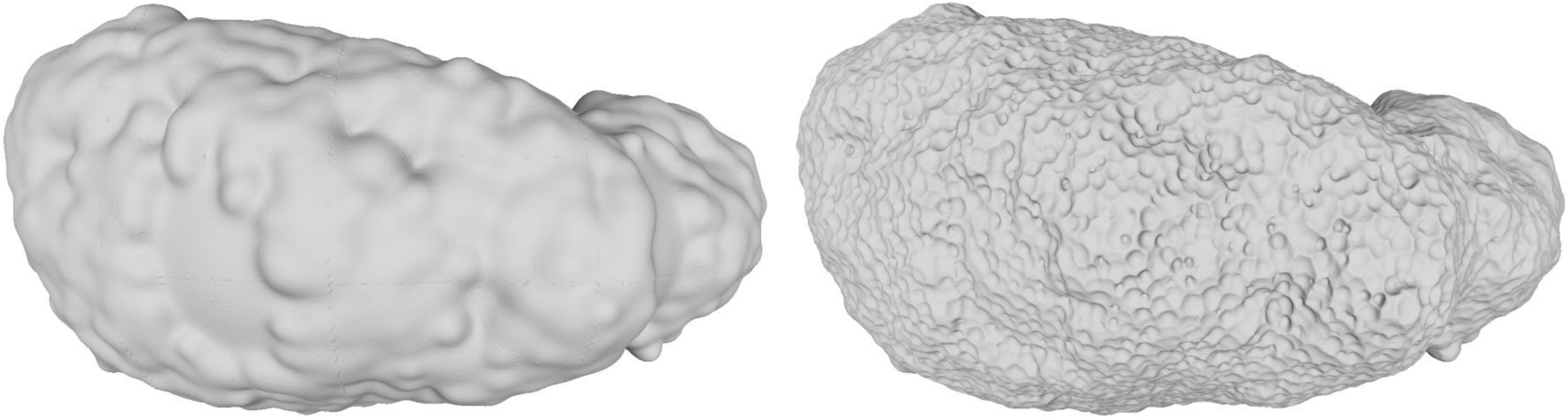


Step 2: Fractal Noise – Worley

- Primitive - Craters
  - 3D Worley noise
    - Points for a distance field
    - Randomly distribute feature points X in space
    - Noise value is the distance to the-closest point $x \in X$



2D Worley noise



Step 2: Optimization – Surface Details

- Optimization parameters

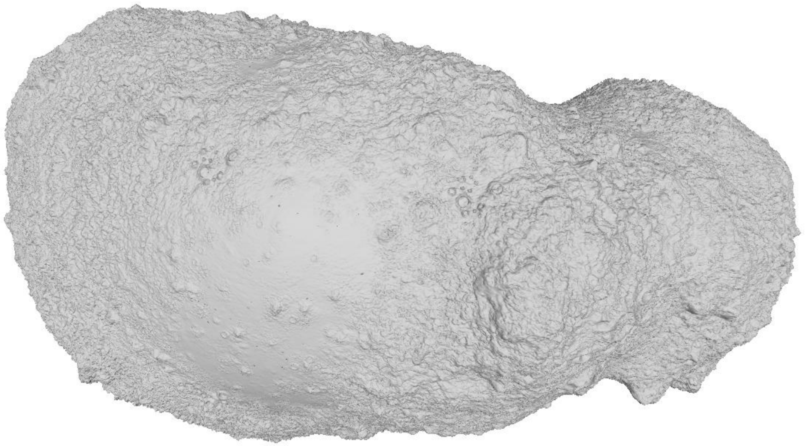
Number of Parameters	Perlin	Simplex	Worley	Gradient
Weight	1	1	1	1
Frequency	1	1	1	0
Octave	1	1	1	0
Amplitude	1	1	1	0
Coords_w	3	3	3	0
Coords_b	3	3	3	0

$\sum = 31$

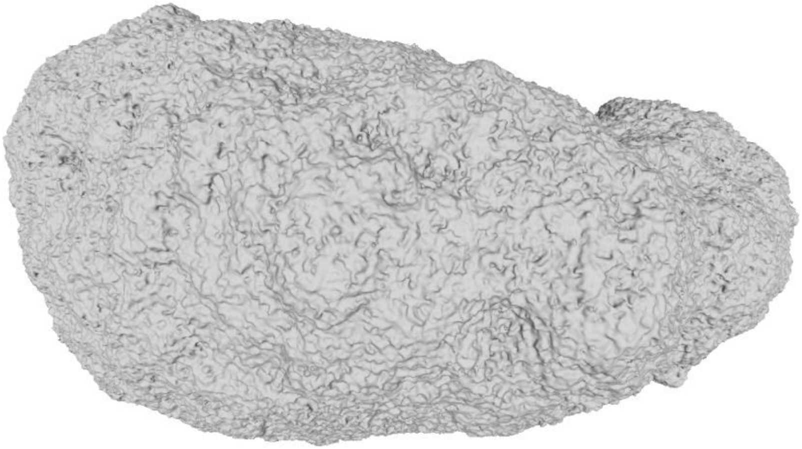
$$T = T_0 + weight \cdot \sum_{i=0}^{octave} amplitude \cdot perlin((2^i x, 2^i y, 2^i z) \cdot f \cdot \vec{w} + \vec{b})) + \sum_{i=0}^{octave} simplex(\ldots) + \sum_{i=0}^{octave} worley(\ldots)$$

- Fitness function
  - Compute histograms [Li 2017] for all models
  - Minimize the histogram's Euclidean distance

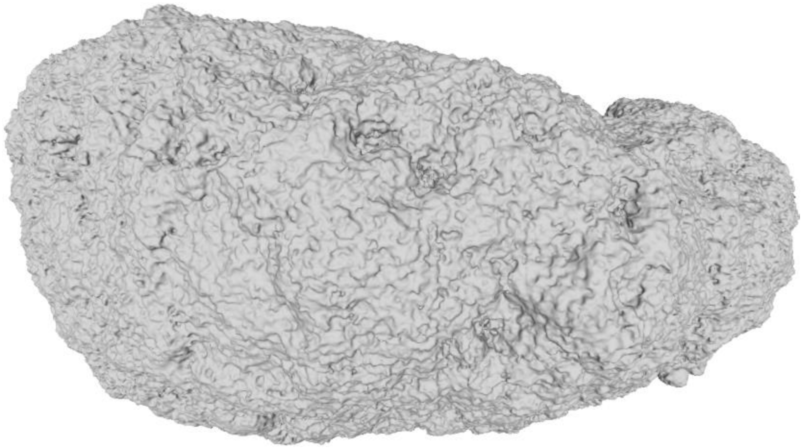
Results – Itokawa



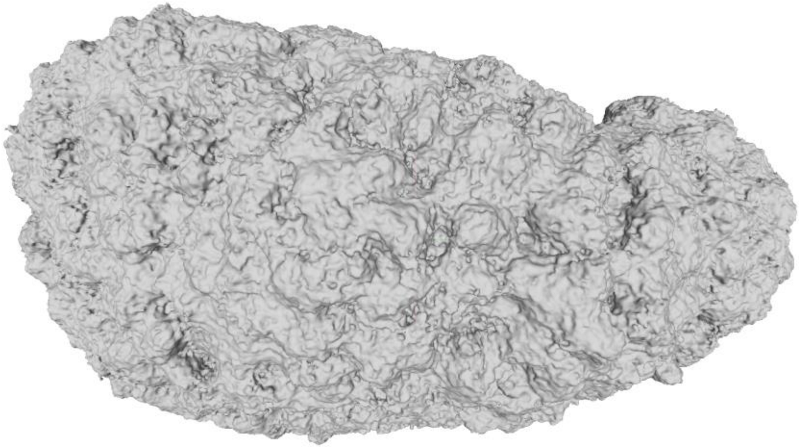
Model from photogrammetry
(Source 1,780k vertices)



“Flat” surface (1,986k vertices)

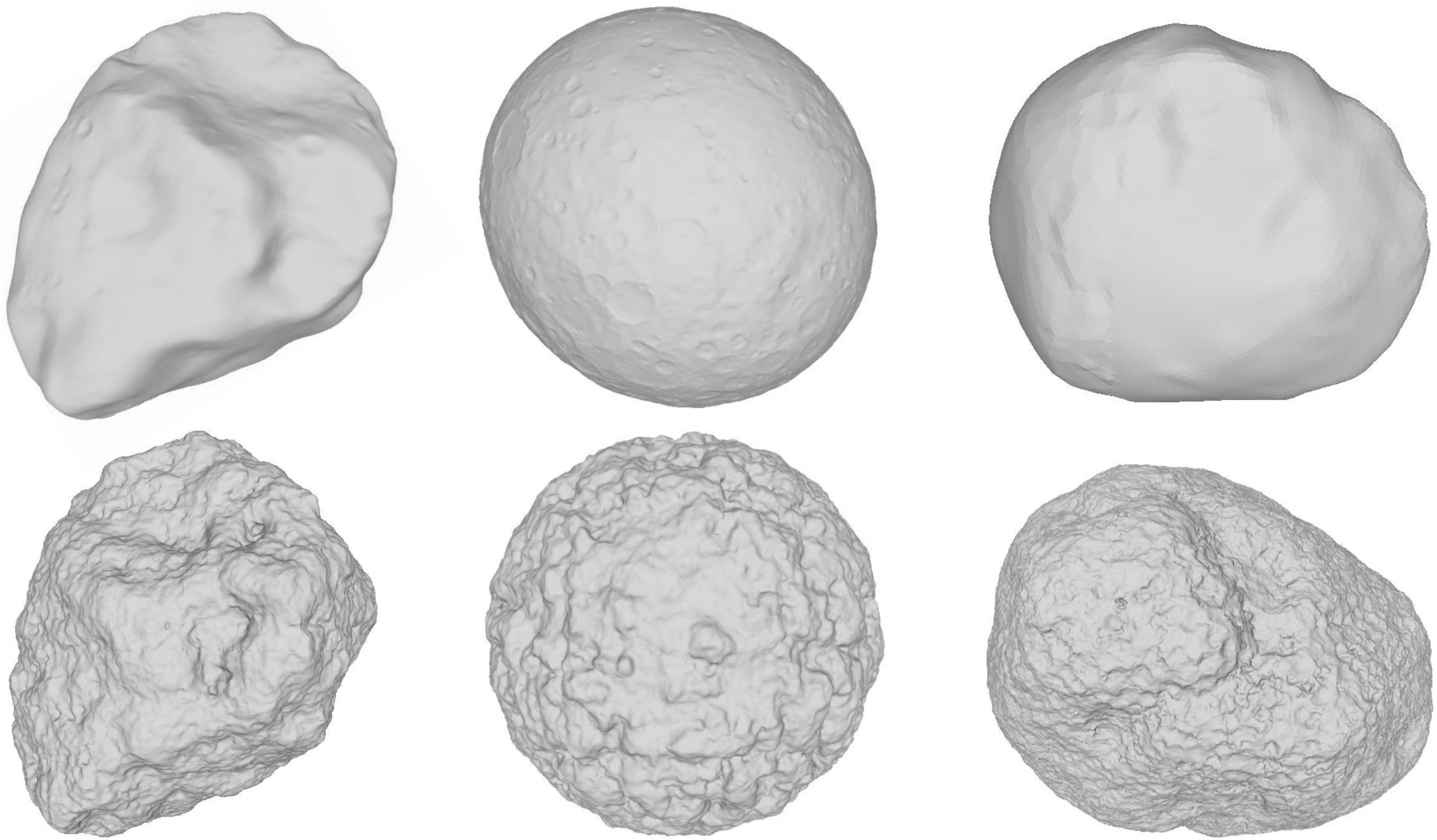


“Medium” surface (2,173k vertices)



“Steep” surface (2,335k vertices)

Results – Transformed Low-Poly Asteroids



Asteroid Lutetia
(710k vertices)

Asteroid Ceres
(1,063k vertices)

Asteroid Stein
(778k vertices)

Conclusions

- Optimization-based generation of 3D asteroid look-alikes
- Major contributions:
  - Create infinite numbers of asteroid shapes similar to prototype shape
  - Users control the similarity/dissimilarity distance to generate different shapes
  - Create arbitrarily high resolution from low-poly models
  - Can be easily implemented on the GPU
- Limitations:
  - The randomness of noise make it hard to control and generate particular patterns

Future Work

- More naturalness
  - AstroGen integrated with physically-based noise such as flow noise and curl noise
  - Incorporate with reinforcement learning or other optimization algorithm to improve the result
  - Different similarity measurements can be compared
- More applications
  - AstroGen in virtual testbed to verify vehicle design
  - Mascon based gravity computing
- Better mesh quality
  - Enhance the visual fidelity by using dual marching cubes

Thank you !
Q&A