Orbital Ecology Simulator

Satellite Networks and Debris Proliferation

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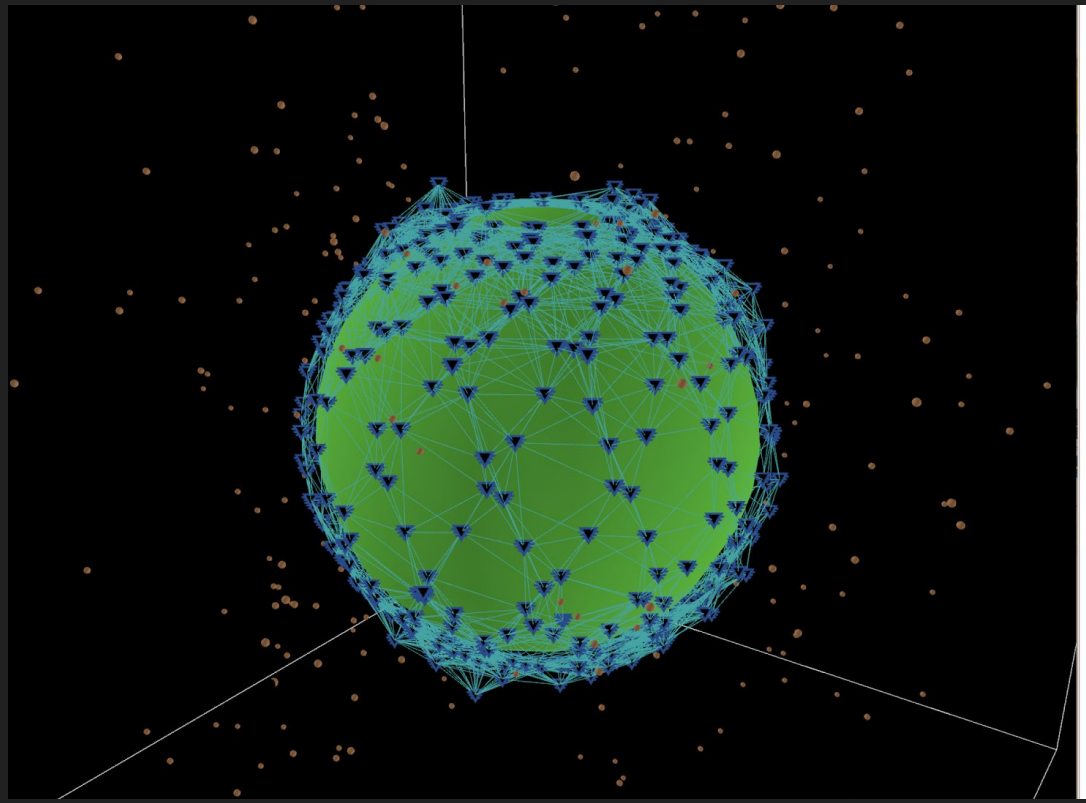
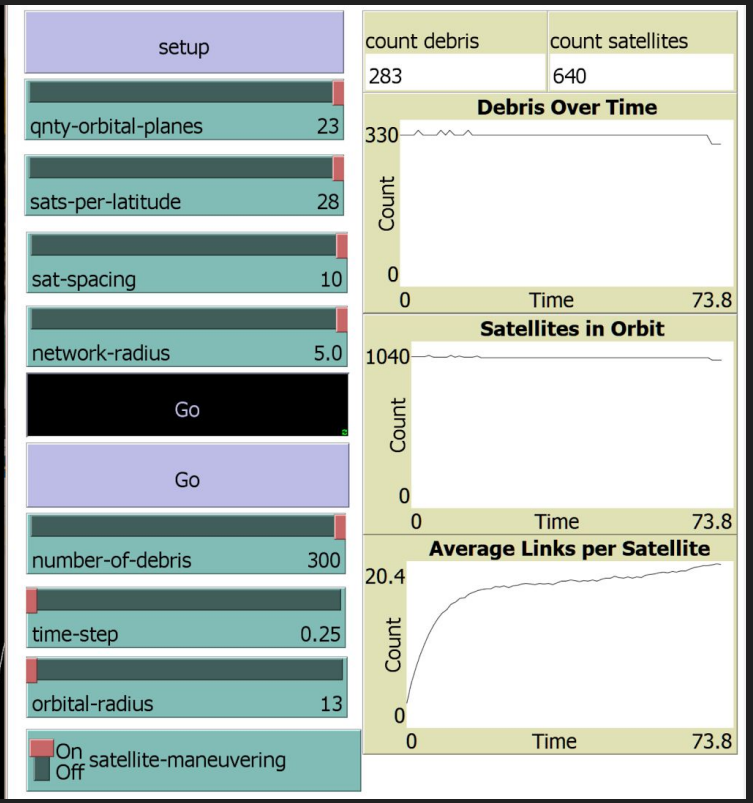
Introduction





Introduction/Background

My interest in pursuing a career in Systems Engineering is tied to the recent successes in space-technology development. One recent development has been the first ever deployment of a satellite mega-constellation, the SpaceX StarLink, which will begin providing internet services from space in 2020.

The purpose of this model is to demonstrate (on a simplified and small scale) the complexity of large satellite constellations in a hostile environment of orbital debris. An initial satellite population is set to provide near-global coverage in low orbit. Debris are dispersed randomly across the whole environment, and will proliferation if contact is made with a satellite (destroying the satellite in the process).

An additional analysis is made of satellite networking, but work is still in process.

Purpose

My starting question in developing this model is:

- Can orbital debris be mitigated by giving satellites autonomy to avoid debris?

A secondary question is:

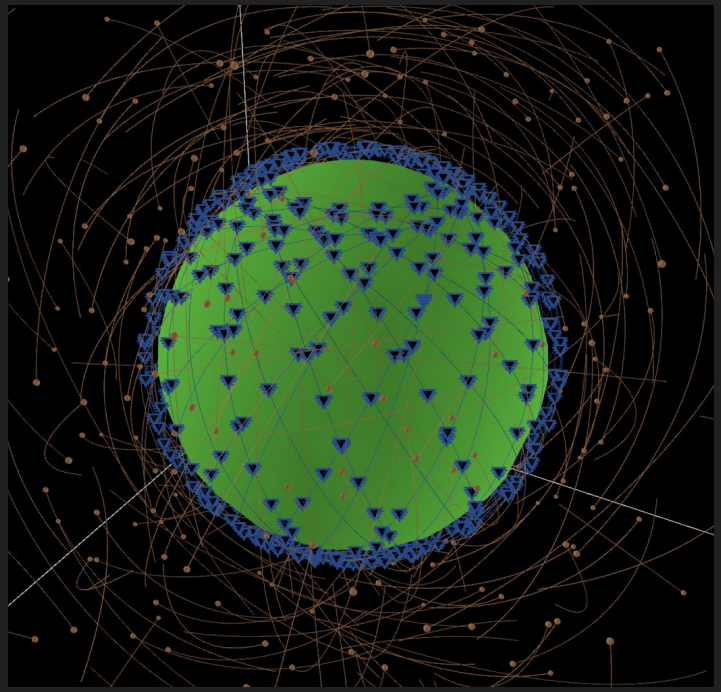
- To what extent could large satellite constellations proliferate more debris?

And finally, I wondered:

- Could distributed networking be used to enhance overall debris avoidance?

Close-up of satellites (blue emblems, not networked) with nearby orbital debris (brown spheres).

Simplifying Assumptions



All orbital objects tracing out circular orbits

- Only a single satellite constellation needs to be simulated
- I can replace gravity with 3D spherical motion
- Only circular orbits need be considered
- Only one orbital inclination for the constellation needs to be considered
- Debris will provide sufficient obstacles (satellites don’t maneuver to avoid each other)

Model Structure: Satellite Parameters

This model allows the user to set several satellite parameters:

- Quantity of orbital planes (determines mean longitudinal satellite coverage)
- Satellites per latitude (determines mean latitudinal satellite coverage)
- Satellite spacing (determines mean coverage along 53° orbital path)
  - Note: 53° inclination was chosen to match the current StarLink constellation path
- Network Radius (sets effective range of local satellite networking)
  - Note: Local satellite networking is yet not fully developed. See video for details
- Satellite Maneuvering (allows satellites to actively dodge debris)
- Fuel (consumed by satellites to stay in stable orbit and to perform maneuvers)

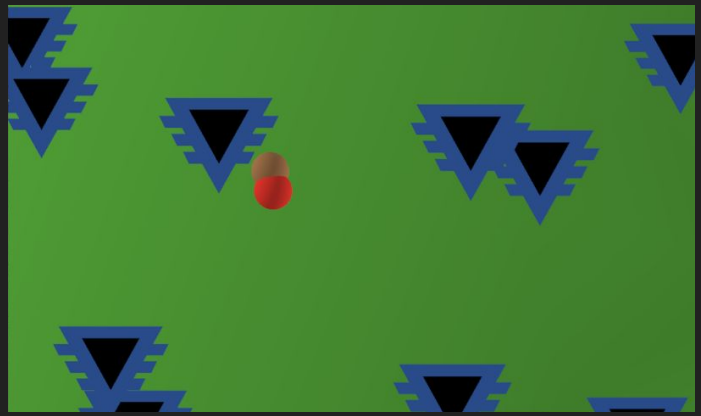
Model Structure: Debris and Global Parameters

This model allows the user to set several other parameters:

- Number of Debris (amount of “space junk” the satellites must avoid)
- Time-step (allows the user to speed through the model as it runs)
- Orbital radius (actually another satellite parameter)
    - Note: Model is currently only designed around the minimum radius

Other key features:

- Debris proliferation
    - Debris are able to kill satellites that fail to evade
    - Each instance produces up to twenty more debris, with slightly different orbits
    - Debris from satellite collisions are red spheres



Applicability

Initial applications include:

- Teaching tool
  - Demonstrates satellite orbits, what a satellite constellation looks like, etc
  - Also demonstrates the messiness of space with debris proliferation
- Effective for showing objects in circular orbits

With further development, further applications may be:

- Explore benefits of local satellite networking
  - May improve debris avoidance
  - Find alternate configurations
  - Improve satellite coverage for providing signals to the whole planet

Limitations

Many limitations are placed on the model due to constraints imposed by necessary simplifications:

- Gravitational attraction is not modeled
  - I attempted this, but it was too computationally heavy for the machine I was using
- The model can only handle a limited debris field and debris size
  - In reality, estimations of space debris are up to 130 million (with most smaller than 1 cm across)

Modeling Process

- First a planet is generated which determines the minimum orbit of all other turtles.
  - Planet will ask turtles (sats AND debris) that come to close to die
- Then satellites are generated iteratively at 53° N and 53° S using parameters set in the user interface.
  - Satellites are then moved forward according to the sat-spacing parameter
  - The total number of satellites produced are the product of qnty-orbital-planes and sats-per-latitude
- Then debris are generated each at a random radius out from the planet.
  - They also have random mass and size to demonstrate the variety of “space junk”.
- Maneuvering may be turned on or off at any time during the model run.

Modeling Testing

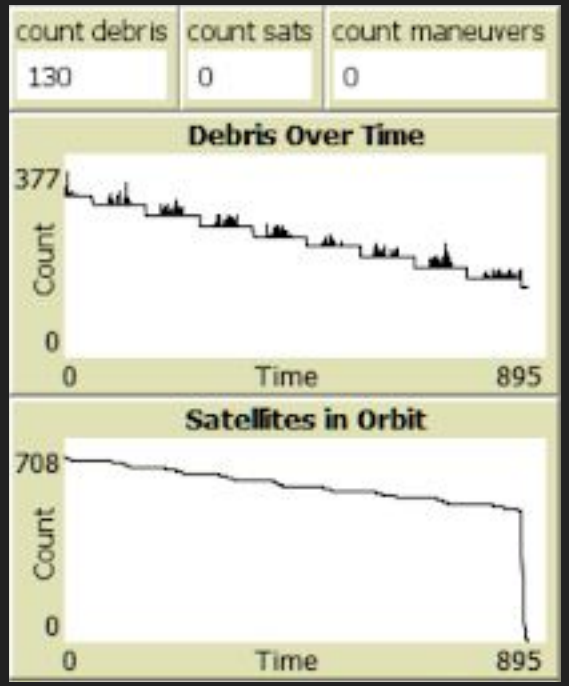
Every parameter required substantial testing. This was particularly true for:

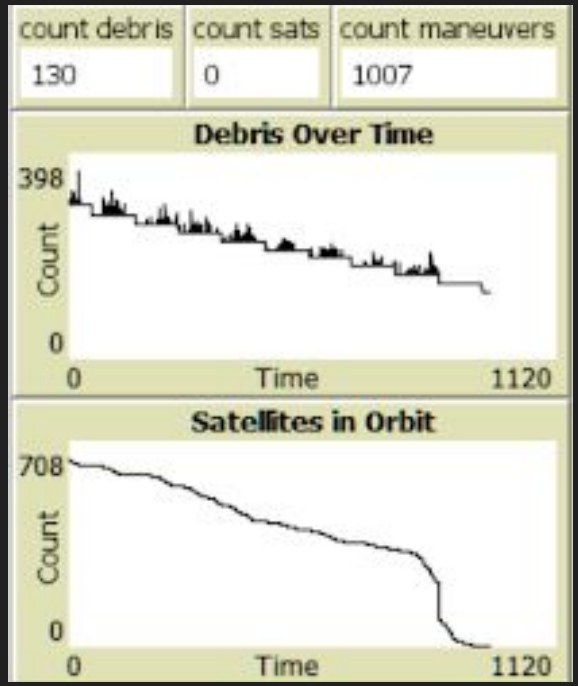
- Placing satellites at setup
  - Several methods to place satellites explicitly were rejected. Settled on iterative method which came closest to the real StarLink configuration.
- Trying to “turn on” gravity
  - Worked on small scales. Too computationally expensive to fully implement
- Local-networking
  - Except for providing a cool visual (see title slide), local networking proved too complex to implement in this model without more time.
  - Attempted to use layout-tutte (promising) for controlling satellite configuration, unable to validate and strange effects.

Experiments

Two primary experiments:

- Satellite population tracking without maneuvering (left)
- Satellite population tracking with maneuvering (right)
    - Related is the average debris count, as debris are produced from collisions with satellites

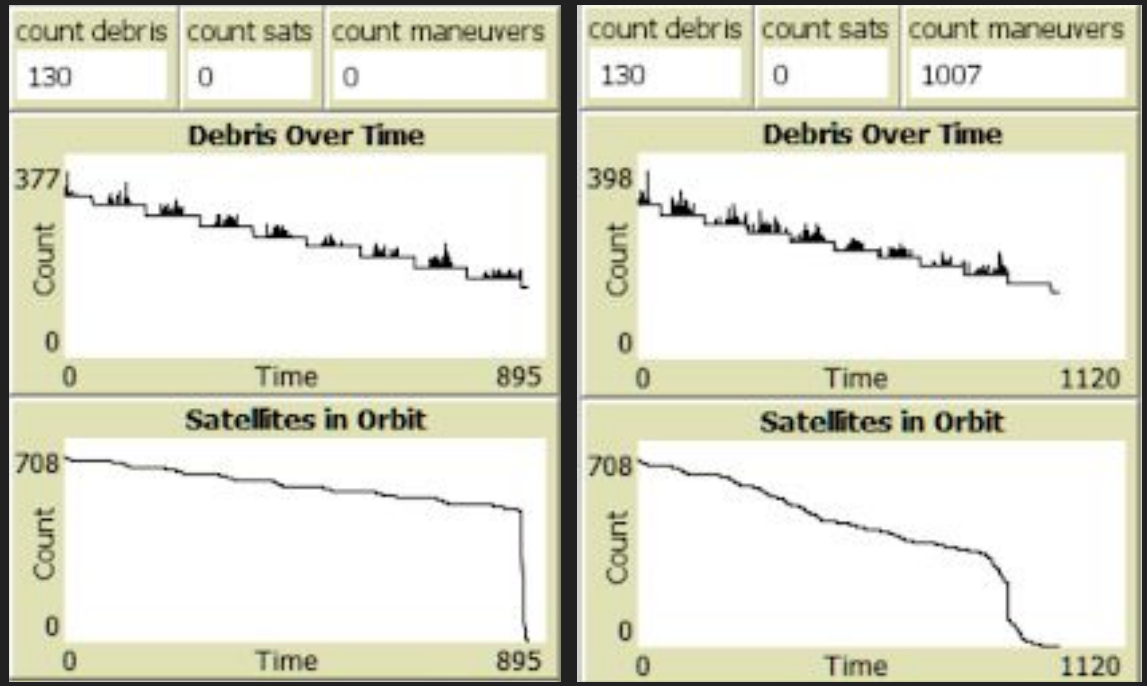




Results Interpretation

The graphs show a typical run given satellite maneuvering and all other parameters equal.

When maneuvering is enables, satellites extend their life by about 8% (until they run out of fuel).



Conclusion

As previously stated, it is important to understand that this model has been simplified too much to be useful for modeling real physical phenomena in low earth orbit.

However this model may make a useful teaching aid for demonstrating to students and the public how circular orbits around the earth work, and the complexity of coordinating the flight paths of large satellite networks in the event that a large and dense debris field is generated in co-orbital space with human created assets (satellites). This point is emphasized by the growth of the debris field as existing debris collide with satellites.