The SGP4 Model

Of the set of all classes of propagators two major groups available are analytical propagators, such as the multiple flavors of **Simplified General Perturbation** (SGP) models, and special perturbation propagators, such as the **ASW Special Perturbation** propagator. Propagators of these classes typically trade off between accuracy and speed. Finding the right propagator for the right task is crucial, especially for users who are interested in performance but may also have large datasets.

The **SGP4** model, see SpaceTrak Report #3, is an analytical general perturbation model. Currently, one of the most widely available sources of orbital data are Two Line Element (TLE) sets, produced by USSPACECOM, which contain the mean set of orbital parameters for Resident Space Objects (RSO). From SpaceTrack Report #3, it is recommended that users of these TLEs use one of five general perturbation models to reconstruct an orbits from a TLE. For instance, users may propagate a TLE using the **SGP4** or **SDP4** algorithms. Without doing this, orbital predictions may contain errors in addition to the inherent error of the **SGP4** model. The inherent errors of this model have been discussed by many groups several reports of these errors can be found in reference 14-16 of Acciarini et al.

An alternative option, that attempts to increase the accuracy and increase the speed of the **SGP4** model is the **δSGP4** model. This model improves upon the **SGP4** model by using automatic differentiation to create a differentiable **SGP4** propagator. The developers of this model demonstrate the advantage of this by training a neural net integrated with the **δSGP4** model. Acciarin et. al show that doing this improves upon both the speed of the **SGP4** algorithm as well as its accuracy.

Questions

In terms of operations, when do groups performing operation use a SP propagator versus an SGP4 propagator?

Acciarin et al. state that,

"The objective of this experiment is to show that even with only three days of ephemeris data, the ML-∂SGP4 model can be leveraged to increase the accuracy of the standard SGP4 propagator while retaining its computational advantages. By feeding more ephemeris data, the model can further enhance its accuracy, potentially being competitive with high-precision numerical propagators in terms of precision, while retaining the advantages of general perturbation techniques in terms of speed. We believe that this will be particularly useful for operators of constellations that possess a large amount of high-precision data. with high-precision numerical propagators in terms of precision, while retaining the advantages of general perturbation techniques in terms of speed. We believe that this will be particularly useful for operators of constellations that possess a large amount of high-precision data."

While **TLE** data, used by the **SGP4** model, is known for its inaccuracies up to several km, could using this differentiable form of the **SGP4** model decrease that inaccuracy and by how much? Acciarin et al. trained their neural net with only three days of data for 1500 satellites in LEO. How much would training a neural net with a month or a year of data improve that accuracy?

How would this compare to the algorithm speeds we have seen with GMAT and ASW?

Is **δSGP4** also valid for deep space objects i.e. objects with periods less than 225 minutes? If not, can we produce a **δSDP4** algorithm?

Propagator Use Cases

Answering these questions could help motivate a path forwards for NGSX to select a propagator or propagators. The advantage of the availability of orbital data and its speed make the **SGP4** model ideal for incorporating large batches of data into NGSX and performing routine updates to maintain the data. Using a propagator such as the **δSGP4** model could improve the accuracy of the orbits predicted from these datasets as well as allow for faster dataset predictions. This machine learning is dependent on highly accurate ephemeris. Currently we have used GNSS ephemeris for "truth" data and we could also include StarLink ephemeris as well. Highly accurate ephemeris for higher altitude orbits will need to be sought out as well as determining whether a **SDP4** analog to **δSGP4** can be produced.

Although more accurate, special perturbation models are slower than general perturbation models. Additionally, the abundant data from TLEs can not be immediately used without being penalized with additional error. Their precision would still benefit NGSX when users want to generate trajectory updates due to maneuvers of spacecraft, simulations of orbits, etc. The Python SciPy package incorporates several Runge Kutta integrators. A force model written in Python based on the force modeling from the **General Missiona Analysis Toolkit** (**GMAT**), could be coupled with these integrators to generate orbital predictions.

Incorporating both an **SGP4** propagator and a **Special Perturbation** methods into NGSX would give users the option to use widely available TLE datasets and quickly propagate them, as well as giving them the ability to propagate orbits with highly accurate special perturbation propagators. A more accurate version of the **SGP4** model, such as **δSGP4**, could improve the accuracy of propagated TLE data, offering a higher fidelity experience for users.

References

Giacomo Acciarini, Atılım Güneş Baydin, Dario Izzo,
Closing the gap between SGP4 and high-precision propagation via differentiable programming,
Acta Astronautica,
Volume 226, Part 1,
2025,
Pages 694-701,
ISSN 0094-5765,
https://doi.org/10.1016/j.actaastro.2024.10.063.

SPACETRACK REPORT NO. 3 Models for Propagation of, Felix Roach Hoots and Roland Louis Roehrich, 1988, https://celestrak.org/NORAD/documentation/spacetrk.pdf