CONJUNTION ANALYSIS & VISUALISATION OF EARTH-ORBIT SPACE OBJECTS

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MATLAB Space Situational Awareness Visualisation (MASSAV)

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Introduction

- Since 1957, the space around our earth has been becoming increasingly congested.
- Over 1300 active satellites in orbit [1]
- 16,000 pieces of catalogued debris larger than 10cm that are being tracked [2].
- In the uncatalogued / (smaller than 10cm) domain there are millions more objects that have yet to be identified.

Why should we care?

- An impact between an active satellite & orbital debris is often critical

(2009 collision between active Iridium 33 and non-active Kosmos 2251 [3])

- Space debris cannot currently be plausibly removed from orbit [4]
- The current overcrowding problem is projected to escalate as additional space missions are launched [4]
- Pre-existing debris collides and shatters, further compounding the problem [4].

Space Situational Awareness/Tracking (SSA/SST)

- SSA concerned with predicting orbital object locations with objective of avoiding collisions
- SST concerned with tracking and surveying threats to orbital satellite systems

SGP4 propagator
(Standard General Perturbations model 4)

- Predicts the effect of perturbations on near earth objects, particularly used with Two-line Element (TLE) sets.
- Given input -> predict where object is at certain time
- Uncertainty/error grows as propagate further into future

Proposal

- The aim of this project is to build a program to visualise and analyse orbital object tracking data in an interactive 3D rendered environment.
- It will explore non-Gaussian uncertainty of orbital objects via particle representations to convey collision risks in an intuitive and innovative way.
- MATLAB Space Situational Awareness Visualisation (MASSAV)

Non-Gaussian Conjunction Analysis

- Traditional conjunction analysis assumes the uncertainty of orbital objects will behave via a roughly Gaussian model [5, 9].
- Assumption supresses the true non-Gaussian nature of orbital object position uncertainties [6, 7, 8, 9].
- Using statistically weighted particle generation techniques, can model the non-Gaussian uncertainty of the any orbital object with known elements [9].

The Gaussian mean can be significantly off centre relative to the true probability density function (pdf) [9].

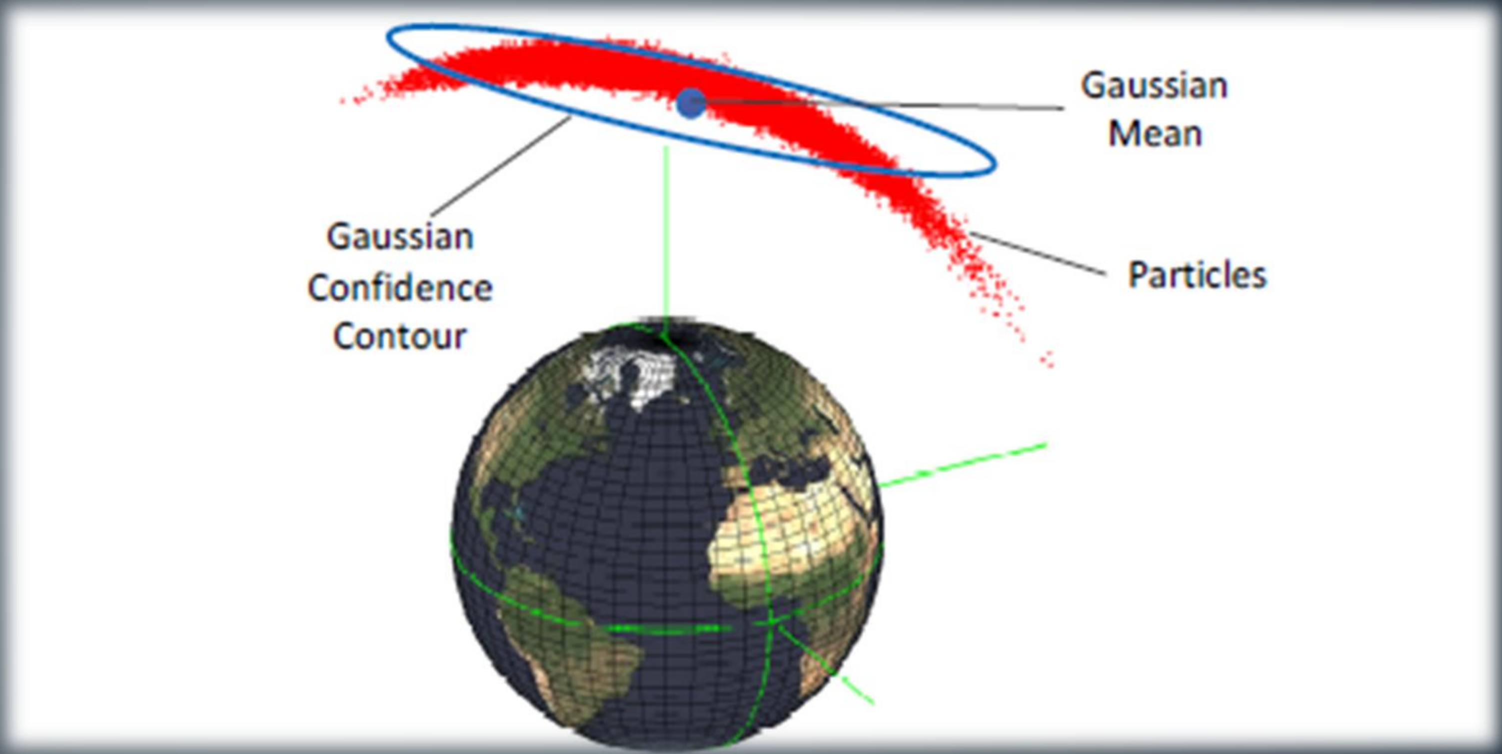

Figure 1 - Gaussian and particle representations of an orbital object's uncertainty (image from [9])

Two-line Element (TLE) Format

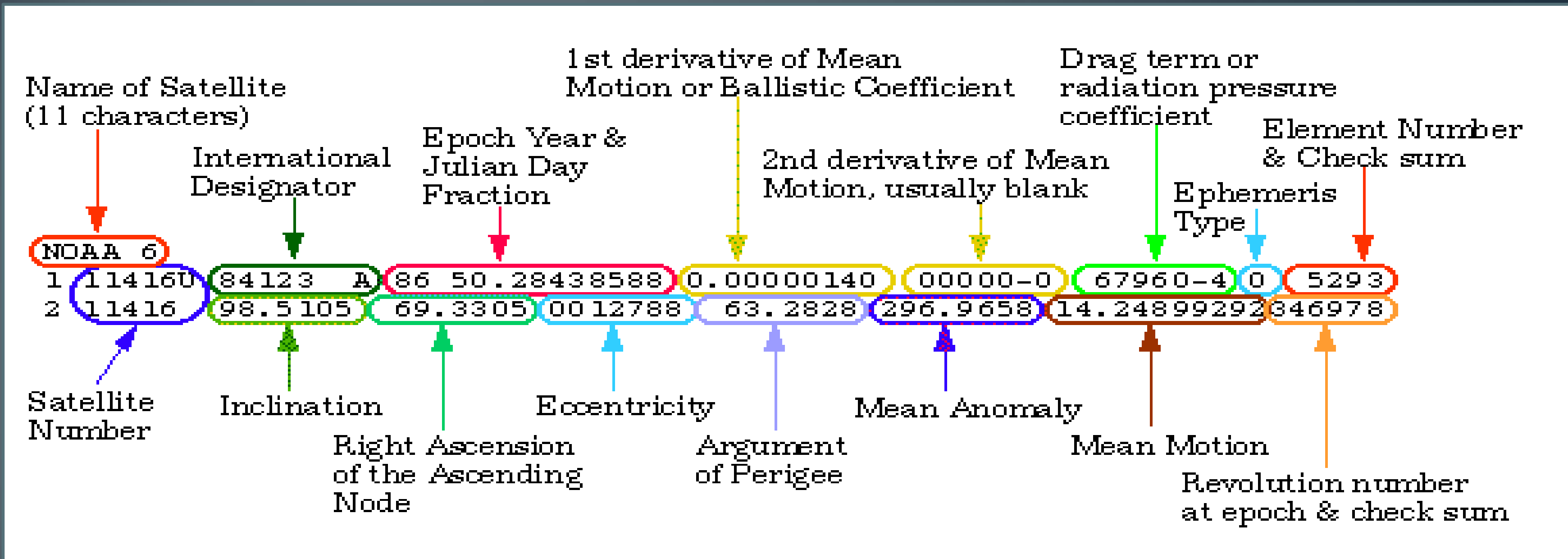

Figure 2 – TLE Format Layout [11]

```
NOAA 14
1 23455U 94089A   97320.90946019  .00000140  00000-0  10191-3 0  2621
2 23455  99.0090 272.6745 0008546 223.1686 136.8816 14.11711747148495
```

Figure 3 – a typical TLE

MASSAV Methodology

- TLE input
- SGP4 propagator to simulate/propagate objects forward in time
- Particle representation of uncertainty (add noise to elements of sgp4 model)
- Collision analysis on bodies that pass within certain distance

- Simulated scenarios for verification/development in reduced scope
- Collision analysis on large TLE catalogue set

Progress?

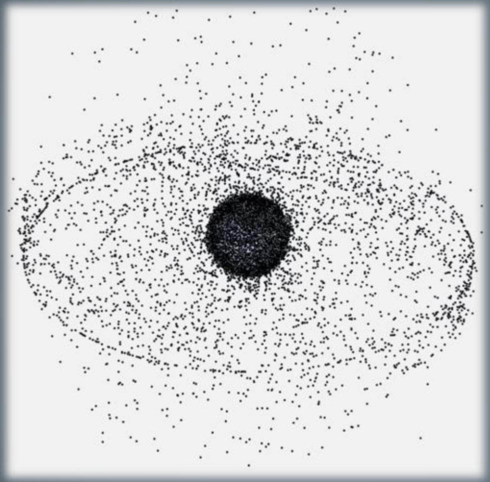

Figure 4- NASA graphic of orbital debris around earth (image from [12])

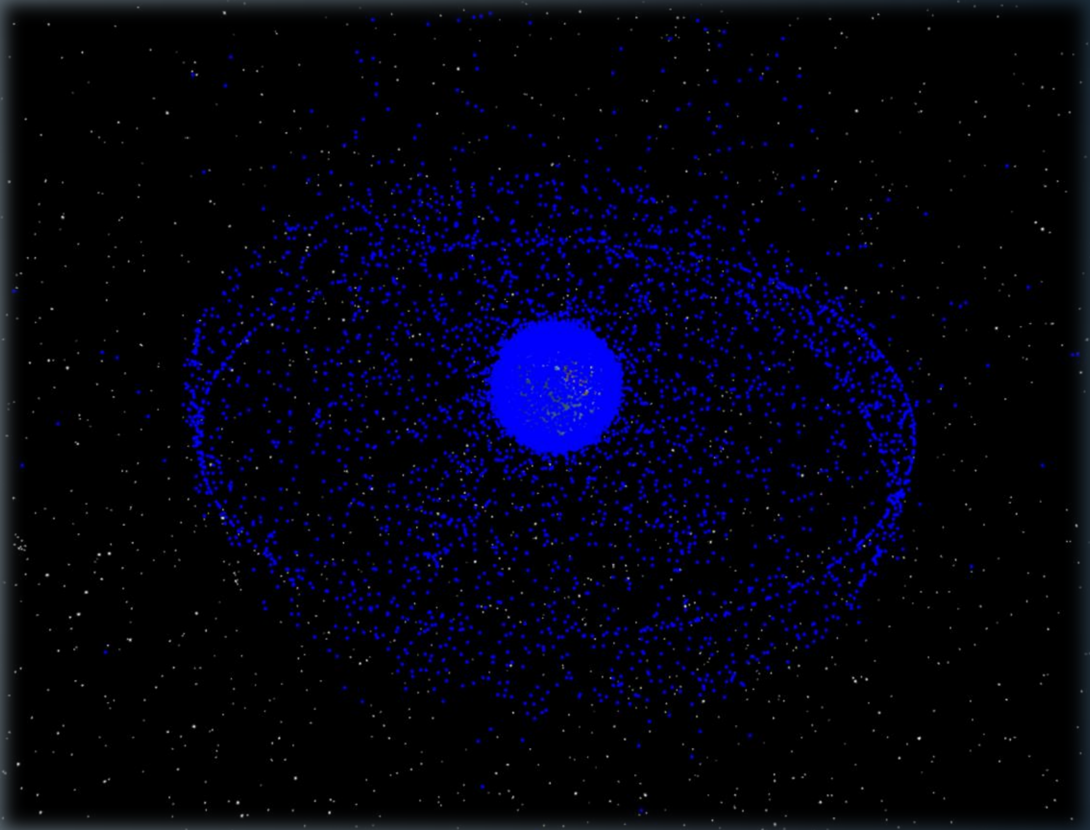

Figure 5 MASSAV screenshot on publicly available full space catalogue TLE [13]

(demonstration)

NVIDIA CUDA (GPU) Processing

Large dataset of objects x time (frames) …x particles (for conjunction analysis)

For example:

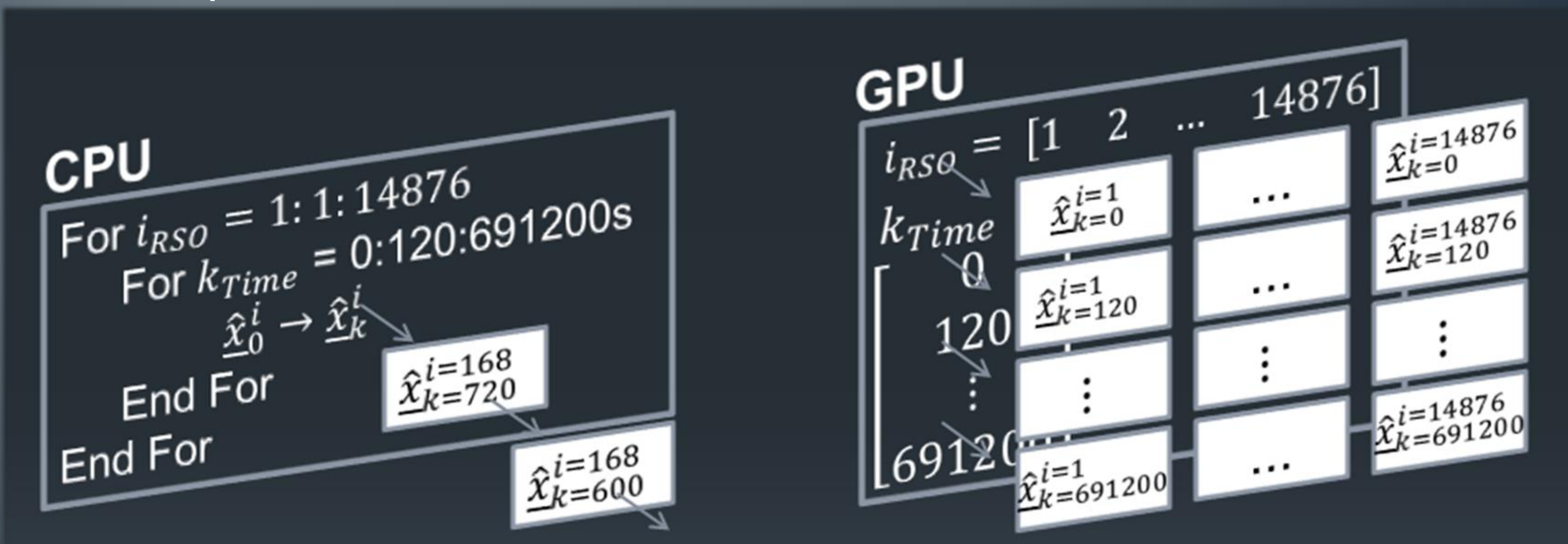

Figure 6 – in-series processing (CPU) vs. parallel processing (GPU) (image from [14])

GPU Processing (in short)

MATLAB host process

↓

Send data to GPU (arrays of objects, times, etc.)

↓

Perform operations in parallel GPU environment (CUDA)

↓

Retrieve propagated position results from GPU

Benchmarks

Table 1 – calculation times of MASSAV CPU/GPU routines at different sizes

Benchmark	1 Frame	10 Frames	100 Frames	1,000 Frames
CPU: 15500 objects	1 min 42 s	1 min 54 s	4 min 31 s 3 min 29s (~78 frames)	23 min 42s
GPU: 15500 objects	13.1s	13.3s	15s (~78 frames)	NaN
CPU: 2200 objects	4.3s	5.8s	32 s	2 min 56s
GPU: 2200 objects	1.7s	1.7s	1.7s	3.0s
CPU: 333 objects	0.692s	0.953s	3.154s	26.85s
GPU: 333 objects	0.292s	0.296s	0.304s	0.413s
CPU: 24 objects	0.133s	0.154s	0.301s	1.993s
GPU: 24 objects	0.050s	0.050s	0.054s	0.058s

Current GPU implementation runs out of memory around 15,500 obj x 80 frames = 1,240,000 frames

Bonus GPU: 24 obj x 80,000 frames = 1,920,000 frames ->0.51s

Current limitations of GPU Processing

- Crashes when working with >1,240,000 frames
- Running out of memory on GPU (using 2GB of laptop GPU)

- Solution would be: split up calculations on large datasets into chunks to run in series on GPU. Further optimisation

Future Plan

- Uncertainty volumes / particles
- Conjunction (collision) analysis in closed scenario
- Iterative / reductive analysis on real datasets
- Interactivity, automation and user options
- Explore 3D visualisation methods

Development Plan

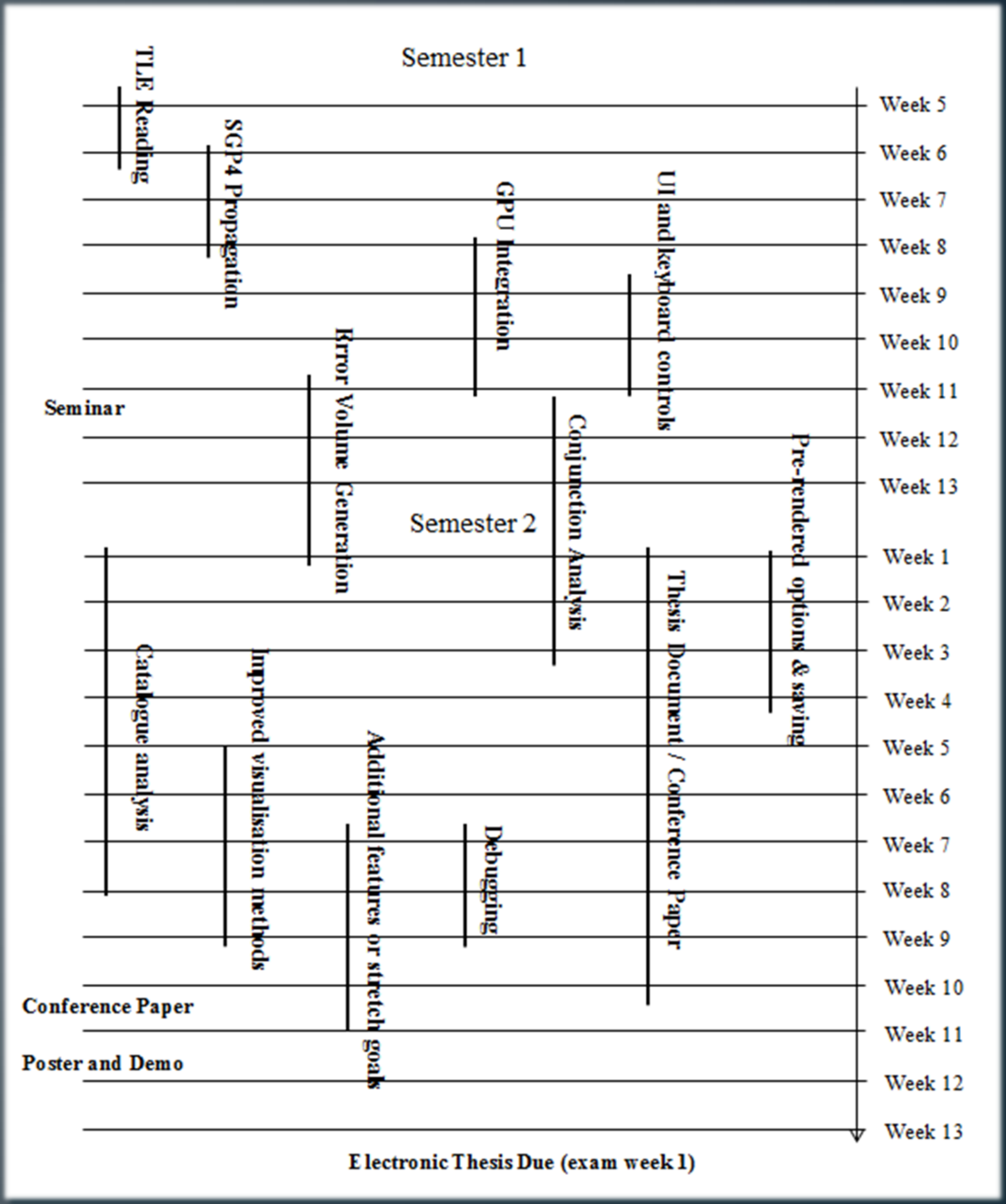

Figure 7 – breakdown of development milestones

References

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Q & A