Design & Development of an Optimized Sensor Scheduling and Tasking Program for Tracking Space Objects

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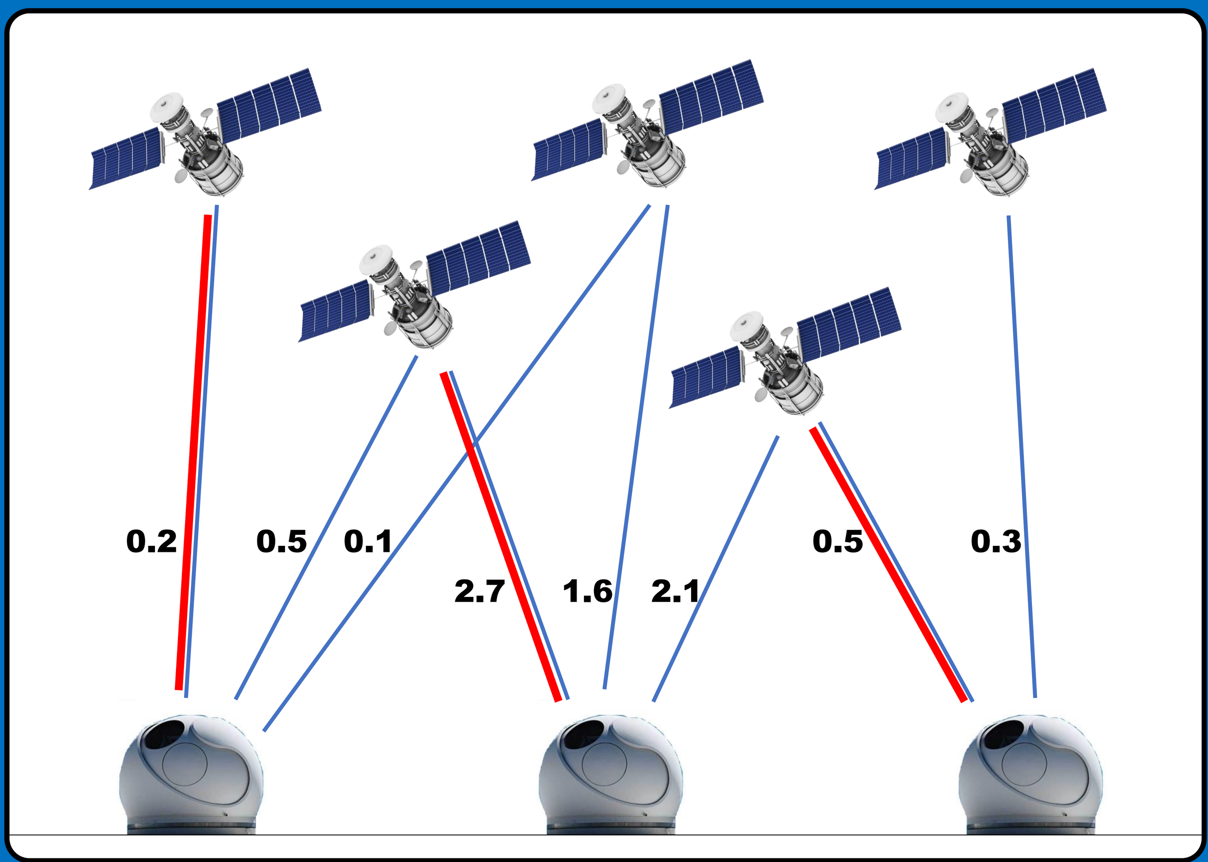
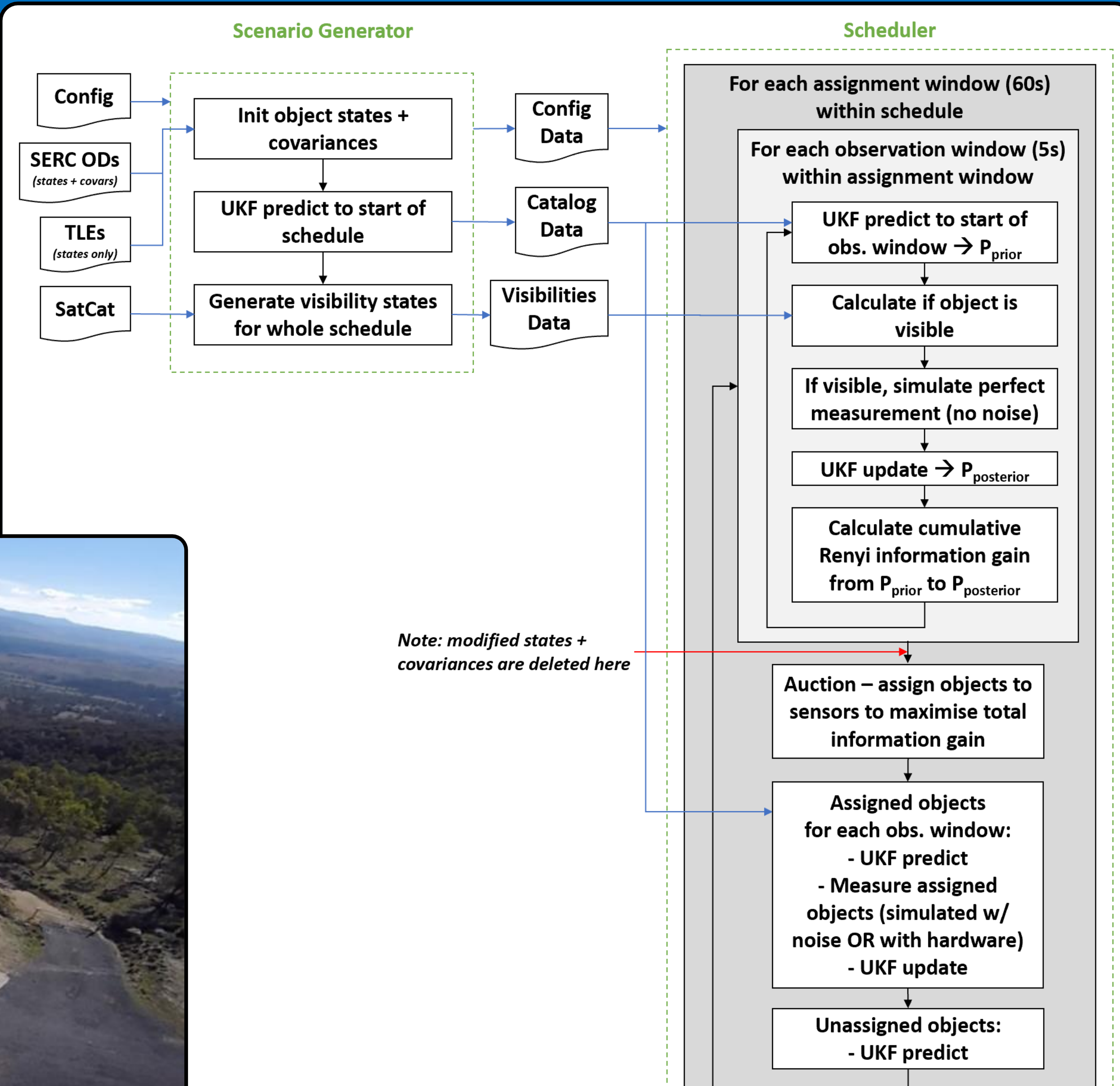
Overview

With a large and ever-growing number of resident space objects (RSOs) in orbit around the Earth, the efficient tasking of sensors is critical to track objects and maintain reliable state estimates of objects across a catalog. In collaboration with Australia's Space Environment Research Centre, The *Industrial Sciences Group (ISG)* developed a scheduler to task sensors in a way that maximizes the total utility of a sensor network, measured in terms of information gain, or the reduction in Rényi α-divergence of object state covariances. The program contains several features such as object prioritization, customizable propagators, and the capability to schedule both optical and laser sensors. The program has been fully implemented in C++ and can schedule a catalog containing over 20,000 objects (building up to 100,000 objects) with up to 6 sensors (building up to 72 sensors) in real-time. The scheduler is currently in use for catalog maintenance by the Space Environment Research Centre at its Mt Stromlo Facility in Canberra, Australia.



Predicted rewards for sensor-satellite pairs.
Blue: visible pairs, with information gain indicated beside links
Red: selected pairs, maximising total information gain

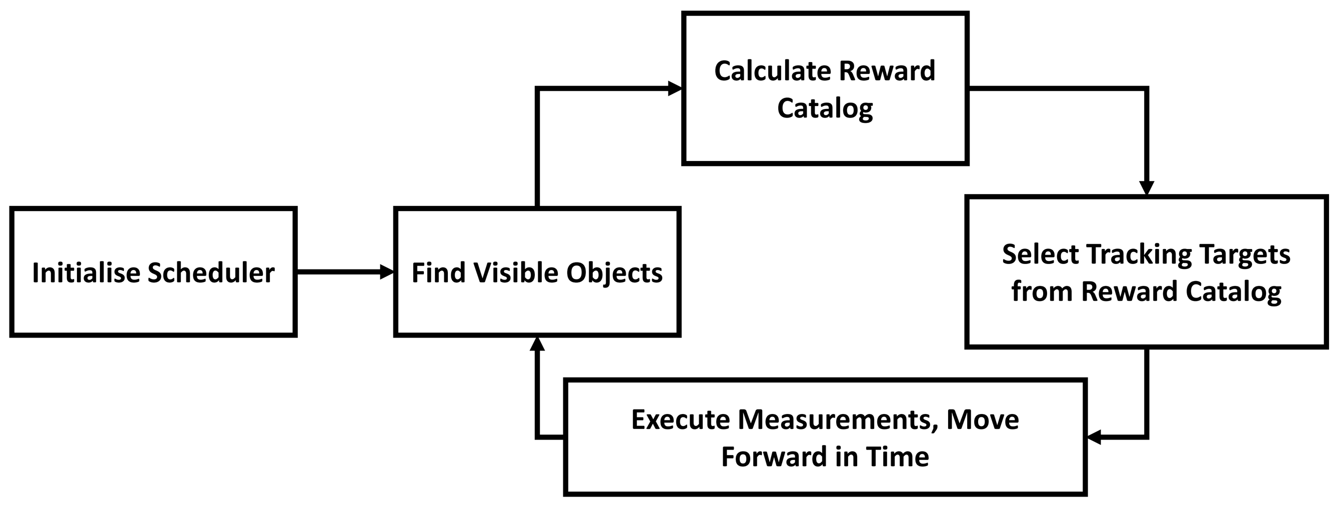
EOS Space Research Centre at Mt Stromlo, Canberra (Credit: Francis Bennet)



Flowchart of the program

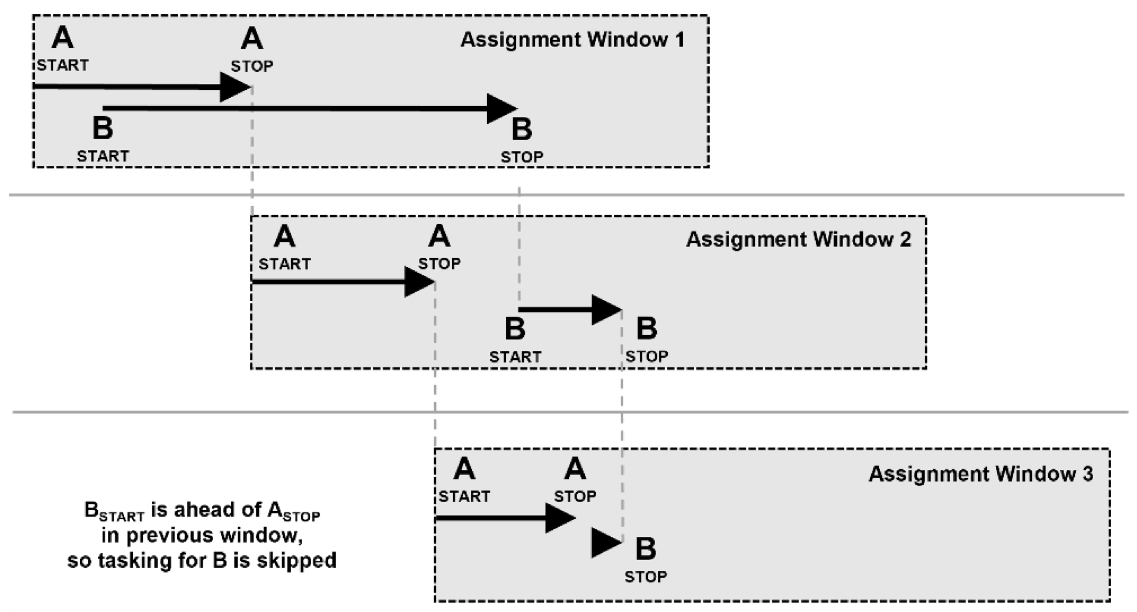
Program Overview

- Uses an unscented Kalman filter (UKF) to calculate object states and covariances
- Produces a schedule that maximises the total information gain across the sensor network
- Implements object prioritisation (based on size, orbital regime, user-defined, etc.)
- Information gain is quantified using Rényi Entropy [1], which quantifies the reduction in covariance due to the measurement of an object
- An auction algorithm [2] is used to select the sensor-object pairs that maximise the total information gained



Asynchronous Scheduling

- 120-second assignment window, starting from earliest-available sensor
- Passes are considered within window
- Objects with highest information gain are selected
- Sensors measure to the end of pass or until information saturation
- Assignment window slides forward in time to earliest-available sensor



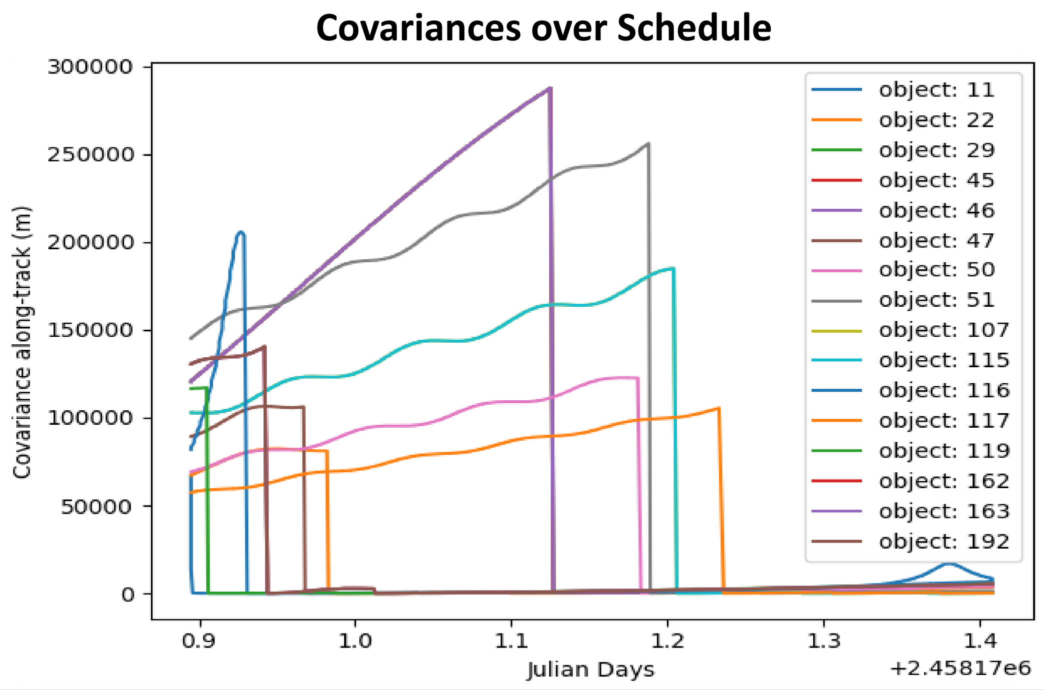
Results and Run-time Performance

Program outputs a schedule that:

- **Reduces sensor idle time**
- **Automatically maintains an object catalog**
- **Maximises sensor utility**

Run-time performance (commercial desktop, 4 cores):

- 100,000 objects with 6 sensors: 2 hours
- 20,000 objects with 72 sensors: 4.4 hours



Applications and Future Work

- RSO catalog maintenance
- Sensor network automation
- Optimization of sensor location by providing a metric for sensor network utility
- Generalisable to problems involving sensor-object assignments to maximise information gain

Visibility module to be used for simulation & planning of a **Continuous Wave Laser Manoeuvre campaign of an RSO** (late 2019)

- Requires knowledge of all objects and their behavior in the vicinity, to ensure a debris object is not moved into a less favorable trajectory
- Objective is to use tracking data of the target RSO before/after the laser firing to provide a statistically valid confirmation and quantification of manoeuvre detection

[1] S. Gehly and J. Bennett, "Incorporating Target Priorities in the Sensor Tasking Reward Function," in Advanced Maui Optical and Space Surveillance Technologies Conference, Sept. 2016, p. 34.
[2] D. P. Bertsekas, "Auction algorithms for network flow problems: A tutorial introduction, "Computational optimization and applications, vol. 1,no. 1, pp. 7–66, 1992.