

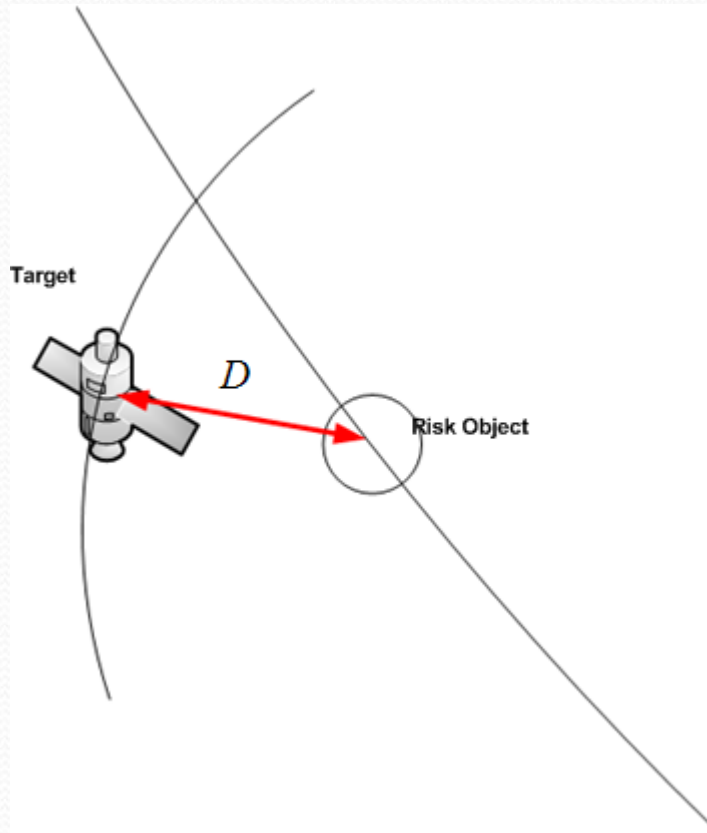
New Method to Determine Close Approaches Between Satellites

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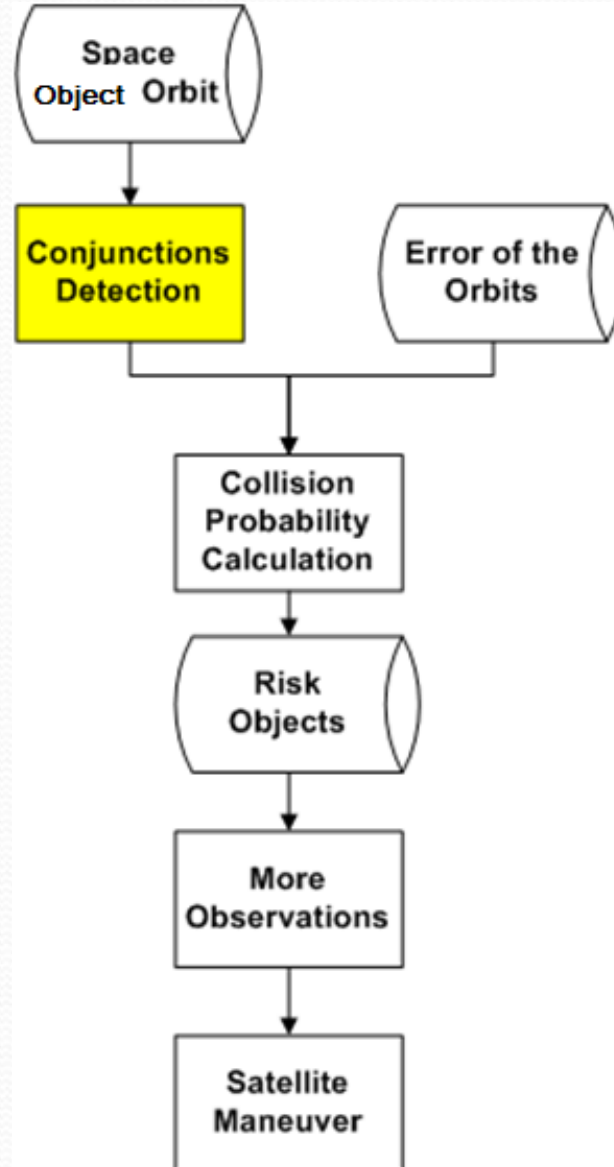
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What is Close Approach/Conjunction?

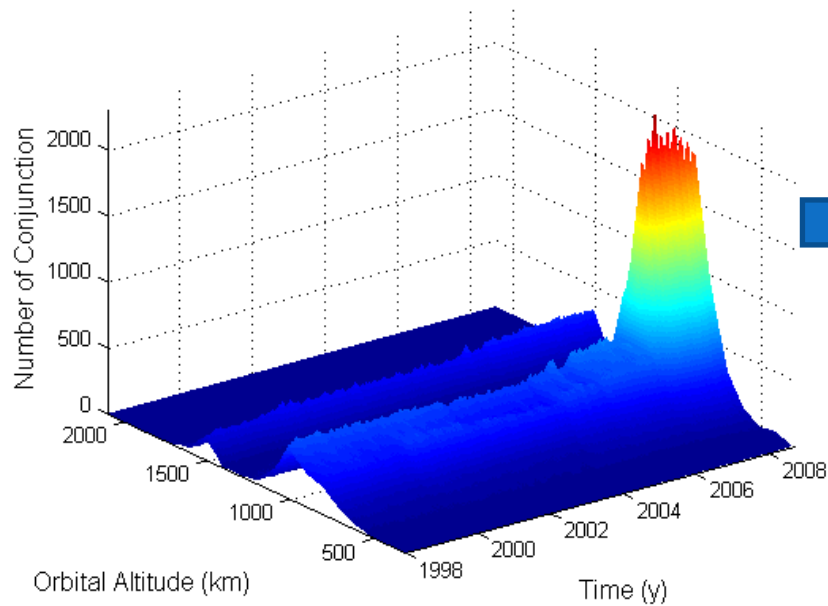


Why do we Calculate Conjunction?

Fundamental Component of Collision Avoidance calculation



- Estimate long-term debris population evolution



	Intact- Intact	Intact- fragment	Fragment- t- fragment	All
2006 Dec	0.44	0.31	0.016	0.77
2008 Aug	0.44	0.50	0.055	1.01

Daily conjunctions Number (Jan 1st 1998 – Aug 1st 2008) (Distance threshold: 5 Km)

Mean collision number of cataloged Fragment for a 10 years span

Current Way to Determine Close Approach

- Satellite Tool Kit (STK)--- CAT Module
 - Expensive,
 - Very Slow in Big Scenario
 - Black Box
- www.CelesTrak.com
 - Black Box
 - Cannot add new data.
 - Can not be used in Debris Environment Research

Goal:

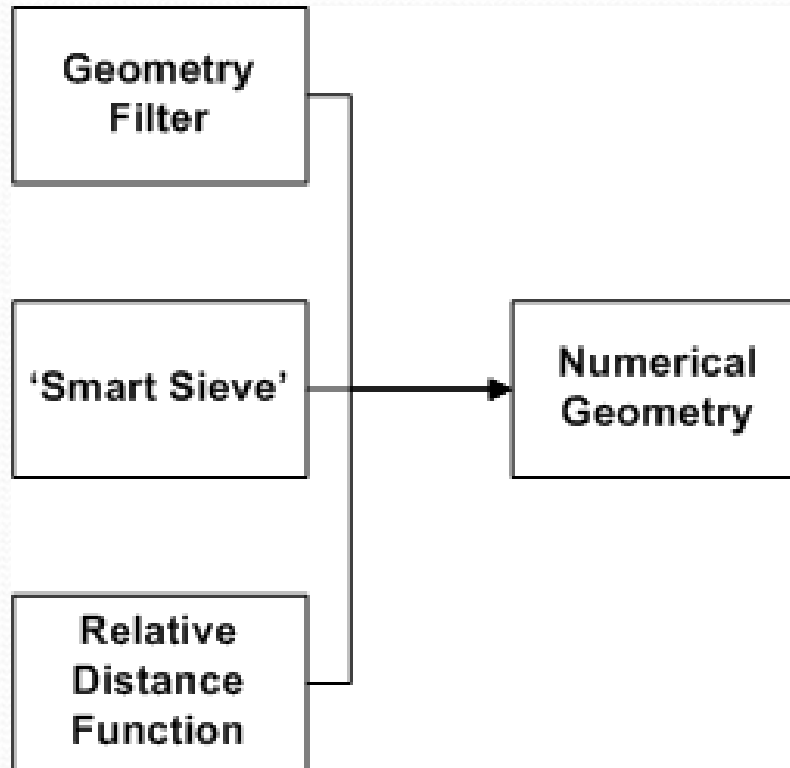
- Provide a **Fast**, **Stable**, **Open-Source** Software for Civil Space Situation Awareness, and other works.


How to calculate the close approach?

Previous Methods:

- Brute Force
- Geometry Filter
- Relative Distance Function
- 'Smart Sieve'

New Method



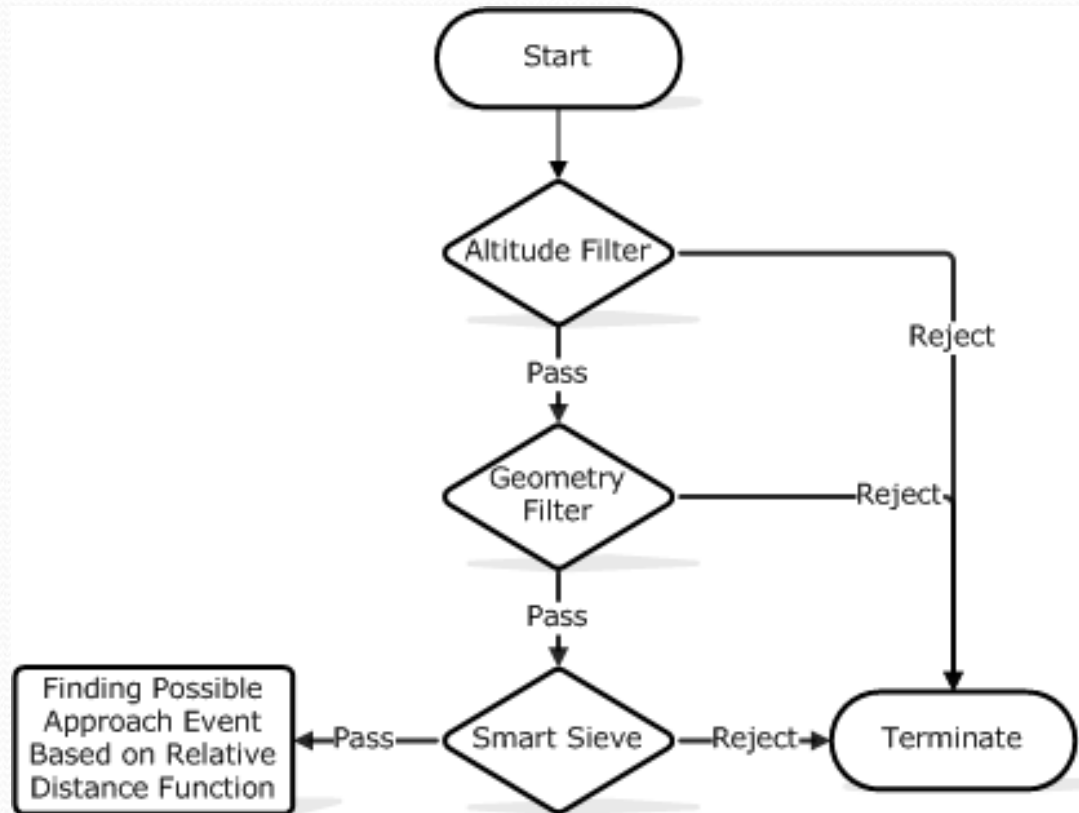
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- Method for calculating conjunctions of **a complete catalog against itself**
 - Method for calculating conjunctions of **a specific spacecraft against the complete catalog**

Method for calculating conjunctions of a complete catalog against itself

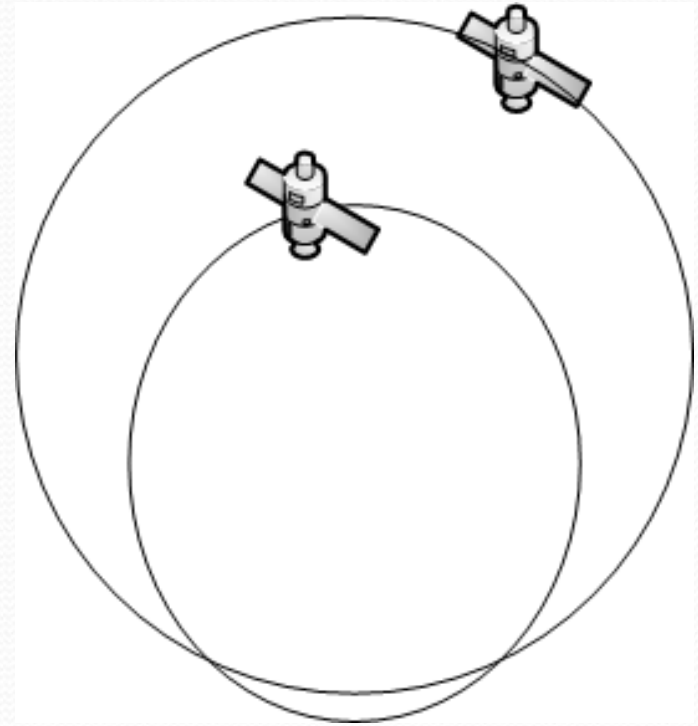
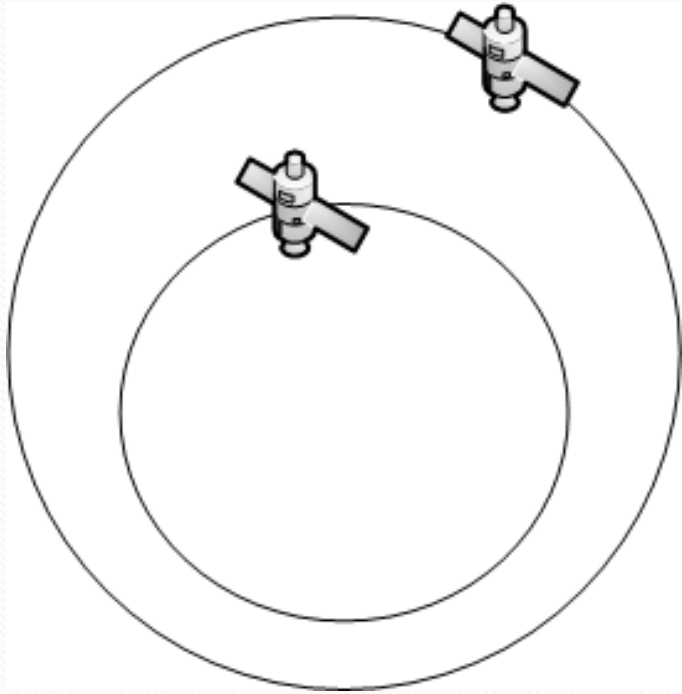
First Step

- the time history of position, velocity, accelerate and classical orbital elements (including arguments of latitude) of **every object in the catalog** is calculated at a even time steps across time span of interest.
- These data are saved in memory to avoid repeated calculation.
- Because it requires $N * (N-1) / 2$ times examinations
- $N = 12,000$

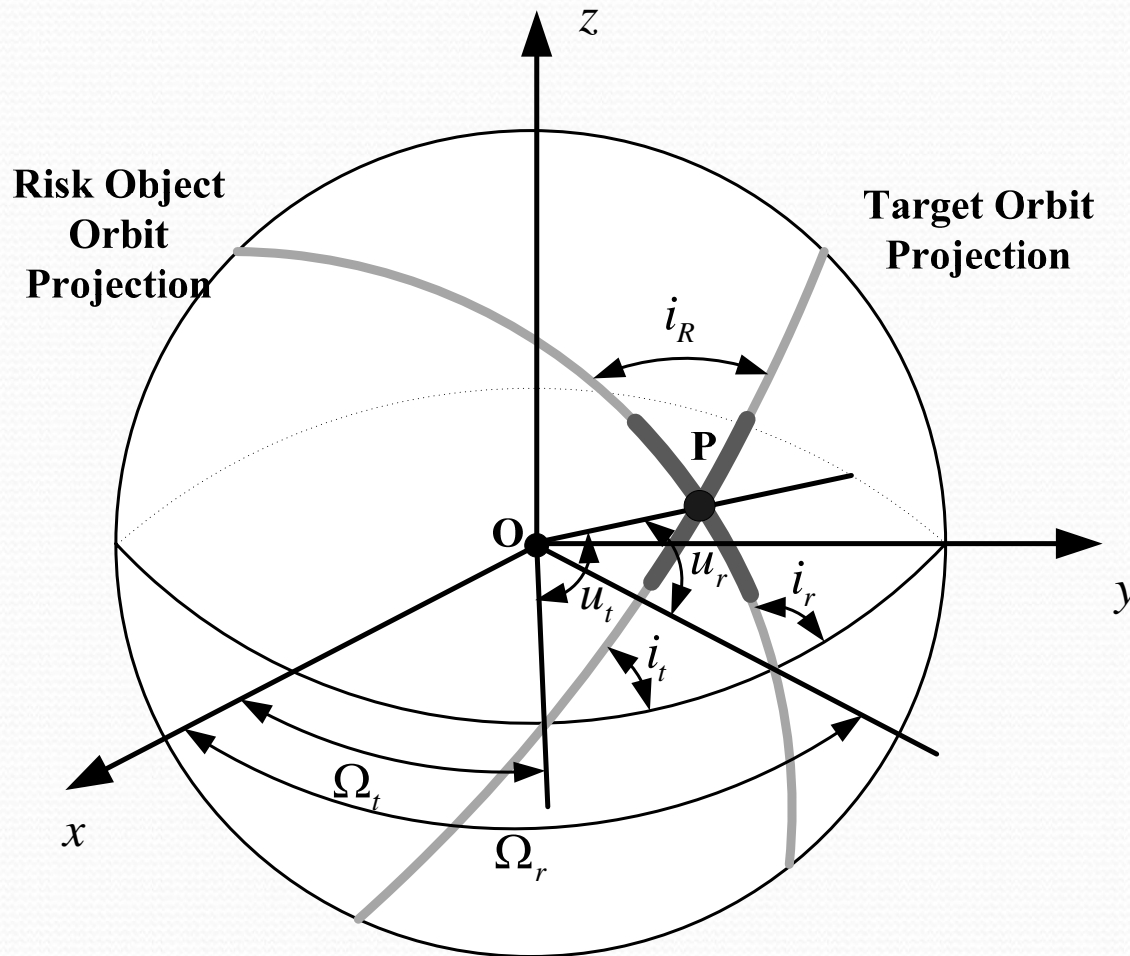
Calculation Process




Altitude Filter



Geometric Filter

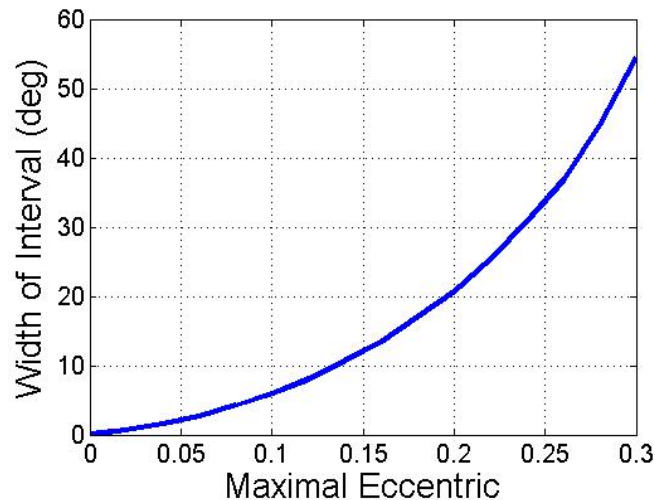
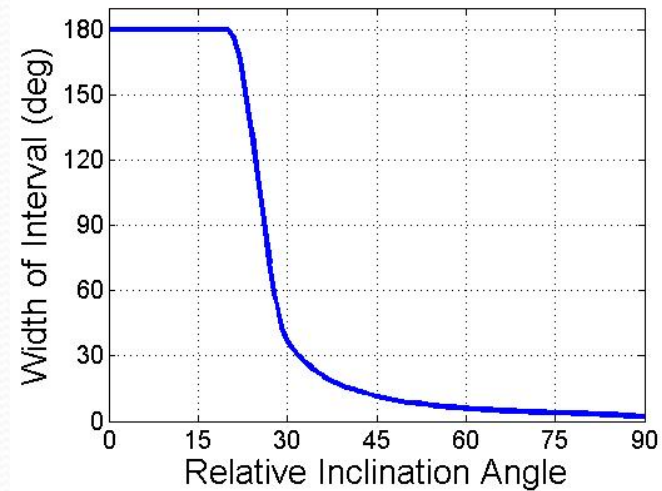
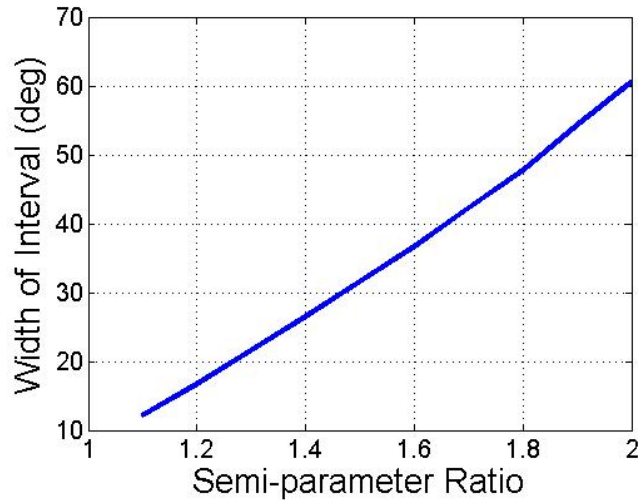


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- Traditional Geometric Method:
 - Find closest points of two orbit
 - For no circle orbit, the points cannot be analytical calculated.
 - Require Iterations
 - Numerical instable-----lost conjunction
 - Slow
 - Difficult to add impacts of perturbations

New Geometric Filter

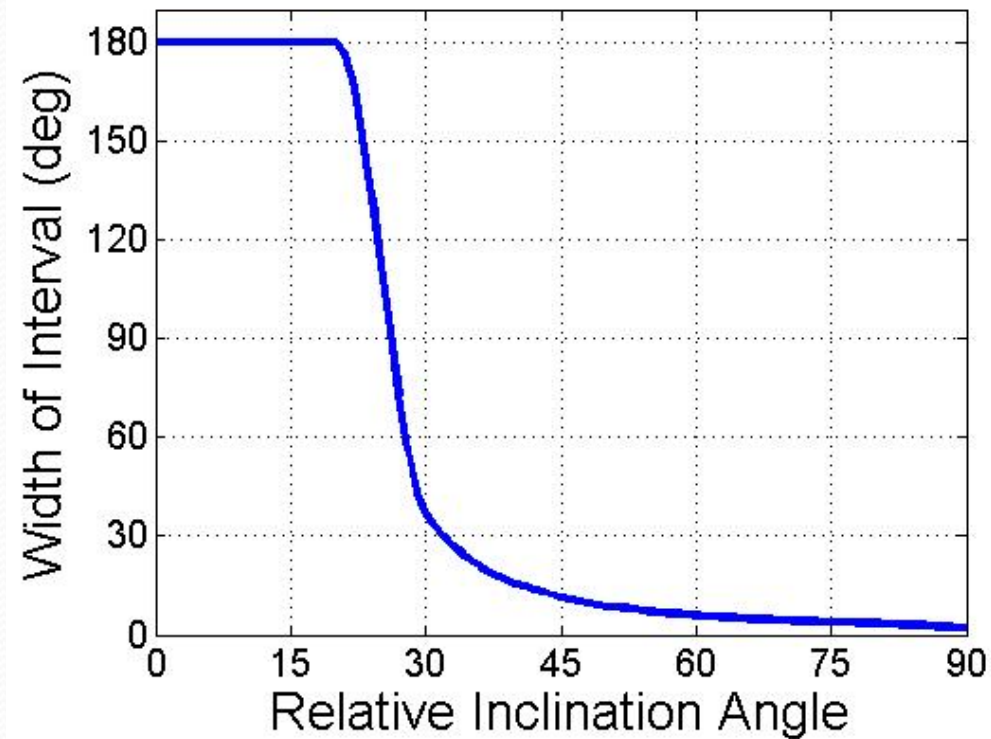
- Find intervals containing the closest points
- The interval is centered at the P.

How the Width of the Interval is determined?

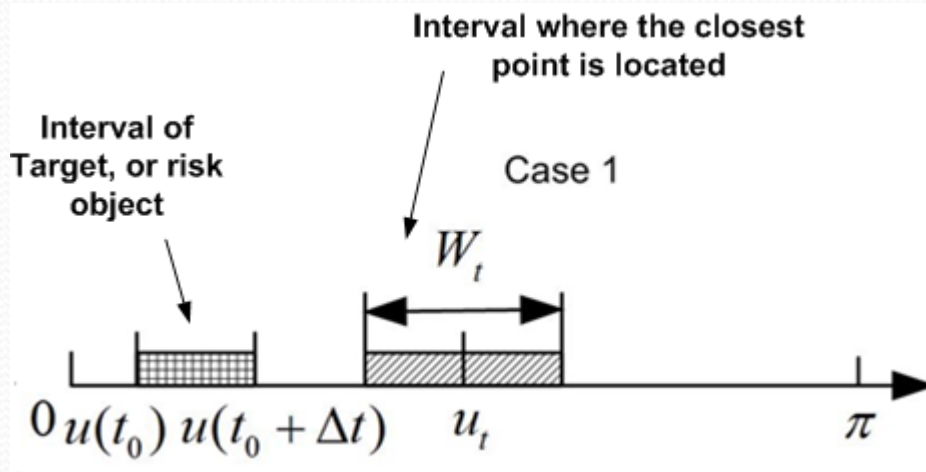


Determined from a three dimension Table

In some cases, the filter does not work.



How to filter?

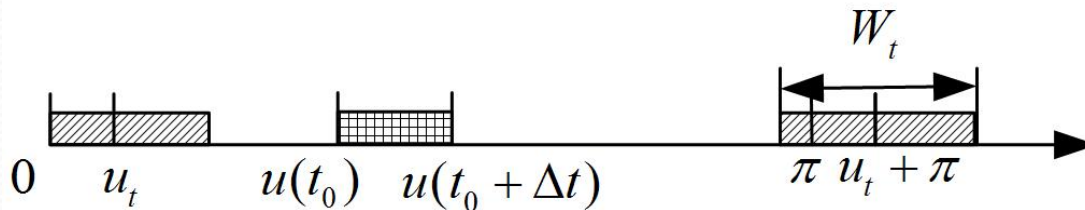


$$[t_0, t_0 + \Delta t]$$

$$u(t_0 + \Delta t) < u_t(t_0) - W_t / 2$$

$$N_{skip} = \text{int} \left[\frac{(u_t(t_0) - u(t_0 + \Delta t) - W_t / 2)}{\omega_p \Delta t} \right]$$

Case 2

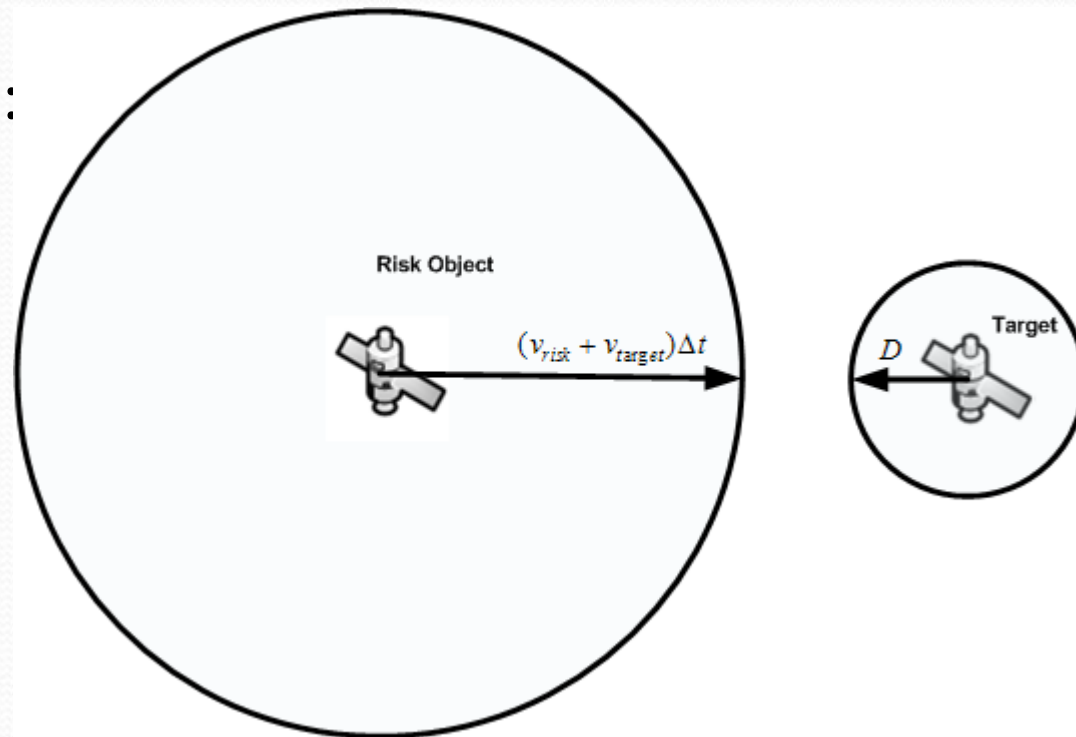


$$(t_0) > u_t(t_0) + W_t / 2 \quad .AND. \quad u(t_0 + \Delta t) < u_t(t_0) + \pi - W_t / 2 \quad N_{skip} = \text{int} \left[\frac{(u_t(t_0) + \pi - u(t_0 + \Delta t) - W_t / 2)}{\omega_p \Delta t} \right]$$

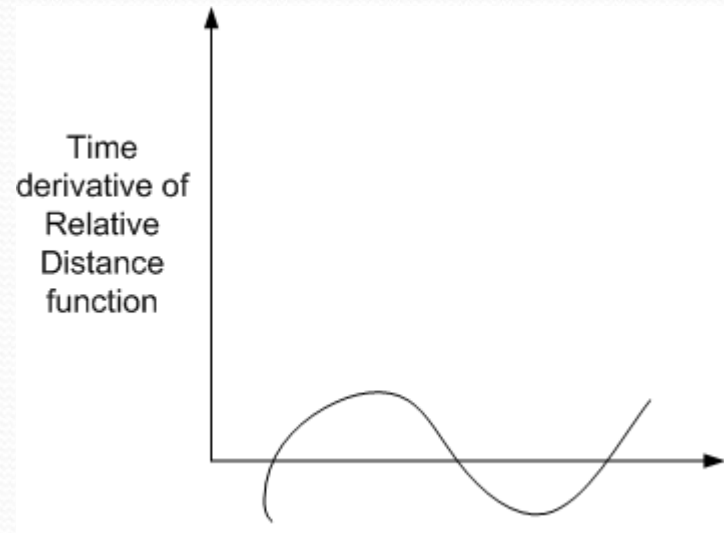
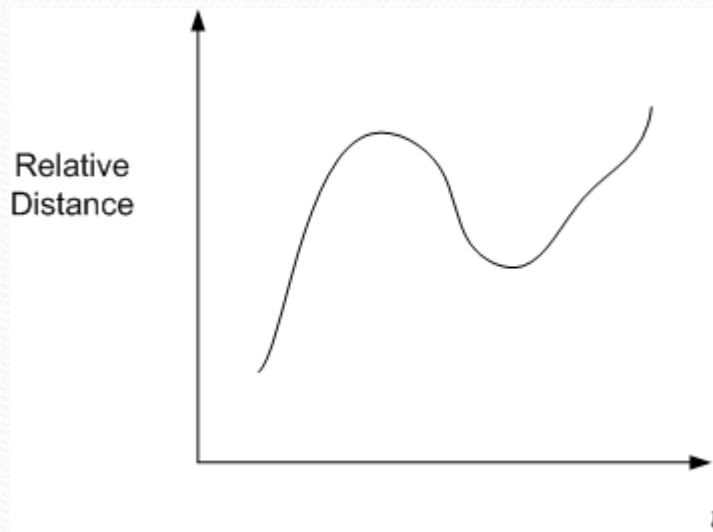
Smart Sieve

- Relative Motion Relationship, Developed By ESA
- Basic idea,
- For example:

$[t, t + \Delta t]$

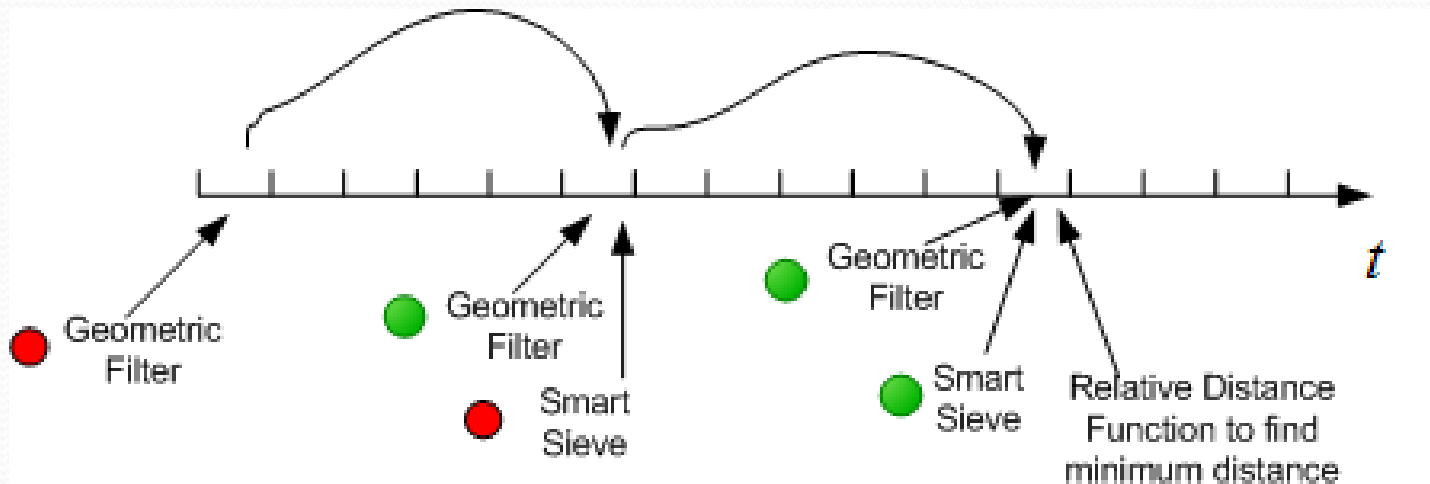


Relative Distance Function



- Advantage: analytical determining approach time and distance.

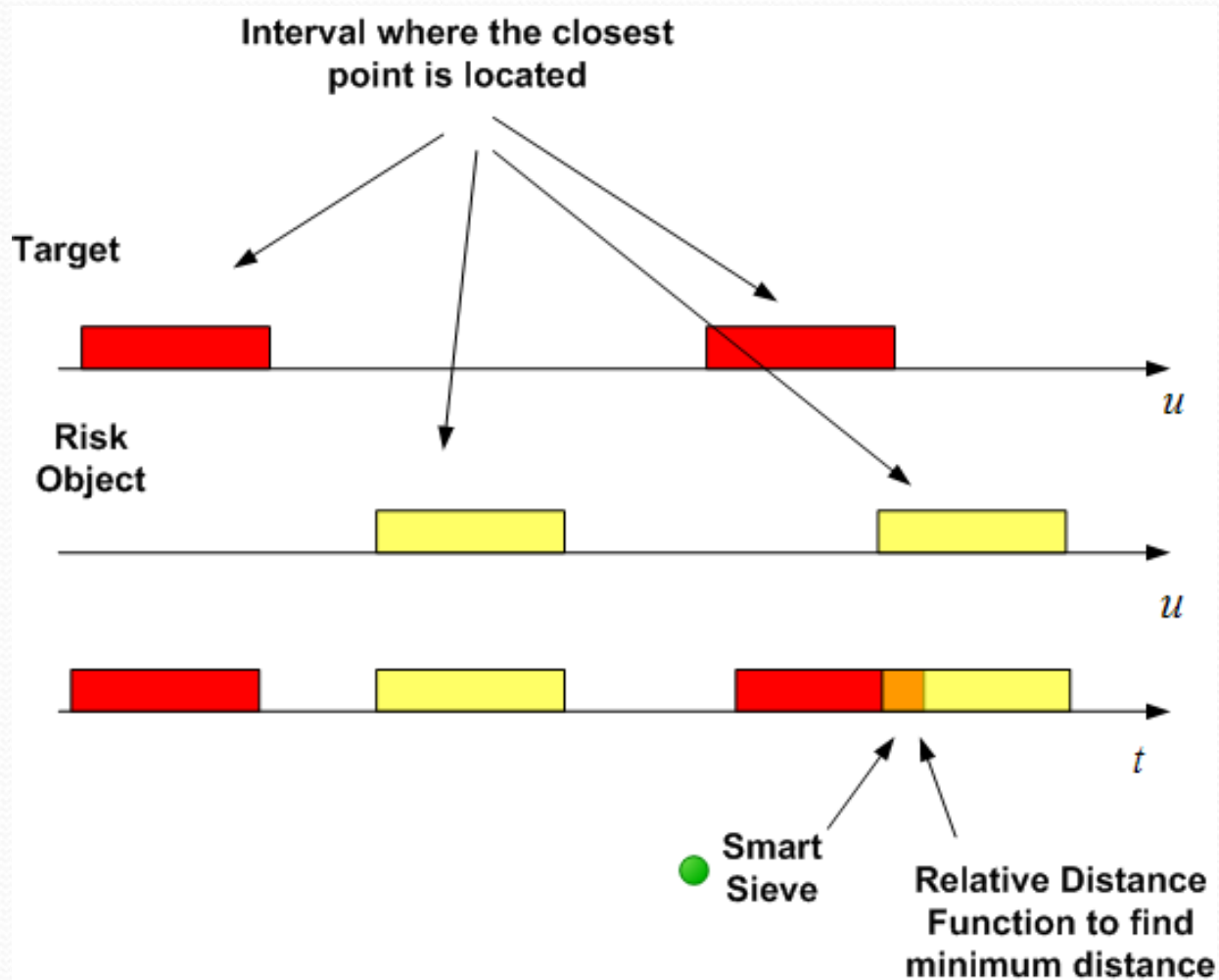
Calculation Process 2



Method for calculating conjunctions of a specific spacecraft against the complete catalog

- The first step:
- **Only** calculate their time history of position, velocity, accelerate and orbital elements of the **spacecraft**.

Calculation Process



Method Validation

Method for calculating conjunctions of a complete catalog against itself

- (Hoots *et al.*, 1984) find only **84** conjunctions for **100** km threshold distance for 24 hours.
- (Rodriguez *et al.*, 2002) found **10, 546** conjunction for **25** km threshold distance on **2002-05-15** .
- We found **116,198** conjunctions for **25** km threshold distance on **2007-08-03**

Method	Running Time	Conjunction Number
The proposed Method	10 min 20 sec	116,198
'Smart Sieve' + Relative Distance Function	18 min 10 sec	116,198
The Relative Distance Function Method	181 min 44 sec	116,198

Method for calculating conjunctions of **a specific spacecraft against the complete catalog**

	The proposed Method	'Smart Sieve' + Relative Distance Function	Relative Distance Function Method
Running Time (sec)	1.735	7.312	64.33

Conclusion

- Methods developed in this paper combines merits of geometry filter, 'smart sieve' and the relative distance function method.
- The methods could be applied to comparisons of a large catalog of orbiting objects against itself. It can also be used for comparisons of specific spacecraft against a large catalog over long periods of time.

Future work

- Test with other Close Approach Software
 - Problem: SGP₄ standard,
 - Communication
- Home made (developing version)code -> open source software
 - No references/note in the code. (Black Box)
 - Black Screen procedure, not a software.

The background is a solid blue color. At the top, there are several decorative wavy lines in shades of blue and teal. A prominent dotted line in a light blue color curves across the upper portion of the slide.

Thanks!