Towards Quantifiable Resident Space Object Activity and Behavior Prediction, Identification, Quantification, and Assessment

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The “What”: Demand Signals from the White House

• **Safety, stability, and operational sustainability are foundational to space activities, including commercial, civil, and national security activities.** It is a shared interest and responsibility of all spacefaring nations to create the conditions for a safe, stable, and operationally sustainable space environment.

• **Timely and actionable SSA data and STM services are essential to space activities.** Consistent with national security constraints, basic U.S. Government-derived SSA data and basic STM services should be available free of direct user fees.

• **Orbital debris presents a growing threat to space operations.** Debris mitigation guidelines, standards, and policies should be revised periodically, enforced domestically, and adopted internationally to mitigate the operational effects of orbital debris.

• **A STM framework consisting of best practices, technical guidelines, safety standards, behavioral norms, pre-launch risk assessments, and on-orbit collision avoidance services is essential to preserve the space operational environment.**

The ability to predict, quantify, and assess the behavior of objects in space is foundational to all of these demands!
Can’t Manage What You Don’t Know; Don’t Know What You Don’t Measure

• Absence of knowing what “normal” behavior is in space
• Anomalies are difficult if not impossible to attribute a cause to
• No true persistent monitoring
  – A sensor working does not imply a sensor detecting!
• Lack of Transparency in space operations
• “Debris or not debris…that is the question…”
The Set of ALL Space Domain Processes and Quantities

Unmodeled, Unmeasured, Non-hypothesized Quantities

Big Data, Artificial Intelligence and Deep Learning

Unknown Unknowns

Multi-Source information Fusion

Targeted Information Tasking

Hypothesized or Modeled Quantities

Known Unknowns

Measured Quantities

Known Unknowns

SSA Venn Diagram
Data vs Information

Fisher State Information

CrA/m Errors with 3 \sigma envelope
Probability of Collision: Subjective

- **Ignorance and Uncertainty are not the same thing!**
- Depends uniquely on the evidence used in supporting the hypothesis
- Given the same evidence to multiple analysts, the answers are likely to all be different
  - Driven by underlying assumptions AND algorithms
- Does not provide measure of confidence to support decision-making
  - e.g. How do you know you have the world’s most accurate clock? You have about 300 of them!
  - How many **independent sources** of information were used to derive any given collision probability?
- What is the single most important thing to make collision warnings decrease?
  - Add Data/Information specifically collected and exploited to remove ambiguity from the “system”
  - Focus on ambiguity removal instead of state estimation

Unique Resident Space Object Identification (URSOI)

To Know it, you MUST Measure it; to Understand it, you MUST Predict it!
Development and Implementation of RSO Biometrics for URSOI

**Enrollment**

1. **NAME (PIN)**
2. User interface
3. Quality checker
4. Feature Extractor
5. Template
6. System DB

**Verification**

1. **NAME (PIN)**
2. User interface
3. Feature Extractor
4. Matcher (1 match)
5. True/False
6. One template
7. System DB

**Identification**

1. **NAME (PIN)**
2. User interface
3. Feature Extractor
4. Matcher (N matches)
5. N templates
6. System DB
7. User’s identity or “user non identified”
Space Object Centered Celestial Sphere and Mollweide Projection
Topex: Photometric “Fingerprint”

Topex “Fingerprint” based upon 100 Hz Photometric Data collected by the Graz SLR station.

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Data Engineering, Modeling, Science, and Analytics

Problem Classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Sample Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anomaly Detection</td>
<td>Given demographic data about a set of customers, identify customer purchasing behavior that is significantly different from the norm</td>
</tr>
<tr>
<td>Association Rules</td>
<td>Find the items that tend to be purchased together and specify their relationship – market basket analysis</td>
</tr>
<tr>
<td>Clustering</td>
<td>Segment demographic data into clusters and rank the probability that an individual will belong to a given cluster</td>
</tr>
<tr>
<td>Feature Extraction</td>
<td>Given demographic data about a set of customers, group the attributes into general characteristics of the customers</td>
</tr>
</tbody>
</table>
## Measureables
- Non-resolved Radiometry
- Angles
- Range
- Range Rate
- Passive Imagery
- Active Imagery
- Vibrometry
- RF Signals
- Radar Cross Section
- Polarimetry
- Gravitmetry
- EM Fields
- Particulates
- Other

## Physical Properties
- Shape
- Mass
- Inertia Tensor
- Materials Composition
- Orientation / Stability
- Temperature
- Internal Components
- External Components
- Age
- Surface Properties
- Size
- Age
- Other

## Functional Properties
- Communications
- Thrusters / Stationkeeping
- Attitude Control
- Mechanical
- Passive Imagery
- Sensing Functions
- Guidance Navigation

## Operational Properties
- Ownership
- Mission
- Operational Modes

### Category
<table>
<thead>
<tr>
<th>Category</th>
<th>Mass Range (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large satellite</td>
<td>&gt; 1000</td>
</tr>
<tr>
<td>Medium-sized satellite</td>
<td>500-1000</td>
</tr>
<tr>
<td>Minisatellite</td>
<td>100-500</td>
</tr>
<tr>
<td>Microsatellite</td>
<td>10-100</td>
</tr>
<tr>
<td>Nanosatellite</td>
<td>1-10</td>
</tr>
<tr>
<td>Picosatellite</td>
<td>0.1-1</td>
</tr>
<tr>
<td>Femtosatellite</td>
<td>&lt; 0.1</td>
</tr>
</tbody>
</table>

To Know it, you MUST Measure it; to Understand it, you MUST Predict it!
From Data to Discovery: Patterns in the Graph

• Discovering Unknown Knowns
• Our framework facilitates multi-source information curation and analytics to identify correlations
  – One must ask the right question (make the correct query)
• Find which correlations have causal relationships
• Link these data (e.g. Vietoris-Rips Complex, Voronoi Clustering)
ASTRIAGraph: RDF-based Knowledge Graph for Space Domain Awareness
http://astria.tacc.utexas.edu/AstriaGraph
Kalman Filtering, Navigation, Parameter Estimation & System Identification, Multi-target Tracking, Machine/Deep Learning, AI, Reasoning, ...

Knowledge Extraction, Quantification and Assessment

Information Sources

System Models

Decision-Making Models

Information and Data Models

System Behavior

Astrodynamics, Attitude Dynamics, Flexible Structure Dynamics, Fracture Mechanics, Information Dynamics, ...

Physics and Empirical based Space Environment, Sensors, Information Mapping, Actuators ...

Instance Data, Physics-based Sensors, Human-based, Structured, Unstructured, ...

Common Operating Picture, Battlespace Management, Command and Control, Tasking, Courses of Action, ...

RDF Graphs, Ontologies, Workflows, Databases, Meta-Data, Provenance...
Way Ahead?

• Strive to make everything detectable = trackable
  – Multi-source Information Fusion leveraging Ontologies (enables big data science and analytics)
  – Develop man-made space object and event taxonomy/classification scheme supported by empirical data
  – Develop method for Unique Resident Space Object Identification (URSOI) based upon “biometrics”
• Monitor and assess the population including social/cultural context
  – identify correlations
  – infer causes
  – test hypotheses (i.e. use the Scientific Method)
• Derive orbital safety, space traffic, long-term sustainability products and policies/guidelines/rules informed by evidence-based information and science
  – Produce quantifiable and measureable risk factors!
  – Develop a Space Sustainability Rating
• Create an international partnership (e.g. public-private non-profit) with a common data lake, transparency, lingua-franca for fusing, managing, and exploiting space traffic data, etc.
• Insurance policies as a mechanism to regulate and manage risk
  – Do people with their own SSA, collision avoidance, and disposal/removal get discounts?
“The problem with the world is that the stupid are cocksure and the intelligent are full of doubt” Bertrand Russell

Questions?

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