Analysis software for land, sea, air, & space

INTEROPERABILITY AND STANDARDS ACROSS THE ENTIRE SPACE ENTERPRISE.

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OUTLINE

- Objective
- Progress in Space Data Transfer Standards
- What's a TLE?
- The TLE Big Picture
- Existing Standards
- Emerging Space Data Standards
- Call to Action

Objective

- **The objective of this paper is to enhance collaboration between the Ground Systems Architecture community and the Satellite Operations and Space Standards communities that depend on the ground systems.**
- **The ground system XML evolution and corresponding efforts in the space operations community must be closely coordinated.**
  - **International space operations standards development may be a paradigm for such collaboration.**
  - **CCSDS, ISO TC20/SC13 (Space Data Transfer) and ISO TC20/SC14 (Space Operations) are collaborating on standards for exchanging orbit data and metadata.**
  - **The division of labor between message format and data content is an important matter that ISO has considered and both the Air Force ground support and space operations must consider.**
    - To the space operations community the data transfer and ground system communities seem focused on formats and bit by bit protocol stacks and electronic transfer interfaces almost to the exclusion of message and packet content.
    - Data transfer and ground system communities have a similar perception of space operators, who make unreasonable demands on data transfer speed and accuracy.
- **We will offer strategies for close collaboration and examples of elements of information that demonstrate these strategies.**
    - ***One of the most important is expanding the content of orbit element information from that contained in Two Line Element Sets (TLE) to include metadata for orbit determination techniques and covariance or uncertainty information essential for collision avoidance and other important operations.***
    - Data management strategies should accommodate the evolution of data needs and not be hard wired to current demands.

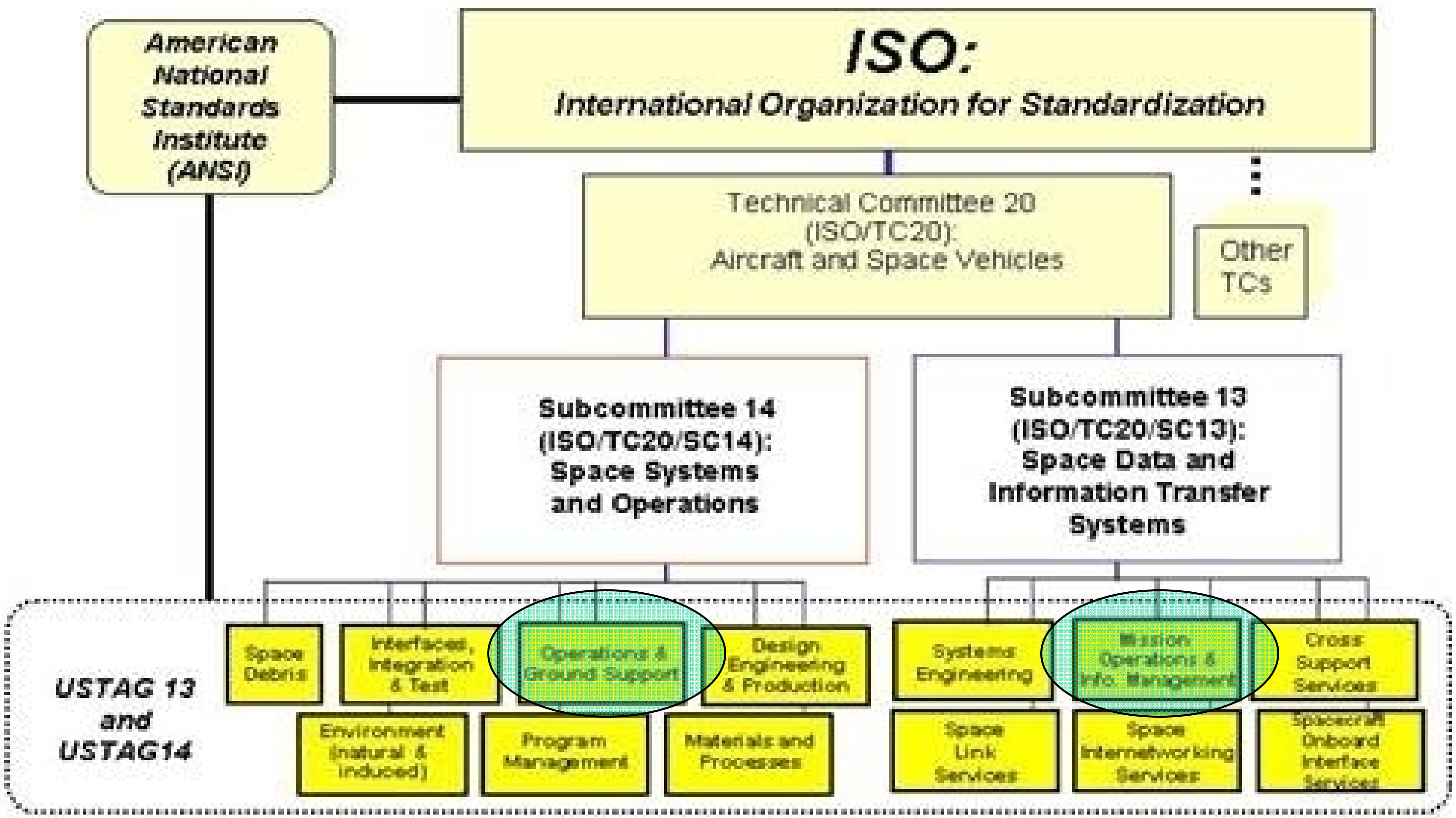
INTRODUCTON

- **Two Line Element Sets are the de facto standard for communicating Earth orbiting satellite information.**
  - **Content and format conceived in an era with limited computational capability and communications.**
- **The world-wide Internet and Communications communities are driving standards independent of user community data needs**
  - **The astro community must engage to assure that institutionalized data transfer practices satisfy our requirements.**
- **Several relatively independent initiatives are establishing frameworks**
  - **DoD Directive 8320.2, Data Sharing in a NetCentric environment**
  - **Consultative Committee for Space Data Standards (CCSDS)**
  - **AF Space and Missile Systems Center Ground Support Architecture**
  - **AF Space Command Command and Control/Space Situational Awareness (C2/SSA) Community of Interest**
  - **International Organization for Standardization (ISO), TC 20, SC 14, Space Operations and Ground Support Working Group**

Progress in Space Data Transfer Standards.

- Standards must consider the elements of information required and the format in which the data and descriptive information (metadata) will be presented.
  - Not necessarily simultaneously, since the same content may be exchanged in different formats if collaborating organizations desire.
- ISO Standard 22644 (CCSDS 505.0-B-1), Orbit Data Messages (ODM), should be confirmed internationally in 2007
  - Developed by a community of interest with strong deep space focus
  - New or complimentary standards must be consistent with it.
- ISO Committee Draft 26885, Orbit Data Exchange is simultaneously under development
  - Developed by the Earth orbiting satellite operations community
  - Specifies elements of information but not format.

ORGANIZATION



TC 20/SC 14
Space systems and operations

- **Participating countries:**
  - **United States**
  - **Brazil**
  - **Canada**
  - **China**
  - **France**
  - **Germany**
  - **Israel**
  - **Italy**
  - **Japan**
  - **Russia**
  - **Ukraine**
  - **UK**
- **Observers and Liaisons:**
  - **ESA**
  - **ECSS**
  - **Belgium**
  - **Australia**
  - **India**

- **Different Community of Interest than SC13**
  - **Primarily commercial, not agency or national, interests**
  - **Spans all aspects of space vehicle development, launch, and on orbit operations**

Comparison of CCSDS and ISO TC 20/SC 14/WG 3 Efforts

22644 Orbit data message

- Pre-flight planning for tracking and navigation support
- Scheduling tracking support
- Carrying out tracking operations
- Metric predicts
- Carrying out navigation operations such as orbit propagation

26885 Orbit data exchange

- Cooperative Operations
  - Phasing and scheduling station keeping within ITU designated Geostationary orbits
- Interpretation of scientific data gathered in Earth orbit
- Collaborative Mission Support
  - Cooperative tracking, telemetry, and commanding
- Conjunction Prediction and Assessment

Comparison of OPM, OEM, and ODE

2.2 ORBIT PARAMETER MESSAGE (OPM)

An OPM specifies the position and velocity of a single object at a specified epoch. This message is suited to inter-agency exchanges that (1) involve automated interaction and/or human interaction, and (2) do not require high-fidelity dynamic modeling.

The OPM requires the use of a propagation technique to determine the position and velocity at times different from the specified epoch, leading to a higher level of effort for software implementation than for the OEM. The OPM is fully self-contained; no additional information is required.

The code allows for modeling of any number of maneuvers (as both finite and instantaneous events) and simple modeling of solar radiation pressure and atmospheric drag. The attributes of this code also make it suitable for applications such as exchanges by FAX or voice, or applications where the message is to be frequently interpreted by humans.

2.3 ORBIT EPHEMERIS MESSAGE (OEM)

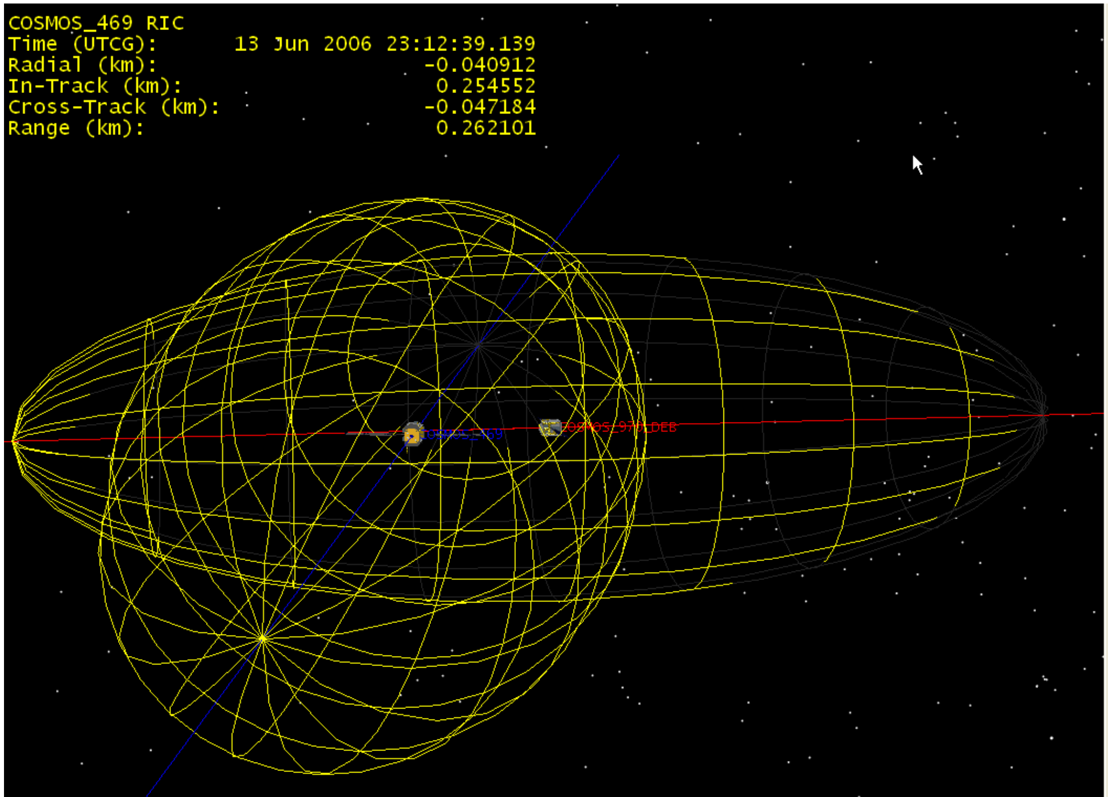
An OEM specifies the position and velocity of a single object at multiple epochs contained within a specified time range. The OEM is suited to inter-agency exchanges that (1) involve automated interaction (e.g., computer-to-computer communication where frequent, fast automated time interpretation and processing is required), and (2) require higher fidelity or higher precision dynamic modeling than is possible with the OPM.

The OEM allows for dynamic modeling of any number of gravitational and non-gravitational accelerations. The OEM requires the use of an interpolation technique to interpret the position and velocity at times different from the tabular epochs. The OEM is fully self-contained; no additional information is required.

SC 14 ORBIT DATA EXCHANGE

Specifies osculating position, velocity, and accelerations in a prescribed reference frame, presentation of mean estimation state variables and their covariances in a prescribed reference frame, and information about physical hypotheses and numerical techniques used to produce these quantities so that parties can independently or collaboratively develop and assess individual or collaborative maneuvers in Earth orbit.

Conjunction Assessment with Covariances




```
COSMOS 469
1 05721U 71117A   06157.45566830 -.00000087  00000-0  36931-5 0  3591
2 05721  64.4882 316.5635 0018850 104.8015 255.5133 13.75915906730795
COSMOS 970 DEB
1 10574U 77121R   06157.22133525  .00000068  00000-0  19579-3 0  4383
2 10574  65.5468  74.6378 0116491  33.2311 327.5985 13.57585168407068
```

Launch STK

STK 6 | STK 7

Save settings?

Build Scenario

Go to time:

Threshold Start	Closest Approach	Theshold End
2006 Jun 13 23:12:38.726	2006 Jun 13 23:12:39.159	2006 Jun 13 23:12:39.592

NORAD Catalog Number	Name	Days Since Epoch	Max Probability / Start (UTC)	Dilution Threshold (km) / TCA (UTC)	Min Range (km) / Stop (UTC)	Relative Velocity (km/sec)
05721	COSMOS 469	7.511	9.873E-04	0.091	0.129	11.541
10574	COSMOS 970 DEB	7.746	2006 Jun 13 23:12:38.726	2006 Jun 13 23:12:39.159	2006 Jun 13 23:12:39.592	

What is a TLE?

- A TLE is a set of two eighty column “cards” in which 69 columns contain data required to propagate with ADCOM (now AFSPACE) physical models satellite orbits determined using congruent models from Air Force Space Surveillance Network (SSN) sensor observations
- SGP models have evolved over the nearly four decades since they were conceived. Object code copies of SGP models are provided to users by the Air Force, most recently as dynamic link libraries (dll’s).

TWO LINE ELEMENT SET

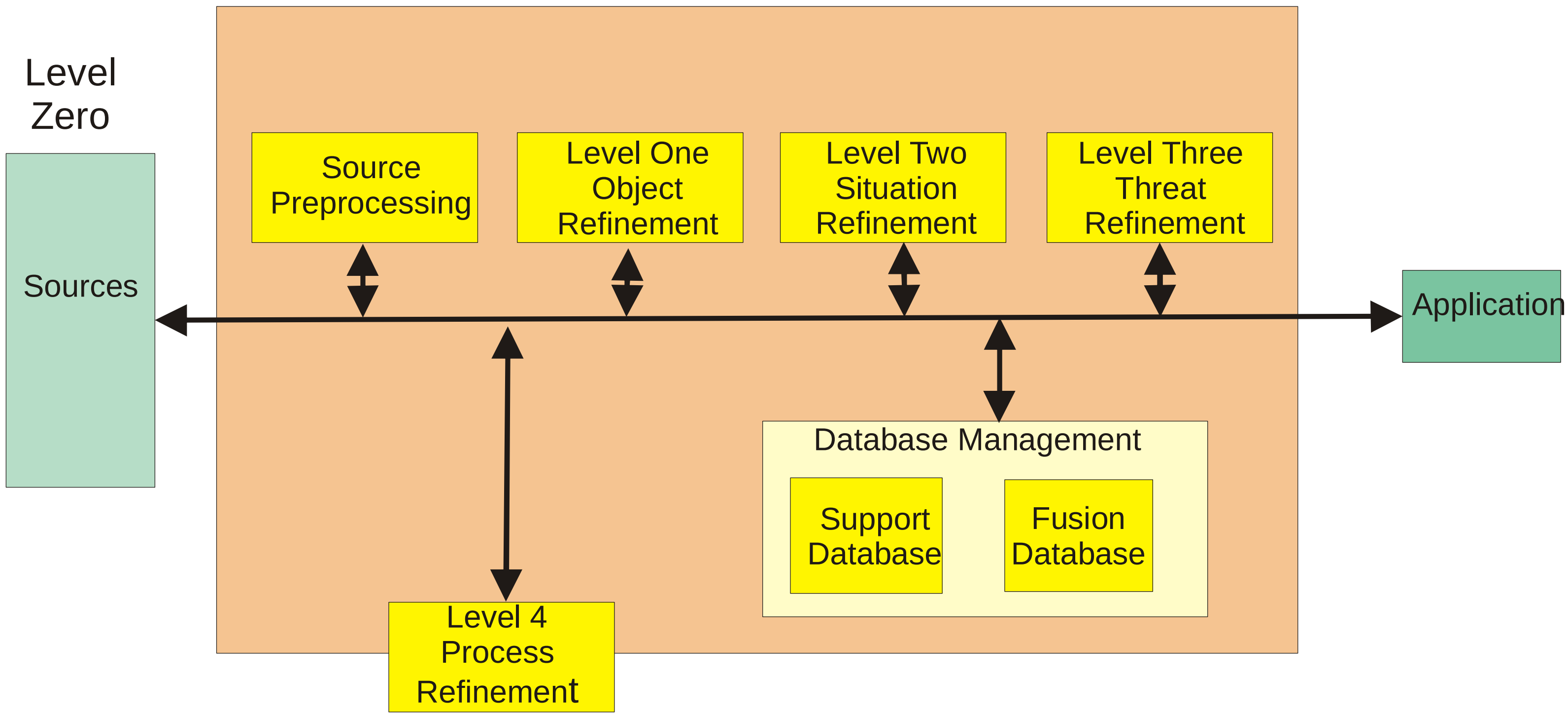
Line 1 Column Description

01Line Number of Element Data03-07Satellite Number08Classification (U=Unclassified)10-11International Designator (Last two digits of launch year)12-14International Designator (Launch number of the year)15-17International Designator (Piece of the launch)19-20Epoch Year (Last two digits of year)21-32Epoch (Day of the year and fractional portion of the day)34-43First Time Derivative of the Mean Motion 45-52 Second Time Derivative of Mean Motion (decimal point assumed)54-61BSTAR drag term (decimal point assumed)63Ephemeris type65-68Element number69Checksum (Modulo 10) (Letters, blanks, periods, plus signs = 0; minus signs = 1)

Line 2 Column Description01Line Number of Element Data03-07Satellite Number09-16Inclination [Degrees]18-25Right Ascension of the Ascending Node [Degrees]27-33Eccentricity (decimal point assumed)35-42Argument of Perigee [Degrees]44-51Mean Anomaly [Degrees]53-63Mean Motion [Revs per day]64-68Revolution number at epoch [Revs]69Checksum (Modulo 10)

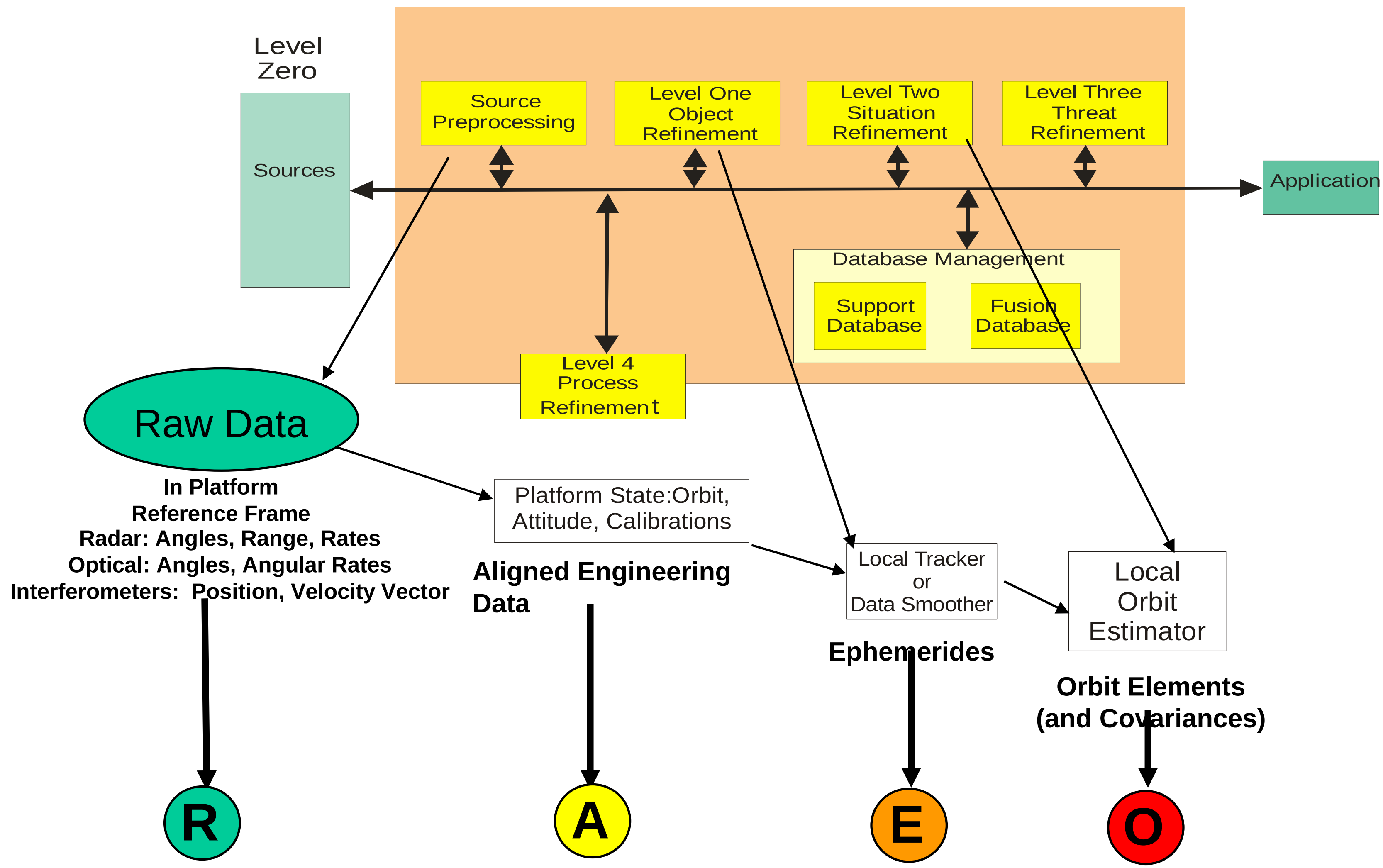
NOAA 14
1 23455U 94089A 97320.90946019 .00000140 00000-0 10191-3 0 2621
2 23455 99.0090 272.6745 0008546 223.1686 136.8816 14.11711747148495

Data Fusion Background



Level 1: Processing Sensor Measurements to a common time base and spatial reference and associating measurements with an object
Level 2: Developing current relationships among objects and events in the context of their current environment
Level 3: Projection of the currentsituation into the future
Level 4: Metaprocess to improve the ongoing data fusion process

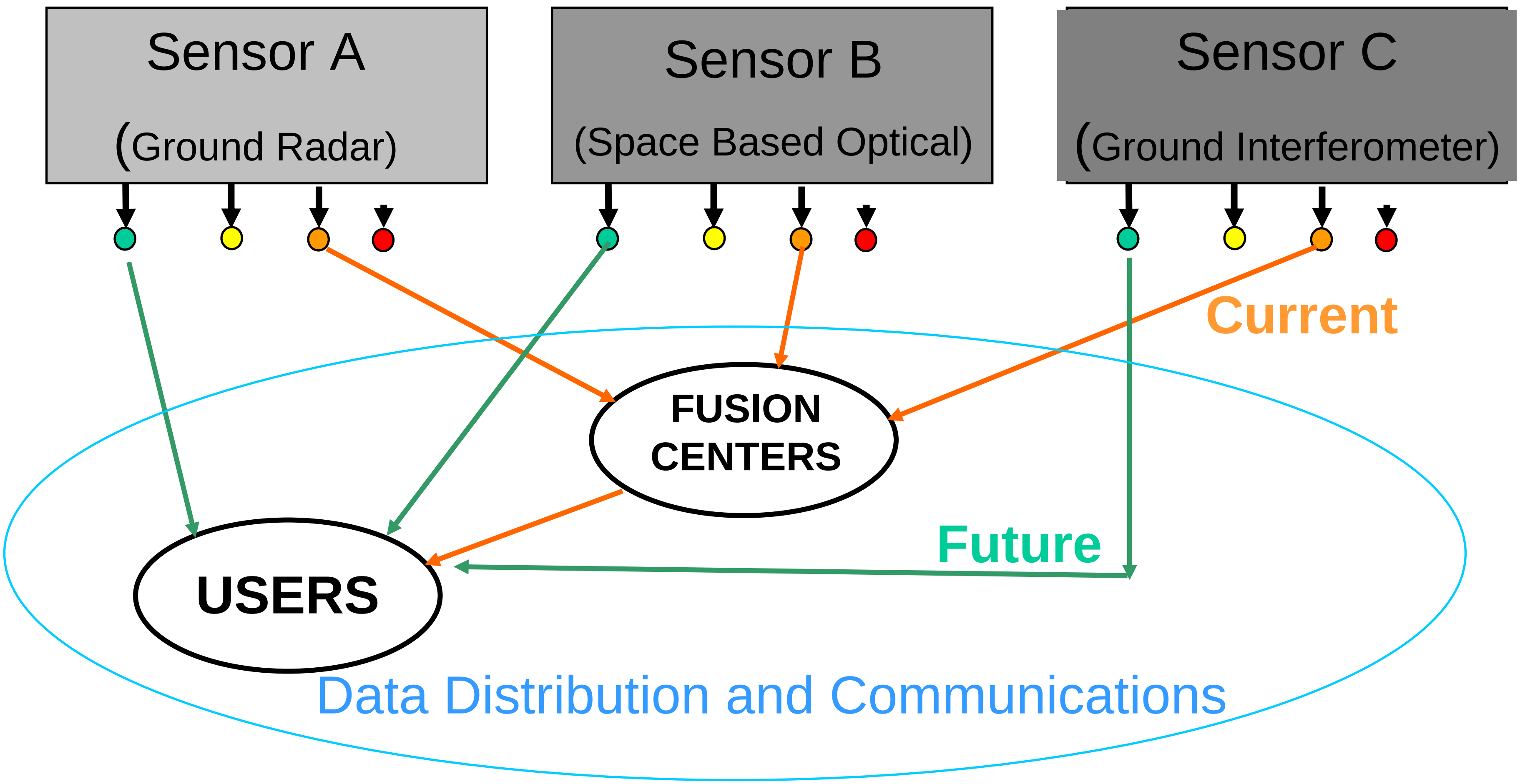
Orbit Product Alternatives



Degrees of Fusion

- **Data Fusion**
  - **Raw data from diverse sources at diverse times, expressed in a common reference frame and time basis, are "fit" to trajectory hypotheses, in order to determine the best description of motion and the deviation of the data set from that hypothesis (covariances)**
- **Track Fusion**
  - **Individual "local" tracks, based on a small number of sources or a single source are combined according to logical rules of association.**
- **Object Fusion**
  - **Final products, abstracted at the highest level are combined or one among them is selected to govern actions**.

Orbit Product Alternatives



BOTTOM LINES

- TLE's are only one of a wide spectrum of possible orbit data products
- TLE's generated in different places might be quite different from each other
  - Different versions of TLE production software
- TLE's centrally fused and distributed as finished products are based on outputs of sensor local data smoothers and not on direct sensor observations

Orbit Data Exchange Elements of Information

- Descriptive Information:
  - Satellite Number, Common Name, International Designator, and Country of Origin, Gravitational Force Information, Non-conservative Force Information.
- Satellite State:
  - Orbit Elements and Epoch
- Temporal and Spatial Information:
  - Coordinate System, Coordinate Reference Frame, International Earth Reference System (IERS) Parameters and Epoch
- State Vector and Covariances:
  - Satellite State of Motion (position, velocity, acceleration, their variances, and coordinate reference); Covariances (estimation state vector solve-for parameters, dimensions, and coordinate reference).

Earth Orbit Element Set Message (ESM)

- **ESM requires orbit elements in the same order and the same format as Line 2 of the TLE.**
- Alphanumeric identifiers and other background data from TLE Line 1 are incorporated in the CCSDS Metadata field;
  - a supplementary field that corresponds to TLE Line 1 is allowed.
- A supplementary ESM Covariance field is specified.
  - The significance of covariances for TLE mean elements is arguable.
  - non-causal correlations may be developed using the variation of TLE's issued at different epochs, and these are more useful for probabilistic assessments than the TLE's themselves.

State Vector Message (SVM)

- **Requires Metadata, osculating ephemerides, and causal covariances.**
- **The metadata is more comprehensive** than ESM metadata, since it includes information about Earth Orientation Parameters, approximations to the Earth's geopotential, atmosphere models, other conservative and nonconservative forces, and other information essential to a recipient's being able to reproduce the provider's result.
- **The mandatory data fields encompass position, velocity, acceleration, and covariance matrix elements all in a specified inertial reference frame and time system**.
  - We felt that users should not be burdened with complicated transformations from a provider's unique reference frames.
- Covariance solve-fors are not standardized, since the state variables one chooses must reflect the provider's unique force, external influence, and measurement uncertainties.
  - However, **the data set must include description of the provider's solve-for set.**
- The SVM allows **supplementary fields to describe the orbit determination scheme** and propagator and supplementary fields in which the specific set of Earth Orientation Parameters can be stated.
- There are specifications for maneuver fields that include timing and delta V information with which a controlled orbit may be propagated through maneuvers. Multiple maneuver fields are allowed.

Progress and Status

- **ESM and SVM collaboratively distilled into a single Orbit Operations Message (OOM)**
  - **Accommodates all essential elements of information but requires either that providers compose a TLE surrogate from that information or that users parse the full content to extract a TLE surrogate.**

CCSDS-SC14 Outcomes (Jan 07)

- That a new message be added to the Orbit Data Message Standard, name to be determined.
- That the message include elements of data from which canonical TLE's may be constructed.
- That the message include a 6x6 covariance matrix abstraction.
- That metadata include covariance solve-fors, but values beyond the 6x6 abstraction need not be provided
- That information about atmospheric models and other elements of analysis (TBD) that cannot be described precisely enough to allow consumers to reproduce the provider's processes be included in optional fields and not in normative requirements.
  - Investigators often tune or modify "standard" models and there may be many uncontrolled versions.

Related and Coordinated Initiatives

- **AFSPC C2/SSA Community of Interest Working Group**
  - **TLE Subgroup**
- **Enhanced Space System Architecture (ESSA) Joint Concept Technology Demonstration led by USSTRATCOM**

Call to Action

- **All providers and users should adopt the same extensible schemas for orbit data**
  - **Those schemas should accommodate the fullness of orbit data products and should not be limited by nor focus on Two Line Element Sets.**