Trade-space Analysis Tool for Constellations (TAT-C)

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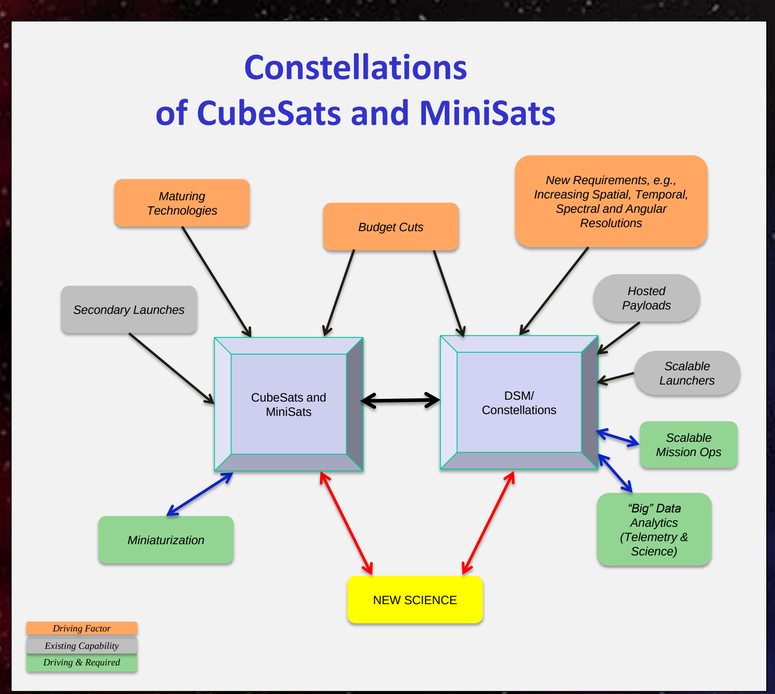
DEFINITIONS

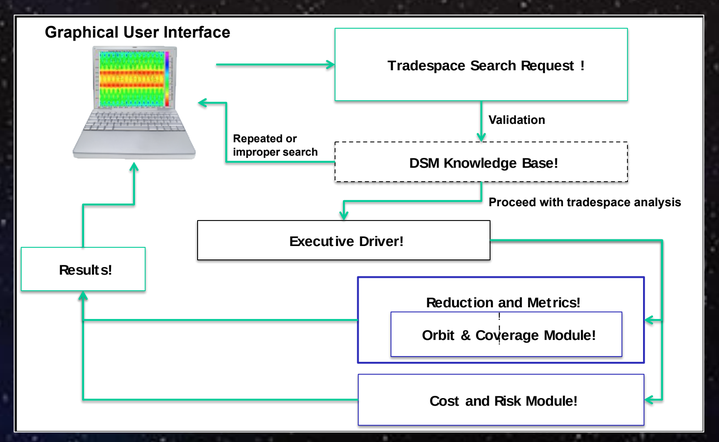
A ***Distributed Spacecraft Mission (DSM)*** **is a mission that involves multiple spacecraft to achieve one or more *common* goals**

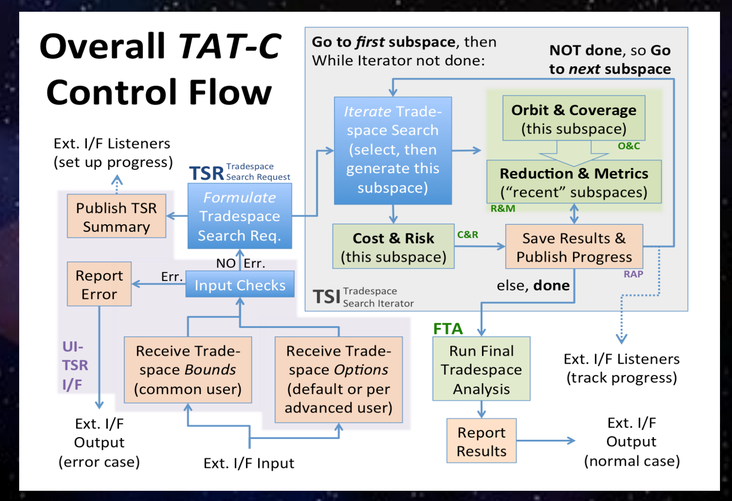
A ***Constellation*** **is a space mission that, beginning with its inception, is composed of two or more spacecraft that are placed into specific orbit(s) for the purpose of serving a common objective (e.g., Iridium)**

OBJECTIVES

- **Provide a framework to perform pre-Phase A mission analysis of Distributed Spacecraft Missions (DSM)**
  - **Handle multiple spacecraft sharing mission objectives**
  - **Include sets of smallsats up through flagships**
  - **Explore trade-space of variables for pre-defined science, cost and risk goals, and metrics**
  - **Optimize cost and performance across multiple instruments and platforms vs. one at a time**
- **Create an open access toolset which handles specific science objectives and architectures**
  - **Increase the variability of orbit characteristics, constellation configurations, and architecture types**
  - **Remove STK licensing restrictions**







SCIENCE REQUIREMENTS - INPUTS

Green highlighted rows correspond to variables needed only for pairs missions, including occultations with satellite pair option.
Blue highlighted rows correspond to variables needed only for occultation missions. Yellow highlighted rows correspond to variables needed only for imaging missions.

Mission Concept		
Attribute	**Characteristics**	**Description**
Start Epoch	UTC time	Date when the satellites will initialize. Default is current time.
Area of Interest	exact Earth locations	Lat/Lon/Alt list or Lat/Lon bounds. Global is default.
Ground Stn options	Select and/or file	If the user has existing satellites to complement. Row=GS num, columns=GS lat, lon, alt, band. Default is NEN.
Launch preferences	Select and/or file	If the user has existing satellites to complement. Row=LV num, columns=LV specs. Default is all.
Propagation fidelity	low, med, high	Three levels of propagators to be selected against (time and description provided). Default is low.
Output options	Select	Which of the output veriables is the user interested in. Default is all but angles.
Output bounds	min, max	Min and Max for any of the variables in the Outputs sheet. Default is in the output sheet.

Satellite Specs		
Attribute	**Characteristics**	**Description**
Existing Sat options	Select and/or file	User has a sat/constellation in mind. Options: Name, KB file, csv (Row=sat num, columns=Initial Kepl. Elems). Default is none.
Number of new Sats	min, max	Number of new sats allowed in the DSM in addition to existing. One and ten is default respectively.
Number of satellite types	exact	Enter 1 if const. is homogeneous or number, if heterogeneous. ***If hetero, all subsequent specs to be provided for each instance.***
Altitude Range of Interest	min, max	Ranges of altitudes the user is interested in, LEO (300-1000 km) is default.
Inclination Range of Interest	min, max	Ranges of inclinations the user is interested in, 50-90 deg is default.
Special Orbits only	Select	Select between only SSO with LT option, frozen, critically inclined, ISS
Angular Rate	min, max	Rotation matrix of the satellite in LVLH. Payload is assumed fixed and rotates at the same rate.
Maximum pointing	exact	Maximum nadir pointing that a sat is capable of, to determine field of regard or FOR. Default is upto Earth Limb.
Comm band	exact bands	For downlinking data to ground stations. Default is Ka-band.

Payload Specs (unnecessary for Stereo)		
Attribute	**Characteristics**	**Description**
Number of payloads/sat	Exact	For multi-instrument sats. Default is one. ***If more than one, all subsequent specs to be provided for each instance.***
Occulation or Imaging or Pairs	Select	Determines payload's measurement conops. Imaging is default.
Payload Mass	Approximate	Default is 40 kg. Payload will be 40% of satellite mass, by default [Tentative]
Payload Volume	Approximate	Default is 150 W. Payload will be 60% of satellite power, by default [Tentative]
Payload Power	Approximate	Default is 0.03 m^3. Payload will be 50% of satellite volume, by default [Tentative]
Radiometric resolution	min	Number of bits per pixel. 12 bits is default.
Occultation or Pairs coupling	Exact	Mark observer or occulter/pair, for every occulting or pairs mission.
Nadir swath or FOV	min, max OR exact	Conical or rectangular dimensions of the full spot size. Default is 15 deg in AT and CT.
Nadir GSD or iFOV	min, max OR exact	Conical or rectangular dimensions of a single pixel. Default is 30 m in AT and CT.
Object/s of interest	Select then specify	Select between celestial body or 'satellite' if an occultation mission. Fill row 33 if latter. Default is Sun.
Occultation Altitude	max, min	Tangent altitudes between which occultation measurements will be made. Default is 10-50 km.
Measurement time	min, max	Sum of exposure and integration time per image or measurement. Default is half-pixel travel time.
Solar conditions	Select	Determines if the sat is sunlit or eclipsed or agnostic when measuring. Default is agnostic.
Sun Glint preference	Select	Select if sun glint (<5 deg relative AZ) to be included, avoided or no preference. Default is no preference.
Spectral or other Channels	Exact wavelengths	Central wavelength for multi-spectral imaging. 300:100:1000 nm is default.
Spectral resolution	exact binwidths	Band or bin width of each central wavelength in the spectral range. 50 nm is default.

SCIENCE REQUIREMENTS - OUTPUTS

All the listed outputs except * will be available per architecture, per ground spot, per unit time. The characteristics just indicate bounds that the user can set as inputs.
Output tabs will include panels for attributes vs. cost, spatial bins and time series. Maybe distributions?

Spatial Metrics		
Attribute	**Characteristics**	**Description**
Effective Spatial Resolution	min, max, average	Ground pixel size. Default is 30m, 100m, none.
Effective Swath	min, max, average	Cross and along track extent of one full image. Default is 100 km, 500 km.
Percentage Image overlap	min, max, average	% of every image that overlaps with another. 100% for complete 2-fold and 0% for none. Default is none.
Covered positions (w/ FOV)	lat, lon	Spatial positions where imaging measurements are made per sat per arch within I/P "Area of Interest". Default is none.
Occultation positions	lat, lon	Spatial positions where occultation measurements are made per sat per arch within I/P "Area of Interest". Default is none.
Inter-Sat Range and Rate	min, max, average	Distances and Rate (AT,CT,R,euclid) between each satellite in the virtual group (stereo)
Possible positions (w/ FOR)	lat, lon	Spatial positions where imaging measurements CAN BE made per sat per arch within I/P "Area of Interest". Default is none.

Temporal Metrics		
Attribute	**Characteristics**	**Description**
Occultation time*	min, max, average	If an occult mission, time which each occultation lasts for
% period time in Sun*	min, max, average	Fraction of the orbit that the sat spends in the Sun (vs. eclipsed)
Time to Coverage*	min, max, average	Time to cover the "Area of Interest" entirely once
Access Time*	min, max, average	Time that any ground spot has access to a satellite (within FOR)
Latency to downlink*	min, max, average	Time between observation and downlink to the next ground station
Repeat Time*	min, max, average	Time between repeats (within 1 deg of view angle) of every point in the "Area of Interest". Calc. for virtual and real sats for Stereo/Comm missions
Revisit Time*	min, max, average	Time between revisits of every point in the "Area of Interest"

Angular Metrics		
Attribute	**Characteristics**	**Description**
View Zenith Angle	min, max	Between the payload-target vector and zenith, if imaging mission. Default is none for all angles.
View Azimith Angle	min, max	Between the payload-target vector projection on target normal plane and true north projection on the same plane, , if imaging mission
Solar Zenith Angle	min, max	Between the sun-target vector and zenith for day measurements, if imaging mission
Solar Azimuth Angle	min, max	Between the sun-target vector projection on target normal plane and true north projection on the same plane, if imaging mission
Lunar phase	min, max, average	For night measurements.

Radiometric Metrics		
Attribute	**Characteristics**	**Description**
Signal to Noise Ratio	min, average	Expected signal and noise (SNR) of each arch's satellites with respect on a selected one. Default is 10.

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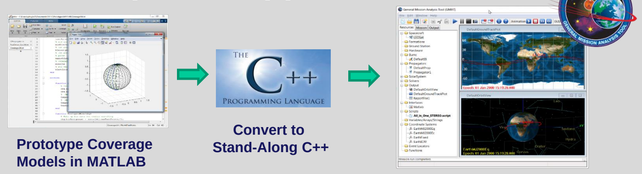
TRADESPACE SEARCH ITERATOR (TSI)

- TSI reads user inputs given to the GUI to create iterator inputs (JSON files). Uses default values from Landsat 8 (w/ ETM+ payload) if no inputs
- TSI generates DSM architectures for a combination of variable values that satisfy iterator inputs
- A DSM architecture is a unique combination variable values (altitude, inclination, FOV, number of satellites, etc.)
- For each arch, TSI creates files and send commands to module 'Reduction & Metrics' to compute architecture performance and to module 'Cost and Risk' to compute architecture cost

ORBIT & COVERAGE MODULE

- **Purpose of Module**
  - Model orbits balancing accuracy and performance
  - Compute coverage metrics for constellation/sensor set
  - Compute ancillary orbit data for performance, cost, and risk
- **Development Approach**



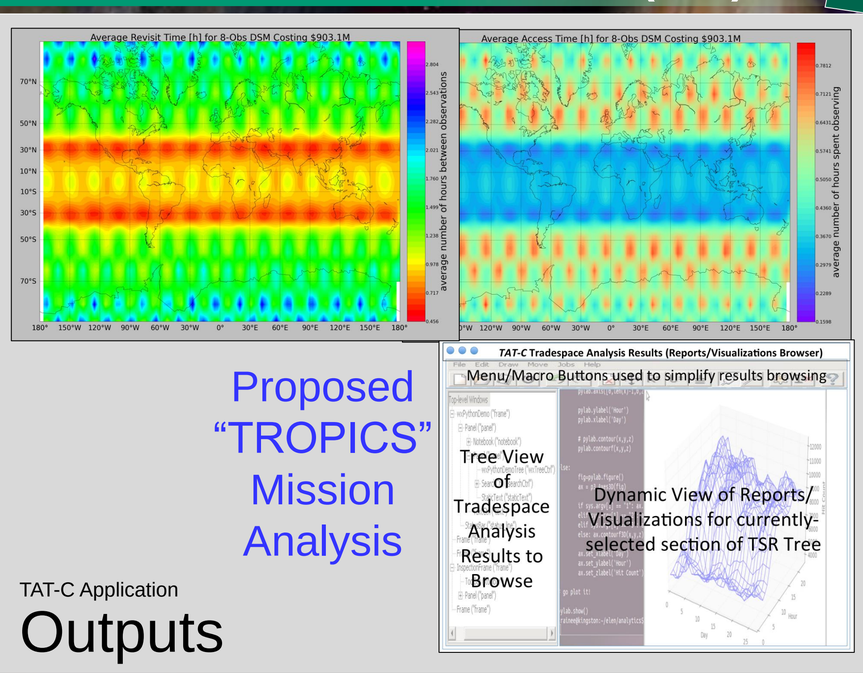
REDUCTION & METRICS MODULE

- Reduction & Metrics is responsible for calling module 'Orbits & Coverage' to propagate the orbit of every sat and compute coverage given payload specs.
- Reduction & Metrics' integrates coverage and computes all performance metrics.

COST & RISK MODULE

- **Motivation**
  - Constellations require that traditional cost estimating assumptions be challenged
  - Previous work highlighted limitations of existing models w/r to constellations
  - No comprehensive cost model for constellations has been developed
- **Implementation**
  - Aggregate model consisting of Cost Estimating Relationships (CERs) from widely accepted, publically available models
  - Output: Proba density function showing most likely cost for mission lifecycle + selected mission components, including recurring, nonrecurring, spacecraft bus, and payload

GRAPHICAL USER INTERFACE (GUI)



KNOWLEDGE BASE

- Centralized store of structured data readable by humans and machines
- Support TAT-C tasks:
  - Analysis: compose new mission concepts from existing model inputs
  - Exploration: discover new mission concepts by querying previous results
- Layered client-server architecture over HTTP

FUTURE DIRECTIONS

- **Various constellations**
- **Launch vehicle and manifest framework**
- **Various sensor models**
- **Add on-off maintenance abilities**
- **Comparative risk model**
- **Knowledge Base development**
- **Complete GUI/Visualization development**