Virtual constellations, ARD and sensor fusion: the future of earth observation

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Background

- **Physical Chemist** by training
- Dabbled in **Systems Biology**
- Helped lead **Planet's Payload Development 2014-2020**
- We undertook the challenge of building the **first dense virtual payload constellation** which abstracted a *virtual instrument from the observatory strategy/topology*
- an old paradigm is **finally validated**
- a new world of **new interesting problems opens up**

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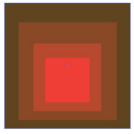
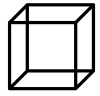


ARD, virtual constellations and sensor fusion

2020 Situation Recap

- More hardware flying than ever, distributed sensor fusion constellations flying de-facto making proprietary sensor fusion products
- Planet flying S2-like payload and generating gap-free fusion product:
  - **1 peer-reviewed paper every 2 days** as of Q4'2020:
  - Small sats can be sharp (CalCon Presentation)
  - Small sats can be interoperable with Sentinel-2 (CalCon Presentation)
  - Small sats can be extremely well calibrated (Calcon Presentation)
  - Small virtual constellation/instrument is operational today (Product Announcement)



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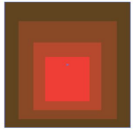

Sensor fusion and virtual constellations

- **Hypotheses for consideration for decision makers**
  - **Data quality** should be defined as interoperability-driven
  - **Readiness for analysis** should be revised:
    - Multi-level philosophy
    - ARD could mean **ready for analysis by non-GIS users**, points to L3 sensor fusion as core product
  - **Sensor fusion** should drive and will drive the deployment of new space assets
  - **Heterogeneous constellations** will become the norm over time

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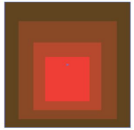
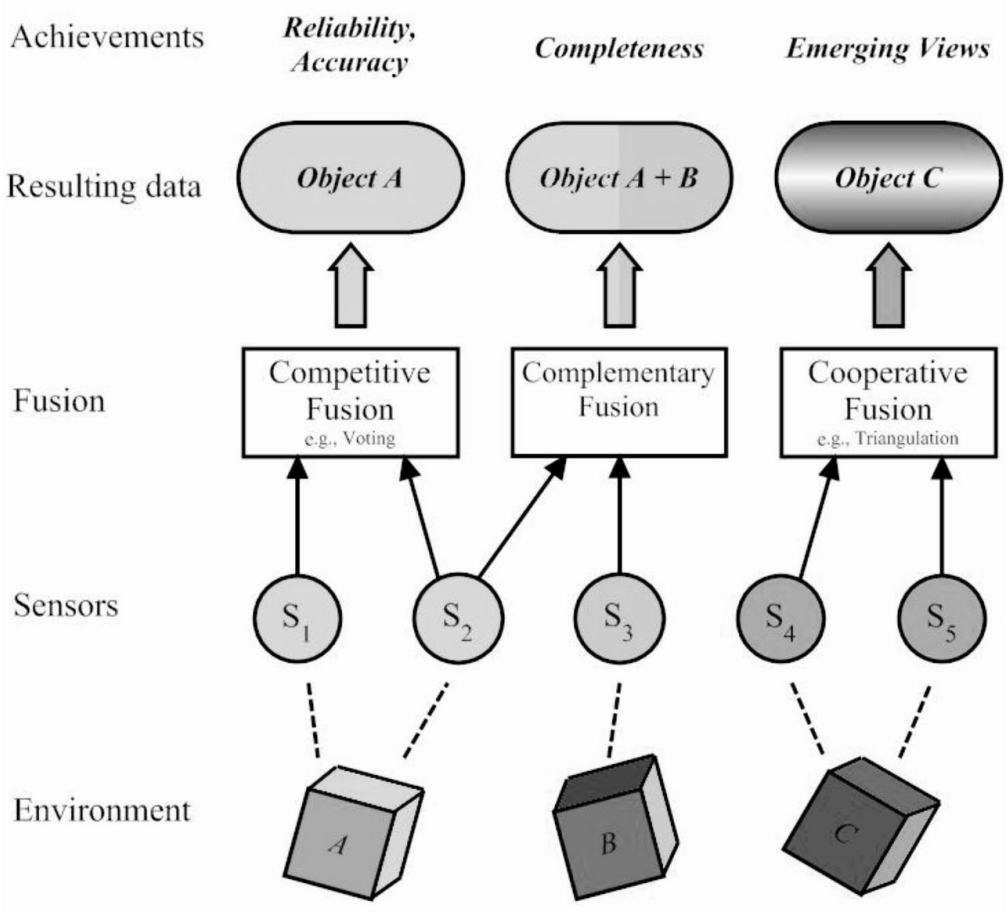


Sensor fusion and virtual constellations



Examples:

- Cooperative Fusion: fusing different images, structure-from-motion, multi-view stereo.
- Complementary Fusion: fusing uncorrelated datasets, SAR-optical fusion, evapotranspiration (ET).
- Competitive Fusion: fusing correlated datasets, image averaging, cross-calibration.

Sensor fusion and virtual constellations

Virtual Constellation	Constellation Design Example	Product Level	Example application
ARL-3	Sentinel-2A/B	L1/L2	Land Cover Type
ARL-2	Sentinel-2A/B + Sentinel-3 (or L8, VIIRS, MODIS)	L3	Near-Realtime Monitoring
ARL-1	All of the above + EO missions of different measurement principles	L4+	Carbon Monitoring, Evapotranspiration

CEOS VC Concept

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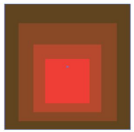
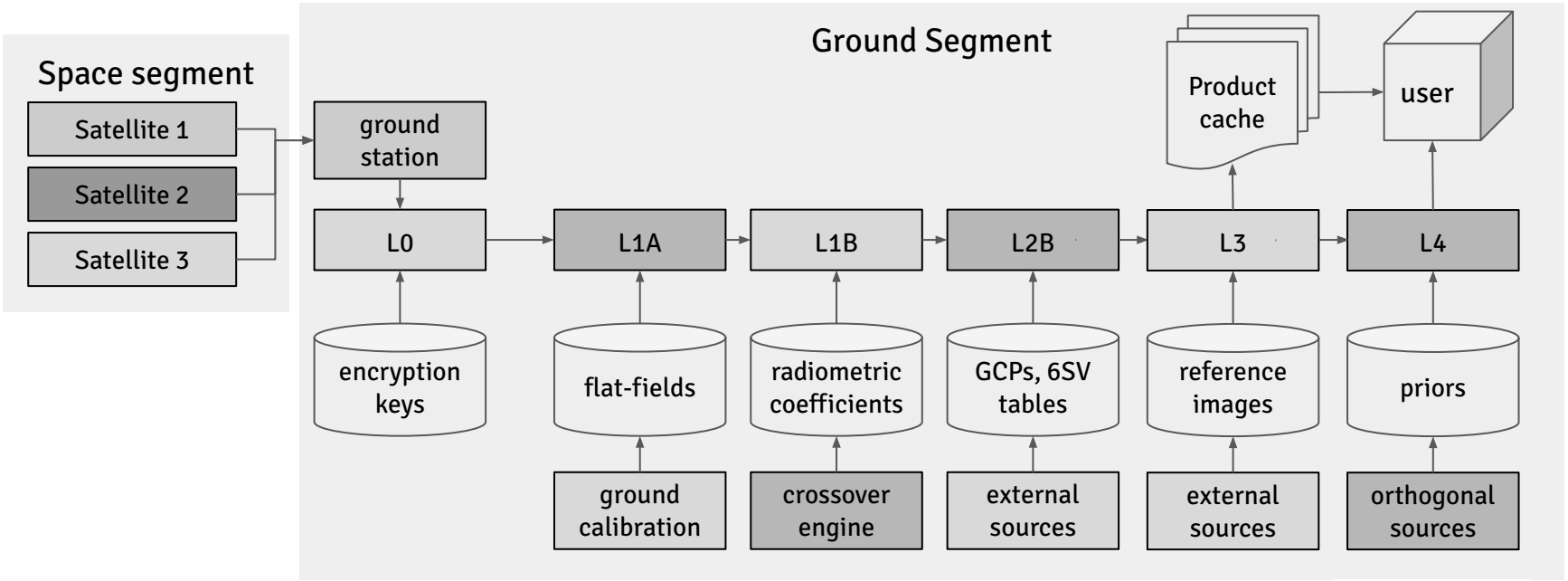


Sensor fusion and product levels



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Sensor Fusion Flavors

L0-L3 Sensor Fusion

Retrieval of an **idealized 2D/3D image**:

- Super-resolution
- Multi-view stereo
- Cross-calibration
- PAN-sharpening
- Registration
- SAR-based optical gap-filling
- Colorization of SAR images
- Atmospheric correction
- Orthorectification
- Photometric Stereo
- Tip-n-cue

L4 Sensor Fusion

Retrieval of **features**:

- SAR-based modelling
- Heterogeneous training datasets: kriging/upsampling of expensive ground measurements
- Model-based interpretation
- Event-based models: eg. planting date detection
- Physically based models: eg. ET
- IoT integration
- Tip-n-cue

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- Daily multi-resolution, gap-free on all dimensions and traceable **model** of the earth, *delivered as a*
- **virtual instrument** that abstracts away a
- spatially, temporally and spectrally sparse and **disaggregated mission**

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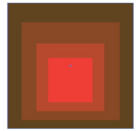

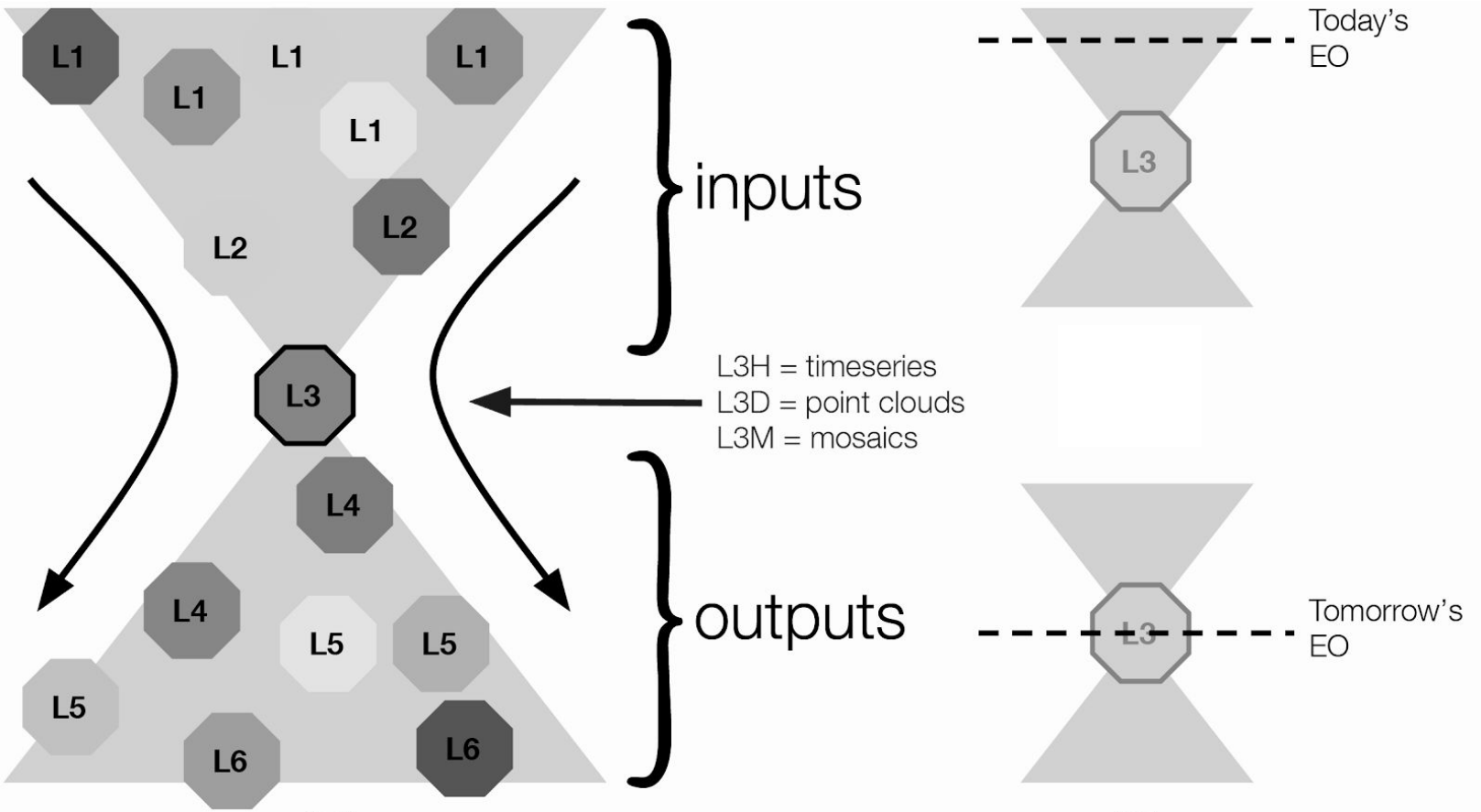
L1
L1
L1
L1
L1
L2
L2
L3
L4
L4
L5
L5
L5
L6
L6
inputs
L3H = timeseries
L3D = point clouds
L3M = mosaics
outputs
Today's
EO
L3
L3
Tomorrow's
EO

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- The future of EO lies in providing inputs for sensor fusion
- This leads to a more nuanced requirement for interoperability
- This expands the concept of interoperability to all processing levels

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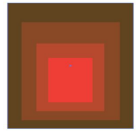
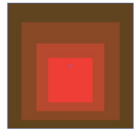
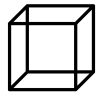


- Most current sensor fusion is ultimately remedial
- Lots of over-determined data
- How do we proactively design and coordinate missions with sensor fusion in mind?
- How do we design payloads with sensor fusion in mind?



ARD Workshop Themes over the years

- ARD18: very payload and data centric ⇒ L0 ARD
- ARD19: software and cal/val centric ⇒ L1/L2 ARD
- ARD20: fusion and pipelines ⇒ L2/L3 ARD
- ARD21: L3/L4 ARD
  - Model-based interpretation?
  - ARD for HR?
  - Bare-metal L0 traceability?
  - Irregular grids?



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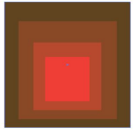

A multi-level view of ARD

Does this work?

- L0 ARD ⇒ ready for correction (payload folks)
- L1 ARD ⇒ ready for calibration (cal/val folks)
- L2 ARD ⇒ ready for fusion (remote sensing folks)
- L3 ARD ⇒ ready for analysis (computer vision)

- L4 ARD ⇒ ready for inference (data science)

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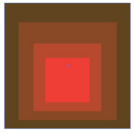
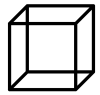


Strategic directions: Specify and abstract

- **Standardize Product Levels:** the vast majority of the assets in EO are varying degrees of repetitive calibration and correction of remote sensing data. The industry has been around in one form or another for a century and standardizing at least the broad strokes of L1/L2/L3/L4+ levels would open up the door to meaningful comparisons and benchmarking based on real-world customer scenarios.
- **Abstract data from hardware:** the definition of product levels would naturally lead to a sensor-fusion-centric stance where the quality of EO data and metadata would be determined by its ability to interoperate with other data during model-based fusion.



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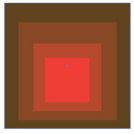

Strategic directions: Standardize and catalog

- **Embrace cloud-based standards:** move around only the data that matters when it matters using COGs and STAC catalogs, expand the standards to include labels and IoT data.
- **Catalog in the open:** much in the same way literature is cataloged, instantiate in the open a proposed Geospatial Digital Object Identifier (GDOI) containing the basic metadata for a given atomic unit of observation. Record, standardize and expose licensing terms, data life-cycle information, endpoints and enable the comprehensive enumeration of all assets collected by participating missions. Make publication of granular per-capture GDOIs a requirement for all licensed missions.

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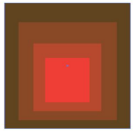

Strategic directions: modernize licensing

- **Decouple licensing from provisioning:** charge what actually costs to provision the data warehousing and decouple it from licensing. Implement DRM technology for phased exercise of licence rights and to further enable co-location of unlicensed assets wherever it is needed.
- **Provide a tiered commercial path to Open-access Licenses:** Open-access does not equal free, let's create a mechanism for someone to pay for some data to be open. Same way you can pay more to make an article open-access, we could provide a path for entities to buy Open-access data for a suitable high price. Let's enable licensing terms where Open-access Licenses can be auctioned, traded and/or paid for by governments or entities for large blocks of GDOIs. List Open Licenses in GDOI records for all to understand which data has already been paid for to be opened to be free. This would unblock large swaths of commercially inviable imagery for ML benchmarking and long term scientific monitoring.

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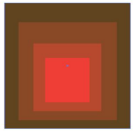
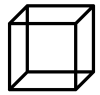


Strategic directions: Open and prioritize

- **Create industry-wide patent pools:** ecosystem building is usually stiffed by the fear litigation for a body of technology that has been for the most part stagnant for the last 20–30 years. The full tech stack in EO is arguably stale and a big part of it is incumbent IP positions from old players in the GIS, aerial imaging and defense spaces. Open source initiatives mitigate some of this risk for the industry but the latent risk of litigation hinders standardization efforts. Much the same way other industries, such as telecommunication and semiconductor, embraced patent pools EO could unblock innovation by aggressively populating IP into patent pools which capture the state of the art. Any algorithm or technology that has been commoditized and is low margin can be subsequently added to the canon of standards and reference designs everyone can build monetizable innovation on.
- **Catalog what matters only!** Sensor-fusion, GDOIs, open licenses, patent pools, virtualization/abstraction and product levels can be leveraged to only surface traceable L3+ products that are actually usable and can be ingested by the mythical long tail of data scientists who do not want to be EO/Remote Sensing experts.



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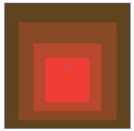

Challenges for 2021

Want to get into the nuts and bolts of virtual constellations and sensor fusion-centric ARD?

- L2 specifications and data structures (as opposed to standards)
- L0/L1 interoperability
- ARD for High resolution and point clouds
- L3 fusion-driven payload/constellation design

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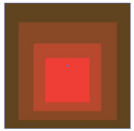

Thank you and next steps!

- Questions/suggestions: ignacio@ard.zone
- Check out www.ard.zone
- Look out to spin off activities before #ARD2021, including focused working groups in 2021.
- See you again next year at #ARD21!

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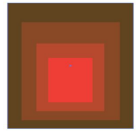

Thank you!

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