Generic Sensor Modeling Approach for Imagery and Geospatial Datasets

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Purpose (1/2)

- The ASPRS PAD had received the following inquiry:

In days gone by when we used stereo plotters to create digital line products we could calculate the scale of the derived lines. We had data stereo pairs that were at 1:60000 scale; we placed them in our plotter and we created lines, and they were assigned a scale of 1:20000. Not sure on this math but it is what it is.

Today we have 1:40000 ortho-rectified imagery with a resolution of 50cm. Using a software of choice we are zoomed in to 1:1000 and we start digitizing polyline features. Is there a way to calculate what the output scale of the line work could/should be considered? Is it even relevant today? **Should we be describing our data not based on scale anymore?** Any insight you can provide would be appreciated.

Purpose (2/2)

- I do not dismiss the value that scale brings to the table when relating multiple datasets; however
- This briefing does provide a possible answer to **"Should we be describing our data not based on scale anymore?"**
- For 10+ years, I have been part of a DoD/IC team that has advocated rigorous sensor models as the basis for reliable exploitation of imagery
- The purpose of this briefing is to review these principles and suggest their applicability to geospatial data in general

Outline

- Properties of a Sensor Model
- Community Sensor Model (CSM) Concept
- Generic Sensor Models
- Time Dependent Sensor Models
- Absolute versus Relative Uncertainty
- Universal Lidar Error Model (ULEM)
- Ground Based ULEM’s Broad Applicability
- Conclusions

Properties of a Sensor Model (1/4)

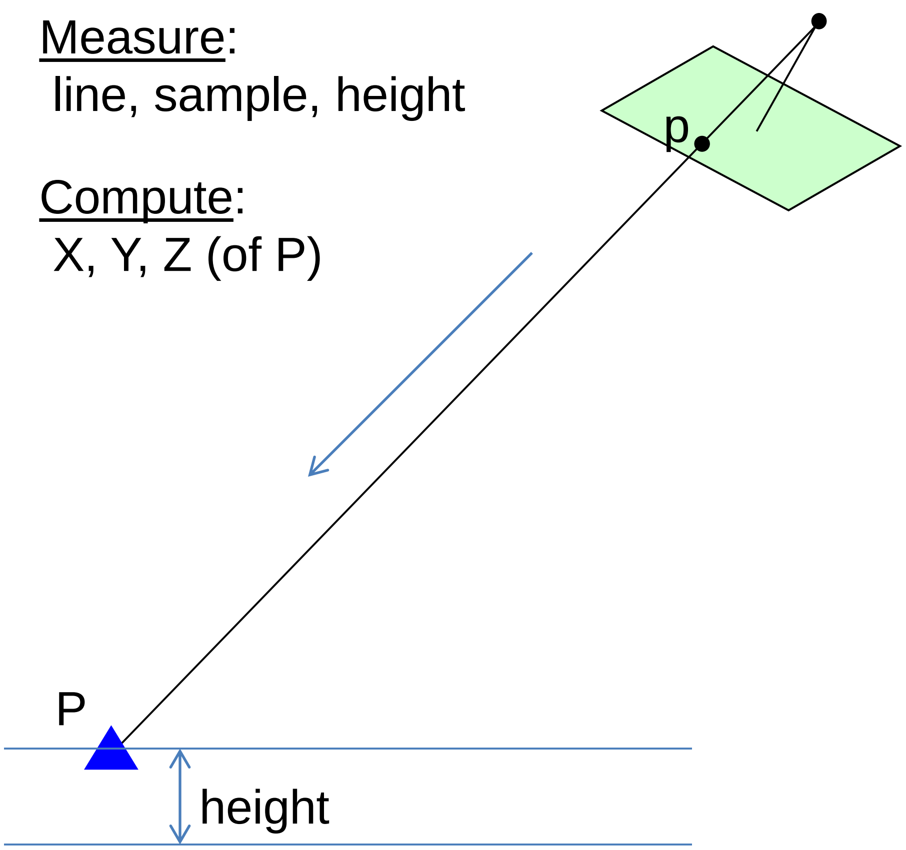
- Supports precise transformation from image-to-ground, and its inverse (ground-to-image)
- Supports error covariance propagation; e.g., to compute CE and LE
- Supports adjustability; e.g., to allow registration to another source

Properties of a Sensor Model (2/4)

Image-to-Ground

Measure:
line, sample, height

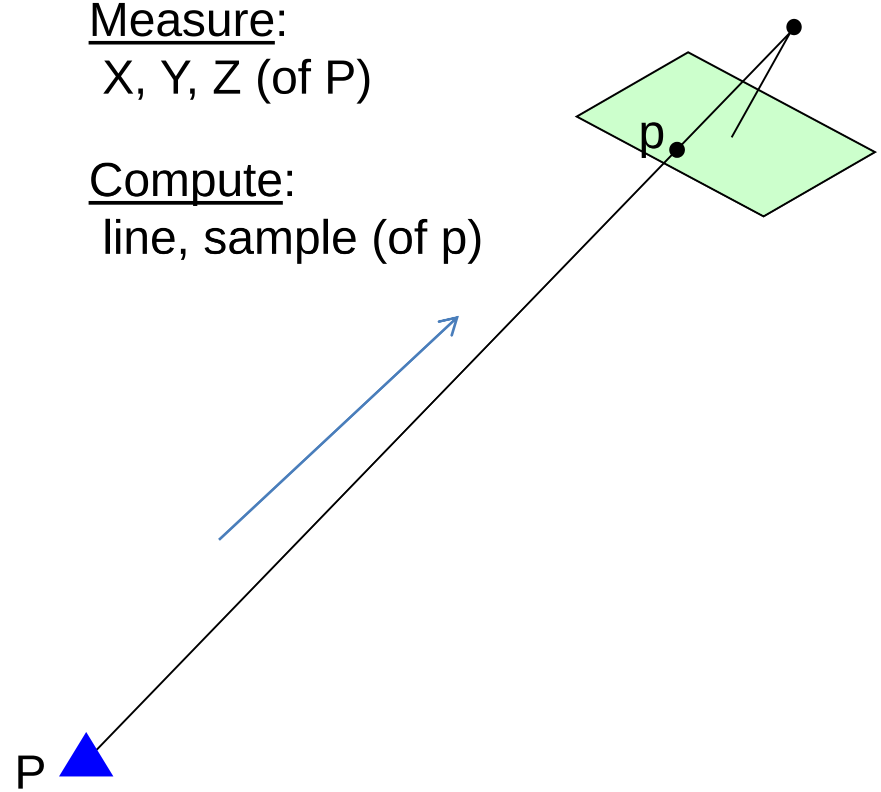
Compute:
X, Y, Z (of P)



Ground-to-Image

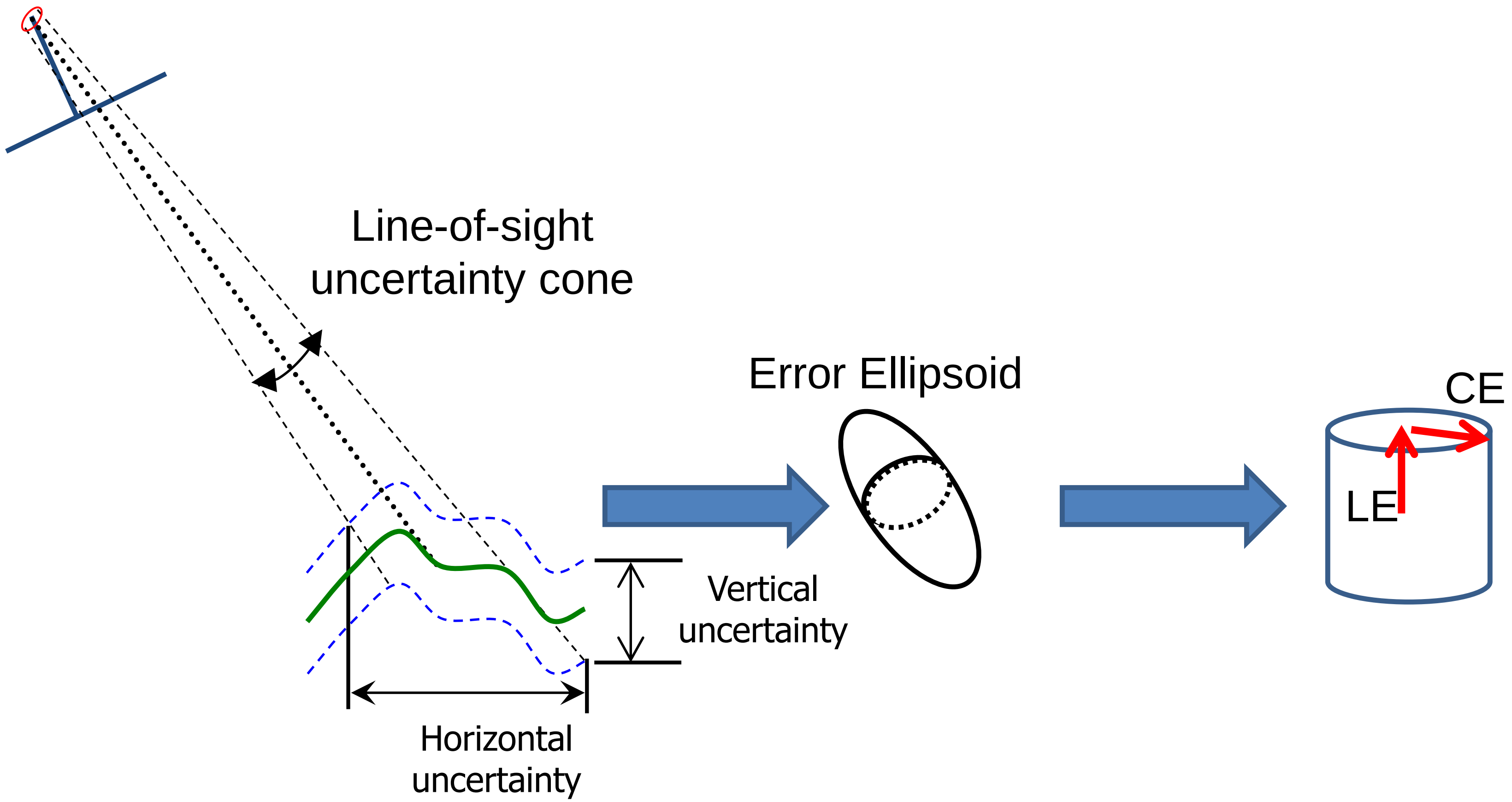
Measure:
X, Y, Z (of P)

Compute:
line, sample (of p)



Properties of a Sensor Model (3/4)

Error Propagation



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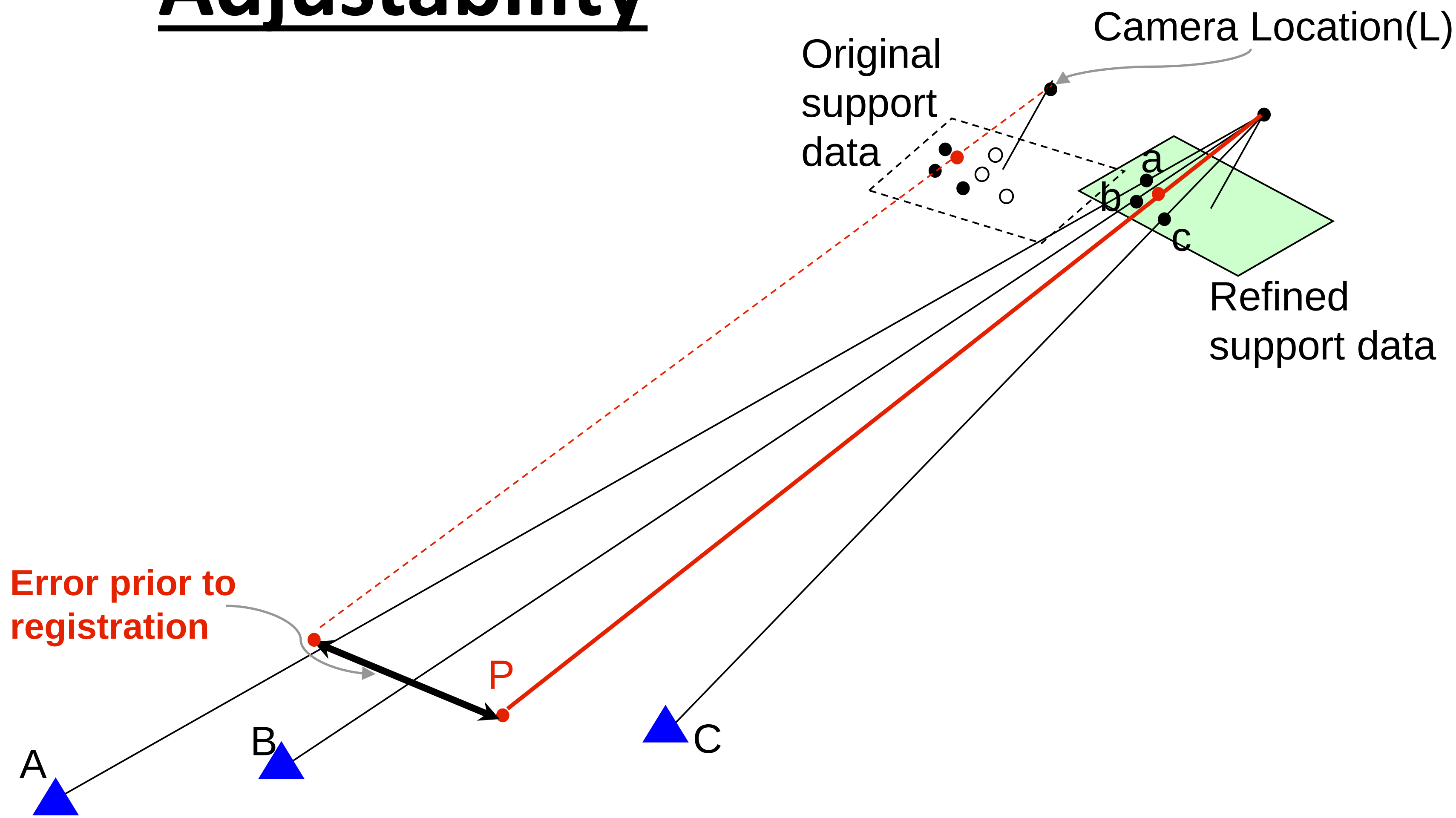
Properties of a Sensor Model (4/4)

Adjustability



CSM Concept (1/2)

Example Sensor Model Functionality

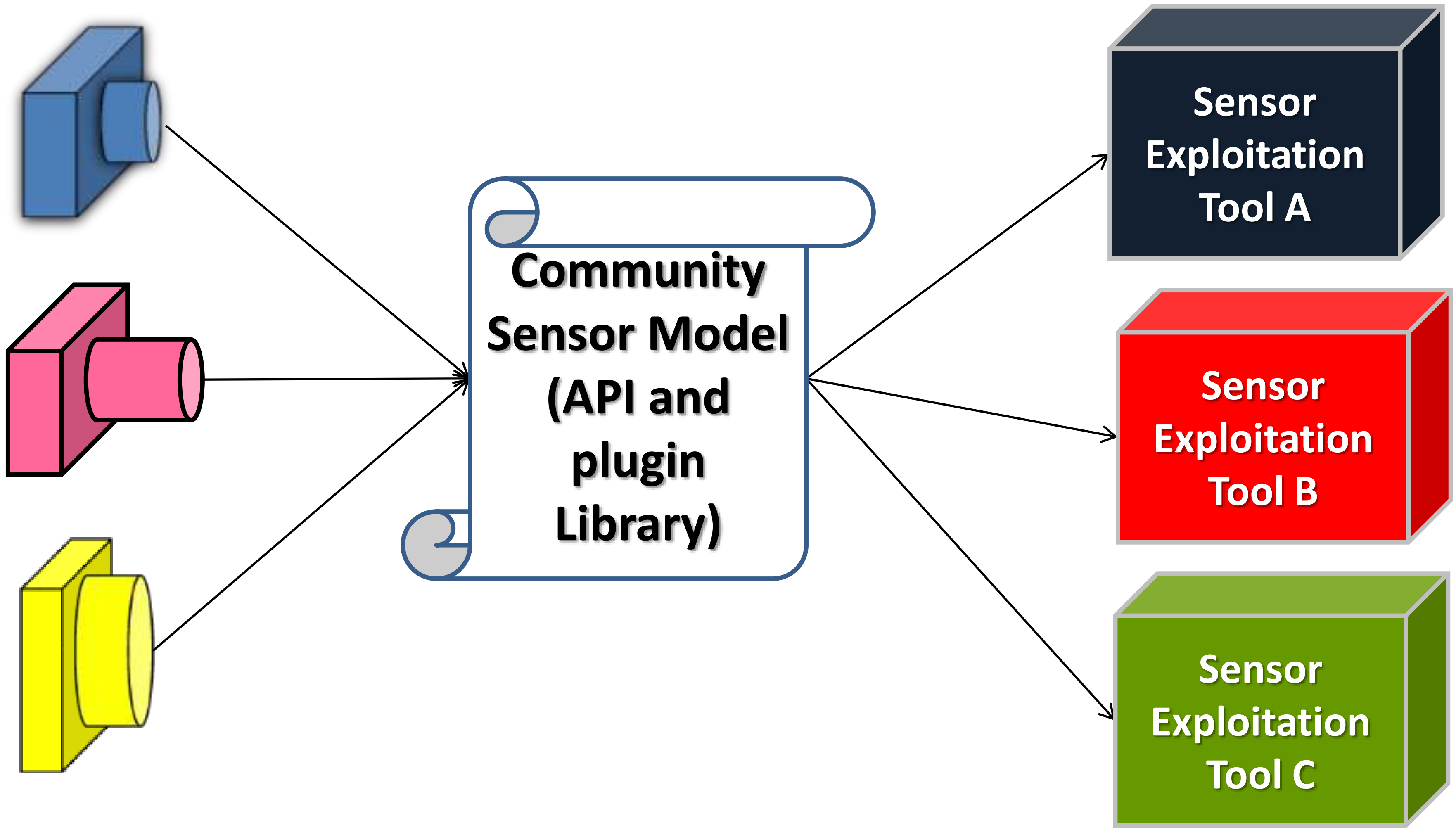
- Image-to-ground
- Ground-to-image
- Compute sensor partials
- Compute ground partials
- Get/set parameter value
- Get/set parameter covariance
- Get cross covariance
- Get un-modeled error

CSM API

Example Sensor Exploitation Tool (SET) Functionality

- Resection
- Triangulation
- Registration
- Multi-image Geopositioning
- Ortho-rectification
- Direct Geopositioning
- Relative Mensuration

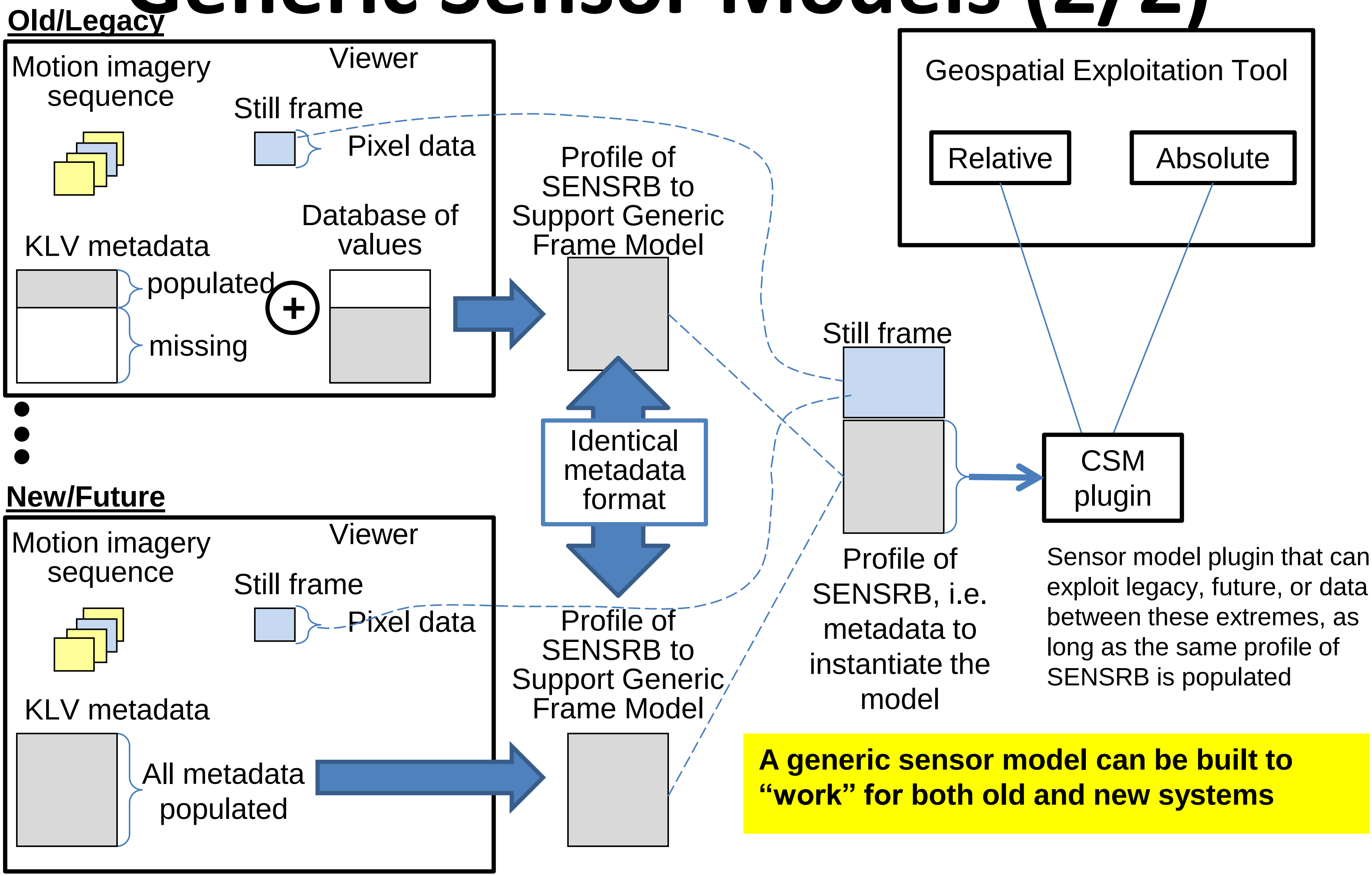
CSM Concept (2/2)



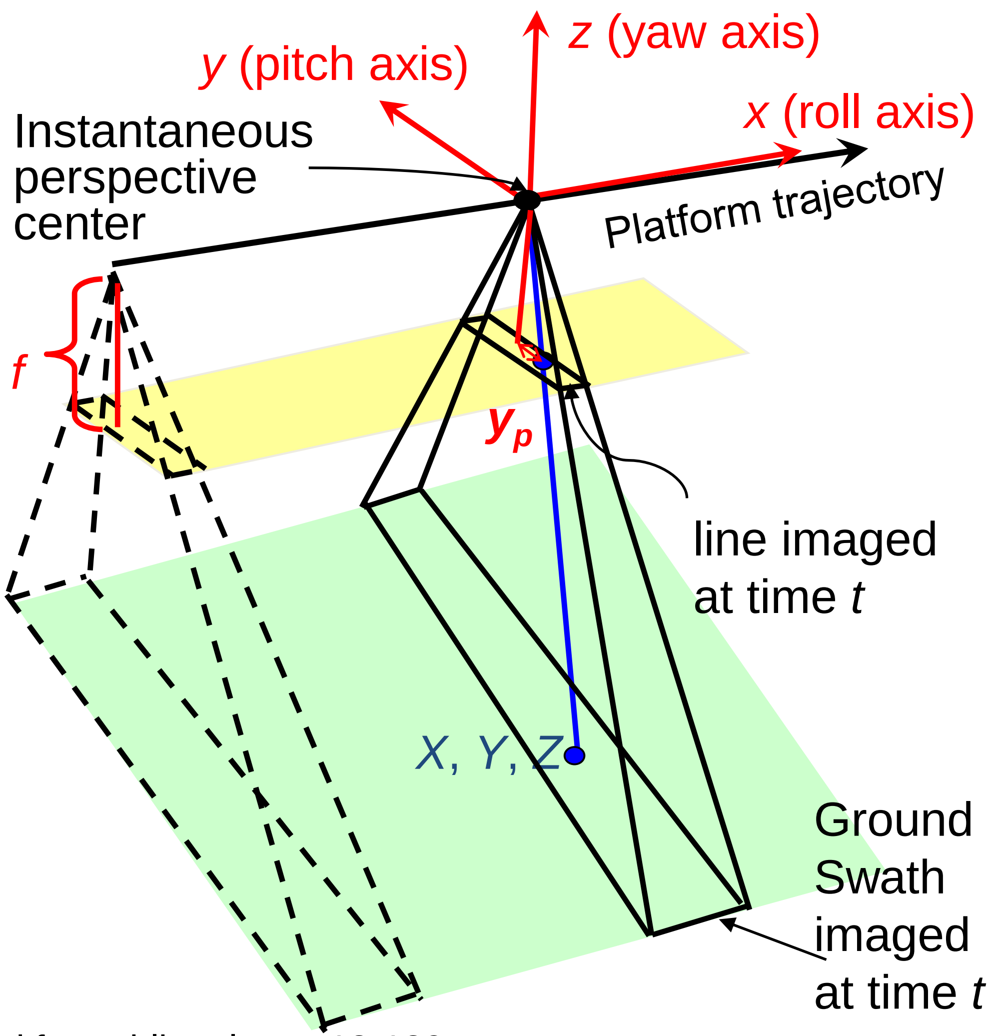
Generic Sensor Models (1/2)

- Still Imagery
  - SAR (SICD/SIDD)
  - EO/IR/HSI/MSI (Passive)
    - Frame ← Example on next slide
    - Pushbroom/Whiskbroom (airborne or spaceborne)
  - Frame with “range image”
- Motion Imagery
- 3D Data (e.g. Point Clouds, or DSMs, from any source)
  - ULEM – sensor based (lidar)
  - ULEM – ground based (lidar or other)

Generic Sensor Models (2/2)



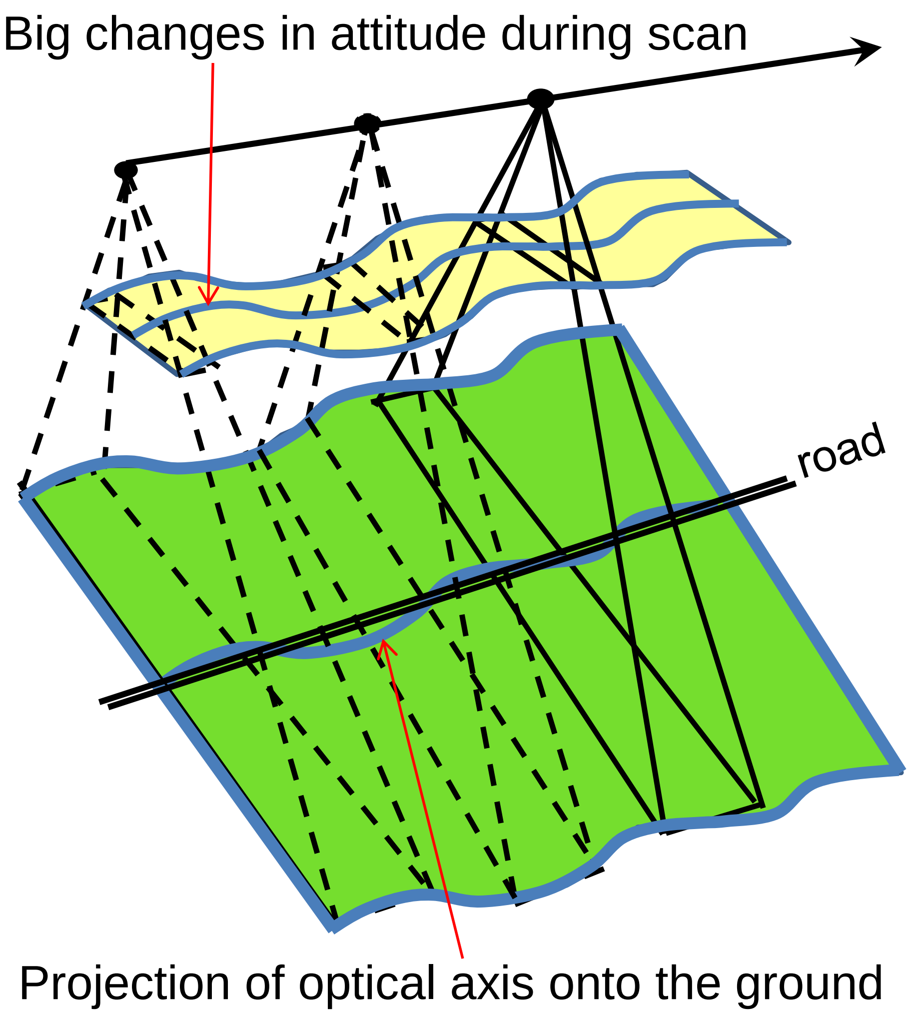
Time Dependent Sensor Models (1/2)



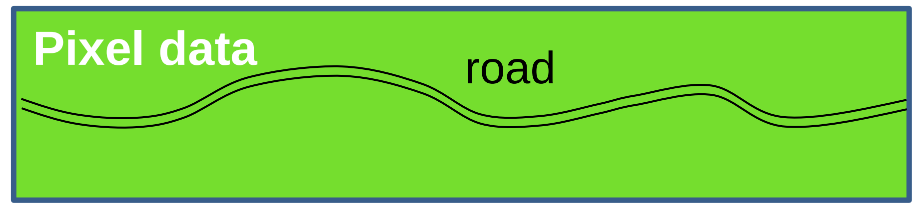
Pushbroom Geometry

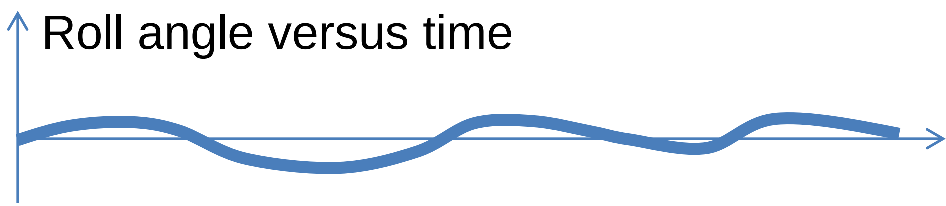
Sensor position and attitude are a function of time (*t*)

Time Dependent Sensor Models (2/2)



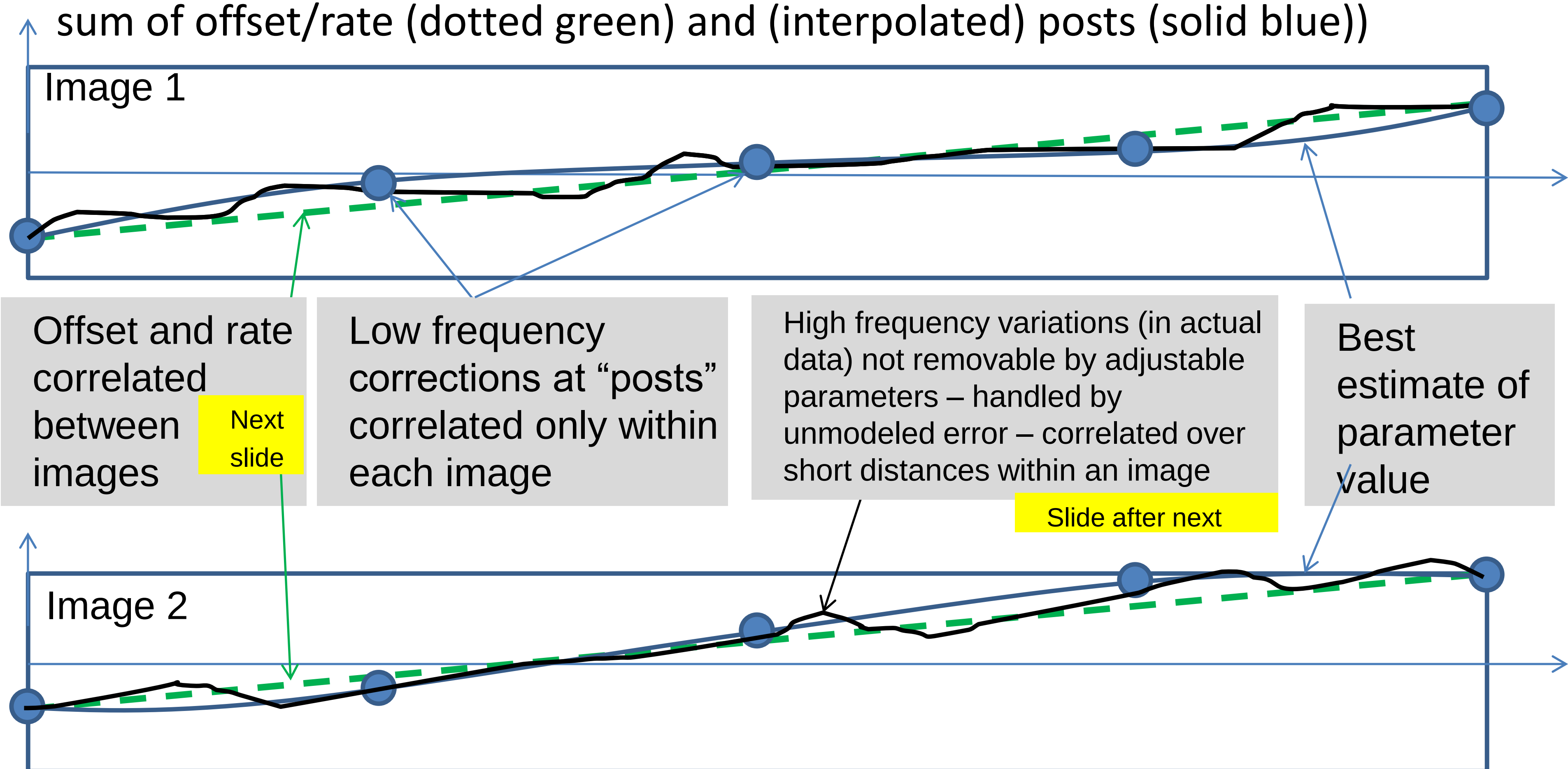
Raw image product





Absolute vs Relative Uncertainty (1/4)

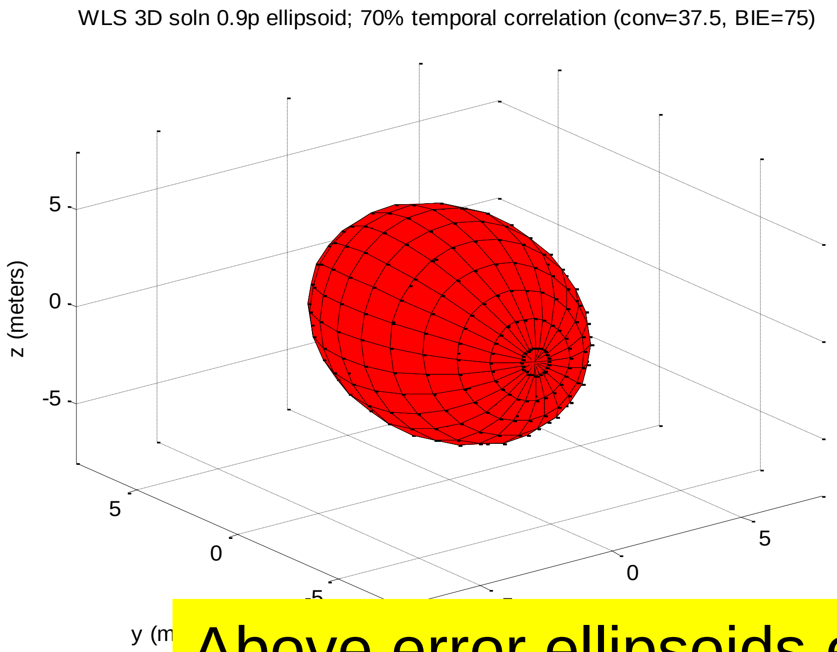
Conceptual example of sensor errors (truth (black); best estimate of truth is sum of offset/rate (dotted green) and (interpolated) posts (solid blue))

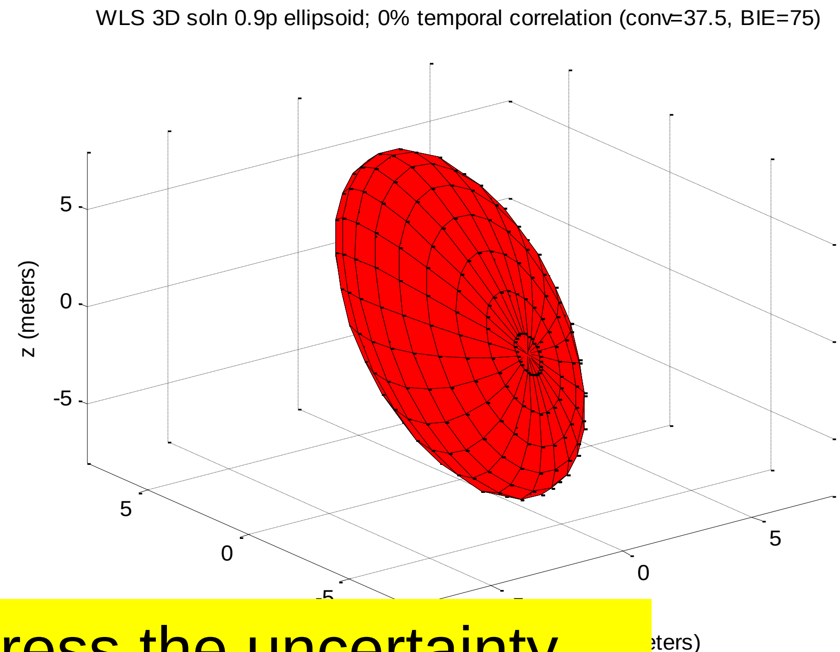


Absolute vs Relative Uncertainty (2/4)

With correlation between image 1 and 2

Ignoring correlation between image 1 and 2





Above error ellipsoids express the uncertainty (predicted accuracy) of a stereo geolocation

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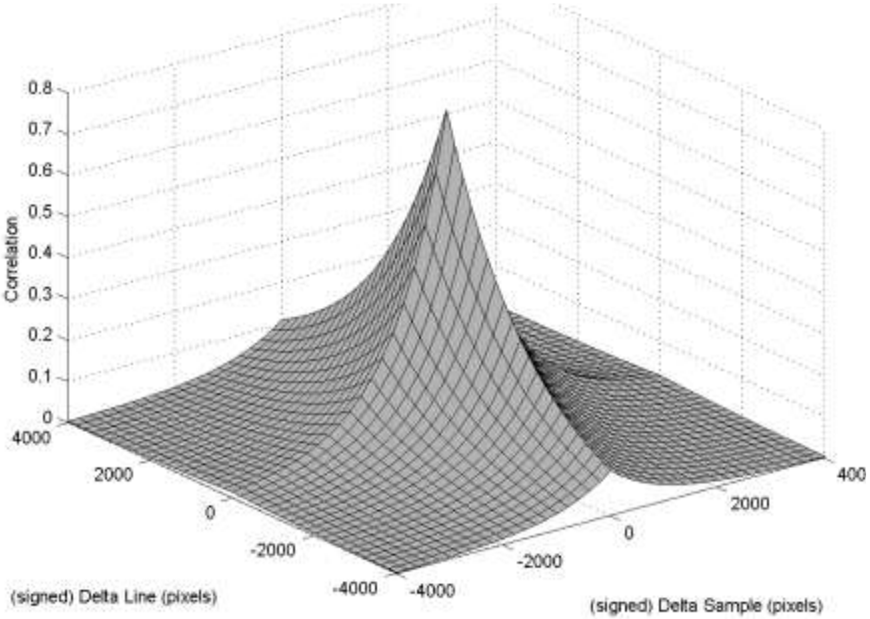
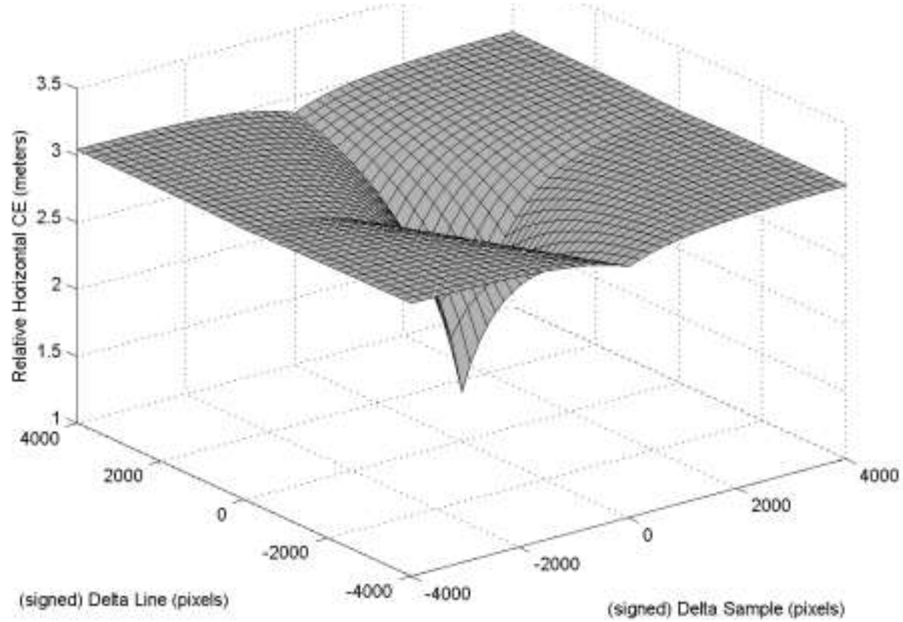
Absolute vs Relative Uncertainty (3/4)

Correlation vs Δ*line* and Δ*sample*



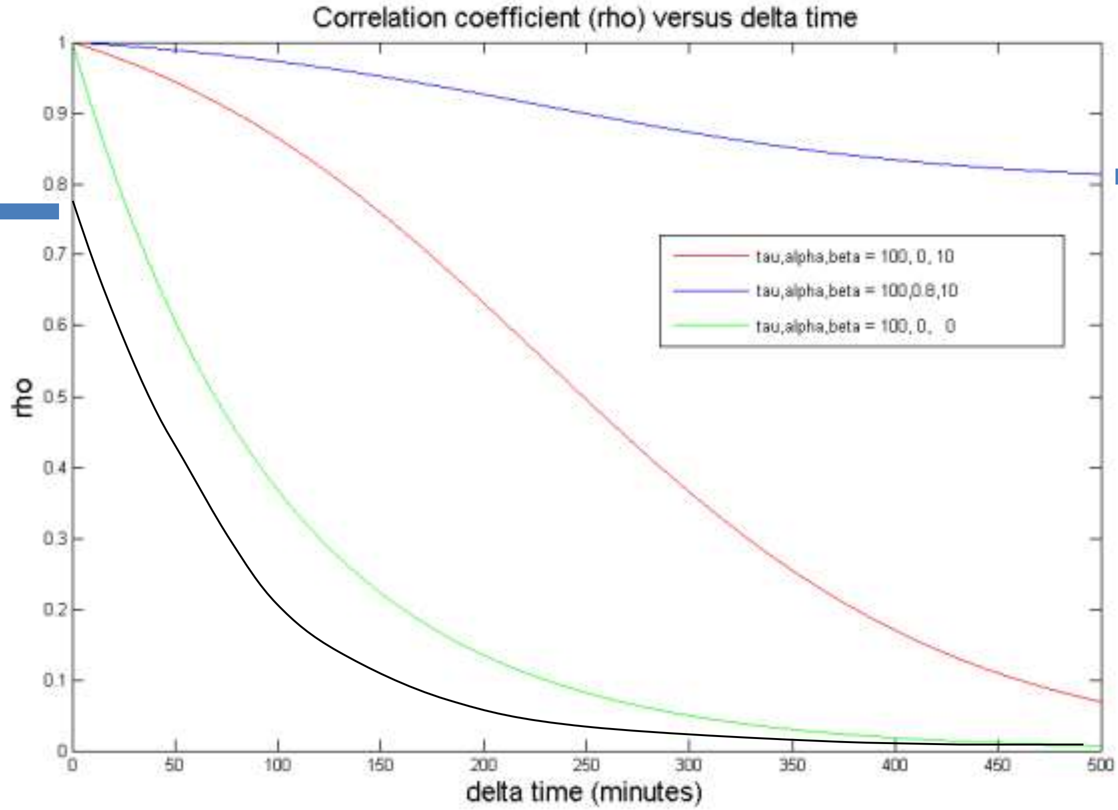
Relative accuracy vs Δ*line* and Δ*sample*



The closer the two points, the higher the correlation and better (smaller) the relative accuracy

Absolute vs Relative Uncertainty (4/4)

A random component exists



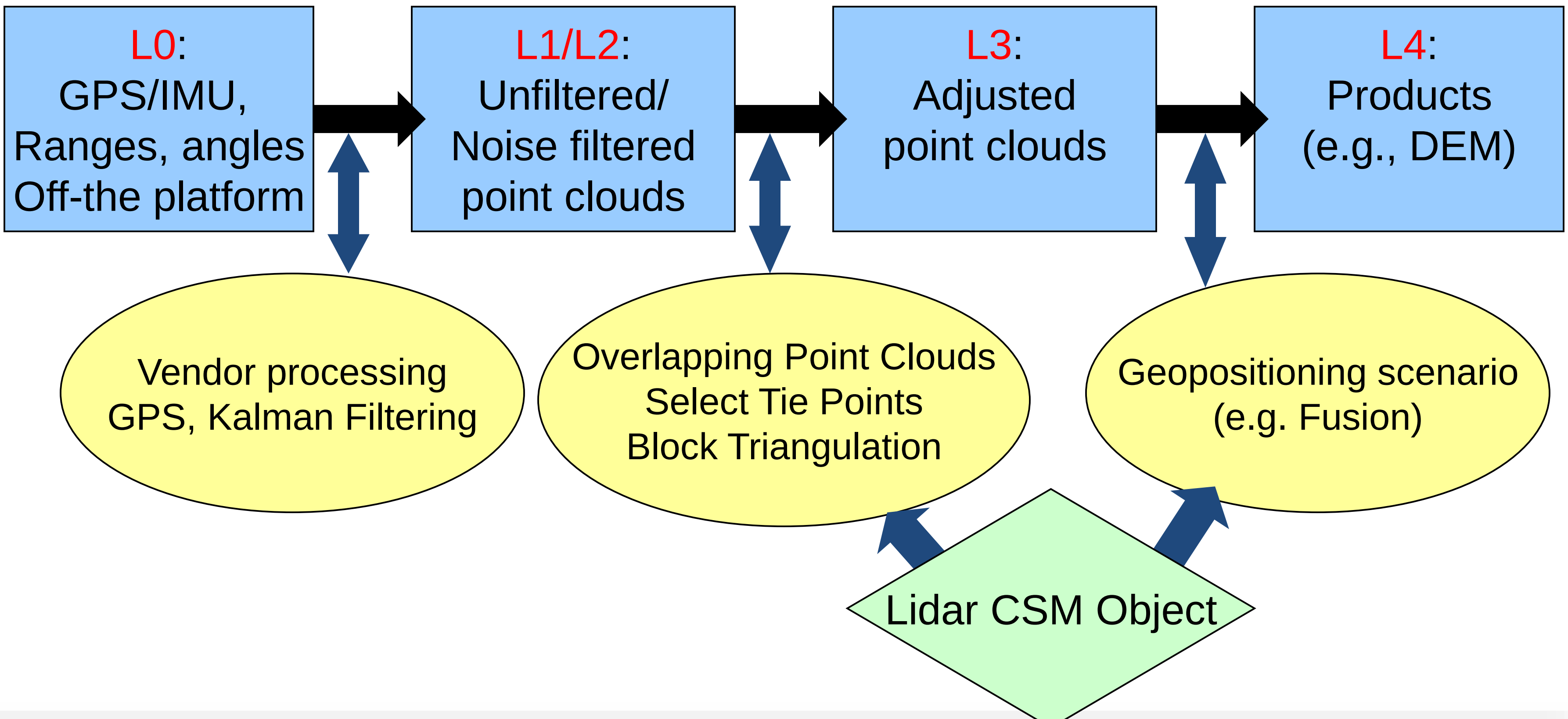
A bias exists

The correlation decay rate (function of Δtime, or Δ*line* and Δ*sample*) can be tailored via 4 parameters

Universal Lidar Error Model

- The Universal Lidar Error Model (ULEM) concept was invented by the Sensor Geopositioning Center (SGC)
  - As a means to efficiently store the error covariance information for large point cloud datasets
  - As the metadata to allow the instantiation of a CSM plugin so that tools could seamlessly exploit imagery and point cloud data at the same time
- The geometry of lidar acquisition (discussed on next slides) is just like that of EO/IR pushbroom/whiskbroom (discussed on previous slides)

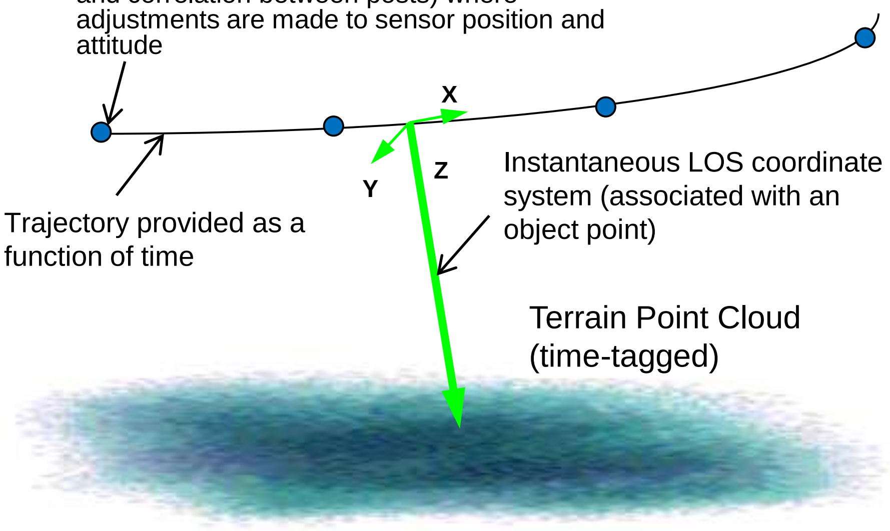
CSM Applicability among LIDAR Processing Levels



CSM will assist in LIDAR processing and exploitation, allowing common applications to be applied to multiple data types using a common interface (CSM API)

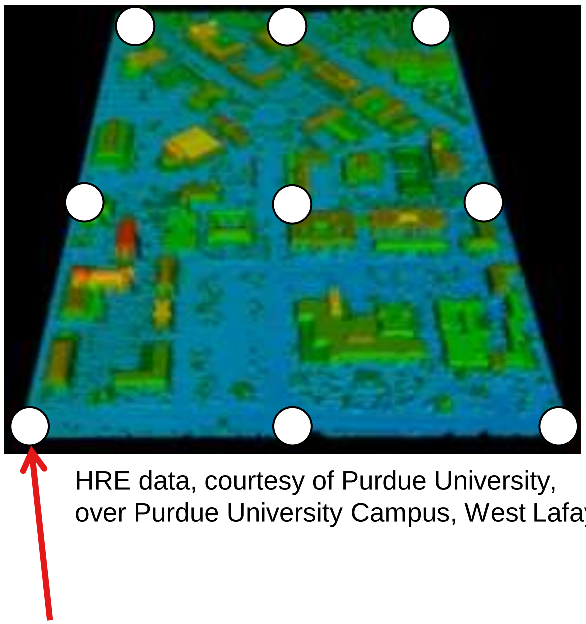
ULEM Cases

ULEM: Sensor Based



- Models errors based on:
  - Adjustable parameters – low frequency systematic
  - "Unmodeled" Errors – high frequency systematic
  - Measurement Errors – purely random

ULEM: Ground Based (point cloud or HRE)

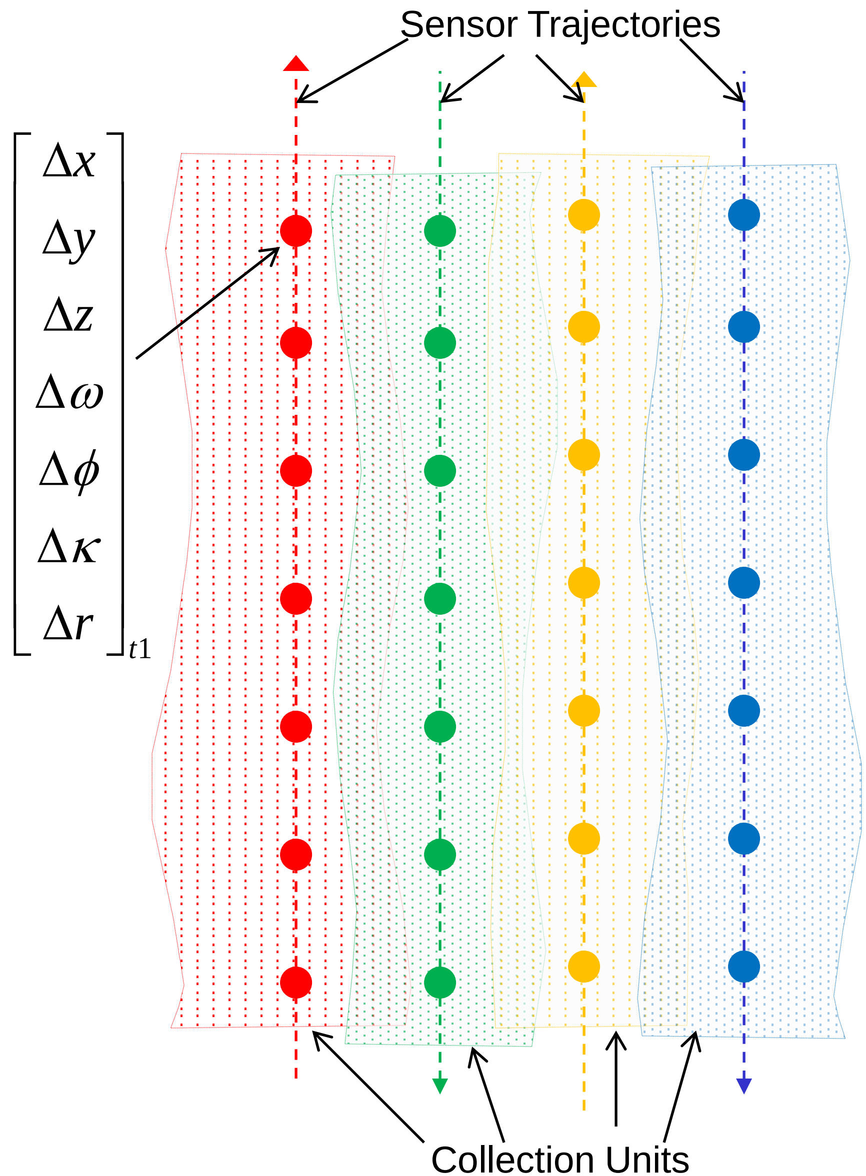


HRE data, courtesy of Purdue University, over Purdue University Campus, West Lafayette, IN

- Location of an "anchor point" where adjustments are made to X,Y,Z components of position
  - rigorously computed full covariance matrix exists between all anchor points
  - supports adjustable model

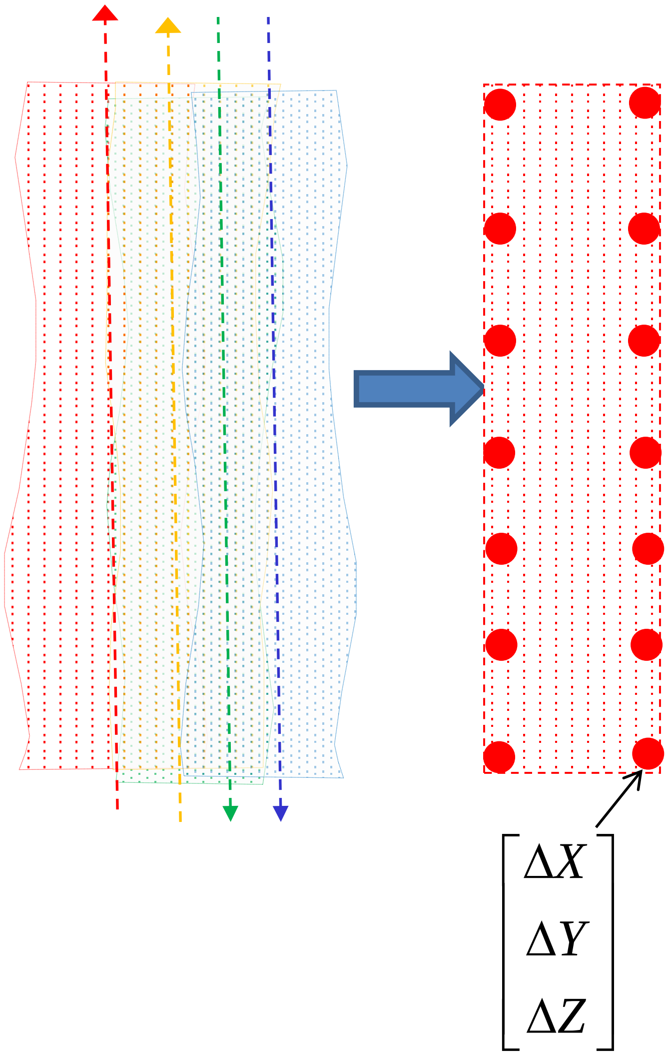
ULEM: Sensor Based Scenario

- Sensor based adjustment by posts is essentially the same as that used for EO/IR imagery



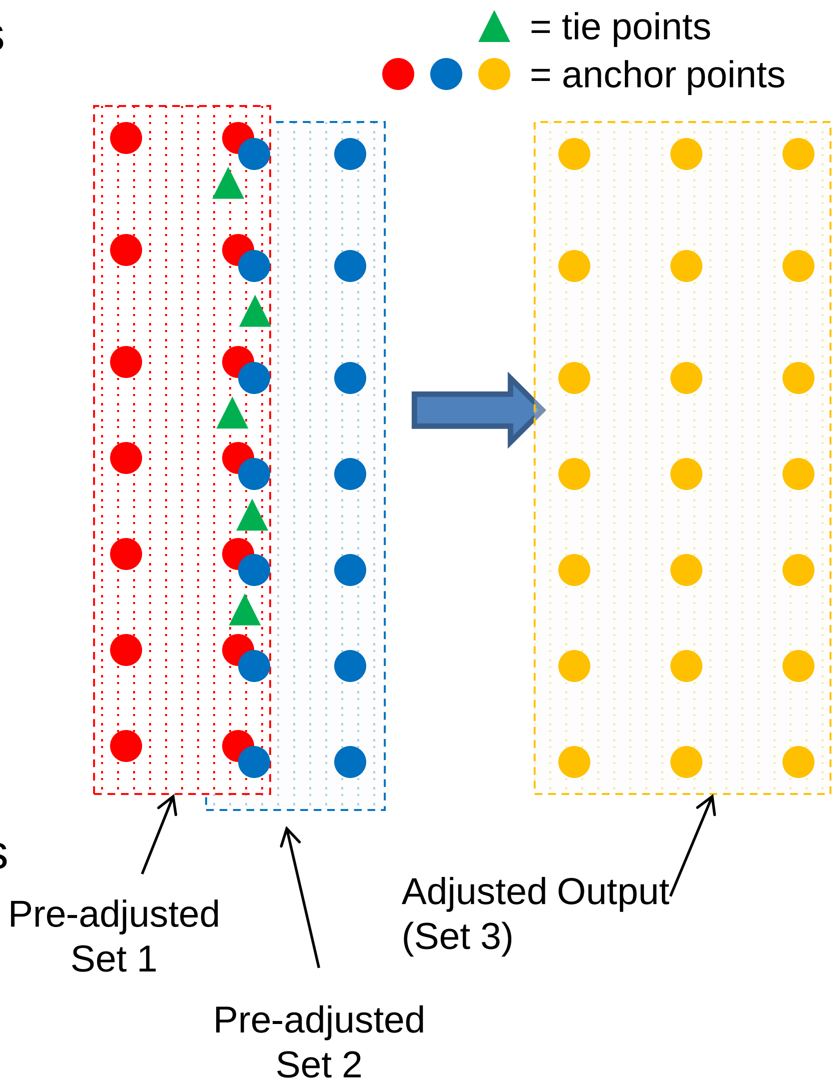
ULEM: Ground Based Scenario

- Ground based scenario primarily used for:
  - Geiger mode collections where:
    - Multiple looks with diverse geometry contribute to each point in the final point cloud.
    - The individual collection geometry and timestamps per point are lost.
  - Pre-defined anchor points are established, whereby X, Y, Z corrections are made to the point cloud
  - Rigorously computed full-covariance exists between all anchor points



ULEM: Ground Based Scenario – Anchor Point Adjustment

- Ground Based: Adjustment of Anchor Points
  - Multiple overlapping datasets or pre-adjusted data
  - Tie points (patches) are selected in the overlap regions
    - Tie points do not need to be coincident with anchor points
  - During adjustment, translations are defined at anchor point locations
    - Between them, adjustment is a weighted value based on surrounding anchor points
  - Output is a new dataset that is a combined version of input, and includes full-covariance at and between anchor points.



Ground Based ULEM's Broad Applicability

- Concept of Ground Based ULEM is applicable to 3D data sets in general
  - Anchor points (correlated within and between collection units) with associated X, Y, Z corrections
  - Unmodeled Error covariance (picks up high frequency systematic errors that cannot be removed in adjustment)
  - De-correlation functions
    - To describe correlation between anchor points
    - To describe correlation between unmodeled errors of nearby points

Conclusions

- Past:
  - Decision about fusibility of datasets based upon the scales of each contributing dataset
- Generic Model Paradigm
  - Tool solves for optimum solution as a function of the many datasets (doesn't care whether comparable scales)
    - E.g., combines excellent absolute accuracy of one dataset with excellent relative accuracy of another dataset
    - Requires rigorous sensor model plugin for each of the datasets, and proper weighting of adjustable parameter errors and unmodeled errors
  - Tool provides realistic predicted accuracy for the fused product
    - Facilitates decision making
    - Facilitates subsequent registration to other sources

Acknowledgments

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  - collaboration and
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