SPC

An Introduction
9 August 2016

What is Stereophotoclinometry

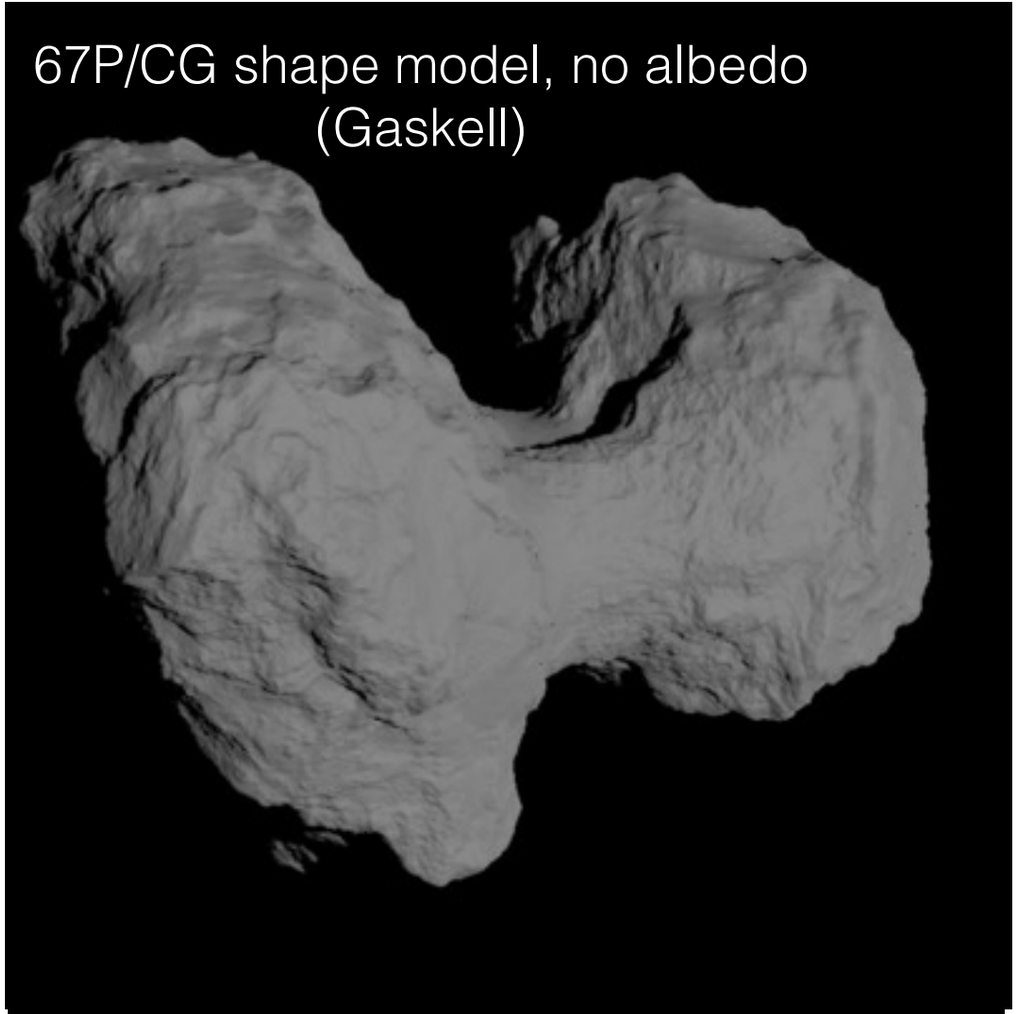
- A suite of tools designed to generate a shape model using all imagery possible

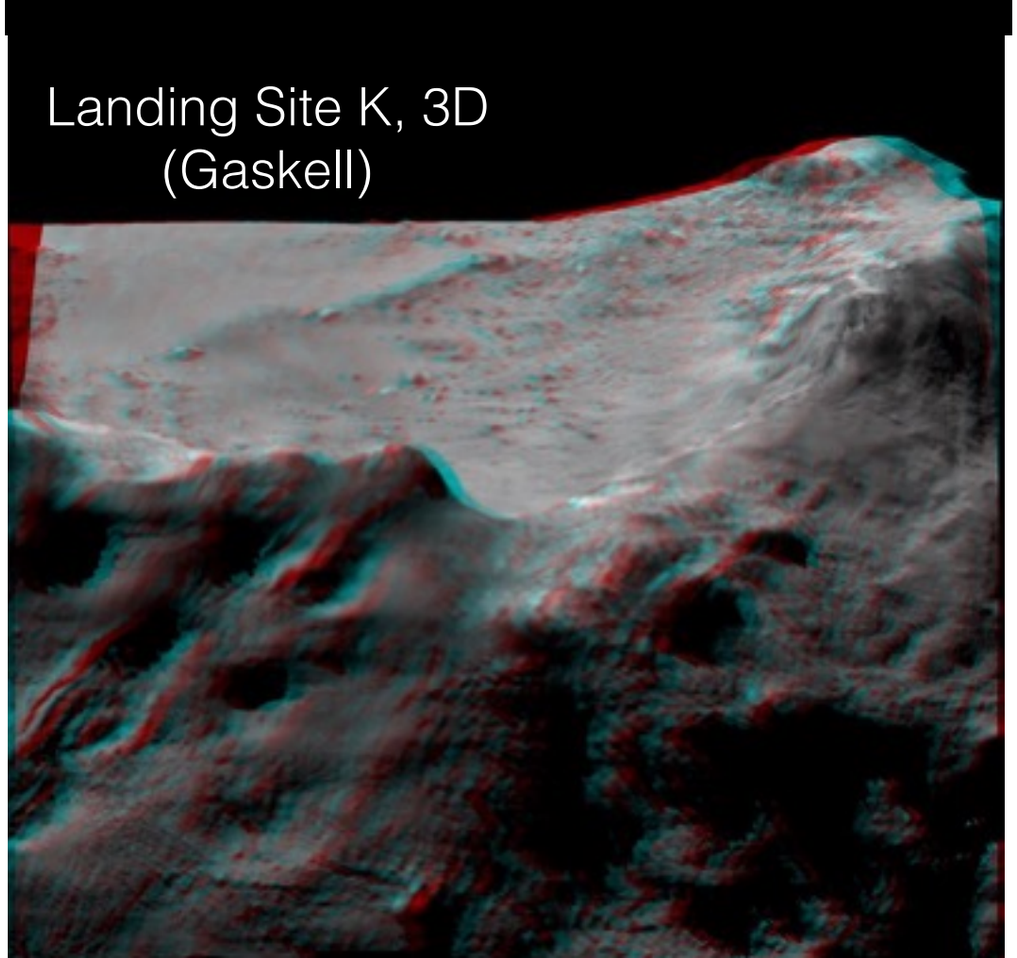
- Solves for topography and albedo, allowing any illumination and observation condition to provide useful data

- Blends the best parts of Stereo with 2D Photoclinometry to minimize the errors of each

    - Stereo: Sets absolute distance

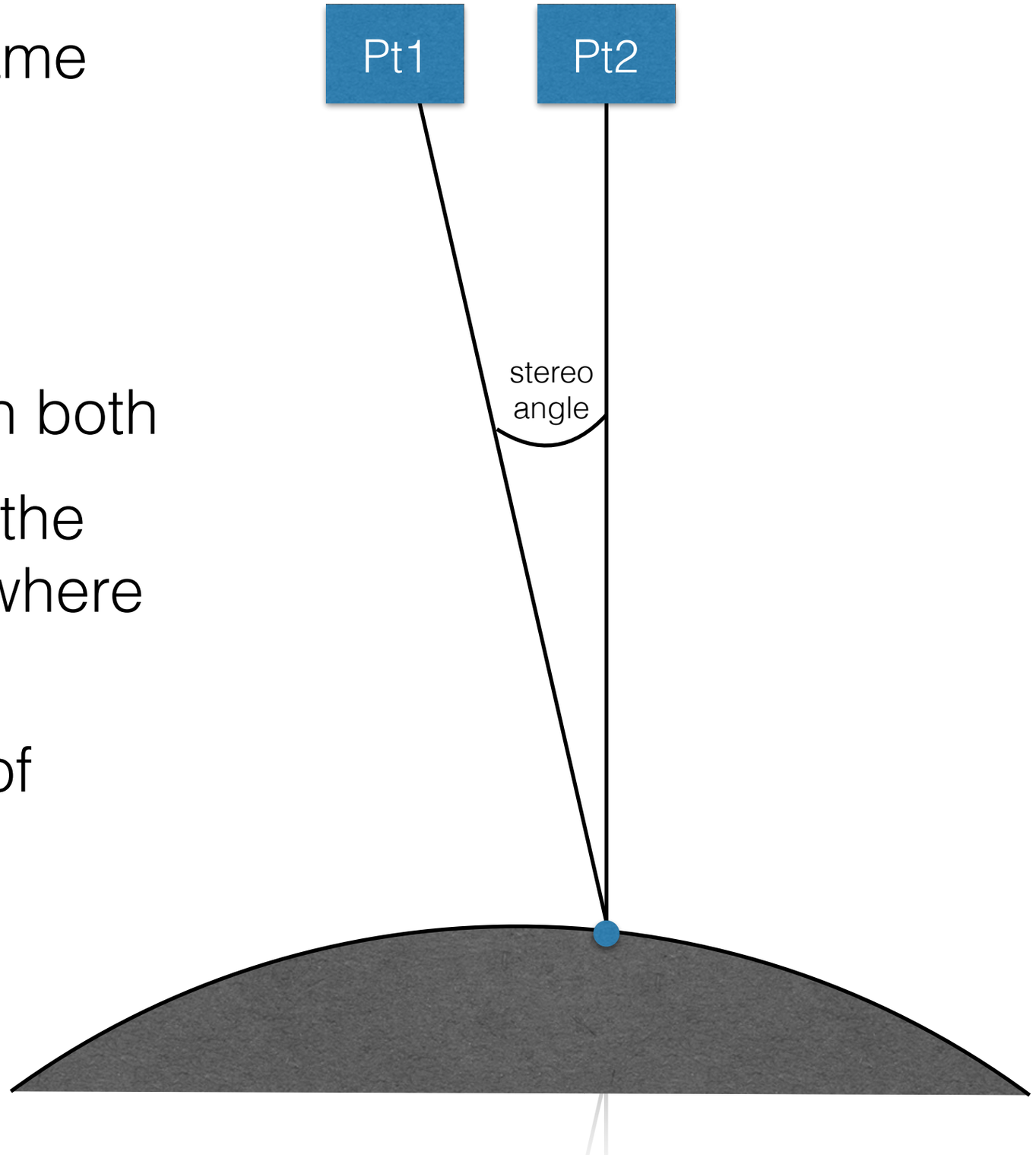
    - Photoclinometry: Allows a wider range of emission and illumination conditions





Stereo

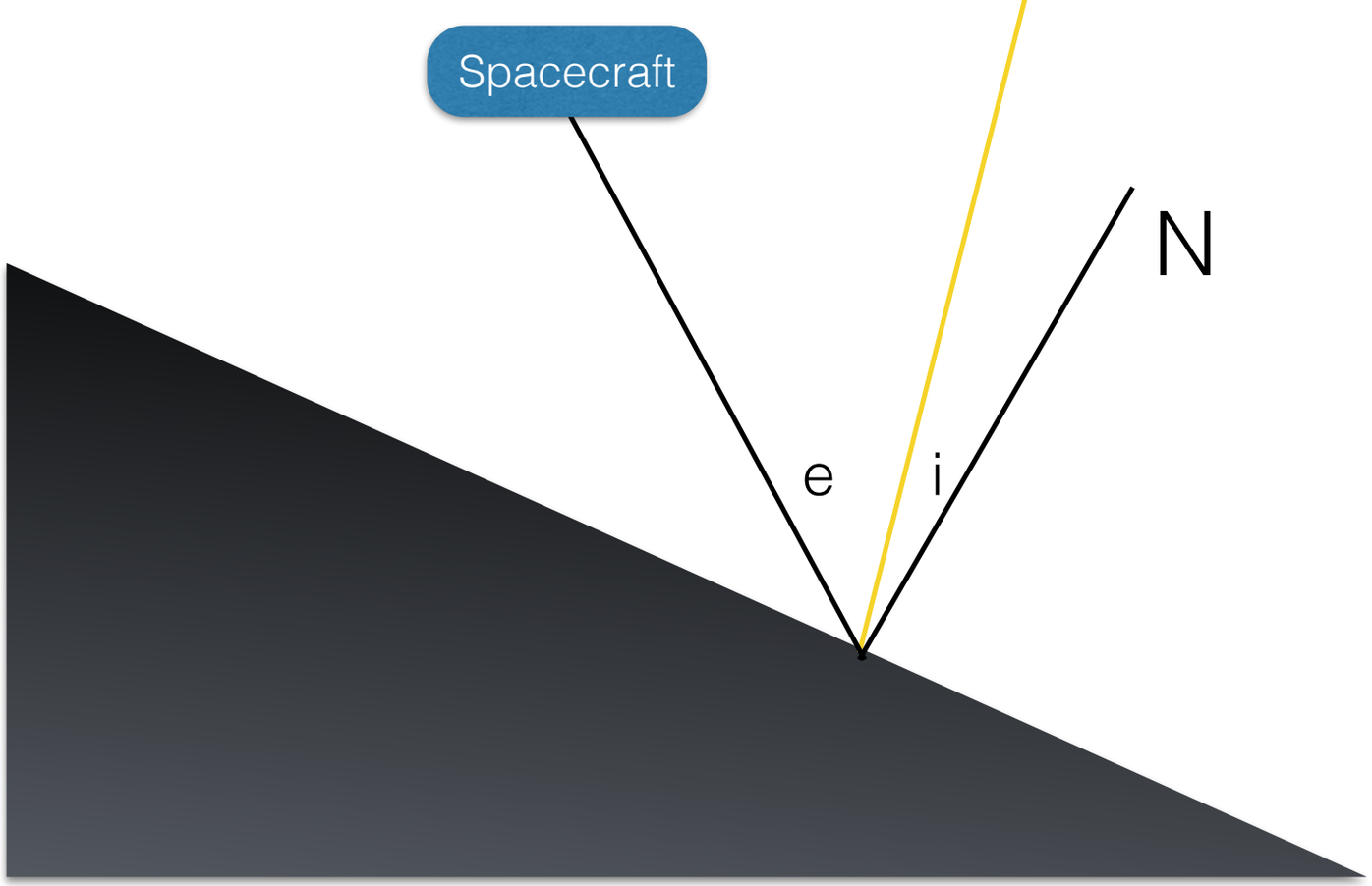
- Have two images of the same terrain
    - Similar illumination conditions
- Identify the same feature in both
- Mathematically determine the distance from spacecraft where the two vectors cross
- Do this for a whole series of location to build up a topographic model



Photoclinometry

Use the variations in reflected light to determine the slope.

- Observed flux is a simple function of incidence angle and albedo, with photometric corrections.
- We use 3 images to solve for $slope_x$, $slope_y$, albedo



i - incidence
e - emission
N - surface normal
A - Albedo (surface reflectance)
So - Solar constant
R - Distance from the Sun (AU)
F - Observed flux

$$F = A\frac{S_o}{R^2}cos(i)$$

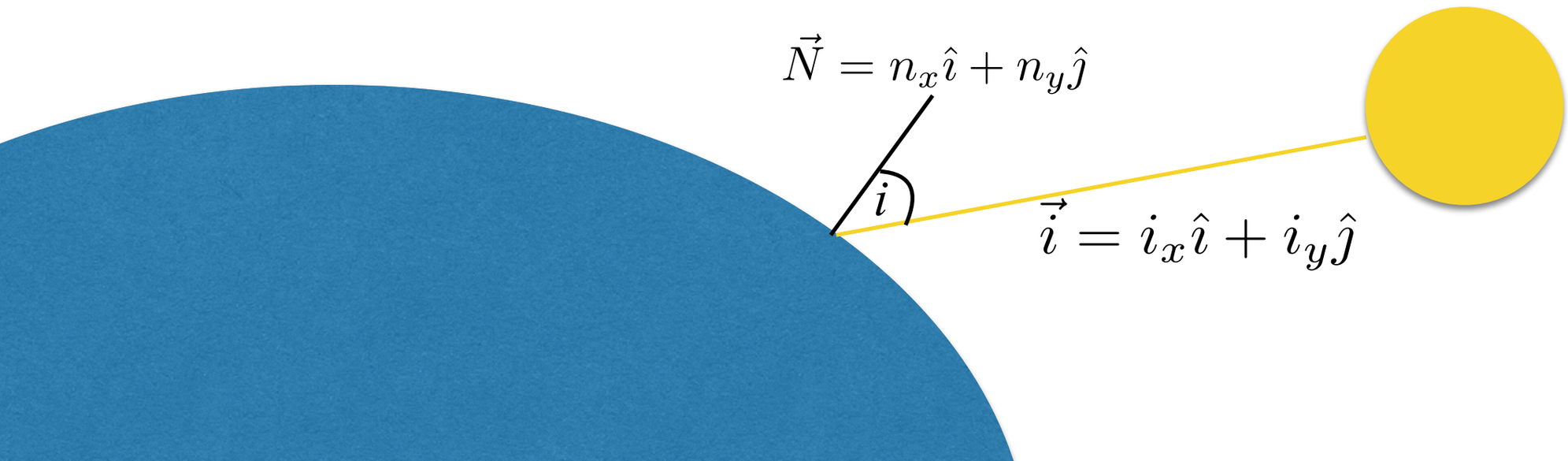
Solving for everything

F1, F2, F3 are measured from different images, but the same point on the surface.
You solve for n_x, n_y and A

$$F_1 = A\frac{S_o}{R^2}cos(i_1)$$

$$F_2 = A\frac{S_o}{R^2}cos(i_2)$$

$$F_3 = A\frac{S_o}{R^2}cos(i_3)$$



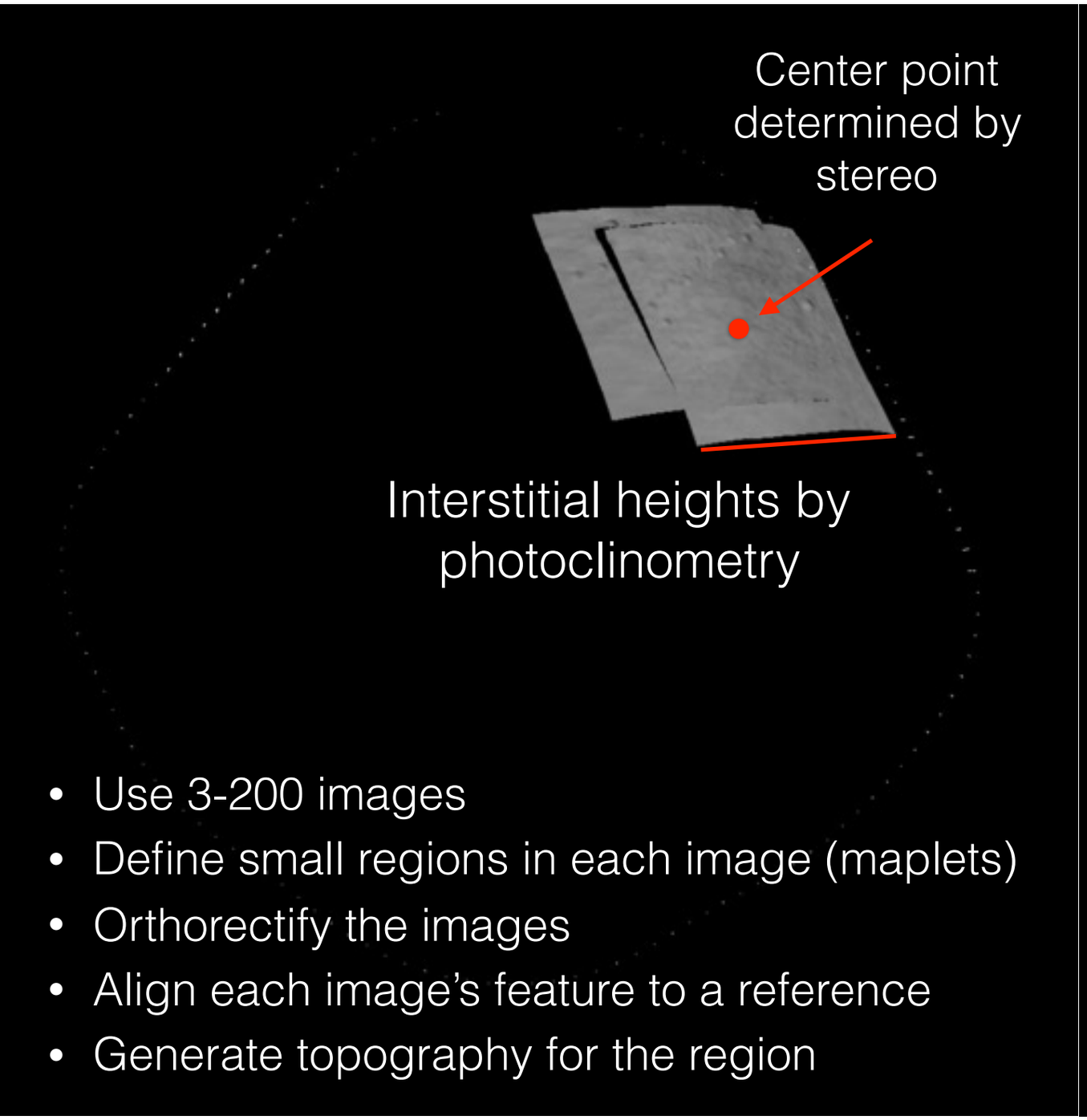
SPC's improves standard photoclinometry

- 2D solutions — 1D solutions could cause error if the line was not allow the maximum slope. SPC avoids this because it solves for the entire surface

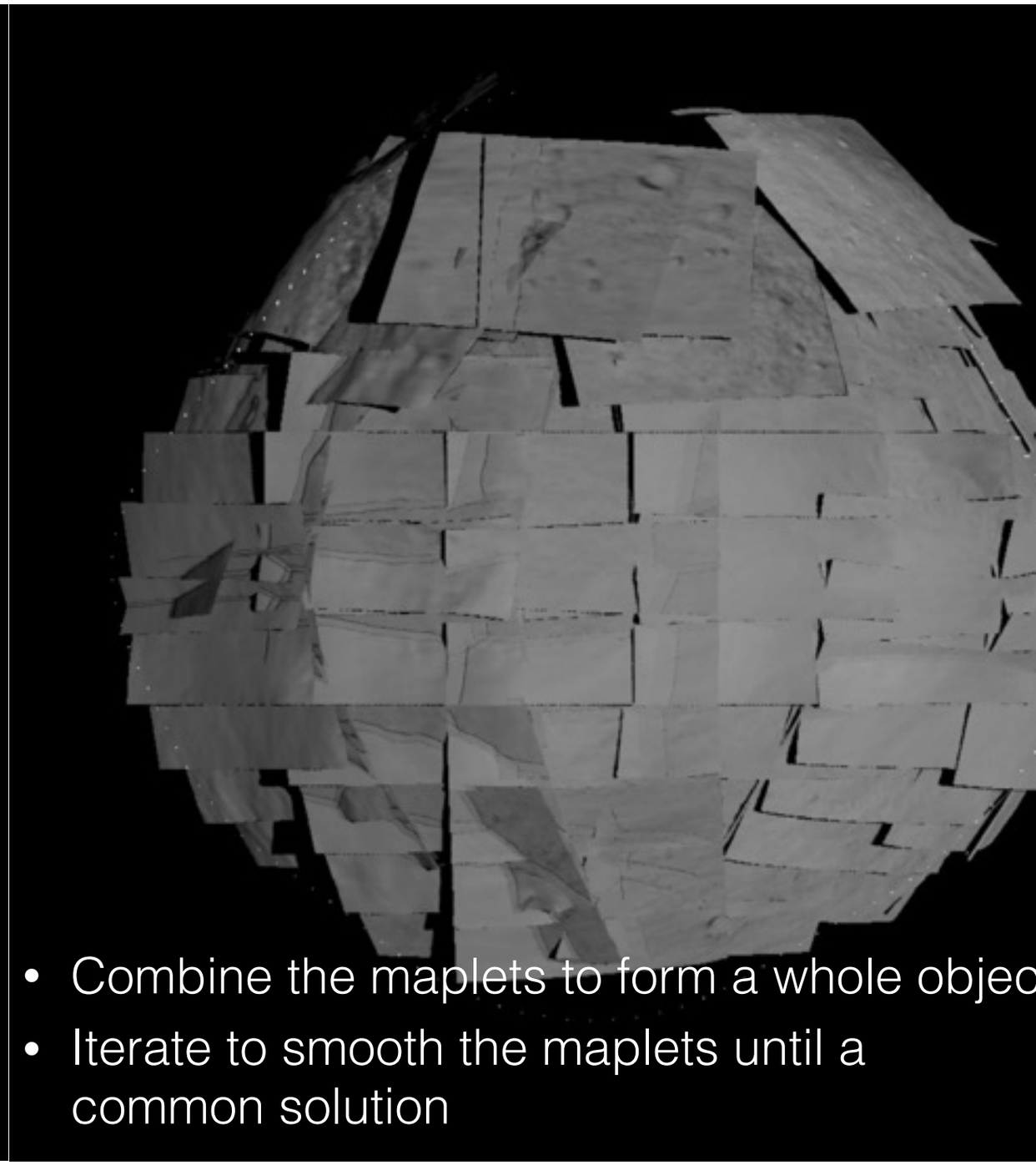
- Solve for albedo — Standard photoclinometry assumes a uniform albedo. SPC solves for the albedo on a pixel-to-pixel basis.

- Multiple images — SPC uses multiple images taken with different phase angles. This reduces the impact of noise, cosmic rays, blur and the photometric response of the surface.

Generate Small Maps



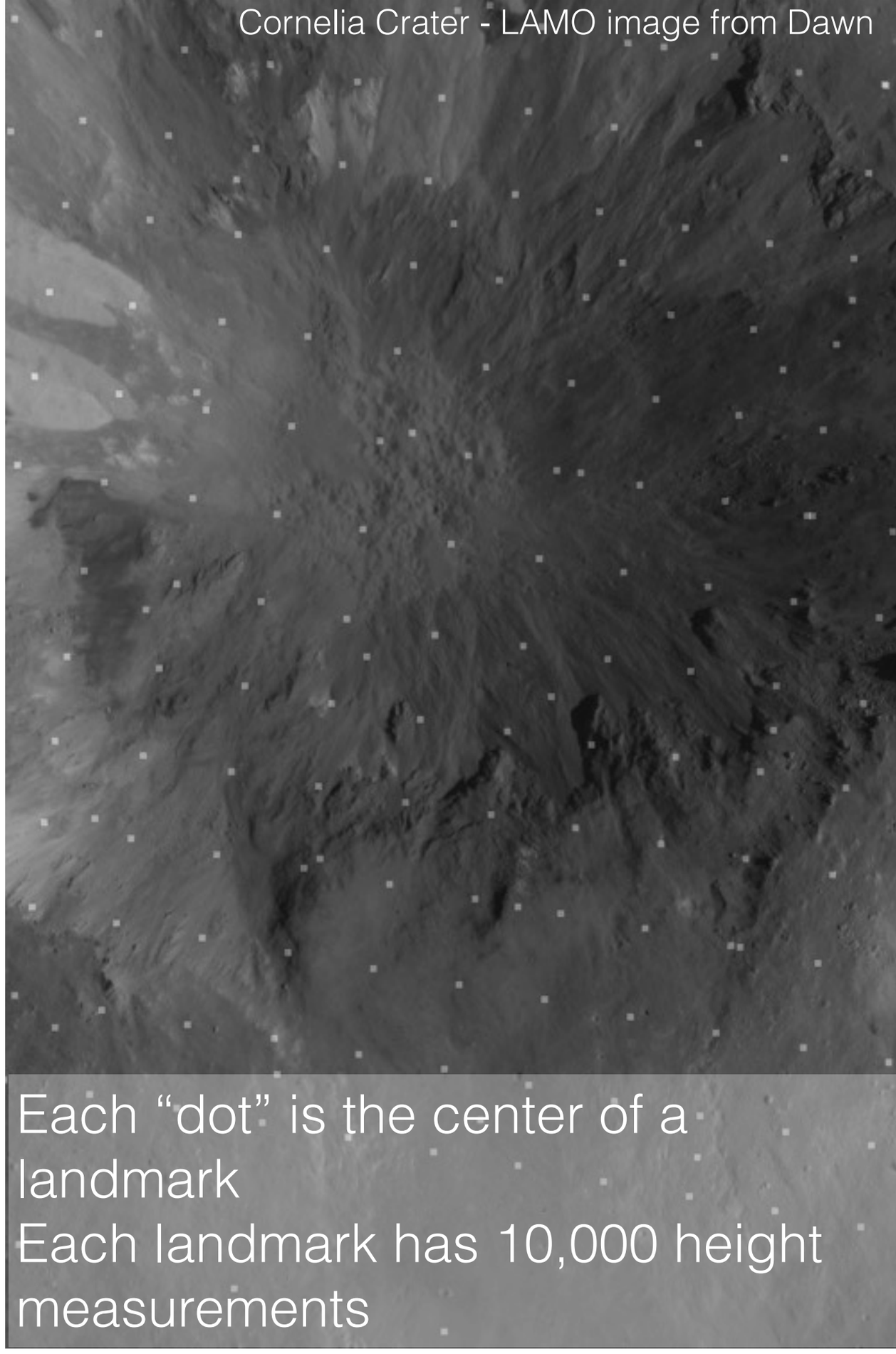
- Use 3-200 images
- Define small regions in each image (maplets)
- Orthorectify the images
- Align each image's feature to a reference
- Generate topography for the region



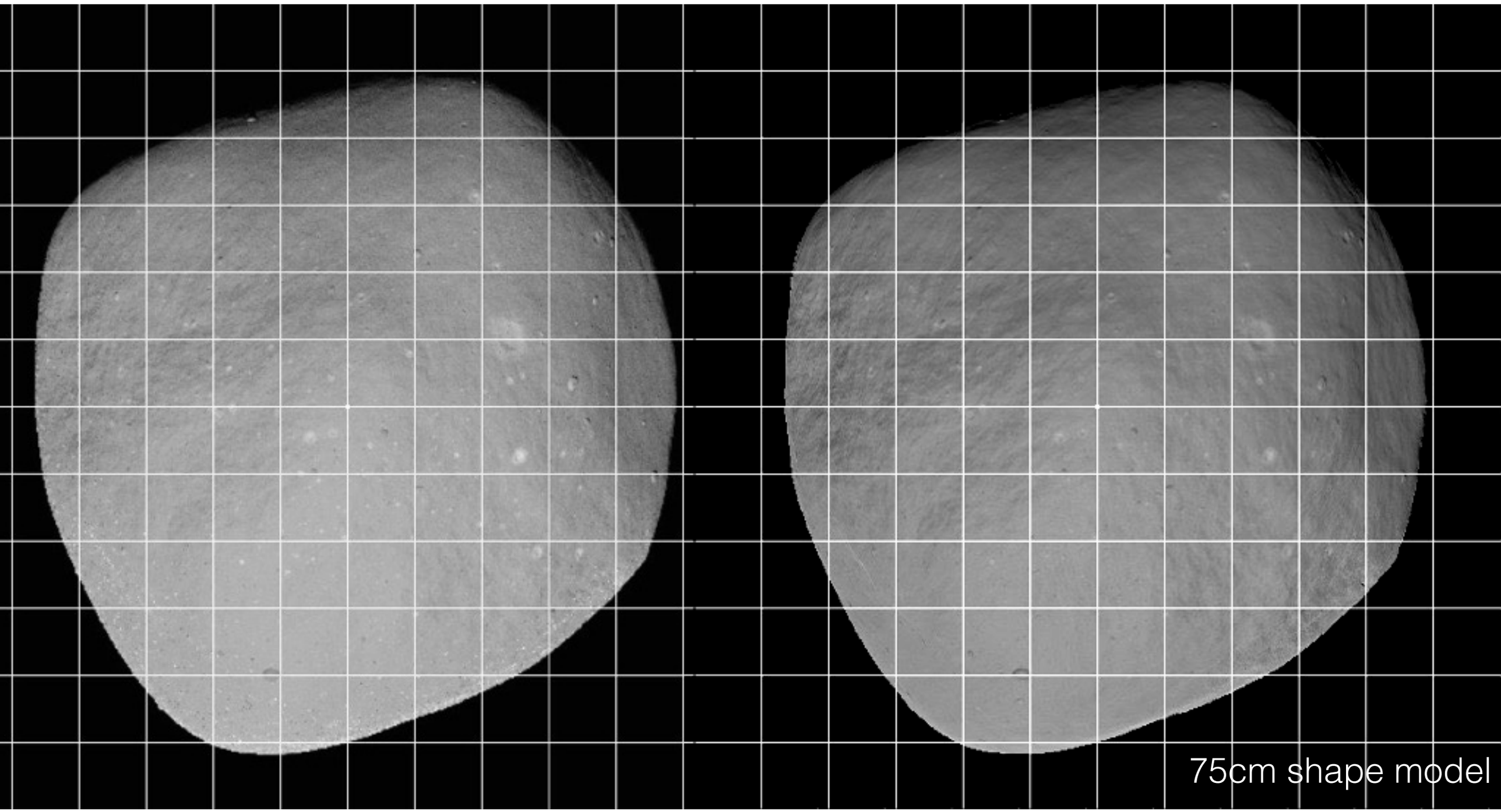
- Combine the maplets to form a whole objec
- Iterate to smooth the maplets until a common solution

Control Points

- Results every image has numerous control points (landmarks)
- These control points allow us to update spacecraft position and pointing (same as a bundle adjustment)
- Each landmark has numerous (50+) images the over constrain the solution



Example result from OSIRIS-REx testing.



Spacecraft image

Model

Increasing Resolution Example

We solved for topography at 5 cm ground sample distance (resolution)

Increasing Resolution Example

Extra processing

Improved these regions at 1 cm ground sample distance
Better images yield better topography

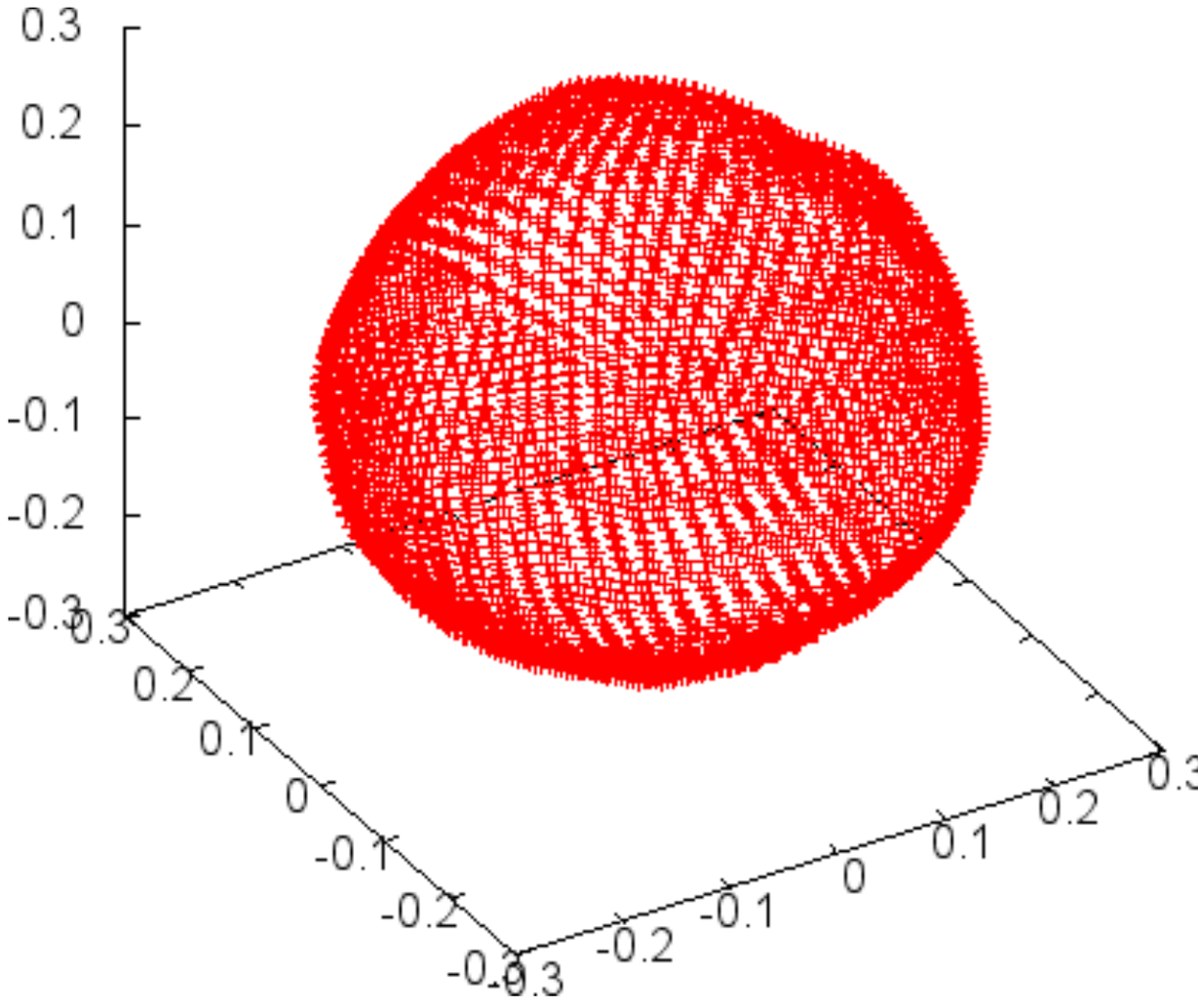
Background Concepts

- DTM

- MAPLETS

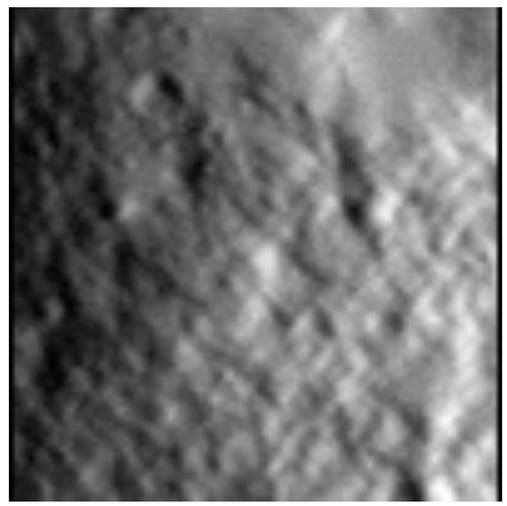
DTM formats

- Scope
    - Closed surface (global)
    - Regional (flat map)
- Types of models
    - Triangular plate model. This has connections between vertices
    - Point Cloud. This is just a list of vectors with no defined connections
- Formats
    - Vector Plate - Used by PDS
    - OBJ - Used by AltWG (APL). Common for 3D printing
    - ICQ - Intrinsically Connected Quadrangle. Used by SPC.



What is a MAPLET

- Maplet vs Landmark - they always come in pairs
- Maplets - data
    - Vectors to the center and normal
    - Height (displacement from the normal plane)
    - Albedo
- Landmark — metadata
    - Coordinates
    - Pictures
    - Neighboring maplets



```
AA0001   T
     49   0.0007500                              SIZE, SCALE(KM)
      -1       -1       -1       -1                    HORIZON
   0.3750000000D-03   0.2120871348D+00                    SIGKM, RMSLMK
   0.7974410662D-01  -0.5741905971D-03   0.2454077806D+00   VLM
   0.9149619937D+00  -0.2081362344D-01  -0.4030028582D+00   UX
   0.2381833643D-01   0.9997133017D+00   0.2444690093D-02   UY
   0.4028364420D+00  -0.1183565613D-01   0.9151954651D+00   UZ
   0.3469010368D-03   0.3725367318D-03   0.6954701621D-03   SIGMA_LMK
PICTURES
P595902930F0   467.45   640.43
P595903597F0   516.23    40.80
P595904281F0   596.99   693.50
P595904947F0   713.34    70.80
P595905631F0   854.09   689.53
P595917125F0   368.92    62.17
P595978335F0   921.60   212.77
M595949288F0   350.24   622.09
M595949718F0   360.75   656.44
OVERLAPS
END
```

SPC Functions

- 4 Major Functions
    - Importing images
    - Landmarks
    - Batch processing
    - Using the data

Importing Images

Bring in images

process_fits
make_sumfiles
lithos - tuck

Correct Flight

dynamics

Support Files:

PICTLIST.TXT
coverage_p
LIST.TXT

Gross alignment

register

Batch

Connect landmarks

autoregister

Batch

Parallel

Landmarks

Create

Create
Load images
Eliminate images manually, auto, correlation
Save

Modify

Adjust size
Rename
Delete
Heights from shape, Z, bigmap

Template

Select by correlation
Select manual
Make template

Align

Align to picture
Manual
Auto align

Overlap

Auto overlaps

Topography

Generate
Save
Center vector

Support Files:

LMKLISTX.TXT

Batch Processing

Landmarks

Bigmap
Map_coverage
Make_tilefile
Make_scriptT
Find_nofitT

Topography

Duplicates
make_lmrklistX
Make_scriptP
LithosP
Find_nofitP

Support Files:

make_scriptA/P/R.seed
make_script.in
map_coverage.pgm
<landmark>.INN

Multiple computers

Export
Import
Make_scriptF
Find_nofit

Using the Data

Visualization

SpheremapB
Display
Mosaic
Panorama
Surface_Imager

Shape

Dumber
Densify
DensifyA

Support Files:

MAPINFO.TXT
PICTINFO.TXT
LMKINFO.TXT
SHAPE.TXT
POLE.TXT
RESIDUALS.pgm

Analysis

Geometry
Residuals
Shape_info - volume, center of figure

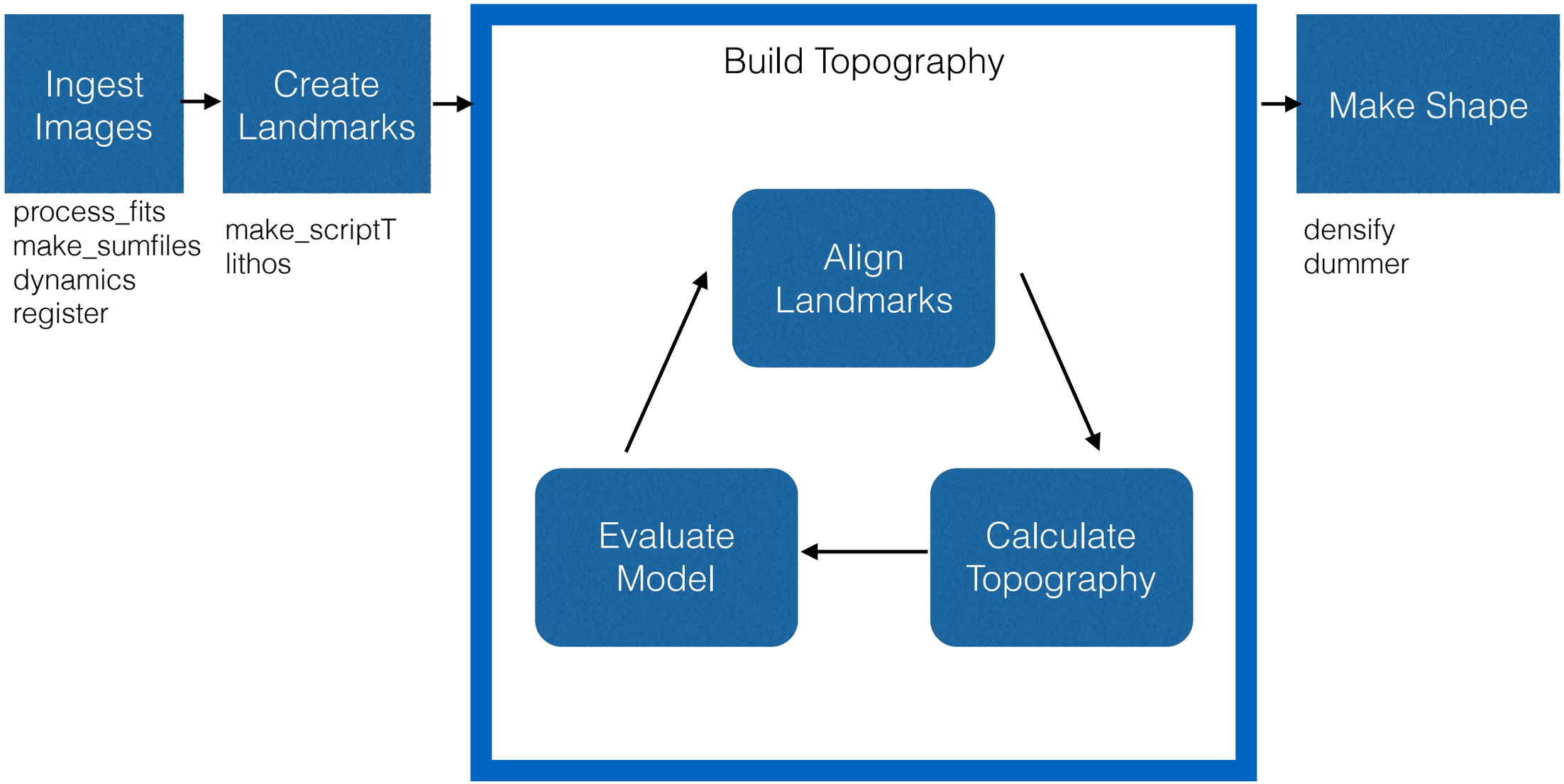
Navigation

Regres
Pole
Omega

Workflow

- Initial Load
- Adding Images
- Increasing Resolution
- Fixing Problems

Stage I Initial Load



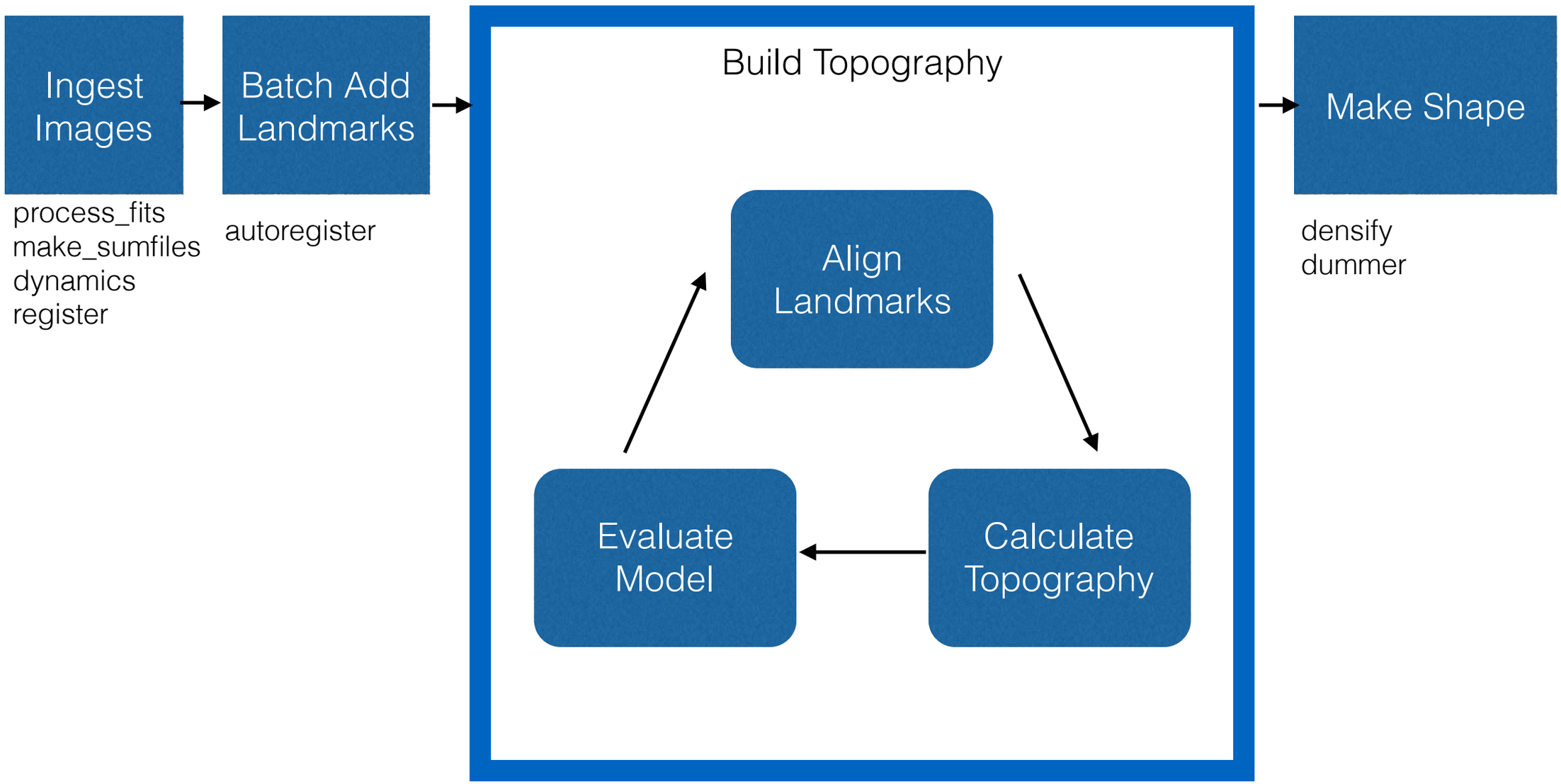
process_fits
make_sumfiles
dynamics
register

make_scriptT
lithos

make_scriptP
lithos
residuals
geometry

densify
dummer

Stage 2 Adding Images



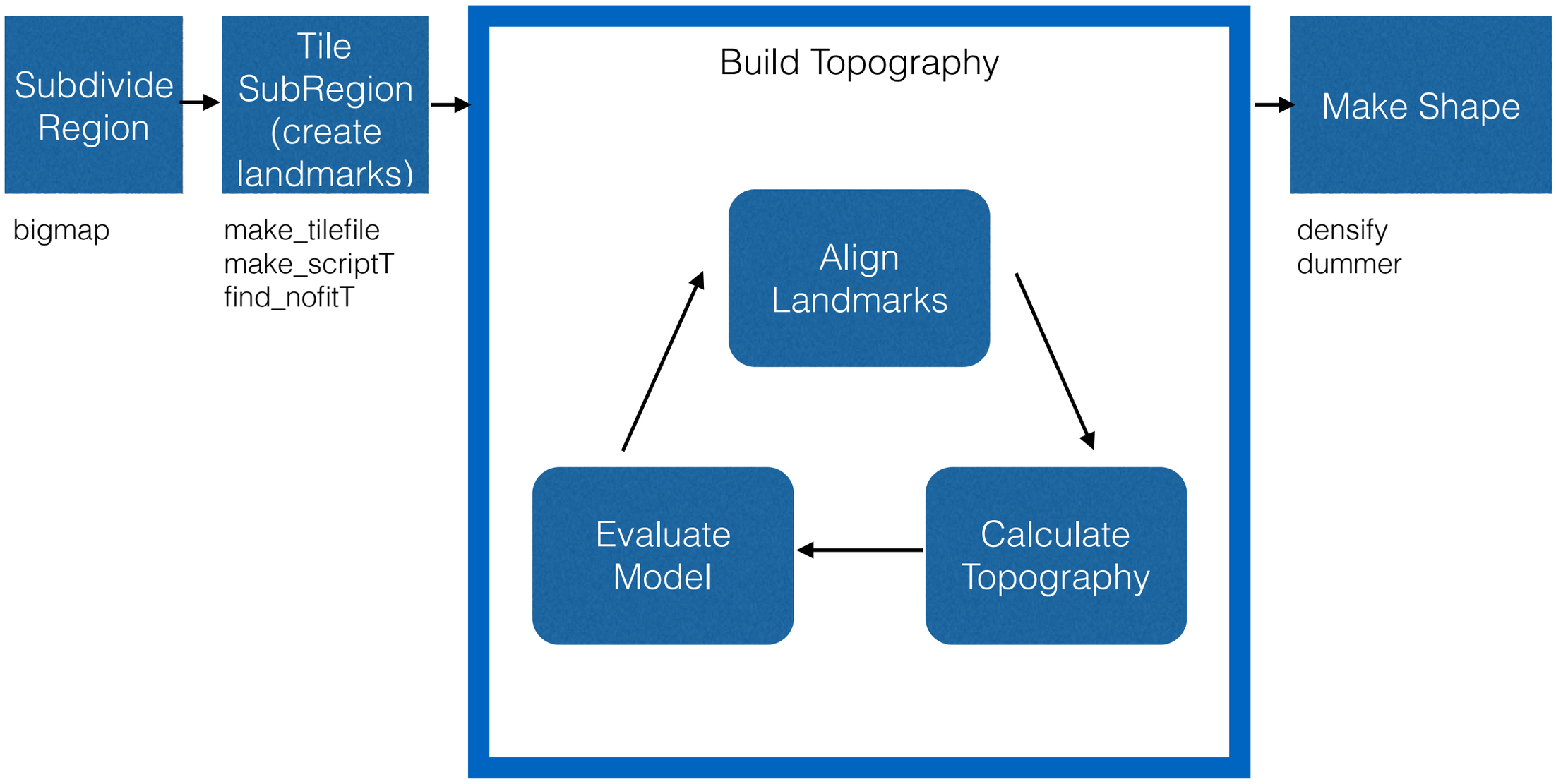
process_fits
make_sumfiles
dynamics
register

autoregister

densify
dummer

lithos
register
geometry
make_scriptP
find_nofitP

Stage 3 Increase Resolution



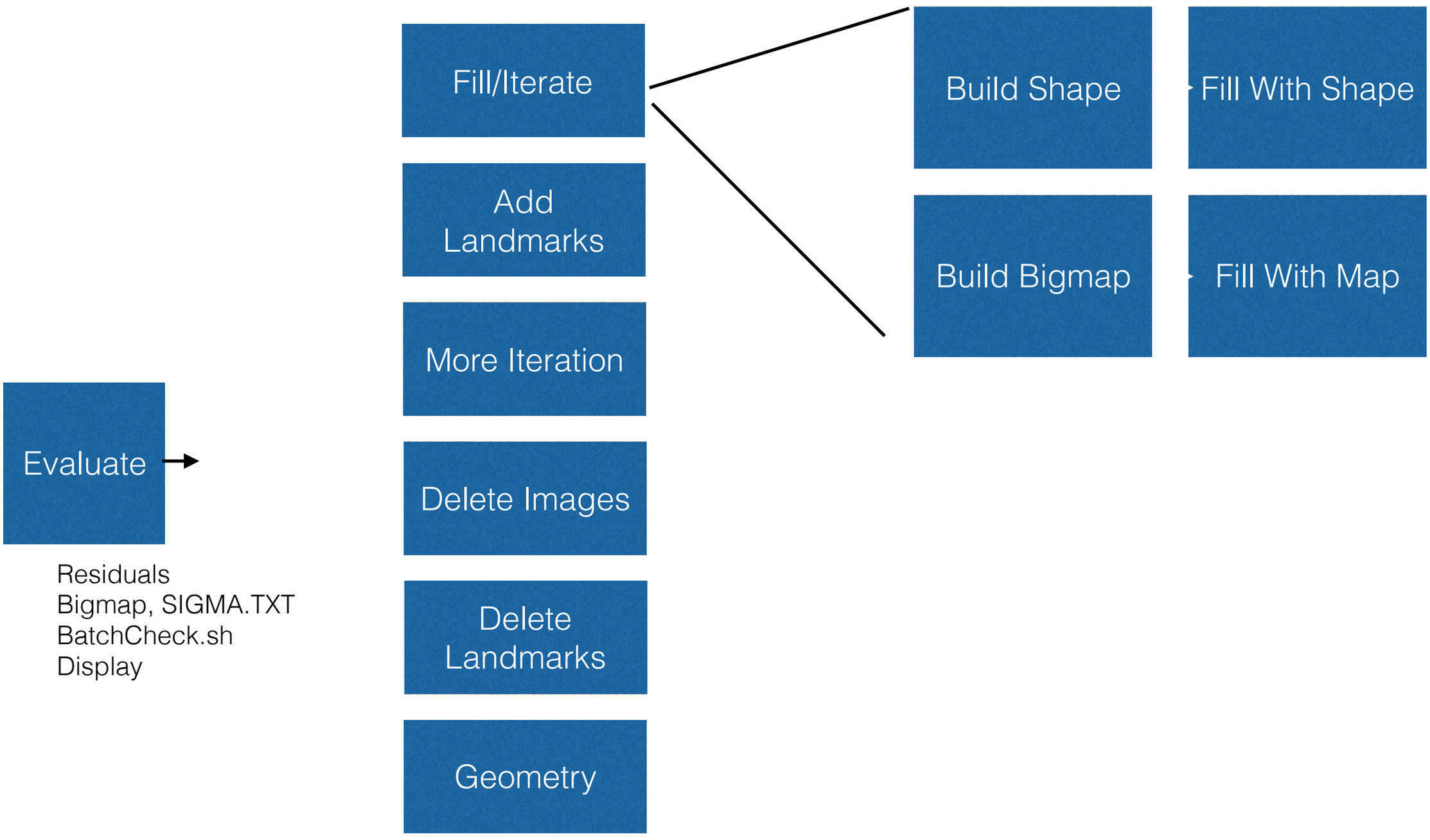
bigmap

make_tilefile
make_scriptT
find_nofitT

lithos
register
geometry
make_scriptP
find_nofitP

densify
dummer

Stage 4 Problems



Helpful Info

(you might want to print these)

Conceptional File Structure

Control Points

LMKLIST.TXT

- LANDMARKS
- MAPFILES

Images

PICTLIST.TXT

- IMAGEFILES
- SUMFILES
- NOMINALS

Shape

SHAPEFILES

- SHAPE.TXT
- SHAPE00.TXT

Configuration

INIT_LITHOS.TXT

make_sumfiles.txt

make_sumfiles.in

File

Directory

Detailed File Structure

- MAPFILES - stores the topography
    - AA0001.MAP - Binary file of center vector, normal plane, delta height and albedo
- LMKFILES - stores the metadata
    - AA0001.LMK - Metadata, images, limbs, overlaps
- SHAPEFILES - Reference shape models
- IMAGEFILES - Binary version of the images
- NOMINALS - Unmodified S/C position and pointing
- SUMFILES - Metadata on the images
    - Landmarks, limbs, S/C position, pointing, Nav uncertainty
- INIT_LITHOS.TXT - configuration file
- PICTLIST.TXT - list of images
- LMRKLIST .TXT- list of landmarks
- (more info at the wiki: http://sbib.psi.edu/spc_wiki/HomePage)

Nomenclature

- All of SPC is in **West Longitude**
- IAU requires asteroids to be in **East Longitude**
    - As you travel to the east, longitude values increase

A- 340-360° W Lon
B- 320-340° W Lon
C- 300-320° W Lon
…..

- Maplet/Landmark names
    - Example: DF0000.LMK
    - D is latitude
        - 20° bins. Valid range A-I
    - F is longitude
        - 20° bins. Valid range A-R

A - N pole
E - N. Equator
F - S. Equator
J - S. Pole

Some Useful Commands

- **How to see a pgm file**
    - **/usr/local/bin/Display**
    - **convert <file.pgm> <file.jpg>**
    - **xv**
    - **ImageMagick display (/opt/local/bin/display)**
    - **GraphicConverter**
- **Recently changed files**
    - **ls -lt l head**
- **Copying large directories**
    - **rsync -hapvP ormacsrv1.lpl.arizona.edu:/SPC_Test/PrevBennuTrng .**
- **Watch a log file**
    - **tail -f <filename>**

Fin

Stereo Error

- Assume
  - 1/10 subpixel registration error
  - 20 meter resolution imagery

Stereo Angle	dy Error
6°	19.0m
12°	9.4m
20°	5.5m
40°	2.4m
60°	1.2m
75	0.5m
89	0.03m