Digital **R**epresentation **E**nvironment for **A**nalysis of **M**icrostructure in **3D**

dream3d.bluequartz.net

Mr. Michael A. Jackson
Owner
BlueQuartz Software

2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

Acknowledgements

Mike Groeber (AFRL)

- Funding (AFRL & NRL)
  - Contract FA8650-07-D-5800
  - Contract FA8650-10-D-5210
  - Contract N00173-07-C-2068
- Code, Ideas, Vision
  - The Ohio State University
  - Carnegie Mellon University
- Anyone who has
  - Tested
  - Provided Feedback
  - Bug Reports
  - Data
  - Corrections
  - Discussions

Development Team

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Dr. Mike Groeber

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Algorithms

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GUI, Design, "CS" Stuff

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Dr. Mike Groeber

Mushy Zone

Algorithms

Topics

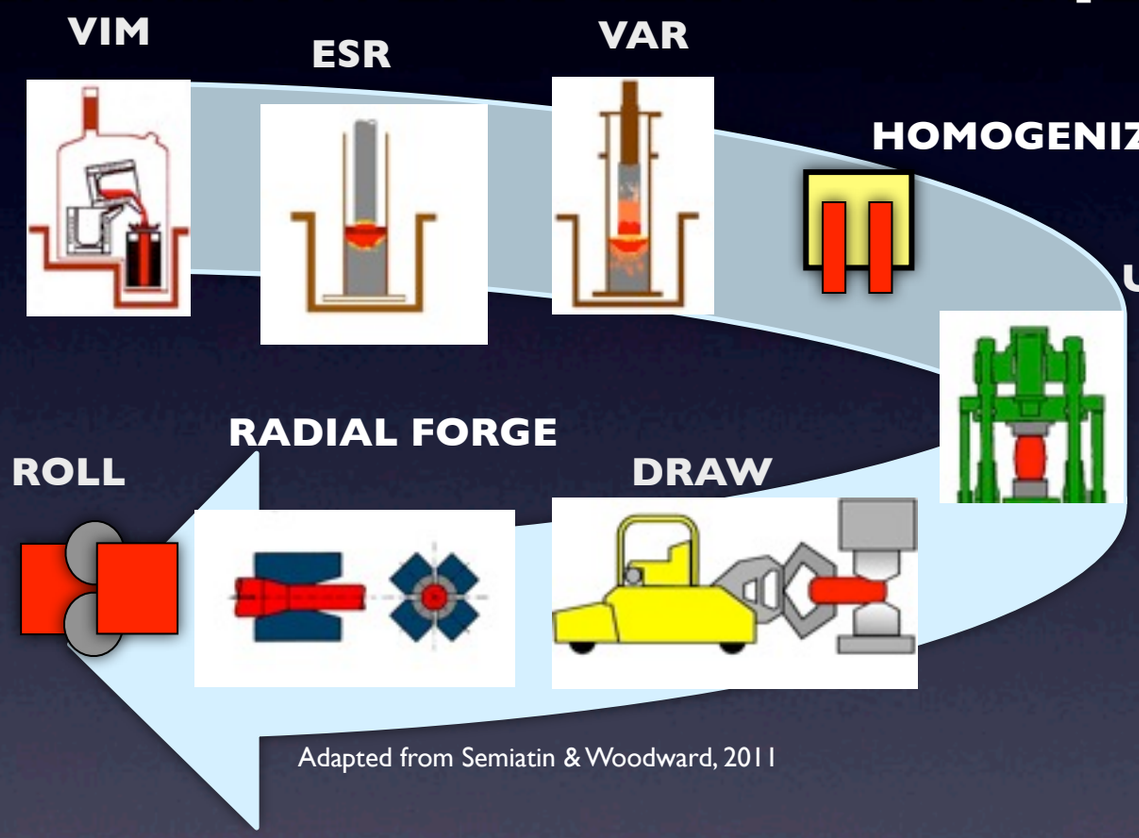
- What is DREAM3D?
- What DREAM3D is NOT
- Examples
- 2D/3D reconstruction & analysis
- Surface Meshing Algorithms
- Synthetic Microstructure Generation

What is it?

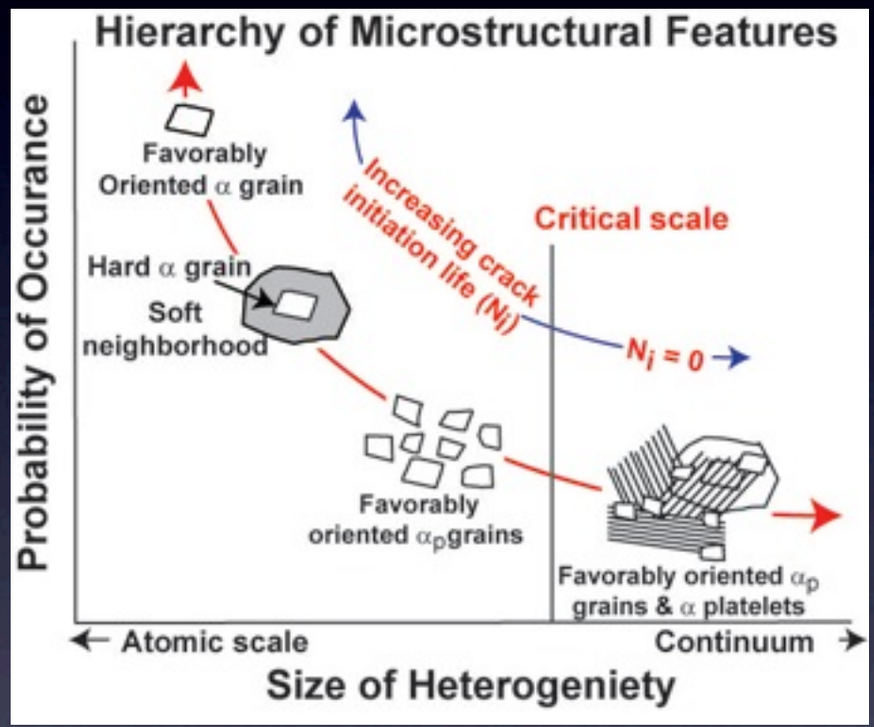
Environment that integrates algorithms in such a way as to allow those algorithms to communicate inputs and outputs between them.

The Motivation for DREAM.3D

Understanding, accounting for and/or utilizing anisotropy and inhomogeneity in materials is critical in the engineering design process



Adapted from Semiatin & Woodward, 2011



Adapted from Larsen & Woodward, 2011

Each processing step affects μ/s, properties & performance

Each μ/s feature contributes to properties & performance

Must control processing & predict microstructure across scale of component

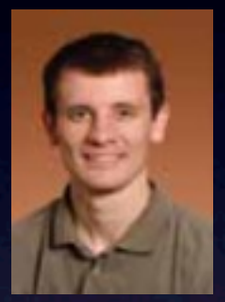
Must understand microstructure effects & predict response for gambit of microstructures

The Evolution to DREAM.3D

Significant, isolated work completed by multiple researchers on different programming platforms and with different data formats

Initial "MBuilder" Created

"SIRI-3D" Created



Various MBuilder Advances

General 2D-3D Demonstrated

Surface Meshing Code Developed

Twin Insertion Code Developed

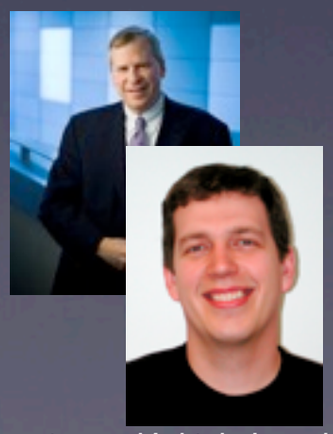
Extreme Values Addressed

2003 2005 2007 2009 2011 2012

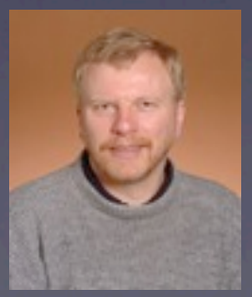
Serial Sectioning Code Developed

Reconstruction Code Developed

5-Parameter GBCD Codes Developed



Demonstration of Data Fusion for Microstructure



Beginning of Integration & First GUI-based Microstructure Tool

Microstructure Design Tool

What DREAM3D is NOT?

- Direct Visualization
  - Use another more capable package
    - ParaView
    - Avizo Fire
    - MATLAB
    - IDL

Data Representation

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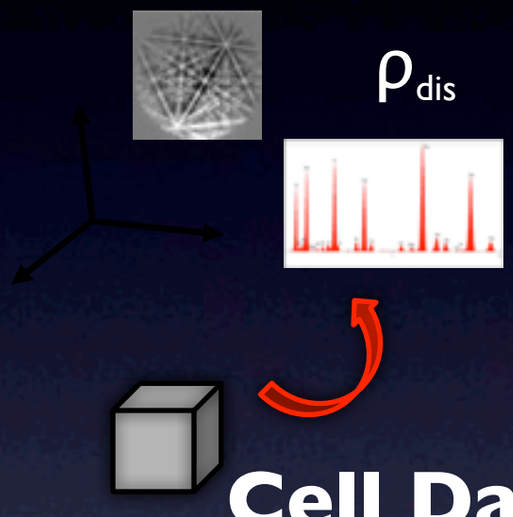
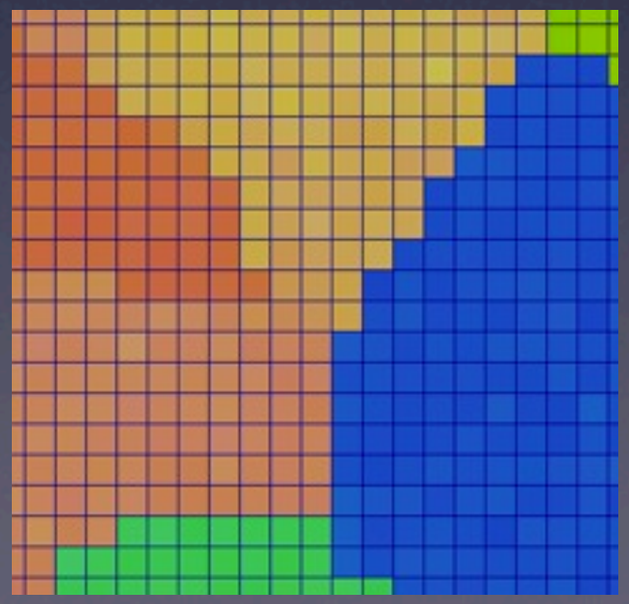
The Backbone of DREAM.3D

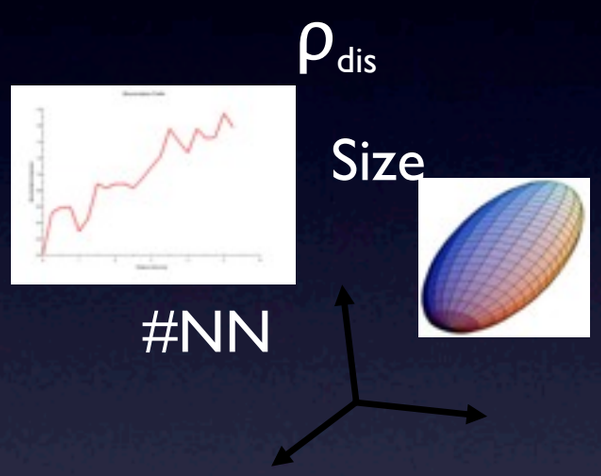
Hierarchy of microstructure features/gradients accounted for in extensible digital data structure

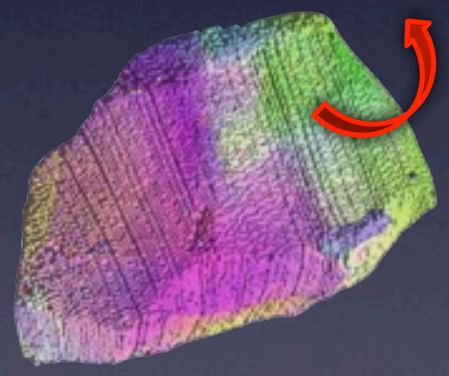


Cell Data

10E6 => 10E9

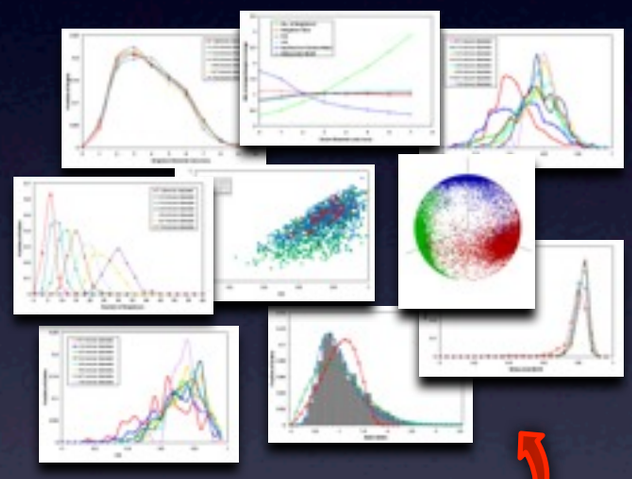


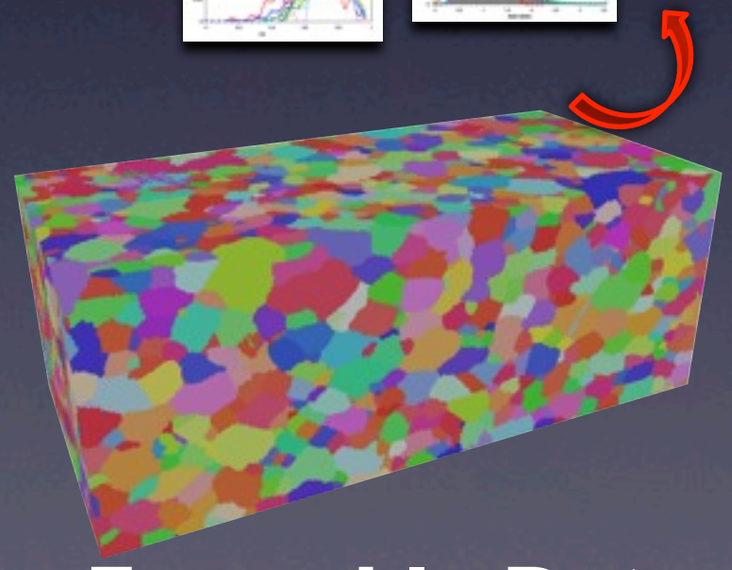




Field Data

100s – 1,000s
(100s – 1,000s of Cells)





Ensemble Data

1s
(100s – 1,000s of Fields)

Getting Data Into DREAM3D

- Input Data
  - TSL, HKL, HEDM for Orientation Data
  - Raw Binary Files
    - You describe it, DREAM3D can read it
  - H5Ebsd for archived Orientation Data
  - Ph, Dx with Grain Ids
  - Pre-Segmented Images ***

Getting Data Out of DREAM3D

- Voxel Based Export Formats
  - VTK Rectilinear Grids and Polydata (.vtk)
  - Xdmf file wrappers (.xdmf)
  - Avizo Rectilinear Grids (.am)
  - CSV File for Statistical data
  - Ph and Dx* files (CMU Legacy)
  - FFT Simulation Codes (Los Alamos)
  - Tif, Bmp, Png for Misc Images (IPF Color Maps)
- Triangle Based Exports
  - STL
  - VTK PolyData
  - XDMF
  - Nodes/Triangles/Edges Ascii Files
  - Abaqus File (Experimental)

HDF5

- Open Source & Free
- Built for LARGE quantities of data
  - 100s GB to TB sizes
  - Fully self describing
  - Rich meta data attachment
  - User selects how to organize the data
- Free HDFView to visualize and export data
- www.hdfgroup.org

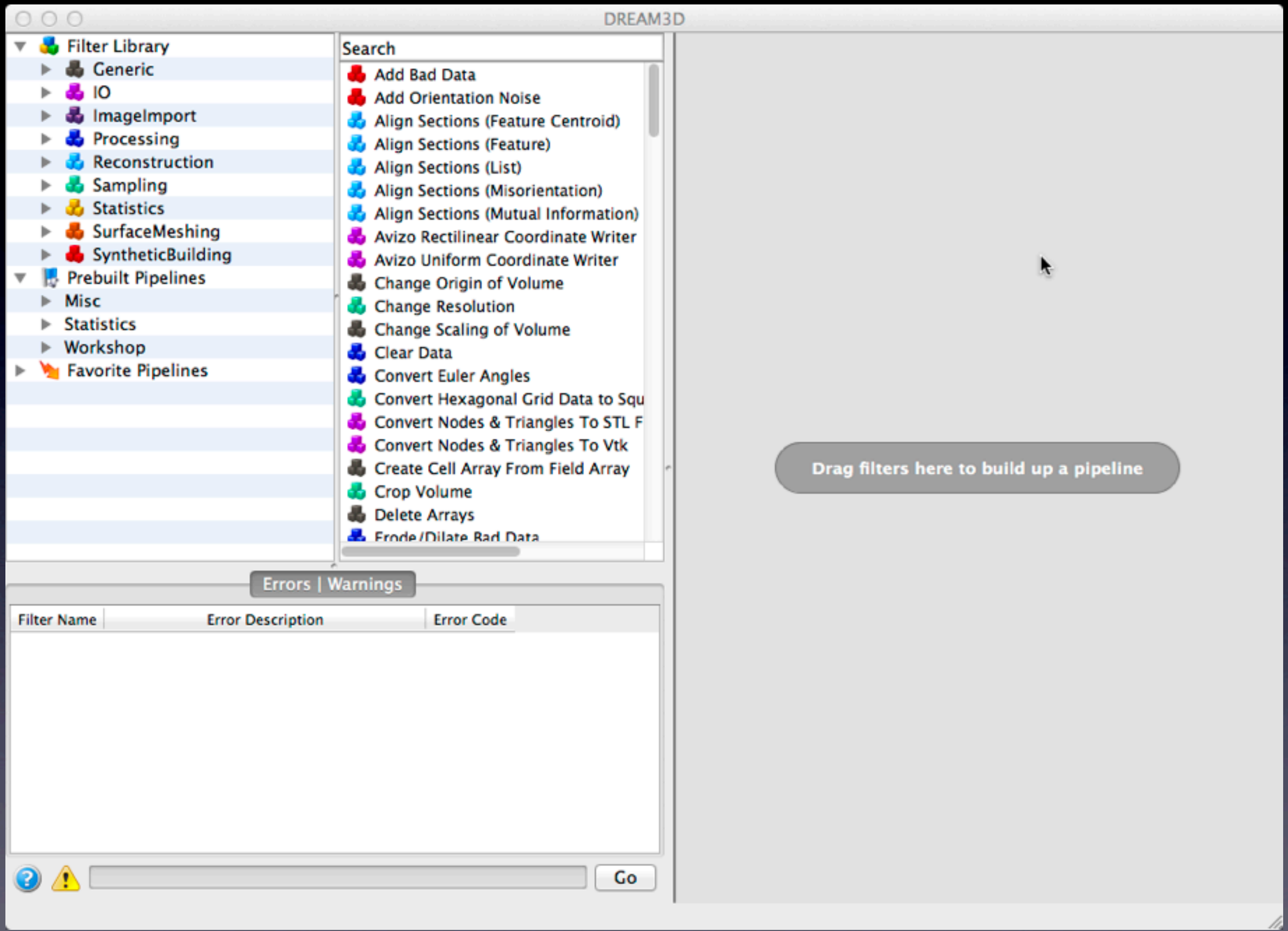
XDMF

- Small XML wrapper file
- Describes the grids used in DREAM3D
- ParaView has native support
- User can selectively load data
- Store BOTH Voxel and Triangle based representations
- HIGHLY recommended to use this file type instead of the .vtk files

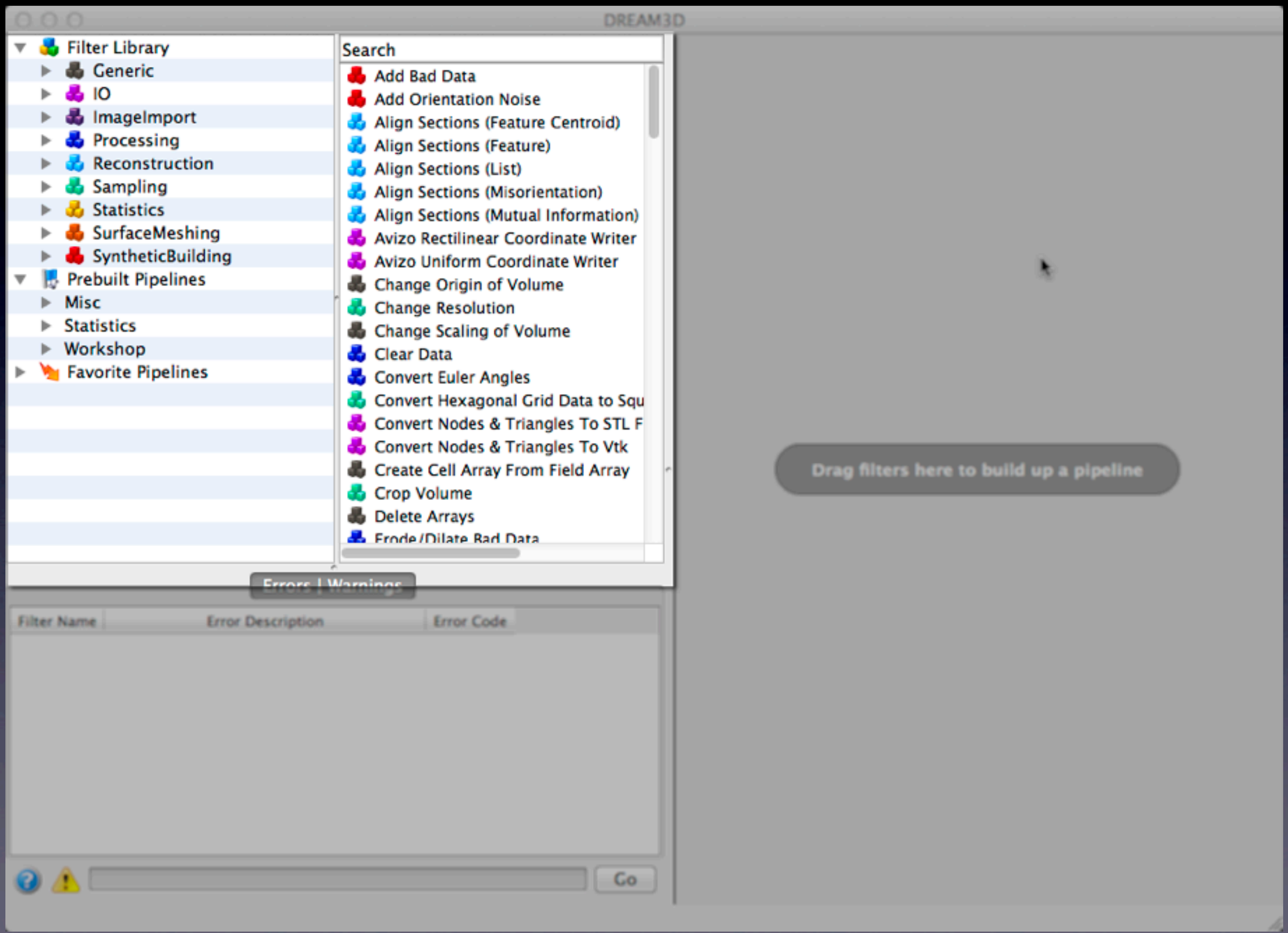
Caution !!

- DREAM3D is just a Tool
- Understand your data
  - Degrees or Radians?
  - Phases? Crystal Symmetry?
- Understand the algorithms
  - Is it appropriate for my data?
- GIGO:
  - Garbage In, Garbage Out

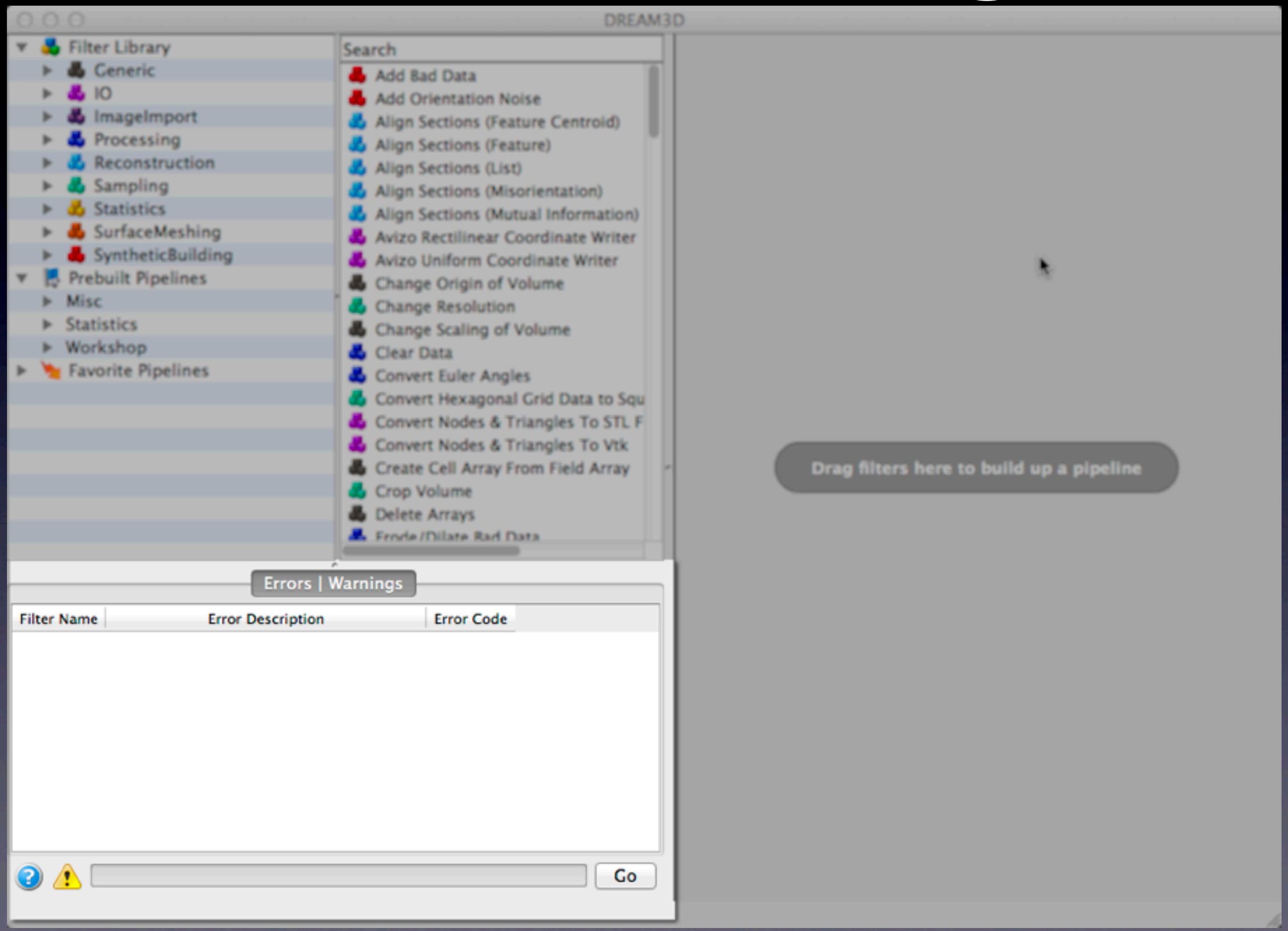
So, what does it look like?


DREAM3D
Filter Library
Generic
IO
ImageImport
Processing
Reconstruction
Sampling
Statistics
SurfaceMeshing
SyntheticBuilding
Prebuilt Pipelines
Misc
Statistics
Workshop
Favorite Pipelines
Search
Add Bad Data
Add Orientation Noise
Align Sections (Feature Centroid)
Align Sections (Feature)
Align Sections (List)
Align Sections (Misorientation)
Align Sections (Mutual Information)
Avizo Rectilinear Coordinate Writer
Avizo Uniform Coordinate Writer
Change Origin of Volume
Change Resolution
Change Scaling of Volume
Clear Data
Convert Euler Angles
Convert Hexagonal Grid Data to Squ
Convert Nodes & Triangles To STL F
Convert Nodes & Triangles To Vtk
Create Cell Array From Field Array
Crop Volume
Delete Arrays
Erode/Dilate Bad Data
Drag filters here to build up a pipeline
Errors | Warnings
Filter Name
Error Description
Error Code
Go

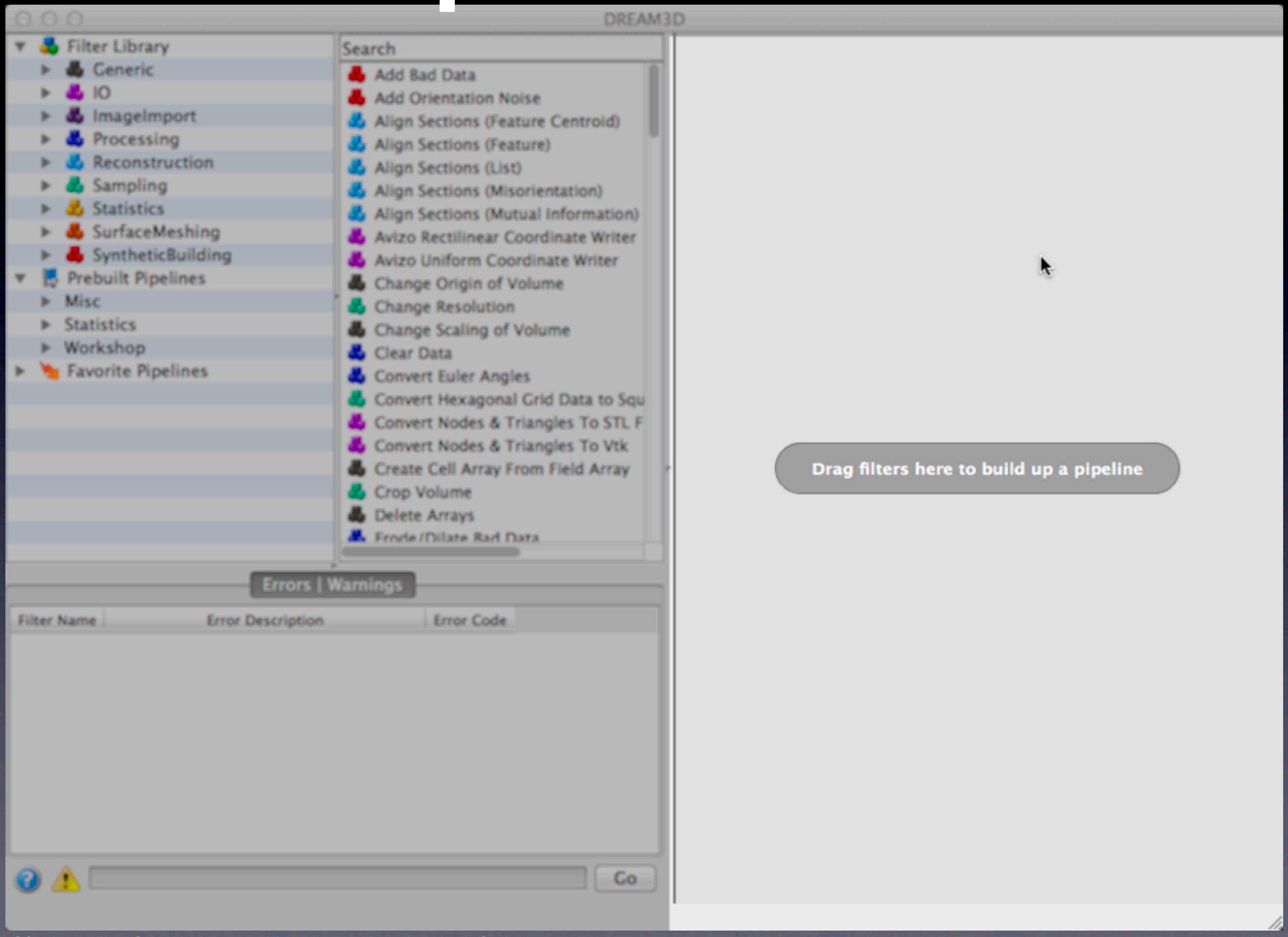
Filter Groups, Prebuilt & Favorites



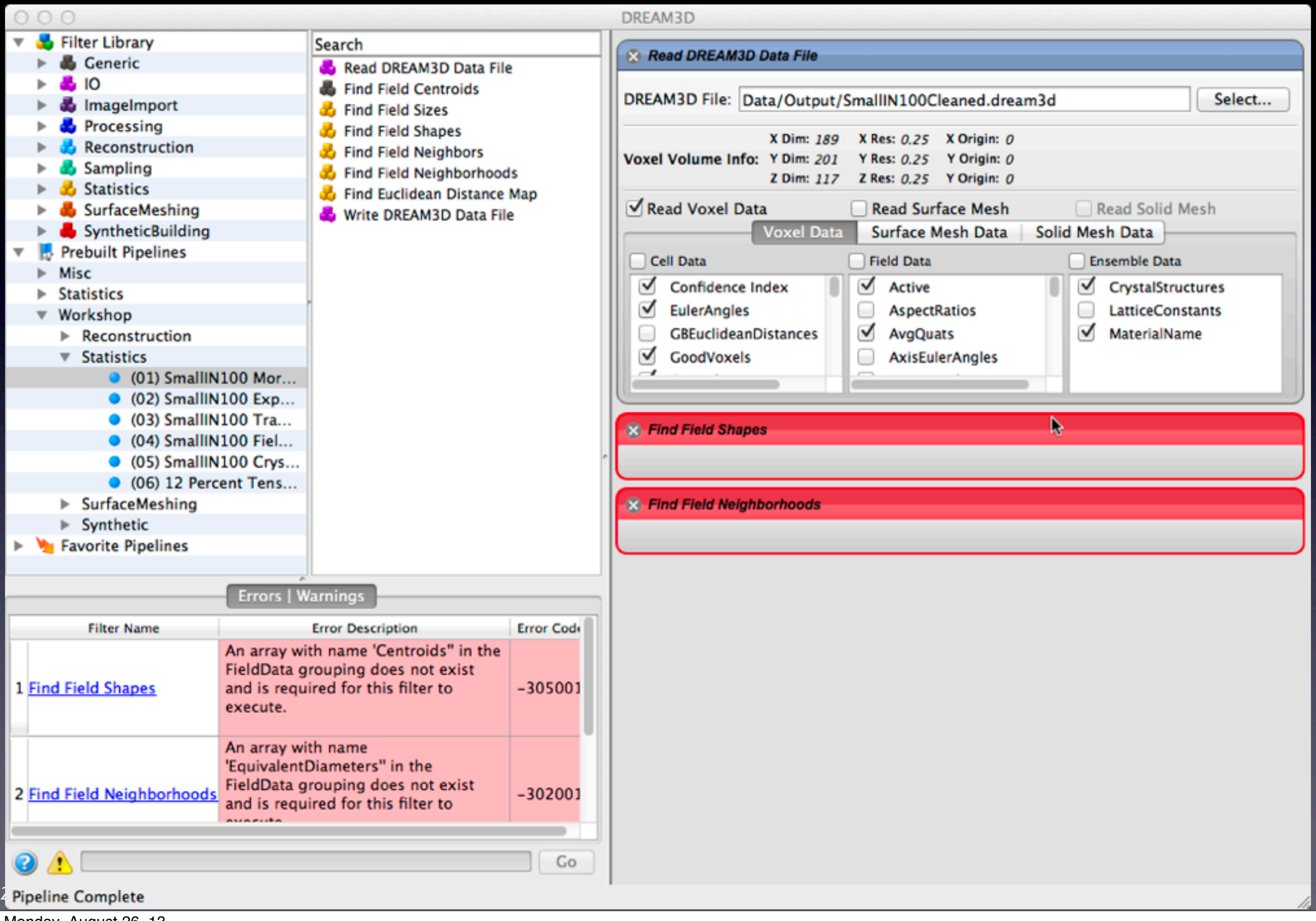
Errors & Warnings



Pipeline Area



Basics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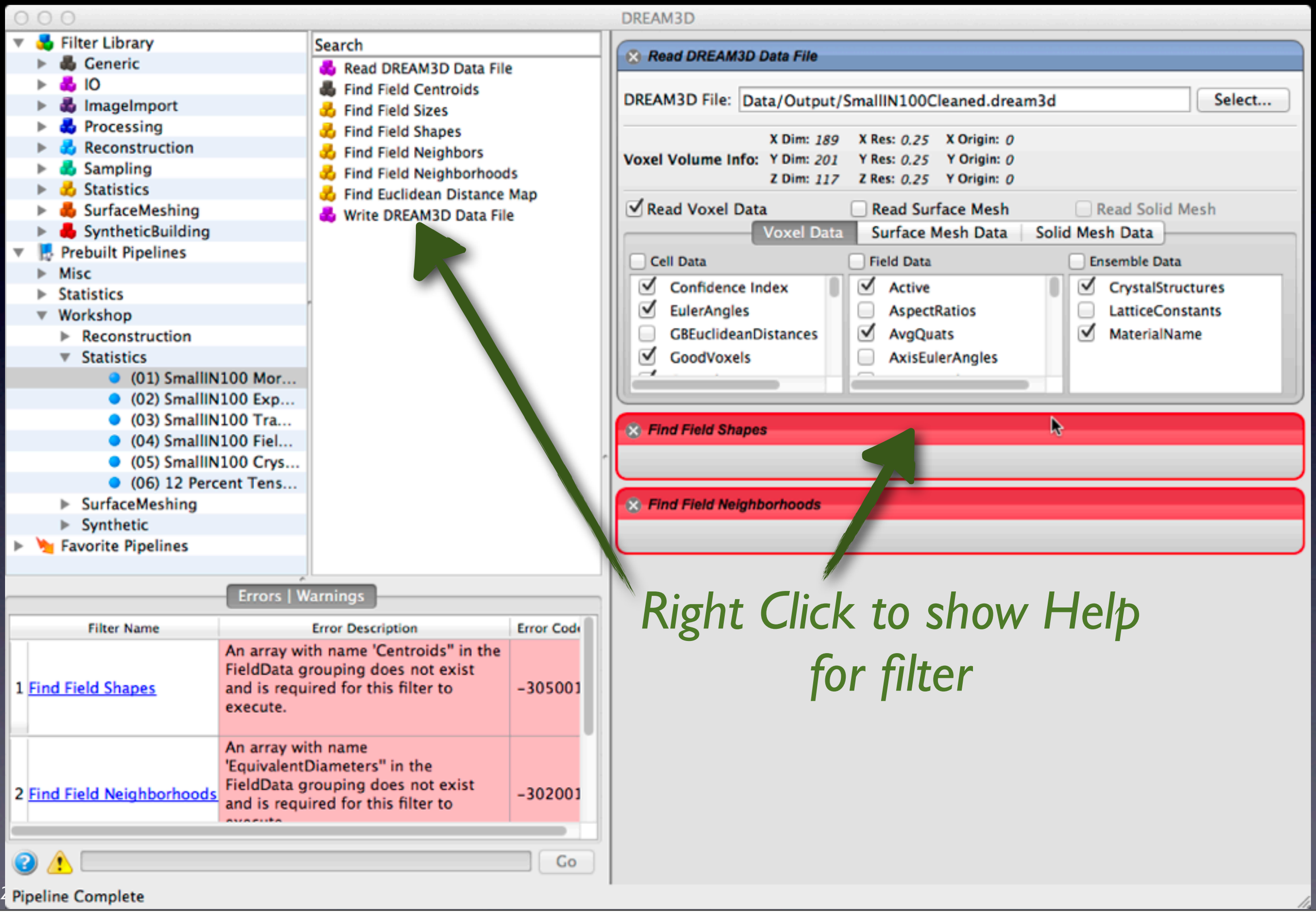
(01) SmallIN100 Mor...
(02) SmallIN100 Exp...
(03) SmallIN100 Tra...
(04) SmallIN100 Fiel...
(05) SmallIN100 Crys...
(06) 12 Percent Tens...
SurfaceMeshing
Synthetic
Favorite Pipelines
Search
Read DREAM3D Data File
Find Field Centroids
Find Field Sizes
Find Field Shapes
Find Field Neighbors
Find Field Neighborhoods
Find Euclidean Distance Map
Write DREAM3D Data File
Read DREAM3D Data File
DREAM3D File: Data/Output/SmallIN100Cleaned.dream3d
Select...
Voxel Volume Info: X Dim: 189 X Res: 0.25 X Origin: 0
Y Dim: 201 Y Res: 0.25 Y Origin: 0
Z Dim: 117 Z Res: 0.25 Y Origin: 0
Read Voxel Data
Read Surface Mesh
Read Solid Mesh
Voxel Data
Surface Mesh Data
Solid Mesh Data
Cell Data
Confidence Index
EulerAngles
GBEuclideanDistances
GoodVoxels
Field Data
Active
AspectRatios
AvgQuats
AxisEulerAngles
Ensemble Data
CrystalStructures
LatticeConstants
MaterialName
Find Field Shapes
Find Field Neighborhoods
Errors | Warnings
Filter Name
Error Description
Error Code
1 Find Field Shapes
An array with name 'Centroids" in the FieldData grouping does not exist and is required for this filter to execute.
-305001
2 Find Field Neighborhoods
An array with name 'EquivalentDiameters" in the FieldData grouping does not exist and is required for this filter to
-302001
Go
Pipeline Complete

Basics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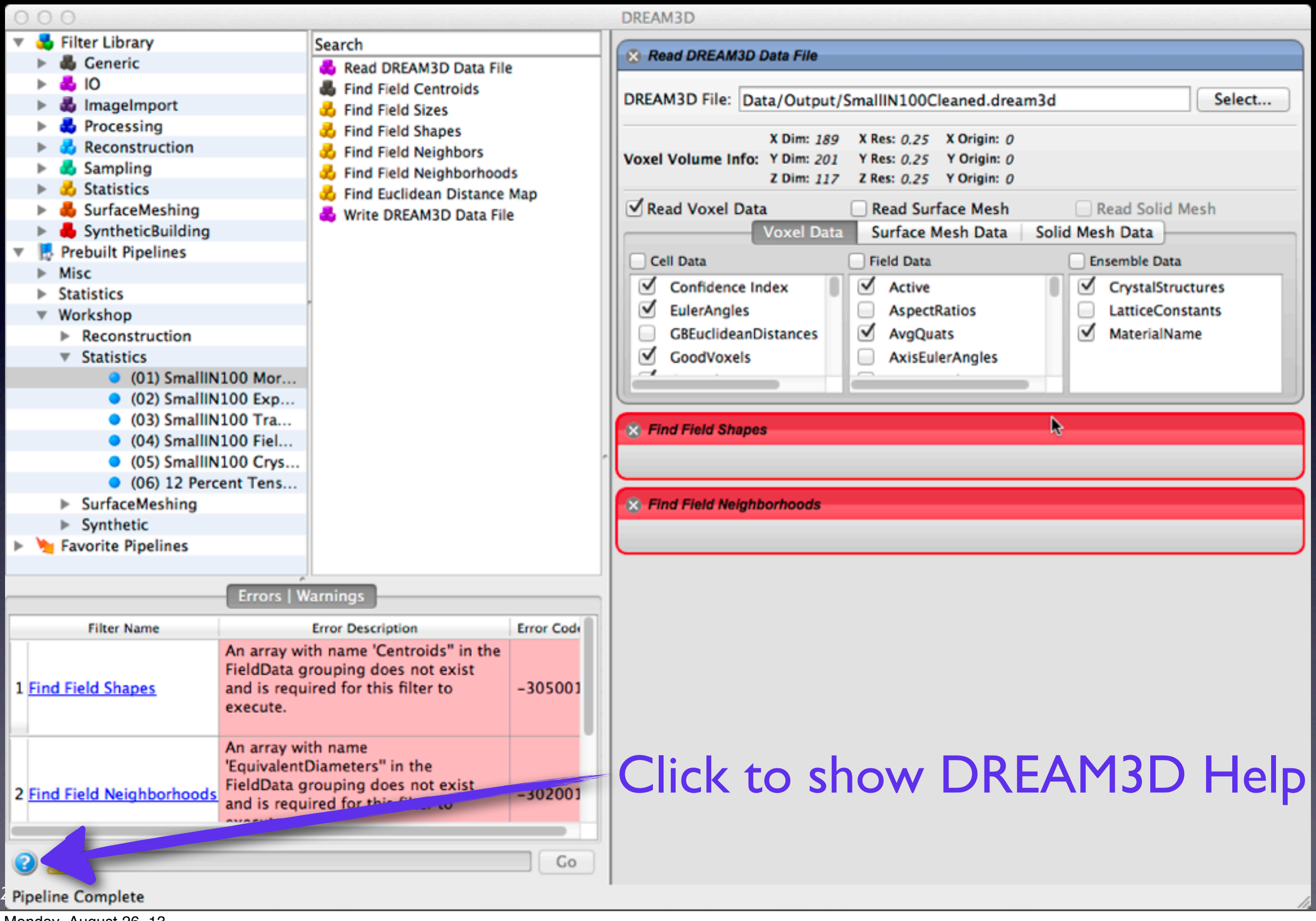
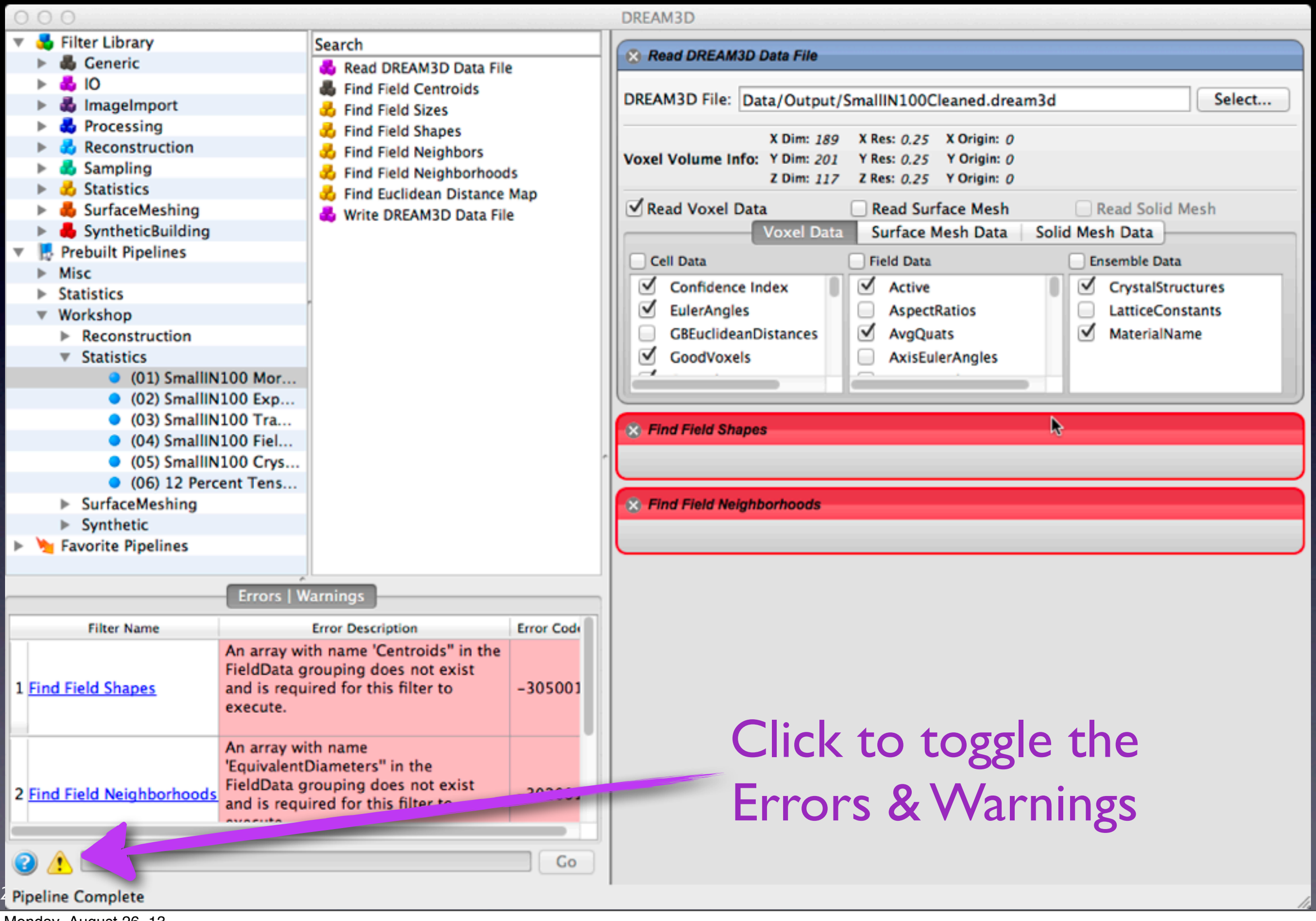
Right Click to show Help for filter

Basics



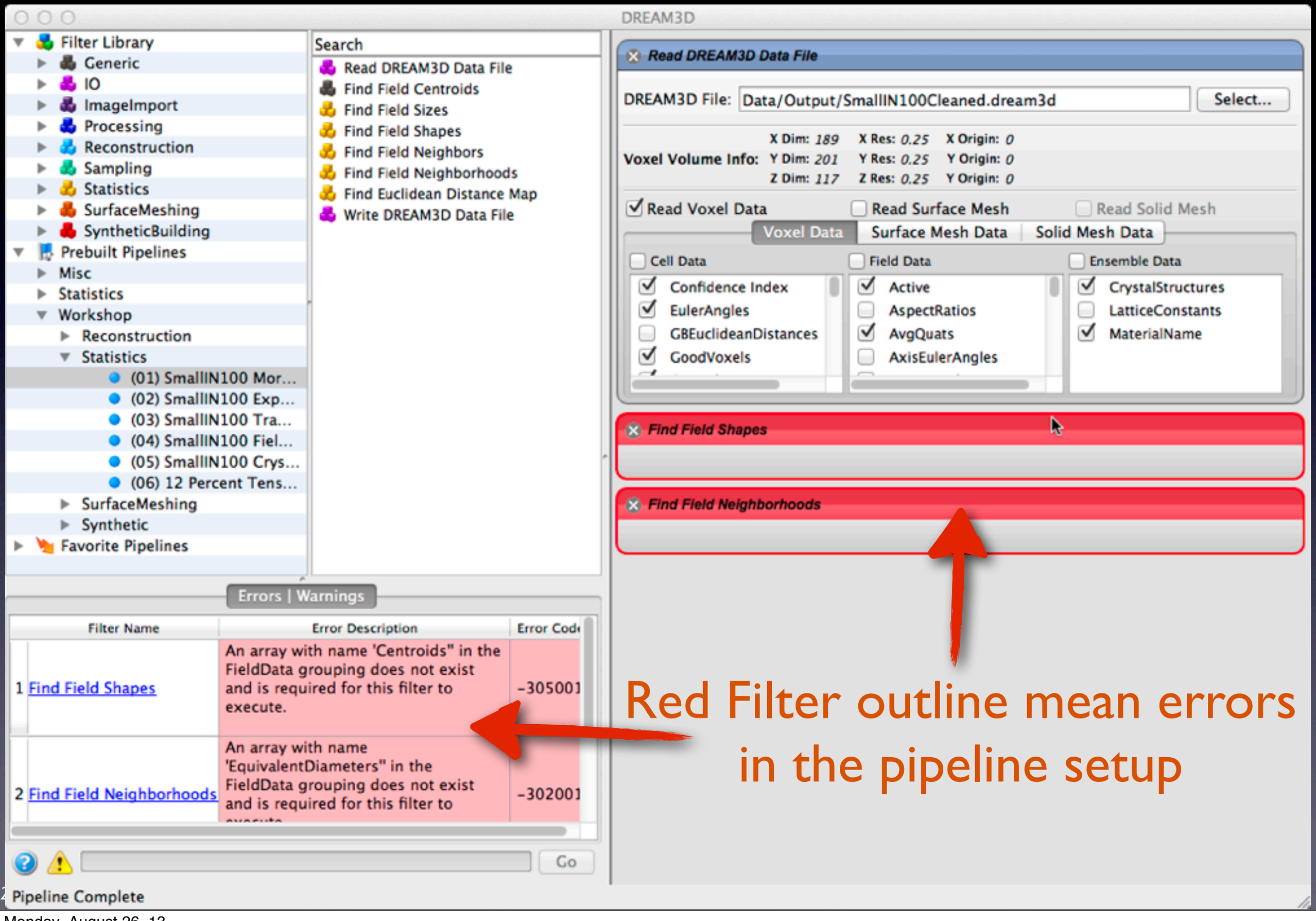
Click to show DREAM3D Help

Basics



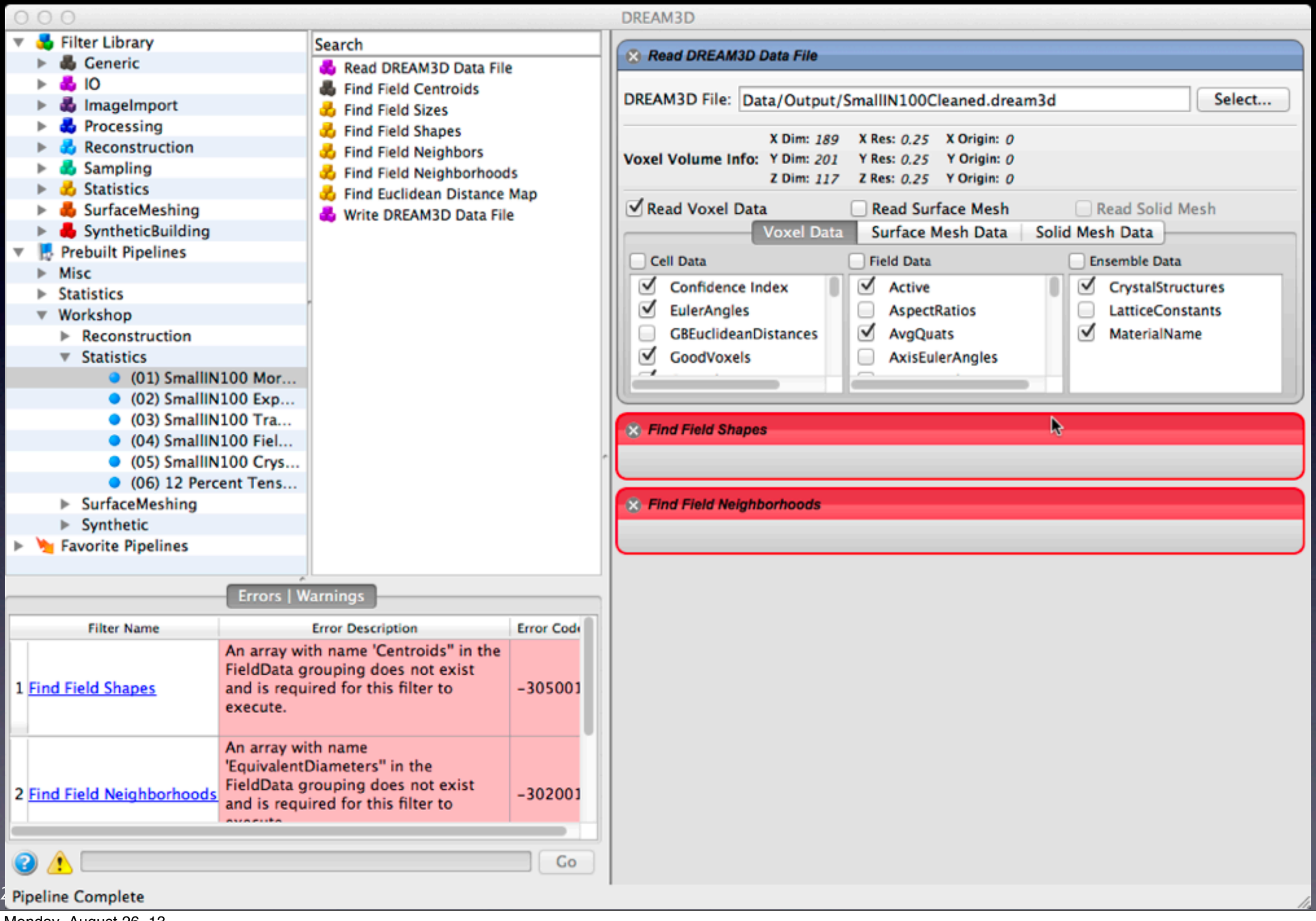
Click to toggle the Errors & Warnings

Basics



Red Filter outline mean errors in the pipeline setup

Basics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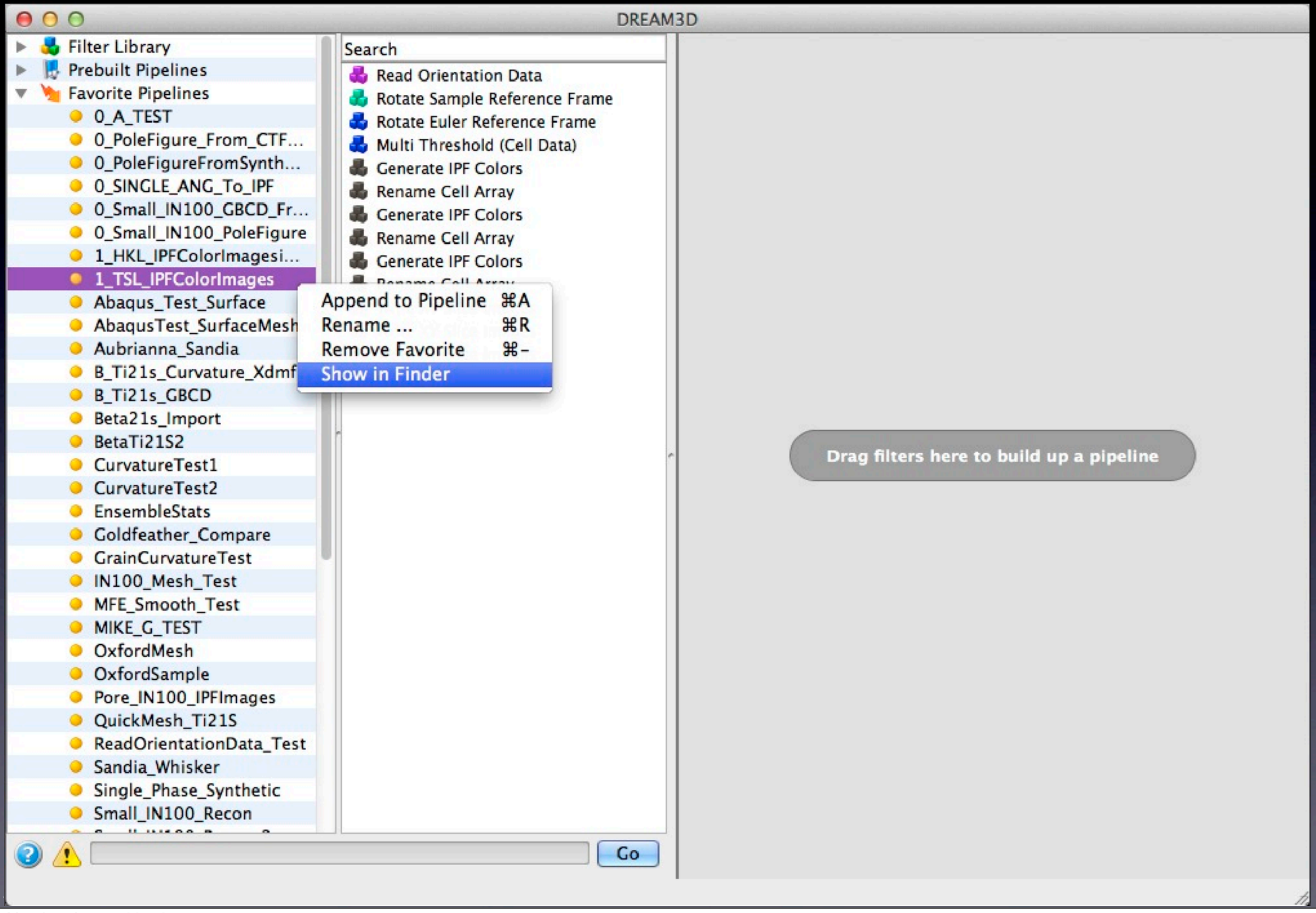
Basics: Favorites



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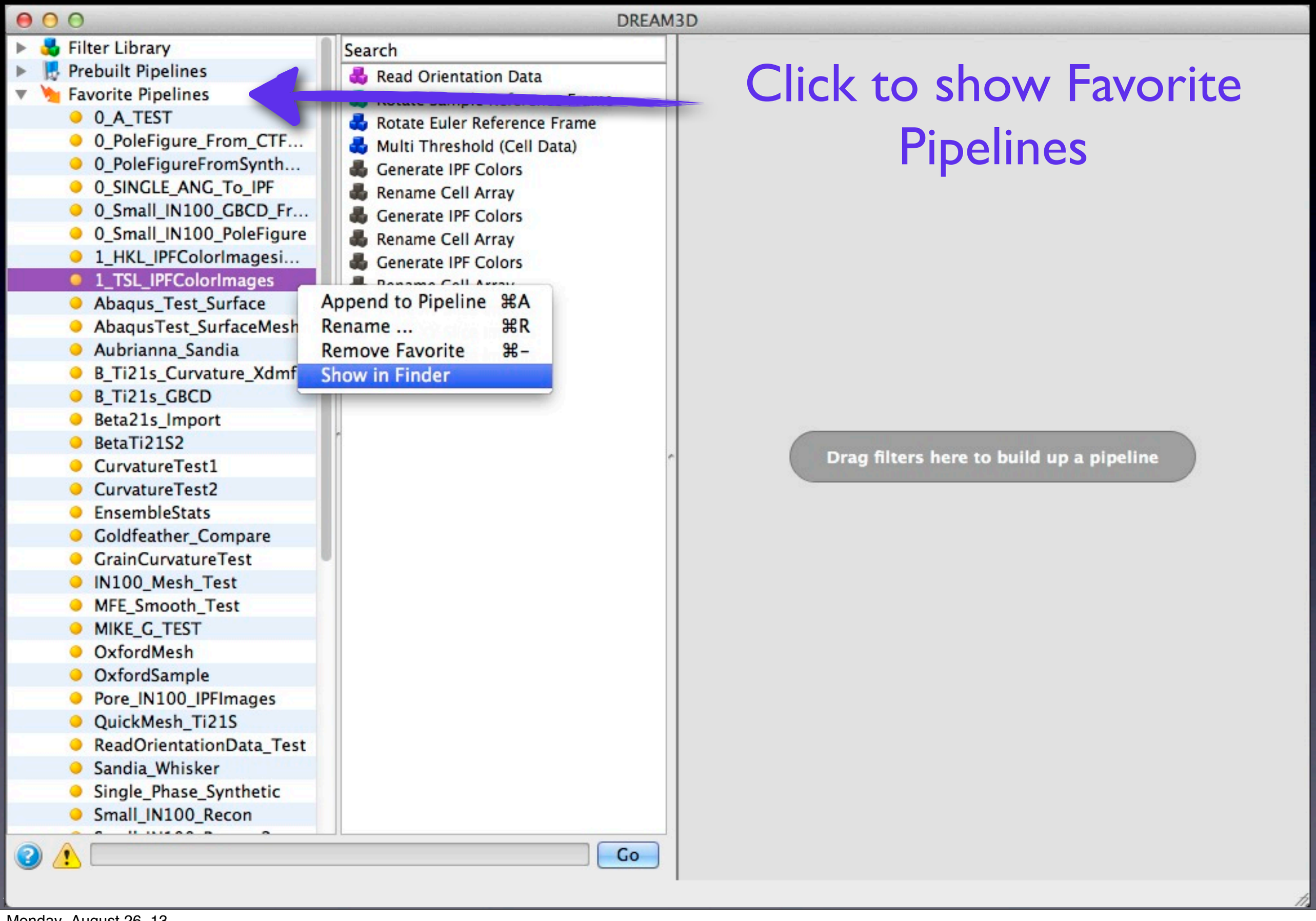
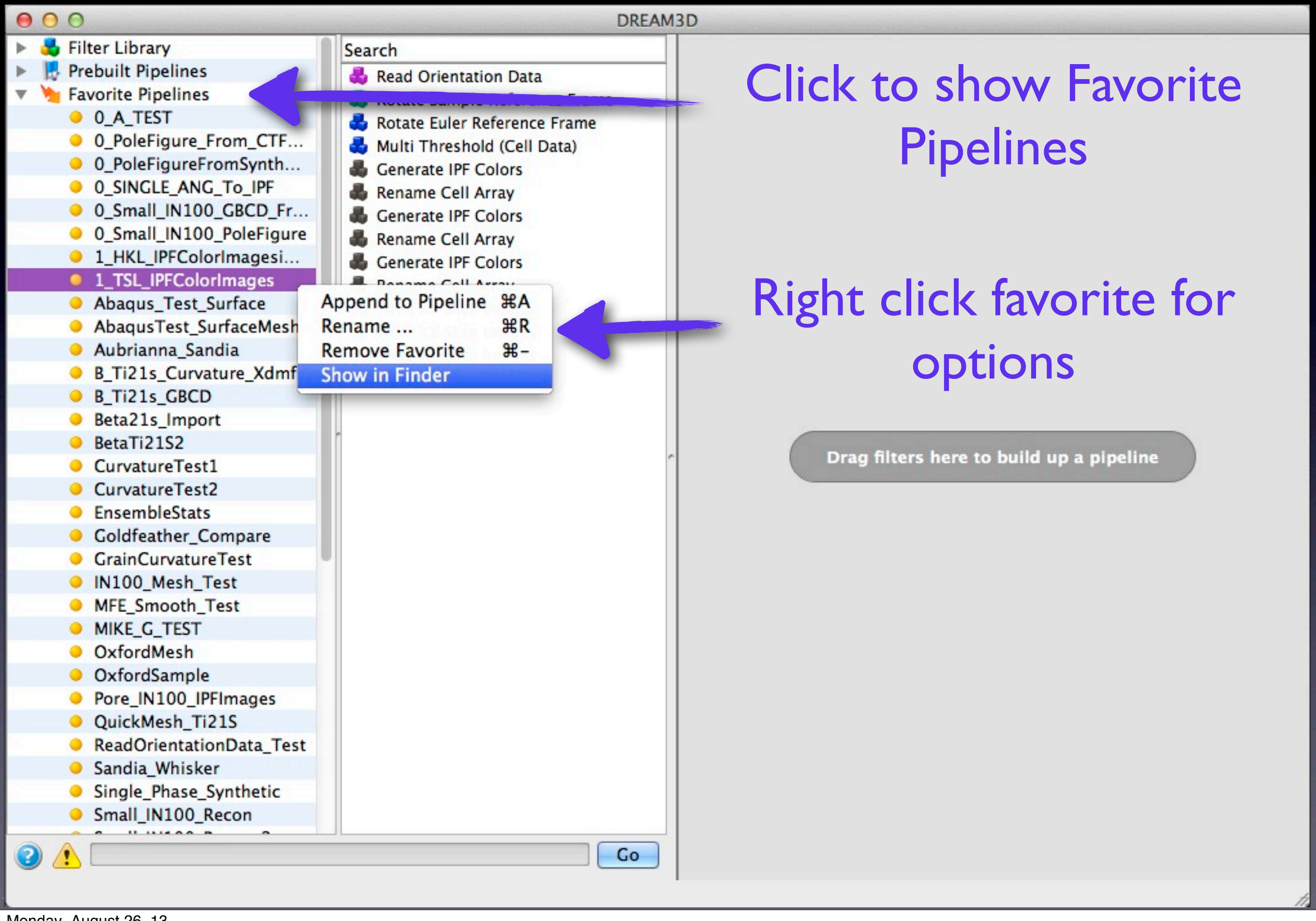


Click to show Favorite Pipelines

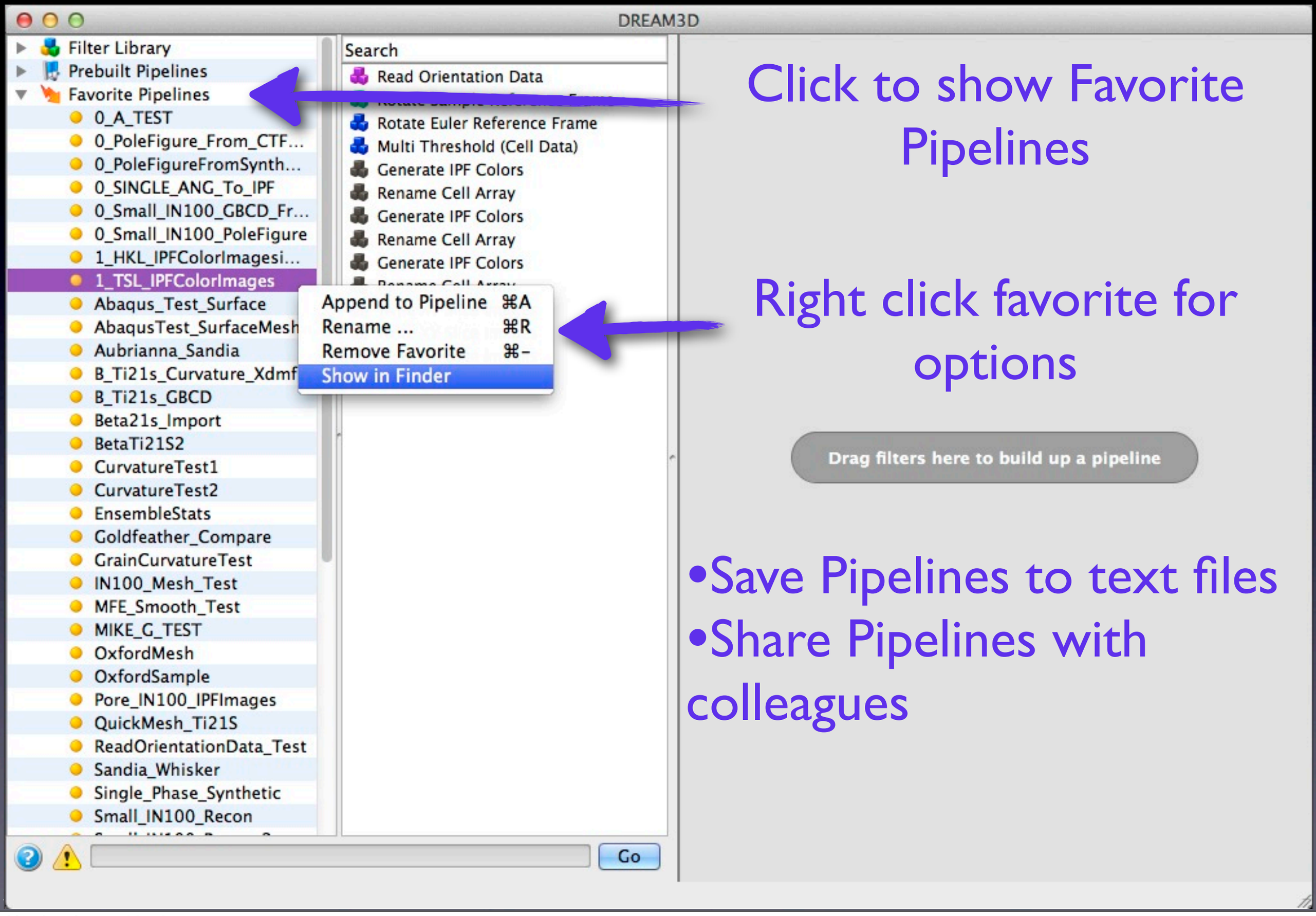
Basics: Favorites



Click to show Favorite Pipelines

Right click favorite for options

Basics: Favorites

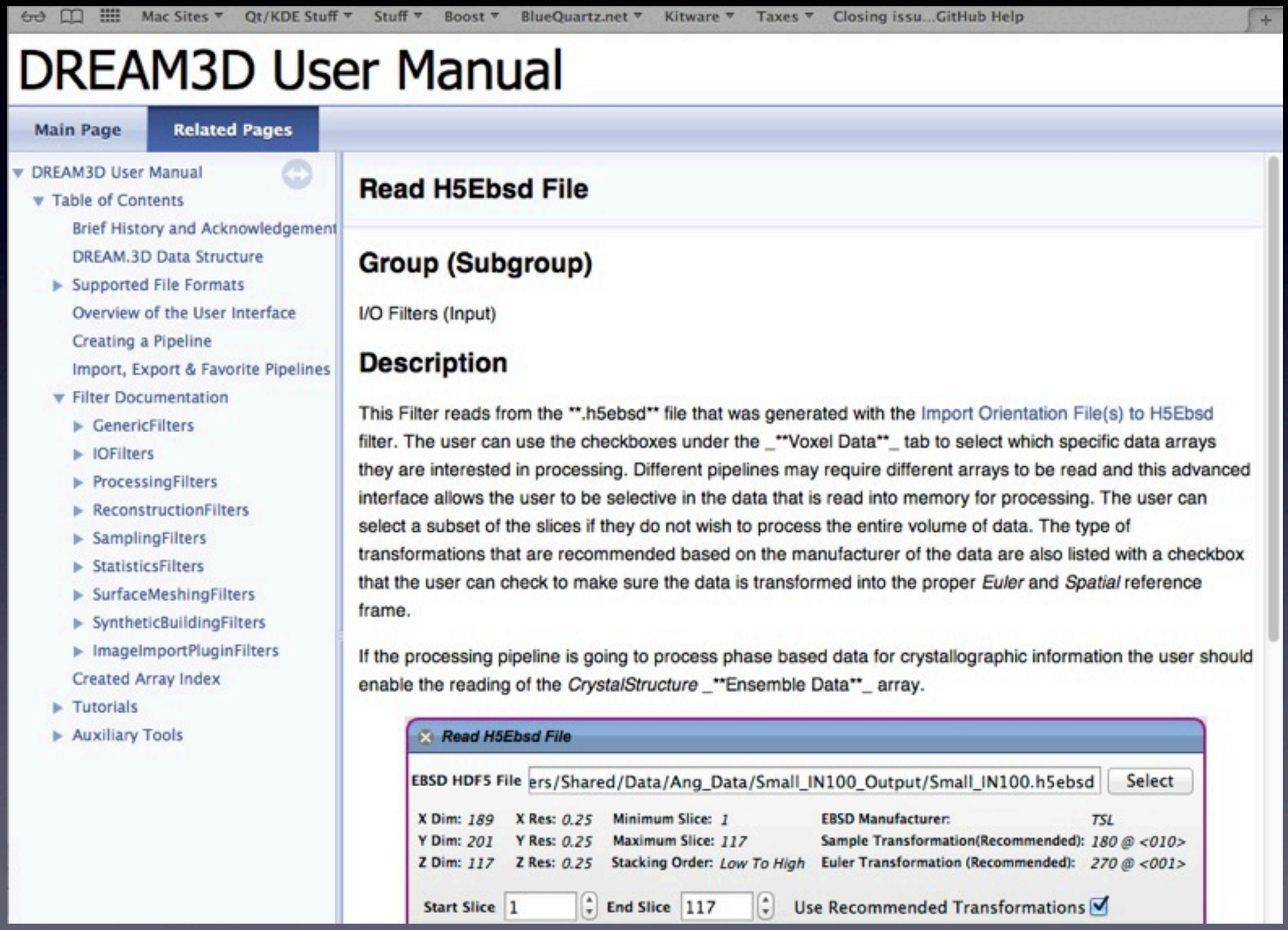


Click to show Favorite Pipelines

Right click favorite for options

- Save Pipelines to text files
- Share Pipelines with colleagues

User Manual/Filter Ref.



Example Pipelines

- Archiving Data
- EBSD Reconstruction
- Microstructure Statistics
- Synthetic Microstructure Generation

Archiving Data

- 3D Data has multiple files
- Meta data scattered throughout extra files
- Keep all the data in a single location
- DREAM3D archives the raw data into HDF5 based files
- EBSD: Watch your Reference Frames!!!!

DREAM3D

- Filter Library
  - Generic
  - IO
    - Input
    - Output
  - ImageImport
  - Processing
  - Reconstruction
  - Sampling
  - Statistics
  - SurfaceMeshing
  - SyntheticBuilding
- Prebuilt Pipelines
  - Misc
  - Statistics
  - Workshop
    - Reconstruction
      - (01) SmallIN100 Import
      - (02) SmallIN100 Initial Vi...
      - (03) SmallIN100 Threshold
      - (04) SmallIN100 Alignment
      - (05) SmallIN100 Alignme...
      - (06) SmallIN100 CleanUp
      - (07) SmallIN100 Segmen...

Errors | Warnings

Filter Name	Error Description

Go

Import Orientation File(s) to H5Ebsd

Orientation Source Data

Input Directory: Data/SmallIN100 Select

Total Files Found: 0

Output Parameters

Output File: Data/Output/SmallIN100.h5ebsd Select

Conversion Parameters

Stacking Order **Z Spacing (Microns)** **Reference Frame Options**

○ Low To High 0.25 Set Reference Frame Have you set the Reference Frame?

◉ High To Low

Advanced File Name Options (You generally should NOT have to change these values)

File Prefix: Small_IN100_ **File Suffix:** **File Extension:** ang

Start Slice: 1 **End Slice:** 117 **Padding Digits:** 1

Generated Input Filename: *Small_IN100_1.ang*

File List (Green=File Exists Red=File Does NOT Exist)

- Data/SmallIN100/Small_IN100_117.ang
- Data/SmallIN100/Small_IN100_116.ang
- Data/SmallIN100/Small_IN100_115.ang
- Data/SmallIN100/Small_IN100_114.ang
- Data/SmallIN100/Small_IN100_113.ang
- Data/SmallIN100/Small_IN100_112.ang
- Data/SmallIN100/Small_IN100_111.ang
- Data/SmallIN100/Small_IN100_110.ang
- Data/SmallIN100/Small_IN100_109.ang
- Data/SmallIN100/Small_IN100_108.ang
- Data/SmallIN100/Small_IN100_107.ang

All files exist.

Pipeline Complete

DREAM3D

- Filter Library
  - Generic
  - IO
    - Input
    - Output
  - ImageImport
  - Processing
  - Reconstruction
  - Sampling
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Orientation Source Data

Input Directory: Data/SmallIN100 Select

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Output Parameters

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- Data/SmallIN100/Small_IN100_110.ang
- Data/SmallIN100/Small_IN100_109.ang
- Data/SmallIN100/Small_IN100_108.ang
- Data/SmallIN100/Small_IN100_107.ang

All files exist.

Pipeline Complete

DREAM3D

- Filter Library
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      - (07) SmallIN100 Segme

Errors | Warnings

Filter Name	Error Description

Go

Pipeline Complete

Import Orientation File(s) to H5Ebsd

Orientation Source Data

Input Directory: Data/SmallIN100 Select

Total Files Found: 0

Select

Have you set the Reference Frame?

these values)

File Extension: ang

Padding Digits: 1

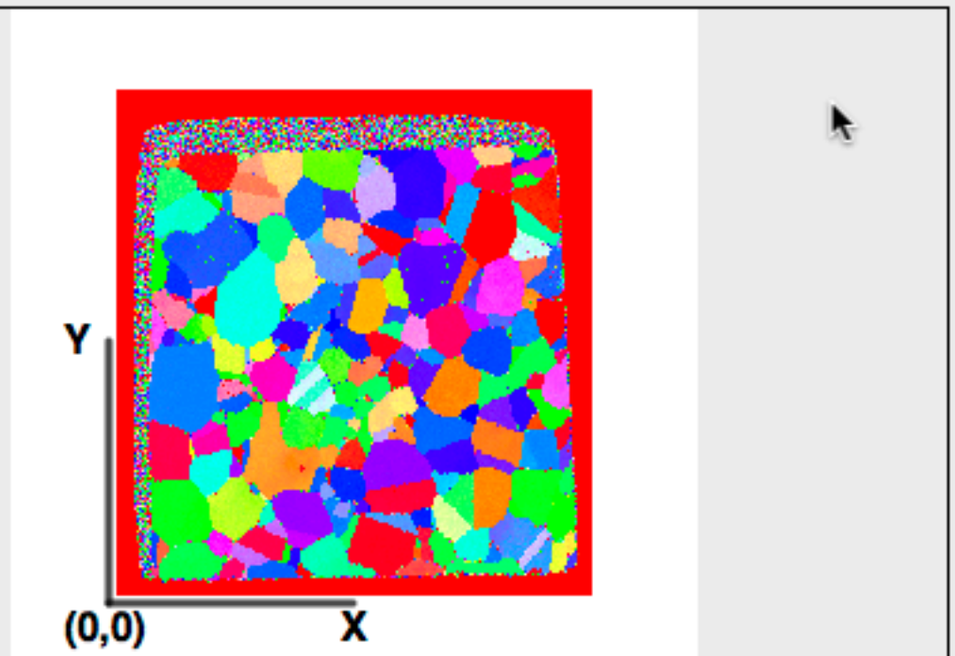
All files exist.

Advanced Reference Frame Options

- ○ No/Unknown Transformation
- ○ HEDM – IceNine (Default)
- ◉ Edax – TSL (Default)
- ○ Oxford – HKL (Default)

Sample Transformation: *180 @ <010>*

Euler Transformation: *90 @ <001>*



X Dim: *189* **Y Dim:** *201* **X Res:** *0.25* **Y Res:** *0.25*

☐ Convert Displayed Data to Radians (Imported Data will NOT be changed)

IPF Reference Direction: Z

Cancel OK

DREAM3D

- Filter Library
  - Generic
  - IO
    - Input
    - Output
  - ImageImport
  - Processing
  - Reconstruction
  - Sampling
  - Statistics
  - SurfaceMeshing
  - SyntheticBuilding
- Prebuilt Pipelines
  - Misc
  - Statistics
  - Workshop
    - Reconstruction
      - (01) SmallIN100 Import
      - (02) SmallIN100 Initial Vi...
      - (03) SmallIN100 Threshold
      - (04) SmallIN100 Alignment
      - (05) SmallIN100 Alignme...
      - (06) SmallIN100 CleanUp
      - (07) SmallIN100 Segmen...

Errors | Warnings

Filter Name	Error Description

Go

Import Orientation File(s) to H5Ebsd

Orientation Source Data

Input Directory: Data/SmallIN100 Select

Total Files Found: 0

Output Parameters

Output File: Data/Output/SmallIN100.h5ebsd Select

Conversion Parameters

Stacking Order **Z Spacing (Microns)** **Reference Frame Options**

○ Low To High 0.25 Set Reference Frame Have you set the Reference Frame?

◉ High To Low

Advanced File Name Options (You generally should NOT have to change these values)

File Prefix: Small_IN100_ **File Suffix:** **File Extension:** ang

Start Slice: 1 **End Slice:** 117 **Padding Digits:** 1

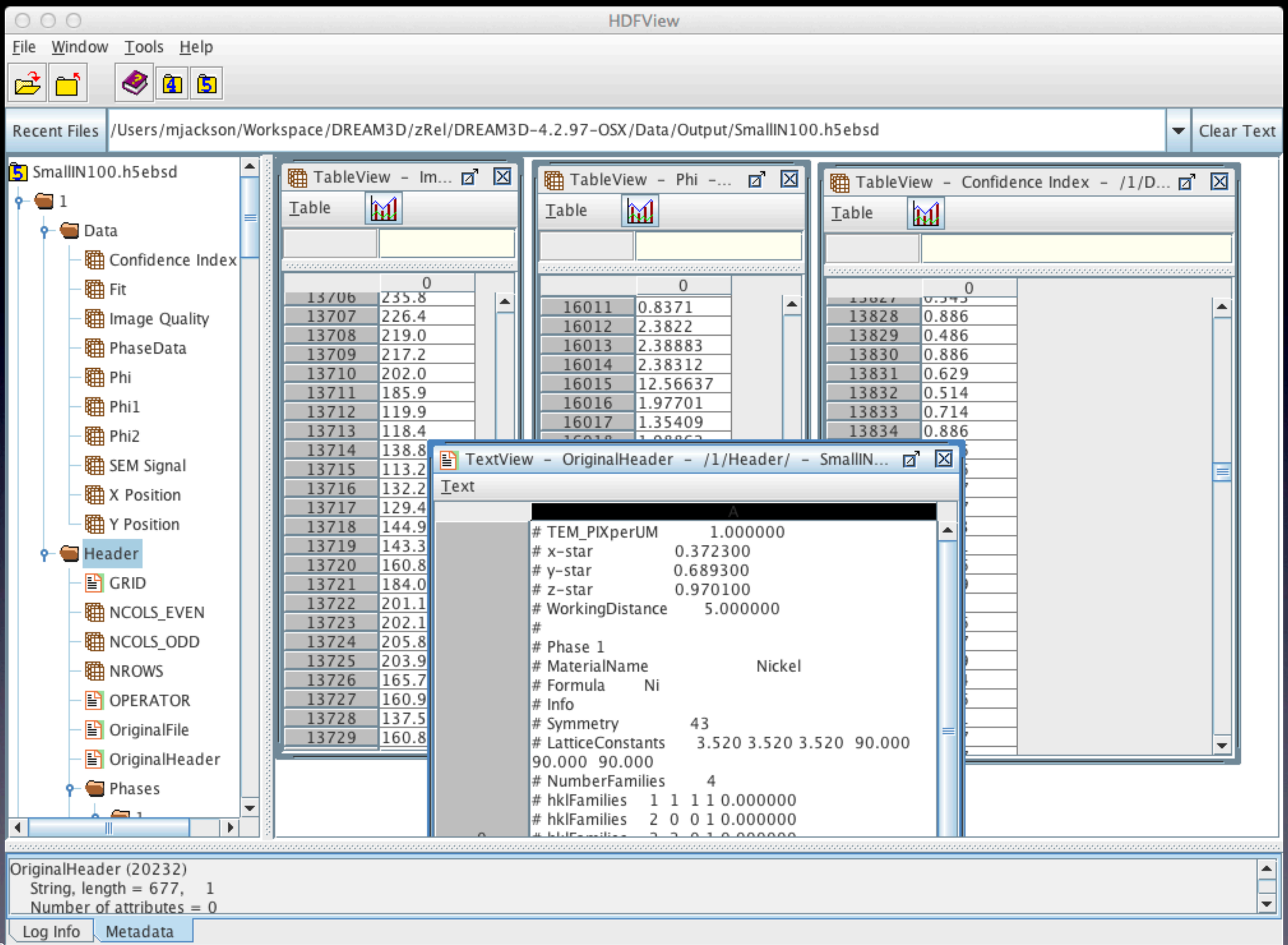
Generated Input Filename: *Small_IN100_1.ang*

File List (Green=File Exists Red=File Does NOT Exist)

- Data/SmallIN100/Small_IN100_117.ang
- Data/SmallIN100/Small_IN100_116.ang
- Data/SmallIN100/Small_IN100_115.ang
- Data/SmallIN100/Small_IN100_114.ang
- Data/SmallIN100/Small_IN100_113.ang
- Data/SmallIN100/Small_IN100_112.ang
- Data/SmallIN100/Small_IN100_111.ang
- Data/SmallIN100/Small_IN100_110.ang
- Data/SmallIN100/Small_IN100_109.ang
- Data/SmallIN100/Small_IN100_108.ang
- Data/SmallIN100/Small_IN100_107.ang

All files exist.

Pipeline Complete


HDFView
File Window Tools Help
Recent Files
/Users/mjackson/Workspace/DREAM3D/zRel/DREAM3D-4.2.97-OSX/Data/Output/SmallIN100.h5ebsd
Clear Text
SmallIN100.h5ebsd
1
Data
Confidence Index
Fit
Image Quality
PhaseData
Phi
Phi1
Phi2
SEM Signal
X Position
Y Position
Header
GRID
NCOLS_EVEN
NCOLS_ODD
NROWS
OPERATOR
OriginalFile
OriginalHeader
Phases
TableView - Im...
Table
0
13706 235.8
13707 226.4
13708 219.0
13709 217.2
13710 202.0
13711 185.9
13712 119.9
13713 118.4
13714 138.8
13715 113.2
13716 132.2
13717 129.4
13718 144.9
13719 143.3
13720 160.8
13721 184.0
13722 201.1
13723 202.1
13724 205.8
13725 203.9
13726 165.7
13727 160.9
13728 137.5
13729 160.8
TableView - Phi -...
Table
0
16011 0.8371
16012 2.3822
16013 2.38883
16014 2.38312
16015 12.56637
16016 1.97701
16017 1.35409
TableView - Confidence Index - /1/D...
Table
0
13828 0.886
13829 0.486
13830 0.886
13831 0.629
13832 0.514
13833 0.714
13834 0.886
TextView - OriginalHeader - /1/Header/ - SmallIN...
Text
TEM_PIXperUM 1.000000
x-star 0.372300
y-star 0.689300
z-star 0.970100
WorkingDistance 5.000000
#
Phase 1
MaterialName Nickel
Formula Ni
Info
Symmetry 43
LatticeConstants 3.520 3.520 3.520 90.000
90.000 90.000
NumberFamilies 4
hklFamilies 1 1 1 1 0.000000
hklFamilies 2 0 0 1 0.000000
OriginalHeader (20232)
String, length = 677, 1
Number of attributes = 0
Log Info
Metadata

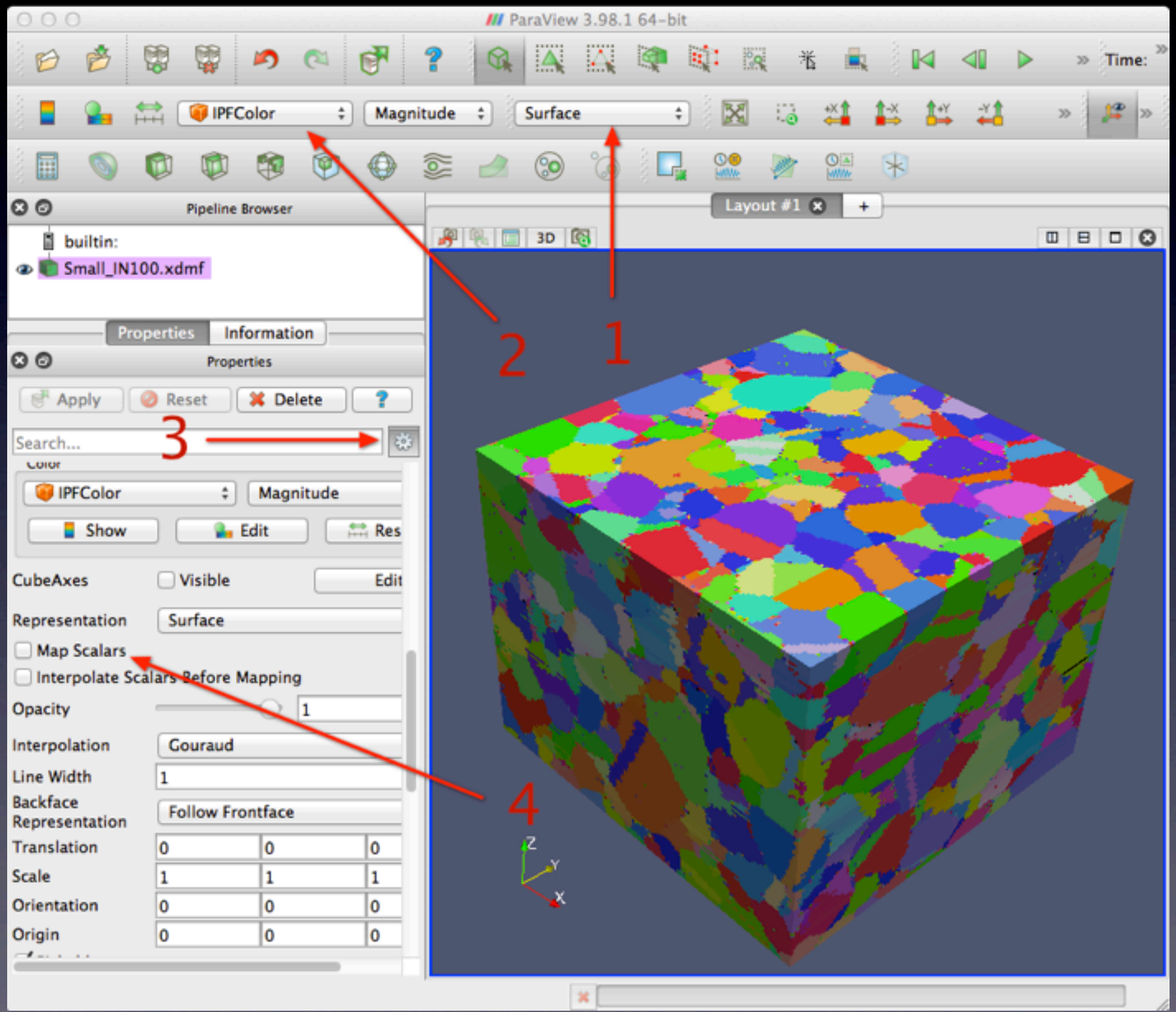
3D Reconstruction

2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

Overview - EBSD

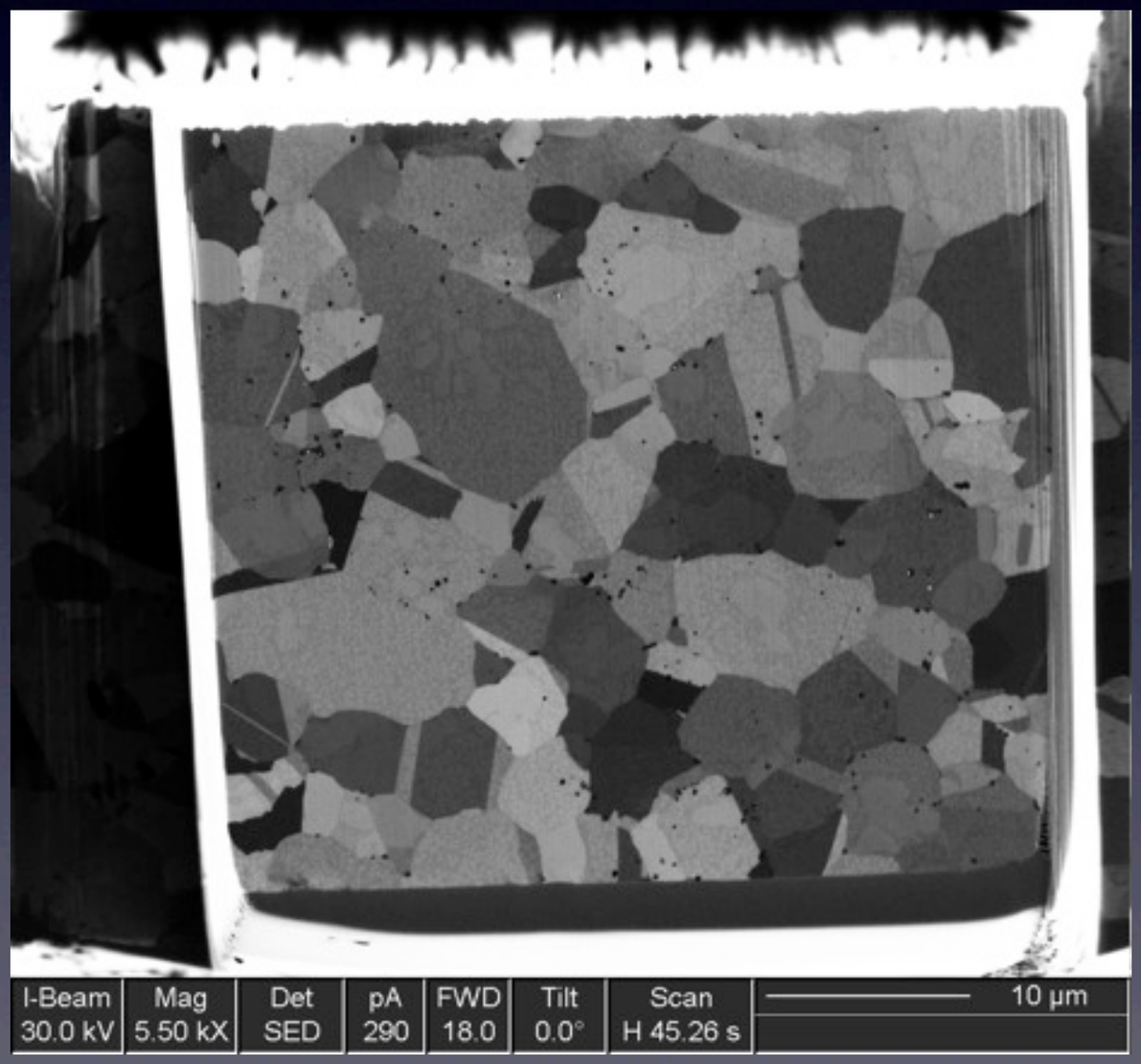
- Import the data
- Align slices
- Segment the grains
- Cleanup the data

ParaView Visualizataion



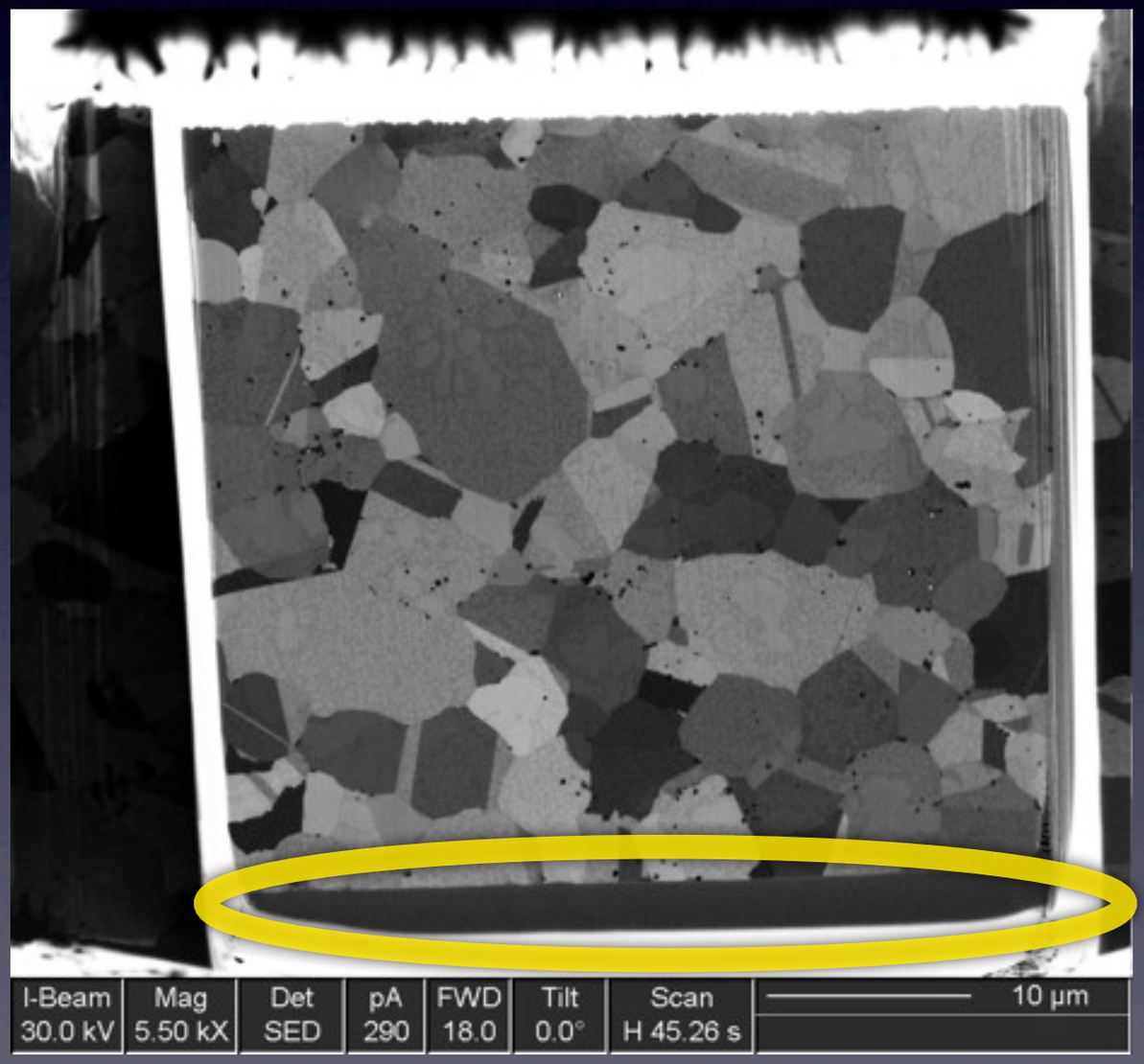
Small IN100

- "The" IN100 3D data (Uchic et. al.)
- 117 Slices
  - EBSD, IISE, 4x SE Tilts
- Pt Cap on sample
- Available on DREAM3D Web Site



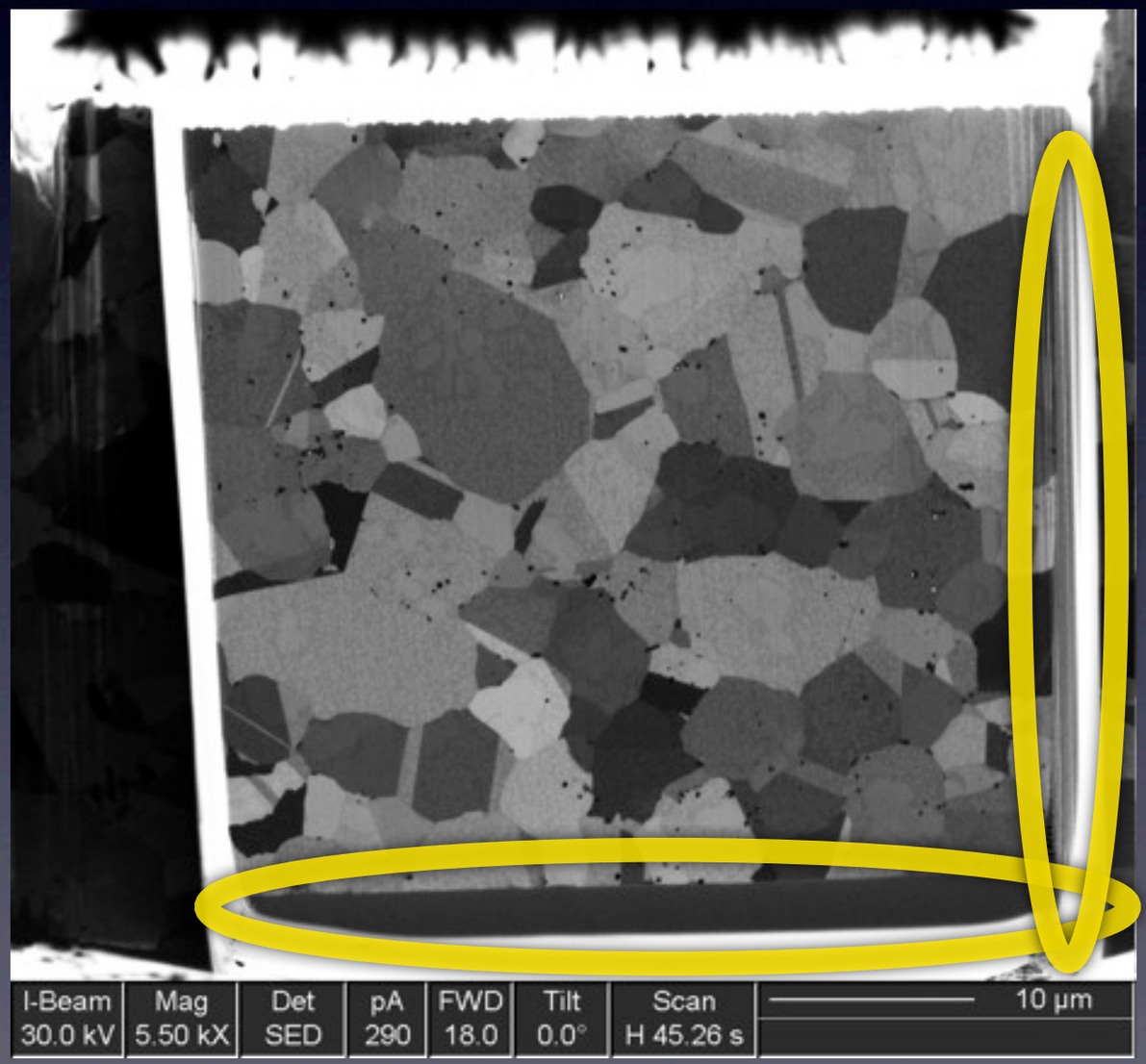
Small IN100

- "The" IN100 3D data (Uchic et. al.)
- 117 Slices
  - EBSD, IISE, 4x SE Tilts
- Pt Cap on sample
- Available on DREAM3D Web Site



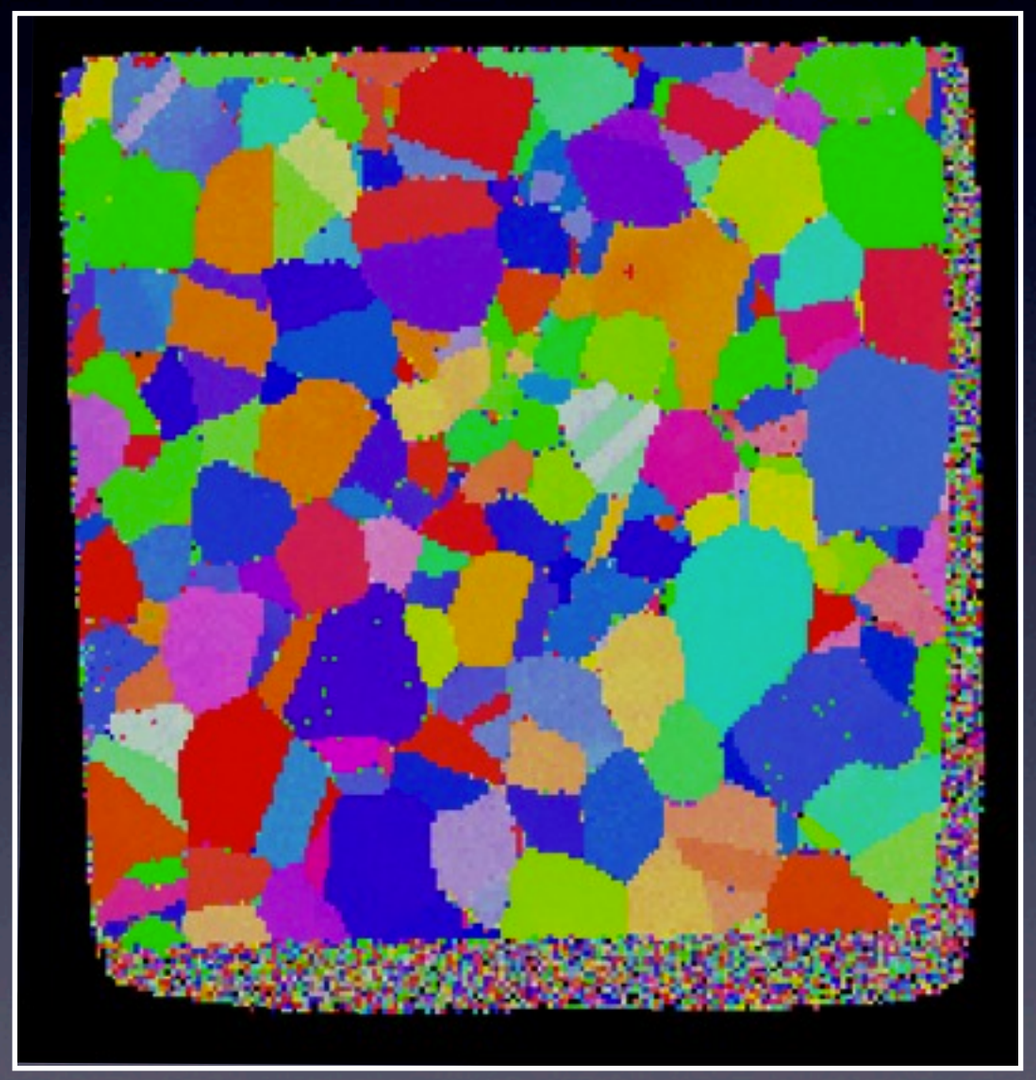
Small IN100

- "The" IN100 3D data (Uchic et. al.)
- 117 Slices
  - EBSD, IISE, 4x SE Tilts
- Pt Cap on sample
- Available on DREAM3D Web Site



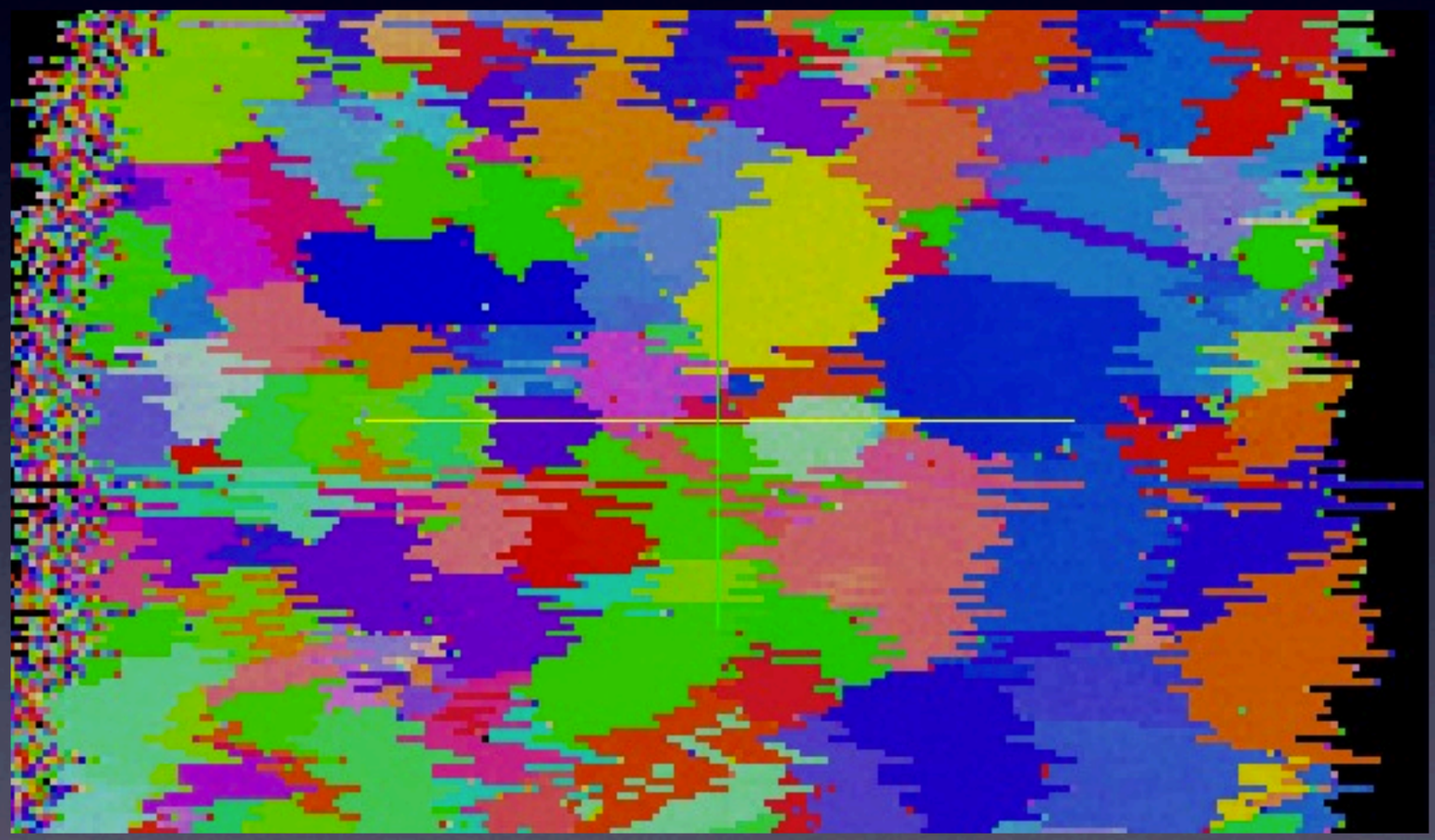
As Imported

- Doesn't look too bad?
- What could be wrong?

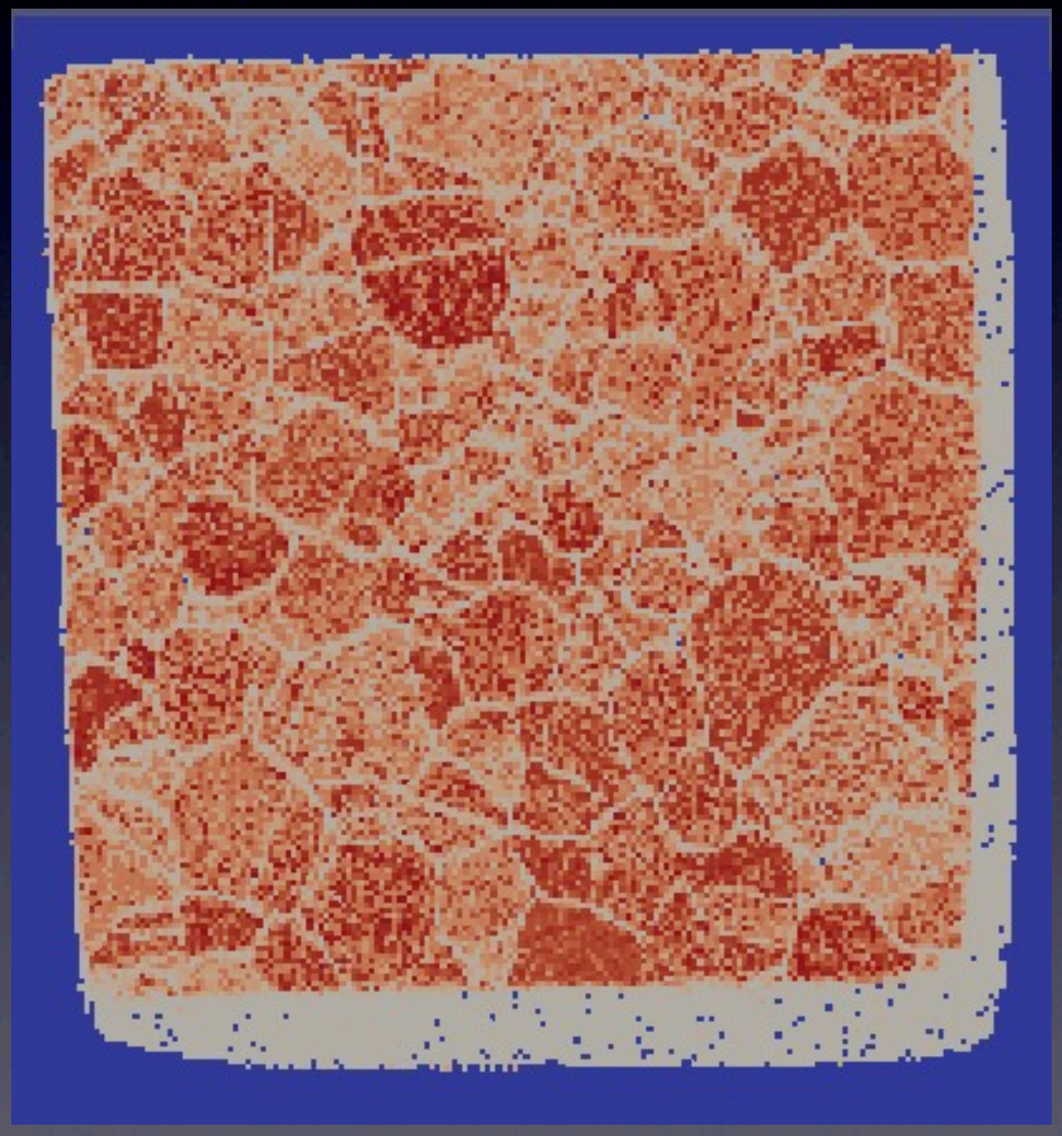


Slice Volume (X Axis)

- Several Slices badly out of alignment



What are Good Voxels?



Confidence Index

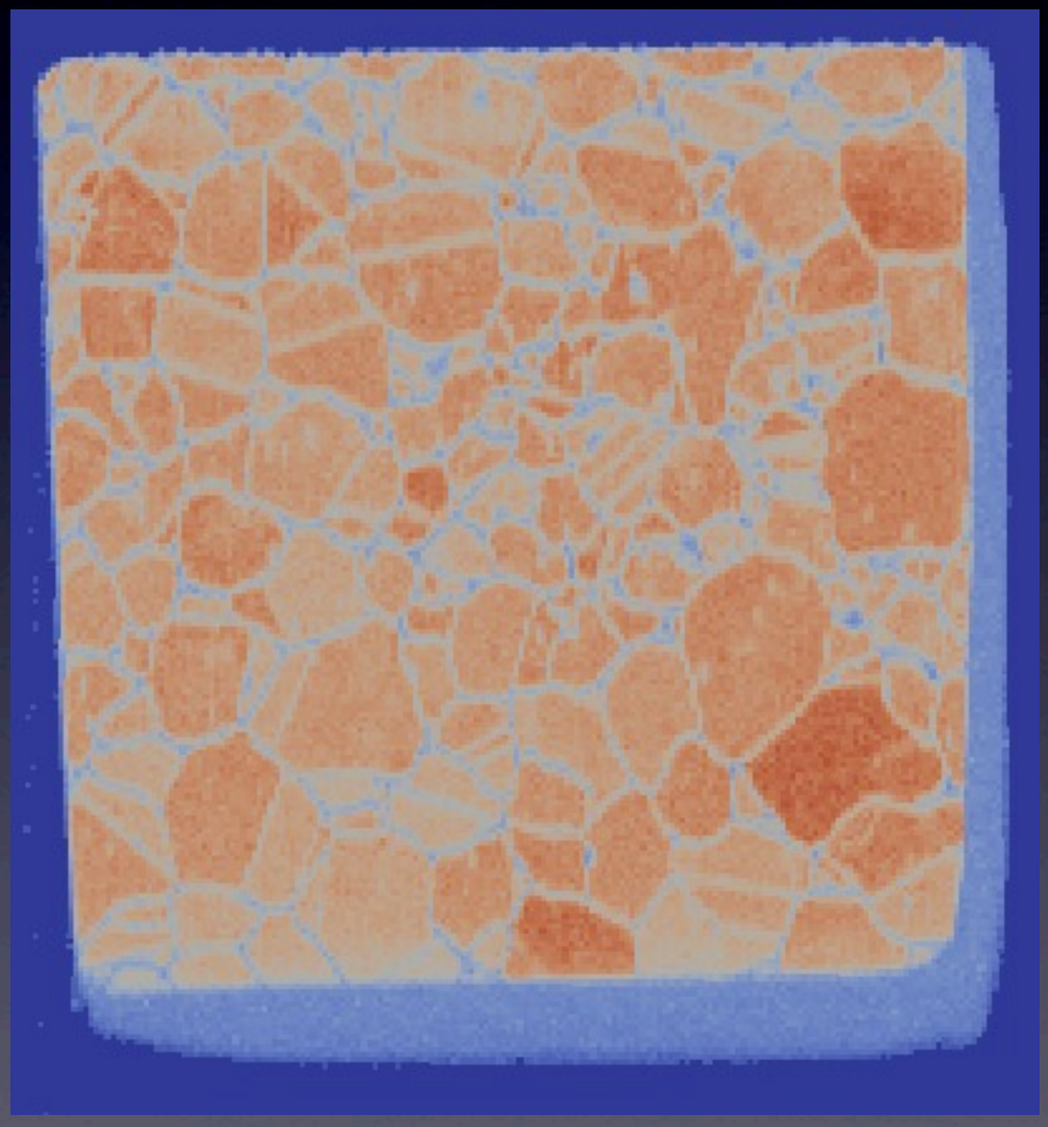
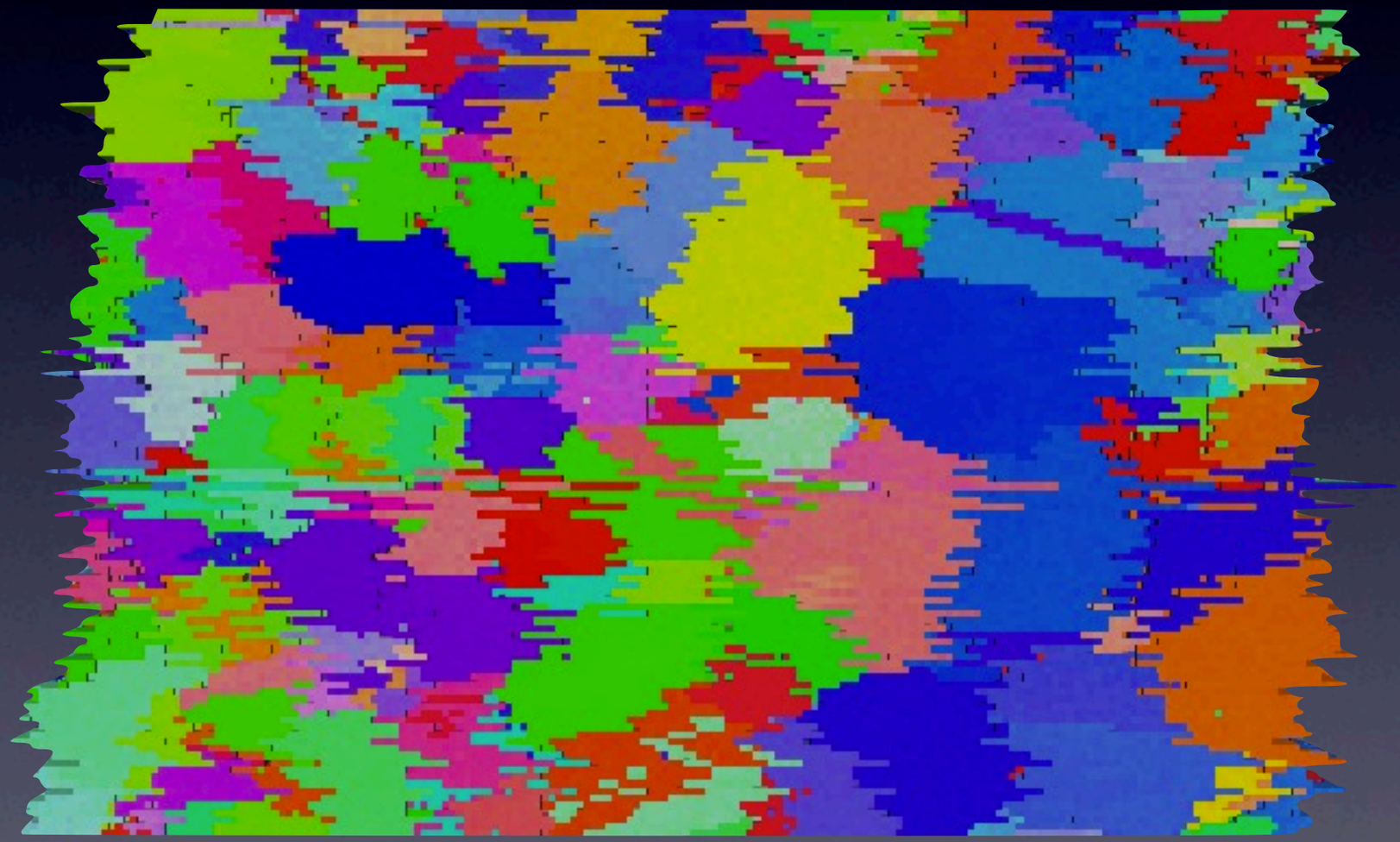
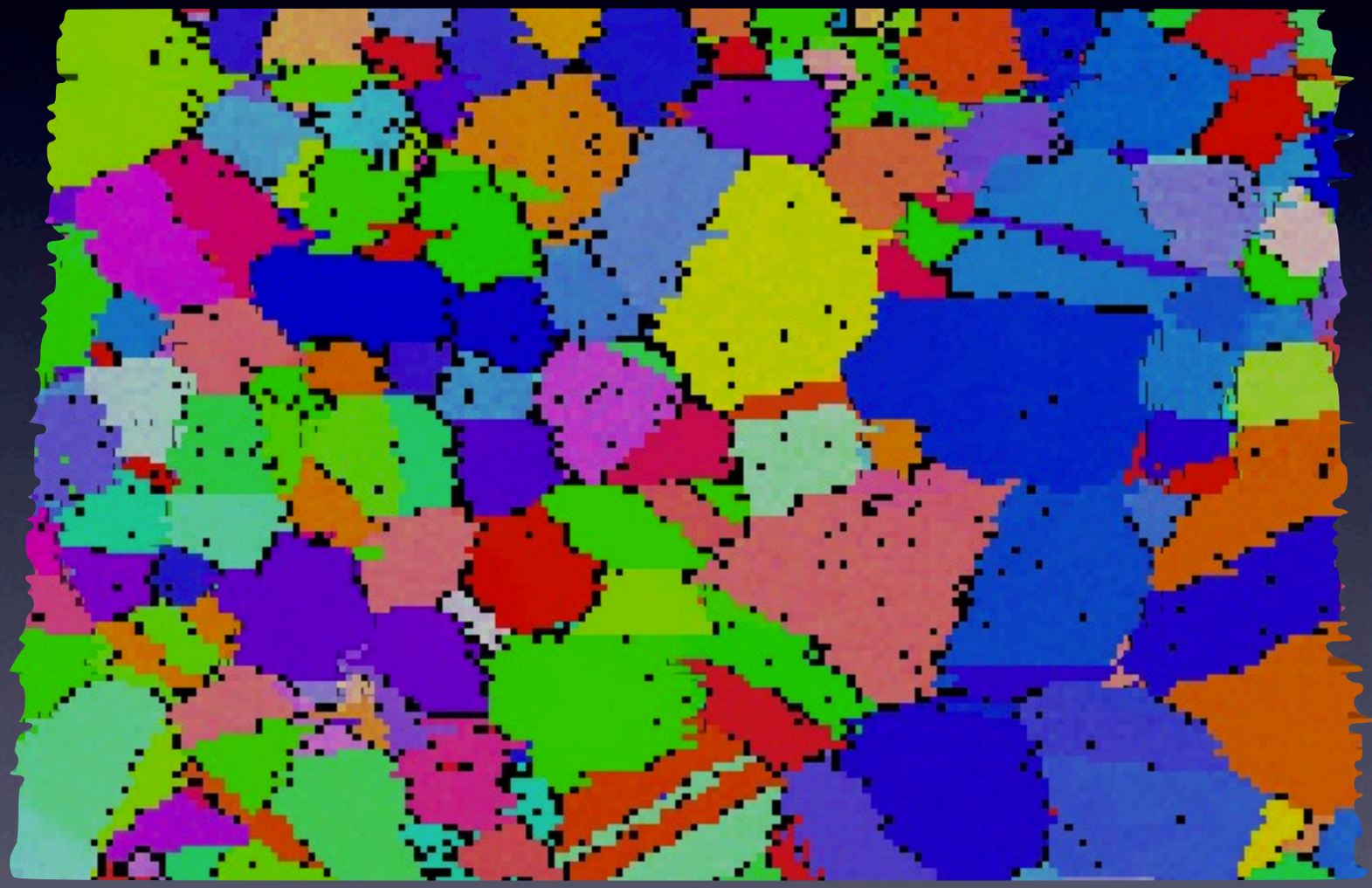


Image Quality

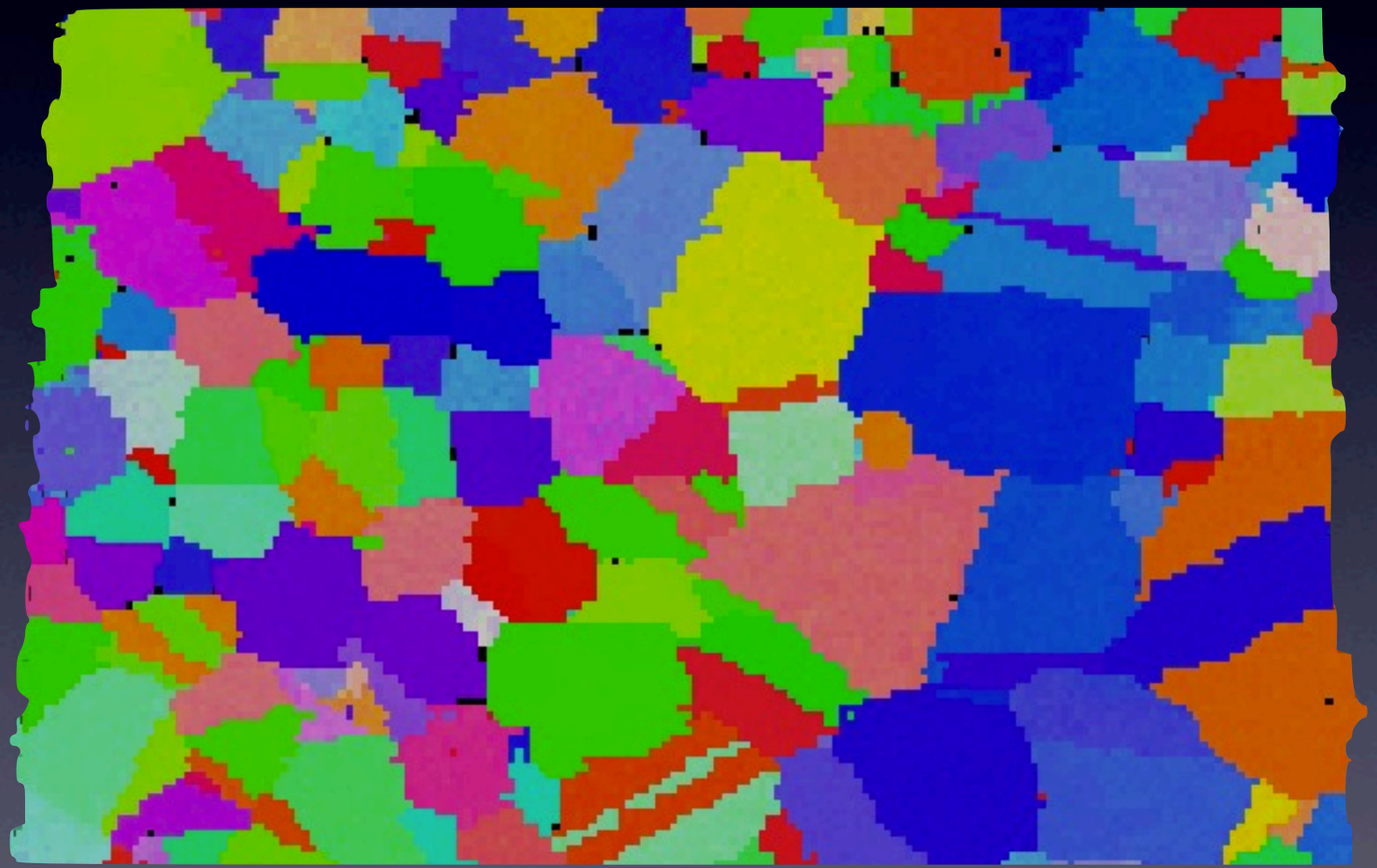
After Defining Good Voxels

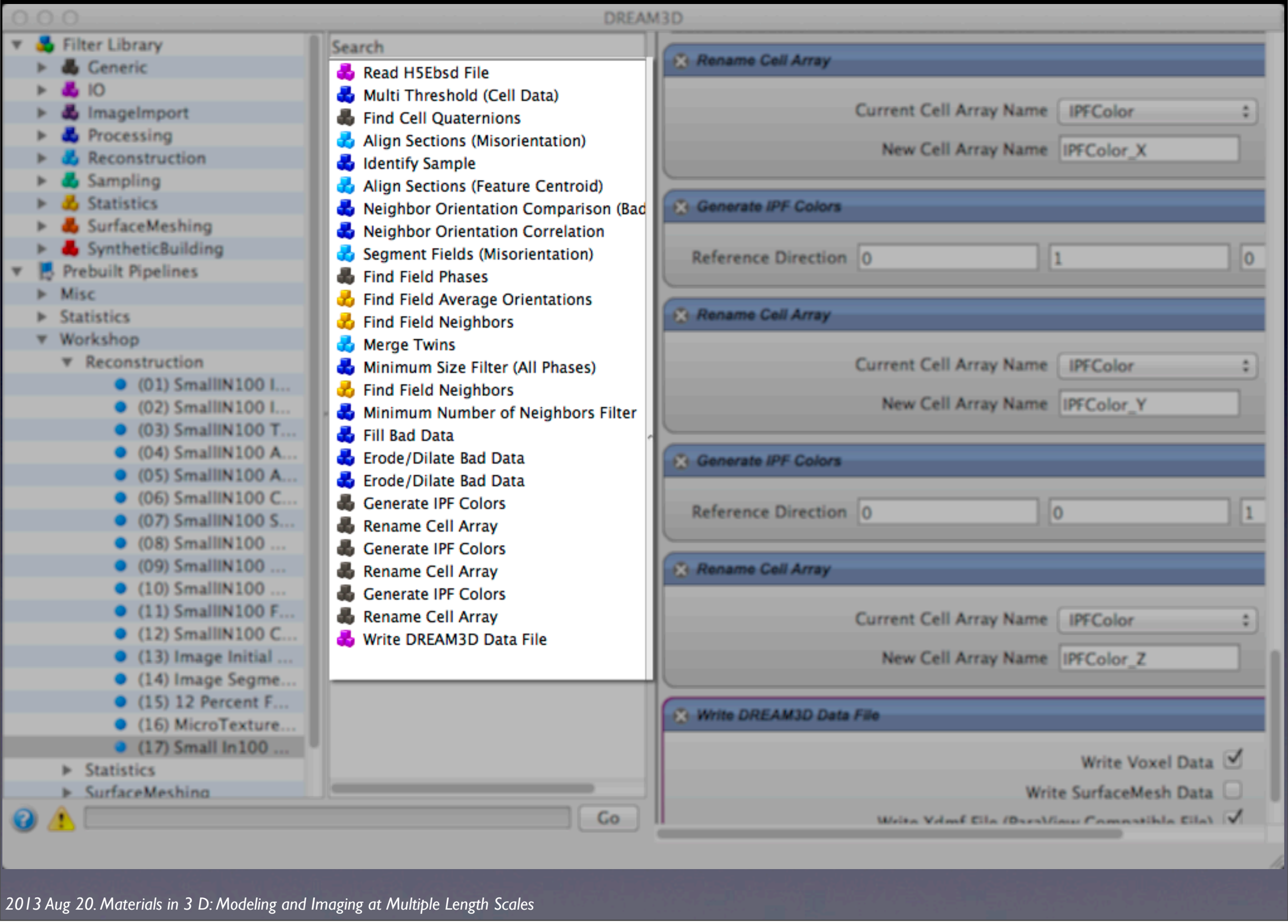


After Alignment Step



After Clean Up Filters

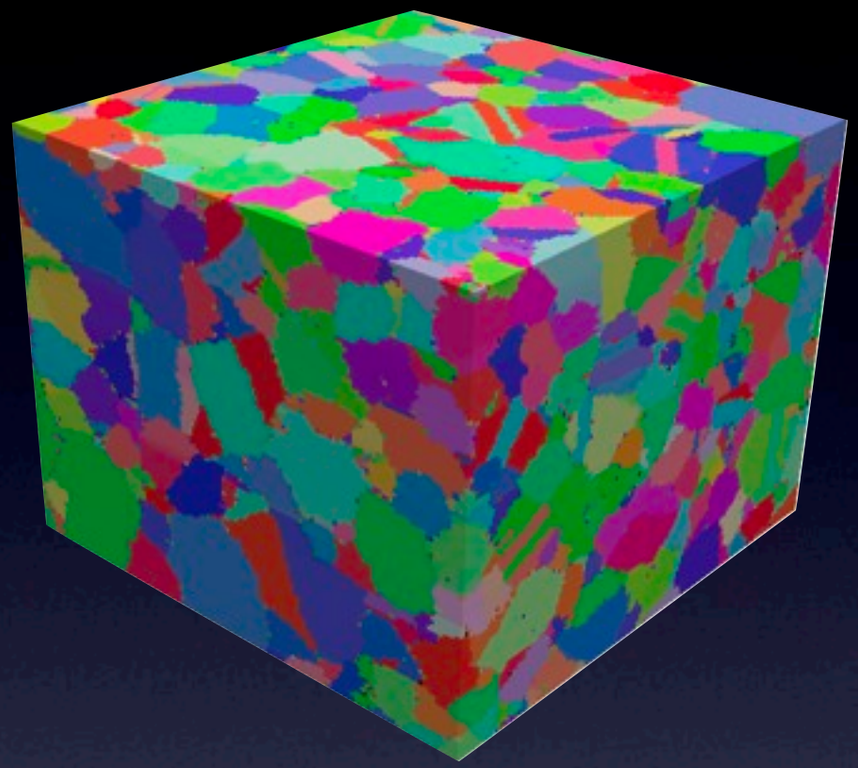



DREAM3D
Filter Library
Generic
IO
ImageImport
Processing
Reconstruction
Sampling
Statistics
SurfaceMeshing
SyntheticBuilding
Prebuilt Pipelines
Misc
Statistics
Workshop
Reconstruction
(01) SmallIN100 I...
(02) SmallIN100 I...
(03) SmallIN100 T...
(04) SmallIN100 A...
(05) SmallIN100 A...
(06) SmallIN100 C...
(07) SmallIN100 S...
(08) SmallIN100 ...
(09) SmallIN100 ...
(10) SmallIN100 ...
(11) SmallIN100 F...
(12) SmallIN100 C...
(13) Image Initial ...
(14) Image Segme...
(15) 12 Percent F...
(16) MicroTexture...
(17) Small In100 ...
Statistics
SurfaceMeshing
Search
Read H5Ebsd File
Multi Threshold (Cell Data)
Find Cell Quaternions
Align Sections (Misorientation)
Identify Sample
Align Sections (Feature Centroid)
Neighbor Orientation Comparison (Bad
Neighbor Orientation Correlation
Segment Fields (Misorientation)
Find Field Phases
Find Field Average Orientations
Find Field Neighbors
Merge Twins
Minimum Size Filter (All Phases)
Find Field Neighbors
Minimum Number of Neighbors Filter
Fill Bad Data
Erode/Dilate Bad Data
Erode/Dilate Bad Data
Generate IPF Colors
Rename Cell Array
Generate IPF Colors
Rename Cell Array
Generate IPF Colors
Rename Cell Array
Write DREAM3D Data File
Go
Rename Cell Array
Current Cell Array Name
IPFColor
New Cell Array Name
IPFColor_X
Generate IPF Colors
Reference Direction
0
1
0
Rename Cell Array
Current Cell Array Name
IPFColor
New Cell Array Name
IPFColor_Y
Generate IPF Colors
Reference Direction
0
0
1
Rename Cell Array
Current Cell Array Name
IPFColor
New Cell Array Name
IPFColor_Z
Write DREAM3D Data File
Write Voxel Data
Write SurfaceMesh Data

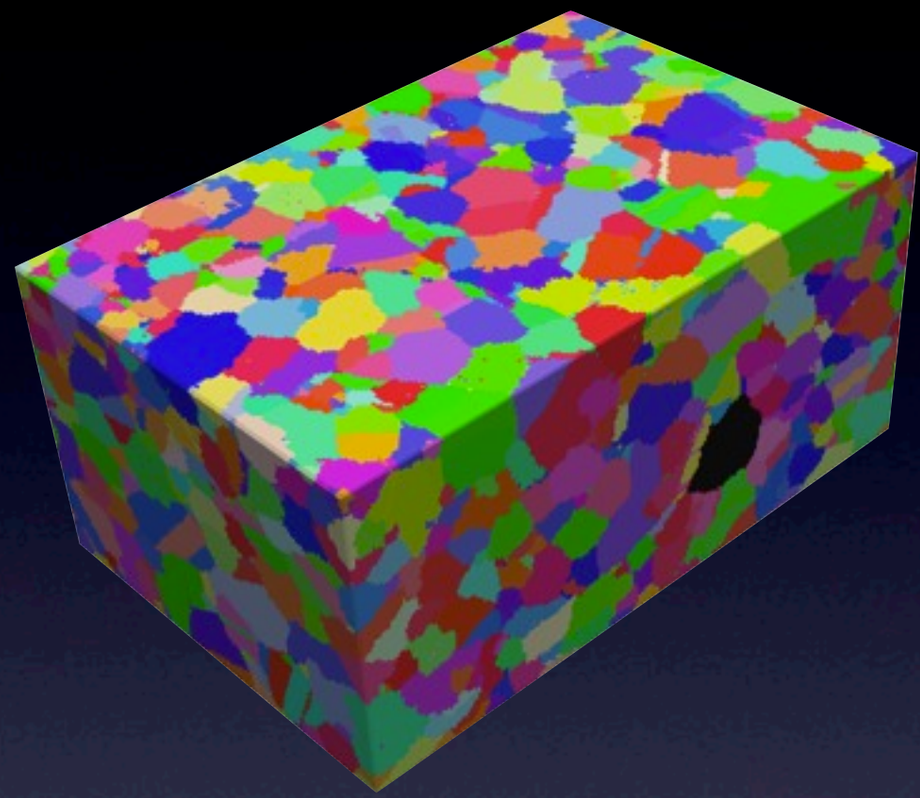
Categories of Reconstruction Filters

- Clean up, Conversion, Thresholds
- Alignment, Grouping, Segmentation
- Cropping, Cutting, Rotation, Resolution
- See DREAM3D User manual for more

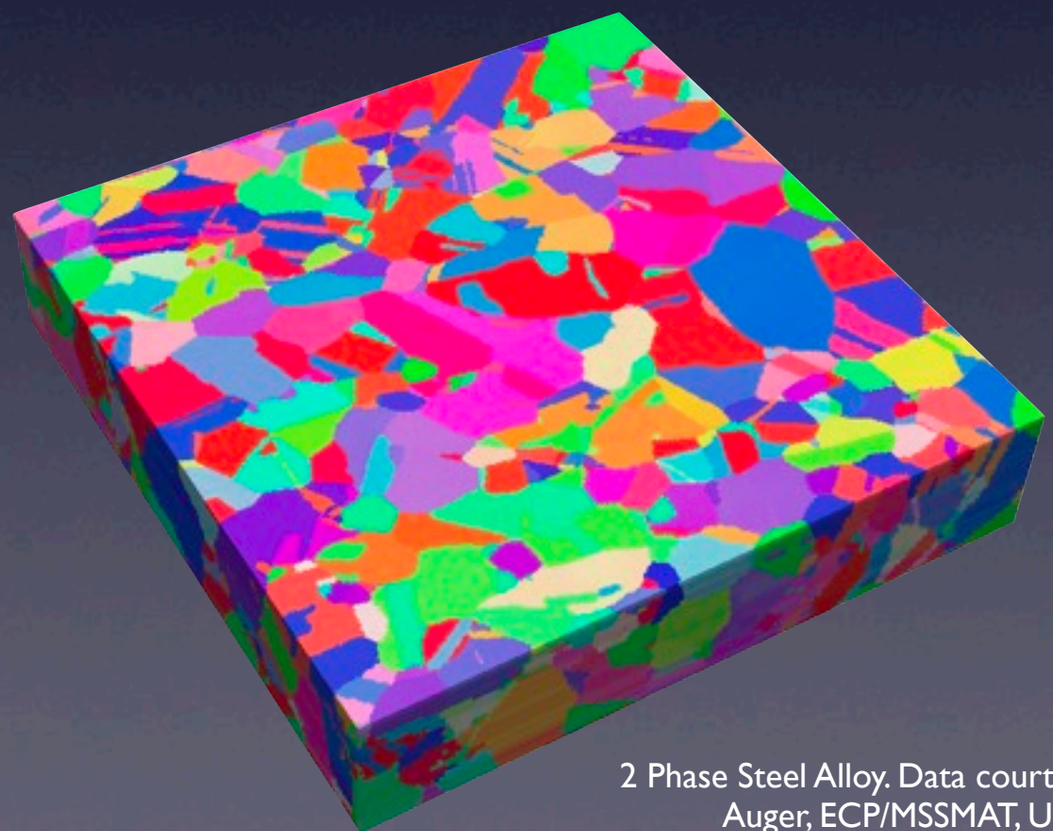
EBSD Reconstruction



Nickel Super Alloy– Data Courtesy of M. Uchic AFRL



Nickel Super Alloy with Internal Pore– Data Courtesy of M. Uchic AFRL



2 Phase Steel Alloy. Data courtesy of Colette Rey and Thierry Auger, ECP/MSSMAT, UMR CNRS 8579, France

Other Data Sources

- HKL .ctf files (EBSD)
- HEDM (from APS)
- Pre-Segmented gray scale Images

HDFView

File Window Tools Help

Recent Files /Users/mjackson/Workspace/DREAM3D/zRel/DREAM3D-4.2.97-OSX/Data/Output/SmallIN100Cleaned.dream3d Clear Text

- SmallIN100Cleaned.dream3
  - Pipeline
  - VoxelDataContainer
    - CELL_DATA
      - Confidence Index
      - EulerAngles
      - GBEuclideanDistar
      - GoodVoxels
      - GrainIds
      - GrainReferenceMi
      - IPFColor_X
      - IPFColor_Y
      - IPFColor_Z
      - Image Quality
      - KernelAverageMis
      - NearestNeighbors
      - ParentIds
      - Phases
      - QPEuclideanDistar

TableView - EquivalentDiameters - /VoxelDat...

Table

	0
0	0.0
1	3.5411265
2	3.976448
3	1.6295329
4	4.4858932
5	4.743659
6	0.855749...
7	4.28255
8	2.0292077
9	5.8334374
10	4.1325445
11	2.5822546
12	2.6576066
13	1.6661638
14	4.898568
15	1.4152994
16	3.9739301
17	2.63201
18	1.3138475
19	2.778754
20	2.2929835

TableView - EulerAngles - /VoxelData...

Table

	0	1	2
0	NaN	0.0	NaN
1	NaN	0.0	NaN
2	NaN	0.0	NaN
3	NaN	0.0	NaN
4	NaN	0.0	NaN
5	NaN	0.0	NaN
6	NaN	0.0	NaN
7	NaN	0.0	NaN
8	NaN	0.0	NaN
9	NaN	0.0	NaN
10	NaN	0.0	NaN
11	NaN	0.0	NaN
12	NaN	0.0	NaN
13	NaN	0.0	NaN
14	NaN	0.0	NaN
15	5.501499	0.96096	5.15689

EulerAngles (17799956)
  32-bit floating-point, 4444713 x 3
  Number of attributes = 2
    NumComponents = 3
    ObjectType = DataArray<float>

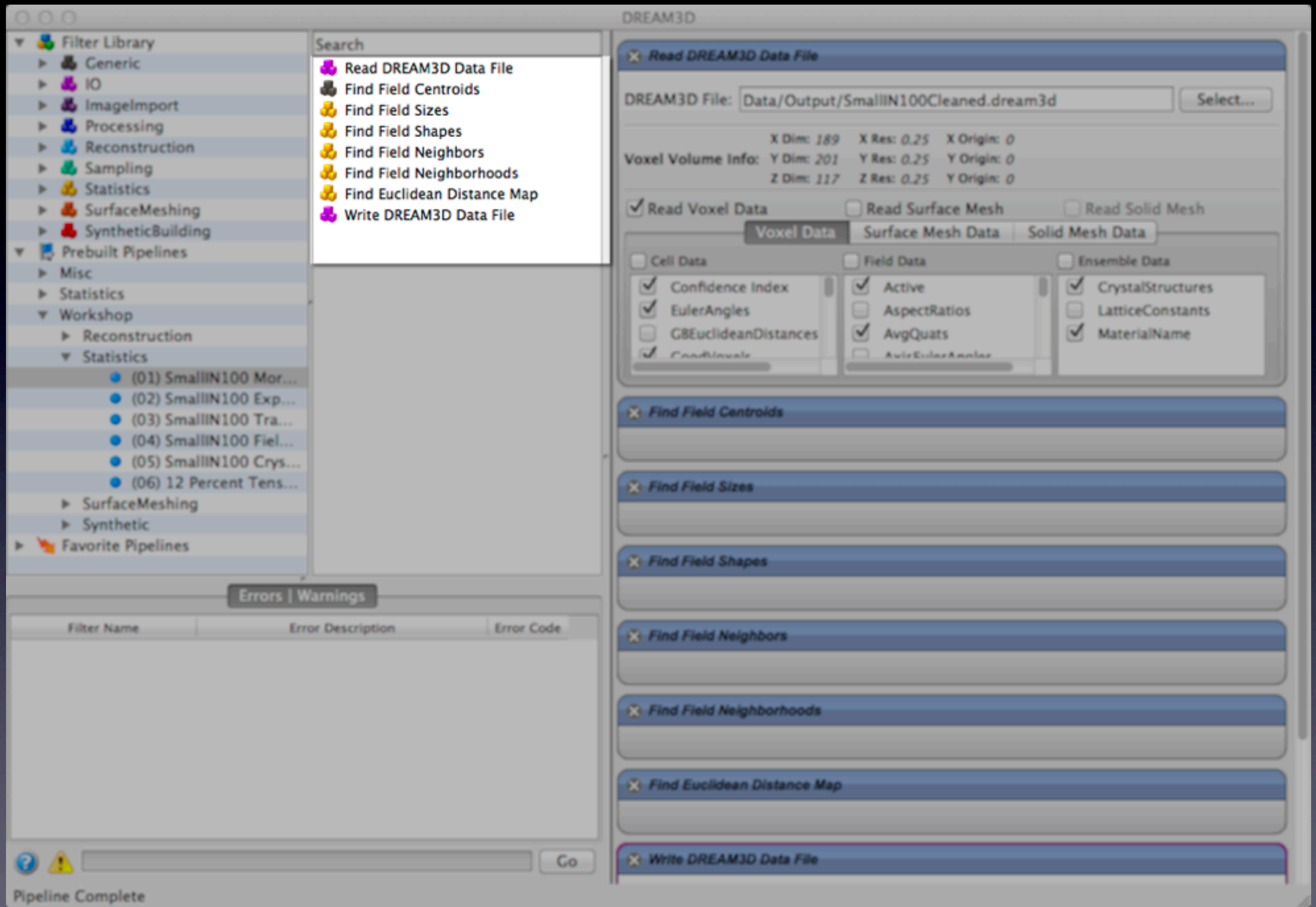
Log Info Metadata

Calculating Statistics

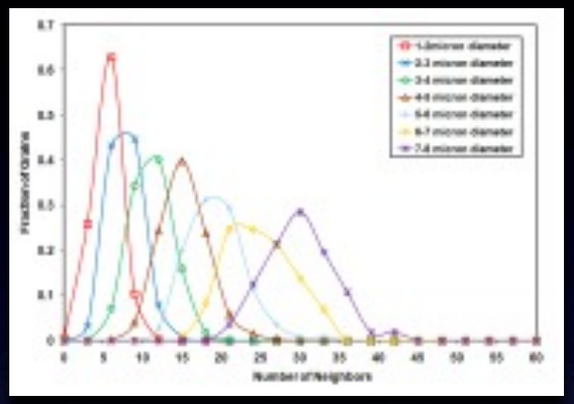
2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

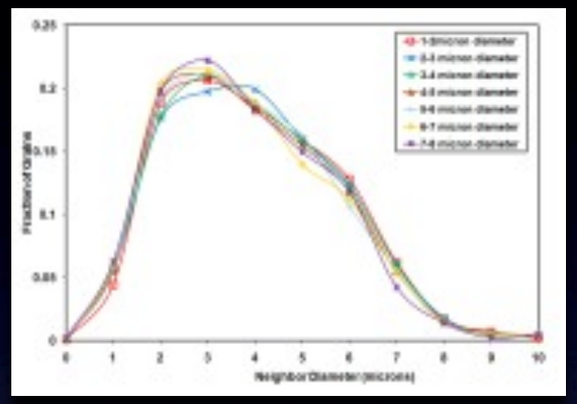
Categories of Stats

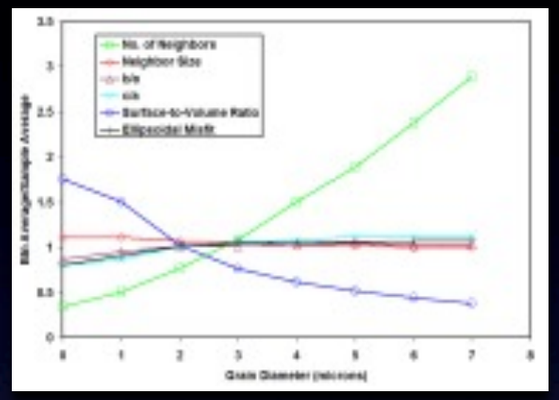
- Crystallographic
  - Avg Orientation...
- Morphological
  - Grain Size, Num Neighbors
- Ensemble Stats
  - To Feed into StatsGenerator
- Export Data as CSV File

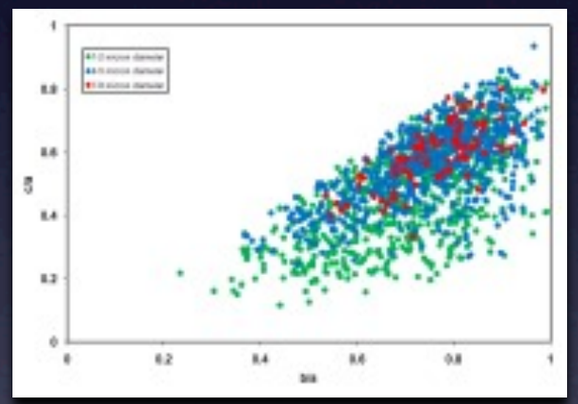

DREAM3D
Filter Library
Generic
IO
ImageImport
Processing
Reconstruction
Sampling
Statistics
SurfaceMeshing
SyntheticBuilding
Prebuilt Pipelines
Misc
Statistics
Workshop
Reconstruction
Statistics
(01) SmallIN100 Mor...
(02) SmallIN100 Exp...
(03) SmallIN100 Tra...
(04) SmallIN100 Fiel...
(05) SmallIN100 Crys...
(06) 12 Percent Tens...
SurfaceMeshing
Synthetic
Favorite Pipelines
Search
Read DREAM3D Data File
Find Field Centroids
Find Field Sizes
Find Field Shapes
Find Field Neighbors
Find Field Neighborhoods
Find Euclidean Distance Map
Write DREAM3D Data File
Errors | Warnings
Filter Name
Error Description
Error Code
Go
Pipeline Complete
Read DREAM3D Data File
DREAM3D File:
Data/Output/SmallIN100Cleaned.dream3d
Select...
Voxel Volume Info:
X Dim: 189
Y Dim: 201
Z Dim: 117
X Res: 0.25
Y Res: 0.25
Z Res: 0.25
X Origin: 0
Y Origin: 0
Y Origin: 0
Read Voxel Data
Read Surface Mesh
Read Solid Mesh
Voxel Data
Surface Mesh Data
Solid Mesh Data
Cell Data
Confidence Index
EulerAngles
GBEuclideanDistances
Field Data
Active
AspectRatios
AvgQuats
Ensemble Data
CrystalStructures
LatticeConstants
MaterialName
Find Field Centroids
Find Field Sizes
Find Field Shapes
Find Field Neighbors
Find Field Neighborhoods
Find Euclidean Distance Map
Write DREAM3D Data File

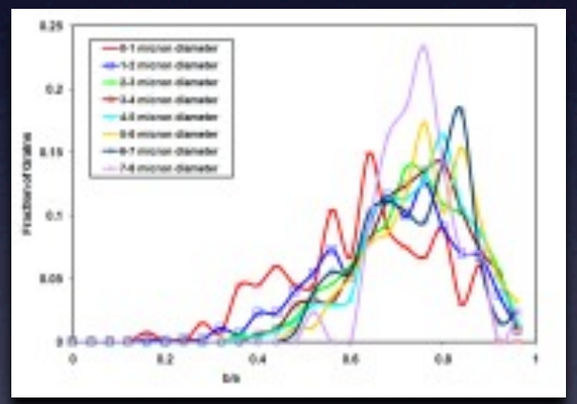
Computed Statistics

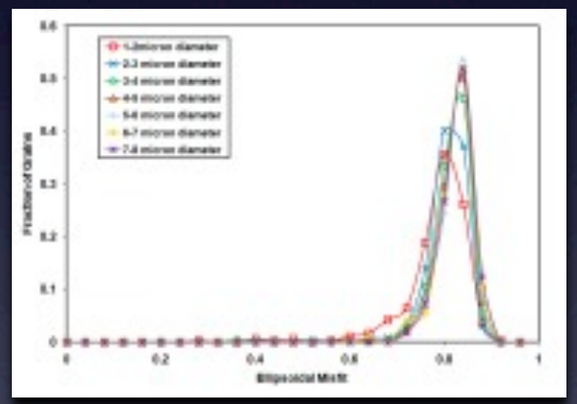


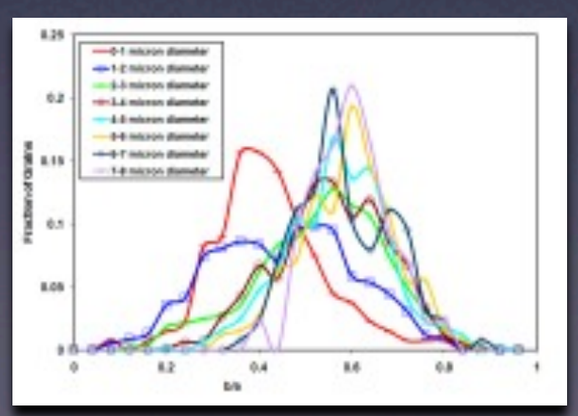


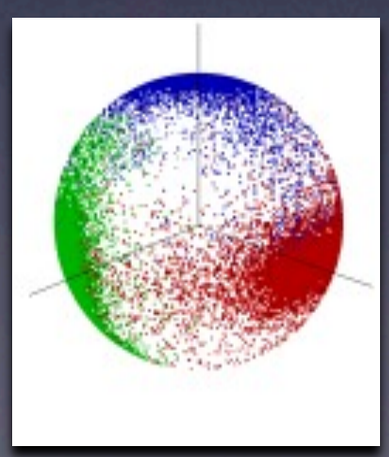


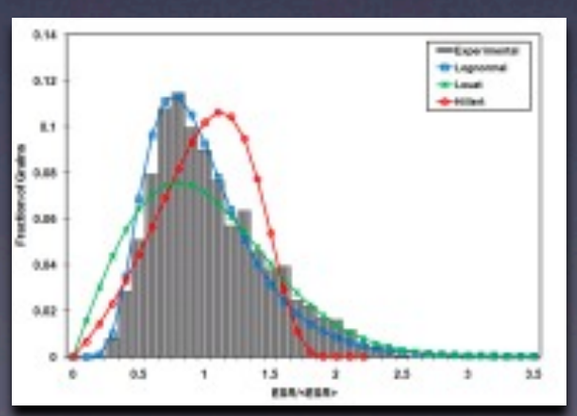






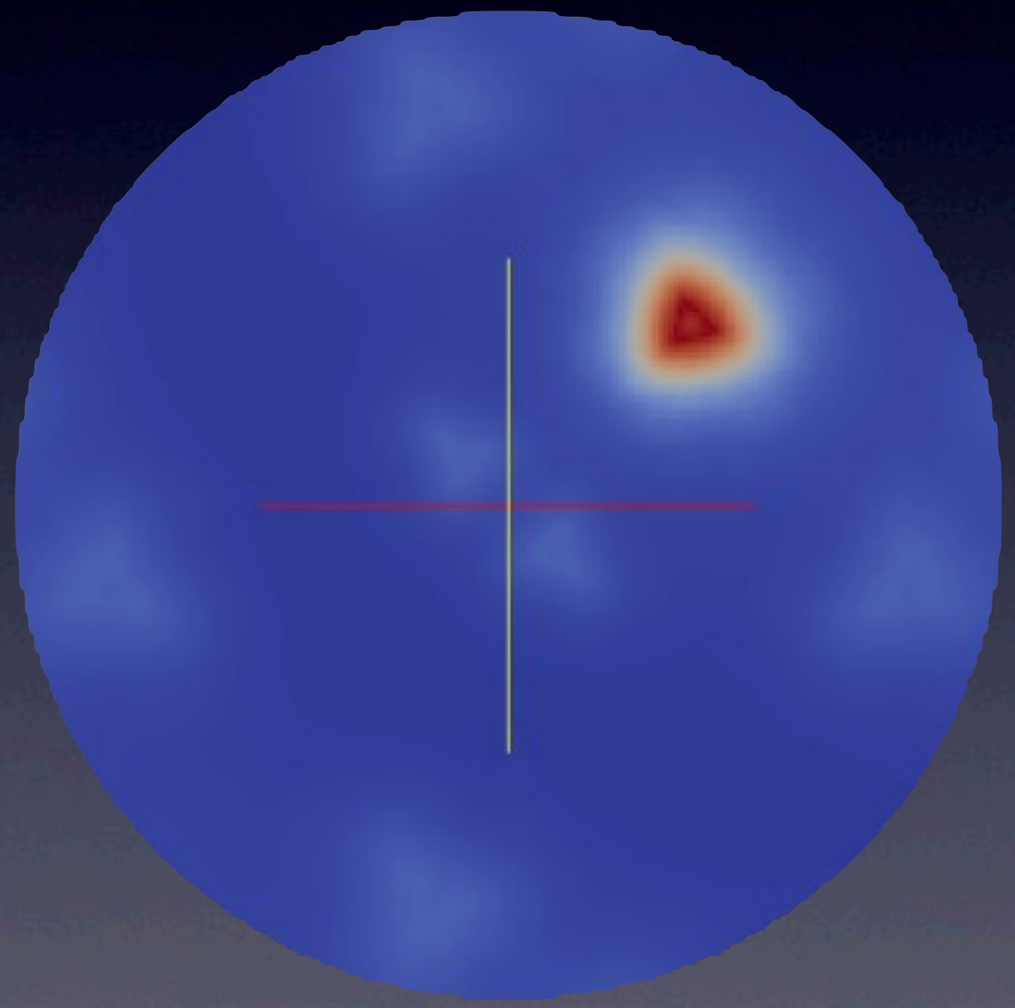






5 Parameter GBCD

- Rohrer, Rowenhorst, Rollett, DeGraef
- Experimental in 4.2.97
- Still in development



Small IN100 60Deg @ <111>

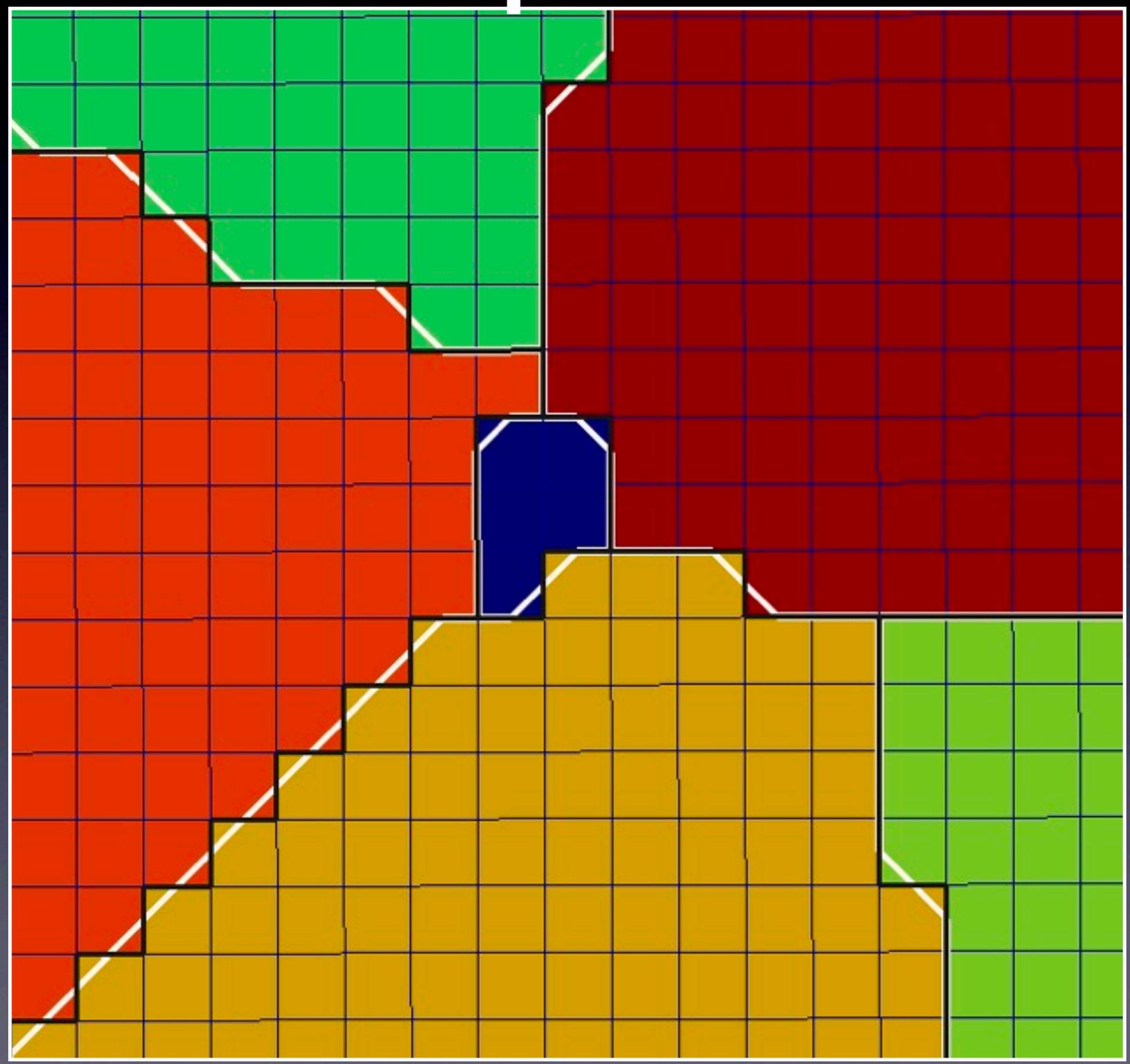
Surface Meshing

2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

Two Algorithms

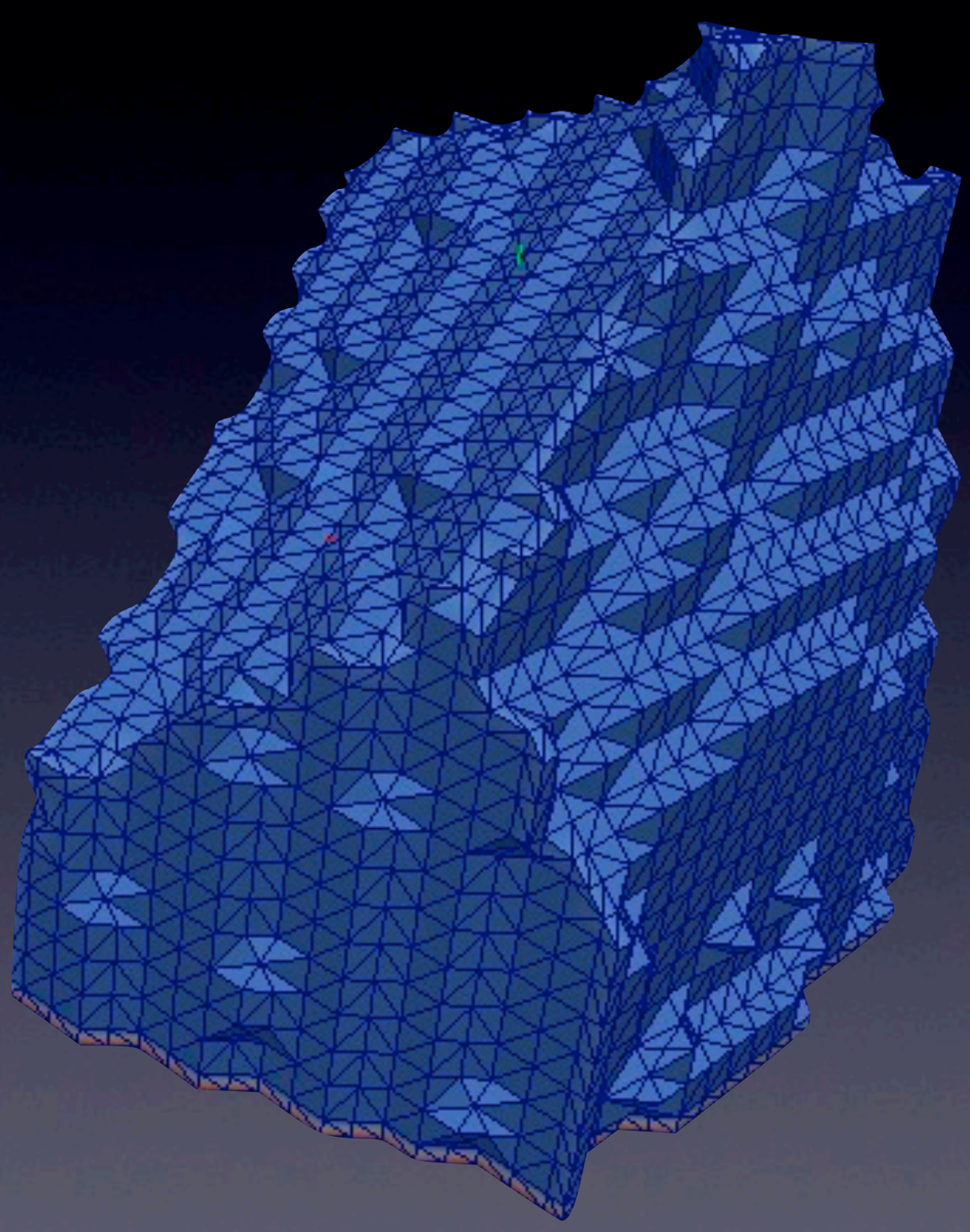
- MultiMaterial Marching Cubes
  - Initially Smoother Structure
  - Slow to run
  - Inconsistent triangle winding
- Quick Mesh
  - Follows exact voxel boundary
  - Very fast to run
  - Consistent Triangle Winding

2D View Comparison

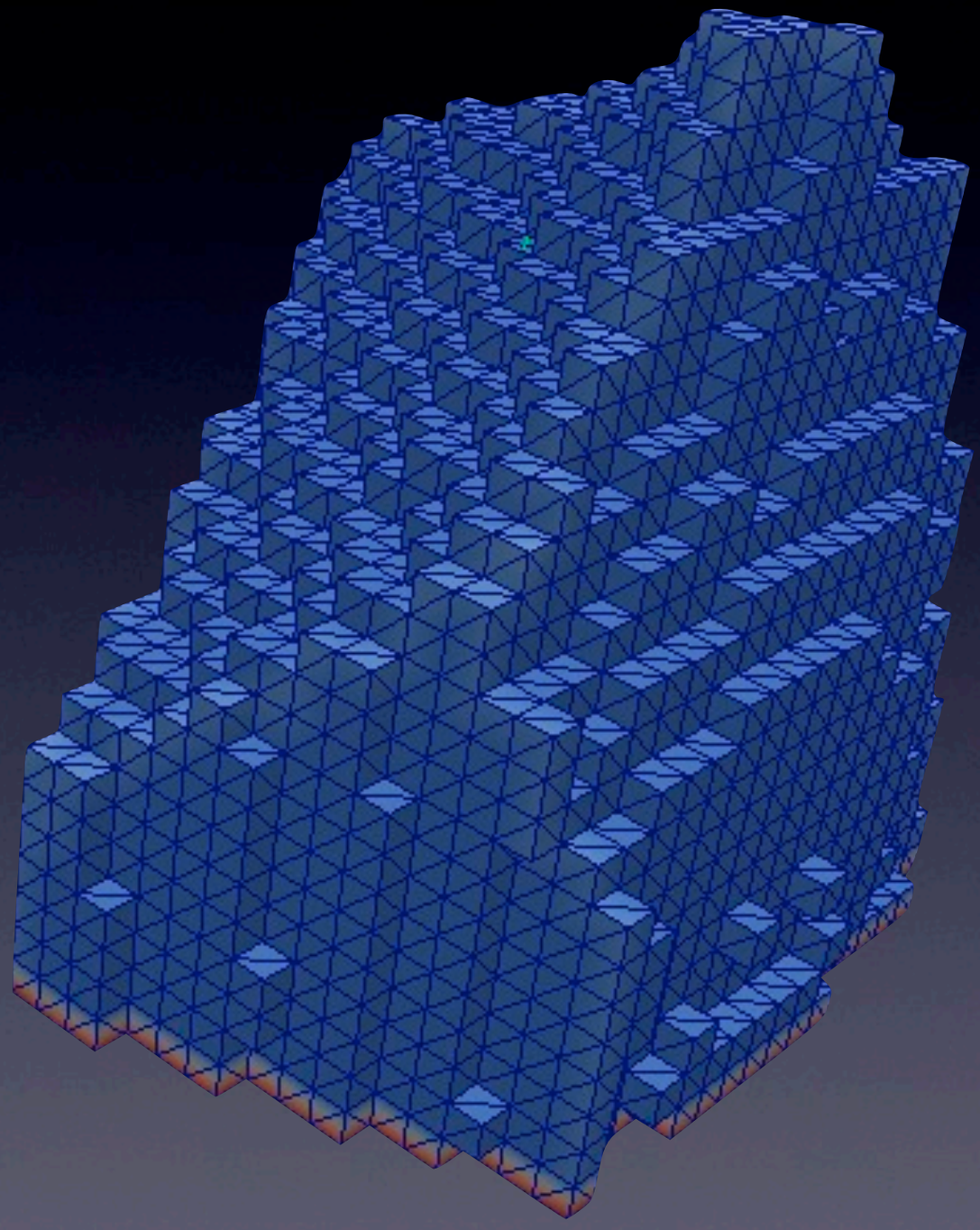


M3C: White
Quick: Black

Meshing Comparison



M3C



Quick

Export Mesh

- Write STL file PER grain
- Write raw nodes & triangles file
- Write an Abaqus file
  - Experimental currently
- Write VTK polydata
- Write a DREAM3D file

Mesh Smoothing Operations

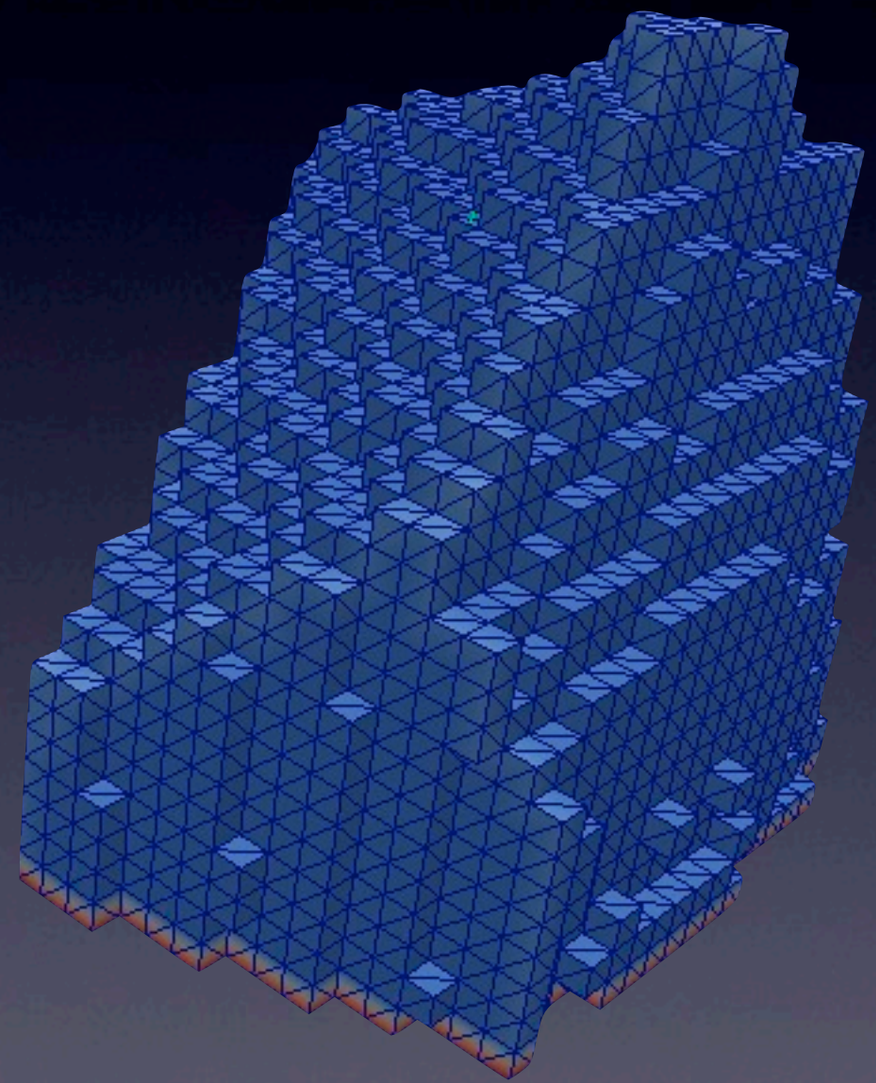
MFE Smoothing

- Donated by A.D. Rollet @ CMU
- Moving Finite Element Method
- Compute intensive
- Guarantees triangle aspect ratios
- Algorithm needs some updating
- Volunteers?

Kuprat, A., 2000. Modeling microstructure evolution using gradient-weighted moving finite elements. SIAM Journal of Scientific Computing 22, 535-560.

Laplacian Smoothing

- Iterative Process
- Node positions changed
- Topology not changed
- Tends to shrink the mesh
- Input Lambda values range 0 to 1.0

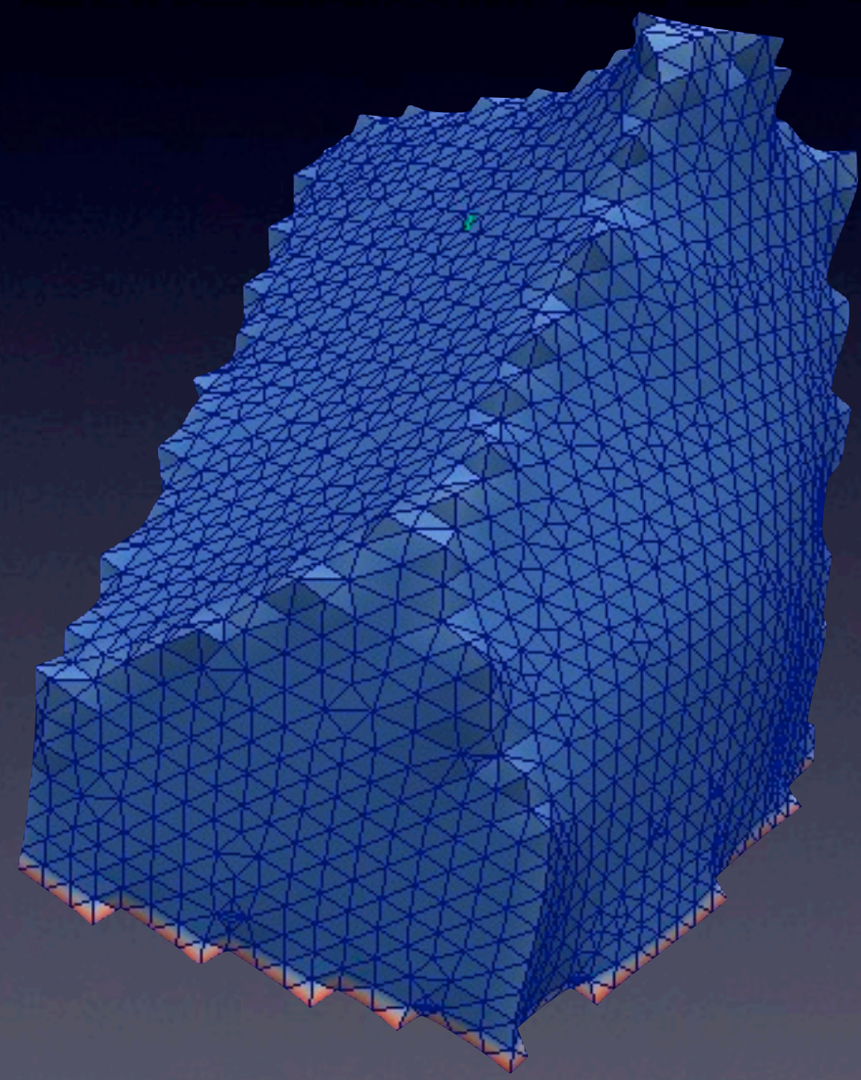


[1] *Field, D. A. (1988), Laplacian smoothing and Delaunay triangulations. Commun. appl. numer. methods, 4: 709–712. doi: 10.1002/cnm.1630040603*

[2] *Alexander Belyaev. "Mesh Smoothing and Enhancing. Curvature Estimation"*

Laplacian Smoothing

- Iterative Process
- Node positions changed
- Topology not changed



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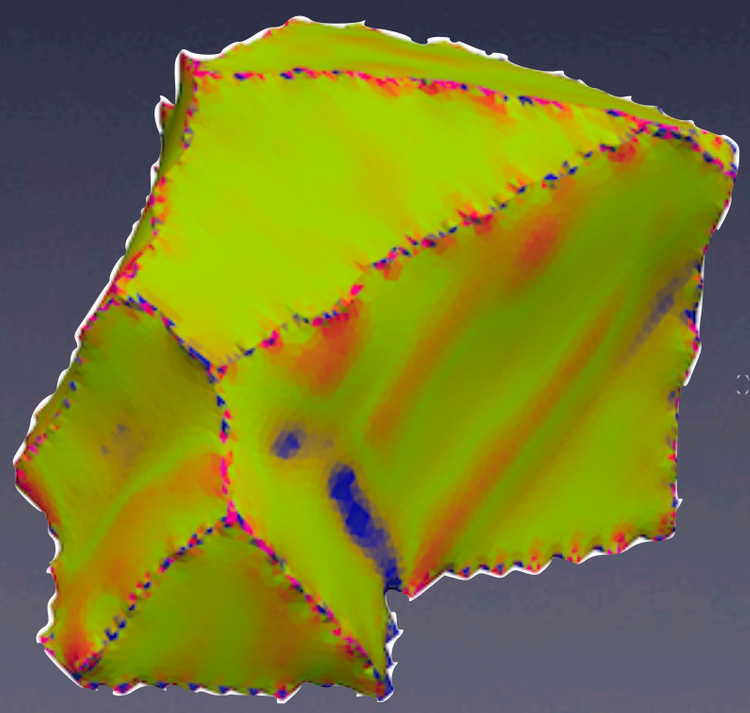
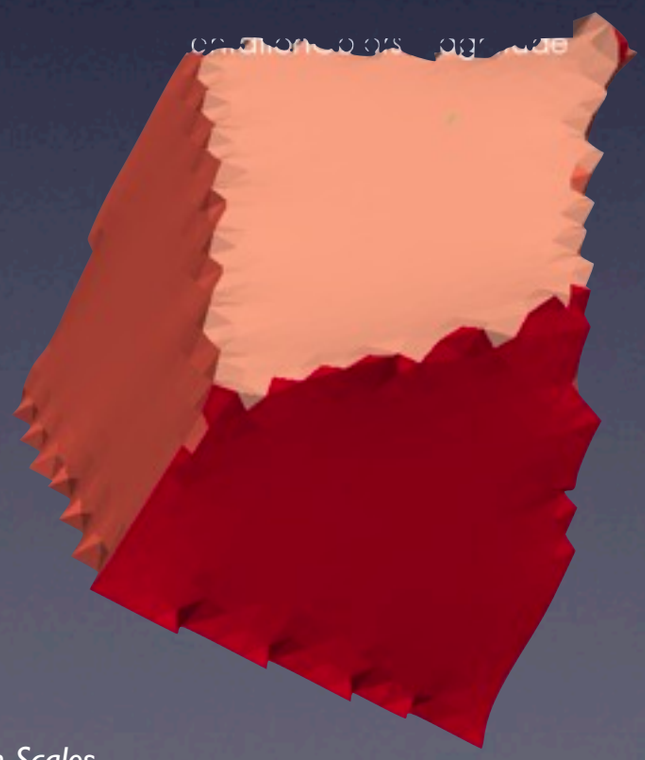
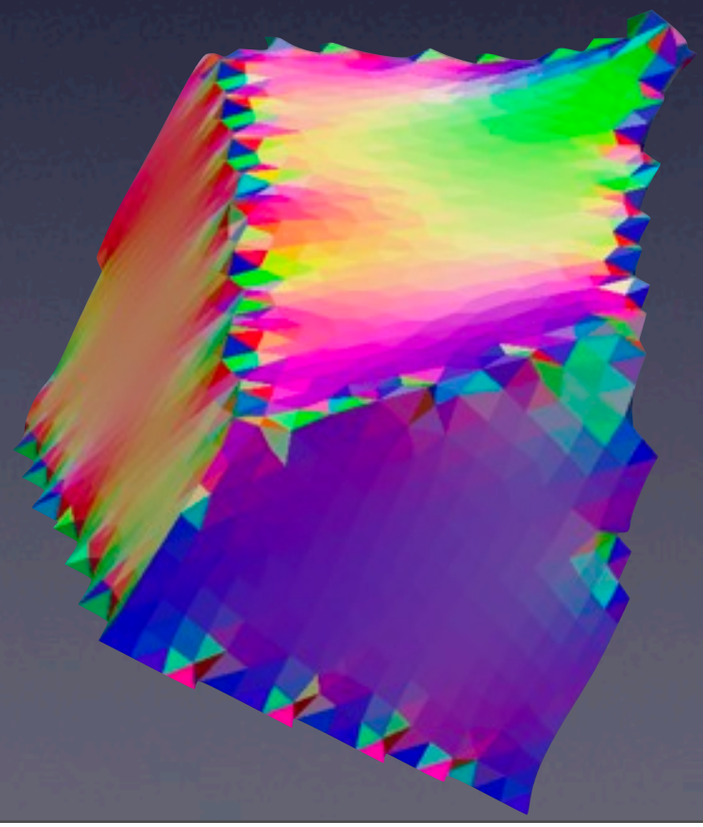
[2] *Alexander Belyaev. "Mesh Smoothing and Enhancing. Curvature Estimation" 2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales*

Filters Applied to Mesh

- Centroids, Normals, Areas
- IPF Colors, Misorientation Colors
- Grain Face Curvature







Generating Synthetic Microstructures

2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

Generating Synthetic Micros

- Need a set of statistics that describe your microstructure
  - Compute or Create
- Distributions
  - Grain Sizes
  - Shapes
  - Neighbors
- Texture
  - ODF, MDF

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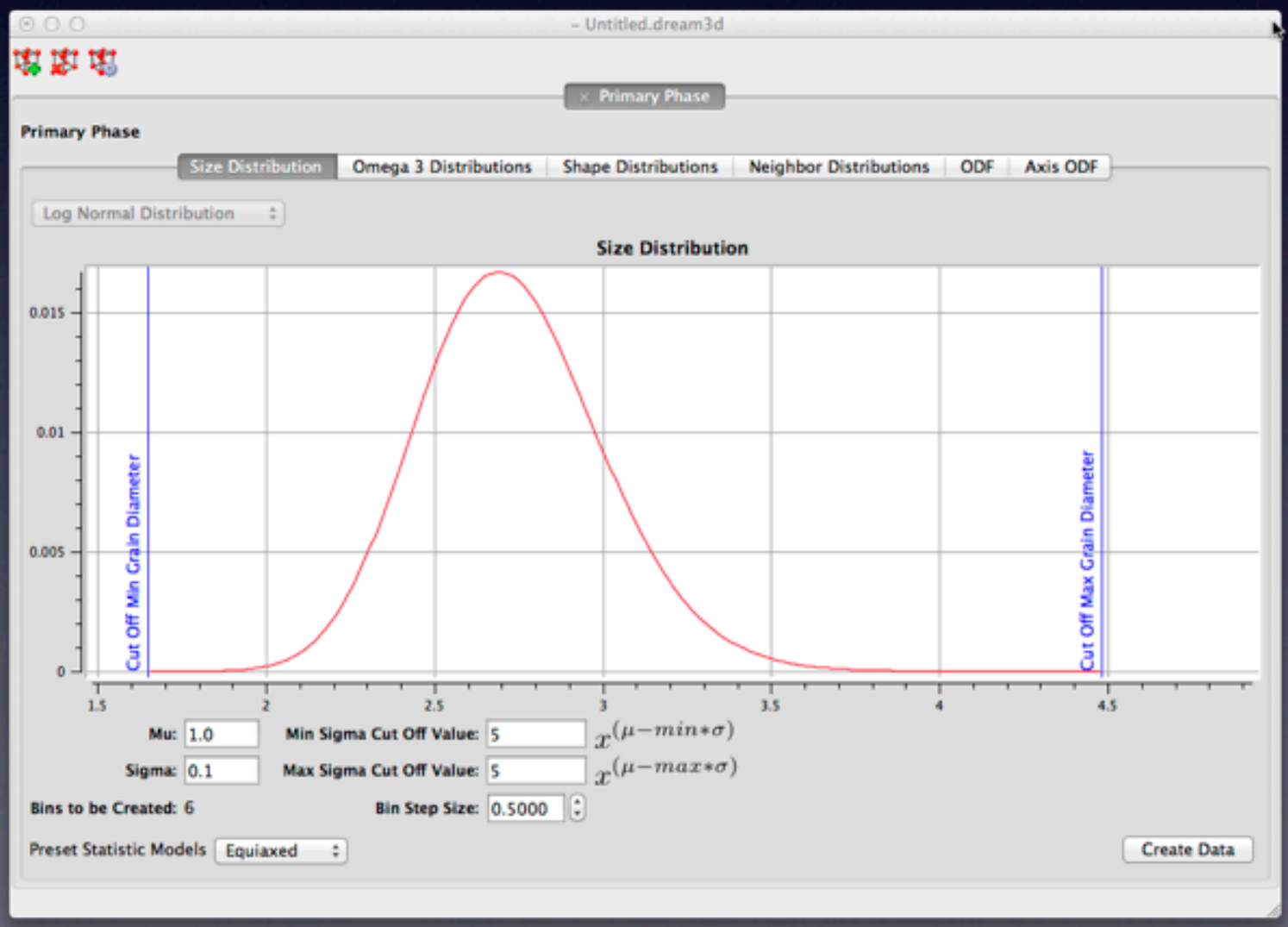

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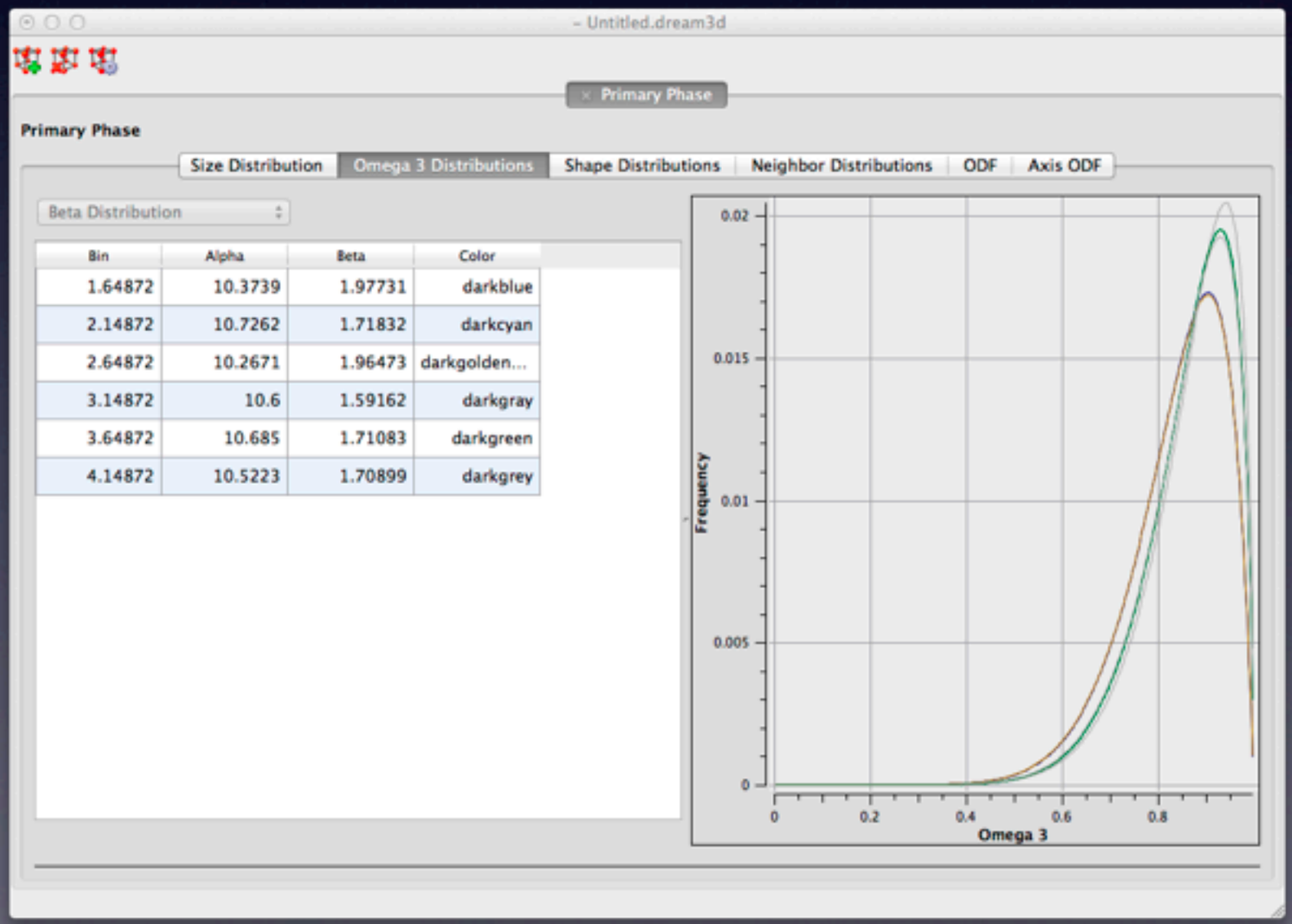

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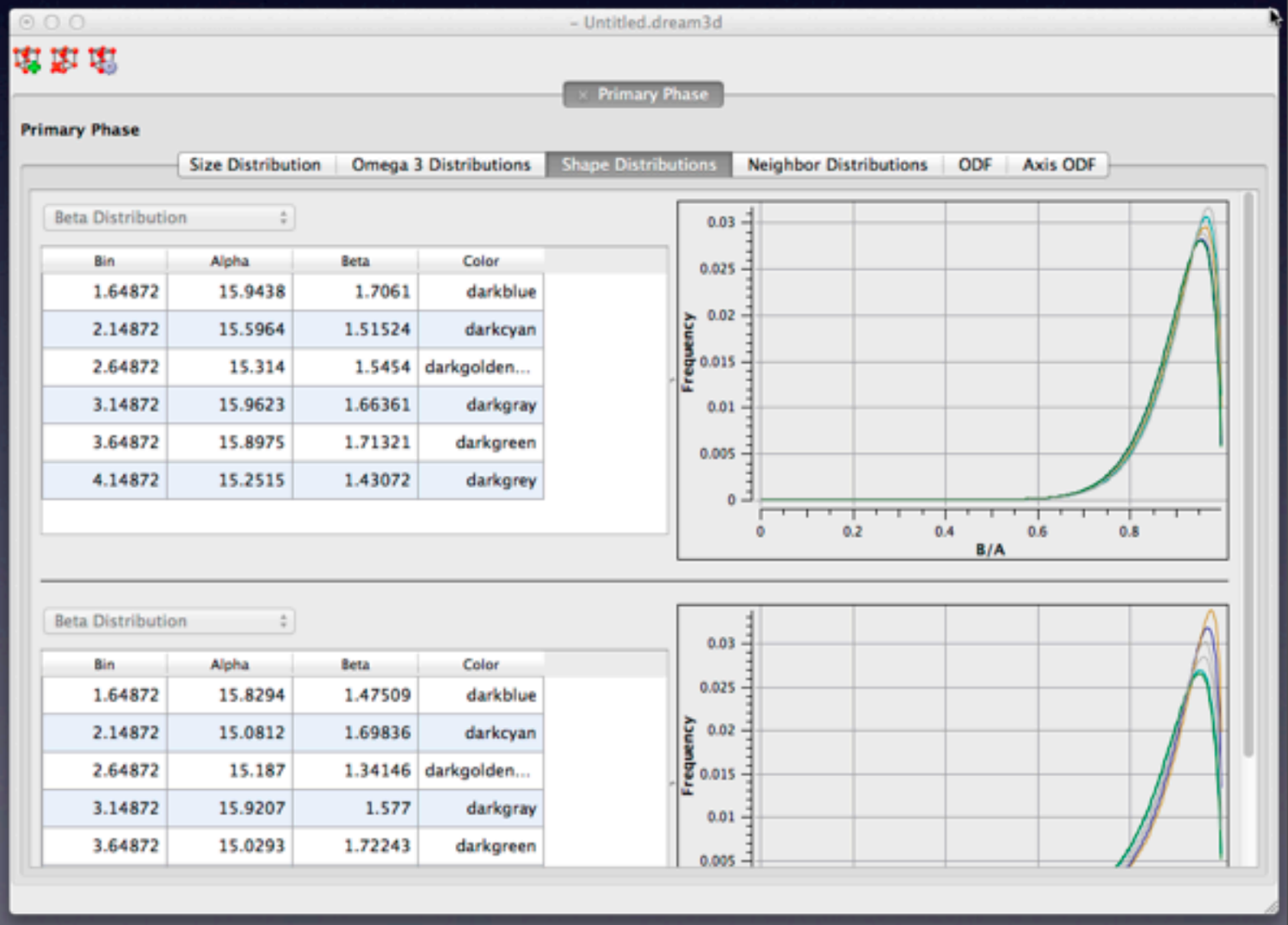

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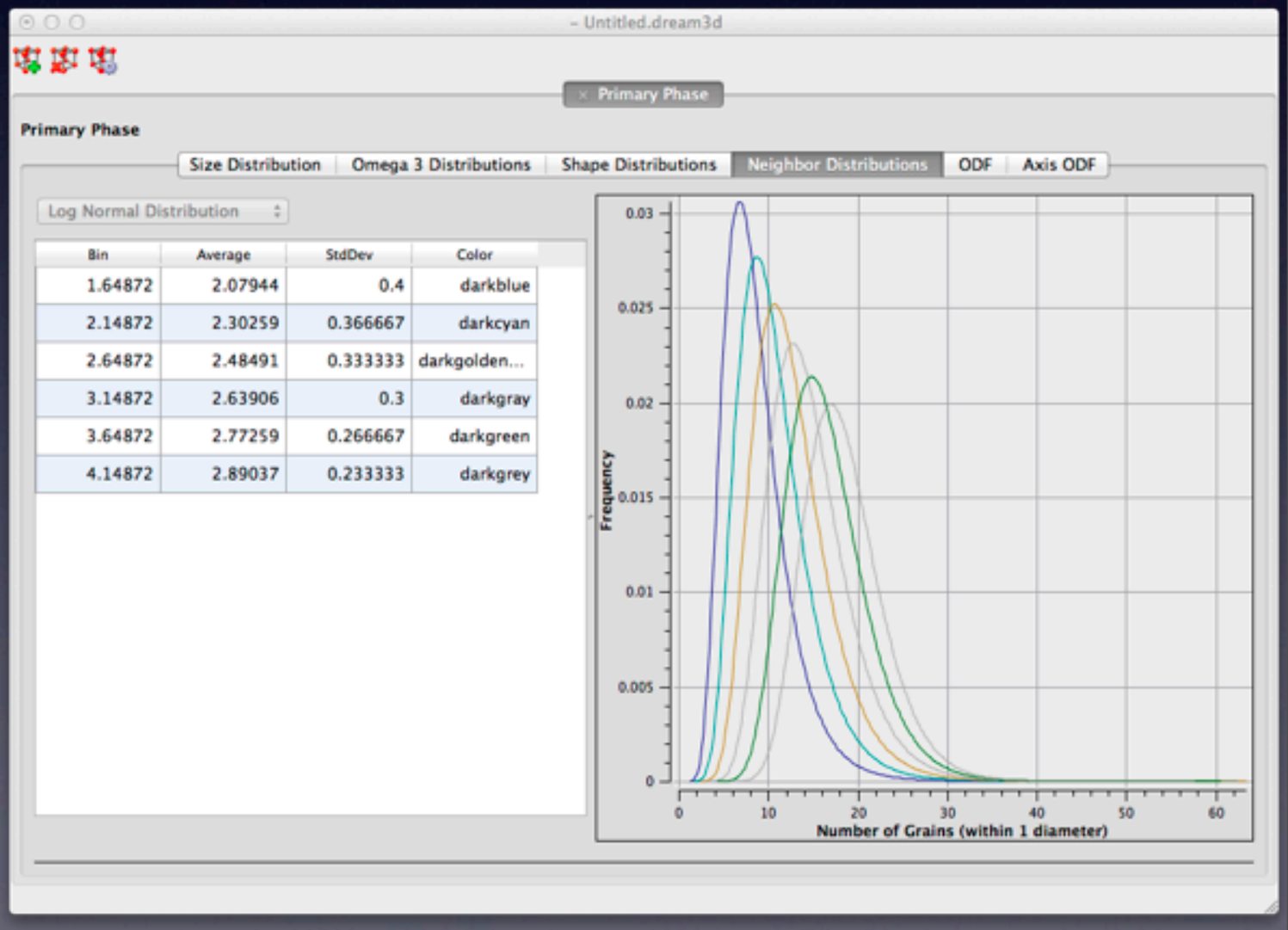

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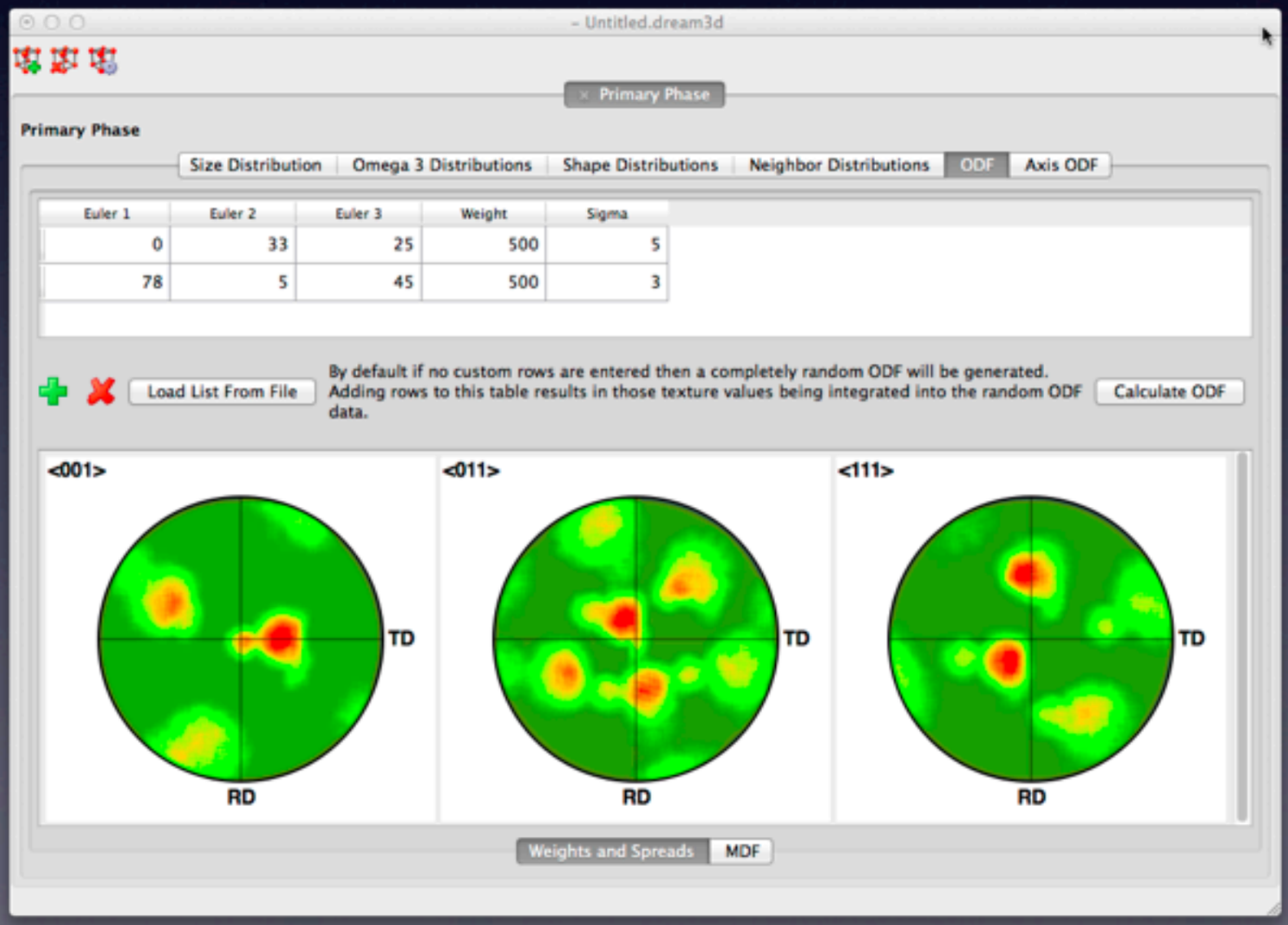

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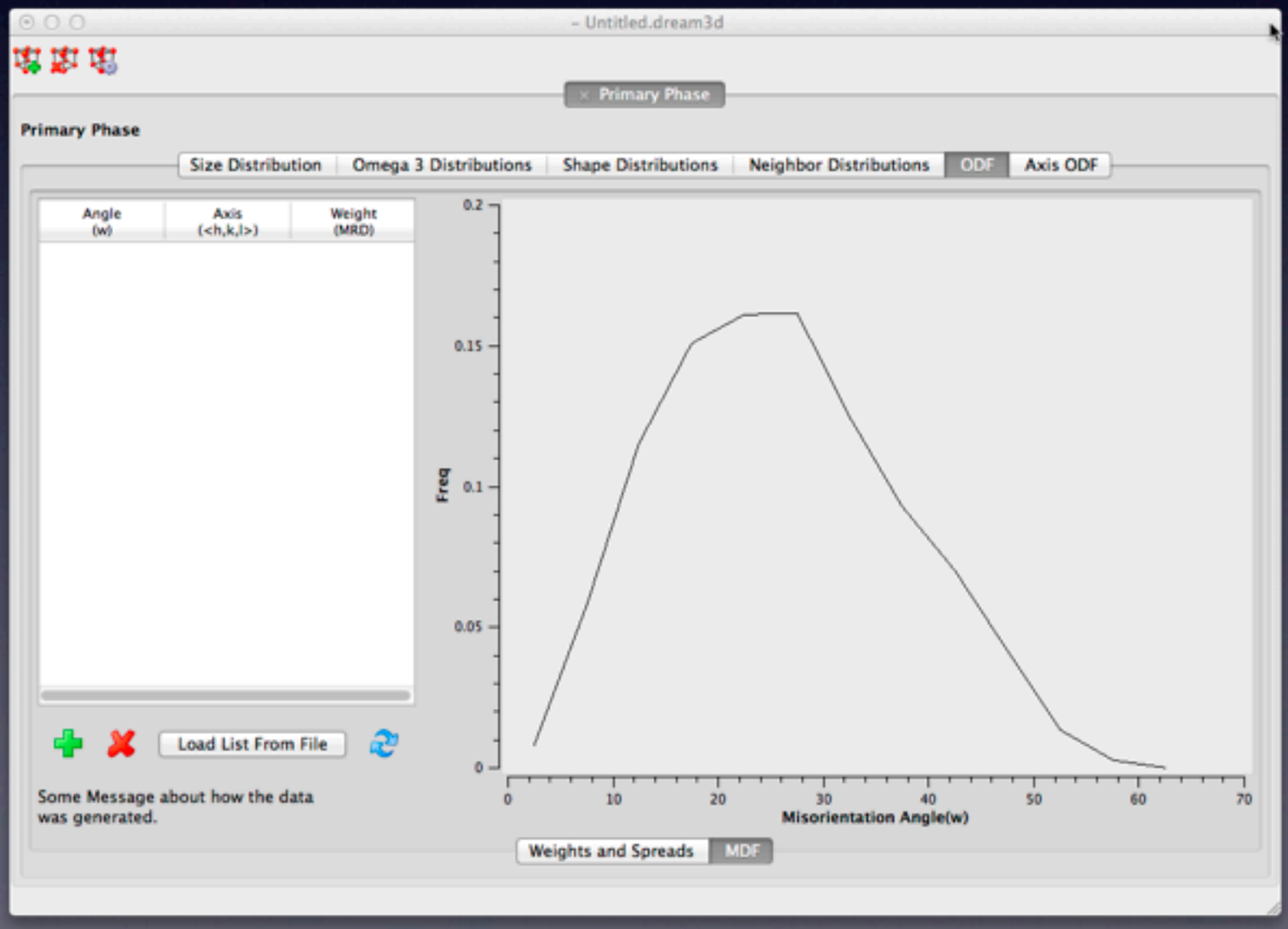

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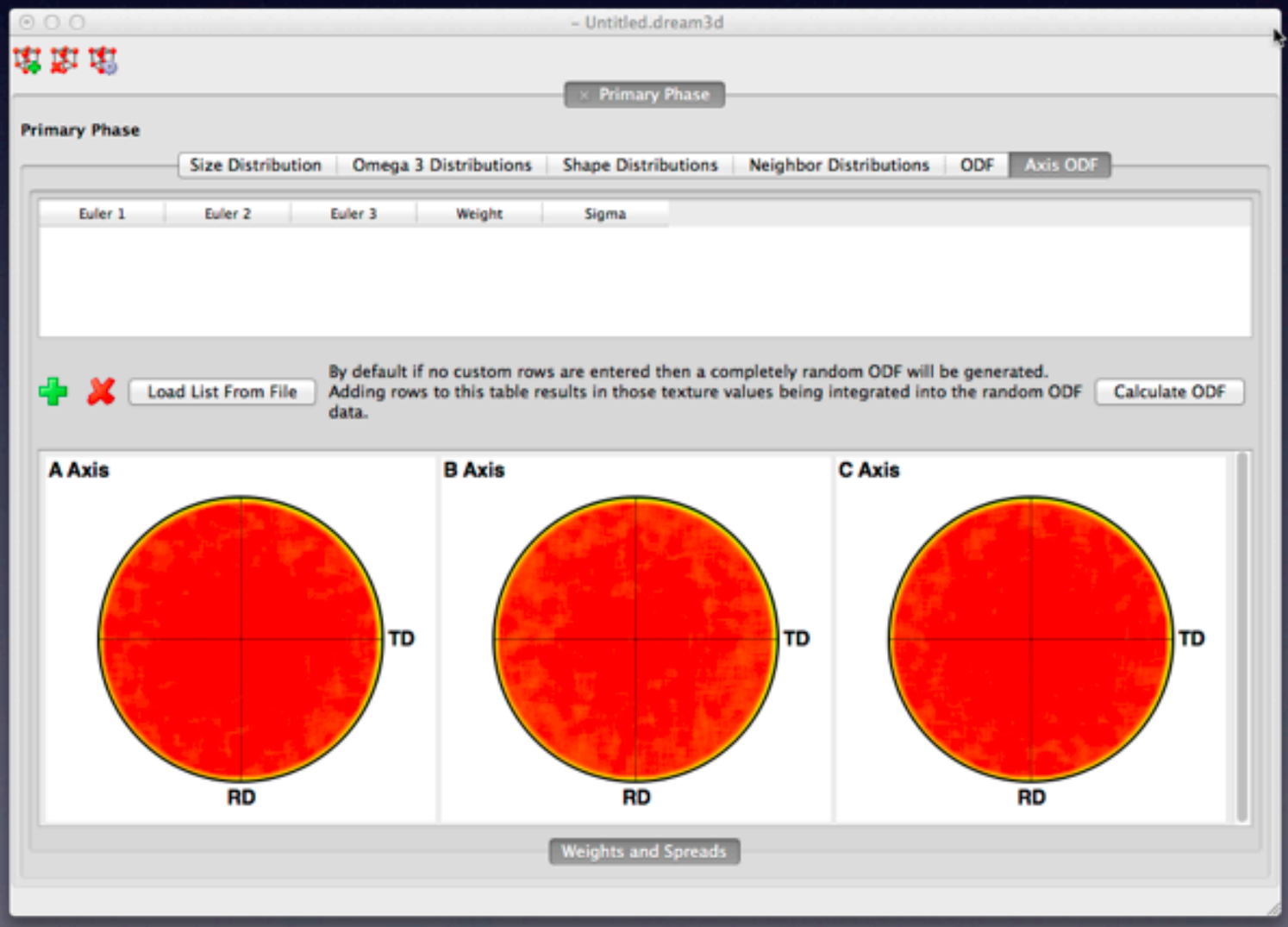

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DREAM3D

- ImageImport
- Processing
- Reconstruction
- Sampling
- Statistics
- SurfaceMeshing
- SyntheticBuilding
- Prebuilt Pipelines
  - Misc
  - Statistics
  - Workshop
    - Reconstruction
    - Statistics
    - SurfaceMeshing
    - Synthetic
      - (01) Single Cubic Phase ...
      - (02) Single Hexagonal Ph...
      - (03) Single Cubic Phase ...
      - (04) Two Phase Cubic He...
      - (05) Composite
    - UCSB
      - (01) Small IN100 2D IPF I...
      - (02) Small IN100 2D IPF ...
- Favorite Pipelines

Errors | Warnings

Filter Name	Error Description

Go

Pipeline Complete

Initialize Synthetic Volume

HDF5 Stats File: Data/CubicSingleEquiaxed.dream3d [Select]

Voxel Dims		Spacing (micron)	
X:	128	X:	0.5000
Y:	128	Y:	0.5000
Z:	128	Z:	0.5000

Estimated No. Grains 270

Shape Types

Phase 1: Ellipsoid

Pack Primary Phases

Periodic Boundary ☐

Write Goal Attributes ☐

Goal Attribute CSV File [Save As...]

Find Field Neighbors

Find Number of Fields

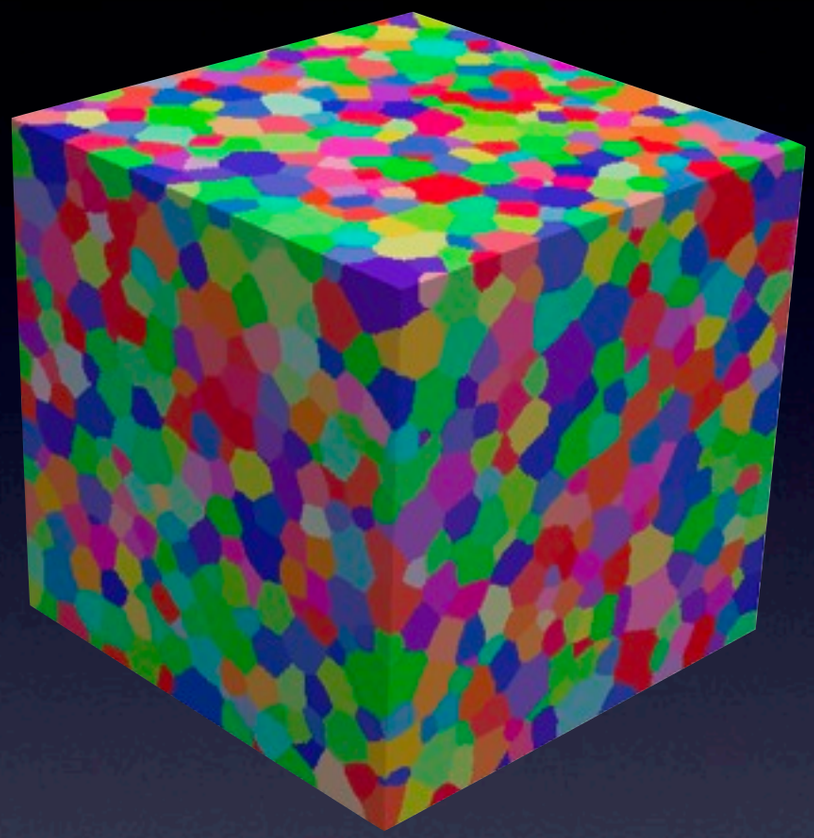
Match Crystallography

Maximum Number of Iterations (Swaps) 100000

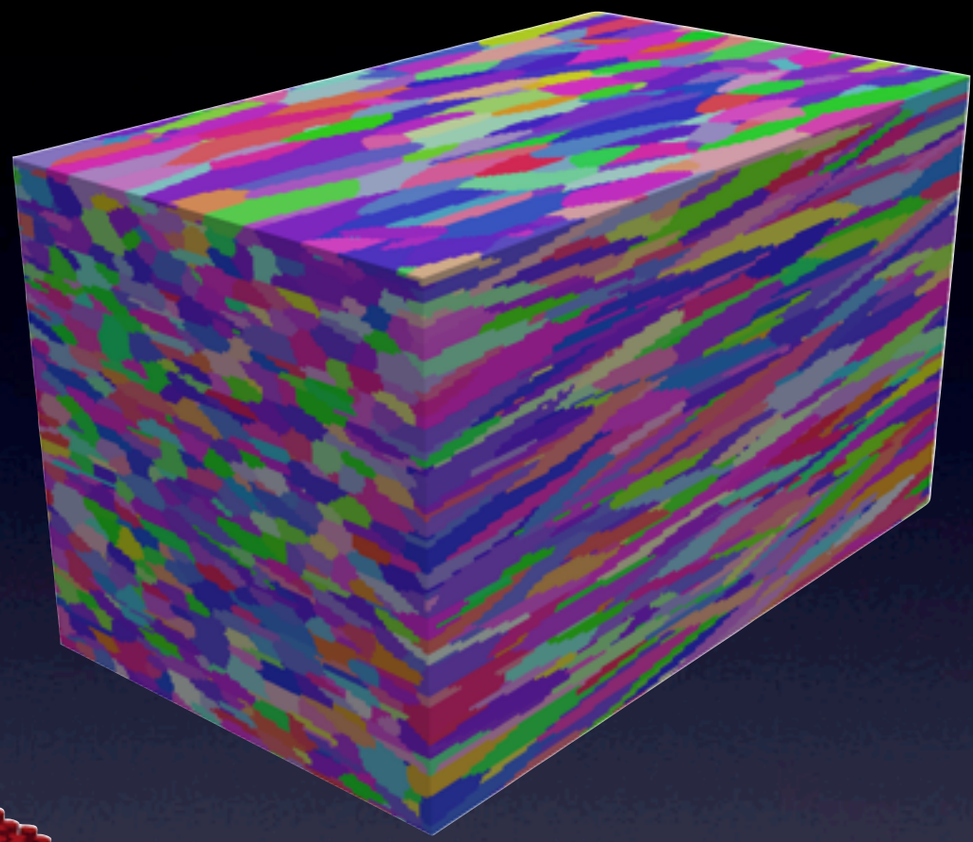
Generate IPF Colors

Reference Direction 0 0 1

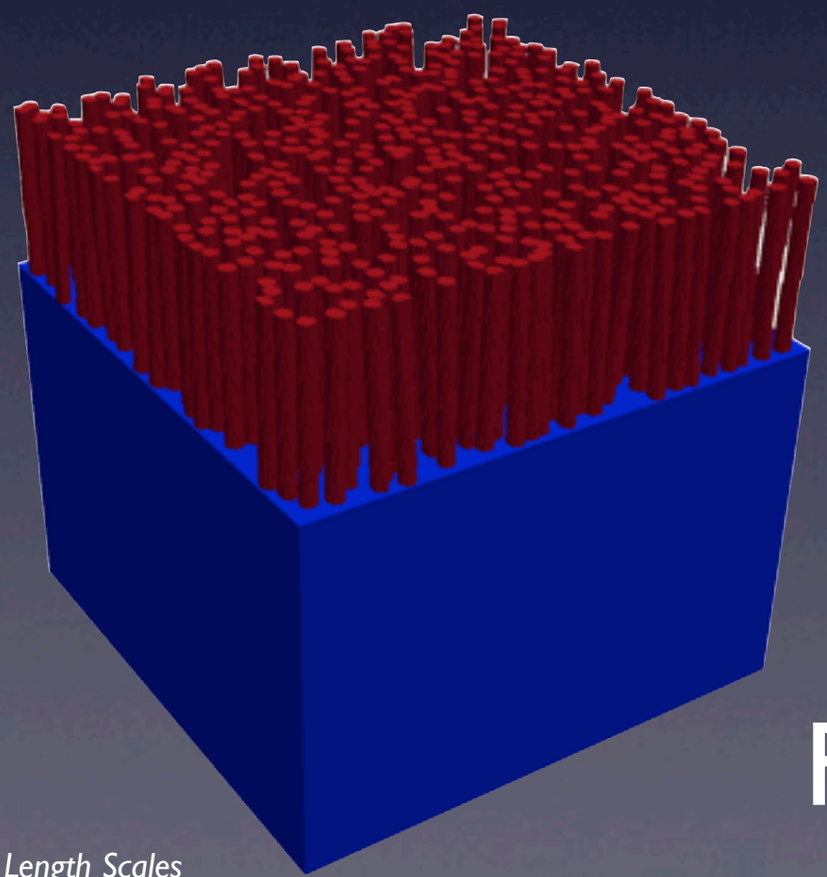
Generating Synthetic Micros



Single Phase Equiaxed



Single Phase Rolled



Fiber Composite

Synthetic Summary

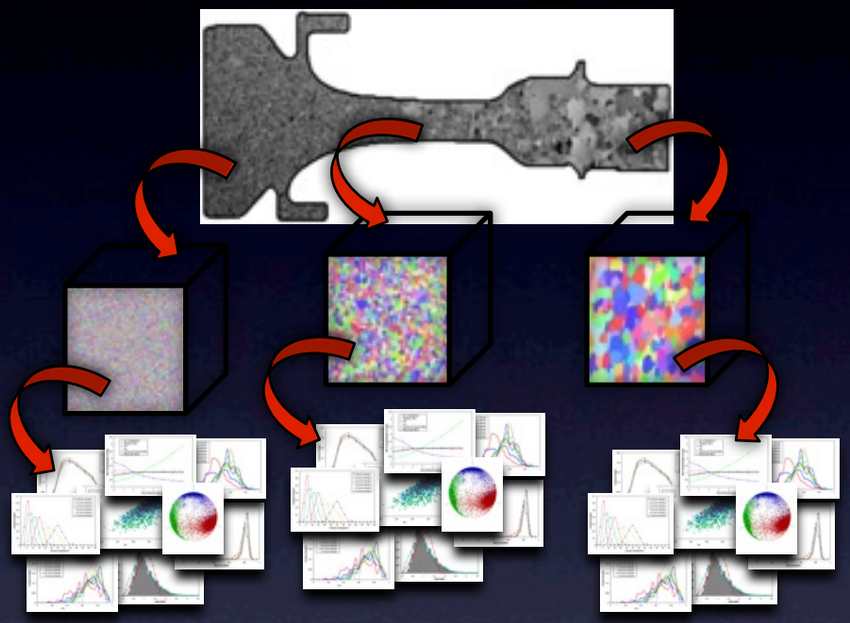
- Define Statistics
  - StatsGenerator
    - DREAM3D itself (Compute Ensemble Statistics)
- Use DREAM3D to generate the structure
- Mesh and Export to modeling program

Real World Uses

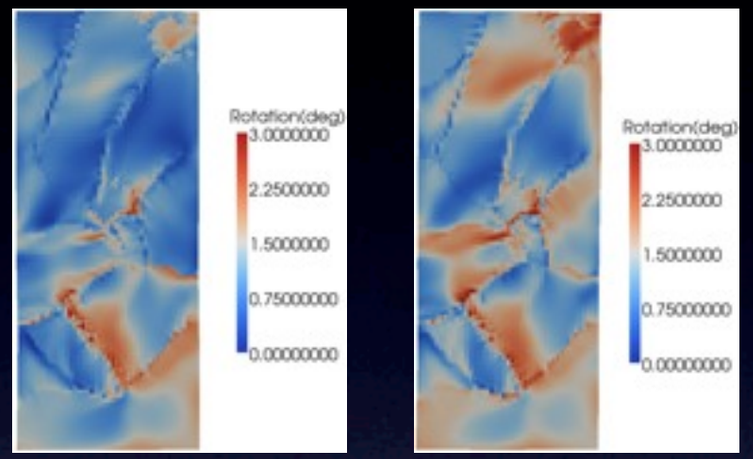
2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

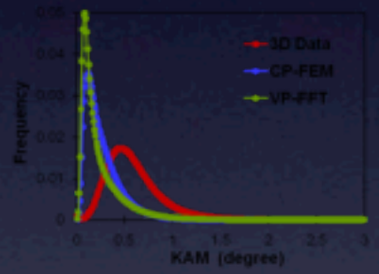
AFRL

Microstructure Quantification



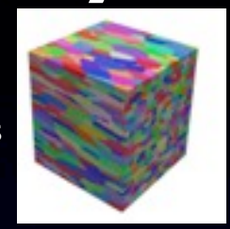
Model Comparison



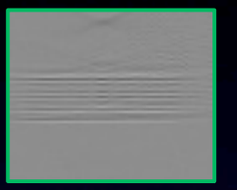


Choi, 2011

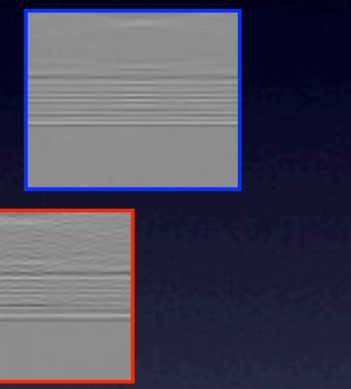
Sensitivity Studies



Rolled Grains

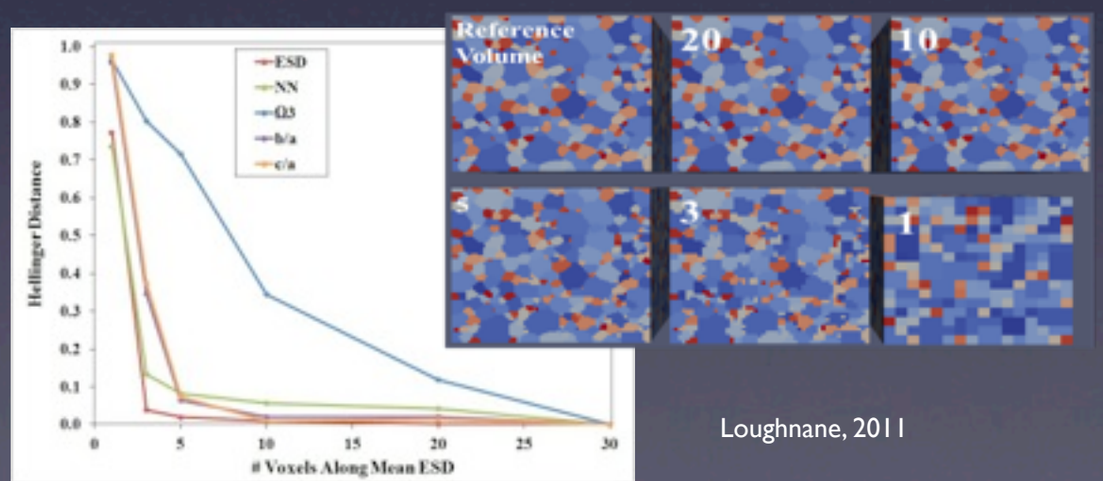


Basket weave Grains



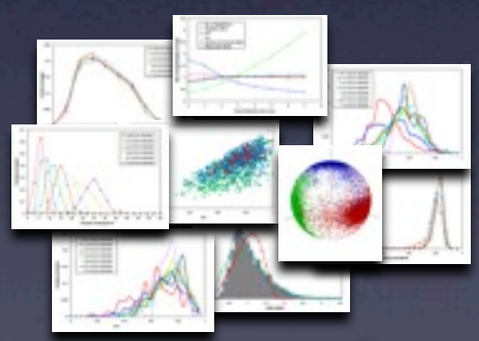
Equiaxed Grains

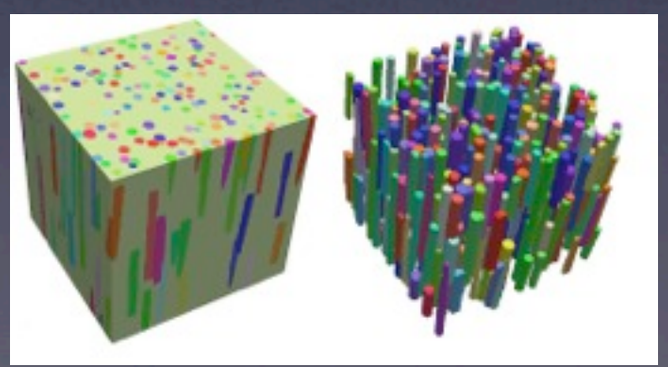
Adapted from Blackshire, 2011



Loughnane, 2011

Data Collection Optimization





Microstructure Design

Carnegie Mellon Univ.

- CMU (rollett@andrew.cmu.edu)
  - Synthetic microstructures that represent complex 2-phase titanium alloys.
  - Synthetic microstructures that represent nano-twinned copper
  - Extract microstructural data (volume fractions etc) from multiphase microstructures for fuel cells.

ARL and UCSB

- ARL
  - Synthetic microstructures that represent pearlitic steel alloys.

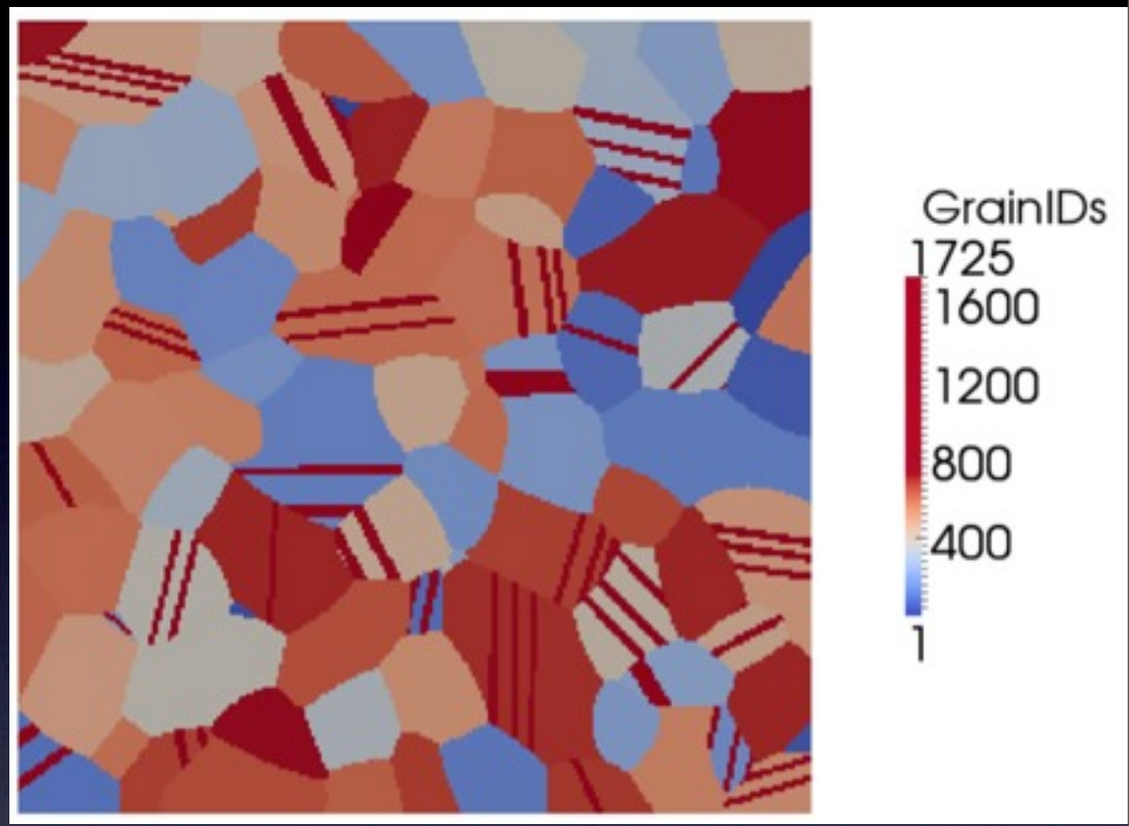
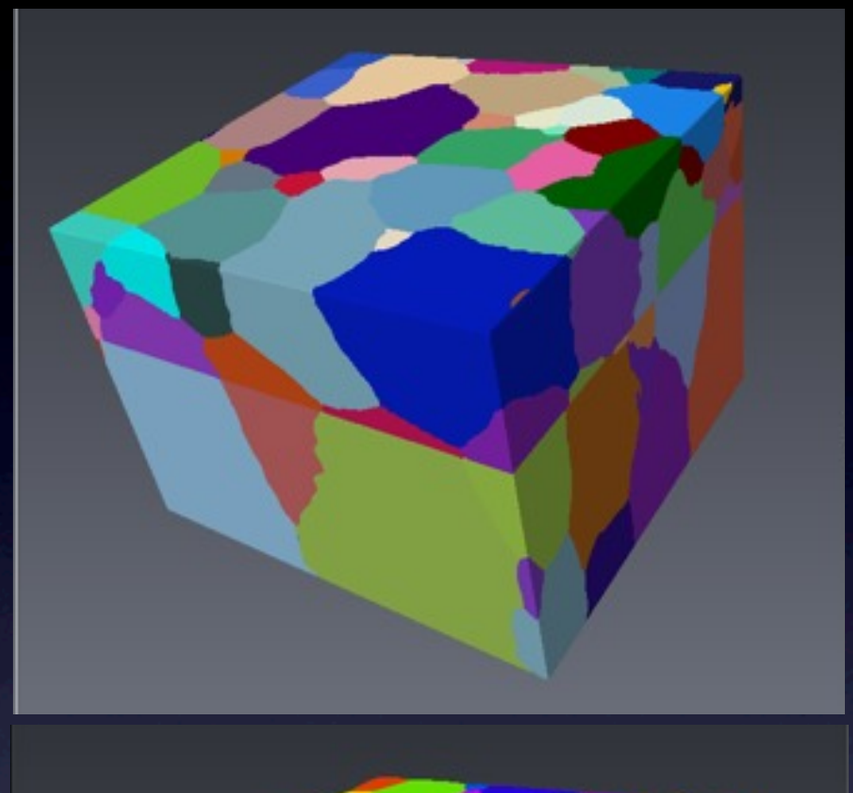


Image courtesy of B. Anglin (ARL)

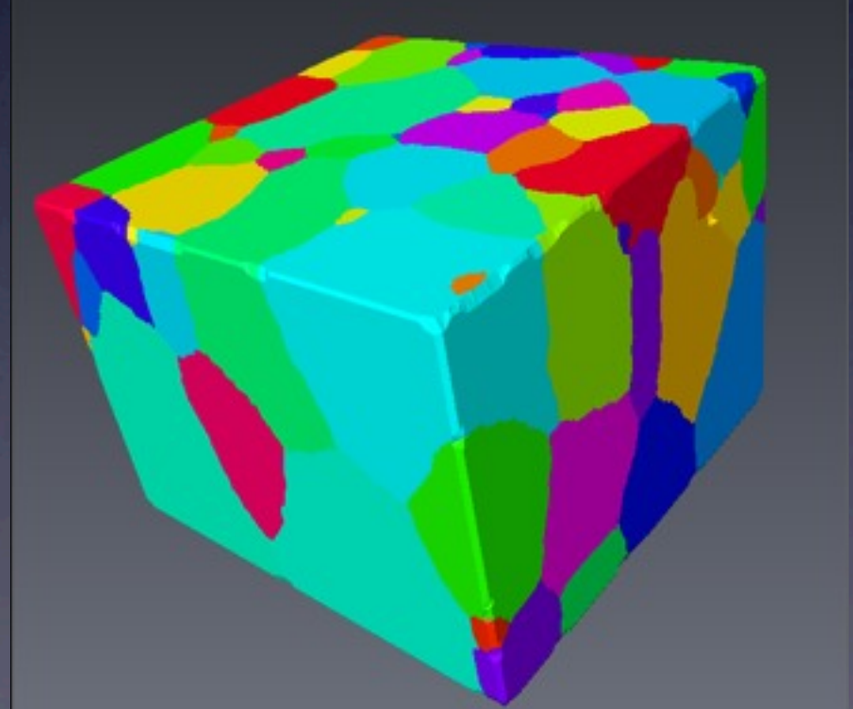
- UCSB
  - Analyze Femto-Second LASER ablated Ti-6-4

Arizona State Univ.

- Manual Reconstruction
- 2 weeks effort
- Inconsistent grain numbering



- DREAM3D/Avizo Fire
  - Initial 3D Reconstruction
  - Surface Mesh
  - 1.5 Hours



K. Rudman, H. Lim, R. McDonald, P. Peralta, E. Luther and K. McClellan, "Spatial and Crystallographic Correlations of Microstructural Features in Depleted Uranium Oxide." Journal of Nuclear Technology, 2013.

Adding Plugin to DREAM3D

2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

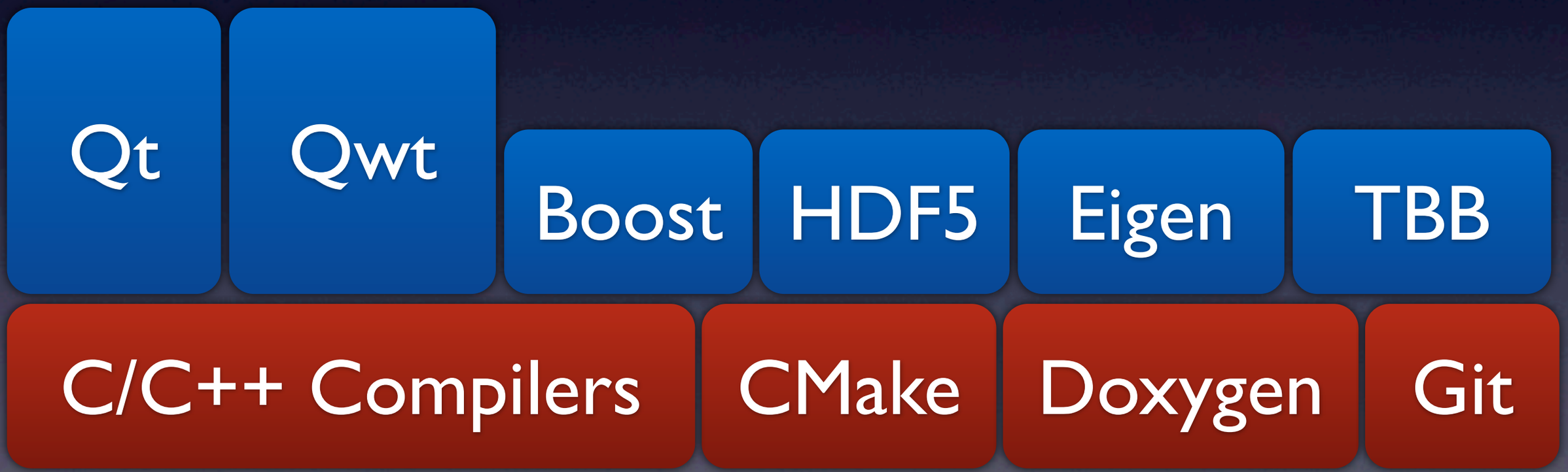
Layers of DREAM3D

2013 Aug 20. Materials in 3 D: Modeling and Imaging at Multiple Length Scales

Layers of DREAM3D

C/C++ Compilers | CMake | Doxygen | Git

Layers of DREAM3D



Layers of DREAM3D

Layers of DREAM3D

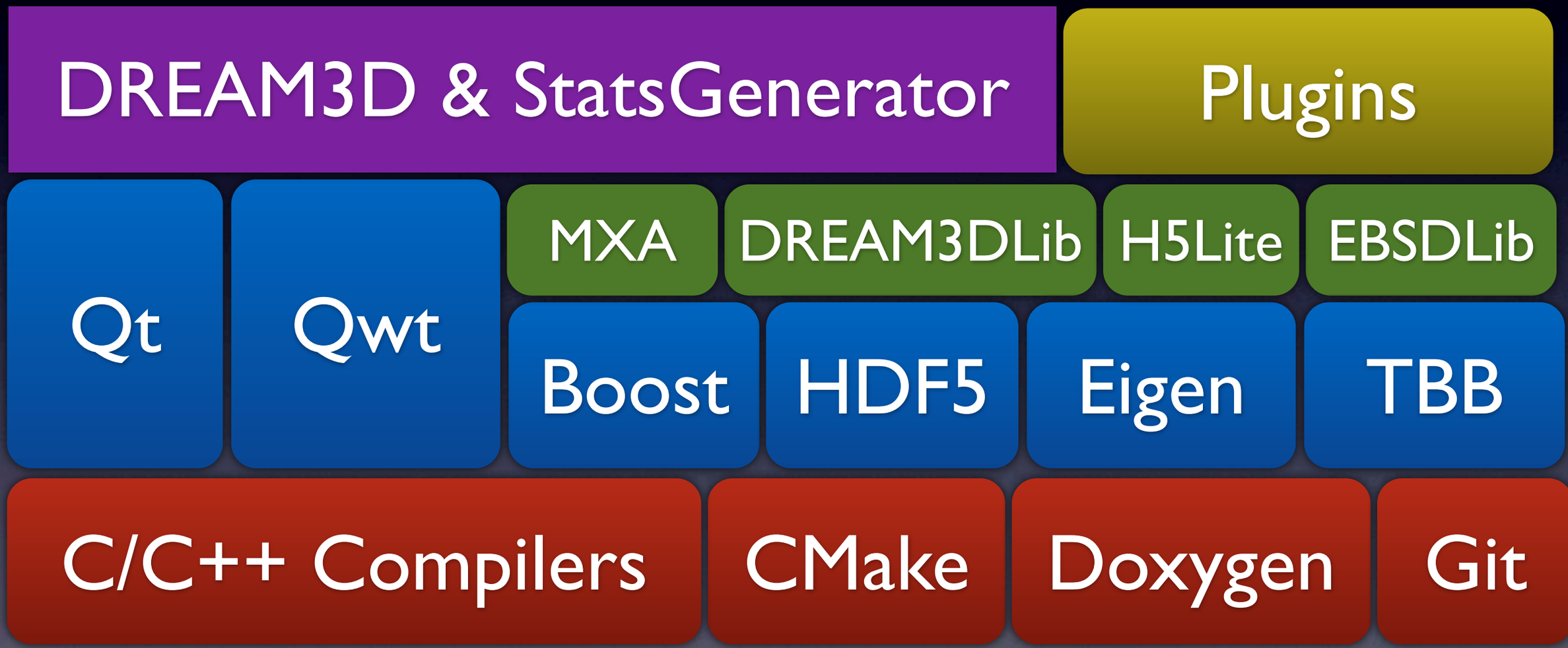
DREAM3D & StatsGenerator

Qt | Qwt | MXA | DREAM3DLib | H5Lite | EBSDLib

Boost | HDF5 | Eigen | TBB

C/C++ Compilers | CMake | Doxygen | Git

Layers of DREAM3D



Why a Plugin?

- Proprietary Codes
  - Company does not want to release sources
  - Protect Intellectual Property
    - Internal development
- Incompatible source codes
  - Codes will not compile on all platforms
- Introduce External Library dependencies

Create a Plugin

- Use the "PluginMaker" application.
  - Compiled with DREAM3D
- Generates all the basic code and support files
- Allows you to concentrate on your filter
- Group all your filters into a single plugin

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- Group all your filters into a single plugin
- Will Lenthe @ UCSB writing Plugins!!

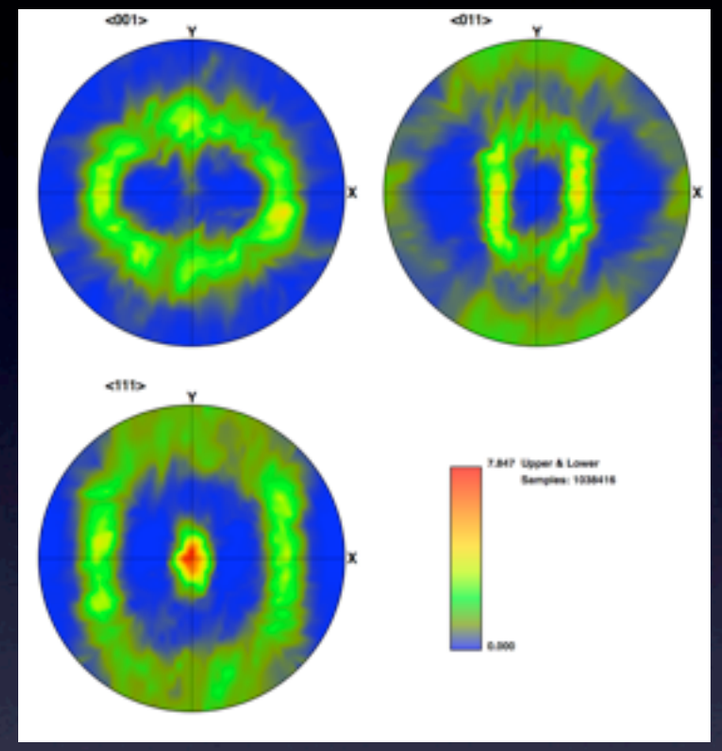
Getting Help

- http://dream3d.bluequartz.net
- Email DREAM3D@bluequartz.net
- User Manual on Web Site
- Several Tutorials in the User Manual

Ideas for the Future

- Process Images
- Improved FEM Workflows
- Pole Figures for Texture Analysis
  - *Currently Testing*
- Python Access to DREAM3D Algorithms
- More Parallelization
  - OpenCL (CUDA)

Ideas for the Future



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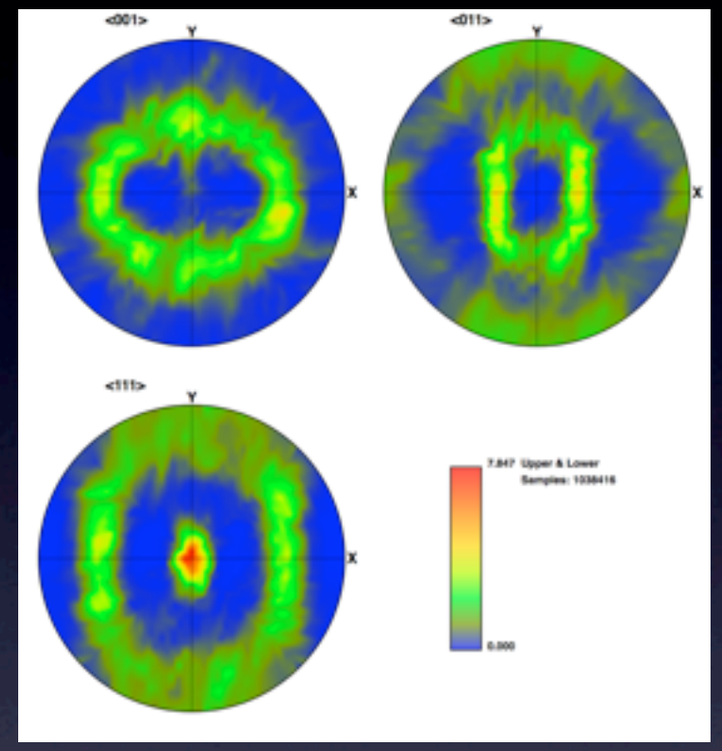

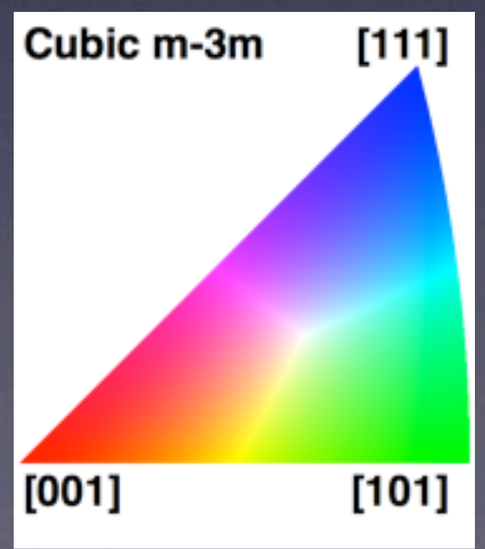

Cost & License

- BSD Licensed
- http://opensource.org/licenses/BSD-3-Clause
- What you have today is FREE to use.

Availability

- http://dream3d.bluequartz.net/downloads/
- Version 4.2.x available NOW.
- System Requirements
  - Windows 32/64 bit
  - OS X 64 Bit (10.6.8/10.7/10.8)
  - Linux RHEL 6.3
- Reasonable Graphics card for Visualization

Source Code

- Hosted at GitHub.com
  - http://github.com/DREAM3D
  - Anyone can get the source code
  - Track Issues, Report Bugs, Wiki
  - Follow development of DREAM3D
  - Work in your own area then request your changes to be merged into DREAM3D

Users*

DoD and DoE Laboratories
- Air Force Research Lab, OH+FL, USA
- Los Alamos National Lab, NM, USA
- Naval Research Lab, VA, USA
- Idaho National Lab, ID, USA
- NASA Langley, VA, USA
- Army Research Lab, MD, USA
- Sandia National Lab, NM, USA

OEMs/Industry
- GE Global, NY, USA
- GE Aviation, OH, USA
- HRL Laboratories LLC, CA, USA

International
- Ghent University, Belgium
- Univ. Paul Verlaine-Metz, France
- Queens Univ., Canada
- Seoul National Univ., S. Korea
- Univ. of Manchester, UK
- Univ. Lorraine, France
- Salzgitter Mannesmann Forschung GmbH, Germany
- Deakin University, Australia
- King Abdullah Univ., Saudi Arabia
- University College, Ireland
- Riso/DTU, Denmark
- Pohang Univ., Korea

U.S. Academia
- Ohio State Univ., OH, USA
- Carnegie Mellon Univ., PA, USA
- Cornell, NY, USA
- Univ. of Michigan, MI, USA
- Drexel Univ., PA, USA
- Lehigh Univ., PA, USA
- Iowa State Univ., IA, USA
- Northwestern Univ., IL, USA
- Purdue Univ., IN, USA
- Georgia Tech, GA, USA
- Univ. of North Texas, TX, USA
- Johns Hopkins Univ., MA, USA
- Boise State Univ., ID, USA
- Univ. of Dayton, OH, USA
- Univ. of Pittsburgh, PA, USA
- Vanderbilt Univ., TN, USA
- Univ. of Kentucky, KY, USA
- Univ. of California Santa Barbara, CA, USA
- Univ. of Florida, FL, USA
- Univ. of Texas at San Antonio, TX, USA
- Wright State Univ., OH, USA
- Case Western Univ.. OH, USA
- Univ. South Carolina, SC, USA
- Mississippi State Univ., MS, USA