Orientation Imaging Microscopy™ (OIM) is a powerful tool enabling the researcher to analyze local texture and grain boundary structure of polycrystalline materials. By rapidly capturing and processing electron backscatter diffraction patterns (EBSPs) from samples in the scanning electron microscope, OIM systems produce thousands of orientation measurements in a matter of minutes.

OIM measurements can be used to create visualizations of the spatial distribution of crystallographic orientation providing a practical and innovative tool to link orientation and microstructure.

EDAX is a business unit of AMETEK, Inc., Materials Analysis Division. You will find a lot of useful information at www.edax.com

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WHAT'S NEW IN 5.1

- **3D** data processing and visualization
- More local misorientation functions
- Major and minor axes distributions
- Auto contrast and brightness function added to gray scale maps
- Kernels for local misorientation functions can now go up to 10th nearest neighbor
- **Coarsening** function
- Close All windows button added to the toolbar.
- **Memory manager** mode added which reduces memory when loading Hough peak and/or EDS data. A utility is also now included with OIM Analysis and OIM Analysis modified to allow for increased available memory allowing OIM Analysis to open large datasets.
- Copy function for maps asks for maps size similar to the same map function.
- Summary text can now be copied in addition to exporting
- A more stringent plane matching criteria has been implemented for identifying twin boundaries.
- Standard deviations are shown on the Chart legends.
- In **boundary highlighting** mode, the distance between the two points clicked can be displayed.
- Grain IDs have been added to the grain boundary export.
- The deformation gradient is shown in the legend for Schmid and Taylor factor maps.
- An option has been added to the **preferences dialog** to re-define the scan x-y coordinates relative to RD, TD & ND.
- Non-indexed and non-partition points can be made transparent by setting the colors in the **preferences dialog** to red, green, blue values of 254, 254, 254.
- The **Generate Partitions** option in the **preferences dialog** has changed to a Auto-generate phase partitions option. An "All Data" partition is always generated when a data set is opened but the creation of partitions for each individual phase in the dataset can be optionally supressed.
- The crop dialog allows the upper-left and lower-right corners of the crop area to be explicitly entered.
WHAT'S NEW IN 5.2

- A Grain Fit Standardization cleanup method has been added.
- An option to default "Show Points" to on or off for discrete plots has been added to the Preferences.
- An option as been added to Preferences to default ranges for color maps to five solid color ranges at 0-20% (blue), 20-40% (green), 40-60% (yellow), 60-80% (orange) and 80-100% (red) to one continuous color range from 0 to 100%.
- An option has been added to Preferences to default the "Show Micron Bar" to on or off for maps. In addition, the user can set a default value for all maps.
- The Batch Processor has been improved so that it now accepts a "Dataset Level Template" so that multiple partitions can be processed. In addition, a project file for each dataset can be created and saved. Also, all of the analyses can be retained in a single large project (assuming enough memory is available).
- Pole figures in the popLA format scan now be imported for plotting.
- The previous grain intercept chart has been added back into 5.2.
- A blended color EDS map has been added.
- A Major Axis Inverse Pole Figure map has been added.
- Several minor bugs have been fixed including the ability to delete datasets from a project.
- The least squares method to create ellipses for grains has been improved - it is a bit slower, but more accurate.
- Memory usage has been improved so that cleanup can be performed on large datasets and larger datasets can be opened.
WHAT'S NEW IN 5.3

- Additional information (number and length) on reconstructed boundaries are now listed in the map legend in the boundary section.
- A “Copy Text” function has been added to the legends.
- Discrete plots can now be plotted with a single marker per grain instead of per pixels. This leads to much faster plotting of very large dataset.
- In addition to the Major Axis maps added to version 5.2, a Major Axis Texture can now be calculated.
- Kernel Average IQ maps and charts have been added.
- An option has been added to Kernel Average Misorientations to include all the points in the kernel instead of just the perimeter points.
- Grains can now be exported along with the misorientations of adjacent grains.
- The size of the crystal wireframe overlays and plane trace overlays can now be set by the user.
- Scan points next to grain boundaries can be partitioned out (or in).
- When importing map data, the IQ value for the scan can optionally be replaced by imported value. This allows a custom to be used for things like partitioning or kernel IQ averages.
- Batch processor can now export legends as text files for maps and charts in addition to dataset and partition summaries.
- Misorientation profile plots are no longer limited to only 500 datapoints for line scan data (i.e. data sets with a single row).
- Several templates have been added to the default template set.
- Texture calculations can be sped up using random orientations or the average grain orientations weighted by the grain area for both the harmonic and binning texture calculation methods.

- Various bugs have been fixed:
  - Partitioning formula inconsistencies with edge grains
  - .ang file loading - working distance always read as 20.0, other bugs associated with exporting and loading .ang files have been fixed as well.
  - Alignment feature in batch processor with hexagonal grids and recipe loading.
  - Default location of almnsp.dat file required for harmonic texture calculations.
  - Local misorientation map properties dialog calculations
  - Reference orientation map not updating correctly after a data rotation
  - Status bar for EDS maps always showing 0 counts when in Map Data mode.
  - Volume fractions of phases change with each redraw of the phase map.
  - Schmid Factor charts were incorrect.
  - Errors associated with data files produced by cropping.
The symmetry inversion field for exported texture pole figure files.

Reconstructed boundaries now retain the selected boundary color and width.

Bug introduced into y-values for Boundary Density charts fixed, the distributions were correct, the scaling factor was incorrect.

Some bugs with saving charts have been corrected.
USER INTERFACE

The OIM (Trademark) Analysis for Windows application interface allows the user to create graphical analysis objects. These objects are representations of the scan data, such as grain and boundary Maps, statistical Charts, and Plots. Analysis objects are stored as documents in the Project File on the disk and viewed as Document windows in the application. The main components of the user interface are the Main Application Window, the Project Tree, the Document windows and the Toolbars.

The Main Application Window for OIM Analysis contains much of the functionality necessary to create and manage projects, and to setup the highlight and interactive data export modes. Its main function is to provide a large area for displaying the Project Tree and individual Document windows. In addition to this, the Main Application Window contains the Main Menu, the Standard Toolbar, the Highlighting Toolbar, the Quick-Gen Toolbar, Utilities Toolbar and the Document Selector.
Toolbars

Four dockable toolbars are available in the OIM application interface: the Standard Toolbar, the Highlighting Toolbar, the Quick-Gen Toolbar and the Utilities Toolbar. All of these toolbars can be "torn-off" of the application frame and “floated” in the middle of the application client area by dragging the background of the toolbar into the middle of the application client area. The toolbars can also be docked against any of the four interior sides of the application client area. Additionally, the toolbars can be dismissed and recalled with the View Menu. After exiting the program, all repositioning and disabling will be displayed with their new configurations upon restarting the program.

OIM also uses two other important non-dockable toolbars: the Document Selector and the Status Bar. While they cannot be torn off like a normal toolbar, they can be dismissed and recalled with the View Menu. It is important to note that hovering the mouse over a button on the toolbar will popup a short description of the button and provide a longer description on the Status Bar.
Standard Toolbar

The Standard Toolbar provides all of the commonly accessed menu options in one handy location.

- **New** - closes the current project file and creates a new project.
- **Open** - opens project files, .osc data files and adds them to the current project and template files. The templates are applied to the active partition.
- **Save** - saves the active document into the project file.
- **Save All** - saves all documents into the project file.
- **Cut** - not implemented for general use - only within specific windows of OIM.
- **Copy** - not implemented for general use - only within specific windows of OIM.
- **Paste** - not implemented for general use - only within specific windows of OIM.
- **Properties** - shows the properties of the active window (map, plot or chart).
- **Fit to Window** - Fits the active map to the window.
- **Zoom** - When this icon is selected, clicking on the map will result in the map being zoomed centered on the data point clicked.
- **UnZoom** - When this icon is selected, clicking on the map will result in the map being "unzoomed" centered on the data point clicked.
- **Zoom Off** - When this icon is selected, the zooming functions are disable and the cursor returns to the standard highlighting mode.
- **Print** - Prints the contents of the active window.
- **Print preview** - previews the printable contents of the active window.
- **Cascade** - reorganize the document window in a cascade manner.
- **Tile Vertically** - reorganize the document windows to fill the document area of OIM vertically.
- **Tile Horizontally** - reorganize the document windows to fill the document area of OIM horizontally.
- **Close All** - close all document windows.
- **Report PowerPoint** - Generate a report using the selected documents using Microsoft (R) PowerPoint.
- **Report Wizard** - Create a template for Word or Powerpoint reports.
- **Batch Processor** - Activates a tool for performing tasks in batch mode.
- **3D Visualizer** - Activates tool for preparing 3D data for rendering and launches 3D Visualizer.
About - Display the About OIM dialog box.

Help - Launches the on-line Help.
Quick-Gen Toolbar

Here is the name and description of each Quick-Gen option from left to right:

- **Quick New** - Pops up the Quick New menu (shown below). Use this to create a new Document based on the active Partition or Dataset. This is a simpler alternative to using the Project Tree to create a new Document.

- **Active Partition** - This drop down list allows the user to select the active Partition and Dataset for use in the other Quick-Gen options.

- **IPF Quick Map** - Generate an 001 Inverse Pole Figure Map for the active Partition.

- **IQ Quick Map** - Generate an Image Quality Map for the active Partition.

- **Unique Grain Color Quick Map** - Generate a Unique Grain Color Map for the active Partition.

- **Grain Boundary Quick Map** - For the active Partition, generate an Image Quality Map with Rotation Angle Boundaries as follows: 1-5 degrees in red, 5-10 degrees in green, 10-180 degrees in black.

- **Phase Quick Map** - Generate a phase map for the active Partition.

- **EDS Quick Maps** - Generates EDS maps for the active Partition an EDS map using a different color is generated for each element for which counts were selected during the OIM scan.

- **User Defined Quick Maps** - Generates a map based on a user-assigned template selected in the preferences dialog.

- **Quick Pole Figure** - Generate a Discrete 001 Pole Figure for the active Partition.

- **Quick Inverse Pole Figure** - Generate a Discrete 001 Inverse Pole Figure for the active Partition.

- **User Defined Quick Plots** - Generates a discrete plot based on a user-assigned template selected in the preferences dialog.

- **Grain Size Quick Chart** - Generate a Grain Size Chart for the active Partition.
Misorientation Angle Quick Chart - Generate a Misorientation Angle Chart for the active Partition.

User Defined Quick Charts - Generates a chart based on a user-assigned template selected in the preferences dialog.

User Defined Quick Partition - Generates a partition based on a user-assigned template selected in the preferences dialog. Partition templates not only contain the partition definition but may also contain maps, plots, charts and textures.
Highlighting Toolbar

The Highlighting Toolbar is the control center for all highlighting operations.

- **Record** - Toggles the interactive data record mode on/off. If toggled on, interactive data is collected with each mouse click in a Map document and displayed in the Interactive List.
- **Undo** - Remove the last highlighting operation from all Documents.
- **Redo** - Resend the last highlighting operation to all Documents.
- **Clear** - Remove all highlighting from all Documents.
- **Tolerance Angle** - Allows the user to change the tolerance angle used for Tolerance Mode highlighting.
- **Plane Trace HKL** - Set the indices for the plane of interest when highlighting plane traces.
- **Use Average Grain Orientations** - For the Boundary and Triple Junction Modes, instead of calculating misorientations based on the actual orientation associated with each point in the pair, calculate the misorientation based on the average orientation of the grain to which each point belongs.
- **Overlay Size** - Change the size of the crystal lattice wireframe and the plane trace overlays.
- **Point Mode** - Highlight an individual point when clicking in a Map, and record the orientation data for that point in the Interactive List.
- **Tolerance Mode** - Highlight all points within a certain tolerance of the point clicked on in a Map, and record the orientation data for each point in the Interactive List.
- **Grain Mode** - Highlight all points of the grain clicked on in a Map, and record the orientation data for the grain in the Interactive List.
- **Boundary Mode** - Highlight the two points clicked on in a Map, and record the misorientation data in the Interactive List.
- **Triple Junction Mode** - Highlight the three points clicked on in a Map, and record the misorientation data in the Interactive List.
- **Vector Profile Mode** - Highlight all points along the line segments drawn on a Map, and record the orientation and misorientation data in the Interactive List.
- **Crystal Direction Mode** - Display the crystal direction parallel to the vector draw on a Map.
- **Plane Traces** - Draw the traces of the specified plane for the datapoint selected on a Map. The length of the traces drawn is proportional to the inclination of the plane relative to the sample surface. The more inclined the plane the longer the trace.
- **Crystal Lattice** - Draw a crystal lattice in the orientation of the datapoint selected on a Map.
- **Tolerance** - Show the points within the specified angular tolerance relative to the point clicked in a Plot.
- **Misorientation** - Show the misorientation between two points clicked in a Plot. For pole figures the angular distance between the two sample directions, for inverse pole figures the angular distance between the two crystal
directions, in ODFs the angular distance between two orientations (the minimum misorientation based on the crystal symmetry). Not implemented for misorientation plots.

- **Color** - Select the current highlighting color, which is used for the Point, Boundary, and Triple Junction Modes.

- **Color Gradient** - Select the current highlighting gradient, which is used for the Tolerance, Grain, and Vector Modes.

Note that the mode for highlighting can be set for maps and plots. However, clicks in Chart documents highlight all of the points that contribute to the chart bar(s) that have been clicked; exceptions to this vary depending on Chart type and will be explained in more detail in the Chart Document section of the help.
Utilities Toolbar

The Utilities Toolbar provides a set of tools to help the user gain a better understanding of crystallography and symmetry.

Symmetric Orientations - Displays a dialog that simulates the crystal lattice for the selected phase for a given orientation. This tool shows the set of symmetrically equivalent orientations for an orientation specified by the user. The orientations can be specified using a variety of representations (various Euler Angle settings as well as the (hkl)<uvw> notation). The symmetric orientation can be listed in a variety of representations as well (Euler angles, (hkl)<uvw> and Rodrigues Vectors). Both crystal (according to the phases loaded in the current project) and sample symmetry (triclinic & orthotropic) can be specified and displayed.

Symmetric Misorientations - Displays a dialog that shows the set of symmetrically equivalent misorientations for a misorientation specified by the user. The misorientations are input and output using the axis/angle notation. The crystal (according to the phases loaded in the current project) and can be specified and displayed.

Symmetric Planes or Directions - Displays a dialog that shows the set of symmetrically equivalent planes or directions for a selected phase.

Misorientation Calculator - Displays a dialog allowing the user to enter two different orientations. These orientations can be of any phase currently loaded in the project. The lattices are visualized and the misorientations given relative to the two specified phases.

Crystal Rotater - Displays a dialog allowing the user to specify an orientation using the structure definition for any phase currently loaded in the project. A rotation about an axis can also be defined. The corresponding rotated crystal is shown along with the corresponding orientation.
Symmetric Orientations

This utility is designed to help users visualize and understand symmetric orientations in terms of both crystal and sample symmetry. The user may select any of the phases currently loaded into the project. The sample symmetry can be either no sample symmetry or orthotropic (sheet symmetry).

The orientation can be entered in Euler Angles (according to Bunge, Roe or Kocks) or in the (hkl)[uvw] notation. The output of symmetrically equivalent orientations can be given in Euler Angles (according to Bunge, Roe or Kocks), in (hkl)[uvw] notations (as integers or as real values) or as a Rodrigues Vector.
Symmetric Misorientations

This allows the utility to enter a misorientation in axis/angle form. For misorientations between two different phases, the misorientation can be defined with respect to the crystallographic structure for either phase. The symmetrically equivalent orientations can be displayed for each angle within the standard unit triangle. This option is shown in the example below. If the option to show all entries were shown, then the first entry in the list would be expanded to:

20.000 @ [-1 1 0 0]
20.000 @ [1 0 -1 0]
20.000 @ [1 -1 0 0]
20.000 @ [0 1 -1 0]
20.000 @ [0 -1 1 0]
20.000 @ [-1 0 1 0]

An option can also be selected to show misorientations with rotations greater than 180 degrees. In this example, the first entry would also expand to:

340.000 @ [1 0 -1 0]
340.000 @ [1 -1 0 0]
340.000 @ [0 -1 1 0]
340.000 @ [-1 1 0 0]
340.000 @ [-1 0 1 0]
340.000 @ [0 1 -1 0]
轴角度对

 Phase A  对称性：六角
 Misorientation angle: 20
 u  v  t  w
 1  0  -1  0
 h  k  i  l
 1  0  -1  0

 Phase B  对称性：六角
 Misorientation angle: 20
 u  v  t  w
 1  0  -1  0
 h  k  i  l
 1  0  -1  0

对称等价旋转

Calculate  显示所有条目  显示一角度一可选

<table>
<thead>
<tr>
<th>参考于 Phase A</th>
<th>参考于 Phase B</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.000 @ [1 0 -1 0]</td>
<td>20.000 @ [-1 0 1 0]</td>
</tr>
<tr>
<td>121.003 @ [7 0 -7 22]</td>
<td>121.003 @ [-7 0 7 -22]</td>
</tr>
<tr>
<td>180.000 @ [8 -4 -4 25]</td>
<td>180.000 @ [-8 4 4 -25]</td>
</tr>
</tbody>
</table>
Symmetric Planes and Directions

This dialog shows equivalent planes and directions for a selected phase. The phases available are any of those currently loaded in the project.
This utility allows users to visualize two orientations and to calculate the misorientation between the specified orientations. The orientations can be entered in Euler Angles (according to Bunge, Roe, or Kocks) or in the (hkl)[uvw] notation. The orientations can be defined for any of the phases currently loaded in the project. The misorientation is displayed in reference to both crystal systems.
Crystal Rotater

This utility allows the user to specify an orientation with the crystallographic parameters for any phase currently loaded into the project. The orientation can be entered in Euler Angles (according to Bunge, Roe or Kocks) or in the (hkl)[uvw] notation. A misorientation is entered in terms of an axis and angle of rotation. This misorientation is applied to the orientation specified and the orientation after applying misorientation is displayed.
Status Bar

The status bar, located at the bottom of the main application window, provides system state information.

At the right of the Status bar, the states of the CapsLock, NumLock and ScrollLock keys are provided. At the left of the Status Bar, information is provided for the object over which the cursor is positioned. If the cursor is positioned over a toolbar button, a description of the functionality of the button is provided at the left of the status bar. If the cursor is positioned over a menu option, a description of that option is provided in the status bar. Pass the cursor over the view pane of a Map window and data point details will be displayed in the status bar, as shown below:

```
Orientation: [312.9, 29.0, 134.0]  x,y microns: 380.00, 277.13  IQ: 0.743  VS: 0  PH: fcc_generic
```

How the orientation is displayed (i.e. Euler Angles, (hkl)[uvw], Rodrigues Vector...) can be set in the preferences dialog. Instead of showing the point information the Grayscale and Color Coded values can be displayed. For the color coded values the number in parentheses refers numerically to one of the color ranges set in the map properties dialog.

```
Grayscale - Image Quality = 33.90  Color Coded - Kernel Average Misorientation = 1.62 (2)
```

For example, consider a map having a grayscale component corresponding to the image quality (IQ) and a color coded component corresponding to the grain size. In this example, the color red corresponds to grains having sizes within 80 to 100% of the maximum, orange 60 to 80%, yellow 40 to 60%, green 20 to 40% and blue 0 to 20%. If a point shaded yellow in the map is selected, the following might be displayed for the gray scale component: "127.34" corresponding to the IQ value for the point selected. For the color component the following might be displayed: "23.45 (3)". In this case, 23.45 is the grain size of the grain the point belongs to and "(3)" denotes that the point belongs to the 3rd range defined for the map (yellow in this case).
Document Selector

The Document Selector provides an easy method for activating any open Document.

Located above the Status Bar at the bottom of the Main Application Window, the Document Selector allows the user to easily switch between open Documents. Clicking the Document name will activate it. This is especially useful if the document windows are maximized in the OIM application frame.
Templates

Templates provide an easy-to-use tool for performing repetitive analysis on OIM data. For example, consider a map template. In the usual course of analysis a user may create a map containing several types of boundaries highlighted in various colors. The map may also highlight some special orientations defined by the user. Once a user is happy with the map, the user can save the various definitions specified in creating the map to disk. In this example, these definitions would include the boundary types and associated line colors and thicknesses and the special orientations and the highlighting colors and ranges. The user can then open the template file and apply the same map definitions to a new dataset. Thus, the same map can be applied over and over again to multiple datasets.

There are six types of templates and they have six types of files associated with them, namely: Maps (*.omt), Charts (*.oct), Discrete Plots (*.odp), Textures (*.ott), Grain Boundary Textures (*.ogt), Partitions (*.opt).

To create a template simply go to the project tree and perform a right mouse click to display the pop-up menu. Select Export->Template from the menu as shown below. A file browser dialog will be displayed. You can then specify the location and name for the template file.

To apply a template, select the level in the project tree to apply the template and select Apply Template from the menu. You will be prompted for the type of template and to load the template file.

OIM 4 provides a new feature that makes applying frequently used templates even easier. Template files can be assigned to new buttons on the QuickGen toolbar. The QuickGen toolbar now contains two custom buttons for maps, discrete plots, charts and partitions. The template file assigned to each of these buttons can be selected in the Preferences dialog accessed through the Settings menu.
Template Types

Map Templates (*.omt)

Map templates can be applied at the project, dataset and partition levels. When applied at the partition level, a map is generated using the map definitions contained in the template applied to the data contained in the partition. When applied at the dataset level, the map template is applied to each partition in the dataset. When applied at the project level, the map definition is applied to each partition in each dataset of the project. An example is shown schematically for each level below.

Chart Templates (*.oct)

Chart templates can be applied at the project, dataset and partition levels. When applied at the partition level, a chart is generated using the chart parameters contained in the template applied to the data contained in the partition. When applied at the dataset level, the chart template is applied to each partition in the dataset. When applied at the project level, the chart definition is applied to each partition in each dataset of the project.

Discrete Plot Templates (*.odp)

Discrete Plot templates can be applied at the project, dataset and partition levels. When applied at the partition level, a discrete plot is generated using the plotting parameters contained in the template applied to the data contained in the partition. When applied at the dataset level, the discrete plot template is applied to each partition in the dataset. When applied at the project level, the plot definition is applied to each partition in each dataset of the project.

Texture Templates (*.ott)

Texture templates can be applied at the project, dataset and partition levels. When applied at the partition level, a Texture is generated using the texture parameters contained in the template applied to the data contained in the partition. When applied at the dataset level, the texture template is applied to each partition in the dataset. When applied at the project level, the texture definition is applied to each partition in each dataset of the project. Texture templates also contain the plotting parameters for any texture plot “children” of the texture. Thus, if a texture is calculated and texture plots are constructed for a Pole Figure, Inverse Pole Figure and an ODF and the texture is saved as a texture template, then when this template is applied the texture would be calculated and the Pole Figure, Inverse Pole Figure and ODF plots would be generated. A schematic is shown at the partition level below.
Grain Boundary Texture Templates (*.ogt)

Grain Boundary Texture templates can be applied at the project, dataset and partition levels. When applied at the partition level, a Grain Boundary Texture is generated using the grain boundary texture parameters contained in the template applied to the data contained in the partition. When applied at the dataset level, the grain boundary texture template is applied to each partition in the dataset. When applied at the project level, the texture definition is applied to each partition in each dataset of the project. Grain Boundary Texture templates also contain the plotting parameters for any texture plot "children" of the texture. Thus, if a grain boundary texture is calculated and a texture plot is constructed for an MDF and the grain boundary texture is saved as a grain boundary texture template, then when this template is applied the grain boundary texture would be calculated and the MDF plot generated.

Partition Templates (*.opt)

Partition templates contain not only the partition definition (i.e. partition formula, grain grouping parameters ...) but also any "children". That is any maps, charts, discrete plots, textures and/or grain boundary textures and their corresponding "children" - i.e. texture plots. Partition templates can be applied at the project or dataset levels. When applied at the dataset level a new partition is created using the definition contained in the template. All of the associated children would be generated as well. When applied at the project level, a new partition is created for every dataset in the project along with the associated children. This is shown schematically below.

Dataset Templates (*.odt)
Dataset templates are essentially "multi-partition templates". They are applied at the dataset level. They allow multiple partition templates to be applied to a dataset. Dataset templates are slightly different than the other templates. Dataset templates can be applied at the Project Level and at the Dataset Level in the project tree, whereas the other templates are applied at one level "up" the tree and above.
Default Templates

Several templates are included in the installation of OIM Analysis. These include:

**CleanupRecipe.txt**

While this is not strictly a template, it provides a similar function for the batch processor. The recipe follows the approach we often use to clean up OIM data: Grain CI standardization followed by a single iteration of Grain Dilation.

(111) Fiber Textures

It is assumed in the templates that the fiber is aligned with ND in the microscope. When analyzing materials with fiber textures it is a good idea to rotate the data as needed to make sure fiber is centered on ND (the pole plot is useful when the fiber is located near ND). (See the Step 4 in the Basic Tutorial as well as sections on fibers in Texture Analysis in the Technical Reference).

- 111 Fiber Texture.opt - A partition which filters out low confidence (CI < 0.1) data and is accompanied by 1) a Harmonic texture calculation with a (111) pole figure; 2) a crystal direction chart showing the volume fraction of materials with the <111> crystal direction aligned with ND as a function of misalignment; 3) a (111) pole plot; 4) a (111) discrete pole figure; 5) an inverse pole figure map for ND; 6) a <111> crystal direction map showing all of the points in the scan having <111> directions within 15 degrees of ND; and 7) a <111> crystal direction map showing the points in the scan having <111> directions within 15 degrees of ND broken into 5 ranges.
- 111 Fiber Graded.omt - a <111> crystal direction map showing the points in the scan having <111> directions within 15 degrees of ND broken into 5 ranges.
- 111 Fiber Total.omt - a <111> crystal direction map showing all of the points in the scan having <111> directions within 15 degrees of ND

(001) Fiber Textures

It is assumed in the templates that the fiber is aligned with ND in the microscope. When analyzing materials with fiber textures it is a good idea to rotate the data as needed to make sure fiber is centered on ND (the pole plot is useful when the fiber is located near ND). (See the Step 4 in the Basic Tutorial as well as sections on fibers in Texture Analysis in the Technical Reference).

- 001 Fiber Texture.opt - A partition which filters out low confidence (CI < 0.1) data and is accompanied by 1) a Harmonic texture calculation with a (001) pole figure; 2) a crystal direction chart showing the volume fraction of materials with the <001> crystal direction aligned with ND as a function of misalignment; 3) a (001) pole plot; 4) a (001) discrete pole figure; 5) an inverse pole figure map for ND; 6) a <001> crystal direction map showing all of the points in the scan having <001> directions within 15 degrees of ND; and 7) a <001> crystal direction map showing the points in the scan having <001> directions within 15 degrees of ND broken into 5 ranges.
- 001 Fiber Graded.omt - a <001> crystal direction map showing the points in the scan having <001> directions within 15 degrees of ND broken into 5 ranges.
- 001 Fiber Total.omt - a <001> crystal direction map showing all of the points in the scan having <001> directions within 15 degrees of ND
Rolled BCC Materials

When analyzing sheet materials it is a good idea to rotate the data as needed to make sure the symmetry is centered. (See the Step 4 in the Basic Tutorial) It is assumed in the templates that the normal direction of the sample is aligned with ND in the microscope and the rolling direction is aligned with RD.

- BCC_Rolling_Ortho.opt - A partition which filters out low confidence (CI < 0.05) data and is accompanied by 1) a crystal direction chart showing the volume fraction as a function of tolerance angle for the ideal fiber components for rolled BCC materials: <110>||RD and <111>||ND; 2) a crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal orientation components for rolled BCC materials: (111)[1-10], (111)[1-21] and (001)[1-10]; 3) a crystal direction map highlighting points with orientations near the ideal fiber components for rolled BCC materials; 4) a crystal orientation map highlighting points with orientations near the ideal components for rolled BCC materials; 5) a Harmonic texture calculation with (110) and (100) pole figures, RD and ND inverse pole figures and the phi1 = 45 degree section of the ODF commonly used for analyzing BCC rolling textures; 6) The corresponding discrete pole figures; and 7) corresponding discrete ODF plots. With the exception of the discrete pole figure plots, All of the charts, plots, maps and textures are calculated assuming orthotropic sample symmetry. The discrete pole figures are excluded so that they can be observed when rotating the data. In the various windows, the color red is used to denote the alpha fiber (<110> parallel to the rolling direction) and blue for the gamma fiber (<111> parallel to the normal direction).

- BCC_Rolling_Components.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components and their orthotropic symmetry variants for rolled BCC materials. In this chart the colors are blue & cyan for (111)[1-10] (2 variants), green & yellow for (111)[1-21] (2 variants) and red for (001)[1-10] (1 variant).

- BCC_Rolling_Components_Ortho.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components for rolled BCC materials. The various orthotropic variants are not considered separately in this case. In this chart the colors are blue for (111)[1-10], green for (111)[1-21] and red for (001)[1-10].

- BCC_Rolling_Fibers.oct - a crystal direction chart showing the volume fraction as a function of tolerance angle for the ideal fiber components for rolled BCC materials: red <110>||RD and blue <111>||ND.

- BCC_Rolling_Components.omt - A crystal orientation map showing the volume fraction as a function of tolerance angle for the ideal components and their orthotropic symmetry variants for rolled BCC materials. In this chart the colors are blue & cyan for (111)[1-10] (2 variants), green & yellow for (111)[1-21] (2 variants) and red for (001)[1-10] (1 variant).

- BCC_Rolling_Components_Ortho.omt - A crystal orientation map showing the volume fraction as a function of tolerance angle for the ideal components for rolled BCC materials. The various orthotropic variants are not considered separately in this case. In this chart the colors are blue for (111)[1-10], green for (111)[1-21] and red for (001)[1-10]

- BCC_Rolling_Fibers.omt - a crystal direction map highlighting points with orientations near the ideal fiber components for rolled BCC materials: red to yellow for <110>||RD and blue to green for <111>||ND.

Rolled FCC Materials

When analyzing sheet materials it is a good idea to rotate the data as needed to make sure the symmetry is centered. (See the Step 4 in the Basic Tutorial) It is assumed in the templates that the normal direction of the sample is aligned with ND in the microscope and the rolling direction is aligned with RD.
Brass_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the two orthotropic symmetry variants of the Brass component (110)<1-12> for rolled FCC materials.

Brass_Component.omt - A crystal orientation map showing the volume fractions of the two orthotropic symmetry variants of the Brass component (110)<1-12> for rolled FCC materials.

Copper_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the two orthotropic symmetry variants of the Copper component (121)<1-11> for rolled FCC materials.

Copper_Component.omt - A crystal orientation map showing the volume fractions of the two orthotropic symmetry variants of the Copper component (121)<1-11> for rolled FCC materials.

Goss_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the Goss component (101)<0-10> for rolled FCC materials.

Goss_Component.omt - A crystal orientation map showing the volume fractions of the Goss component (101)<010> for rolled FCC materials.

S1_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the four orthotropic symmetry variants of the S1 component (241)<1-12> for rolled FCC materials.

S1_Component.omt - A crystal orientation map showing the volume fractions of the four orthotropic symmetry variants of the S1 component (241)<1-12> for rolled FCC materials.

S2_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the four orthotropic symmetry variants of the S2 component (231)<1-24> for rolled FCC materials.

S2_Component.omt - A crystal orientation map showing the volume fractions of the four orthotropic symmetry variants of the S2 component (231)<1-24> for rolled FCC materials.

S3_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the four orthotropic symmetry variants of the S3 component (231)<3-46> for rolled FCC materials.

S3_Component.omt - A crystal orientation map showing the volume fractions of the four orthotropic symmetry variants of the S3 component (231)<3-46> for rolled FCC materials.

Taylor_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the tow orthotropic symmetry variants of the Taylor component (4 4 11)<11 11 -8> for rolled FCC materials.

Taylor_Component.omt - A crystal orientation map showing the volume fractions of the two orthotropic symmetry variants of the Taylor component (4 4 11)<11 11 -8> for rolled FCC materials.

FCC_Rolling_Components.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components and their orthotropic symmetry variants for rolled FCC materials. In this chart the colors are orange for Copper - (121)<1-11> (2 variants), green for S1 - (241)<1-12> (4 variants), purple for S2 - (231)<1-24> (4 variants), blue for S3 - (231)<3-46> (4 variants), cyan for Taylor (4 4 11)<11 11 -8> (2 variants), yellow for Brass (110)<1-12> (2 variants) and red for Goss (101)<0-10> (1 variant).

FCC_Rolling_Components.omt - A crystal orientation map showing the volume fractions for the ideal components and their orthotropic symmetry variants for rolled FCC materials. In this map the colors are orange for Copper - (121)<1-11> (2 variants), green for S1 - (241)<1-12> (4 variants), purple for S2 - (231)<1-24> (4 variants), blue for S3 - (231)<3-46> (4 variants), cyan for Taylor (4 4 11)<11 11 -8> (2 variants), yellow for Brass (110)<1-12> (2 variants) and red for Goss (101)<0-10> (1 variant).

FCC_Rolling_Components_Ortho.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components for rolled FCC materials. The various orthotropic variants are not considered separately in this case. In this chart the colors are orange for Copper - (121)<1-11>, green for S1 - (241)<1-12>, purple for S2 - (231)<1-24>, blue for S3 - (231)<3-46>, cyan for Taylor (4 4 11)<11 11 -8>, yellow for Brass (110)<1-12> and red for Goss (101)<0-10>.
• FCC_Rolling_Components_Ortho.omt - A crystal orientation map showing the volume fractions for the ideal components for rolled FCC materials. The various orthotropic variants are not considered separately in this case. In this map the colors are orange for Copper - (121)<1-11>, green for S1 - (241)<1-12>, purple for S2 - (231)<1-24>, blue for S3 - (231)<3-46>, cyan for Taylor (4 4 11)<11 11 -8>, yellow for Brass (110)<1-12> and red for Goss (101)<0-10>.

• FCC_Rolling_Components_Ortho.opt - A partition that includes 1) a crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components for rolled FCC materials; and 2) a crystal orientation map showing highlighting points with orientation near the ideal components for rolled FCC materials. The various orthotropic variants are not considered separately in this case. In this chart the colors are orange for Copper - (121)<1-11>, green for S1 - (241)<1-12>, purple for S2 - (231)<1-24>, blue for S3 - (231)<3-46>, cyan for Taylor (4 4 11)<11 11 -8>, yellow for Brass (110)<1-12> and red for Goss (101)<0-10>.

• FCC_Rolling_Components_Ortho2.opt - A partition which filters out low confidence (CI < 0.1) data and is accompanied by 1) a crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components for rolled FCC materials; 2) a crystal orientation map highlighting points with orientations near the ideal components for rolled FCC materials; and 3) a Harmonic texture calculation with (111), (110) and (100) pole figure plots. The various orthotropic variants are not considered separately in this case. In this chart the colors are orange for Copper - (121)<1-11>, green for S1 - (241)<1-12>, purple for S2 - (231)<1-24>, blue for S3 - (231)<3-46>, cyan for Taylor (4 4 11)<11 11 -8>, yellow for Brass (110)<1-12> and red for Goss (101)<0-10>.

Rolled and Recrystallized FCC materials

• Cube_Component.oct - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the Cube component (001)<100> for materials with cubic symmetry.

• Cube_Component.omt - A crystal orientation map showing the volume fraction of the Cube component (001)<100> for materials with cubic symmetry.

• P_Component.oct - A crystal orientation chart showing volume fraction as a function of tolerance angle for the two orthotropic symmetry variants of the P component (011)<1-11> for recrystallized rolled FCC materials.

• P_Component.omt - A crystal orientation map showing the volume fractions of the two orthotropic symmetry variants of the P component (011)<1-11> for recrystallized rolled FCC materials.

• Q_Component.oct - A crystal orientation chart showing volume fraction as a function of tolerance angle for the two orthotropic symmetry variants of the Q component (013)<3-31> for recrystallized rolled FCC materials.

• Q_Component.omt - A crystal orientation map showing the volume fractions of the four orthotropic symmetry variants of the Q component (013)<3-31> for recrystallized rolled FCC materials.

• R_Component.oct - A crystal orientation chart showing volume fraction as a function of tolerance angle for the two orthotropic symmetry variants of the R component (132)<4-21> for recrystallized rolled FCC materials.

• R_Component.omt - A crystal orientation map showing the volume fractions of the four orthotropic symmetry variants of the R component (132)<4-21> for recrystallized rolled FCC materials.

• FCC_Rx_Components.oct - A crystal orientation chart showing volume fraction as a function of tolerance angle for the ideal components and their orthotropic symmetry variants for recrystallized rolled FCC materials. In this chart the colors are rust for Cube - (001)<100> (1 variant), blue gray for P - (011)<1-11> (2 variants), tan for Q - (013)<3-31> (4 variants), purple for R - (132)<4-21> (4 variants), and red for Goss (011)<100> (1 variant).

• FCC_Rx_Components.omt - A crystal orientation map showing the volume fractions for the ideal components and their orthotropic symmetry variants for rolled FCC materials. In this map the colors are rust for Cube - (001)<100> (1 variant), blue gray for P - (011)<1-11> (2 variants), tan for Q - (013)<3-31> (4 variants), purple for
R - (132)<4-21> (4 variants), and red for Goss (011)<100> (1 variant).

- **FCC_Rx_Components_Ortho.oct** - A crystal orientation chart showing the volume fraction as a function of tolerance angle for the ideal components for rolled FCC materials. The various orthotropic variants are not considered separately in this case. In this chart the colors are rust for Cube - (001)<100> (1 variant), blue gray for P - (011)<1-11> (2 variants), tan for Q - (013)<3-31> (4 variants), purple for R - (132)<4-21> (4 variants), and red for Goss (011)<100> (1 variant).

- **FCC_Rx_Components_Ortho.omt** - A crystal orientation map showing the volume fractions for the ideal components for rolled FCC materials. The various orthotropic variants are not considered separately in this case. In this map the colors are rust for Cube - (001)<100> (1 variant), blue gray for P - (011)<1-11> (2 variants), tan for Q - (013)<3-31> (4 variants), purple for R - (132)<4-21> (4 variants), and red for Goss (011)<100> (1 variant).
Main Menu

The Main Menu is a menubar that consists of six pull-down menus. These menus are: File, Edit, View, Settings, Window, and Help.

As the cursor is passed over the menu options, brief descriptions for each menu option are displayed in the Status Bar at the bottom of the Main Application Window. Also, many menu options have shortcut key combinations associated with them. These shortcuts are listed to the right of the menu option.
The File Menu is for creating and manipulating document objects. New, Open, Close, Save, and Save All are standard functions for handling document files. Open Project, Save Project, and Close Project perform the standard functions for an OIM Project. Printing is done from the File Menu using the Print Setup, Print Preview, and Print functions. After the printing section of the menu is a list of the most recently used Projects. This allows the user to quickly open Projects without needing to use the open file dialog. The very last item on the File Menu is the Exit function. Select this to exit OIM Analysis.
The Edit Menu contains menu items useful for editing text documents. The user will find this helpful when writing notes for the analysis document objects. Undo removes the last change made to the text, restoring it to its previous state. Cut, Copy, and Paste allow quick repositioning or duplication of text.
View Menu

The View Menu allow the user to dismiss and recall the various dockable objects, including Toolbars, the Project Tree and the Document Selector. A checkmark signifies that the object is visible. Absence of a checkmark means that the object has been dismissed. Select the desired object to toggle its visible/dismissed state. The list of options in the bottom two sections of the View Menu toggle various display options for the active document, and may change depending on which document is currently active. These options are also displayed on the pop-up dialog for the active document. These options are discussed in the corresponding menu sections of the help for each individual document type.

Map
Discrete Plot
Intensity Plot

Chart

- Standard Toolbar
- Highlighting Toolbar
- Quick-Gen(erate) Toolbar
- Status Bar
- Project Tree Ctrl+T
- Document Selector Ctrl+D
- Show Highlighting
- Show SEM Image Ctrl+I
- Show OIM Map Ctrl+M
- Show Boundaries Ctrl+B
- Show Grain IDs (1st 500)
- Show Flexiview Labels
- Show Micron Bar
- Fit To Window Ctrl+F
- Zoom In
- Zoom Out
- Zoom Off
- Magnification...
The Settings Menu allows the user to change highlighting options and global application preferences. From it the user can access the Highlighting Menu and the Preferences Dialog.

### Highlighting Menu

- **Record** - Toggles the interactive data record mode on/off. If toggled on, interactive data is collected with each mouse click in a Map document and displayed in the Interactive List.
- **Undo** - Remove the last highlighting operation from all Documents.
- **Redo** - Resend the last highlighting operation to all Documents.
- **Clear** - Remove all highlighting from all Documents.
- **Tolerance Angle** - Allows the user to change the tolerance angle used for Tolerance Mode highlighting.

Selecting the Highlighting option pops up another menu listing all the highlighting options. Here is a brief description of each option:

- **Record**
- **Undo**
- **Redo**
- **Clear**
- **Tolerance Angle**
HKL - Set the indices for the plane of interest when highlighting plane traces.

- Point Mode - Highlight an individual point when clicking in a Map, and record the orientation data for that point in the Interactive List.
- Tolerance Mode - Highlight all points within a certain tolerance of the point clicked on in a Map, and record the orientation data for each point in the Interactive List.
- Grain Mode - Highlight all points of the grain clicked on in a Map, and record the orientation data for the grain in the Interactive List.
- Boundary Mode - Highlight the two points clicked on in a Map, and record the misorientation data in the Interactive List.
- Triple Junction Mode - Highlight the three points clicked on in a Map, and record the misorientation data in the Interactive List.
- Vector Profile Mode - Highlight all points along the line segments drawn on a Map, and record the orientation and misorientation data in the Interactive List.
- Crystal Direction Mode - display the crystal direction parallel to the vector draw on a Map.
- Plane Traces - Draw the traces of the specified plane for the datapoint selected on a Map. The length of the traces drawn is proportional to the inclination of the plane relative to the sample surface. The more inclined the plane the longer the trace.
- Crystal Lattice - Draw a crystal lattice in the orientation of the datapoint selected on a Map.
- Tolerance - Show the points within the specified angular tolerance relative to the point clicked in a Plot.
- Misorientation - Show the misorientation between two points clicked in a Plot. For pole figures the angular distance between the two sample directions, for inverse pole figures the angular distance between the two crystal directions, in ODFs the angular distance between two orientations (the minimum misorientation based on the crystal symmetry). Not implemented for misorientation plots.

- Color - Select the current highlighting color, which is used for the Point, Boundary, and Triple Junction Modes.
- Gradient - Select the current highlighting gradient, which is used for the Tolerance, Grain, and Vector Modes.

Note that the mode for highlighting can be set for maps and plots. However, clicks in Chart documents highlight all of the points that contribute to the chart bar(s) that have been clicked; exceptions to this vary depending on Chart type and will be explained in more detail in the Chart Document section of the help.

Preferences Dialog

Click on the dialog to link to the appropriate description.
Selecting the Preferences option brings up a dialog containing the global preferences. Here is a brief description of each preference option:

**Use Direct Draw** - When toggled on, Direct Draw is used for the drawing the maps. If off, standard Windows rendering is used. Some systems have trouble with Direct Draw. Direct Draw is slightly faster than the standard Windows rendering.

**Save Workspace** - When toggled on, a Project will remember which Documents the user has open and where each window is located, and will restore these when the Project is reopened.

**Save Boundary Segments** - Allows for quicker redrawing of boundaries on Maps by saving segment information to disk with each Map. Projects require more disk space, but speed is increased.

**Default External Highlighting On** - When a new Document is created, its Show Highlighting option is set based on this preference. Toggle on if you want all documents to show highlighting.

**Split Windows** - Toggle on to have OIM automatically split the Document windows based on the Document aspect ratio. Toggle off to have OIM remember where the user manually splits the window.

**Tile Windows** - Automatically tile the Document windows each time a Document window is opened or closed.
Auto-Generate Phase Partitions - When a new Dataset is added to the Project, automatically generate an 'All Data' partition and a separate partition for each phase. If this is not checked, then only the 'All-Data' partition will be created.

Always Expand Project Tree - When a new Document is added to the Project, automatically expand the corresponding branch in the Project Tree.

Calculate Grain Shapes Automatically - When a new partition is constructed, automatically calculate the grain shape information. Otherwise, it won't be calculated until requested.

Display Triple Points - When a new partition is constructed, display the number of triple points in the summary window. This takes some calculation time.

Freeze Crystal Lattice Wireframe - Allows the user to freeze the lattice wireframe in order to save it as an image or copy it to the clipboard.

Minimize Memory Usage - Reduces the number of Hough peaks read in to the Maximum number of EBSD bands. Also reduces some of the Hough and EDS data from floating point values to integer values.

Default 5 Color Ranges - If this is turned on, then for many of the color maps five solid color default ranges are as shown below at left. If this is off, then the default is a single range with a continuous color gradient as shown below at right.

Default Show Points On - If this is checked, then when a discrete plot is initially shown all of the points will be shown in the plot. If off, then no points are shown. This can be helpful when looking at very large datasets where a user intends to perform highlighting as the time required to draw all of the points can be substantial.

Default Show Micron Bar On - When maps are generated a micron bar may be displayed by selecting from the pull-down menu for the map. Clicking this option on will default the maps to be drawn with a micron bar. The length of the bar may be set as well. If a value of 0 or less is entered the the length of the bar will be automatically determined by the software.

Status Bar Text - Sets what is to be displayed in the status bar when the mouse hovers over a point in a map - the point data (orientation, x, y, iq, ci, fit, phase) or the value corresponding to the gray hue or color the point in the map is shaded. In addition, if the point data is shown the orientation representation used can be selected. (Euler Angles, Rodrigues Vector, ...).

Grain Size Representation - Determines how grain sizes are shown in the dialogs and statistical outputs, whether by Diameter, Area, or Points.

Grain Shape Calculation Method - There are three approaches available. The first one is based on a least squares fit to the perimeter points of grain. The other two are based more simply (hence faster calculations) on finding the maximum distance between any two points on the perimeter of the grain. This distance becomes the vector defining the major axis of the grain. The length of the minor axis can then be calculated one of two ways. First based on averaging of pairs of points on the perimeter of the grain where the vectors connecting the these
point pairs are nearly aligned with the vector perpendicular to the vector defining the major axis. The second method defines the length of the minor axis such that the area of the fitted ellipse matches that calculated from the points which make up the grain.

**Document Bitmap Size** - This defines the size of the bitmaps used in creating Plot documents. On High setting, large bitmaps are used to display the Plot documents, and this can cause poor performance on lower end machines. Reduce this to Medium or Low to gain faster performance at the cost of reduced image quality.

**Hough Peak Mode** - With Hough Plus in OIM DC it is possible to save Hough information for each point in an OIM Scan. This can be displayed in the new FlexiView pane for Maps. However, reading in the Hough information will add to the amount of memory used by OIM Analysis. It is possible to select one of the three options in order to optimize the performance for a selected application. These options include 1) Always read and store the Hough Peak data in memory, 2) discard the Hough Peak data or 3) prompt the user each time a dataset is added to the project.

**Pole Figure Coordinate Setting** - The user can define how pole figures are to be displayed. Four options are available (1) RD at the bottom and TD at the right; (2) RD at the right and TD at the top; (3) RD at the top, TD to the right; and (4) RD at the left and TD at the bottom. Note that ND always comes out of the screen and that the right-handed rule is followed. Remember that the reference system in OIM is set up such that RD is down the tilted direction of the sample, ND is the sample normal and TD is the transverse direction.

**Orientation Spread Calculation** - In 3.x versions, the orientation spread in a grain was determined by calculating the misorientation (angle) between all points in the grain. The orientation spread is the average misorientation value. In the 4.0 version the calculation was changed to first calculate the average orientation for each grain. The spread is then the average deviation between the orientation of each point in the grain and the average orientation for the grain. These values are generally nearly the same. The 3.x approach is considerably slower.

**Header and Footer Text** - Text that is appended to text files when a document is exported.

**Application Font** - Allows the user to change the font that OIM uses for most Document views.

**Color For Non-Indexed Points** - The color assigned to bad points (points that could not be indexed) in all Maps. A value of 254, 254, 254 for red, green, blue will make the non-indexed points transparent on a color map overlaid on a gray scale map.

**Color For Non-Partition Points** - The color assigned to points in the map when the points not a part of the current partition. A value of 254, 254, 254 for red, green, blue will make points outside the partition transparent on a color map overlaid on a gray scale map.

**Manual Data** - If misorientations are to be calculated from manual data, the data can take two different forms. The user has the option of selecting how misorientations are calculated: (1) between points 1 & 2, points 3 & 4, points 5 & 6... or (2) between points 1 & 2, points 2 & 3, points 3 & 4...

**Scan Coordinate System** - Allows a user to coordinate the x-y coordinates of a map (left to right and top to bottom) with the microscope reference frame defined by RD, TD and ND. This can vary from SEM to SEM depending on how the scan rotation is set. It should be noted that this will effect some of the overlays, most notably functions based on reconstructed boundaries and how plane traces are drawn. However, it does not effect Taylor Factors, Schmid Factors or Elastic Modulus calculations - it does not rotate the data.

Default Edge Grain Setting - When a partition is created this option defines whether edge grains are included in the anlaysis of are excluded when the partition is initially created.

**Custom Templates** - The preferences dialog box is where a user may specify the templates used for the custom QuickGen buttons. To assign a template to a button, simply browse for the template. Whenever a user clicks on the corresponding button the map, plot, chart or partition will automatically be generated without any other operator intervention. It should be noted that partition templates not only serve as templates defining the filtering used to partition the data, but also contain maps, plots, charts, textures and so forth.
Maximum Indices for (hkl)[uvw] notation - When converting an orientation to (hkl)[uvw] (or (hkl)[uvtw] for trigonal or hexagonal symmetries) there can be a bit of approximation in converting from an orientation specified in real values (such as Euler angles or an orientation matrix) to an integer representation given by (hkl)[uvw]. The user can specify how larger the indices are allowed to be. The larger the allowed value the closer the resulting (hkl)[uvw] will be to the real valued orientation.

Minimum Boundary Misorientation - Minimum misorientation angle which is used to decide if a grain boundary exists between to points. This is an important value for boundary statistics. The total number of boundaries which serves as a denominator for many boundary fraction calculations is based on this value.

Monitor Size - Entering the monitor size allows the software to specify magnification.

Number of Undo Levels - The maximum number of highlighting events saved for undo and redo can be set.

Maximum number of EBSD bands - The maximum number of bands in the EBSD patterns reconstructed from the Hough data can be set.

These global preferences are saved in the windows registry and apply to all Projects.
Window Menu

The Window Menu provides control over the open document windows in the current session. Cascade, Tile Vertically, Tile Horizontally, and Arrange Icons are the basic window arrangement functions. The bottom half of the menu lists all of the windows, with a check mark by the active window. Select another window to make it the active one.
Help Menu

Selecting Help Topics on the Help Menu will bring up the online help.
**Project Tree**

The project tree shows all of the analysis completed on a specific project. There are five levels to the project tree:

**Project:** The top level for a project.

**Dataset:** This level contains datasets and multicharts.

**Partition:** This level contains only partitions.

**Document:** This level includes Maps, Charts, Discrete Plots, Textures, GB Textures

**Texture Plots:** The level contains Texture Plots and is only available under Texture and GB Textures.

An example tree is shown below. From each level a pop-up menu may be accessed by a right hand mouse click on the item of interest. An explanation of the menus at each level is given in the help pertaining to the item of interest. It should be noted that double-clicking on one of the graphical documents (Maps, Charts, Discrete Plots or Texture Plots) will open the corresponding window if it is not open or activate and push it to the top if it is open. Selecting open from the popup menu will open another view of the same window. This allows, for example, the same map to be viewed at two different magnifications simultaneously without having to create a duplicate of the map within the project tree.

The project tree is displayed in the project tree window.
Project Tree Window

If the project tree is closed it can be reopened from the View Menu. The project tree is displayed in the project tree dockable window. This window can be docked vertically or horizontally.
Or it can float as a regular document window.
To make the window float, press the float icon as shown.
To dock the window, drag the floating window horizontally or vertically until the window outline changes. The window will then dock against the edge of the application window.
There are two kinds of document windows. The first are **Summary Windows**. These display summary information about Datasets and Partitions. The second type of window is displayed for Maps, Charts (and Multicharts), Discrete Plots, and Texture Plots. An example is shown below for a map. The window is divided up into two panes (the size of the panes can be changed by dragging the splitter bar separating the panes).

In the example shown here the left pane is the **display pane** and the right pane is the **information pane**.
Summary Window

These windows, available for datasets and partitions, give some overall information on the dataset or partition. They can be viewed by selecting Summary View from the right-hand pop-up menu on the project tree for both datasets and partitions. Both of the summary view windows have a pop-up menu for right-hand mouse clicks. This menu contains an Export function which export the data displayed in the window to a text file.

Dataset Summary View
The number of points is the total number of points scanned. Number of good points is the number of patterns that were indexed in the scan. Dimensions are the x and y dimensions of the scan grid in microns. Step is the step size between points on the scan grid.

The average confidence index, image quality and confidence are displayed also. For older versions of OIM some of these parameters were not recorded. They will have average values of 0 in this case.

The number of boundary segments with misorientations greater than the minimum boundary misorientation value (see the Preferences dialog) is displayed as well as the cumulative length of these boundary segments.

The names of all phases present in the dataset are displayed.

If chemical information in the form of counts for specific elements were recorded during the scan, the element names are displayed as well.

Partition Summary View
The **Name** is the name of the partition. The **formula** is the formula used in partitioning the data from the dataset. The **number of good points** is number of indexed points belonging to the partition. The average confidence index and image quality for the partition are displayed.

The number of triple points may be displayed (if selected in the preferences dialog) if the dataset grid is hexagonal. A triple point is a point on the interface grid where the surrounding three points are all identified as three separate grains. (If one of the three neighboring points does not belong to a grain, i.e. a non-indexed point, then the interface grid point is not identified as a triple point.) Two triple points are highlighted in red below.
The names of the phases in the partition are displayed as well. Parameters describing the grain size are given. These statistics are given for all grains in the partition and again for grains, which do not touch the edges of the scan. Unlike older versions of OIM the ASTM number and diameter averages are true averages. i.e. for the diameter:

\[
\bar{d} = \frac{1}{N} \sum_{n=1}^{N} d_n = \frac{1}{N} \sum_{n=1}^{N} 2\sqrt{A_n / \pi} = \frac{1}{N} \sum_{n=1}^{N} 2\sqrt{f_A M_n / \pi}
\]

where \( N \) is the number of grains in the partition and \( d_n \) is the diameter of the \( n^{th} \) grain. \( A_n \) is the area of the \( n^{th} \) grain and is determined by the number of points, \( M_n \), in the \( n^{th} \) grain multiplied by a factor, \( f_A \), dependent on the step size of the scan grid and whether the grid is square or hexagonal.

Some older versions of OIM used the following average:

\[
\bar{d} = 2\sqrt{f_A / \pi M} = 2\sqrt{f_A / \pi \frac{1}{N} \sum_{n=1}^{N} M_n}
\]

If the grain shape option is selected in the preferences dialog, information on the average grain shape is displayed. The average grain shape is calculated by first calculating the average major axis length and the average aspect ratio. The minor axis length is then the major axis length multiplied by the average aspect ratio. This methodology preserves the average aspect ratio. Given two ellipse as shown below in black there appear to be two sensible choices for the average ellipse as shown in red and blue. The methodology used in OIM follows that of preserving the aspect ratio as shown in the red example.
The average angle is somewhat problematic at well. If the major axes are thought of as vectors then the sum vector (which would have an angle corresponding to the average angle) could be considered either of two ways as shown as the green vectors in the following diagram.

In order to overcome this difficulty, the average angle is calculated in the following way. The endpoints of the major axes for all grains are calculated. A straight line is fit to the endpoint data. The angle of this line represents the average angle.
Display Pane

This pane in a document window displays the document such as a Map, Chart (and Multichart), Discrete Plot, Texture, GB Texture and Texture Plot. A right-hand pop-up menu is available for changing the attributes of the window as well as copying the attributes or the window display contents. The specific functions available on the menu are described in the individual helps.
Information Pane

The information displayed in the information pane can be changed by selecting one of the tabs at the bottom of the pane. The options include Legend, FlexiView, Lattice and Notes.
Legend

OIM will output information pertinent to that displayed in the display pane. In the example, shown here the color-coding for the IPF map, and information on the boundaries are shown. For charts, the data used to build the chart is displayed along with some averages. The legend pane can be copied or saved as a bitmap for import into other programs. Alternatively, a text version can be exported to a text file or copied. When exporting, a header (or footer) can be set up in the Preferences Dialog.

When using the highlighting functions, the fraction of highlighted points will be displayed in the Legend Tab. The fractions are highlighted in yellow in the example below.
Highlighted Points)/(Total Number of Points) = 0.123
Highlighted Points)/(Number of Good Points) = 0.123
Highlighted Points)/(Number of Partition Points) = 0.167

Gray Scale Map Type: Image Quality
28.364...123.596 (28.364...123.596)

Color Coded Map Type: <none>

Boundaries: <none>
FlexiView

FlexiView is a enhancement to the lattice tab. FlexiView not only allows a visualization of the lattice to be viewed, but also allows the user to define a variety of other items to view.
Three different types of view can be displayed. These include the crystal lattice, pole figures (or inverse pole figures) and reconstructed EBSD patterns. These optional views can be selected by pressing on the "Add" button.
The "Flyby" options show the particular figure for the orientation at which the cursor is currently located. These figures will change as the cursor is moved around in the map. The "Static" options require the user to shift-click (with the left-mouse button) on a point in the map. A number will be placed on the map where the mouse was clicked. Multiple copies of each of these figures can be added to FlexiView (as shown above). In this way, the different figures can be displayed for consecutive clicks in the map. Individual figures can be removed from FlexiView by first clicking on the "Remove" button. The cursor will change to the \( \Box \) cursor. Click on any of the views to be removed. Once all the views have been removed, click with the right-mouse button to return the cursor to the normal mode. The individual figures can also be placed within FlexiView using the "Configure" button. The cursor will be changed to the \( \Box \) cursor. With the left-mouse button click and drag the figure to be moved. Once you are done reconfiguring the layout, click with the right-mouse button to return the cursor to the normal mode. The individual views can also be saved to disk or copied. This is done by clicking on the individual views with the right-mouse button.

**Pole Figures**

The pole figure properties can be accessed by a right mouse click on a pole figure view.

The following dialog box will be displayed. The options available are similar to those found for discrete pole figures and discrete inverse pole figures.
Reconstructed EBSD Patterns

The EBSD patterns are only available if the dataset was saved using Hough Plus. Hough Plus is an OIM DC feature that records information from the Hough Transform used to detect the bands in the patterns during the indexing procedure. The reconstructed patterns show the position of the bands in the patterns as well as the relative band intensity and width.
Lattice

When the cursor is passed over a valid point in a map, a wireframe schematic of the crystal lattice at that point is displayed. Thus, a visualization of the orientation of the point of interest is shown. On discrete and texture plots of orientations, the wire frame is also displayed. However, for discrete and texture Pole Figures and Inverse Pole Figures, the full orientation is not fully specified (only one axis is defined) and therefore the wireframe cannot be displayed. This view is not available for charts. The mode can be changed to a "freeze" mode so that the user is required to click (left-hand shift-click) in the map or plot to change the orientation visualization to correspond to the point clicked. This is done in the Preferences Dialog.
Interactive

This view is available for highlighting in maps and highlighting in discrete and texture plots. It shows the result for interactive highlighting when highlighting is placed in Record Mode. Which columns are displayed and how they are displayed may be set in the Properties dialog accessible from the pop-up menu as shown. The pop-up menu also allows Individual entries in the list to be deleted or the whole list to be cleared. The menu also allows the user to add the data collected to the project as well as to export the data as it appears on the screen to text file. Selecting properties from the menu will allow the user to define which columns are displayed and how they are displayed according to the current highlighting mode. The representation used for orientation and misorientation may also be set. See the topic on the interactive view in the highlighting section.
The notes view allows the user to enter textual notes. These are carried with the document as part of the project. The Notes pane is essentially a simple text editor. The Notes (text) can be pasted in from the clipboard as well. Notes in the pane can also be copied (or cut) and pasted in other texture editors.
Introduction to Highlighting

Highlighting is a powerful feature in OIM. A click in any of graphical document windows of OIM (Maps, Charts, Discrete Plots and Texture Plots) will correspond to a set of measurement points in the dataset. These points will be highlighted in all of the windows pertaining to the dataset. The highlighted data can then be converted to a partition for further analysis. It is important to remember that highlighting occurs at the dataset level, whereas the graphical document windows belong to the partition level.

The highlighting behavior is controlled through the highlighting toolbar. Each of the different buttons are explained in the corresponding highlighting sections (Maps, Charts and Plots) of the help.
Highlighting in Maps

This feature in OIM allows the user to extract orientation information by manual interaction with the maps. It should be noted that any highlighting done on a map can be exported as a partition of the current dataset to the project using Highlighted->Partition in the pop-up menu in the display pane of the map window. Conversely, the points that are not highlighted in the map can be exported as a partition as well using the Non-Highlighted->Partition function.

The information displayed in the interactive tab of the information pane of the map document window can be modified by selecting Properties from the pop-up menu activated by a right mouse click in the information pane.

This help will go through all of the modes available for manual interaction with the maps (the modes can be set using the Highlighting Toolbar).

- **Point Mode** - Highlight an individual point when clicking in a Map, and record the orientation data for that point in the Interactive List.

- **Tolerance Mode** - Highlight all points within a certain tolerance of the point clicked on in a Map, and record the orientation data for each point in the Interactive List.

- **Grain Mode** - Highlight all points of the grain clicked on in a Map, and record the orientation data for the grain in the Interactive List.

- **Boundary Mode** - Highlight the two points clicked on in a Map, and record the misorientation data in the Interactive List.

- **Triple Junction Mode** - Highlight the three points clicked on in a Map, and record the misorientation data in the Interactive List.

- **Vector Profile Mode** - Highlight all points along the line segments drawn on a Map, and record the orientation and misorientation data in the Interactive List.

- **Crystal Direction Mode** - display the crystal direction parallel to the vector draw on a Map.

- **Plane Traces** - Draw the traces of the specified plane for the datapoint selected on a Map. The length of the traces drawn is proportional to the inclination of the plane relative to the sample surface. The more inclined the plane the longer the trace.

- **Crystal Lattice** - Draw a crystal lattice in the orientation of the datapoint selected on a Map.
• **Point Mode**

In this mode only the individual points clicked on are highlighted. An example is shown below.

The interactive view can display several items associated with the highlighted point. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \(\{hkl\}\)\(<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the \(x, y\) coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit (in degrees), the phase, the misorientation angle the point makes relative to a specified crystal orientation, the full misorientation the point makes relative to a specified crystal orientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation the point makes relative to a specified crystal orientation and the deviation of the CSL sigma value from the ideal definition.
This mode will apply the color gradient to all points within the Tolerance Angle of the point clicked. In this case, the color varies from blue at 0 degrees away from the clicked point to red at 2 degrees away.

The interactive view can display several items associated with the points highlighted from the click in the map. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the x,y coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit, the phase, the misorientation angle the point makes relative to a specified crystal orientation, the full misorientation the point makes relative to a specified crystal orientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation the point makes relative to a specified crystal orientation and the deviation of the CSL sigma value from the ideal definition.
Grain Mode

This mode will apply the color gradient to all points within the grain to which the clicked point belongs. In this case, the color varies from blue at 0 degrees away from the clicked point to red at 2 degrees away.

The interactive view can display several items associated with the individual points in the highlighted grain. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the x,y coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit and the phase. In addition, information on the grain itself can be displayed. Namely: the ID number assigned to the grain, the average orientation of the grain (in Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the coordinates of the centroid of the grain in microns, the average image quality, confidence index and fit, the area in square microns, the diameter in microns, the length of the major and minor axes of an ellipse fit to the grain in microns, the ratio of the minor axis to the major axis, the angle of the major axis relative to the horizontal, the spread in orientation within the grain and the twin fraction. The twin definition is set on the grain page of the partition properties dialog.
**Boundary Mode**

In this mode two points must be selected. The boundary normal is calculated to lie coincident with a vector connecting the two points.

The interactive view can display several items associated with the individual points making up the grain boundary pair. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the x,y coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit and the phase. In addition, information on the boundary separating the two points can be displayed. Namely: the misorientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation, the deviation of the CSL sigma value from the ideal definition and the boundary plane in the crystals (assuming the boundary plane is perpendicular to the viewing plane). The misorientation and boundary plane are given relative to the crystal lattice at each point. The minimum angle between a given crystal direction in both lattices can also be calculated.

The misorientation can be calculated based on the orientation of the two highlighted points or according to the average orientation of the grains to which the two highlighted points belong. To use the average grain orientations, select from the highlighting toolbar.
Triple Junction Mode

In this mode three points must be selected. Once again, the boundary normals are calculated to lie coincident with the vectors connecting the points.

The interactive view can display several items associated with the individual points making up the grain boundaries separated by the three pairs of points. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \((hkl)\angle(uvw)\) as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the \(x, y\) coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit and the phase. In addition, information on each of the boundaries can be displayed. Namely: the misorientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation, the deviation of the CSL sigma value from the ideal definition and the boundary plane in the crystals (assuming the boundary plane is perpendicular to the viewing plane). The misorientation and boundary plane are given relative to the crystal lattice at each point.
In this mode the user can collect points along line segments. To create a set of 2 segments as shown below: First use the left mouse button to define the starting point, the cursor will then change to show the line segment. Use the right hand mouse button to end the current segment and start a new segment. Finish the line by clicking on a point with the left mouse button again.

The interactive view can display several items associated with the individual points making up the line segments. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \( \{hkl\}<uvw> \) as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the image quality, the confidence index, the fit and the phase. In addition, information on the point relative to other points on the line can be given displayed as well. Namely: the misorientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix) relative to the originating point of the line and also relative to the previous point in the line and the distance from the origin along the line in microns.

In addition to showing the points in the interactive view, a line profile is also displayed as a misorientation profile chart. Three different parameters can be displayed as a function of distance along the line in the chart.

1) The misorientation between a point on the line and the previous point on the line.

2) The misorientation between a point on the line and the first point (origin) on the line.

3) Either the value associated with the parameter used in making the color component of the map or the value associated with the parameter used in generating the gray scale component of the map.

For example, in a combined map of the average kern el misorientation used for the color scheme, and IQ used for the gray scale, the following two charts could be generated. The red curve shows the point-to-point misorientations (1 above), the blue curve the point-to-origin (2 above) and the green curve is either the average kern el misorientation in degrees or the IQ value associated with the point.
Crystal Direction Mode

In this mode the user can click the endpoints of a vector and determine the direction in the crystal parallel to the vector. Both points should lie within the same grain. First use the left mouse button to define the starting point, the cursor will then change to show a vector. Use the right hand mouse button to end the current vector.

The interactive view can display several items associated with the highlighted point. The most important is the crystal direction parallel to the prescribed vector. In addition information on the starting point can also be displayed. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the x,y coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit (in degrees), the phase, the misorientation angle the point makes relative to a specified crystal orientation, the full misorientation the point makes relative to a specified crystal orientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation the point makes relative to a specified crystal orientation and the deviation of the CSL sigma value from the ideal definition.
Plane Traces Overlay

This mode shows the traces of user prescribed planes at highlighted points. The length of the trace is proportional to the inclination of the plane. The more inclined the plane (relative to the same surface) the longer the trace drawn. Alternatively, the trace of the plane normals can be drawn as well.

The selection of these two options as well as the definition of the plane to highlight is done using the HKL button on the Highlighting toolbar. In this dialog, 4 indices are shown so that the (hkl) entered are applicable for all symmetries. For hexagonal and trigonal symmetry all 4 indices are used, for all other symmetries only the h, k and l indices are used.
The interactive view can display several items associated with the highlighted point. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the x,y coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit (in degrees), the phase, the misorientation angle the point makes relative to a specified crystal orientation, the full misorientation the point makes relative to a specified crystal orientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation the point makes relative to a specified crystal orientation and the deviation of the CSL sigma value from the ideal definition.
Crystal Lattice Overlay

This mode will draw small wireframe lattice at the point highlighted.

The interactive view can display several items associated with the highlighted point. Namely: the orientation (in Euler Angles after Bunge, Roe and Kocks, as (hkl)<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix), the x,y coordinates in microns relative to the top-left corner of the map, the image quality, the confidence index, the fit (in degrees), the phase, the misorientation angle the point makes relative to a specified crystal orientation, the full misorientation the point makes relative to a specified crystal orientation (in Euler Angles after Bunge, Roe and Kocks, as misorientation angle only, as an Axis/Angle pair with integers defining the axis, as an Axis/Angle pair with real values defining the axis, as a Rodrigues Vector or as a rotation matrix), a CSL sigma value for the misorientation the point makes relative to a specified crystal orientation and the deviation of the CSL sigma value from the ideal definition.
Highlighting in Charts

In charts, the behavior is independent of the highlighting mode set in the highlighting toolbar. To highlight a chart, drag the cursor with a left-hand mouse click to select the region of interest in the chart as shown:

All of the bars in the chart encompassed by the selection rectangle will be selected. In this example, a gradient from blue to green to yellow was selected. The bars selected will be colored according to the gradient set in the highlighting toolbar as shown.
Depending on the chart type, correlated points in a discrete plot and points or boundaries in a map will be highlighted. For this example, a misorientation angle chart has been shown. This will result in the Color Gradient being applied to the chart and the corresponding boundaries in the map as well as in a discrete Axis/Angle plot. As shown below.
Highlighting in Plots

This feature in OIM allows the user to extract orientation information by manual interaction with the plots (both discrete plots and texture plots).

The information displayed in the interactive tab of the information pane of the map document window can be modified by selecting Properties from the pop-up menu activated by a right mouse click in the information pane.

This help will go through all of the modes available for manual interaction with the plots (the modes can be set using the Highlighting Toolbar).

- **Tolerance** - Show the points within the specified angular tolerance relative to the point clicked in a Plot.

- **Misorientation** - Show the misorientation between two points clicked in a Plot. For pole figures the angular distance between the two sample directions, for inverse pole figures the angular distance between the two crystal directions, in ODFs the angular distance between two orientations (the minimum misorientation based on the crystal symmetry). Not implemented for misorientation plots.

When highlighting texture plots, no highlighting will be displayed on the plot itself. However, the highlighted points would be visible in any concurrent maps or discrete plots.
**Plot Tolerance Mode**

This mode will apply the color gradient to all points within the *Tolerance Angle* of the point clicked. In this case, the color varies from blue at 0 degrees away from the clicked point to red at 5 degrees away.

The highlighting behavior differs somewhat depending on the type of Plot being highlighted.

**Orientation plots (Euler and Rodrigues ODFs)**

The closest point in the dataset to the point clicked serves as the basis for the highlighting. All points in the dataset within the *Tolerance Angle* (set on the Highlighting toolbar) of the selected data point will be highlighted.

In the interactive tab of the information pane of the plot window, the color, the orientation of the data point selected (in Euler angles or a Rodrigues vector corresponding to the ODF plot type) and the fraction of points in the partition within the tolerance angle of the point selected are recorded.

**Pole Figures**

In a pole figure, a point corresponds to a sample direction - the sample direction used in the highlighting is that corresponding to the data point closest to the pixel clicked in the pole figure. The points highlighted will be those that have their poles (denoted by the hkl of the pole figure clicked) aligned with the clicked sample direction within the Tolerance Angle set on the Highlighting toolbar.

In the interactive tab of the information pane of the plot window, the color, the hkl of the pole figure the mouse click was made in, the sample direction, the angular distance of the point clicked from the center of the pole figure and the fraction of points in the partition within the tolerance angle of the point selected are recorded.

**Inverse Pole Figures**

In an inverse pole figure, a point corresponds to a crystal direction - the crystal direction used in the highlighting is that corresponding to the data point closest to the pixel clicked in the inverse pole figure. The points highlighted will be those that have their poles (denoted by the hkl of the pole figure clicked) aligned with the selected sample direction within the Tolerance Angle set on the Highlighting toolbar. The selected sample direction is that associated with the inverse pole figure clicked in.
In the interactive tab of the information pane of the plot window, the color, the sample direction of the inverse pole figure the mouse click was made in, the crystal direction, the angular distance of the point clicked from the center of the inverse pole figure and the fraction of points in the partition within the tolerance angle of the point selected are recorded.

**Misorientation Plots (Rodrigues and Axis/Angle MDFs)**

For misorientation plots (Rodrigues and Axis/Angle Misorientations) instead of highlighting individual points the boundary segments associated with the point clicked are highlighted. For a point clicked in a misorientation plot, the misorientation corresponds to a boundary with a specific angle and axis of rotation. Boundaries with misorientations within the Tolerance Angle of the specific misorientation selected are highlighted.

In the interactive tab of the information pane of the plot window, the color, the misorientation and phase of the boundary selected, and the fraction of boundaries in the partition within the tolerance angle of the point selected are recorded. In Axis/Angle MDFs, if more than one phase is represented in the MDF plot, then for each click the misorientation is listed the same number of times as the number of phases. In each listing the misorientation is given with respect to each phase. (The angle remains the same, but the indices used in defining the axis are a function of the crystal structure.)
Plot Misorientation Mode

This mode will calculate the misorientation between two points in a plot. This mode is not applicable to misorientation plots (i.e. the Rodrigues and Axis/Angle MDFs). The current highlighting color is applied to the points selected.
The highlighting behavior differs somewhat depending on the type of Plot being highlighted.

**Orientation plots (Euler and Rodrigues ODFs):**

The two points in the dataset corresponding to the two points clicked are highlighted. (Other points will appear in the plot, these "extra" points are symmetrically equivalent.)
In the interactive tab of the information pane of the plot window, the color, the orientations of the two data points selected (in Euler angles or a Rodrigues vector corresponding to the ODF plot type) and the misorientation (angle only) between the two points is recorded.

**Pole Figures:**

The two points in the dataset corresponding to the two points clicked are highlighted. (Other points will appear in the plot, these "extra" points are actually symmetrically equivalent poles for the same orientation.)

In the interactive tab of the information pane of the plot window, the color, the hkl indices of the pole figure clicked in, the sample directions corresponding to the two points selected and angular distance between the two points is recorded. This distance is not the minimum distance between any of the symmetrically equivalent points, but the actual distance of the particular variants of the pole at the locations clicked.

**Inverse Pole Figures:**

The two points in the dataset corresponding to the two points clicked are highlighted. (Other points will appear in the plot, these "extra" points are actually symmetrically equivalent poles for the same orientation.)

In the interactive tab of the information pane of the plot window, the color, the sample direction (RD, TD, ND) of the pole figure clicked in, the crystal directions corresponding to the two points selected and the angular distance between the two points is recorded.
The interactive view in the information pane of map document windows displays the results of interactive highlighting in the map. What is displayed is dependent on the highlighting mode. The user may also define what is displayed and the format used. This is done via the properties dialog shown below. Checking any of the boxes in the list box will result in a column being added to the interactive view to display the parameter for the points highlighted. The list of display parameters available for selection will vary according to the highlighting mode currently selected.

The following is a description of the various options in the dialog.

**Individual Points** ✡ ⛩ ★ ✱

**Orientation** - The crystallographic orientation of the highlighted point using the representation specified in the Orientation(s) combo box. Choices include representing the orientation as Euler Angles after Bunge, Roe and Kocks, as \(\{hkl\}<uvw>\) as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix. OIM calculates the \(\{hkl\}<uvw>\) as floating point values then attempts to convert them to integers while maintaining the dot product to zero and trying to keep the orientation as close as possible to the precise description given by the floating point values.
**x coordinate (microns)** - The x coordinate of the highlighted point relative to the left hand side of the OIM scan.

**y coordinate (microns)** - The y coordinate of the highlighted point relative to the top of the OIM scan.

**Image Quality** - The image quality of the diffraction pattern used to get the orientation of the highlighted point during the OIM scan.

**Confidence Index** - The confidence index generated during indexing of the diffraction pattern used to get the orientation of the highlighted point during the OIM scan. The bounds of this value are 0 to 1. However, a value of -1 is used to designate points that were not indexed.

**Fit** - The fit parameter generated during indexing of the diffraction pattern.

**Phase** - A name identifying the phase the highlighted point was identified as during the OIM scan.

A reference orientation may be specified on the **Orientation Page** of the dialog shown above. A reference direction may also be defined using the **Direction Page** on the dialog shown above.

**Angle of specified crystal direction relative to reference direction** - For the highlighted point, the angle the crystal direction specified on the **Direction Page** makes with the sample direction also specified on the **Direction Page**. The angle is given in degrees.

**Misorientation relative to reference orientation** - The misorientation the highlighted point makes relative to the reference orientation specified on the **Orientation Page**. The misorientation representation used is set in the **Misorientation(s)** combo box. Choices include Euler Angles after Bunge, Roe and Kocks, as a misorientation angle only, as an Axis/Angle pair with integers defining the rotation axis, as an Axis/Angle pair with real numbers defining the rotation axis, as a Rodrigues Vector or as a rotation matrix. OIM calculates the rotation axis using floating point values then converts the values to integers while keeping the direction as close as possible to the precise definition given by the floating point values.

**CSL sigma value relative to reference orientation** - For the misorientation between the highlighted point and the reference orientation the CSL value for the misorientation is calculated assuming Brandon's criterion and the result displayed. If the boundary is not an identifiable CSL boundary then a "-" appears in the column.

**CSL deviation relative to reference orientation** - The angular deviation of the CSL boundary from the ideal definition in degrees.

**Map - Grayscale value** - This is the value corresponding to the gray hue used to shade the point in the map (assuming a gray scale map has been selected, otherwise a value of "-" will be displayed.) For example, if the map has a grayscale component corresponding to the image quality (IQ) the IQ for the point selected is displayed.

**Map - Color Coded value (Range ID)** - This is the value corresponding to the color used to shade the point in the map (assuming a color coded map has been selected, otherwise a value of "-" will be displayed). The value in parentheses corresponds to the range set. For example, if the map has a color coded component corresponding to the grain size where the color red corresponds to grains having sizes within 80 to 100% of the maximum, orange 60 to 80%, yellow 40 to 60%, green 20 to 40% and blue 0 to 20%, then if a point shaded yellow in the map is selected, the following might be displayed 23 (3) where 23 is the grain size and "(3)" denotes that the point belongs to the 3rd range defined for the map (yellow in this case).

**Point Pairs**

For each of the points in the pairs, the Orientation, x and y coordinates, confidence index, fit and phase as for individual points may be displayed and recorded.

**Misorientation** - For a pair of highlighted points this describes the misorientation of the point relative to the crystal lattice define by the phase at each of the two points. The suffix p1 is applied to the misorientation given in the reference frame of the first point and p2 to the misorientation given in the reference frame of the second point. The misorientation representation used is set in the **Misorientation(s)** combo box. Choices include Euler Angles after
Bunge, Roe and Kocks, as a misorientation angle only, as an Axis/Angle pair with integers defining the rotation axis, as an Axis/Angle pair with real numbers defining the rotation axis, as a Rodrigues Vector or as a rotation matrix. OIM calculates the rotation axis using floating point values then converts the values to integers while keeping the direction as close as possible to the precise definition given by the floating point values.

**CSL sigma value** - For a pair of highlighted points (of cubic crystal symmetry) the CSL value for the misorientation is calculated assuming Brandon's criterion and the result displayed. If the boundary is not an identifiable CSL boundary then a "-" appears in the column.

**CSL deviation** - The angular deviation of the CSL boundary from the ideal definition in degrees.

**Boundary Plane** - This assumes the boundary plane is normal to the scan surface plane and that the boundary normal is coincident with a vector connecting the pair of highlighted points. The indices of the crystal plane coincident with the boundary plane are displayed for both points. The indices are calculated using real numbers. When *Use integers for describing boundary planes* is checked on the software will convert the values to integers while maintaining the definition of the plane as close as possible to the precise definition given by the floating point numbers.

**Angle between equivalent direction in two orientations** - For the crystal direction specified, all symmetric variants of the crystal direction are calculated. The direction of each of these variants with respect to the sample reference system for the orientation selected is calculated. The minimum angular distance between any pair of these vectors is determined and displayed. For example, consider the <100> directions in a cubic crystal. There are three variants [100], [010] and [001] as shown below.

![Diagram of crystal directions](image)

**Deviation from Reference Misorientation** - A reference misorientation may be defined on the *Axis and Angle Page* of the dialog. The deviation the misorientation for the pair of highlighted points makes relative to this reference misorientation can be displayed and recorded.

**Distance between Points (microns)** - The distance between the two points clicked can be displayed in microns.

Grains 🌱
For each of the points in the pairs, the Orientation, x and y coordinates, confidence index, fit and phase as for individual points may be displayed and recorded.

**Grain ID Number** - A unique integer value assigned to each grain in the scan.

**Grain - Average Orientation** - The average orientation of the highlighted grain will be displayed using the representation specified in the Orientation(s) combo box. Choices include representing the orientation as Euler Angles after Bunge, Roe and Kocks, as \{hkl\}<uvw> as integers or floating point values, as a Rodrigues Vector or as a 3x3 orientation matrix. OIM calculates the \{hkl\}<uvw> as floating point values then attempts to convert them to integers while maintaining the dot product to zero and trying to keep the orientation as close as possible to the precise description given by the floating point values.

**Grain - Average x** - The x coordinate of the shape ellipse fit to the grain is calculated and displayed in microns relative to the left edge of the OIM scan.

**Grain - Average y** - The y coordinate of the shape ellipse fit to the grain is calculated and displayed in microns relative to the top edge of the OIM scan.

**Grain - Average Image Quality (IQ)** - The average IQ of all points making up the grain.

**Grain - Average Confidence Index (CI)** - The average CI of all points making up the grain.

**Grain - Average Confidence Fit** - The average fit of all points making up the grain.

**Grain - Area [microns^2]** - The area of the grain given in square microns.

**Grain - Diameter [microns]** - The diameter of the grain given in microns. The diameter is calculated from the area assuming the grain is a circle.

**Grain - Major Axis Length [microns]** - The length of the major axis of the ellipse fit to the grain in microns.

**Grain - Minor Axis Length [microns]** - The length of the minor axis of the ellipse fit to the grain in microns.

**Grain - Aspect Ratio (Minor/Major)** - The ratio of the minor axis to the major axis of the ellipse fit to the grain.

**Grain - Angle of major axis with horizontal** - The angle (in degrees) the major axis of the ellipse fit to the grain makes with respect to the horizontal direction in the scan grid.

**Grain - Spread in orientation** - The angular spread in orientation within the grain given in degrees.

**Grain - Twin fraction** - The fraction of twins in a grain. The twin definition is set on the grain page of the partition properties dialog. The point clicked defines the matrix orientation; the points making up the grain are searched to see if they belong to the matrix or a twin related.

**Points on Lines**

For each point on the line all of the parameters used for individual points may be displayed and recorded. In addition the following parameters may be accessed.

**Misorientation angle with respect to origin** - The misorientation angle (in degrees) the highlighted point makes with the first point in a line.

**Misorientation angle with respect to neighbor** - The misorientation angle (in degrees) the highlighted point makes with the previous point in a line.

**Distance from origin** - The distance (in microns) the highlighted point is from the first point in the line along the line. This value is obtained by summing the distance between all neighboring pairs on the line.

**Points defining a Vector**
For the starting point of the vector, the parameters used for individual points may be displayed and recorded. In addition the following parameters may be accessed.

**Sample Direction** - The sample direction parallel to the vector.

**Crystal Direction** - The crystal direction parallel to the vector.
Using the Report Generator

OIM 4 introduces a Report Generator. This tool allows users to create Microsoft Word or PowerPoint templates. The templates allow for a customized header to be setup as well as place holders for maps, charts and plots. The user can also enter fixed text. The following is a sample template for a map with the accompanying legend along with some fixed text.

There are three steps to using the report generator in OIM Analysis:

1) Create Report Templates - the template creator should be used to both create and edit report templates.
2) Add project item to the report
3) Generate the report
Creating Templates

To create a template click on the wizard button from the Standard Toolbar.

This will bring up the report wizard, which will guide you through the process of creating a report template.

Troubleshooting Note: If the wizard fails to appear and instead you see a blank Word document, you may need to change your security settings in Word.

Notice that from this screen you have three choices: preview/edit, convert, or create new template. For help on preview/edit or convert, click on the highlighted links. If you select the next button the next page of the wizard will pop up.
From here you can choose to copy a header from another document or template. You can also elect not to have a header at all.

This part of the wizard allows you to choose a header bitmap and a name for the template that is to be created.
Finally choose the paper size and the page orientation for the template.

Click finish. You are now ready to create placeholders for maps, charts, and plots.

Help on Placing Objects
Placing Objects

Upon completing the report creator wizard, the following toolbox will be displayed:

To place an object, simply click on the appropriate button for the type of object you want. For more information click on the question mark button at the bottom left corner of the tools dialog. This will bring up the Word Assistant. When you are finished placing objects, click on the Done button. This will save your template to the file specified in the third page of the wizard dialog.

The report template is designed to contain one map, plot or chart per page along with the accompanying legend if desired. The size of the containers for these objects can be resized by clicking on the graphic handles in Word. However, when the actual object is placed into the container the aspect ratio of the object in OIM Analysis will be retained in the final report.
Add Project Items

Adding items in the OIM Analysis project tree is very simple. Right click on the tree item you wish to add to the report. Choose Report from the pop-up menu as shown in the diagram below. Next choose Add to Report which will pop-up a list of the available report templates. Simply select one from the list with a left click. A check mark will appear to the left of the item in the project tree to indicate that it has been added to the report.
Generate the Report

You have two options in generating reports: Microsoft Word or Microsoft PowerPoint. Once you have added project tree items to the report you can generate the report by clicking on one of the following toolbar buttons:

![Word Button](w.png) ![PowerPoint Button](pp.png)

The button on the left is for Word and the one on the right is for PowerPoint.
To preview a particular template, left click on any template that appears in the file list. The preview appears to the right. If you would like to edit a template, choose the template from the list and then click on the Open button. To exit the preview screen, click the Cancel button.
Convert

The convert button is included in the report wizard for converting old templates to the latest version. At the current time there is only one version available. Clicking on the convert button brings up the following dialog:

To convert a template, choose one from the list and click the **Save** button.
Changing Security Settings in Microsoft Word

1. Open Microsoft Word
2. Select **Tools --> Macro --> Security**

3. Set the security to the low setting. Keep in mind this will allow all macros to run, and you may want to reset the security to high after using OIM Analysis.
BATCH PROCESSOR

-The batch processor allows the same set of analysis functions to be performed on multiple datasets. The ability to apply the same analyses to a batch of data without any user intervention can be especially helpful when successive datasets are obtained during serial sectioning or during in-situ measurements.

Upon selecting the 📀 Batch Processor button from the Standard Toolbar, the user is first prompted to select the files on which to operate. Once the files are selected, the following dialog box will appear.
Alignment will attempt to align each dataset in the set selected to the previous dataset.

Will crop each dataset according to the cropping parameters selected. These can be defined on a user specified dataset from the set selected.

Perform 3 successive cleanup procedures on each dataset. The parameters associated with each procedure
can be defined as well.

Apply at [dataset template](#) to each dataset. Save all of the associated graphics as either bitmaps or in jpeg format. A given maximum dimension can be applied to each graphics. The legends associated with the graphics can be saved as text files. This allows various numerical parameters associated with the graphics to be recorded.

The modified datasets can be saved as either .osc files or .ang files. The Hough peak data in these data sets is removed (to save space) and the file name is changed from ds10.osc to ds10_Mod.osc. All of the analysis performed can be saved to individual project files for each dataset. Alternatively, a project containing all of the analysis for all of the datasets can be retained after the batch processor completes. However, this may running into memory problems if there are many datasets, particularly if the datasets are relatively large.

All of the analysis parameters selected can be saved so that the same analyses can be applied to a subsequent batch.
The datasets are sorted in alphabetical order. However, there is one nuance to this order. It is not necessary to have leading zeros in the file name as required in Windows. In other words the file ds1.osc will precede file ds10.osc in the list. However, if multiple numbers are listed in the file name this can cause problems, e.g. ds0_1.osc and ds0_10.osc. For alignment all of the datasets are required to have the same scan grid dimensions.

The alignments are performed using cross-correlations based on Fast-Fourier Transforms (FFTs). The FFTs are calculated on images generated from user specified maps. Several types of images may be used as listed in the dialog.

The batch processor will first determine the offsets required to align each dataset with its predecessor in the list. Once all of the offsets are calculated, then the software is able to determine how the scans must be expanded to account for all of the data offsets to avoid data being lost. A dialog will be displayed to show the results of the offset calculations as shown below.
After proceeding the offsets are applied to each dataset. An example is shown for the same sequence of datasets used to produce the calculation results plotted in the dialog above.

Before:

After:
The analysis software is organized in a series of documents. At the top-most level is the project document. The next level down is the Dataset level. A project may contain several datasets. A Dataset can contain several partitions. A partition is essentially a filtered subset of Dataset. Under the Partitions level there a series of different documents. These include maps, charts, discrete plots, textures and grain boundary textures. The last level are texture plots, which are children of the textures and grain boundary textures.
The project contains all of the recorded information generated during analysis of a data set or multiple data sets. It contains the datasets, partitions and analysis documents. All of these data are recorded in a single *.oim file. However, individual components of the project can be exported to individual files. The project is made up of 5 levels.

**Project**: The top level for a project.

**Dataset**: This level contains datasets and multicharts.

**Partition**: This level contains only partitions.

**Document**: This level includes Maps, Charts, Discrete Plots, Textures, GB Textures

**Texture Plots**: The level contains Texture Plots and is only available under Texture and GB Textures.

An example tree is shown below. In this example project there are four items as the dataset level - three datasets and 1 multichart.

The project tree is displayed in the project tree window.
Project Menu

A right hand mouse click on a dataset will display the following menu:

**New**: Add a new dataset or multichart to the project. A file dialog box is shown. The dataset(s) of interested can then be loaded from disk. Multiple datasets can be added in the file dialog.

**Apply Template**: In the case of a partition template apply the partition template to each dataset currently loaded in the project. For the Maps, Discrete Plots, Charts, Textures and Grain Boundary Textures, the template is applied to all partitions in the project.

**Paste**: Pastes a dataset from the clipboard into the project.

**Rename**: Allows the project to be renamed.
Dataset

The dataset contains the actual data from OIM Data Collection. The dataset is added to the project as either a *.osc file or as a *.ang file. The *.osc is a binary proprietary file. The *.ang file is a text file.

A right hand mouse click on a dataset will display the following menu:

**New**: The new menu allows new partitions to be added to the dataset.

**Apply Template**: Allow templates to be applied to the dataset. For a partition template a new partition will be created for the dataset using the definition in the template. In addition any other documents (maps, plots, charts...) will also be created for the new partition. For the Map, Discrete Plot, Chart, Texture and Grain Boundary Texture templates. The corresponding documents will be created for every partition of the dataset.

**Summary View**: Displays a window containing summary information on the dataset.

**Rotate**: Allows the orientation data to be rotated.

**Cleanup**: The data can be cleaned up. This allows stray points (as sometimes appear near grain boundaries) to be reassigned to match nearby measurements.

**Crop**: Allows the user to extract a subset of the data.
**Merge**: Allows datasets (with the same grid type and step size) to be merged together.

**Coarsen**: Allows every other point in a row and every other row to be removed from a dataset. This is helpful for shrinking the size of oversampled datasets.

**Export**: Allows various data to be exported.

Three options are available. 1) Export scan data as an *.osc file (TSL's proprietary data format) or as a *.ang file, which is an ASCII text file. 2) Export the EDS data in a text file. The data is in the following form: the first two columns are the x and y coordinates of the data point, these are followed by columns of integers. One column for each element for which EDS data was collected. 3) Export misorientations. The user is prompted which two partitions the exported misorientations should be calculated from. The misorientation file is actually a *.ang file, where the point pairs for each misorientation are recorded in the form of 1-2, 3-4, 5-6 (see the preferences dialog). Thus for each misorientation, two orientations are recorded in the file.

**Cut**: Cuts the dataset. The cut data can be pasted into the project allowing the dataset to be replicated within the project.

**Copy**: Copies the dataset. The data can be copied into the project allowing the dataset to be replicated within the project.

**Paste**: Allows a partition to be pasted into the dataset from another dataset. Only the definition used to create the partition is pasted in, not the actual data. Rather the parameters in the definition are used to create a new partition from the dataset. In addition any maps, plots, charts, textures... will also be applied to the partitioned data.

**Delete**: Removes the dataset from the project.

**Rename**: Allows the name of the dataset appearing in the project tree to be changed.
OIM data can be rotated so that the user can work with the data in a familiar reference frame. Consider an imaginary drawn wire sample where the (100) plane normals are aligned parallel to the center axis of the cylinder. If the cylinder is sectioned as shown below and placed in the SEM as shown then we would get a pole figure similar to that shown. However, a 90 degree rotation of the data about the transverse direction would transform the data into the more familiar reference frame with the fiber texture aligned with ND.

The user may perform the rotations about any of the three principle axes of the sample/SEM reference system (i.e. RD, TD & ND). When Rotate is selected from the Dataset pop-up menu in the project tree the following dialog is displayed. The direction of the rotations is shown in the schematic in the Rotate dialog below.
The rotation can be done in-place - the current data set will be replaced by a data set containing the rotated data all of the maps, plots, charts... belonging to the dataset will be updated to reflect the rotation. Alternatively, the rotated data can be placed into the current project as a new data set and will appear in the project tree as such. The rotated data can also be exported as a new data file.
Clean Up

The pattern indexing in OIM is generally quite effective in identifying the orientation from a diffraction pattern. However, at times OIM has difficulty identifying some orientations such as at grain boundaries where the patterns often are made up of two superposed diffraction patterns from both crystal lattices separated by the grain boundary. OIM may index the pattern correctly for either grain or OIM may come up with an incorrect solution based on bands detected from both of the superposed patterns. This will lead to erroneous results near boundaries and triple points. (Of course other factors may result in erroneous results including uneven topography of the sample surface.) OIM provides several clean up methods, which attempt to "clean-up" the erroneous data. These methods generally clean up individual data points based on the neighboring orientations. These methods change the data so that care must be taken to avoid introducing any artificial trends into the data. The clean up algorithms work best when the grain size is considerably greater than the step size of the scan. CleanUp is activated from the Dataset popup menu in the project tree. The following dialog box is displayed.

*Clicking on a cleanup type will jump you to the description of the method.*
**Grain Dilation**

This clean up method is an iterative method. The routine only acts on points that do not belong to any grains; yet have neighboring points, which do belong to grains. A point may not belong to any grain due to the point either not being indexed or due to it belonging to a grain group having fewer members than the Minimum Grain Size. If the majority of neighbors of a particular point belong to the same grain then the orientation of the particular point is changed to match that of the majority grain - otherwise the orientation is randomly changed to match any of the neighboring points, which belong to grains. This process is repeated until each point in the data set becomes a member of a grain. (Alternatively, the user may set the code to only perform a single iteration.) In the schematic below, in the left hand figure the data point in white is not part of any grains. After dilation it's orientation is changed to match that of the neighboring member of the green grain with the highest CI.

![Grain Dilation](image)

**Grain CI Standardization**

This clean up method changes the CIs of all points in a grain to the maximum CI found among all points belonging to the grain. Upon selecting this cleanup routine the user is prompted for the grain tolerance angle to be used in performing the clean up routine. This method is useful when a minimum CI value greater than 0 is used in analyzing the data. It essentially enables a point with a low CI, yet having an orientation similar to that of the surrounding measurements (and thus likely representing a correct indexing of the corresponding EBSP), to be distinguished from a point with a low CI where no correlation exists between the point and its neighbors (most likely representing an incorrect orientation measurement). In the schematic below, the gray scale represents the confidence index.

![Grain CI Standardization](image)

**Grain Fit Standardization**

Same as the Grain CI Standardization except the Fit values are upgraded instead of CI values.

**Neighbor CI Correlation**

This clean up method is only performed on data points with CIs less than some user defined value. If a particular point has a CI less than the minimum value then the CIs of the nearest neighbors are checked to find the neighbor with the highest CI. The orientation and CI of the particular point are reassigned to match the orientation and CI of the neighbor with the maximum CI. In the schematic below the color represents the orientation and the number in each hexagon is the CI.
### Neighbor Orientation Correlation

This clean up method operates by examining each data point individually and testing for two conditions. The first condition is a check to determine if the orientation is different from its immediate neighbors. For cleanup level 0, all nearest neighbors must differ in orientation more than a given tolerance angle (the Grain Tolerance Angle) for cleanup level 1, all but one of the nearest neighbors must be different and so on up to cleanup level 5 where only one nearest neighbor must be different. If the required number of nearest neighbors is different, the second condition is tested. This condition determines the number of nearest neighbors which represent like orientations to within the given tolerance angle. For cleanup level 0, all nearest neighbors must be of similar orientation, cleanup level 1 requires all but one of the nearest neighbors to be of the like orientation and so on up to cleanup level 5. If both conditions are satisfied, the orientation of the point in question changed to one of the neighbors involved in meeting conditions 2 and 3 (the choice is random). A schematic of the clean up scheme is shown below. For clean up levels greater than 0 all the each lower clean up levels is performed sequentially. Thus If level 4 is selected then clean up level 0 is applied, followed by level 1, then level 2, then level 3 and the cleanup procedure is finished with level 4.

![Schematic of Neighbor Orientation Correlation](image1)

### Neighbor Phase Correlation

This clean up method is only performed on data points with CIs less than the Minimum Confidence Index. The phase (and orientation) of such points are changed to match the phase (and orientation) to which the majority of its neighbors belong. If there is no majority then the point is randomly changed. In the schematic below the color represents the phase. In the left hand figure, the white data point has a CI less than the Minimum Confidence Index.

![Schematic of Neighbor Phase Correlation](image2)

### Asymmetric Domain

This clean up method is performed on all data points. During indexing, symmetrically equivalent orientations may be determined for different measurements of the same grain. Thus, two measurements of the same orientation may produce two sets of quite different Euler Angles. This clean up method converts all orientations into the same asymmetric domain or fundamental zone to reduce this apparent ambiguity. For example, two neighboring
orientations may have Euler angles of (11.0, 27.0, 83.0) and (183.2, 63.2, 3.6) respectively. After the cleanup procedure the Euler Angles would be (11.0, 27.0, 83.0) and (11.0, 27.0, 83.0) respectively. The asymmetric domain selected is that which produces the Rodrigues Vector with the smallest magnitude.

It should be noted, that the results may not always be as expected especially for orientations nears the boundaries of the asymmetric domain. Consider two orientations of cubic crystal symmetry belonging to the same grain of (0,80,79.8) and (0,80,79.9). These orientations differ by only 0.1 degrees from each other. However, (0,80,79.8) is inside the asymmetric domain and (0,80,79.9) is not. The symmetrically equivalent orientation lying inside the asymmetric domain is (268.2,80.1,10.2) which, at first glance, appears to be quite a bit different from the (0,80,79.8). It is important to remember when working with crystallographic orientations that the symmetry be included in any types of analyses.
**Single (Average) Orientation per Grain**

In deformed materials, we often see changes in orientation between the individual measurements which constitute a grain. Some very slight misorientations are also sometimes observed in recrystallized materials. These slight misorientations may arise simply from minute differences in indexing of the patterns from individual measurement points. All measurements, which make up a grain can be replaced by the average orientation for the grain. This results the grain having a single orientation at each constituent measurement point.

**Normalize EDS per Grain**

In this clean up procedure, the EDS counts for each point within a grain are replaced by either the average value or by the sum value for the grain. This process is performed for each element for which EDS counts have been collected.

**ACT (TEM)**

In the conical scan measurement performed by OIM and ambiguity can exist for highly symmetric orientations. This cleanup eliminates the ambiguity by always selecting a single orientation for the ambiguity.

**Pseudosymmetry**

Some orientations for certain symmetries may be difficult to distinguish from one another, as the patterns are quite similar. However, these orientations will have a given orientation relationship. If this relationship can be identified then a grain containing these orientations will be "cleaned up" so that it contains only the orientation that is most prevalent in the grain. The following example is for a sample with trigonal crystal symmetry. The large grain at the center and touching the bottom edge of the scan is dominated by two orientations as represented by the blue and rose colors. Using the boundary highlighting mode, the misorientation between these two orientations was found to be approximately a 64 degree rotation about the \(<100>\) crystal direction. This misorientation was entered into the dialog displayed when the "Define Pseudosymmetry Relations" button is pressed. You can see the result below. Warning: if two neighboring grains are related through the pseudosymmetry relation the smaller grain will become part of the larger one. This can be seen in these results as well (note the golden rod and purple grain on the left, the goldenrod grain consumes the purple one after cleanup).
Operation

The user has three options for handling the data after clean up. (1) Simply clean up the data in-place. All of the open documents will be recalculated to reflect the changes as appropriate. (2) Create a new data set and add it to the current project. (3) Export the data as a new data file - the user must supply the file name.
Cropping

It is possible to crop the dataset to focus on an area of interest within a scan. When crop is selected from the Dataset pop-up menu in the project tree the following dialog is displayed.

The map in the window will default to an image quality map of the scan. It is possible to change the type of map by selecting Properties... from the pop-up menu activated by a right hand mouse click in the map window. It is also possible to show current highlighting or the boundaries on the map. From the pop-up menu it is also possible to expand the map for more detail by deselecting Fit To Window. This will expand the map to full size and place scroll bars on the window. To select the area to crop, simply click on the map and drag out the rectangle to define the area to be extracted. The corresponding coordinates of the rectangle will be shown in the Left, Top, Right and
Bottom fields. Alternatively, these coordinates may be entered by simply typing in the edit boxes. The extraction can be done in-place - the current data set will be replaced by a data set containing only the extracted region. The cropped data will be lost. Alternatively, the extracted region can be placed into the current project as a new data set and will appear in the project tree as such. The extracted region can also be exported as a new data file.
Merge

Merge allows two datasets to be combined together into 1. The two datasets must have the same step size. When merge is selected from the pop-up menu in the project tree for a given dataset this data set becomes the reference data set. The following dialog will be displayed. In the combo box at the top of the dialog, all data sets with the same step size are made available. The user must select the data set he/she wants to merge to the reference data set. Using the dialog shown below the user can drag the IQ map of the second dataset into position relative to the first dataset as shown below. Since OIM requires scan data to be in rectangular grids, empty spaces in the scan area may occur for unequal scan dimensions or the selected placement of the two scans relative to one another. Once the dialog is closed by pressing the OK button, the software will merge the two data sets together into one and fill in any empty space with "unindexed" points as shown in the resulting map below.
When the dialog is initially displayed, the two maps will be placed with the reference map on the left and the second map on the right with the tops of the maps aligned. Select the second map by left-clicking on it with the cursor. It can then be dragged to any desired position within the window.

From the pop-up menu activated by a right-hand mouse click in the map window it is possible to expand the map for more detail by deselecting *Fit To Window*. This will expand the map to full size and place scroll bars on the window allowing for more accurate placement. Alternatively, the coordinates may be entered by simply typing in the edit boxes.

The merging can be done in-place - the current data set will be replaced by a data set containing the combined data set. Alternatively, the merged data can be placed into the current project as a new data set and will appear in the project tree as such. The merged data can also be exported as a new data file.
Coarsen

Coarsen removes every other point on each row and every other row from a dataset. This shrinks the number of points in a dataset by a factor of 4.
Partition

A partition is a subset of the dataset. When a dataset is opened an All data partition is automatically generated as well as a partition for each phase in the data set. The data can be partitioned in a variety of other ways. For example, a partition may include only data with confidence indexes greater than 0.1. All analysis done on the data will be done using only the data with CIs greater than 0.1. Each partition in the dataset contains its own grain definition as well as parameters needed for reconstructed boundaries.

A right hand mouse click on a dataset will display the following menu:

**New**: Will create a new Map, Discrete Plot, Chart, Texture or GB Texture using the data in the partition.

**Apply Template**: Imports a template to create a new Map, Discrete Plot, Chart, Texture or GB Texture based on the definitions held in the template using the data in the partition.

**Export**: Four types of data are available for export at the partition level:

- Template...
- Grain File...
- Reconstructed Boundaries...
- Partition Data...
- Triple Points...
**Cut**: Cut a partition from the dataset. The cut partition (or rather the parameters defining the partition formula) can then be pasted into a dataset to form a new partition based on the partition formula using the data in the new dataset and will also include all of the maps, plots, charts... belonging to the partition.

**Copy**: Copies a partition from the dataset. The copied partition (or rather the parameters defining the partition formula) can then be pasted into a dataset to form a new partition based on the partition formula using the data in the new dataset and will also include all of the maps, plots, charts... belonging to the partition.

**Paste**: Paste the parameters needed to create a new Map, Discrete Plot, Chart, Texture or GB Texture from another partition applied to the data in the selected partition.

**Delete**: Deletes the selected partition from the dataset.

**Rename**: Allows the user to change the name of the partition appearing in the project tree.

**Properties**: Opens up a dialog where the parameters defining the partition formula, grain size, neighbors and reconstructed boundaries can be changed.
Export: Five types of data are available for export:

1. Export the parameters defining the partition formula to a template file along with the defined parameters for any maps, plots, charts... belonging to the partition.

2. Export the grain data. Two formats are available. The first is a standardized format similar to the *.ang format and can thus be imported back into OIM. In this format each datapoint is written out to file with some information identifying the grain the point belongs to. The second is a format where information about each grain is written out individually. The information recorded for each grain can vary according to the options the user sets in the following dialog box.
A header in the exported file identifies the parameters associated with each column in the file as shown in the following example:

```
# Header: Project1::capdtest::All data::Grain Size 3/14/2003

#
# Column 1: Integer identifying grain
# Column 2-4: Average orientation (phi1, PHI, phi2) in degrees
# Column 5-6: Average Position (x, y) in microns
```
(3) Export the reconstructed boundary data to a text file. The file is in the following format (as denoted in the file header):

Columns 1-3: right hand average orientation (phi1, PHI, phi2 in degrees)
Columns 4-6: left hand average orientation (phi1, PHI, phi2 in degrees)
Column 7: length (in microns)
Column 8: trace angle (in degrees - relative to the horizontal)
Columns 9-12: x,y coordinates of endpoints (in microns)
Column 13-14: IDs of right hand and left hand grains

(4) Export all of the data in the partition as a *.ang file.

(5) Export the triple point data to a text file. The file is in the following format (as denoted in the file header):

Column 1-2: x, y [microns]
Column 3-5: w1, w2, w3 [misorientations in degrees]

The misorientations recorded are calculated from average orientations in the grains surrounding the triple point. This file can only be created for data collected on hexagonal scan grids.
Partition Formula

The formula used to define the partition can be set using the following dialog

Some of the parameters the partition can be defined on are based on the values of individual points in the data set.

Confidence Index

Image Quality

Fit

Video Signal - the intensity at a particular point from whichever detector was hooked up to OIM during data collection, Typically, a forward scatter detector.

Phase - the identified phase for a particular point.
Crystal Direction
Crystal Orientation
Taylor Factor
Schmid Factor
EDS Counts
Other parameters are based on grain properties.

Size
Aspect Ratio
Rotation Angle
Orientation Spread
Average IQ
Average CI
Average Fit
Average Video Signal

The formula window shows explicitly the definition used to form the partition. The & sign denotes an absolute value whereas the % sign denotes a relative value. The formula shown in the dialog says that only those points in the dataset with CIs greater than 0.2 AND IQs greater than 10% of the maximum value in the data set will be included in the partition. The formula can be entered directly by the user.
Grains Size Tab

Characterizing grains in OIM requires the user to specifically define what constitutes a grain. Each partition in OIM has its own grain definition parameters. Thus, to set these parameters, open the properties dialog for the partition by selecting properties from the partition pop-up menu (accessed by a right hand mouse click on the partition in the project tree). The grain size page is where these parameters are accessed as shown below.

**Grain Tolerance Angle**
If two neighboring points in the scan grid have orientation within this value they are considered part of the same grain.

**Minimum Grain Size**
Once the grain grouping algorithm has completed, if the sum number of measurements constituting a grain are less than this value then the grain is excluded.

**Minimum Confidence Index**
Points less than the Minimum Confidence Index are excluded from the grain grouping algorithm.

**Apply partition before calculation**
The grain grouping algorithm can be run prior to creating the partition or after creating the partition. This subtlety is actually quite important. If the Apply partition before calculation box is checked on, OIM will first set up the partition so that the grain size calculation uses only the points in the partition. If this is not done, then the grain size distributions for the partition and any others without the box checked on will be the same. Note the differences in the two maps on the right in the figure below. In the right-most figure grains are created when connectivity is lost between regions of similar orientation due to the filtering.
Include Grains at Edges of Scan in Statistics
As part of the grain grouping algorithm, grains at the edges of the scan are identified. The user can specify whether these grains are to be used in statistical calculations based on grain size, grain shape, grain based averages or any other characteristic where the grouping of measurement points into grains is required. This can be a bit confusing when combined with a partition based on grain size where this same option is available in building the partition formula.

In the set of grain average IQ maps and unique grain color maps below, the full set of permutations of these options are shown. Note in the two right most maps in the top row, the points in white. These are points not included in constructing the grains. These do not appear in the second row in white because this maps are not colored according to any statistics associated with the grains, just the grains themselves.
Twin Boundaries
The grain grouping algorithm can also be configured to ignore boundaries that are twin boundaries. To specify the twin criteria press the Define... button in the dialog. It should be noted that the average orientation for grains
containing twins is the average orientation of all measurements belonging to the parent portion of the grain.
Neighbors

This tab of the partition properties dialog allows neighbors of points or grains of a specific type to be filtered. A very good example would be necklace grains in abnormal grain growth. These grains could easily be isolated and characterized using this feature of OIM. The tab appears as below.

If a partition is defined using the formula tab, then clicking ON the "Create a neighbor partition" checkbox would change the partition so that instead of the partition containing points satisfying the formula, the points in contained in the partition would be those neighboring the points satisfying the formula. Instead of just those neighboring points by changing the Neighbor Type to Grains, then the grain containing those neighboring points would be included as well.

In the following example the points in red in the left figure were defined (by phase) in the formula tab of the partition. When an IPF map is drawn these points are in color while the points not belonging to the partition are shaded black as shown in the center figure. If the "Create a neighbor partition" checkbox is selected, the neighboring points are those that belong to the partition as shown in the figure at right.
Reconstructed Boundary Tab

On this page, the maximum deviation between the boundaries defined by the scan grid between two neighboring grains and the reconstructed boundary can be defined. This will determine how tight the reconstructed boundaries will follow any curved or segmented boundaries in the microstructure. However, if this value is too small, the reconstructed boundaries will simply follow the scan grid closely.
Maps

Maps allow colors to be assigned to points in an OIM scan based on some parameter associated with the point such as orientation or image quality. Only the points in the current partition are mapped. Points not in the partition are colored according to the setting in the Preferences Dialog. The following properties dialog will appear when constructing a new map.

Name: The Name is simply a name to be used for the map within the project tree.

Map Style Group

Two different styles of maps may be generated - Gray Scale and Color Coded.

Gray Scale - In gray scale maps a specific parameter (selected from the pull down combo box) is assigned a gray level. For example, a gray scale image quality map would be white were the image quality is high and black where the image quality is low. The scale can be modified slightly so that it only covers a range of the parameter values
instead of from the minimum to the maximum. Pressing the Edit>> button allows this range to be defined as shown below (along with other user inputs specific to the type of parameter selected).

If the parameter is not pre-calculated - such as in the case of the Taylor Factor - then pressing the Calculate button will calculate the parameter at each point in the scan and display the minimum, maximum and average values for the specified parameter. More detail on the specifics gray scale map styles available is given in Map Styles.

Pressing the ACB will select minimum and maximum contrast values that will produce gray scale maps with nice contrast and brightness.

**Color Coded**: These maps are similar to Gray Scale maps but use a color gradient that can be configured by the user. More detail on the specifics color-coded map styles available is given in Map Styles. Color coded maps can be overlaid on gray scale maps so the two parameters can be visualized together as shown below.
**Boundaries Group**

In this section of the dialog box, boundaries to be overlaid on the map can be configured.

**Second Partition:** For boundaries to be draw between the current partition and a second partition, select the second partition from this pull-down combo box.

**Type:** Several types of boundaries may be selected. These include Rotation Angle, Rotation Axis, Axis/Angle, Grain, Phase, CSL, Shape Ellipses, Reconstructed, Reconstructed Twins and Plane Traces boundaries.

**Boundary List:** The boundaries displayed in the list are those associated with the current Type selection. The boundaries are drawn in the order they appear in the list, thus boundaries at the bottom of the list will be drawn on top of boundaries at the top of the list. In addition, boundaries are drawn in order of style in inverse order of how they appear in the Type pull down combo box, i.e. Rotation Angle boundaries on top, Reconstructed boundaries on the bottom. To add to the list press the Add or Insert buttons. To modify a boundary, definition double-click on the entry in the list. A dialog will be displayed allowing parameters specific to the boundary type to be changed as well as parameters defining the width and color of the line used to represent the boundary as shown:
Segment values specify the color and line width of the boundary segments:

- Color: [Selected Color]
- Line Width: [Selected Width]
Map Menu

A right hand mouse click on a map will display the following menu. The menu is broken into 7 functional sections:

Properties Section
Overlay Section
Zooming Section
Highlighting Section
Image Section
Export Section
Project Section

Properties Section

Show Highlighting
Show SEM Image Ctrl+I
Show OIM Map Ctrl+M
Show Boundaries Ctrl+B
Show Grain IDs (1st 500)...
Show Flexiview Labels
Show Micron Bar
Set Micron Bar Length...

Fit To Window Ctrl+F
Zoom In
Zoom Out
Zoom Off
Magnification...

Apply Colors As Highlight
Highlighted -> Partition
Non-Highlighted -> Partition

Copy Image
Save Image...
Print... Ctrl+P

Export Template...
Export Data...

Close
Save Ctrl+S
Copy Document
Delete
**Properties**: Shows the map properties dialog box.

**Overlay Section**

**Show Highlighting**: Enable highlighting results to be displayed on the map, both those from interactive highlights on the map itself or from other maps, plots or charts.

**Show SEM Image**: The map is shown overlaid on the SEM image the OIM Scan was originally defined from in OIM DC. The following example shows an IPF/IQ map overlaid on the original SEM image from OIM DC.

**Show OIM Map**: This option is available so that the SEM image can be view without the map overlaid on the image.

**Show Boundaries**: Show the boundaries as defined in the map properties dialog box overlaid on the map.

**Show Grain IDs**: Each grain in the partition has an identification number assigned to it. When this is checked on the ID at the center of each grain is displayed. Only the IDs up to 500 will be displayed. When, this option is turned on, a dialog box will be displayed so that the size of the labels can be modified as needed.

**Show FlexiView Labels**: Show labels for static FlexiView views. These are numbered labels corresponding to the labels used in FlexiView.

**Show Micron Bar**: Shows a micron bar overlaid on the map.
Set Micron Bar Length...: Allows the user to set a specific length for the micron bar. Helpful in comparing maps from different scans.

**Zoom Section**

- **Fit To Window**: When this mode is turned on, the map is drawn to fit the display window.
- **Zoom In**: When this option is selected, the cursor changes to a magnifying glass with a plus, "+", sign in it. A click in the window will result in the map being magnified 125% of the current magnification. The map will reset its location in the window so that the point clicked will be at the center of the window after magnification. If a rectangle is dragged in Zoom In mode, the map will be magnified so that the selected area fills the display window.
- **Zoom Out**: When this option is selected, the cursor changes to a magnifying glass with a minus, "-", sign in it. A click in the window will result in the map being shrunk to 80% of its current magnification. The map will reset its location in the window so that the point clicked will be at the center of the window after the map is shrunk.
- **Zoom Off**: Returns to the normal mode for pointing-and-clicking in the map. That is, to highlighting mode.

**Magnification...**: Allows the user to set the magnification of the map to a specific value in percent. OIM polls the display hardware to determine how to display the map. Helpful in comparing maps from different scans.

**Highlighting Section**

**Apply Colors**: This function will apply the color at each point in the map to any concurrent Discrete Plots. An example is shown below. (The top plot has Show Highlighting turned on, the bottom plot doesn't).

![Highlighted Maps](image)

**Highlighting->Partition**: All of the points highlighted in the map will be exported to the project as a partition under the current dataset. This essentially allows a manually defined partition to be created.
**Non-Highlighting->Partition**: All of the points not highlighted in the map will be exported to the project as a partition under the current dataset. This essentially allows a manually defined partition to be created.

**Image Section**

**Copy Image**: Copies the map to the clipboard as a bitmap. The user is prompted for the resolution before copying the map to the clipboard.

**Save Image**: Enables map to be saved to disk as a bitmap. The user is prompted for the resolution before saving the map.

**Print**: Prints the map.

**Export Section**

**Export Template**: Allows the properties definition used to generate the map to be saved to disk. This definition can be read in later so the same map can be generated for a different partition or dataset.

**Export Data**: Export the quantitative data corresponding to the map colors to a text file. The data exported will be dependent on the map type. However, the header in the file explains the contents. For example, the following is the beginning of the exported file for a combined IQ and <111>, <110> and <111> crystal direction map:

```
# Header: Project1::NiSlipLines::All data::Auto IQ 3/18/2003
#
# column 1: x
# column 2: y
# column 3: Grayscale value - Image Quality
# column 4: Color coded value - Crystal Direction
# (Minimum distance for all specified directions recorded)
# Only values for members of the partition on recorded
#
0.000 0.000 106.9 6.42166
1.000 0.000 43.9 5.01985
2.000 0.000 75.7 6.79945
3.000 0.000 143.7 6.61924
4.000 0.000 167.7 6.61924
```

**Project Section**

**Close**: Close the map display window. It can be reopened from the project tree.

**Save**: Save the map within the project structure.

**Copy**: Copies the properties definition so it can be pasted to another partition or database.

**Delete**: Delete the map from the project.
Map Styles

The following map styles are currently available in OIM

- Image Quality
- Confidence Index
- Fit
- Detector Signal
- Phase
- EDS
- EDS Blended Color
- Kernel Average IQ
- Inverse Pole Figure Map
- Crystal Direction
- Crystal Orientation
- Euler Angle RGB
- Unique Grain Color
- Grain Size
- Grain Shape Orientation
- Grain Shape Aspect Ratio
- Grain Shape Major Axis
- Grain Shape Minor Axis
- Major Axis Inverse Pole Figure
- Grain Average IQ
- Grain Average CI
- Grain Average Fit
- Grain Average Video Signal
- Kernel Average Misorientation
- Grain Orientation Spread
- Grain Average Misorientation
- Grain Reference Orientation Deviation
- Local Average Misorientation
- Local Orientation Spread
- Taylor Factor
- Schmid Factor
- Elastic Stiffness
- Twin Parent/Daughter
- Import

**Image Quality**: Each point in the scan is shaded according to its *image quality*. 
**Confidence Index:** Each point in the scan is shaded according to its confidence index.

**Fit:** Each point in the scan is shaded according to its fit value.

**Detector Signal:** Each point in the scan is shaded according to its detector signal. The detector signal refers to intensities from a detector on the SEM.

**Phase:** Each point is shaded according to the phase to which it belongs.

**EDS:** For a selected element, each point is shaded according to the number of counts within the energy range corresponding to the selected element.

EDS Blended Color: The user selects an element for red, an element for green and an element for blue. Each point is then colored according to the ratio of counts for the red element at the point to the maximum counts for the red element in the partition and similarly for the green and blue elements. For example, a point that is the max for all three elements would be shaded white, a point which was the minimum for all three would be black, a point that is near the maximum for the red element but near the minimum for the other two would be red and so on for other combinations.

**Kernel Average IQ:** Calculate the average IQ within a kernel of user specified size (up to 10th nearest neighbors). A kernel is a set of neighboring points of size that can be defined by the user. The IQ for the pixel at the center of the kernel is equal to the average over all pixels in the kernel.

**Inverse Pole Figure Map:** Each point is colored according to an automatically color coded unit triangle of the inverse pole figure. For example, for an OIM scan of a cubic material, the color red is assigned to the [001] crystal direction, blue to [101] and green to [111]. A particular point is then shaded in the OIM scan according to the alignment of these three directions in the crystal to some user specified sample direction. Thus, if a point in the scan is oriented such that the crystal direction aligned with the specified sample direction is somewhere between an [001] (red) and [101] (blue) direction (i.e. [112]) then the point would be shaded in purple such as the large grain in the example below.
**Crystal Direction**: Each point is shaded according to the alignment a specified crystal direction makes with a specified sample direction.

**Crystal Orientation**: Each point is shaded according to its angular distance from a specified reference orientation.

**Euler Angle RGB**: Each point is shaded according to the three Euler Angles. phi1 is assigned to the red component, PHI to the green and phi2 to the blue. The stronger the color intensity, the higher the value. Several users have asked for this type of map to be included in OIM Analysis. However, it is important to note that this map can be misleading due to the periodicity arising from the crystallographic symmetry and non-linearity of Euler Space. In order to minimize these effects for each point in the map, all symmetric orientations are considered. The orientation selected for the color mapping is that lying within the asymmetric domain. However, it is still quite possible that two orientations that are actually quite similar could be mapped to quite different colors. This problem is particularly prevalent for orientations lying near the boundaries of the asymmetric domain in Euler space. Consider two orientations having cubic crystal symmetry of (0,80,79.8) and (0,80,79.9). These orientations differ by only 0.1 degrees from each other. However, (0,80,79.8) is inside the asymmetric domain and (0,80,79.9) is not. The symmetrically equivalent orientation lying inside the asymmetric domain for the second orientation is (268.2,80.1,10.2). This results in two similar orientations having quite different colors in the map.
**Unique Grain Color:** This feature permits a map to be drawn where each grain is shaded with a random color. The software checks to make sure neighboring grains are not shaded the same color. This map is useful for distinguishing grains from one another. The colors used in this option do not correspond in any way to lattice orientation. Grains smaller than the minimum grain size are shaded white and “bad” points (points for which the corresponding EBSP could not be indexed) are shaded according to the color set in the Preferences Dialog.

**Grain Size:** Each point in the scan is shaded according to its size. The size may be defined as points per grain, area in square microns or diameter in microns according to the setting in the Preferences dialog.

**Grain Shape Orientation:** Each point is shaded according to the shape orientation of the grain to which it belongs. The orientation in this instance is the orientation of the major axis of an ellipse fit to the grain makes with the horizontal.

**Grain Shape Aspect Ratio:** Each point is shaded according to the aspect ratio of the grain to which it belongs. The aspect ratio is given by the length of the minor axis divided by the length of the major axis of an ellipse fit to grain.

**Grain Shape Major:** Each point in a grain is shaded according to the length of the major axis of an ellipse fit to the grain.

**Grain Shape Minor:** Each point in a grain is shaded according to the length of the minor axis of an ellipse fit to the grain.

**Major Axis Inverse Pole Figure:** A map is color coded in the same style as the inverse pole figure map, except instead of a single sample direction for the map, the sample direction is different for each grain; namely, parallel to the major axis of an ellipse fit to the grain. See the example below, the left most map is a vertical axis inverse pole figure map (RD), the middle map is a horizontal axis inverse pole figure map (TD) and the right most map is a Major Axis Inverse Pole Figure Map.
Grain Average IQ: Each point is shaded according to the average image quality for the grain to which it belongs.

Grain Average CI: Each point is shaded according to the average confidence index for the grain to which it belongs.

Grain Average Fit: Each point is shaded according to the average fit for the grain to which it belongs.

Grain Average Video Signal: Each point is shaded according to the average detector signal for the grain to which it belongs.

Kernel Average Misorientation: Shows the distribution of local misorientation based on a kernel average misorientation of the grain to which the point belongs.

Grain Orientation Spread: Each point is shaded according to the orientation spread of the grain to which the point belongs.

Grain Average Misorientation: Each point is shaded according to the average neighbor-to-neighbor misorientations within the grains in the active partition.

Grain Reference Orientation Deviation: Each point is shaded according to its angular deviation to a reference orientation for the grain to which it belongs. The reference orientation can be either the average orientation for the grain or the point within the grain with the lowest kernel average misorientation.

Local Average Misorientation: The point at the center of a kernel is shaded according to the average misorientation all points in the kernel make with their neighbors.

Local Orientation Spread: The point at the center of a kernel is shaded according to the average misorientation all points in the kernel make with all other points in the kernel.

(See Local Misorientation Measures for more detail.)

Taylor Factor: Each point is shaded according to the Taylor factor for the point. The Taylor factor gives an indication of the resistance to deformation of a particular point for a given stress state.

Schmid Factor: Each point is shaded according to the Schmid factor for the point. The Taylor factor gives an indication of the resistance to deformation of a particular point for a given stress state.

Elastic Stiffness: Each point is shaded according to its elastic stiffness.

Twin Parent/Daughter: In twinned grains, the parent material is colored blue and the daughter material is
shaded red. Points that belong to grains without twins are shaded in white.

**Import:** The user can create a file containing the x-y coordinates for each point in the scan and an associated floating point value. The user can then use the usual tools for defining the color or gray scale associated with a given value or range of values. When this option is used for the gray scale map, the gray scale map can be combined with any of the color maps in the usual way. The same is true when using the *Import* option for the color maps. If the import file contains the x-y coordinates and two values (the format used when exporting map data) then the second value will be used.
Map Mouse Behavior

Several functions can be performed using the mouse in maps. The following summarizes the mouse behavior:

**Move**: Information is displayed in the status bar and the contents change in the Lattice and FlexiView panes of the window dynamically with the mouse movement.

**Left Button Click**: Performs the current highlighting mode operation.

**Shift-Left Button Click**: The point will be numbered and the static displays in FlexiView pane of the window will change.

**Ctrl-Left Button Click**: Zoom in.

**Right Button Click**: Displays the map menu.

**Shift-Right Button Click**: Finds the closest reconstructed boundary, and displays boundary information such as endpoints, misorientation, and trace analysis.

**Ctrl-Right Button Click**: Zoom out.

**Middle Button Click**: For a set of serial sections, OIM exports data to a text file for each section for the grain clicked for 3D grain reconstruction.

**Shift-Middle Button Click**: May display information unique to the map style. For example, in Elastic Stiffness maps a dialog box displaying the stiffness tensor values is displayed.
Chart Introduction

The following properties dialog will appear when constructing a new chart.

**Name**: Allows the name of the chart to be changed. This is the name that appears in the project tree.

**Type**: This pull down combo box allows the user to specify the type of chart to be created.

**Edit>>**: This button displays a properties dialog specific to the type of chart selected. The last page of this dialog is the parameters page and is generally generic to all charts. In addition, many of the chart types also display a range page.

**Base Partition**: Shows the partition to be used in creating the chart.

**Second Partition**: For charts related to grain boundaries, a second partition may be selected. The boundaries used in the calculations for creating the chart will then be limited to those boundaries between neighboring data point where one point is in the base partition and one point is in the second partition. Thus, only interpartition boundaries would be used in these calculations.
Chart Menu

A right hand mouse click on a chart will display the following menu:

Properties... Displays the Chart properties dialog.

Copy Image: Allows the chart to be copied to the clipboard as a bitmap, meta file or enhanced meta file.

Export Template...: Allows the properties definition used to generate the chart to be saved to disk. This definition can be read in later so the same chart can be generated for a different partition or dataset.

Close: Closes the chart window.

Save: Saves the chart into the project.

Print: Print the chart.

Copy: Copies the chart definition so that it can be pasted into another partition and the chart constructed using the partition data.

Delete: Closes the chart window and deletes the chart from the project.

Graphics: OIM using a third party library for building the charts. This library enables the user considerable freedom for modifying the appearance of the chart. Selecting graphics shows the following dialog allowing the user to make modifications to the presentation of the chart data. Any changes made are not recorded by OIM. However, this dialog allows the user to save the changes to a file (Control->General->Save... and Load...). In this way a color scheme or other properties can be applied to multiple charts. To learn more about these capabilities use the help on this dialog.
One of the pages generally available for modification after pressing the Edit>> button on the chart properties dialog is the parameters page. Some of the options will be disabled depending on the type of plot constructed.

**Number of Bins:** Sets the number of bins to use in making the chart. For example, a misorientation angle chart is shown below where range of misorientation is set to 5 to 65 degrees with the number of bins is set to 6, 12 and 24 degrees. In this case, these would correspond to bins of 10, 5 and 2.5 degrees.
**X-axis:** A linear or log scale may be used for the x-axis on some plots. Primarily this is of interest to grain size distributions. An example is shown below.
**Vertical Axis:** The vertical axis may be changed to show the number, number fraction, area or area fraction where applicable. Examples are shown below for the distribution of grain averaged image quality. Note that while the vertical scale may change between number and number fraction and area and area fraction the actual distributions are nearly the same. The area and area fraction modes are only available when plotting charts based on grains such as the average IQ per grain or the grain diameter distribution.
The choice of mode for the Vertical Axis also affects the averaging method used. When the Vertical Axis is in Number or Number fraction mode the numerical average is shown whereas when the Area or Area Fraction mode is selected the area weighted average is shown.
Chart Range

One of the pages generally available for modification after pressing the Edit>> button on the chart properties dialog is the range page. Some of the options will be disabled depending on the type of plot constructed.

This dialog allows the user to modify the limits on the data. The page shown above is for an image quality distribution. It allows the user to specify the range on the image quality. If percentage is selected and the range is set to 0 to 100% then all of the data values will be used (ranging from 11.5 to 67 in this case). If the percentage is set to 0 to 50% then only data ranging from the minimum value to 50% of the maximum will be used (11.5 to 33.5 in this case). Alternatively the absolute values for the range can be set as well. For information, the absolute values for the minimum, maximum and average are displayed. In some cases, these will need to be calculated. For some types of plots these calculations require a bit of time and thus the calculation must be specified explicitly.
The following chart types are currently available in OIM:

- Image Quality
- Confidence Index
- Fit
- Video Signal
- Kernel Average IQ
- Grain Size (points)
- Grain Size (diameter)
- Grain Size (area)
- Grain Size (ASTM)
- Grain Size (Intercept)
- Grain Shape Orientation
- Grain Shape Aspect Ratio
- Grain Shape Major Axis
- Grain Shape Minor Axis
- Grain Average IQ
- Grain Average CI
- Grain Average Fit
- Grain Average Video Signal
- Grain Orientation Spread
- Grain Average Misorientation
- Kernel Average Misorientation
- Local Average Misorientation
- Local Orientation Spread
- Crystal Orientation
- Crystal Direction
- Pole Plot
- Pseudo Rocking Curve
- Kearns Parameter
- Kearns Parameter
- Taylor Factor
- Schmid Factor
- Elastic Stiffness
- Misorientation Angle
- Misorientation Profile
- CSL Boundaries
- CSL Deviation
- GBCD - Grain Boundary Character Distribution
- Boundary Density
- Boundary Normal Angle
- Twin Trace Deviation
- Average Twin Trace Deviation
- Texture Fiber
- Texture Index
- Texture Gradient
- EDS
- Phase

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Quality</td>
<td>Shows the distribution of image quality of all data points in the current active partition.</td>
</tr>
<tr>
<td>Confidence Index</td>
<td>Shows the distribution of confidence index of all data points in the current active partition. However, points that could not be index (having CIs equal to -1) are not included in the distribution.</td>
</tr>
<tr>
<td>Fit</td>
<td>Shows the distribution of the fit parameter of all data points in the current active partition.</td>
</tr>
<tr>
<td>Video Signal</td>
<td>Shows the distribution of video signal of all data points in the current active partition. The video signal refers to intensities from a detector on the SEM.</td>
</tr>
<tr>
<td>Kernel Average IQ</td>
<td>Calculates the distributions of kernel average IQs.</td>
</tr>
<tr>
<td>Grain Size (points)</td>
<td>Shows the distribution of grain size in points of all grains in the current active partition.</td>
</tr>
<tr>
<td>Grain Size (diameter)</td>
<td>Shows the distribution of grain size in diameter of all grains in the current active partition.</td>
</tr>
<tr>
<td>Grain Size (area)</td>
<td>Shows the distribution of grain size in area of all grains in the current active partition.</td>
</tr>
<tr>
<td>Grain Size (ASTM)</td>
<td>Shows the distribution of grain size in ASTM number of all grains in the current active partition.</td>
</tr>
<tr>
<td>Grains Size (Intercept)</td>
<td>This chart shows the distribution of grain size calculated using the linear intercept method. Horizontal or vertical intercept lines can be used. The number of horizontal lines defaults to the number of rows in the scan divided by 3, however, the number of lines used may be set by the user. Similarly, the number of vertical lines defaults to the number of columns divided by 3. The x-axis is in Intercepts per line length. The bins of the histogram are incremented by calculating the number of intercepts in each scan line.</td>
</tr>
<tr>
<td>Grains Size (Intercept Lengths)</td>
<td>This chart shows the distribution of grain size calculated using the linear intercept method. Horizontal or vertical intercept lines can be used. The number of horizontal lines defaults to the number of rows in the scan divided by 3, however, the number of lines used may be set by the user. Similarly, the number of vertical lines defaults to the number of columns divided by 3. The x-axis is in Intercepts Lengths. The bins of the histogram are incremented from each intercept length in each scan line.</td>
</tr>
</tbody>
</table>
Grain Shape Orientation: Shows the distribution of grain shape orientation of all grains in the current active partition.

Grain Shape Aspect Ratio: Shows the distribution of grain shape aspect ratio of all grains in the current active partition.

Grain Shape Major Axis: Shows the distribution of the length of the major axis of ellipses fit to each of the grains in the current active partition.

Grain Shape Minor Axis: Shows the distribution of the length of the minor axis of ellipses fit to each of the grains in the current active partition.

Grain Average IQ: Shows the distribution of the grain average image quality for each grain in the active partition.

Grain Average CI: Shows the distribution of the grain average confidence index for each grain in the active partition.

Grain Average Fit: Shows the distribution of the grain average fit for each grain in the active partition.

Grain Average Video Signal: Shows the distribution of the grain average video signal for each grain in the active partition.

Grain Orientation Spread: Shows the distribution of orientation spread within the grains in the active partition.

Grain Average Misorientation: Shows the distribution of average neighbor-to-neighbor misorientation s within the grains in the active partition.

Kernel Average Misorientation: Shows the distribution of local misorientation based on a kernel average misorientation between neighbors on the scan grid.

Local Average Misorientation: Shows the distribution of local average misorientation based on the misorientation between neighboring points within a user specified kernel.
**Local Orientation Spread**: Shows the distribution of local orientation spread based on the misorientation between the points within a user specified kernel.

**Crystal Orientation**: Shows the fraction of points in the partition within a given angular distance from a particular crystal orientation. Optionally, the chart can show the fraction of points in the partition within a given range of angular distance from a specified crystal orientation. This is essentially the derivative of the first option. However, not precisely because of crystal symmetry effects. This mode is displayed when the *Cumulative* check box is toggled off.

**Crystal Direction**: Shows the fraction of points in the partition within a given angular distance from a particular crystal direction. Optionally, the chart can show the fraction of points in the partition within a given range of angular distance from a specified crystal direction. This is essentially the derivative of the first option. However, not precisely because of crystal symmetry effects. This mode is displayed when the *Cumulative* check box is toggled off. An example is shown below.

For cumulative it really shows what fraction of the measurement points have <uvw> directions within a given tolerance of a specific sample direction. For the non-cumulative it shows the fraction of measurement points having <uvw> directions within a given range of a specific sample direction. Now consider the crystal symmetry. For example, consider the <100> crystal direction in a cubic crystal. If there is one <100> axis 45 degrees away, then a second <100> type axis would located 45 degrees away as well. If the chart is in 1 degree boxes, then in both the cumulative and non-cumulative charts, the corresponding bin (say the 45 to 46 degree bin) would be incremented just once. Now imagine you tilt the crystal just a 1.5 degrees. Now one <100> axis lies in the 43-44 bin (at 43.5 degrees) and the other <100> axis lies in the 46-47 bin (at 46.5 degrees). So now both bins are incremented by one. in the non-cumulative case. However, in the cumulative case, the 43-44 bin gets 1 count and the 46-47 bin gets 1 count as well (not two as would be expected if we were to simply add the bins).
Pole Plot: A pole plot is essentially the integration of a pole figure about the azimuthal as shown in the example below.
This type of texture analysis is really only appropriate in materials exhibiting a single fiber texture. When selecting this type the following property page will appear after pressing the Edit>> button:

The crystal direction must be specified. The maximum angle specifies how far out the calculation should be carried. If the corresponding pole figure has a strong central peak similar to that shown above then it may be helpful to set the maximum angle to a smaller value to see the detail of the central peak. The distribution is calculated as follows. The line shown in the pole figure is broken up into 0.25 degree bins. For each data point in the data set the angular distance the specified crystal direction the point makes with the specified sample direction is calculated and the appropriate bin incremented. Several bins will be incremented due to crystal symmetry (i.e. in a cubic crystal the 001, 100 and 010 crystal directions are symmetrically equivalent). This curved formed by the bins is normalized by $2 \sin(q)$, where $q$ is the angle along the x-axis. The smoothing is done on a bin-by-bin basis. For each bin, the first derivative of the curve running through the neighboring bins (+ or - the smoothing amount) is to a straight line. This is then used to modify the value for the bin. The data may be rotated to maximize the height of the central peak. This function is only valid wher
fiber is near the sample direction specified. Several summary values for the pole plot are displayed in the legend window. These are calculated assuming a strong central peak.

**FWHM**: The first point (beyond the point of maximum value) where the value of the curve is one-half the maximum value of the curve.

**Peak Width**: The peak width is simply FWHM multiplied by 2.

**Random Fraction**: The area outside the peak divided by the total area under the curve excluding the area that arises because of symmetry.

**Peak Fraction**: The fraction of measurements where the specified pole \((hkl)\) is aligned within the **Peak Width** of the specified sample direction \((xyz)\).

**Omega 50**: Angular distance where the peak fraction just exceeds 50 percent.

**Omega 63**: Angular distance where the peak fraction just exceeds 63 percent.

**Omega 90**: Angular distance where the peak fraction just exceeds 90 percent.

**Omega 95**: Angular distance where the peak fraction just exceeds 95 percent.

The random and peak fractions and the omega values are actually calculated directly from the measurements instead of from the curve itself. This leads to more accurate results, for example the effects of smoothing are removed from the calculations. For example, the random fraction is calculated as the number of measurements that do not have the specified crystal direction aligned with the specified sample direction divided by the total number of measurements.

**Pseudo Rocking Curve**: Shows a pseudo rocking curve. This simulates an x-ray rocking curve using the discrete OIM data and is similar to the pole plot. When this chart is selected, pressing the Edit>> button in the Chart Properties dialog box displays the following:

The **maximum angle** specifies how far out the calculation should be carried. If the corresponding pole figure has a strong central peak similar to that shown above then it may be helpful to set the maximum angle to a smaller value to see the detail of the central peak. To calculate the pseudo rocking curve the scan line across the pole figure is divided up into 181 bins. For each bin, the number of orientations in the active partition with \(hkl\) coincident with a vector at the center of each bin (within the **smoothing** value) is determined. The value of each bin is then divided by the total number of orientations in the active partition. The vector at the center of each bin corresponds to a sample direction and is a function of the **scan angle** and the bin's corresponding polar angle.
**Kearns Parameter**: The Kearns Parameter or Kearns Texture Factor was developed for materials with hexagonal symmetry. It gives the effective contribution of the [0001] basal poles to the overall texture. It is defined as follows:

\[ f = \sum V_i \cos^2 \phi_i \]

where \( V_i \) is the fraction of OIM data points with basal pole poles oriented at a tilt angle, \( \phi_i \), to a specified reference direction. OIM Analysis allows a more general extension of the parameter to any crystal direction in crystals of any symmetry. However, it should be noted that if the symmetry associated with the specified crystal direction produces equivalent directions within 180 degrees of the specified direction, the results are not as intended for the Kearns parameter. However, directions such as [001], [010] and [001] in orthorhombic materials would be appropriate.


**Taylor Factor**: Shows the distribution of the Taylor factor for a given stress state.

**Schmid Factor**: Shows the distribution of the Schmid factor for a given stress state.

**Elastic Stiffness**: Plots the distribution of the Elastic Modulus in a specific direction.

**Misorientation Angle**: Shows the distribution of grain boundary misorientations. In addition, the uncorrelated (see discussion on correlated vs. uncorrelated in the MDF section) and random distributions (i.e. the MacKenzie plot which shows the misorientation distribution for a purely random texture) can be shown. Another option allows the user to force the software to only consider boundaries between recognized grains in the distribution. This will generally affect the low angle boundaries much more than the high angle boundaries as shown in the figure below.
Misorientation Profile: Show the misorientations along a line through the scan area. The misorientations between neighboring points on the line as well as misorientations between points on the line and the starting point can be shown. It will show up to 100 points on a line. The misorientation profile can be accessed in one of two ways. 1) in the usual creation of a chart. In this case, the data points will be selected in the order they were collected during a scan. It is, therefore only applicable to data from a line scan or collected manually. 2) By pressing the vector button on the highlight toolbar and then drawing a line on a map. The profile is then calculated for the points on the line on the map. (After pressing the vector button, several continuous line segments may be drawn by first clicking the left mouse button and then dragging the mouse to the next position and clicking with the right mouse button - to end the line segments use left mouse button again). An example is shown below.

CSL Boundaries: Shows the distribution of CSL boundaries by sigma value.

CSL Deviation: Shows the distribution of the deviation of CSL boundaries from the ideal misorientation. For example, a boundary classified as a Sigma 3 boundary may not have the precise 60 degree rotation about <111> misorientation. Brandon's criterion is used, it could deviate as much as 8.6 degrees from the ideal misorientation. This chart allows the distribution of these deviations to be plotted.

GBCD - Grain Boundary Character Distribution: This function allows the user to plot a GBCD. The GBCD divides grain boundaries into three types: low angle boundaries, special boundaries (i.e., CSL boundaries), and high angle boundaries. The user can define the cutoff value used to distinguish low-angle from high-angle boundaries (the default is 15 degrees). The user can also specify which CSL boundaries (in terms of sigma value) qualify as special boundaries. (For example, Watanabe, T. (2002). "Texturing and Grain Boundary Engineering for Materials Design and Development in the 21st Century." Proceedings. ICOTOM 13, Seoul, Korea, Trans Tech Publications Inc., 39-48.)

Boundary Density: This plot is essentially the integral of the Misorientation Angle chart, except that the units of this chart are given in terms of boundary length per unit area. (See Wheeler, J., D. J. Prior, et al. (2001). "The Petrologic Significance of Misorientations Between Grains." Contributions to Mineralogy and Petrology 141, 109-124.)

Boundary Normal Angle: Shows the distribution of grain boundary normals relative to the horizontal. Since y is down and x is to the right. The angles are measured clockwise with the origin being horizontally to the right relative to a map. Two other points should be noted about these types of boundaries. First, while these boundaries are based on grains, they ignore the minimum size rule. That is, boundaries are drawn surrounding every grain whether they contain the
minimum number of points per grain or not. Thus, it is wise to perform some clean up before using these routines so all grains require the minimum number of points per grain and so that all points in the scan belong to a grain. Otherwise, the distribution will be influenced unduly by the collection grid. As the average number of points per grain becomes small the distribution begins to collapse to that of the collection grid. Second, in the Boundary Normal Chart, the area fraction mode uses the boundary lengths; whereas, in the number fraction mode all boundary segments are considered to have unitary length.

**Twin Trace Deviation**: This chart shows a scatter plot of the deviation between the trace of the boundary plane (what appears as a boundary in a 2d OIM scan) and the closest twinning planes of the two neighboring separated by the boundary (see twin boundaries). The deviations are plotted as a function of the CSL Deviation. (See Wright, S. I. and J. Larsen (2002). “Extracting Twins from Orientation Imaging Microscopy Scan Data.” *Journal of Microscopy* **205**, 245-252.)

**Average Twin Trace Deviation**: This chart shows the distribution of the twin trace deviations.

**Texture Fiber**: Shows a plot of a texture fiber through Euler space. A texture fiber must first be calculated.

**Texture Index**: The texture index is a scalar parameter describing the strength of a given texture. To create a texture index chart the texture must first be calculated. For textures calculated using the harmonic series expansion, the texture index is a function of the rank of the series expansion. In this case the textures calculated using the discrete binning approach, the texture index is a single scalar value. The figure below shows texture index charts for textures calculated using both methods.

![Harmonic Texture](image1)

![Binned Texture](image2)

**Texture Gradient**: The Texture Gradient is a metric describing how homogeneously/heterogeneously the local texture distributed within the scan area. A second metric is also displayed which gives an idea whether the texture consists of alternating bands. The texture variations are assumed to vary horizontally or vertically. Only one phase can be inspected at a time. The actual mathematics behind the calculations are reported in: Wright, S. I. and D. P. Field (2005). "Scale Measures of Texture Heterogeneity" to be published in *Proceedings of ICOTOM 14* to be held in Leuven, Belgium, July 2005. In the following plot \( H \) is the measure describing the heterogeneity and ranges in value from 0 for a perfectly homogeneous distribution of the texture and 1 for a heterogeneous structure. Similarly, \( B \) describes the banding and value of 0 denotes no banding whereas a value of 0.5 would describe an extreme banded case as shown for the idealized microstructures.
EDS : Shows the distribution of a particular element as given by counts within an energy range.

Phase : Shows the distribution of phases within a scan.
Multicharts allow 2-dimensional chart data from different partitions to be plotted together in a single chart. Multicharts appear at the data set level in the project tree. To create a multichart select New>Multichart from the pop-up menu in the project tree at the project level or pressing QuickNew from the QuickGen toolbar. This will bring up the following dialog.

**Name**: A name used to identify the multichart in the project tree and the display window.

**Type**: The chart type.

**Parameters**: This button allows the parameters associated with the chart to be set.
Constituent Charts: This allows the user to select a partition where the data for individual curves in the chart to come from. When adding or editing, it will display the same dialog seen when creating a regular chart. Except that the Type field is disabled and the Base Partition is enabled for selection of the partition.
Discrete Plots

Discrete plots allow individual data points (or boundaries between data points) to be plotted discretely in a variety of representations.

Individual orientations can be plotted in

- **Pole Figures**
- **Inverse Pole Figures**
- **Euler Space**
- **Rodrigues Vector Space**

Boundaries between individual orientation pairs can be plotted as

- **Rodrigues Vectors**
- **Axis/Angle Pairs**

When creating a new plot the following dialog is displayed
The *Sections* group allows multiple pole figures, inverse pole figures or plot sections through a given (mis)orientation space to be plotted together in a single window. To modify the parameters for a given section simply double-click on the section in the list. The order the sections appear in the list is the order they will appear in the display window.

*Second Partition* allows a second partition to be defined when plotting misorientations. This allows boundaries to be limited to boundaries between two different partitions. For example, if a material has a bimodal distribution then the data can be partitioned based on grain size. A discrete misorientation plot can be generated for the boundaries between the large and small grains allowing the user to investigate any possible orientation relationships between the two different grain sizes.

*Axis Format* allows various grid lines or tick marks to be shown on the plots. The angular increment between the tick marks and grid lines can also be entered. The grid format is shown at left on a pole figure and tick marks in the figure at right. For *discrete inverse pole figures*, these formats are not available if only the unit triangle is displayed.
Enforce Orthotropic Sample Symmetry (Rolled Sheet). This option allows the orthotropic sample symmetry to be enforced. This means that for every point in the pole figure 4 other points will be drawn. In pole figures these points will be mirrored about the horizontal and vertical axes of the pole figures. The sample symmetry will not be as apparent in inverse pole figures and ODFs. In fact, it can't be seen in inverse pole figures for the principle sample axes (i.e. the [001], [010] or [100] inverse pole figures). The figures below show pole figures and an ODF with this option turned on and turned off (default).

Once the Plot Type is set, the Edit>> button allows the parameters associated with the representation to be set. However, one of the parameters that is generic to all types is the color and size of the marker used in plotting. This can be accessed from the Point Page as shown below.
In addition, the user can select a single point per grain to be plotted. The point will be scaled according to the size of the grain. This enables much faster plotting of the discrete plot and is helpful for very large datasets. Examples are shown for two different datasets belows. The left pole figures show markers for each point per measurement in the scan, the pole figures at right show individual markers for each grain weighted by size.
A pop-up menu can be accessed by a right-mouse click in the Discrete Plot display window.

Properties...: Brings up the Discrete Plot Properties dialog.

Fit To Window: The plot is stored in memory at a much higher resolution than can generally be displayed. To view the plot at the memory resolution, turn Fit To Window off. The plot will be cropped in the display window. Scroll bars are available to position the plot as desired within the display window.

Show Highlighting: Enable highlighting results to be displayed on the plot, both those from interactive highlights on the plot itself or on other plots, maps or charts.

Show Points: When this is turned off the plot is cleared and only the highlighted points are shown (if Show Highlighting is turned on).

Copy Image: Copies the plot to the clipboard as a bitmap.

Save Image...: Enables plot to be saved to disk as a bitmap.

Export Template...: Allows the properties definition used to generate the plot to be saved to disk. This definition can be read in later so the same plot can be generated for a different partition or dataset.

Close: Close the plot display window.

Save: Save the plot within the project structure.

Print...: Prints the plot.

Copy: Copies the properties definition so it can be pasted to another partition or database.

Delete: Delete the plot from the project.
Discrete Pole Figure

A Discrete Pole Figure will plot the 3 dimensional orientation of a given pole (with respect to the sample reference frame) as a 2 dimensional projection. The parameters associated with pole figures are shown in the following dialog.

**Symmetry:**

*Improper Rotations*: When plotting a pole figure consider poles directed away from the plotting plane - i.e. in a [001] inverse pole figure consider the [00-1] direction as well. However, it is much more important for inverse pole figures than pole figures.

*Show points in positive hemisphere only, Show points in both hemispheres, Show points in negative hemisphere only*: Some of the projections in 3d space will be below the projection plane. It is possible to either show these points or exclude them from the pole figure. When points are being shown in both hemispheres, the points in the negative hemisphere will be drawn with open symbols.

An example of these effects is shown below for a crystal of cubic symmetry. The pole figure is a 100 pole figure. The points in the negative hemisphere are shown as open circles.
**Projection**: Select the method for projecting from 3 dimensional space to 2.

**Maximum Polar Angle**: This allows the center of a pole figure to be magnified.

**User-Defined Axis**: This allows the user to define the position of a axis in the pole figure with a label. In the example below *Axis angle from horizontal* is set to 120 degrees.

**SECTION**: The following dialog is displayed when adding a pole figure to the section list on the main *Discrete Plot Properties* dialog.
The user must define the phase in multiphase samples and the hkl for the pole figure. The hkl define the crystal plane to be considered in create the plot.
Discrete Inverse Pole Figure

A Discrete Inverse Pole Figure will plot the 3 dimensional orientation of a given sample direction (with respect to the crystal reference frame) as a 2 dimensional projection. The parameters associated with inverse pole figures are shown in the following dialog.

Symmetry:

Unit Triangle: Inverse pole figures can be plotted in unit triangles for all symmetries. This is a portion of the full inverse pole figure in which all points are unique (i.e. symmetric points would be plotted outside of the unit triangle).

Improper Rotations: When plotting an inverse pole figure consider poles directed away from the plotting plane - i.e. in a [001] inverse pole figure consider the [00-1] direction as well.

Show points in positive hemisphere only, Show points in both hemispheres, Show points in negative hemisphere only: Some of the projections in 3d space will be below the projection plane. It is possible to either show these points or exclude them from the inverse pole figure. When points are being shown in both hemispheres, the points in the negative hemisphere will be drawn with open symbols.

An example of these effects is shown below for a crystal of cubic symmetry. The points in the negative hemisphere are shown as open circles. The row of inverse pole figures at the top are shown with the Unit Triangle option turned off, the row below with it turned on. The inverse pole figures in the left column are shown with Improper Rotations turned off and the column at right with it turned on.
**Projection:** Select the method for projecting from 3 dimensional space to 2.

**SECTION:** The following dialog is displayed when adding an inverse pole figure to the section list on the main Discrete Plot Properties dialog.

The user must define the phase in multiphase samples and the coordinates for the sample direction.
Discrete Euler Space Plot

A Discrete Euler Angle plot will plot sections through Euler Space. An orientation can be described in terms of three rotation angles which bring the sample coordinate system into coincidence with the crystal coordinate frame. One method of defining these three rotations is to use Euler angles. However, more than one definition of these angles exist. The space containing all possible orientations defined as Euler angles is Euler space.

The parameters associated with Euler space plots are shown in the following dialog.

![Euler Angle Plot](image)

**Type**: Euler angles can be defined in several ways, OIM has Euler angles after the manner of Bunge, Roe and Kocks (see Crystal Orientation for more information).

**Section Configuration**: Tells OIM how to section up Euler Space. The three angles 1, 2 and 3 refer to \((\phi_1, \phi_2)\) for Bunge’s Euler angles and \((\psi, \chi)\) for Roe and \((\phi, \theta)\) for Kocks. The matrix of radio buttons is to define along which angle the constant angle sections should be made. Which of the other two axes should appear vertical in the plot and which should define the horizontal.

**Ranges**: These define the range of Euler space to consider when plotting for the angles defining the vertical and horizontal axes. The range on the constant angle is set in the Section part of the Discrete Plot Properties dialog as shown below.

**SECTION**: The following dialog is displayed when adding a new section to the section list on the main Discrete Plot Properties dialog.
The range is 0° to 65°.

Minimum | Maximum
---|---
17.5 | 22.5
Discrete Rodrigues Orientation Plot

A Discrete Rodrigues Orientation plot will plot sections through Rodrigues Vector Space. An orientation can be described in terms of an axis of rotation and the amount of rotation about the axis. The Rodrigues vectors are obtained by defining the rotation axis in Cartesian coordinates and then normalizing it so the magnitude of the vector is equal to one. The resulting vector components are then multiplied by \( \tan(\theta/2) \) where \( \theta \) is the degree of rotation. The magnitude of the vector is then limited by symmetry - however, for cyclical crystal symmetries the maximum rotation angle is equal to 180 degrees and the magnitude extends to infinity. However, because of symmetry only the \( R_1 \) and \( R_2 \) vector components are indefinite, and \( R_3 \) remains bounded. In these cases, the magnitudes of the \( R_1 \) and \( R_2 \) are artificially limited to 1 for the plot and then the reciprocal space is plotted \( (1/R_1, 1/R_2, R_3) \) as well. For triclinic symmetry all of the components are infinite and thus the user is not allowed to generate Rodrigues plots for triclinic symmetry.

The parameters associated with Rodrigues space plots are shown in the following dialog.

![Rodrigues Plot Dialog](image)

**Phase:** Because the size and shape of Rodrigues space is dependent on crystal symmetry only one phase can be plotted at a time. This allows the phase to be selected for multiphase partitions.

**Ranges:** These define the allowable ranges of the components of the Rodrigues Vector to consider when plotting.
A Discrete Rodrigues Misorientation plot will plot sections through Rodrigues Vector Space. A (mis)orientation can be described in terms of an axis of rotation which the two crystal lattices have in common and the amount of rotation about the axis to bring the two lattices into coincidence. The Rodrigues vectors are obtained by defining the rotation axis in Cartesian coordinates and then normalizing it so the magnitude of the vector is equal to one. The resulting vector components are then multiplied by tan(\( \theta \)/2) where \( \theta \) is the degree of rotation. The magnitude of the vector is then limited by symmetry - however, for cyclical crystal symmetries the maximum rotation angle is equal to 180 degrees and the magnitude extends to infinity. However, because of symmetry only the R1 and R2 vector components are infinite, and R3 remains bounded. In these cases, the magnitudes of the R1 and R2 are artificially limited to 1 for the plot and then the reciprocal space is plotted (1/R1, 1/R2, R3) as well. For triclinic symmetry all of the components are infinite and thus the user is not allowed to generate Rodrigues plots for triclinic symmetry.

The parameters associated with Rodrigues space plots are shown in the following dialog.

Phase: Because the size and shape of Rodrigues space is dependent on crystal symmetry only one phase can be plotted at a time. This allows the phase to be selected for multiphase partitions.

Ranges: These define the allowable ranges of the components of the Rodrigues Vector to consider when plotting.
Discrete Axis/Angle Misorientation Plot

A Discrete Axis/Angle Misorientation plot will plot sections through Axis/Angle Space. A (mis) orientation can be described in terms of an axis of rotation which the two crystal lattices have in common and the amount of rotation about the axis to bring the two lattices into coincidence. The axis of rotation can be plotted in the same manner as an inverse pole figure. While the axis is generally described in crystal coordinates (i.e., uvw), in reality only two angles are needed to describe the axis, a polar and azimuthal angle. Thus Axis/Angle space is defined by three angles, the polar and azimuthal angles defining the rotation axis and the angle describing the amount of rotation. If no symmetry is considered then the polar angle ranges from 0 to 90 degrees, the azimuthal angle from 0 to 360 degrees and the rotation angle from 0 to 180 degrees.

The parameters associated with Axis/Angle plots are shown in the following dialog.

Symmetry: If the misorientations are within a single phase then instead of showing the full circle to represent the axis of rotation containing all symmetric axes as well, the unit triangle can be used where only a single unique axis will be plotted. When plotting misorientations between points of different crystal symmetry the unit triangle may not be used. In addition, for a single boundary misorientation all symmetric equivalents of the misorientation may be shown or only the one with the minimum rotation angle. Thus, only one point per misorientation will be displayed. The figure at left below is with this option turned off, the figure at right has the option on.
**Ranges**: Sets the type of projection (stereographic, equal area or equal angle) to use for the plot.
Texture Introduction

Texture analysis is a statistical methodology for analyzing the distribution of crystallographic orientation in polycrystalline materials. The figure below shows a set of orientations plotted in constant sections through orientation space (Euler angle in this example). Clustering can be observed in the discrete plot. However, several problems arise in attempting to use such discrete plots to quantitatively analyze the orientation data.

The first problem is that when many points are plotted they begin to overlap making it difficult to ascertain the degree of clustering. A second problem is that using any of the current popular descriptions of orientations (e.g. Euler angles or Rodrigues vectors) the associated space is inherently non-linear. Thus, while there may appear to be significant clustering at a particular point in orientation space, the clustering may be less significant than it appears due to the volume in the orientation space associated with the particular point. The Orientation Distribution Function (ODF) provides a quantitative means for overcoming these problems. The ODF is a means of statistically describing the texture or preferred orientation and is the keystone of texture analysis. The following figure shows a plot of the ODF corresponding to the discrete plot above of the individual orientations from which the ODF was calculated. The ODF is shown as a color intensity plot. The regions of high intensity (near the red end of the color scale) are associated with clustering of points in the discrete plot shown above.
The ODF is essentially an attempt to fit the distribution of the discrete three dimensional orientation data. To outline some of the issues involved in this multivariate data fitting consider a simple example of a set of one dimensional data as shown in the number line below.

If the range is split up into twelve equal sized bins and the number or orientations in each bin counted, then the following histogram would result. The histogram gives some indication of the distribution.

A smooth curve could be also used to represent the distribution as shown in the following figure.
However, this is only one possible distribution. The following figure shows two other possible distributions. The green curve would be analogous to the histogram where less bins are used to discretize the range of the variable and the orange curve would be analogous to using more bins.

In the language of statistics, the orientation distribution function \( f(g) \) or ODF is a probability density function describing the probability of finding a grain with an orientation \( g \) within a given distance in orientation space \( D_g \) of a specified orientation \( g_0 \) in a polycrystal or alternatively the volume fraction of material oriented within \( g \) of \( g_0 \).

The expression for \( f(g) \) must satisfy the following condition:

\[
\int f(g) \, dg = 1
\]

Texture analysis was historically developed for orientation distribution data obtained from X-Ray or neutron diffraction pole figures - thus much of the literature focuses on determining the ODF from pole figures. However, it should be noted that one advantage of texture calculated by OIM data is that volume fractions of a given texture component can be determined quite accurately in a well-defined manner. For example, the volume fraction of material oriented within 15 degrees of the orientation \( (0,0,0) \) can be directly calculated by finding the number of orientation measurements in the OIM data set which satisfy this condition and dividing this number by the total number of measurements in the set. Data obtained from conventional x-ray or neutron diffraction pole figures cannot be directly interrogated. Pole figure methods require ODFs to be calculated from the pole figures and the
volume fraction calculated from the ODFs by integration over an appropriate volume of the ODF and are thus dependent on the calculation method as well as the parameters used in the calculation.

One restriction on the ODF arises due to crystallographic symmetry. For a given orientation \( g \), all symmetrically equivalent orientations, \( g^e \) must have the same value in the ODF. Mathematically this is given as:

\[
f(g) = f(g^e) = f(L_1 g)
\]

where \( L_1 \) represents an element of the crystal symmetry group. If the processing of the material is symmetric, then the texture may also exhibit this symmetry. OIM allows this processing, sample or statistical symmetry to be enforced such that:

where \( R_j \) represents an element of the sample symmetry group.

Besides the ODF, OIM allows other representation of the texture to be calculated including pole figures, inverse pole figures, texture fibers and the texture indices. The texture index is a scalar description of the strength of the texture. In OIM, the texture index and texture fibers are plotted as *Charts* whereas ODFs, pole figures and inverse pole figures are displayed as *Texture Plots*.

OIM allows textures to be calculated using two different approaches: a *discrete binning* approach and a series expansion of generalized spherical harmonics. These are set in the Calculation Method pull-down list in the Texture Properties dialog. In addition some other “Texture Calculation Methods” available, these are intended for importing textures and for *Scalar Parameter Textures*.

In OIM, the term texture refers to a collection of these various representations along with the mathematical framework needed to calculate the representations.

The properties dialog for a texture is shown below:
The Name is simply a name you may enter to describe the texture. The phase for the texture calculations must be selected for multiphase partitions. The calculation method must also be selected. Various parameters associated with selected method can be set using the Edit>> button. An explanation of these parameters is given in the sections for each of the two methods. The next region of the dialog box is where various presentations of the texture can be selected. The parameters associated with each of the different representations are described below. Double clicking on a particular presentation in the list box allows the parameters to be modified.
References

For more information on texture analysis a good overall reference is


For a description of the representation of orientation description used by OIM and the mathematics behind the harmonic expansion of the ODF see:


For a general overview of textures in metals see:


For a general overview of textures in hexagonal materials see the first few chapters of:


A good place to become familiar with the general body of literature in texture analysis is in the proceedings of the *International Conference on Texture of Materials (ICOTOM)* held every three years.
Pole Figures

When the Add PF button is pressed the following dialog box is shown where the pole can be set by the user as well as the resolution for the calculation.

The effect of the Inversion Symmetry option is more apparent in some symmetries than others. The followings shows pole figures for a single orientation of a crystal with trigonal symmetry - the center pole figure has the Inversion Symmetry turned on - note the indices in the pole figures on the left and right with inversion symmetry turned off. The inversion symmetry considers poles directed away from the plotting plane - i.e. (hkl) and (-h-k-l) planes.
Inverse Pole Figures

When the Add IPF button is pressed the following dialog box appears.

The sample direction and resolution of the inverse pole figure may be set by the user. Checking on inversion symmetry forces the software to calculate the average of the [x,y,z] and [-x,-y,-z] inverse pole figures.
ODFs

When the Add ODF button is pressed the following dialog box is displayed.

This dialog allows the user to select an orientation representation and the volume of the particular orientation space to be sampled.

For Euler space, OIM makes no presumption of the volume of the orientation space to be sampled in the ODF calculation. Complete Euler space ranges from 0 to 360 degrees in the first and third angles and 0 to 180 degrees in the second angle. However, the axisymmetric region of Euler Space is much smaller when crystal symmetry and sample symmetry are taken into account. (see crystal orientation in the Technical Reference section of the help)

For Rodrigues vectors a suggested sampling is presented based on the current crystallographic symmetry used in the texture calculation. However, it should be noted that for the cyclical symmetries $R_1$ and $R_2$ are not bounded and for triclinic symmetry $R_3$ is not bounded as well.
The texture fiber is a one dimensional description of a texture. It is essentially the value of the ODF along a given “fiber” in Euler space. The idea of texture fibers first arose in the analysis of texture from rolled face centered cubic materials. In these materials, local maxima tend to align themselves along a characteristic fiber. Thus, the description of the texture can be reduced from three-dimensional ODF to a one-dimensional trace along the fiber. However, this characteristic fiber tends to shift slightly from sample to sample. Thus, instead of using exact locations in Euler space to define the fiber, local maxima along the fiber are used. In OIM the search for local maxima is performed for constant $j_2$ and is limited to 10 degrees in $j_1$ and $F$. However, this maxima searching is only done for the so-called fiber in fcc materials. See chapter 5 in the book by Kocks, Tomehi and Wenk for a more extensive discussion of the various texture fibers.

The following figure shows the beta-fiber for rolled fcc materials for aluminum rolled to varying reductions. Note the movement of the $j_1$ and $F$ values (as a function $j_2$) due to the movement of local maxima from reduction to reduction. The labels G, B, S and C refer to specific texture components (Goss, Brass, S and Copper - see the Component Analysis section of the Texture Analysis Technical Reference topic.

The following dialog appears when the Add Fiber button is pressed. It allows the user to select the fiber of interest.
The texture fibers are given in Euler angles (after the method of Bunge) below.

**alpha (fcc rolling)**

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**beta (fcc rolling)**

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**epsilon (bcc rolling)**

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Texture Data can be exported as two different types of text files. One for **general export** of all of the information pertaining to a texture and one formatted for entry into **Slicer Dicer**.

### General Texture Export

This format exports to an ASCII text file in the following formats. The lines preceded by the "#" are comment lines.

**Pole Figure:** the polar angle, azimuthal angle in degrees followed by the intensity.

```plaintext
# Pole Figure
# Resolution [degrees]: 5.000000
# Inversion: 0.000000
# (hkl): 0 0 1
# Polar Angle, Azimuthal Angle, Pole Figure value
0.0 0.0 0.134035
0.0 5.0 0.134035
0.0 10.0 0.134035
0.0 15.0 0.134035
0.0 20.0 0.134035
```

**Inverse Pole Figure:** the polar angle, azimuthal angle in degrees followed by the intensity.

```plaintext
# Inverse Pole Figure
# Resolution [degrees]: 5.000000
# RD, TD, ND: 0 0 1
# Inversion Symmetry Off
# Polar Angle, Azimuthal Angle, Inverse Pole Figure value
0.0 0.0 0.134035
0.0 5.0 0.134035
0.0 10.0 0.134035
0.0 15.0 0.134035
0.0 20.0 0.134035
```

**ODF:** phi1, PHI, phi2, ODF Intensity. The Euler angles are given in degrees.

```plaintext
# ODF
# Resolutions [degrees]: 5.0 5.0 5.0
# Bunge Euler Angles: phi1, PHI, phi2, ODF value
0.0 0.0 0.0 0.217005
0.0 0.0 5.0 0.310389
0.0 0.0 10.0 0.626076
0.0 0.0 15.0 1.32838
```

**Fiber Plot:** This is given as x, intensity where x corresponds to the particular angle used for horizontal axis of the fiber plot and is given in the degrees.

```plaintext
# Texture Fiber
# Beta - fcc rolling
# phi1, ODF Intensity, PHI, phi2
45.0 4.419779 83.0 45.3
50.0 9.094456 75.5 45.7
55.0 11.821443 65.1 46.1
60.0 8.698604 60.6 46.4
```
"Texture": For Textures calculated using the **discrete binning** method, the "Texture" is exported as an ODF as above. For the **Harmonic** method, the "Texture" is output as C-Coefficients. The first 3 columns are the indices l, mu, nu and the 4th and 5th columns are the real and imaginary values.

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**Slicer Dicer Format**

Slicer Dicer ([www.slicerdicer.com](http://www.slicerdicer.com)) is a software package for viewing volumetric data. Slicer dicer can be used in several ways to examine the ODF data. The ODF can be sliced in orthogonal sections in a manner similar to OIM. In addition oblique slices through the ODF can be generated. It is possible to make specified intensity levels transparent so as to see better the location and shape of peaks and fibers in the ODF. The ODF can also be rotated so as to better investigate the location and shape of peaks and fibers in the ODF. OIM can export the data into a format (.gm) that can be read into the Slicer Dicer software. A template is included (OIMODF_SlicerDicer.dcr) to assist in the import to Slicer Dicer.

The following shows how to import the odf *.gm file produced by OIM into the Slicer Dicer software (version 3.5).

First open the file exported in the slicer dicer format. Select the OIMODF_SlicerDicer.dcr template included in the OIM install. This will simplify the importing process.
The following dialog will be displayed:
In this case, an ODF on a 5x5x5 degree grid ranging from 0 to 90 degrees in phi1, PHI and phi2 was calculated and exported. To import the data, it is recommended to first "Survey" the data to find the minimum and maximum values in the ODF. This is done by pressing the "Survey Data" button in the dialog. These values can then be used in the data visualization by pressing the "Use Survey" button as shown below:
The size of the three dimensional data array in all three dimensions (phi1, PHI and phi2) is displayed in the size column. In this case the data was calculated on a 5x5x5 degree grid ranging from 0 to 90 degrees in phi1, PHI and phi2, thus the size of the arrays is $90/5 + 1 = 19$. To show all of the data modify the end values to 18, 18 and 18 as shown below:
Pressing the "OK" button will complete the import process. The file should be opened and a default visualization of the data displayed.
ODF Slicing

The following animation shows this feature for slices along phi2 for a typical fcc rolling texture.
The following animation shows the capability of the Slicer Dicer software to make specific levels of intensity in the ODF transparent in the 3-d visualization.
The following animation shows the capability of the Slicer Dicer software to make specific levels of intensity in the ODF transparent in the 3-d visualization as well as allow a rotation of the ODF.
Texture Calculation Method

OIM allows textures to be calculated using two different approaches: a discrete binning approach and a series expansion of generalized spherical harmonics. These are set in the Calculation Method pull-down list in the Texture Properties dialog. In addition some other "Texture Calculation Methods" available, these are intended for importing textures and for Scalar Parameter Textures.
Discrete Binning

OIM uses the direct space approach as suggested by Matthies (Matthies, S., and Vinel, G. W., "On some Methodical Development Concerning Calculations Performed Directly in the Orientation Space", *Materials Science Forum (Proceedings of ICOTOM-10)*, 157-162, pp. 1641-1646.).

The implementation used in the OIM is based on a discretization of Euler orientation space into discrete bins. The user may select the bin size. The orientation (as well as all symmetrically equivalent orientations) of each measurement is checked to determine in which bin in Euler space it falls and the value for that bin is incremented by 1. The array of bins is then normalized to 1. Once the binning process is complete, the ODF is smoothed by convolution of the ODF with a Gaussian of user-specified half-width. The smaller the half-width, the faster the smoothing calculation and the less smoothing applied to the ODF.

Some of the drawbacks of this method are: 1) Since the middle Euler angle, $F$, is not well defined at $F = 0$ degrees (when $F = 0$ degrees, the angles $j_1$ and $j_2$ cannot be completely defined, only the sum $j_1 + j_2$ is defined), when an orientation is found to lie in a bin associated with $F = 0$, then all bins for $j_1 + j_2 = a$ constant are also incremented by 1. 2) The binning does not rigorously enforce symmetry on the ODF due to the artificial boundaries created between the bins. However, OIM explicitly enforces the symmetry on the binned ODF after the smoothing step. 3) The volume of the bins are not equal. For example the volume of a 5x5x5 degree bin centered at $F = 2.5$ degrees is 0.044 and 0.999 centered at $F = 87.5$ degrees. Despite some of these failings, the method generally produces reliable results. The results are least reliable when the texture contains a lot of cube component (i.e., $(j_1=0, F=0, j_2=0)$ degrees).

Pole figures and inverse pole figures can be derived from the binned ODF via the General Axis Distribution Function, $A(h, y)$. $h$ represents a crystal direction and $y$ represents a sample direction. For the pole figure the crystal direction, $h$, is fixed and for the inverse pole figure the sample direction $y$ is fixed. The general axis distribution function (and in-turn the pole figure and inverse pole figure) can be calculated by appropriate integrations of the ODF according to the following expression:

$$A(h, y) = \frac{1}{2\pi} \int_{0}^{2\pi} f(g_y \cdot g_h) d\psi$$

where $g_y$ describes the rotation required to bring the crystal coordinate system into coincidence with an intermediate coordinate system and $g_h$ describes the rotation required to bring the sample coordinate system into coincidence with the same intermediate coordinate system. These are given by:

$$g_y = \left\{ \gamma_y + \frac{\pi}{2}, \Phi_y, \psi \right\} \quad \text{and} \quad g_h = \left\{ \psi, \Phi_h, \frac{\pi}{2} - \beta_h \right\}$$

where $\gamma_y$ and $\gamma_h$ are spherical angular coordinates describing the direction $h$ in the crystal coordinate system and $\gamma_y$ and $\gamma_h$ describe the direction $y$ in the sample coordinate frame.
Pole figures and inverse pole figures are calculated in this way when using the discrete binning method for textures in OIM.

The texture index is given by summing over all of the bins according to:

\[ J = \frac{1}{8\pi^2} \sum_i [f(g_i)]^2 \Delta g_i \]

where \( g_i \) is the volume of the \( i \)th bin.

The properties dialog for the discrete binning method is shown below.

![Binning Parameters](image)

The bin size and the degree of smoothing both effect the sharpness of the resulting texture as described in the Introduction. Sections from ODF calculated using 2, 4 and 8 degree bins are shown below.
Two sample symmetries are available - triclinic (no sample symmetry) and orthotropic as is typical with rolled sheet materials.

Instead of using each point in the texture calculation, a subsampling of the points in the scan can be used or the average orientation weighted by the grain size or unweighted can be used. It has been found that in materials with moderate texture strength that using about 10,000 grains gives very similar results to X-Ray pole figure measurements. Sharper texture require less. In materials without a lot of internal orientation spread within grains, using the weighted grain orientations should give results very similar to those obtained by using each point in the scan. These approaches can greatly speed up the texture calculation.
Harmonic Series Expansion

The harmonic analysis used in OIM follows the formulation of Bunge (see the references). In this method, the ODF can be expanded into a series of generalized spherical harmonics. The form of this expansion is:

\[ f(g) = \sum_{L=0}^{\infty} \sum_{m=-l}^{l} \sum_{n=-l}^{l} C_{lmn}^{\text{ODF}} T_{lmn}^\text{ODF}(g) \]

The generalized spherical harmonics, \( T_{lmn}^m(g) \), are given as follows:

\[ T_{lmn}^m(g(\varphi_1, \Phi, \varphi_2)) = e^{\text{i}mn_1} P_{lmn}^m(\Phi) e^{\text{i}np_1} \]

Where the \( P_{lmn}^m(\cos \Phi) \) are associated Legendre functions given as:

\[ P_{lmn}^m(\cos \Phi) = -\frac{l-m}{2^l (l+m)!} \sqrt{(l-m)! (l+m)!} (1-\Phi)^{-m-n} \frac{d^{l-n}}{d\Phi^{l-n}} [(1-\Phi)^{l+m} (1+\Phi)^{l-n}] \]

The number of terms needed in the series expansion can be greatly reduced by taking advantage of the crystal and sample symmetries. If the symmetry is considered then the expression for the series expansion can be written as:

\[ f(g) = \sum_{L=0}^{\infty} \sum_{\mu=0}^{M(L)} \sum_{\nu=0}^{N(L)} C_{\mu\nu}^{\text{symm}} T_{\mu\nu}^\text{symm}(g) \]

Where the \( T_{\mu\nu} \) functions are symmetrized spherical harmonics (the double dot signifies the crystallographic symmetry and the single dot denotes the sample symmetry). In the current version, the \( T_{lmn}^m(g) \) functions were not symmetrized for all crystal symmetries. In these cases, the symmetry was enforced explicitly on \( g \).

If it were possible to take a polycrystal apart grain by grain (while tracking of the crystallographic orientation of each grain) then the series coefficients, \( C_{\mu\nu} \), could be given as follows:

\[ C_{\mu\nu}^{\text{pol}} = (2l + 1) \frac{\sum_{i=1}^{N} V_{\mu\nu_i} T_{\mu\nu_i}^{\text{pol}}(g_i)}{\sum_{i=1}^{N} V_i} \]
where $N$ is number of grains sampled, $V_i$ is the volume of an individual grain and $g_i$ its orientation. Of course we can only approximate this volumetric sample of the grain orientations using single orientation measurements on the plane. Using the systematic grid sampling approach employed by OIM, the series coefficients are then given as:

$$C_i^{l\nu} = \frac{(2l + 1)}{N} \sum_{i=1}^{N} \hat{A}_i^{l\nu}(g_i)$$

It should be noted that measuring a single point per grain will lead to erroneous results using the expression above. A more correct calculation would require the orientation measurements to be made randomly on the sample or to weight the individual grain orientations by the apparent grain area (as in the volumetric approach).

The previous expression uses a Dirac delta representation for each orientation. Using a Dirac delta function in a Fourier series type expansion inevitably leads to negative regions surrounding peaks in the function. Since the ODF is a probability density function it should be positive everywhere. To alleviate the negativity problem, a Gaussian spread function can be introduced into the expression for $C_i$ as follows:

$$C_i^{l\nu} = \frac{(2l + 1)}{N} \sum_{i=1}^{N} K^{l\nu}_i(g_i)$$

where $K$ is a function of the angular half-width of the Gaussian per:

$$K = \frac{\exp(-i\omega^2/4) - \exp(-(l+1)^2\omega^2/4)}{1 - \exp(-\omega^2/4)}$$

where $\omega$ is the half-width of the Gaussian peak located at the orientation $g_i$. However, the choice of $\omega$ is somewhat arbitrary.

Pole figures and inverse pole figures can be derived from the binned ODF via the General Axis Distribution Function, $A(h, y)$. $h$ represents a crystal direction and $y$ represents a sample direction. For the pole figure the crystal direction, $h$, is fixed and for the inverse pole figure the sample direction $y$ is fixed. The general axis distribution function (and in-turn the pole figure and inverse pole figure) can be calculated via:

$$A(h, y) = \sum_{l=0}^{\infty} \sum_{\mu=1}^{M(l)} \sum_{\nu=1}^{N(l)} C_i^{l\nu} \tilde{k}_i^{l\nu}(h) \tilde{k}_i^{l\nu}(y)$$

where the $k_i's$ are symmetrized spherical surface harmonics and can be calculated in a manner similar to that used to calculate the $T$ functions.

The texture index is given as a function of the rank, $L$, of the series expansion as follows:
The properties dialog for the harmonic method is shown below.

\[ J(L) = \sum_{L=0}^{L} \frac{1}{2l+1} \sum_{\mu \varphi} |C_{\mu \varphi}^L|^2 \]

The series rank is the order in which the series expansion is carried out to. The rank and the degree of smoothing (Gaussian Half-Width) both effect the sharpness of the resulting texture as described in the Introduction. The following set of figures shows a section of an ODF calculated at \( L = 22, 16 \) and 8. Note that the main peak location stays the same but broadens with decreasing \( L \). \( L \) can be set as high as 34.

Instead of using each point in the texture calculation, a subsampling of the points in the scan can be used or the average orientation weighted by the grain size or unweighted can be used. It has been found that in materials with moderate texture strength that using about 10,000 grains gives very similar results to X-Ray pole figure.
measurements. Sharper texture require less. In materials without a lot of internal orientation spread within grains, using the weighted grain orientations should give results very similar to those obtained by using each point in the scan. These approaches can greatly speed up the texture calculation. (See S. I. Wright, M. M. Nowell and J. F. Bingert (2007). “A Comparison of Textures Measured Using X-Ray and Electron Backscatter Diffraction.” Metallurgical and Materials Transactions A 38: 1845-1855).

Three sample symmetries are available - triclinic or no sample symmetry, orthotropic as is typical with rolled sheet materials and axial. The following figure shows a pole figure generated with all three symmetries

Some texture calculations are made (particularly in geological samples) where the orientation measurements are not weighted by the grain size in the cross-section. Rather each grain is weighted uniformly. This capability is included for comparison against these types of texture calculations. OIM measurements are inherently take into account the cross-sectional area of each grain in the a scan. Since regular grids are used larger grains contain more points, whereas smaller grains contain less. Thus each grain is weighted in the texture calculations by the number of constituent measurement points. When this option is turned on only one orientation per grain is used (the grain average orientation).

So the following equation

\[ C_i^{\mu\nu} = \frac{(2l + 1)}{N} \sum_{i=1}^{N} \hat{K}^{\mu\nu}_i (g_i) \]

becomes

\[ C_i^{\mu\nu} = \frac{(2l + 1)}{N^G} \sum_{j=1}^{N^G} \hat{K}^{\mu\nu}_i (g_j^G) \]

Where the \(N^G\) denotes the number of grains in the scan, \(g_j^G\) is the average orientation of the jth grain in the scan.
Texture Import

Texture data can be imported into OIM in 3 formats.

Import for plotting only

Import for plotting only: This option allows pole figure, inverse pole figure, ODF and fiber chart data to be imported from an ASCII text file. The import format should be the same as the export format. Alternatively a few other formats are accepted from the popLA (preferred orientation package - Los Alamos) or BearTex texture analysis packages.

Import ODF for calculations

In this format, an ODF can be imported from a text file into OIM generated. The text file should be in the same format as the export format. This ODF can be used in the same manner as that used in the discrete binning approach. Pole Figures and Inverse pole figures can be derived from this imported ODF.

Import C-Coefficients

In this format, the C-coefficients can be imported from a text file into OIM. This will allow OIM to calculate ODFs, pole figures and inverse pole figures and fiber plots to be generated using the harmonic method. The text file must be in the same format as that used for exporting C-Coefficients.
Scalar Textures

A question that often comes goes something like this: "Do points with a low IQ have a different texture than points with high IQ - is there an relationship between IQ and the crystallographic orientation?" Such a question can be answered to a certain extent using the partitioning function of OIM. A partition containing low IQ points can be constructed and a texture calculated. The same came be done for high IQ points and the two textures compared.

We have developed a new "texture" type to look at such questions in a slightly different way. The way this is done is based somewhat on the discrete binning approach used for texture calculations. The first step is to discretize orientation space into bins (10 degrees by 10 degrees by 10 degrees for example). Create two arrays of bins. For each point in the dataset do the following. Increment the bin in the first array corresponding to the orientation of the data point by 1. Increment the corresponding bin in the second array by the IQ value (or some other selected parameter such as confidence index or grain size). After performing this process for each orientation measurement, calculate the average value for each bin in the second array by dividing the bin sum in the second array by the sum in the corresponding bin in the first array. This means that for each bin we know the average IQ. We can now plot an "ODF", however, now the intensity in the Scalar Texture ODF does not show the orientation distribution not in times random but shows the average IQ as a function of orientation. This process we have termed a "scalar texture" and is shown schematically in the following diagram.
Just as in the discrete binning case, each time a bin is incremented, bins corresponding to symmetrically equivalent orientation must also be incremented. It should be noted that some bins will not be populated if the binning size is too small or if the texture is very sharp. In these cases, the value in the Scalar Texture is replaced with the overall average value for the scalar parameter being investigated.

In this version of OIM, the parameters for which Scalar Textures can be calculated are the following:

- Image Quality
- Confidence Index
Fit
Detector Signal
Grain Size
Grain Shape Orientation
Grain Shape Aspect Ratio
Grain Orientation Spread
Grain Average Misorientation
Kernel Average Misorientation
Major Axis Texture

An ellipse can be fit to each grain in the OIM scan. The ellipse can be described in three parameters, the length of the major axis, the length of the minor axis and an angle describing the direction of the major axis. The orientation of each grain is rotated so that the direction parallel to the elongation direction is normal to the sample and the texture calculated using the harmonic series expansion approach. Thus, a normal direction (ND) inverse pole figure will show which crystal direction is aligned with the elongation direction of the grains. The example below shows that the grains have a very strong tendency to be aligned with the [0001] crystal direction.
Grain Boundary Texture Introduction

Before considering Grain Boundary Textures it is helpful to review the concepts related to Textures. The cornerstone of analysis of grain boundary textures is the Misorientation Distribution Function or MDF. It is described in the same way as the Orientation Distribution Function or ODF:

\[
\frac{\Delta V_{(g_0+\Delta g)}}{V} = \int_{g\in(g_0+\Delta g)} f(g) dg
\]

except that \( g \) no longer represents an orientation but rather a misorientation and grain boundaries are areas instead of volumes so the expression for the MDF should be rewritten as:

\[
\frac{\Delta A_{(g_0+\Delta g)}}{A} = \int_{\Delta g\in(g_0+\Delta g)} f(g) dg
\]

However, the symbol \( g \) is often used to represent a misorientation (or alternatively disorientation or orientation difference) and the MDF expressed as \( f(g) \). Like the ODF the MDF is a probability density function describing the probability of finding a grain boundary with a misorientation \( g \) within a given distance in misorientation space of a specified misorientation in a polycrystal. The misorientation \( g \) at the boundary separating two crystals with orientations \( g_A \) and \( g_B \) is given by the following expression:

\[
\Delta g = g_B g_A^{-1}
\]

Where the T represents the transpose. This has implications on the symmetry that must be exhibited by the MDF. For a given misorientation \( g \), all symmetrically equivalent orientations, \( g^e \), must have the same value in the MDF. Mathematically this is given as:

\[
f(\Delta g) = f(\Delta g^e) = f((g_B g_A^T)^e) = f(g_B^e g_A^T) = f(L_i^B g_B (L_i^A g_A)^T) = f(L_i^B g_B g_A L_i^A T)
\]

where \( L_i^A \) and \( L_i^B \) are symmetry elements associated with the crystals A and B. For a given misorientation between two cubic crystals there \( 24 \times 24 = 576 \) symmetrically equivalent misorientations. In addition if we also consider \( g_{AB} = g_B g_A^{-1} \) equivalent to \( g_{BA} = g_A g_B^{-1} \) then there would be \( 1152 \) symmetrically equivalent misorientations.

If the spatial distribution of grain orientations were random, the MDF could be simply derived from the ODF. For a simple example consider an ODF with two major peaks (which are not symmetrically equivalent). The MDF would contain a single peak (along with the other symmetrically equivalent peaks) at a location corresponding directly to the misorientation between the two peaks in the ODF. MDFs of this type are sometimes termed uncorrelated or texture-derived MDFs or the ODDF (orientation difference distribution function). Uncorrelated MDFs are calculated using the misorientations from every point pair in the scan - not just the misorientations between neighboring points.
In real microstructures, a directly measured MDF (i.e. directly measuring the orientations at grain boundaries) generally differs from an MDF derived from the ODF. This MDF has sometimes been termed the correlated or measured MDF. Some authors have proposed dividing the Correlated MDF by the Uncorrelated MDF in order to delineate those features of the Correlated MDF that arise from correlated nearest-neighbor orientation relationships. This resulting MDF has been termed a texture-reduced MDF or a correlated MDF (or less aptly, a 'normalized' MDF, the term OCF or orientation correlation function has also been used). It should be noted, however, that dividing the measured MDF by the texture-derived MDF can lead to spurious results whenever zero-ranges (or near zero-ranges) exist in the texture-derived MDF. The following example shows a correlated and uncorrelated "MDF" for a single grain.

![Correlated MDF](image1)

![Uncorrelated MDF](image2)

All three of these types of MDFs may be calculated by OIM. They can be plotted using Texture Plots. The same methodologies for calculating textures can be use to calculate grain boundary textures. Namely, discrete binning and harmonic analysis with some special considerations for uncorrelated MDFs. In OIM, the term grain boundary texture refers to a collection of MDFs along with the mathematical framework needed to calculate them.

The properties dialog for a grain boundary texture is shown below:
The *Name* is simply a name you may enter to describe the texture. The phases for the texture calculations must be selected for multiphase partitions. The calculation method must also be selected. Various parameters associated with selected method can be set using the Edit>> button as described in the sections on discrete binning and harmonic analysis.

The *Partitions* section allows the user to control which boundaries are used in the calculations. Both the partitions

The *Partitions* section allows the user to control which boundaries are used in the calculations. Both the partitions
and the phases can be set. This allows MDFs to be calculated within in a given phase, between all phases, between two specific phases, within a partition or between partitions. For example, in a sample with a two phase structure the MDFs for boundaries between grains of the same phase or between grains of the different phases could be calculated. Similarly if a sample has two distinct grain sizes, the following MDFs could be calculations: between small grains, between large grains and/or between the large and small grains.

The next region of the dialog box is where MDFs can be selected. Double clicking on a particular MDF in the list box allows the parameters to be modified. The C, U and T columns denote Correlated, Uncorrelated and Texture Derived MDFs.
When the *Add MDF* button is pressed the following dialog box is displayed.

The type of MDF may be selected (both a correlated and an Uncorrelated MDF are needed to calculate the Texture Reduced MDF).

MDFs may be calculated in Axis/Angle misorientation space, in Rodrigues Vector space and in Euler angle space (after the manner of Bunge).

For Axis/Angle space, OIM makes no presumption of the volume of the misorientation space to be sampled in the MDF calculation. Complete Axis/Angle space ranges from 0 to 180 degrees in the misorientation angle 0 to 360 degrees for the azimuthal angle and 0 to 90 degrees for the polar angle. The maximum misorientation angle varies with crystal symmetry. For example, for cubic symmetry the maximum angle is 62.8 degrees. The maximum azimuthal and polar angles can also be reduced for crystal symmetry to essentially inscribe the unit triangle.

For Euler space, OIM makes no presumption of the volume of the misorientation space to be sampled in the MDF calculation. Complete Euler space ranges from 0 to 360 degrees in the first and third angles and 0 to 180 degrees in the second angle. However, the axisymmetric region of Euler Space for misorientation is much smaller when crystal symmetry is taken into account.
For Rodrigues vectors a suggested sampling is presented based on the current crystallographic symmetry used in the texture calculation. However, it should be noted that for the cyclical symmetries $R_1$ and $R_2$ are not bounded and for triclinic symmetry $R_3$ is not bounded as well.

When MDFs for boundaries of mixed symmetry are calculated it is generally recommended to use the complete misorientation space.
**GB Texture - Discrete Binning**

The Grain Boundary texture is calculated in a manner similar to that for the discrete binning. To calculate the correlated MDF, the misorientations between all neighboring pairs of points (with misorientations exceeding a set tolerance value and included in the partition) on the data collection grid are sorted into bins in Euler space.

In version 4 of OIM Analysis using the binning method, the uncorrelated MDF is calculated differently than in previous versions in order to make the calculation time more tractable. Instead of calculating the MDF from every possible point pair in the scan, 1000 points from the scan are picked out at random. This results in approximately 200,000 pairs. This speeds up the calculations considerably and gives a fairly good approximation to that calculated using every possible point pair.
GB Texture - Harmonic Series Expansion

The Grain Boundary texture is calculated in a manner similar to that for the harmonic series expansion of the ODF. Uncorrelated MDFs are calculated using the following expression.

\[ M'(\Delta g) = \sum_{l=0}^{\infty} \sum_{\mu=0}^{M(l)} \sum_{\nu=0}^{M'(l)} \hat{C}_l^{\mu\nu} I_l^{\mu\nu}(\Delta g) \]

where \( M'(\Delta g) \) represents the uncorrelated MDF and the \( C \) coefficients are derived from those used to calculate the texture as:

\[ \hat{C}_l^{\mu\nu} = \frac{1}{2l+1} \sum_{v=0}^{M(l)} C_l^{\mu v} C_l^{\nu v} \]

where the \( C \) are the coefficients used to calculate the ODF from the crystals separated by the grain boundaries.

See J. Zhao, B. L. Adams and P. R. Morris, A Comparison of Measured and Texture-Estimated Misorientation Distributions in Type 304 Stainless Steel Tubing, Textures and Microstructures, 1988, Vols. 8 & 9, pp. 493-508 for a more complete description of the mathematics behind the uncorrelated MDF harmonic calculations.
Texture Plots

In version 4, the texture plots become children of the textures and grain boundary textures in the project tree. Texture plots allow orientation and misorientation distributions to be presented in a variety of representations. Texture plots are for plotting the results of texture and grain boundary texture calculations. Thus, they require a texture or grain boundary texture to be calculated prior to displaying the results. The types of plots available include for textures:

- Pole Figures
- Inverse Pole Figures
- ODFs in Euler Space
- ODFs in Rodrigues Space

and for grain boundary textures

- MDFs in Axis/Angle Space
- MDFs in Rodrigues Space
- MDFs in Euler Space

To create any of these plots, not only must the texture or grain boundary texture be already generated but the texture document must also contain the appropriate plot data. When creating a new plot the following dialog is displayed.
Name: The Name is simply an identifying name for the plot.

Plot Style: The Texture identifies the precalculated texture. The Plot Type defines which member type of the texture should be plotted.

Sections: The Sections group allows multiple pole figures, inverse pole figures or plot sections through a given (mis)orientation space to be plotted together in a single window. To modify the parameters for a given section simply double-click on the section in the list. The order the sections appear in the list is the order they will appear in the display window. The Add and Insert buttons enable new sections to be added to the plot. The Generate button allows the sections through the space to be automatically generated (not applicable to pole figures or inverse pole figures.) For ODFs and MDFs the following dialog will appear when adding a new section:
This section out of the distribution will be plotted. For pole figures and inverse pole figures the following dialog box will be displayed allowing the user to select the pole figure or inverse pole figure to be plotted.

**Axis Format**

This option allows various grid lines or tick marks to be shown on the plots. The angular increment between the tick marks and grid lines can also be entered. The grid format is shown at left on a pole figure and tick marks in the figure at right. For inverse pole figures these formats are not available if only the unit triangle is displayed.
Once the Plot Type is set, the Edit>> button allows the parameters associated with the particular type of plot to be set along with the color scale used. The color scale is common to all types of plots. The dialog for modifying the color scale is shown below.

**Generate scale levels**: This section provides a means for automatically generating a scale. The colors can be set using the color gradient. A log or linear scale may be used as well. *No. Levels* are the number of levels to use in generating the scale. *Levels<1* is the number of intensity or contour levels to use below the random value of 1. If more detail is desired in the plots at the lower functional value then this number should be increased. The Generate
button will cause an automatic scale to be generated and placed into the *Scale Levels* list control. If *Auto Maximum* is turned on the scale is calculated based on the maximum in the file. Otherwise, the scale is generated using the value in the *Maximum* edit box. Any changes to parameters in this section immediately override the levels shown in the *Scale Levels* list with automatically generated levels.

**Scale Levels**: This list box allows the user to manually modify the colors and values for the scale levels. If *Auto Maximum* is turned on then the list cannot be modified. Scale levels can be added or removed from the list. To modify the color and/or numerical value associated with a scale level simply double-click on the desired level.

**Plotting Style**: Generate an intensity plot or a contour plot. An example of each (along with the corresponding discrete plot) are shown below.

![Plotting Style Examples](image)

**Interpolate**: The texture results are calculated on grids through the particular representation space. The plotting interpolates from the calculation grid to the screen pixels. Alternatively, the data can be shown as calculated by turning off *Interpolate*.
Texture Plot Menu

A pop-up menu can be accessed by a right-mouse click in the Discrete Plot display window.

Properties...: Brings up the Texture Plot Properties

Texture Properties...: Brings up the corresponding Texture Properties or Grain Boundary Texture Properties.

Fit To Window: The plot is stored in memory at a much higher resolution than can generally be displayed. To view the plot at the memory resolution turn Fit To Window off. The plot will be cropped in the display window. Scroll bars are available to position the plot as desired within the display window.

Copy Image: Copies the plot to the clipboard as a bitmap.

Save Image...: Enables plot to be saved to disk as a bitmap.

Export Template...: Allows the properties definition used to generate the plot to be saved to disk. This definition can be read in later so the same plot can be generated for a different partition or database.

Close: Close the plot display window.

Save: Save the plot within the project structure.

Print...: Prints the plot.

Copy: Copies the properties definition so it can be pasted to another partition or database.

Delete: Delete the plot from the project.
Pole Figure

This will plot a pole figure for a given texture. The pole figures to be plotted must already be calculated as part of the texture. The parameters associated with the pole figure plots are shown in the following dialog.

**Projection:** For pole figure plots, the user can choose from three types of projections.

**User-Defined Axis:** This allows the user to define the position of a axis in the pole figure with a label. In the example below *Axis angle from horizontal* is set to 120 degrees.

---

**0 0 1**

Fiber Axis
Inverse Pole Figure

This will plot an inverse pole figure for a given texture. The inverse pole figures to be plotted must already be calculated as part of the texture. The parameters associated with the inverse pole figure plots are shown in the following dialog.

**Symmetry:** For MDF plots in Axis/Angle space the user can choose whether to reduce the plotting region for the axis by turning on use *Unit Triangle* or not. For MDFs in Euler or Rodrigues space the choices are irrelevant and therefore disabled.

**Projection:** For inverse pole figure plots, the user can choose from three types of *projections.*
ODF Plot

This will plot the sections of the orientation distribution function or ODF for a given texture. The ODF to be plotted must already be calculated as part of the texture. The parameters associated with the ODF plots are shown in the following dialog.

**ODF List**: The user must simply select the appropriate ODF to plot. The list control will list all possible ODFs contained in the texture selected in the initial Texture Plots dialog.

**Section Configuration**: Tells OIM how to section up Euler Space. The three angles 1,2 and 3 refer to ($\alpha$, $\beta$, $\gamma$) for Bunge's Euler angles and ($\alpha$, $\beta$, $\phi$) for Roe and ($\alpha$, $\beta$, $\phi$) for Kocks. The matrix of radio buttons allows the user define along which angle the constant angle sections should be made and which of the other two axes should appear vertical in the plot and which should define the horizontal. For ODFs calculated in Rodrigues space the configuration is fixed and the dialog elements disabled.

**Ranges**: The user may select how much of the ODF is to be presented. The allowed minimum and maximum correspond to the minimum and maximum values in the ODF calculated as part of the texture. For ODFs calculated
in Rodrigues space the ranges, are fixed and the dialog elements disabled. The constant angle sections are set from the initial Texture Plots dialog.
MDF Plot

This will plot the sections of the misorientation distribution function or MDF for a given grain boundary (GB) texture. The MDF to be plotted must already be calculated as part of the GB texture. The parameters associated with the MDF plots are shown in the following dialog.

**MDF List**: The user must simply select the appropriate MDF to plot. The list control will list all possible MDFs contained in the texture selected in the initial Texture Plots dialog.

**Projection**: For MDF plots in Axis/Angle space the user can choose from three types of projections. For MDFs in Euler or Rodrigues space the choices are irrelevant and therefore disabled.

**Symmetry**: For MDF plots in Axis/Angle space the user can choose whether to reduce the plotting region for the
the axis by turning on use *Unit Triangle* or not. For MDFs in Euler or Rodrigues space the choices are irrelevant and therefore disabled.

**Section Configuration:** Tells OIM how to section up Euler Space. The three angles 1, 2 and 3 refer to $(\theta_1, \theta_2)$. The matrix of radio buttons is to define along which angle the constant angle sections should be made and which of the other two axes should appear vertical in the plot and which should define the horizontal. For MDFs calculated in Rodrigues or Axis/Angle space the configuration is fixed and the dialog elements disabled.

**Ranges:** The user may select how much of the MDF is to be presented. The allowed minimum and maximum correspond to the minimum and maximum values in the MDF calculated as part of the grain boundary texture. For MDFs calculated in Rodrigues or Axis/Angle space, the ranges are fixed and the dialog elements disabled. The constant angle sections are set from the initial *Texture Plots* dialog.
The 3D Visualizer button launches a tool for creating 3D visualizations from a set of serial sections. It is assumed the sections are collected at a fixed step (in z). Essentially two types of visualizations are available - 1) visualizations of the data block or portions of it and 2) visualizations of individual grains or sets of grains.

Before creating the visualization, it is generally good practice to run the data through the batch processor to perform cleanup on the individual sections or any other required processes. The next step is to create a map template on a single 2-d section. There are a few limitations to be aware of prior to creating a template. Most of the maps can be used in 3D. However, there are a few exceptions. Currently the exceptions are: Grain Rotation Angle, Grain Aspect Ratio, Grain Major Axis, Grain Minor Axis, Twin Parent Child, Import, Kernel Average Misorientation, Local Spread. It should also be noted that the Local Average Misorientation is currently fixed to first nearest neighbors only. Also, grain boundaries are not shown in the current version of the 3D visualizer. Once the map template has been constructed, launch the 3D tool by hitting the button on the toolbar. The following dialog box will be displayed.
To build the 3D file select "Build and OIM 3D file (*.o3d)"; alternatively, if a 3D file has already been constructed select the other option to launch the visualizer. Select a name and location for the 3D file and the map template. You will also have to enter the distance (in microns) between the individual scans in the series. Grain IDs do not necessarily need to be calculated. This can save a considerable amount of time. However, the grains can not be rendered individually in the visualizer. Once the "OK" button is pressed the user will be prompted to select the individual sections (use the shift button to select a whole set, or individual sections using the "Ctrl" key in the usual manner. The processing will then commence - this can take a considerable amount of time. Once the processing has completed the 3D visualizer is launched. In addition to the *.o3d file, two other types of files can be exported:

*.o3p - this file contains an entry for each field in the full 3D dataset. It is similar to a .ang file or one of the grain file types in three dimensions. The first three columns are the x, y & z coordinates in microns. The next three columns are the Euler angles in radians ( , ), column 7 is the IQ, column 8 is the CI, column 9 is an index to the associated phase, column 10 is the detector intensity (from the SED, FSD or whatever is being collected), column11 is the fit and column 12 a number identifying the grain the point belongs to. The file is in a text format with the same name as the corresponding .o3d file except with the .o3p extension.

*.o3g - this file contains one entry for each 3D grain. Column 1 is a number identifying the grain, the next three columns describe the average orientation in radians as Euler angles ( , ), column 5 is the orientation spread within the grain, column 6 is the volume in points (voxels) and column 7 is the volume in cubed microns. The file is in a text format with the same name as the corresponding .o3d file except with the .o3g extension.

The following sections describe use of the visualizer.
It should be noted that the Visualization software will operate much faster with a higher end video card. Look for a card that offers the most VRAM. Most on the market today offer 128 M-bytes which is great. Look for a card that advertises “full OpenGL 2.0 compliance” or has an “OpenGL ICD” implementation (not a MCD - mini-client driver). Avoid cards that seem to only exist to make one specific game work well.
The menus of the 3D Visualizer can be accessed either from the menu bar at the top or from the pop-up menu in the rendering window.

There are two modes in which the 3D data may be view - Map View Method & Grain View Method.
No Grain Selected. Double-click to select. Left-click + drag to rotate.

Grain ID# 1231, Centroid=(10.6,10.1,9.0), Volume=4294.31, Average
Some of the menu items are particular to the individual viewing methods and are discussed in those sections. However, there are menu items of general application.

**Load** - Loads a *.o3d file into the Visualization software.

**Export** - Saves a copy of the current visualization to either a bitmap, jpeg or PNG file.

**Start Recording** - This begins a recording sessions. All subsequent manipulations of the visualizer will be recorded.

**End Recording** - The session is saved to either a MPEG file or a set of individual frames in JPEG file format. The user may also simply playback the session.

**Map View Mode** - Toggles the Visualizer to the Map View mode.

**Grain View Mode** - Toggles the Visualizer to the Grain View mode.

**Home** - Resets the rotations, translations and zooms to the default "home" position.

**Show Annotations** - Toggles the display of the x-y-z axes.

**Cursor Mode** - Defines the actions of the left hand mouse button between rotation, panning and zooming.

The other menu times are best described in the Grain and Map View sections.
Double clicking on a grain in the data block will automatically activate the Grain View Mode, and the selected grain will be rendered. Multiple grains can be selected by holding down the shift key while clicking on the data block. However, a single grain must first be selected and then the mode must be returned to Map View mode before multiple grains can be selected.

**Highlight Grain under Cursor** - Show the grain that would be selected upon double clicking at the current mouse position. A grain must first be selected and then the mode must be returned to Map View mode before this function will activate.

**Cutting Plane** - The data can be sliced along the principle axes of the data cube. This can be done in either a positive (shown in the figure below on the left) sense or a negative sense (at right in the figure below).
Map View Render Method - The data block can be rendered as individual maps or as a volume with color interpolated between the slices. The volume mode is considerably more time consuming.

Adjust Transparency - The data block can be shown transparent with the current highlight grains opaque. This mode can be helpful when selecting multiple grains. A grain must first be selected and then the mode must be returned to Map View mode before this function will activate.
Select Grains by Color Threshold - Grains within a given color range from the currently selected grain can also be included in the selection. These can then be viewed as grains by switching to Grain View Mode.
Grain View Render Method - The grain can be visualized in four different ways: 1) Filled Smooth Color, 2) Filled Flat Color, 3) Wireframe or 4) Point Cloud. These are shown below from left to right.

Surface Smoothing - The amount of smoothing used to render the grain can also be varied. From "none" to "low" to "medium" to "high". The amount of smoothing will impact the speed of rendering.
TUTORIALS

The following set of tutorials will help you get started learning both the basic as well as some of the intricacies of OIM Analysis.
Basic Tutorial

The following tutorial should help you get started with OIM Analysis as well as show some of the analytical procedures a researcher might use for investigating the crystallographic structure of a polycrystalline material. For this tutorial, we will be using a dataset obtained from rolled aluminum sheet for a friction stir welding application. This dataset is installed during the OIM Analysis installation procedure. Assuming the defaults were selected during the installation procedure, this data file is most likely located in Program Files/TexSEM/OIM Analysis 4/Samples. To get started launch OIM Analysis.
Step 1 - Loading a Dataset

The first step is to create a new project. The easiest way to do this is to left-click the Quick New button on the QuickGen Toolbar and select Project from the pop-up menu as shown below.

This will create a default project. (there are multiple ways to open project, this is true with many functions in OIM so that users can operate the software in the way that is most convenient - projects can also be created from the New Project button on the Standard Toolbar or using New Project from the File Menu.) The next step is to add a dataset to the project this is done by clicking on the project icon in the project tree with the right hand mouse button. Select New->Dataset from the pull down menu as shown below.
You will now be prompted to open the file containing the dataset as shown below.

Select the file FSW Al.osc. Once the file is successfully opened the screen should look something like that shown below. In the project tree window you will see the project, dataset and partition. The partition was automatically created and contains all of the data in the data set. A window providing some summary information on the dataset will be displayed when the dataset is opened.
FSW AI

Operator: XL

Number of points: 37751
Number of good points: 37729

Dimensions:
X Min: 0.00 microns
X Max: 362.00 microns
Y Min: 0.00 microns
Y Max: 358.53 microns
Step: 2.00 microns

Average Confidence Index: 0.70
Average Image Quality: 79.18
Average Fit [degrees]: 1.09

Minimum boundary misorientation: 2.0 degrees (see Settings>Preferences)
Number of boundary segments: 59785
Length of boundary segments: 6.90337 cm

Phases:
Aluminum
Step 2 - Creating Maps

We will now create an inverse pole figure map. This is most easily done by pressing the IPF Quick Map icon on the QuickGen Toolbar as shown below.

This should result in the screen appearing as below. The inverse pole figure map is color coded map where the color gives an indication of the crystal direction aligned with the sample normal. For example, in this case, the points colored blue have \( \langle 111 \rangle \) directions aligned with the sample normal, the points in red are \( \langle 100 \rangle \) oriented and the points in green are \( \langle 110 \rangle \). It should be noted that in this map, only the crystal direction parallel to the sample normal is fixed. The in-plane orientation is not indicated in this map.

The orientations can be confirmed by switching to \textit{Lattice} in the Information Pane of the window as shown below. As the cursor moves around the map, a wire frame schematic of the crystal is displayed.
Now, let's create a second type of map using an alternative approach. On the project tree click on the Partition (a Partition contains a filtered subset of the data - in this case it contains all of the data) entitled All Data with the right mouse button. This will bring up a pull-down menu. Select New>Map from the menu as shown below.

This will display the Map Properties dialog. This dialog allows the map to be configured. In this case, we want to create an Image Quality (IQ) map overlaid with low and high angle boundaries. To do this we set the Map Grayscale Type to Image Quality. We then need to set the Grain Boundary Type to Rotation Angle and press the
Add button to configure the low angle boundaries to be displayed.

Pressing the Add button bring up the following Add Boundary dialog. We will define "low angle" boundaries as boundaries with misorientation between 1 and 15 degrees as shown.
We want to assign a specific color to these types of boundaries. This is done by hitting the Segment tab in the dialog. In this page of the dialog the color and thickness of the boundary segments can be defined. Make these types of boundaries yellow as shown.

Close the *Add Boundary* dialog by pressing the *OK* button and hit the Add button again in the *Map Properties* dialog to configure the high angle boundaries. In this case, define the "high angle" boundaries as boundaries with misorientations exceeding 15 degrees and set the color to blue. Once the boundaries are configured they should be listed in the *Map Properties* dialog as shown below.
After the OK button is pressed in the Map Properties dialog, the following map will be generated. The window has been maximized to show more detail.

Note in the legend for the map the fraction of the low and high angle grain boundaries. There will also be a note defining the Minimum Boundary Misorientation for calculating fractions. The default is 2 degrees, however, we have defined low angle boundaries as boundaries with misorientations lying between 1 and 15 degrees. To change the minimum boundary misorientation, select Preferences from the Settings menu. This will bring up the Preferences dialog. Set the Minimum Boundary Misorientation to 1 for this example.
This will result in more boundaries being shown in the map.
Grains have a well-defined meaning in OIM, however, the definition differs from that used in tradition metallography. In OIM, two neighboring scan points belong to the same grain if the misorientation between them is less than some value prescribed by the user - the *Grain Tolerance Angle*. This means, that two neighboring points in a grain may differ in orientation by 0.1 degrees, but the misorientation between points at one end of a grain and the opposite end may differ considerably more. This is especially true in deformed materials like the rolled aluminum used in this tutorial. The best way to see how the points are grouped into grains is to use a Unique Grain Color Map. In this map, each grain is assigned a color. The colors do not denote an orientation; the grains are simply colored to distinguish them from neighboring grains. To generate a *Unique Grain Color Map*, select a Grain Map from the *QuickGen Toolbar*.

This will produce the following map.

In order to understand the parameters used in constructing the map, click on the *All Data* partition in the project tree with the right mouse button and select *Properties* from the pull-down menu.
This will bring up the *Partition Properties* dialog. Switch to the *Grain Size* page of the dialog by hitting the *Grain Size* tab. Note the default value of 5 degrees misorientation for the *Grain Tolerance Angle* and a value of 2 for the *Minimum Grain Size*. The minimum grain size defines the number of scan points before a group of neighboring and similarly oriented points is identified as a grain in the OIM software.

In order to illustrate the impact these parameters have on the Grains in OIM, we will create a new partition. This is done using the right mouse pull down menu at the dataset level as shown below.
Once again, the Partition Properties dialog will be displayed. Switch to the Grain Size page and change the Grain Tolerance Angle to 15 degrees.

Close the dialog by pressing on the OK button. This will add a new Partition to the Dataset. This is indicated in the Project Tree.

The name of the two partitions can be changed to reflect the differences the Grain Tolerance Angle. This can be done using the right mouse activated pull-down menu and selecting Rename.

With the new partition active (activate it by simply left-mouse clicking on it), create a new Unique Grain Color Map
using the QuickGen Toolbar.

Now we can compare the resulting maps. To display the maps as shown here, close all of the windows except the two grain color maps and then hit the Tile Vertically button on the Standard Toolbar. Note the larger grains in the map with 15 degree tolerance.

While it should be recognized this is a relatively small area scan to keep the file size small for the tutorial, we want to look at Grain Size Distribution. Before starting this process we need to make some more changes to the Grain Size page in the Partition Properties dialogs for both partitions. Because the grains are elongated many of the grains touch the edges of the scan area. In general, these are excluded from any kind of statistical analyses like Grain Size Distribution. However, because our sampling area is small we need to include these scan edge grains. Open the Partition Properties dialog for each partition by selecting Properties from the pull-down menu for each partition. Check on the "Include grains at edges of scan in statistics" option as shown below.
Now we will create a chart showing comparing the Grain Size Distribution for each partition. This is done using the pull-down menu at the project level and selecting New>Multichart.

This will bring up the Multichart Dialog. The type of chart needs to be selected as shown, and a chart added for the two partitions.
This is done by pressing the Add button to bring up the Multichart Entry dialog where the partition can be selected. Name is the name used in the chart legend.

The resulting chart should appear as follows. Even with the small sampling of grains, it is clear that setting the Grain Tolerance Angle to 15 degrees produces more large grains, whereas a value of 5 degrees produces smaller grains.
Step 4 - Discrete PF and Rotation

In this step of the tutorial we will begin to look at the orientations themselves with respect to the sample. The sample was obtained from rolled aluminum sheet used for friction stir welding. The sample scanned was sectioned from a plane normal to the rolling direction as shown in the schematic below.

One of the most common tools for visualizing orientations in polycrystalline materials is the pole figure. Before plotting a pole figure close all of the document windows. Generate an IPF map from using the appropriate button on the QuickGen toolbar and plot a pole figure. The pole figure is most easily generated by simply hitting the Pole Figure button on the QuickGen Toolbar. This will automatically generate a 001 pole figure.

However, for FCC rolled materials, the most common pole figure displayed in the literature is the (111) pole figure. We want to change the (001) to a (111) pole figure. This is easily done by clicking in the pole figure with the right hand mouse button and selecting Properties from the pull-down menu.
In the resulting Pole Figure dialog, change the pole figure to an (001) pole figure by double-clicking on the (001) pole figure in the list.
The resulting pole figure should appear similar to that shown below.

However, this doesn't look like a typical (111) pole figure for rolled aluminum. This is because of the plane on which
the scan was performed. Pole figures from rolled materials are more typically obtained from a plane as shown in the following schematic.

In order to get the data into this configuration we need to rotate it 90 degrees about the transverse direction or TD. This can be accomplished by selecting **Rotate** from the Dataset pull-down menu in the project tree.

The Rotate dialog will be displayed. We want to rotate 90 degrees about TD in a negative sense. We can rotate the data, creating a new dataset within the project or simply rotate the data in place. For this example we will rotate the data in place. The change in orientation will be reflected immediately in the pole figure and the IPF map.
The map and pole figure should appear as follows.
The pole figure looks much more like that expected for rolled aluminum. However, it is clearly not exactly centered. This is likely due to tilts introduced during the sectioning or subsequent sample preparation. Successive rotations of -1 degree about ND, 4.5 degrees about TD and -3 degrees about RD seem to work well. (One way to identify the amount of rotation needed is to use Highlighting in Plot Misorientation Mode \( \uparrow \uparrow \) in the pole figure.) The pole figure should appear as follows after these finer rotations.
Step 5 - Texture

While the discrete pole figures give a general impression on the clustering of orientations in orientation space, they are not very quantitative. For quantitative information on the orientation distribution we need to use the tools of Texture Analysis. OIM Analysis has many tools for characterizing the textures of polycrystals. In OIM 4 the texture analysis is contained within a Texture Document at the same level in the project tree as the maps, charts or discrete plots. The Texture Document contains all of the calculation parameters and resultant data needed to generate texture plots such as pole figures or ODFs. The actual texture plots are maintained at a level below the Textures themselves. To calculate a texture, select New>Texture from the Partition pull-down menu.

The following Texture Properties dialog will be displayed. First we need to select the calculation method and associated parameters by hitting the Edit>> button.
We want to compare the discrete (111) pole figure already plotted against one derived from the texture calculations. This is done by pressing the Add PF button on the texture properties dialog. This will bring up the
following dialog. The (hkl) should be set to (111).

![Add Pole Figure dialog](image)

Once all of the dialogs are closed using the OK buttons, the texture calculations will commence. For this file, this should only take a couple of minutes. When the calculations have completed an icon representing the texture is included into the project tree. To generate the pole figure plot, right-mouse click on the new texture in the project and select New>Texture Plot from the pull down menu.

![Project tree with Texture Plot option](image)

The (111) pole figure should already be selected and ready to display.
Once the OK button is pressed the pole figure will be generated.
Step 6 - Templates

It may take a considerable amount of effort to get all of the partitions, textures, plots... configured precisely as desired. OIM Analysis has several features that make it possible to reuse the configurations developed during an analysis session. For example, a pole figure can be copied from one data set to another; this doesn’t mean the actual pole figure plot is copied but rather the plot is generated using the data from the new dataset and the parameters from the old pole figure. As an example, let’s construct a map showing the fraction of material within 10 degrees of the “S” orientation (this is a specific orientation, (123)<63-4>, that is frequently observed in rolled FCC materials). This is done by going to the dataset icon in the project tree and selecting New>Map from the pull-down menu. Select Crystal Orientation for the Color-Coded Map Type and Image Quality for the Gray Scale Map Type from the resulting Map Properties dialog.

Now press the Edit>> button for the Color Coded Map Type. This brings up the following dialog. First turn on the orthotropic (rolled sheet) symmetry as we are looking at a rolled aluminum sheet that exhibits strong processing symmetry (the pole figure is symmetric about the horizontal and vertical axes).
Press the Add button to set the software to look for the "S" orientation as shown below. (You only need to enter one set of orientation angles/indices)

Once these parameters are all defined, the resulting map should appear as follows.
The colored points are those, which have "S" Orientations. The map legend indicates that the volume fraction of the "S" component is 33%.

Now open a new dataset (use FSW Al 2.osc), apply the appropriate rotations. And then use the copy document function and paste the map into the new dataset.

This should result in the following.
The map definition can also be saved as a Template and applied during later analysis sessions. To save the template use the Export>Template function from the pull down menu on the project tree or in the map window.
This template can then be applied at a later time using Apply Template at either the Partition, Dataset or Project levels, the template will be applied to all partitions in the dataset when applied at the Dataset level and in all datasets when applied at the Project level. As an example, a template containing a more extensive set of analyses for rolled fcc materials is included with the OIM 4 installation. Apply this template to the FSW AI 2 dataset.

This will result in a new partition being created with a Crystal Orientation Map for several orientations as well as a Crystal Orientation chart showing their distribution as a function of tolerance angle.
In fact, templates can be attached to user specified buttons in the QuickGen Toolbar using the Preferences dialog under the Settings menu making a whole set of analyses tied to a single push of a button.
Highlighting and Partition Tutorial

This tutorial will use OIM scan data from dual phase titanium sample. The sample has large grains of alpha titanium and a lath structure composed of both alpha and beta titanium. The tutorial consists of four parts.

1. Opening the file, creating a combined image quality and phase map, using manual highlighting on the map in grain mode to create a partition containing the lath area.

2. Operating in the lath partition, identify the character of the interphase boundaries using the Discrete Axis/Angle Misorientation.

3. Use an alternative (more automated) method based on the grain size chart to isolate the lath areas.

4. Use the misorientation profile highlighting function to characterize the internal structure of the large alpha grains. This will also introduce the user to the interactive view properties.

In the process the tutorial introduces many aspects of OIM Analysis including:

- Loading scan data.
- Creating maps.
- Overlaying boundaries on maps (axis/angle type)
- Highlighting in maps.
  - Configuring the highlighting gradient.
  - Setting the highlighting mode.
  - Using the grain highlighting mode.
  - Using the vector profile highlighting mode.
  - Recording highlighting data in a tabular list.
  - Configuring the recorded highlighting table.
  - Exporting the recorded highlighting table.

- Partitioning
  - By highlighting in maps.
  - By highlighting in charts.
  - Using an explicit formula.
- Creating a Discrete Misorientation Plot using the axis/angle representation
  - Highlighting in discrete plots
  - Configuring discrete plots
- Zooming in on maps
- Using the Flexiview Tab
- Creating a Grain Size Chart
  - Highlighting charts
Manually Isolating Lath Areas: Step 1 - Load File

Assuming OIM Analysis has just been launched and that no project has yet been created, the easiest thing to do is to open the scan data file. This is done by selecting Open from the File menu. This results in the following dialog being displayed. Set the file type to OIM Scan Files (*.osc). Open the file entitled "Dual Phase Titanium.osc".

When the file is opened it will be automatically placed under a new project in the project tree. In addition, 3 partitions will be created under placed under the data set in the project tree. One partition containing all points within the scan data, one containing only those points identified with the alpha phase and one partition for the beta phase. When the partitions are created, the points in the scan belonging to each partition will be grouped into grains.
When the file is opened a window containing summary information about the data set is displayed. To access similar information for each of the phases, position the mouse cursor over the phase of interest in the project tree and press the right mouse button. A pop-up menu will be displayed. Select *Summary View* from this menu.
The next step is to create an Image Quality (IQ) map overlaid with colors identifying the phase each data point belongs to. The easiest way to do this is to hit the IQ map button from the Quick-Gen toolbar.

After the button is pressed, an IQ map is displayed in a window.

To overlay colors identifying the phases, position the mouse cursor over the map and press the right-mouse button to activate the pop-up menu. Select *Properties* from the menu.
This will display the Map Properties dialog. Select Phase from the Color Coded Map Type list.

This will result in the map being changed from simply an IQ map to an IQ map overlaid with colors identifying the phases. Note the volume fraction of each phase in the Legend displayed in the right hand window pane.
Gray Scale Map Type: Image Quality
28.126...123.596 (28.126...123.596)

Color Coded Map Type: Phase

<table>
<thead>
<tr>
<th>Phase</th>
<th>Total Fraction</th>
<th>Partition Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium (Alpha)</td>
<td>0.737</td>
<td>0.737</td>
</tr>
<tr>
<td>Titanium (Beta)</td>
<td>0.263</td>
<td>0.263</td>
</tr>
</tbody>
</table>

Boundaries: <none>
Manually Isolating Lath Areas: Step 3 - Configure Highlighting

In order to isolate the lath area from the large alpha grains we will manually highlight the large alpha grains in the map. To do this, we first need to configure the highlighting. The first step is to change the highlighting mode to *Grain Mode*. This is done by clicking on the appropriate icon in the map highlighting mode portion of the *Highlighting Toolbar*.

Now we need to reconfigure the Highlighting Gradient for easier visualization of the grains. To change the color gradient, press on the gradient icon in the *Highlighting Toolbar*.

This will bring up the following dialog box. We want to set the gradient to a single color - blue. This can be done by setting each of the colors in the gradient to blue or more simply by setting the number of colors to 1.
Manually Isolating Lath Areas: Step 4 - Highlight Alpha Grains

We want to manually highlight all of the large alpha grains in the map. This is done by simply clicking on the grains. The resulting map should appear as follows where all of the large alpha grains are highlighted in blue.
Manually Isolating Lath Areas: Step 5 - Create Lath Partition

Now that the alpha grains have been highlighted we want to create a partition containing only the remaining lath areas. This is easily done by performing a right mouse click on the map to bring up the map pop-up menu. Select Non-Highlighted -> Partition from the pop-up menu.

This will create a new partition in the project tree. The name of the partition can be changed by selecting Rename from the pop-up menu displayed when clicking on the partition with the right mouse button.

To show that this partition only contains the lath structure, make the partition active by left clicking on it in the project tree. Hit the IQ map button in the Quick-Gen toolbar. This will result in the following map, where the blacked out points are those points in the dataset excluded from the partition.
Characterizing Boundaries: Step 1 - Create MDF

Before creating the Discrete Misorientation Plot, close all the windows in the workspace portion of OIM Analysis with the exception of the IQ map for the Lath partition. Make sure the Lath partition is active by clicking on it in the project tree with the left mouse button. (The active partition is shown on the Quick-Gen Toolbar as shown below.)

Using the right mouse button click on the Lath Partition in the project tree to pop-up the following menu. Select New Discrete Plot from the pop-up menu.

This will bring up the following dialog box. The first step is to set the Plot Type to *Axis/Angle Misorientations*.
The Discrete MDF is a series of sections through Axis/Angle Misorientation space. We want to configure the MDF sections. The first step is to clear the default sections from the Sections part of the dialog by pressing the Clear button. Now press the Generate button, which will display the following dialog. Change the maximum in the range to 90 degrees from the default value of 180 degrees as shown.
Press OK in this dialog and the parent. The discrete axis/angle misorientation plot will be calculated and displayed.

To display the map and the discrete plot side-by-side as shown here, select the *Tile Vertically* icon from the Utilities Toolbar.
Characterizing Boundaries: Step 2 - Reconfigure Highlighting

Before starting the highlighting we need to reconfigure the highlighting. First we want to change the *Highlighting Tolerance Angle*. This is done by clicking on the corresponding icon in the *Highlighting toolbar*.

This will display a dialog box for changing the tolerance angle. Set the tolerance angle to 5 degrees. On a click in the discrete plot, the tolerance angle defines the spread in orientation (or misorientation) from the exact orientation (or misorientation) clicked.

We also need to make sure that highlighting is turned on - both for the Discrete Misorientation Plot and for the IQ Map. This is done using the right mouse pop-up menus for the map and the plot.

Set the Highlighting Gradient color to a single color - green.

In order to see the individual misorientations plotted in the Discrete Misorientation Plot either maximize the OIM Analysis window using the standard Windows maximize button in the upper right-hand corner of the application and retile the windows using the Tile Vertical button on the *Standard Toolbar*.

Or change the display mode of the Discrete Misorientation Plot to not *Fit to Window*. This can be done either from the pop-up menu for the plot window or making the Plot Window active by clicking on the window's title bar and deselecting the *Fit To Window* button on the *Standard Toolbar*.

Make sure that Plots: Tolerance highlighting is selected instead of Plots: Misorientation.
Characterizing Boundaries: Step 3 - Discrete MDF Highlighting

Using the scroll bars, scroll the discrete MDF plot until the 10 degree section is centered in the window as shown below. With the left mouse button click on the cluster of misorientations at the center of the section. Note that a few boundaries have been highlighted in the map.

Scroll the Discrete MDF Plot window until the 30 degree section is centered in the pattern. Switch the color gradient to cyan and click on the cluster of orientation at 45 degrees and halfway out from the center as shown below. The other 3 clusters will be highlighted as well as they are symmetrically equivalent misorientations. Once again, note the few short boundaries highlighted in cyan.

To get a better view of the boundaries highlighted in the map, click on the Title Bar of the Map window to activate it. Then, select the Zoom-Icon from the Standard Toolbar.
The cursor will change to a magnifying glass. With the cursor click on the map a few times to zoom in on the highlighted boundaries.
Characterizing Boundaries: Step 4 - Boundary Specifics

Return the map to *Fit-To-Window* mode by clicking on the icon on the Standard Toolbar.

Change the color of the *Highlighting Color Gradient* once again - to yellow. Locate the 45 degree section of the Discrete Misorientation Plot and click on one of the two clusters at 3 o'clock and 9 o'clock. This cluster is clearly associated with many of the boundaries in the lath area.

What type of boundaries are these? We know they correspond to 45 degrees of misorientation, but what rotation axis? This can be determined easily by positioning the cursor over the (now yellow) cluster in the 45 degree section and looking at the status bar at the bottom of the application. (If the status bar does not appear, select it from the View Menu.)

The misorientation can be described with respect to either the alpha phase or with respect to the beta phase. This is why the misorientation is listed twice. In addition, it should be noted that while the axes are given in integer values these are determined from real values and may not be precise. The highest integer used in the indices describing the rotation axes can be set in the Preferences Dialog accessible from the Settings Menu.

For further understanding of these boundaries, we want to change the map to give an indication of the phases associated with each scan point. This can be done by making the map the active window by clicking on the window title bar and selecting the *Properties* icon off the Standard Toolbar.

In the Properties Dialog for the map, set the *Color Coded Map Type* to *Phase* and press the *Edit* button.
Because we already have some green boundaries, change the color associated with the beta phase to blue.

In the resulting map, the yellow boundaries are nearly always boundaries between the alpha and beta phases.
We can find out more information about these boundaries using the information we have learned from the highlighting procedure followed in this tutorial. Once again bring up the Map Properties Dialog. Now we want to add the information about the boundaries learned here. The first step is to select Axis/Angle from the Boundary Types list.
Hit the add button and set the Phase to Beta, the Angle to 45 degrees and the Direction to [901] as shown. Before closing this dialog, select the Segment tab and set the color to magenta.
After closing the dialog box, the boundaries will be drawn. However, the highlighting boundaries will be overlaid on the boundaries defined. To remove the highlighting, press on the Clear button on the Highlighting Toolbar.

The following map should appear. The fraction these boundaries represent of all boundaries in the Lath partition can be found in the Legend in the right-hand pane of the window. In fact, nearly 70% of the boundaries in the lath area are of this type (within our tolerance of 5 degrees).
One way to visualize these misorientations is to use Flexiview in the right hand pane of the map window. Select the Flexiview tab at the bottom of the right-hand pane of the map window. Then press the Add button and select Unit Cell Static from the pull-down menu. Repeat the procedure to get two boxes displayed in the Flexiview window pane.
You may first want to zoom in on one of the Lath regions before proceeding. With shift button down, do a left mouse click on one of the red grains and a second left mouse click on a neighboring blue grain.
Automated Highlighting: Step 1 - Grain Size Chart

Before proceeding through this stage of the tutorial, let's clean up the container of OIM Analysis by closing all of the windows in the container part of the application. In the All Data partition, double click on the IQ/Phase map if it still exists, or create one if it doesn't. Also, clear any highlighting as well. OIM Analysis should appear as follows.

The next step is to modify the properties of the All Data partition and the Titanium(Alpha) partition to include edge grains. This is done by doing a right-mouse click on the partition and selecting Properties. In the resulting properties dialog, select the Grain Size tab and turn on the Include Edge Grains checkbox.
Make sure the Titanium(Alpha) partition is active by clicking on it in the project tree. We want to make a grain size chart. The easiest way to do this is to click on the Grain Size map icon in the Quick-Gen Toolbar. However, we want to modify the properties of this chart. This is done by doing a right-mouse click in the chart pane of the window and selecting Properties from the pop-up menu. Press the Edit button in the Chart Properties dialog box. Select the Parameters tab. Change the X-Axis style to linear.

This should result in the following chart showing the grain size distribution for the alpha phase grains.
Automated Highlighting: Step 2 - Chart Highlighting

Before highlighting we need to reconfigure the Highlighting color gradient to the Rainbow type.

If we were using a much larger dataset, it may be cumbersome to use the manual approach of manually clicking on each large alpha grain. It would be nice to find a more automated approach. One approach would be to filter out the large alpha grains using a grain size criterion. Now, in the chart, click and drag a box starting at approximately a value of 1.5 on the x-axis and extending out to the maximum.

The chart and map will then be highlighted as follows.

Note that a few of the large lath grains are colored in the grayish-green color and we miss a few of the large alpha grains at the edges. This is one of the drawbacks of using an automated approach is that it is difficult to catch every feature exactly correct. However, statistically the results may be adequate. Note in the legend of the chart window that the green box just to the right of the grayish-green box, the value is 2.25. We will use this value to
demonstrate an alternative way of building partitions.
Now let's use a more quantitative approach to building a partition. First, create a new partition by selecting New>Partition form the data set pull-down menu in the project tree.

The Partition Properties dialog will be displayed. The buttons in the dialog allow for filters based on various aspects of the OIM data to be constructed using Boolean operators. In this example, we want to build a partition containing the lath areas surrounding the large alpha grains. We will do this by NOT-selecting the large alpha grains.
The first step is to limit the phase to alpha only. This is done by pressing the phase button in the dialog and selecting alpha from the phase list and setting the operator to "=" as shown below.

The resulting formula should appear as follows.

$$\text{PPH}=[\text{Titanium (Alpha)}]$$

Now we want to isolate the large grains, so hit the AND Boolean operator button followed by the Size button in the Grain Properties section of the Partition Properties dialog. We want to select grains with diameters greater
than 2.25 microns so make sure the button is pressed and enter 2.25 as shown below. It should be noted that the grain size descriptor used in this dialog is that set in the Preferences Dialog in the Settings Menu.

The resulting formula should appear as follows.

\[ \text{PPH} = \{ \text{Titanium (Alpha)} \} \land \text{GSZ} \{ 5.000, 2.0.000, 0.0, 0.8, 0.1; \} > 2.25 \]

We have set the formula to only include the large alpha grains. To select everything but these grains, move the cursor to the beginning of the formula and press the \( \text{NOT} \) button followed by the \( \land \) button. Move the cursor to the end of the formula and press the \( \text{NOT} \) button. The resulting formula should appear as follows.

\[ \text{NOT} (\text{PPH} = \{ \text{Titanium (Alpha)} \} \land \text{GSZ} \{ 5.000, 2.0.000, 0.0, 0.8, 0.1; \} > 2.25) \]

Close the Partition Properties dialog with the OK button. A new partition will now appear in the project tree. With a right mouse click on the new partition, select New>Map from the pull down menu. This will bring up the Map Properties dialog. Set the Gray Scale Map Type to Image Quality and the Color Coded Map Type to Phase. Press the Edit >> button for the Color Coded Map Type. In the resulting dialog add entries for the both the alpha and beta phase. I have selected red and blue for the color respectively in constructing the following map. Note the large alpha grains in black. The color black denotes point excluded from the partition. (The "Non-Partition" color can be set in the Preferences Dialog from the Settings Menu.) Note the fraction of each phase within the partition in the Legend Pane of the Map Window.
In order to prepare for this stage of the tutorial, clear all the highlighting and set the Highlighting Color Gradient to Rainbow. Switch the highlighting mode to Vector Profile Mode in the Highlighting Toolbar. Also turn on Record Highlighting. Make sure a map containing the large alpha grains is available. In the right pane of the map window set the view to Interactive.

In the large alpha grain at the center of the scan do a left mouse click at one end of the grain followed by a left mouse click at the right end of the grain. This will create a chart showing the misorientation profile. In the misorientation profile chart the blue curve shows the misorientation from a point on the vector to the point at the origin of the vector. The red curve shows the misorientation from a point on the vector to the previous point on the vector. The features of low IQ, which appear as boundaries in the grain appear to be low angle boundaries.
Misorientation Profile: Step 2 - Profile Analysis

To look at the low angle boundaries in the grain in more detail we will use the data appearing in the Interactive Tab in the right-hand pane of the map window. Dragging on the bar separating the map pane from the information pane will allow the interactive data to be viewed more closely. Now, let's make sure the low angle boundaries we see in the point-to-point profile correspond to the low IQ values. To do this do a right mouse click in the Interactive Tab and select properties from the pop-up menu.

This will bring up a Interactive Properties dialog box allowing the user to set which items will be displayed in the list. Modify the options to display the Misorientation angle with respect to neighbor, Distance from origin and Image Quality.
Now scroll through the list and notice that the higher misorientations are indeed accompanied by low IQ values.

The data in the list can be exported to a text file and imported into other programs such as Microsoft Excel to allow users to customize their analysis of OIM data. The text files are comma delimited and a header defines the different columns (in the example below, only the misorientation angle is shown - this can be selected from the Misorientation Representation in the Interactive Properties dialog box.
<table>
<thead>
<tr>
<th>Column 1: Color or Gradient</th>
<th>Column 2: IQ</th>
<th>Column 3: Neighboor</th>
<th>Column 4: Distance</th>
</tr>
</thead>
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<td>Blue RGB(0 255 0), 92.3, 0, 0</td>
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<tr>
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<td>Dark Blue RGB(0 95 159), 90.7, 0.2, 0.3605</td>
<td>Dark Blue RGB(0 95 159), 90.7, 0.2, 0.3605</td>
<td>Dark Blue RGB(0 95 159), 90.7, 0.2, 0.3605</td>
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<td>Dark Blue RGB(0 121 133), 87.9, 0.4, 0.4583</td>
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</tr>
<tr>
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<td>Dark Green RGB(0 191 63), 75.7, 0.6, 0.7211</td>
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</tr>
<tr>
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<td>Green RGB(22 255 0), 77.3, 0.3, 1.002</td>
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<td>Dark Green RGB(76 255 0), 60.9, 0.7, 1.249</td>
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<tr>
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<td>Dark Green RGB(102 255 0), 67.7, 2.3, 1.345</td>
<td>Dark Green RGB(102 255 0), 67.7, 2.3, 1.345</td>
</tr>
</tbody>
</table>
Twins, Cleanup & Partitioning

OIM 4 has some new features for characterizing twins. There are really two criteria for defining twins.

1) The orientation of the twin is related to the parent through a specific misorientation. For example, the primary recrystallization twin in a face-centered-cubic material is related to the parent by a 60 degree rotation about the <111> crystal direction.

2) The twinning plane must be aligned with the boundary plane separating the twin from the parent.

Twins which satisfy the first criterion but not the second are sometimes called incoherent twins. Those that satisfy both criteria are sometimes termed coherent twins. OIM is performed on a section plane through the material. The boundary plane cannot be determined from a single section plane. Three dimensional information must be obtained to reconstruct the boundary plane. Thus the alignment between the twinning plane (which can be obtained from the OIM measurements) and the boundary plane cannot be confirmed from an OIM scan on a single section plane. However, the trace of the boundary can be observed and checked against the trace of the twinning plane to confirm alignment.

(For more information see Wright, S. I. and R. J. Larsen (2002). Extracting Twins from Orientation Imaging Microscopy Scan Data. *Journal of Microscopy* 205 , 245-252.)

This tutorial shows an example of using OIM to characterize twinning using a scan from copper interconnect lines. In the process the tutorial introduces many aspects of OIM Analysis including:

- Loading scan data.
- Creating Maps
• IQ
• Confidence Index (CI)
• Grains
  Overlaying boundaries on maps (rotation angle, axis/angle, reconstructed, twins type)
  ▸ Cleanup
• Dilation
• CI Standardization
  ▸ Partitioning
• Using an explicit formula.
  ▸ Grains and Twinning
• General twins
• Coherent Twins
  ▸ Preferences Dialog
  ▸ Using the Status Bar
Step 1 - Getting Started

The first step is to create a project and load the appropriate dataset. One easy way to do this is to hit the QuickNew button on the QuickGen Toolbar. This will bring up a pop-up menu.

Select Project from the menu. To add the dataset to the project, hit the QuickNew button on the QuickGen Toolbar again and select dataset from the pop-up menu. The file open dialog will appear. Go to the folder containing the OIM Demo Data and select the file entitled Cu IC Lines.osc. In order to get a quick impression of the data create an IPF map by hitting the IPF Map button on the QuickGen Toolbar. This will produce a map that should appear as follows.
The area between the interconnect lines is both low IQ and low CI data. The data is from the silicon substrate, but in this case, the substrate does not produce indexable patterns.
Step 2 - Cleanup

In order to analyze grain boundaries it is a good idea to clean up the data points at the boundaries. When the electron beam is on a boundary, the diffracting volume can contain two crystal lattices. One for each grain on either side of the boundary. The resulting pattern will be a superposition of the patterns from both lattices. The indexing routines in OIM DC do a pretty good job of deconvoluting the pattern to identify one or the other of the orientations associated with the two grains. However, sometimes, OIM indexes the patterns with an orientation associated with neither of the grains resulting in an incorrect orientation. However, OIM Analysis has several cleanup routines to deal with these types of problems.

One very good way to clean up data at the boundaries is to use the Dilation clean up method. This method will modify the orientations of points which do not belong to any grains (in OIM grains are groups of similarly oriented and neighboring data points.) An incorrectly indexed point at a boundary would not belong to either of the grains separated by the boundary. It would be considered a grain all by itself. However, for a point or group of points to be identified as a grain in OIM it must contain some minimum number of data points. This minimum number of points can be configured by the user. For a relatively high resolution scan as this, an appropriate minimum number would be 5, this means a potential grain group would need to contain at least five points before denoting it a grain. The following grain maps show this effect. This map can be generated using the Grain Map button in the QuickGen toolbar and then using the Zoom In feature to zoom in on the Magenta/Green grain boundary. In these maps, points in white do not belong to any grains. (There appear to be a few very small grains in the area between the interconnect lines - however, these points are actually colored black - the color I have chosen to give points that could not be indexed at all.)
To perform clean-up on this data proceed as follows.

1) In the project tree, click on the dataset with the right mouse button and select Cleanup from the pop-up menu.

2) In the resulting dialog box, set the cleanup method to Dilation and set the associated parameters as follows, 5 degrees for the Grain Tolerance angle (the default), 5 for the Minimum Grain Size and make sure the Single Iteration box is checked on. Hit the OK button.
3) After hitting the OK button, the Grain Dilation cleanup procedure will commence. Once it is completed, the number of points modified will be displayed and a new dataset will be created in the project tree.
4) We need to check the grain size parameters. This is done by clicking on the All data partition icon in the project tree with the right mouse button and selecting properties from the menu. In the resulting Partition Properties dialog we need to select the grain size tab. We need to change the Minimum Grain Size to 5. This procedure should be followed for both data sets (Cu IC Lines cleaned and the original Cu IC Lines).

5) Now create a Grain map for the cleaned dataset to see the effect of the clean up procedure. The intermediate points at the grain boundaries have been removed for the most part as well as interior points in the grains. It should also be noted that the interconnect lines have widened by two points on either side of each line.
In step 2, remember we set the Cleanup to go through only one iteration. The Grain Dilation cleanup method essentially grows grains one point at a time around the perimeter. The dilation process can continue to iterate until each point in the scan is associated with an OIM grain. In this interconnect line data this would result in the lines growing into each other as shown below. (It is interesting to note, that there are grains with the same orientation in neighboring lines (e.g., the large cyan grain extends across 3 lines). This is a result of the damascene process used to form the interconnects.)
Step 3 - Isolating the IC Lines

Several methods could be used to isolate the IC lines from the substrate regions in the scan. The following shows a CI, an IQ and Grain map. The substrate region is clearly correlated with low CI, low IQ and small grains. One problem with filtering out the low CI or low IQ data is that the grain boundaries also exhibit low CI and low IQ. If we simply filter on CI or IQ, we are likely to also exclude scan points near the grain boundaries. However, there are various approaches to eliminating this problem.

We will show one approach based on a different clean up method - Grain CI Standardization. If a point with low CI is surrounded by points with similar orientation, then we are confident the correct orientation has been measured and we would want to upgrade the CI. Grain CI Standardization performs this upgrading procedure. Since a grain is a collection connected similarly oriented points, we can perform the upgrade procedure using the grains. The CIs of all points within a grain are upgraded to the CI of the point in the grain with the maximum CI. To perform the Cleanup procedure, right-click on the dataset and select Cleanup from the pull-down menu. In the Cleanup dialog, select Grain CI Standardization.

To confirm the results of the Grain CI Standardization, we will generate a new CI map. This is done by right-mouse clicking on the All data partition in the new dataset - Cu IC Lines cleaned cleaned. Select New>Map from the pull
down menu. In the Map Properties dialog set the Grayscale Map Style to Confidence Index as shown.

The new map will appear as at left in the screen shot below. Note the boundaries are no longer identified by low CI values.
Now we want to filter out the data from the substrate regions based on CI. In order to identify an appropriate cutoff value for CI, move the cursor to areas of low CI in the map and note the CI value in the status bar as shown below. Performing this procedure, a value of 0.3 was found to be appropriate. Let's create a new partition under the most recent cleaned data set as shown below. Select **Confidence Index** in the **Formula Tab** of the **Partition Properties** Dialog.

Set the Boolean operator to and enter the value of 0.3 in the **Confidence Index** dialog. The result formula should appear as follows after closing the **Confidence Index** dialog with the **OK** button.
After pressing the OK button to close the Partition Properties dialog, the new partition will be created. We can check how well the filter works by creating a new Unique Grain Color Map within the New Partition. This is easily done using the Grain Map button on the QuickGen Toolbar. In the screen shot below, I have maximized the Grain Map window.

The areas in black are those excluded from the partition. The color used to identify the points excluded from the partition can be set on the Preferences Dialog accessed from the Settings menu as shown below.
Step 4 - Twins

Recall from the introduction that incoherent twins are those twins who meet the twinning misorientation criterion. In our copper interconnect lines, these are twin boundaries that represent 60 degree rotations about <111>. In this step we will identify the boundaries that meet the misorientation criterion but not necessarily the second criterion of the twinning plane aligned with the boundary plane. We will also see the impact of using the twins in the grain grouping algorithm.

1) In the final partition created in Step 3 - Isolating the IC Lines, create an IQ image using the IQ Map button on the QuickGen Toolbar. After the map has been created open the properties dialog.

![Map Properties dialog](image)

2) Let's first draw general boundaries with misorientations greater than 2 degrees. This is done by setting Type in the Boundaries section of the Map Properties dialog to Rotation angle as shown above. Press the Add button to add a boundary to the map. In the Add Boundary dialog set the minimum misorientation to 2 degrees and switch to the Segment page of the dialog and change the color to yellow and make the boundaries fairly thick as shown below.

![Add Boundary dialog](image)
3) Now let's focus on the twin boundaries. In the Map Properties dialog, switch the boundary Type to Axis Angle and hit the Add button again. In the Add Boundary dialog set the rotation axis to <111> and the rotation angle to 60 degrees. This can be done manually or by clicking on the corresponding entry in the Twin Presets list. Leave the Tolerance set to 5 degrees.
4) Add the secondary twin by hitting the add button once again and entering $<110>$ for the rotation axis and 38.9 degrees for the rotation angle or select the secondary twin from the Twin Presets. Change the color to blue for the boundary. Now close the Add Boundary dialog and the Map Properties dialog. The resulting map should appear as follows. Using the Zoom In function once can inspect the few blue secondary twins and note they appear at triple junctions where the two boundaries are the red primary twins.

5) Now lets look at the impact of excluding these twins from the grain grouping algorithm. Two neighboring points separated by a twin boundary will be considered to belong to the same grain instead of separate grains. To do this, click on the current partition with the right mouse button and select copy document from the pop-up menu.
6) Paste the partition into the Cu IC Lines cleaned dataset using the right mouse pull-down menu at the dataset level of the project tree. This will create a copy of the partition with the low CI (CI < 0.3) point filtered out. It also copies any maps or other documents.

7) Select properties from the right mouse click pull-down menu for the new partition. We will modify the Grain Size page of the Partition Properties dialog. After selecting the Grain Size tab hit the Define button in the Twin Boundaries section. Ignore the first page of the Twin Boundaries Wizard for now by pressing the Next button. On the next page of the Twin Boundaries Wizard add the boundaries in same manner used in defining the boundaries for the map. Once the boundaries have been added, hit the Finish button followed by the OK button. The grain grouping algorithm will then operate on the scan data.

8) Now compare the Grain Maps from the two filtered partitions. (I've renamed the partitions in my example to show which is which - this can be done using pull-down menu for the partition and selecting Rename.)
Note that the twins have been excluded from the grain grouping algorithm. However, note the IC line second from the right. It is now all one single grain. This is unlikely and points to the need for looking at the second twin criterion.
Step 5 - Coherent Twins

We will now expand our definition of twins to include the alignment of the twinning plane with the boundary plane. As mentioned in the tutorial introduction, the boundary plane cannot be completely characterized using a single section plane. However, we can identify the boundary trace. In OIM boundaries appear as a set of line segments that follow the scan grid. In order to characterize the trace we would like to determine the angle the boundary trace makes with respect to some sample axis (in this case the horizontal axis in the map). If we simply use the boundary segments the angle is limited to multiples of 60 degrees. However, we can link the segments together and fit a straight line to the segments. In OIM these lines are termed Reconstructed Boundaries. We will investigate the boundaries in the scan data to see which boundaries satisfy both the twin misorientation relationship as well as the alignment in boundary and twin plane traces.

1) Create an IQ map in the partition without twins defined for the grain size calculations. Open the map properties and setup the twin boundaries similar as done before with the 60@<111> boundaries in red and the 38.9@<110> boundaries in blue. Now we also want to see all of the reconstructed boundaries. Select Reconstructed Boundaries from the Boundary Types pull down list and hit the Add button. I've made these boundaries green in the portion of the map shown below.

3) Now lets identify which of the boundaries satisfying the twin misorientation criteria (i.e. the red and blue boundaries in the above map) also satisfy the plane trace alignment criterion. Once again open the Map Properties. Set the Boundary Type to Reconstructed Twins and press Add. For the primary twin, set the rotation angle to 60 degrees, the rotation axis to <111> and the twinning plane to {111} as well. Use the default tolerances. Set the
color to magenta. For the secondary twin set the angle to 38.9 degrees, the rotation axis to <110>, twinning plane to {110} and the color to cyan. Of course the Twin Presets can be used in defining twin boundaries. This will result in the following map. Note that some of the red boundary segments are not associated with the corresponding magenta reconstructed boundaries. This means that while the grain boundary satisfies the misorientation relationship of 60 degrees about <111>, the twinning plane is not aligned with the boundary plane.

3) Now we can apply the plane trace criterion to the grain formation in OIM. First copy the most recent partition with the twins defined and paste it into the dataset. Open the Partition Properties and hit the Define button on the Grain Size page of the dialog. On the first page, check on the Enforce Trace Matching check box. Hit the Next button. On the next page, double click on each of the twin and make sure the twin planes are correct (i.e. {111} for the primary twin and {110} for the secondary). After hitting Finish for the Twin Wizard and OK for the Partition Properties dialog the grains grouping algorithm will be performed using the stricter twin criterion. The resulting grains maps should appear as follows.
While the methodology is not perfect (for reconstructed boundaries the smaller ones do not capture the trace angle very well) it gives the best approximation to the true grain size distribution.
The Technical Reference section is encyclopedic, containing documentation on most of the operations, document objects and concepts the user will encounter while using OIM™ Analysis for Windows. The entries in this section are sorted alphabetically in a flat organizational format.
Averaging - Area vs. Number

Two types of averaging are use in OIM when considering values associated with grains. One is the conventional numerical average. This is calculated as follows:

\[ \bar{v} = \frac{1}{N} \sum_{i=1}^{N} v_i \]

where \( N \) is the total number of grains and \( v_i \) is the value of the parameter of interest for grain \( i \).

Another approach to averaging is to weight the value being averaged by the area of each grain:

\[ \bar{v} = \frac{\sum_{i=1}^{N} A_i v_i}{\sum_{i=1}^{N} A_i} \]

where \( A_i \) is the area of grain \( i \).

If the grain size is uniform these two values will be quite close to one another. However, if the grains are non-uniform then these values can be quite different. Consider the following case. A scan is made up of one very large grain surrounded by a matrix of 999 smaller grains. The one large grain consumes 50% of the total scan area. The large grain has a high confidence index (say 0.8) and the small grains have, in general, low confidence indexes (say 0.2). If we use the numerical average, the average image quality would be

\[ 0.2006 = \frac{0.8 + 999 \times 0.2}{1000} \]

whereas the area weighted average would be

\[ 0.5 = \frac{0.5 \times 0.8 + 0.5 \times 0.2}{1} \]

In this case, the average CI for the "scan" is best represented the area average.

Depending on the parameter of interest, one averaging scheme may be more appropriate than the other.
Boundaries

In conventional metallography a grain boundary denotes the line separating two grains. Generally, in OIM a grain boundary refers to a line segment separating two measurement points in a scan. To completely describe a grain boundary 5 parameters are needed, two to describe the orientation of the boundary plane normal and three to describe the misorientation. The boundary plane cannot be recovered direction from OIM data. Since the OIM data is collected on a plane only a trace of the boundary can be observed. Thus, serial sectioning or other stereological approaches are needed to extract the complete boundary normal information. However, since the orientations at both points separated by the line segment are known, the misorientation associated with a line segment can be calculated.

Misorientations are similar to orientations, but instead of bringing the crystal lattice into coincidence with the sample axes, a misorientation refers instead to bringing the crystal lattice of one grain into coincidence with another grain. For any two crystal lattices of different orientation there exists a axis common to both crystal lattices. Two parameters are needed to describe the orientation of the axis with respect to the crystal reference frame (generally three are used, i.e. [uvw] but two angles can be used instead) and another parameter is needed to describe the rotation about this common axis required to bring the two crystal lattices into a coincidence. This axis/angle description is the most common for describing misorientations. However, the the misorientation can be represented as Euler Angles or Rodrigues vectors as well.

Consideration of the crystal symmetry of the two lattices separated by the boundary is important. The symbol \( g \) is often used to represent a misorientation (or alternatively disorientation or orientation difference). The misorientation \( g \) at the boundary separating two crystals with orientations \( g_A \) and \( g_B \) is given by the following expression when representing the orientations as orthogonal matrices:

\[
\Delta g = g_B g_A^{-1}, \quad \Delta g = g_B g_A^T
\]

Where the \( T \) represents the transpose. Because of symmetry a given misorientation \( g \) will have symmetrically equivalent orientations, \( g^e \). Mathematically this is given as:

\[
\Delta g = \Delta g^e = (g_B g_A^T)^e = g_B^e g_A^e = L_i^B g_B (L_j^A L_i^A)^T = L_i^B g_B g_A^T L_j^A
\]

where \( L_i^A \) and \( L_j^B \) are symmetry elements associated with the crystals A and B. For a given misorientation between two cubic crystals there 24x24 = 576 symmetrically equivalent misorientations. In addition if we also consider \( g_{AB} = g_B g_A^{-1} \) equivalent to \( g_{BA} = g_A g_B^{-1} \) then there would be 1152 symmetrically equivalent misorientations. This means that there are 1152 axis/angle pairs that can be used to describe a misorientation.

Currently in OIM there are seven ways of defining boundaries for overlaying on maps. The distribution of various parameters relating to these different boundary types can be displayed as charts.

Rotation Angle Boundary

The misorientation angle is the minimum rotation angle (out of all symmetrically equivalent possibilities - based on the axis/angle description of orientation) required to bring two lattices into coincidence. In OIM, the user may specify the range in misorientation angle for boundaries. For example, the map below is overlaid with boundaries ranging from 2 to 5 degrees in red, 5 to 15 in orange, 15 to 25 in yellow, 25 to 35 in light green, 35 to 45 in dark green and greater than 45 degrees in blue.
Rotation Axis Boundary
Boundaries can be specified by axis as well. Thus, boundaries separating crystal lattices sharing a specific axis can be highlighted. The axis (in terms of a direction \(uvw\) in the crystal frame or as a plane normal, \(hkl\)) can be specified as well as a tolerance value. The phase must also be selected. The phase is used as a reference frame for the crystal direction.

Axis and Angle Boundary
It is possible in OIM to isolate boundaries using all three misorientation parameters. For example, boundaries satisfying the twin relationship in fcc materials can be described as a 60 degree rotation about the [111] crystal
These boundaries can be highlighted in OIM.

**CSL Boundary**

Coincident Site Lattice or CSL boundaries are boundaries with a special character. These boundaries are classified in terms of $S$ values. CSL boundaries are special because they have a given fraction of atoms in the grain boundary plane which are coincident to both lattices separated by the grain boundary. The $S$ value denotes the fraction of atoms in coincidence, e.g. an $S=5$ boundary has $1$ in $5$ atoms at coincident sites as shown in the two dimensional example below. (the green dots are the coincident sites).

Currently, OIM only performs CSL analysis on materials with cubic crystal symmetry. In order to specify whether a
boundary is a CSL boundary, a tolerance is used. This is given by \( D = \frac{K}{n} \). Common values are 15 degrees for \( K \) and 1/2 for \( n \). This is the so-called Brandon's criterion. There are often multiple misorientations that can achieve a given value. For example, \( S_{33} \) can be achieved by a 20.05 degree rotation about [110], a 33.56 degrees about [311] and 58.99 about [110]. These three descriptions may be combined in the distribution. The various axis/angle descriptions corresponding to each sigma type are also listed below.

<table>
<thead>
<tr>
<th>( \Sigma ) Type</th>
<th>Angle</th>
<th>Axis</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>1 1 1</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>1 1 1</td>
</tr>
<tr>
<td>5</td>
<td>36.86</td>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>31b</td>
<td>52.20</td>
<td>2 1 1</td>
</tr>
</tbody>
</table>

### Phase Boundary
If two neighboring data points belong to different phases then a boundary segment is drawn.

### Grain Boundary
If two neighboring data points belong to two separate grains then a boundary segment is drawn.

### Reconstructed Boundary
A feature new to OIM 3.0 is the ability to create reconstructed boundaries. Automated EBSD scans are performed using a fixed grid of equispaced points. These grids are usually square or hexagonal. The boundary segments drawn between neighboring points on the grid are thus prescribed by the grid. The angles of these line segments are prescribed by the collection grid. For a square grid, the allowable angles are restricted to 0 and 90 degrees. For a hexagonal grid the allowable angles are 0, 60, 90 and 120 degrees. This limited range makes it difficult to characterize the angle a boundary normal makes with respect to the sample reference frame. The software uses a least squares fitting algorithm to reconstruct straight boundaries from the segmented boundaries prescribed by the measurement grid. An example is shown below. The distribution of the angle the boundaries (or more correctly boundary traces) make with the horizontal can be plotted in a Boundary Normal Chart. Some material properties such as fracture resistance or superplasticity are assumed to be at least partially dependent on this angle.
Reconstructed Twins
For these boundaries, both twin criteria must be specified, namely the misorientation (as a specific axis/angle pair) and the twinning plane (as well as deviations allowed for both of these criteria). This can only be done on reconstructed boundaries - not the small boundary segments.

Plane Traces
Draws a trace of a specific plane in the center of each grain in the scan. The indices of the plane must be specified. The relative size of the clusters are a function of the grain size. The relative size of the individual traces within a cluster is dependent on the inclination of the plane. (See also the section on plane traces in the highlighting section).

Boundary Planes
As described previously, two dimensions are needed to describe the boundary plane. The boundaries observed in OIM are only a trace of a boundary plane. However, in thin film sample or bamboo type microstructures it is possible to assume that the boundary plane is normal to the sampling surface. In this case, it is then possible to possible to ascertain which crystallographic plane is in coincidence with the boundary plane. The current version of OIM allows the measurements to be made using interactive highlighting. Select the boundary mode from the Interactive Highlight Toolbar. In this mode, clicking on two points defines a boundary - where the line connecting the two points defines the boundary normal and the orientations at each of the points are used to calculate the misorientation. The boundary plane is then calculated and can be displayed in the interactive view pane.
The software allows the gradients used in OIM to be modified using the following dialog box. Several presets are available, and custom defined gradients can be saved and loaded as needed.

The color at any of five locations can be modified using the pull down color palette. The two sliders allow the location for the corresponding color to be modified as well. The Save... and Load... buttons allows color gradient definitions to be saved to a file. The last gradient saved or loaded will automatically be loaded and applied when the dialog is launched.
It is also possible to use color at only the end settings to form a monochromatic gradient from one color to another as is shown in the gradient below.

It is also possible to use a single color.
Confidence Index (CI)

This parameter is calculated when during automated indexing of the diffraction pattern. For a given diffraction pattern several possible orientations may be found which satisfy the diffraction bands detected by the image analysis routines. The software ranks these orientations (or solutions) using a voting scheme. The confidence index is based on the voting scheme and is given as $CI = \frac{(V_1 - V_2)}{V_{\text{ideal}}}$ where $V_1$ and $V_2$ are the number of votes for the first and second solutions and $V_{\text{ideal}}$ is the total possible number of votes from the detected bands. The confidence index ranges from 0 to 1. (It should be noted, however, that an EBSP that could not be analyzed is assigned a CI of -1.) The confidence index can be a bit misleading. For example, a confidence index of 0 is achieved when $V_1 = V_2$, however, the pattern may still be correctly indexed. A sample study of the confidence index on an fcc material is shown in the figure below.
Crystal Direction (CD)

A direction in a crystal can be specified using the principal axes of the unit cell of the crystal structure. For example consider the simple cubic crystal shown below. A direction (OA) can be resolved by resolving the components of the direction - call them uvw - onto the principle axes a, b and c where the unit distance along these axes, a, b and c are equal to the lattice parameters. For the example direction OA, the components uvw would be 1, 0 and 1/2. The uvw are then reduced to set of integers with the same ratios, 201 in this example. Because of symmetry in the crystal lattice there may be several symmetrical equivalent directions for any given direction. The notation [uvw] is used to denote a single direction and <uvw> denotes the family of symmetrically equivalent directions. For example, in cubic symmetry there are 24 equivalent <uvw> for any given crystal direction [uvw] (e.g. uwv, wuv, vwu...).

Thus a uvw denotes a given direction relative to the crystal reference frame. However, sometimes it is desired to investigate the alignment of a given crystal direction with a given sample direction. In this case the sample direction (relative to the sample reference frame) must also be defined. For maps and charts where crystal directions are considered the following dialog is used.

![Crystal Direction Dialog](image)

When adding, inserting or modifying (by double-clicking an entry) an entry in the list the following dialog is displayed.
The direction page allows the crystal direction (denoted by uvw) and the sample direction (denoted by RD, TD, ND) to be defined. The sample reference frame is displayed in the schematic. In addition, a tolerance on the alignment between the crystal and sample directions can be defined on the tolerance page. If the phase is hexagonal or trigonal in symmetry then the direction will be entered using 4 index notation where the third index (t) is redundant, i.e., \( t = -(u+v) \) as shown below:

![Direction Page Schematic](image)
Crystal Orientation (CO)

The figure below shows a schematic of a crystal with cubic symmetry oriented in a plate of material. The term orientation describes the orientation of the principle axes of this crystal ($e^C_i$) relative to the principle axes of the sample ($e^S_i$). The Euler angles are the three rotations required to bring the principle axes of the crystal into coincidence with the principle axes of the sample. In OIM we use Bunge's description of the Euler angles. This is a so-called passive description - the rotations needed to bring the sample coordinate frame into coincidence with the crystal coordinate frame. (The converse would be the active description which would describe the rotation necessary to bring the crystal coordinate frame into coincidence with the sample frame.) In the case of Bunge's form of the Euler angles ($\gamma_1$, $F$, $\gamma_2$) this is a rotation ($\gamma_1$) about the $e^S_3$ axis followed by a rotation ($F$) about the $e^S_1$ axis followed by a third rotation ($\gamma_2$) about the $e^S_3$ axis again. The angles $\gamma_1$ and $\gamma_2$ range from 0 to $2\pi$ and $F$ ranges from 0 to $\pi$. These limits form a bounded space referred to as Euler space.

Other descriptions are available for representing orientations. These have their own sets of advantages and disadvantages. The Euler angle approach is used primarily due to convention. It has a weakness in that it is a non linear space and is ill defined as $F$ approaches 0. However, much of the mathematics developed for the analysis of orientation and the distribution of orientations in polycrystals (texture) has been developed for the Euler angle representation. Another common description is the $\{hkl\}<uvw>$ representation, where $\{hkl\}$ is the crystal plane perpendicular to the sample normal and $<uvw>$ is the crystal direction aligned with the "1" axis of the sample. This has an advantage over the Euler angle description in that it relates directly back to planes and directions in the crystal. Similar to the $\{hkl\}<uvw>$ representation, this description is easily related back to crystallographic directions in the material. For any combination of rotations of a rigid body one axis in the body remains in the same orientation during all rotations. Thus a orientation can also be described by an axis and angle of rotation about that axis. This is the Axis/Angle representation. Similarly, the Rodrigues vector defines an orientation by the rotation axis as in the Axis/Angle representation, but the vector has a magnitude, which is given by the tangent of the rotation angle divided by two. This representation is the most mathematically elegant and has received a lot of attention in recent years. In practice, all of these representations are reduced to orientation matrices and most of the calculations are done using the matrices. The following figure shows a graphical representation of some of these orientation representations.
The following summarizes the mathematical relationships between these different orientation representations.
Because of symmetry a crystal of a given orientation cannot be distinguished from a crystal in a symmetric orientation. For example, in cubic symmetry there are 24 symmetrically equivalent orientations for each orientation. Thus, the existence of symmetry reduces the size of the orientation space needed to contain all possible unique orientations to a so-called fundamental or asymmetric region. An example for cubic symmetry is shown below for

\[ g = \begin{bmatrix}
\cos \varphi_1 \cos \varphi_2 - \sin \varphi_1 \sin \varphi_2 \cos \Phi & \sin \varphi_1 \cos \varphi_2 + \cos \varphi_1 \sin \varphi_2 \cos \Phi & \sin \varphi_2 \sin \Phi \\
-\cos \varphi_1 \sin \varphi_2 - \sin \varphi_1 \cos \varphi_2 \cos \Phi & -\sin \varphi_1 \sin \varphi_2 + \cos \varphi_1 \cos \varphi_2 \cos \Phi & \cos \varphi_2 \sin \Phi \\
\sin \varphi_1 \sin \Phi & -\cos \varphi_1 \sin \Phi & \cos \Phi 
\end{bmatrix} \]

Axis Angle

A rotation about the axis \( \vec{d} = [d_1, d_2, d_3] \) is given by:

\[ g = \begin{bmatrix}
(1 - d_1^2) \cos \omega + d_1^2 & d_1 d_2 (1 - \cos \omega) + d_3 \sin \omega & d_1 d_3 (1 - \cos \omega) - d_2 \sin \omega \\
d_1 d_2 (1 - \cos \omega) - d_3 \sin \omega & (1 - d_2^2) \cos \omega + d_2^2 & d_2 d_3 (1 - \cos \omega) + d_1 \sin \omega \\
d_1 d_3 (1 - \cos \omega) + d_2 \sin \omega & d_2 d_3 (1 - \cos \omega) - d_1 \sin \omega & (1 - d_3^2) \cos \omega + d_3^2 
\end{bmatrix} \]

\[ 2 \cos \omega = \text{Trace}(g) - 1 = g_{11} + g_{22} + g_{33} - 1 \]

Rodrigues Vector

\[ R = \vec{d} \tan \frac{\omega}{2} \text{ where } |\vec{d}| = \sqrt{d_1^2 + d_2^2 + d_3^2} = 1 \]

\[(hkl)[uvw]\]

\[ h = n \sin \varphi_2 \sin \Phi = m(g_{32} - g_{23}) \]

\[ k = n \cos \varphi_2 \sin \Phi = m(g_{13} - g_{31}) \]

\[ l = n \cos \Phi = m(g_{21} - g_{12}) \]

\[ u = n'(\cos \varphi_1 \cos \varphi_2 - \sin \varphi_1 \sin \varphi_2 \cos \Phi) \]

\[ v = n'(\cos \varphi_1 \cos \varphi_2 - \sin \varphi_1 \sin \varphi_2 \cos \Phi) \]

\[ w = n' \sin \varphi_2 \sin \Phi \]

\[ \cos \Phi = \frac{l}{\sqrt{h^2 + k^2 + l^2}} \]

\[ \cos \varphi_2 = \frac{k}{\sqrt{h^2 + k^2}} \quad \sin \varphi_2 = \frac{h}{\sqrt{h^2 + k^2}} \]

\[ \sin \varphi_1 = \frac{w}{\sqrt{u^2 + v^2 + w^2}} \sqrt{\frac{h^2 + k^2 + l^2}{h^2 + k^2}} \]
the representation by Euler angles after the manner of Bunge. This fundamental region is 1/24th of the full space:
0< \phi<360, 0< \phi_1<360, 0< \phi_2<360

For maps and charts where crystal directions are considered the following dialog is used. The orientations can be represented using a variety of (hkl)<uvw>, Euler Angles or Rodrigues Vectors.

To add or modify (double-click on an entry in the list) an entry the following dialog is used. If any one element of any representation is changed the elements of the other representations are automatically updated. Thus, the user can enter the orientation using whichever representation he/she is most comfortable with.
Crystal Plane

Planes in a crystal can be defined in a manner similar to Crystal Directions. In this case the indices are termed Miller indices. This notation is used by first locating the intercepts of a plane on the axes, a, b and c. For the plane defined by BCD in the figure at right the intercepts hkl are 1/2, 3/4 and 1. Next take the reciprocals of the intercepts and clear the fractions. For the BCD plane this would produce the numbers 6, 4 and 3.

A given plane is denoted as (hkl) and a family of crystallographically symmetric planes as {hkl}. For a cubic crystal the normal to a plane (hkl) is the direction [hkl]. Thus, the precise definition of the indices used to describe planes and directions is sometimes loosely used. However, in non-cubic crystal systems, one must be precise in distinguishing between the indices used to define directions and those used to define planes.

In trigonal and hexagonal crystal systems, OIM uses 4 index notation: hkl where the i is redundant and given as i = -(h+k).
For OIM data collections systems integrated on the EDAX Phoenix or Falcon platforms it is possible to record OIM data simultaneously with EDS (Energy Dispersive Spectroscopy) data. This is only possible on microscopes where the EDS and EBSD detectors can be positioned so that they can operate simultaneously.

When the electron beam impinges on a sample it not only produces diffracted electrons but x-rays as well. The x-rays give an indication of the chemical composition of the material. Different elements scatter x-rays at different energies. Thus an x-ray spectrum like the one below is produced where the horizontal axis is for the energy and the vertical axis shows the number of x-ray counts detected at a given energy.

During an OIM scan it is possible to record the number of counts within a given energy range (or Region Of Interest) at each point in the scan. The ROI can be set up to correspond to a given element. Thus, the spatial distribution of both orientation via EBSD and elemental composition data via x-rays can be correlated together.
Elasticity

The relationship between stress and strain in the elastic regime can be expressed using generalized form of Hooke's law \[1\]

\[ \varepsilon_{ij} = S_{ijkl} \sigma_{kl} \]

where \( ij \) represents a component of the second rank strain tensor and \( kl \) is a component of the stress tensor. (Einstein notation is used in the expression where summation is assumed for repeated indices.) The \( S_{ijkl} \) are the eighty-one elastic compliance constants for the material in question. The previous expression can be expressed alternatively; the stresses can be expressed in terms of strains:

\[ \sigma_{ij} = C_{ijkl} \varepsilon_{kl} \]

In this expression, the \( C_{ijkl} \) are the elements of the fourth rank stiffness tensor for the crystal. In this expression, the indices are representative of directions in the sample. In terms of the OIM reference system, the "1" direction corresponds to RD, "2" to TD and "3" to ND. So, \( e_{33} \) refers to the strain in ND and \( \sigma_{33} \) denotes the stress parallel to ND.

In general materials behavior modeling, Hooke's law is applied assuming isotropy. If isotropy is assumed, the stiffness tensor reduces to only two unique components (i.e. the Lame constants). This is a reasonable assumption, if either the single elastic tensor is nearly isotropic (as is the case for aluminum) or if the texture of the material is nearly random. In the first order, the degree of elastic anisotropy in polycrystals is governed by two factors 1) the inherent single crystal anisotropy of the constituent grains and 2) the distribution of orientation of the constituent grains. If the material possesses a random distribution; the anisotropic nature of the constituent crystals is averaged out in the bulk making the macroscopic elastic properties isotropic. However; if the constituent crystals exhibit a preferred orientation (or texture), then the elastic anisotropy of the constituent crystals will be manifest in the macroscopic properties. If the single crystal elastic constants are known and the texture characterized, then the stiffness tensor for the polycrystal can be approximated using various averaging schemes \[2\]. For example, if OIM measurements are used to characterize the texture, the macroscopic compliance and stiffness tensors can be approximated using the so-called Voigt and Reuss averaging schemes (these actually provide bounds on the tensors):

\[
C_{ijkl}^V = \frac{1}{N} \sum_{n=1}^{N} \varepsilon_{ip}^n T \varepsilon_{jq}^n T \varepsilon_{kr}^n T \varepsilon_{ls}^n T \varepsilon_{pqrs}^n C_{ijkl}^X
\]

\[
S_{ijkl}^R = \frac{1}{N} \sum_{n=1}^{N} \varepsilon_{ip}^n T \varepsilon_{jq}^n T \varepsilon_{kr}^n T \varepsilon_{ls}^n T \varepsilon_{pqrs}^n S_{ijkl}^X
\]

Where the \( X \) denotes a single crystal tensor. The 2nd rank tensor \( g \) is the orientation matrix derived from the OIM measurements (and \( T \) denotes the transpose which is equivalent to the inverse for rotation matrices) and \( N \) is the number of measurements in the OIM scan. It should be noted that elastic tensors can also be represented as matrices[1]. This means that the Voigt compliance tensor can be inverted so that a corresponding stiffness tensor can be calculated. If this is done the Voigt and Reuss stiffness tensors can be averaged to calculate an approximate polycrystal average stiffness tensor (this is known as the Bishop-Hill average).

While characterizing the average stiffness tensor is useful to predictions of macroscopic elastic anisotropy, it is helpful to be able to characterize elastic anisotropy at the microstructural scale in order to better understand the effect of microstructure on elastic properties. Since OIM measurements provide spatially specific measurements on crystallographic orientation then if the single crystal elastic properties are also known the spatial distribution of elastic properties can be characterized. The elastic modulus at each point in the scan can be calculated and
mapped onto a color scale to help visualize local variances in elastic properties.

It is important to remember that while the stress and strain tensors are defined relative to the sample, the stiffness tensor is defined relative to the principles axes of the crystal lattice and have the same symmetry. For example, the “3” direction would represent the c-axis of a hexagonal crystal lattice. Since we know the orientation at each point in the OIM scan we can rotate the single crystal stiffness tensor into coincidence with the sample reference system according to

$$C_{ijkl}^S = g_{ip}^{n} T g_{jq}^{n} T g_{kr}^{n} T g_{ls}^{n} T C_{pqr}^X$$

where the $S$ denote the sample reference frame in this case.

In the OIM Analysis software, the “modulus” is mapped as opposed to individual elements of the stiffness tensor. This can be accomplished by defining the strain tensor. For example consider a uniaxial tensile test where the stress is applied in ND. The modulus of interest would likely be $s_{33}/e_{33}$. OIM, allows any modulus $(s_{ij}/e_{kl})$ to be calculated and mapped. See the discussion on Taylor Factor for a more detailed description of the strain states.

Bibliography


The following is a short list of single crystal elastic constants for some cubic materials and some hexagonal materials (See [3] for a more complete listing). These are given in matrix form. OIM performs the conversion to the 4th rank tensor.

Cubic Materials

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<tr>
<th>Material</th>
<th>Notes</th>
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<th>C44</th>
<th>C12</th>
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Pb, Lead & 48.8 & 14.8 & 41.4 \\
Li, Lithium & 13.4 & 9.6 & 11.3 \\
Mo, Molybdenum & 459 & 111 & 168 \\
Ni, Nickel & Saturation & 249 & 124 & 152 \\
Nb, Niobium & & 245 & 28.4 & 132 \\
Pd, Palladium & & 224 & 71.6 & 173 \\
Pt, Platinum & & 347 & 76.5 & 251 \\
K, Potassium & & 3.71 & 1.88 & 3.15 \\
Rb, Rubidium & & 2.96 & 1.9 & 2.44 \\
Si, Silicon & & 165 & 79.2 & 64 \\
Ag, Silver & & 123 & 45.3 & 92 \\
Na, Sodium & & 7.59 & 4.3 & 6.33 \\
Sr, Strontium & & 14.7 & 5.74 & 9.9 \\
Ta, Tantalum & & 262 & 82.6 & 156 \\
Tl, Thallium & & 40.8 & 11 & 34 \\
Tl, Thallium & & 47.7 & 11.2 & 40.5 \\
Th, Thorium & & 75.3 & 47.8 & 48.9 \\
W, Tungsten & & 517 & 157 & 203 \\
V, Vanadium & & 230 & 43.2 & 120 \\

**Hexagonal Materials**

<table>
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<tr>
<th>Material</th>
<th>Notes</th>
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<th>C44</th>
<th>C44</th>
<th>C12</th>
<th>C13</th>
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</tr>
<tr>
<td>Quartz</td>
<td>§-SiO2 873K (piezoel.)</td>
<td>117</td>
<td>110</td>
<td>36</td>
<td>16</td>
<td>33</td>
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<td>624</td>
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<td>240</td>
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<td>105</td>
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<td>Sc</td>
<td>Scandium</td>
<td>99.3</td>
<td>107</td>
<td>27.7</td>
<td>39.7</td>
<td>29.4</td>
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<td>AgI</td>
<td>Silver iodide (piezoel.)</td>
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<td>35.4</td>
<td>3.73</td>
<td>21.3</td>
<td>19.6</td>
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<td>Terbium</td>
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<td>21.4</td>
<td>24.3</td>
<td>23</td>
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<td>75.9</td>
<td>23.7</td>
<td>22.3</td>
<td>15.9</td>
</tr>
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<td>Thallium</td>
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<td>52.8</td>
<td>7.26</td>
<td>35.4</td>
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<td>160</td>
<td>181</td>
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<td>90</td>
<td>66</td>
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<td>TiB2</td>
<td>Titanium diboride</td>
<td>690</td>
<td>440</td>
<td>250</td>
<td>410</td>
<td>320</td>
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<tr>
<td>Y</td>
<td>Yttrium</td>
<td>77.9</td>
<td>76.9</td>
<td>24.3</td>
<td>29.2</td>
<td>20</td>
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<tr>
<td>Zn</td>
<td>Zinc</td>
<td>165</td>
<td>61.8</td>
<td>39.6</td>
<td>31.1</td>
<td>50</td>
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<td>ZnO, Zincite</td>
<td>Zinc Oxide (piezoel.) E</td>
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<td>209.5</td>
<td>44.8</td>
<td>117.7</td>
<td>106.1</td>
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<tr>
<td>ZnO, Zincite</td>
<td>Zinc Oxide (piezoel.) D</td>
<td>209.6</td>
<td>221</td>
<td>46.1</td>
<td>120.4</td>
<td>101.3</td>
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<tr>
<td>ZnSe</td>
<td>Zinc Selenide</td>
<td>107</td>
<td>116</td>
<td>25</td>
<td>45</td>
<td>35</td>
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<td>ZnS, Wurtzite</td>
<td>alpha-Zinc Sulfide (piezoel)</td>
<td>122</td>
<td>138</td>
<td>28.7</td>
<td>58</td>
<td>42</td>
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<tr>
<td>ZnTe</td>
<td>Zinc telluride</td>
<td>86</td>
<td>93</td>
<td>20.2</td>
<td>37</td>
<td>30</td>
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<tr>
<td>Zr</td>
<td>Zirconium alpha</td>
<td>144</td>
<td>166</td>
<td>33.4</td>
<td>74</td>
<td>67</td>
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<tr>
<td>Zr-O</td>
<td>Zirconium Oxygen 7 at % O</td>
<td>153</td>
<td>176</td>
<td>46</td>
<td>67</td>
<td>78</td>
</tr>
<tr>
<td>Zr-O</td>
<td>Zirconium Oxygen 8 at % O</td>
<td>154</td>
<td>179</td>
<td>49</td>
<td>62</td>
<td>79</td>
</tr>
<tr>
<td>Zr-O</td>
<td>Zirconium Oxygen 24 at % O</td>
<td>202</td>
<td>242</td>
<td>75</td>
<td>57</td>
<td>101</td>
</tr>
</tbody>
</table>
A "Fit" parameter is determined as part of the indexing procedure. This is done by calculating where the bands should appear based on the orientation obtained from the voting procedure. The fit parameter defines the average angular deviation between the recalculated bands and the detected bands. An example is shown below for a pattern with a good fit (0.28 degrees) and a pattern with a poor fit (2.08 degrees). It can be tempting to think of the fit as a measure of angular resolution. This would only be true if the orientation of the sample were already known somehow and could be compared to that obtained by the indexing routine. Several variables come into play in determining the fit. For example, the indexing of the pattern, the band detection routine as well as the calibration.
Grains in OIM

While the concept of a grain in conventional metallography is commonly understood, the definition of a grain in an OIM scan is slightly different. Grains in OIM are formed by an algorithm that groups sets of connected and similarly oriented points into "grains". For each point in the OIM scan, the neighbors of this point are checked to see if they are within the Grain Tolerance Angle of the given point. If a neighboring point is found to be within the tolerance angle then the neighbors of this point are checked to see if they are within the tolerance angle of this point. The procedure is repeated over and over again until the set of connected grains is bounded by points, which exceed the tolerance angle to their neighbors. Using this approach, the point to point misorientation in a "grain" will be quite small but the spread of orientation among all points in the "grain" can be relatively large. The number of points required to decide whether a given group of points should be considered a "grain" group (the Minimum Grain Size) can be specified by the user along with the Grain Tolerance Angle. Thus, the definition of a grain in OIM can vary depending on user-specified values. An example is shown below. In the figure on the left the Grain Tolerance Angle used was 3 degrees and 15 degrees for the figure on the right. These parameters are set using the Grain page in the partition dialog.

Grain Size
Grain size can be mostly simply specified as the number of data points contained within a grain. Alternatively the grain size may be specified by area. The area is calculated by summing up the number of points in a grain multiplied by the product of the square of the step size and a factor depending on the type of scanning grid. For square grids the factor is one and for hexagonal grids the factor is the one half times the square root of 3. The grain size may also be specified by diameter. The diameter of a particular grain is calculated by determining the area of a grain and then assuming the grain is a circle. The diameter is then equal to 2 times the square root of the area divided by . The ASTM number is given by \( G = -3.3223 \log_{10}(A) - 2.955 \) where \( A \) is the grain area given in square mm. (See G. F. Vander Voort (1999), Metallography Principles and Practice, Materials Park, OH: ASM International, pp. 442-446)

Grain Shape
Grain shape is determined by fitting an ellipse to the points making up a grain as shown below. One measure of the shape is the aspect ratio. The aspect ratio is defined as the length of the minor axis divided by the length of the
major axis and thus ranges from 0 to 1. The grain shape orientation is defined as the angle between the major axis of an ellipse fit to a grain and the horizontal direction as shown as in the figure below.

![Grain Shapes](image)

**Grains Shape Calculation Methods**

Three methods are available for fitting the ellipse to the grains.

**Method 1 - Least Squares**

Least squares approach adapted from S. Biggin and D. J. Dingley, Journal of Applied Crystallography (1977) 10, 376-385. The governing equation is:

\[
A x_i^2 + 2Hx_i y_i + By_i^2 + 2Gx_i + 2Fy_i + C = 0
\]

where \(x_i, y_i\) are the coordinates of each boundary segment endpoint for all of the boundaries surrounding the grain. The goal is to minimize the squared error, \(E\), between the proposed ellipse and all of the boundary endpoints, \(x_i, y_i\).

\[
E = \sum_{i=0}^{N} (A x_i^2 + 2Hx_i y_i + By_i^2 + 2Gx_i + 2Fy_i + C)^2
\]

Where \(N\) is the number of boundary endpoints. The partial of \(E\) is then taken with respect to each of the coefficients and set to 0. e.g. for the \(A\) coefficient:

\[
\frac{\partial E}{\partial A} = 0 = 2 \sum_{i=0}^{N} (A x_i^2 + 2Hx_i y_i + By_i^2 + 2Gx_i + 2Fy_i + C)x_i^2
\]

This results in the following set of linear equations.

\[
\begin{bmatrix}
\sum x_i^4 & 2 \sum x_i^3 y_i & \sum x_i^2 y_i^2 & 2 \sum x_i^2 y_i & 2 \sum x_i^3 \\
2 \sum x_i^3 y_i & 2 \sum x_i^2 y_i^2 & \sum y_i^4 & 2 \sum y_i^3 & 2 \sum y_i^2 \\
\sum x_i^2 y_i & 2 \sum x_i y_i^2 & \sum y_i^2 & 2 \sum y_i & 2 \sum y_i \\
2 \sum x_i y_i^2 & \sum y_i & 2 \sum y_i & 2 \sum y_i^2 & 2 \sum y_i \\
\sum x_i^3 y_i & 2 \sum x_i^2 y_i & \sum x_i y_i^2 & 2 \sum x_i y_i & 2 \sum x_i^2 y_i & 2 \sum x_i^3 y_i
\end{bmatrix}
\begin{bmatrix}
A \\
H \\
B \\
F \\
G
\end{bmatrix}
= \begin{bmatrix}
\sum x_i^2 \\
\sum y_i^2 \\
\sum y_i \\
\sum y_i \\
\sum x_i y_i
\end{bmatrix}
\]


The angle the major axis makes with respect to the horizontal direction, \(\gamma\), is given by:

\[
\gamma = \frac{1}{2} \tan^{-1} \frac{2H}{A - B}
\]

The coordinates at the center of the ellipse are given by:

\[
\bar{x} = \frac{HF - BG}{AB - H^2}
\]

and
\[
\bar{y} = \frac{GH - AF}{AB - H^2}
\]

To calculate the lengths of the major and minor axes, \(a\) and \(b\) respectively, the first step is to transform the \(x_i, y_i\) coordinates into the reference frame of the ellipse.

\[
x_i' = (x_i - \bar{x}) \cos \gamma + (y_i - \bar{y}) \sin \gamma
\]
\[
y_i' = -(x_i - \bar{x}) \sin \gamma + (y_i - \bar{y}) \cos \gamma
\]

Now consider the equation of an ellipse:

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1
\]

The squared error, \(E\), is then given by:

\[
E = \sum \left[1 - \frac{x_i'^2}{a^2} - \frac{y_i'^2}{b^2}\right]
\]

Taking the partial derivatives of \(E\) with respect to \(a^2\) and \(b^2\) and setting them to zero results in the following set of linear equations.

\[
\begin{align*}
\sum_{i=1}^{N} x_i'^4 & = \frac{\sum_{i=1}^{N} x_i'^2 y_i'^2}{\sum_{i=1}^{N} y_i'^4} \\
\sum_{i=1}^{N} x_i'^2 y_i'^2 & = \frac{\sum_{i=1}^{N} x_i'^2}{\sum_{i=1}^{N} y_i'^4}
\end{align*}
\]

The linear solver is used again to solve for \(a^2\) and \(b^2\).

**Method 2 - Major = Maximum Distance, Minor = averaging scheme**

The distance, \(d_{ij}\), between each endpoint of each boundary segment, \(x_i, y_i\), is calculated:

\[
\begin{align*}
d_{ij} &= \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \\
\end{align*}
\]

The maximum value of \(d_{ij}\) is then assumed to be equivalent to the length of the major axis, \(a\), of the ellipse. The angle the major axis makes with respect to the horizontal direction, \(\gamma\), is given by:

\[
\gamma = \tan^{-1} \frac{y_j \text{max} - y_i \text{max}}{x_j \text{max} - x_i \text{max}}
\]

Where \(x_j \text{max}, y_j \text{max}\) and \(x_i \text{max}, y_i \text{max}\) are the coordinates of the two boundary endpoints, which are the maximum distance apart. The coordinates at the center of the ellipse are given by:

\[
\bar{x} = \sum_{k} x_k
\]

and

\[
\bar{y} = \sum_{k} y_k
\]

where \(x_k\) and \(y_k\) are the coordinates of all data points contained in the grain. To calculate the length of the minor axis, \(b\), the first step is to transform the \(x_i, y_i\) coordinates into the reference frame of the ellipse.

\[
x_i' = (x_i - \bar{x}) \cos \gamma + (y_i - \bar{y}) \sin \gamma
\]
\[
y_i' = -(x_i - \bar{x}) \sin \gamma + (y_i - \bar{y}) \cos \gamma
\]

The length of the minor axis, \(b\), is then calculated using the following averaging scheme.

\[
b = \frac{1}{N} \sum_{i=1}^{N} \sqrt{\frac{y_i'^2}{(1 - x_i'^2 / a^2)}}
\]

**Method 3 - Major = Maximum Distance, Minor = enforce size**
The distance, \( d_{ij} \), between each endpoint of each boundary segment, \( x_i, y_i \), is calculated:

\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}
\]

The maximum value of \( d_{ij} \) is then assumed to be equivalent to the length of the major axis, \( a \), of the ellipse. The length of the minor axis, \( b \), is calculated using the following expression:

\[
b = \frac{A}{\pi a}
\]

Where \( A \) is the area of the grain calculated by summing up the number of data points within the grain multiplied by the scan step size squared for a square scan grid or the scan step size squared times the square root of 3 divided by 2 for a hexagonal grid.

The angle the major axis makes with respect to the horizontal direction, \( \gamma \), is given by:

\[
\gamma = \tan^{-1} \left( \frac{y_j^{\max} - y_i^{\max}}{x_j^{\max} - x_i^{\max}} \right)
\]

Where \( x_i^{\max}, y_i^{\max} \) and \( x_j^{\max}, y_j^{\max} \) are the coordinates of the two boundary endpoints, which are the maximum distance apart. The coordinates at the center of the ellipse are given by:

\[
\bar{x} = \sum x_k
\]

and

\[
\bar{y} = \sum y_k
\]

where \( x_k \) and \( y_k \) are the coordinates of all data points contained in the grain.

**Grain Averages**

The average image quality, confidence index, fit and video signal can be calculated for each grain. This is simply done by summing the parameter of interest for each data point within the grain and then dividing by the number of points in the grain.

**Orientation Spread**

In 3.x versions, the orientation spread in a grain was determined by calculating the misorientation (angle) between all points in the grain. The orientation spread is the average misorientation value. In the 4.0 version the calculation was changed to first calculate the average orientation for each grain. The spread is then the average deviation between the orientation of each point in the grain and the average orientation for the grain. These values are nearly the same. (See also Local Misorientation Measures)

**Average Misorientation**

The average misorientation is the average misorientation (angle) between all neighboring pairs of points in the grain. (See also Local Misorientation Measures)
Hexgonal Orientation Definition

OIM uses the following definition for the orientation of a hexagonal (and trigonal) crystal.

![Hexagon Diagram]

A second definition is sometimes used in the literature as well.

![Alternative Hexagon Diagram]

In pole figures and inverse pole figures, the definition used is accounted for. However, in ODF plots, there is a 30 degree difference between the two definitions. This can be important when comparing ODFs calculated with OIM with ODFs in the literature. There will be a 30 degree shift in the phi2 angle.
The image quality parameter or IQ describes the quality of an electron backscatter diffraction pattern. While the IQ is dependent on the material and its condition, it is not an absolute value but a function of the technique and parameters used to index the pattern as well as other factors such as the video processing. The left-hand pattern below has a higher IQ than the right-hand pattern.

The factor affecting the quality of diffraction patterns of most interest, from a materials science standpoint, is the perfection of the crystal lattice in the diffracting volume. Thus, any distortions to the crystal lattice within the diffracting volume will produce lower quality (more diffuse) diffraction patterns. This enables the IQ parameter to be used to give a qualitative description of the strain distribution in a microstructure. (A good example in the literature is S.T. Wardle, L. S. Lin, A. Cetel and B.L. Adams, “Orientation Imaging Microscopy: Monitoring Residual Stress Profiles in Single Crystals using an Image-Quality Parameter, IQ” in Proc. 52nd Annual Meeting of the Microscopy Society of America, eds. G. W. Bailey and A.J. Garratt-Reed, San Francisco Press: San Francisco (1994) pp. 680-1.) However, the IQ parameter has some dependence on orientation. Thus, the IQ cannot be used to distinguish small differences from grain to grain in strain. Nonetheless, the IQ is useful for gaining some insight into the distribution of strain in a microstructure. The picture below shows an example of an IQ map (a map formed by mapping the IQ obtained for each point in an OIM scan onto a gray scale.) Darker gray shades in the image denote lower IQ values.

Three interesting features appear in this map. The first are the precipitates at the grain boundaries. The weaker patterns from these points may be due to a difference in the elements present. The quality of diffraction patterns is not only affected by the crystal lattice but the material itself as well. Elements with higher atomic numbers generally
produce stronger patterns due to increased scattering. Thus scans on multiphase specimens will show contrast in the IQ map simply due to the different phases present. However, the weak patterns in this case were probably due to some other effects, namely the precipitates were small relative to the resolution of the technique and possible topographic effects (a rough surface will also produce variations in IQ due to the deviation in the surface plane from the ideal 70 degree tilt for diffraction). Another feature that is readily apparent in the IQ map is the presence of grain boundaries. When the electron beam is situated near a grain boundary the diffraction volume may contain both crystal lattices separated by the boundary. Thus, the diffraction pattern will be composed of a mix of both patterns leading to a lower quality pattern. The feature of most interest in this map is areas that appear to be of high dislocation density. A microhardness indent was made just beyond the bottom right corner of the scan area. The "waves" of darker gray areas within the grains are likely to be areas of higher dislocation density. It is interesting to note that deformation is not uniformly spread within the grains or does not diminish uniformly away from the indent.

The IQ parameter is the sum of the detected peaks in the Hough transform. Thus, any parameters that effect the operation of the Hough Transform would effect the resulting IQ parameter calculation. In addition, changing conditions in the microscope or video processing (such as simply changing the contrast and brightness) will also affect the IQ values. Similarly, the orientation independence is introduced into the calculation due to the fact that different bands of varying intensity will appear depending on the orientation.
Inverse Pole Figure (IPF)

An inverse pole figure shows the position of a sample direction relative to the crystal reference frame. The user enters the sample direction to consider by entering indices defining a vector by components of the sample's axes (RD, TD and ND). Thus, a [001] inverse pole figure shows which crystal direction in the crystal lattice is aligned with the normal (ND) of the sample reference frame (as defined by RD, TD & ND).

Consider a cubic crystal in a rolled sheet sample with "laboratory" or "sample" axes as shown below.

The example below is a normal direction inverse pole figure. In the full pole figure all symmetrically equivalent points are shown. In the unit triangle only one unique orientation is shown. Because of symmetry each orientation or misorientation will produce several points at symmetrically equivalent locations in the plot. The number of equivalent points shown will be related to the portion of the space shown. For example, consider an inverse pole figure discrete plot for cubic crystal symmetry as shown in the figures below. If the inverse pole figure is plotted using only the unit triangle, then only one point per orientation will appear in the plot. However, if the unit triangle is not used then 24 equivalent points will be plotted.

While OIM does not consider improper rotations when indexing patterns some materials may have symmetry containing improper rotations. This can be accounted for when plotting inverse pole figures. An example of these effects is shown below for a crystal of cubic symmetry. The left-hand inverse pole figure is excludes improper rotations whereas the right hand inverse pole figure includes them. The open circles are points in the negative hemisphere.
Local Misorientation Measures

On good indicator of strain in crystalline materials are local variations in misorientations. OIM Analysis has several tools for characterizing local misorientation. There are essentially two types of local misorientation analyses in the software: 1) Grain based and 2) Kernel based. The Grain based functions are helpful for identifying grains with varying local misorientation or the local orientation variations within a grain. However, these functions are all quite dependent on the parameters used to define a grain. Kernel based functions are based on a given area - the size of which will be defined by the user.

Grain Based

Three types of grain based local misorientations are available within OIM.

Grain Average Misorientation. In this mode each point in the grain is shaded the same color in maps of this type. The misorientation between each neighboring pair of points within the grain is calculated. The average misorientation value is then determined and assigned to each point within the grain.(see also Grains in OIM)

Grain Orientation Spread. In this mode each point in the grain is shaded the same color in maps of this type. The average orientation of the grain is calculated. The misorientation between this average orientation and the orientation of each individual measurement point within the grain is calculated. The average or these misorientations is then determined and assigned to each point within the grain. (see also Grains in OIM)

Grain Reference Orientation Deviation. Maps constructed using this method are quite helpful in visualizing the distribution of local misorientation within a grain. The average orientation for the grain is calculated. Each point is shaded according the misorientation it makes relative to the average for the grain. Alternatively instead of using the average orientation of the grain as the reference, the point within the grain with the smallest kernel average misorientation (see below) is used.

Kernel Based

Local misorientation can be characterized using a misorientation kernel approach. For a given point the average misorientation of that point with all of its neighbors is calculated with the proviso that misorientations exceeding some tolerance value (Maximum misorientation) are excluded from the averaging calculation as shown in the example below.
There are three methods in the software for kernel based analysis

**Kernel Average Misorientation.** In this mode, the misorientation between a grain at the center of the kernel and all points at the perimeter of the kernel are measured. The local misorientation value assigned to the center point is the average of these misorientations. An option is available to use only the points at the perimeter of the kernel or to use all the points in kernel.

**Local Average Misorientation.** In this method, the average misorientation between all neighboring points within the kernel area are measured and the average calculated (excluding misorientation exceeded a maximum value set by the user. This is essentially the approach outlined by E. M. Leheckey, Y.-P. Lin and O. E. Lepik (2000). Mapping Residual Plastic Strain in Materials Using Electron Backscatter Diffraction. *Electron Backscatter Diffraction in Materials Science*. A. J. Schwartz, M. Kumar and B. L. Adams. New York, Kluwer Academic/Plenum Publishers: 247-264.

**Local Spread.** The magnitude of the kernel average misorientation will be affected by the scan step size. One way to overcome this is to calculate a spread. In the approach implemented here the misorientation between each point in the kernel and all others in the kernel is calculated. The average value for the kernel is determined (excluding the misorientations exceeding the maximum value set by the user.) This is similar to calculating the average orientation for a kernel and then finding the average deviation of each constituent point with the kernel average orientation. However, the approach implemented here overcomes the difficulty of multiple kernel average
orientations for kernels straddling grain boundaries. However, be forewarned that the calculation is quite time consuming.
Memory

OIM Analysis can require large amounts of memory, particularly for large datasets. A small utility is included with OIM Analysis 5.1. It should appear as "Toggle Virtual Memory for OIM Analysis" on the Start Menu under TexSEM. It is located in the OIM Analysis bin directory. This utility chances some system properties to allows OIM Analysis to expand into the virtual memory more than what is generally enabled. This allows OIM Analysis to open very large datasets. Of course, when opening very large data sets it is generally wise not to load the Hough peak data.

Requirements

- The computer must be running Windows XP
- A version of OIM Analysis that has been modified to recognize the memory increase

Potential Problems

- Some video drivers for video cards with a lot of memory will fail on startup
- System man see decreased performance in general.
Orientations can be plotted as two dimensional projections in pole figures. Such figures can be useful for simplifying the analysis of the orientation distribution. A pole figure shows the position of a pole (a normal to a lattice plane) relative to the sample reference frame (as defined by RD, TD & ND).

Consider a cubic crystal in a rolled sheet sample with "laboratory" or "sample" axes as shown below.

The example below is a (001) pole figure. Note the three points shown in the pole figure are for three symmetrically equivalent planes in the crystal. (The clear points correspond to point extending into the bottom half of the sphere.)
Plot Sections

Orientations are inherently three dimensional. Thus to plot a set of orientations requires a method of representing three dimensions in two. This is done using two dimensional sections through the three dimensional space. To facilitate the description on how this is done we will focus on representing crystallographic orientation by Euler angles after the formalism of Bunge. We will return to other representations at a later point. Euler angles describe the rotation required to bring the sample coordinate system into coincidence with the crystal coordinate frame. The space containing all possible orientations defined as Euler angles is Euler space. The space can be thought of as a bounded rectangular volume. The three axes of the rectangular volume are the three Euler angles. A schematic is shown below along with sections through the space. In this example the constant angle sections are those along $\phi_1$. If 36 sections were used, then the first section would be located at $\phi_1 = 5$ degrees and would contain all orientations within $0 < \phi_1 < 10$ degrees.

![Schematic of Euler space](image)

The following example shows a discrete plot of individual orientations and the corresponding texture plot in a subregion of Euler space ($0 < \phi_1 < 90$, $0 < \phi_2 < 90$, $0 < \phi_3 < 90$).
The following is a reconstruction of the plot sections with color to convey depth in the discrete case and some layers have not been included in the texture plot case to avoid occlusion of detail. While such plots may be visually appealing, the individual sections give much more detail.
In OIM the user is allowed to section along any of the angles for Euler space. To set up the sections the following portion of a dialog box is used.

- **Section Configuration**
  - Angle 1
    - Constant
    - Vertical
    - Horizontal

- **Vertical Range**
  - The range is 0° to 90°
  - Minimum: 0
  - Maximum: 90

- **Horizontal Range**
  - The range is 0° to 90°
  - Minimum: 0
  - Maximum: 90
**Section Configuration**: Tells OIM how to section up Euler Space. The three angles 1, 2 and 3 refer to \( (\theta_1, \theta_2, \theta_3) \) for Bunge's Euler angles and \( (\phi, \theta, \lambda) \) for Roe and \( (\phi, \theta, \psi) \) for Kocks. The matrix of radio buttons is to define along which angle the constant angle sections should be made. Which of the other two axes should appear vertical in the plot and which should define the horizontal.

**Ranges**: These define the range of Euler space to consider when plotting for the angles defining the vertical and horizontal axes. The range on the constant angle is set in the Section part of the Discrete Plot Properties dialog as shown below.

For individual sections the range covered by the section is set using the following dialog.

![Add Section Dialog](image)

For other spaces the sectioning is fixed. In Rodrigues space the sections are always done about the 3rd component of the Rodrigues Vector, \( R_3 \). For axis angle space, the sectioning is always done on the angle. For axis angle instead of horizontal and vertical axes the azimuthal and polar angles of the projection are used. Schematics of the sectioning of these spaces are shown below. (The Rodrigues Space example is for cubic crystal symmetry.)
Projection (Stereographic, Equal Area, Equal Angle)

In pole figures, inverse pole figures and Axis/Angle MDF sections three different methods for plotting the 2-dimensional projections of the 3-dimensional orientation data are available. The projections types include stereographic, equal area and equal angle. The Equal Angle is not a true projection method but a simple mapping that is sometimes used. The Stereographic projection expands any features near the outside edges of the plot; whereas, the Equal Area projection expands detail at the center of the plot. Examples of the different types are shown below for a (111) intensity pole figure.

A schematic of the projection methods is shown below:
In conventional OIM measurements, boundary segments follow the prescribed scanning grid. Thus, the angles of the boundary segments are restricted to those prescribed by the scan grid. For example, if a regular hexagonal grid is used, the boundary segments are limited to 0, 120 and 240 degrees as shown in the following. The goal is to reconstruct a boundary trace from the boundary segments that matches the actual boundary angle as closely as possible.

The first step in reconstructing the boundaries from the OIM measurements is to group neighboring and similarly oriented measurement points together to form "grains".

The second step in generating the reconstructed boundaries is to identify which boundary segments can be grouped together to form "reconstructed" boundaries. Once each point has been identified with a particular grain, triple points need to be identified. Triple points are defined as points in the network of grain boundary segments where the three surrounding orientation measurements belong to three different grains. One of the three boundary segment paths emanating from a triple point is followed until the next triple point along the path is discovered.
The two triple points then define a reconstructed boundary as shown in the first figure. However, since boundaries are not always perfectly straight lines, the reconstructed boundary may be segmented to follow the boundary segment path more closely. This is done by finding the point on the segment path farthest from the reconstructed boundary. If the perpendicular distance between this point and the reconstructed boundary exceeds some tolerance distance, then the reconstructed boundary is split into two line segments. The endpoints of the two line segments are the original triple points and the common endpoint is that point on the segment path farthest from the original reconstructed boundary. This procedure is repeated until all points on the boundary segment path are within the tolerance distance from the reconstructed boundary segments. This procedure is illustrated below.

At this juncture in creating the reconstructed boundaries, the reconstructed boundary is simply defined by its endpoints. This allows the angle of the reconstructed boundary to be calculated as well as the length. In addition to
the geometrical parameters, a boundary also separates grains of a specific orientation. Thus, each boundary also has two orientations associated with it. In OIM, these two orientations are the average orientations calculated from all of the points in the two neighboring grains.

There are two limitations to the methodology used in generating the reconstructed boundaries. First, it only applies to data collected on a hexagonal grid. Second, since the reconstructed boundaries connect triple points, boundaries around interior grains cannot be reconstructed due to the lack of triple points.
Reference System

The reference system in OIM is set up such that the first axis of the system or Reference Direction (RD) is down the tilted direction of the sample as shown below, the third axis is the Sample Normal direction (ND) and the second axis is the Transverse Direction or TD. This notations RD-TD-ND is used in the analysis software to define directions in the sample reference frame.
Sample Direction (RD, TD & ND)

A direction can be specified with respect to the sample coordinates (RD, TD & ND) just like it can be specified with respect to the crystal coordinates (i.e. [uvw] is with respect to [100], [010] and [001]). For example the 001 sample direction denotes the ND or normal direction. A schematic of the geometry for imaging electron backscatter diffraction patterns is shown below. The important thing to note in this figure is the definition of sample reference frame as this is used throughout the OIM software. The axes defining the reference system are RD (reference direction) for the “1” axis, TD (transverse direction) for the “2” axis and ND (normal direction) for the “3” axis. ND is a direction normal to the sample surface; RD is parallel to the direction of tilt of the sample. In maps generated by OIM the horizontal or x direction is from left to right and corresponds to the horizontal direction or TD on the sample. The vertical direction in these maps is from top to bottom and corresponds to the tilt direction of the sample in the microscope or RD.
Symmetry

Crystal Symmetry

The symmetry of a crystal refers to rotations of the unit cell, which produce a rotated structure that cannot be distinguished from the original structure prior to the rotation. For example, in the case of a cubic crystal, a rotation of 90 degrees about one of the principle axes of the cube would produce a structure that is crystallographically equivalent to the original structure prior to the rotation. For cubic crystals there are 24 such rotations. A sampling of these are shown below:

Sample Symmetry

Some samples may exhibit sample or statistical symmetry. Sample symmetry is generally imposed on a material by the processing conditions used to form a material. An example would be rolled sheet. Rolled sheet generally exhibits orthotropic sample symmetry. A two dimensional example is shown below.

In a rolled piece of material we would expect to see the same number of crystals oriented as in the left hand figure as in the right, thus, this symmetry is referred to as statistical symmetry.
Deformation in Polycrystals

Many metals, ceramics and geological materials are polycrystalline in their natural state. That is, we can view them as an aggregate of many small crystals (grains). The constituent grains each have a different lattice orientation with respect to one another (and with respect to some sample reference frame). Most polycrystalline materials (at ordinary temperatures) deform by slip in the individual grains. Slip occurs on specific crystallographic planes in specific crystallographic directions. The slip planes are generally planes of high atomic packing density. The following table lists the characteristic slip systems for some selected materials.

<table>
<thead>
<tr>
<th>Material Class</th>
<th>Primary System</th>
<th>Secondary Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face-centered cubic metals</td>
<td>(111) &lt;110&gt;</td>
<td></td>
</tr>
<tr>
<td>Body-centered cubic metals</td>
<td>(110) &lt;110&gt;</td>
<td>(112) &lt;1120&gt;</td>
</tr>
<tr>
<td>Hexagonal close-packed metals</td>
<td>(0001) &lt;1120&gt;</td>
<td>(1010) &lt;1120&gt;</td>
</tr>
<tr>
<td>(e.g. Be, Cd, Zn and Mg)</td>
<td></td>
<td>(1122) &lt;1123&gt;</td>
</tr>
<tr>
<td>Hexagonal close-packed metals</td>
<td>(1010) &lt;1120&gt;</td>
<td>(1010) &lt;1120&gt;</td>
</tr>
<tr>
<td>(e.g. Zr, Ti and Hf)</td>
<td></td>
<td>(1122) &lt;1123&gt;</td>
</tr>
<tr>
<td>Diamond cubic (fcc) (e.g. Si, Ge and diamond)</td>
<td>(111) &lt;110&gt;</td>
<td></td>
</tr>
<tr>
<td>Rock Salt (fcc) (e.g. MgO, LiF, NaCl)</td>
<td>(110) &lt;110&gt;</td>
<td></td>
</tr>
<tr>
<td>CsCl (simple cubic)</td>
<td>(110) &lt;001&gt;</td>
<td></td>
</tr>
<tr>
<td>Al2O3 (hexagonal)</td>
<td>(0001) &lt;1120&gt;</td>
<td>(1120) &lt;1101&gt;</td>
</tr>
<tr>
<td>BeO (hexagonal)</td>
<td>(0001) &lt;1120&gt;</td>
<td>(1120) &lt;1101&gt;</td>
</tr>
</tbody>
</table>

While slip in bcc metals generally occurs in the <111> type direction, it may be restricted to {110} planes or it may involve other planes.


Two important observations are that slip occurs only when a critical resolved shear stress is reached on any particular slip system (Schmid’s law) and that when slip occurs in a given grain the crystal orientation associated with the grain changes.

There has been a substantial effort over the past sixty years (or more) to understand and model the polycrystalline deformation process. It is now known that we must understand how the distribution of crystalline orientations (texture) changes during deformation in order to understand fundamental characteristics such as strain hardening. Substantial directionality (anisotropy) in mechanical properties is a common consequence of preferred orientation distributions in polycrystalline materials. Among the most important of mechanical properties is the yield strength and its anisotropy in textured materials. EDAX-TSL has developed software which couples together Orientation Imaging Microscopy (OIM) with classical yield strength analysis based upon Schmid’s Law for single crystals and Taylor’s theory for polycrystalline yielding (G. I. Taylor, 1938). The following two sections give a brief introduction to Schmid’s law and Taylor’s theory. These sections are followed by a description of the implementation of these analyses into the OIM.
In a single crystal subjected to a particular stress state, plastic flow can be accomplished by slip on one or more particular slip systems. For a given stress state, the various potential slip systems are generally oriented differently with respect to the principal stress axes; therefore, the resolved shear stress, \( \tau_{\text{RSS}} \), on each slip system will be different. Plastic flow is initiated by slip on those systems where \( \tau_{\text{RSS}} \) reaches a critical value characteristic of the material. This critical stress is denoted \( \tau_{\text{CRSS}} \) and is related to the tensile yield stress, \( \sigma_y \), through the expression:

\[
\sigma_y = m \tau_{\text{CRSS}}
\]

This is known as Schmid's law. The parameter \( m \) is a geometrical factor which is derived from the orientation of a particular slip system with respect to the stress state. Consider the case of uniaxial tension of a single crystal as shown in the following figure.

To resolve the applied tensile stress \( \sigma = F/A \) into a shear stress acting on a slip plane in a given slip direction, the slip plane area, \( A_s \), and the resolved force, \( F_s \), must be determined. The slip plane area is given by \( A_s \cos \phi \), where \( \phi \) is the angle between the tensile axis and the slip plane normal. The resolved force in the slip direction is \( F \cos \lambda \), where \( \lambda \) is the angle between the tensile axis and the slip direction. The resolved shear stress, \( F_s/A_s \), can thus be expressed as \( \cos \phi \cos \lambda \). The geometrical factor, \( m \), is then given by:

\[
\frac{1}{m} = \cos \phi \cos \lambda
\]

The critical resolved shear stress, \( \tau_{\text{CRSS}} \), constitutes a material property that may be influenced by external conditions such as temperature and strain rate as well as on microstructural features such as impurity content and dislocation density. While the Schmid factor, \( 1/m \), is useful for identifying which slip systems are most likely to be activated for a single crystal of a given material, most materials are polycrystalline and an average Schmid factor is needed to predict the response of a textured polycrystal to a given stress state. Taylor’s theory provides a framework for modeling the anisotropic response of a polycrystal to a given applied deformation.
Schmid Factors in OIM

Introduction

In OIM the Schmid Factors are calculated by

1) Reducing the stress tensor to a set of principle stresses and their directions

2) Calculating the Schmid Factor for the defined slip plane assuming the force, \( F \), corresponds to that defined by the principal stress, both in magnitude and direction. The angles \( f \) and \( g \) (see the Schmid Law definition) can be determined relative to the direction of the principle stress and orientation of the slip plane within the crystal lattice (the orientation of the lattice is that measured by OIM and is given relative to the sample coordinate system as defined by RD, TD and ND).

3) Repeating the Schmid Factor calculation for each symmetrical equivalent of the slip system.

4) Selecting the maximum value.

Principal Stresses

There are various locations on the Internet and textbooks introducing the concept of stress analysis. The following provides a brief review of the essentials needed to understand the implementation of the Schmid factor calculation in OIM.

The stress state of a material can be described by a 2nd rank tensor of the form

\[
\begin{bmatrix}
\sigma_x & \tau_{xy} & \tau_{xz} \\
\tau_{yx} & \sigma_y & \tau_{yz} \\
\tau_{zx} & \tau_{zy} & \sigma_z
\end{bmatrix}
\]

Where \( \sigma_x, \sigma_y \) and \( \sigma_z \) are the normal stresses and \( \tau_{xy}, \tau_{yz} \) and \( \tau_{zx} \) are shear stresses as shown in the 3d and 2d schematics below.

Knowledge of the stress state is important to understanding how a material will flow or fracture. To simplify the impact of the stress state on the material response it is helpful to transform the stress tensor on to a set of axes...
where the stress is defined solely by three orthogonal stresses. These are the so-called principal stresses. The stress tensor defined with respect to this new coordinate system would be simply:

\[
\begin{bmatrix}
\sigma_1 & 0 & 0 \\
0 & \sigma_2 & 0 \\
0 & 0 & \sigma_3 \\
\end{bmatrix}
\]

These principal stresses act on planes where the shearing stress vanishes.

The components of principal stress are the three eigenvalues of the stress tensor. The eigenvalues are the three solutions to the following expression (where the parallel lines denote the determinant):

\[
\begin{vmatrix}
\sigma_x - \sigma & \tau_{xy} & \tau_{xz} \\
\tau_{yx} & \sigma_y - \sigma & \tau_{yz} \\
\tau_{zx} & \tau_{zy} & \sigma_z - \sigma \\
\end{vmatrix} = 0
\]

In equation form the eigenvalues are the roots to the following expression

\[
\sigma^3 - (\sigma_x + \sigma_y + \sigma_z)\sigma^2 + (\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_x\sigma_z - \tau_{xy}^2 - \tau_{yz}^2 - \tau_{zx}^2)\sigma
- (\sigma_x\sigma_y\sigma_z - 2\sigma_x\sigma_x\sigma_z + \sigma_y\tau_{yz}^2 + \sigma_z\tau_{zx}^2) = 0
\]

The directions associated with the principal stresses can be described by 3 unit vectors, $\hat{n}_1$, $\hat{n}_2$, and $\hat{n}_3$. These vectors are mutually orthogonal. The components of these vectors can be calculated according to:

\[
(r_j - \sigma_i \delta_{ij})v_j^1 = 0
\]

\[
(r_j - \sigma_i \delta_{ij})v_j^2 = 0
\]

\[
(r_j - \sigma_i \delta_{ij})v_j^3 = 0
\]

Where $\delta_{ij}$ is the Kronecker delta

\[
\delta_{ij} = \begin{cases} 1 & \text{when } i = j \\ 0 & \text{when } i \neq j \end{cases}
\]

and the subscripts $i, j$ refer to the coordinate axes: $1 = x, 2 = y, 3 = z$. This results in three sets of equations for each unit vector of the form (for the first vector using the original notation for the tensor):

\[
(\sigma_x - \sigma_1)v_1^1 + \tau_{yx}v_1^2 + \tau_{zx}v_1^3 = 0
\]

\[
\tau_{xy}v_1^1 + (\sigma_y - \sigma_1)v_1^2 + \tau_{zy}v_1^3 = 0
\]

\[
\tau_{zx}v_1^1 + \tau_{zx}v_1^2 + (\sigma_z - \sigma_1)v_1^3 = 0
\]

Also recall these are unit vectors so that the following must be satisfied

\[
v_1^2 + v_2^2 + v_3^2 = 1
\]

In two dimensions this reduces to the following equations
where $\sigma_1$ is the principal stress and $\phi$ defines the principal direction.

It should be noted that large differences in the principal stresses promote plastic flow due to high shear stress; whereas, a large sum of the principal stresses promotes fracture.

**Mohr's Circle Diagram**

A graphical method has been developed for describing these relations called the Mohr's circle diagram. Allowable stress states are bounded by the shaded area.

**Example Stress States**

Uniaxial Tension on ND

\[
\begin{bmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

Uniaxial Compression on TD

\[
\begin{bmatrix}
0 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & 0
\end{bmatrix}
\]
Remember that the Schmid Factor is simply a geometrical factor; thus, a stress of 1 adequately describes the stress state for calculation of the Schmid Factor.

**Limitations**

It should be noted that the Schmid Factor approach is limited. The stress state is simplified considerably, i.e. it is reduced to a single principal stress of magnitude \( s_1 \), and direction defined by the vector \( \mathbf{n}_1 \). In a polycrystal, slip generally occurs on more than one slip system at a time in order to achieve continuity with its neighbors. The Taylor approach is generally more applicable when investigating polycrystals.

**Bibliography**


Taylor's Theory

The Taylor model describes deformation in polycrystals based on slip in the individual crystals. The model can be used to predict the evolution of texture during deformation. In metals, deformation is accomplished through slip on specific slip systems. Which slip systems are active is a function of their orientation relative to the imposed macroscopic stress state. A Taylor Factor is a geometric factor which describes the propensity of a crystal to slip (or not slip) based on the orientation of the crystal relative to the sample reference frame. In this sense, the Taylor factor is a multiplication factor on the yield strength of an individual crystal. The key assumption in the Taylor model is that of uniform strain within each constituent crystal equal to the macroscopic strain. The following introduction is by no means comprehensive but provides and introduction to the calculation of the Taylor Factor in OIM.

The deformation gradient (or displacement tensor) is defined as

\[
F_{ij} = \frac{\partial u_i}{\partial x_j} \quad F = \begin{bmatrix}
\frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} & \frac{\partial u}{\partial z} \\
\frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} & \frac{\partial v}{\partial z} \\
\frac{\partial w}{\partial x} & \frac{\partial w}{\partial y} & \frac{\partial w}{\partial z}
\end{bmatrix}
\]

where \(u_i\) are the displacements (e.g. \(u, v, w\)) and \(x_i\) define a Cartesian coordinate system (e.g. \(x, y, z\)). The individual displacement components of this tensor tend to produce both shear strains and rigid-body rotations. Thus, the tensor can be decomposed into a symmetric tensor and an antisymmetric (or skew-symmetric) tensor. The strain is the symmetric part of the tensor and is given by

\[
\varepsilon_{ij} = \frac{1}{2} (F_{ij} + F_{ji}) = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)
\]

and the spin (or rotation) is the skew-symmetric part:

\[
\omega_{ij} = \frac{1}{2} (F_{ij} - F_{ji}) = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i} \right)
\]

Thus the deformation gradient can be written as the sum of two tensors:

\[
F = + I + 
\]

The diagonal terms of the strain tensor are the normal strains and the off-diagonal terms are shear strains. For an incompressible solid the sum of the shear strains must be zero, thus the trace of the strain tensor is zero. For the spin or rotation tensor the diagonal elements are all zero, thus, the trace of this tensor is also zero. Since the traces of the strain and spin tensors are zero for an incompressible solid the trace of the deformation gradient must necessarily be zero as well. (Later in the implementation, the identity tensor, I, is added to the spin to convert it to a pure rotation that can be used to evolve the orientations - some authors thus express the deformation gradient as: \(F = + I + \).
This definition of the deformation gradient would produce a trace equal to three.

Similarly, within a crystal the following relationship holds

\[ \mathbf{F}^C = \mathbf{e}^C + \mathbf{\omega}^C + \mathbf{\omega}^* \]

Taylor requires that

\[ \mathbf{e} = \mathbf{e}^C \]

The lattice rotation can then be identified as the difference in rotations:

\[ \mathbf{\omega}^* = \mathbf{\omega} - \mathbf{\omega}^C \]

Taylor further assumed that the (plastic) deformation occurs entirely by dislocation slip, and therefore

\[ \mathbf{e}^C = \frac{1}{2} \sum_s \gamma^{(s)} \left( \hat{b}^{(s)} \times \hat{n}^{(s)} + \hat{n}^{(s)} \times \hat{b}^{(s)} \right) \]

and

\[ \mathbf{\omega}^C = \frac{1}{2} \sum_s \gamma^{(s)} \left( \hat{b}^{(s)} \times \hat{n}^{(s)} - \hat{n}^{(s)} \times \hat{b}^{(s)} \right) \]

In these relations \( \hat{b}^{(s)} \) and \( \hat{n}^{(s)} \) denote unit vectors associated with the slip direction and slip plane normal and \( s \) is the slip magnitude of slip plane \( s \) (respectively). The summation is over all active slip systems.

Given that \( \mathbf{C} \) is a symmetrical tensor of second order, it follows that a minimum of five (independent) slip systems are required to satisfy relation (6) for an arbitrary (volume conservative) plastic deformation. Taylor’s analysis requires that we find the set (sets) of slip systems which satisfy this requirement with the least amount of plastic work. Using the principle of virtual work, the expression:

\[ \delta W = \sum_s \gamma^{(s)} \mathbf{\tau}^{(s)}_{\mathbf{C}} = \sum_{i=1}^{3} \sum_{j=1}^{3} \sigma_{ij} \varepsilon_{ij} \quad \left( \gamma^{(s)} \geq 0 \right) \]

is obtained, where \( \mathbf{\tau}^{(s)}_{\mathbf{C}} \) denotes the critical resolved shear stress on slip system \( s \). Taylor requires that we find the required slips, ... for one or more sets of five slip systems which satisfy relation (6) while minimizing \( \delta W \). Thus, equations (6) and (8) provide a system of five linear equations in as many unknowns as there are slip systems. For the case that Taylor originally considered, the case of \{111\}<110> slip in the fcc crystal lattice, this amounts to 24 slip systems. As illustrated by this case, the system of equations is generally underdetermined. However, by invoking the assumptions proposed by Taylor, and minimizing the plastic work, it is possible to solve for sets of five slip systems which are considered physically realistic. (Taylor assumed that appropriate stress states were available to enforce the required slips. Some years later, Bishop and Hill demonstrated for slip in fcc materials that indeed stress states can be realized which simultaneously activate either six or eight slip systems according to Schmid's law.)

An important output of Taylor's analysis is a parameter which is now called the "Taylor Factor". Originally it was defined for uniaxial straining of materials assuming \( \mathbf{C} \) is equivalent for all slip
systems enabling equation (10) can be rewritten as

\[ \delta W = \tau_c \sum_s \gamma^{(s)} = \sigma \varepsilon \]

where \( \varepsilon \) is the (infinitesimal) uniaxial strain, and \( \sigma \) is the uniaxial stress. It is also assumed that only one critical resolved shear stress is relevant. The Taylor factor, \( M \), is defined in relation to (10) as

\[ M = \sum_s \frac{\gamma^{(s)}}{\varepsilon} = \frac{\sigma}{\tau_c} \quad \{ \gamma^{(s)} \geq 0 \} \]

\( M \) is a function of the lattice orientation of the crystal (grain) as well as the imposed deformation. Large values of \( M \) indicate that the deformation requires large amounts of slip, expending large plastic work. For grains with lower values of \( M \) more efficient slip sets are available.

Here we require a more general definition of the Taylor Factor, since more general states of strain are of interest. For this purpose it is convenient to express the plastic work in terms of the principal components of the strain:

\( \tilde{\varepsilon}_1, \tilde{\varepsilon}_2, \tilde{\varepsilon}_3 \quad (|\tilde{\varepsilon}_1| \geq |\tilde{\varepsilon}_2| \geq |\tilde{\varepsilon}_3|) \)

Relation (11) now becomes

\[ \delta W = \tau_c \sum_s \gamma^{(s)} = |\tilde{\varepsilon}_1| \left( \tilde{\sigma}_{11} + \lambda \tilde{\sigma}_{22} - (1 + \lambda) \tilde{\sigma}_{33} \right) \]

\[ = |\tilde{\varepsilon}_1| \left( \tilde{\sigma}_{11} + \lambda \tilde{\sigma}_{22} - (1 + \lambda) \tilde{\sigma}_{33} \right) \quad \{ \gamma^{(s)} \geq 0 \} \]

where

\( \tilde{\varepsilon}_2 = \lambda \tilde{\varepsilon}_1, \tilde{\varepsilon}_3 = -(1 + \lambda) \tilde{\varepsilon}_1 \)

according to the volume conservation requirement. It follows that a generalized Taylor factor can be defined as

\[ M = \frac{\sum_s \gamma^{(s)}}{|\tilde{\varepsilon}_1|} = \frac{\left| \left[ \tilde{\sigma}_{11} + \lambda \tilde{\sigma}_{22} - (1 + \lambda) \tilde{\sigma}_{33} \right] \right|}{\tau_c |\tilde{\varepsilon}_1|} \]

References

Taylor Factors in OIM

The input parameters are one or more slip systems \( \{hkl\}<uvw>, \) the critical resolved shear stress for each slip system, and the nine components of the imposed deformation gradient, \( F_{ij} \) (or the stress tensor for the Schmid factor). Two conditions must be met for the input data. The first is that the slip system must be real, that is the dot product \( hu + kv + lw \) must equal zero. Second, the trace of the deformation gradient must also equal zero.

The primary output data are the Taylor factors (or alternatively the Schmid factors). Coupled with the OIM data files and graphical post-processing capability, maps of the spatial variation of the Taylor factor can be generated as well as histograms showing the distribution for a given data set. An example for a recrystallized nickel based superalloy is shown in the following figure. 5 degree boundaries are overlaid on the map.

Sharp differences in Taylor factor across grain boundaries can be an indication of strain incompatibility leading to local stress concentrations. The software only calculates the Taylor factors, it will not predict the texture evolution with strain, i.e. it does not perform grain rotations or stress/strain calculations. Most OIM data sets contain a few points for which the corresponding diffraction pattern could not be indexed and therefore an orientation could not be obtained. In the Taylor Factor calculation these points are assigned a value exactly between the minimum and
maximum Taylor Factor for the data set. This is done so that these points do not stand out in the resulting map.

The following schematics show some deformation gradient tensors, $F$, for some typical sample deformations. In the OIM software the direction RD corresponds to the "1" direction, TD to "2" and ND to "3" in the deformation gradient tensor $F$. Note the need to consider the relationship between the principle processing axes and how the sample is mounted in the microscope. It may be necessary to rotate the orientation data after scanning to get it into the right reference frame.

$$
F = \begin{bmatrix}
1 & 0 & 0 \\
0 & 0 & -1 \\
0 & 0 & 0
\end{bmatrix}
$$

Rolling

$$
F = \begin{bmatrix}
0 & 1 & 0 \\
1 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
$$

Torsion about ND

$$
F = \begin{bmatrix}
1 & 0 & 0 \\
0 & 0 & -0.5 \\
0 & 0 & 0
\end{bmatrix}
$$

Wire drawing in RD

$$
\begin{bmatrix}
1 & 0 & 0 \\
0 & -0.5 & 0 \\
0 & 0 & -1
\end{bmatrix}
$$

Uniaxial Compression in ND

$$
\begin{bmatrix}
0.5 & 0 & 0 \\
0 & 0.5 & 0 \\
0 & 0 & 0
\end{bmatrix}
$$

Uniaxial Tension in RD

$$
\begin{bmatrix}
1 & 0 & 0 \\
0 & -0.5 & 0 \\
0 & 0 & -0.5
\end{bmatrix}$$

Uniaxial Tension in TD
Since torsion is somewhat loosely defined, it is better to think in terms of pure shear and simple shear.

Simple shear: imagine placing a stack of cards on a table and while pressing down on the stack sliding it to the right. If the cards slid past one another uniformly the stack would deform as shown. If a cube were deformed in this manner two sides of the cube would remain the same length and direction during the deformation whereas the third side would progressively change in direction and lengthen.

\[
F = \begin{bmatrix}
0 & \gamma & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
\]

If we imagine two shears added together one in x as shown above and one in y then we get pure shear.

\[
F = \begin{bmatrix}
0 & \frac{1}{2} \gamma & 0 \\
\frac{1}{2} \gamma & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
\]
Traditional X-Ray Analysis

Some materials exhibit a texture dominated by the alignment of a particular crystal direction with a given sample direction. This type of texture is often observed in thin films. For example, aluminum films often exhibit an alignment of <111> crystal directions with the film normal. Such a texture is commonly termed a (111) fiber texture. An ideal pole figure from such a film is shown in figure 1.

![Figure 1 - (111) Pole figure for an idealized 111-fiber texture.](image)

X-ray rocking curves (see figure 2) are commonly used to characterize such textures. A rocking curve is essentially an intensity profile of the pole figure along an arbitrary line passing through the center of the pole figure. In the example used here we show only one half of the rocking curve, assuming the peak is centered about $\phi = 0$ degrees.

![Figure 2 - (111) Rocking Curve for an idealized 111-fiber texture.](image)

Rocking curves can be analyzed to further simplify the parameterization of the texture. The key parameters are the width of the peak (w), the fraction of randomly oriented material and the fraction of material in the peak as shown schematically[1]. The large peak at $\phi = 0$ degrees is due to a strong alignment of <111> crystal directions with the sample normal. The smaller peak at $\phi = 70.5$ degrees is due to symmetrical variants of <111> directions. If a <111> crystal direction is exactly aligned with the sample normal, then the other three <111> variants are located at 70.5
degrees from the sample normal as shown in the schematic in figure 3. A (100) fiber texture would exhibit a similar secondary peak at 90 degrees and a (110) fiber texture would exhibit a secondary peak at 60 degrees and a tertiary peak at 90 degrees. The fact that these secondary peaks appear as rings in the pole figure indicates that the material has no preferred in-plane orientation.

Figure 3 - Schematic showing location of symmetrically equivalent (111) poles in a (111) pole figure.

A similar plot to the rocking curve is the so-called pole plot. Imagine an x-ray diffraction measurement where the sample is continuously rotated during the measurement of the rocking curve. The resulting plot is essentially an azimuthally averaged rocking curve. For a perfectly axisymmetric fiber texture the pole plot and rocking curve will be identical - all rocking curves regardless of the azimuthal angle would be identical as well.

Figure 4 - A rocking curve and a pole plot for a (100) fiber texture

While some materials exhibit the perfectly (or near-perfect in the case of figure 4) axisymmetric textures presented so far, many do not. Two other types of commonly observed textures are an annular texture and a "near" (111) fiber texture.

An annular texture is a texture where the main peak in the pole figure is not precisely aligned with the sample normal and the texture is axisymmetric about this peak instead of about the sample normal as shown in figure 5. Such textures can be real - that is they arise from the processing. However, it is important to verify that the measured texture is not an artifact of the measurement itself. If the sample surface normal is not precisely aligned in the X-ray goniometer, a fiber texture would appear as an annular texture. This can easily happen when the two sides of a sample are not parallel.

Figure 5 - (111) Pole figure of an annular texture.
A "near" (111) fiber texture means that there is an alignment of the (111) poles just off of the sample normal. However, the resulting texture is still axisymmetric about the sample normal. Figure 6 shows an example of an annular texture.

![Figure 6 - (111) Pole figure of a "Near" (111) fiber texture.](image)

It should be noted; that the pole plots for both of these types of textures would be very similar. They would both appear as the plot shown in figure 7. However, the rocking curves for these two textures could be quite different or quite similar (especially if the line profile only goes from 0 to 90 degrees) depending on the choice of azimuthal angle. In fact, the rocking curve for the annular texture could completely miss the offset peak shown in figure 6 for an azimuthal angle of 135 degrees with respect to the horizontal axis. However, a choice of 45 degrees for the azimuthal angle would give a correct impression of the offset peak (if the rocking curve extends from -90 to +90 degrees).

![Figure 7 - Pole plot corresponding to both an annular texture and a near (111) fiber texture](image)

Textures may become even more complex than the simple single fiber textures discussed so far. Some films may exhibit multiple fibers arising from twinning or variations in processing parameters. Good examples are the textures observed in copper interconnect lines formed by the damascene process. In these materials, the texture receives contributions from the interconnect sidewalls and bottom leading to a relatively complex texture. An example of a more complex texture from a tantalum sputter target is shown in figure 8. This texture is most simply characterized as having (111) fiber texture along with a near cube texture. (Cube texture denotes a grain orientation where the cube face normals are aligned with the principle axes of the sample.)

![Figure 8 - (100) Pole figure from a forged tantalum sputter target.](image)

In order not to miss critical details or make incorrect assumptions when analyzing these more complex textures,
more complete texture analysis is needed. For many years such analyses has been done using x-ray pole figures, which can be used to calculate the complete orientation distribution function (ODF) for a very complete description of texture[2]. However, the ODF can be difficult for a non-expert in texture analysis to interpret, especially when presented in Euler angles that lack the intuitive feel of the (hkl)<uvw> representation of orientation familiar to most materials scientists.

**OIM Analysis**

Orientation Imaging Microscopy or OIM refers to "micro"-texture measurement technique based on electron backscatter diffraction (EBSD) in the scanning electron microscope (SEM) [3]. In OIM, the orientations of individual grains can be measured. Thus, OIM not only allows the texture to be measured, but also enables the spatial distribution of texture or microtexture to be characterized as well. When orientation measurements are made on a regular array of points, visualizations of the orientation aspects of the microstructure can be generated. In these OIM "maps", each point in the measurement grid is assigned a color based on the orientation measured. Figure 9 shows an example of one type of map that can be generated. The color in this map is based on a color-coded inverse pole figure. In this case, grains colored in blue have (111) poles aligned with the sample normal. Grains colored red are (100) oriented and grains in green are (110) oriented. One weakness of this technique when applied to microelectronic materials (where the microstructures are generally quite fine) is the resolution limitation. However, in modern SEM's, grains as small as 25 nm have been successfully imaged using OIM.

![OIM map of an aluminum thin film.](image)

The most accepted advantage of OIM over traditional x-ray pole figure texture analysis is that OIM provides spatially specific sampling of the orientation aspects of the microstructure. Thus, not only can the random fraction be determined but the location of randomly oriented grains in the observed microstructure can be determined as well. While OIM maps are useful and visually satisfying, the advantages of OIM in characterizing the more mundane aspects (such as pole plots, pole figures and ODFs) of texture should not be overlooked. Traditionally the shortcoming of OIM measurements in calculating texture has been the lack of statistics. However, with new technology it has become quite practical to sample the number of grain orientations needed for statistical reliability. The remainder of this technical note demonstrates the utility of OIM in texture analysis.

**Single Fiber Textures**

As an example of the utility of OIM for characterizing textures, consider first the case of a material exhibiting a single fiber texture such as the aluminum thin film used to generate the OIM map in figure 9. For a material with a single fiber (in this case a (111) fiber) the pole plot provides a good description. An OIM pole plot is essentially a
radial cross-section through the pole figure, averaged along the azimuthal angle. It is calculated by binning along the radial direction in 0.25 degree steps. For each measurement in the OIM scan, the deviation of the <111> crystal direction with the sample normal is calculated. The corresponding bin is then incremented by 1. A smoothing algorithm and normalization algorithm are subsequently applied. The OIM software can analyze the data automatically and determine the peak width in the same manner as is done for x-ray rocking curves. An example output is shown in figure 10. (*Pseudo* rocking curves can be constructed from the OIM data in a similar manner.)

In this example, the peak width (w) was determined to be 27.3 degrees. The peak and random fractions were determined to be 0.83 and 0.17, respectively. Omega 50 refers to the angle at which 50% of the grains have <111> crystal axes aligned within Omega50 of the sample normal.

It should be noted that the peak in the pole plot is not precisely centered on $\phi = 0$ degrees. This degrees could be produced by either a near (111) fiber texture or an annular (111) texture. It is important to distinguish between the two. This can be done by calculating the pole figure from the OIM data. The result is shown in figure 11.

The pole figure does not seem to indicate the presence of neither an annular (111) fiber nor a near (111) fiber texture. The peak is not offset from the center and appears to be at it's highest at the center. However, if we look at the discrete pole figure shown in figure 13 in detail where the radial direction now extends only out to 30 degrees we see a small gap in the measurements right near the center of the cluster. Thus, the texture can be considered a near (111) fiber texture. One other feature of the intensity pole figure is the lack of perfect axial symmetry. This could be due to a lack of statistics. In order to create detailed maps in OIM, a good goal is to get about 25
measurement points per grain. However, if the only objective is to get good statistics for texture analysis, a coarser grid can be used, as 1 point per grain is adequate.

The OIM software allows annular textures to be treated in one of two ways. The first would be to rotate the data until the (111) fiber is aligned with the sample normal. Rotating the data in this manner will result in a pole figure where the peak of highest intensity is at the center of the pole figure (as in figure 11). The typical analyses of the fiber texture using pole plots or rocking curves can then be performed. The other option would be to determine the offset. This can easily be done in the OIM software by simply placing the cursor at the center of the fiber; the corresponding sample direction is displayed as shown in figure 13. This offset direction can then be used to calculate the pole plot instead of using the standard sample normal. For example, for the pole figure in the screen shot, the sample direction corresponding to the peak would be \([3 \ -4 \ 18]\). Where 3 is the component in the vertical direction (down is positive), -4 in the horizontal direction and 18 in the sample normal direction.

Multiple Fibers

Consider now a case where multiple fibers are observed. Figure 15 shows an OIM map of a copper thin film with a significant fraction of twins. In contrast to figure 9, where the map is predominately blue - corresponding to the associated (111) fiber texture, the map in figure 15 shows a wide variety of colors corresponding to varied crystallographic orientations.
If we assume that the texture is composed of multiple fibers aligned with the sample normal, we can ascertain which fibers are present by calculating the orientation distribution function or ODF and plotting the texture results in the form of an inverse pole figure as shown in figure 16.

The inverse pole figure shows a primary peak at (111) and two secondary peaks at (001) and (325). However, some knowledge of the material can help in determining which fibers are to be expected. The (001) fiber lies very near the (115). The (115) fiber is expected in this material due to the presence of a strong (111) fiber coupled with twinning. The (115) peak is related to the (111) peak through a twin relationship. To ascertain whether the peaks observed in the inverse pole figure correspond to real fiber textures, corresponding pole figures should be generated as shown in figure 17. All of the pole figures shown in figure 17 exhibit the axial symmetry assumed present in thin films.
If pole plots are calculated for the (111), (115) and (325) fibers the following results are obtained.

<table>
<thead>
<tr>
<th>Fiber</th>
<th>PeakWidth</th>
<th>PeakFraction</th>
<th>RandomFraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(111)</td>
<td>9.0</td>
<td>0.25</td>
<td>0.23</td>
</tr>
<tr>
<td>(115)</td>
<td>6.5</td>
<td>0.02</td>
<td>0.42</td>
</tr>
<tr>
<td>(325)</td>
<td>9.5</td>
<td>0.15</td>
<td>0.66</td>
</tr>
</tbody>
</table>
Figure 19 - (111), (115) and (325) pole plots for the copper thin film along with a table of measurements obtained from each curve.

Clearly, these pole plots are not as easily interpreted as those for nice neat single fiber textures. In fact, this type of analysis is not really appropriate to determine the fraction of each of the fibers independently. This is apparent from the fact that the random fraction measured from each of the three plots differs considerably. While the inverse pole figure in figure 16 gave an indication for (001), a closer investigation of the (001) pole figure and pole plot did not show a significant contribution. For a (001) fiber texture there should be a ring at 90 degrees in the pole figure. While the ring is absent there are four symmetrically equivalent peaks at 90 degrees (see figure 20). These peaks suggest that the (001) oriented material is not axisymmetric; rather it is exhibits a preferred in-plane orientation also.
As in the analysis of the (001) pole figure, it is useful to know where the secondary peaks should appear in the pole figures and pole plots. For example, for a (111) fiber texture a secondary ring should appear at 70.5 degrees in the pole figure and a corresponding peak should appear at 70.5 degrees in a (111) pole plot. For the (115) and (325) peaks, there are considerably more secondary peaks due to multiplicity. For (115), there are symmetric peaks at 22.2, 31.6, 66.0, 70.5 and 87.8 degrees; and for (325) at 13.2, 26.5, 35.3, 37.9, 40.3, 46.8, 48.9, 58.2, 60.0, 70.0, 71.6, 73.2, 76.3, 84.0 and 88.5 degrees. One quick way to find the secondary peaks is to use the highlighting function in OIM. For example, to find the location of secondary peaks for (115) simply click with the mouse at the center of the (115) pole figure. The secondary peaks will appear as rings (a 3 degree highlighting tolerance was used in the example shown in figure 21). While evidence for some of these peaks are evident in the corresponding pole plots, the plots tend to be dominated by peaks relating to the (111) fiber. For the (115) fiber the peaks at 38.9, 56.3 and 70.5 degrees arise from the (111) fiber and at 20.5, 55.8, 68.0 and 90.0 degrees for the (325) fiber. Clearly, a good understanding of the relationship between the competing peaks is necessary to analyze the pole plots correctly.

OIM has features that make the determination of volume fractions associated with the multiple fibers relatively simple. A good example is the crystal direction map. In this map, the data shaded in blue has <111> crystal axes oriented within 15 degrees of the sample normal. Similarly, the points in red are (115) oriented and the points in green are (325) oriented. Note the volume fractions displayed in the legend pane of the window. Volume fractions can also be calculated from x-ray data. This can be done by integrating the rocking curves over the width of the peaks. However, we have already shown the identifying the width of the peaks in rocking curves when multiple fibers are present is a difficult task. Another approach would be to measure pole figures and then calculate the orientation distribution function or ODF. The ODF could then be integrated over particular fibers or peaks to determine the volume fractions. However, the OIM data has the advantage that the volume fractions (within a given tolerance) can be calculated directly from the data. Thus, the ambiguities and errors associated with calculating ODFs from pole figures (or OIM data for that matter) do not come into play. (Two potential errors would arise from 1) the truncation if the series expansion method is used in the ODF calculations, and 2) the amount of smoothing applied with all ODF calculation methods.)
The choice of 15 degrees is a somewhat arbitrary selection [4]. With 15 degrees, the (111), (115) and (325) fibers actually overlap slightly. If we also consider (001) oriented material, then 15 degrees would create considerable overlap with (115). (The distance between (115) and (001) is only 15.8 degrees.) We need not use the same tolerance value for all three fibers. It would be more correct to use the peak width values obtained from the pole plots for each fiber. The crystal direction map shown in figure 23 was generated peak widths determined from the pole plots are used. Even in this map (and accompanying discrete inverse pole figure) the tolerance of 9.5 degrees for the (325) fiber still appears to be a bit too large. In fact, the volume fractions obtained in this manner are still considerably different (0.28 for (111), 0.0.09 for (115) and 0.39 for (325)) than those obtained from the pole plots (0.25 for (111), 0.02 for (115) and 0.15 for (325)). The manner of volume fraction calculations is quite different between the pole plot and crystal direction map. In the pole plot, a random component is assumed to exist, even within the material oriented so that it falls in the initial peak. In the crystal direction map, no random component is assumed. Thus, the fractions obtained from the crystal direction map will always be somewhat larger than in the pole plot unless the peak in the pole plot falls off to exactly 0 intensity. Volume fractions in the crystal direction maps are obtained from the OIM measurements directly. In the pole plot, the fractions are obtained by interrogating the plot and are thus subject to the smoothing, binning and other parameters used in generating the pole plot. It is also interesting to note that the difference between the two methods is most glaring for the (325) oriented material.
It is not completely clear why the difference is so large. In looking in more detail, the (111) oriented material is quite closely aligned whereas the (325) oriented material is much more scattered in orientation - this is evident in the crystal direction plot shown in figure 24. The crystal direction plot shows the fraction of material having a particular crystal direction aligned with the sample normal. Note that the (111) curve increases very quickly and nearly plateaus after 2 degrees, whereas the (325) curve increases slowly up to 1 degrees and then continues to increase almost monotonically beyond 1 degrees with a slight change in slope at about 4 degrees.

The analysis performed here shows the value of the OIM measurements in gaining a clear understanding of the distribution of texture in the material. Both the pole plot (figure 19) and standard texture analysis (figures 16 and 17) give the impression of a material that is dominated by (111) oriented material. However, even the initial map shown in figure 15 shows that this is not the case. The (111) peak is large, not necessarily due to the overall volume fraction of (111) oriented material, but rather the fact that the (111) oriented material is very tightly aligned whereas the weaker (325) peak which actually represents a larger volume fraction of material is made up of grains that are only loosely (325) oriented. These results show that the pole plot analysis is best suited to investigating sharp single fiber textures and is not as well suited for analyzing textures with multiple fibers, especially for the broader peaks.

While an absolute standard value such as 15 degrees for all fibers would be quite helpful for standardizing analysis of a matrix of samples it is clear for this example that 15 degrees is too large. For highly symmetric fibers, like (111), (001) and (011), a value as large as 15 degrees may be appropriate. However, consider an arbitrary (hkl) fiber in a cubic material. There would be 24 symmetrically equivalent planes in the crystal. Thus, for any given orientation of the crystal one of the symmetric (hkl) poles will be relatively closely aligned to the sample normal. For example, the minimum deviation between two symmetrically equivalent (100) poles is 90 degrees, 70.5 degrees for (111), 60 degrees for (110) and only 22 degrees for (115) and 13.2 degrees for (325). In order to select good tolerance values some of the analyses presented here needs to be performed.

Fibers in Multiple Directions

In addition to the difficulties in characterization presented by multiple fibers, some materials exhibit textures with fibers aligned with different sample directions. A good example is the type of texture sometimes observed in copper damascene interconnects in which a fiber normal to the bottom of the trench is often observed along with a fiber normal to the sidewalls of the trench. This results in a pole figure similar to that shown in figure 25. The two fibers could be analyzed individually by generating a sample normal pole plot for the scan data in the usual way, then repeating the calculation after rotating the data to make the sidewall normal correspond to the sample normal.
Figure 25 - Diagram of a (111) pole figure showing the two competing (111) fibers observed in textures from interconnects formed by the damascene process.

Alternatively, OIM can analyze the two fibers simultaneously. For example, the texture shown in the pole figures in figure 26 was obtained from an OIM scan of copper interconnect lines formed by the damascene process. The pole figures do not show as clear a mix of the normal and sidewall fibers as shown schematically in figure 25 - the normal fiber is not nearly pronounced as the sidewall fiber. Nonetheless, there is evidence for alignment of the (111) poles with the surface and sidewall normals.

Figure 26 - Discrete and intensity (111) pole figures for a copper damascene interconnect lines.

The volume fractions of these two competing fibers can be characterized using the crystal direction map. The map should be constructed in a manner similar to that already shown for characterizing textures with multiple fibers. However, in this case, the crystal directions are the same (i.e. the hkls for both fibers are 111); but the sample directions are vary for the two fibers - [001] for the fiber aligned with the trench bottom normal and [010] for the fiber aligned with the sidewall normal. A map constructed in this manner is shown in figure 27.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Min</th>
<th>Max</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 1 1&gt;</td>
<td></td>
<td>[0 0 1]</td>
<td>0°</td>
</tr>
<tr>
<td>&lt;1 1 1&gt;</td>
<td></td>
<td>[0 1 0]</td>
<td>0°</td>
</tr>
</tbody>
</table>
Component Analysis

Some textures do not exhibit any prevalent fibers in any directions. Nonetheless, these textures may sometimes be simplified to a few ideal components. This type of analysis has been successfully applied to the analysis of textures in rolled, face-centered cubic materials for many years. For example, consider the (111) pole figure from rolled copper shown in figure 28. The texture exhibited in the pole figure is quite typical for a rolled fcc material. The accompanying schematic shows the location of some key "components" that appear frequently in rolled fcc materials. The analysis of textures in these materials can be simplified to the volume fraction of these ideal components (see Hirsch and Luecke [5] for a good example of such analysis.). The reason for the names of "copper" and "brass" has to do with changes in texture with alloying. The copper component is stronger in rolled copper and decreases in brass with increasing zinc content. The brass component is weak in pure copper and increases in brass with increasing zinc content.

![Diagram of rolled fcc materials](image)

The volume fraction of material with an orientation equivalent to a given component can be obtained through integration of the ODF. However, component fractions can be obtained directly from the OIM data. Whereas the crystal direction map can be used to obtain the fraction of various fibers, the crystal orientation map can be used to determine the fraction of particular components - specific orientations with an allowed deviation. The crystal orientation map is essentially a three-dimensional analog to the crystal direction map. An example is shown below for a rolled aluminum sample.
Another good example would be texture of forged tantalum used in sputter targets shown in figure 8. In these materials, the textures are generally composed of a cube component, (001)[100], and a (111) fiber. Analysis of the volume components of the volume fractions of these texture components would require both the crystal direction and crystal orientation maps.

When established components are unknown, the ODF is a useful tool for identifying these components. Peaks in the ODF may correspond to particular key components. However, the confirmation of a particular orientation as a key component, for a particular process, would have to be established through observation with a matrix of samples. If the same peaks appear in ODFs from different samples, albeit with varying intensities, then the locations of the peaks in orientation space could be considered as components. The fraction of these components would then provide a relatively simple means of comparing textures.

Summary

OIM can provide helpful visualizations of the orientation aspects of microstructure; but it is important to remember that behind the visualizations is a wealth of quantitative information. The OIM Analysis software provides tools to interrogate that quantitative information and extract numbers that can give real insight into materials. In the materials described here, it is relatively easy to analyze the single fiber textures. However, if multiple fibers are present or the texture has an even more complex character, then the analysis must be pursued in more detail.

Bibliography


Twin Boundaries

Twinning Criteria

Twin boundaries have unique properties relative to other types of boundaries. In addition, coherent twins are considered to have even more special properties than non-coherent twins. However, previous versions of OIM could not distinguish between the two types of twins.

For a boundary to be considered a twin boundary two criteria must meet:

First, the misorientation across the grain boundary must be very near the twin misorientation relationship. For example, the primary recrystallization twin in FCC materials can be described as a 60 degree rotation about a \(<111>\) crystal axis. Thus, a boundary segment which has a misorientation of 60.7 degrees about a \(<10\ 10\ 11>\) axis could be considered a twin.

For a boundary segment to be considered a coherent twin it must satisfy a second requirement. The boundary plane must coincide with the twinning plane. For the example already given, this means the \{111\} planes of the crystals on either side of the grain boundary must be aligned (within a given tolerance) with the grain boundary plane. Since, OIM scans are inherently two dimensional, it is not possible to determine whether a given boundary satisfies this criterion without performing serial sectioning or some other three-dimensional sampling technique. However, assessing whether the trace of the boundary plane is aligned with the trace of the twinning plane provides a partial check. By examining the three dimensional character of many twin boundaries, Randle (Scripta Mat. 44, 2789-2794, 2001), has shown that when the traces are aligned the boundary and twinning planes are also aligned 90% of the time. Since the boundary segments in an OIM map follow the scan grid, reconstructed boundaries are used for making the alignment check between the boundary and twin plane traces.
A non-coherent (top) and a coherent twin (bottom) in deformed zirconium.

The dashed circles in the pole figures show the position of the two twinning planes most closely aligned in the two grains separated by the highlighted boundary. In the top example, the most closely aligned twinning planes are not aligned with trace of the boundary plane. In the bottom example, the aligned twinning planes lie on the vector for the boundary trace normal. If we could reconstruct the actual inclination of the boundary, then it is assumed that it would match the aligned twinning planes and we would be able to draw the boundary trace normal with a given magnitude - since we only measure the trace of the boundary, we only know the direction of the vector.

The implementation in OIM has two levels. First enforcing the matching between the twinning planes and second enforcing the matching between the boundary trace and the twin plane traces.


**Twin Fraction**

OIM calculates the parent material vs. the daughter material based on a simple majority rule. That is, a grain is made up of orientation measurements of similar orientation. A grain containing a single twin will be made up of orientation measurements of two types. The orientation to which the majority of the measurements belong is considered the parent orientation. It should be noted that the average orientation for grains containing twins is the average orientation of all measurements belonging to the parent portion of the grain.
The following sections contain various bibliographies. The first section contains references that provide a historical perspective on the development of OIM. The second section provides some introductory papers for describing crystallographic orientation and texture analysis. The EDAX website also contains a snap shot in time of papers published using EBSD. (http://www.edax.com/technology/EBSD/bib-pages/index.html)
**History**

The following papers give a historical perspective on OIM in terms of Orientation Determination, Orientation Mapping and Phase Identification.

## Orientation Determination

Considerable work has been done in identifying the lattice orientation associated with an electron backscatter pattern. The technology has progressed considerably - to the point of being able to rapidly collect tens of thousands of orientation measurement without any operator intervention. The following lists the important developments in achieving this level of automation.

<table>
<thead>
<tr>
<th>Early observations of grazing incidence diffraction patterns were reported. Several other authors report the observation of Wide-Angle Kikuchi patterns, High-Angle Kikuchi Patterns (later termed Electron Backscatter Patterns, EBSPs and Backscatter Electron Kikuchi Patterns, BEKPs).</th>
<th>S. Nishikawa, S. Kikuchi (1928) &quot;The Diffraction of Cathode Rays by Calcite&quot;, <em>Proc. Imperial Academy (of Japan)</em>, 4, 475-477.</th>
</tr>
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<tr>
<td></td>
<td>H. Boersch (1937) &quot;About bands in electron diffraction&quot;, <em>Physikalische Zeitschrift</em>, 38, 1000-1004</td>
</tr>
<tr>
<td>Use of bands instead of zone axes to determine the orientation. The advantage here is that an operator is not required to identify the crystallographic parameters of the bands but to simply digitize them. These ideas were first applied to Electron Channeling patterns but later extended to EBSPs.</td>
<td>N.-H. Schmidt and N. O. Olesen (1989) &quot;Computer-Aided Determination Of Crystal-Lattice Orientation From Electron-Channeling Patterns In The SEM&quot;, <em>Canadian Mineralogist</em>, 27, 15-22.</td>
</tr>
</tbody>
</table>

In order to automate orientation determination from EBSPs some form of image analysis for either detecting the zone axes or the diffraction bands in the images was needed. The following lists the sequence of developments in
The first attempt to automatically determine the lattice orientation from an EBSP was done by trying to detect zone axes in the pattern.


Another attempt to find the bands using gradients of the EBSPs via the Burns algorithm was successfully employed.


The next step was to automate the system so that repeated measurements of orientations could be made without any operator intervention.

The application of the Hough Transform for band detection. This is the most widely used method today.

The first attempt to detect the bands instead of the zones was done by segmenting EBSPs into smaller binary images. Lines were detected in these smaller images and then linked together with lines detected in other segments to form the detected bands.
The first completely automated scan was performed using the Burns method. 4167 points were measured. The scan was performed by translating the sample under a stationary electron beam.

Results were presented by S. I. Wright as part of an unpublished talk entitled "Local Volume Fraction Fluctuations and Clustering in Polycrystals" at the "Microscale Textures of Materials Symposium" at Materials Week '91, Cincinnati, Ohio October 1991.

The first published description of the fully automated system.


Current systems tend to generally perform scans by controlling the electron beam instead of translating sample stages.

The first commercial beam control system was developed by TexSEM Laboratories (TSL) - for Lawrence Livermore National Laboratory, September 1994.

Confidence index parameter devised. This parameter allows an operator to distinguish between data that is correctly indexed from data that may be suspect (generally due to weaker patterns).


Similar techniques were developed for ECP and Laue Patterns from Synchrotron Radiation.


A dramatic improvement in differentiating phases during OIM scans was realized through integrating results obtained by simultaneous collection of EBSD and EDS data.


**Orientation Mapping**

One of the more eye-catching uses of the automated systems is to created color-coded orientation maps. However, the ideas for such maps have been existence for some time. Dark Field Imaging in the TEM, Polarized Light Microscopy, Backscatter Imaging are all forms of orientation mapping. Thus, the idea of forming microstructural images based on crystallographic orientation have existed for some time. However, such methods are generally not very quantitative. The following are some quantitative methods.
The mapping of orientation onto a microstructure was done by "hatching" and coloring a pole figure using different patterns at different locations in the pole figure and then using the same patterns on a microstructure traced from micrographs.


The stereographic unit triangle (i.e. and inverse pole figure) was used in a continuous color coding scheme where red is assigned to the <110> direction, blue to <111> and yellow to <100> and then points lying between these three corners of the stereographic triangle are combinations of these three colors. This color coding is then used to shade grains in digitized maps of the microstructure according to their orientation.


The images published in this received awards in 1986 by the Japanese Institute of Metals and TMS.

A similar continuous color coding scheme was devised by assigning red, green and blue to the three axes of Rodrigues-Frank space and then coloring digitized microstructures accordingly.


The first reconstruction of a microstructure from automated orientation measurements was performed by drawing line segments between neighboring points in a hexagonal measurement grid wherever the misorientation between a pair of neighboring points exceeded some user defined value. The first color coding of such maps was done by selecting a few ideal components of the texture and then shading measurement points according to their distance in orientation space from these ideal orientations.


Some of the images in this thesis were also published in the following:


This paper was awarded the Marion Howe Medal by ASM for the best paper in the 1993 volume of Metallurgical Transactions


### Phase ID

Besides using EBSP technology for determination of lattice orientation there has been much interest recently in the use of EBSP technology for identifying crystal phase. The following list some of the key works done in this area.
Manual Use of EBSPs for phase identification.


The groundwork for an automated system for phase identification based on both interplanar angles and d-spacings was published.


The first commercial system with built in tools for differentiating phases based on a best fit approach according to indexing of EBSPs was released. This system also enables chemical and orientation data to be measured simultaneously using an integrated OIM/EDS system.

- TSL OIM version 2.5 - March 1997.
Orientation Descriptions and Texture Analysis


Mackenzie, J. K., "Second Paper on Statistics Associated with the Random Disorientation of Cubes", *Biometrika, 45*, pp. 229-240 (1958). This paper shows the distribution plot for a random set of cubic orientations or the so-called Mackenzie plot.

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