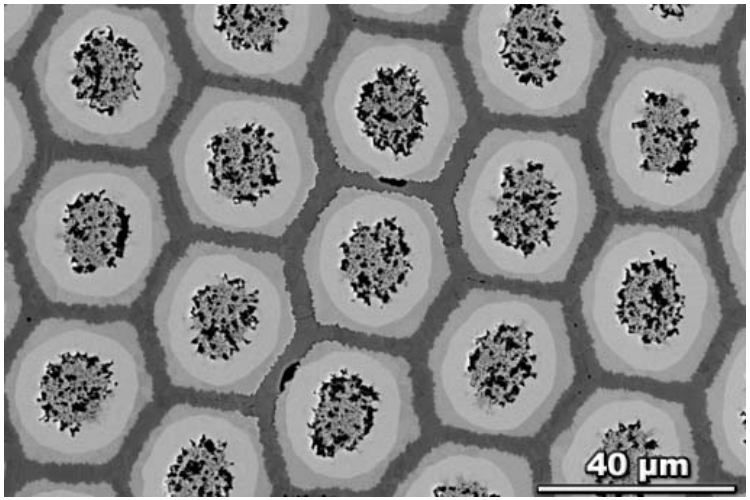
Minimum wall thickness macro

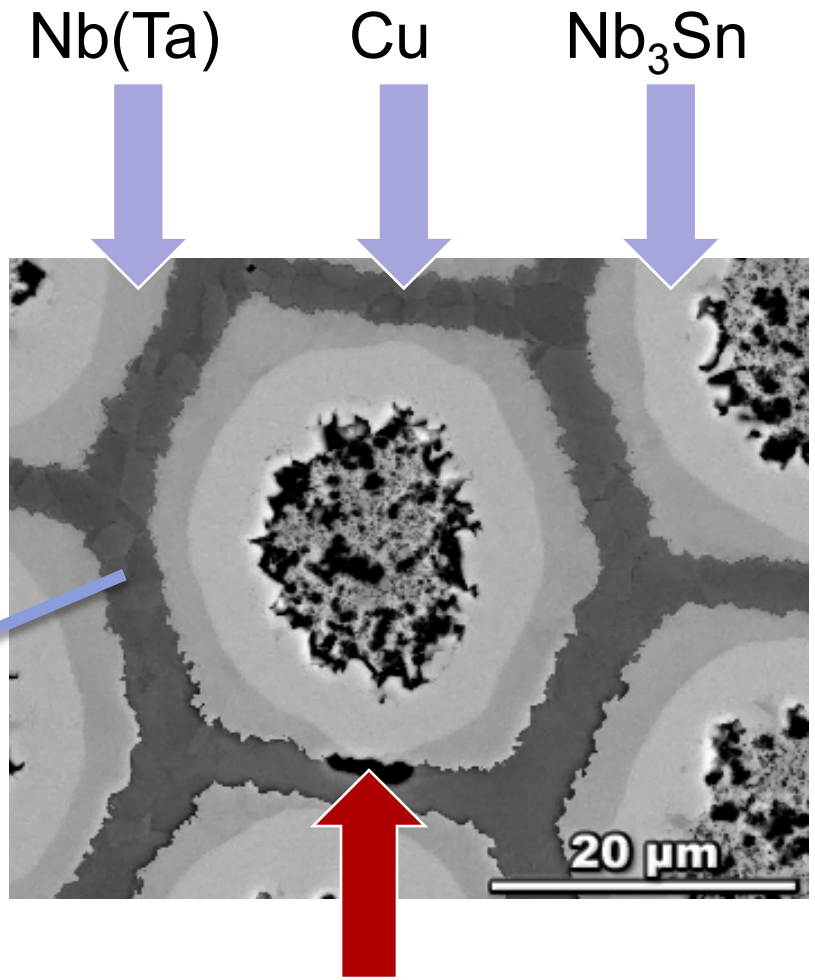
- This demo uses a 15 year old image of a strand that was manufactured by a company now out of business.
  - I wanted to use this example in a publication without any commercial issues.
- This Powder-in-Tube ("PIT") has Sn-rich powder cores that supply Sn for the outward reaction of the Nb(Ta) tube to superconducting Nb_3Sn.



Analysis of interest: unreacted tube thickness

- In some of our tubes the tube has reacted through so the minimum unreacted tube thickness is zero

Thresholded unreacted tube (wall) (broken ring)

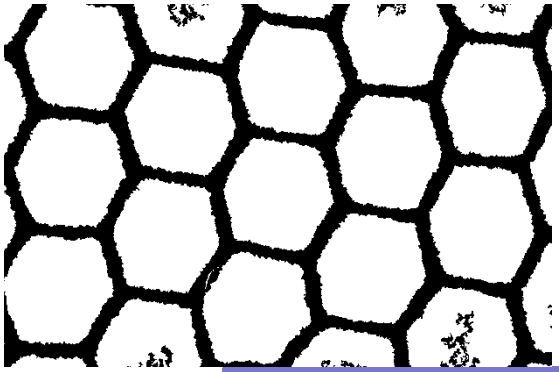


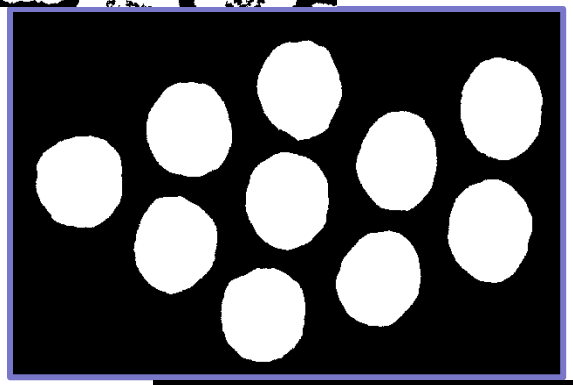
React-through

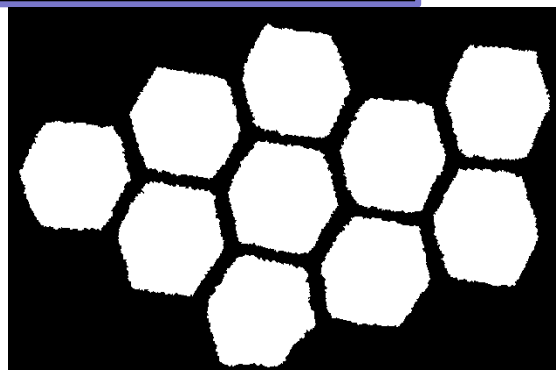
Analysis Steps (before running macro): Broken Rings

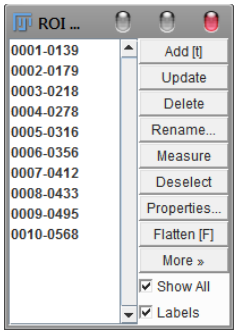
1. Start with thresholded full objects (tubes, cells etc.).
2. Also create image of inner objects (source of inner outline).
   - This allows zero-thickness measurements (broken ring)
   - If the outer image filename has "_outer" in the name and this is replaced by "_inner" for the inner image the _inner image will be loaded automatically
3. Remove Edge Objects i.e. morphology/KillBorders
4. Run ImageJ Analyze Particles or the Gabriel Landini Particles4/8 to obtain ROIs in the ROI manager *(if there are no roi objects the macro will ask if you want to run Analyze Particles)*.

   If you leave the Results Table open the statistical data will be added to new columns to the right. If you have previously closed the Results Table a new one will be created with the new columns only.







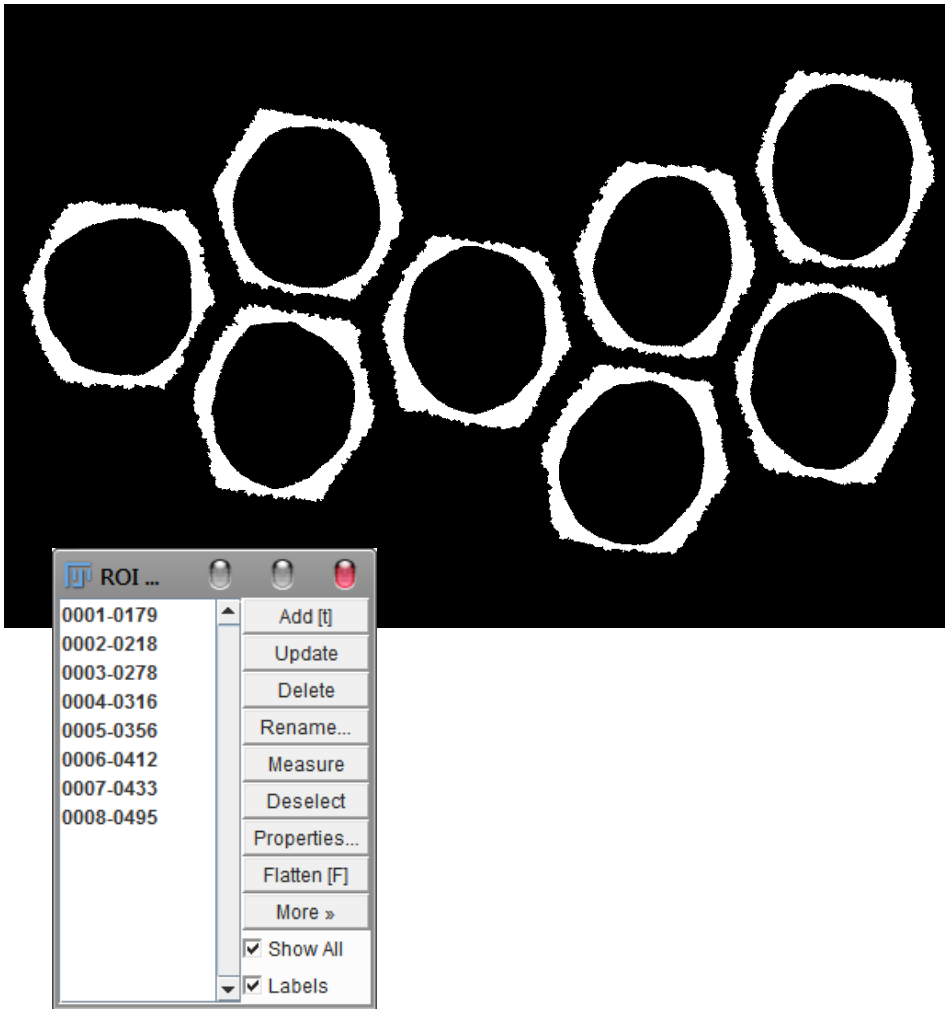


Fewer Steps for Continuous Rings

1. Start with thresholded full rings.

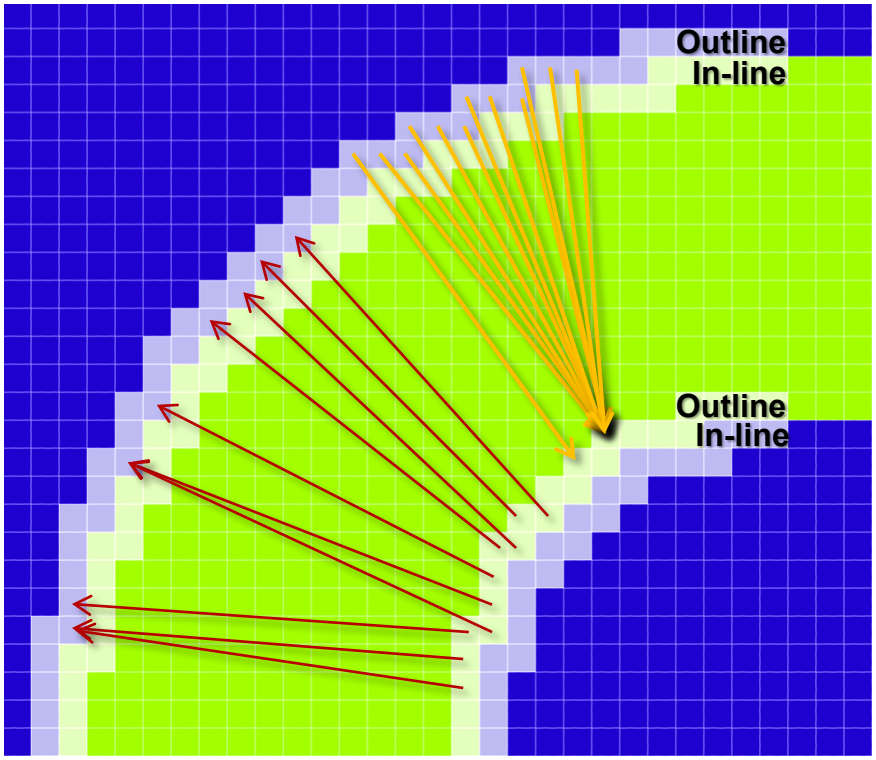
2. Run ImageJ Analyze Particles or the Gabriel Landini Particles4/8 to obtain ROIs in the ROI manager (*(if there are no roi objects the macro will ask if you want to run Analyze Particles)*.

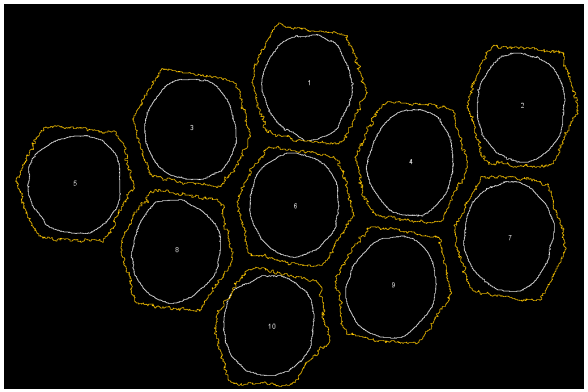
   If you leave the Results Table open the statistical data will be added to it. If you close it Results Table a new one will be created for the statistics as well as a separate results table containing all the minimum distances.



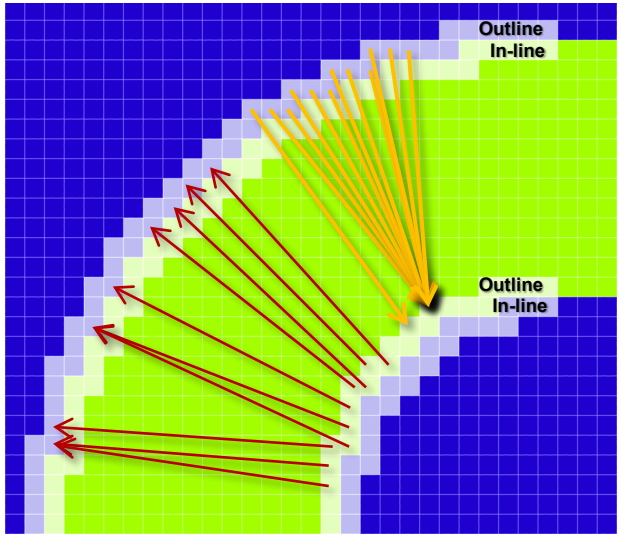
Macro: non-"ring" versions

1. Run Macro . . .
    1. There are 2 main variants
        1. **Outwards** (our diffusion direction).
        2. Inwards (Osmosis?).
2. For the "Ring" versions you will be requested to load the file containing the image of the cores (inner objects). The macro will convert to 8-bit and threshold if not already in this format.
3. In the "+options" versions you will be asked if you want to skip some of the "from" points (all "to" points will be retained to maintain resolution).





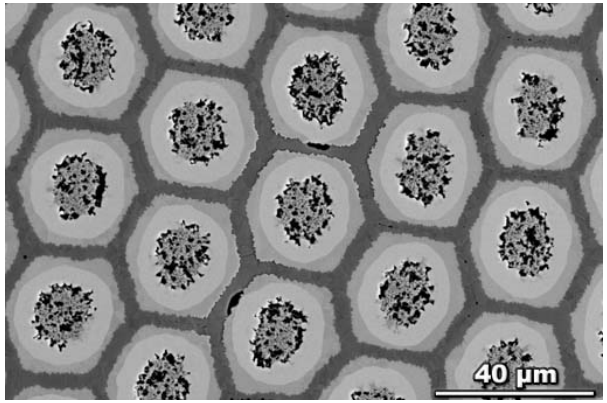
8 Basic Variants



1. Inwards using object Outlines
2. Inwards using object "In-lines"
3. Outwards using object Outlines
4. Outwards using object "In-Lines"
5. Rings (faster if no breaks) Inwards using object Outlines
6. Rings (faster if no breaks) Inwards using object "In-lines"
7. Rings (faster if no breaks) Outwards using object Outlines
8. Rings (faster if no breaks) Outwards using object "In-Lines"

Does it matter which version: Minimum Thickness

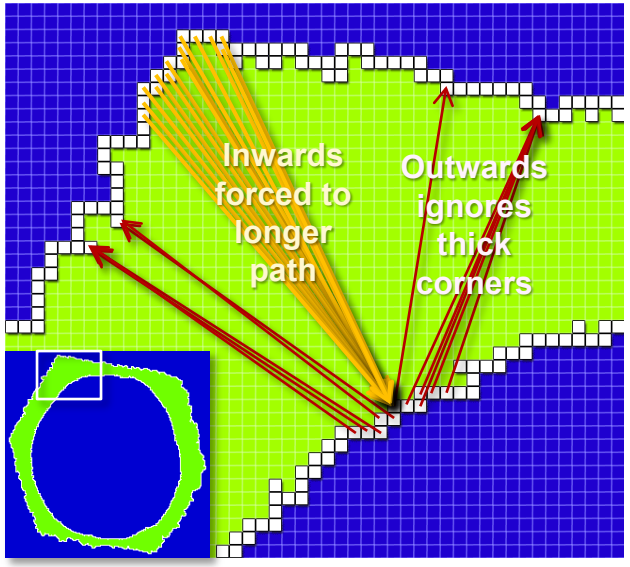
- For the PIT example it does not matter.
- The "Rings" version is faster but cannot record the thickness values for incomplete rings (objects 1 and 10)



Object ID	1	2	3	4	5	6	7	8	9	10		Time (s)
Outlines Inw (µm)	0.000	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	0.000		18.3
Inlines Inw (µm)	0.000	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	0.000		18.3
Outlines Outw (µm)	0.000	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	0.000		18.8
Inlines Outw (µm)	0.000	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	0.000		19.3
Rings Outlines Inw (µm)	Open	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	Open		14.8
Rings Inlines Inw (µm)	Open	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	Open		12.4
Rings Outlines Outw (µm)	Open	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	Open		14.9
Rings Inlines Outw (µm)	Open	0.593	0.741	0.901	0.611	0.419	0.611	0.741	0.593	Open		12.1

Does it matter which version? Maximum Thickness

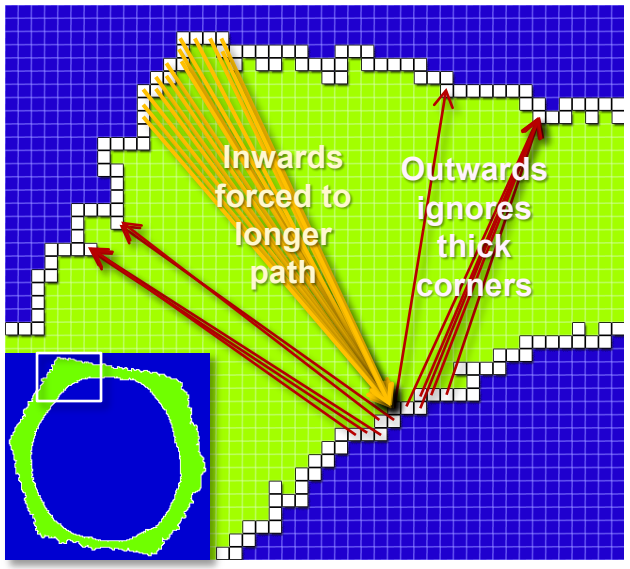
- For the PIT example it ***does*** matter.
- In this "PIT" example the outward "maximum" thickness is significantly shorter.



Object ID	1	2	3	4	5	6	7	8	9	10
Outlines Inw (µm)	5.037	4.807	4.576	4.182	4.576	5.028	4.652	5.028	4.837	5.134
Inlines Inw (µm)	5.037	4.807	4.576	4.182	4.576	5.028	4.652	5.028	4.837	5.134
Outlines Outw (µm)	3.797	3.559	3.914	3.846	4.011	4.098	3.877	4.098	3.823	4.405
Inlines Outw (µm)	3.797	3.521	3.914	3.846	4.011	4.098	3.877	4.044	3.823	4.314
Rings Outlines Inw (µm)	Open	4.807	4.576	4.182	4.576	5.028	4.652	5.028	4.837	Open
Rings Inlines Inw (µm)	Open	4.807	4.576	4.182	4.576	5.028	4.652	5.028	4.837	Open
Rings Outlines Outw (µm)	Open	3.559	3.914	3.846	4.011	4.098	3.877	4.098	3.823	Open
Rings Inlines Outw (µm)	Open	3.521	3.914	3.846	4.011	4.098	3.877	4.044	3.823	Open

Does it matter which version?
Mean Thickness

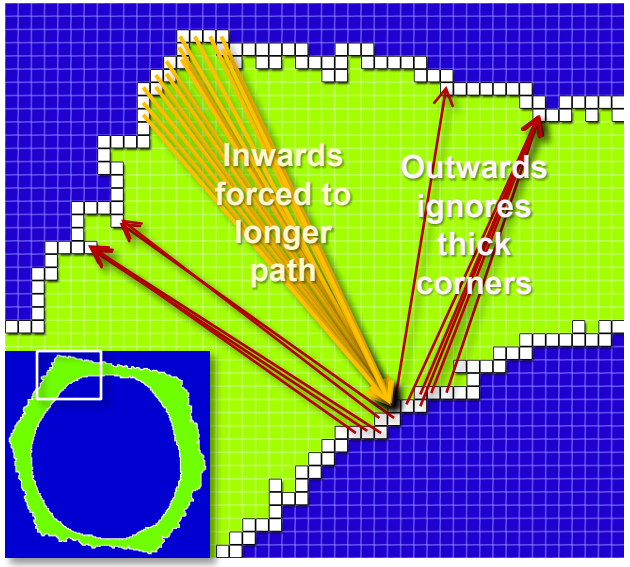
- For the PIT example it ***does*** matter.
- In this "PIT" example the outward "maximum" thickness is significantly shorter.
- Very small differences between "Outline" and "In-line" perhaps due to sampling.



Object ID	1	2	3	4	5	6	7	8	9	10		Time (s)
Outlines Inw (µm)	2.56	2.39	2.53	2.70	2.52	2.66	2.43	2.61	2.73	2.44		18.3
Inlines Inw (µm)	2.54	2.35	2.51	2.68	2.50	2.63	2.41	2.58	2.71	2.42		18.3
Outlines Outw (µm)	2.23	2.04	2.24	2.42	2.21	2.34	2.20	2.27	2.39	2.08		18.8
Inlines Outw (µm)	2.23	2.05	2.24	2.44	2.21	2.33	2.20	2.28	2.38	2.07		19.3
Rings Outlines Inw (µm)	Open	2.39	2.53	2.70	2.52	2.66	2.43	2.61	2.73	Open		14.8
Rings Inlines Inw (µm)	Open	2.35	2.51	2.68	2.50	2.63	2.41	2.58	2.71	Open		12.4
Rings Outlines Outw (µm)	Open	2.04	2.24	2.42	2.21	2.34	2.20	2.27	2.39	Open		14.9
Rings Inlines Outw (µm)	Open	2.05	2.24	2.44	2.21	2.33	2.20	2.28	2.38	Open		12.1

Does it matter which version? Std. Dev

- For the PIT example it ***does*** matter.
- In this "PIT" example the outward variation is small because it ignores the thick outer corners.
- Very small differences between "Outline" and "In-line" perhaps due to sampling.



Note: changed order of methods in table

Object ID	1	2	3	4	5	6	7	8	9	10		Time (s)
Outlines Inw (µm)	0.86	0.79	0.84	0.77	0.77	0.88	0.82	0.80	0.88	1.07		18.3
Inlines Inw (µm)	0.85	0.79	0.84	0.78	0.77	0.87	0.82	0.80	0.88	1.07		18.3
Rings Outlines Inw (µm)	Open	0.79	0.84	0.77	0.77	0.88	0.82	0.80	0.88	Open		14.8
Rings Inlines Inw (µm)	Open	0.79	0.84	0.78	0.77	0.87	0.82	0.80	0.88	Open		12.4
Outlines Outw (µm)	0.74	0.61	0.75	0.69	0.68	0.73	0.75	0.64	0.75	0.91		18.8
Inlines Outw (µm)	0.74	0.60	0.73	0.69	0.67	0.73	0.75	0.63	0.75	0.91		19.3
Rings Outlines Outw (µm)	Open	0.61	0.75	0.69	0.68	0.73	0.75	0.64	0.75	Open		14.9
Rings Inlines Outw (µm)	Open	0.60	0.73	0.69	0.67	0.73	0.75	0.63	0.75	Open		12.1

Output: "Results_Distances"

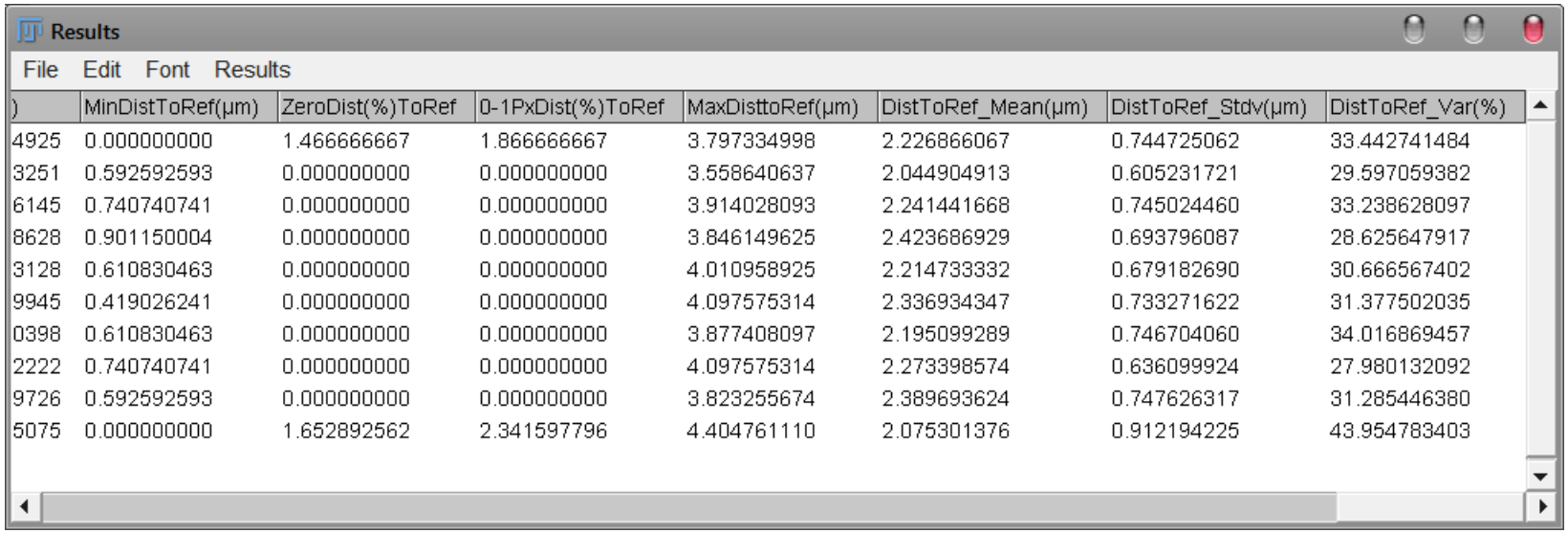
- All the minimum distances from each pixel are save for future analysis using a Results table (switching between tables slows the macro down but it is nice to have the originals.
- The results table expands unfilled rows with zeros so it marks the end of the *real* data with "End"
- The results are scaled with a unit if a measurement scale is set.
- It adds <10% to the run time to keep this full result set.

Results_Distances

File Edit Font

	MinDist(0)toRef	MinDist(1)toRef	MinDist(2)toRef	MinDist(3)toRef
728	1.000000000	7.071067812	6.324555320	10.295630141
729	1.000000000	7.810249676	6.708203932	6.324555320
730	2.828427125	7.280109889	7	6.324555320
731	3.162277660	7.071067812	7.071067812	6.082762530
732	3.605551275	7	End	6.324555320
733	3.605551275	6.324555320	0	6.708203932
734	2.828427125	6.082762530	0	7.211102551
735	1.000000000	6	0	7.810249676
736	1.000000000	6	0	8.485281374
737	1.000000000	6.082762530	0	9
738	1.414213562	6.324555320	0	9
739	2.000000000	6.403124237	0	9.055385138
740	End	5.656854249	0	9.219544457
741	0.000000000	5	0	9.486832981
742	0.000000000	4.472135955	0	9.848857802
743	0.000000000	4.123105626	0	10
744	0.000000000	4	0	10.049875621
745	0.000000000	4	0	10.198039027
746	0.000000000	4	0	10
747	0.000000000	4.123105626	0	8.944271910
748	0.000000000	4.472135955	0	8.544003745
749	0.000000000	5	0	8.246211251
750	0.000000000	5.656854249	0	8.062257748
751	0.000000000	End	0	8
752	0.000000000	0	0	8

Output: "Results"



Results

File Edit Font Results

)	MinDistToRef(µm)	ZeroDist(%)ToRef	0-1PxDist(%)ToRef	MaxDisttoRef(µm)	DistToRef_Mean(µm)	DistToRef_Stdv(µm)	DistToRef_Var(%)
4925	0.000000000	1.466666667	1.866666667	3.797334998	2.226866067	0.744725062	33.442741484
3251	0.592592593	0.000000000	0.000000000	3.558640637	2.044904913	0.605231721	29.597059382
6145	0.740740741	0.000000000	0.000000000	3.914028093	2.241441668	0.745024460	33.238628097
8628	0.901150004	0.000000000	0.000000000	3.846149625	2.423686929	0.693796087	28.625647917
3128	0.610830463	0.000000000	0.000000000	4.010958925	2.214733332	0.679182690	30.666567402
9945	0.419026241	0.000000000	0.000000000	4.097575314	2.336934347	0.733271622	31.377502035
0398	0.610830463	0.000000000	0.000000000	3.877408097	2.195099289	0.746704060	34.016869457
2222	0.740740741	0.000000000	0.000000000	4.097575314	2.273398574	0.636099924	27.980132092
9726	0.592592593	0.000000000	0.000000000	3.823255674	2.389693624	0.747626317	31.285446380
5075	0.000000000	1.652892562	2.341597796	4.404761110	2.075301376	0.912194225	43.954783403

- Summaries of the results are added to the existing or to a new table if the original table has been closed.
- For the non-Ring versions the % of zero thickness is recorded.

Summary

- Performing these analyses using arrays within ImageJ/Fiji is very fast compared to VB-macros in Excel.
- A variety of analysis can be performed based on the direction of diffusion/osmosis and type of layer.
- ImageJ macros are easy to edit to perform additional functions.
- "+options" versions simplify choices and allow faster operation by skipping data points but these versions will not be so easy to adapt for unattended batch operation.