FracPaQ

User Guide

Version 1.8, February 2017

Summary of changes in this release – FracPaQ version 1.8

Bugs fixed

For rectangular areas, the numbers of scan circles used in the estimated Intensity and Density maps are now scaled in the x- and y-directions. The user input number of scan circles is used on the widest axis, and the number of scan circles on the narrower axis is calculated to give the same scan circle spacing in x and y.

Enhancements added

Rose plot now has option to include length weighting; thus the contribution of each segment to the frequency in each bin is multiplied by its length. The rose plot now also includes circular statistics with estimated mean, standard deviation and resultant printed on the MATLAB command window, and a red line on the rose plot marking the estimated mean azimuth.

The ternary ('triangle') plot for connectivity now has grid lines, and has been re-written to use triplt.m from Middleton (2000).

Permeability plots now include an ellipse for ***k*** in the direction of the pressure gradient, to complement the existing ellipse for ***k*** in the direction of flow.

MLE graphs now include an annotation box with the parameter values of the best-fitting power law, log-normal or exponential distribution.

Summary of changes in this release – version 1.8 – continued

Enhancements added…
GUI now has a button for X-axis flip, to match the existing Y-axis flip.

The estimated Intensity and Density contour maps now use the **`cmocean`** colormap 'thermal' (Thyng, 2016). This colormap, and others in the **`cmocean`** package, have a linear spread of colour intensity over the mapped interval, with no false 'steps' or potentially misleading gradients. In addition, the scan circles are drawn on the **`FracPaQ2D_scancircle.tif`** at the correct size.

A new plot for 2-dimensional crack tensors has been added, based on the equations and methods in Oda et al. (1987) and Suzuki et al. (1998). 0^{th}, 2^{nd} and 4^{th} rank crack tensors are displayed.

The **FracPaQ** GUI can now read in *.svg files as input and convert them into node text files. This removes a platform or OS-dependence from previous versions of **FracPaQ**, whereby we only provided this functionality through Unix shell scripts. Windows users can now choose *.svg files as input.

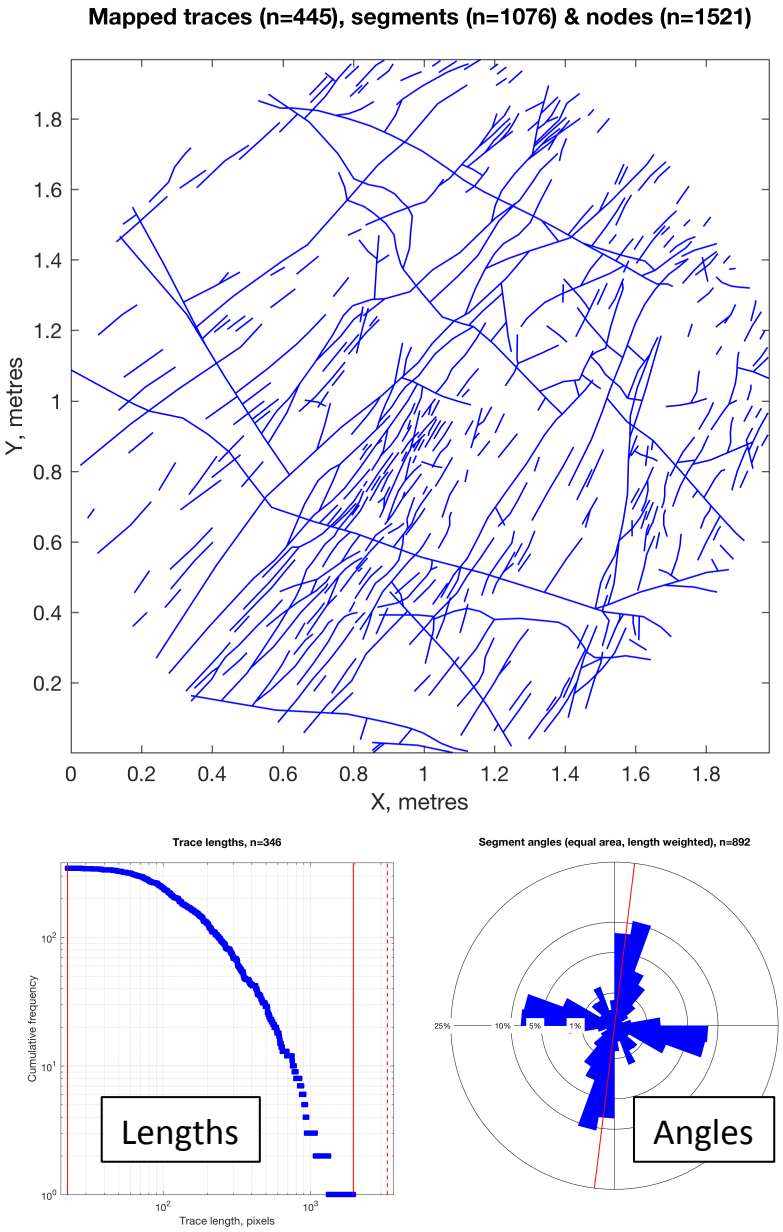
User Guide re-written to include all of these code enhancements, plus new sections on preparing input files from digital images, revised bibliography and more detailed explanations of each **FracPaQ** output.

Introduction

FracPaQ is an open source toolbox written in MATLAB™ and publicly available on GitHub and Mathworks FileExchange. FracPaQ runs on any computer with MATLAB installed – Windows, OS X or Linux. The current version is v1.8. We developed **FracPaQ** using MATLAB R2016a.

FracPaQ is designed to quantify fracture patterns in rock. The user supplies either an image file of fractured rock or a text file of traced fractures and their (x,y) coordinates. From either kind of input, the code calculates fracture lengths, angles and connectivity. These are displayed as maps and graphs, and saved as *.tif files. Estimates are made of fracture intensity (P21) & density (P20), and permeability in 2D using a simple parallel-plate model.

We hope that the code will enable researchers to quantify fracture patterns in an open, objective, and consistent way. **We also hope that people will contribute new functions and new tools, and report any bugs ☺**

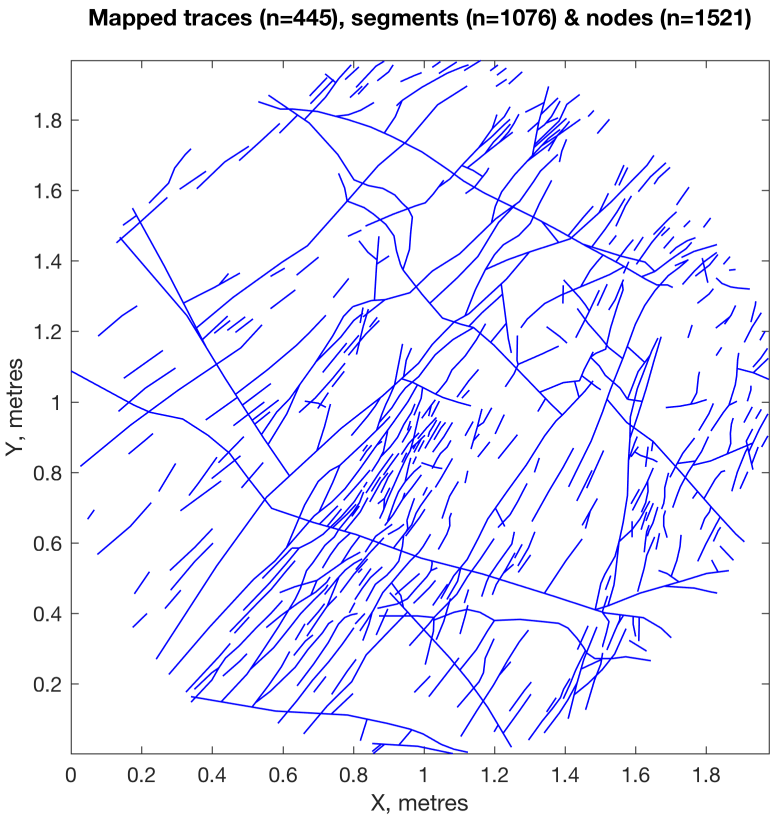


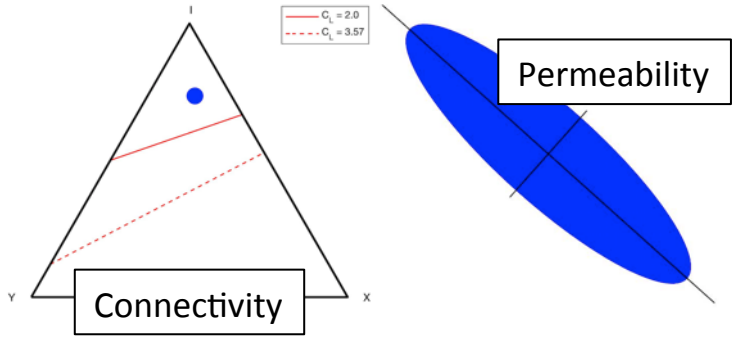
Introduction

FracPaQ is written in MATLAB™ and totals over 4,000 lines of code. As in any software project of this scale, there will be 'bugs' – i.e. coding errors. If you encounter a bug, please let us know – through GitHub, Mathworks FileExchange or by e-mail (d.healy@abdn.ac.uk); please provide as many details as you can, including (where possible) a screen shot of the error, the input file you were using at the time, and the MATLAB version.

FracPaQ uses code written by others: **`lineSegmentIntersect.m`** by U. Murat Erdem and **`readtext.m`** by Peder Axensten (both available on Mathworks FileExchange).

The handling of image file input in **FracPaQ** also uses functions from the Image Processing Toolbox (version 9.4), a MATLAB™ add-on.





Installing FracPaQ

You can get all the source code and run it directly from the MATLAB command window.

The source code and this User Guide are available on **GitHub**:
http://davehealy-aberdeen.github.io/FracPaQ/

and on the **Mathworks FileExchange**:
https://uk.mathworks.com/matlabcentral/fileexchange/58860-davehealy-aberdeen-fracpaq

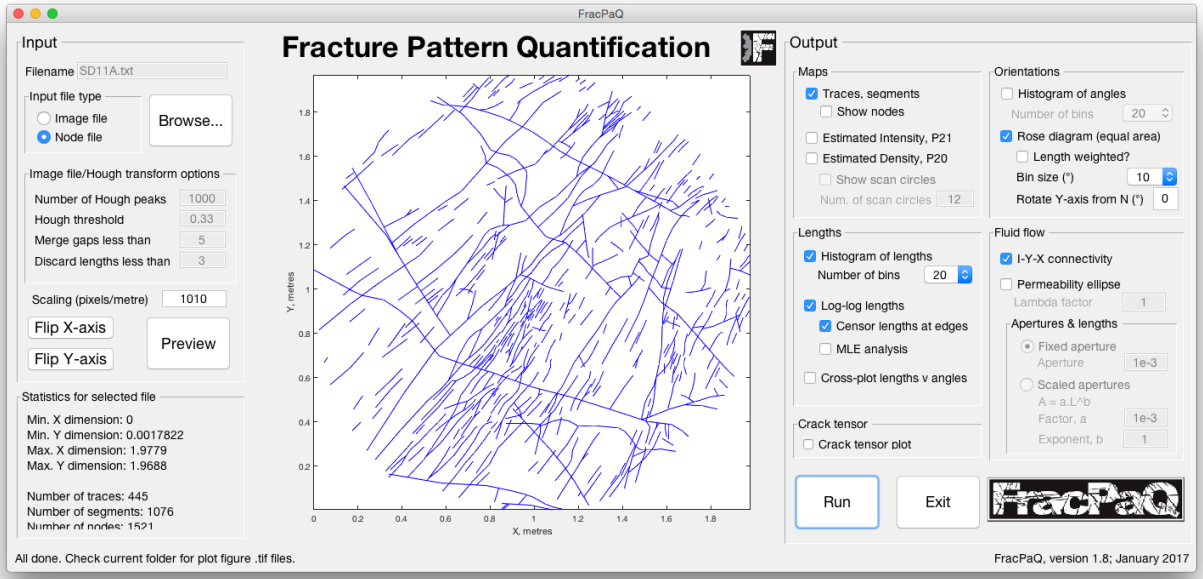
Steps:

1. Download the source code as a .zip or .tar.gz file, and extract all of the files
2. Put all of these files into a single folder
3. Start MATLAB
4. Set the current working folder in MATLAB to the folder you installed the code in
5. At the MATLAB command prompt type 'guiFracPaQ2D' and hit Enter

Output files (graphs, maps and data) will appear as *.tif and *.txt files in the same folder as the code.

Starting FracPaQ

There is only one window in the application (see right). The window can be minimised or closed using the standard GUI controls (top left in the Mac OS X version shown). Input parameters are on the left side, and output options are on the right. The central area is for previewing the input data as a fracture trace map.



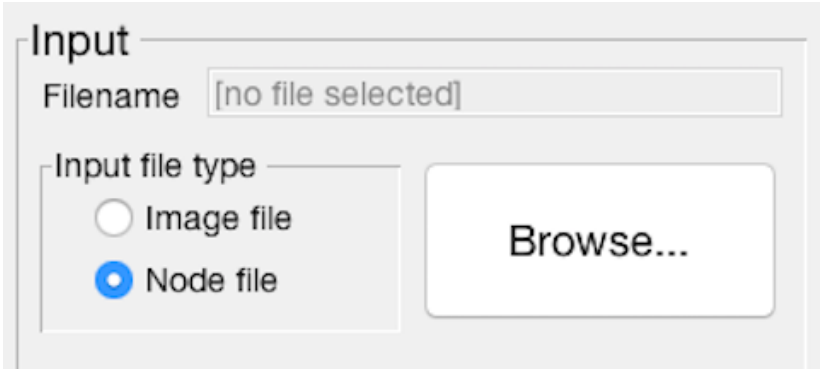
To get started, click **Browse…** to see a list of possible input files in the current working folder.

Then click **Preview** to open the data file and view the traces in the main window; basic statistics on the pattern are also shown (lower left box).

Select the Outputs you need (right hand side), and then click **Run** to produce the selected maps and graphs. Each output is shown in a separate figure window, and saved as a separate .jpeg in the current folder.

Click **Exit** to quit **FracPaQ**.

Choosing an input file



Click **Browse…** to select an input file. The file types shown are filtered to file extensions *.txt, *.svg, *.jpeg, *.jpg, *.tiff and *.tif.

If you select a *.txt or *.svg file of (x,y) fracture trace nodes, the Input file type changes automatically to 'Node file'.

If you choose a graphic file format (*.jpeg, *.jpg, *.tiff, *.tif), the Input file type changes to 'Image file'.

You can manually override these defaults if you wish.

*.txt file example

```
325.5   424.6   340.6   424.2   360.1   428.4
340.6   424.2   360.4   421.4   372.7   420.6
372.7   420.6   392.1   418.3
344.6   418.7   362.1   421.3
392.1   418.3   403.2   417.9
243.5   425.4   263.7   427     283.9   427.3   304.5   427
279.5   432.9   297.8   431.7   310.1   432.5   325.5   435.2   339.8   436     353.3   438
360.1   428.4   378.3   447.1   383     453.8   387.8   460.1
326.3   474     345.4   466.9   361.6   459     369.1   455.4
360.4   445.9   369.1   455.4
369.1   455.4   377.1   462.9
354.6   462.4   365.2   463.3   377.1   462.9
377.1   462.9   393.3   457.4   406.4   452.6
356.1   443.2   373.5   446.7
277.6   370.5   270.8   411.9   269.2   442.4   268     475.5   269.6   499.3
124.9   434.5   145.5   436.4   163.8   435.6   180.4   436.8   190.7   437.6
185.2   439.6   213.3   446.7   240.7   452.6   256.9   455.8   268.7   455.8
283.1   462.5   304.9   463.3   315.2   464.1
247.3   400.5   263.7   402.1   281.9   402.5   296.6   401.7
300.2   404.4   316     405.2
```

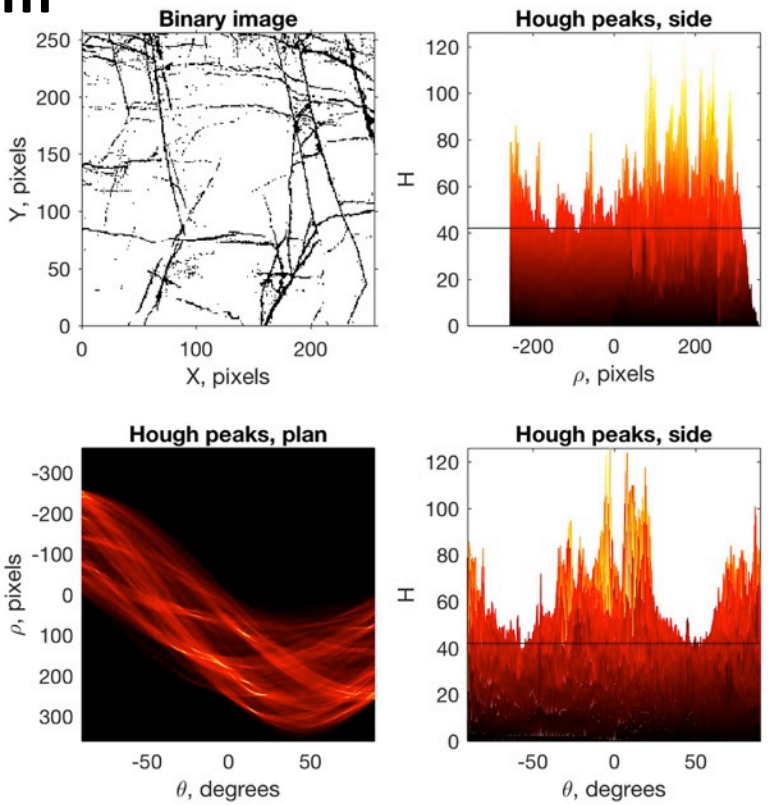
Shown above is an **example of a *.txt file** for input. The file contains (x,y) nodes along each fracture trace. The (x,y) data are **tab-delimited**, and **each fracture trace is on one line**. There is a minimum of 4 columns for each line (i.e. each fracture trace) – so (x1, y1) for node 1, and (x2, y2) for node 2.

A fracture trace can be made of many segments; in the example shown above the longest trace (line 7) has 5 segments, bounded by 6 nodes – i.e. 12 columns = 6 x 2 (x,y) pairs.

Image file input – the Hough transform

FracPaQ can also read binary **image files** as input. Two examples are provided, **`MacduffBinary.tif`** and **`OrkneyBinary.tif`**. The code uses a Hough transform to find straight lines within the pixels. The user can choose the values at which these lines are merged (if they are close enough together) or discarded (if they are too short). More details on the Hough transform method can be found in the MATLAB Help documentation.

The key parameters that affect the number and length of the fracture traces found are the number of **peaks** and the **threshold**. Using the Hough transform is a 'trial and error' procedure: load an image file and click **Preview**. Then use the graphs (shown on the right, created as Figure 1) and the trace map displayed in the main window to tune the Hough transform parameters. Set the **threshold** to a value between 0.0 and 1.0 that captures only the significant peaks (in orange/yellow on the graphs). 0.33 is a good start.



NB: the Hough transform method can **only find straight line fractures** each made of a single trace; multi-segment traces cannot be found. $N_{traces} = N_{segments}$ for this method.

Text file input – conversion from *.svg format

If you select a file type of *.svg, **FracPaQ** converts this into a *.txt node file of the same name, with 'converted.txt' at the end. An example of an *.svg file is shown on the right.

Standard graphics packages, such as Adobe Illustrator, CorelDraw and Inkscape, can all produce *.svg files. Typically, the user imports a photograph or map of fractured rock, and then traces all of the fractures onto a new layer in the software using a 'Pen' tool. After deleting the original image layer, the traces can be saved as *.svg format. **We recommend using *.svg format version 1.1.**

FracPaQ now converts the *.svg file into *.txt file format. Note that **FracPaQ** only reads **`<polyline>`** and **`<line>`** tags from the *.svg file. All other tag types are ignored.

Scaling

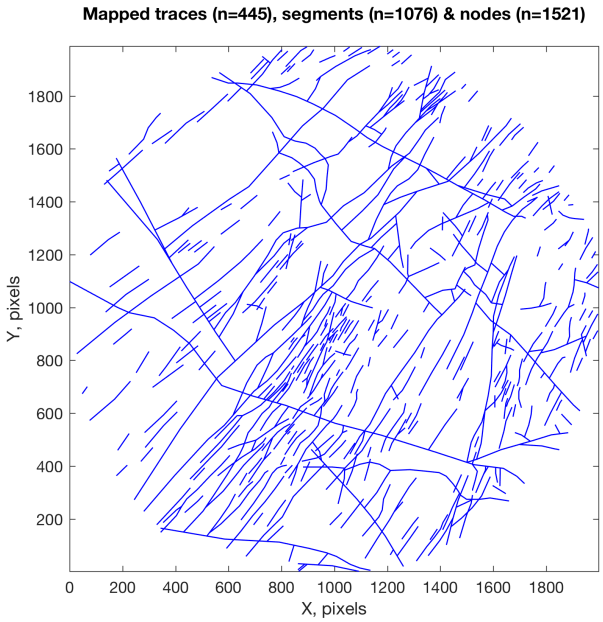
Scaling (pixels/metre)

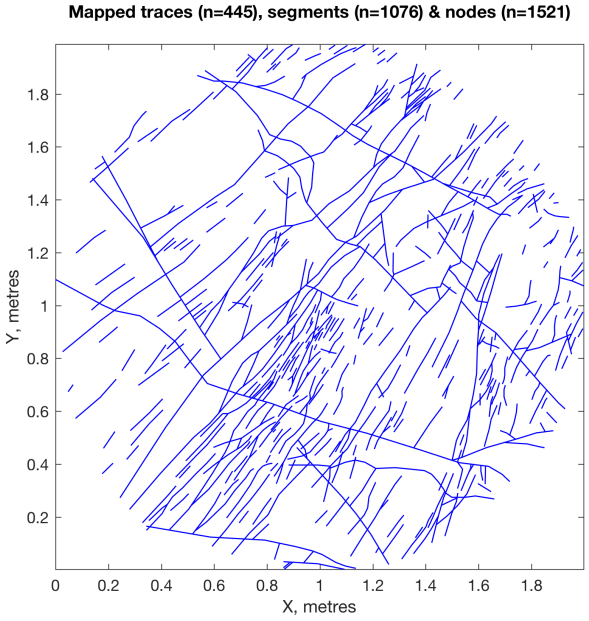
By default, **FracPaQ** uses length units of pixels. You can change this to metres by entering a value in the "Scaling" text box.

For the example shown, the field of view is 2 metres across. The image is 2,000 pixels wide. After typing a value of 1,000 in the Scaling box, and clicking on Preview, the corrected units are shown in the map.

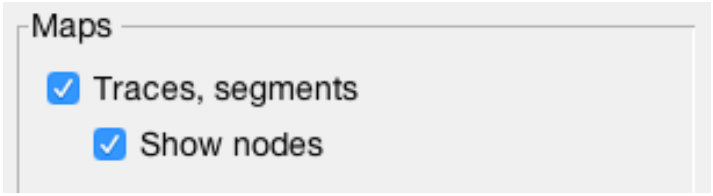
These units are carried forward into all of the subsequent plots (length graphs, intensity and density maps, and permeability estimation).

You can change the scaling at any time by entering a new value in the text box and clicking on Preview.





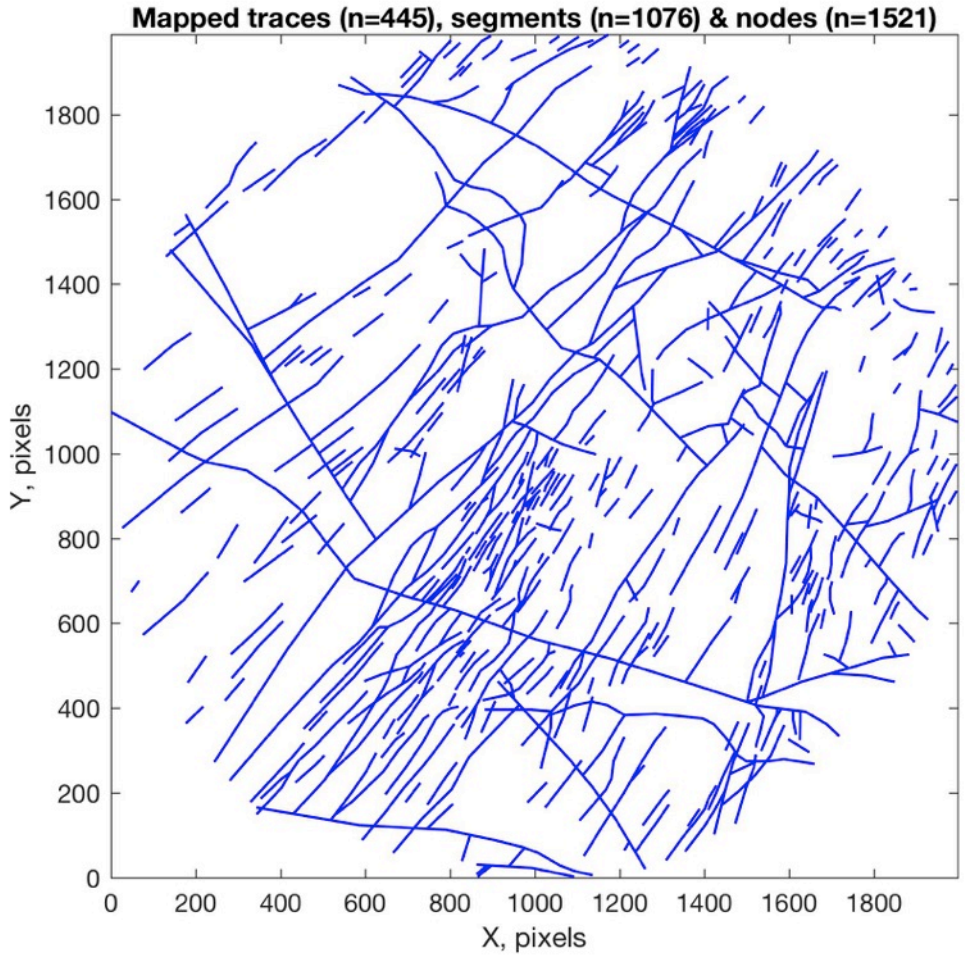
Maps – Traces, segments



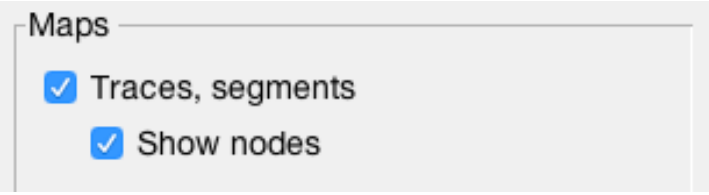
Click on the checkbox “Traces, segments” in the Maps output panel to see a map of all fracture traces and segments. The numbers of traces, segments and nodes (i.e. the end points of traces and segments) are shown in the figure title.

This plot is saved in the current folder as **`FracPaQ2D_tracemap.tif`**, at a default resolution of 300 dpi.

The figure is produced by the script **`guiFracPaQ2Dtracemap.m`**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.

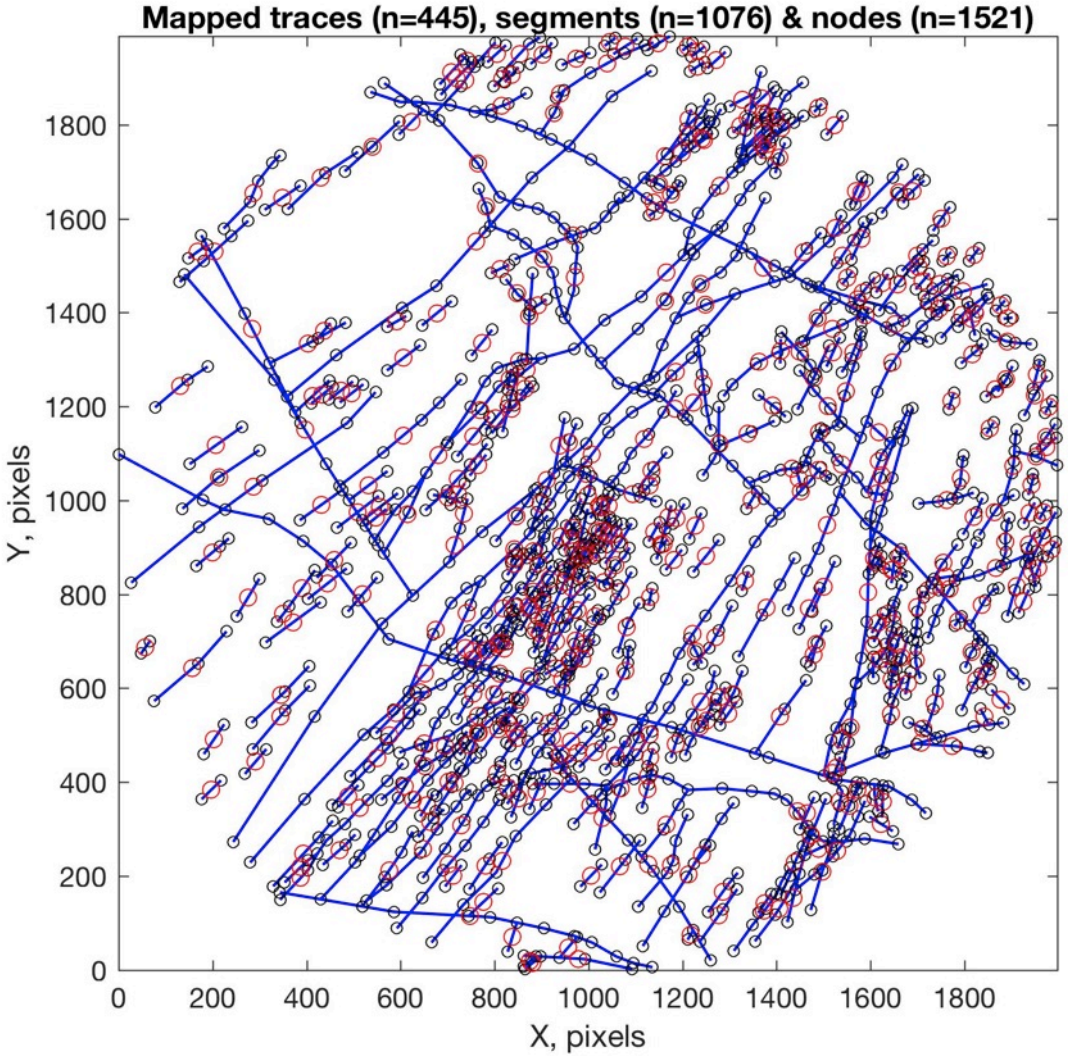


Maps – Traces, segments; Show nodes

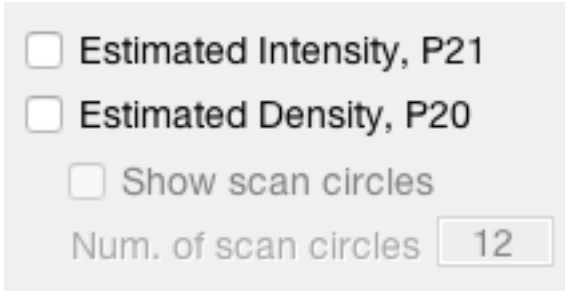


Click on the checkbox “Traces, segments” and also check “Show nodes” to see a map of all fracture traces and segments **with all the nodes displayed**. The numbers of traces, segments and nodes (i.e. the end points of traces and segments) are shown in the figure title. Trace and segment end nodes are shown with black circles, and trace centres are shown with red circles.

This plot is saved in the current folder as **`FracPaQ2D_tracemap.tif`**, at a default resolution of 300 dpi. The figure is produced by the script **`guiFracPaQ2Dtracemap.m`**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.

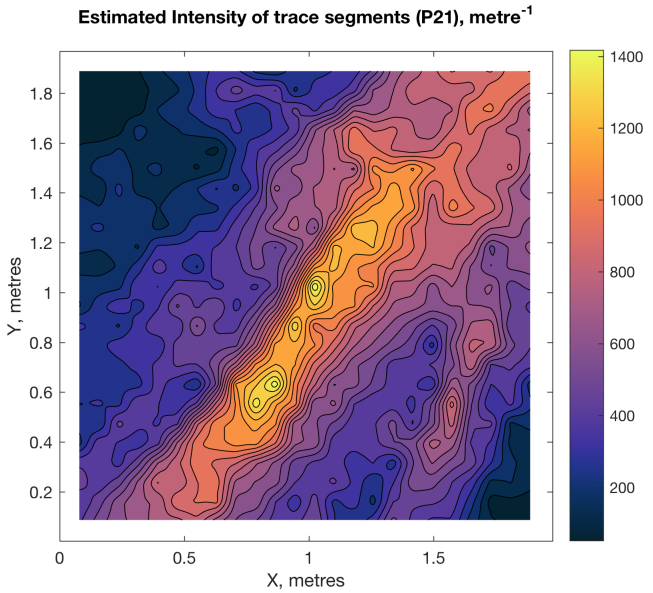


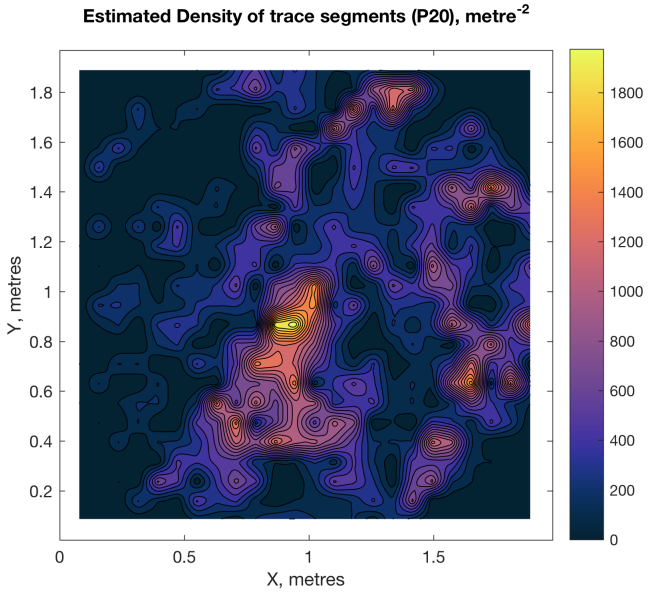
Maps – Estimated Intensity & Density



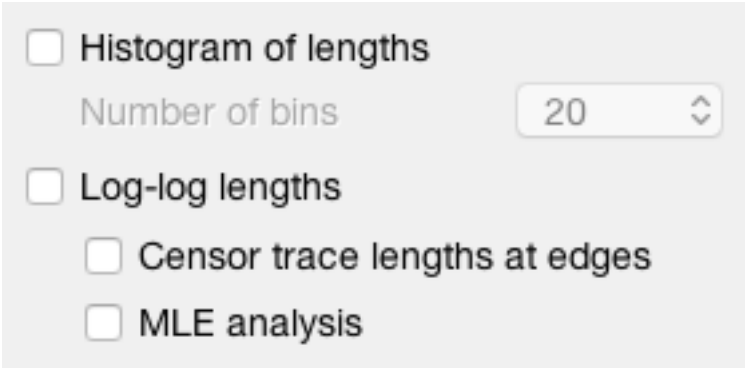
Click on the checkbox “Estimated Intensity, P21” and/or “Estimated Density, P20” to see maps of estimated fracture intensity and/or density. These contour maps are produced from the fracture segment data using the circular scan line method of Mauldon et al. (2001). **FracPaQ** places scan circles (default of 12) in the *x*- and *y*-directions, and counts the intersections of fracture segments with the circle perimeter (*n*), and the number of segments that terminate inside the circle (*m*). These measures are used to estimate Intensity (units of L^{-1}) and Density (units of L^{-2}) from the equations in Mauldon et al. (2001). P21 and P20 refer to the measures used by Dershowitz & Herda (1992).

These plots are saved in the current folder as **`FracPaQ2D_intensityP21.tif`** and **`FracPaQ2D_densityP20.tif`**, at a default resolution of 300 dpi. The figure is produced by the script **`guiFracPaQ2Dpattern.m`**. Edit this script file to change any default settings, such as the contour interval or the print resolution.





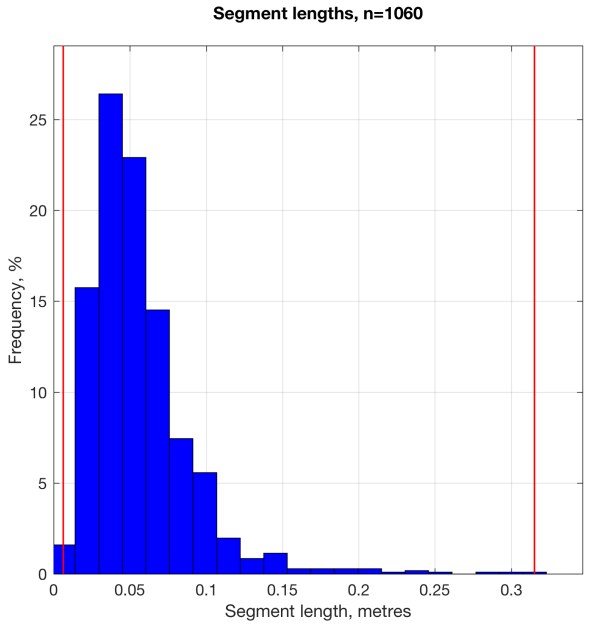
Graphs – Lengths

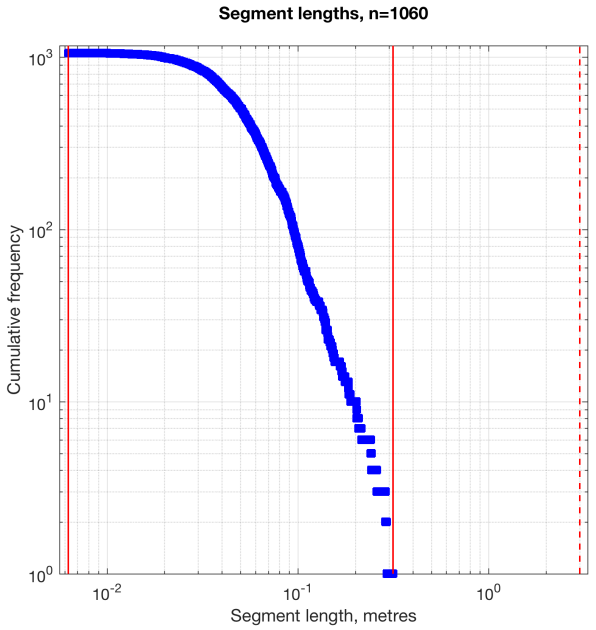


Click on the checkbox “Histogram of lengths” and/or “Log-log lengths” to see a histogram and/or log-log plots of of fracture lengths. **Separate plots are produced for fracture traces** (trace length = sum of segment lengths) **and fracture segments.** Select the number of bins for the histogram from the drop-down list.

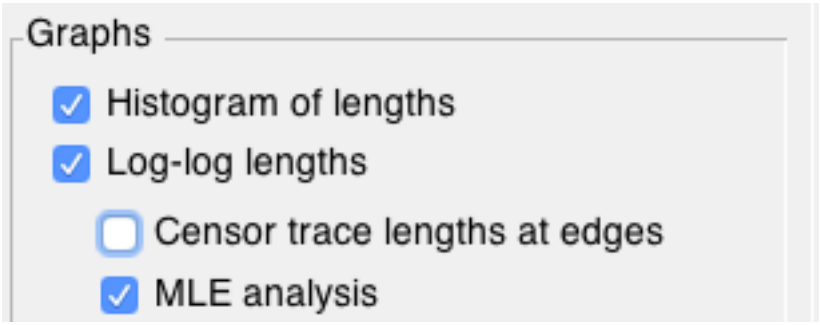
Check “Censor trace lengths at edges” to remove from the graphs any fractures with nodes on the edges of the trace map area. The red lines on the graphs show the minimum, maximum and maximum possible (dotted) lengths.

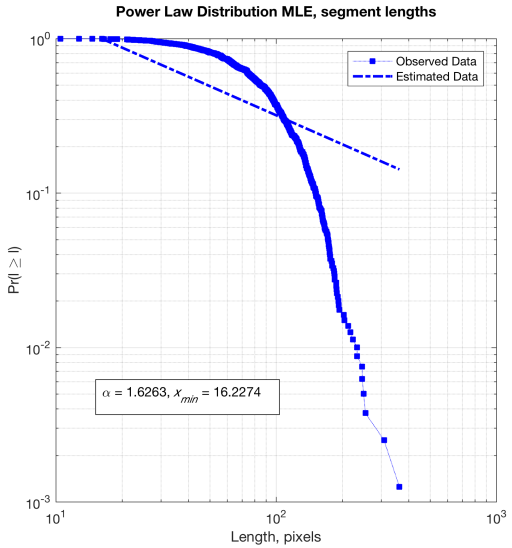
The plots are saved in the current folder as **`FracPaQ2D_*length.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dlength_new.m`**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.





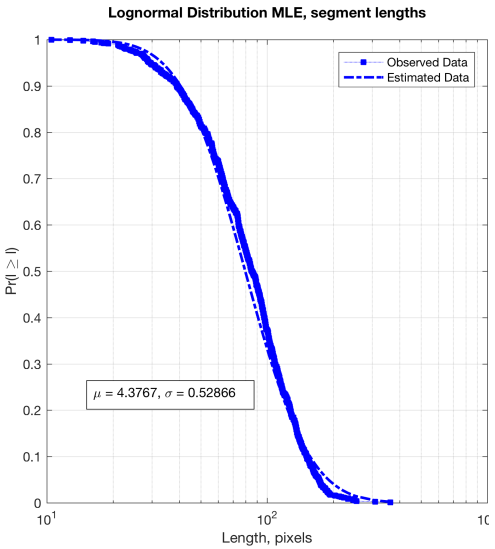
Graphs – MLE Statistical Analysis

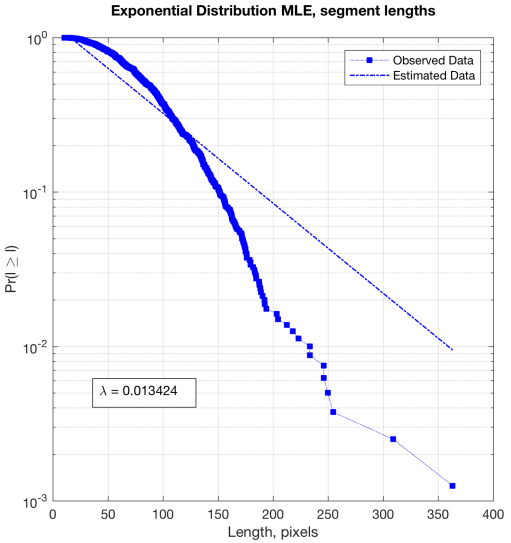




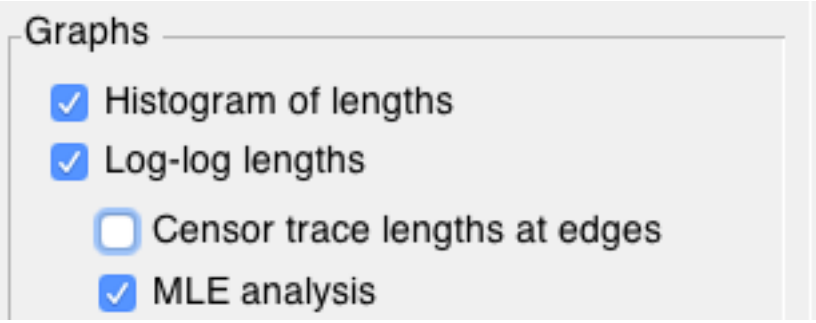
Click on the checkbox “MLE analysis” to perform a Maximum Likelihood Estimation (MLE) for fracture trace and segment lengths. Separate plots are produced for three possible underlying statistical distributions: Power Law, Log-Normal and Exponential. See Clauset et al. (2007) and Rizzo et al. (2017) for further details on MLE.

The plots for fracture segments are saved in the current folder as **`FracPaQ2Dlengths_Fitting*.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dlength_new.m`**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.



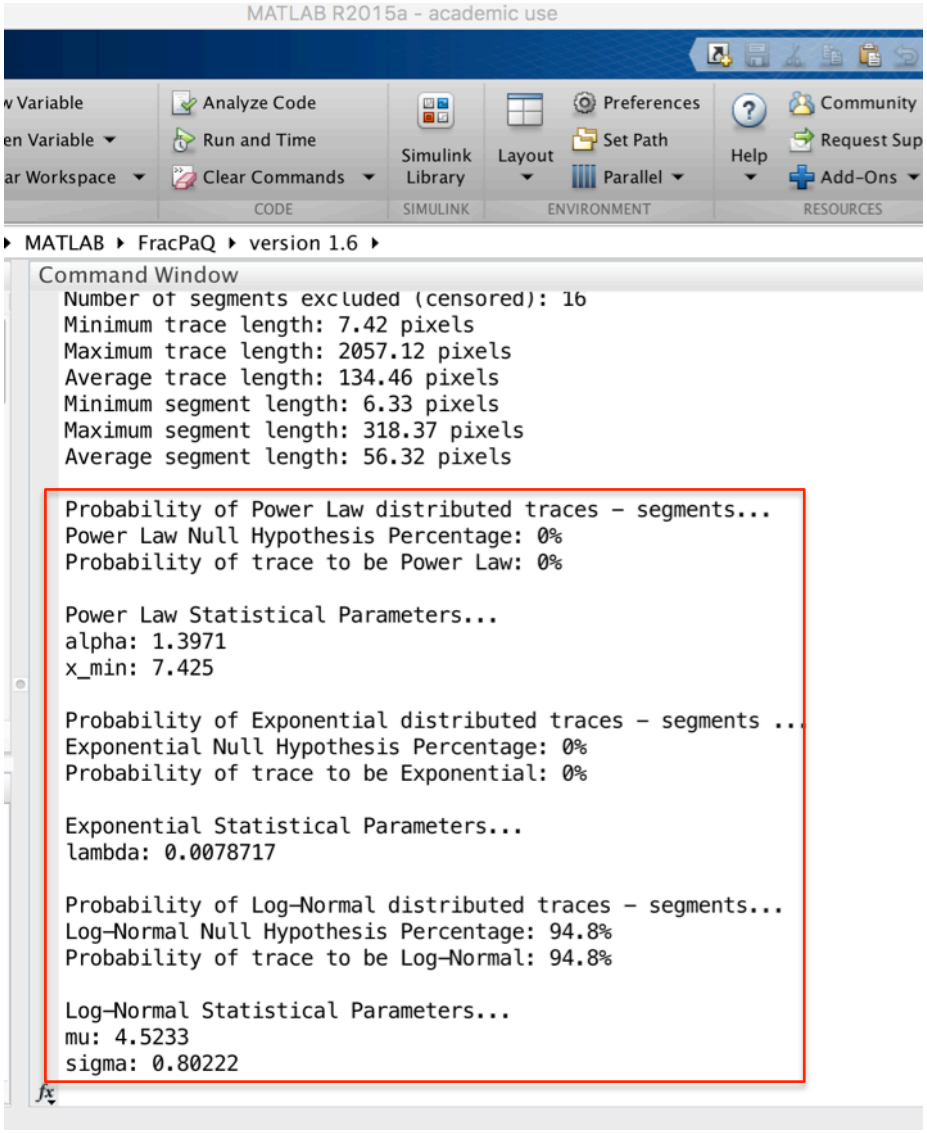


Graphs – MLE Statistical Analysis

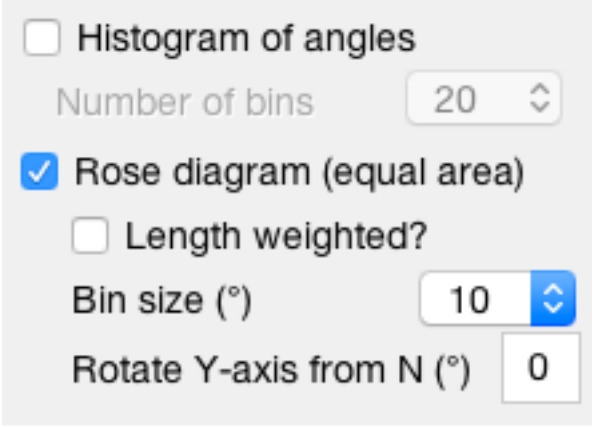


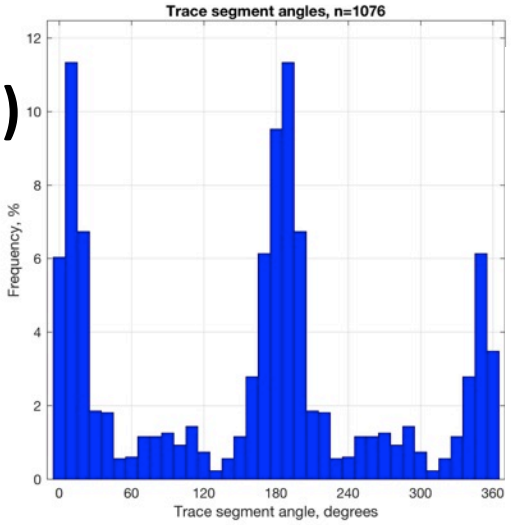
The MLE plots are supplemented with text outputs in the MATLAB™ Command Window. For each of the 3 distributions, the corresponding statistical parameters are given and the probability – expressed in % and calculated based on a Kolmogorov-Smirnoff (KS) test – that the analysed fracture lengths are distributed according to one of the distributions. These statistics are now also included on the graphs themselves (see previous page).

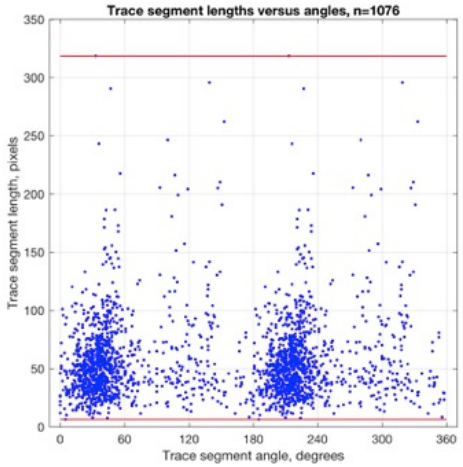
More details and related references can be found in the functions **`fitting*.m`**. called by **`guiFracPaQ2Dlength_new.m`**. Edit this script to change the variables 'uc' and 'lc' to cut off a certain percentage from the beginnig ('uc') or the end ('lc') of the data set. Default values are 0% cut-off.



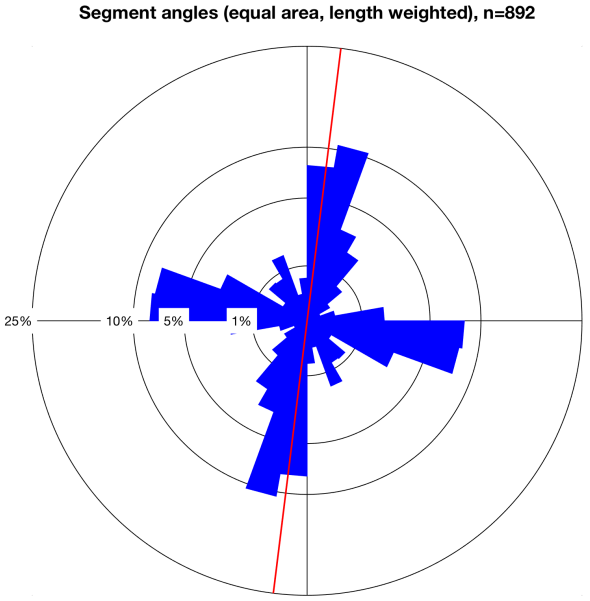
Graphs – Angles (Orientations)





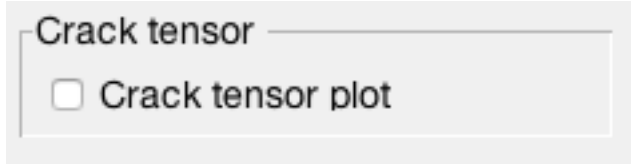


FracPaQ provides plots of orientation data, using the angles of the trace segments. Angles are calculated with respect to the Y-axis, clockwise as positive. In the event that the Y-axis is not aligned due North, enter a number in the text box 'Rotate Y-axis from N'. This is then subtracted from each of the segment angles to produce a 'corrected' plot. The number of bins in the histogram and the bin size in the rose diagram can be changed. The rose diagram is plotted as equal area as this provides a more robust measure of orientation distributions in 2D (Nemec, 1988). In version 1.8 you can also select length weighting of the rose plot. The circular mean is shown with a red line on the rose diagram.



The plots are saved in the current folder as **`FracPaQ2D_*angle.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dangle.m`**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.

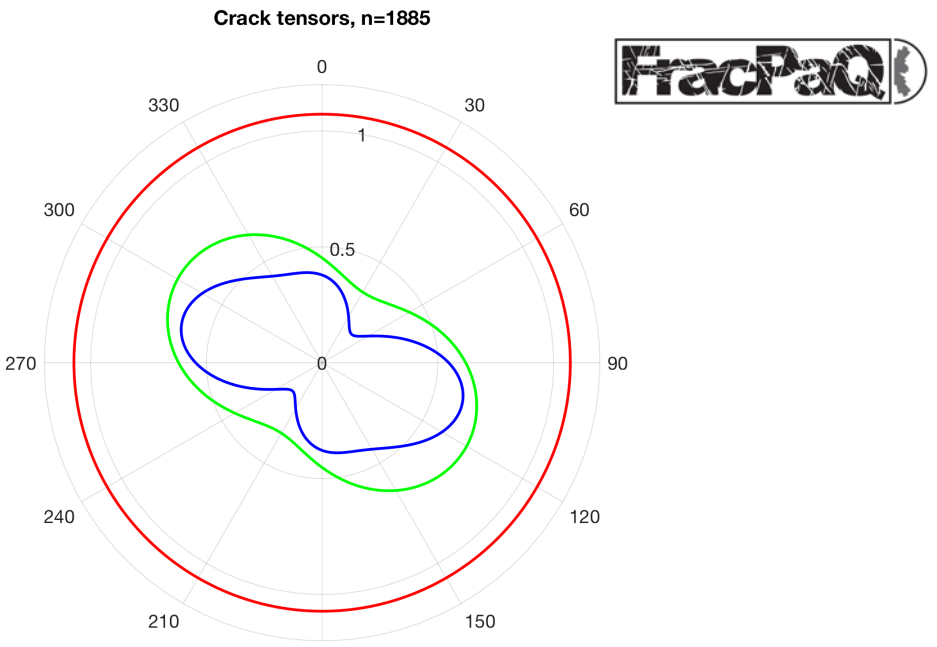
Crack tensor plot

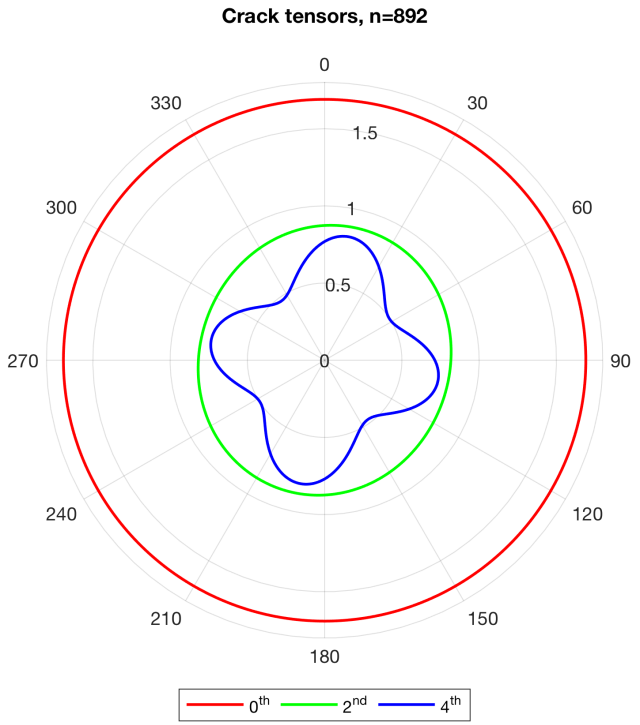


Click on the checkbox “Crack tensor plot” to see a polar plot of crack tensors for the 2D fracture network. Separate lines are shown for the 0th (or scalar, red), 2nd (green) and 4th order (blue) crack tensors using the equations in Oda et al. (1987).

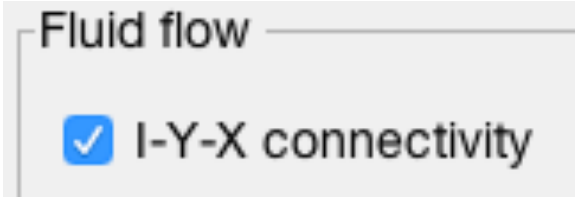
Crack tensors combine data from the segment lengths and orientations with their spatial density to provide another potentially useful measure of a fracture pattern. The 2nd order crack tensor is the basis for the permeability calculations used in **FracPaQ**, from the method of Suzuki et al. (1998).

The figure is saved in the current folder as **`FracPaQ2D_cracktensor.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dcracktensor.m`**. Edit this script file to change any default settings, such as the colour or the print file resolution.





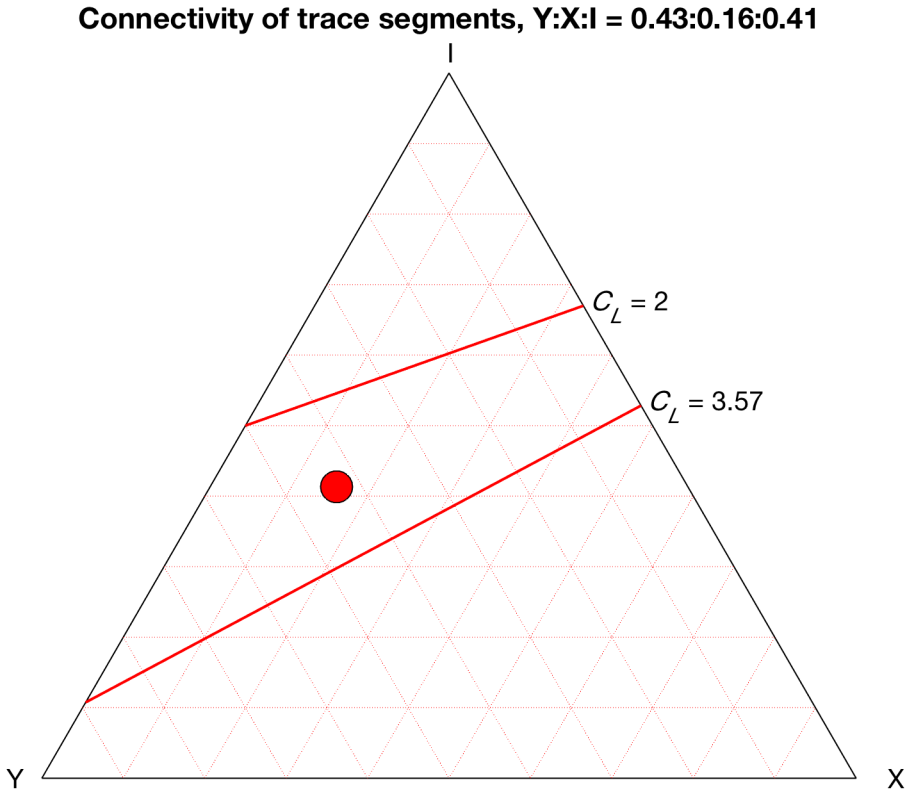
Fluid flow – Connectivity



Click on the checkbox "I-Y-X connectivity" to see a ternary plot of relative proportions of I, Y and X nodes in the fracture network (Manzocchi, 2002). I nodes are the isolated ends of traces, Y nodes are splays or abutments, and X nodes are intersections.

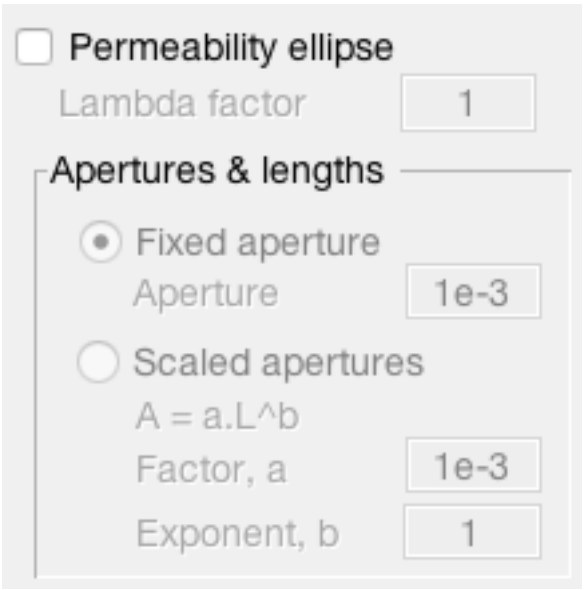
Also shown on this plot are two contour lines for C_L – the number of connections per line (or trace in our terminology) from Sanderson & Nixon (2015). Higher values of C_L are indicative of better connectivity, although the contours depend on other attributes of the fracture network, such as the length distribution and the spatial distribution.

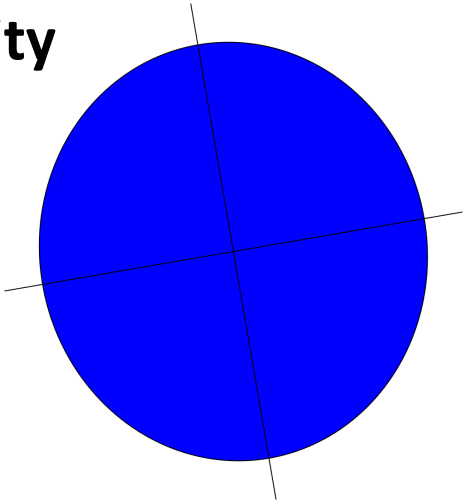
Better connected networks tend to plot towards the bottom of this diagram (higher proportions of Y and X nodes).

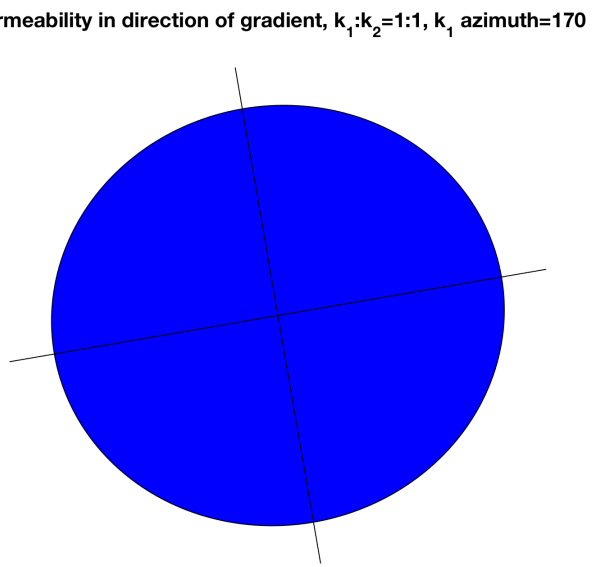


The figure is saved in the current folder as **`FracPaQ2D_IYXtriangle.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dpattern.m`**. Edit this script file to change any default settings, such as the colour or the print file resolution.

Fluid flow – Permeability



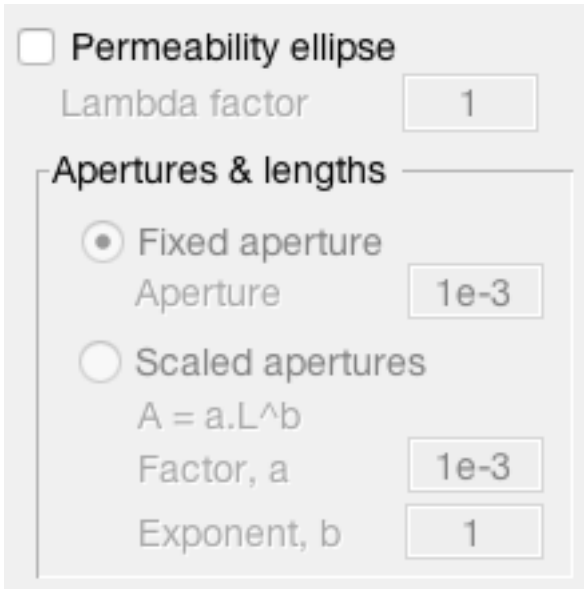


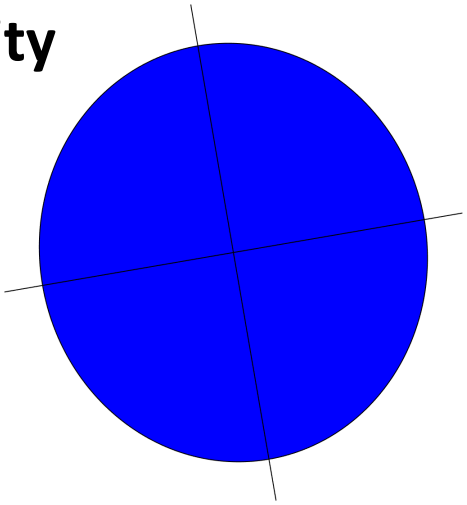


Click on the checkbox “Permeability ellipse” to see the 2D permeability anisotropy for the fracture network. The estimate is produced from a combination of lengths, orientations and spatial densities using the tensorial method of Suzuki et al. (1998). Two ellipses are plotted. For **permeability in the direction of flow**, we plot the long axis proportional to the maximum permeability ($\sqrt{\mathbf{k}_1}$), and the short axis proportional to the minimum permeability ($\sqrt{\mathbf{k}_2}$). For **permeability in the direction of gradient**, we plot the long axis proportional to $1/\sqrt{\mathbf{k}_1}$, and the short axis proportional to $1/\sqrt{\mathbf{k}_2}$ (see Long et al., 1982 for details).

The figures are saved in the current folder as **`FracPaQ2D_permtensor_flow.tif`** and **`FracPaQ2D_permtensor_gradient.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dtensor.m`**. Edit this script file to change any default settings, such as the colour or the print file resolution.

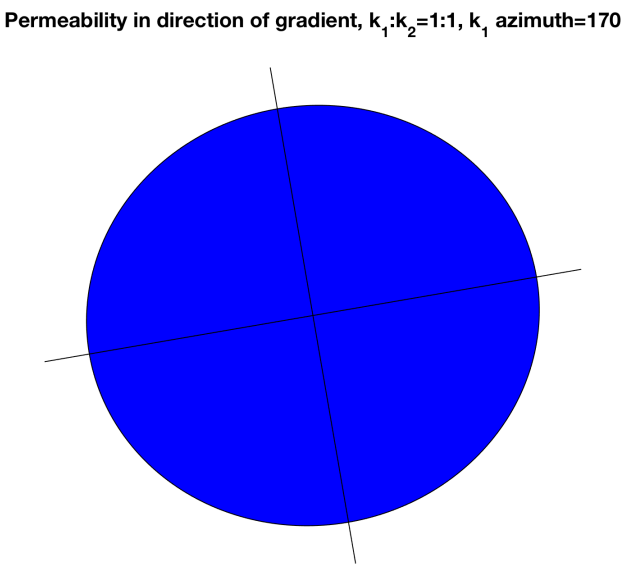
Fluid flow – Permeability





The user can change the Lambda factor, which lies between 0 and 1. If all fractures are fully connected, Lambda can be set to 1 (Suzuki et al., 1998). The user can adjust this variable based on the results obtained from the connectivity plot.

From version 1.8, **FracPaQ** also allows the user to scale apertures with the trace segment lengths using a scaling law derived from Vermilye & Scholz (1995). Enter the factor **a** (default = 1 x 10^{-3}) and an exponent **b** (default = 1 for linear aperture-length scaling).



The figures are saved in the current folder as **`FracPaQ2D_permtensor_flow.tif`** and **`FracPaQ2D_permtensor_gradient.tif`**, at a default resolution of 300 dpi. The figures are produced by the script **`guiFracPaQ2Dtensor.m`**. Edit this script file to change any default settings, such as the colour or the print file resolution.

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`lineSegmentIntersect.m` written by **U. Murat Erdem**; available on Mathworks FileExchange:
http://uk.mathworks.com/matlabcentral/fileexchange/27205-fast-line-segment-intersection

`readtext.m` written by **Peder Axensten**; available on Mathworks FileExchange:
http://uk.mathworks.com/matlabcentral/fileexchange/10946-readtext

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