Image Processing - wxmv95

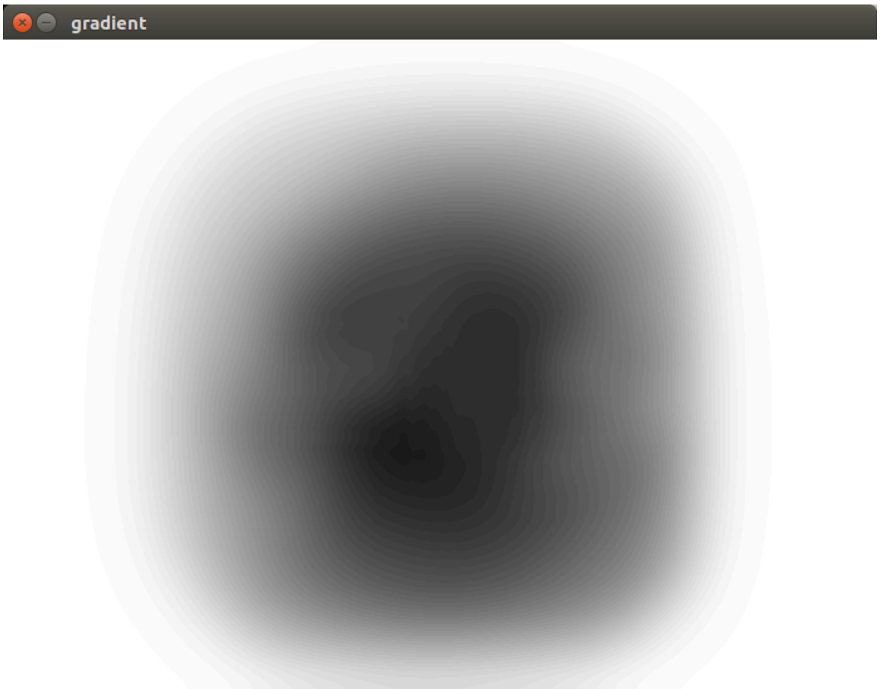
This description will use the following example (displayed with equalised histograms to improve contrast for display in this document:

Channel 1

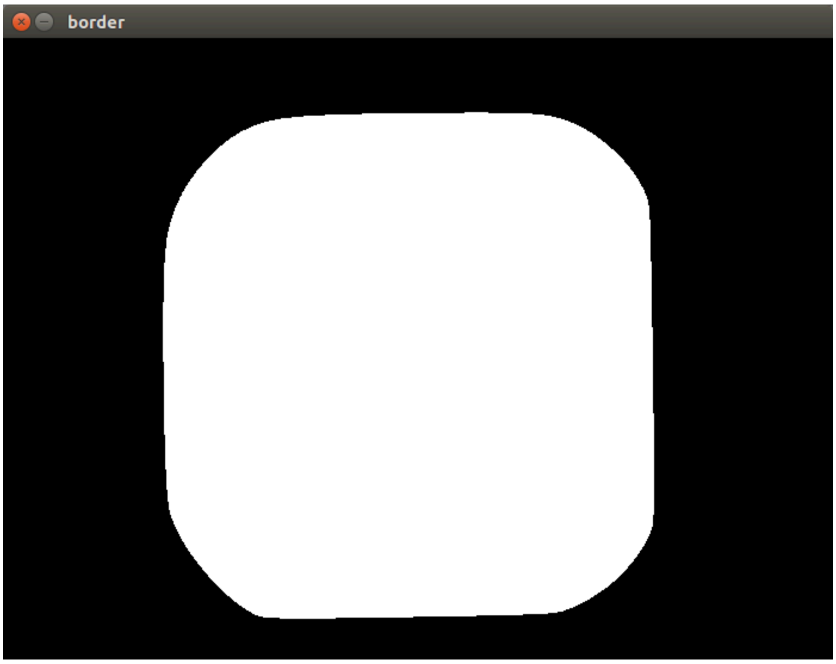
Channel 2

The first channel is thresholded, denoised (median blur) and then subtracted from the second channel, ensuring that any worms present in just one image are detectable. Images are read at 16 bit and multiplied by a constant factor to expand the typically useful range before reducing to 8 bit in order to avoid loss of precision in the useful range of values.

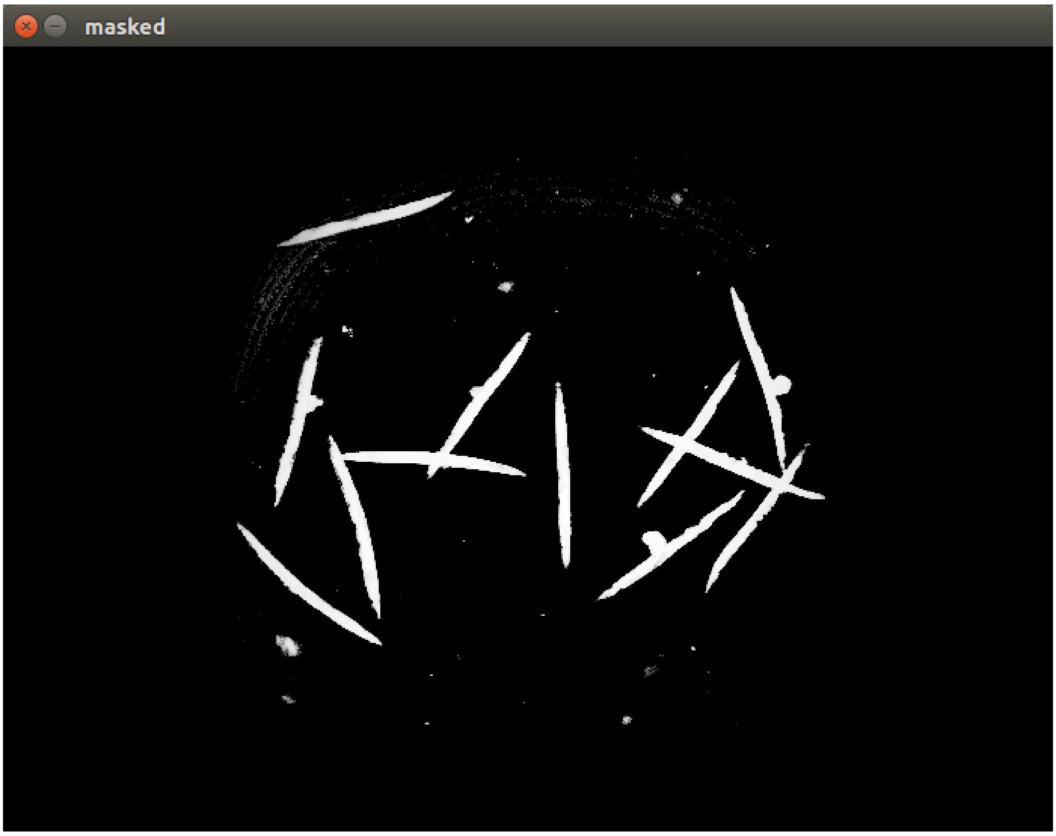
The second channel is blurred to create an approximation of the background gradient - see inverted gradient below, which is added to the original image to even out the gradient so that thresholding with a constant value can separate the worms from the background.



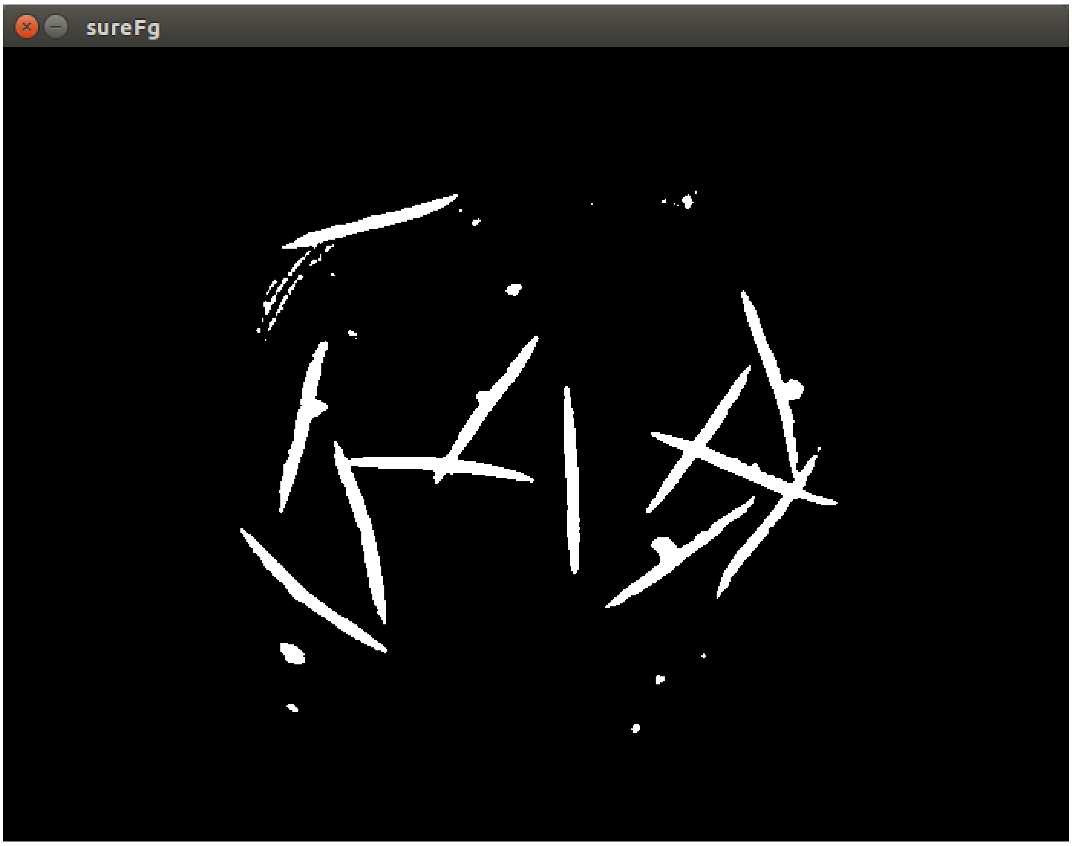
Artefacts appeared at the border so the original image was used to produce this mask by thresholding, dilating and eroding.



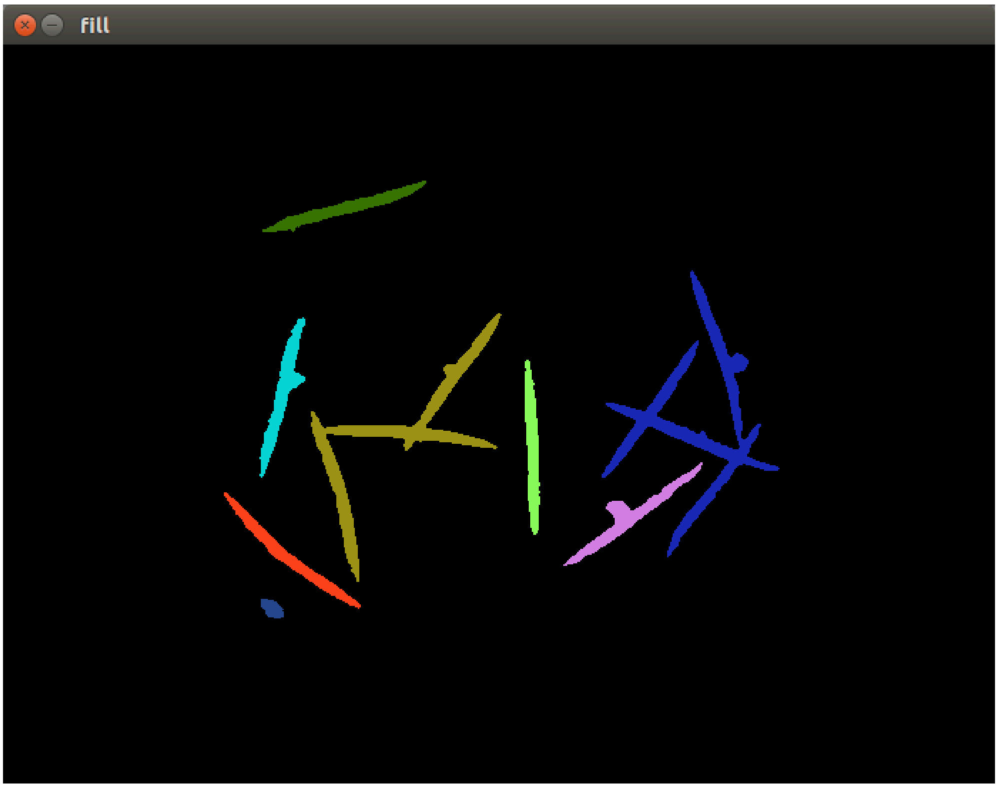
Removed gradient and masking out border:



Denoising:

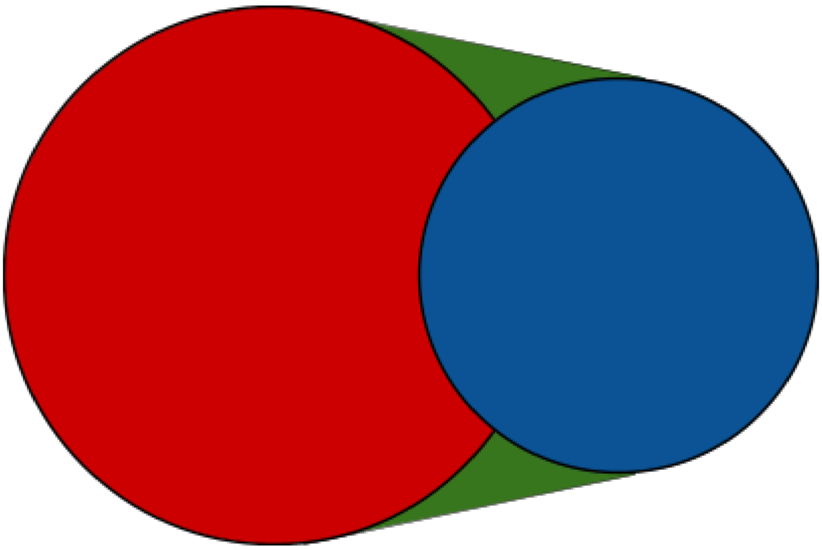


Connected sections are found by finding contours. Any contours that don't enclose a large enough area are assumed to be noise.

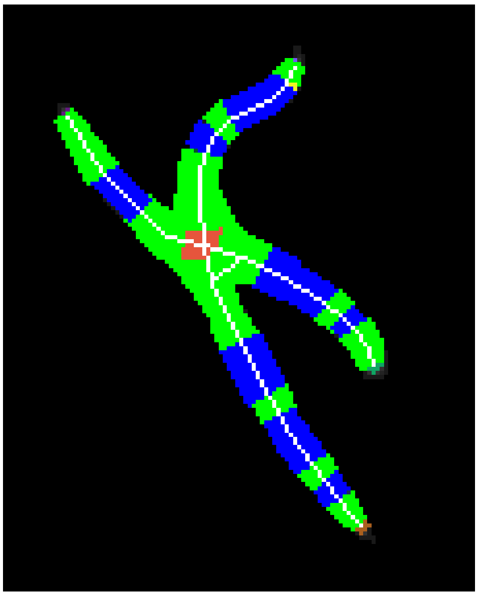


A “skeleton” is constructed for each connected area. A distance transform is applied, then repeat the following steps until all the pixels are below a threshold:

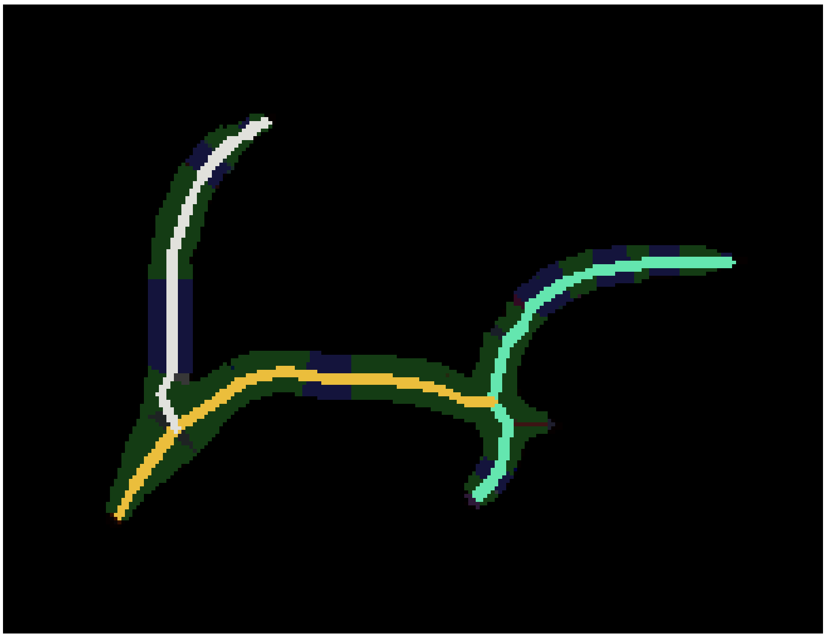
1. Find the maximum valued pixel (V) and its location (P).
2. Create a circle (representing a vertebra) at P with size V.
3. Create an edge between any overlapping circles.
4. Draw a black circle of radius V (to stop further circles being created in this area).
5. Draw a black polygon where any circles touch using circle-circle tangents (see http://mathworld.wolfram.com/Circle-CircleTangents.html). This prevents other circles being placed in the area shown in green:



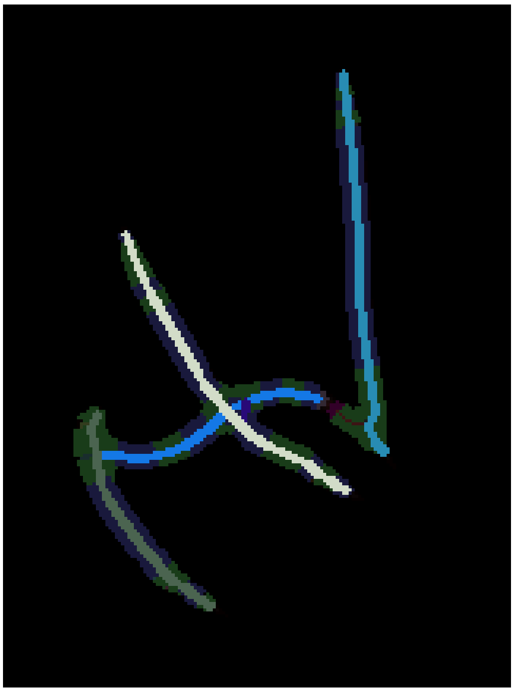
Below is an example of a skeleton. The blue and green areas are circles and their connecting polygons, the red in the middle is the root of the graph and the white line is the skeleton.

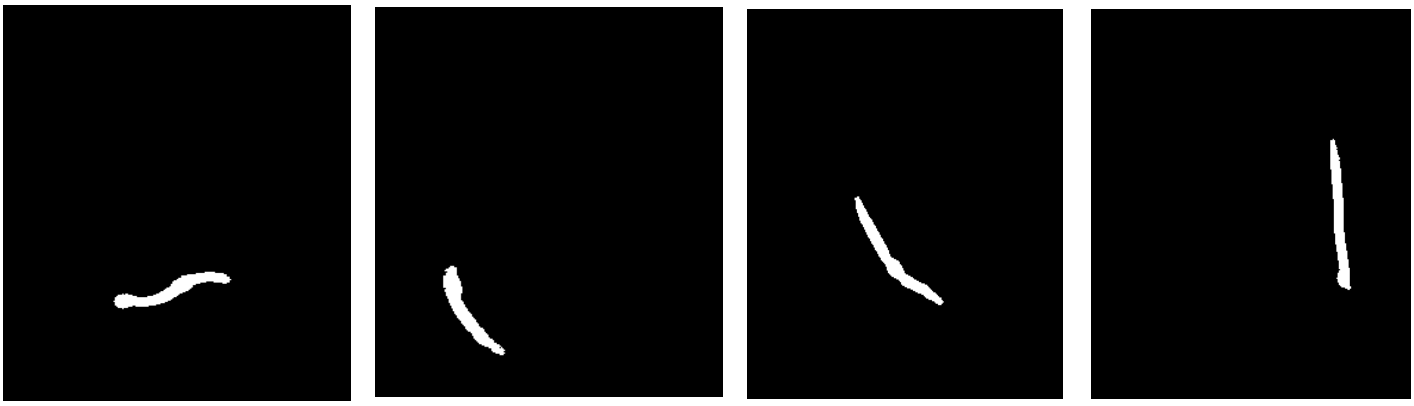


By walking along the graph following the most-straight course, individual worms are separated. Example skeletons are marked in different colours.

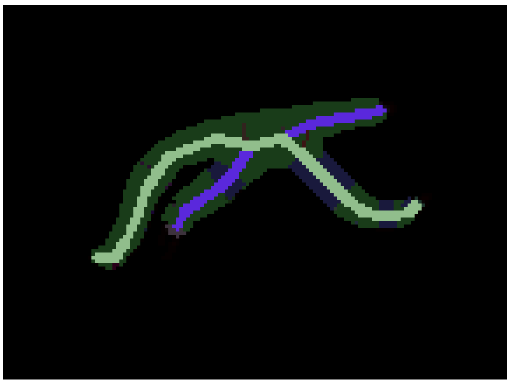


Worms that cross or meet at their ends are often successfully separated:

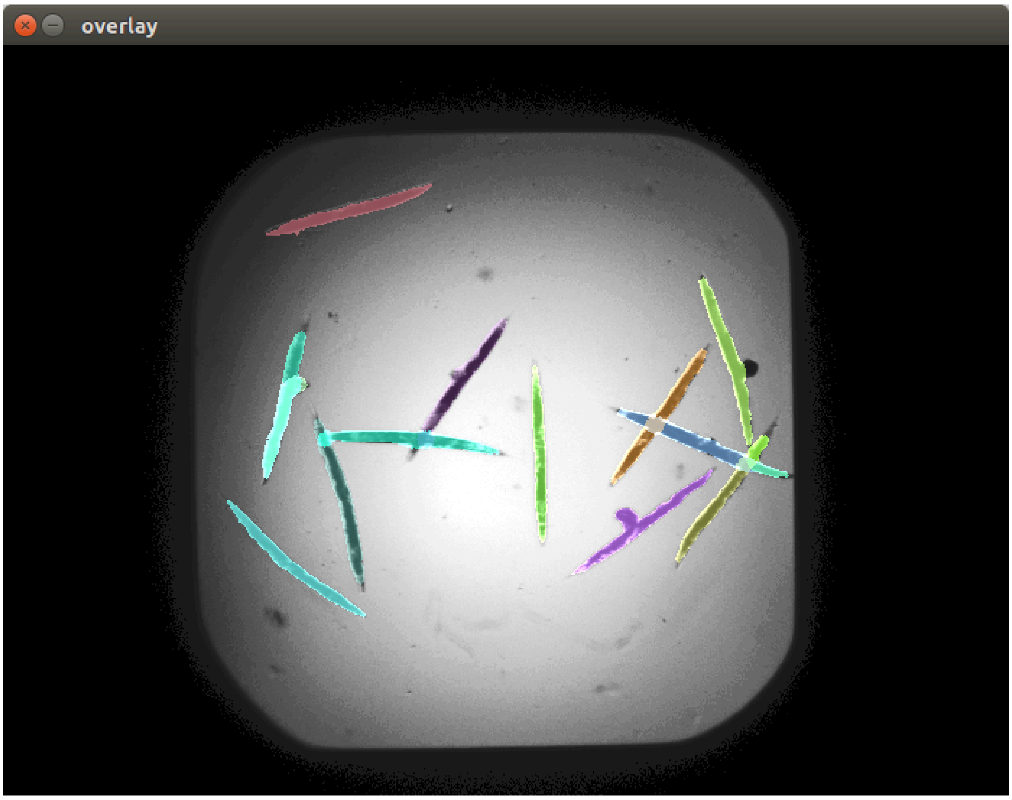




Curved worms that briefly touch and parallel straight worms often cause errors.



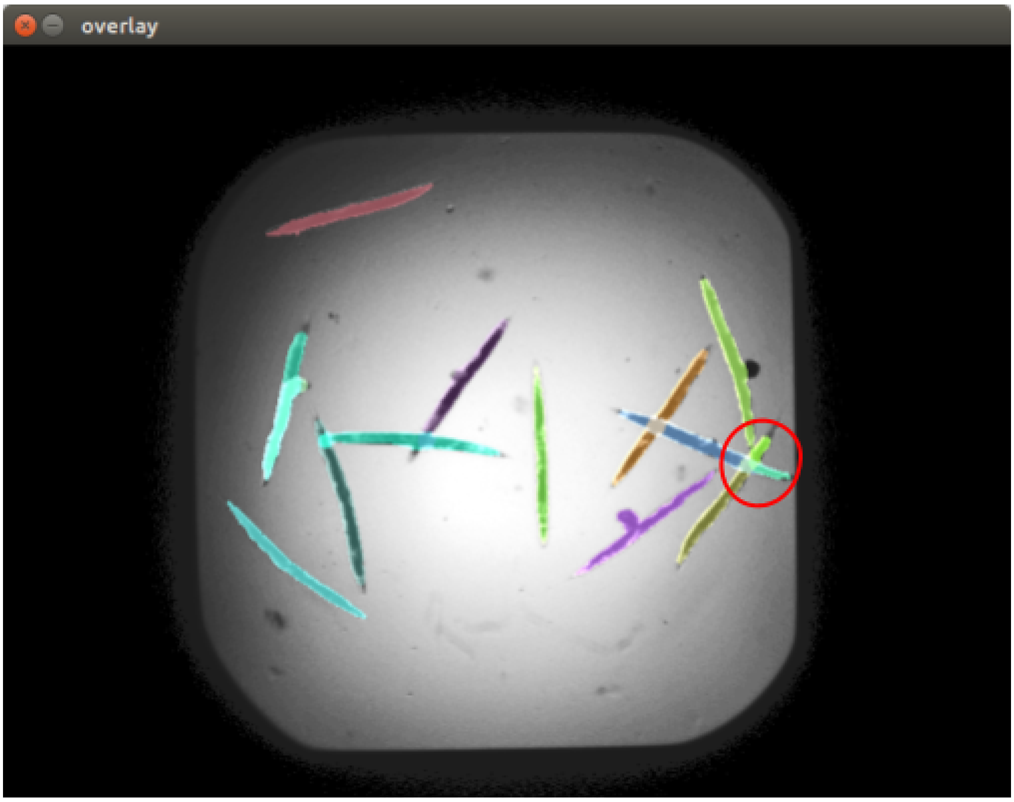
An example set of separated worms:



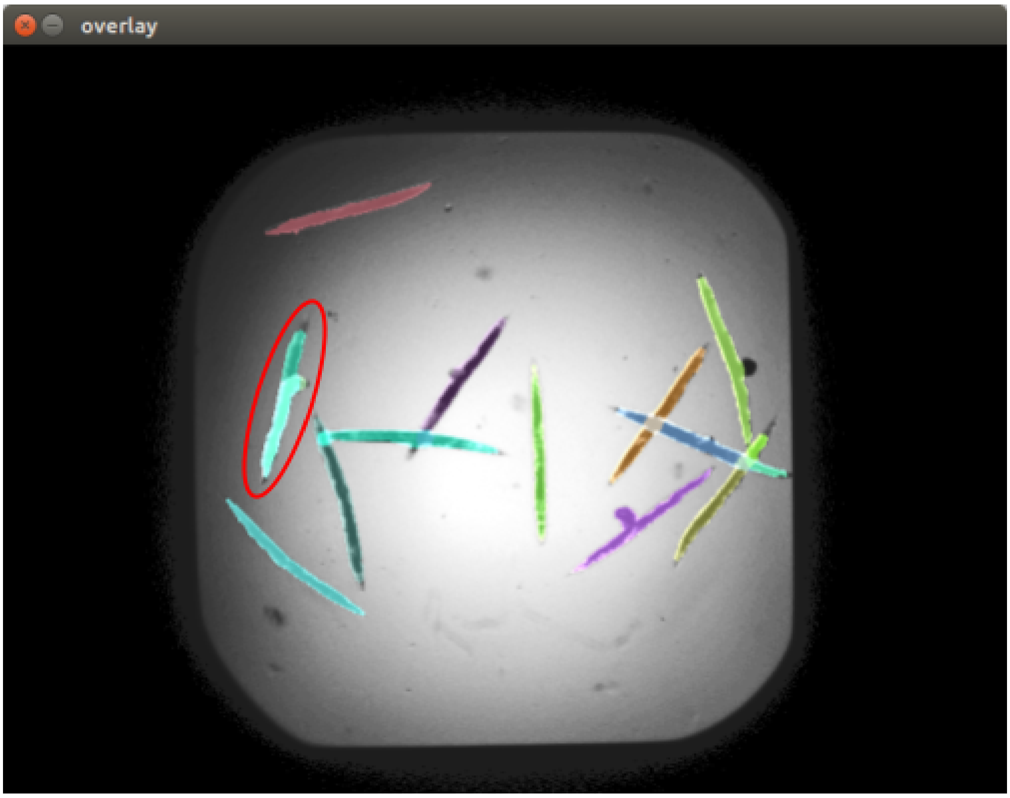
Dead worms are identified by averaging the dot product of the normalised edges in the skeleton. Yellow sections caused by separation errors.

Issues and improvements

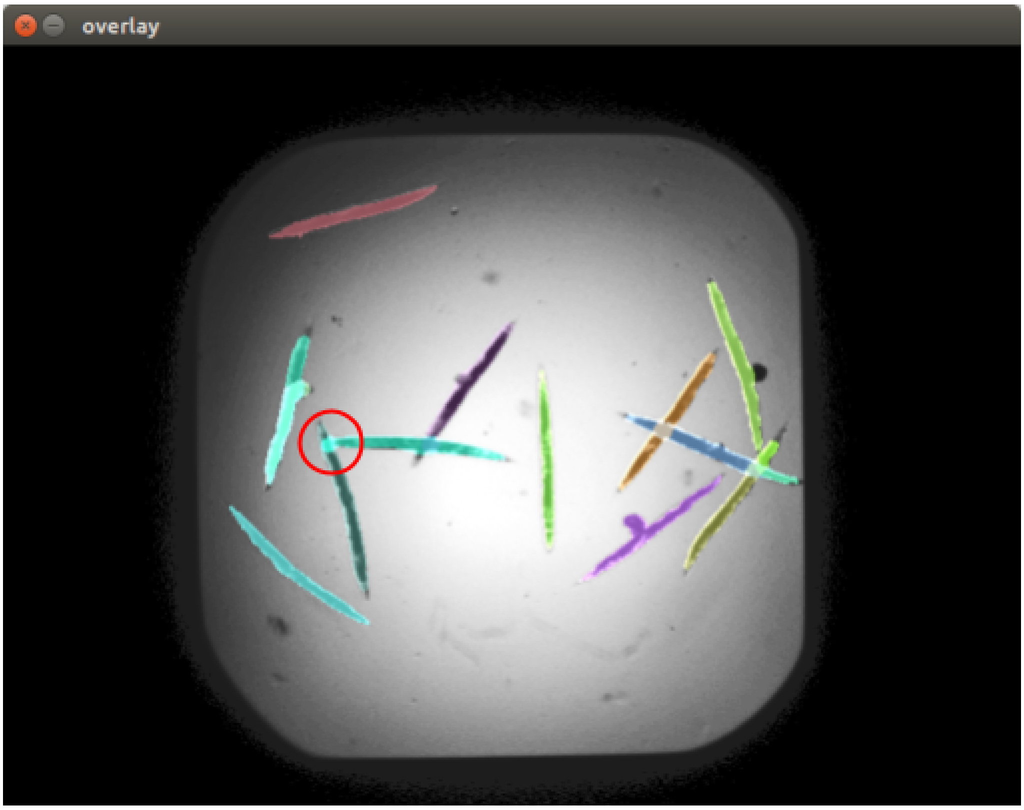
1. Not all crossovers are successfully handled.



2. Despite being just one worm the lump part way down this worm causes it to be identified as 2.

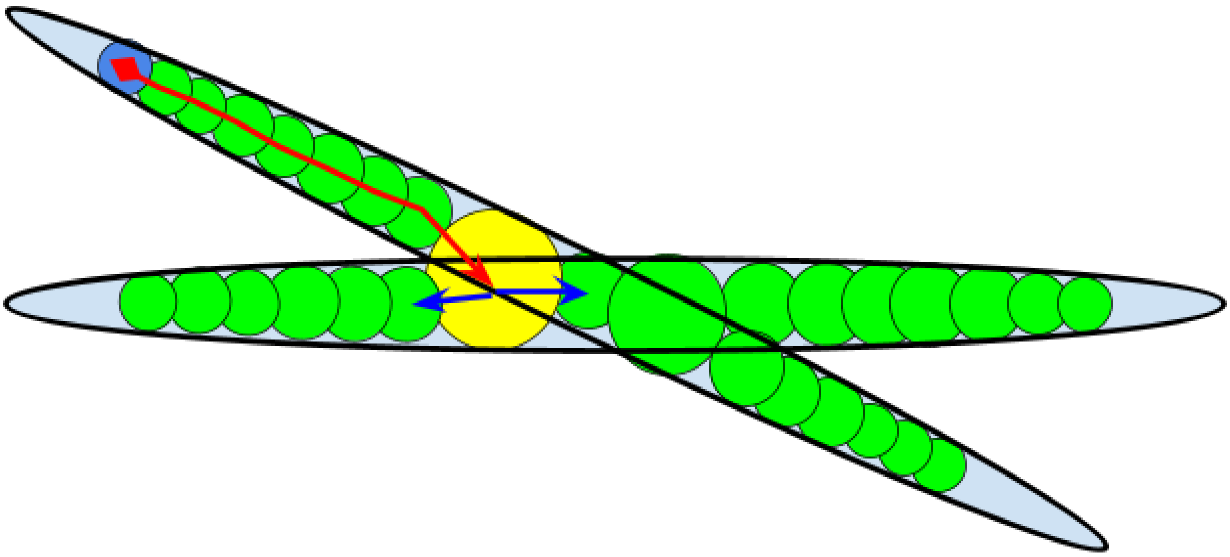


3. Too much is included of any worms that end touching another worm.



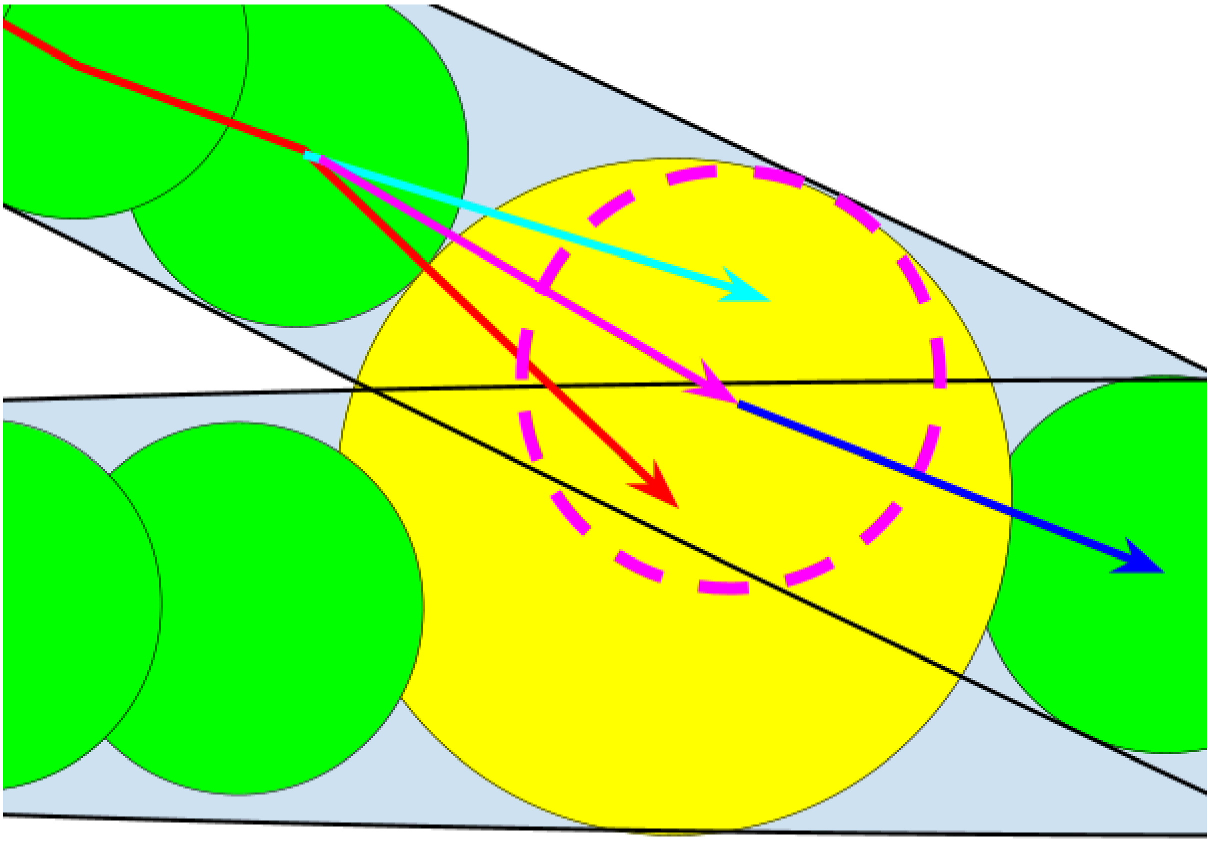
Case 3 should only require a special case to be added when walking along the skeleton, which excludes the last point if this situation is identified.

Cases 1 and 2 are likely caused by the the larger circles placed at intersections during the construction of the skeleton:



The yellow circle is larger because the area created by the crossover is wider than any other point. The blue circle is an end point so the skeleton decomposing function might start there and walk along the path shown in red. The path abruptly changes direction at the yellow circle the walk to halt.

A way to solve this would be to relax the steps in the walk rather than stepping to the centre of each circle.



The turquoise line is a continuation of the penultimate section of the red line. The pink line is an average of the red and turquoise lines. A circle that has a centre at the point reached by the pink line and that is contained within the yellow circle (pink dotted circle) is added rather than the yellow circle. This should improve the separation and shape of separated worms and the quality of the skeleton produced (so better curvature measurements for detecting dead worms).

Results

By comparing the number of white pixels a result of 80.8% correct pixels is reached and 19.2% of white pixels in the ground truth missed. Furthermore, 9.6% of the actual area of the worms was labelled as being a worm when really it wasn't. The average error in the number of worms counted was 16.5% where the error was the sum of individual worms not accounted for plus worms identified that weren't in the ground truth or were counted more than once. An identified worm was counted as matching a worm in the ground truth if the area of the intersection was greater than 40% of the area of the union.