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## Abstract

Automatized acquisition systems of Root System Architecture (RSA) are now readily available for developmental research and provide high-throughput image data. Here we consider root system grown in petri plates. The analysis of these data (RSA) is currently a major challenge in understanding root development. However, suitable tools to process them efficiently are usually missing, thus reducing the possible scaling of processing and results. Existing tools either focus on specific applications, on simple structures (e.g. one root segment) or require long manual work.

We present a processing pipeline that makes it possible to extract from an image the whole architecture of root systems, with minimal or no user intervention. In order to obtain this result, the problem was decomposed in several steps: filter and label the input image, extract the image skeleton as a general graph structure and then convert it into a tree structure representing the visualised RSA, using a priori knowledge to solve inconsistencies. The presented algorithm is inspired from publication of different scientific fields (blood vessel system extraction from 3D images, skeletization of virtual objects), but have been developed specifically for the extraction of the whole RSA from images acquired with traditional experimental protocol.

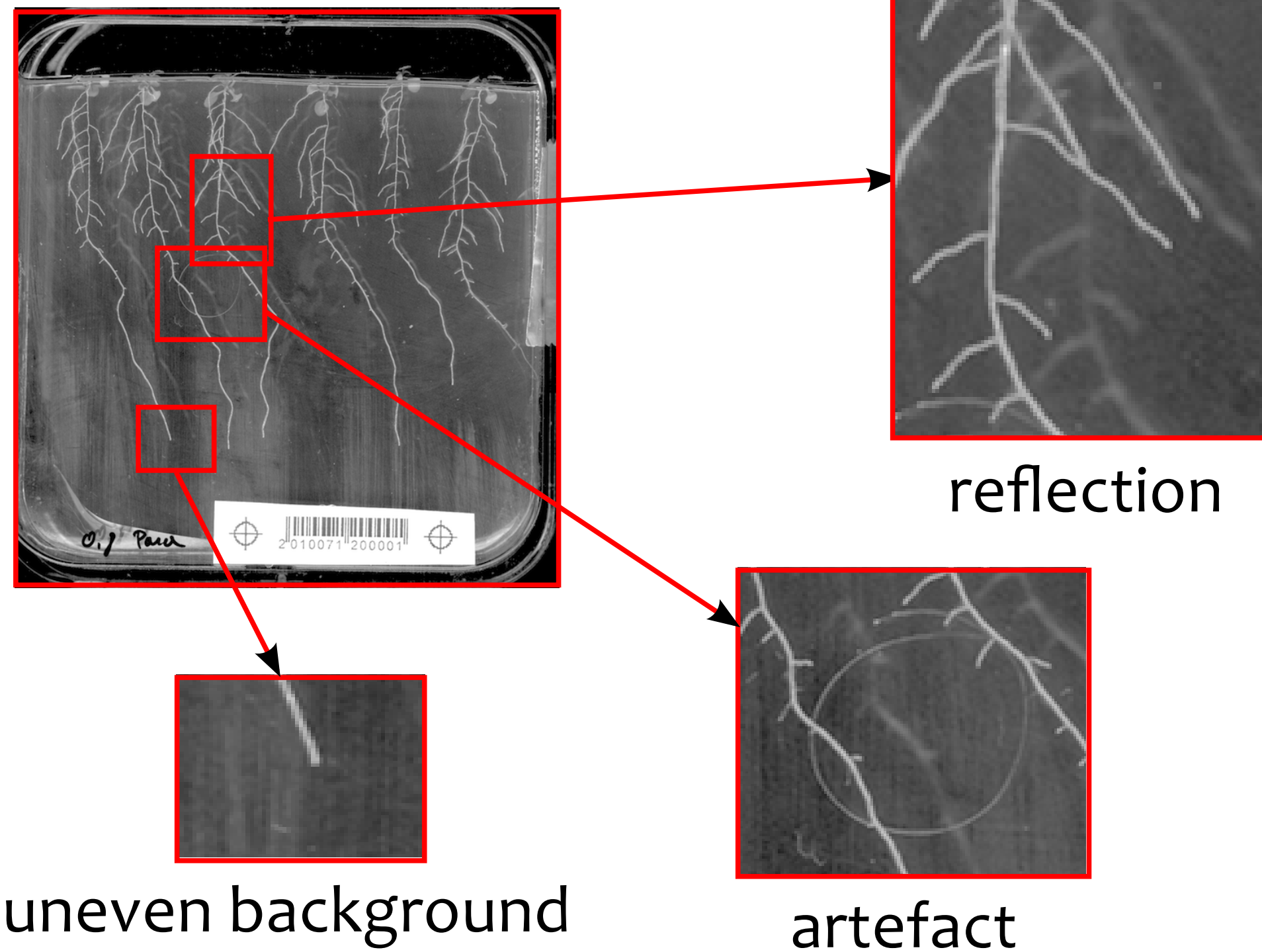
## Material

The goal of the presented work is to provide a computer software which is able to process experimental image data on roots obtained using traditional imaging protocol. One of the main focuses is then to cope with typical image quality limitation of such data.

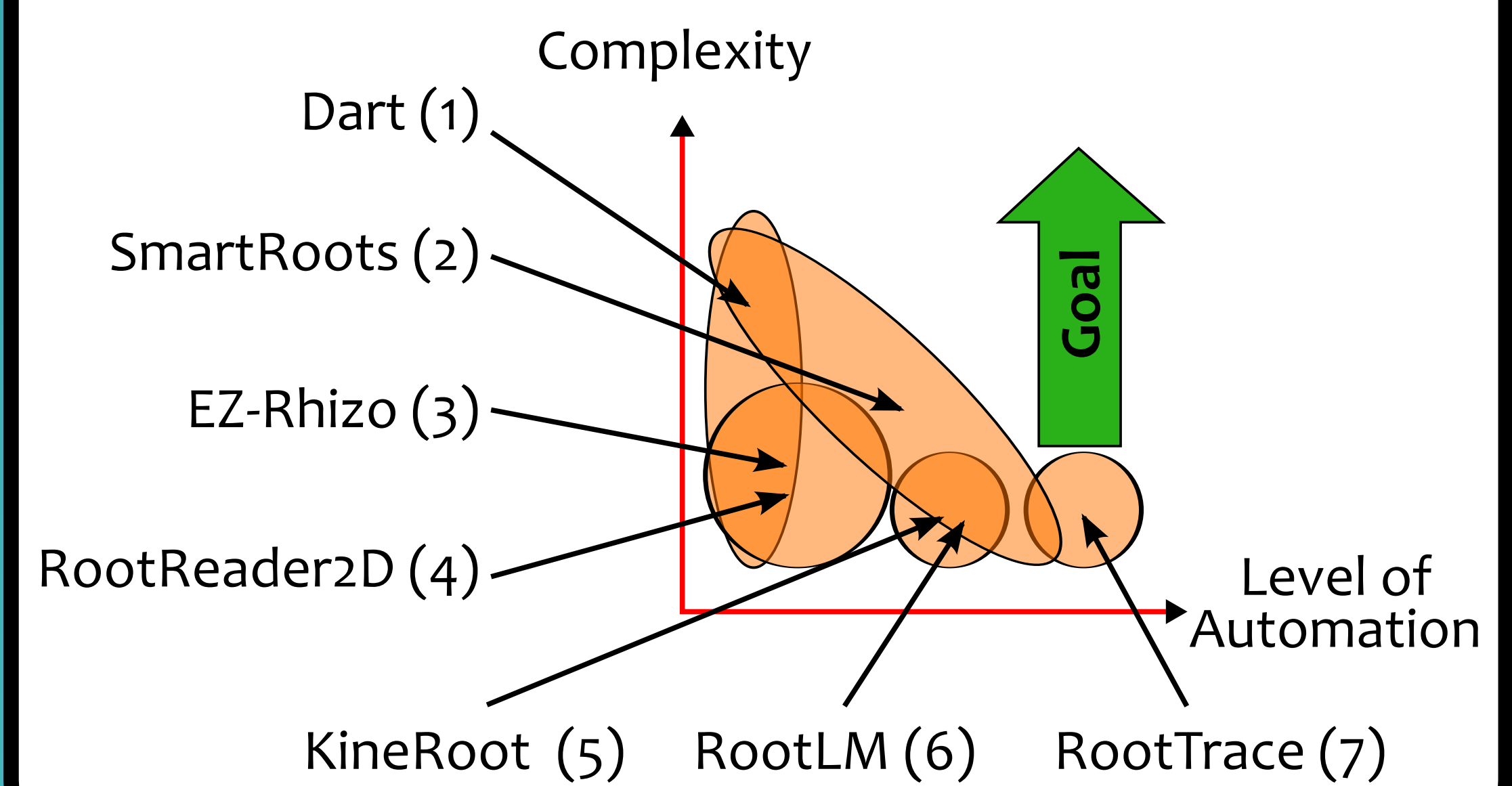
We consider image of root grown in petri plates possibly acquired using simple office scanners. Without more constraint on the imaging protocol, the image processing has to cope with issues such as:

- uneven background lighting. The average intensity of the background is not uniform over the whole plate.
- reflection of the root on the plate glass.
- other artefacts such as air inclusion, dirt, condensation.

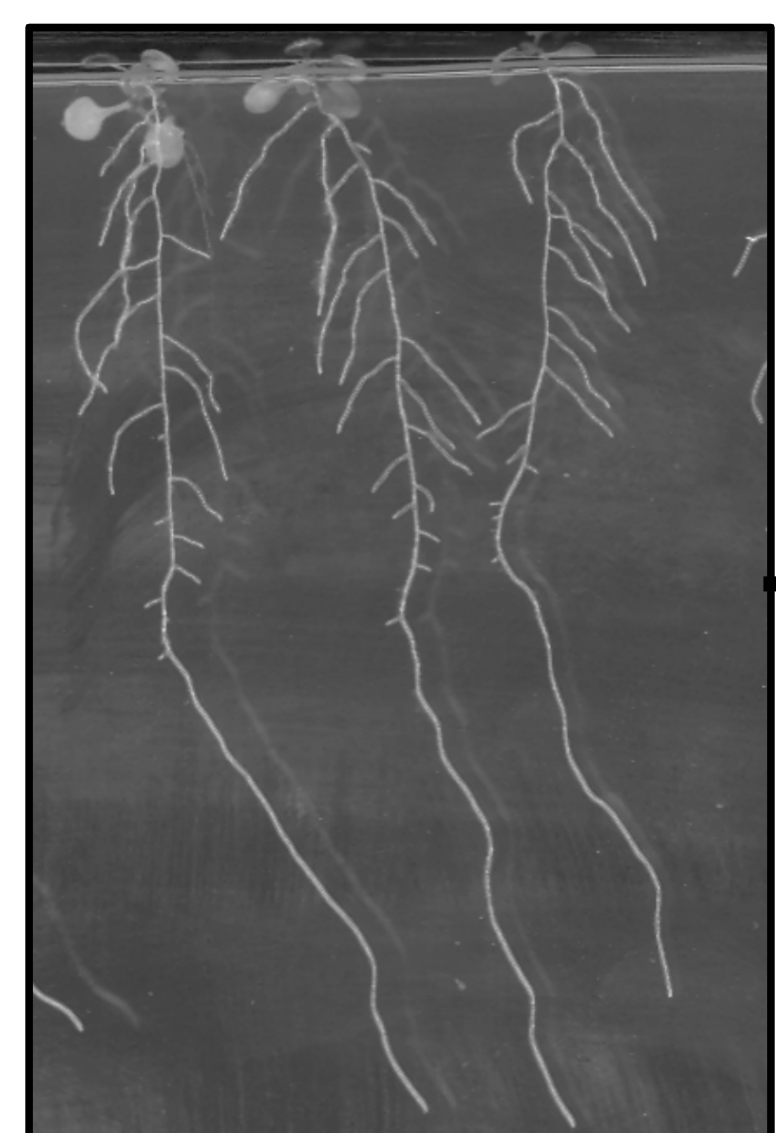
Typical scanned petri plate



## Complexity versus automation



## Method



Extract linear segments

List of segments area



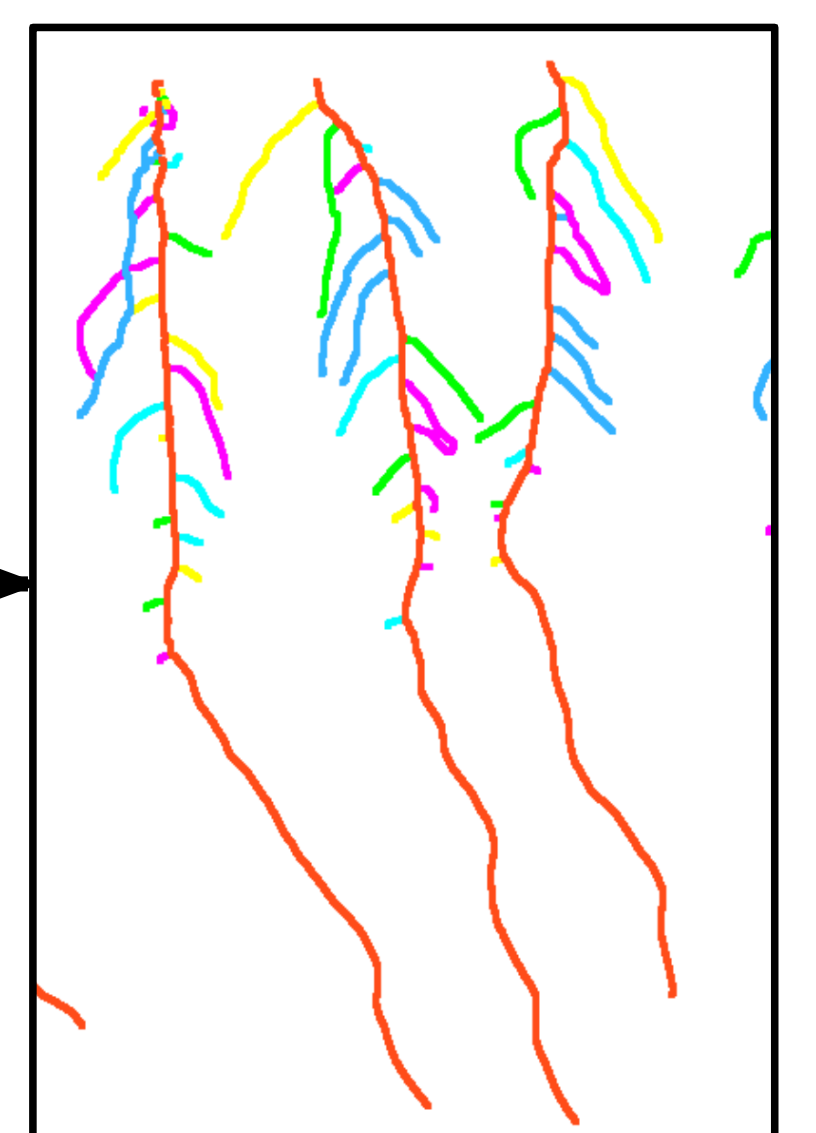
segments connection Graph

Cluster of connected segments



Convert to RSA tree

Architecture of connected roots



### Extraction of linear segments:

First adaptive thresholding is applied on the grey level image to select pixels of local hill shaped area (i.e. pixels that have greater value than their surroundings).

All connect components of the binary map obtained are extracted and segmented in a set of linear segment corresponding to the linearly connected pixels (i.e. with 2 neighbors) of their skeleton.

Finally, a selection of the segment representing a root area is made, based on two criteria: both the mean pixel intensity and the mean pixel gradient per segment are high enough.

### Segments connection graph:

A graph structure is constructed containing all selected segments. An edge is added between each pair of segments that are separated by less than 2 pixels. The clusters, i.e. the set of segments which are connected in the graph, represent root structures (RSA) but specific roots (primary, secondary, ...) are not identified. And the graph might contain loops.

### Conversion to an RSA tree graph:

Each cluster of the graph is converted to a tree graph representing the RSA using shortest path algorithm and a priori knowledge on a root appearance.

The primary root is defined as the set of segments which start from the highest one and end to the segment which is furthest away (i.e. the longest shortest path, in red in the picture).

Then, the same algorithm is used iteratively to select lower order roots, starting at segments that are connected to the primary root.

## Results

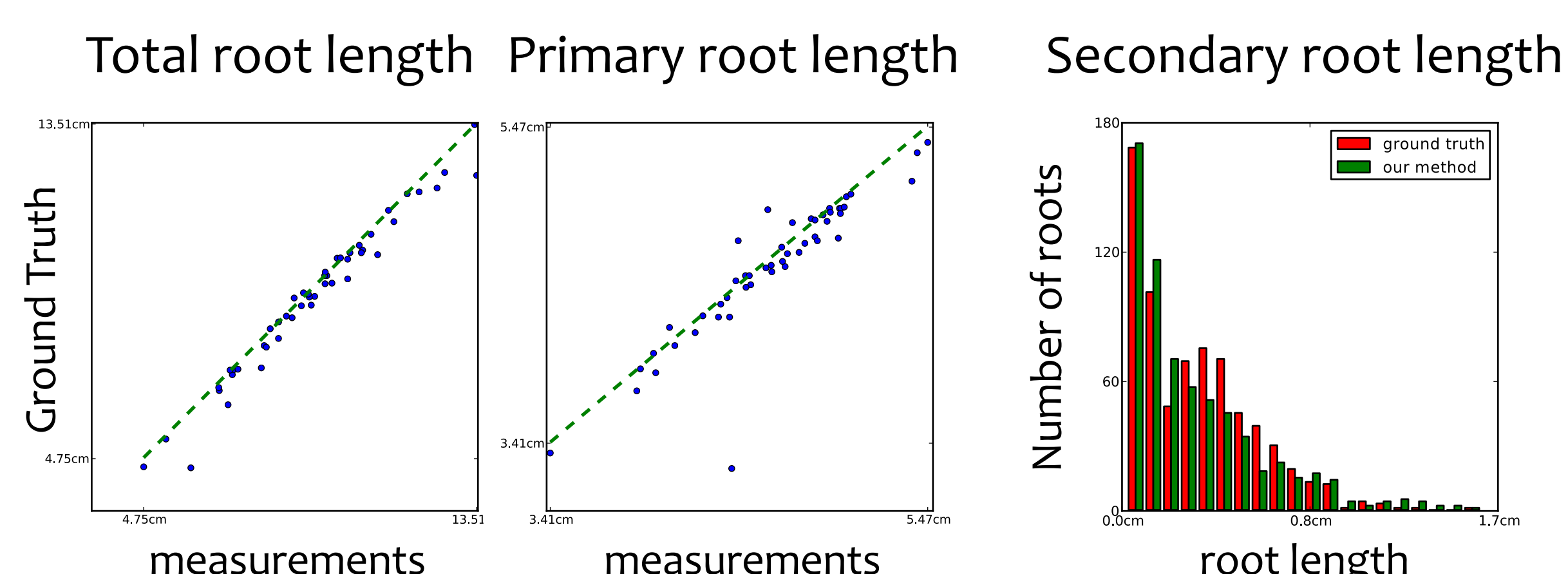
The presented method has been run on images of 10 agar plates containing 5 to 6 Arabidopsis root systems. The extracted RSA structures have then been compared to ground truth data created by the same scientists who have made the image acquisition.

These reference RSA structures have been manually created using the DART software (1), which provide fully manual input. It thus represents data that have not been inferred by any automated algorithm.

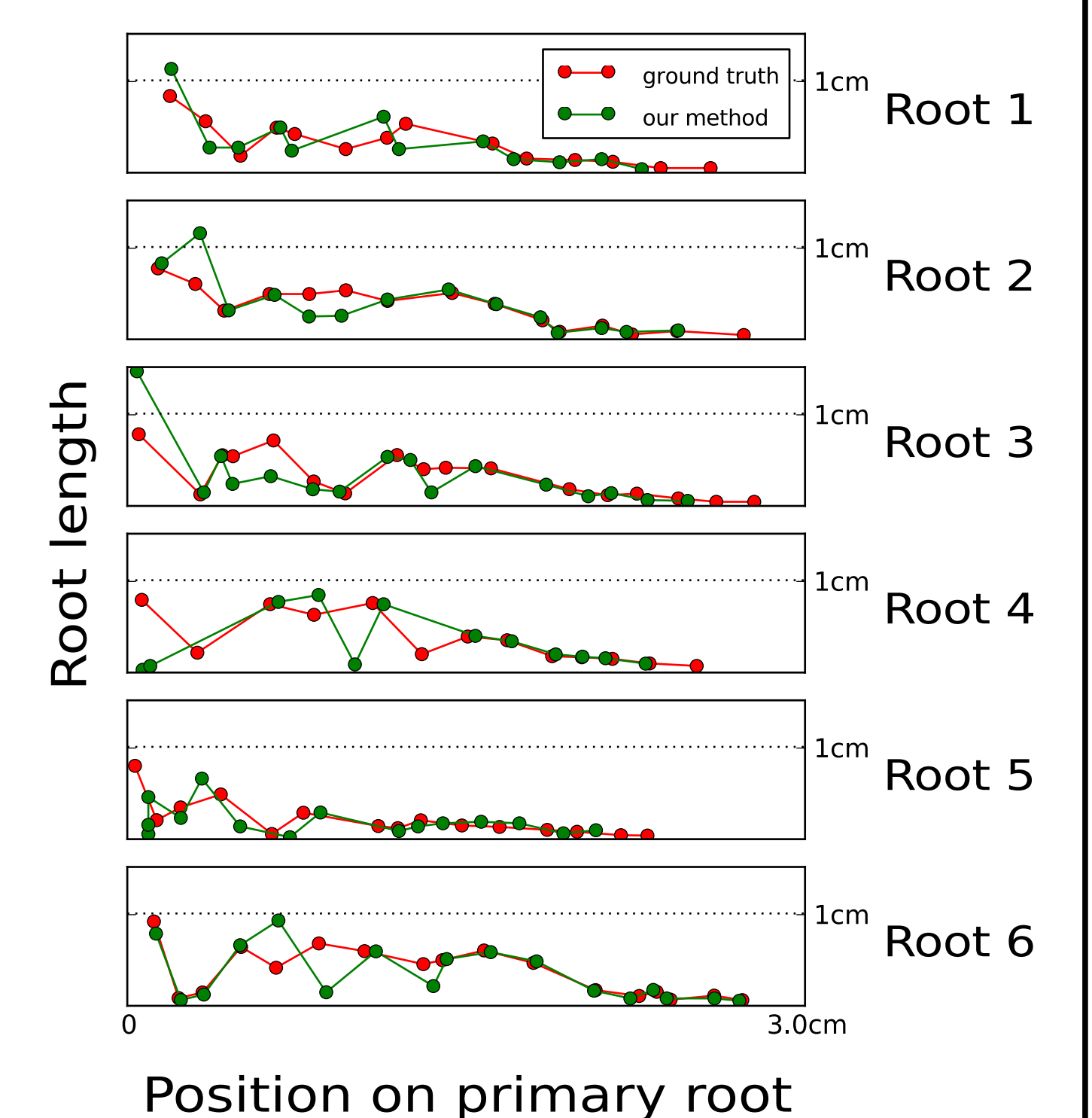
On the approximately 50 root systems compared, two are considered failure: the extracted RSA structures obviously appear not to fit the observed roots. This represents a four percent failure rate. The following results do not take these outliers into account.

Distance between ground truth and automatically detected **primary root apex**:

mean: 0.21 mm  
std: 0.18 mm



### Secondary roots length (plate 4)



(1) J. Le Bot et al, 2010, Plant and Soil, pp. 261  
(2) G. Lobet et al 2011 Plant Physiology  
(3) P. Armengaud et al, 2009 The Plant Journal, pp. 945  
(4) <http://www.plantmineralnutrition.net/rootreader.htm>

(5) P. Basu et al, 2007, Plant Physiology, pp. 305  
(6) X. Qi et al, <http://digital.cs.usu.edu/~xqi/RootLM/>  
(7) A. French et al 2009, Plant physiology, pp. 1784