Mitglied der Helmholtz-Gemeinschaft

Imaging and Image Processing for Plant Phenotyping

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IBG-2: Plant Sciences

Dynamic plants in a dynamic environment

- Founded in 2001
- 160 employees
- Main topics:

  Plant Phenotyping

  Sustainable Bio-economy
- Multi-disciplinary: biology, chemistry, physics, mathematics, computer sciences, engineering

Why Plants?

- Plants are socially and industrially relevant
  - 4F: Food, Feed, Fibre, Fuels, but also
  - bio-chemicals like in medical plants etc.
- Industries: Farming, Seed production, plant production, fertilizers

?

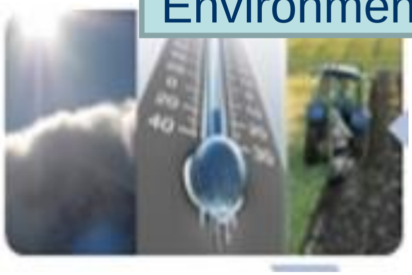
Central Question

How to grow plants optimally under natural or controlable conditions?

!

Mechanistic understanding of interactions between environmental conditions and plant traits required!

What exactly is phenotyping?



Environment

Plant phenotype

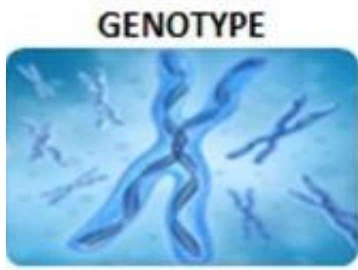
Genome

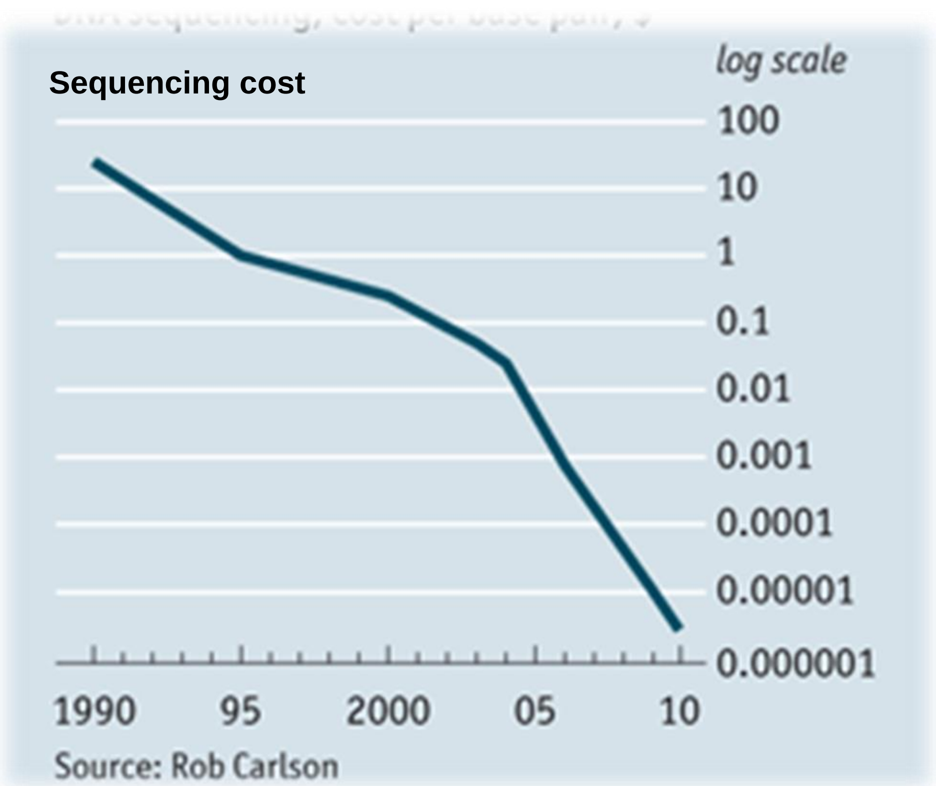
CCGTTGGAA

Dynamics of morphology

Dynamics of physiology

Genotyping



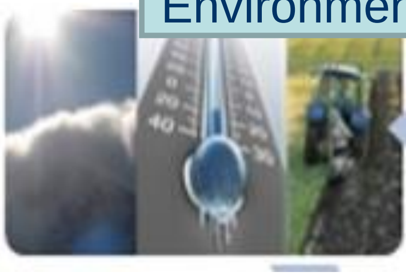


Sequencing cost is falling all the time

Illumina Hiseq X10

600 Gbases per day

What exactly is phenotyping?



Environment

Plant phenotype

Genome

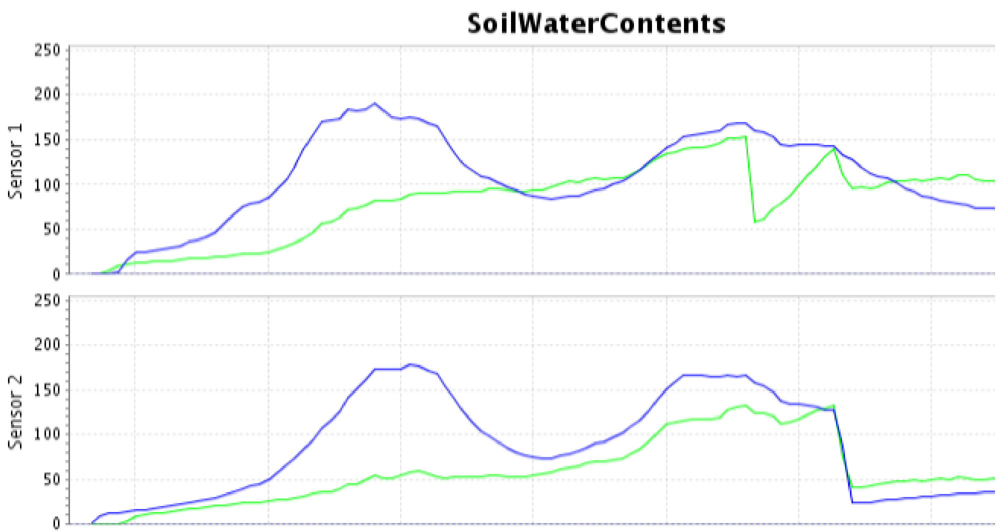
Dynamics of morphology

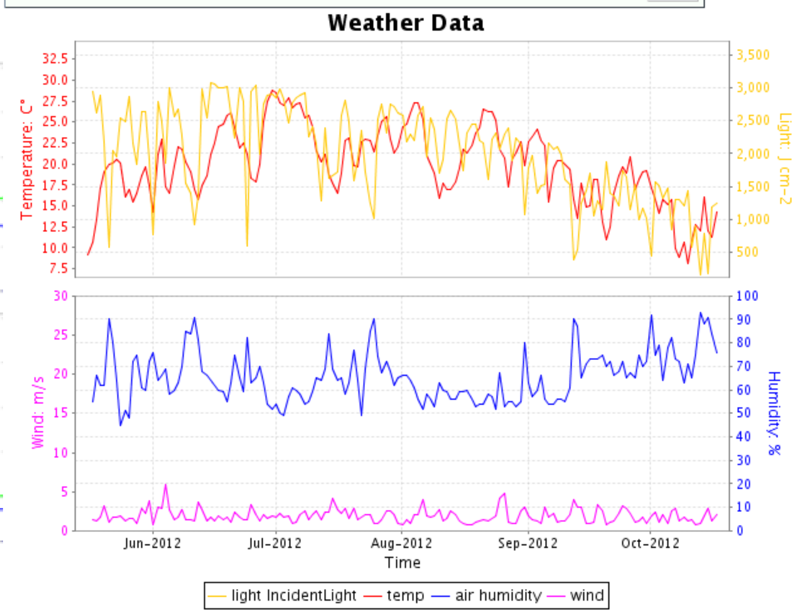
Dynamics of physiology

Environmental data

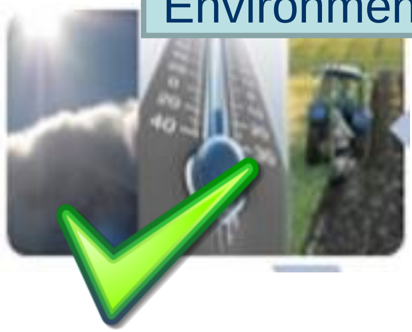
Weather data, Soil Water content

- temperature, light, wind, humidity
- Summarized by day
- Min, max, average etc
- Structure and chemical properties of soil





What exactly is phenotyping?



Environment

Plant phenotype

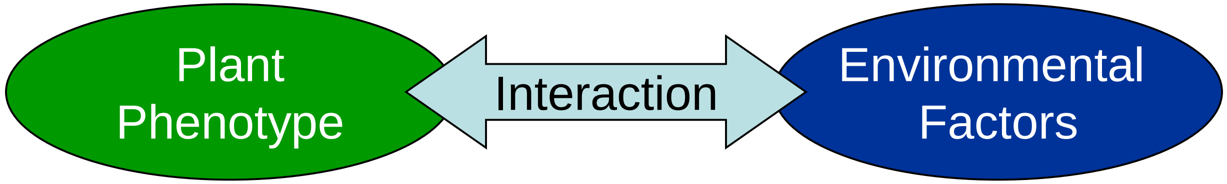
Genome

Dynamics of morphology

Dynamics of physiology

… but soil is still a problem

Experimental Approach



Mechanistic understanding of the plant system by variation of

- Environmental factors: Humidity, temperature, CO_2, nutrients, neighboring plants, …
- Arabidopsis, barley, maize, tomato…
- Genotype (regulates biochemistry)

PhyTec at IBG II

Measurement of phenotype

- Leaf, fruit and root growth
- Photosynthesis, gas exchange, active genes, ...

An ideal Experiment

Environment

Genome

Phenotype

We will image a lot, and genotype everything

Experiment time ***60 days***

Sample Size ***300 plants***

Genotyping ***Full Sequencing***

Sequencing the plants yiels ~**30 TB** of data

- would take about 50 days on the HiSeq X10

Images, 3D models etc. ~300MB per plant per day

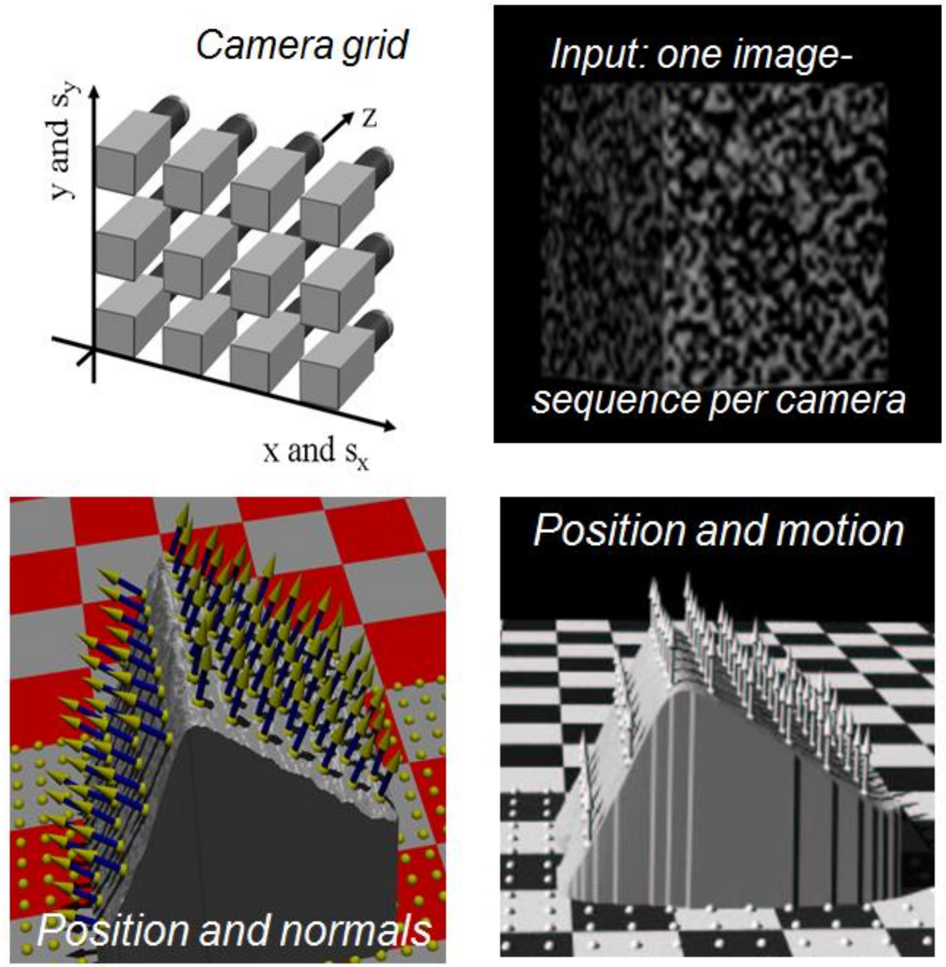
- **~6TB** per experiment

P = GxE: test many genotypes (species) at many environmental conditions: **big data problem**

Image Processing @ IBG-2

Local da

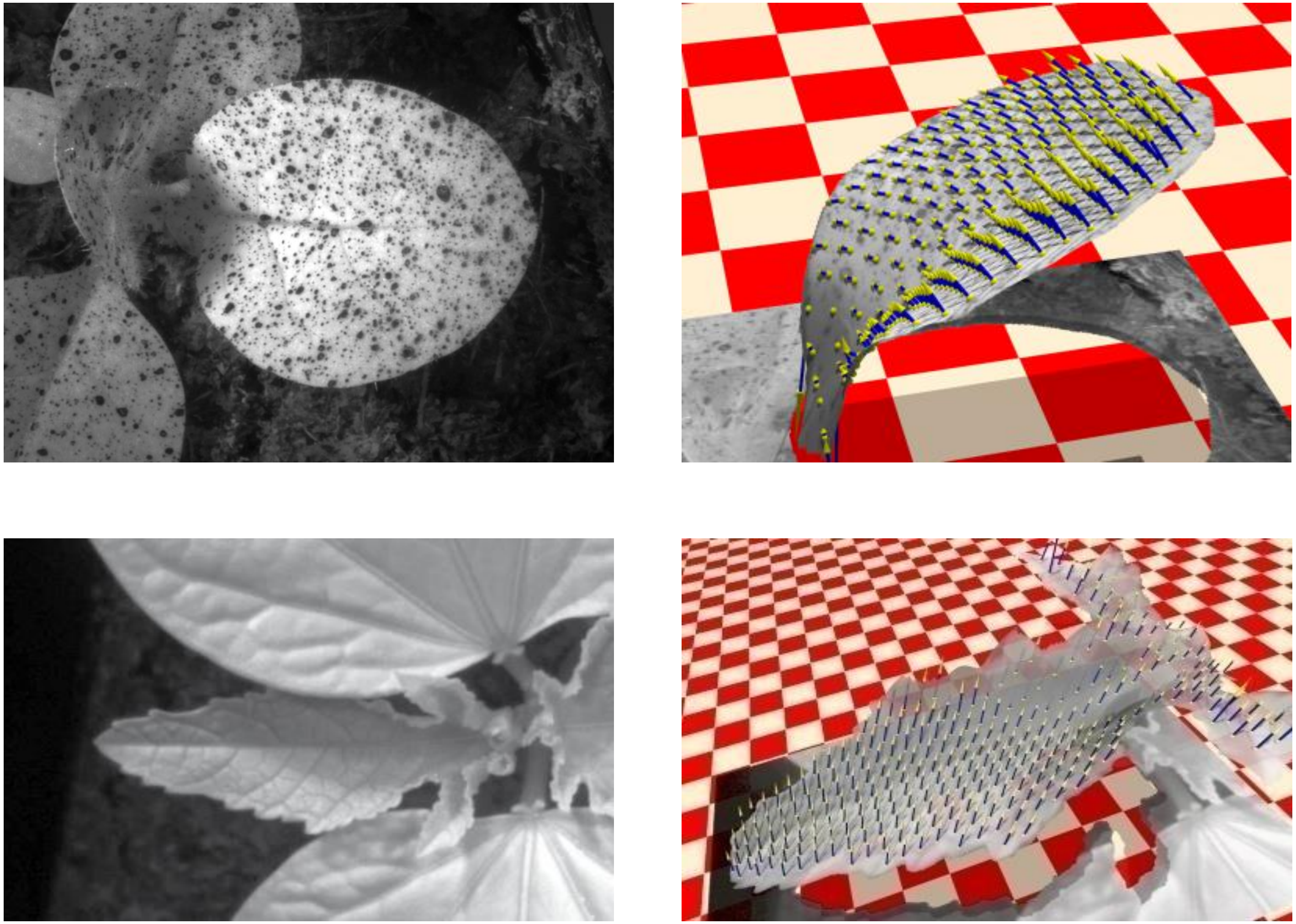
- Optical
- Transp
  brightne
- Dynami
  reconst
- Optimiz



Scene flow estimation from light fields

K. Krajsek, C. Heinemann, H. Scharr, Visapp 2014
T. Schuchert, T. Aach, and H. Scharr. PAMI 2010
T. Schuchert and H. Scharr. ECCV 2010
H. Scharr. Complex Motion 2007

Image Processing @ IBG-2

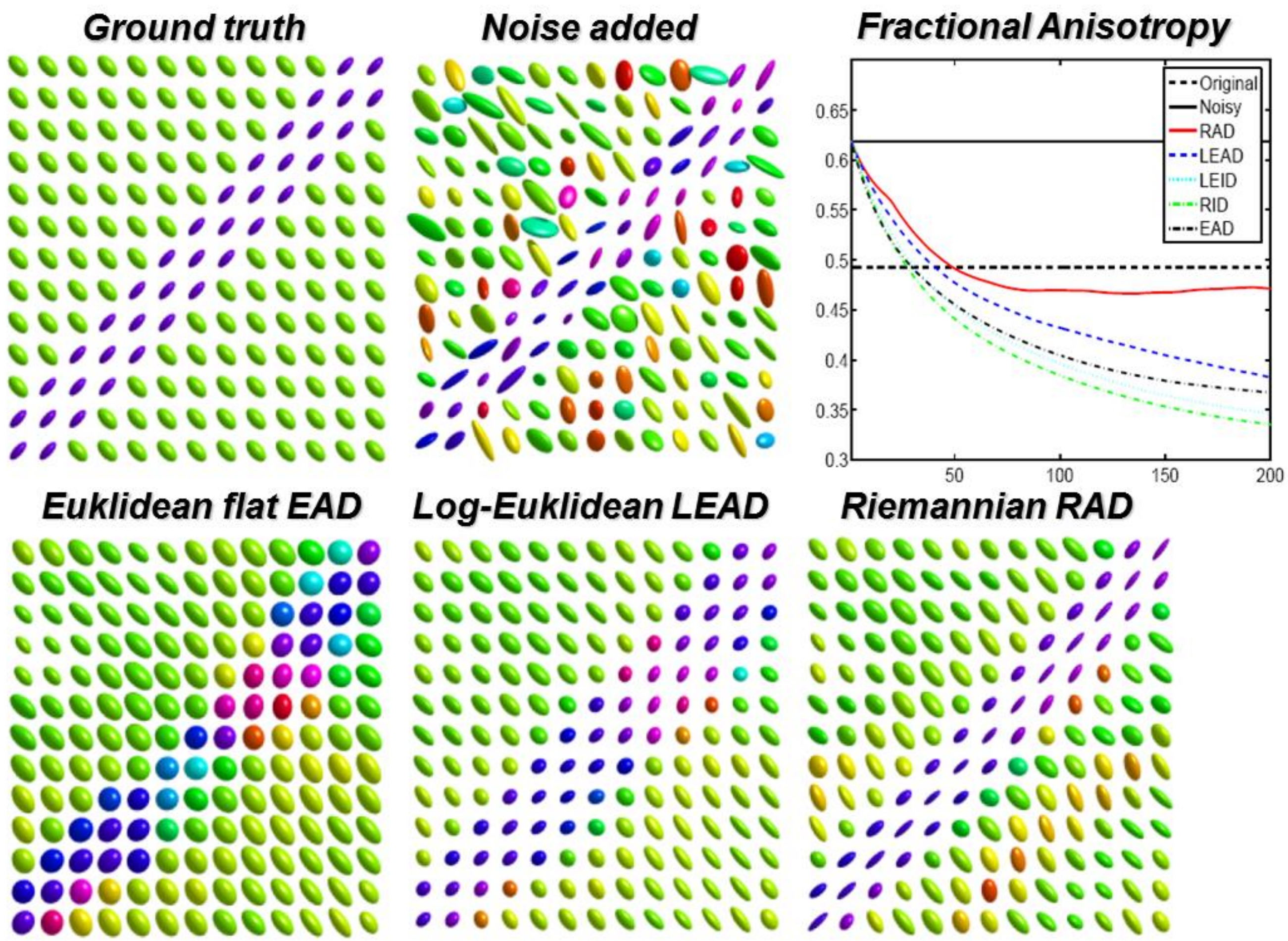


T. Schuchert, Plant Leaf Motion Estimation Using A 5D Affine Optical Flow Model, Dissertation, 2010

Image Processing @ IBG-2

Loca ... ian ... es ... ed

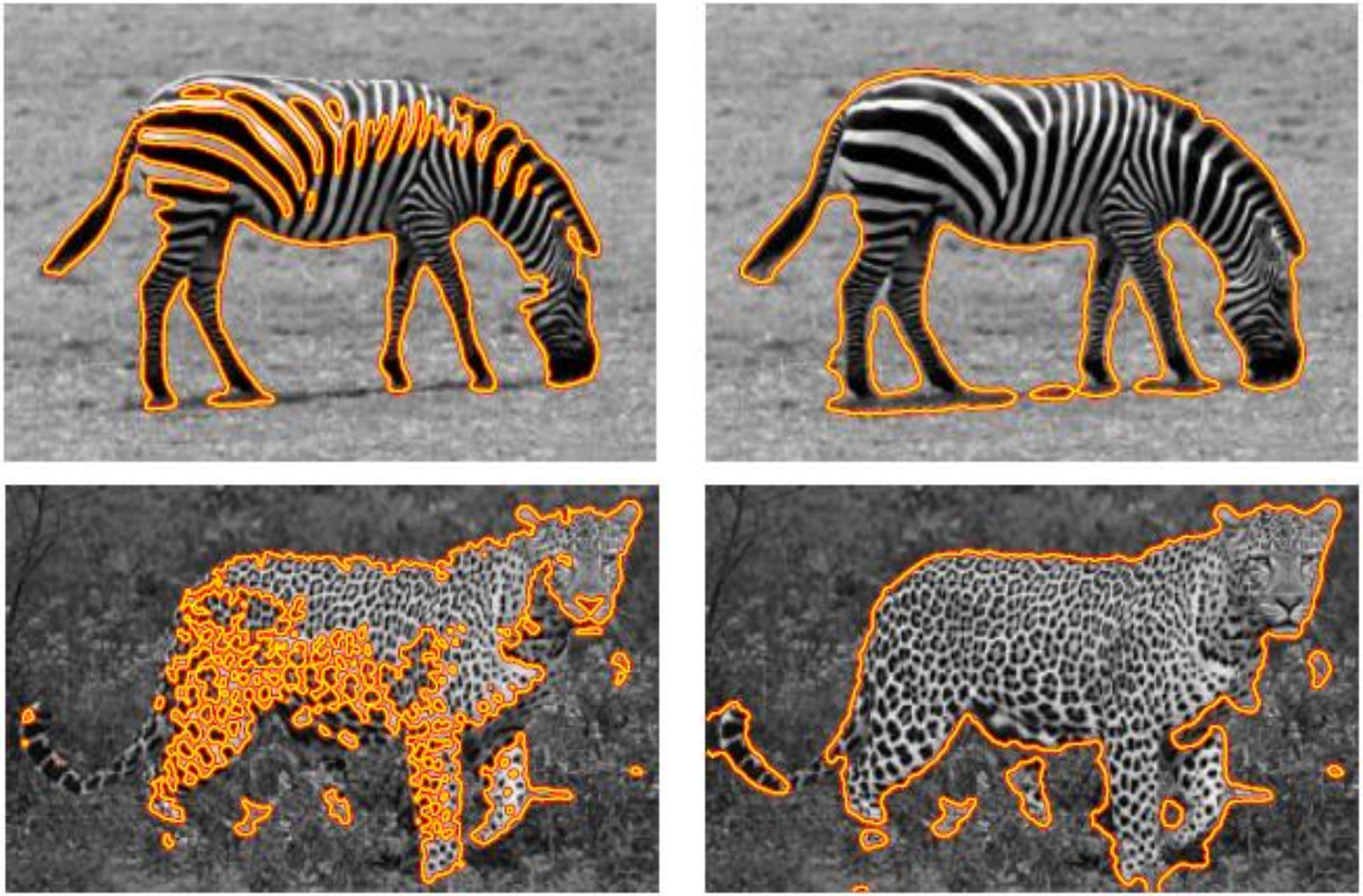
Data



Regularized Riemannian reconstruction of diffusion tensor fields from DTMRI data.

K. Krajsek, M.I. Menzel, and H. Scharr. IJCV 2015 (subm.)
K. Krajsek and H. Scharr. CVPR 2012 (HARDI)
K. Krajsek, M.I. Menzel, and H. Scharr. ICCV 2009 (DTMRI)

Image Processing @ IBG-2



Mixture of Gaussian vs. channel representations

K. Krajsek and H. Scharr, (unpublished)

Image Processing @ IBG-2

S. Bergsträsser et al., Plant Methods, 2015.
C. Plückers et al., Nova Acta Leop. 2013.
K.A. Nagel et al., Functional Plant Biology, 2012.
F.-L. Luo et al., Annals of Botany, 2011.
R.C. Meyer et al., Theoretical and Applied Genetics, 2010.
K.A. Nagel et al., Functional Plant Biology, 2009.
M. Jansen et al., Functional Plant Biology, 2009.
B. Biskup et al., Plant Physiology, 2009.
R. Pieruschka et al., New Phytologist, 2008.
A. Chavarria-Krauser et al., New Phytologist, 2008.
A. Walter et al., New Phytologist, 2007.
B. Biskup et al., Plant, Cell and Environment, 2007.

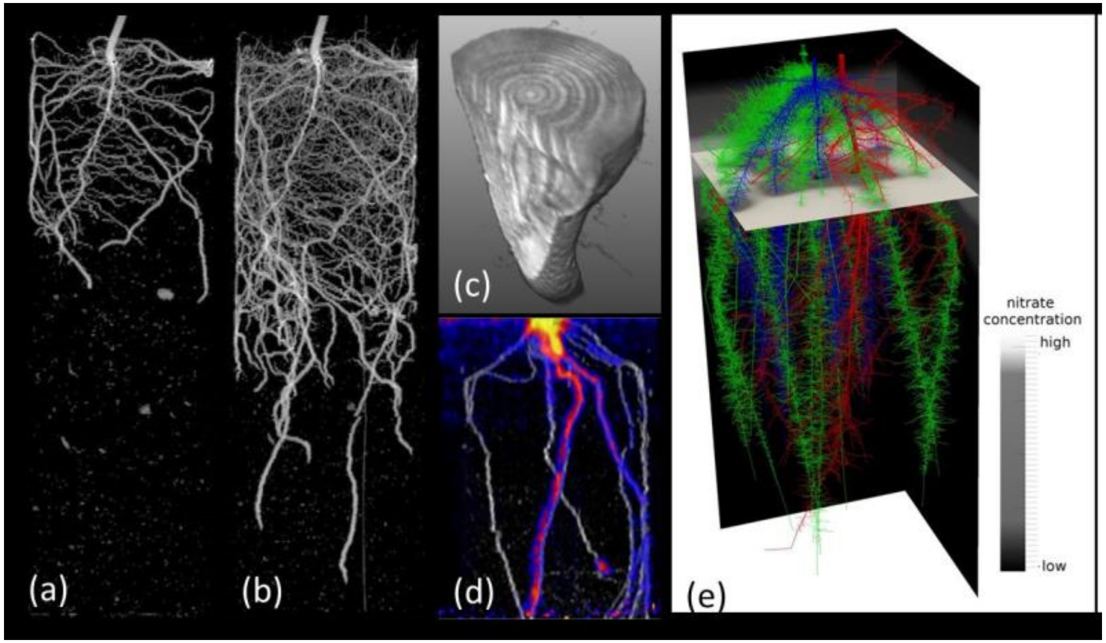
Deep Phenotyping

- Precise analysis of individual traits
- Typically done at organ level

Example: Root

Approach :
Understand key processes of root **structure and function** for resource use efficiency

Basis for novel root trait identification



See e.g. Jahnke *et al.* 2009, "**Combined MRI-PET dissects dynamic changes in plant structures and functions**", The Plant Journal, Vol. 59, 634-644

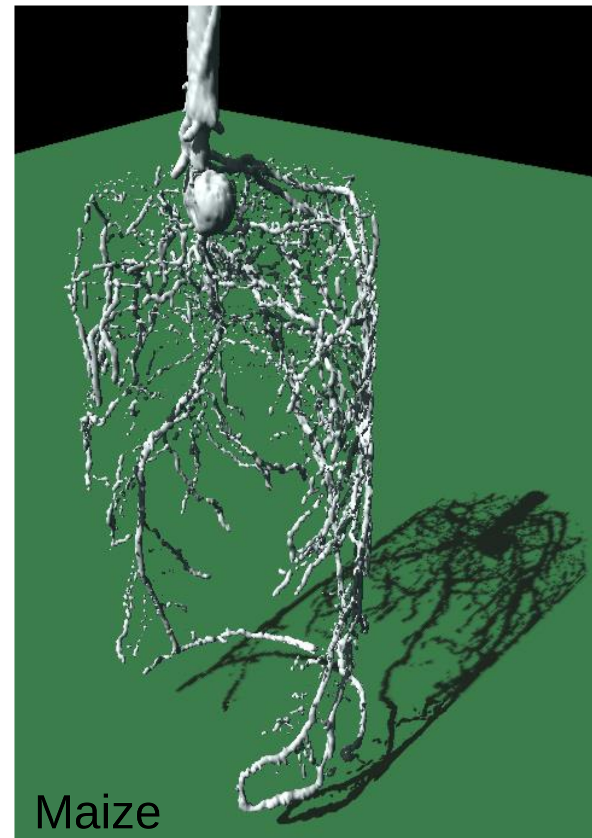
Metzner et al., unpublished
Postma et al., unpublished

MRI (Magnetic Resonance Imaging) for structural and functional imaging of roots

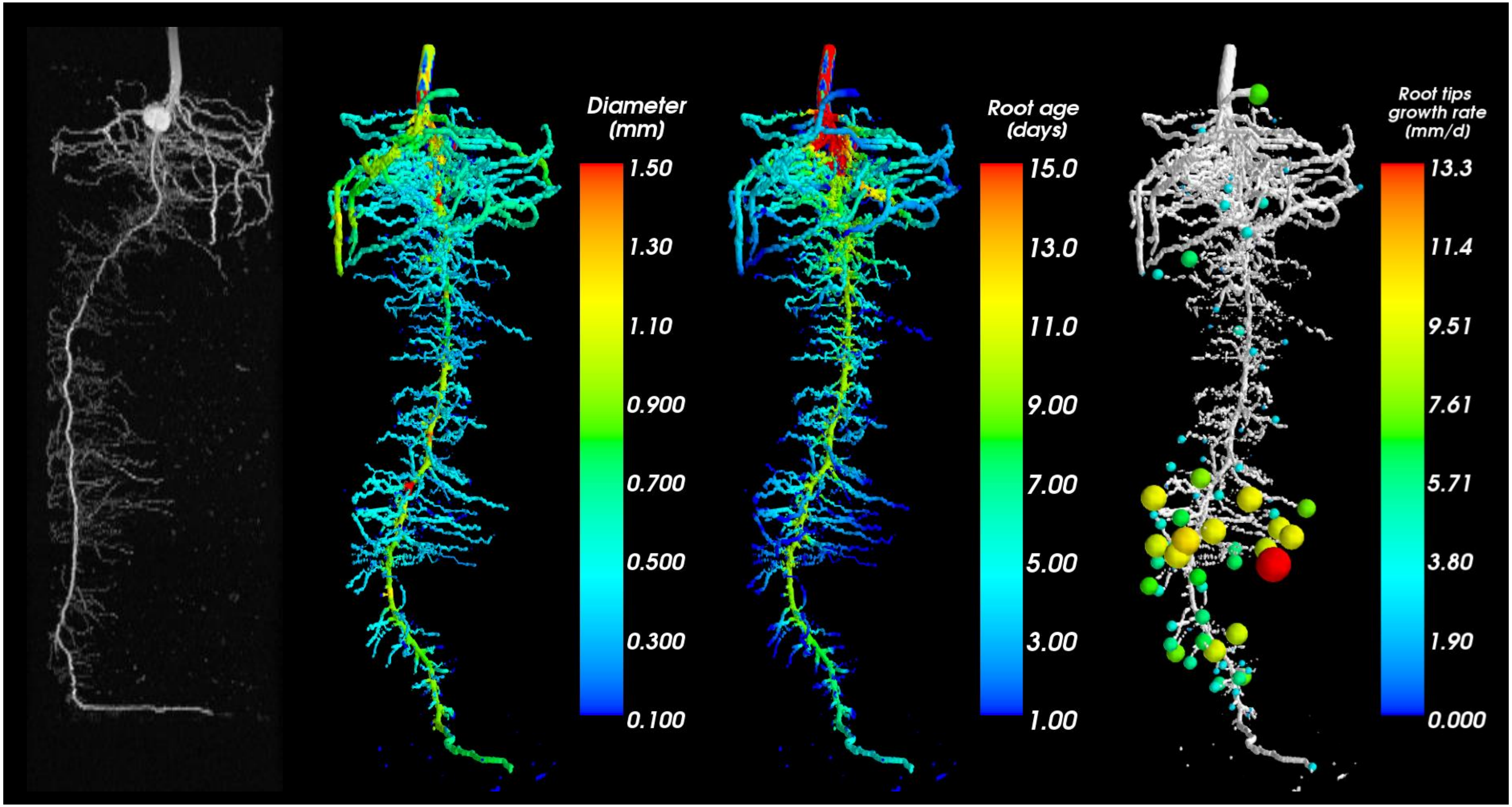
4.7T magnet, vertically oriented, 30cm opening

Robot systems for automated delivery of plants

Structural analysis of root system architecture in 3D



Root System Analysis: 3D MRI



D. Pflugfelder, 2015, unpublished

Screening: Seeds

- Automated measurement of seed properties
- Done individually for each single seed

Approach:
Start with seed properties

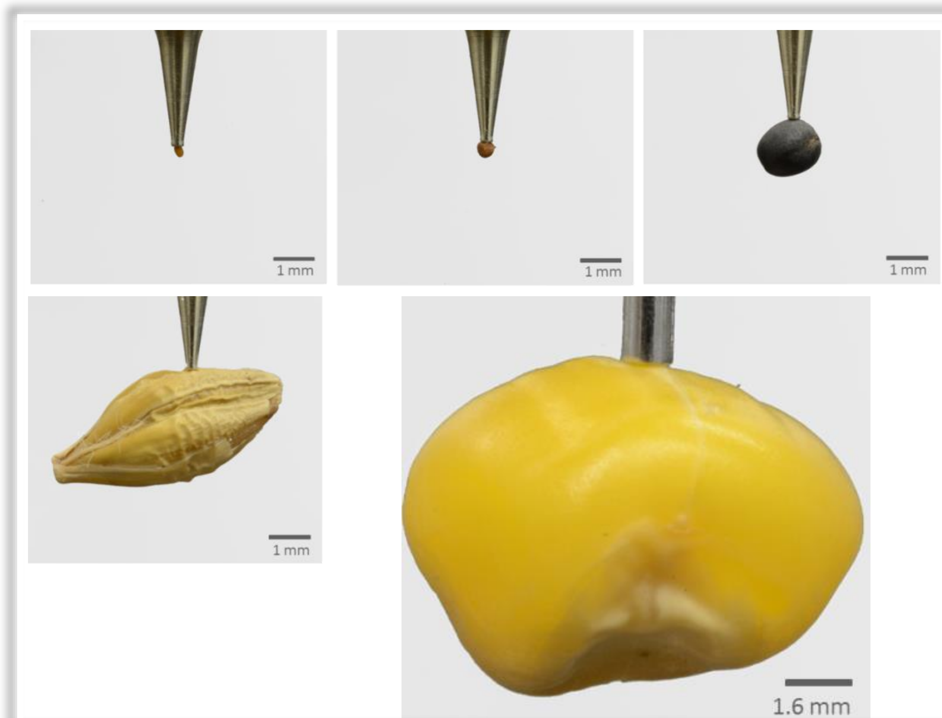
Relate to plant performance at an early stage

Basis for experiments with these plants later on

*pheno*Seeder

*pheno*Seeder

- 2D projected seed area, length, width
- Scales for weighing
- 3D shape



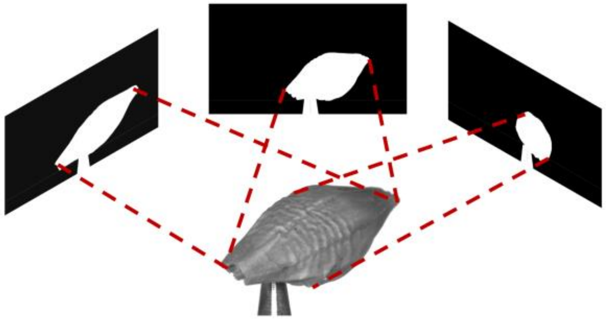
J. Roussel et al., 3D Surface Reconstruction of Plant Seeds by Volume Carving, British Mach. Vis. Conf., 2015

Reconstructing Seed Shape from Silhouettes

Idea: use simple volume carving

1. **Rotate** seed in front of camera

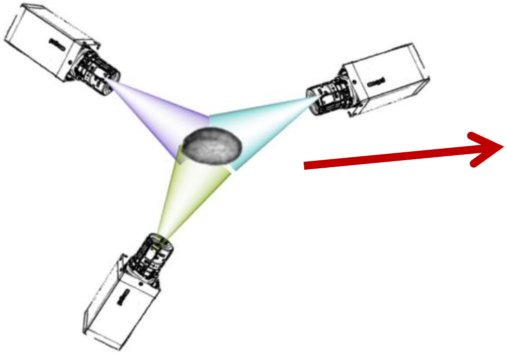
2. Reconstruct from **silhouettes**



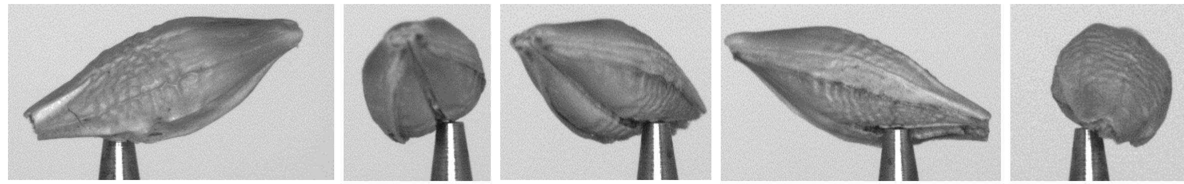
J. Roussel et al., 3D Surface Reconstruction of Plant Seeds by Volume Carving, British Mach. Vis. Conf., 2015

Reconstructing Seed Shape from Silhouettes

image acquisition

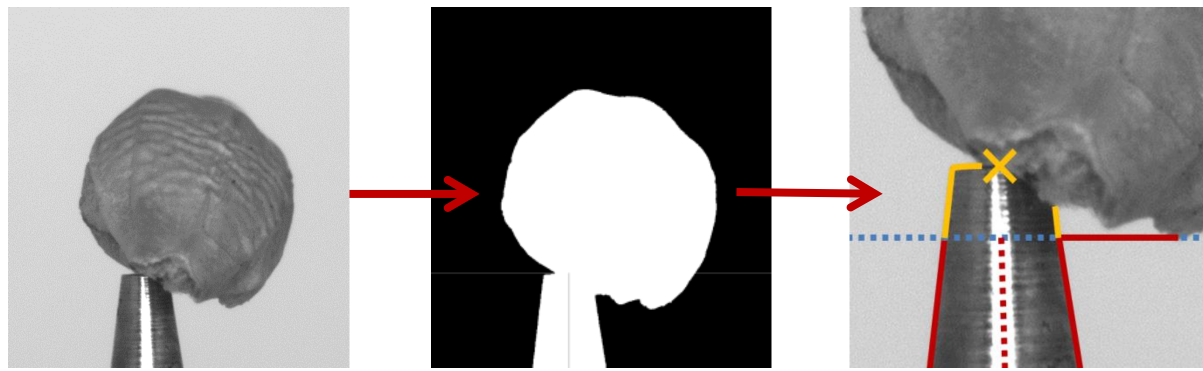


36 grey value images from different viewing angles

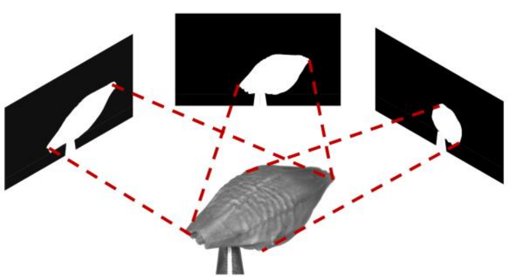


mask image

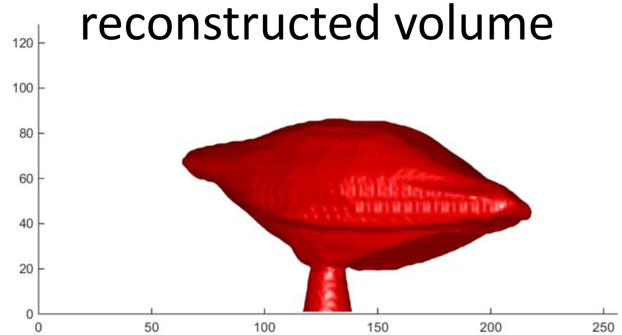
TCP detection



volume carving



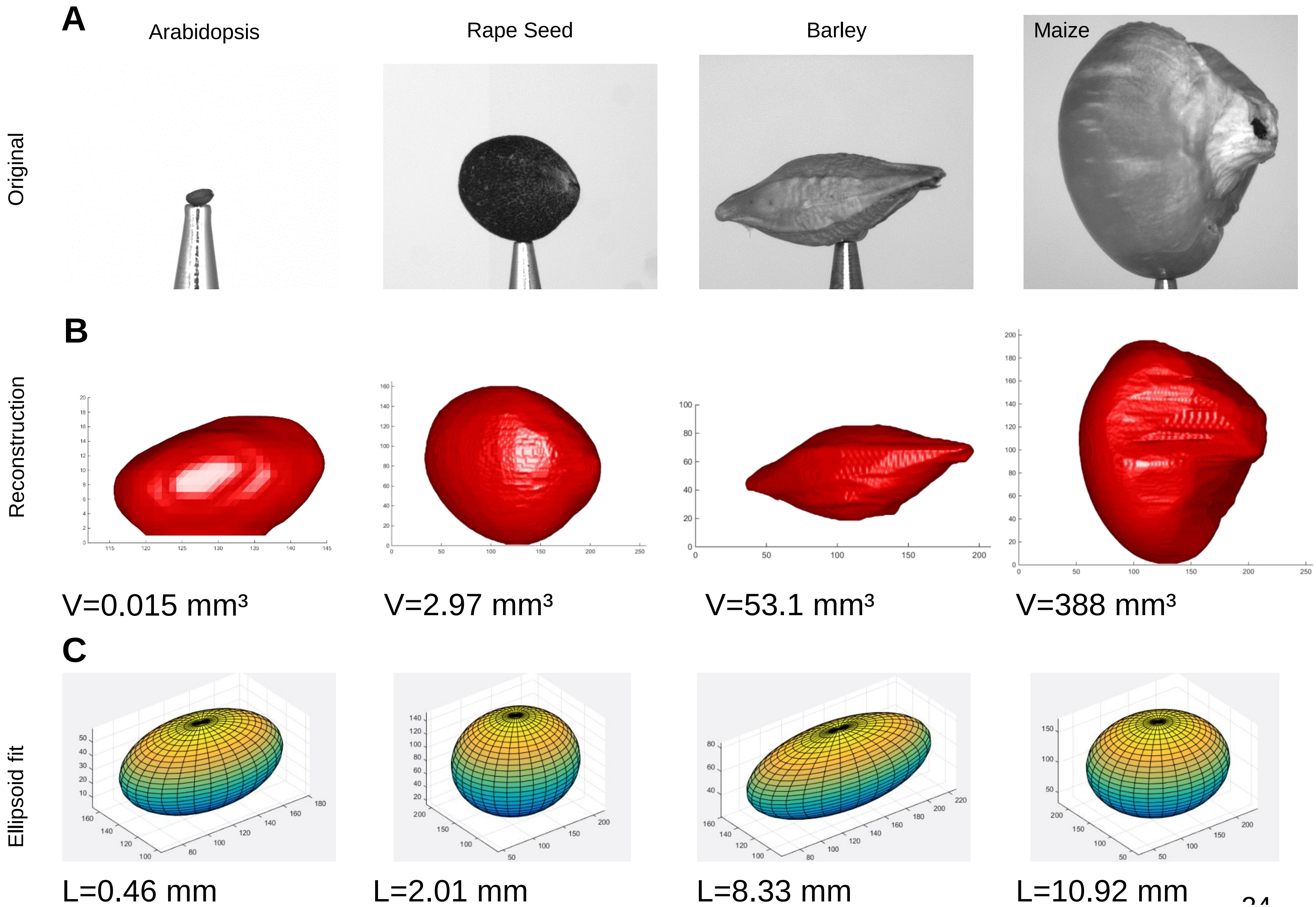
surface of reconstructed volume



tool – seed separation

J. Roussel et al., 3D Surface Reconstruction of Plant Seeds by Volume Carving, British Mach. Vis. Conf., 2015

Examples – Different seeds



J. Roussel et al., 3D Surface Reconstruction of Plant Seeds by Volume Carving, British Mach. Vis. Conf., 2015

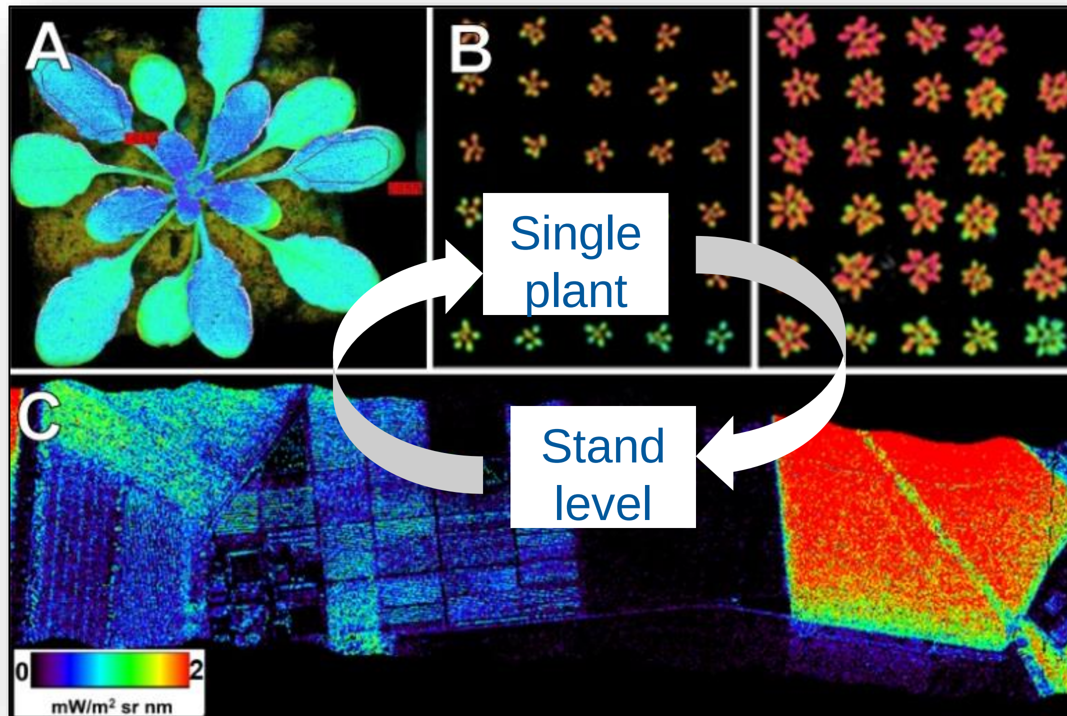
Screening: Shoot

- Transfer from single plant to stand level

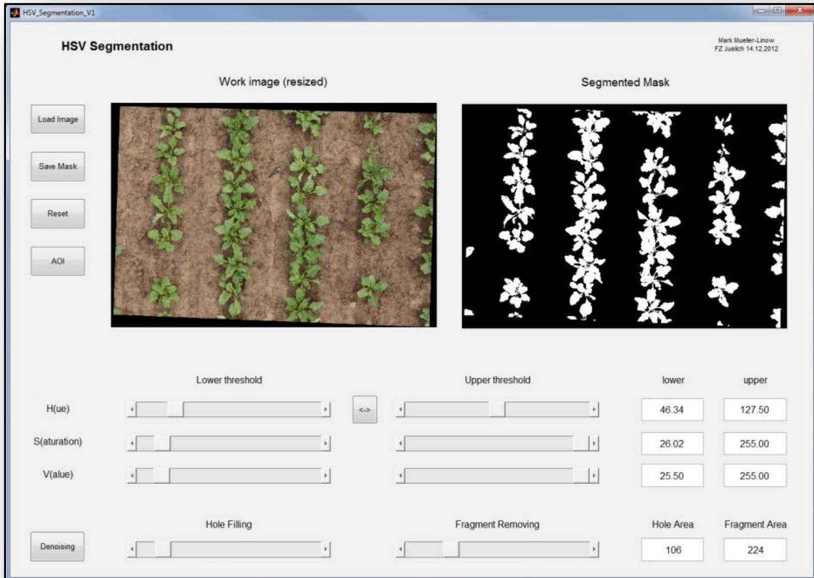
Approach:
Dynamic environment

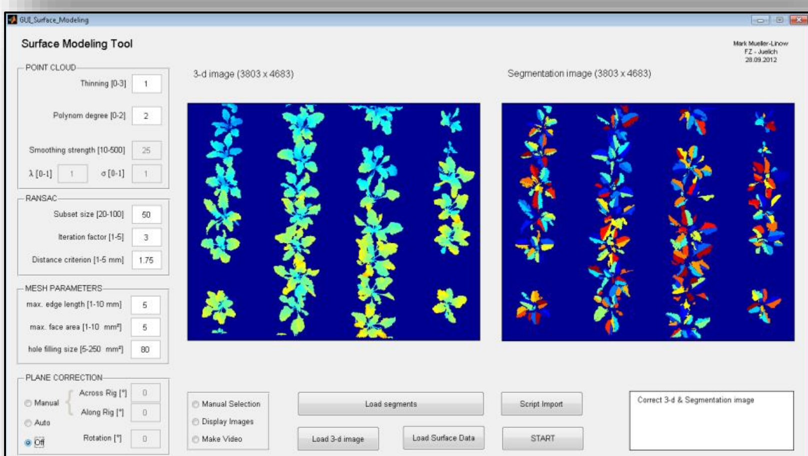
Photosynthesis and growth control from single plants to stands

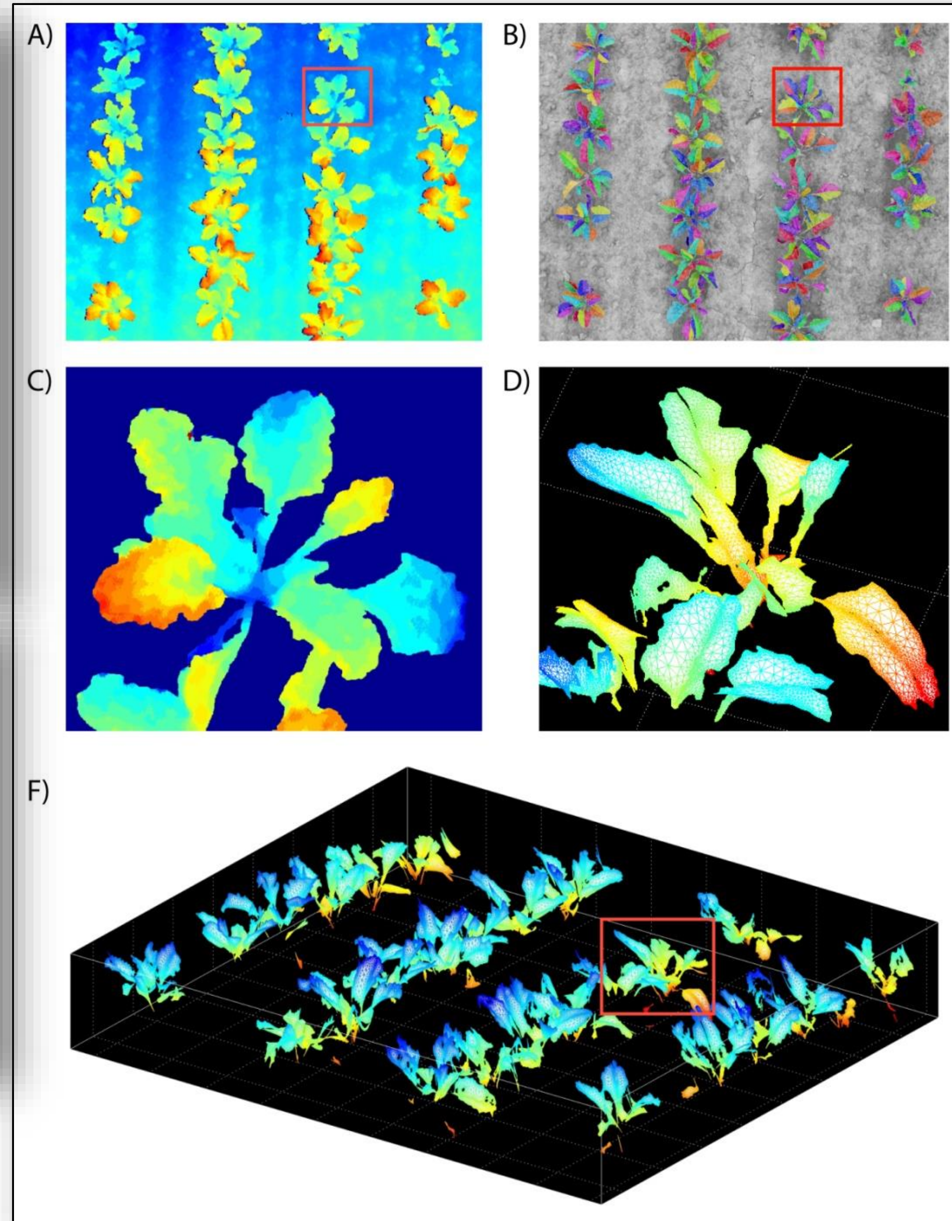
Basis for novel shoot trait identification



3-D Canopy structure: Stereo imaging allows quantification of canopy structure







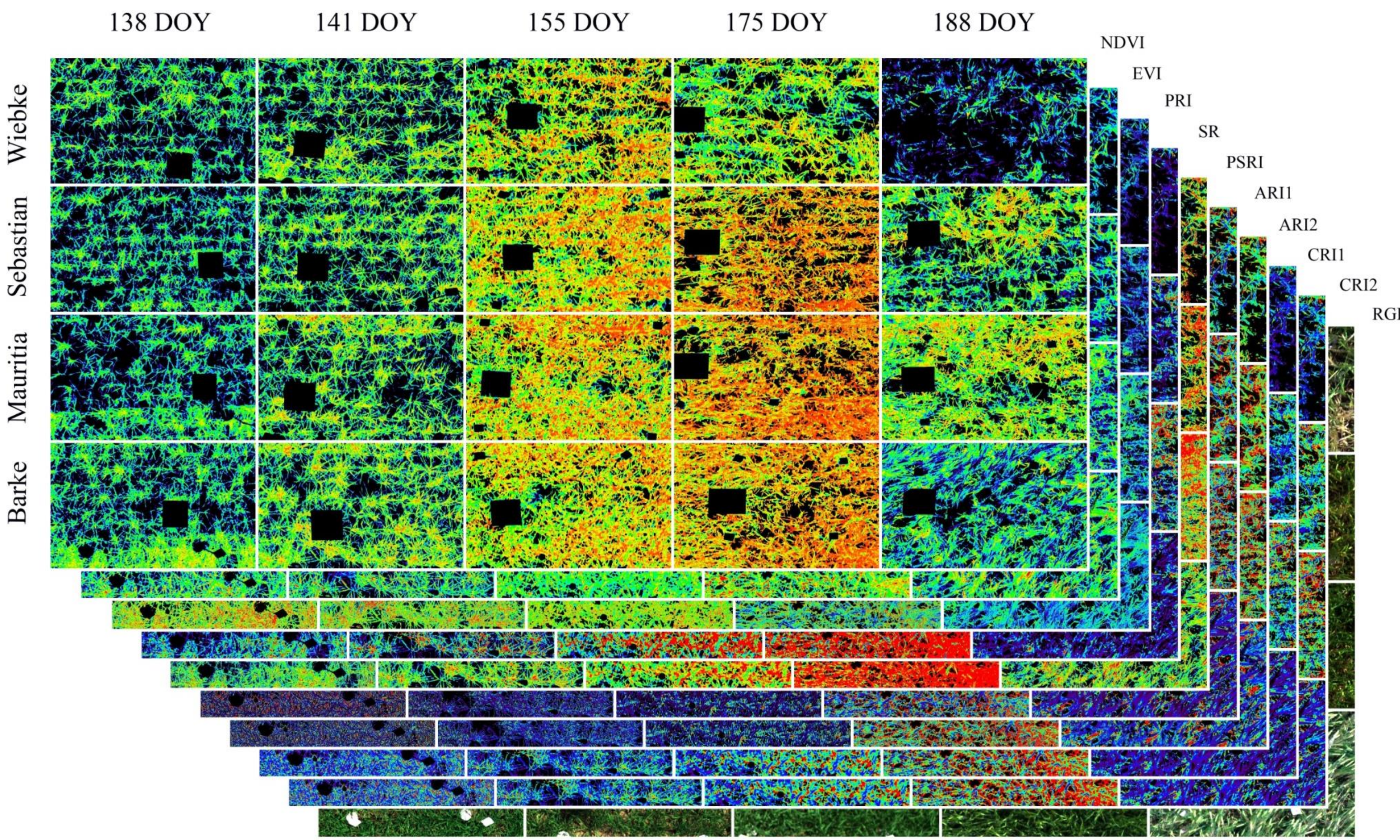
Müller-Linow et al., Plant Methods, 11(11), doi 10.1186/s13007-015-0052-z, 1-16, 2015

Mapping of spatio-temporal canopy dynamcis in the field by imaging spectroscopy and 3-D canopy reconstruction

Corn, sugar beet, and barley
Measurements at 7 m
Area: 1.5 x 2.7 m

http://www.plant-phenotyping-network.eu/lw_resource/datapool/_items/item_207/rascher-hyperspectral.pdf

Mapping of spatio-temporal canopy dynamcis in the field by imaging spectroscopy and 3-D canopy reconstruction



Barley varieties

- quantify dynamics in the multidimensional data space
- relate spectral data to structural and functional aspects of canopies

http://www.plant-phenotyping-network.eu/lw_resource/datapool/_items/item_207/rascher-hyperspectral.pdf

Screening: Roots

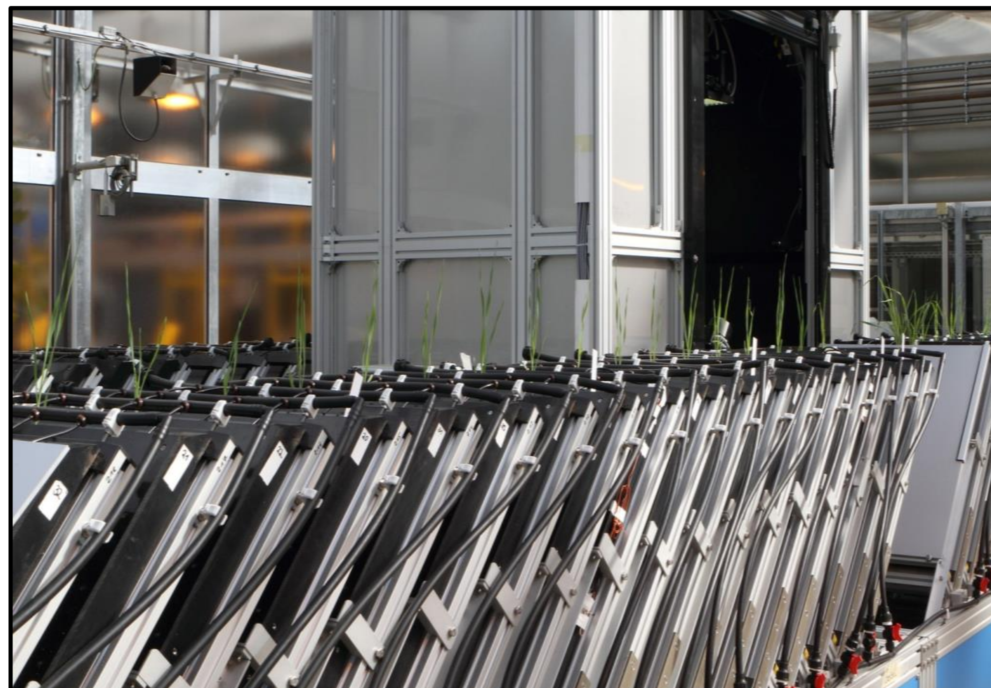
- Automated measurement of many plants
- Typically done at single plant level

Approach:
High-throughput screening for root system traits

Apply heterogenous and dynamic conditions

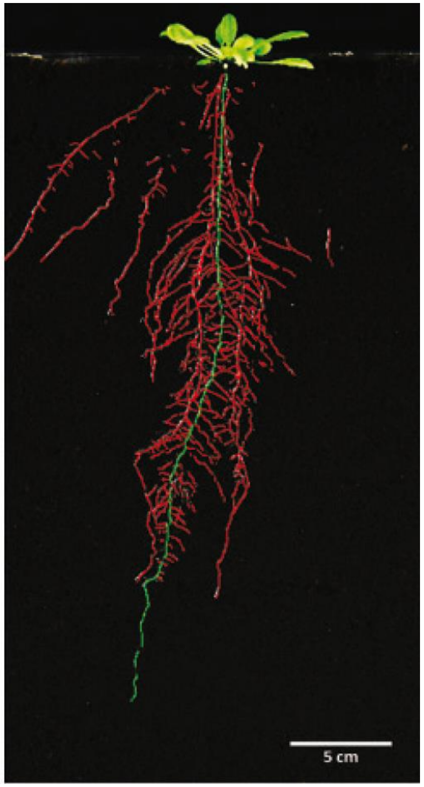
Screening for optimized root structure and function

Improve nutrient and water use efficiency



Nagel et al. *Functional Plant Biology* 2012

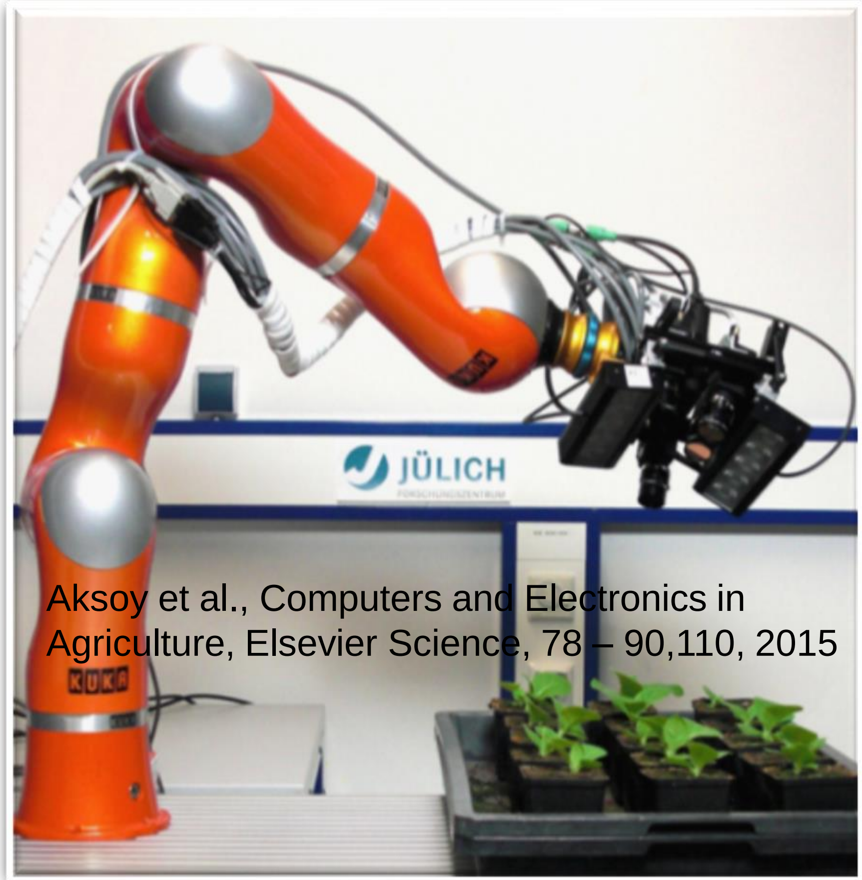
Screening: Root System Analysis: Rhizotrons



Nagel et al. *Functional Plant Biology* 2012

GARNICS: Robot Gardener

- EU FP7 project – cognitive systems and robotics call
- GARNICS: Gardening with a Cognitive System
- Robot Gardener
  - Measure plant status from images, treatments and environmental data
  - Learn to treat plants optimally



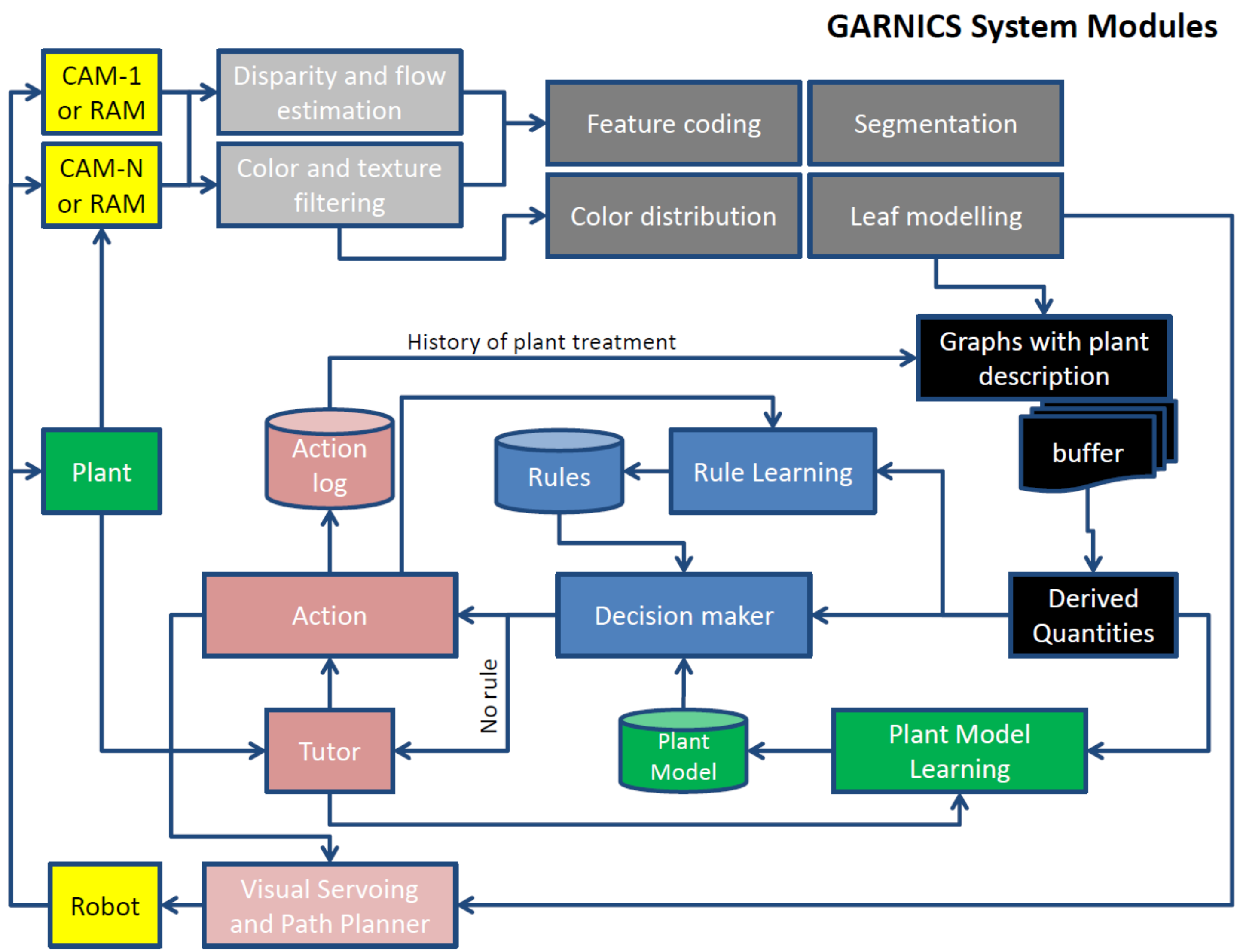
Aksoy et al., Computers and Electronics in Agriculture, Elsevier Science, 78 – 90,110, 2015

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

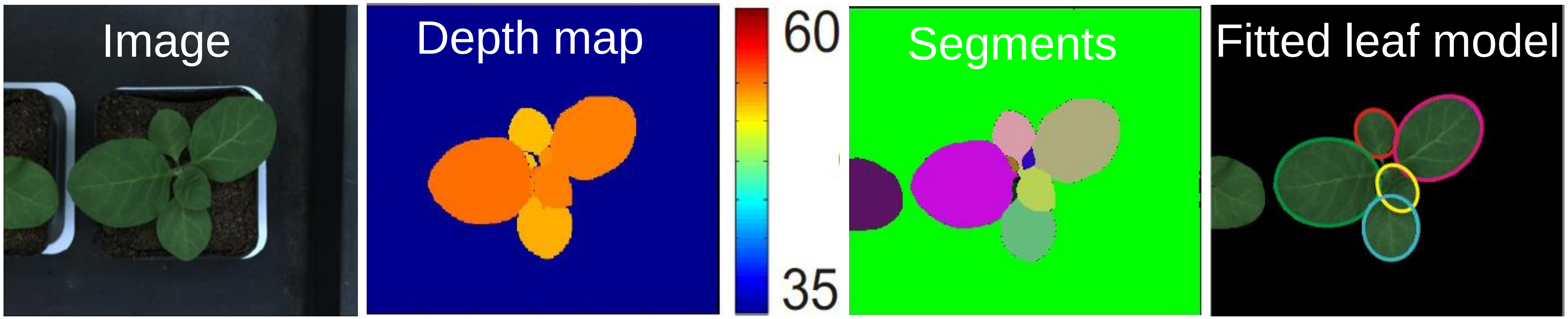
CSIC

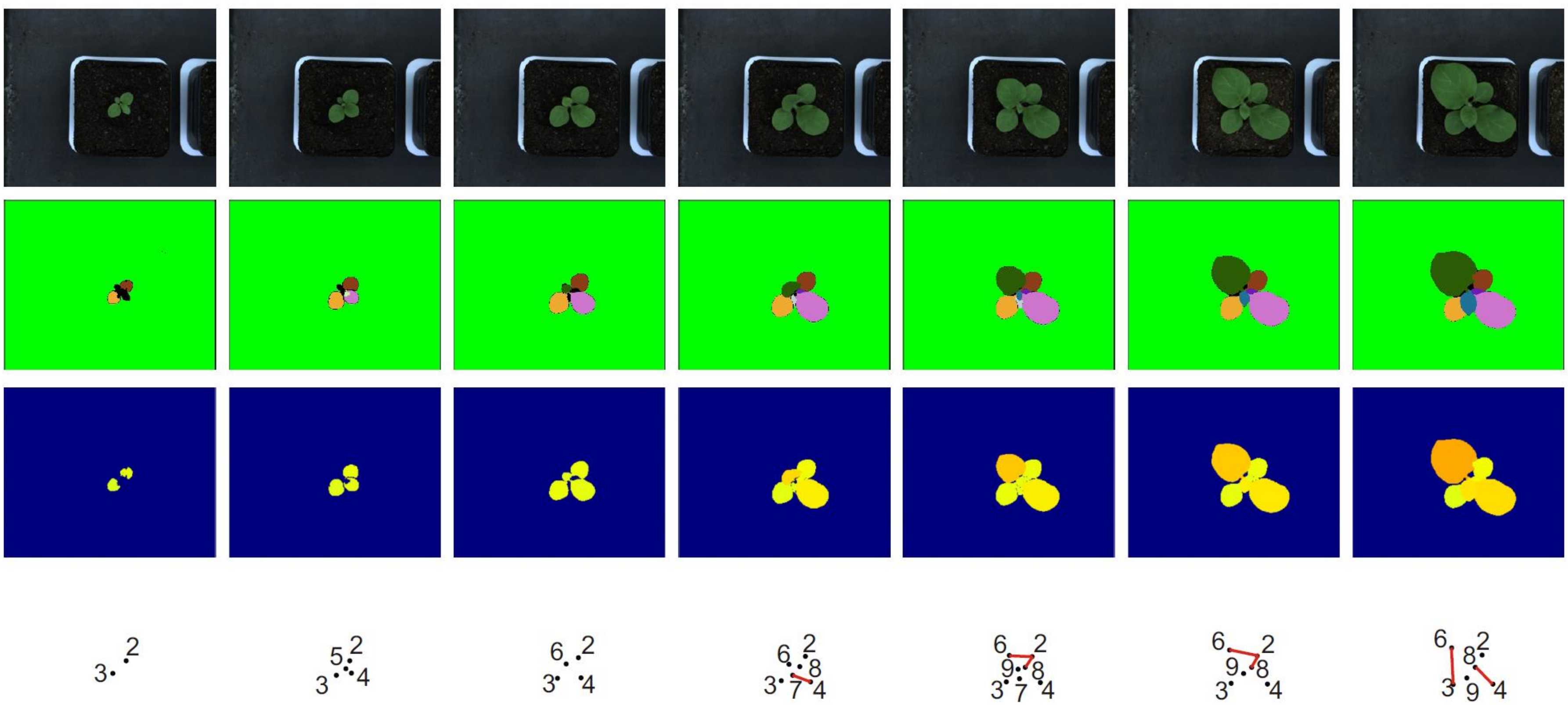
JÜLICH FORSCHUNGSZENTRUM

Simplified GARNICS Action-Perception Loop with Memory for Plant Treatment History



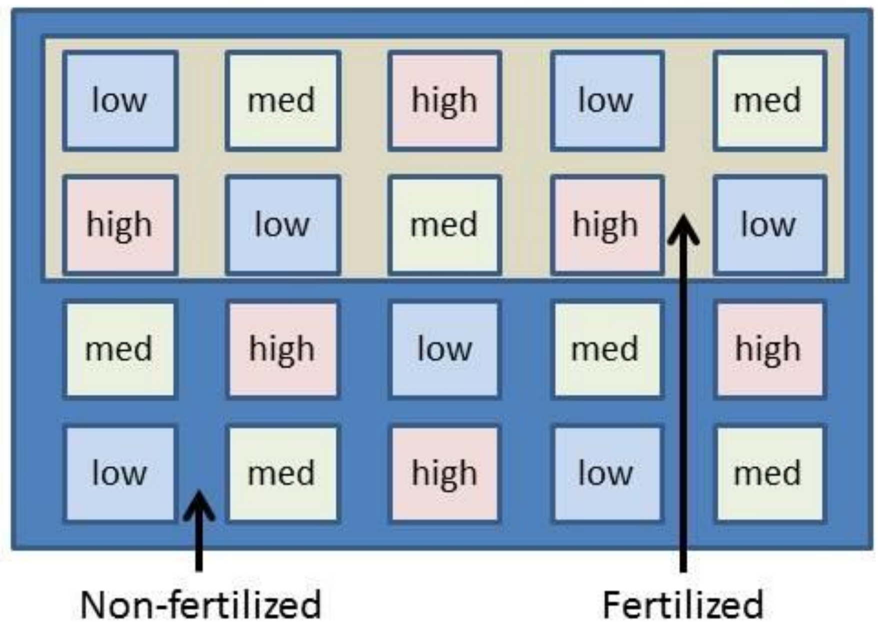
GARNICS: From Images to Plant Graphs



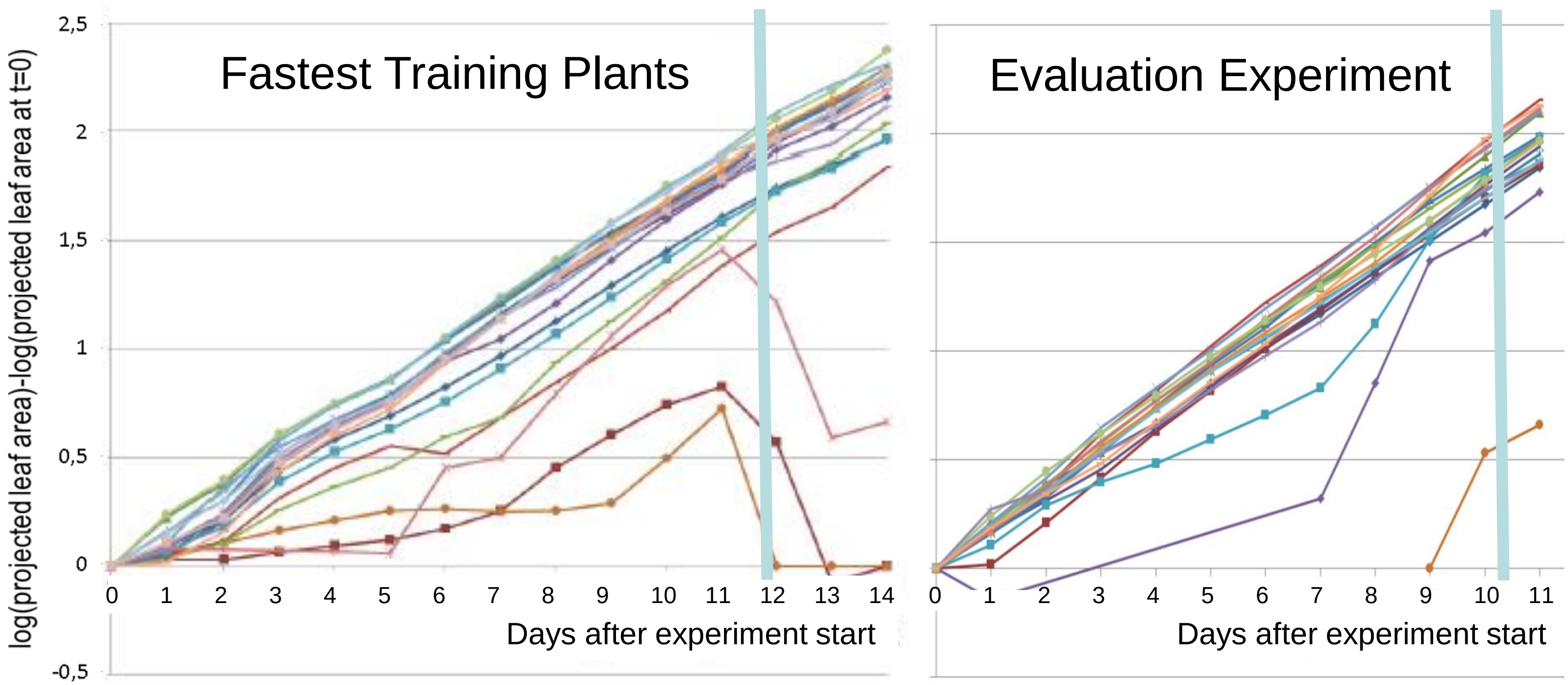


Aksoy et al., Computers and Electronics in Agriculture, Elsevier Science, 78 – 90,110, 2015

GARNICS: Training Data

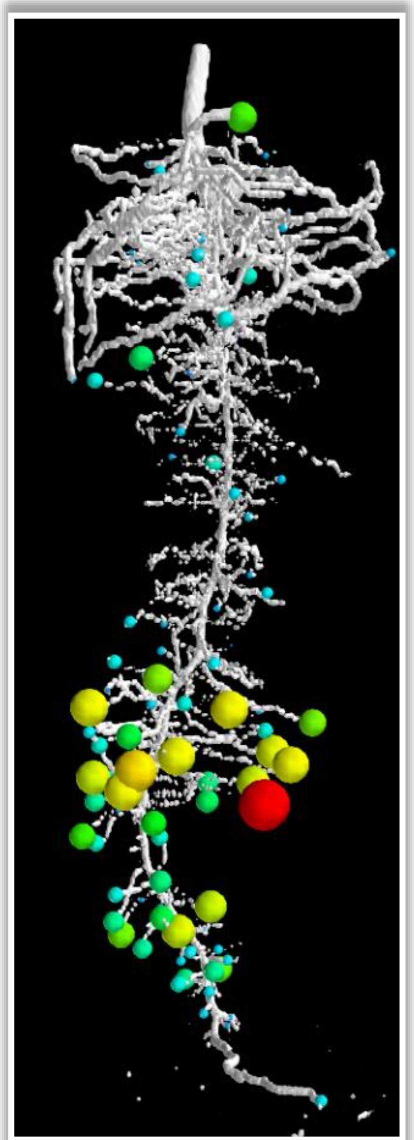


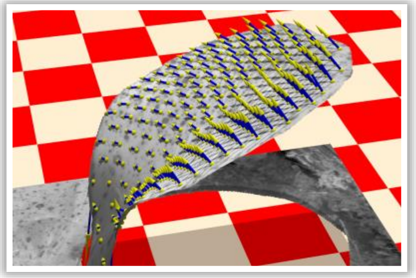
GARNICS: Better Treatment Plan Found

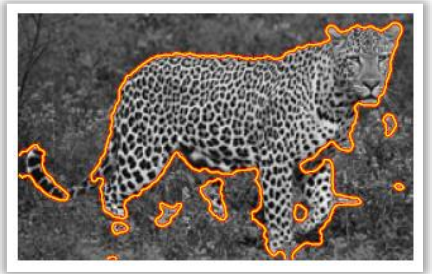


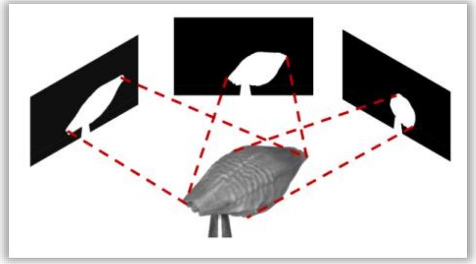
- Faster growth by treatment found by the GARNICS system
- Beats best-performing training plants
- Status from day 12 reached at day 10 to 11.

Image Processing @ IBG-2









Mitglied der Helmholtz-Gemeinschaft

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