Phenotyping large tomato plants in the greenhouse using a 3D light-field camera

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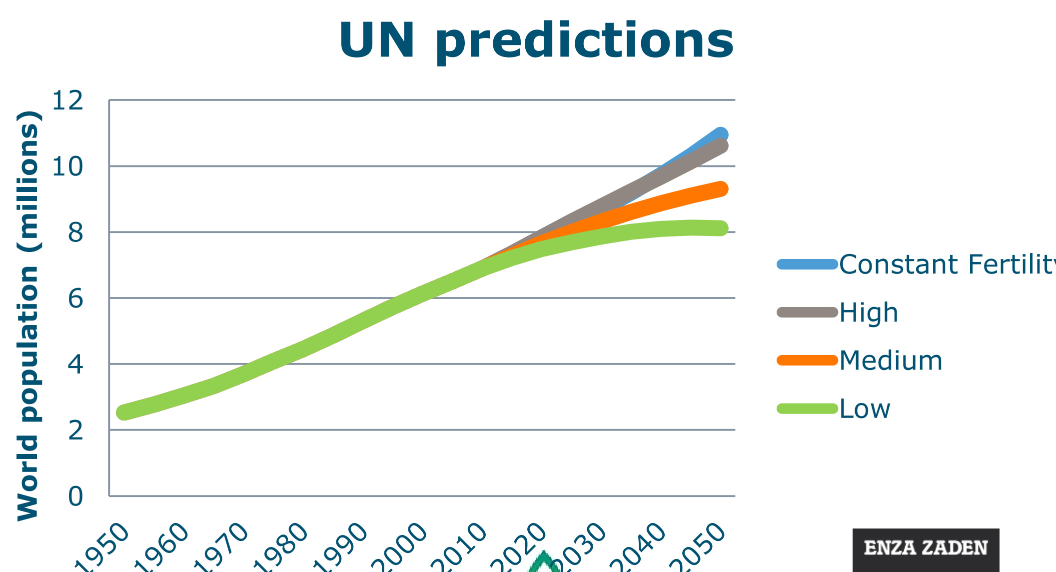
Outline

- Why digital phenotyping
- Phenotyping methods
- Phenotyping applications
  - Spicy
  - PhenoBot
- The view of Enza
- Discussion

Challenges in food and environment

- Increasing global population: 9 billion in 2050
- Environment, nature, climate, and food supply under pressure
- Need of sustainable breakthroughs in knowledge and technology: produce more with less...



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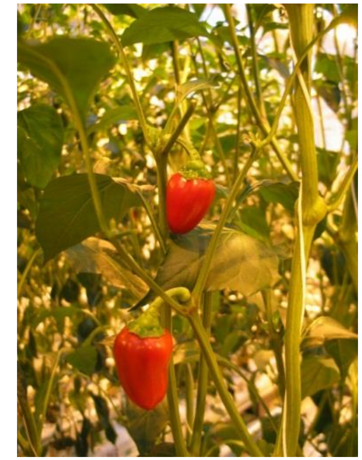
Produce more with less: breeding

- Plant breeding has achieved great results, but it is levelling off and new approaches are required.
- Bottleneck is not the production of molecular data anymore. It is the combination of genomics, phenotyping and the G2P link.
- To bring breeding further, we need to characterise huge numbers of genotypes by objective, reliable and informative measurements, preferably automated.
- Therefore: **digital phenotyping**.



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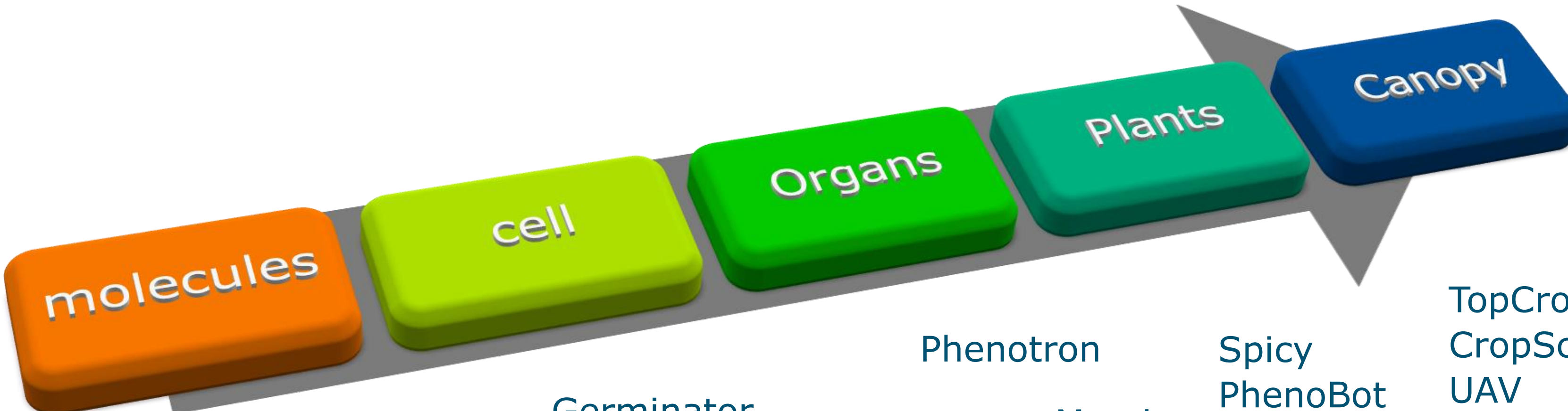
Phenotyping: molecular – canopy level



TopCrop Viewer
CropScan
UAV

Phenotron

Spicy
PhenoBot

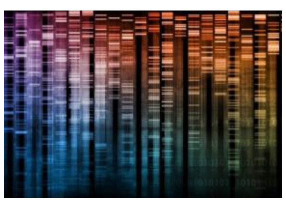
Germinator

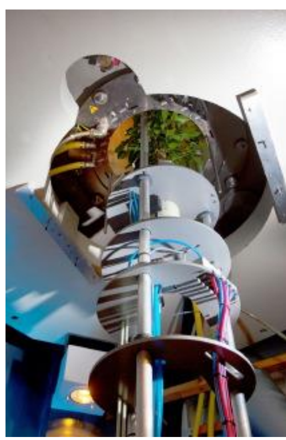
Marvin

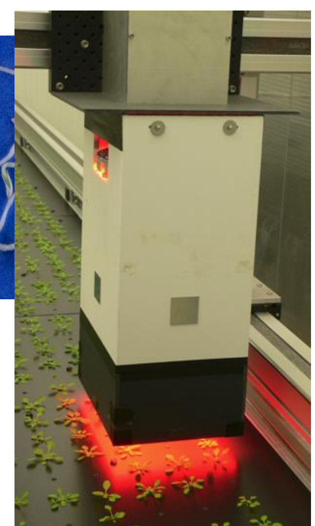
MRI

X-Ray tomograph

Proteomics
Metabolomics







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Phenotyping applications

Laboratory
- Semi-automatic phenotyping
- Small cabinet

Climate cell
- Bring plants to camera
- Use of multiple cameras
- Use of robotic arm

Greenhouse
- Conveyer belt system
- Platform in greenhouse

Open field
- Mobile system
- Remote sensing

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SPICY: Smart tools for Prediction and Improvement of Crop Yield

- Develop tools to predict phenotypic response of a genotype under a range of environmental conditions:
- Molecular tools
- Analysis tools
- Phenotyping tools
- Applied to pepper

- http://www.spicyweb.eu

SpySee (EU project Spicy)

Song, Y., Glasbey, C. A., van der Heijden, G. W. A. M., Polder, G., & Dieleman, J. A. (2011). Combining stereo and time-of-flight images with application to automatic plant phenotyping (Vol. 6688, pp. 469–478). Presented at the 17th Scandinavian Conference on Image Analysis, SCIA, Ystad, Sweden.

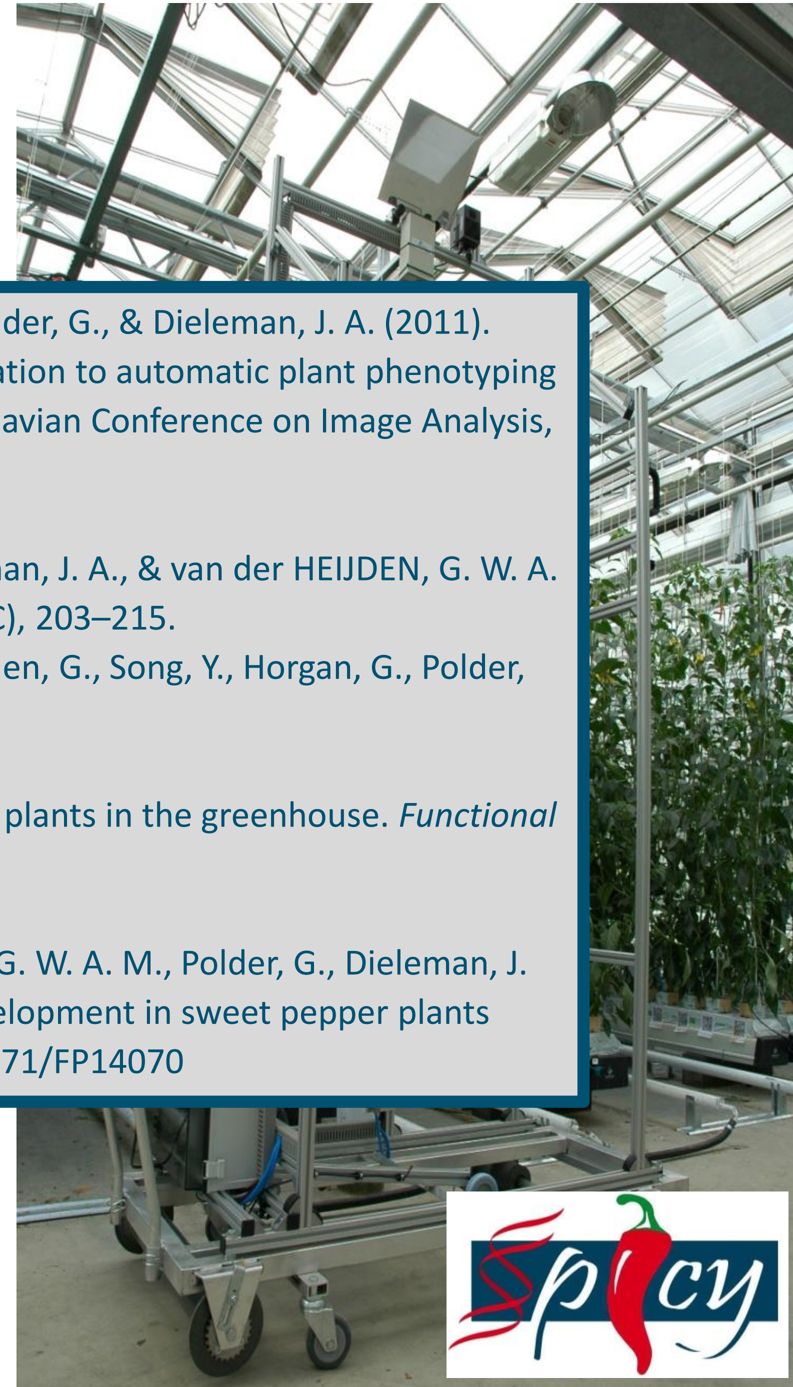
Song, Y., Glasbey, C. A., horgan, G. W., Polder, G., Dieleman, J. A., & van der HEIJDEN, G. W. A. M. (2014). ScienceDirect. *Biosystems Engineering*, *118*(C), 203–215. doi:10.1016/j.biosystemseng.2013.12.008 van der Heijden, G., Song, Y., Horgan, G., Polder, G., Dieleman, A., Bink, M., et al. (2012).

SPICY: towards automated phenotyping of large pepper plants in the greenhouse. *Functional Plant Biology*, *39*(11), 870– 877. doi:10.1071/FP12019

Horgan, G. W., Song, Y., Glasbey, C. A., van der Heijden, G. W. A. M., Polder, G., Dieleman, J. A., et al. (2014). Automated estimation of leaf area development in sweet pepper plants from image analysis. *Functional Plant Biology*. doi:10.1071/FP14070

4* IR

cameras



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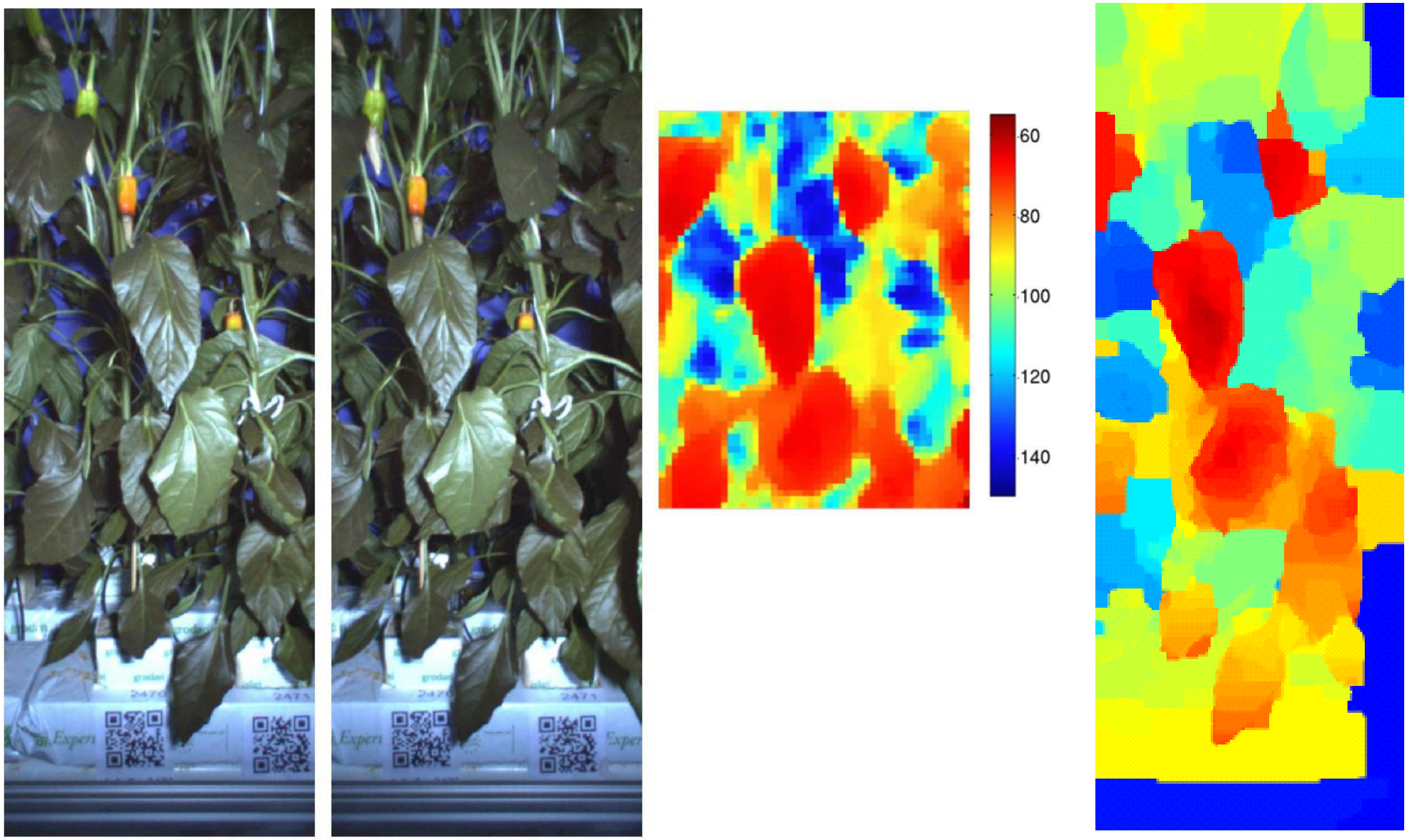
3D imaging

- Apparent size is not only dependent on the object, but also on camera, lens, distance
- Need to correct for this
- Different techniques: stereo, laser triangulation, Time of Flight, ...
- 3D is also helpful in segmentation
- Can be complex

SpySee – combining stereo and ToF



Stereo pair + ToF range image ⇨ detailed range image

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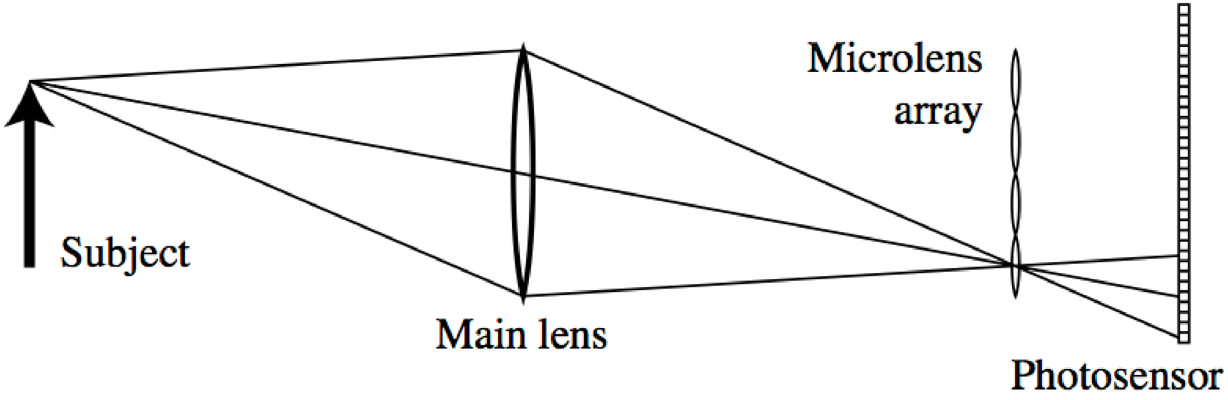
PhenoBot = SpySee II

SpySee (limitations)	PhenoBot
Hand driven	Autonomous Robot
Colour + Time of Flight camera	3D Light field Camera
Cumbersome sensor fusion for pixel registration of depth and colour image	Camera promises to output direct registered depth and colour image
Small depth of focus	Image is in focus over whole depth range
Blue background screen needed in adjacent lane	No background screen needed.
Occlusion due to stereo approach	Reduced occlusion due to micro lenses

3D Light Field Camera

- Placing a micro lens array in front of an image sensor transforms a normal camera into a single lens 3D camera, which also allows the user to change the focus and the point of view after a picture has been taken
- While the concept of such plenoptic cameras is known since 1908, only recently the increased computing power of low-cost hardware and the advances in micro lens array production, have made the application of plenoptic cameras feasible



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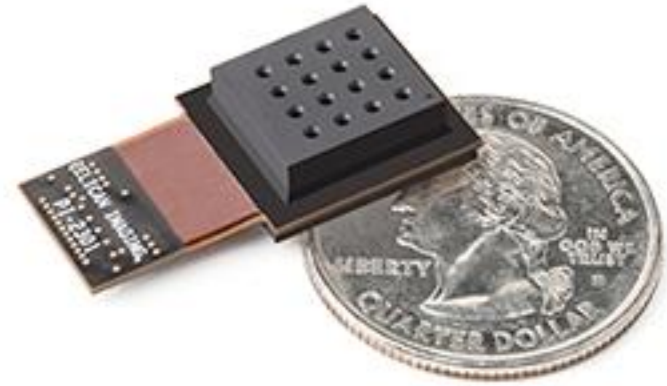
3D Light Field Camera

- Commercial available cameras:



pelican imaging
Life in 3D

LYTRO

raytrix

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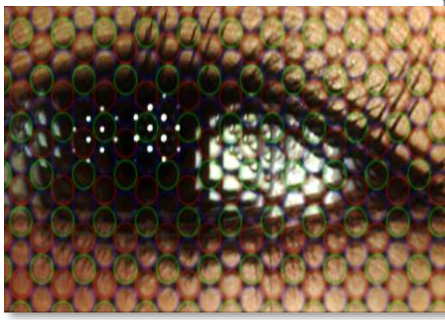
3D Light Field Camera Technology*

raytrix

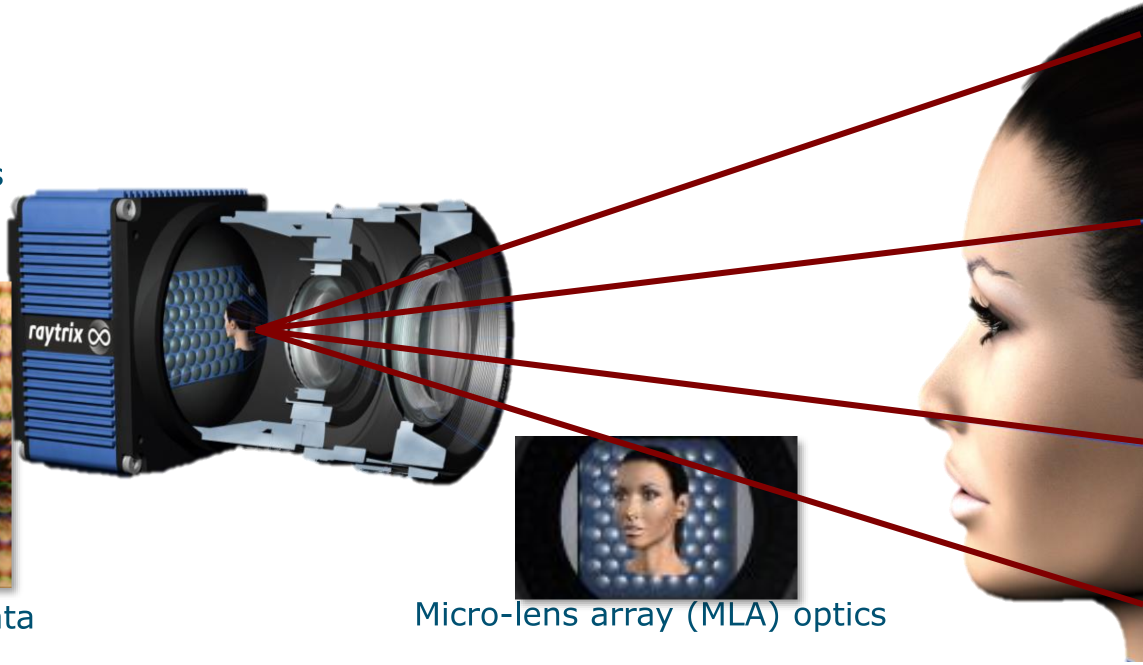
3D reconstruction and extended depth-of-field based on only one snapshot and a single-lens camera

- calibration-free monocular camera
- robust & space-saving setup
- down to micron resolution
- extended depth-of-field by software re-focus
- captures fast moving objects by single shot

Light field engine

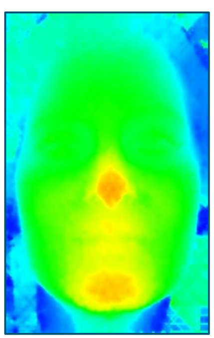


4D light field raw image data



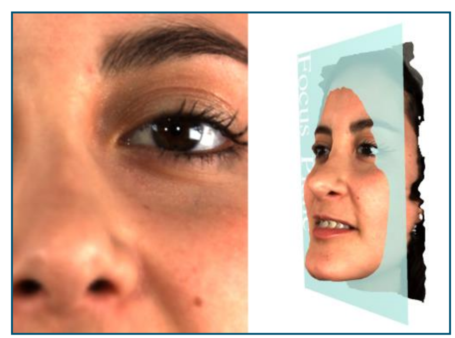
Micro-lens array (MLA) optics

perspective shift

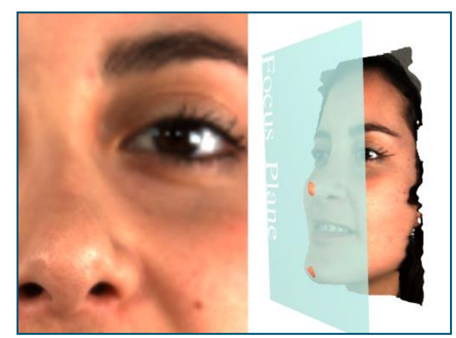


3D depth map

in total focus 3D view



re-focus plane on eye



re-focus plane on nose

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- US-Pat.-No.: 2012/0050562 A1 , CHIP-Award 2012: „Innovation of the year"

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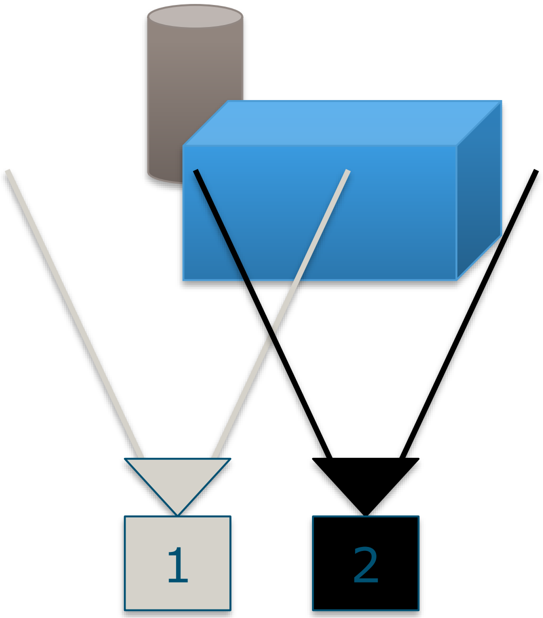
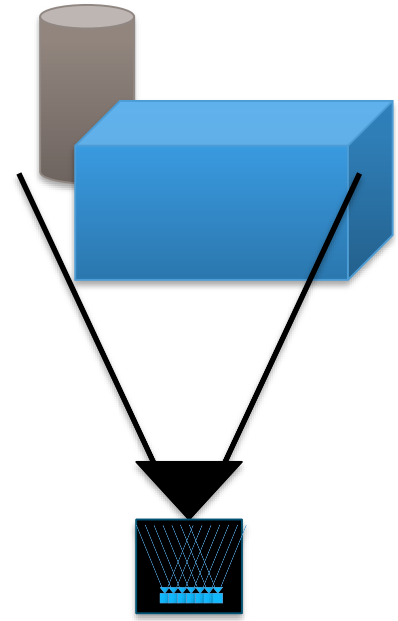
Occlusion

Example of a setup that is prone to occlusion



- Due to the large baseline a stereoscopic system suffers from occlusion. Cylinder occluded in one of the images, no matching possible



- Due to thousands of micro lens images, with about the same perspective through the object lens, occlusion is exceptionally reduced

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PhenoBot – Greenhouse measurements

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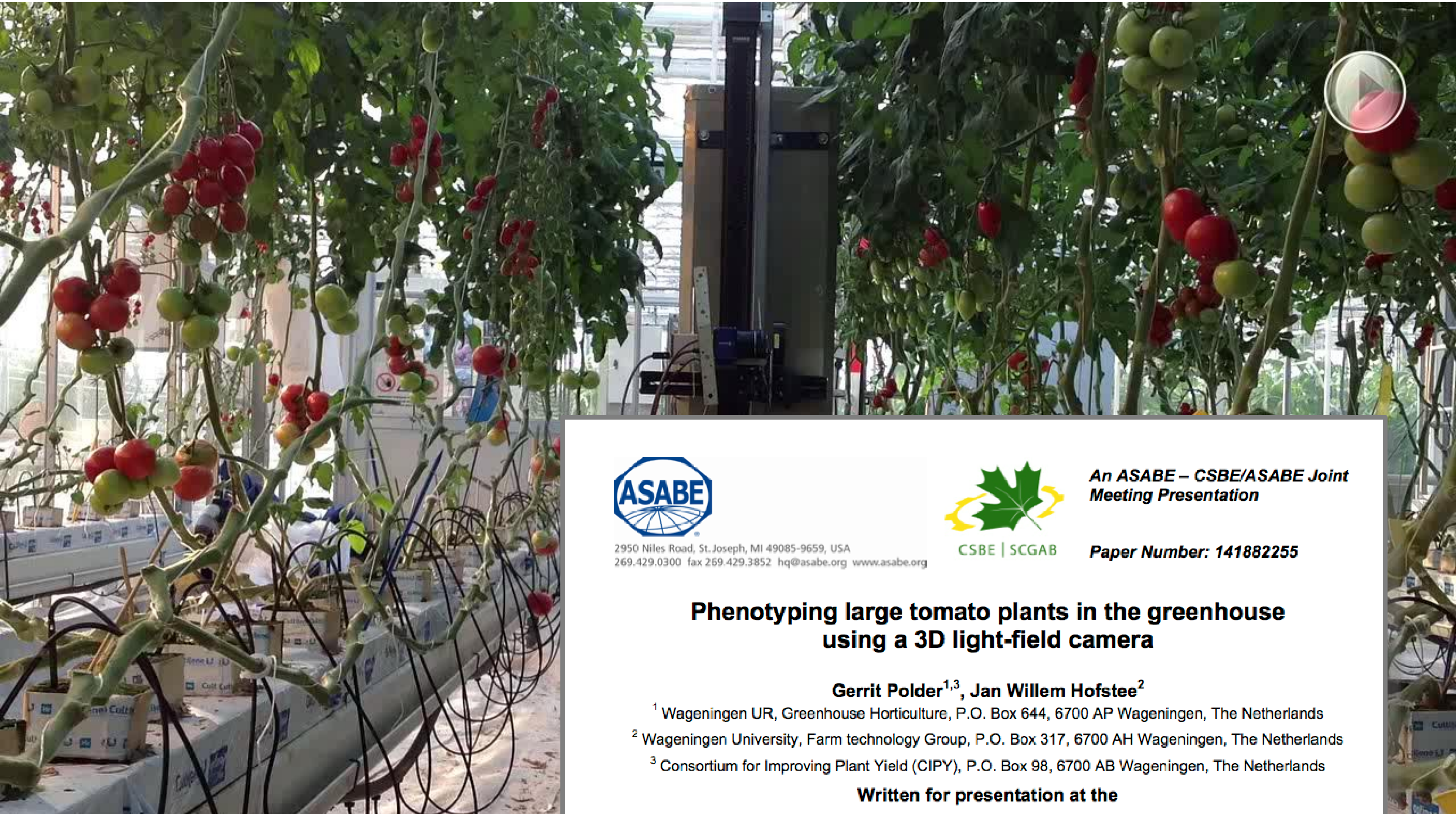

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Phenotyping large tomato plants in the greenhouse using a 3D light-field camera

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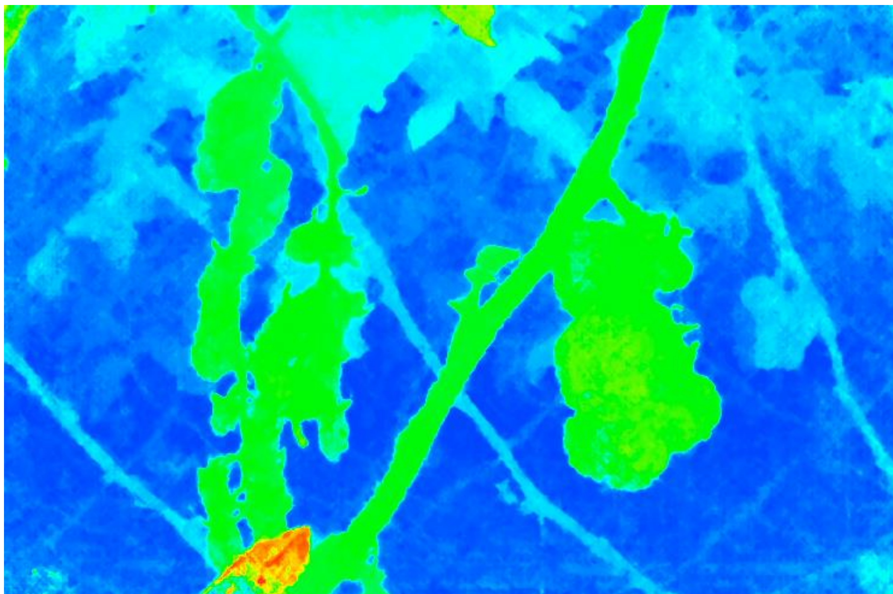
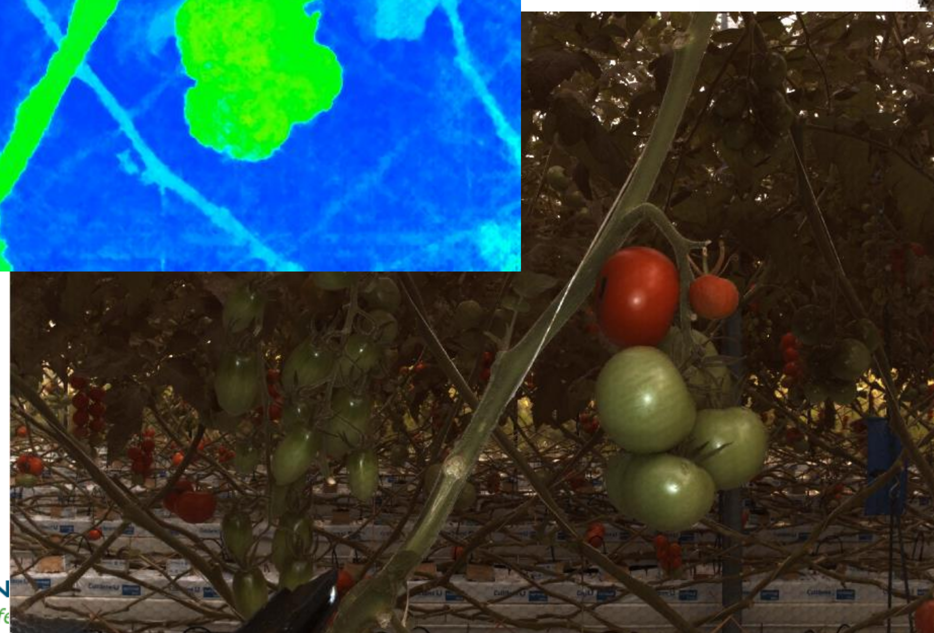
PhenoBot – Greenhouse measurements

- Example data





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PhenoBot – Greenhouse measurements

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Questions?

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