Crops as Time-Invariant Keypoints

M. Bos

Dr. N.V. Budko (Delft Univsersity of Technology)
Ir. E. Verhoeff (VanBoven Drones)

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Problem Introduction

Drone Images

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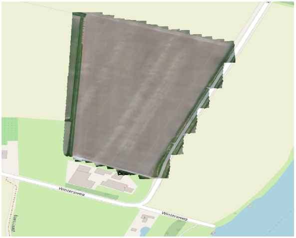

Orthophoto

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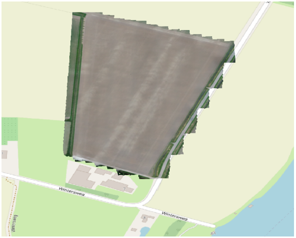

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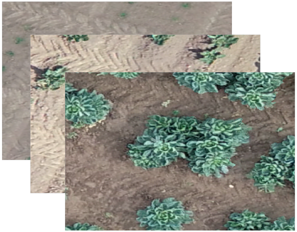
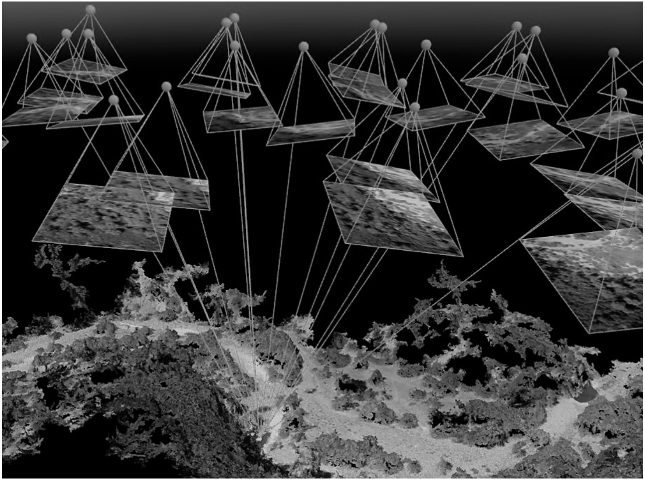


Time-Series

Overview

Creating an Orthophoto

- Aim to unite image data into a common reference frame.
    - Use 3D geometry of the problem.



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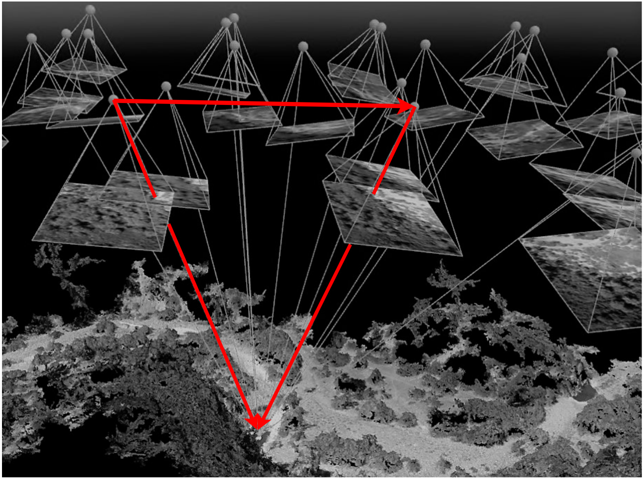
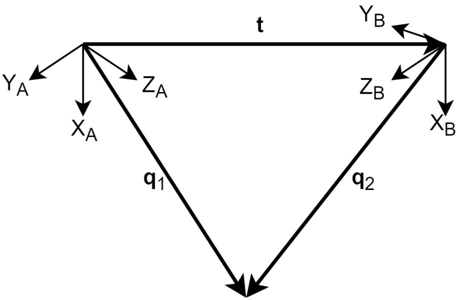


Essential Matrix



- $\boxed{\boldsymbol{q}_1 \cdot (\boldsymbol{t} \times R\boldsymbol{q}_2) = 0}$
  - by coplanarity between $\boldsymbol{t}$, $\boldsymbol{q}_1$, and $R\boldsymbol{q}_2$.

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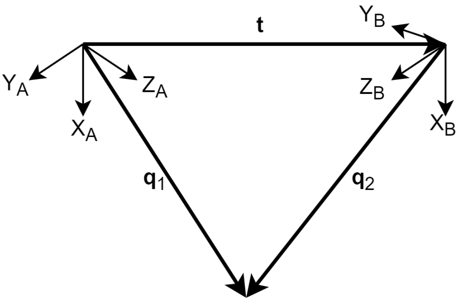

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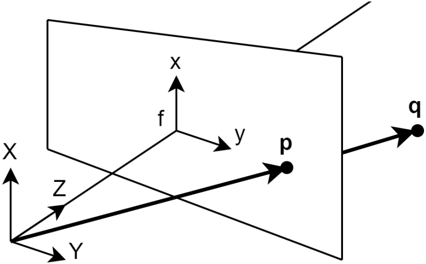
  - by coplanarity between $\boldsymbol{t}$, $\boldsymbol{q}_1$, and $R\boldsymbol{q}_2$.
- $\boxed{\boldsymbol{q}_1^T E \boldsymbol{q}_2 = 0}$
  - by defining *essential* matrix $E = \boldsymbol{t} \times R$, or $E = R[\boldsymbol{t}]_\times$.

Essential Matrix



$$\boldsymbol{p} = \begin{bmatrix} p^x \\ p^y \\ f \end{bmatrix} = \frac{f}{q^Z} \begin{bmatrix} q^X \\ q^Y \\ q^Z \end{bmatrix} = \frac{f}{q^Z} \boldsymbol{q}$$

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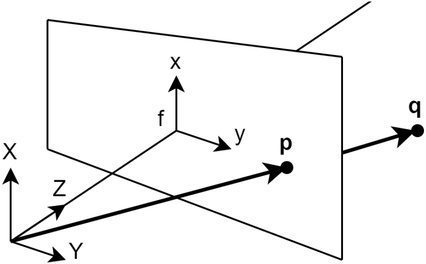

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- $\boldsymbol{q}_1^T E \boldsymbol{q}_2 = 0$ becomes $\boxed{\boldsymbol{p}_1^T E \boldsymbol{p}_2 = 0}$

Essential Matrix

- For a known $(\boldsymbol{p}_1 \leftrightarrow \boldsymbol{p}_2)$ between two images, we rewrite:

$$\begin{bmatrix} p_1^x p_2^x & p_1^x p_2^y & p_1^x & p_1^y p_2^x & p_1^y p_2^y & p_1^y & p_2^x & p_2^y & 1 \\ & & & & \vdots & & & & \end{bmatrix} \begin{bmatrix} E_{11} \\ E_{12} \\ \vdots \\ E_{33} \end{bmatrix} = 0.$$

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- Can be solved for $\boldsymbol{e}$ using a singular value decomposition of A.

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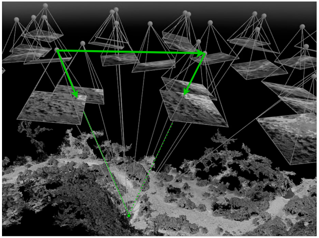

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- For example using the scale-invariant feature transform (SIFT).

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- Accept candidate if there is no 'close' second-nearest neighbour:
  - $\|\boldsymbol{f}_i - \boldsymbol{f}_\iota\| < C \min_{\tau \in S^B \setminus \{\iota\}} \|\boldsymbol{f}_i - \boldsymbol{f}_\tau\|$ with $C \leq 1$.

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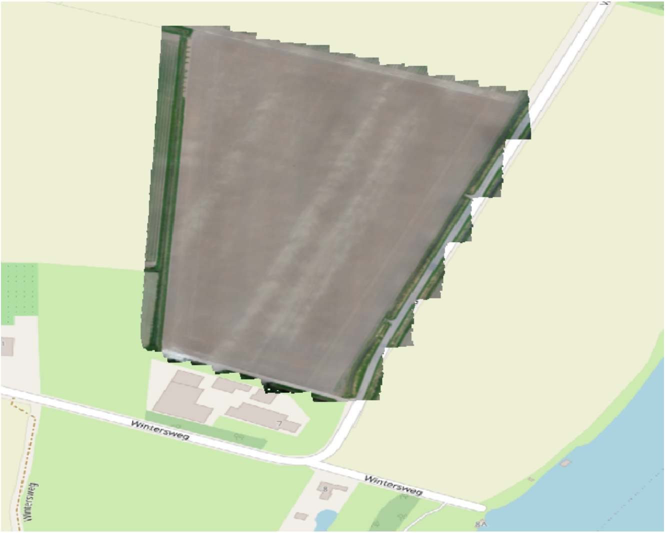
- Image pair with a set of matches $(\boldsymbol{p}_i \leftrightarrow \boldsymbol{p}_\iota)$
- Filter data and fit E using random sample consensus (RANSAC):

for N iterations **do**
    select random subset of $(\boldsymbol{p}_i \leftrightarrow \boldsymbol{p}_\iota)$ and determine $\tilde{E}$
    count inliers on all data that satisfy $(\boldsymbol{p}_i)^T \tilde{E} \boldsymbol{p}_\iota < \varepsilon$
    if count $>$ best count **then**
        $E \leftarrow \tilde{E}$
    end if
end for

Time Alignment of Orthophotos



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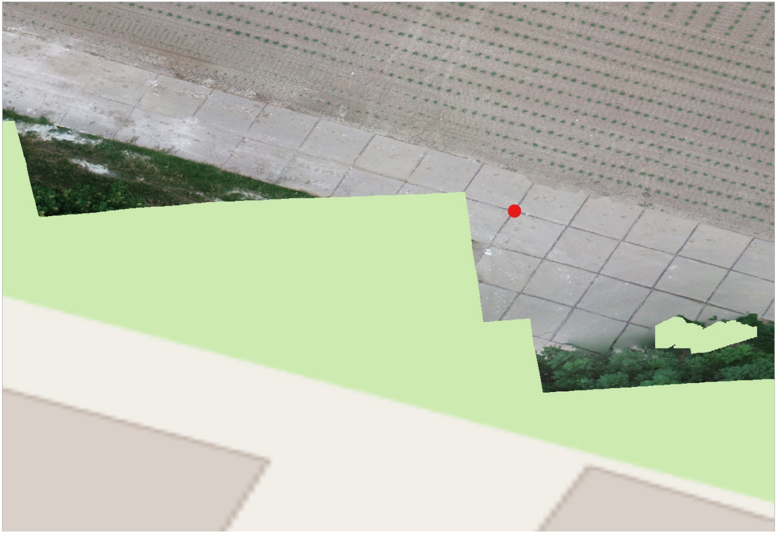

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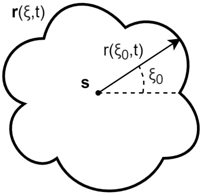
- Need point correspondences between orthophotos to correct the error.
- Do not require e.g. scale-invariance, but time-invariance.
- **Use crops as time-invariant keypoints.**
  - Guaranteed to be present.
  - Evenly distributed.

Model Growth

- Polar parametrization of crop:

$$\boldsymbol{r}(\xi, t) = r(\xi, t)\boldsymbol{n}(\xi) + \boldsymbol{s}, \quad \boldsymbol{n}(\xi) = \langle \cos\xi, \sin\xi \rangle.$$



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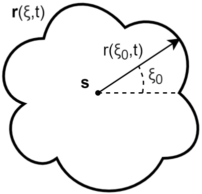
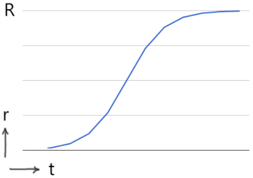
- Assume logistic growth model:

$$\frac{\partial r}{\partial t} = \alpha r \left(1 - \frac{r}{R}\right).$$





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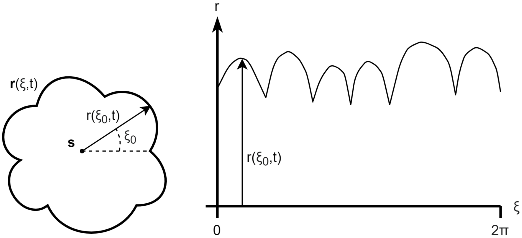
- Position $\boldsymbol{p}_i$ is ideally selected as the stem $\boldsymbol{s}$, which is time-invariant.
- Two possible descriptors $\boldsymbol{f}_i$ are suggested:
  - Shape and size based descriptor
  - Planting pattern based descriptor

Shape and Size Descriptor



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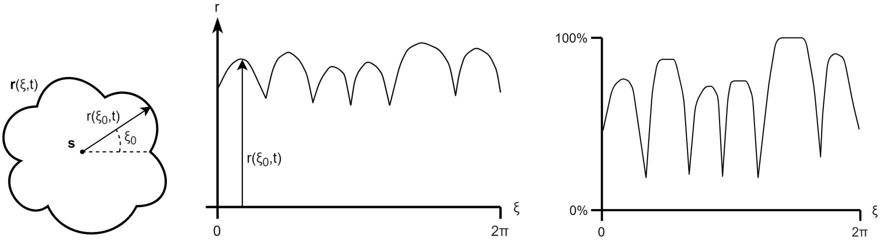
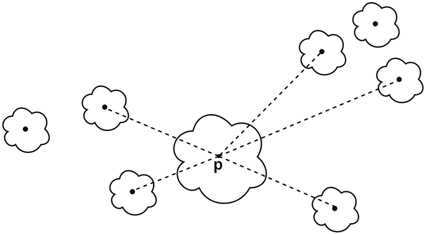
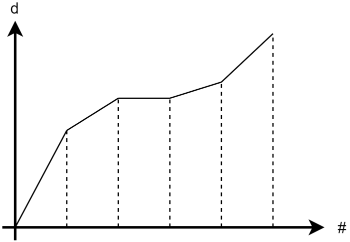


Planting Pattern Descriptor





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- Filtering and model fitting is done by RANSAC again.

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- Tested effectiveness on a time-series of seven orthophotos.

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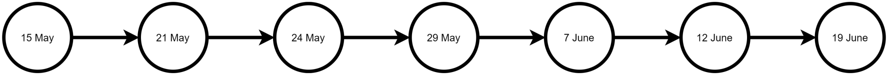

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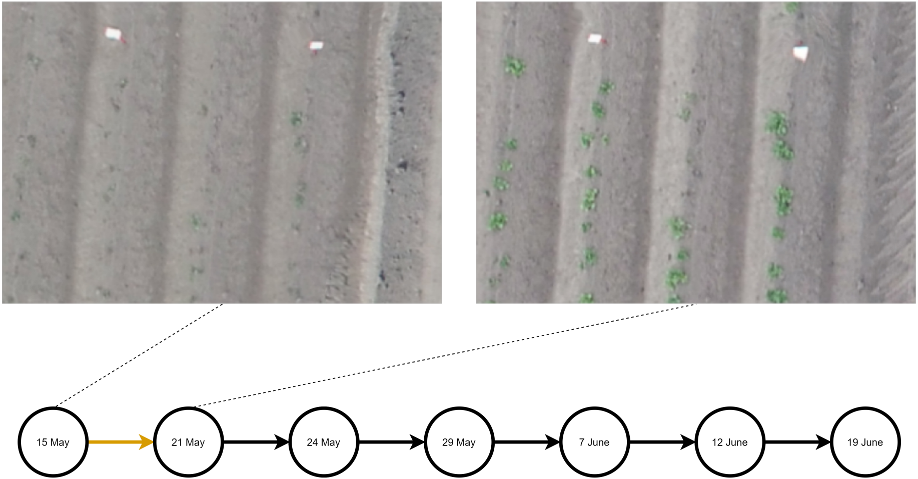

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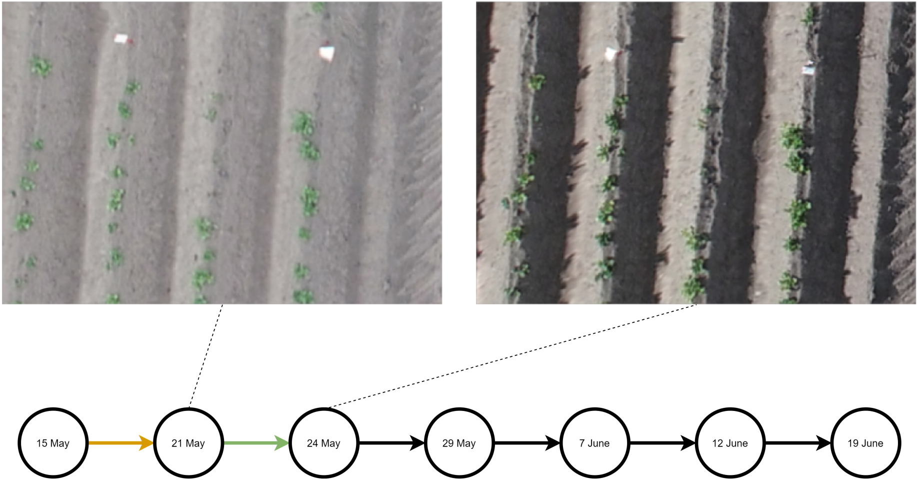

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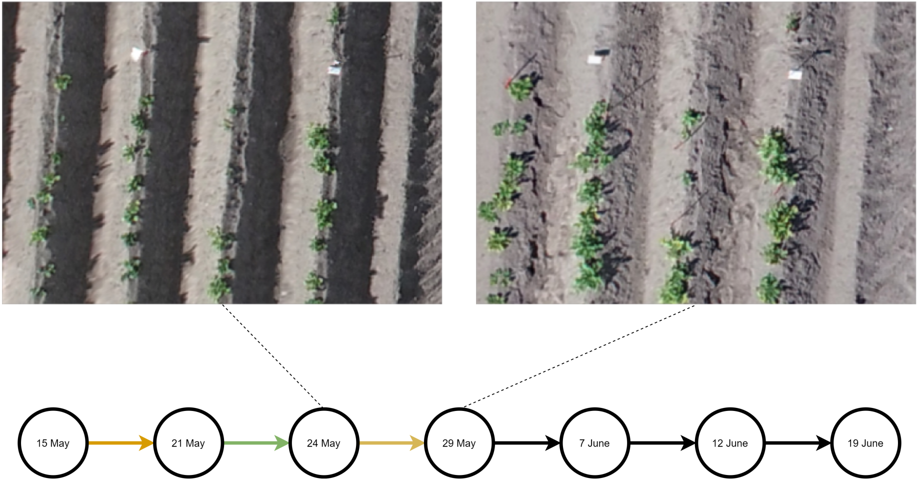

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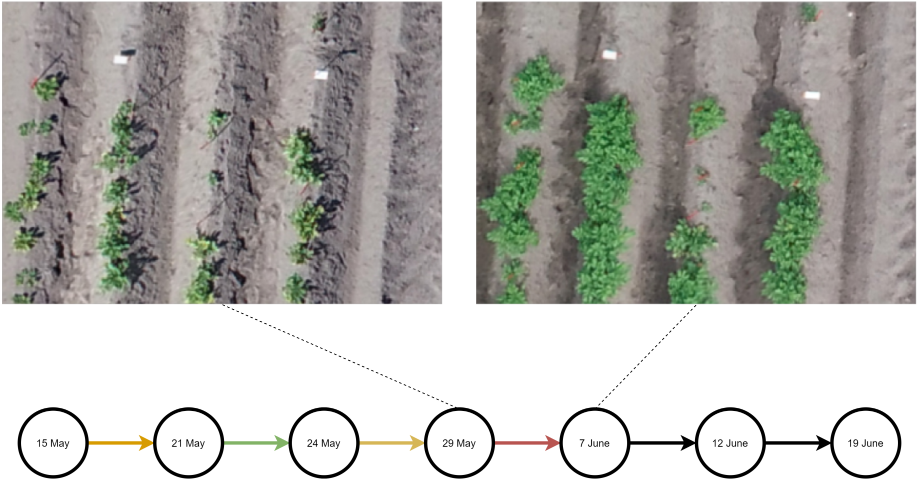

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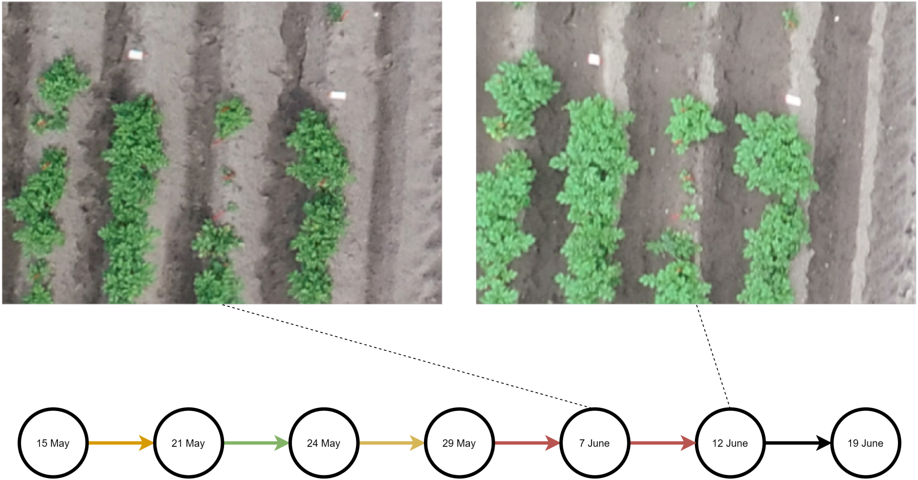

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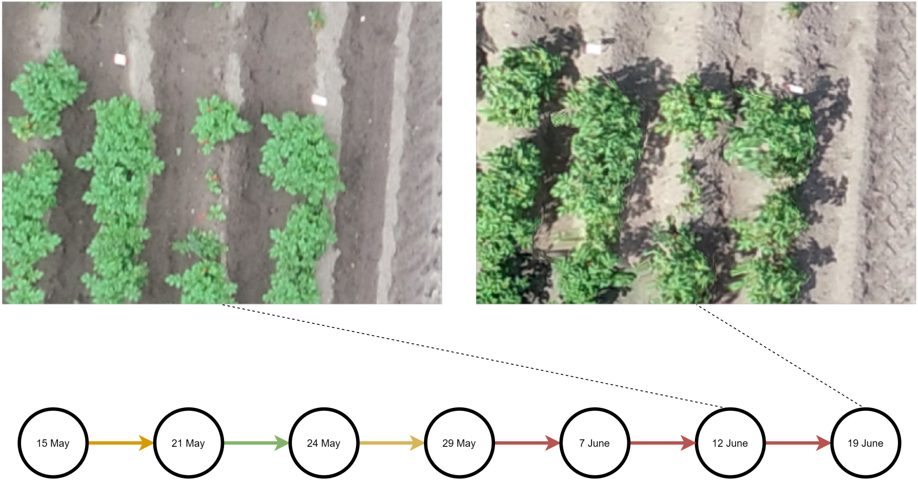

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- In early growth stages resolution is problematic.
- In later growth stages **merging of crops** is problematic.
  - Split connected components by shrinkage and buffer operations.
  - Account for merging in the model $\rightarrow$ planting pattern descriptor.
  - Identify crops not by image thresholding but by e.g. convolutional neural networks.