Drone swarms for precision agriculture

Vito Trianni

Institute of Cognitive Sciences and Technologies, CNR, Italy

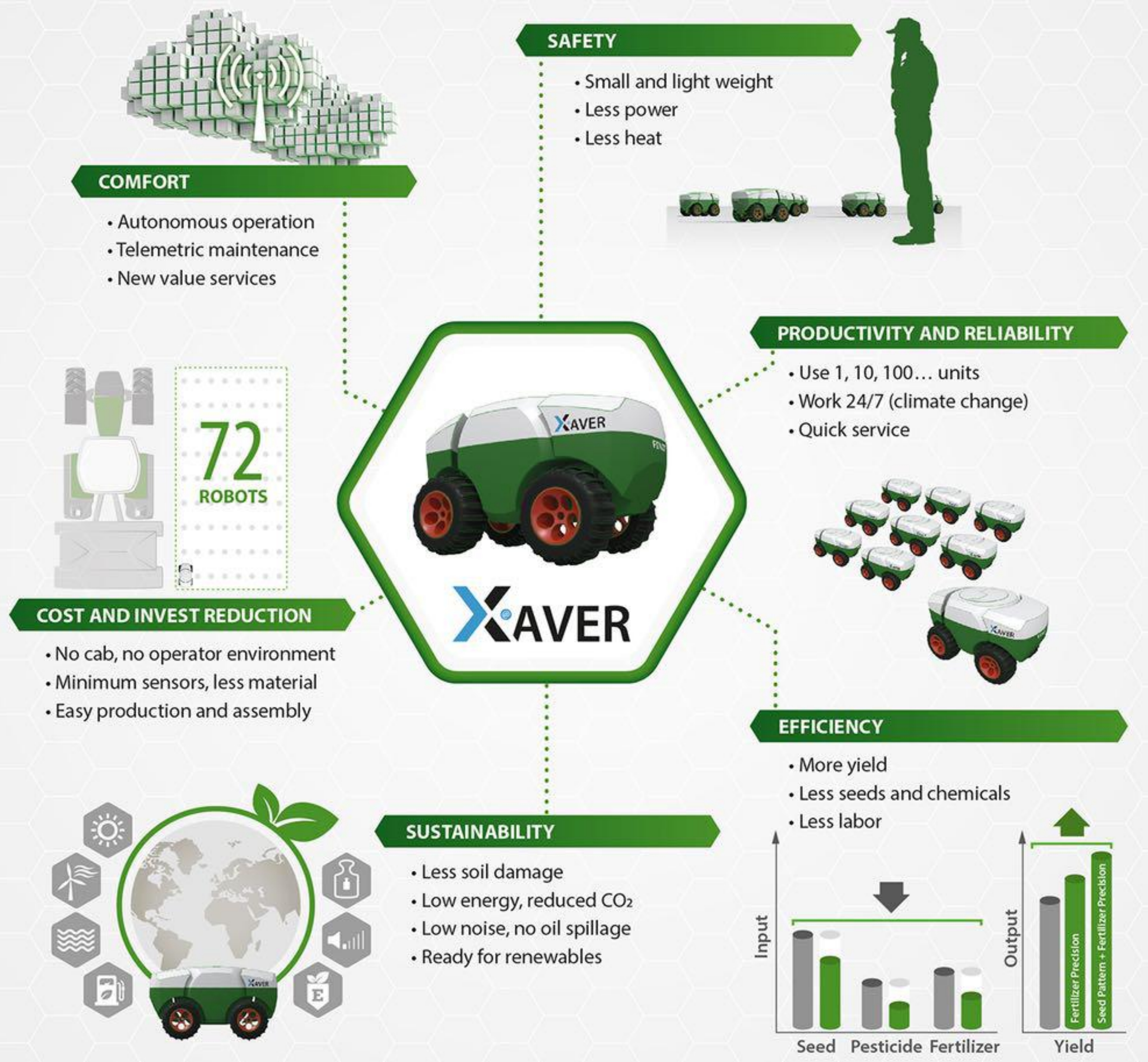
vito.trianni@istc.cnr.it

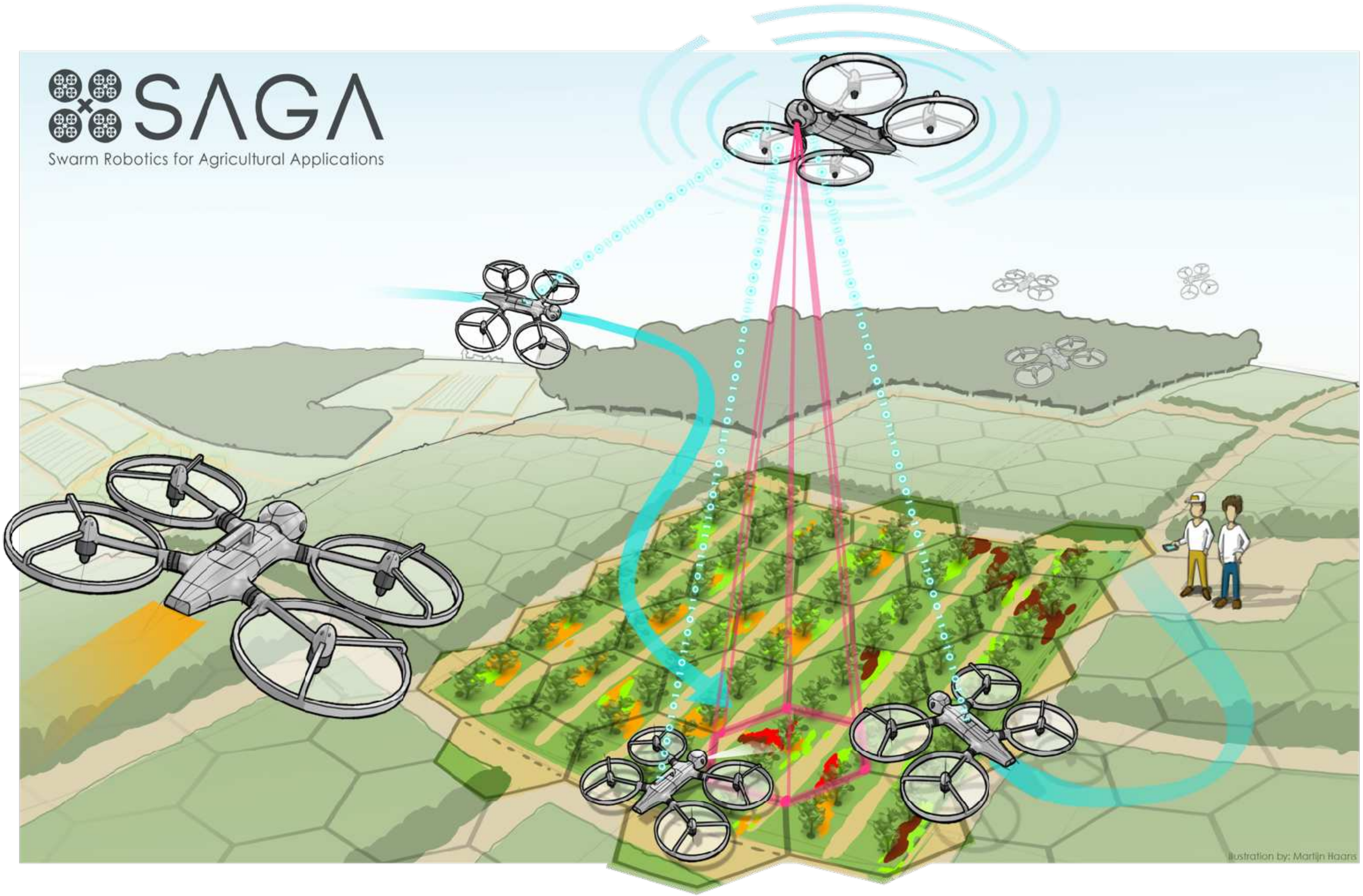
SAGA

Swarm Robotics for Agricultural Applications

Why swarms?

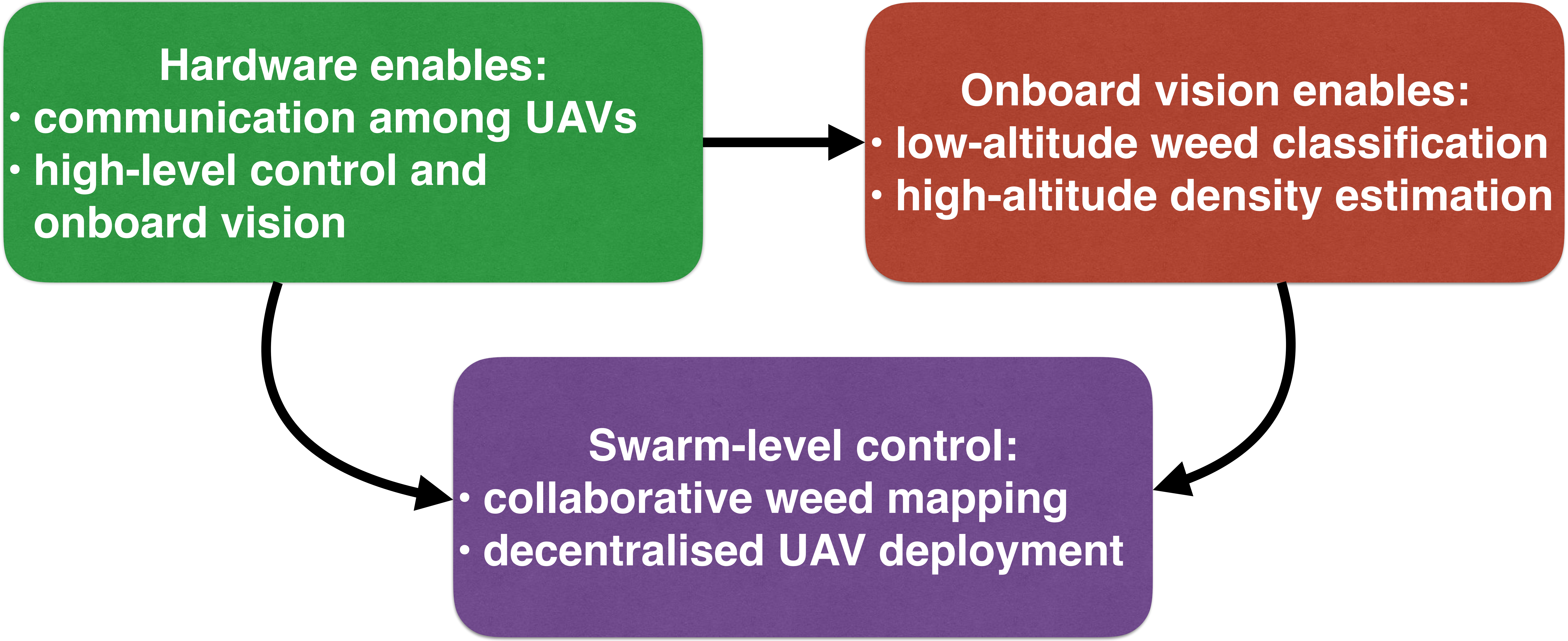
- Parallelise operations → higher efficiency
- Collaborative action → higher accuracy
- Redundant systems → higher robustness
- Decentralised algorithms → higher scalability




SAGA
Swarm Robotics for Agricultural Applications
Illustration by: Martijn Haans

Non-Uniform Coverage

SAGA in a nutshell



Hardware

avular™

Aerial **Curiosity**

- **2x Real Cortex M4** real-time cores
- **Raspberry Pi 3** Compute module
- **8M Pixel** CSI camera
- **Optical Flow** position sensor
- **Standard GNSS** GPS receiver
- **Dual IMU** & magnetometer
- **25 min** flight time

\+ **UWB**: indoor positioning
\+ **ZigBee**: swarm communication

Onboard Vision

Crop-Weed Detection


10m distance
WAGENINGEN
UNIVERSITY & RESEARCH


10m distance
WAGENINGEN
UNIVERSITY & RESEARCH

10m distance

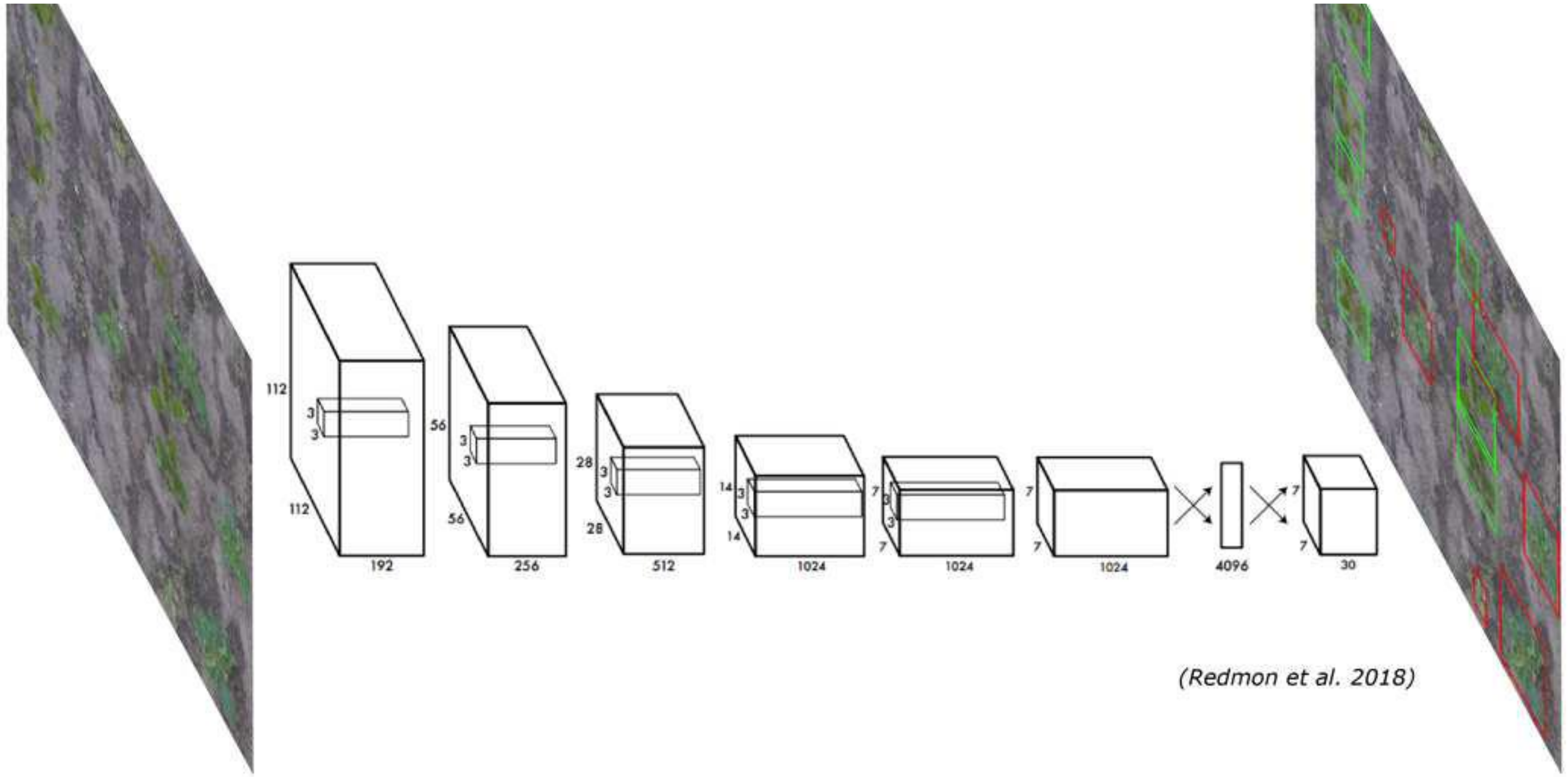

10m distance

WAGENINGEN
UNIVERSITY & RESEARCH

10m distance

10m distance

Classification with YOLO



(Redmon et al. 2018)

altitude: 3m

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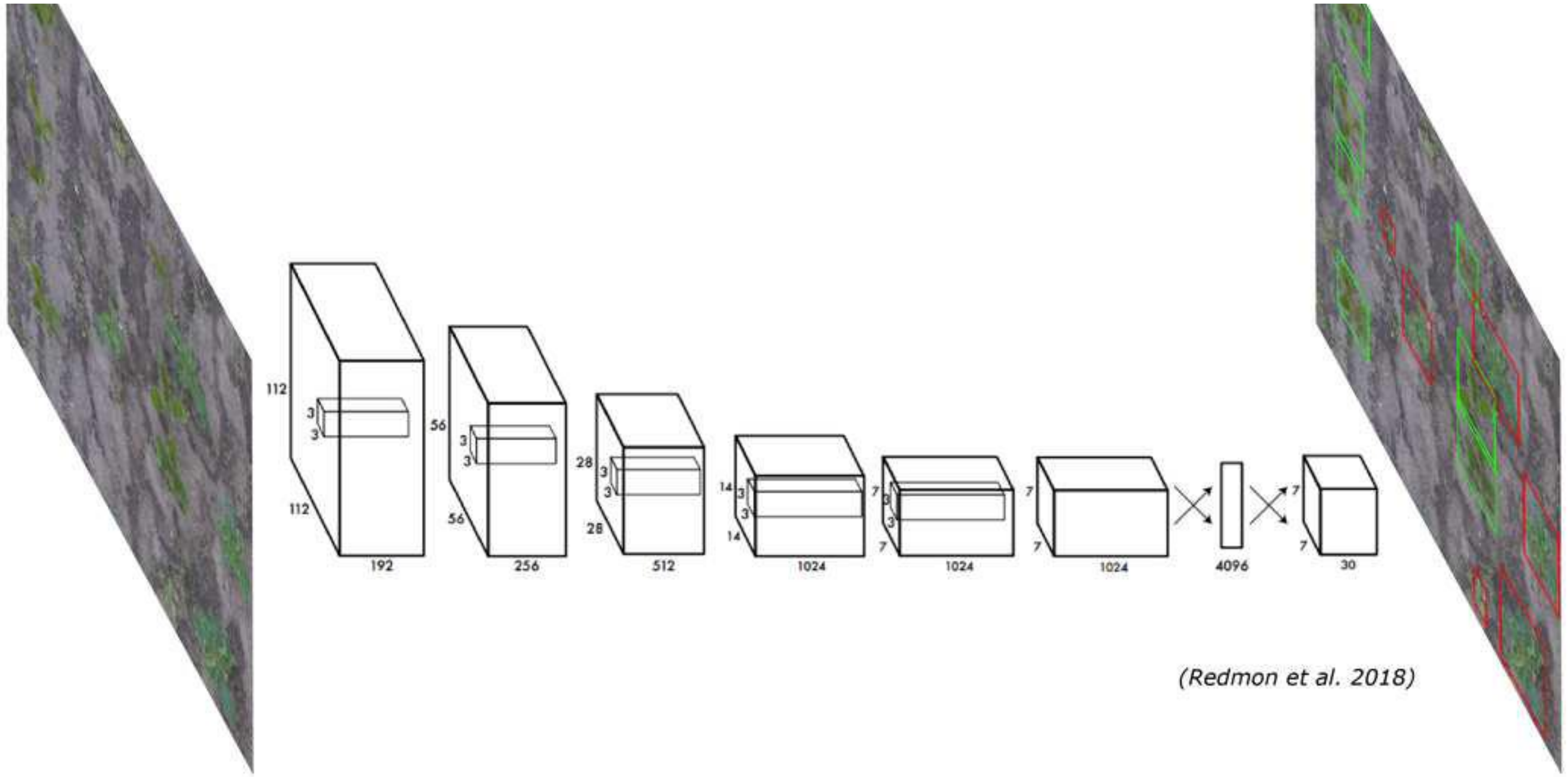

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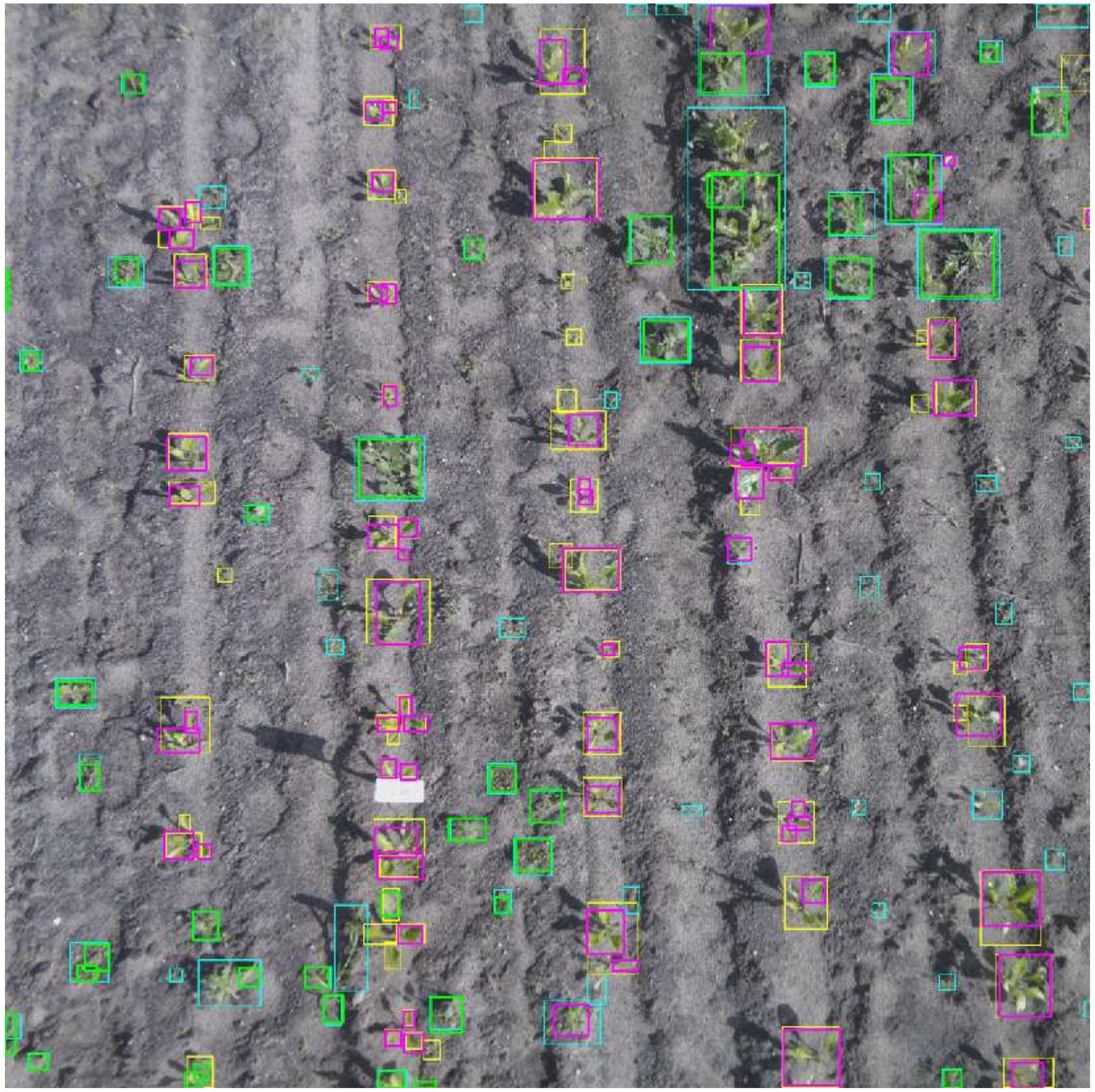
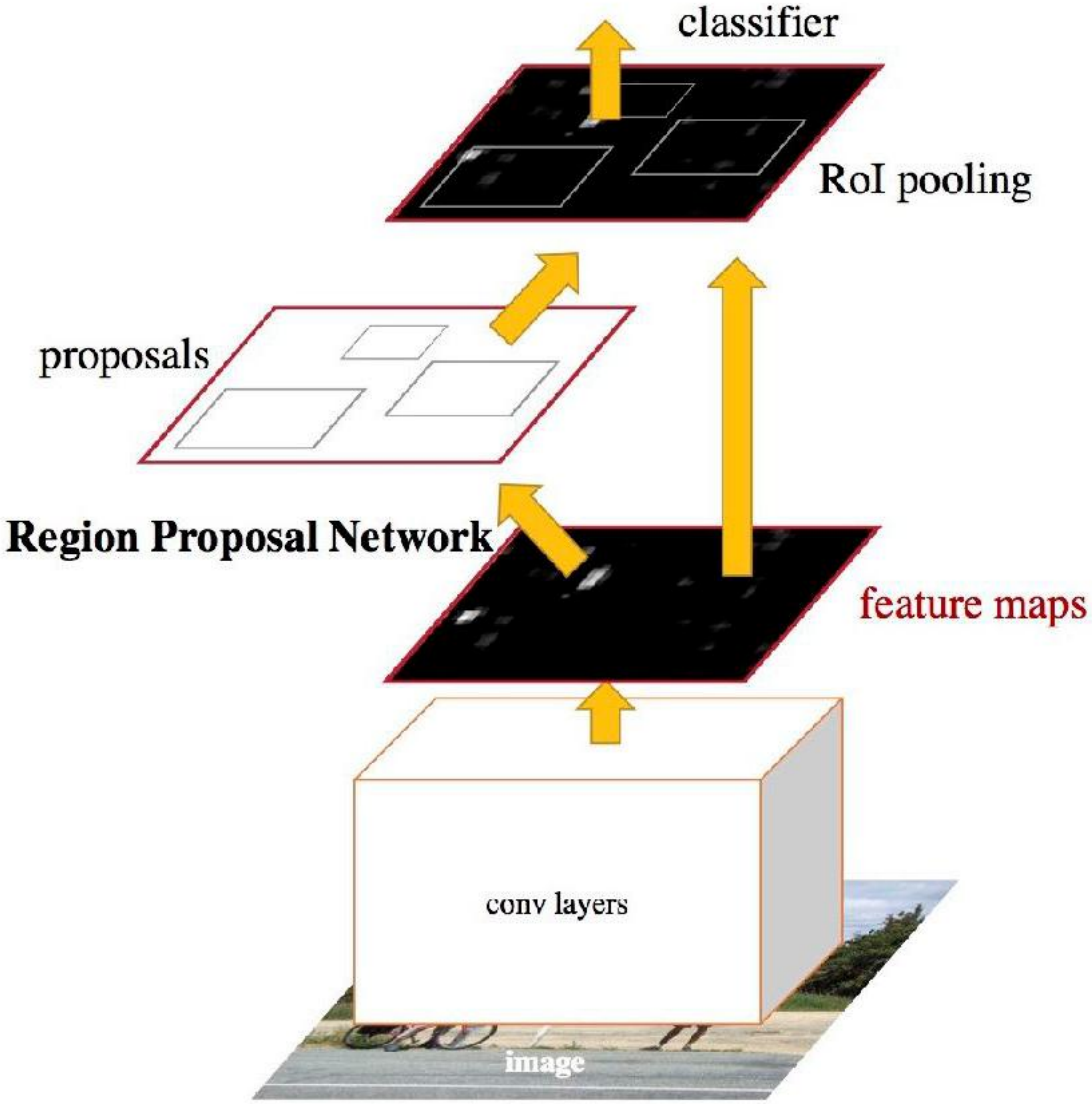
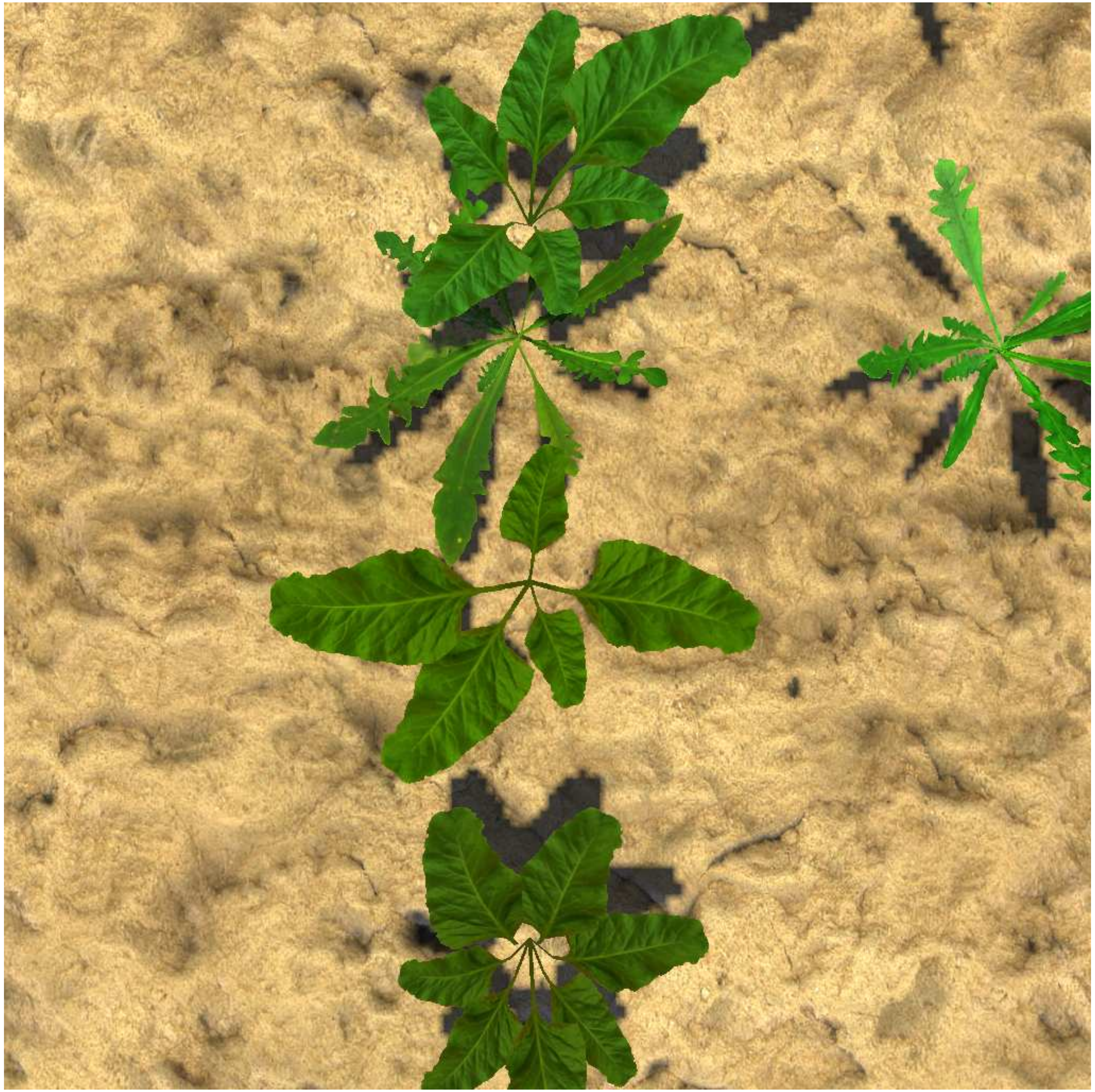


Faster RCNN


classifier
RoI pooling
proposals
Region Proposal Network
feature maps
conv layers
image



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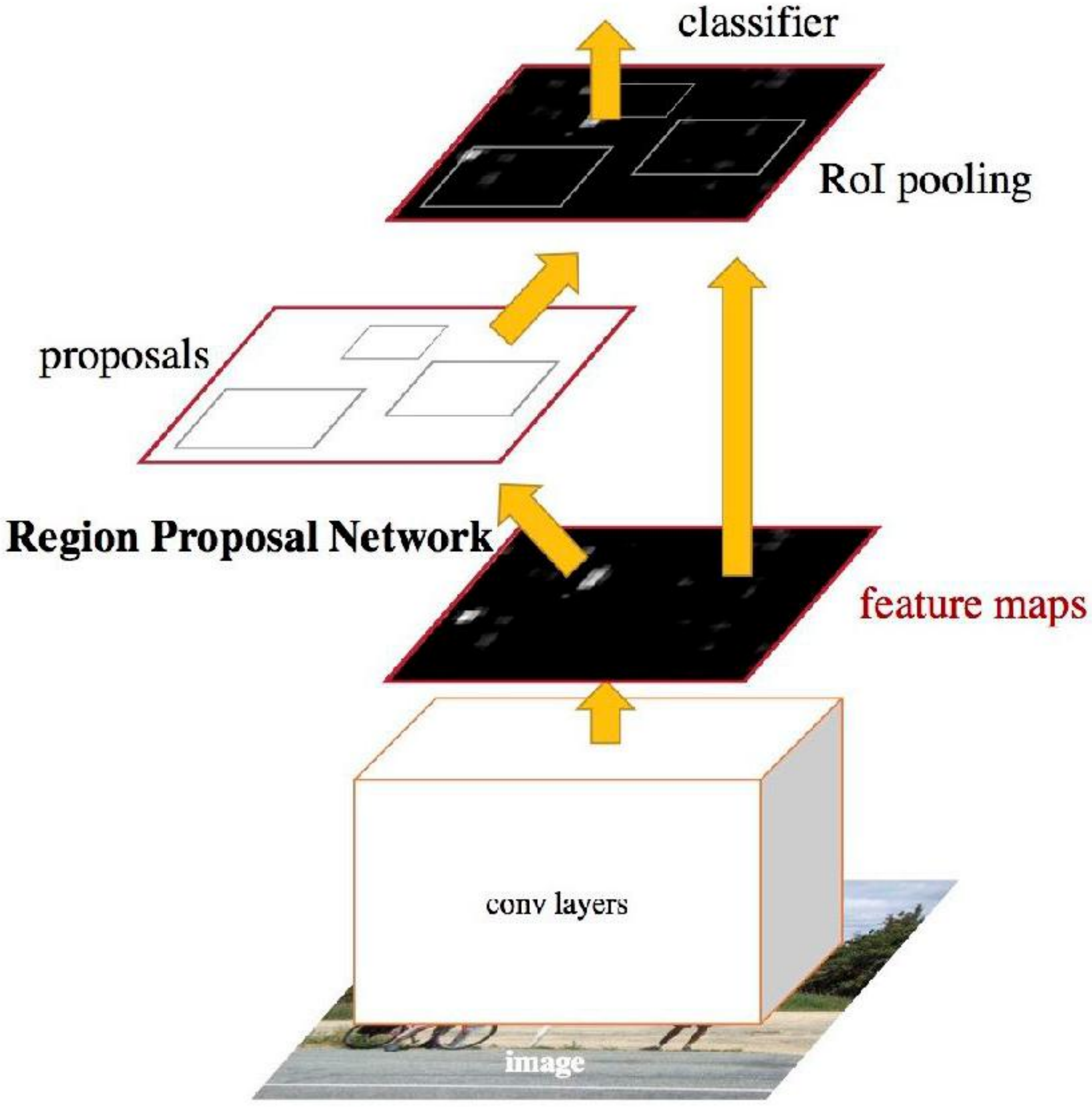
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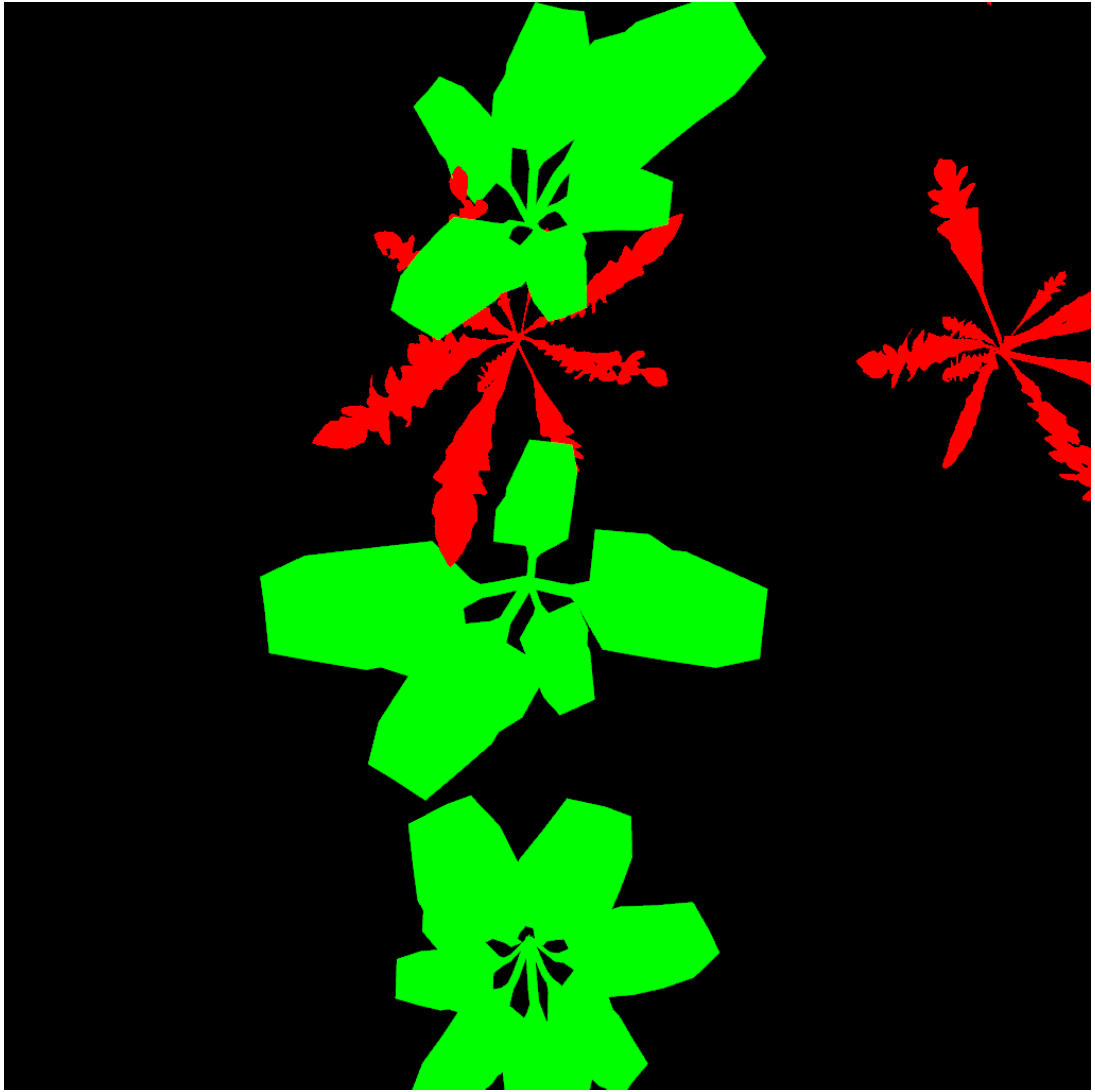

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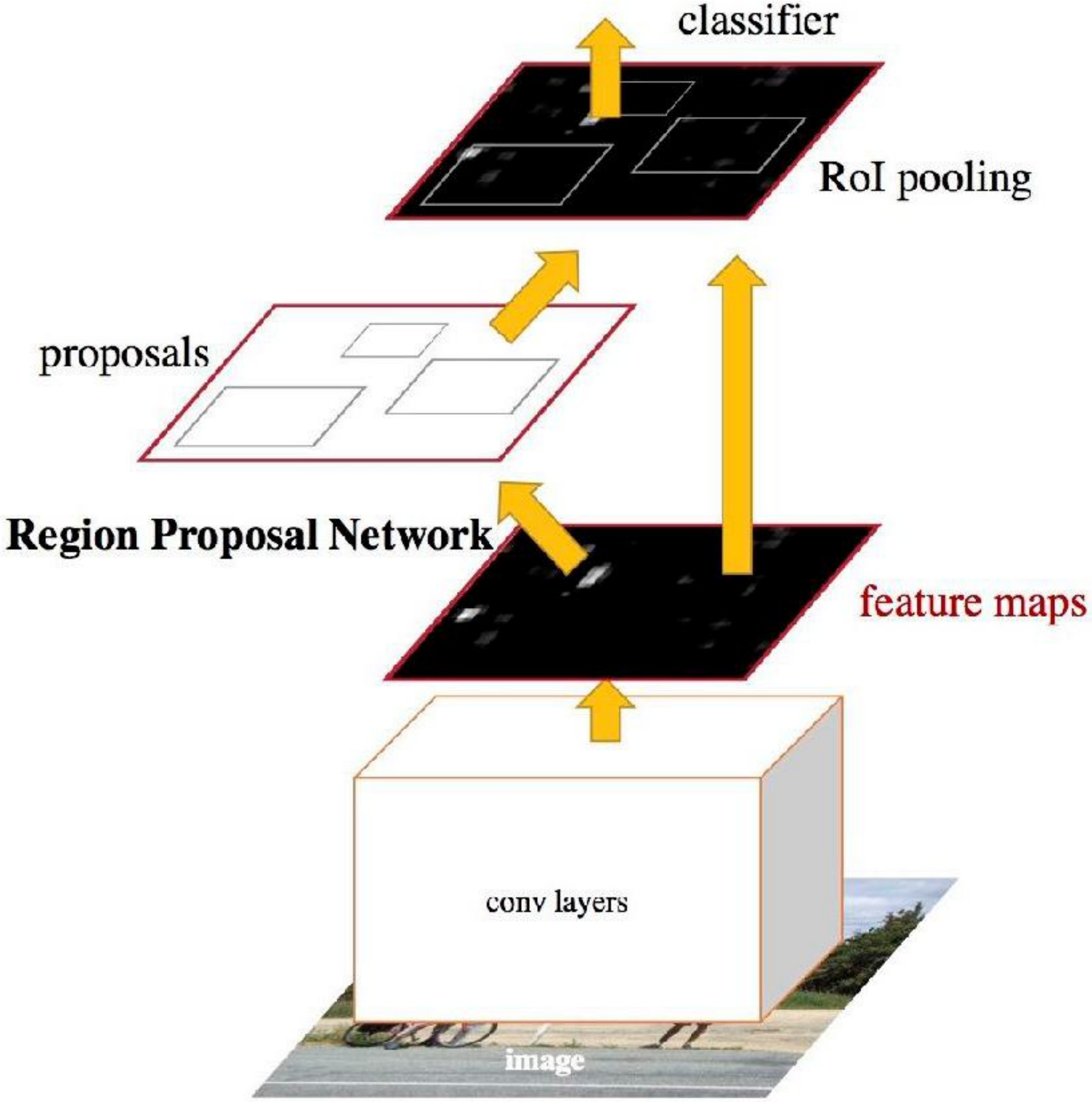
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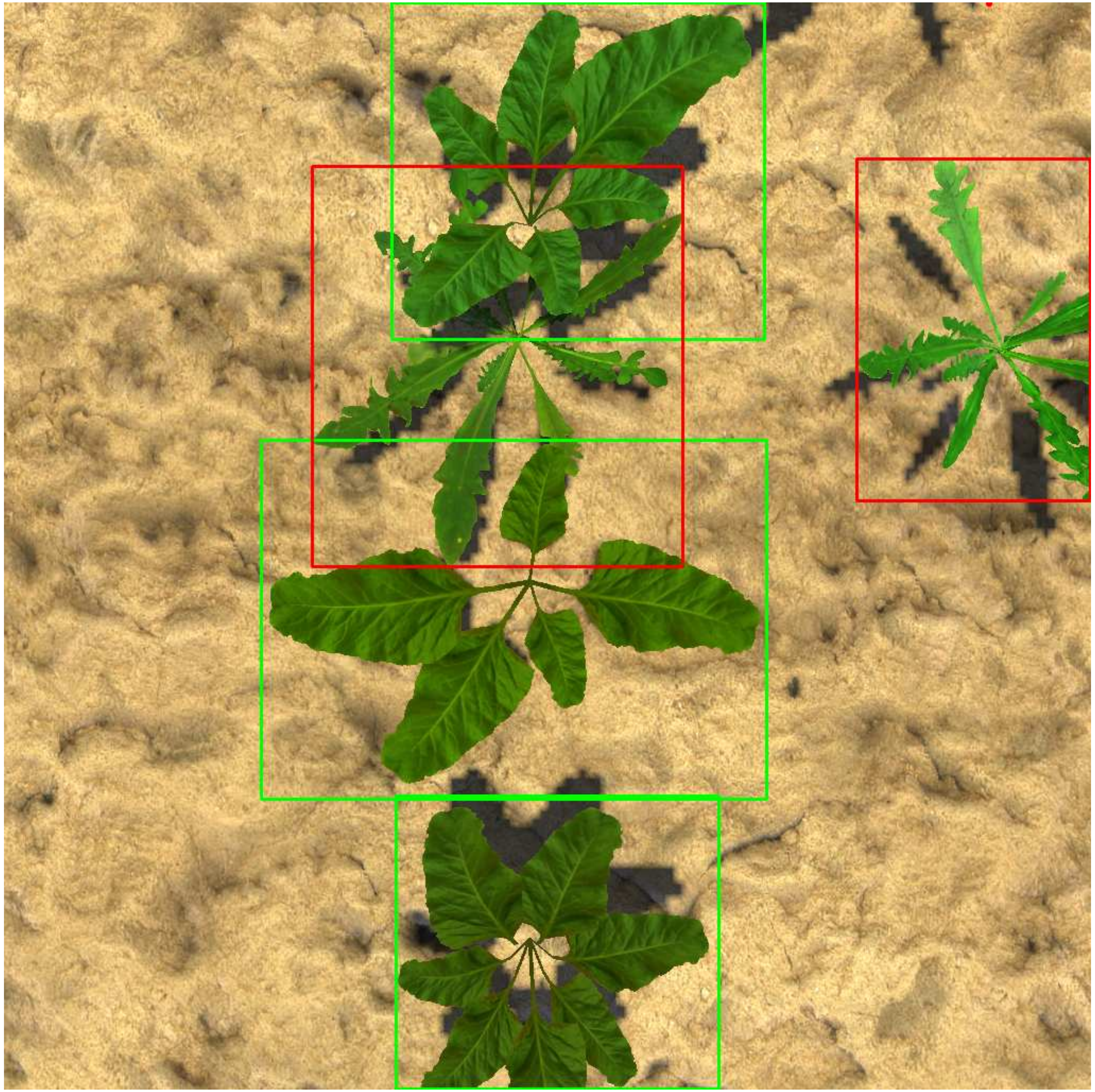
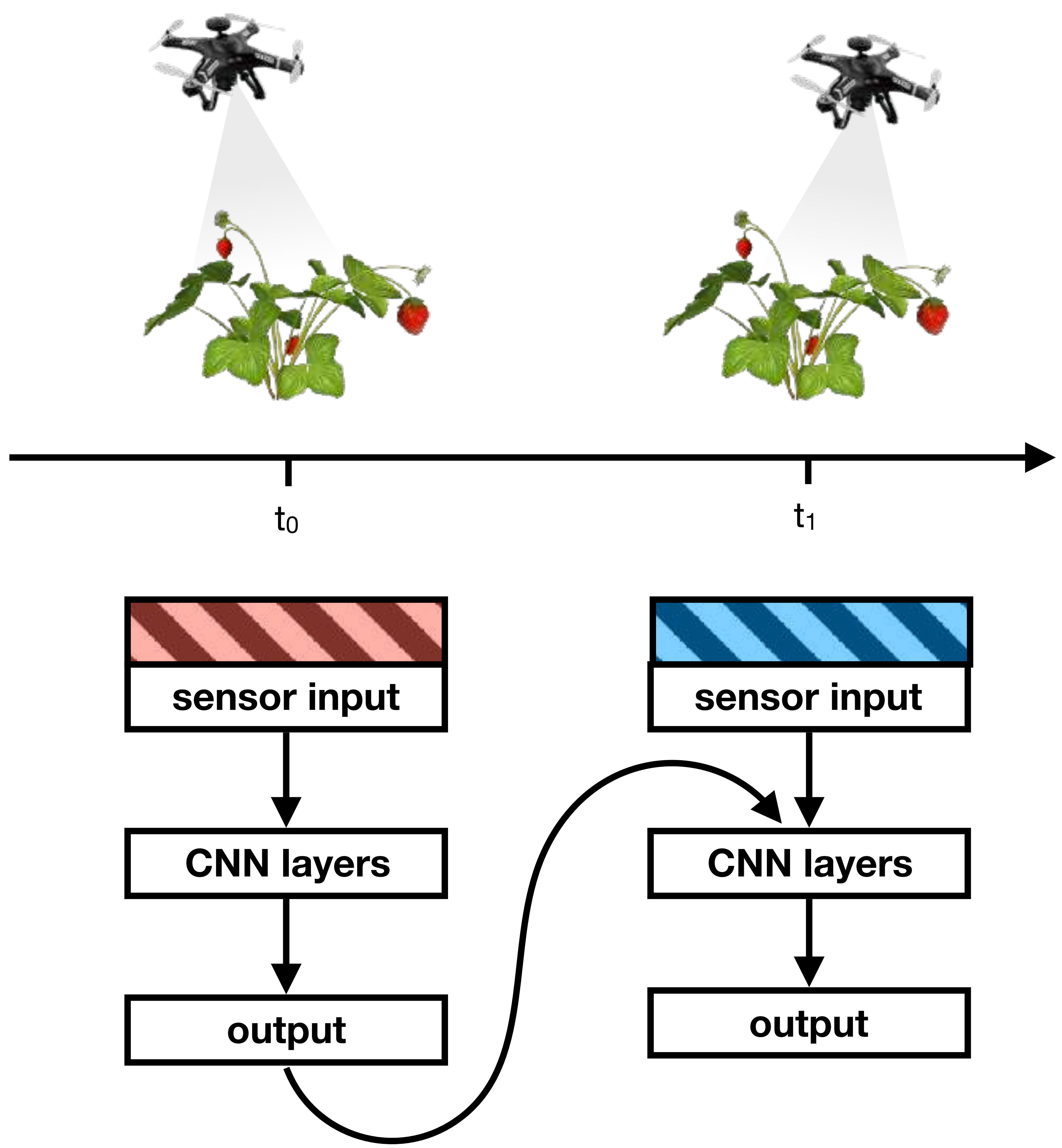


Exploiting Swarms



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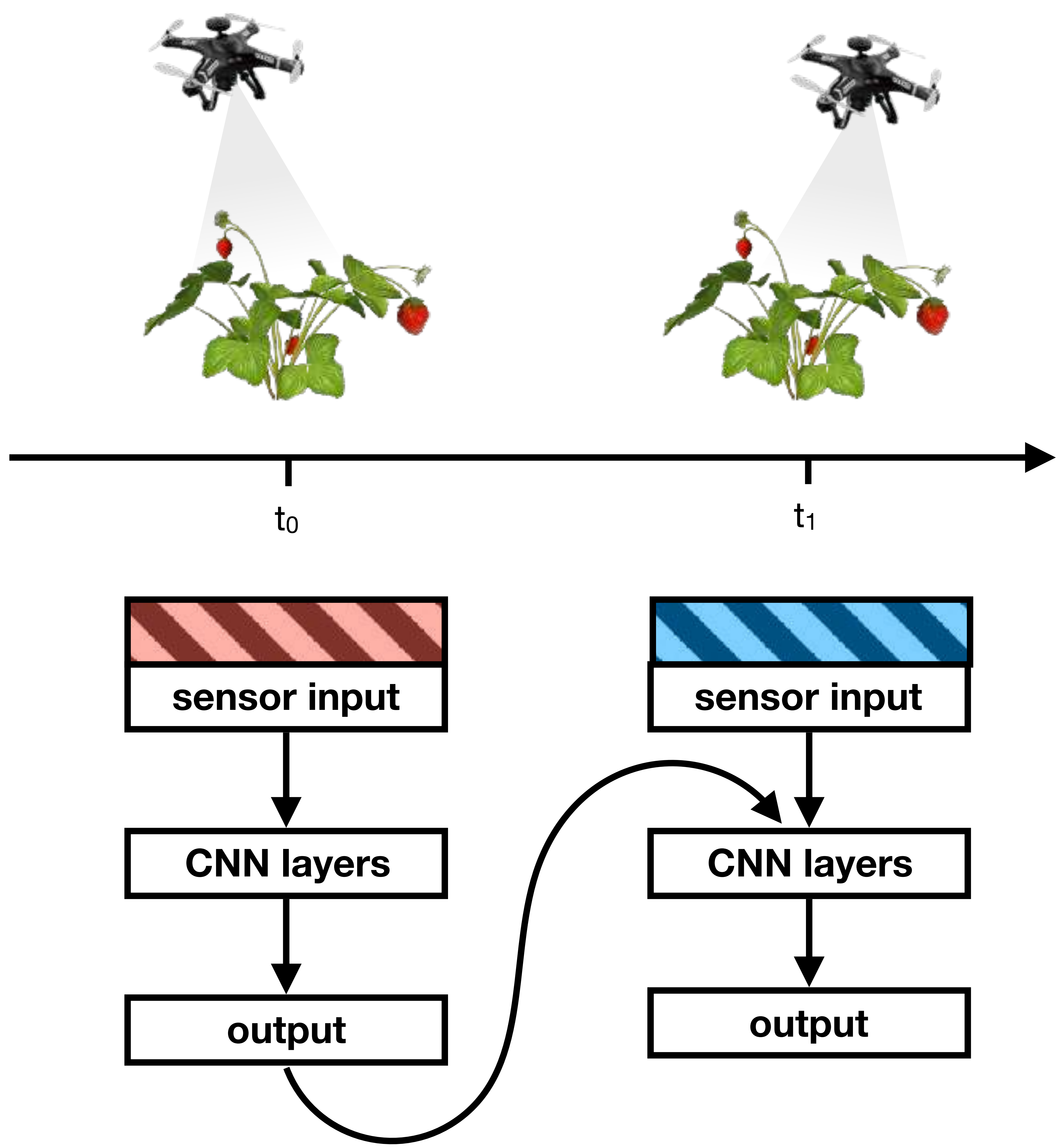

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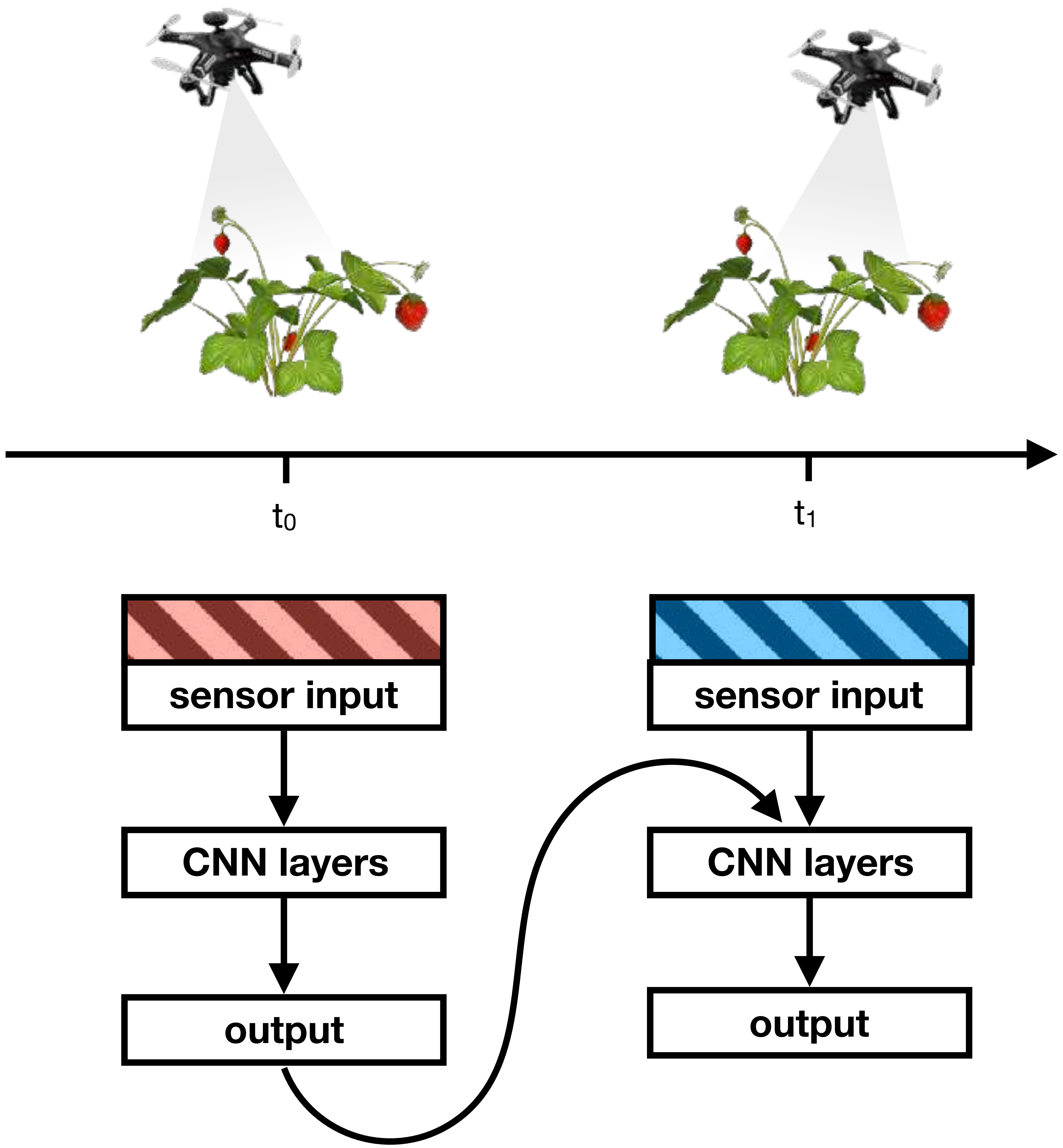

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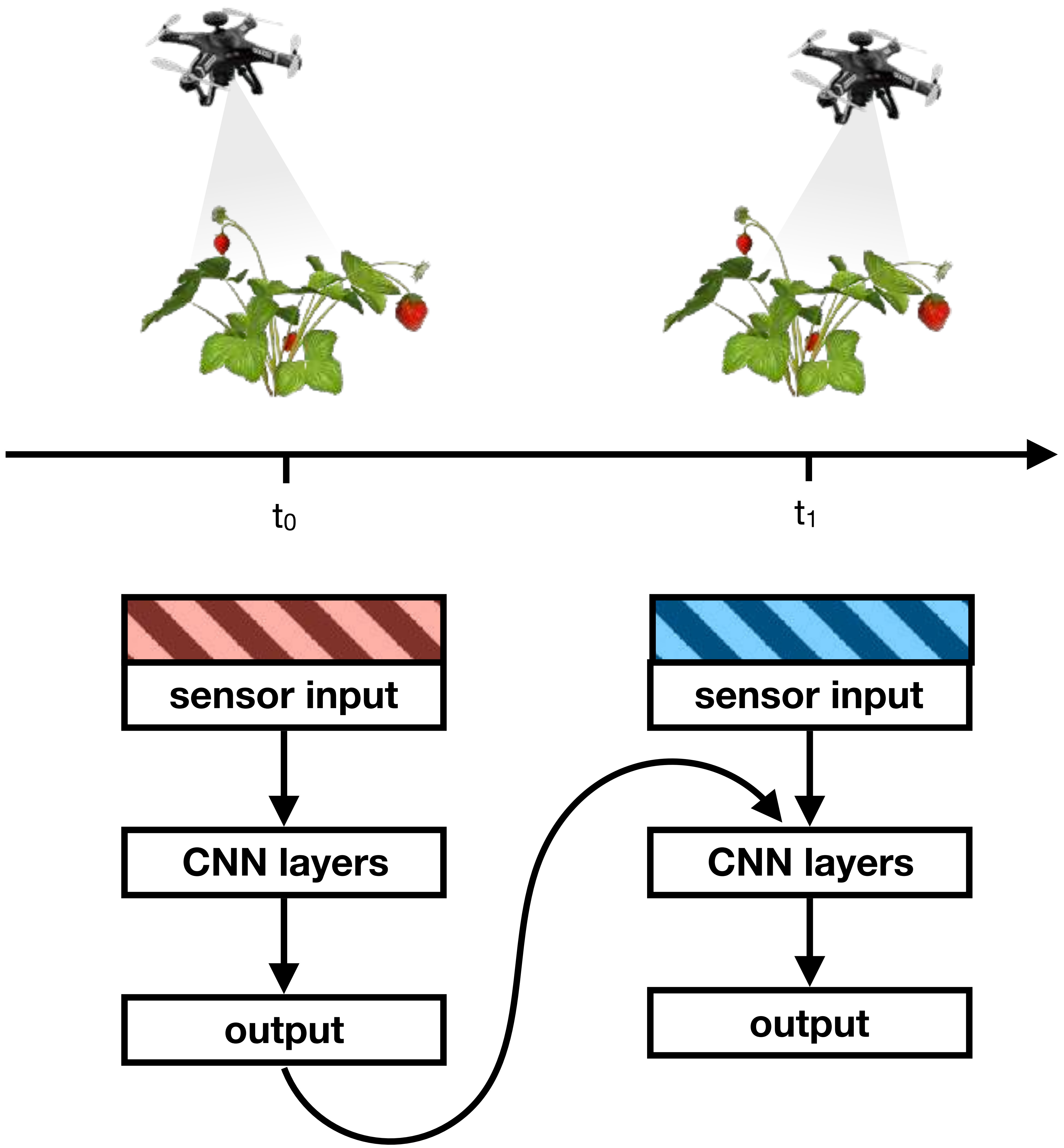

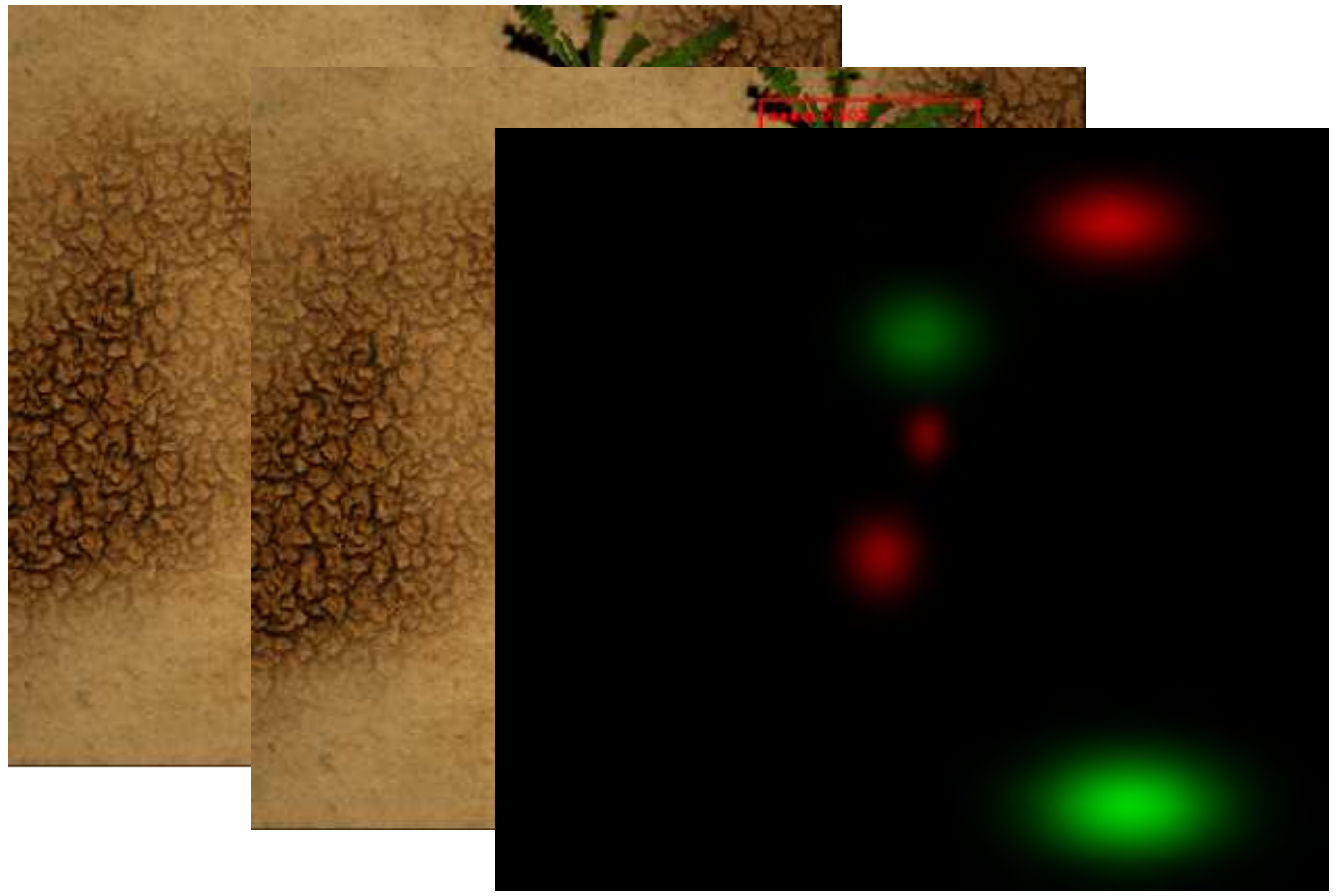

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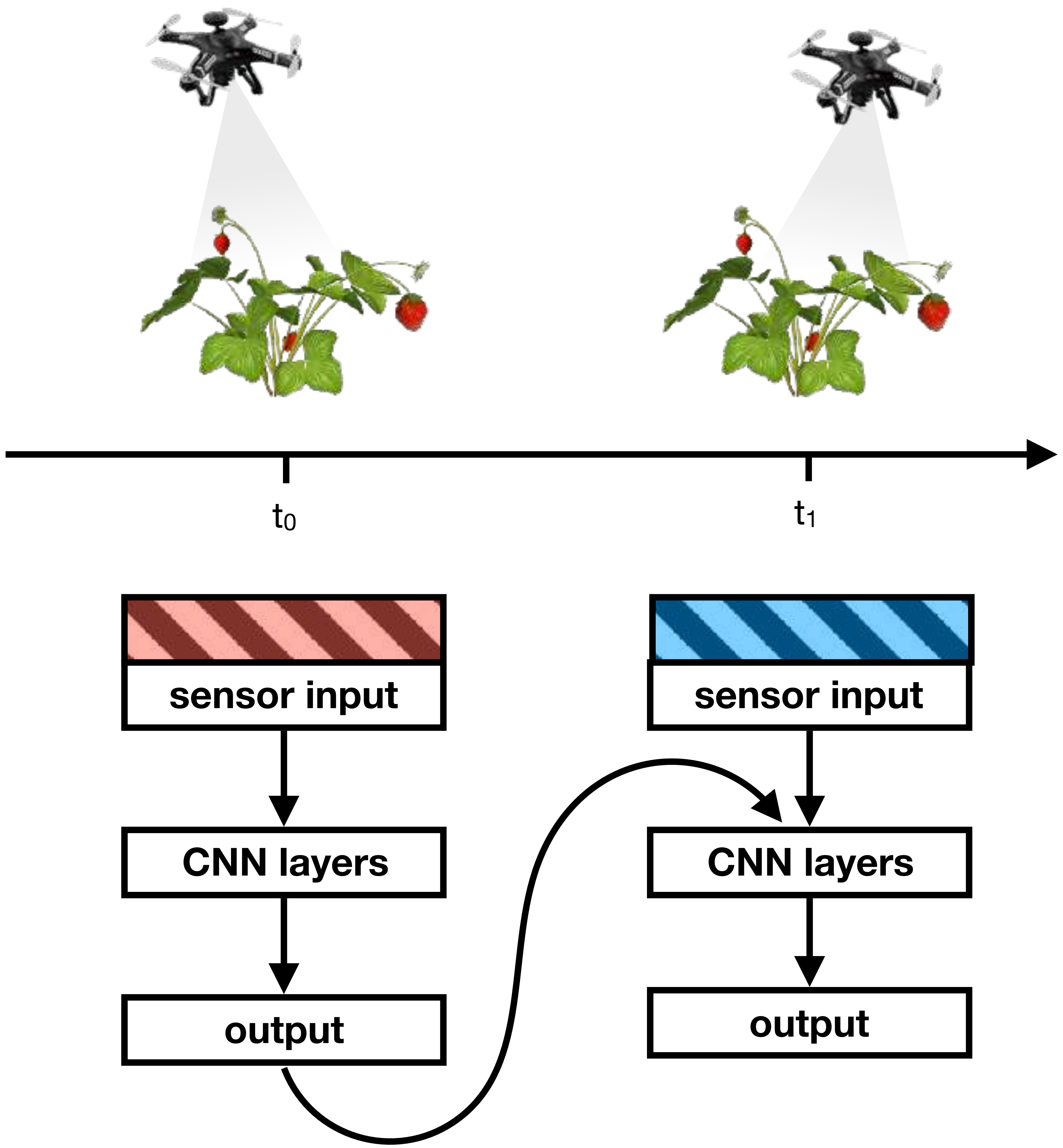

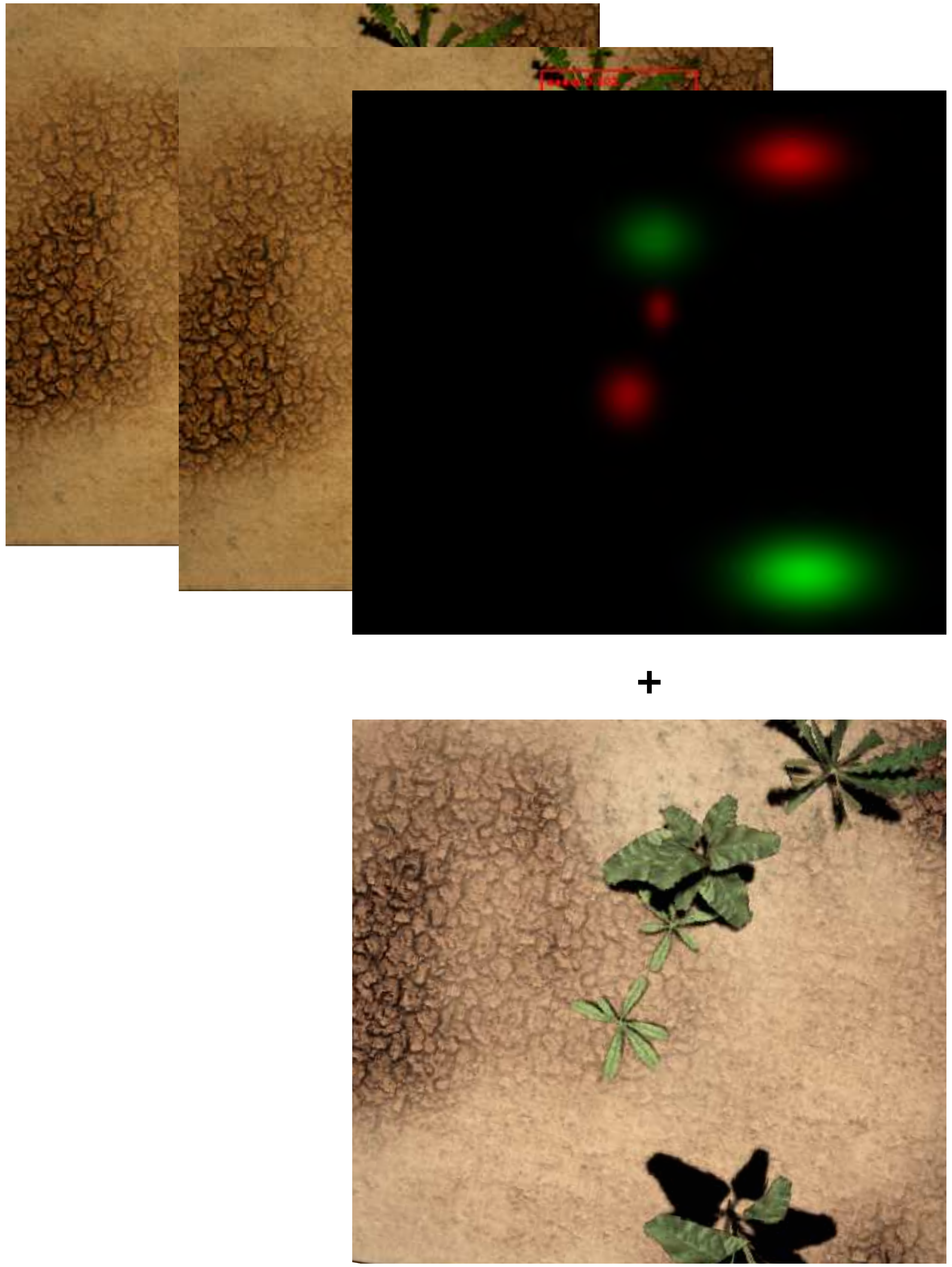

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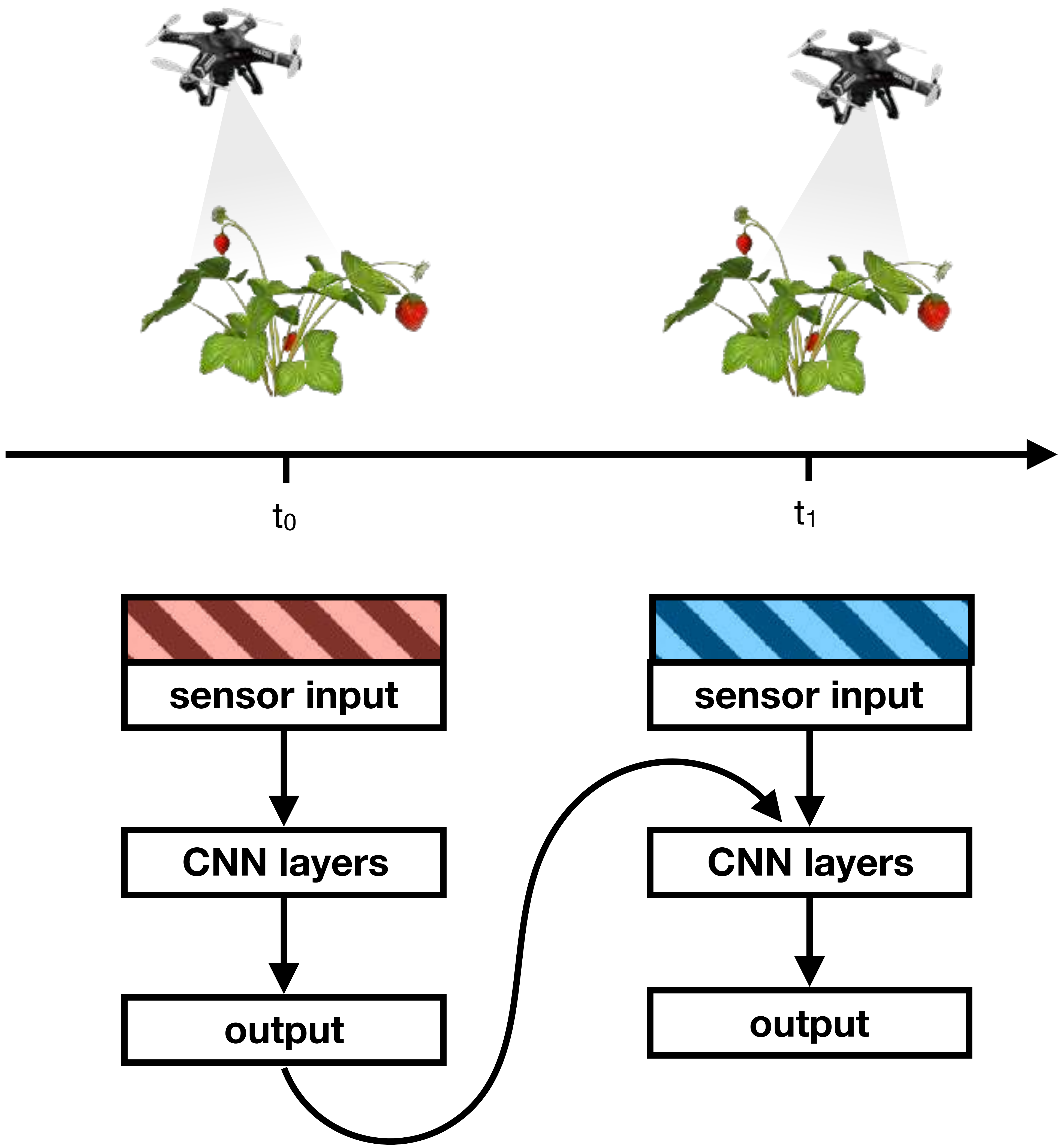
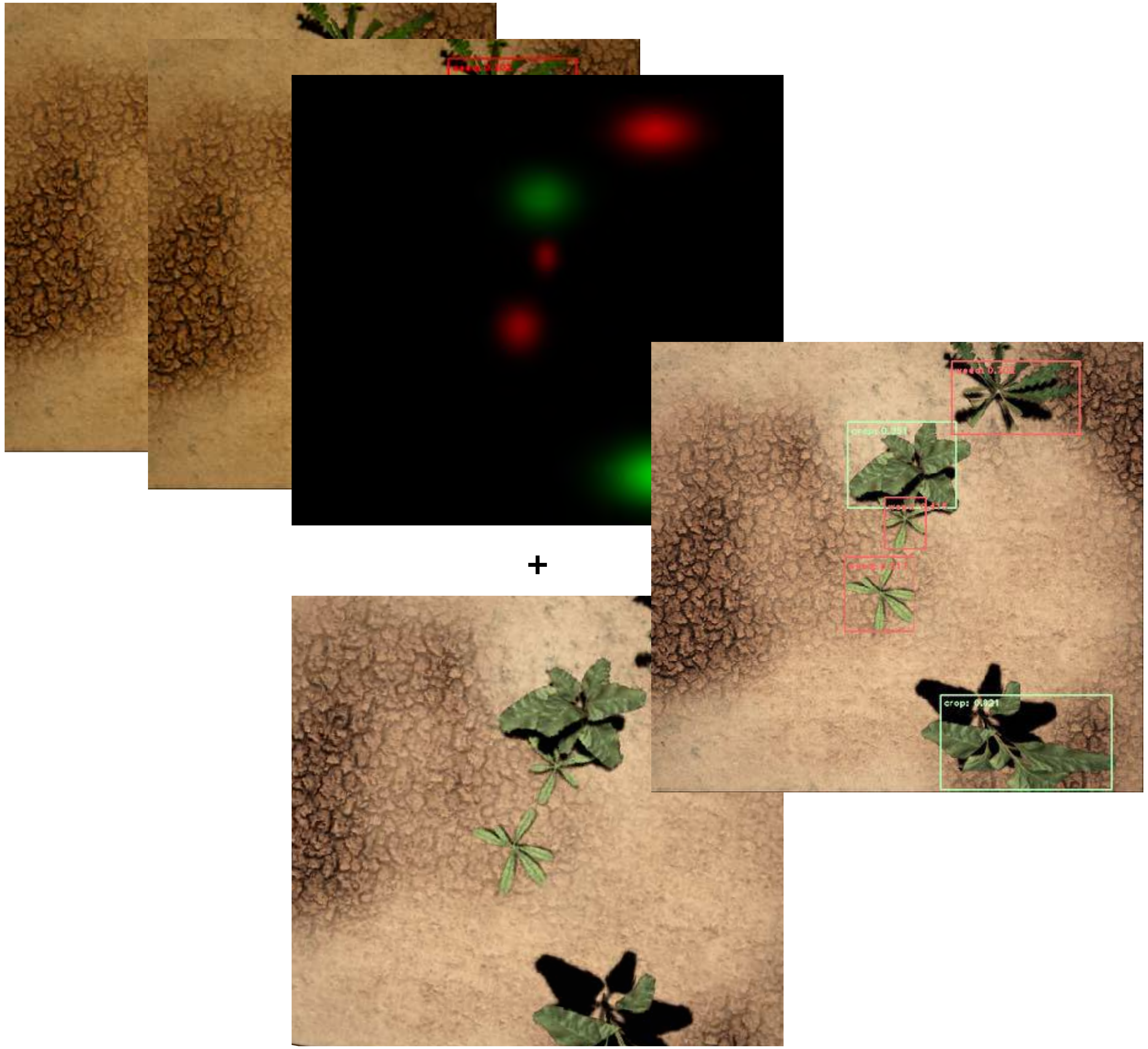




Collaborative Weed Mapping

Collaborative Weed Mapping

- **Full coverage** of a cultivated field to inspect for weeds
- **Collaboratively map** weed presence minimising classification errors

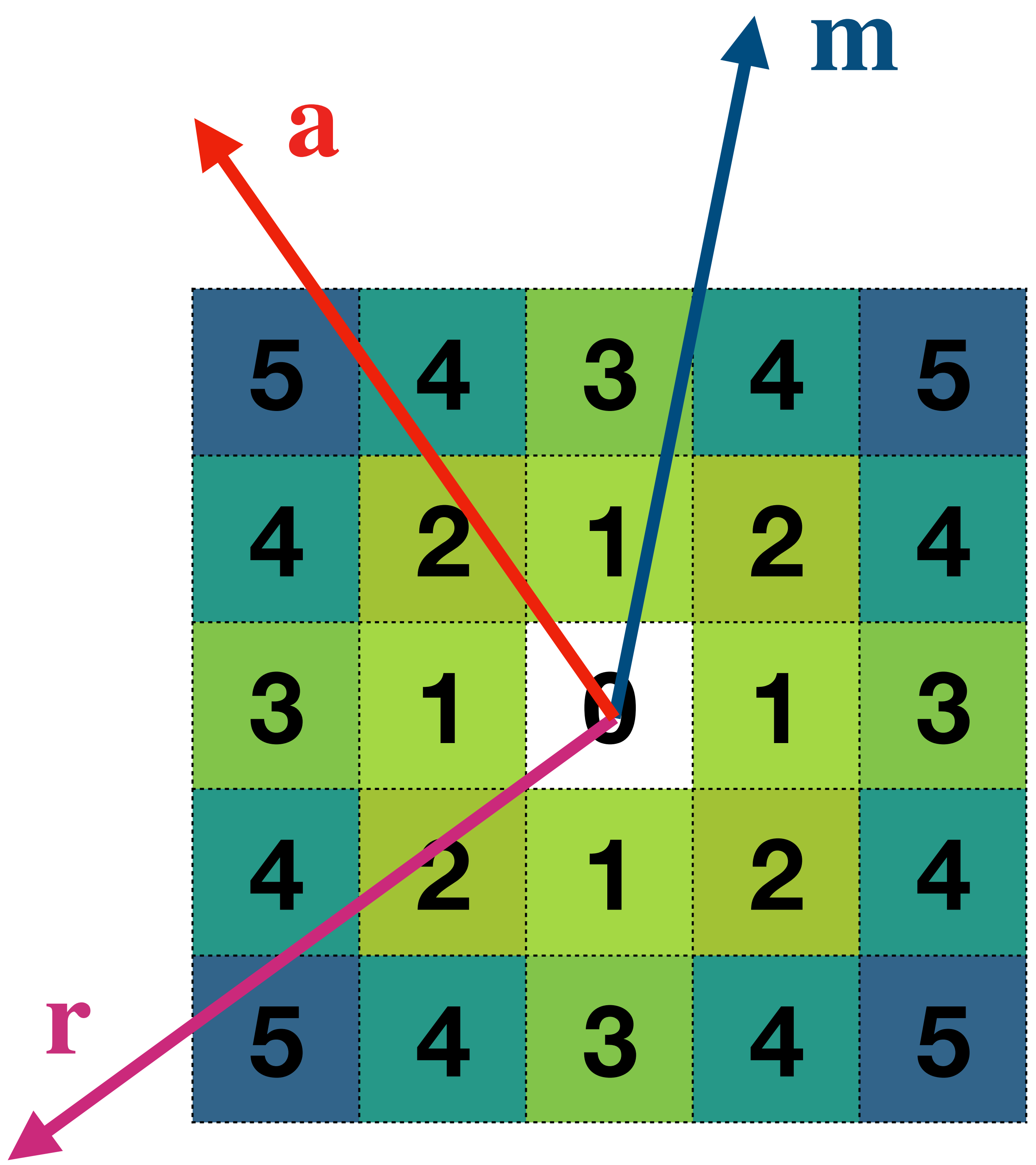
- Deal with UAVs seamlessly entering/leaving an area
- Aim at robustness, efficiency and scalability
- Adapt to environmental heterogeneities
- Avoid collisions with other UAVs

- Proposed solution: **reinforced random walks (RRW)**

Albani, D., Nardi, D., & Trianni, V. (2017). Field Coverage and Weed Mapping by UAV Swarms
Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2017), Vancouver, Canada, Sept. 2017

RRW for coverage and mapping

- Isolated agents perform a correlated random walk
  - Random selection among those cells that are **closer** and **not yet visited**
  - Preferential choice of cells in the motion direction
- Neighbour agents repel each other (gaussian decay with distance, width σ_A)
- Agents are attracted towards areas of interest (gaussian decay with distance, width σ_B)



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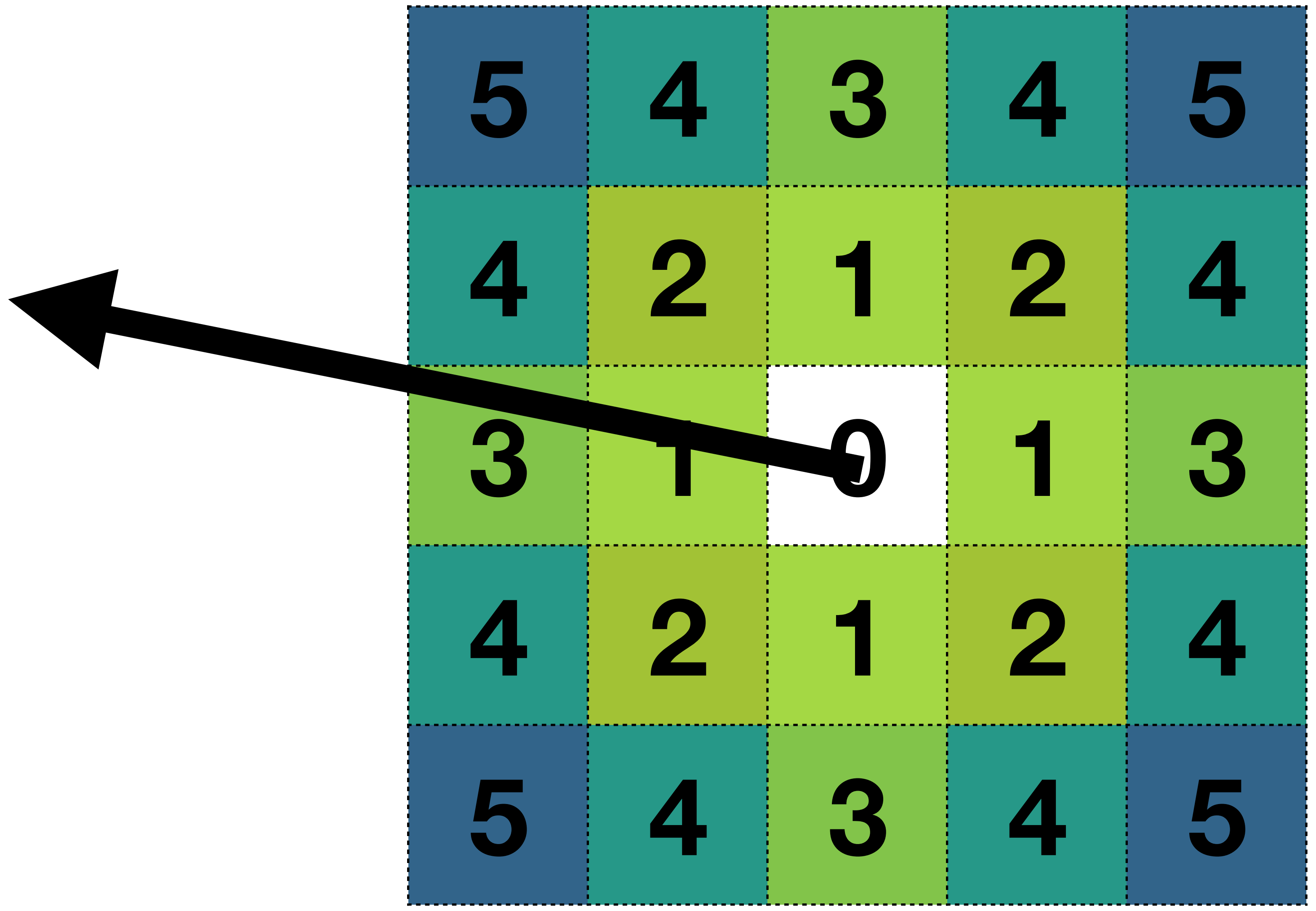
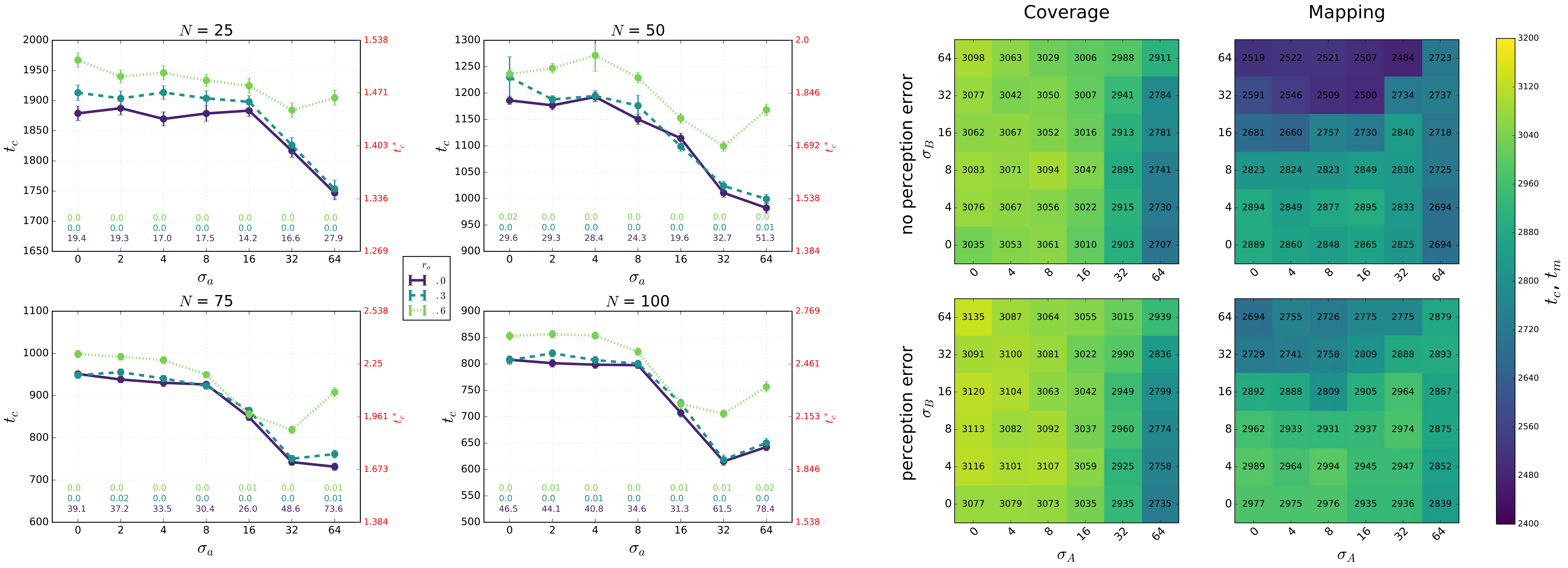
- Agents are attracted towards areas of interest (gaussian decay with distance, width σ_B)
- Resultant vector determining
  - Direction of bias
  - Persistence of the correlated random walk



RRW for field coverage/mapping



Mapping error goes down from 20% to 5%

Decentralised UAV deployment

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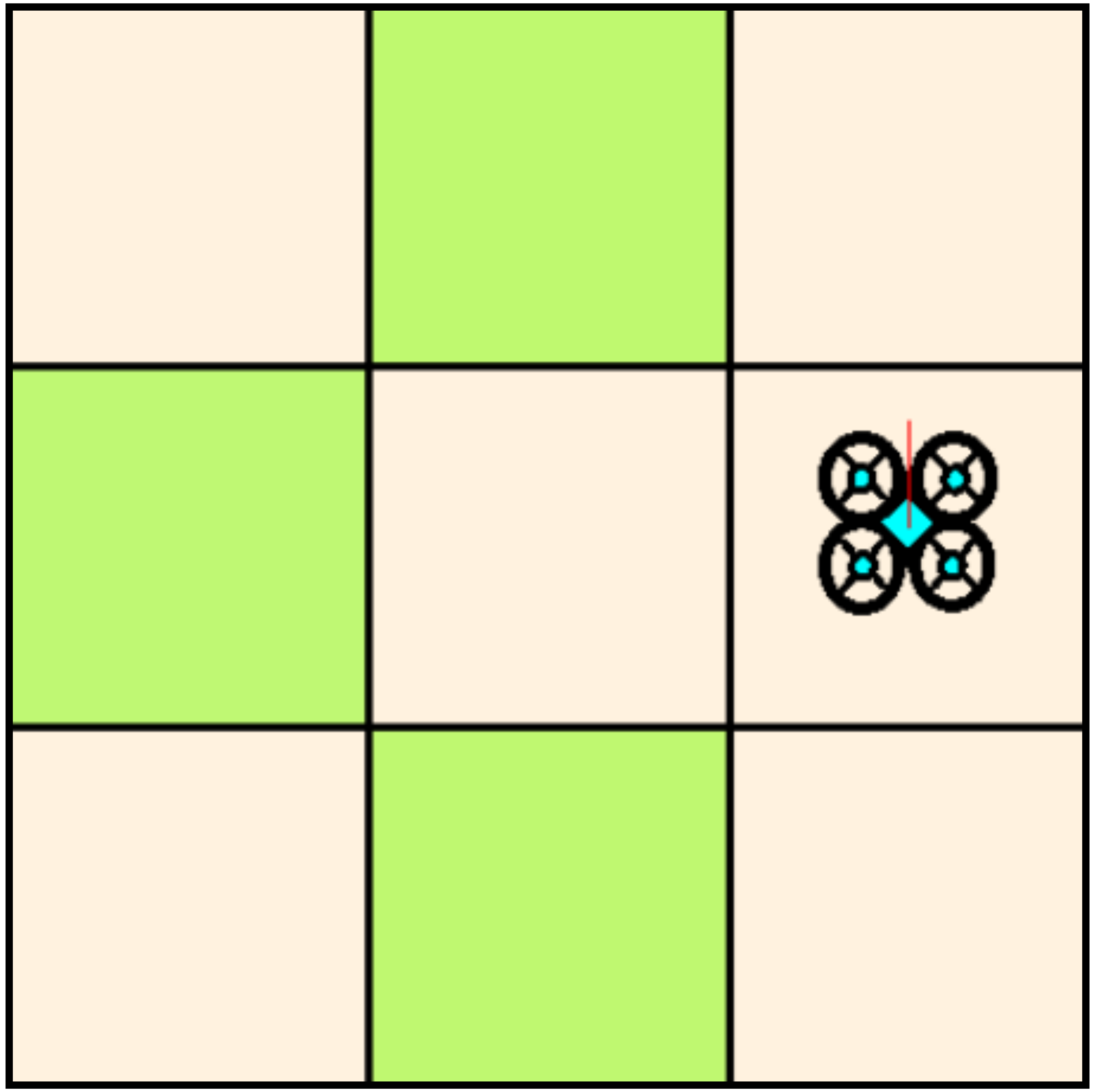
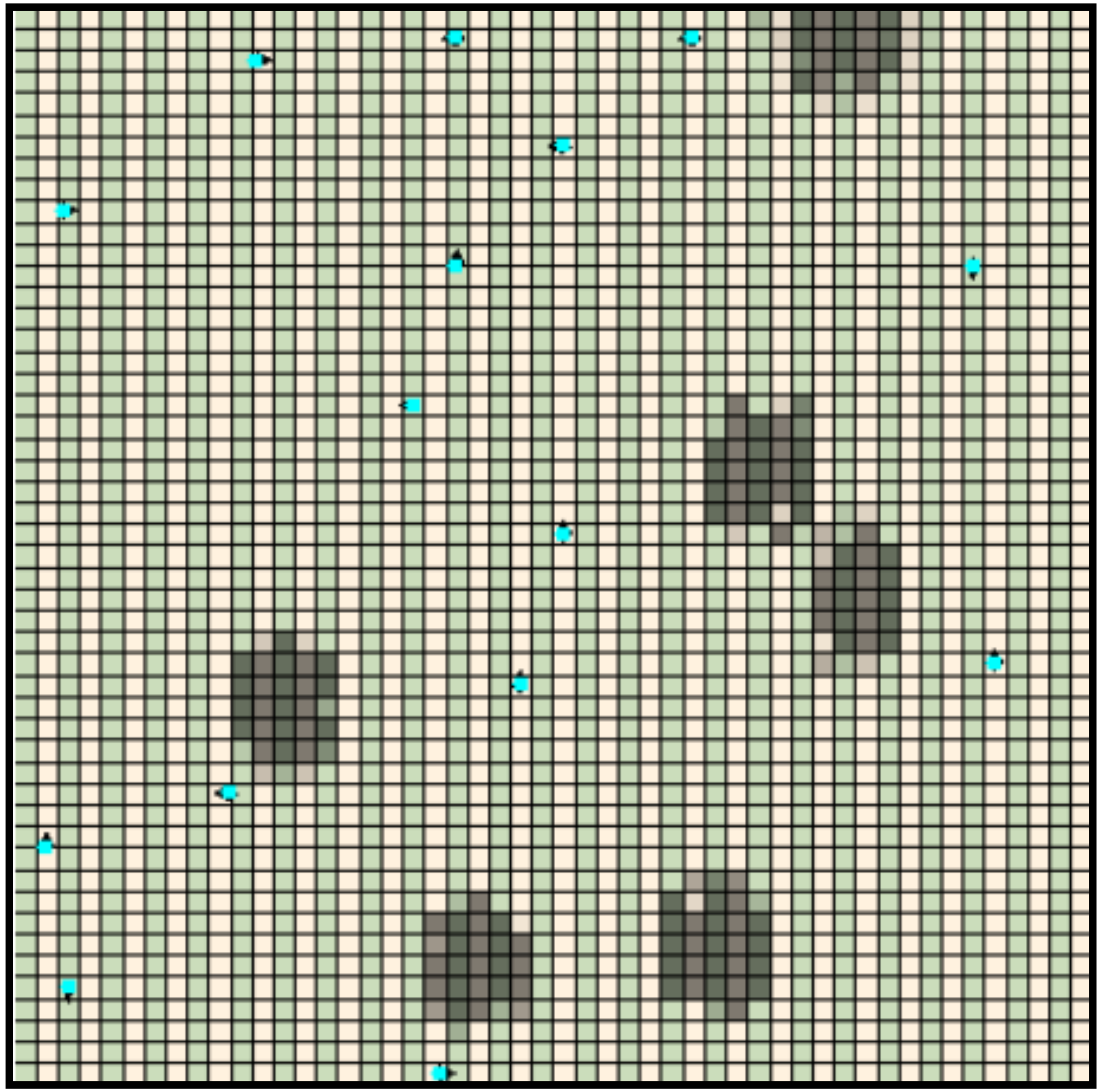
- High-altitude estimation of weed density



Decentralised UAV deployment

- Onboard vision and autonomous control allow for **non-uniform coverage**
- High-altitude estimation of weed density
- Low-altitude collaborative weed mapping



Decentralised UAV deployment

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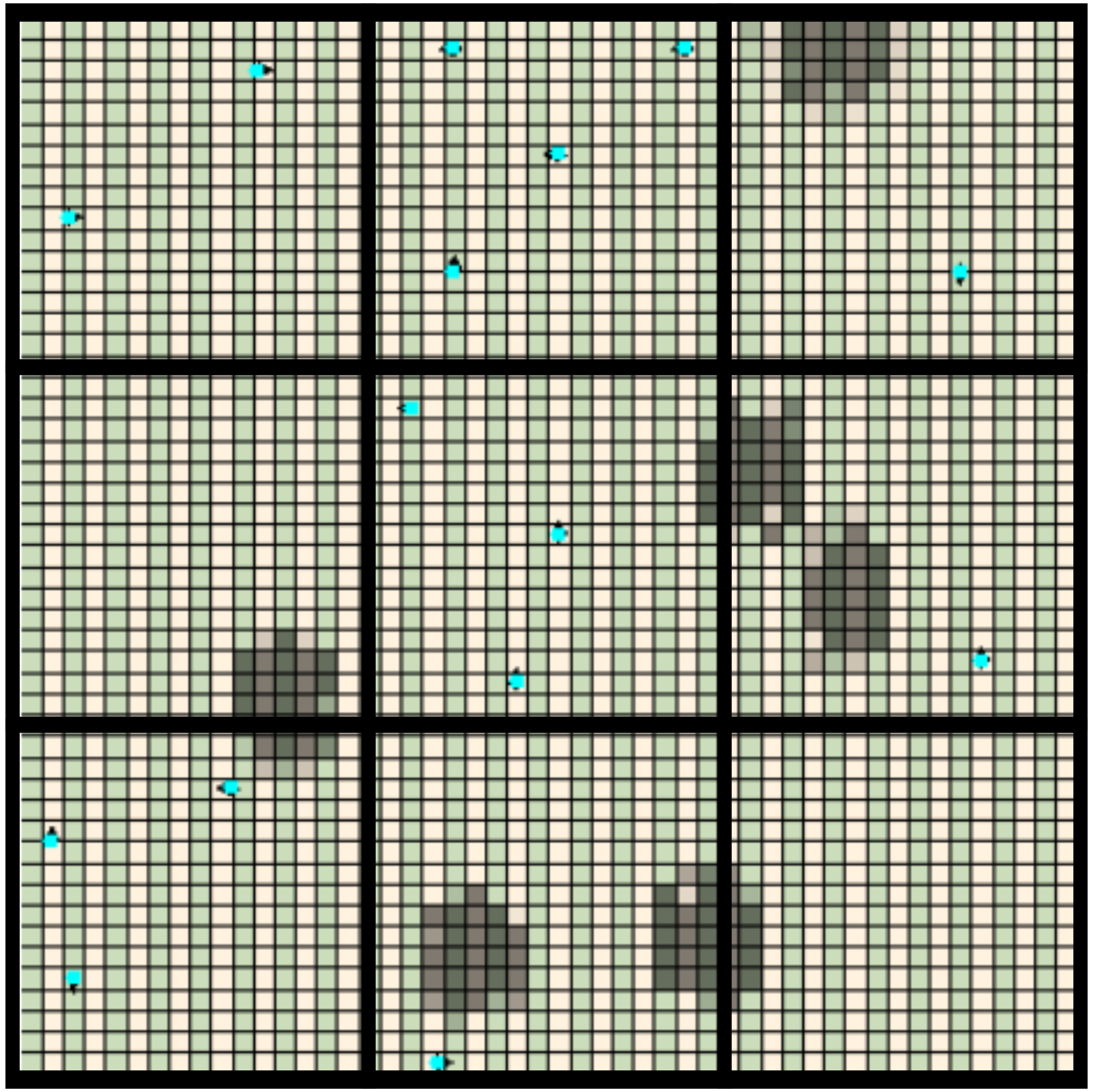
- Attention should be focused only to those areas that contain weed patches



Decentralised UAV deployment

- Onboard vision and autonomous control allow for **non-uniform coverage**
- High-altitude estimation of weed density
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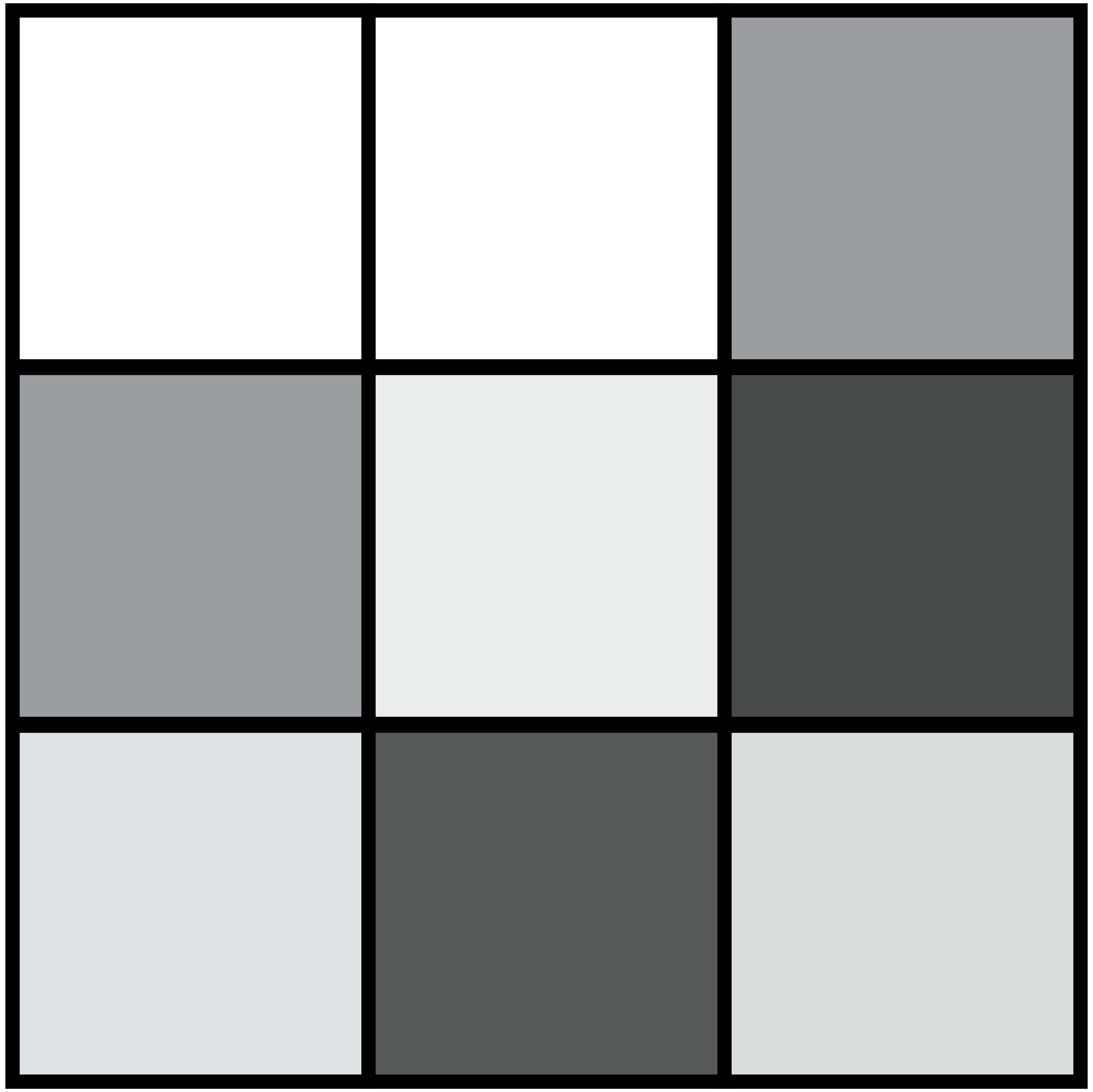
- Attention should be focused only to those areas that contain weed patches
- The problem translates to utility-dependent UAV deployment



Decentralised UAV Deployment

Collective decision	vs	Task allocation
• There are less UAVs than the optimal number for a single area		• UAVs are in excess with respect to the optimal number
• Collaboration improves mapping efficiency		• Area utilities do not vary considerably

Identify a deployment strategy that can be easily tuned

Determine optimal number of UAVs given the mapping dynamics

Modelling Utility Dynamics

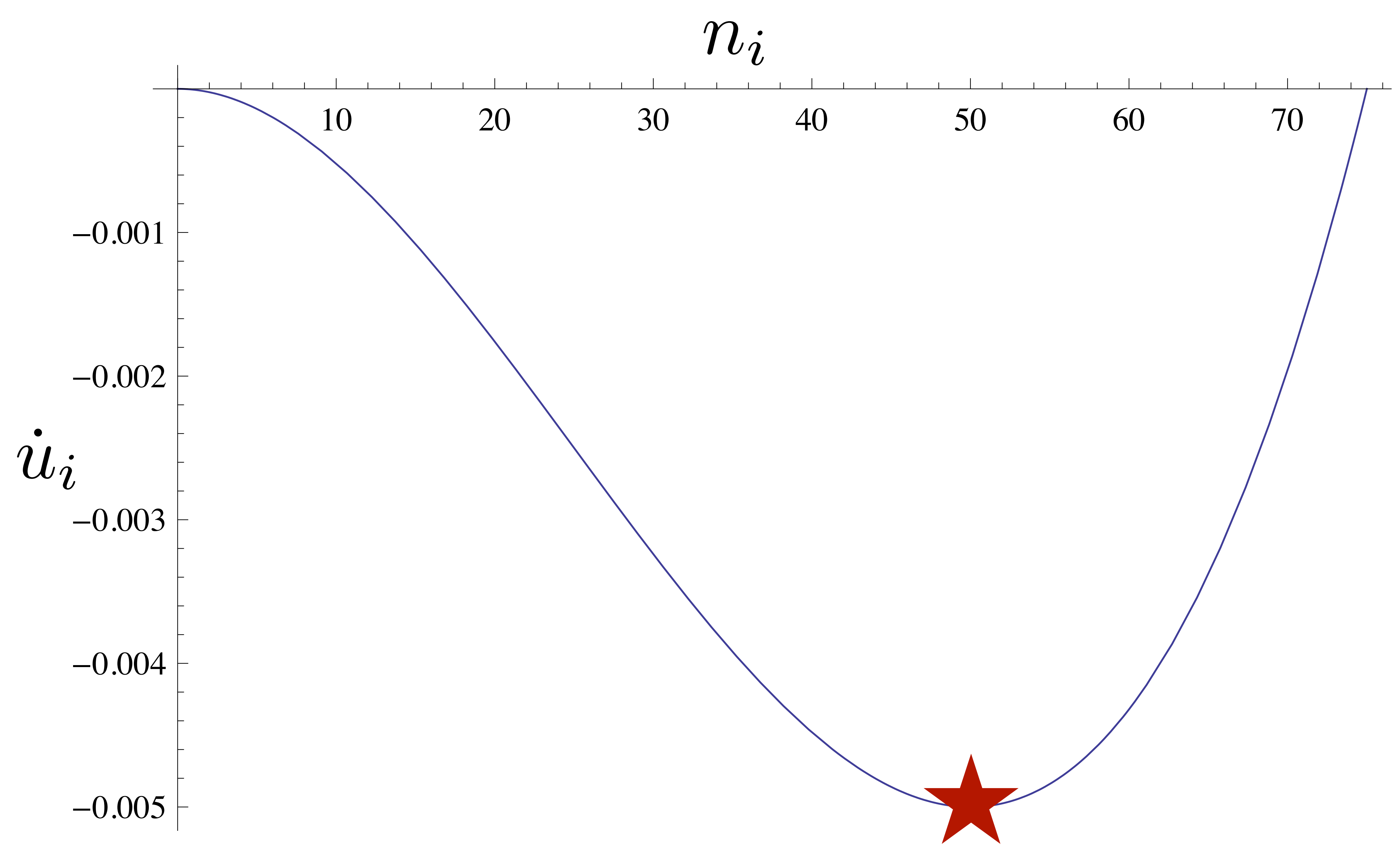
collaborative effort

utility variation

$$\dot{u}_i = -u_i n_i(\delta n_i - \xi n_i^2), \quad u_i \in [0,1], n_i \in \left[0, \frac{\delta}{\xi}\right]$$

exponential decay

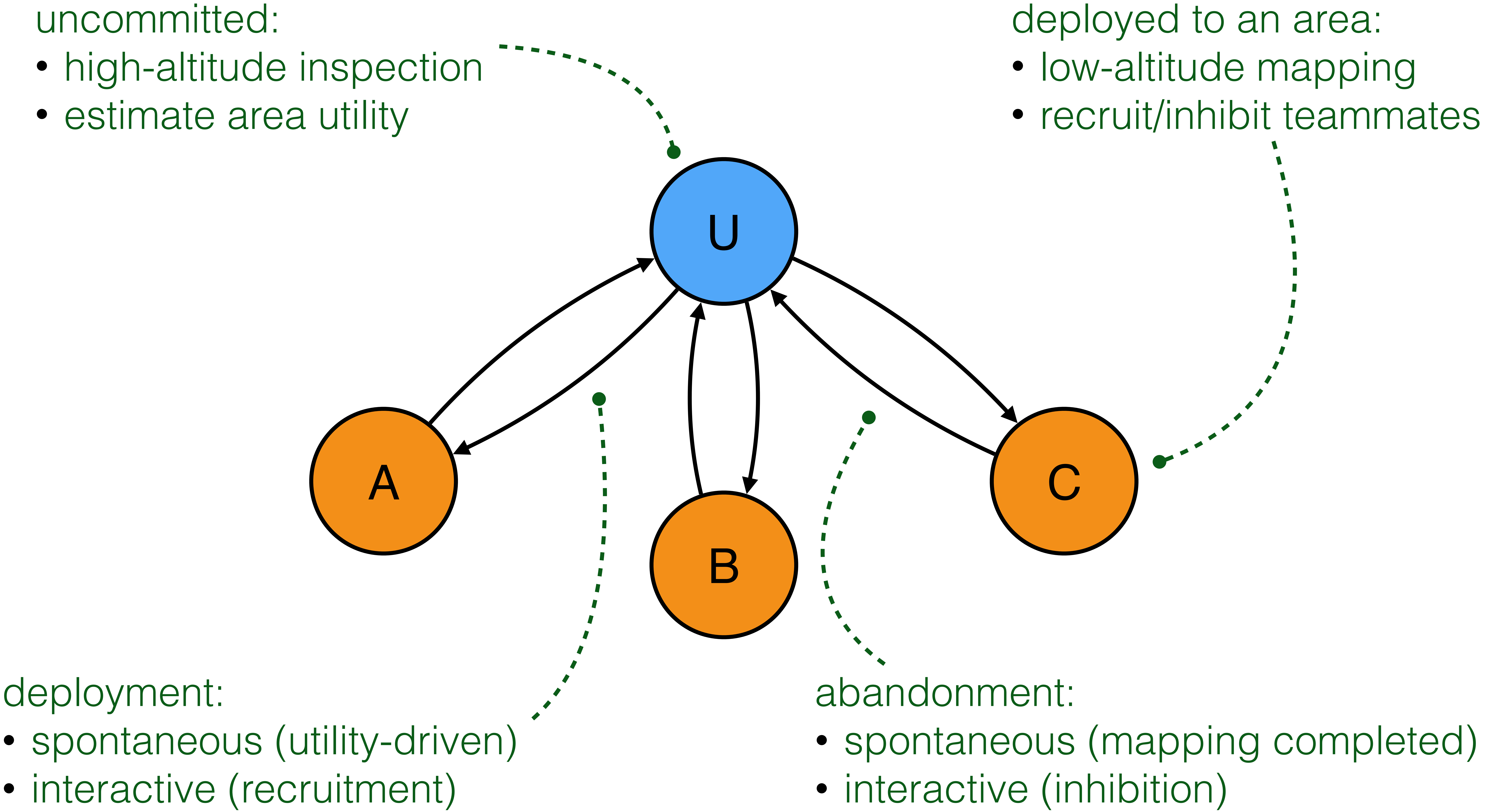
interference among UAVs



best efficiency: $n^\star = \frac{2\delta}{3\xi}$ $\quad \delta = 3\text{E–}6, \xi = 4\text{E–}8 \quad \rightarrow \quad n^\star = 50$

UAV Deployment Strategy

- UAVs **explore** and **estimate the utility of areas** during high-altitude/low-resolution inspection
- UAVs prioritise low-altitude/high-resolution inspection for **high-utility areas**
- UAVs form a **wireless communication network** and **recruit** other UAVs to areas of high utility
- UAVs are inhibited from monitoring a certain area when
    - other areas of high utility need attention (**cross-inhibition** among UAVs deployed to different areas)
    - there are too many teammates (**self-inhibition** among UAVs deployed to the same area)


uncommitted:
• high-altitude inspection
• estimate area utility
deployed to an area:
• low-altitude mapping
• recruit/inhibit teammates
U
A
B
C
deployment:
• spontaneous (utility-driven)
• interactive (recruitment)
abandonment:
• spontaneous (mapping completed)
• interactive (inhibition)

Decentralised Deployment Model

variation of agents deployed to area i

spontaneous abandonment

inhibition

$$\dot{x}_i = \gamma_i x_u - \alpha_i x_i + \rho_i x_u x_i - \sum_{j=1}^{M} x_j \beta_{ji} x_i, \qquad x_u = 1 - \sum_{i=1}^{M} x_i$$

spontaneous deployment

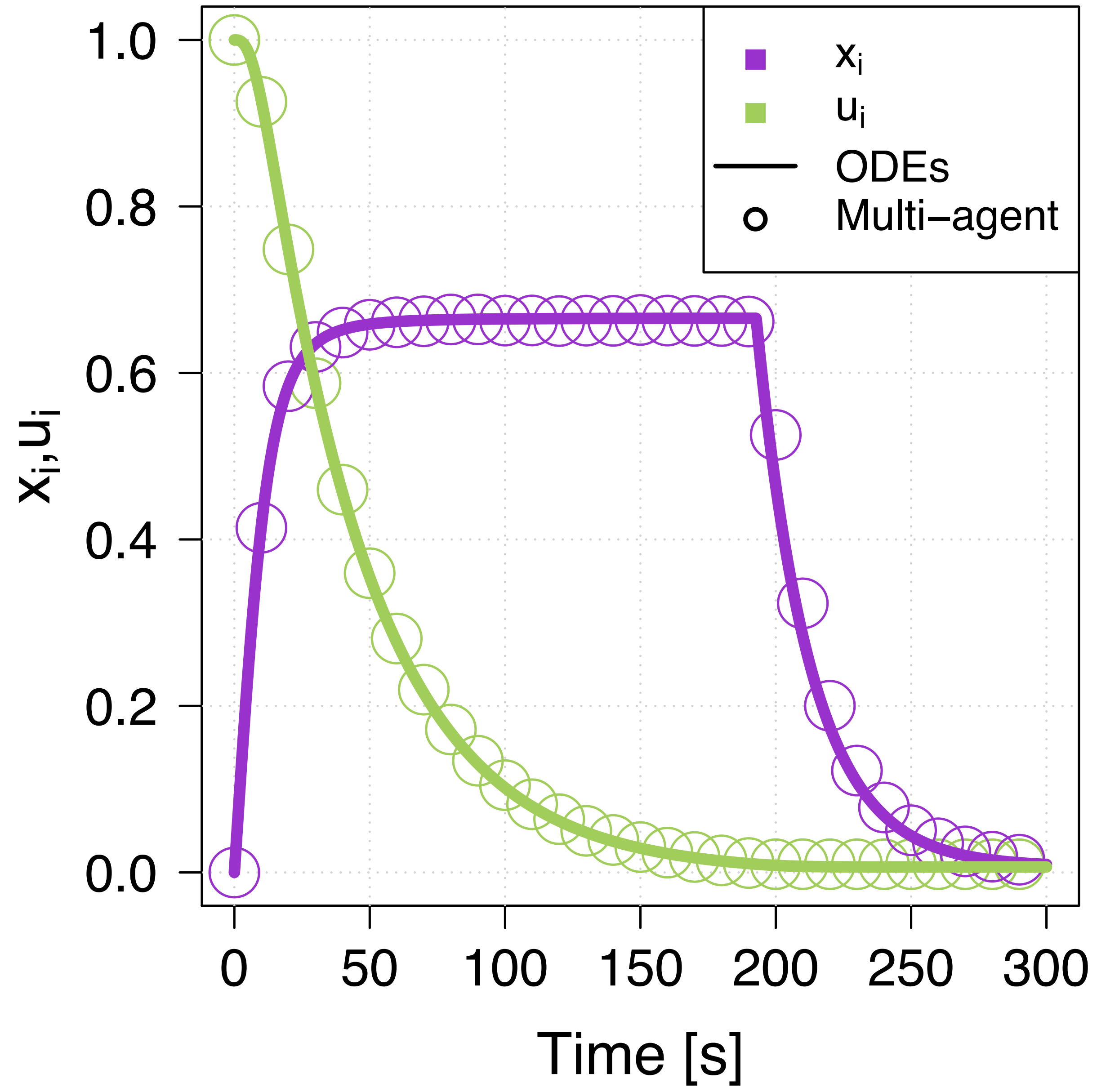
recruitment

Parameterisation choice

$$\gamma_i \propto k u_i \qquad \rho_i \propto h u_i$$

$$\alpha_i = 0 \text{ unless } u_i \approx 0 \qquad \beta_{ij, i \neq j} \propto h u_i$$

$$\beta_{ii} = f(\gamma_i, \rho_i)$$



Reina, A., Marshall, J. A. R., Trianni, V., & Bose, T. (2017). Model of the best-of-N nest-site selection process in honeybees. Physical Review E, 95(5), 052411–15.

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We study the **ratio** $r{=}h/k$ between interactive and spontaneous transitions

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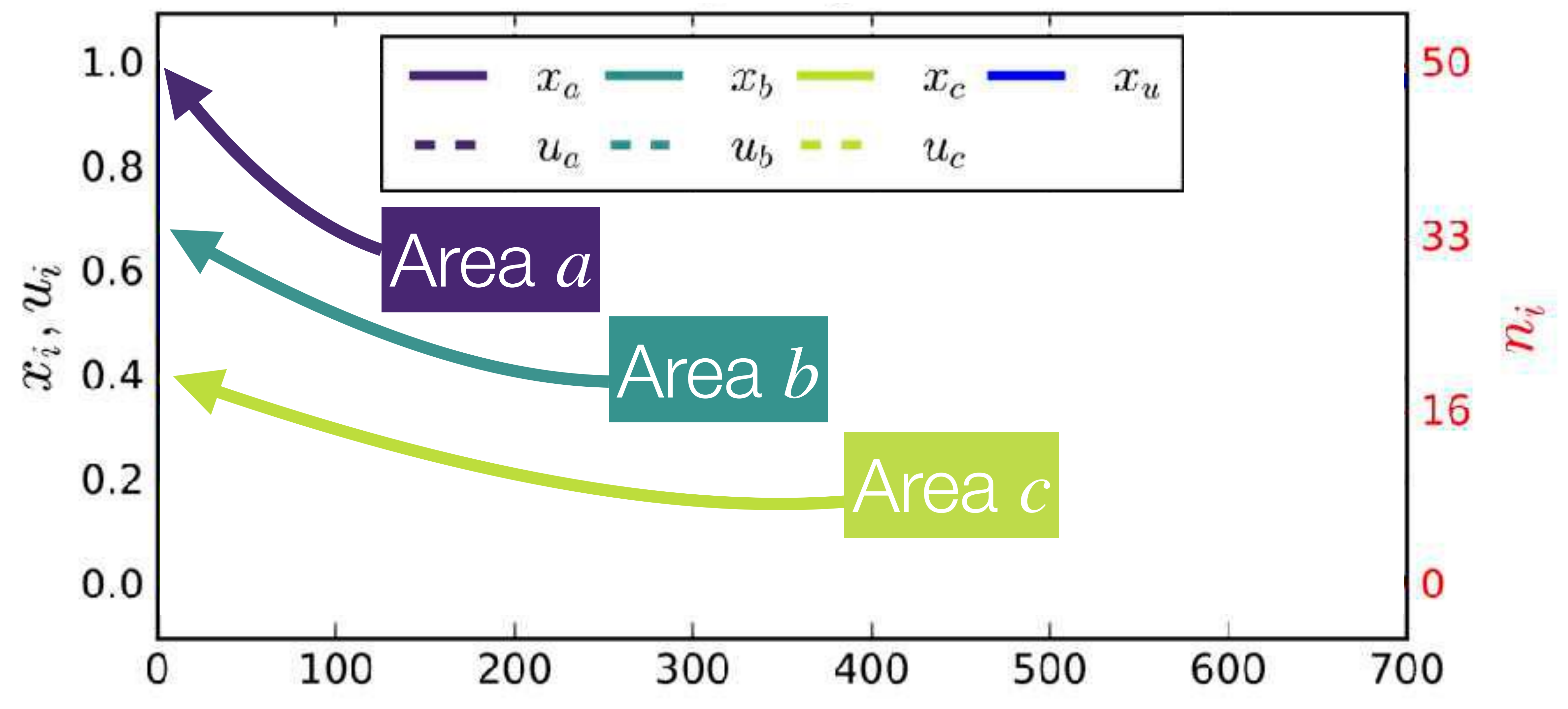
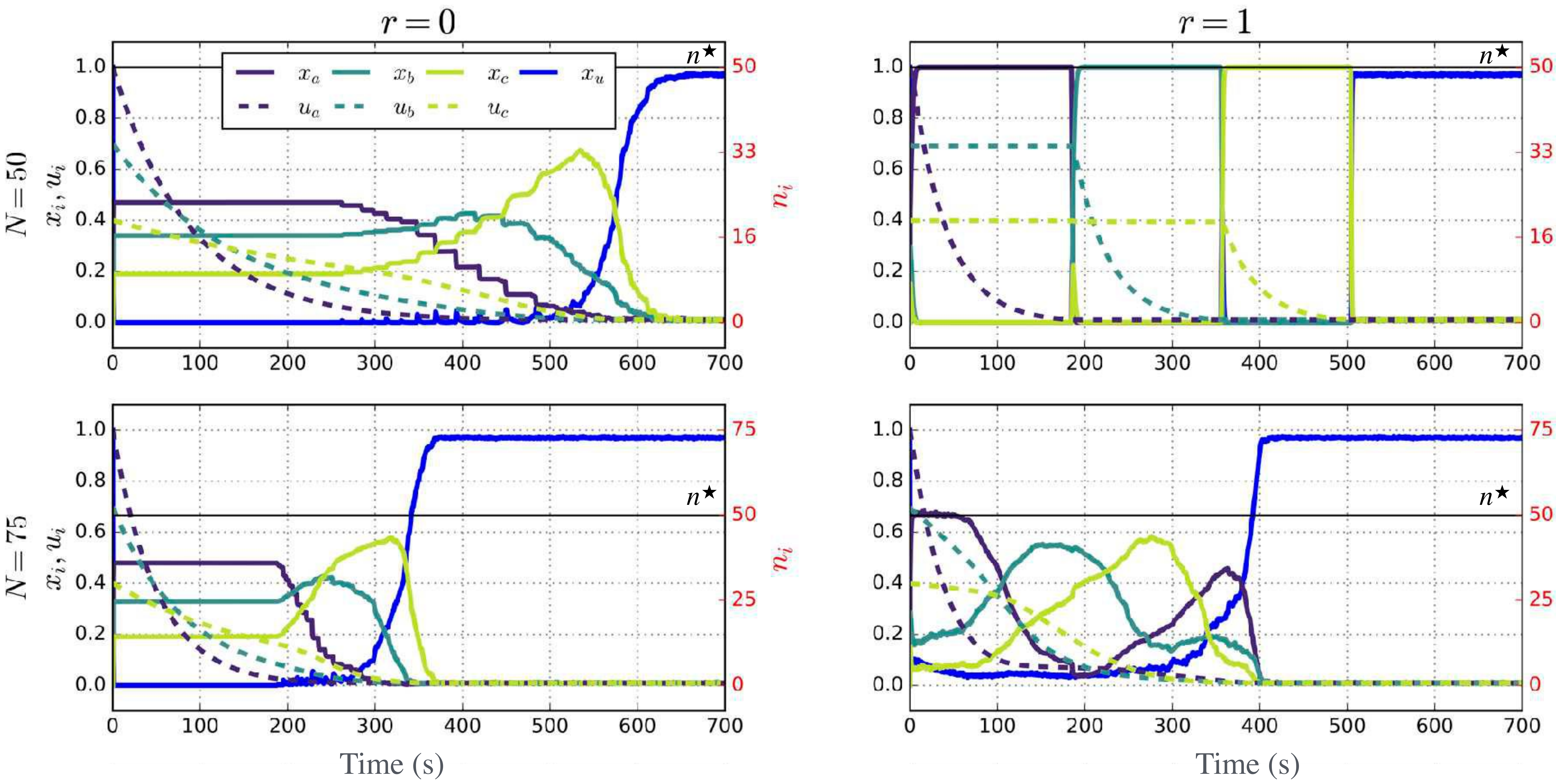


x_a x_b x_c x_u
u_a u_b u_c
Area a
Area b
Area c
x_i, u_i
n_i
1.0
0.8
0.6
0.4
0.2
0.0
50
33
16
0
0
100
200
300
400
500
600
700



$r = 0$
$r = 1$
$N = 50$
$N = 75$
x_i, u_i
n_i
$n^\star$
x_a x_b x_c x_u
u_a u_b u_c
Time (s)

Results Achieved

- Decentralised deployment and re-deployment provides
  - ability to focus only on areas of high interest
  - ability to enforce utility-responsive strategies

- The proposed strategy can be tuned by a single parameter
  - Utility-proportional deployment ($r = 0$)
  - Winner-takes-all deployment ($r \succcurlyeq 1, N \leq n^\star$)
  - Utility-responsive deployment ($r \succcurlyeq 1, N > n^\star$)

- Strategy tested with UAV simulations
  - Spatial distribution of agents over areas influences deployment
  - Communication range must be sufficiently high

Summing up

- Collaborative field monitoring and mapping provides
    - parallel operation (efficiency) and collaboration (accuracy)
    - robustness and scalability: group size can vary in real time
- Decentralised deployment and re-deployment provides
    - ability to focus only on areas of high interest
    - ability to enforce utility-responsive strategies

Thanks for your attention