AI for an autonomous hydroponic system

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Outline

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1. Context: Life Support Systems for Space Missions

2. Experiment at Pic du Midi

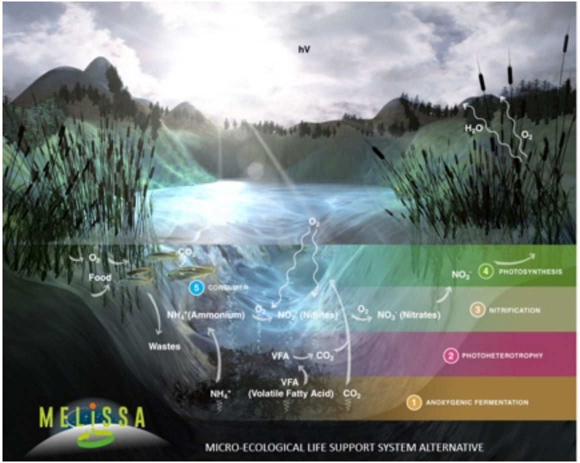
Context: Advanced Space Concepts

- Context of **future international missions to explore the solar system** (e.g. manned missions to Mars, or sustainable settlement on the Moon).
- Scientific topic: **Advanced Space Concepts** (DCAS)
  → Stéphanie Lizy-Destrez, Thibault Gateau.

Context: BLSS

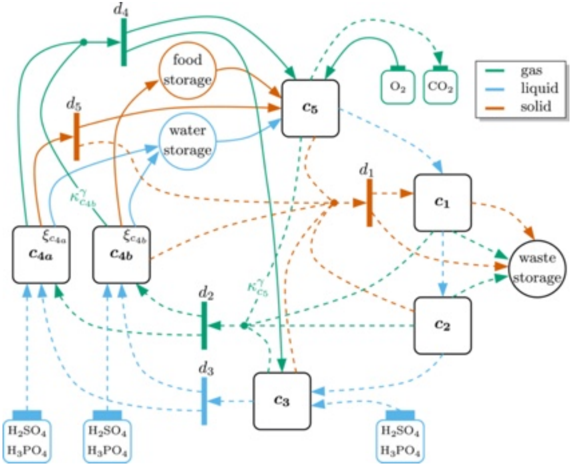
Longer and farther missions with humans:

- resupply from Earth is too expensive (energy/time)
- need for **Biogenerative Life Support System (BLSS)**



The concept of the MELiSSA loop with its five compartments and their interconnections. Picture from [Vermeulen et al., 2023].

Precise representation of the MELiSSA loop [Cimini et al., 2025].

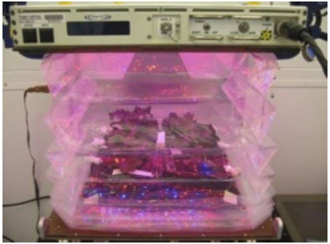


Growing plants in space

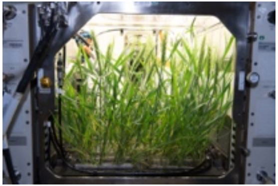
Oasis (1971)

Lada (2002)

Veggie (2014)

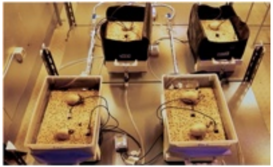


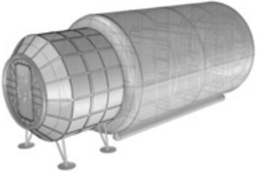
Advanced Plant Habitat (2018)



Eden ISS (ground demo, 2019)

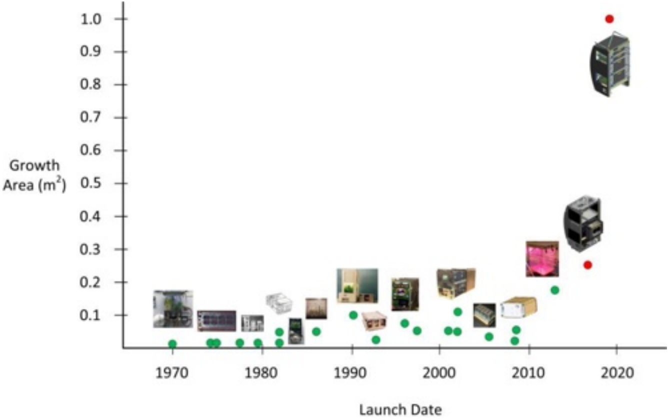
MELiSSA (current european project)





Growing plants in space

Comparison of growth area of plant growing systems for space



From *Review and analysis of plant growth chambers and greenhouse modules for space*, [Zabel et al., 2014].

Automate growing systems

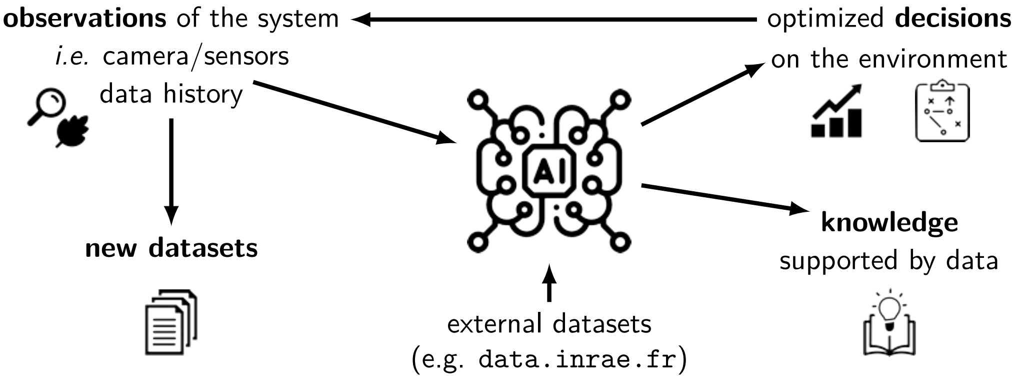
Some practical issues

- **Human time and attention are very precious** during space missions.
- Cultivation and care of plants is a **long and repetitive daily task**,
- even longer with the large growth areas necessary to **meet human needs**.
- **Limited resources** in space require very **precise agriculture**.

  $\Rightarrow$ **increase the autonomy** of plant growth systems.

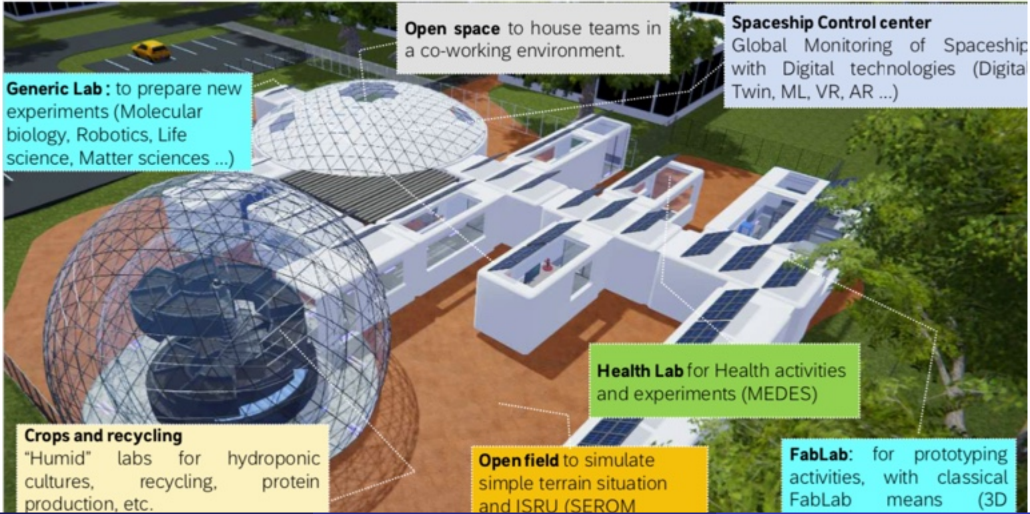
Artificial Intelligence

- Research group: **Decision and Command** (DCAS)
  → Caroline Chanel, Nicolas Drougard.
- Usecase for research works on **Supervised Learning and Automated Planning**.



A favorable context (CNES Toulouse)

- **SPACESHIP FR** (from 2018): anticipate a future lunar and/or martian base by gathering the technologies developed in France and in Europe – spaceship.cnes.fr.



SPACESHIP FR

Biomebox

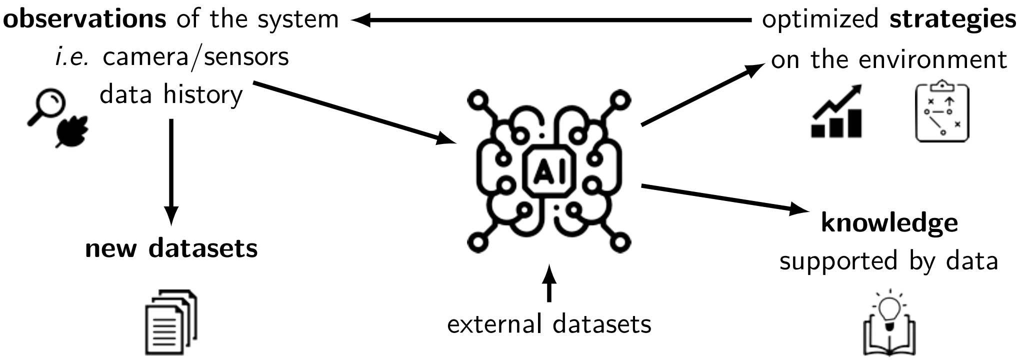
A few words about ALICE

ALICE – Artificial intelligence for Life In spaCE

- Support from **Fablab** INNOVspace by ISAE SUPAERO
- 20 students from 2019 (internships and research projects).

Context: Life Support Systems for Space Missions

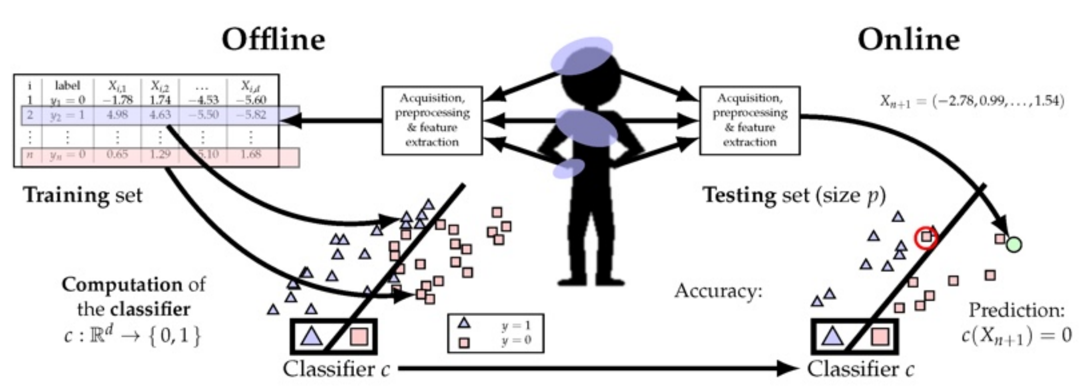
- Supervised Learning + Long-term planning
  → crop production/greenhouse management with AI



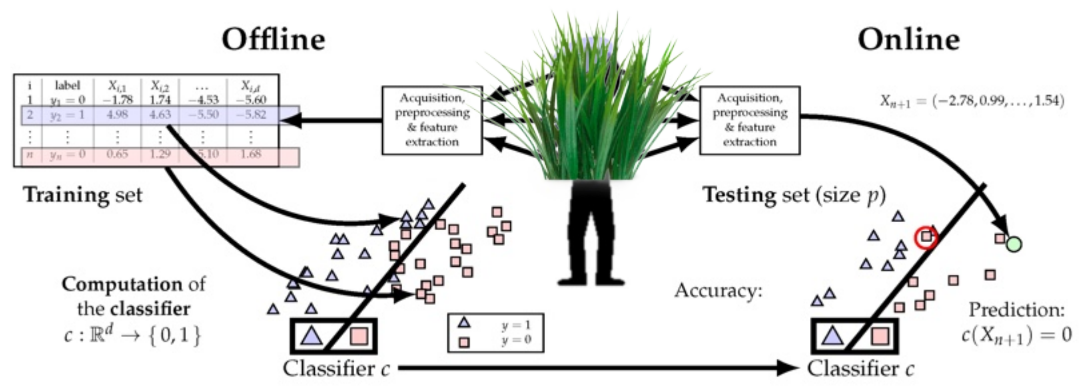
Context: Life Support Systems for Space Missions

- Observation
  $\rightarrow$ from raw data (picture, temperatures, moisture, pH rate, etc.)
  $\rightarrow$ to symbol/real number (growth stage, health, etc.)
- Long-term decisions
  $\rightarrow$ from model/data history + criterion (production - ressource consumption)
  $\rightarrow$ to sequence of actions or "strategy" (water, nutrients, heat, light, etc.)

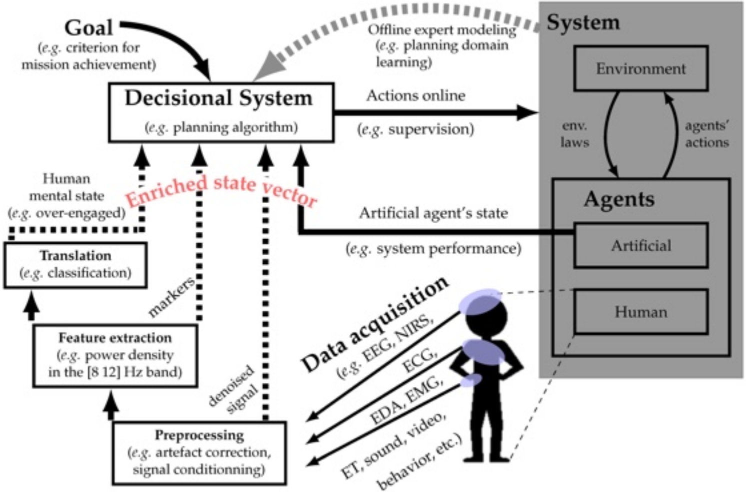
Brain-Computer Interface (BCI)



Brain-Computer Interface (BCI)

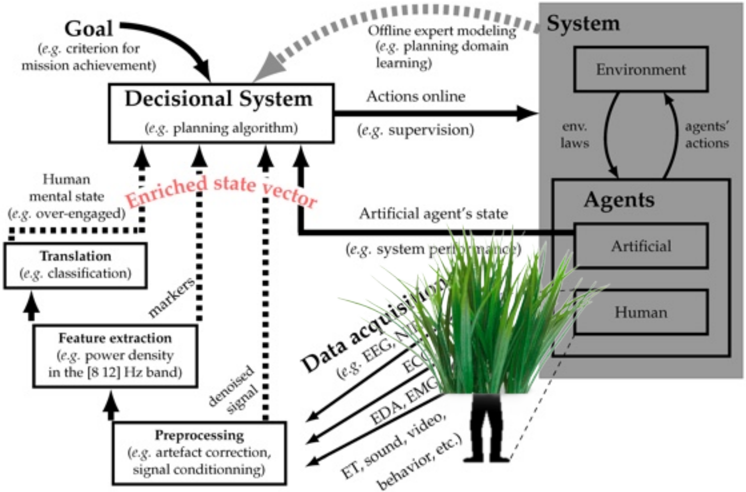


Benefit from previous framework?



How can physiological computing benefit human-robot interaction? [Roy et al., 2020]

Benefit from previous framework?



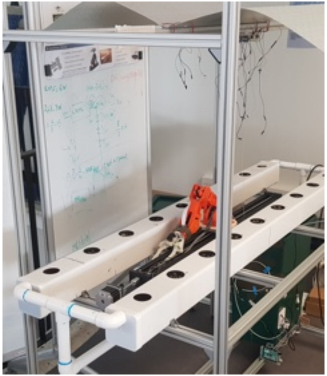
How can physiological computing benefit human-robot interaction? [Roy et al., 2020]

Demo units

For data collection (observations) and demonstration (decisions).

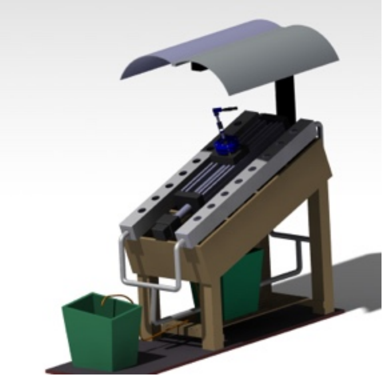
- Farmbot
  - Available **observation**:
    → takes pictures & measures the soil moisture.
  - Possible **actions**:
    → plants seeds, waters plants & removes weeds.
- Hydroponic Robot
  - Available **observation**:
    → takes pictures, measures the temperature & the pH of the water.
  - Possible **actions**:
    → controls light intensity/frequency, nutrient level, water flow & moves plants pots.

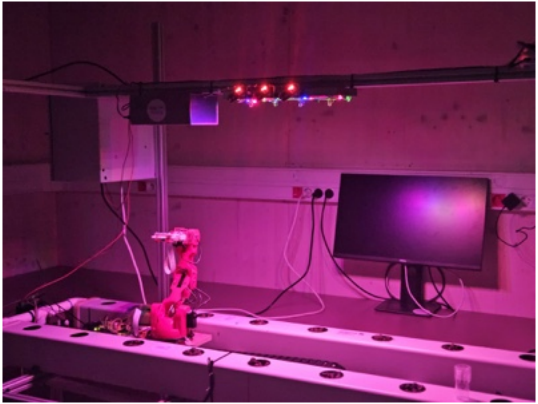
Hydroponic Robot

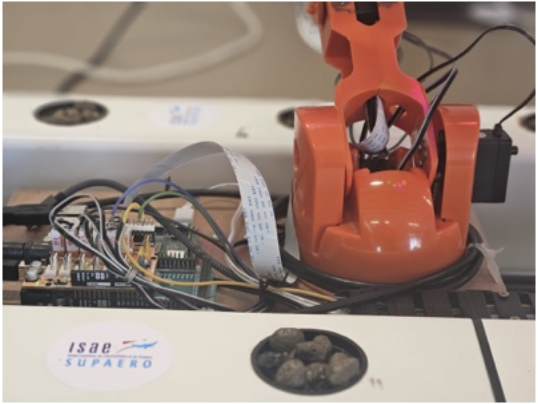


Hosted in the Fablab of ISAE-SUPAERO, this project was rated 5^{th} among 49 as a **Nanostar challenge**!

Developped and used by Gabriela Catalan-Medina, Barbara Espinosa-Fortes-Ferreira, Laurent Frédéric, Adrien Mencik-Von-Zebinsky, Jonathan Sancho-Gonzalez, and a great help from Jérôme Dartigues.



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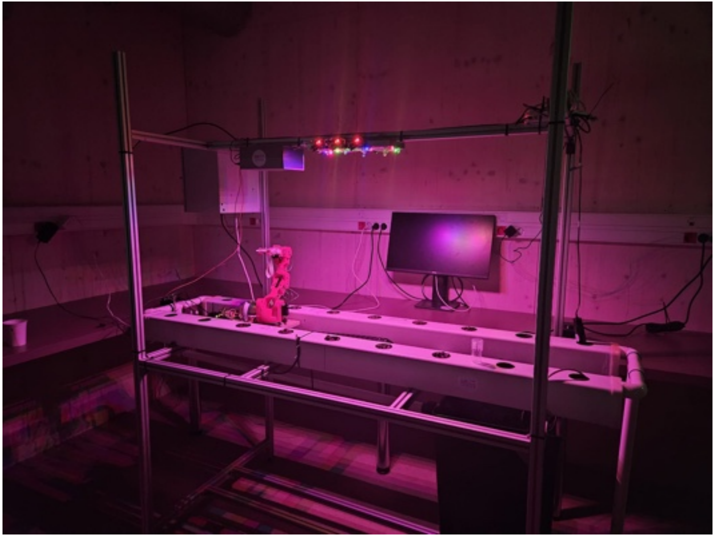
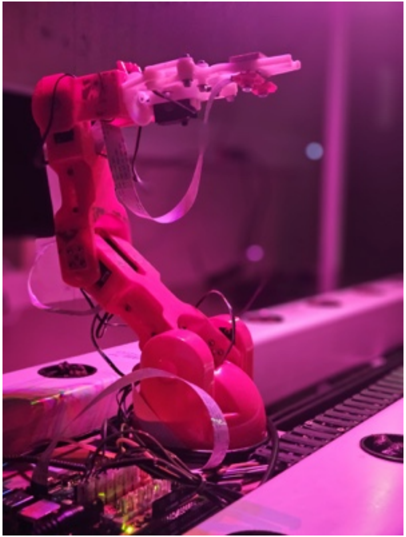
Hydroponic Robot





Pictures from the hydroponic system

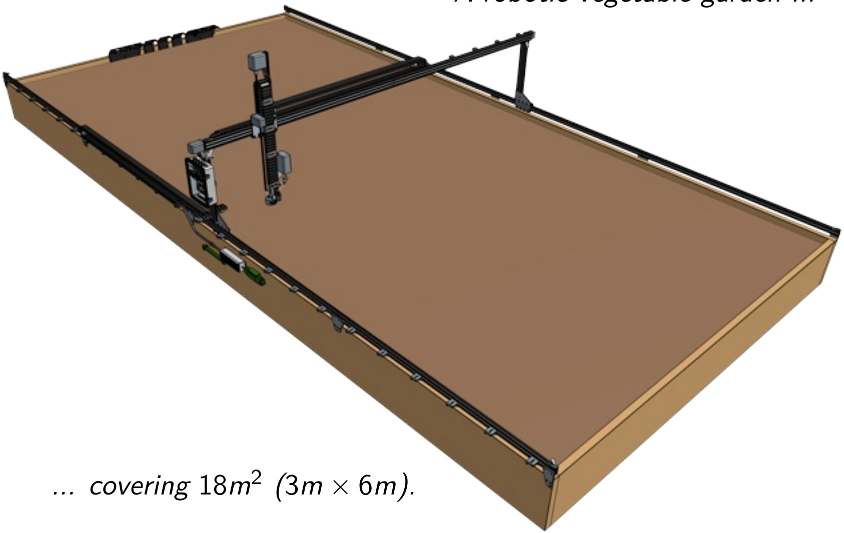
Farmbot system

FARMBOT: Open source Cartesian coordinate robot farming machine

selection, feasibility study and acquisition within the framework of the european project Nanostar

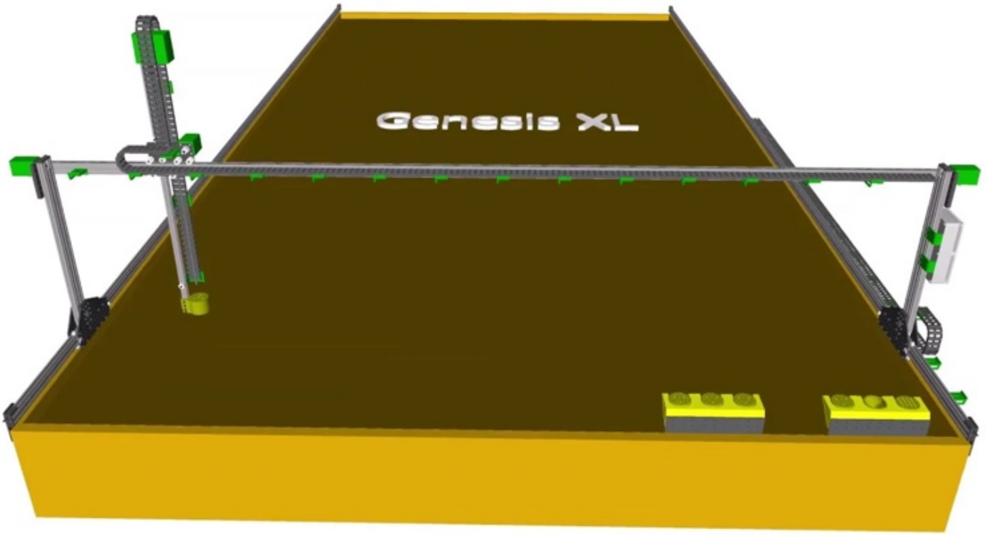
Farmbot Genesis XL

A robotic vegetable garden ...

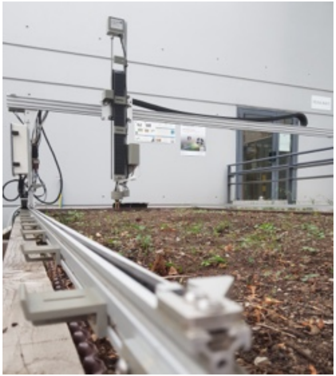


... covering $18m^2$ $(3m \times 6m)$.

Farmbot Genesis XL



Top view

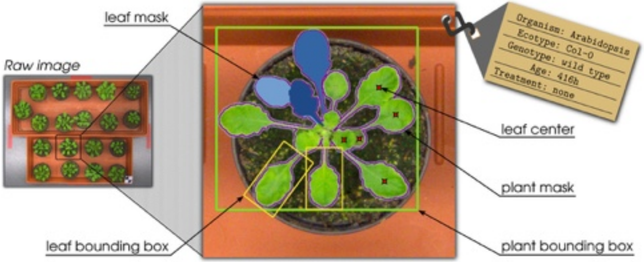


Aside ISAE-SUPAERO's restaurant, **computed growth strategies** are currently tested on it and recorded with an external camera.

Set up and used by Joan Bessa Sanz, Lorenzo Buizza, Victor Clerc, Gowtham Govind-Reddy, Margherita Pomilio, Krupal Kanti Prajapati, Antoine Sfeir, and a great help from Jérôme Dartigues.

Computer Vision

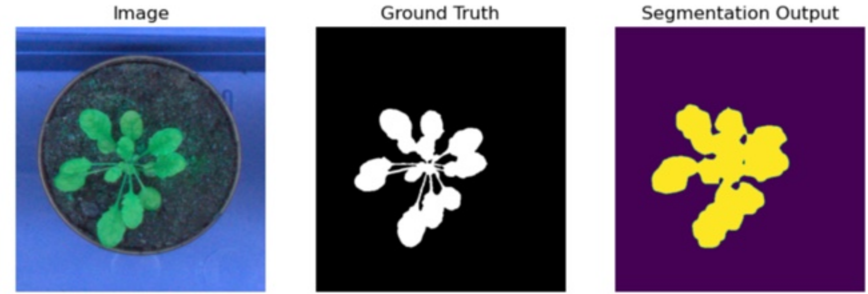
- Useful information on the plant and its environment (*e.g.* size, disease, or needs) can be the output of an **estimator** (classifier or regressor).
- **Estimators** take as input raw data (*e.g.* pictures or measures) and are computed using **labeled datasets** and **Supervised Learning** algorithms.
- **Image segmentation**, *i.e.* dividing image into regions corresponding to plants or leaves, can bring sound information.



[Minervini et al., 2016]

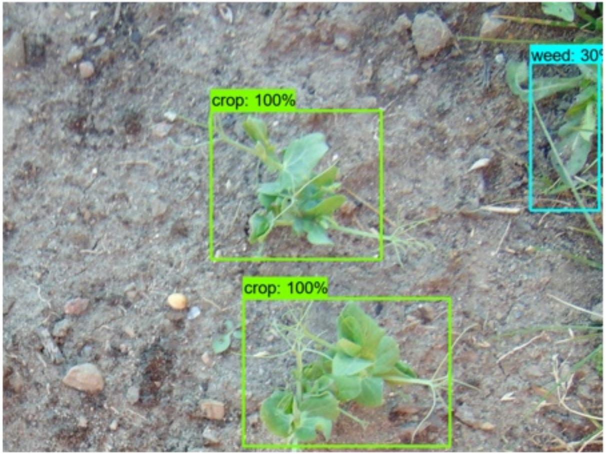
Computer Vision

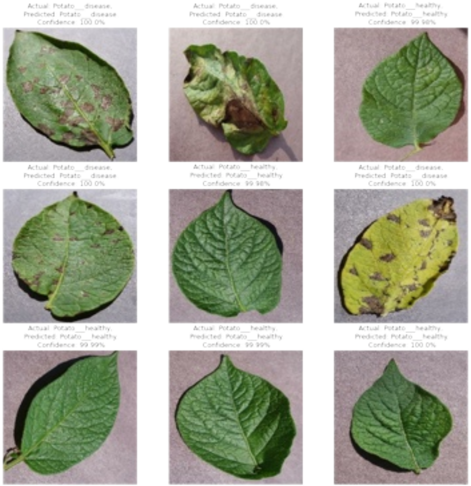
Hanqing Yang's internship (MRCNN)



Many publicly available datasets are recently offered online (segmentation and disease detection).

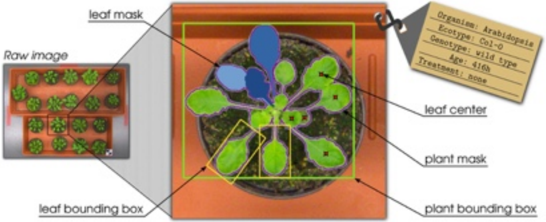
Deep Convolutional Networks for **crop/weed detection** and **disease classification**.
Margherita Pomilio's research project.





Available computer vision datasets

PhenoBench (Weyler 2023) & EWS (Zenkl 2022) CosegPP (Quiñones 2021).



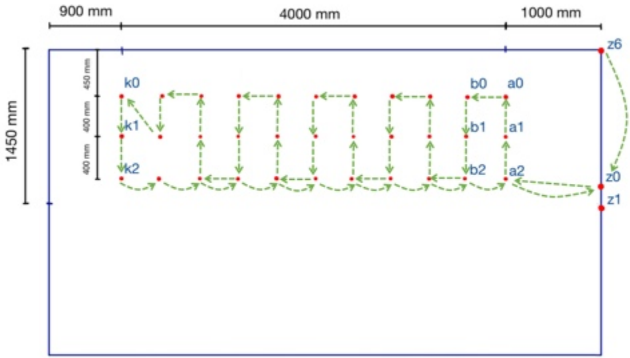
Plant Phenotyping Dataset (PPD, Minervini 2016).

Planning for plant growing systems

Planning for the Farmbot and the Hydroponic Robot
ANANDA Sanjay & Lorenzo Buizza's research projects.

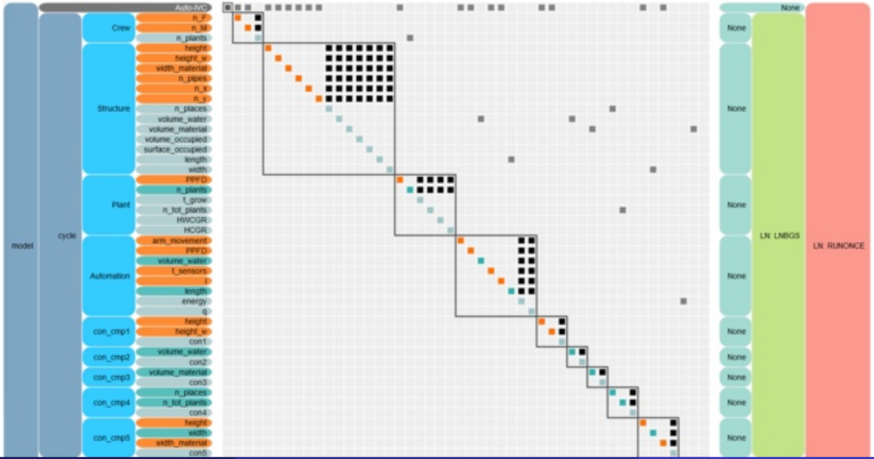
- Deterministic Planning
  - Description of the systems and problem
    → with **PDDL** (Planning Domain Definition Language).
  - Solved with **Fast Forward**
    → binary criterion, *e.g. check and water all plants*.
  - Solved with **Metric-FF**
    → quantitative criterion, *e.g. same, with the least consumption of resources*.
- Perspectives: Planning under Uncertainty (MDP), with partial observability (PO-MDP), with Offline RL, etc.

Farmbot top view illustration of the movements



Marina Mileni Munari's research project: Multi-Disciplinary Analysis and Optimization (MDAO)

→ *optimization of the system design*



Outline

Main goal

In a nutshell,

- Autonomy of the Plant Growth System:
  - perception using sensors and Machine Learning
  - decisions using strategies computed with Reinforcement Learning
- Optimization of its execution:
  - maximize the long-term production
  - minimize resource use
- need for data variability
  $\rightarrow$ deployment of data collection systems at various locations!

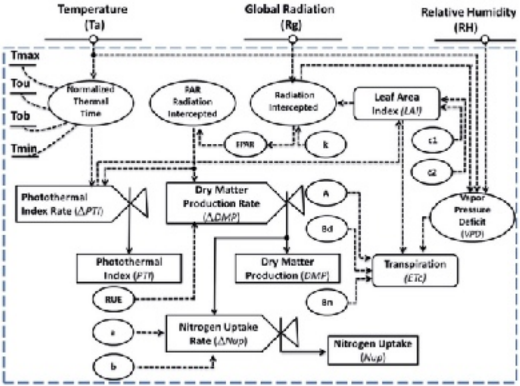
Needs

- Sufficiently diverse data
  - to cover a fairly broad spectrum of plant growth contexts
  - to train and evaluate perception tools

Pic du Midi

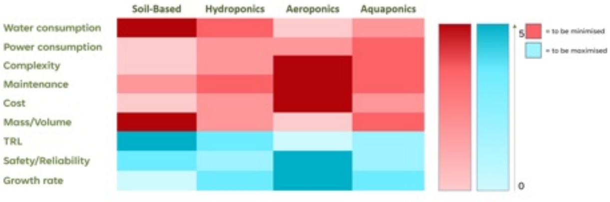
Needs

- Sufficiently accurate models
  - to compute efficient strategies
  - with Planning or Reinforcement Learning
    [Solow et al., 2025, Gautron et al., 2022, Maillard et al., 2023]



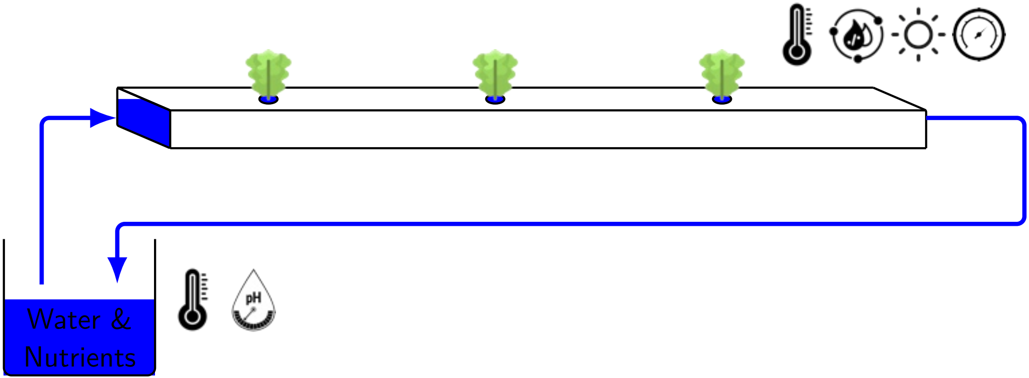
[Martínez-Ruiz et al., 2019]

- 1 growing system: Hydroponics (optimal for constraints in space)

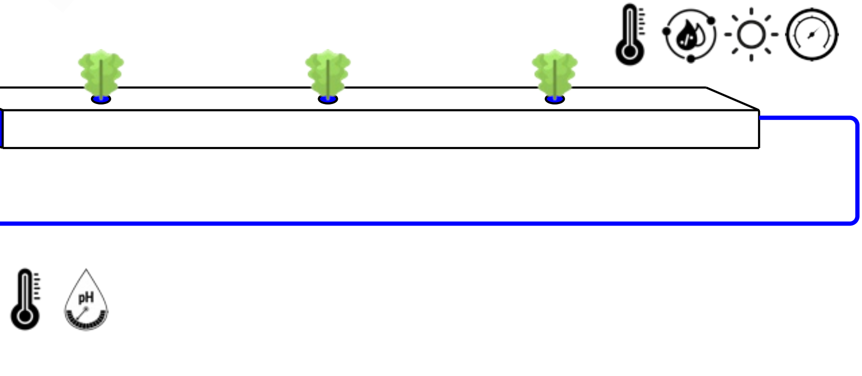


(*Marina Mileni Munari's research project*)

- 1 plant: Arugula (fast growth, entire plants are nutrients, medicinal properties)


Water &
Nutrients
pH

Experiment



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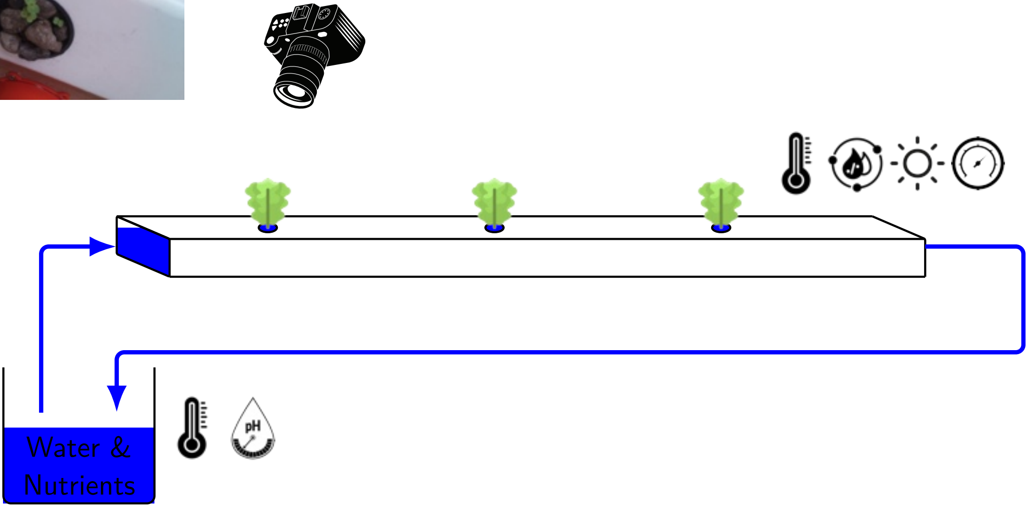

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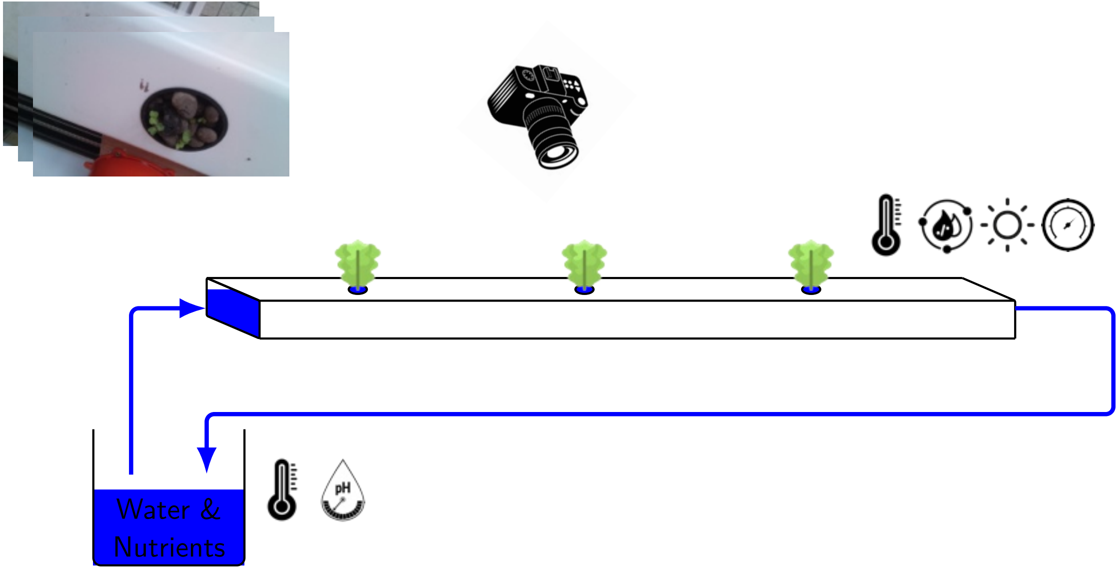
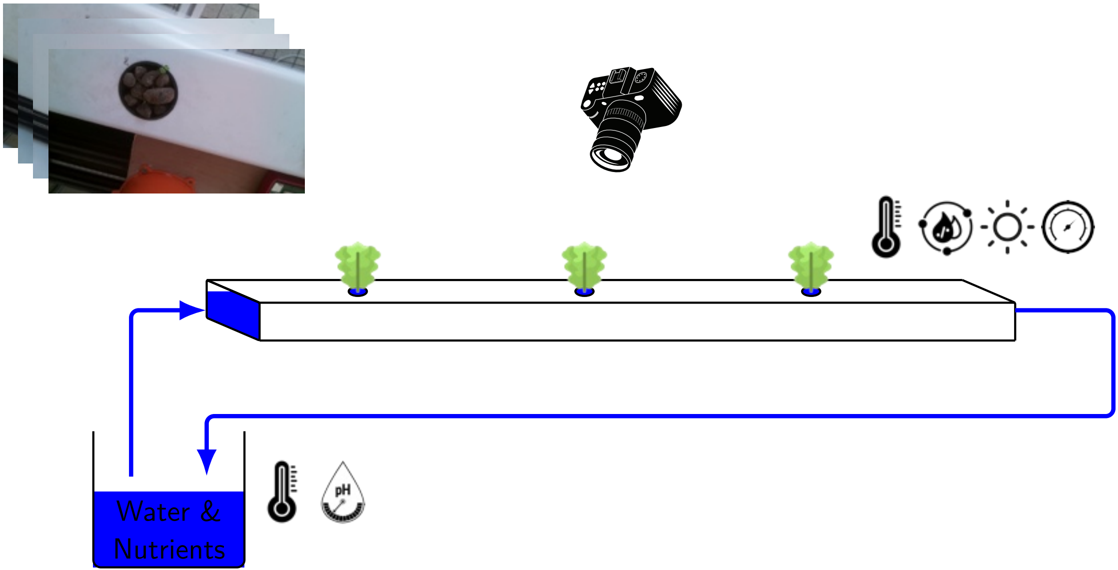
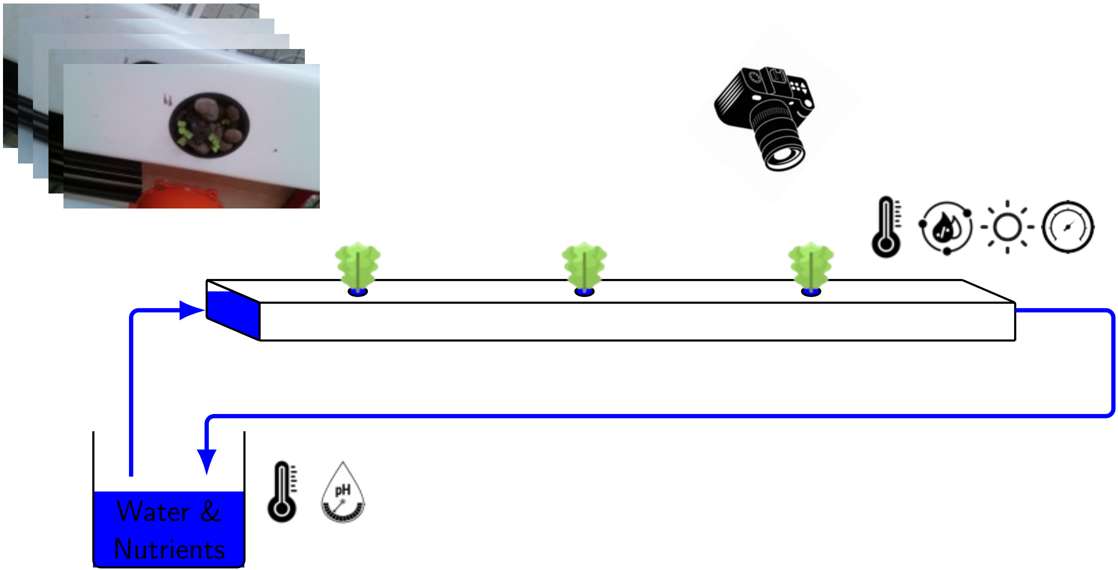


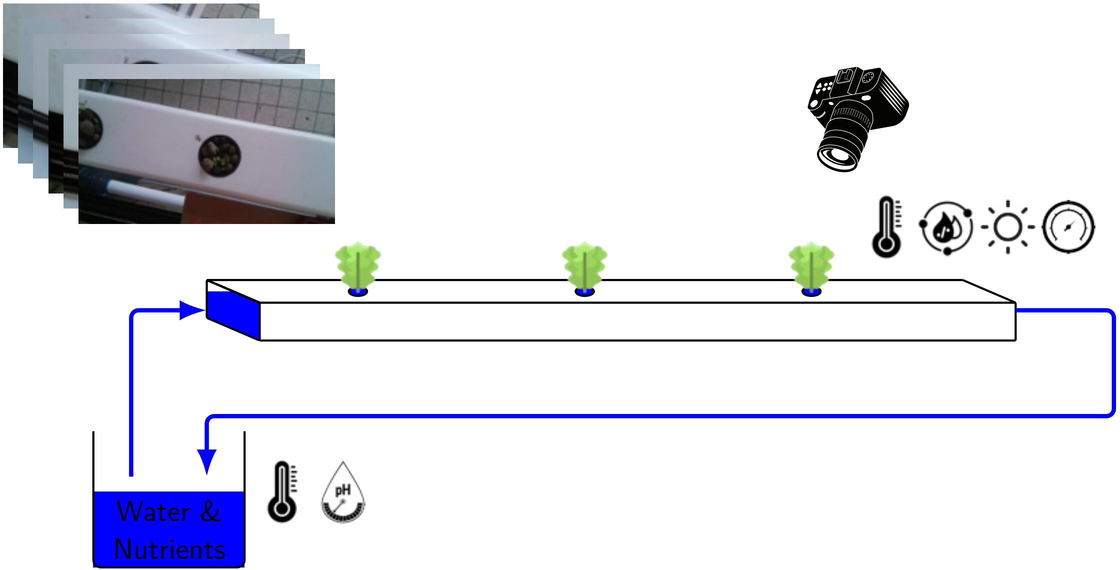
Experiment

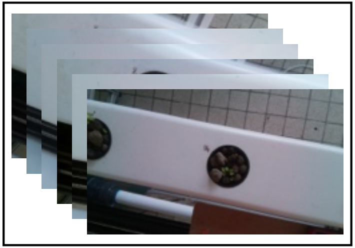


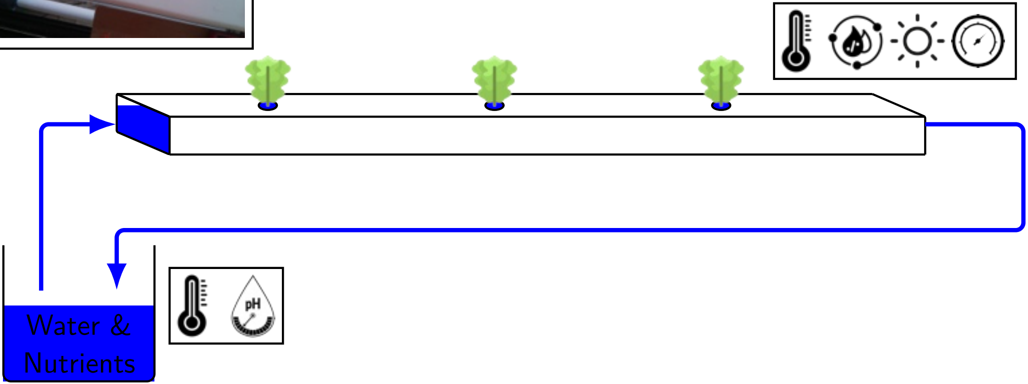
Experiment



Experiment



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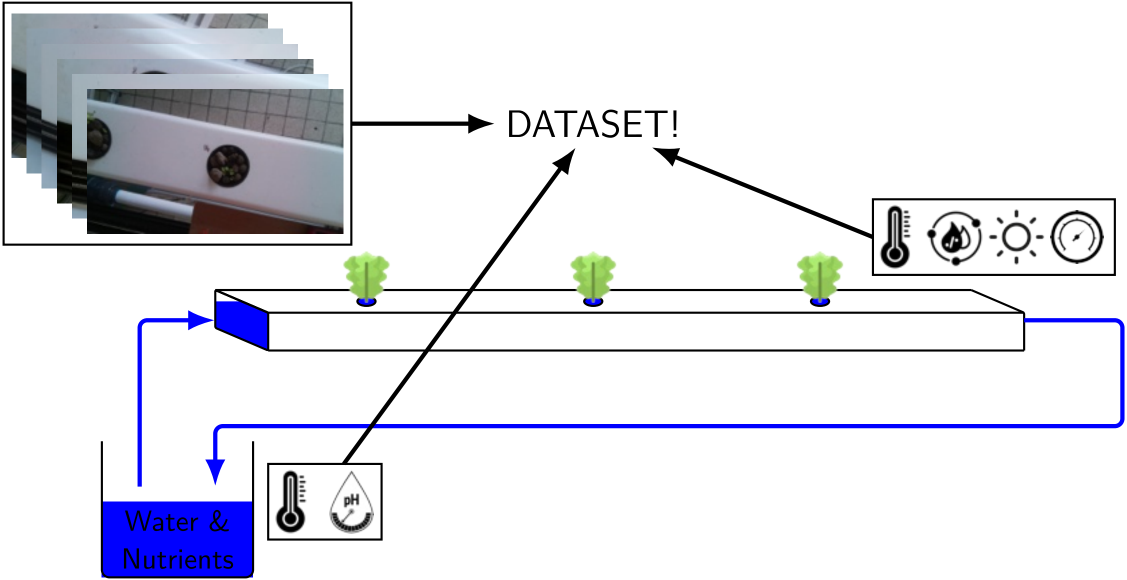
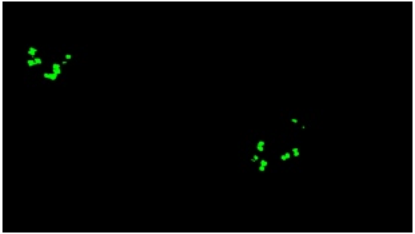
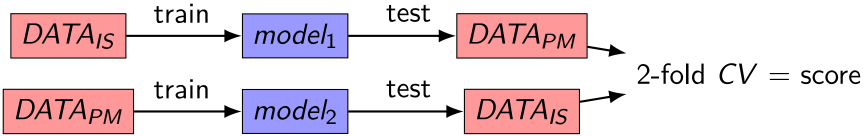


Data exploitation

- Train ML algorithms, like segmentation algorithms:



- Test that acquired data change according to the location (experimental statistics)
- Validate perception and decision models, as well as their robustness



Thank you!

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