Pic Users Committee
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Collecting Data on Plant Growth in a Hydroponic System at Pic du Midi

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Outline

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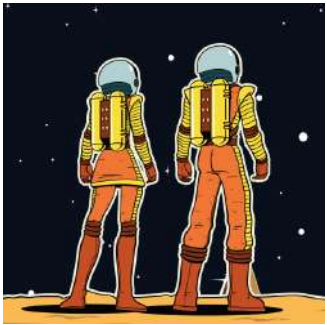
Context: Advanced Space Concepts

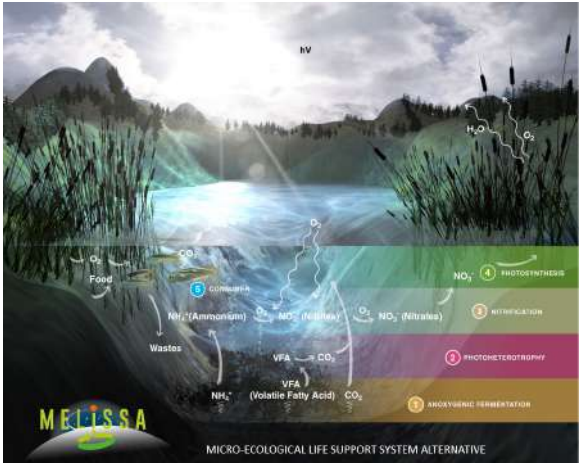
- Context of **future international missions to explore the solar system** (e.g. manned missions to Mars, or sustainable settlement on the Moon).
- Scientific topic: **Advanced Space Concepts** (DCAS)
  → Stéphanie Lizy-Destrez, Thibault Gateau.



Context: BLSS

Longer and farther missions with humans:

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



Growing plants in space

Oasis (1971)

Lada (2002)

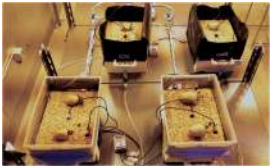
Veggie (2014)

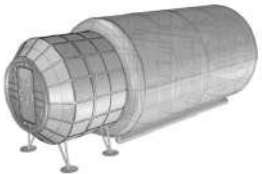
Growing plants in space

Advanced Plant Habitat (2018)

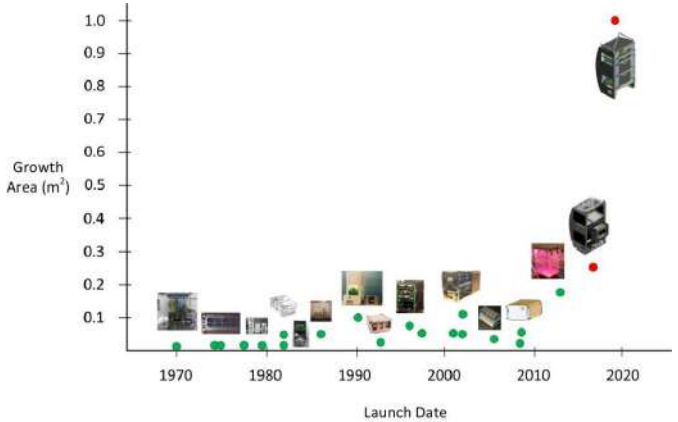
Eden ISS (ground demo, 2019)

MELiSSA (current european project)





Comparison of growth area of plant growing systems



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

Automate growing systems

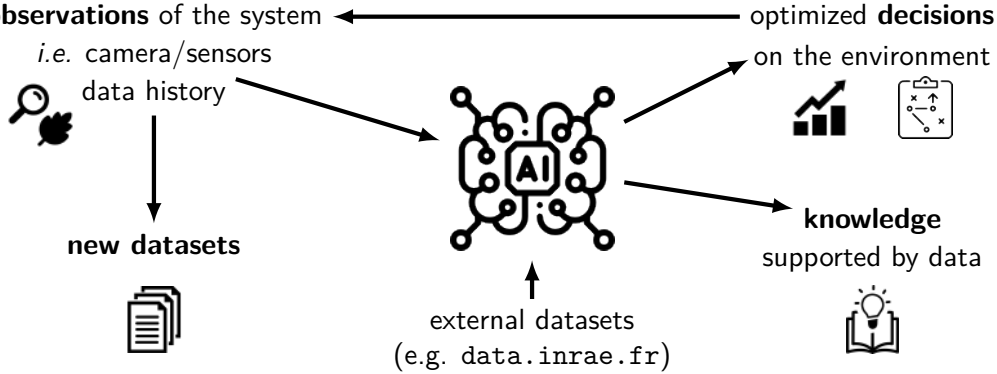
Some practical issues

- **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.

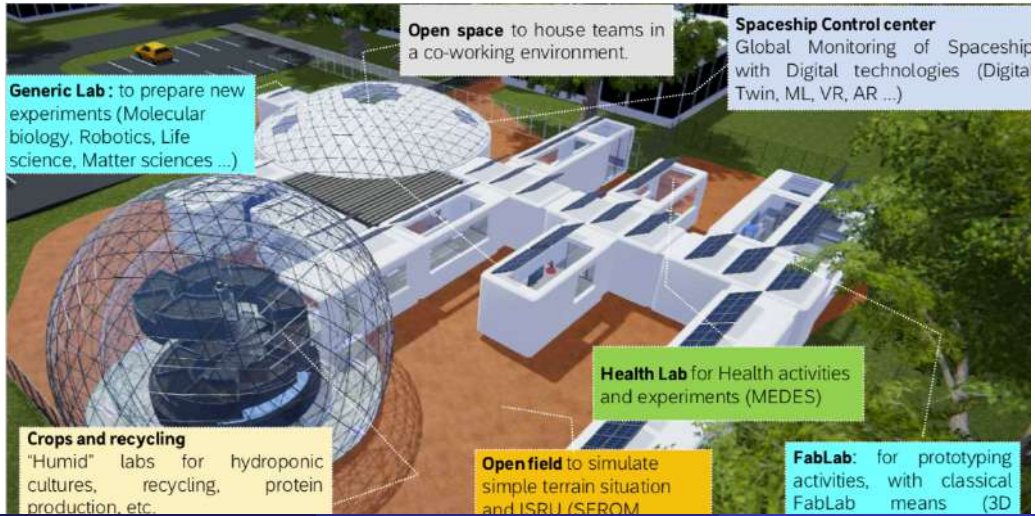
Artificial Intelligence

- 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

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

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

observations of the system
i.e. camera/sensors
data history

optimized **strategies**
on the environment

new datasets

AI

knowledge
supported by data

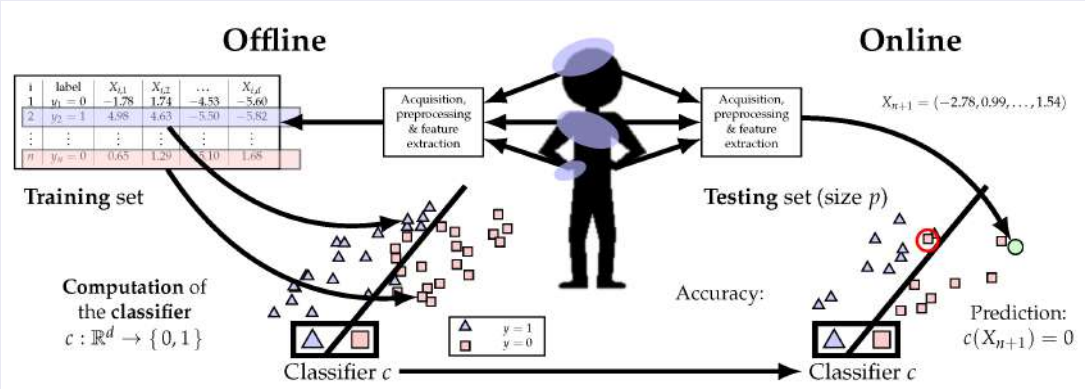
external datasets

Context: Life Support Systems for Space

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

Benefit from previous framework?

Brain-Computer Interface (BCI)



Benefit from previous framework?

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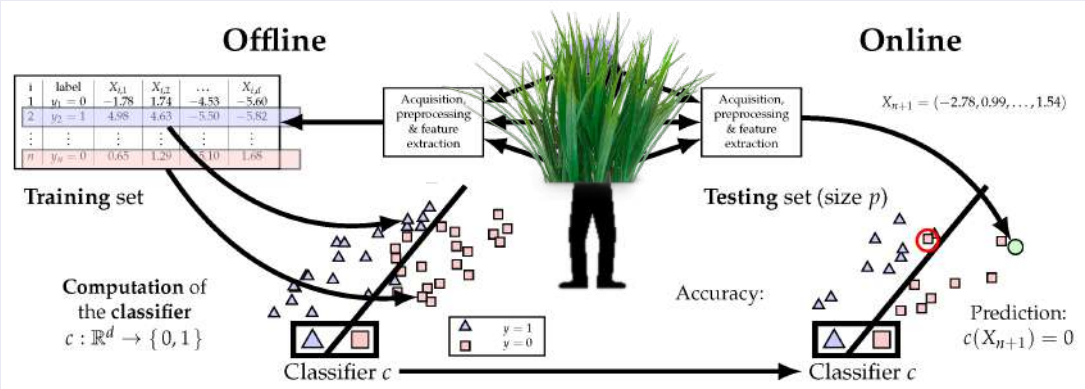
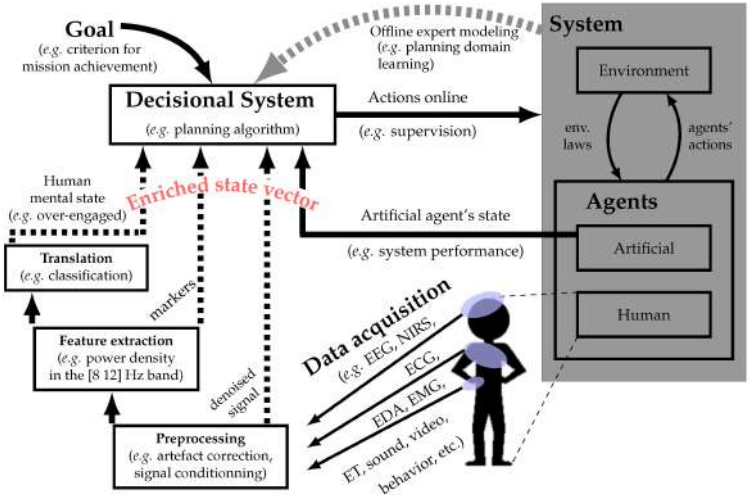
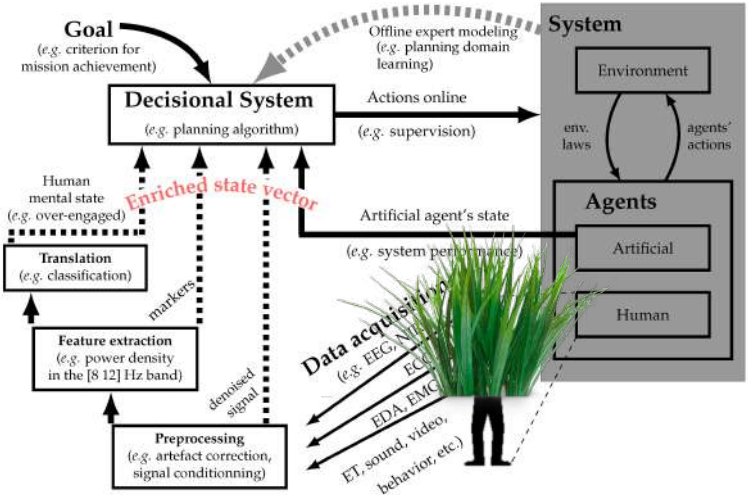


Benefit from previous framework?



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

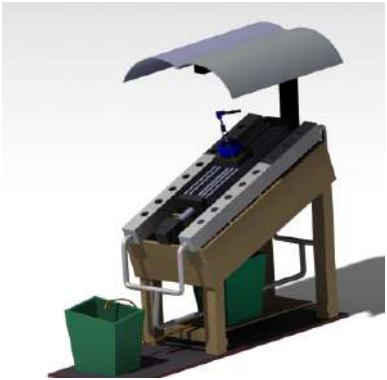
For data collection (observations) and demonstration (decisions).

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

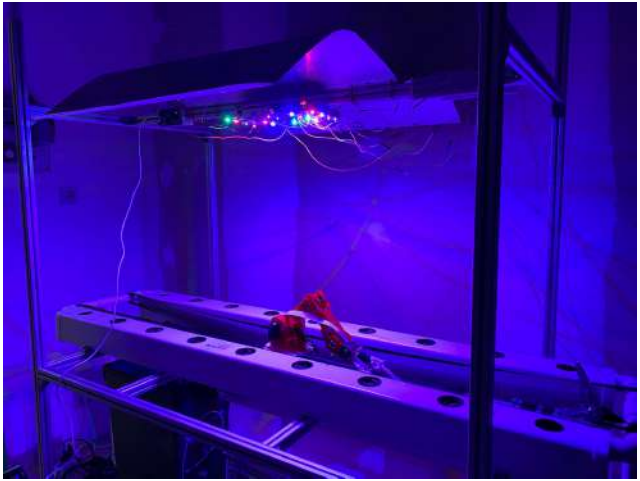
Hydroponic Robot

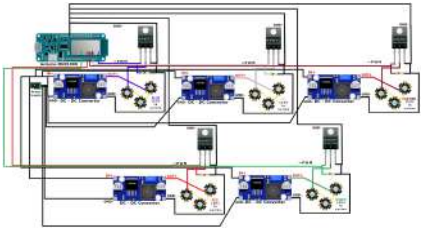
Hosted in the Fablab of ISAE-SUPAERO, this project was rated 5^{th} among 49 as a **Nanostar challenge**!

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.



Efforts on a LED system: control of the intensity and the frequency.





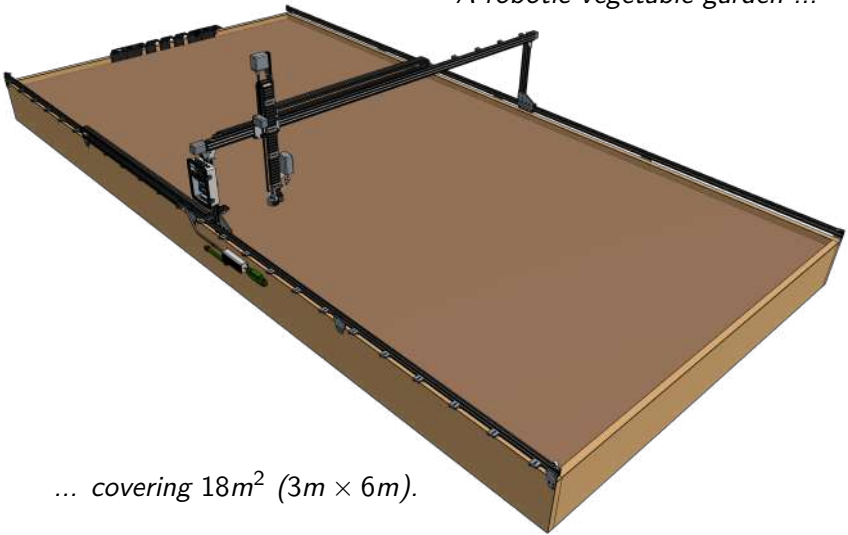
Farmbot system

FARMBOT: Open source Cartesian coordinate robot farming machine

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

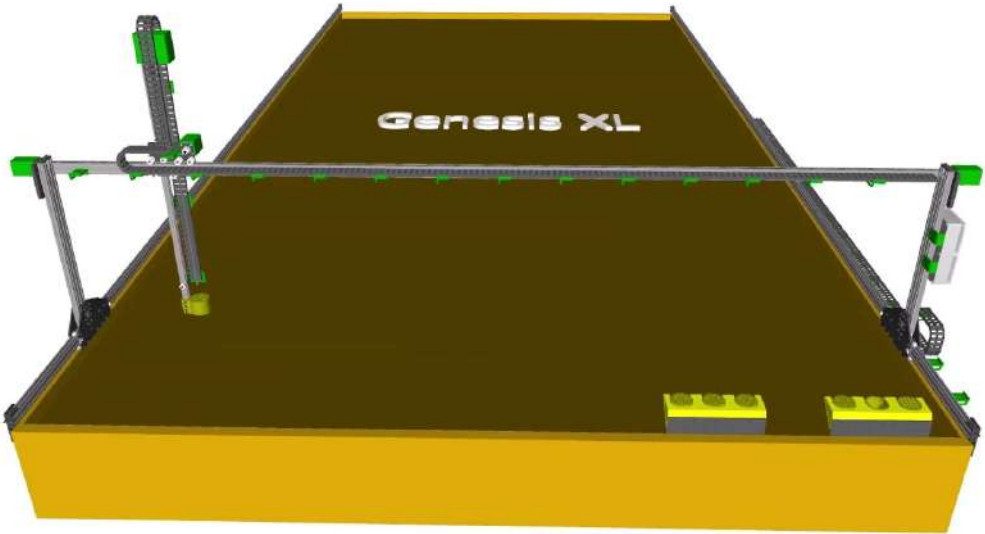
Farmbot Genesis XL

A robotic vegetable garden ...



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

Farmbot Genesis XL



Top view

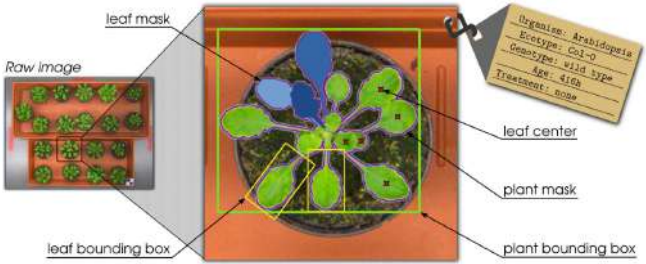
Farmbot System

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.

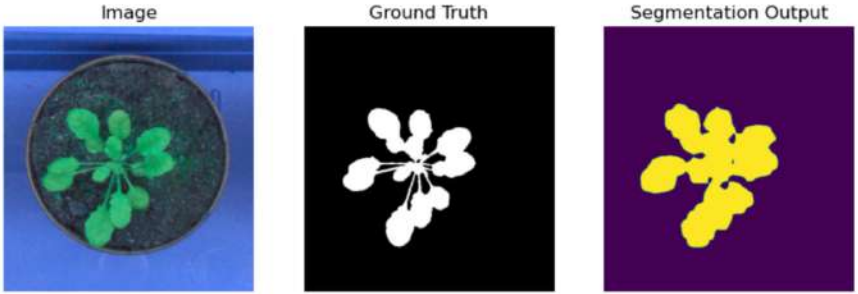
Computer Vision

- 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]

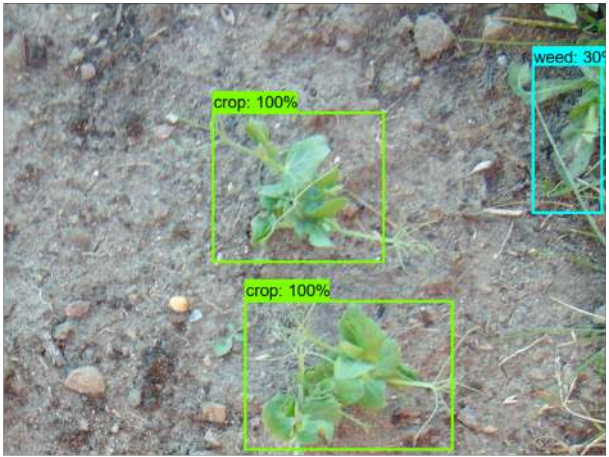
Hanqing Yang's internship (MRCNN)

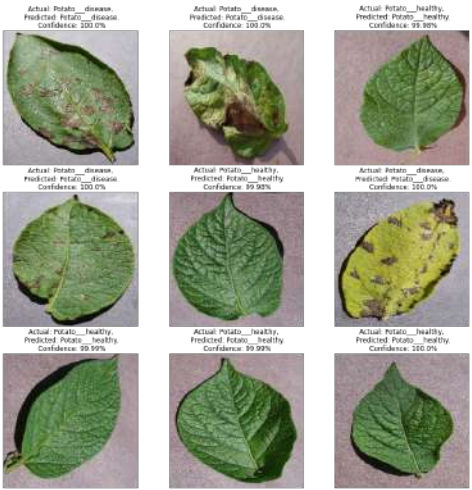


Many publicly available datasets are recently offered online (segmentation and disease detection).

Context: Life Support Systems for Space

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





Planning for plant growing systems

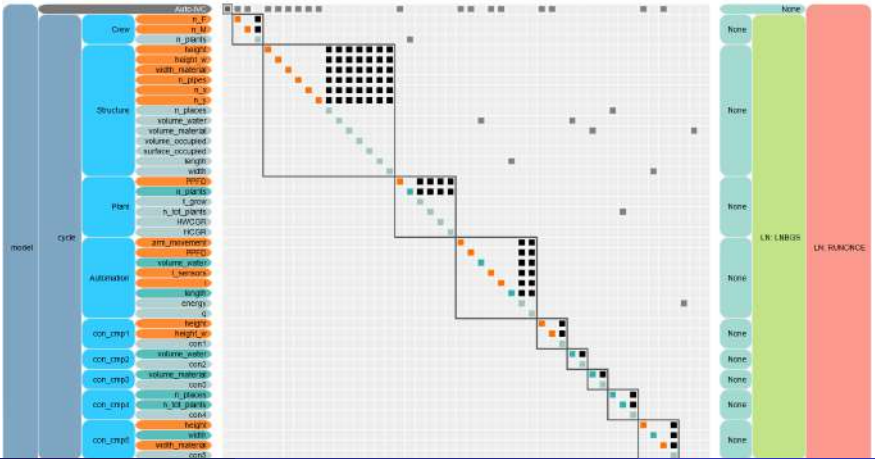
Planning for the Farmbot and the Hydroponic Robot
ANANDA Sanjay & Lorenzo Buizza's research projects.

- Deterministic Planning
  - Description of the systems and problem
    $\rightarrow$ with **PDDL** (Planning Domain Definition Language).
  - Solved with **Fast Forward**
    $\rightarrow$ binary criterion, *e.g. check and water all plants*.
  - Solved with **Metric-FF**
    $\rightarrow$ 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.

Toward system design optimization

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

→ *optimization of the system design*



Outline

Main goal

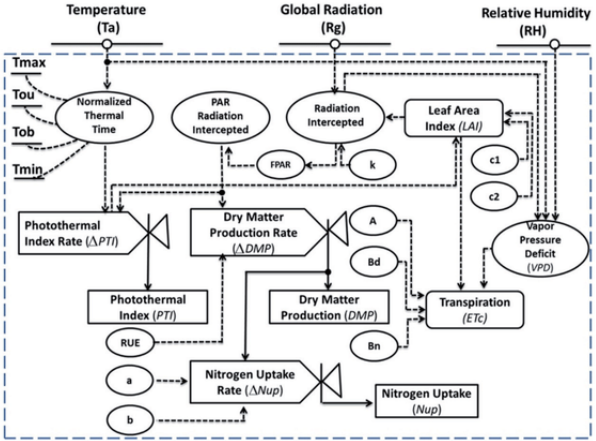
In a nutshell,

- 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

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

Needs

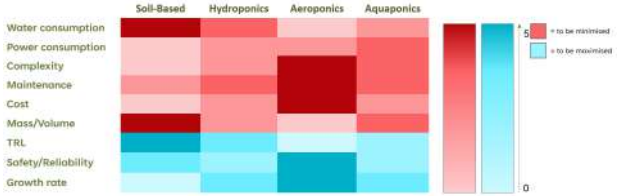
- Sufficiently accurate models
  - to compute efficient strategies
  - with Planning or Reinforcement Learning



[Martínez-Ruiz et al., 2019]

Setup

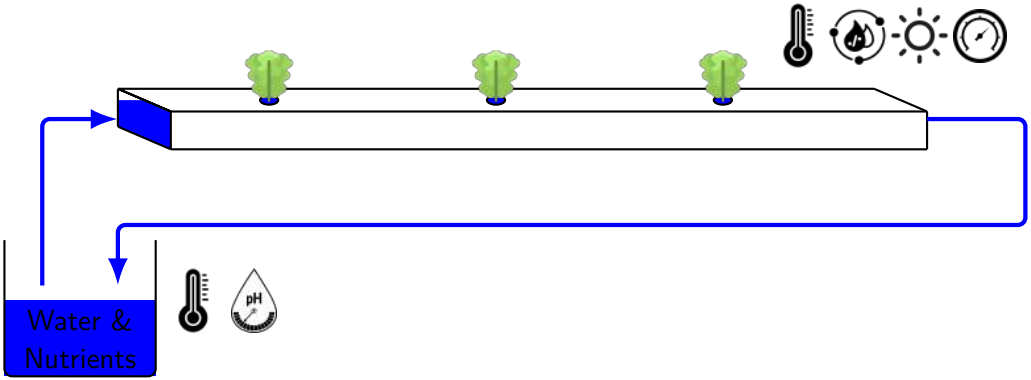
- 1 growing system: Hydroponics (optimal for constraints in space)



(*Marina Mileni Munari's research project*)

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

Experiment



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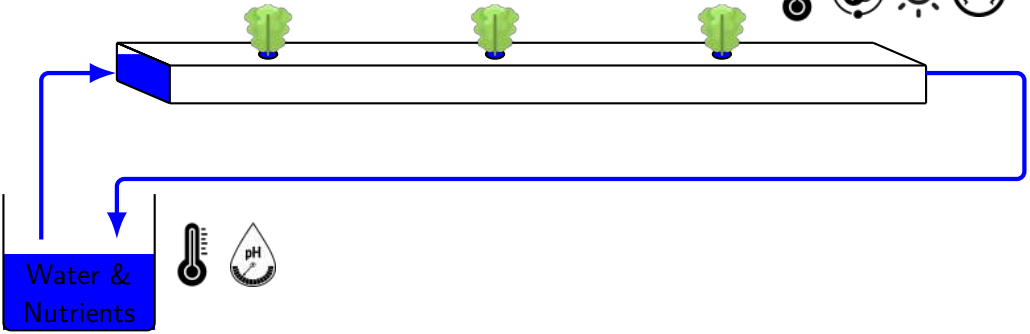

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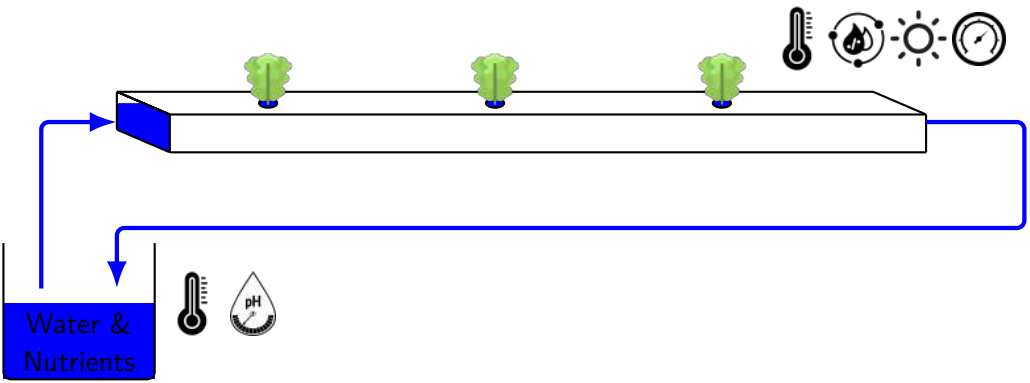

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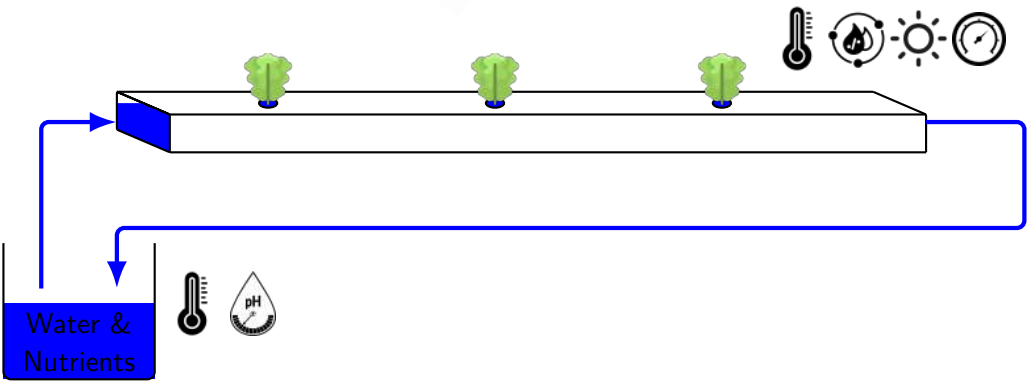

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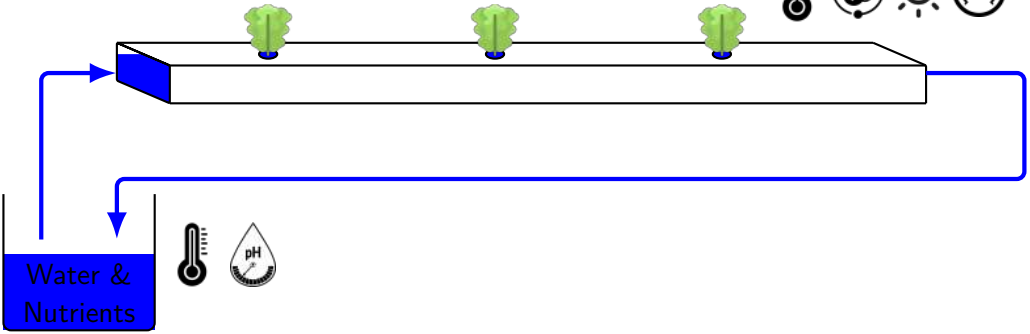
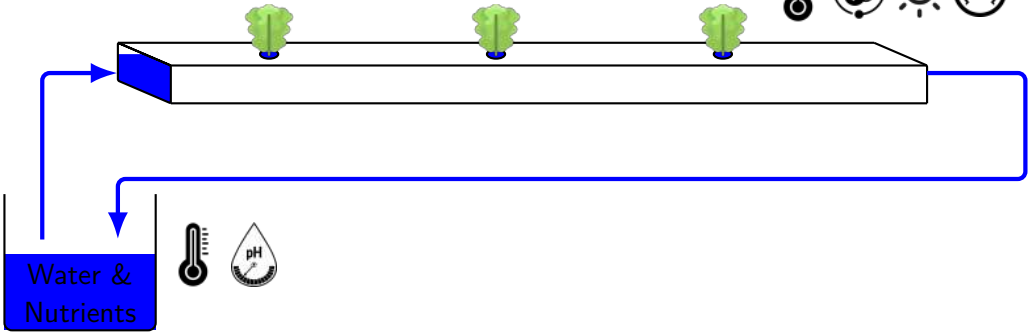


Experiment



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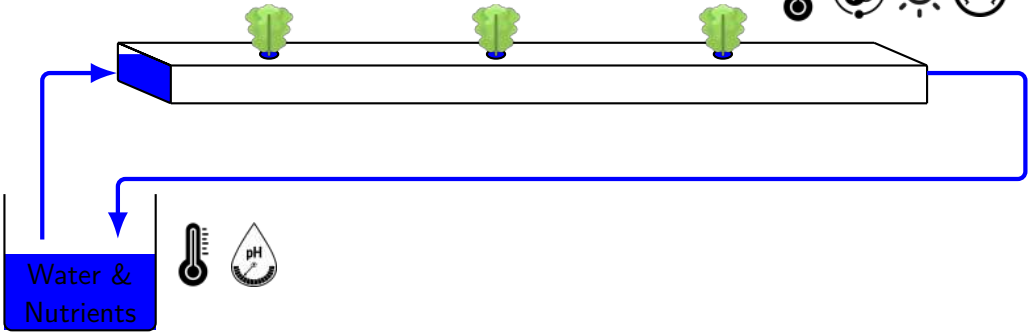

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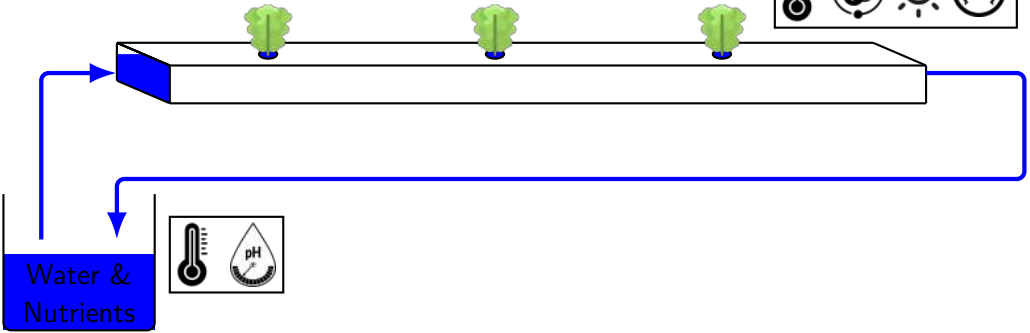
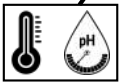


Experiment

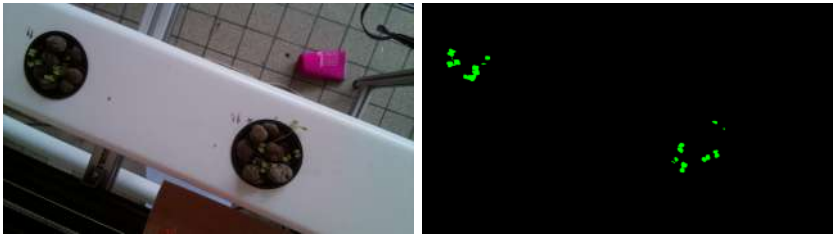
DATASET!



Water &
Nutrients

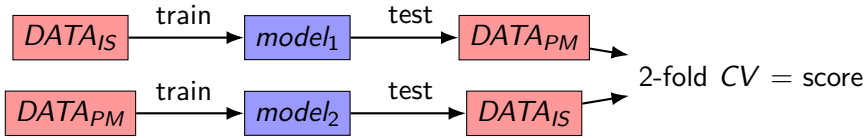
Data exploitation

- Train ML algorithms, like segmentation algorithms:



Data exploitation

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



Thank you!

References I

- [Martínez-Ruiz et al., 2019] Martínez-Ruiz, A., López-Cruz, I. L., Ruiz-García, A., Pineda-Pineda, J., and Prado-Hernández, J. V. (2019).
  Hortsyst: A dynamic model to predict growth, nitrogen uptake, and transpiration of greenhouse tomatoes.
  Chilean journal of agricultural research, 79(1):89–102.
- [Minervini et al., 2016] Minervini, M., Fischbach, A., Scharr, H., and Tsaftaris, S. A. (2016).
  Finely-grained annotated datasets for image-based plant phenotyping.
  Pattern recognition letters, 81:80–89.
- [Roy et al., 2020] Roy, R. N., Drougard, N., Gateau, T., Dehais, F., and Chanel, C. P. (2020).
  How can physiological computing benefit human-robot interaction?
  Robotics, 9(4):100.
- [Zabel et al., 2014] Zabel, P., Bamsey, M., Schubert, D., and Tajmar, M. (2014).
  Review and analysis of plant growth chambers and greenhouse modules for space.
  44th International Conference on Environmental Systems.

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