Artificial Intelligence in Greenhouse Horticulture: A Student's Perspective

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Autonomous Greenhouse Challenge 2021

TU Delft

Today's Topics

1. What is Artificial Intelligence?
2. How can AI in help horticulture?
3. Lessons learned
4. Stimulating innovation

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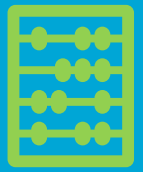
What is Artificial Intelligence?

Definition

Relevant Branches with Examples



Challenges and Downsides

Definition of Artificial Intelligence (AI)

- “Intelligence demonstrated by machines”
- “… mimics cognitive functions that humans associate with the human mind, such as learning and problem solving”

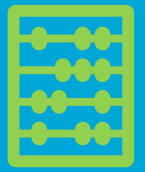
Definition of Artificial Intelligence (AI)

- The Understanding and Decision Making by a computer/machine
- Data
- Machine Learning: Improve AI through experience, examples and data
- Robot materialistic version of AI

What is Artificial Intelligence?

Definition

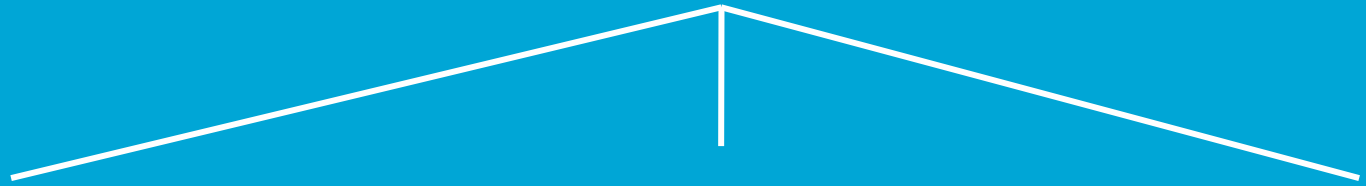
Relevant Branches with Examples



Challenges and Downsides

What is Artificial Intelligence?

Relevant Branches with Examples



Modeling and Predicting

Perception and Computer Vision

Decision Making and Robotics

1. Modeling and Predicting

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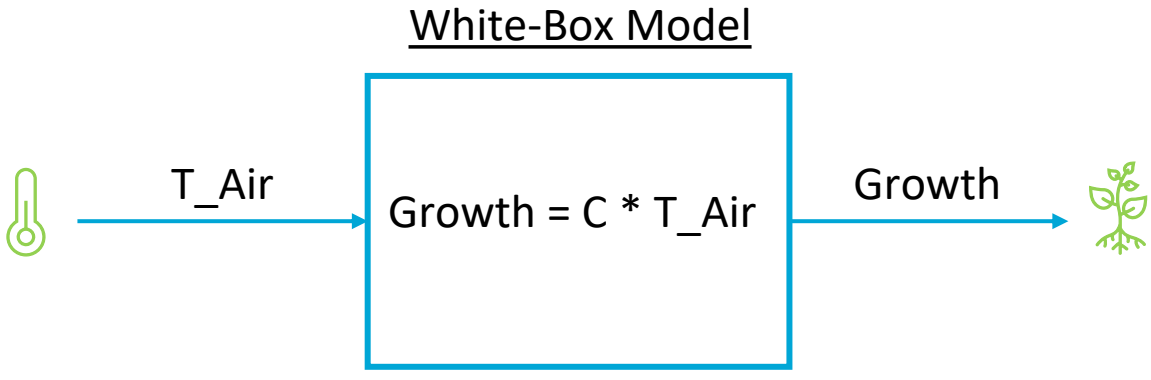


1. Modeling and Predicting

$$\lim_{x\to 1}\frac{\ln(x)}{x-1}\times\lim_{x\to\infty}\frac{68x^4-4x^3+3x^2-8x}{4x^4}+\lim_{x\to 0}\frac{e^{13x}-1}{x}$$

$$-2e^{\pi i}\times\lim_{x\to 0}\frac{e^{13x}-1}{x}+\lim_{x\to 0}\frac{x^2-16}{x-4}$$

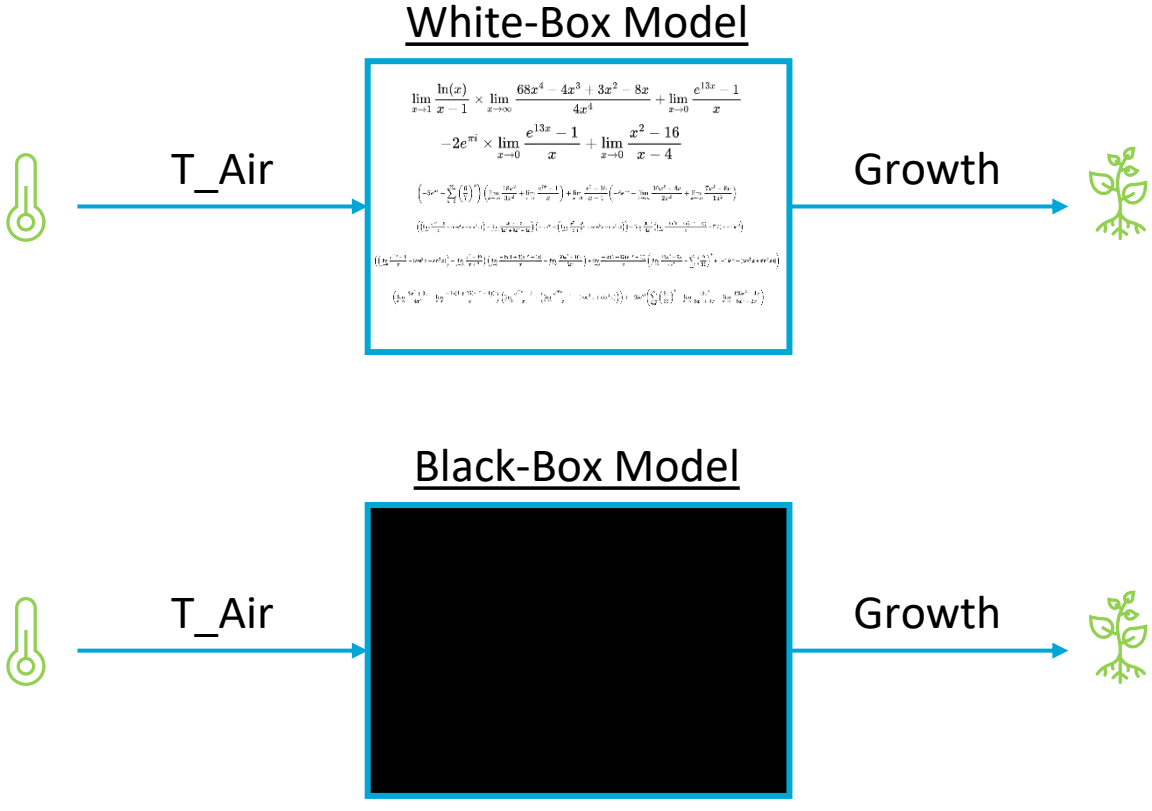
$$\left(-5e^{\pi i}-\sum_{k=0}^{\infty}\left(\frac{6}{7}\right)^k\right)\left(\lim_{x\to\infty}\frac{18x^2}{3x^2}+\lim_{x\to 0}\frac{e^{7x}-1}{x}\right)+\lim_{x\to 3}\frac{x^2-16}{x-4}\left(-6e^{\pi i}-\lim_{x\to\infty}\frac{10x^2-4x}{2x^2}+\lim_{x\to\infty}\frac{7x^2-8x}{1x^2}\right)$$

$$\left(\left(\lim_{x\to 0}\frac{e^{3x}-1}{x}-(\cos^2 x+\sin^2 x)\right)-\lim_{x\to\infty}\frac{45x^3+3x}{3x^3+9x^2-4x}\right)\left(-15e^{\pi i}+\left(\lim_{x\to 22}\frac{x^2-49}{x+7}\times(\cos^2 x+\sin^2 x)\right)\right)+\lim_{x\to\infty}\frac{60x^2}{4x^2}\left(\lim_{x\to 0}\frac{-\ln(1+15(e^{-x}-1))}{x}-\Gamma(3)+-15e^{\pi i}\right)$$

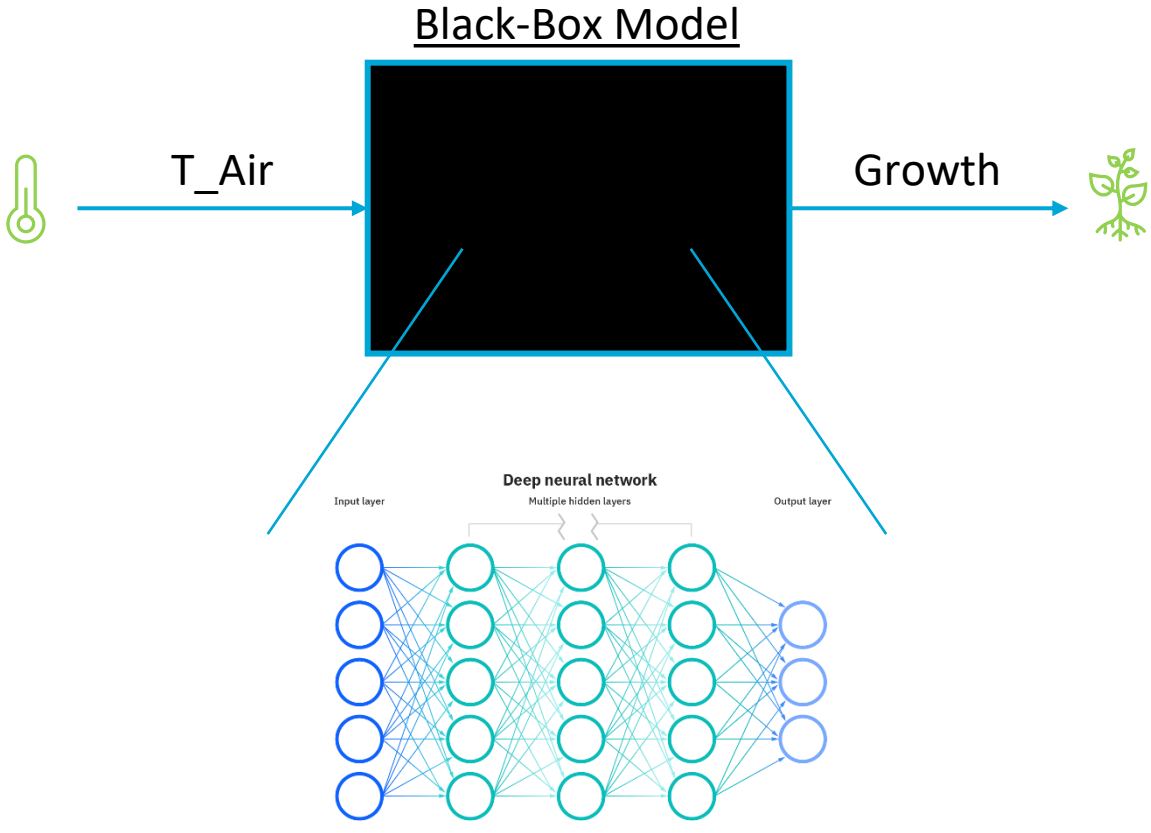
$$\left(\left(\lim_{x\to 0}\frac{e^{11x}-1}{x}-(\cos^2 x+\sin^2 x)\right)-\lim_{x\to 19}\frac{x^2-49}{x+7}\right)\left(\lim_{x\to 0}\frac{-\ln(1+3(e^{-x}-1))}{x}+\lim_{x\to\infty}\frac{60x^2-10x}{5x^2}\right)+\lim_{x\to 0}\frac{-\ln(1+12(e^{-x}-1))}{x}\left(\lim_{x\to\infty}\frac{12x^2+7x}{4x^2}-\sum_{k=0}^{\infty}\left(\frac{9}{10}\right)^k+(-13e^{\pi i}-(\cos^2 x+\sin^2 x))\right)$$

$$\left(\lim_{x\to\infty}\frac{8x^3+3x}{4x^3}-\lim_{x\to 0}\frac{-\ln(1+25(e^{-x}-1))}{x}\right)\left(\lim_{x\to 0}\frac{e^{22x}-1}{x}+\left(\lim_{x\to 0}\frac{e^{26x}-1}{x}-(\cos^2 x+\sin^2 x)\right)\right)+-25e^{\pi i}\left(\sum_{k=0}^{\infty}\left(\frac{21}{22}\right)^k-\lim_{x\to\infty}\frac{10x^2}{5x^2+9x}+\lim_{x\to\infty}\frac{125x^2-4x}{5x^2+2x}\right)$$

1. Modeling and Predicting

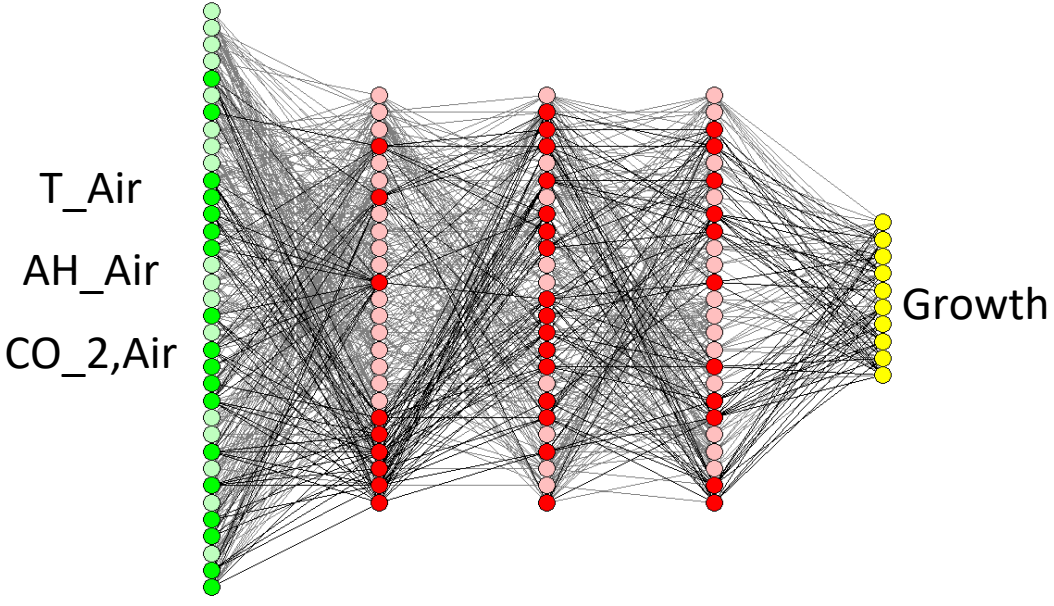


1. Modeling and Predicting: Black-Box Modeling



1. Modeling and Predicting: Neural Network

- Machine Learning: training by showing examples in the form of data



1. Modeling and Predicting

- Why?
- AI driven optimal greenhouse controller

What is Artificial Intelligence?

Relevant Branches with Examples

Modeling and Predicting

Perception and Computer Vision

Decision Making and Robotics

2. Perception and Computer Vision

- Computer/Machine understanding from digital images or videos
- Perception and Classification

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- Computer/Machine understanding from digital images or videos
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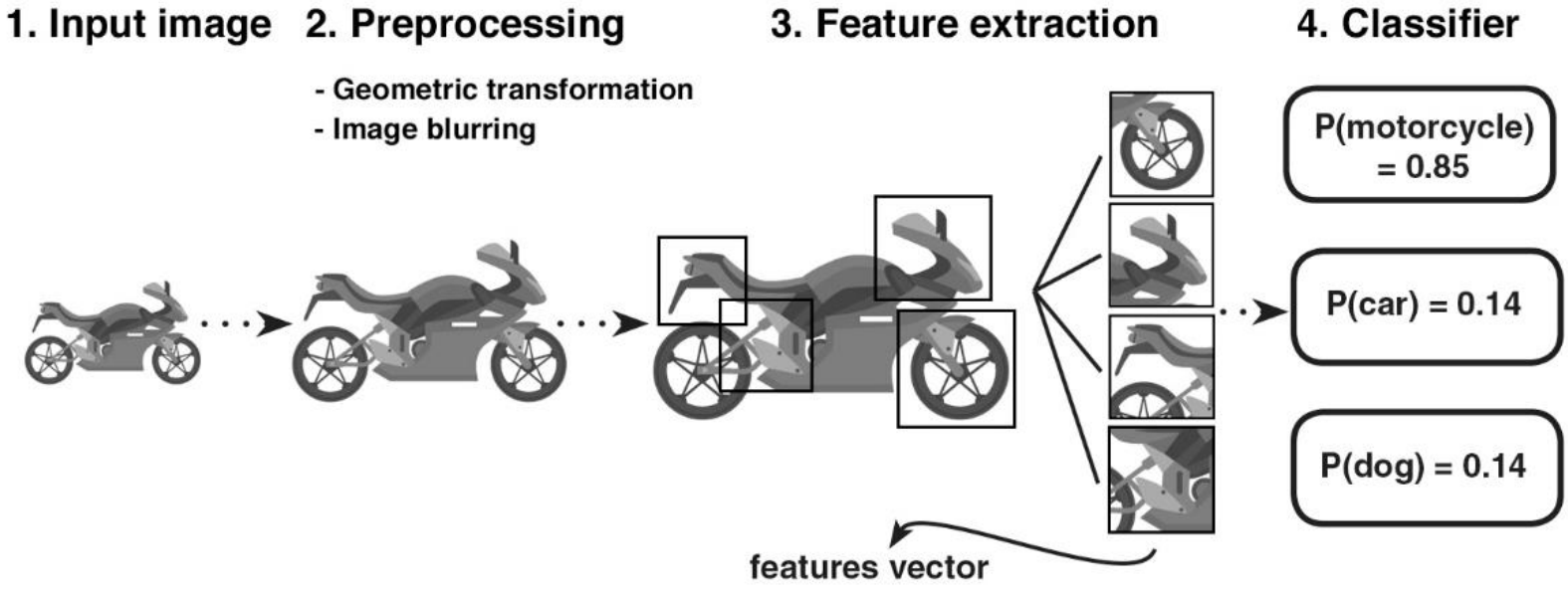
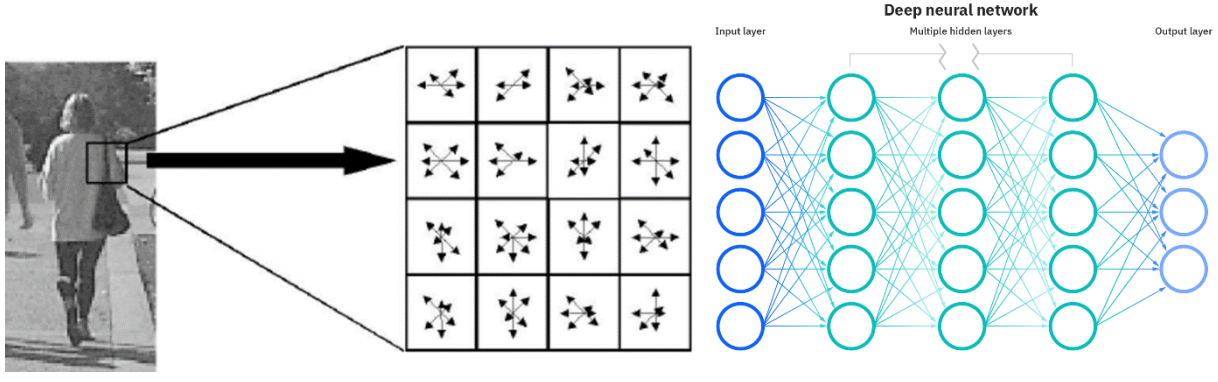
2. Perception and Computer Vision



2. Perception and Computer Vision: Classification

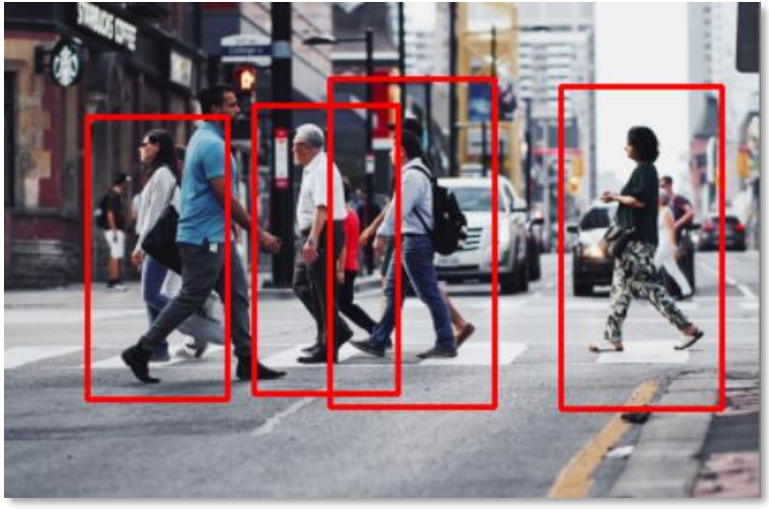
- Step 4: Classifier
- Neural Network



Pedestrian

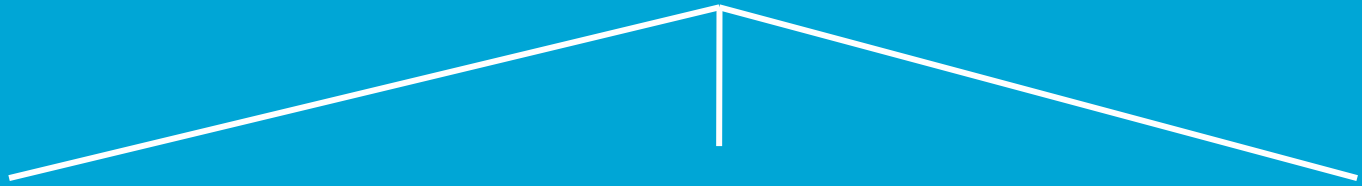
2. Perception and Computer Vision:Machine Learning

- How?
- Machine Learning: Training by examples (a lot)



What is Artificial Intelligence?

Relevant Branches with Examples



Modeling and Predicting

Perception and Computer Vision

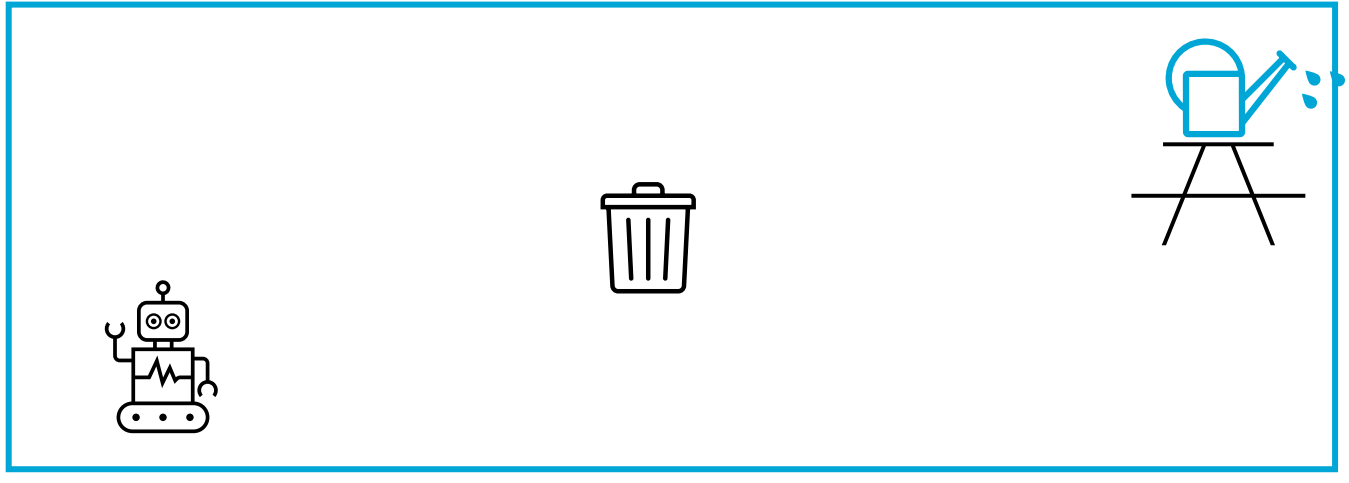
Decision Making and Robotics

3. Decision Making and Robotics

- Combining Perceptions and Predictions to Decisions/Actions

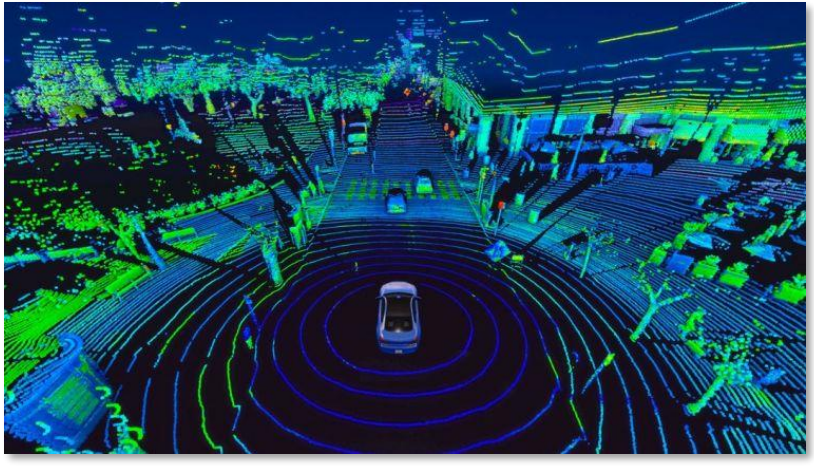
3. Decision Making and Robotics

- Combining Perceptions and Predictions to Decisions/Actions
- Sense-Plan-Act



3. Decision Making and Robotics: Sense

- Sense: Perceiving the surroundings
- Building a knowledge database



3. Decision Making and Robotics: Sense

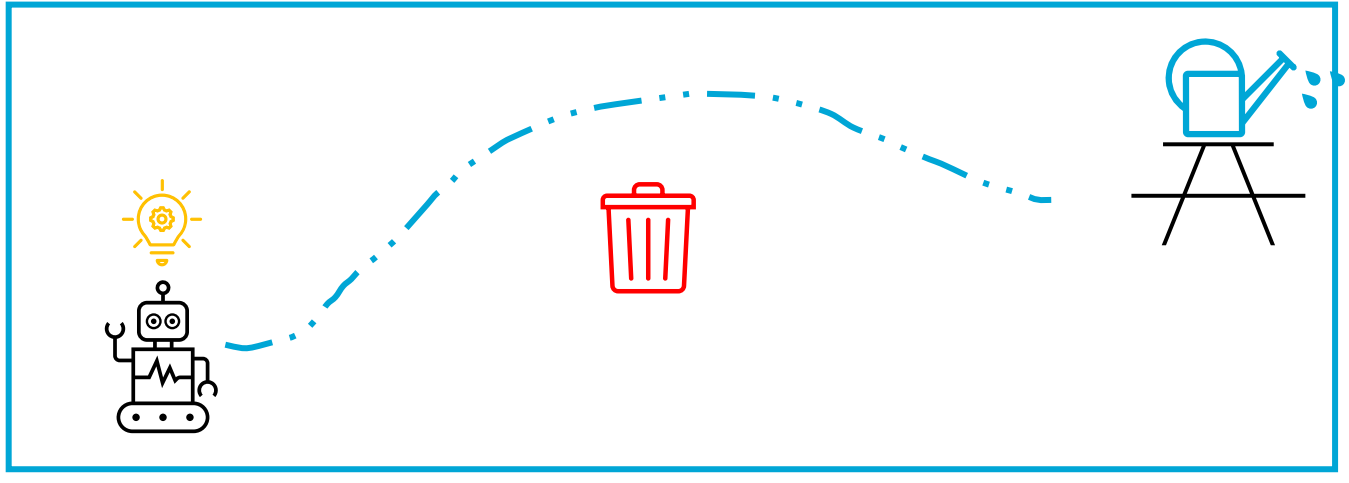
- Sense: Perceiving the surroundings
- Building a knowledge database

3. Decision Making and Robotics: Sense

- Sense: Perceiving the surroundings
- Building a knowledge database

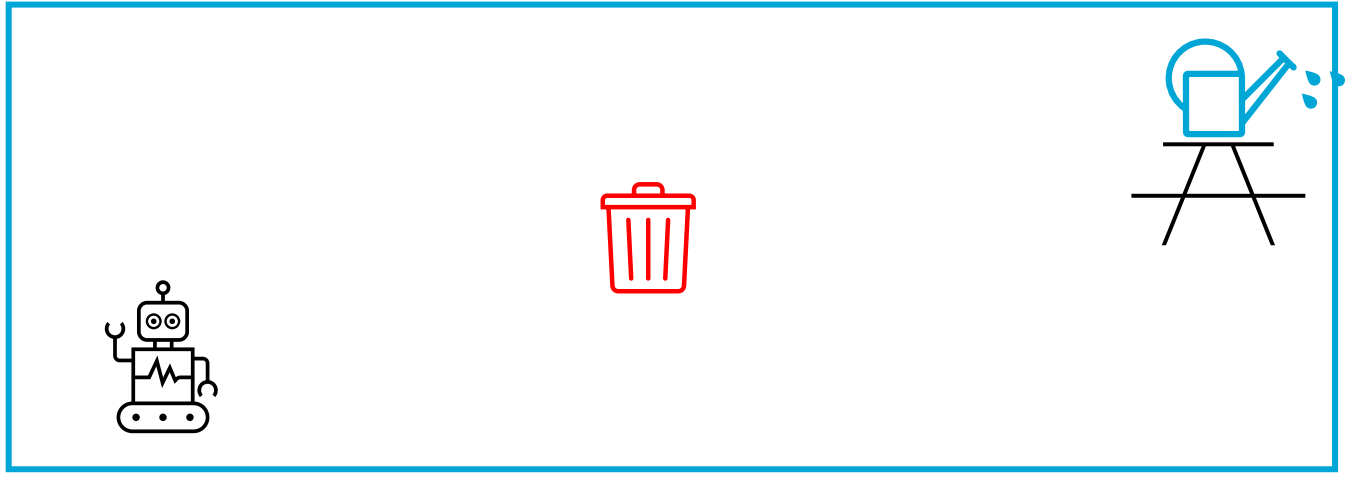
3. Decision Making and Robotics: Plan/Predict

- Plan/Predict: Planning actions
- Reasoning from knowledge base and decision making on actions



3. Decision Making and Robotics: Act

- Act: Actuators



3. Decision Making and Robotics

Machine Learning and AI:

- Sens: Perception; Classifying objects and mapping surroundings

3. Decision Making and Robotics

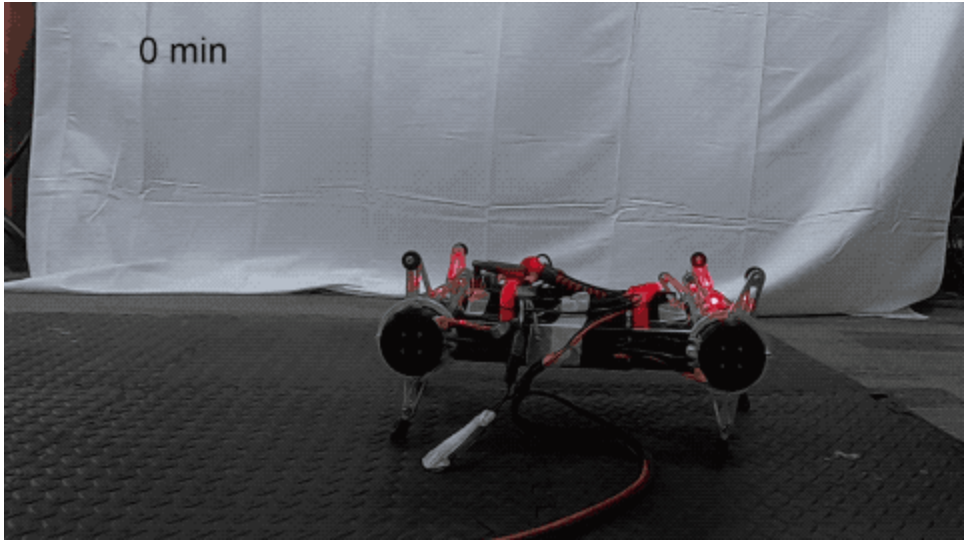
Machine Learning and AI:

- Sens: Perception; Classifying objects and mapping surroundings
- Plan: Reasoning and Decision Making

3. Decision Making and Robotics

Machine Learning and AI:

- Sens: Perception; Classifying objects and mapping surroundings
- Plan: Reasoning and Decision Making
- Acting: learn by trial and error. Reinforcement Learning example:



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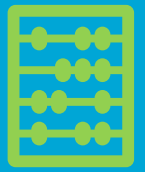
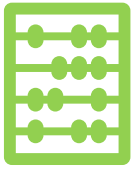
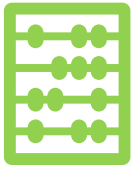


Challenges and Downsides

Challenges and Downsides of AI

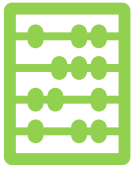


Challenges and Downsides of AI



1. Understandability and Trust

Challenges and Downsides of AI



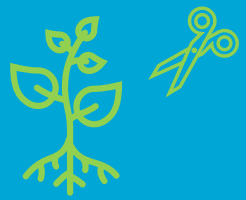
1. Understandability and Trust
2. Ethical problems/Bias
   Amazon example:

Amazon scraps secret AI recruiting tool that showed bias against women

By Jeffrey Dastin

8 MIN READ

Challenges in Horticulture
AI to the rescue!



Lack of
Skilled Labourers

Sustainable and
Resource Efficient Growth

Lack of
Knowledgeable Growers

Lack of Skilled Labourers

a. Tough work

b. Delicate tasks

Lack of Skilled Labourers

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Lack of Skilled Labourers

a. Tough work
b. Delicate tasks

Lack of Skilled Labourers: Robotic solutions

a. Harvesting and Pruning Robots

Lack of Skilled Labourers: Robotic solutions

a. Harvesting and Pruning Robots

b. AI plays a major role:

1. Perception and Computer Vision: Recognizing the tomato
2. Planning the actions: moving and picking

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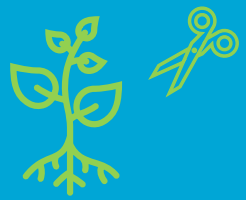
Robotic solutions: Technical difficulties

1. Reliability
2. Speed

Challenges in Horticulture
AI to the rescue!



Lack of
Skilled Labourers

Sustainable and
Resource Efficient Growth

Lack of
Knowledgeable Growers

Sustainable and Resource Efficient Growth

a. Resource Efficient Growth

Sustainable and Resource Efficient Growth

a. Resource Efficient Growth
b. Automatic Optimal Climate Controllers
c. Objective function = W_1 * growth – W_2 resource usage
d. Predicting the future

Sustainable and Resource Efficient Growth: AGC

a. Autonomous Greenhouse Challenge by Wageningen University and Research
b. TU Delft: Automatoes 2020

automatoes

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Challenges in Horticulture
AI to the rescue!

Lack of
Skilled Labourers

Sustainable and
Resource Efficient Growth

Lack of
Knowledgeable Growers

Lack of Knowledgeable Growers

a. Taking away tasks of the grower

Lack of Knowledgeable Growers

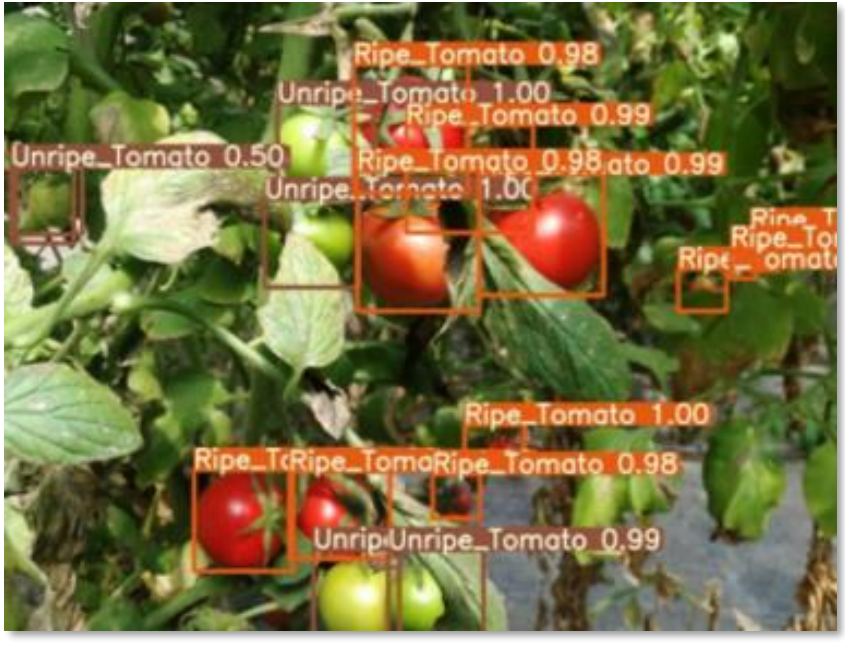
a. Taking away tasks of the grower
b. Automated measurements to generate more data:

Lack of Knowledgeable Growers

a. Taking away tasks of the grower

b. Automated measurements to generate more data:

1. Quality and ripeness inspection

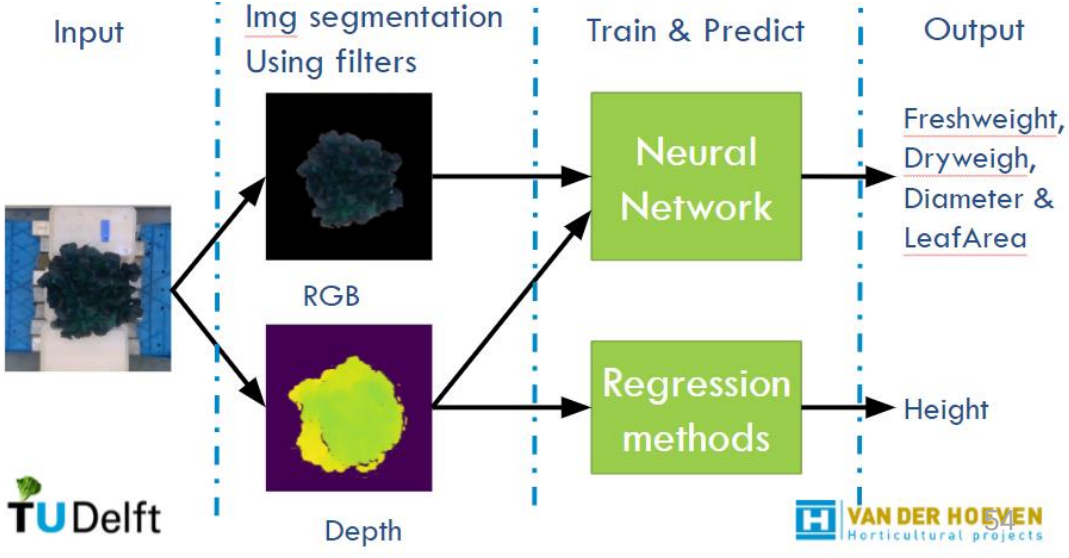


Lack of Knowledgeable Growers

a. Taking away tasks of the grower

b. Automated measurements to generate more data:

1. Quality and ripeness inspection
2. Leaf Area and Dry Weight detection



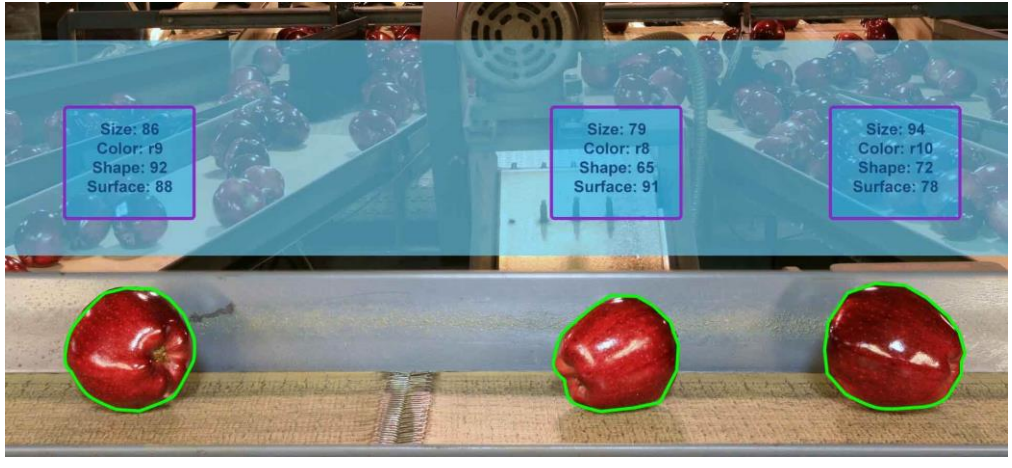
Lack of Knowledgeable Growers

a. Taking away tasks of the grower

b. Automated measurements to generate more data:

1. Quality and ripeness inspection
2. Leaf Area and Dry Weight detection

Can be used for predicting harvest moment and sorting



Lessons Learned

Gradual Automation

Human/AI Interaction

1. Gradual Automation

“Rome was not build in one day”

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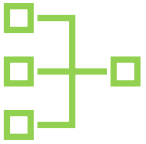
1. Gradual Automation



"Rome was not build in one day"

"Autonomous greenhouses will not be build in one day"

1. Gradual Automation

a. Gradual sustainability and automation

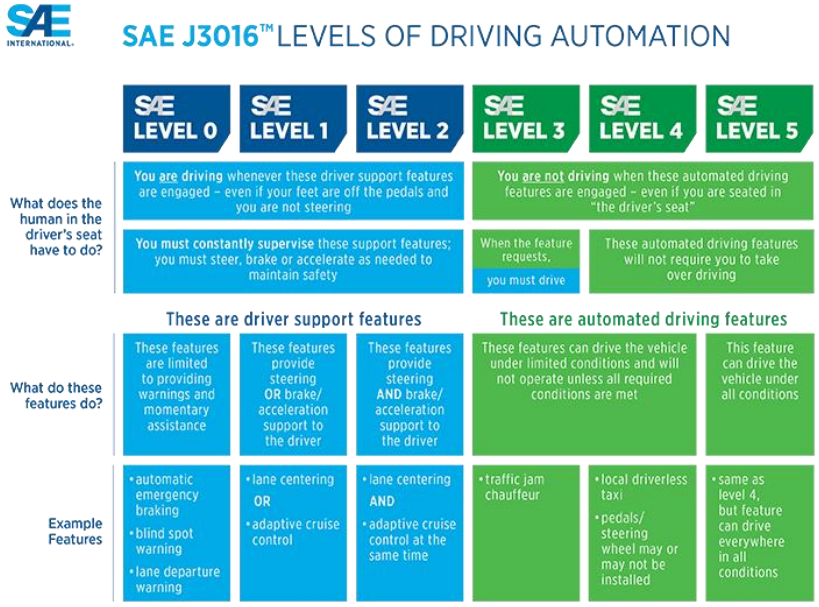
b. Classification Framework for autonomous growing methods

1. Gradual Automation

a. Gradual sustainability and automation

b. Classification Framework for automatous growing methods

c. SAE Framework for Autonomous Driving



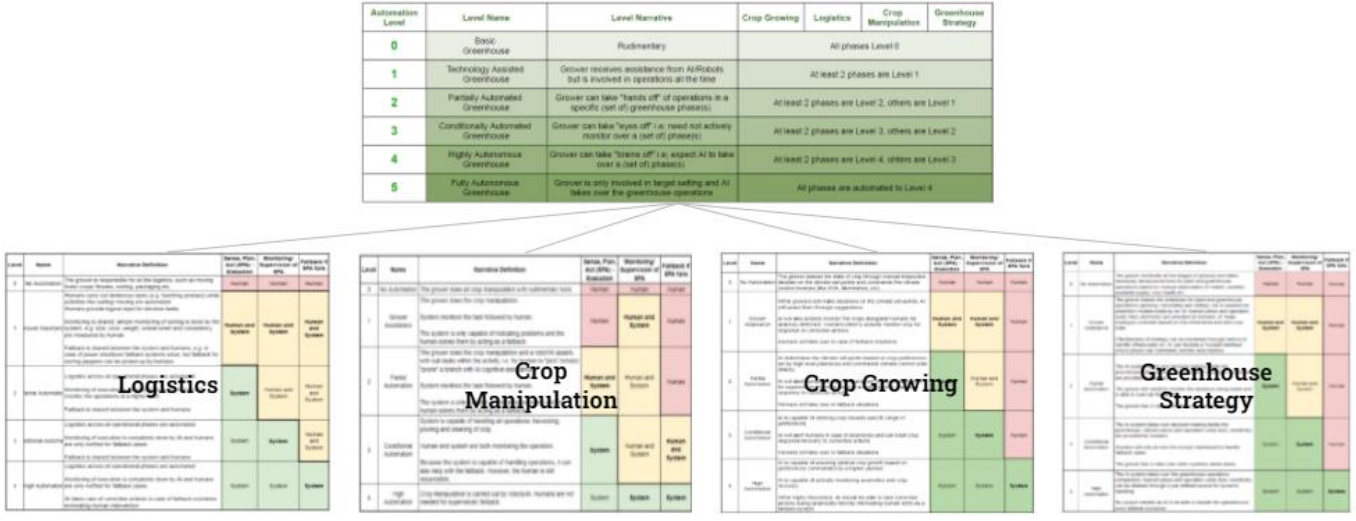
1. Gradual Automation

a. Gradual sustainability and automation

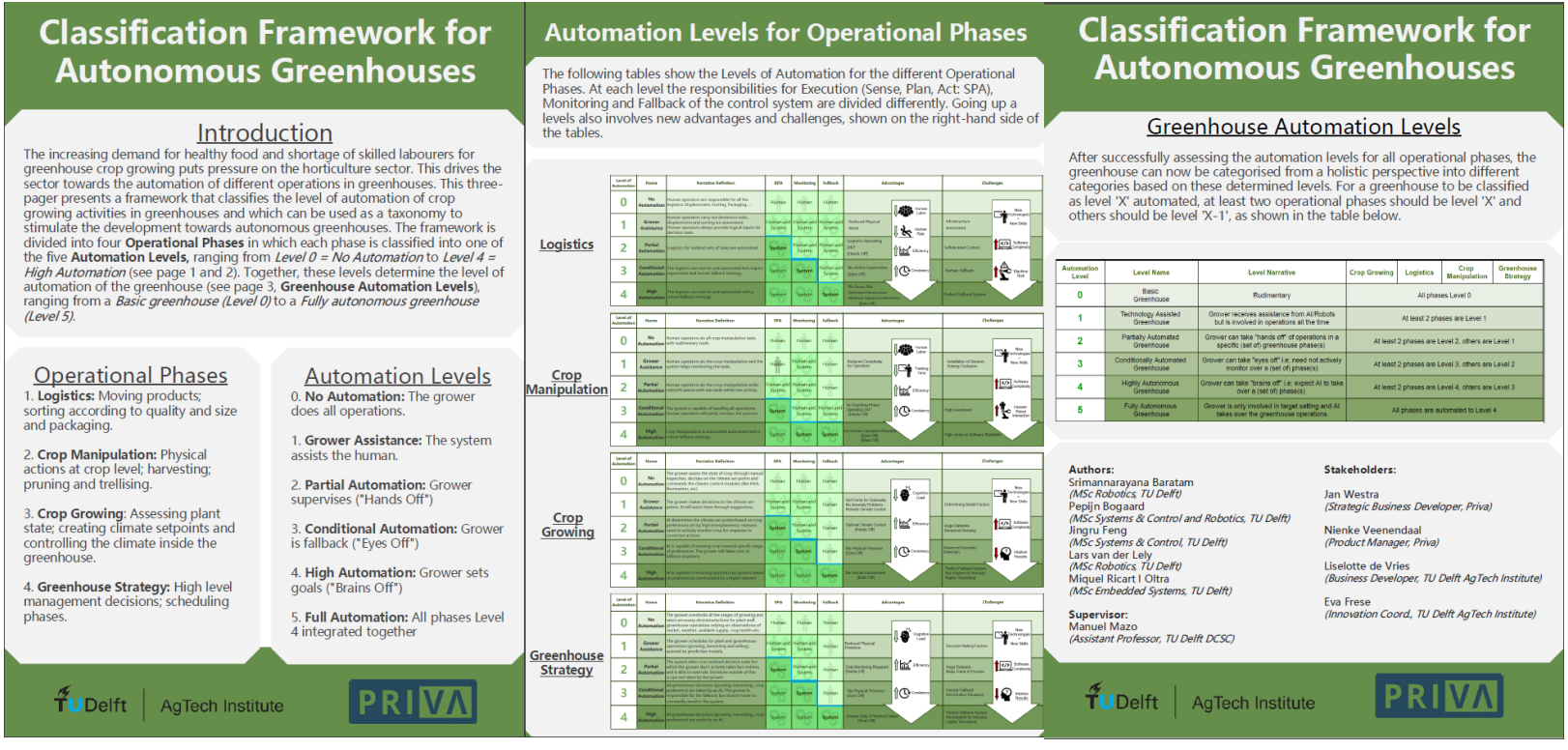
b. Classification Framework for automatous growing methods

c. SAE Framework for Autonomous Driving

d. Our version



1. Gradual Automation



Classification Framework for Autonomous Greenhouses

Introduction

The increasing demand for healthy food and shortage of skilled labourers for greenhouse crop growing puts pressure on the horticulture sector. This drives the sector towards the automation of different operations in greenhouses. This three-pager presents a framework that classifies the level of automation of crop growing activities in greenhouses and which can be used as a taxonomy to stimulate the development towards autonomous greenhouses. The framework is divided into four **Operational Phases** in which each phase is classified into one of the five **Automation Levels,** ranging from *Level 0 = No Automation* to *Level 4 = High Automation* (see page 1 and 2). Together, these levels determine the level of automation of the greenhouse (see page 3, **Greenhouse Automation Levels**), ranging from a *Basic greenhouse (Level 0)* to a *Fully autonomous greenhouse (Level 5).*

Operational Phases

1. **Logistics:** Moving products; sorting according to quality and size and packaging.

2. **Crop Manipulation:** Physical actions at crop level; harvesting; pruning and trellising.

3. **Crop Growing**: Assessing plant state; creating climate setpoints and controlling the climate inside the greenhouse.

4. **Greenhouse Strategy:** High level management decisions; scheduling phases.

Automation Levels

0. **No Automation:** The grower does all operations.

1. **Grower Assistance:** The system assists the human.

2. **Partial Automation:** Grower supervises ("Hands Off")

3. **Conditional Automation:** Grower is fallback ("Eyes Off")

4. **High Automation:** Grower sets goals ("Brains Off")

5. **Full Automation:** All phases Level 4 integrated together

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Automation Levels for Operational Phases

The following tables show the Levels of Automation for the different Operational Phases. At each level the responsibilities for Execution (Sense, Plan, Act: SPA), Monitoring and Fallback of the control system are divided differently. Going up a levels also involves new advantages and challenges, shown on the right-hand side of the tables.

Logistics

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	Human operators are responsible for all the logistics (Replacement, Sorting, Packaging, ...)	Human	Human	Human	Reduced Physical Work	Infrastructure Investment
1	Grower Assistance	Human operators using tools or devices (tools, replacement and sorting are automated). Human operators always provide logical inputs for decision tasks.	Human with System	Human with System	Human with System	Logistics Operating 24/7 (Hands Off)	Self-Actuated Control
2	Partial Automation	Logistics for isolated sets of tasks are automated.	System	Human with System	Human	Not Active Supervision (Eyes Off)	Human Fallback
3	Conditional Automation	The logistics are end-to-end automated but require supervision and human fallback strategy.	System	System	Human	No Human Effort (Brains Off)	Machine Trust
4	High Automation	The logistics are end-to-end automated with a robust fallback strategy.	System	System	System	No Human Effort (Brains Off)	Perfect Fallback System

Crop Manipulation

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	Human operators do all crop manipulation tasks with rudimentary tools.	Human	Human	Human	Reduced Complexity for Operators	Installation of Sensors Taking Outcomes
1	Grower Assistance	Human operators do the crop manipulation and the system helps monitoring the tasks.	Human	Human with System	Human	Training Time	New Technologies
2	Partial Automation	Human operators do the crop manipulation while network assists with sub-tasks within the activity.	Human with System	Human with System	Human	Efficiency	Software Complexity
3	Conditional Automation	The system is capable of handling all operations. Human operators still partly monitor the process.	System	System	Human	No Training Phase Operating 24/7 (Hands Off)	High Investment
4	High Automation	Crop manipulation is automated and has a robust fallback strategy.	System	System	System	No Human Operations (Eyes Off)	Human Human Interaction

Crop Growing

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	The grower assess the state of crop through manual inspection, decides on the climate set-points and constructs the climate control modules (like HVA, thermostat, etc.)	Human	Human	Human	Cognitive Load	New Technologies
1	Grower Assistance	The grower makes decisions on the climate set-points. A staff exact them through suggestions	Human	Human with System	Human	Bad Name for Optimality, No Anomaly Problems Maintain Climate Control	Determining Model Factors
2	Partial Automation	It determines the climate set-points based on crop preferences set by high-level planners). Humans need to actively monitor crop for response to corrective actions	System	Human with System	Human	Efficiency	Software Complexity
3	Conditional Automation	It is capable of steering crop towards specific range of preferences. The grower still takes over in fallback situations.	System	System	Human	Optimal Climate Control (Hands Off)	High Datasets Advanced Sensing
4	High Automation	It is capable of steering optimal crop growth based on preferences commanded by a higher planner.	System	System	System	No Physical Presence (Eyes Off)	Advanced Anomaly Detection
						No Human Involvement (Brains Off)	Perfect Fallback System Not Applicable for Humans Highly Theoretical

Greenhouse Strategy

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	The grower overlooks all the stages of growing and takes necessary decisions/actions for plant and greenhouse operations relying on observations of market, weather, available supply, crop health etc).	Human	Human	Human	Cognitive Load	New Technologies
1	Grower Assistance	The grower schedules for plant and greenhouse operations (growing, harvesting and selling), assisted by prediction models.	Human with System	Human with System	Human	Reduced Physical Presence	Decision Making Factors
2	Partial Automation	The system takes over isolated decision tasks for which the grower don't actively take, but reviews and is able to override. Decisions outside of the crop are taken by the grower.	System	Human with System	Human	Efficiency	Huge Datasets Keep Track of Process
3	Conditional Automation	The system schedules (growing, harvesting, crop preferences) are taken by an AI. The grower is responsible for the fallback, but doesn't have to constantly monitor the system.	System	System	Human	No Physical Presence (Eyes Off)	Human Fallback Not Intuitive Situations
4	High Automation	All greenhouse decisions (growing, harvesting, crop preferences) are made by an AI.	System	System	System	Green Body Of Physical Presence (Brains Off)	Perfect Fallback System Not Applicable for Humans Highly Theoretical

Classification Framework for Autonomous Greenhouses

Greenhouse Automation Levels

After successfully assessing the automation levels for all operational phases, the greenhouse can now be categorised from a holistic perspective into different categories based on these determined levels. For a greenhouse to be classified as level 'X' automated, at least two operational phases should be level 'X' and others should be level 'X-1', as shown in the table below.

Automation Level	Level Name	Level Narrative	Crop Growing	Logistics	Crop Manipulation	Greenhouse Strategy
0	Basic Greenhouse	Rudimentary	All phases Level 0			
1	Technology Assisted Greenhouse	Grower receives assistance from AI/Robots but is involved in operations all the time	At least 2 phases are Level 1			
2	Partially Automated Greenhouse	Grower can take "hands off" operations in a specific (set of) greenhouse phase(s)	At least 2 phases are Level 2, others are Level 1			
3	Conditionally Automated Greenhouse	Grower can take "eyes off" i.e. need not actively monitor over a (set of) phase(s)	At least 2 phases are Level 3, others are Level 2			
4	Highly Autonomous Greenhouse	Grower can take "brains off" i.e. expect AI to take over a (set of) phase(s)	At least 2 phases are Level 4, others are Level 3			
5	Fully Autonomous Greenhouse	Grower is only involved in target setting and AI takes over the greenhouse operations	All phases are automated to Level 4			

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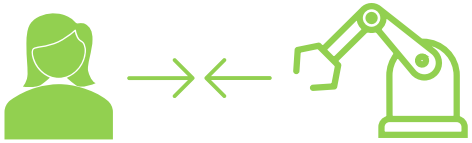
Lessons Learned

Gradual Automation

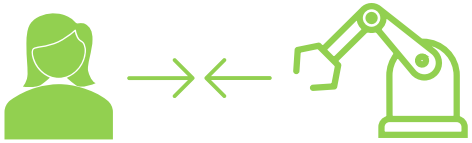
Human/AI Interaction

2. Human/AI Interaction



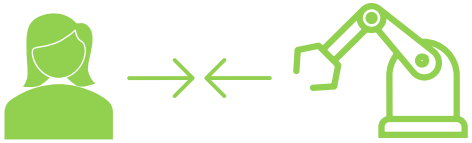
a. AI and human working together

2. Human/AI Interaction



a. AI and human working together
b. AI: Complex Correlations, Automation of known Processes and Consistency
c. Human: Problem Solving and Delicate Tasks

2. Human/AI Interaction : Example



AI detects consistently; Human cuts

2. Human/AI Interaction : Example

AI detects consistently; Human cuts

Stimulating Innovation

TU Delft AgTech Institute

- Industry/University collaboration
- Create opportunities for students: Classification project, Autonomous Greenhouse Challenge

AI for strawberry harvest predictions

- Mathijs de Weerdt
- Harvest time has major impact on quality
- Machine Learning and Computer Vision to predict harvest time per fruit. Continuous measumerements at larger scale.
- AI processes Images

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New generation

- Hackathon
- We need new engineers!
- How can data help the grower?

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Thank you for your interest and attention

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Question to you!

How can AI in improve horticulture ?