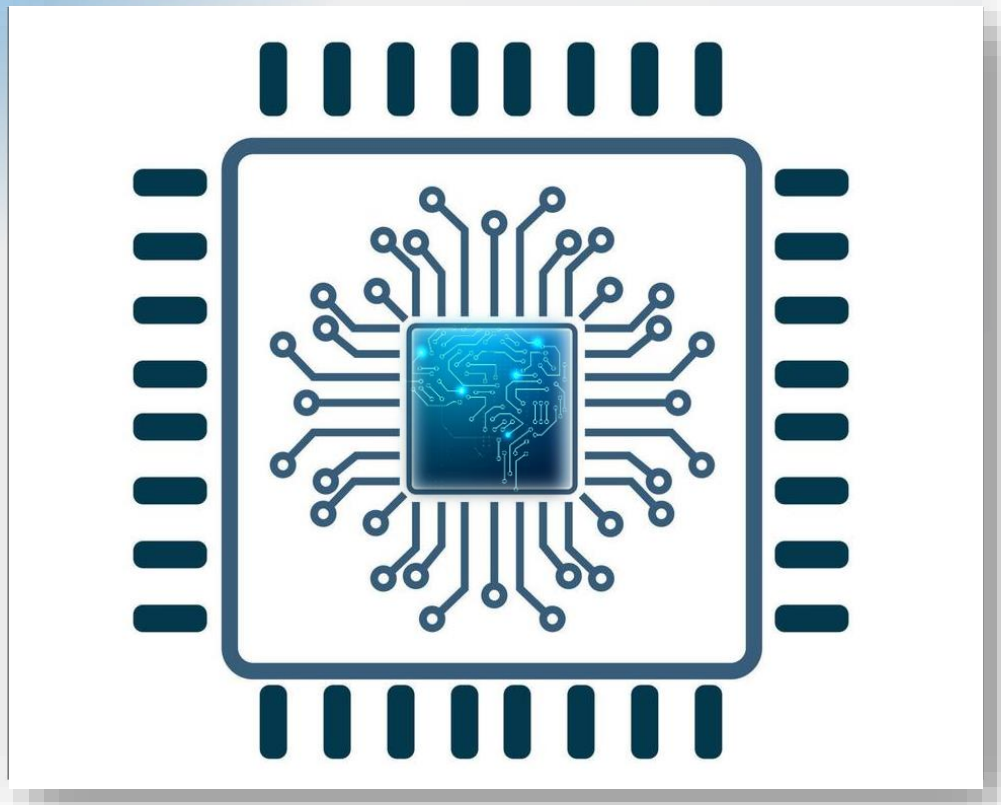
AI-Autonomous Robots for Agriculture – Weeding with Laser

WeLASER Summer School



AI controllers for autonomous robots

Luis Emmi
luis.emmi@car.upm-csic.es

Monday, July 10, 2023

Funded by the Horizon 2020 programme of the European Union

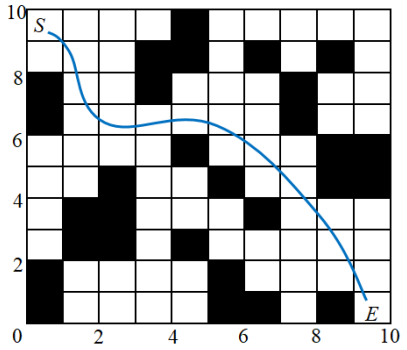
Index

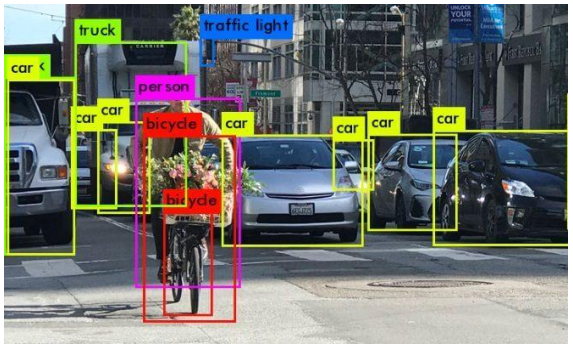
- Fundamentals of AI Controllers
- Sensing and Understanding the Environment
- Decision-Making: Intelligent Algorithms and Planning
- Controlling Robot Movements
- WeLASER case study
- Challenges and Future Directions

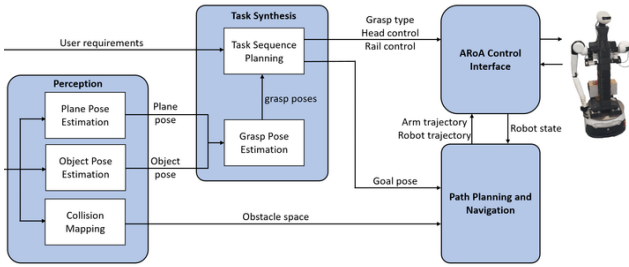
Fundamentals of AI Controllers

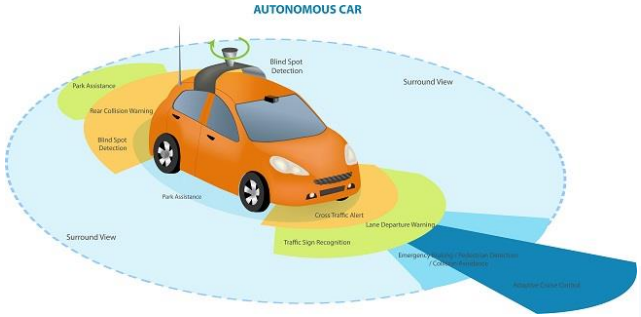
❑ Control systems in autonomous robots

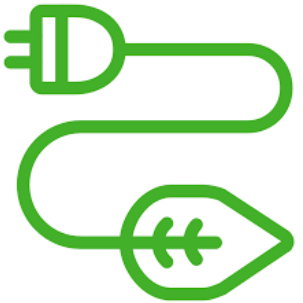
- ❖ Navigation and Path Planning
- ❖ Object Detection and Recognition
- ❖ Manipulation and Grasping
- ❖ Task Execution and Coordination
- ❖ Collision Avoidance and Safety
- ❖ Energy Management





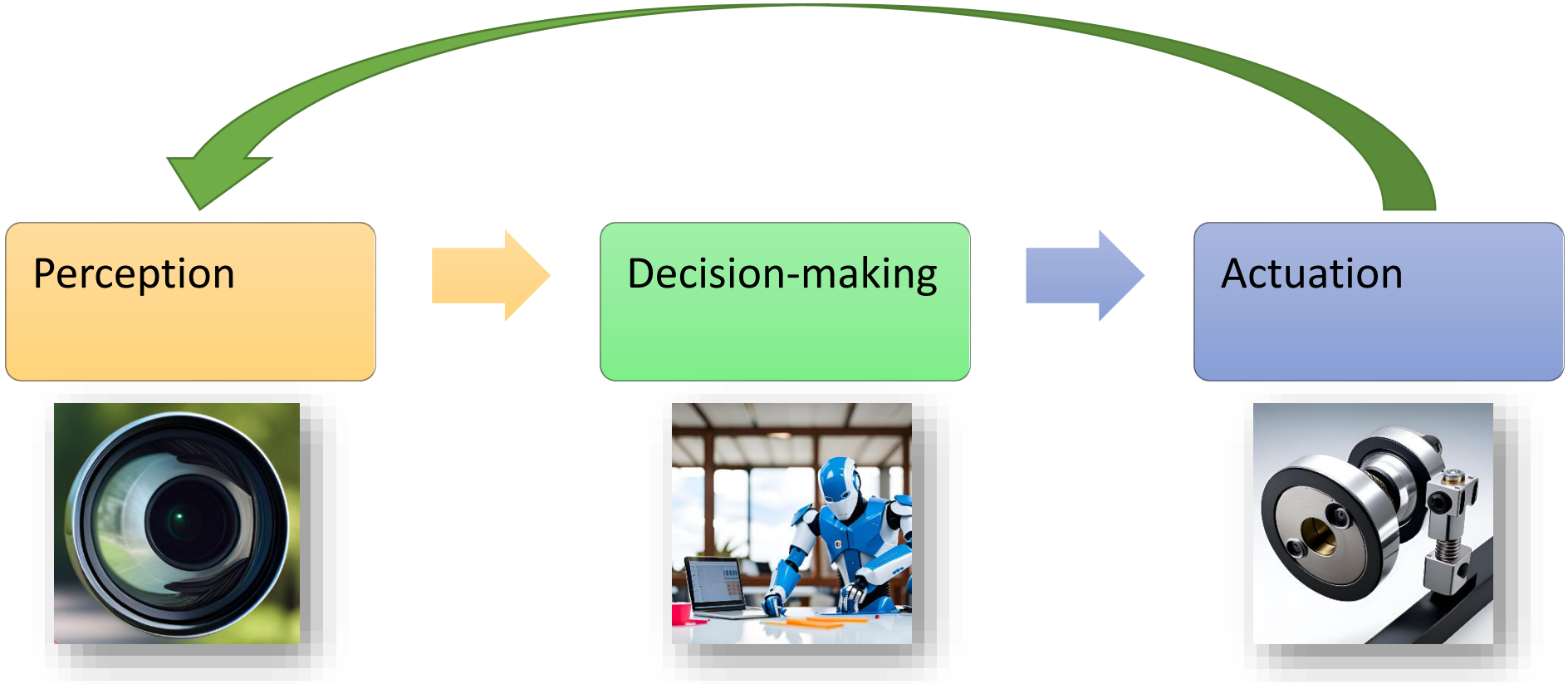






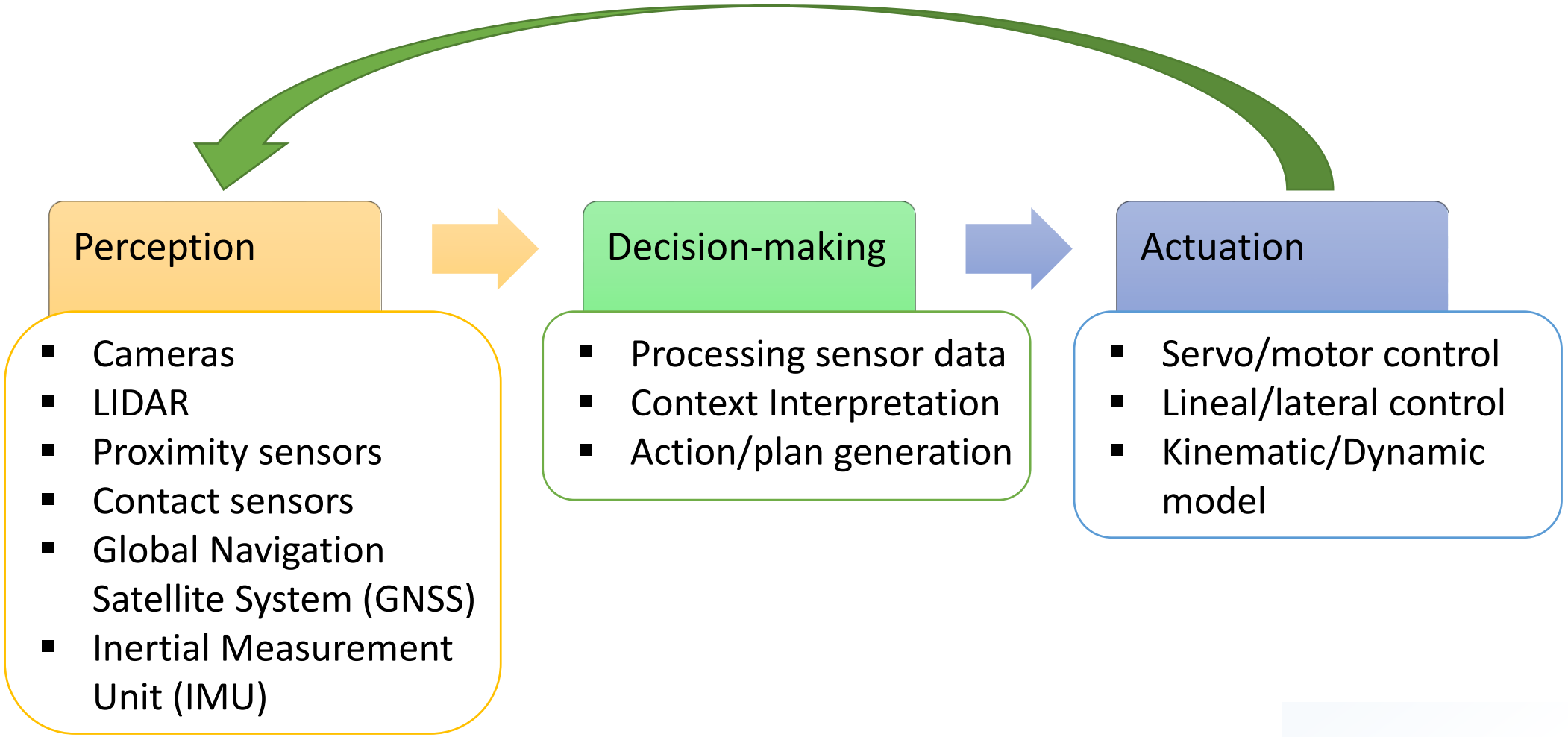
Fundamentals of AI Controllers

❑ Control System for autonomous navigation



Fundamentals of AI Controllers

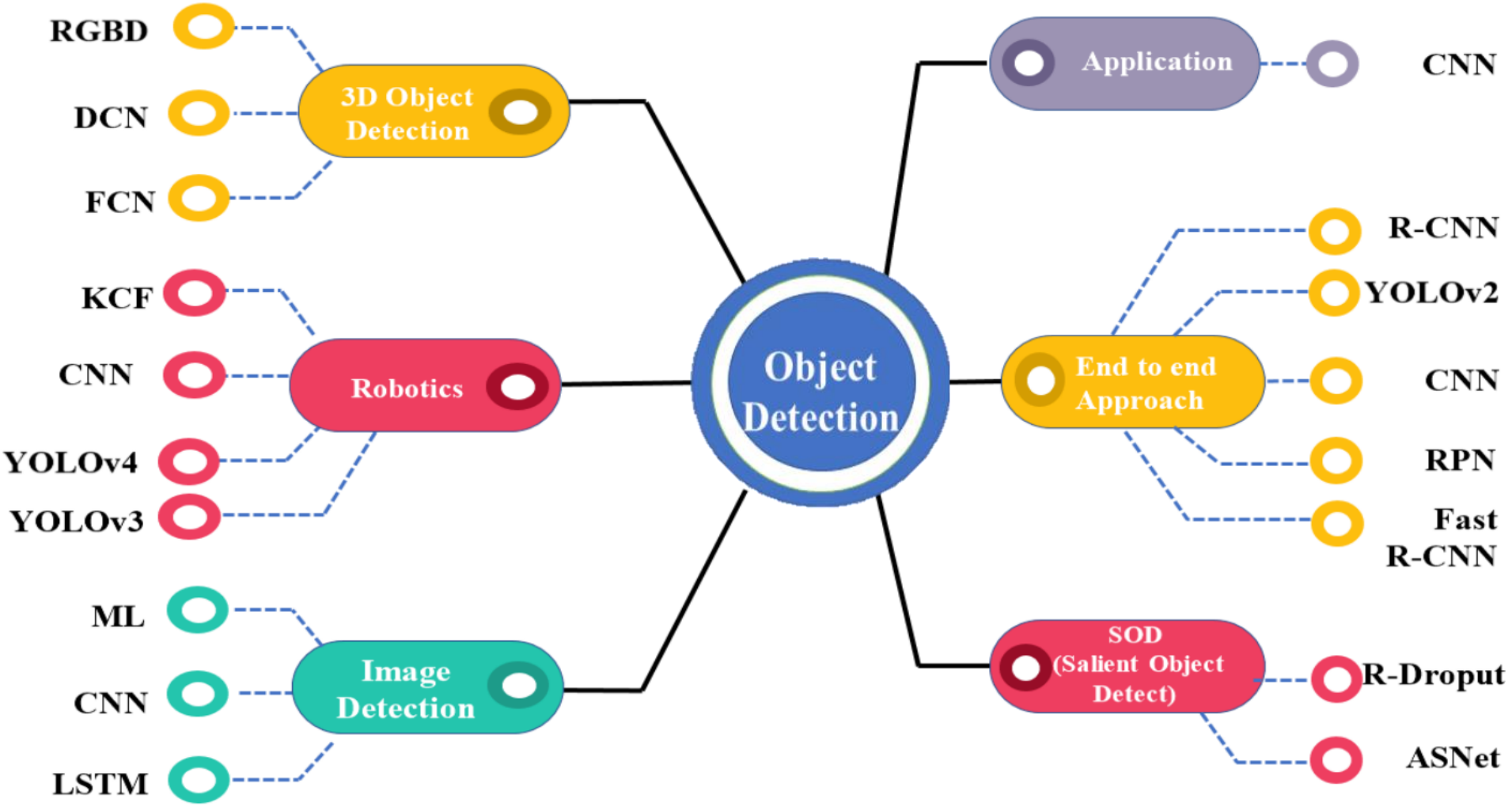
❑ Control System for autonomous navigation



Sensing and Understanding the Environment

Perception

❑ Object detection



Xu, G., Khan, A. S., Moshayedi, A. J., Zhang, X., & Shuxin, Y. (2022). The Object Detection, Perspective and Obstacles In Robotic: A Review. EAI Endorsed Transactions on AI and Robotics, 1(1).

❑ Image-based object detection: Mask R-CNN

He, K., Gkioxari, G., Dollár, P., & Girshick, R. (2017). Mask r-cnn. In Proceedings of the IEEE international conference on computer vision (pp. 2961-2969).

WeLASER

❑ Image-based object detection: Mask R-CNN

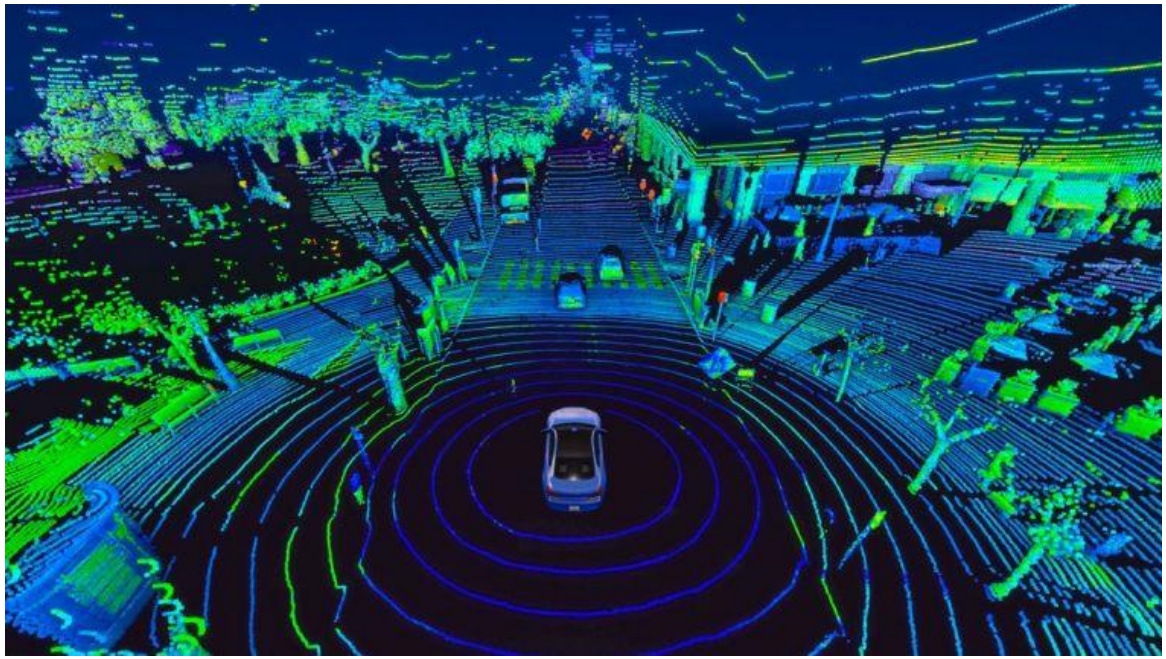
Jia, W., Tian, Y., Luo, R., Zhang, Z., Lian, J., & Zheng, Y. (2020). Detection and segmentation of overlapped fruits based on optimized mask R-CNN application in apple harvesting robot. Computers and Electronics in Agriculture, 172.

Santos, T. T., de Souza, L. L., dos Santos, A. A., & Avila, S. (2020). Grape detection, segmentation, and tracking using deep neural networks and three-dimensional association. Compag, 170.

Sensing and Understanding the Environment

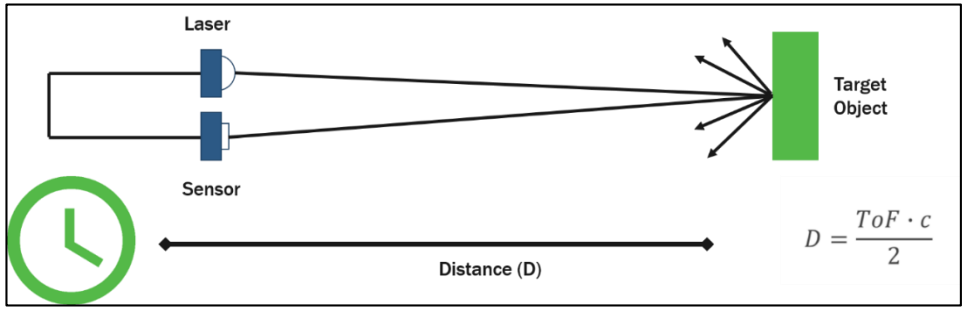
Perception

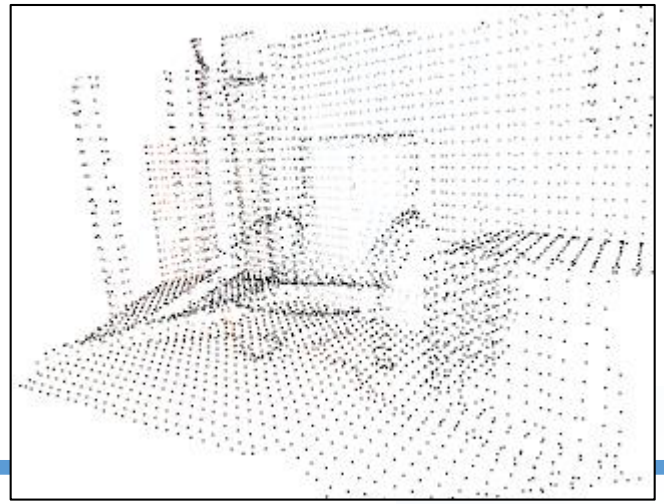
❑ Point cloud segmentation



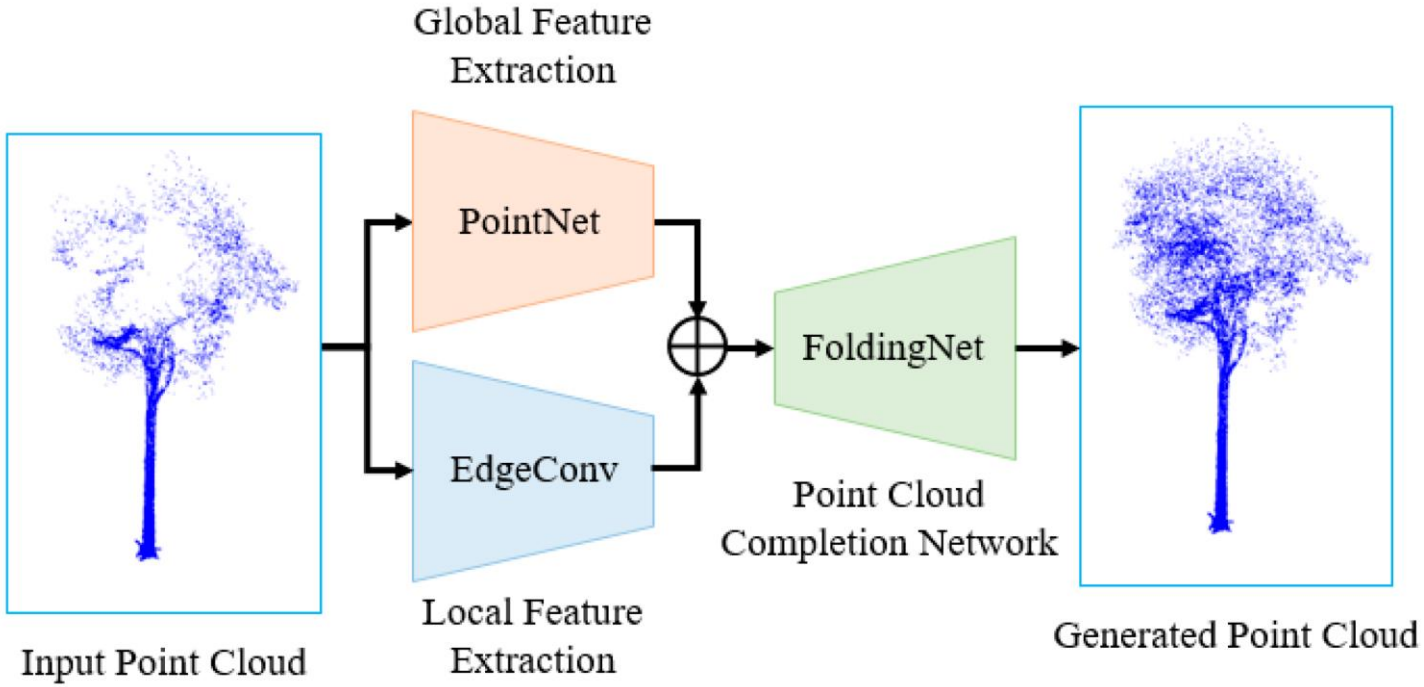
3D LIDARS

Time of Flight (ToF) Cameras





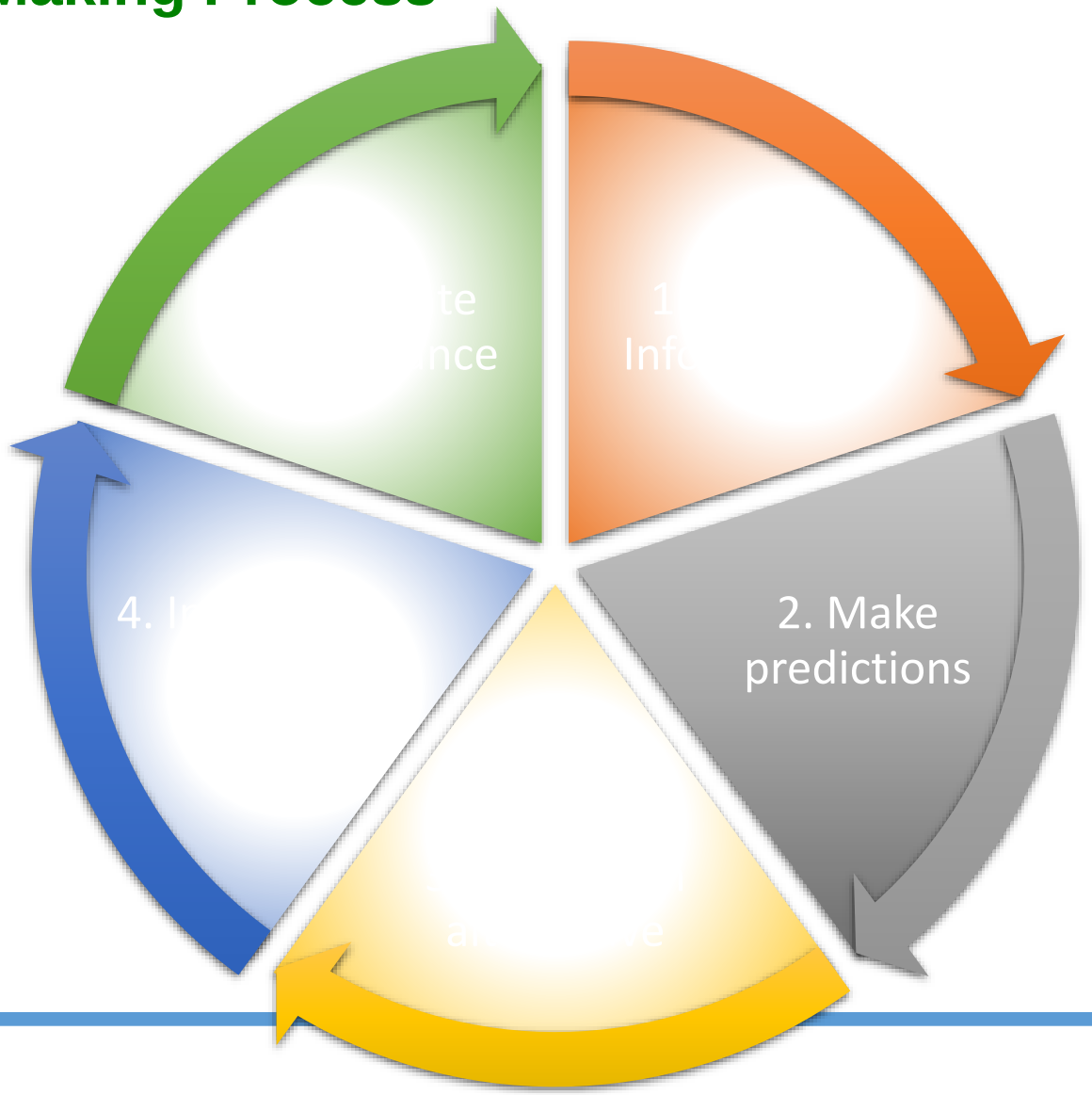
❑ Point cloud segmentation



Xu, D.; Chen, G.; Jing, W. A Single-Tree Point Cloud Completion Approach of Feature Fusion for Agricultural Robots. Electronics 2023, 12, 1296.

Decision-Making: Intelligent Algorithms and Planning

❑ Decision Making Process



Decision-Making: Intelligent Algorithms and Planning

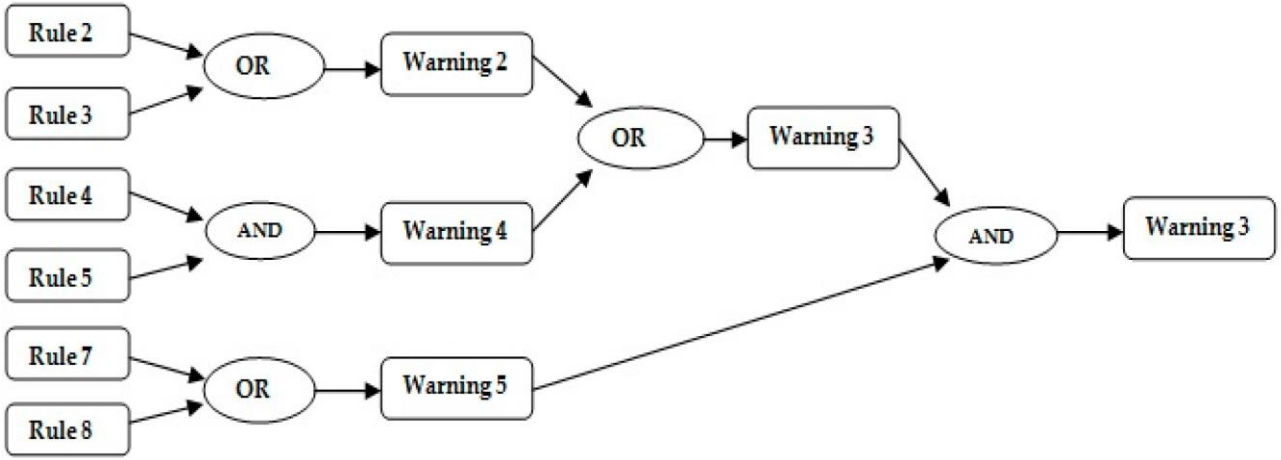
❑ Decision-making techniques

- ❑ Rule-based systems
- ❑ Expert systems
- ❑ Machine learning algorithms

Decision-Making: Intelligent Algorithms and Planning

❑ Decision-making techniques

- ❑ Rule-based systems



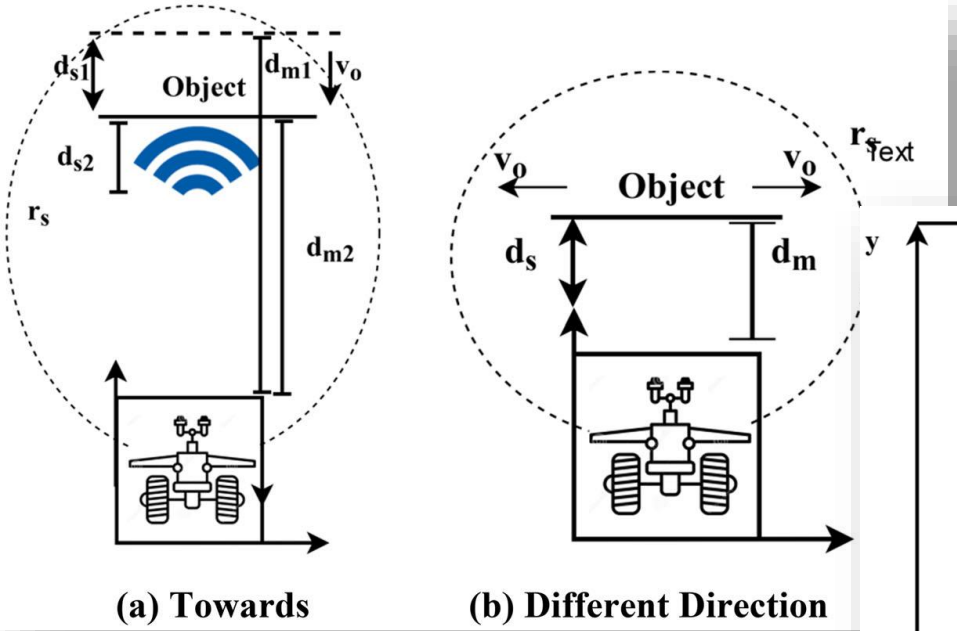
- ❑ Expert systems

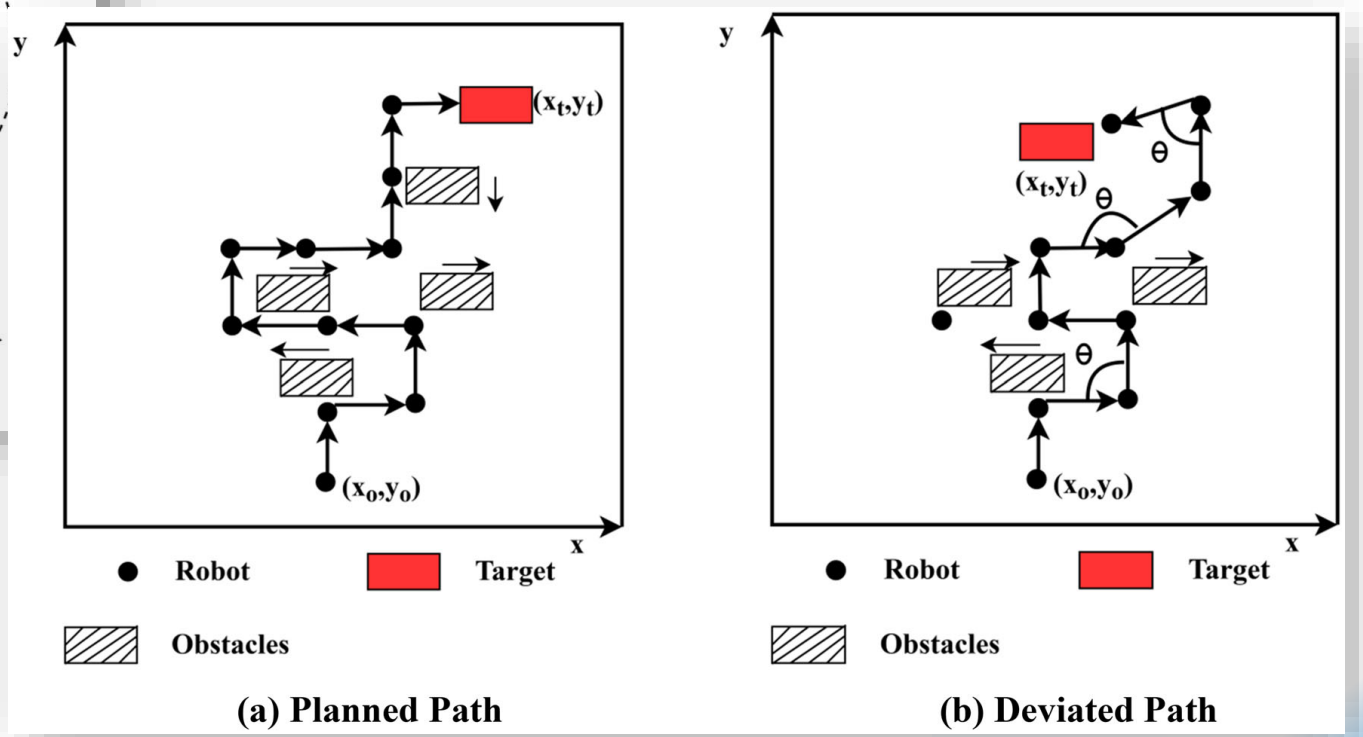
- ❑ Machine learning algorithms

Decision-Making: Intelligent Algorithms and Planning

❑ Decision-making techniques

❑ Rule-based systems

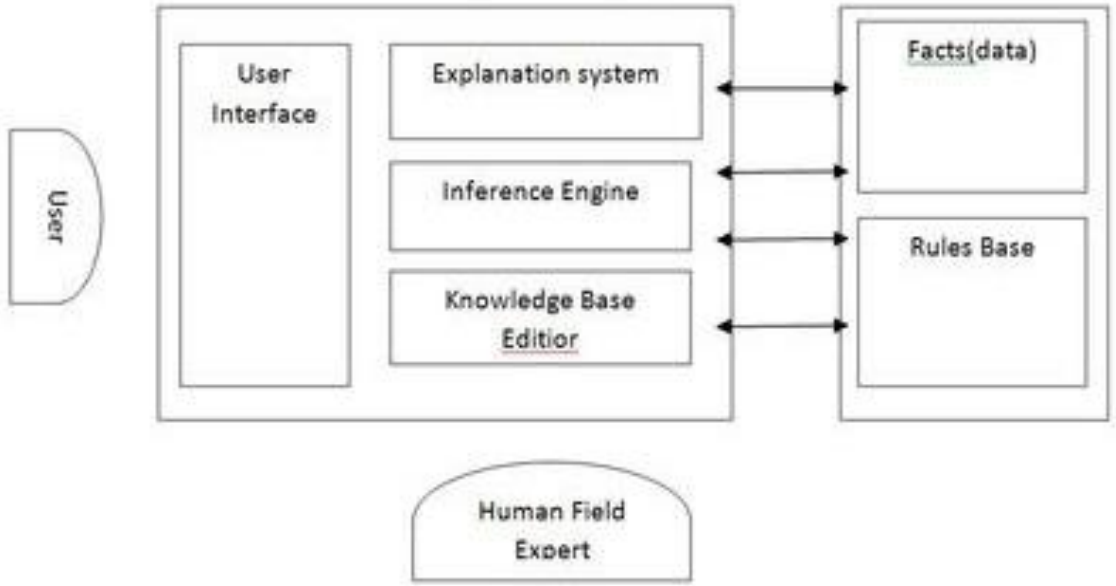




Arun, K.K., Mydhili, S.K., Baskar, S. et al. Fuzzy rule-based environment-aware autonomous mobile robots for actuated touring. Intel Serv Robotics 15, 427–436 (2022).

❑ Decision-making techniques

- ❑ Rule-based systems
- ❑ Expert systems



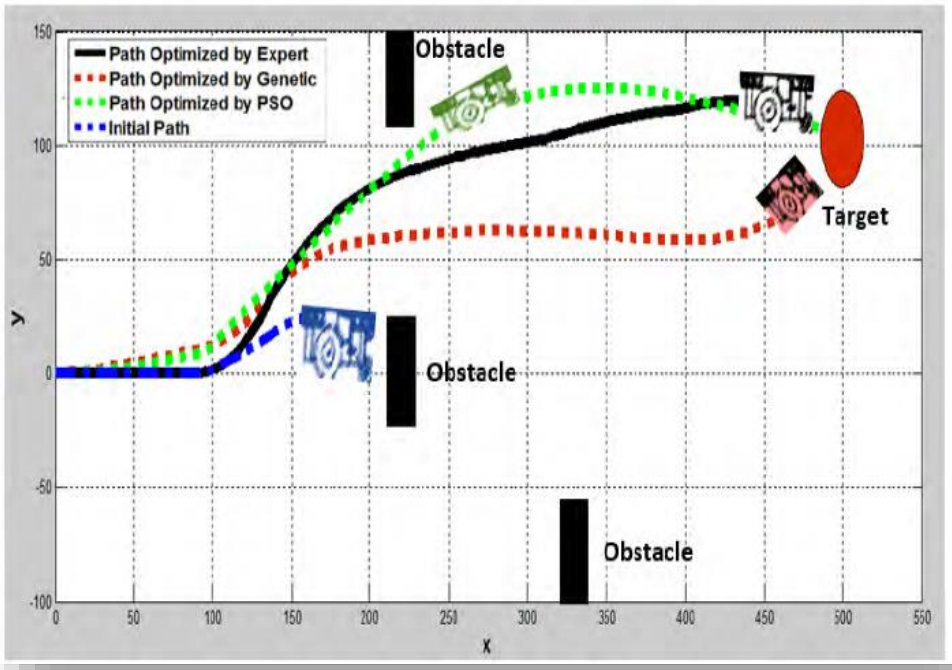
- ❑ Machine learning algorithms

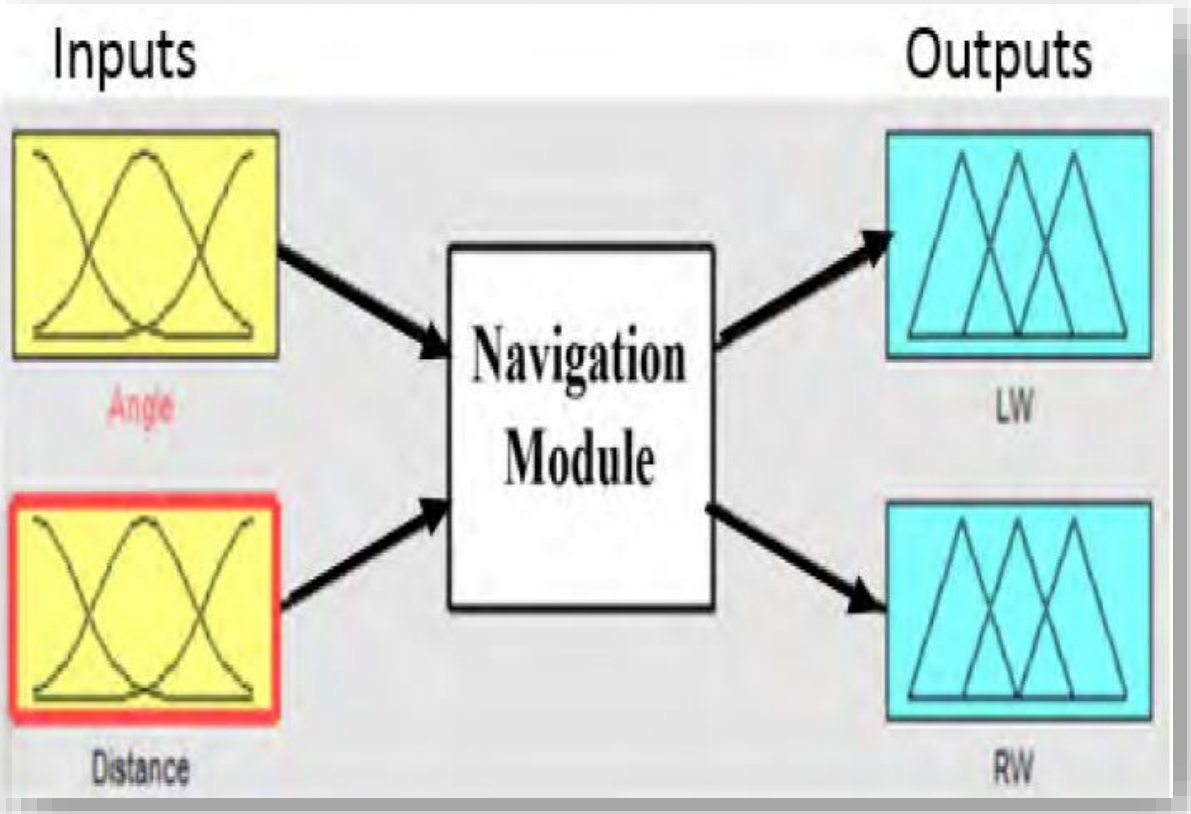
Decision-Making: Intelligent Algorithms and Planning

❑ Decision-making techniques

❑ Expert systems

- ❖ Inexperienced human (naive)
- ❖ Genetic algorithm (GA)
- ❖ Particle swarm optimization (PSO)
- ❖ Human expert (FLC-Expert)

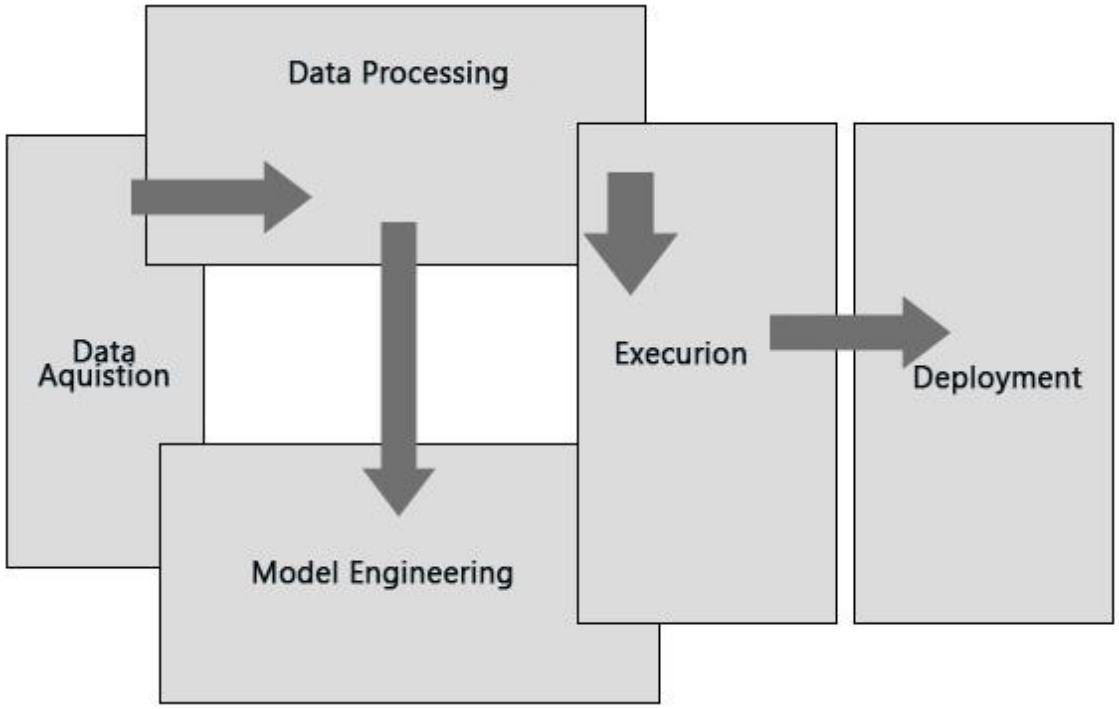




Faisal, Mohammed, et al. "Human expertise in mobile robot navigation." IEEE Access 6 (2017): 1694-1705.

❑ Decision-making techniques

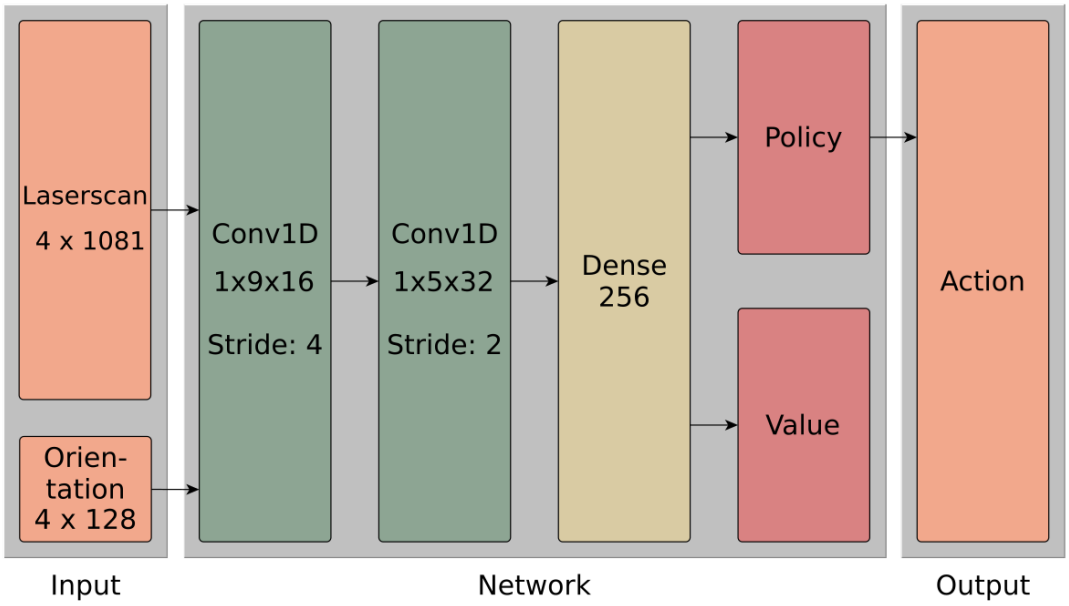
- ❑ Rule-based systems
- ❑ Expert systems
- ❑ Machine learning algorithms



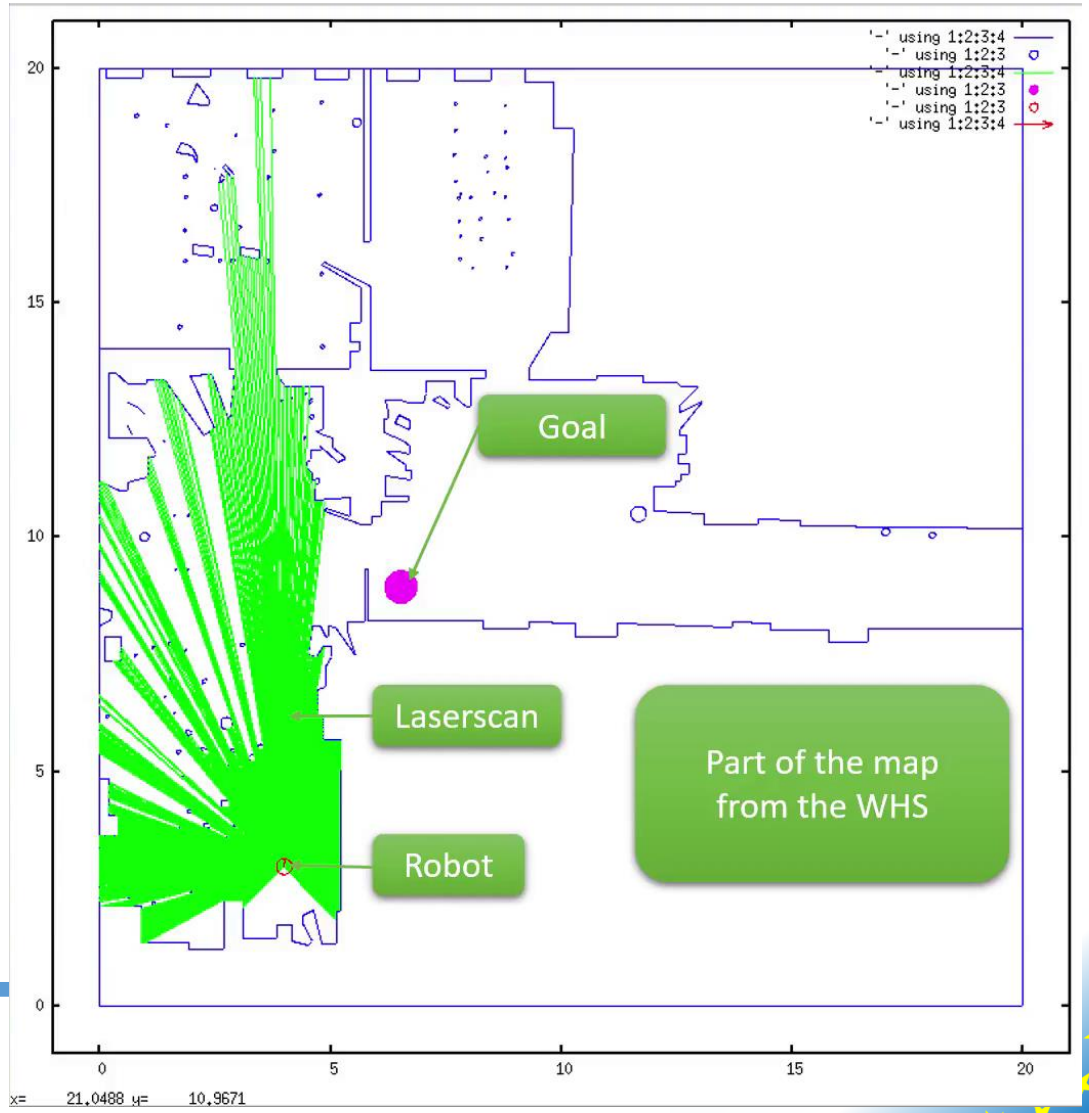
Decision-Making: Intelligent Algorithms and Planning

❑ Decision-making techniques

❑ Machine learning algorithms



Surmann, Hartmut, et al. "Deep reinforcement learning for real autonomous mobile robot navigation in indoor environments." arXiv preprint arXiv:2005.13857 (2020).



Controlling Robot Movements

Actuation

❑ Mobile robots actuation

Differential steering

Skid-steering

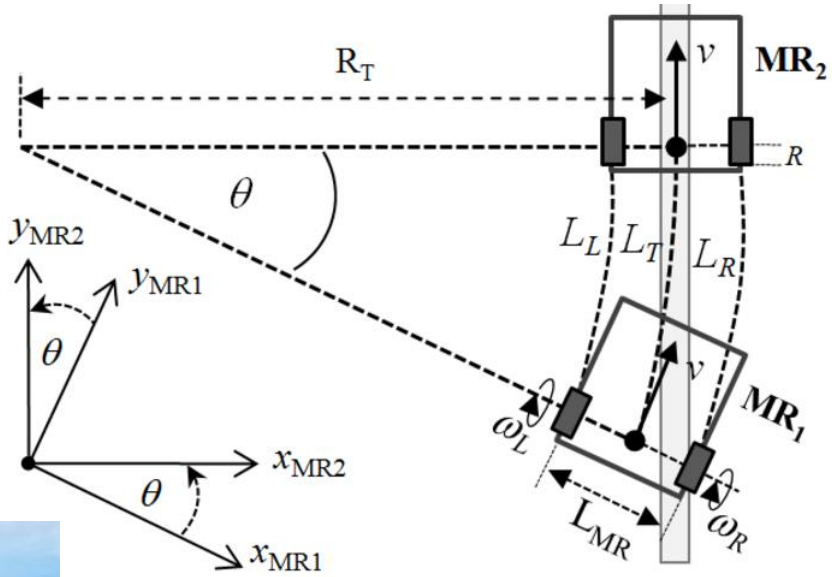
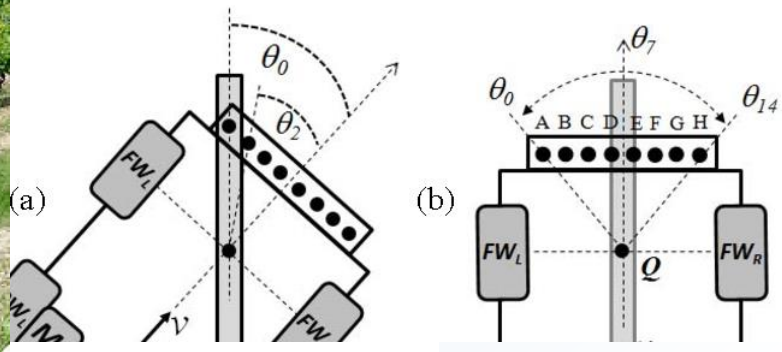


Fig. 2. Notations of the TWD mobile robot

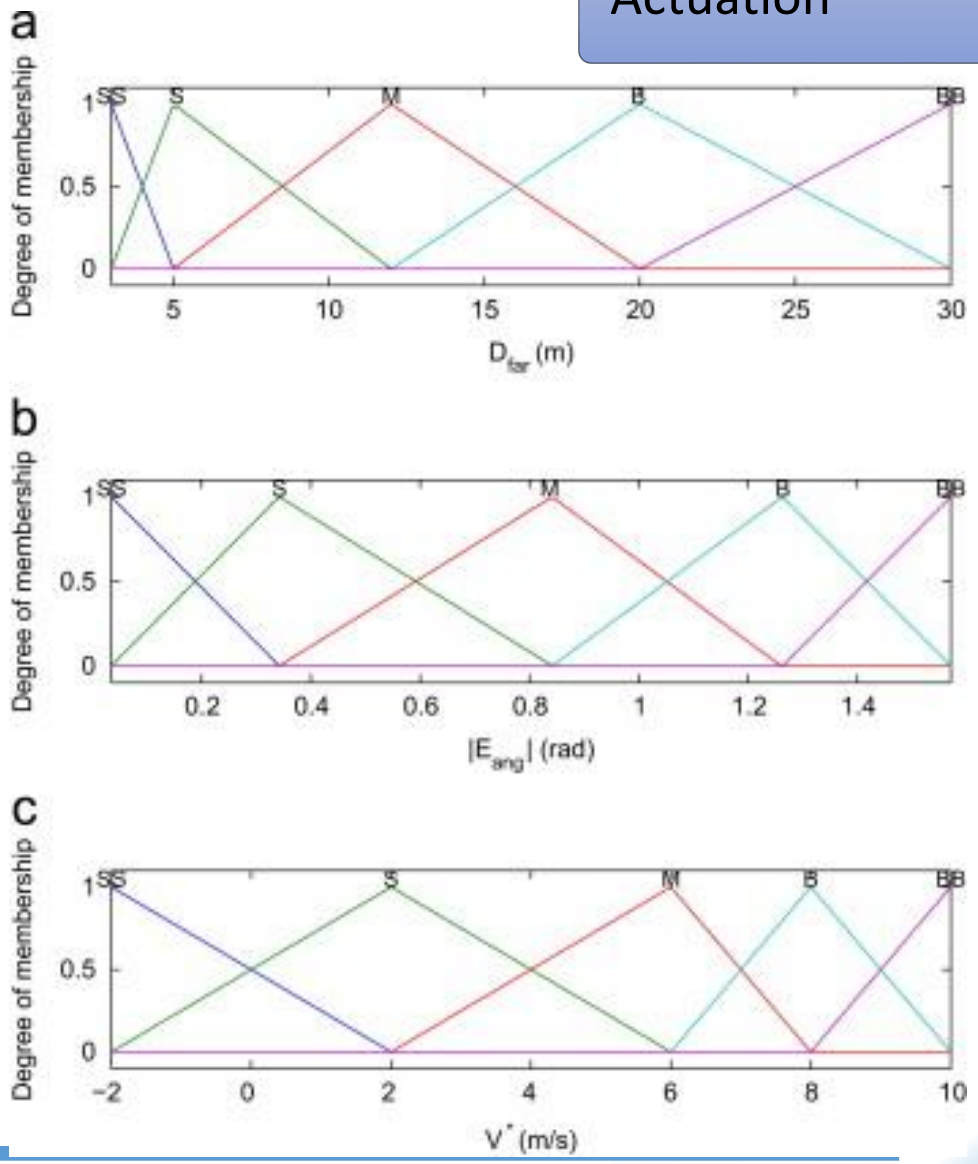


Controlling Robot Movements

Actuation

❑ Mobile robots actuation

❑ Speed control (lineal and lateral)

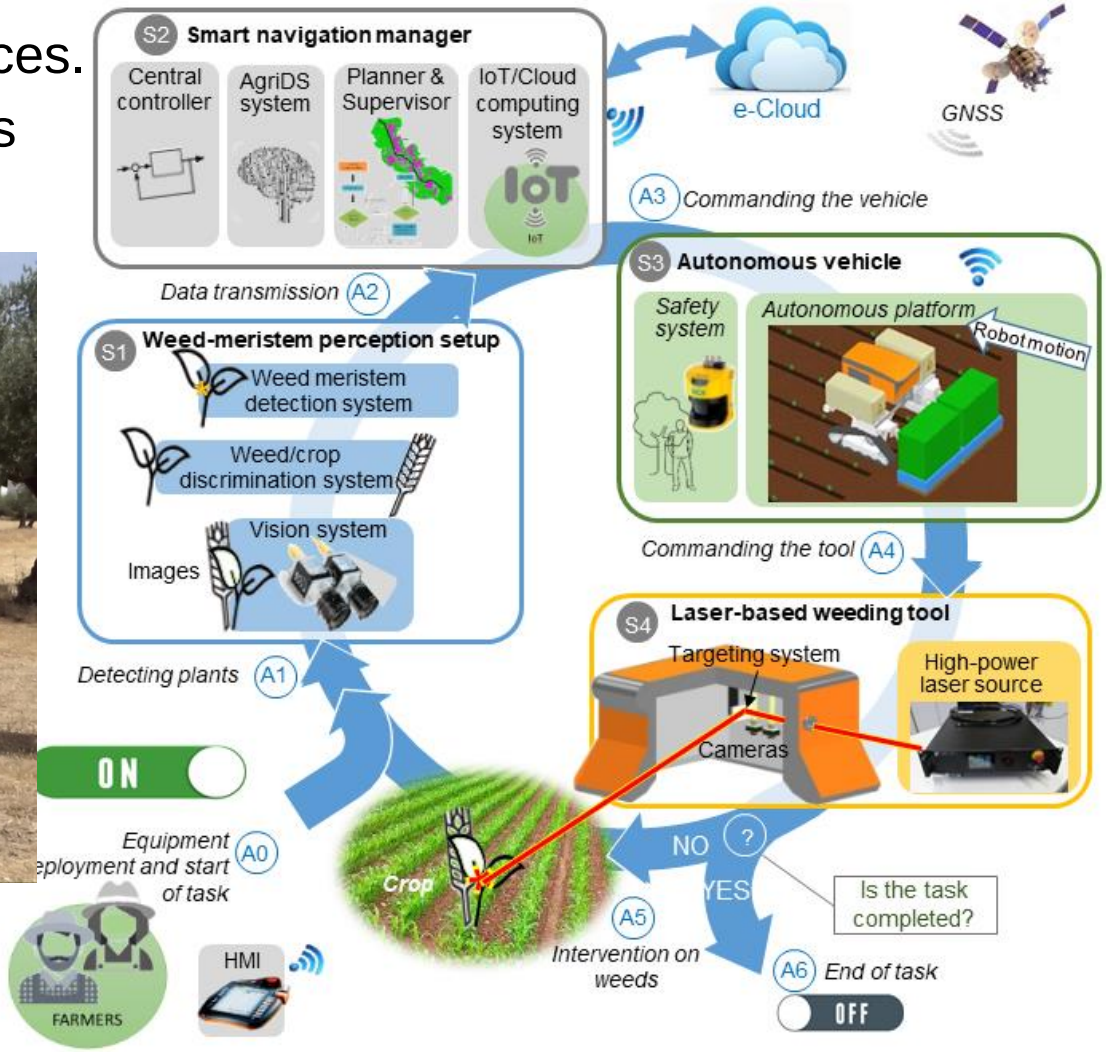


CSIC
Consejo Superior de Investigaciones Científicas

Wang, X., Fu, M., Ma, H., & Yang, Y. (2015). Lateral control of autonomous vehicles based on fuzzy logic. Control Engineering Practice, 34, 1-17.

WeLASER case study

- **Sustainable Weed Management in Agriculture with Laser-based Autonomous Tools (WeLASER), H2020 101000256**
  - Merge current technologies
  - Based on high power laser sources.
  - Laser is focused to hit meristems



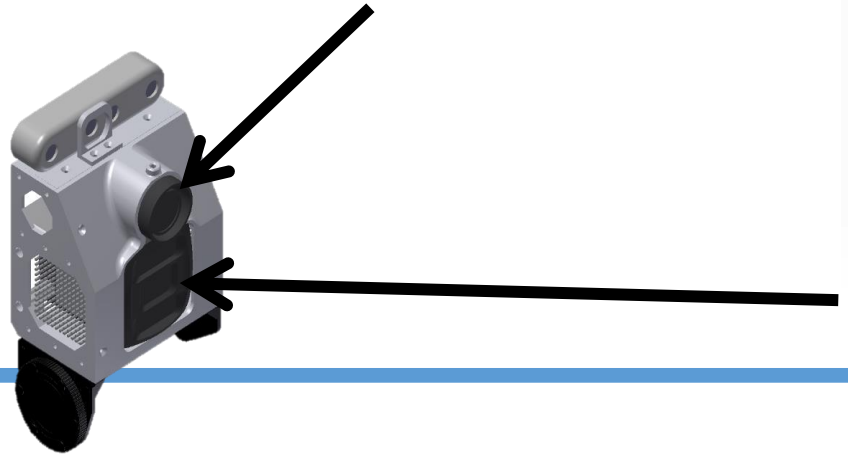
WeLASER case study

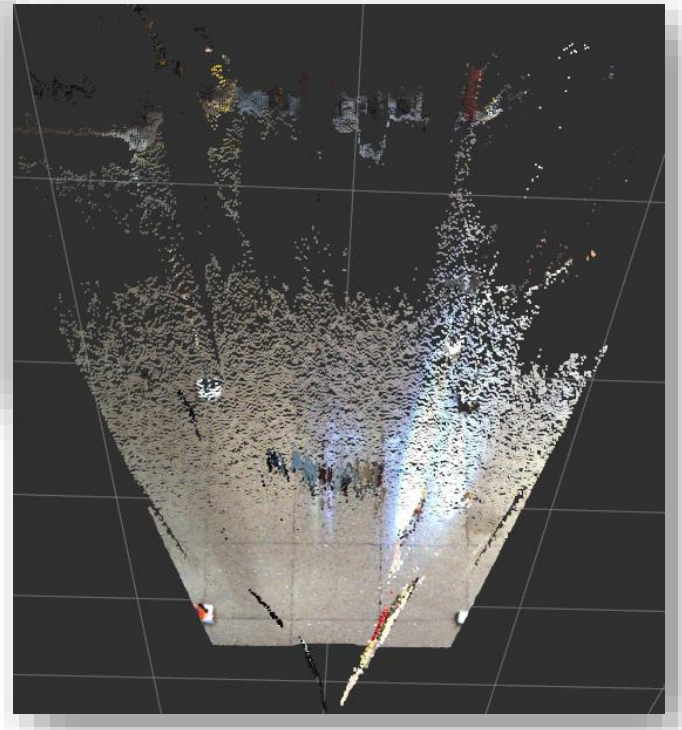
- **Sustainable Weed Management in Agriculture with Laser-based Autonomous Tools (WeLASER), H2020 101000256**

WeLASER case study

- **Sustainable Weed Management in Agriculture with Laser-based Autonomous Tools (WeLASER), H2020 101000256**
  - Guiding vision-system

RGB Camera



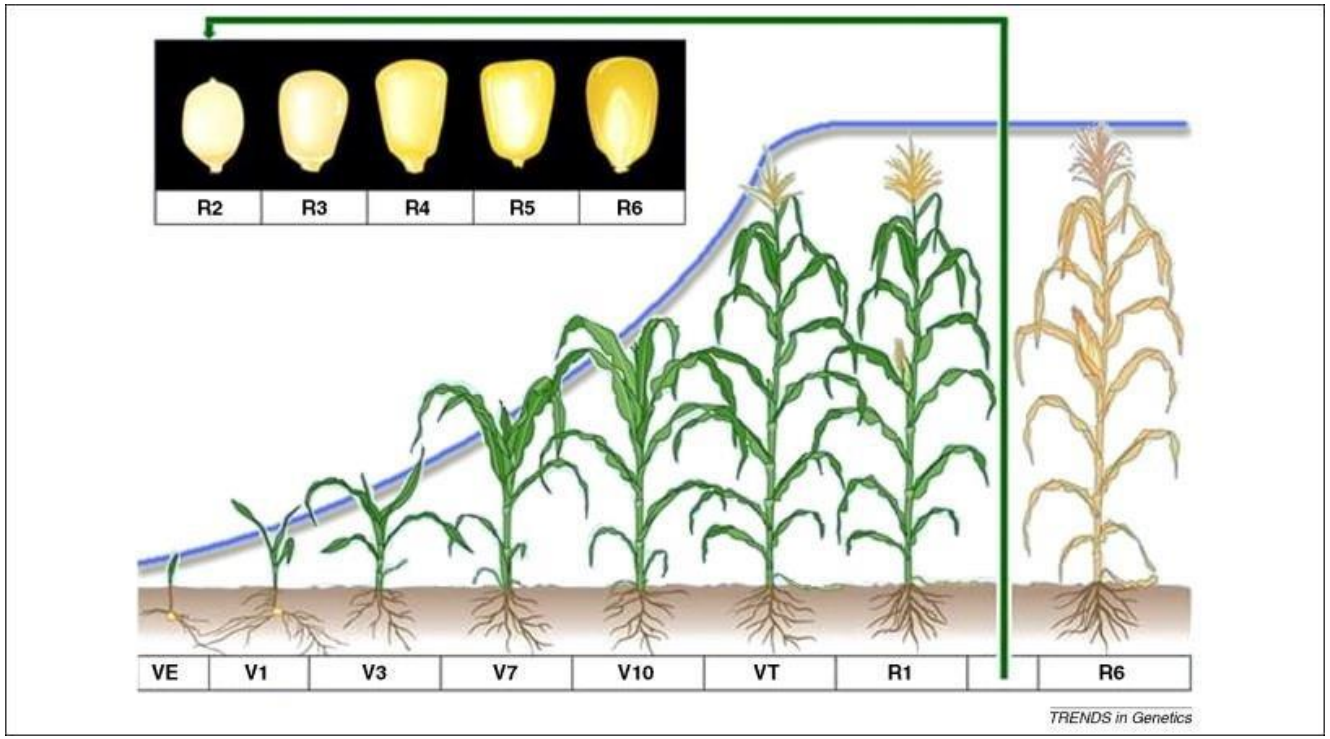


ToF Camera

WeLASER case study

❑ Toward autonomous mobile robot navigation in early-stage crop growth

❑ Early-stage crop growth: maize



Dlamini, Jerry. (2015). Maize growth and yield as affected by different soil fertility regimes in a long-term trial

	Nomenclature	Stages
Vegetative	VE	Emergence
	V1	First leaf collar
	V2	Second leaf collar
	V(n)	n^{th} leaf collar
	VT	Tasseling
Reproductive	R1	Silking
	R2	Blister
	R3	Milk
	R4	Dough
	R5	Dent
	R6	Maturity

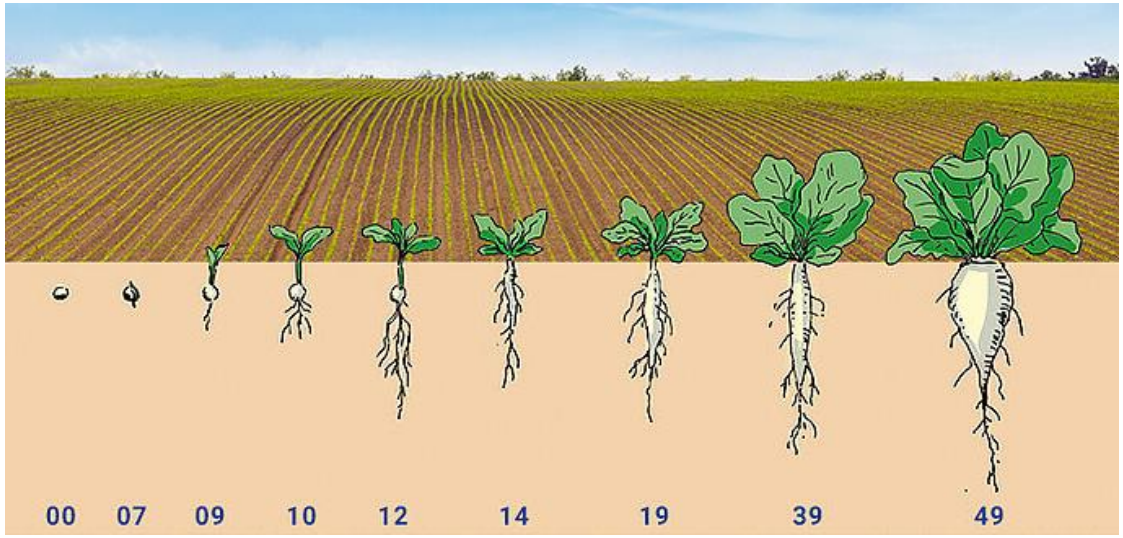
WeLASER case study

- **Toward autonomous mobile robot navigation in early-stage crop growth**
  - Early-stage crop growth: maize

WeLASER case study

❑ Toward autonomous mobile robot navigation in early-stage crop growth

❑ Early-stage crop growth: sugarbeet



Meier, U.; L. Bachmann; H. Buhtz; H. Hack; R. Klose; B. Marlander; E. Weber (1993). "Phänologische Entwick-lungsstadien der Beta-Rüben (Beta vulgaris L. ssp.). Codierung und Beschreibung nach der erweiterten BBCH-Skala (mit Abbildungen)". Nachrichtenbl. Deut. Pflanzenschutzd. 45: 37–41.

Growth stage	Code	Description
1: Leaf development (youth stage)	10	First leaf visible (pinhead-size): cotyledons horizontally unfolded
	11	First pair of leaves visible, not yet unfolded (pea-size)
	12	2 leaves (first pair of leaves) unfolded
	14	4 leaves (2nd pair of leaves) unfolded
	15	5 leaves unfolded
	1 .	Stages continuous till ...
	19	9 and more leaves unfolded
	75	Pericarp green; fruit still mouldable; perisperm milky; colour of seed coat: beige

WeLASER case study

- **Toward autonomous mobile robot navigation in early-stage crop growth**

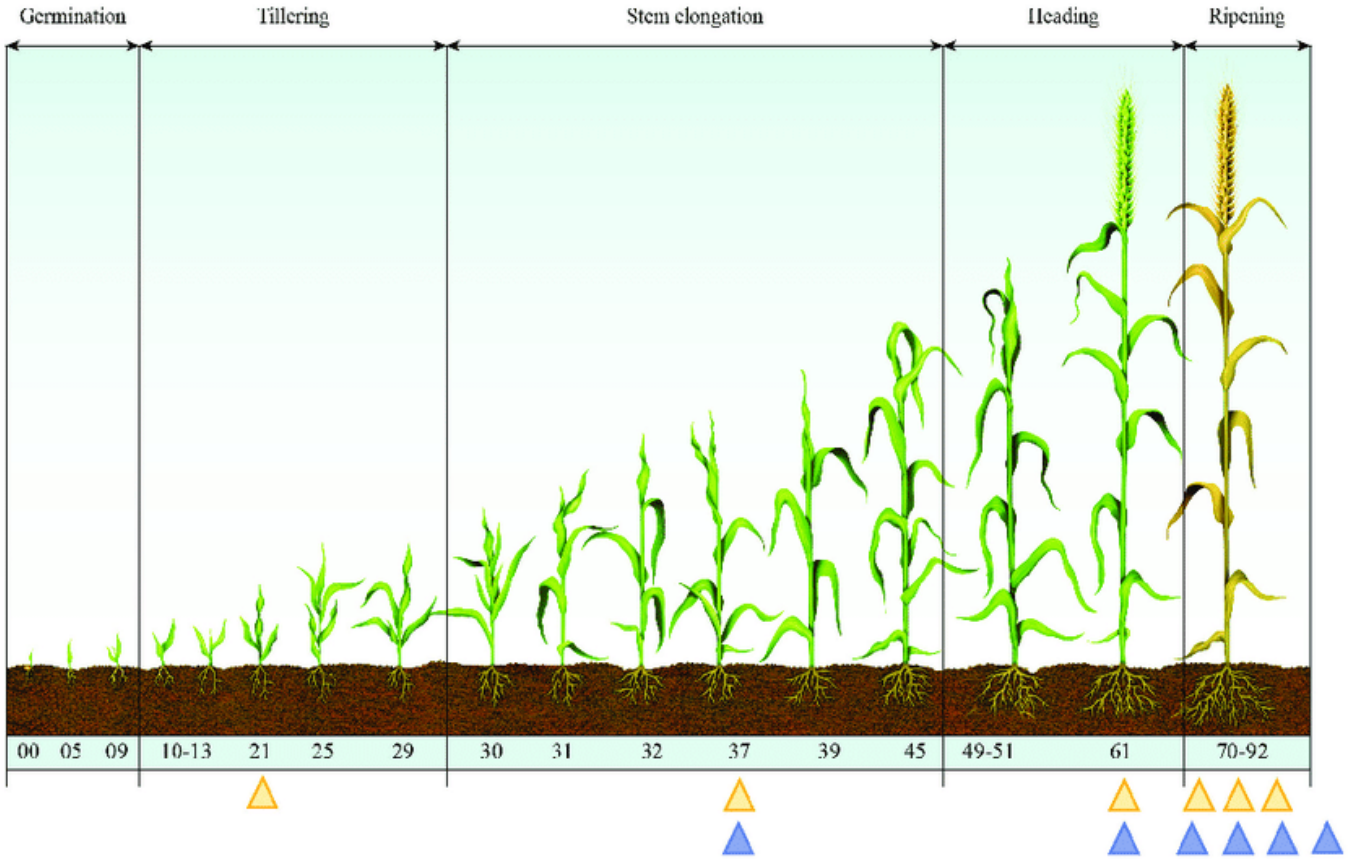
th stage	Code	Description
	10	First leaf visible (pinhead-size): cotyledons horizontally unfolded

CSIC
Consejo Superior de Investigaciones Científicas

WeLASER case study

❑ Toward autonomous mobile robot navigation in early-stage crop growth

❑ Early-stage crop growth: sugarbeet



Seedling growth stage		
	10	First leaf through coleoptile
	11	First leaf unfolded
	12	2 leaves unfolded
	13	3 leaves unfolded
	14	4 leaves unfolded
	15	5 leaves unfolded
	16	6 leaves unfolded
	17	7 leaves unfolded
	18	8 leaves unfolded
	19	9 or more leaves unfolded

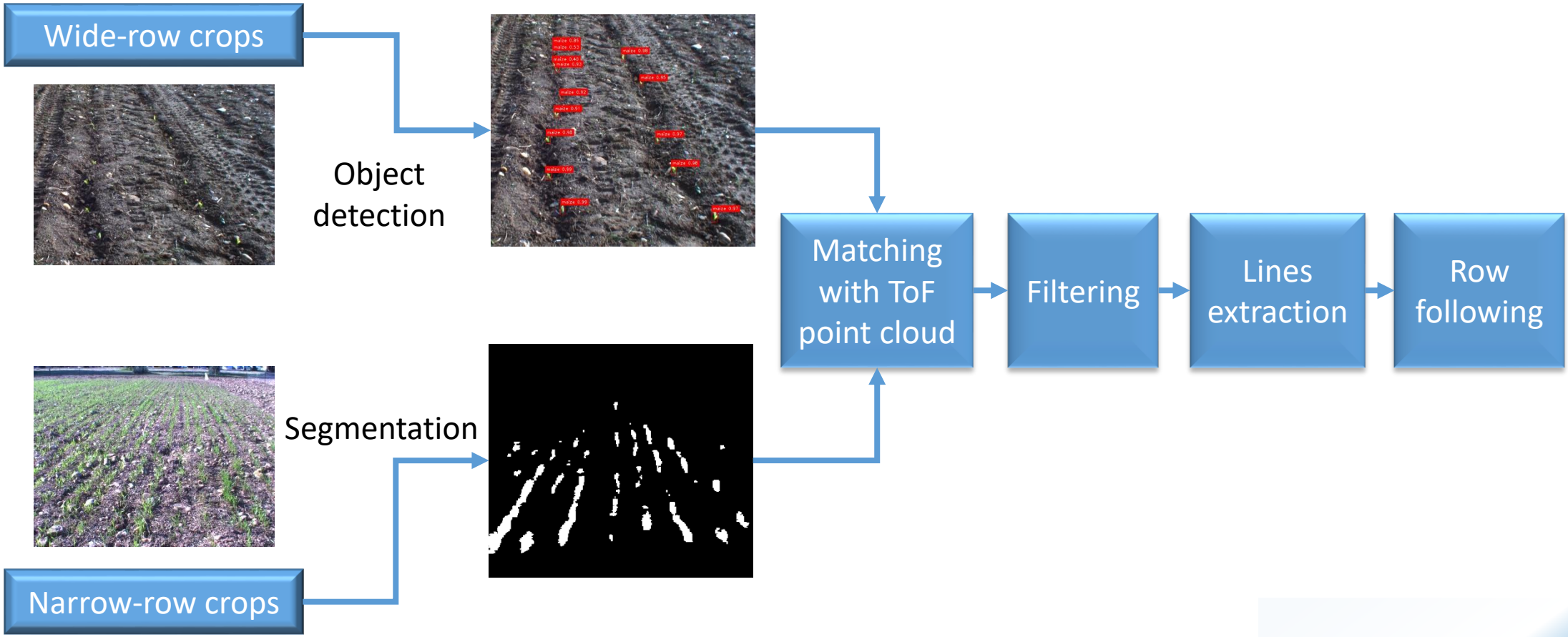
Growth stages in spring wheat adapted from Bayer Crop (2011). Triangles indicate stages when deposition was carried out (2010 and 2011) (Illustration by Elsevier B.V. Illustrator, 2012).

WeLASER case study

- **Toward autonomous mobile robot navigation in early-stage crop growth**

WeLASER case study

❑ Toward autonomous mobile robot navigation in early-stage crop growth



WeLASER case study

- **Toward autonomous mobile robot navigation in early-stage crop growth**
  - Segmentation strategy

Segmentation
mAP 80%

SegNet
U-Net
MobileNets

		Segmentation
10	ResNet50	SegNet
11	MobileNet	SegNet

CSIC
Consejo Superior de Investigaciones Científicas

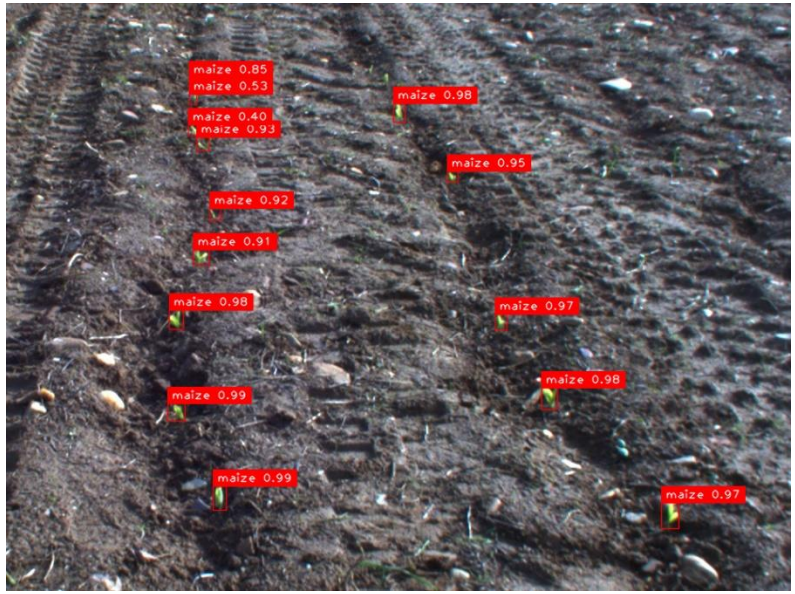
WeLASER case study

❑ Toward autonomous mobile robot navigation in early-stage crop growth

❑ Object detection strategy

Object detection

YOLOv4



WeLASER case study

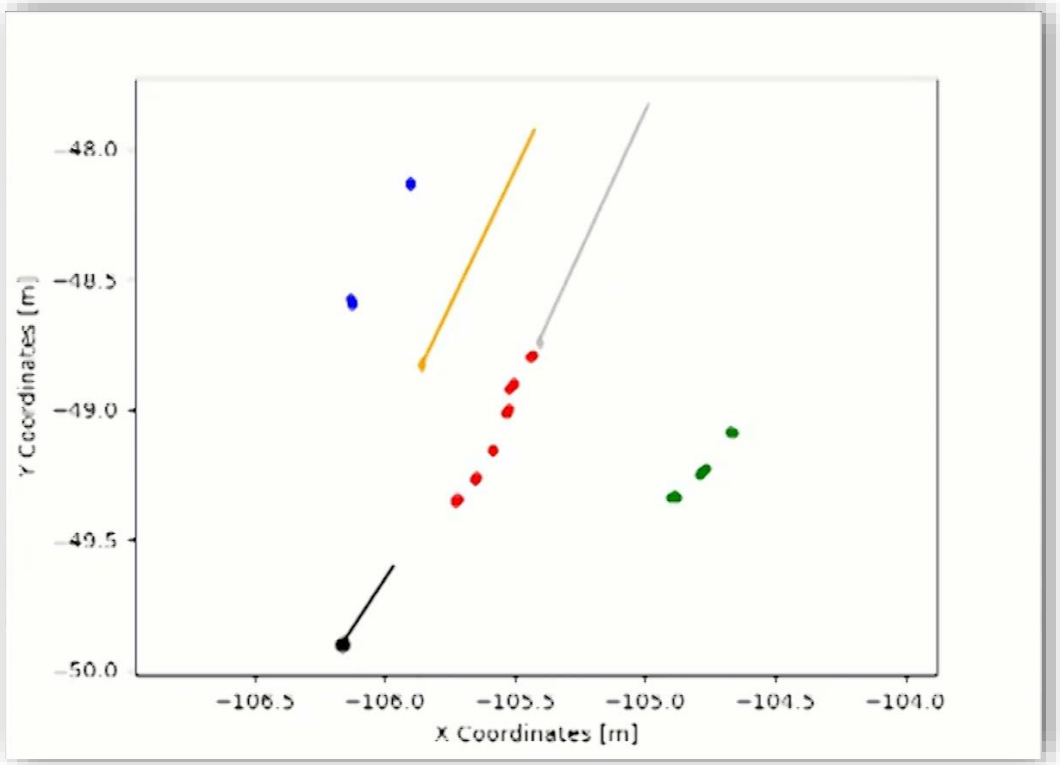
- **Toward autonomous mobile robot navigation in early-stage crop growth**
  - Object detection strategy: Sugarbeet annotation

WeLASER case study

- **Toward autonomous mobile robot navigation in early-stage crop growth**
  - Object detection strategy: Maize annotation

WeLASER case study

- **Toward autonomous mobile robot navigation in early-stage crop growth**
  - Crop detection and row following



Challenges and Future Directions

Computation

- Computation requirements for deep learning
- Large data sets for supervised learning
- High dimensional problems
- Simulation requirements for sample inefficient techniques

Architectures

- Lack of clear rules for network architectures
- Reliance on heuristics and trial-and-error

Goal Specification

- Well designed reward functions for complex tasks
- Multi-objective reward functions

Challenges and Future Directions

- **Adaptability & Generalization**
  - Wide variety of the operational environment
  - Overfitting to training data/environment
- **Verification & Validation**
  - Inability to test in all possible scenarios
  - High cost of field testing
  - Inaccuracies in simulation
  - Biases and gaps in data sets
- **Safety**
  - Complexity and opaqueness of DNNs
  - Safe training in the real world

Question

THANK YOU FOR YOUR ATTENTION!