Introduction

Multi Robot Systems

- Rosario Aragüés raragues@unizar.es
- Gonzalo López-Nicolás gonlopez@unizar.es
- Enrique Teruel eteruel@unizar.es
- Materials (theory and labs): http://moodle2.unizar.es/

Departamento de
Informática e
Ingeniería de Sistemas
Universidad Zaragoza

CESKE ZEMSKE DIVADLO V PRAZE

NÁRODNÍ DIVADLO

V úterý 25. ledna 1921. — Mimo předplacení.

Poprvé.

R. U. R.

(Rossum's Universal Robots.)

- Word "**robot**" used for the first time in Czech playwright: *Karel Capek, 1921 Play 'Rossums's Universal Robots (R.U.R)'*

- Czech word "*robota*" (**forced laborer**)

- Definition: A robot is an autonomous system which exists in the physical world, can **sense** its environment, and can **act** on it to achieve some **goals**.

- Definition: An **autonomous robot** acts based upon its own decisions, and is not controlled by a **human**.

Departamento de Informática e Ingeniería de Sistemas Universidad Zaragoza

Multirobot Systems. Creative commons Attribution-NonCommercial-ShareAlike 3.0

2

Is this a robot?
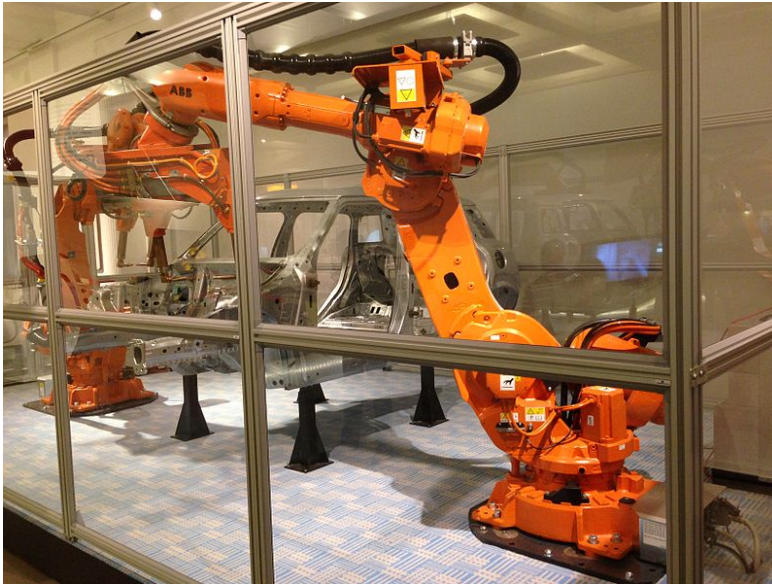
Industrial robot arm
Projekt ANA, CC0, via Wikimedia Commons
https://commons.wikimedia.org/wiki/File:ABB_
Schweissroboter_Technisches_Museum_Wien
_Februar_2013_File2.JPG

Mobile manipulator, KUKA
Laboratories GmbH, CC BY-SA 3.0
<https://creativecommons.org/licens
es/by-sa/3.0>, via Wikimedia
Commons.
https://commons.wikimedia.org/wiki/
File:KUKA_omniRob.jpg

Is this a robot?

Roomba
Michael Movchin, CC BY-SA 3.0
<https://creativecommons.org/licenses/b
y-sa/3.0>, via Wikimedia Commons.
https://commons.wikimedia.org/wiki/File:I
FA2012_IMG_4573.JPG

Quadcopter
Piedmont Virginia Community College
from Charlottesville, VA, CC BY 2.0
<https://creativecommons.org/licenses/b
y/2.0>, via Wikimedia Commons.
https://commons.wikimedia.org/wiki/File:
PVCC_Dominion_Engineering_Lab_Ded
ication_(30262296393).jpg

Is this a robot?

Spot, Boston dynamics
JJxFile, CC BY-SA 4.0
<https://creativecommons.org/licenses/by-sa/4.0>, via
Wikimedia Commons.
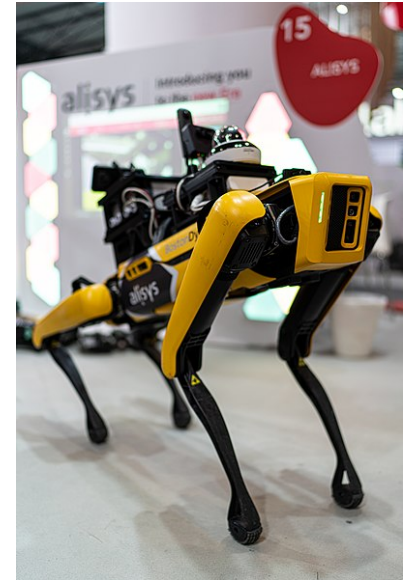https://commons.wikimedia.org/wiki/File:MWC21_-_24.jpg

Nao Aldebaran Robotics
ubahnverleih, CC0, via Wikimedia
Commons.
https://commons.wikimedia.org/wiki/File:
Nao_Robot_(Robocup_2016).jpg

- Ok, so… what is a **Robot**?

- Definition: A robot is an autonomous system which exists in the physical world, can **sense** its environment, and can **act** on it to achieve some **goals**.

- Definition: An **autonomous robot** acts based upon its own decisions, and is not controlled by a **human**.

Departamento de
Informática e
Ingeniería de Sistemas
Universidad Zaragoza

Why robots?

- "Autonomous": Replace humans

Departamento de
Informática e
Ingeniería de Sistemas
Universidad Zaragoza

Why robots?

- "Autonomous": Replace humans
  - Tasks that have to be done
  - No human desires to do

- Dangerous, hazard
- Repetitive
- Dirty

- Optimization:
  - Efficiency
  - Safety
  - Comfort
  - etc…

The future

Image: Hans-J. Brehm, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Car2x_communication.jpg

Future: Connected cars and automated highways
IEEE Spectrum, 20 Jun 2019 "Internet of Things Technology Will Connect Highways, Street Lights, and Vehicles. Cars have gotten smart. Can roads catch up?"

https://spectrum.ieee.org/the-institute/ieee-products-services/internet-of-things-technology-will-connect-highways-street-lights-and-vehicles

The future

Autopilot Tesla

https://www.tesla.com/es_ES/autopilot

Truck platooning
IEEE Spectrum, 17 July 2019 " One Driver Steers Two Trucks With Peloton's Autonomous Follow System." Silicon Valley startup Peloton.

https://spectrum.ieee.org/view-from-the-valley/transportation/self-driving/will-autonomous-following-be-a-game-changer-for-trucking

https://youtu.be/lpuwG4A56r0

The future

Image: Mollyrose89, CC BY-SA 4.0
<https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia
Commons. https://commons.wikimedia.org/wiki/File:Delivery_drone.jpg

https://aeroarms-project.eu/category/multimedia/

https://spectrum.ieee.org/energywise/energy/environment/drone-delivery-if-done-right-could-cut-emissions
Drone package and medicine delivery (JD.com, DHL, Zipline, Amazon, Google, UPS). IEEE Spectrum, 13 Feb. 2018 " Drone Delivery, If Done Right, Could Cut Emissions"

https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011

M. Gassner, T. Cieslewski, D. Scaramuzza. Dynamic Collaboration without Communication: Vision-Based Cable-Suspended Load Transport with Two Quadrotors, ICRA 2017.
https://www.youtube.com/watch?v=8pFBufXOumw

The future

CO4ROBOTS. Multi-robot cooperative object handling, transportation, pick & delivery. Industrial facilities.

http://www.co4robots.eu/demonstration.html

https://www.youtube.com/watch?v=T9jt1JK5XZg

COMMANDIA: Collaborative Robotic Mobile Manipulation of Deformable Objects in Industrial Applications

http://commandia.unizar.es/es/category/news-es/
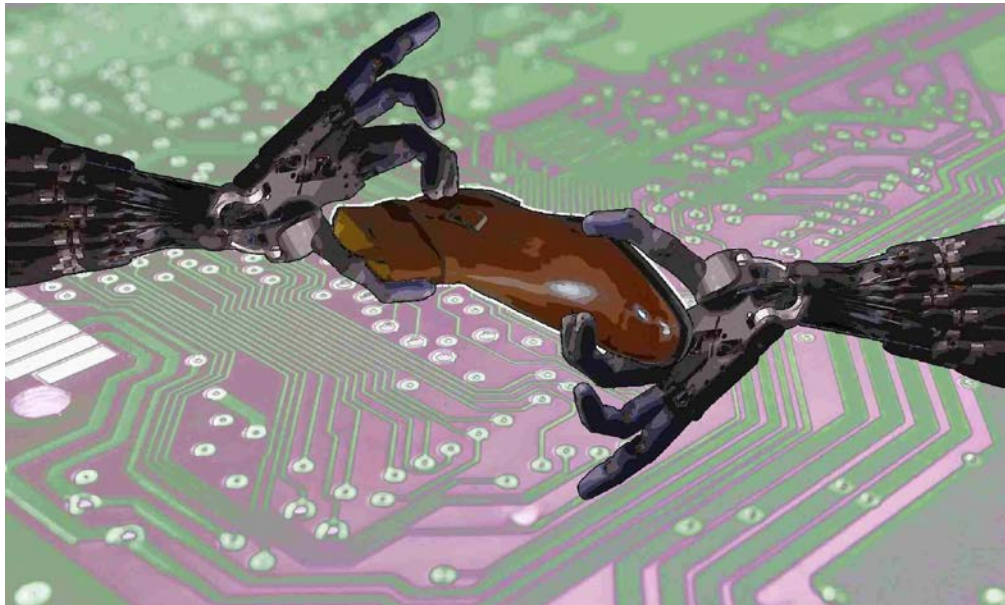
Image: Created by the course lecturer G. López-Nicolás

The future

https://spectrum.ieee.org/automaton/robotics/industrial-robots/amazon-introduces-two-new-warehouse-robots

Warehouse automation. Amazon
IEEE Spectrum. 05 Jun 2019. "Amazon
Uses 800 Robots to Run This Warehouse.

https://youtu.be/lMPbKVb8y8s?t=193

Cooperative transport

https://www.youtube.com/watch?v=kxRu426UVdM

Alonso-Mora, J, Knepper, R, Siegwart, R, & Rus, D (2015). Local motion planning for collaborative multi-robot manipulation of deformable objects. *IEEE int. Conf. robotics automation,* pp. 5495-5502.

The future

Image: Amazone GmbH & Co. KG, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Amazone_BoniRob_Feldroboter-Entwicklungsprojekt.jpg

http://flourish-project.eu/

Flourish Project.
Precision farming

http://www.sweeper-robot.eu/

Sweet Pepper Harvesting Robot
https://www.youtube.com/watch?v=DUgjFaYyecE

CNET. May 19, 2020. "See Boston Dynamics robot dog Spot herd sheep like a pro in new video"

https://www.cnet.com/news/boston-dynamics-robot-dog-spot-herds-sheep-like-a-pro-in-new-video/

https://youtu.be/RBLnAhzPpTQ

https://youtu.be/CTjVjKClpyU

Yaxley, K. J., Joiner, K. F., & Abbass, H. (2021). Drone approach parameters leading to lower stress sheep flocking and movement: sky shepherding. *Scientific reports*, *11*(1), 1-9.

Departamento de Informática e Ingeniería de Sistemas Universidad Zaragoza

Multirobot Systems. Creative commons Attribution-NonCommercial-ShareAlike 3.0

14

The future

Autonomous border surveillance (criminal activities and marine pollution). Water surface, underwater and ground vehicles

Heterogeneous robot swarms for monitoring the aquatic environmental conditions in the Venice lagoon

Departamento de Informática e Ingeniería de Sistemas Universidad Zaragoza

Multirobot Systems. Creative commons Attribution-NonCommercial-ShareAlike 3.0

15

The future

Why study robotics?

- Transport
  - Self-driving vehicles

    CNBC May 2 2019 .Elon Musk to investors: Self-driving will make Tesla a $500 billion company. https://www.cnbc.com/2019/05/02/elon-musk-on-investor-call-autonomy-will-make-tesla-a-500b-company.html (co-founder of e.g., Paypal)

- Warehouses
  - Amazon increases its robot fleet
- Pickup and delivery
  - JD.com, DHL, Zipline, Amazon, Google, UPS
- Search and rescue, environmental monitoring, security and defense…

Why did we choose these examples? Anything in common?

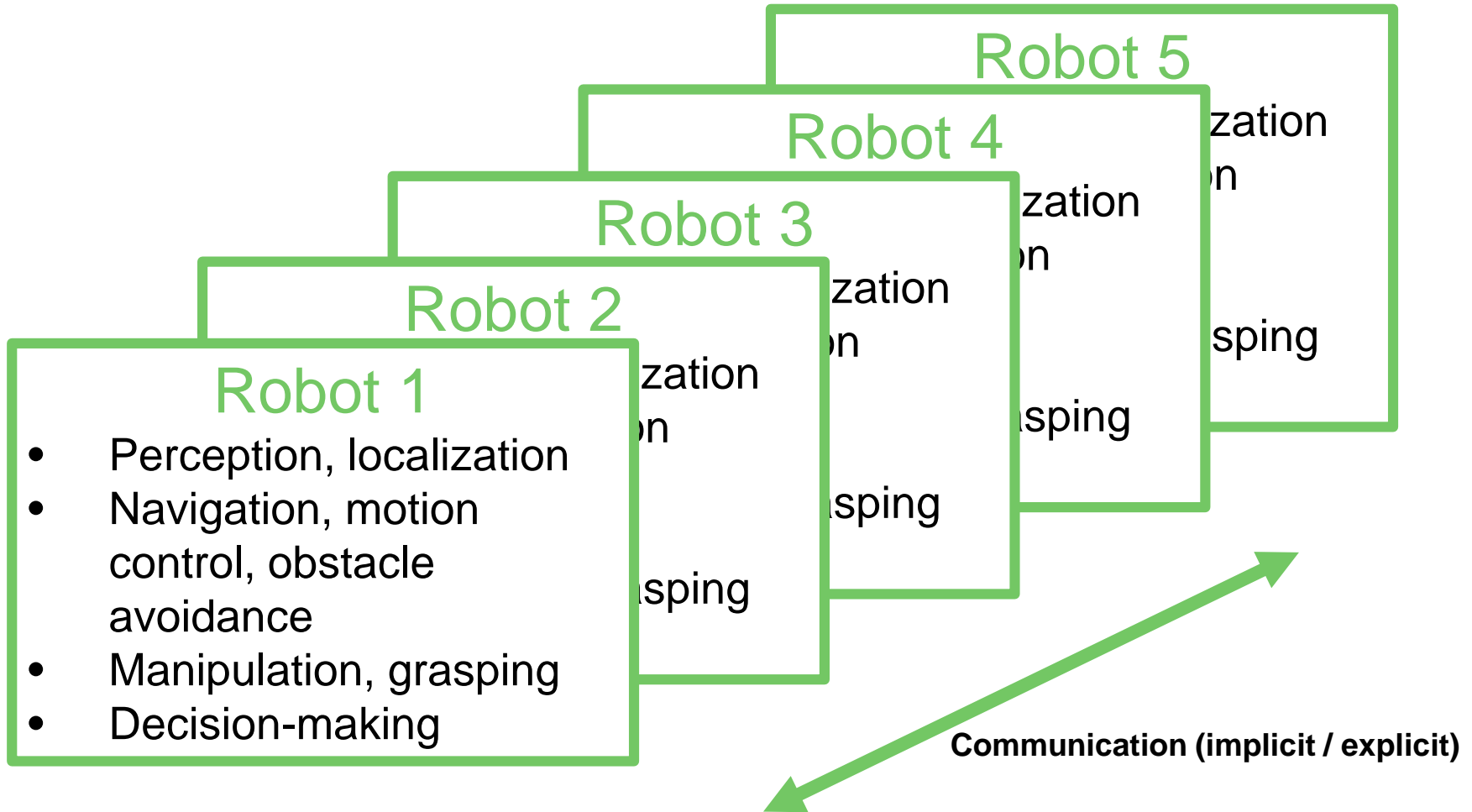Why did we choose these examples? Anything in common?

Multi Robot Systems

- ■ Cooperating, collaborating
- ■ Coordination
- ■ Heterogeneous

From single to multi-robot systems

Robot 5

Robot 4

Robot 3

Robot 2

Robot 1

- Perception, localization
- Navigation, motion control, obstacle avoidance
- Manipulation, grasping
- Decision-making

Communication (implicit / explicit)

From single to multi-robot systems

Robot 5

Robot 4

Robot 3

Robot 2

Robot 1
- Perception, localization
- Navigation, motion control, obstacle avoidance
- Manipulation, grasping
- Decision-making

Communication (implicit / explicit)
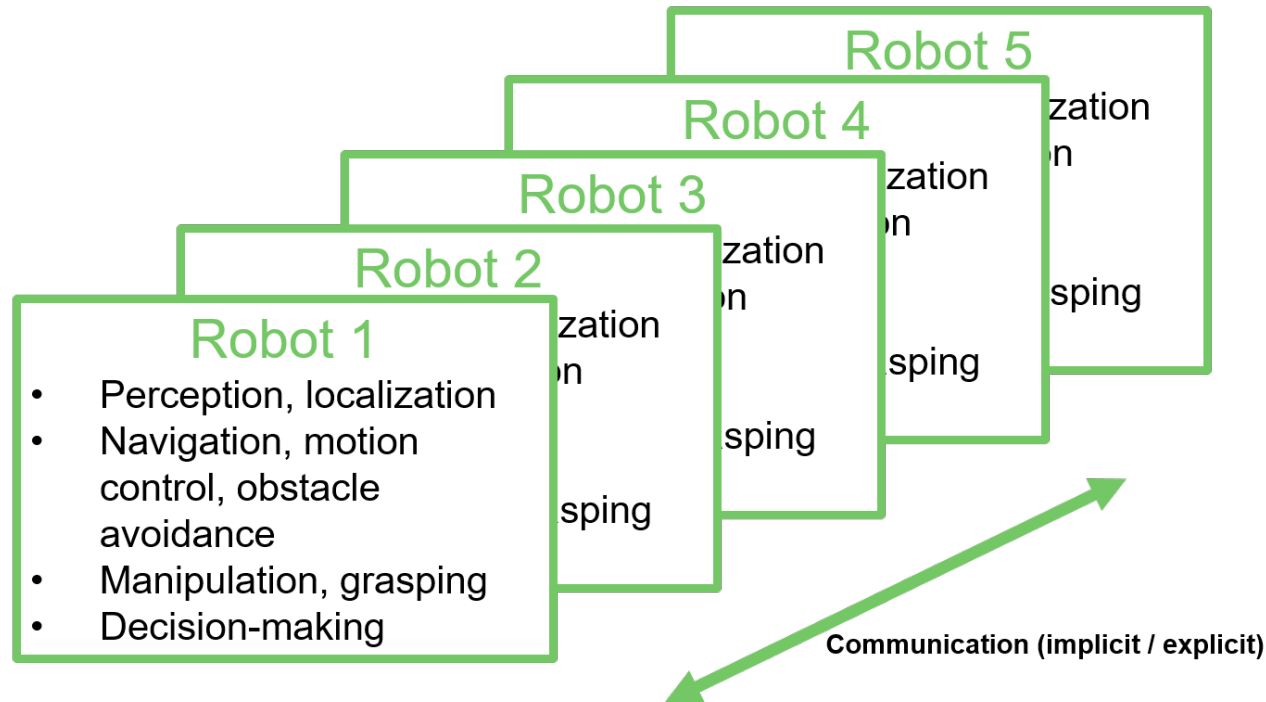
❑ Architecture: centralized vs. decentralized

❑ Communication: explicit vs. implicit

❑ Homogeneous vs. heterogeneous robot teams

• The most appropriate for each scenario

In this course

- Modeling of multi-robot systems: Dynamics and Interconnections
- Analysis of multi-robot systems
  - Stability and performance, convergence
- Robot swarms
- Applications of multi-robot systems (***Formation Control, deployment, collision avoidance***)

Which requires…

- Graph theory and algebraic graph theory
- Consensus and agreement protocols
- Undirected / directed /switching communication

Courses in other institutions covering similar topics:

"Control of Autonomous Multi-Agent Systems II", Dr. Antonio Franchi and Prof. Giuseppe Oriolo. Dipartimento di Ingegneria Informatica, Automatica e Gestionale, Sapienza Università di Roma. http://www.diag.uniroma1.it/oriolo/cams_part2/

"Mobile Robot Systems", Dr. Amanda Prorok. University of Cambridge, Dep. Of Computer Science and Technology. https://www.cl.cam.ac.uk/teaching/1819/MobRobot/

In this course

- **Formation control** https://www.youtube.com/watch?v=YQIMGV5vtd4&t=31s
  https://www.youtube.com/watch?v=lHbzKnbvT0s

- **Rendezvous** https://www.youtube.com/watch?v=mAmdrta8jio
  https://youtu.be/uaiCnw79Sb8?t=229

- **Coverage** https://www.youtube.com/watch?v=1cOafOc1bIk
  https://www.youtube.com/watch?v=80YAsC3wVIk

- **Swarm flocking** https://www.youtube.com/watch?v=QbUPfMXXQIY

- **Herding** https://www.youtube.com/watch?v=0NXQNRFqICU

- **Collision avoidance (Shape formation, navigation..)**
  https://www.youtube.com/watch?v=_APqkrhvv7w   https://gamma.cs.unc.edu/ORCA/videos/ORCA-2.m4v

Chung, S. J., Paranjape, A. A., Dames, P., Shen., Kumar, V. (2018). A survey on aerial swarm robotics. *IEEE Tr. Robotics*, *34*(4), 837-855

Parasuraman, R., Kim, J., Luo, S., & Min, B. C. (2018). Multipoint rendezvous in multirobot systems. IEEE Tr. Cybernetics, 50(1), 310-323.

Lee, S. G., Diaz-Mercado, Y., & Egerstedt, M. (2015). Multirobot control using time-varying density functions. IEEE Transactions on Robotics, 31(2), 489-493.

Wang, H., Rubenstein, M. (2020). Shape formation in homogeneous swarms using local task swapping. IEEE Tr. Robotics, 36(3), 597-612.

Pierson, A., Schwager, M. (2017). Controlling noncooperative herds with robotic herders. IEEE Transactions on Robotics, 34(2), 517-525.

C. W. Reynolds, Flocks, herds and schools: A distributed behavioral model, ACM SIGGRAPH Comput. Graph 21 (4): 25–34, 1987

Van Den Berg, J., Guy, S. J., Lin, M., & Manocha, D. (2010, April). Optimal reciprocal collision avoidance for multi-agent navigation. In Proc. of the IEEE International Conference on Robotics and Automation, Anchorage (AK), USA.

In this course

- **Programming skills**
  - ❏ Python, C++
- **Hands on experience, learn by doing**
  - ❏ Explanations
  - ❏ Exercises, labs
- **Environments**
  - ❏ Google Colab, Visual Studio Code, ROS

Multirobot Systems. Creative commons Attribution-NonCommercial-ShareAlike 3.0

22
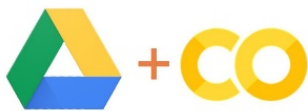
How large are **existing** swarms?

4 team members
Aprox. 10
Aprox. 20
?

Departamento de
Informática e
Ingeniería de Sistemas
Universidad Zaragoza

Multirobot Systems. Creative commons Attribution-NonCommercial-ShareAlike 3.0

23

How large are existing swarms?

https://www.intel.com/content/www/us/en/technology-innovation/aerial-technology-light-show.html

On July-15-2018 **Intel** set a drone world record at their Folsom California campus. It was a spectacular light show featuring **2,018** drones

https://www.guinnessworldrecords.com/news/commercial/2020/10/3051-drones-create-spectacular-record-breaking-light-show-in-china

On September 20-2020, Shenzhen Damoda Intelligent Control Technology Co., Ltd. (China), **3,051** UAVS.

https://www.youtube.com/watch?v=44KvHwRHb3A