Part 2: Building Network Digital Twins for Next-Generation WLANs using with traditional AI/ML/DL

Miguel Camelo

IDLab, imec research group at Ghent University and University of Antwerp

Agenda

- Part 0 – Network Digital Twins – 6G-TWIN vision
  - Motivation
  - Technology enablers
  - Architectural concept
- Part I - Introduction to Wireless Networking Management
  - Background in Wi-Fi and its medium access mechanisms.
  - Background in Channel Bonding
  - Challenges in Channel Bonding
  - Necessity for digital twins
- **Part II – Hands-on: Building an NDT for Next-Generation WLANs with traditional AI/ML/DL**
  - Introduction to dataset
  - Introduction to AI/ML/DL techniques
  - Hands-on: Building an NDT with traditional AI/ML/DL
- Part III – Hands-on: Building an NDT for Next-Generation WLANs using Graph Neural Networks
  - Motivation for using Graph Neural Networks (GNNs) in topology-based problems
  - Introduction to GNNs
  - Hands-on: Building an NDT for Next-Generation WLANs using GNNs
- Part IV – What is next?

Introduction to AI/ML/DL techniques

What is Machine Learning?

- Branch of Artificial Intelligence.
- Can be used to solve problems.
- The models are not explicitly programed.
- Machines learn without human intervention.
- But it needs human guidance.

Heuristics

Machine Learning

The Machine Learning cycle

- Train: Procedure to build a model.
- Inference: Test your mode with (real/different) data.
- Re-train.

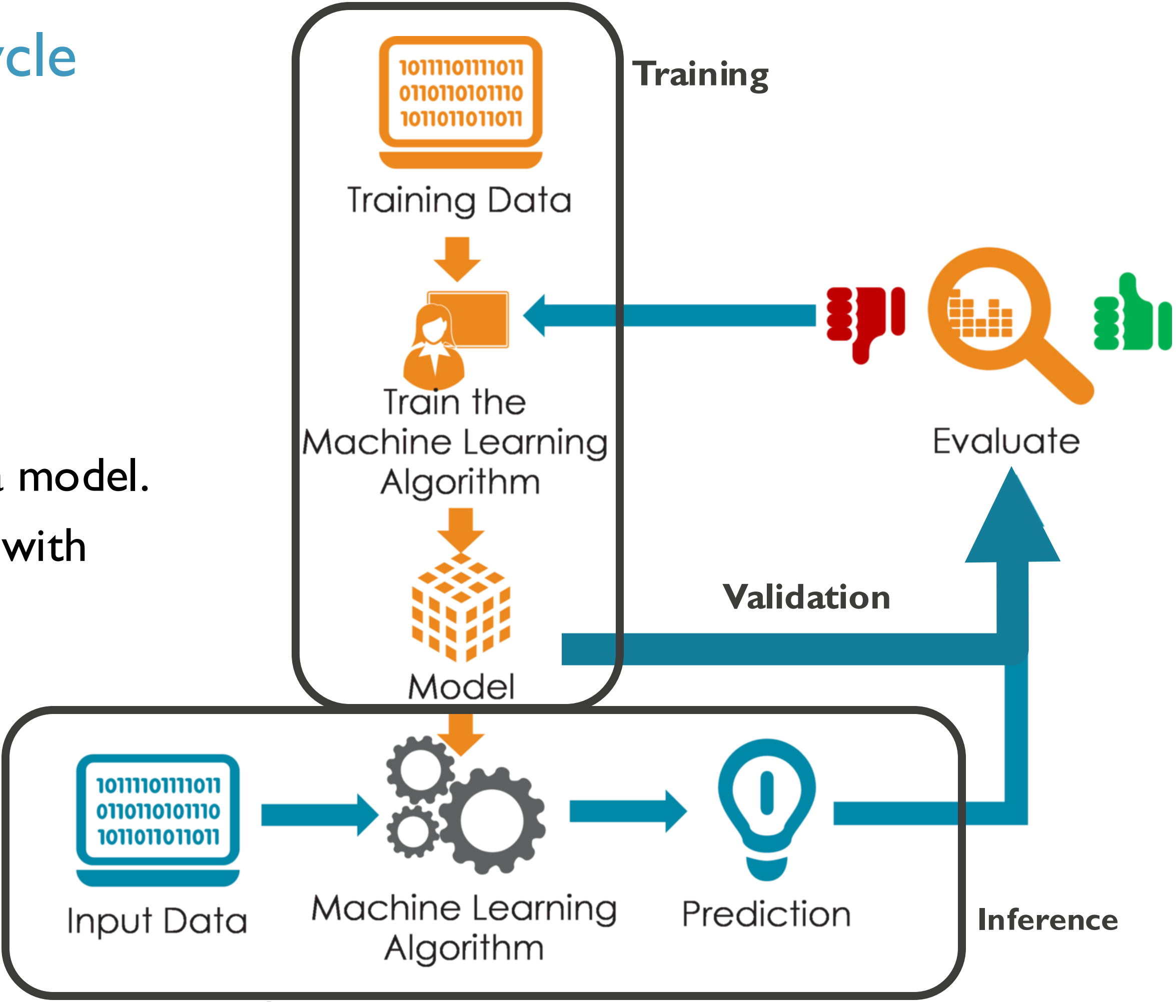


Image taken from: https://bit.ly/3hLvKHD

Machine Learning Types

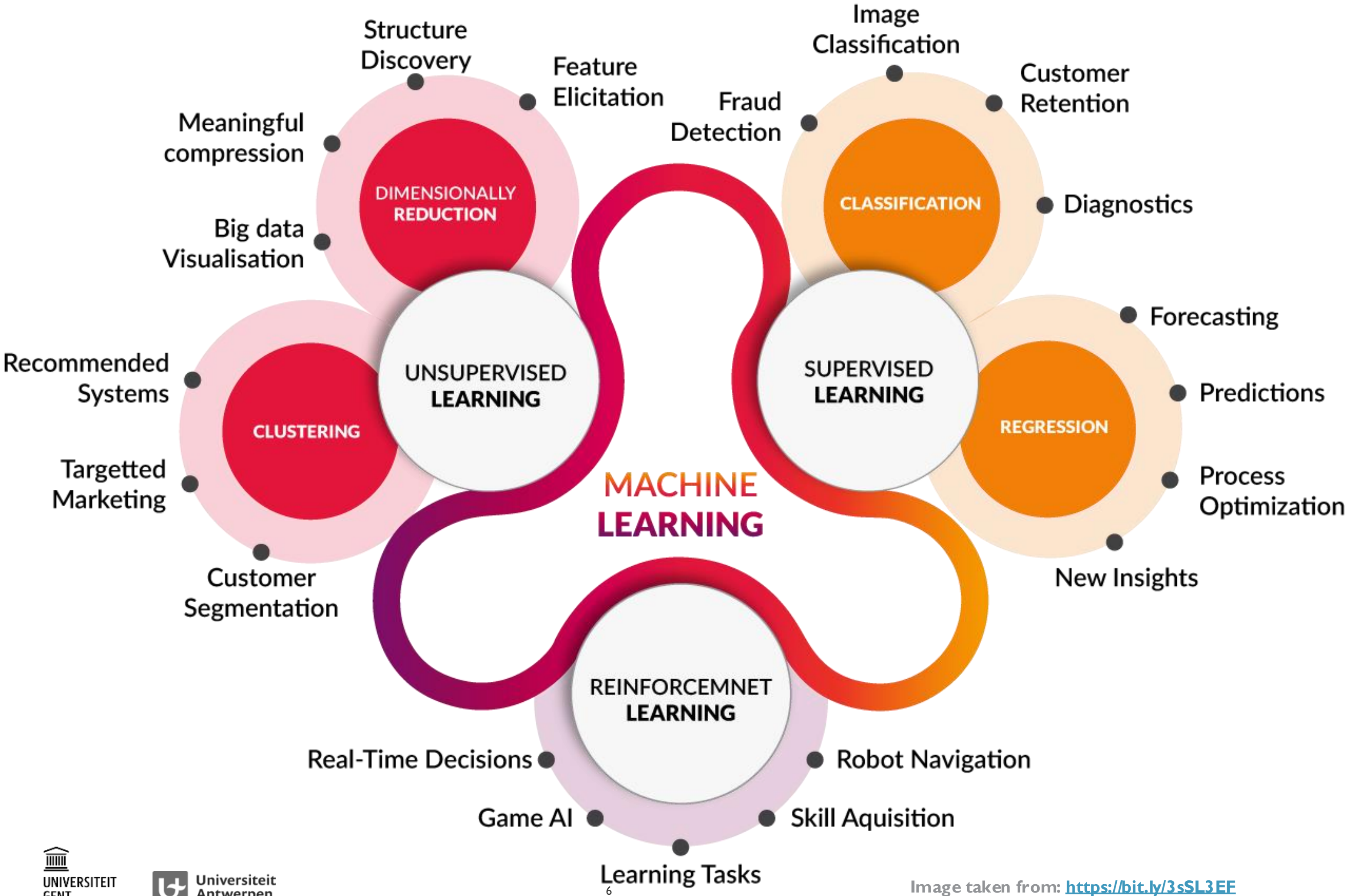


Image taken from: https://bit.ly/3sSL3EF

Supervised Learning

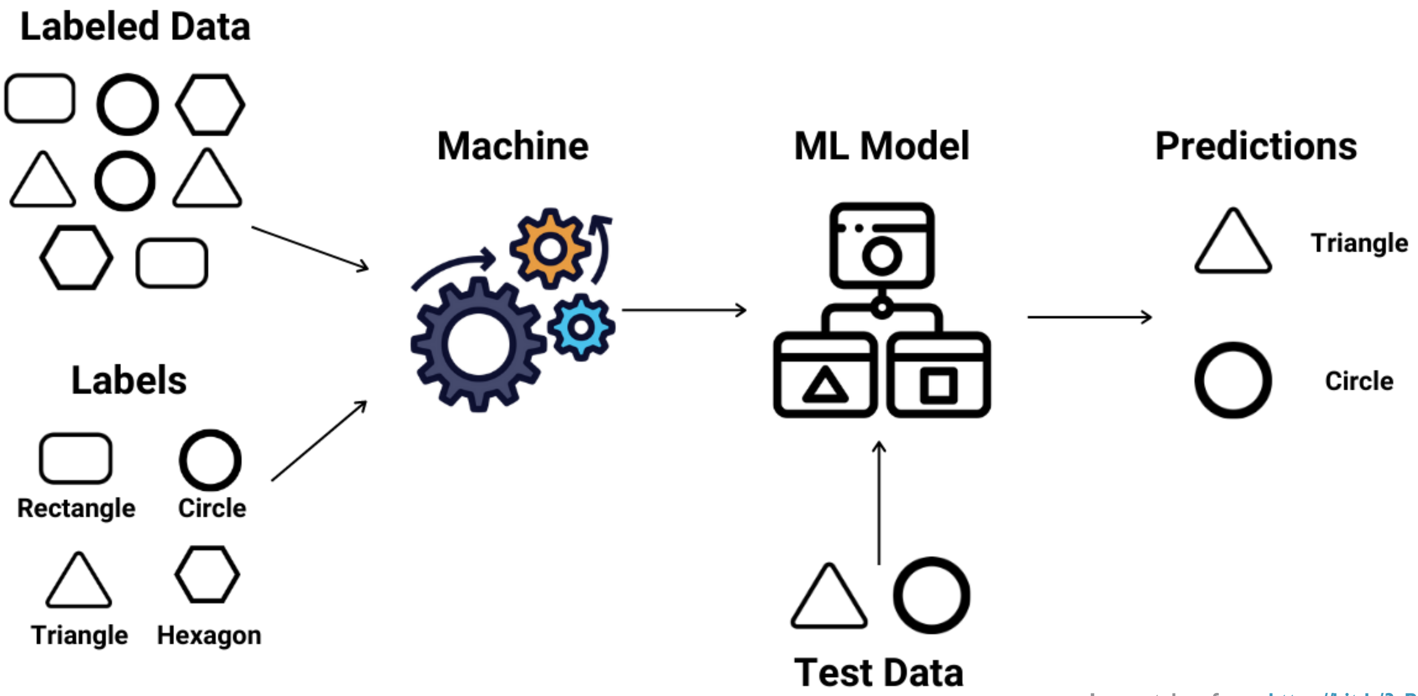


Image taken from: https://bit.ly/3sRIQKE

Unsupervised Learning

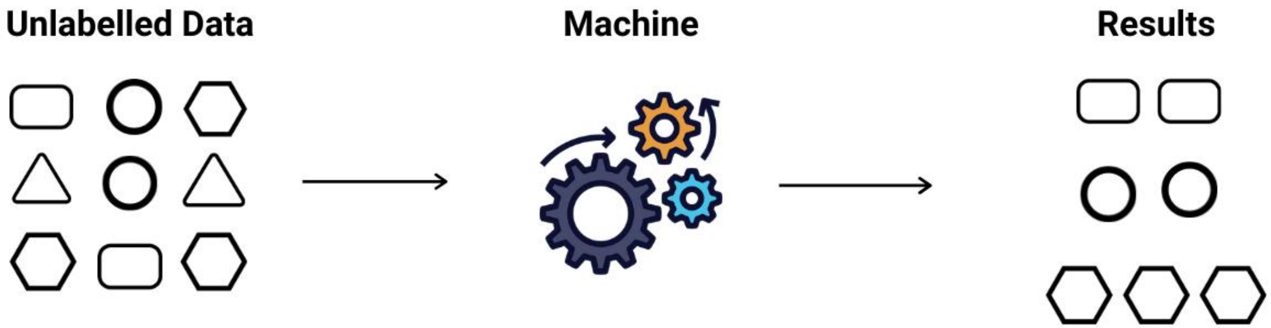


Image taken from: https://bit.ly/3HT5iGo

Reinforcement Learning

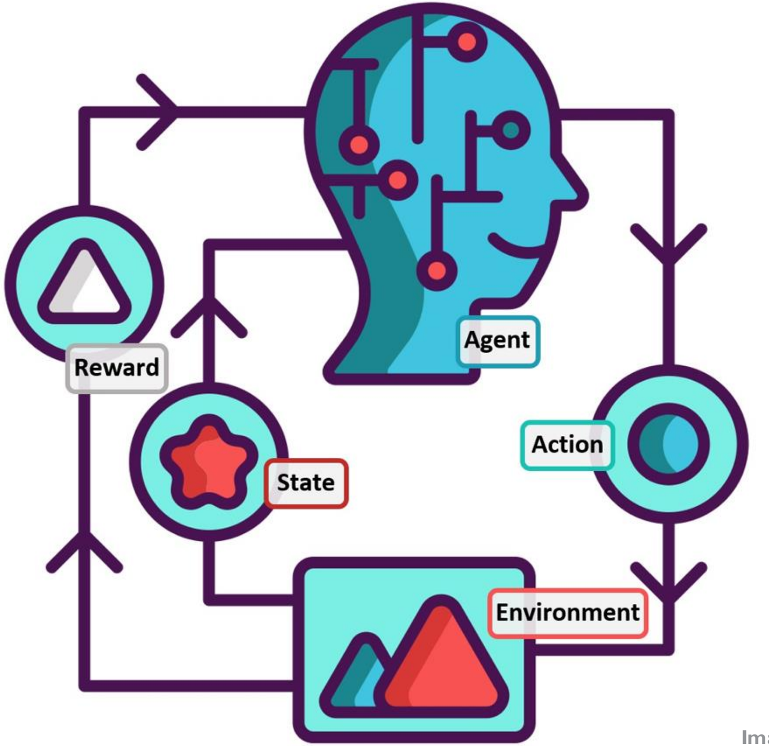
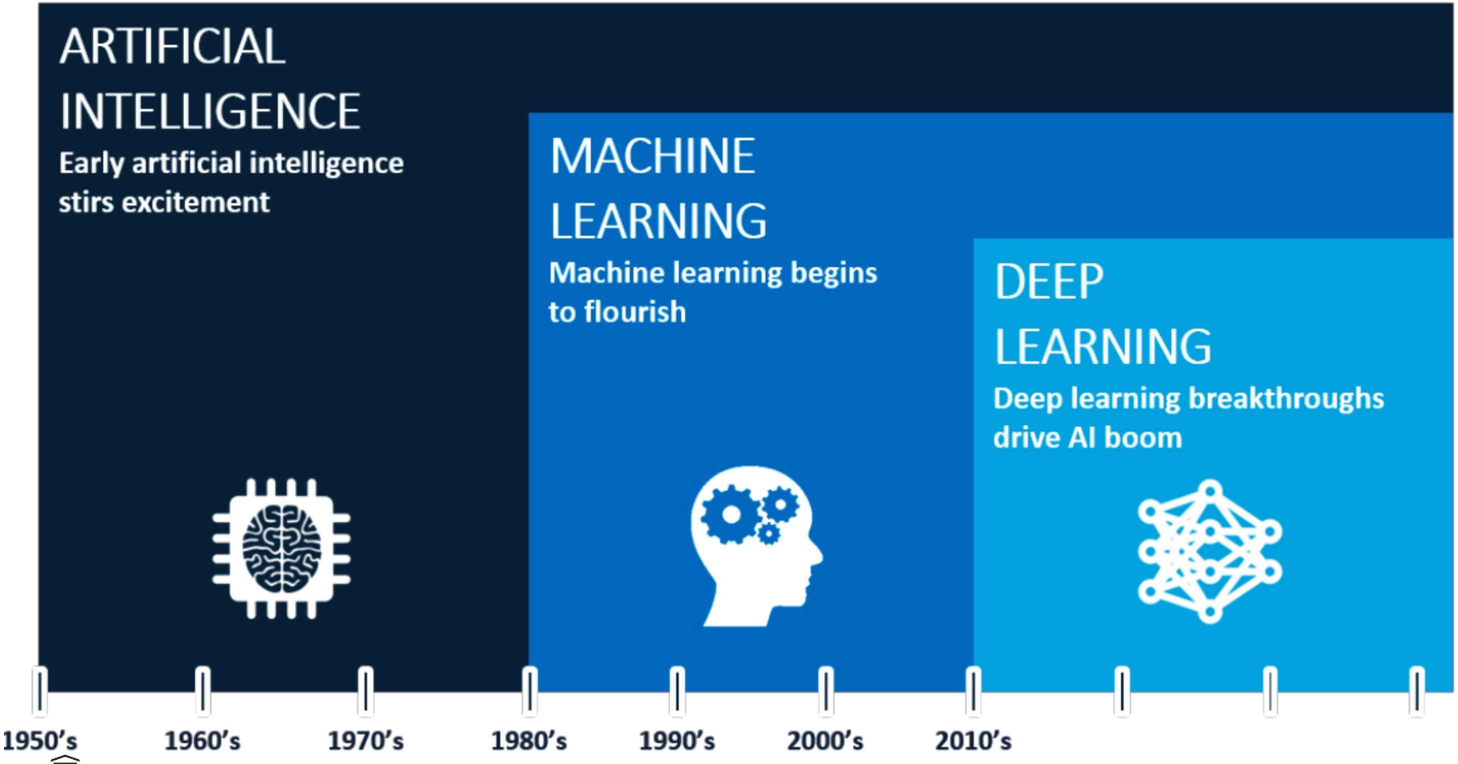
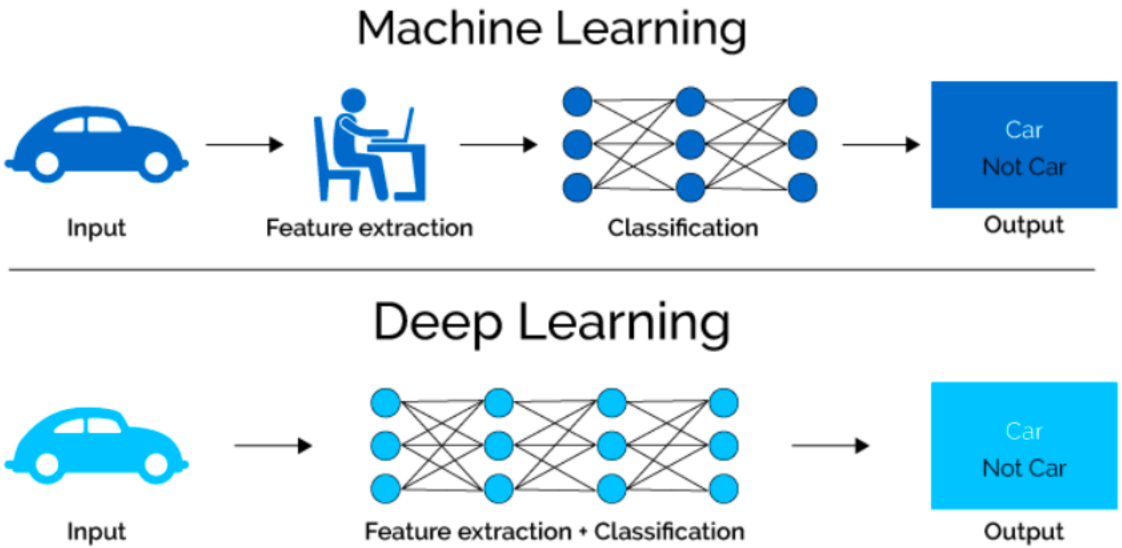


Image taken from: https://bit.ly/3tykdAE

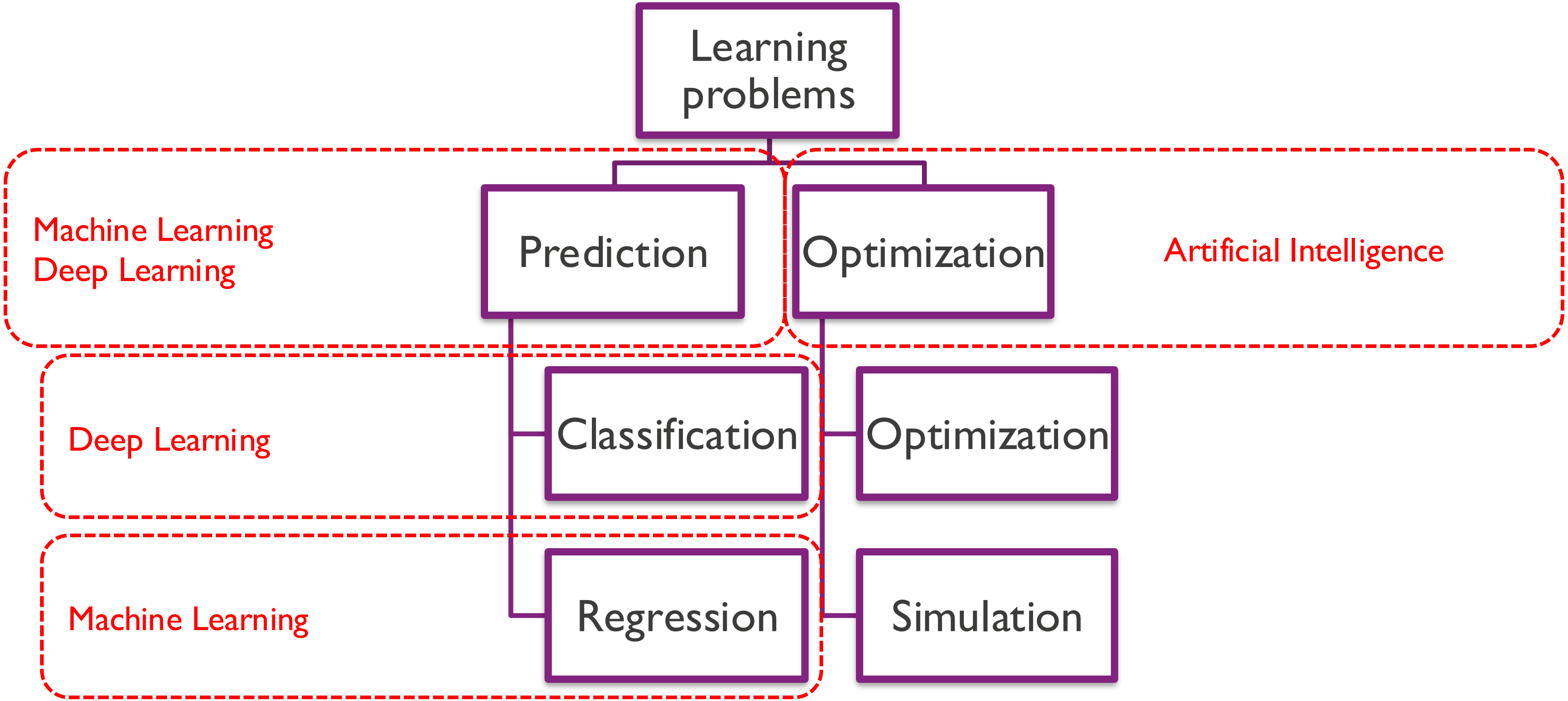
AI vs ML vs DL


ARTIFICIAL INTELLIGENCE
Early artificial intelligence stirs excitement
MACHINE LEARNING
Machine learning begins to flourish
DEEP LEARNING
Deep learning breakthroughs drive AI boom
1950's
1960's
1970's
1980's
1990's
2000's
2010's

AI vs ML vs DL

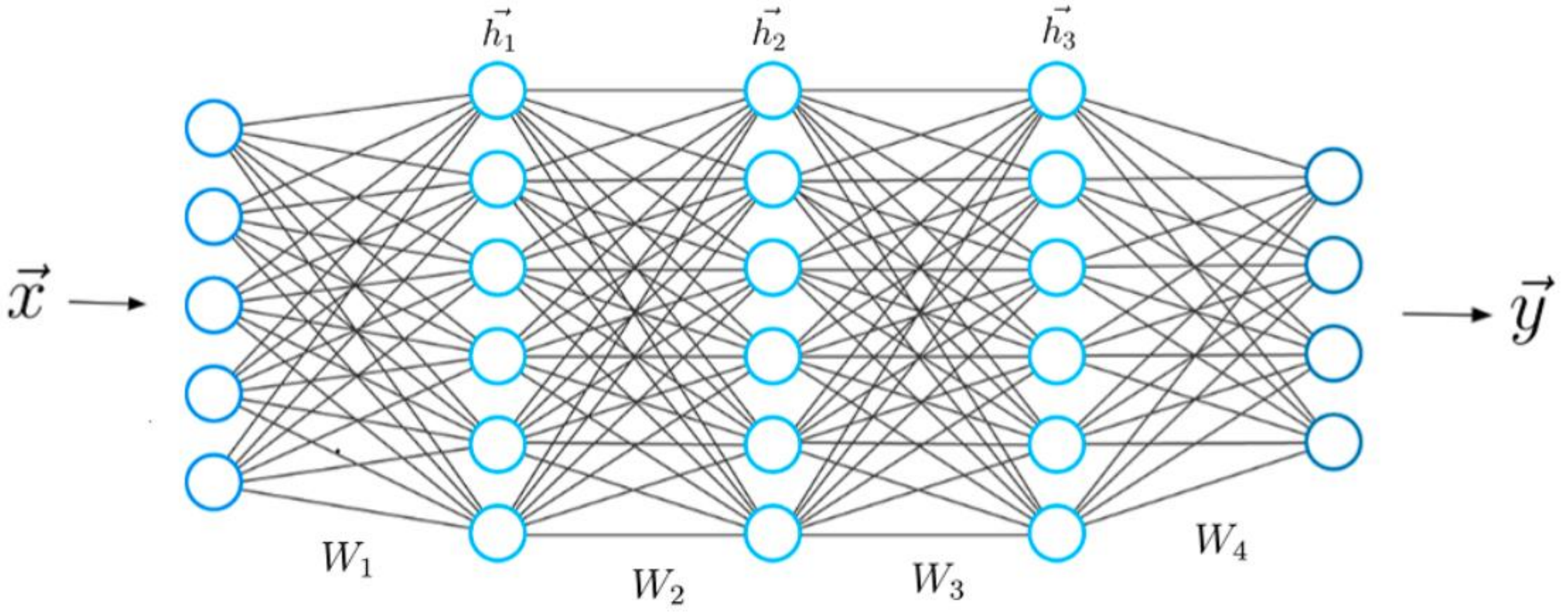

Machine Learning
Car
Not Car
Input
Feature extraction
Classification
Output
Deep Learning
Car
Not Car
Input
Feature extraction + Classification
Output

AI vs ML vs DL


Learning problems
Machine Learning
Deep Learning
Prediction
Optimization
Artificial Intelligence
Deep Learning
Classification
Optimization
Machine Learning
Regression
Simulation

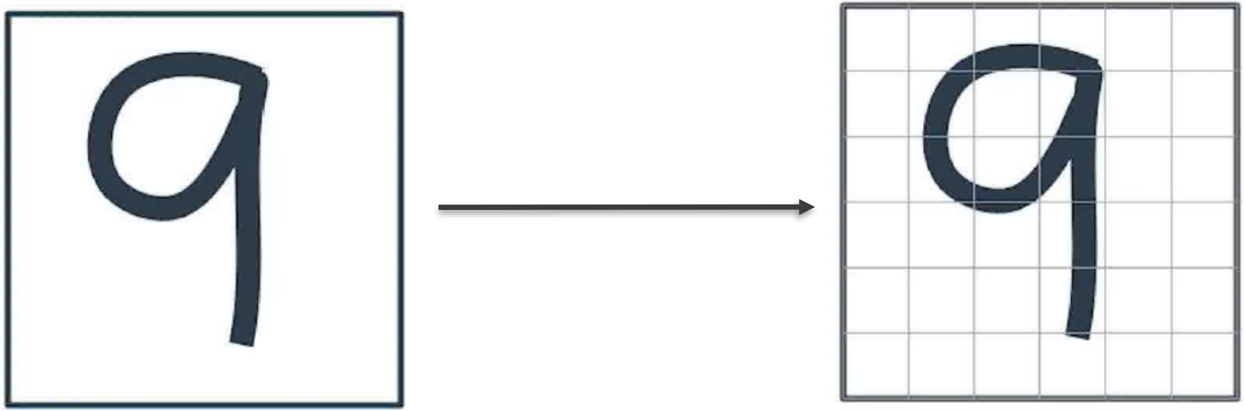
How the models learn?

Neural Networks



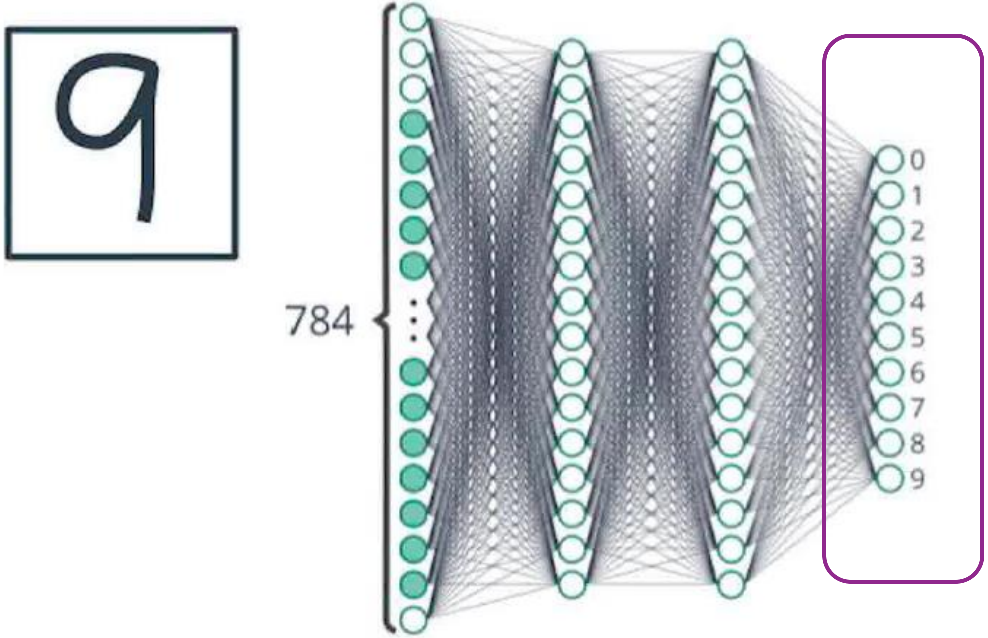
Classification problems

Working with Images – MNIST dataset



Classification problems

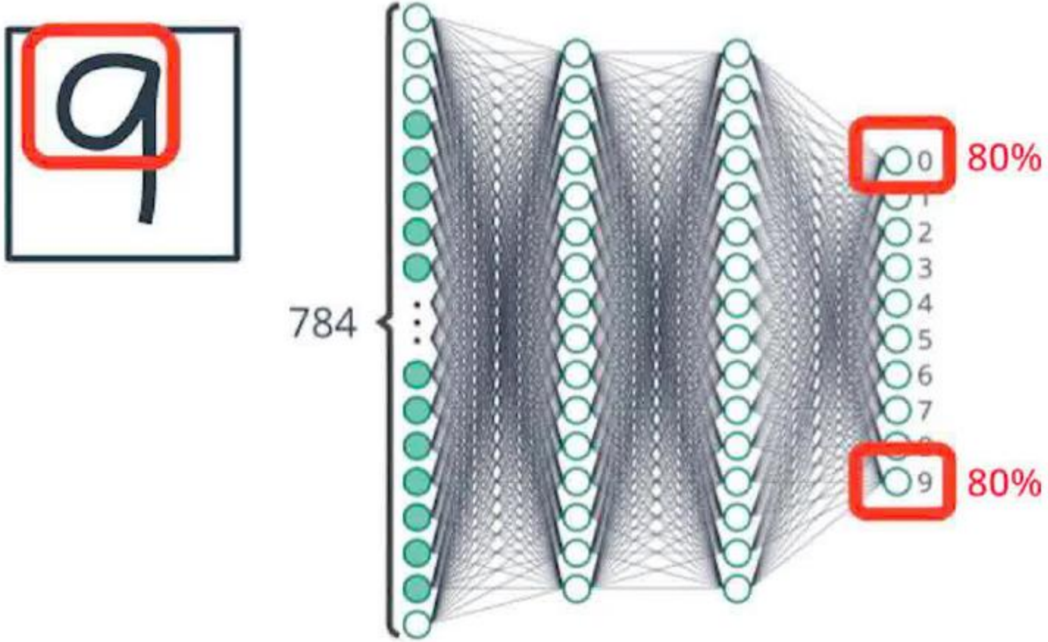
Working with Images – MNIST dataset



Output of the neural network

Classification problems

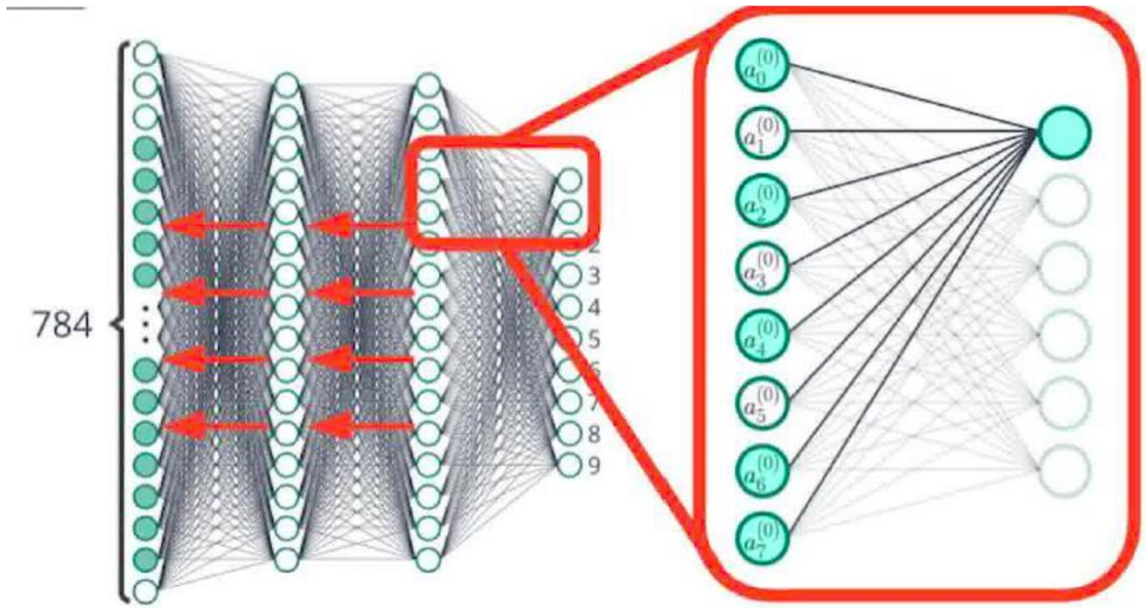
Working with Images – MNIST dataset



publicd

Classification problems

Working with Images – MNIST dataset



Backpropagation

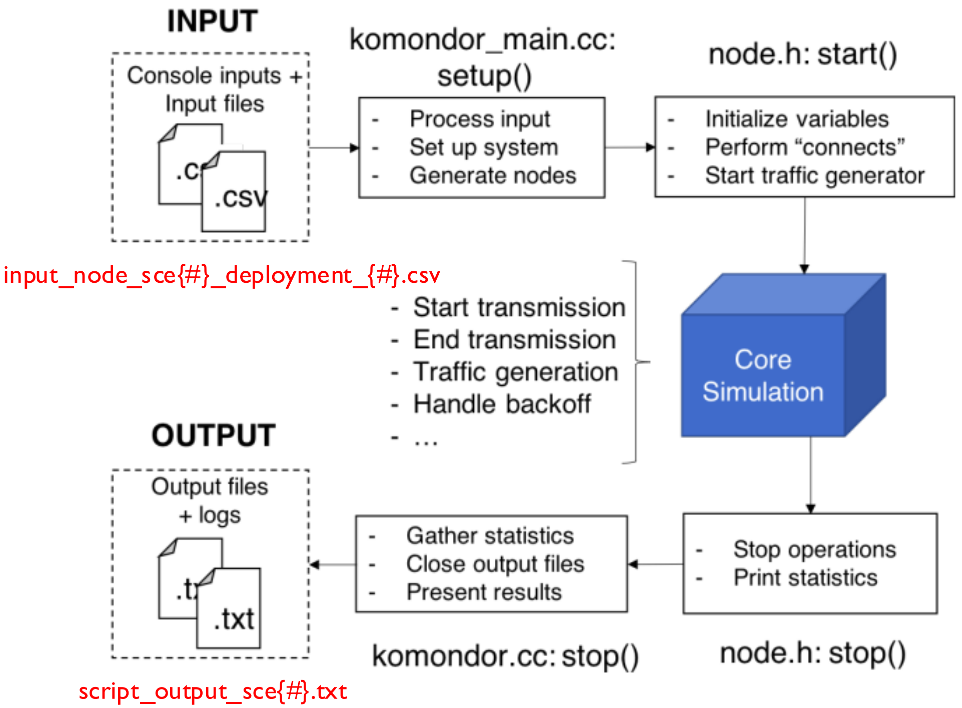
Introduction to Dataset

Dataset

Introduction

- Generated through Komondor
- A Wireless network simulator that includes novel mechanisms for next-generation WLANs, such as dynamic channel bonding or enhanced spatial reuse in dense scenarios.
- Validated against ns-3[2]

Komondor



2. Barrachina-Muñoz, S., Wilhelmi, F., Selinis, I., & Bellalta, B. (2019, April). Komondor: a wireless network simulator for next-generation high-density WLANs. In 2019 Wireless Days (WD) (pp. 1-8). IEEE.

Dataset

Overview

Nodes input files

- Node ID
- BSS ID
- Node position
- Channels selected
- Transmission capabilities (tx power, sensitivity, etc.)
- Other information (CW, traffic load, etc.)

Output Komondor

- RSSI list (power that each STA receives from its AP)
- Interference map (power sensed by each AP from other AP)
- Airtime (percentage of time occupying the channel)
- SINR ()

Features

- Throughput (effective transmission rate)

Label

Source: https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20AI_ML%20Challenge%20-%20UPF.pdf

Dataset

Example input data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1		node_type	wlan_code	x(m)	y(m)	z(m)	central_freq(	channel_bon	primary_cha	min_channel	max_channe	tpc_default(	cca_default(	traffic_mode	traffic_load[	packet_lengt	num_packets	capture_effe	capture_effe	constant_pe	pifs_activate	cw_adaptati	cont_wind	cont_wind_st
2	AP_A	0	A	10	10	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
3	STA_A1	1	A	0.0713	108.079	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
4	STA_A2	1	A	19.627	41.427	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
5	STA_A3	1	A	137.849	167.538	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
6	STA_A4	1	A	67.112	17.487	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
7	STA_A5	1	A	131.934	23.628	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
8	STA_A6	1	A	176.857	76.662	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
9	STA_A7	1	A	194.473	84.359	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
10	STA_A8	1	A	43.802	20.739	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
11	STA_A9	1	A	160.383	109.948	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
12	STA_A10	1	A	178.436	98.488	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
13	STA_A11	1	A	120.082	172.247	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
14	STA_A12	1	A	47.865	52.762	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
15	STA_A13	1	A	197.406	78.867	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5
16	STA_A14	1	A	158.196	87.287	0	5.0	4	4	4	5	20	-82	99	10000.0	12000	64	0	10	0.0	0	0	16	5

Dataset

Example output data

Scenario ID

```
KOMONDOR SIMULATION 'sim_input_nodes_sce1a_deployment_000.csv' (seed 1992)
```

Throughput per STA

```
{111.77,5.79,6.11,6.91,9.99,9.44,7.25,5.88,7.38,10.91,10.05,10.26,7.93,4.88,8.99,111.11,8.10,10.44,9.23,7.57,8.45,12.21,12.98,12.36,6.98,11.83,10.94,77.72,0.23,1.
46,7.91,7.76,5.30,7.53,7.37,2.00,7.99,2.07,4.76,4.99,7.60,1.15,2.38,3.00,4.22,43.05,3.49,1.98,2.46,2.80,3.10,4.72,4.92,4.30,3.49,4.58,2.83,4.38,79.87,2.69,6.45,4.
07,5.61,6.37,0.69,5.61,1.61,6.53,5.38,4.53,3.84,6.99,5.91,6.37,1.61,5.61,57.14,7.45,0.69,7.07,5.53,0.08,7.83,0.08,3.38,7.14,2.00,0.00,4.07,0.15,3.38,7.83,0.00,0.4
6,37.31,8.91,0.08,0.08,0.84,7.45,7.30,1.45,2.60,0.15,0.54,0.38,7.53,48.08,2.94,1.57,5.68,3.76,4.04,3.63,2.53,4.72,3.66,4.53,1.92,5.15,3.96,90.93,9.37,8.52,9.45,12
.52,5.38,3.53,1.46,9.06,7.83,0.84,11.83,10.06,1.08,21.43,3.53,1.23,1.61,0.23,0.00,0.23,3.07,0.54,0.61,3.30,2.53,0.31,0.84,3.38,185.09,17.89,16.90,16.67,19.28,15.4
4,16.82,15.67,16.82,4.07,13.29,15.67,16.59,155.09,14.75,12.13,10.88,13.06,10.98,10.53,13.98,11.90,11.67,12.24,11.83,8.46,12.67}
```

Airtime

```
{95.80,95.69;95.42,83.85;85.40,65.61,51.22,51.22;47.07,30.64;68.65,33.03,33.03,33.03;26.52,25.56,25.56,25.56,25.54,25.54,25.54,25.54;29.24,19.37,13.97,13.97,12.33
,12.33,12.33,12.33;51.18,39.69;74.32,52.33,52.33,52.33;9.66,7.43,7.43,7.43,7.43,7.43,7.43,7.43;83.80,70.91,70.91,70.91;94.92,94.79;}
```

RSSI

```
{Inf,-65.37,-65.35,-61.41,-63.52,-62.42,-61.96,-64.72,-64.96,-58.06,-61.61,-60.94,-60.01,-65.38,-57.69,Inf,-64.99,-53.92,-63.43,-65.14,-58.34,-53.70,-58.88,-
58.30,-63.01,-62.51,-62.16,Inf,-67.94,-65.62,-64.13,-68.37,-68.18,-55.09,-66.02,-66.43,-58.11,-67.41,-66.83,-61.76,-52.60,-66.25,-66.26,-65.22,-65.41,Inf,-59.48,-
64.97,-60.21,-61.57,-65.04,-59.08,-43.67,-58.02,-59.81,-59.78,-65.31,-53.29,Inf,-61.12,-62.56,-60.28,-63.43,-67.26,-66.15,-66.51,-68.28,-64.42,-54.39,-60.57,-
59.98,-60.58,-62.17,-56.46,-65.15,-62.59,Inf,-56.77,-70.66,-47.70,-60.46,-64.42,-56.19,-68.86,-65.15,-62.06,-69.77,-71.11,-66.60,-64.31,-65.73,-52.91,-69.58,-
70.72,Inf,-59.22,-70.73,-69.49,-68.14,-44.75,-58.07,-67.20,-65.37,-68.91,-69.29,-69.11,-54.56,Inf,-63.68,-63.52,-58.63,-58.82,-61.61,-60.35,-61.99,-60.93,-64.54,-
57.52,-62.13,-56.31,-64.42,Inf,-61.53,-65.56,-64.15,-68.18,-67.68,-62.29,-63.65,-62.28,-67.81,-66.76,-64.35,-60.08,-65.89,Inf,-58.79,-69.48,-64.61,-70.35,-70.99,-
70.10,-61.73,-69.77,-69.29,-58.55,-54.68,-70.78,-68.44,-50.89,Inf,-57.09,-61.57,-46.62,-55.89,-66.20,-64.41,-68.21,-58.94,-67.14,-62.37,-55.71,-57.17,Inf,-49.00,-
55.70,-61.54,-48.57,-53.97,-61.43,-53.93,-47.07,-54.15,-59.72,-59.08,-64.17,-43.74}
```

Interference Map

```
{Inf,-79.34,-103.96,-119.98,-82.35,-94.85,-111.61,-122.95,-103.96,-111.61,-119.82,-130.96;
-79.34,Inf,-82.35,-100.95,-91.84,-85.36,-94.85,-105.59,-108.60,-106.97,-108.60,-116.81;
-100.95,-79.34,Inf,-79.34,-108.60,-94.85,-85.36,-88.83,-119.82,-111.61,-103.96,-105.59;
-119.98,-100.95,-82.35,Inf,-125.96,-111.61,-94.85,-79.34,-133.97,-122.83,-108.60,-100.95;
-79.34,-88.83,-108.60,-122.95,Inf,-85.36,-106.97,-119.98,-82.35,-94.85,-108.60,-122.95;
-88.83,-79.34,-91.84,-105.59,-82.35,Inf,-85.36,-100.95,-91.84,-85.36,-91.84,-105.59;
-105.59,-88.83,-82.35,-88.83,-103.96,-85.36,Inf,-79.34,-108.60,-94.85,-82.35,-88.83;
-122.95,-105.59,-91.84,-79.34,-122.99,-106.97,-85.36,Inf,-125.96,-111.61,-91.84,-79.34;
-100.95,-105.59,-119.82,-130.96,-82.35,-94.85,-111.61,-122.95,Inf,-85.36,-103.96,-119.98;
-105.59,-100.95,-108.60,-116.81,-91.84,-85.36,-94.85,-105.59,-82.35,Inf,-82.35,-100.95;
-116.81,-105.59,-103.96,-105.59,-108.60,-94.85,-85.36,-88.83,-103.96,-85.36,Inf,-79.34;
-130.96,-116.81,-108.60,-100.95,-125.96,-111.61,-94.85,-79.34,-122.99,-106.97,-82.35,Inf}
```

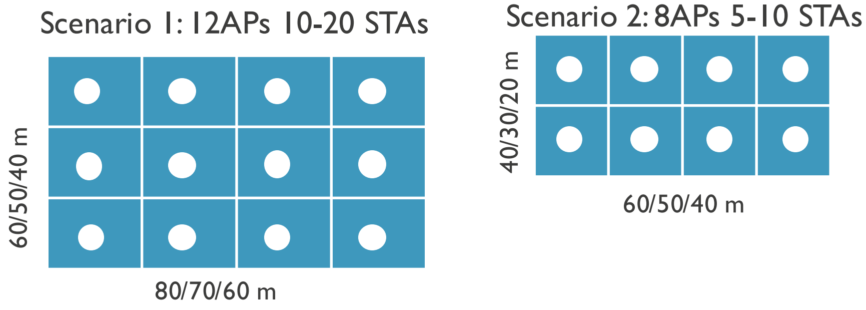
SINR

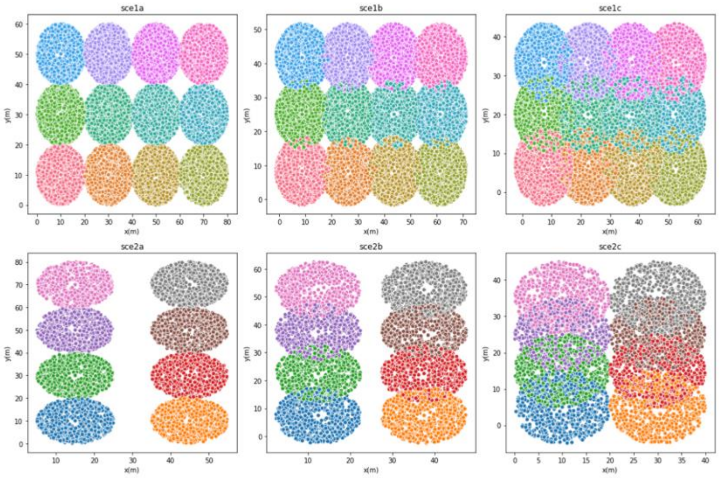
```
{Inf,29.36,29.48,31.97,31.26,32.05,31.69,29.04,29.86,35.60,31.86,32.88,34.69,28.28,36.28,Inf,28.86,38.73,30.25,28.93,34.73,39.24,34.55,35.41,30.07,31.14,31.39,Inf
,10.85,18.50,27.65,22.15,23.95,30.27,23.36,15.03,28.14,15.05,22.13,25.96,34.20,21.96,20.53,17.99,25.83,Inf,31.79,25.28,30.42,30.40,27.95,31.98,47.05,33.54,30.79,3
1.81,26.71,36.84,Inf,26.80,27.69,29.35,26.08,22.71,24.95,24.16,25.37,24.34,32.63,26.06,26.80,29.16,27.74,31.05,21.39,25.33,Inf,22.19,11.10,31.66,18.27,9.51,25.29,
7.26,16.37,11.85,11.73,8.51,16.16,14.34,13.53,28.73,8.13,11.27,Inf,20.39,9.32,17.40,15.97,33.99,22.32,20.33,20.57,12.03,18.03,10.55,23.13,Inf,23.64,24.70,32.93,27
.38,28.13,26.38,25.74,26.90,26.39,30.65,25.66,33.30,24.76,Inf,27.01,24.85,25.68,23.86,16.25,24.94,26.07,27.66,20.63,18.19,23.81,30.32,22.57,Inf,23.42,19.31,17.74,
13.32,16.99,18.37,20.43,12.07,15.21,25.88,29.51,15.87,13.33,33.98,Inf,33.49,29.58,43.45,34.36,25.26,27.16,23.67,31.55,20.03,26.02,34.78,31.17,Inf,45.31,38.89,32.5
3,45.62,40.10,32.75,40.62,47.10,40.36,34.97,35.40,29.68,50.69}
```

Training Dataset

Characteristics

- Two scenarios with modifications on user density per m^2
- 3 map sizes per scenario.
- 100 deployments per scenario.
- Each scenario introduce more interference than the other.
- Different channel configurations.
- 80% Training – 480 Graphs.
- 20% Validation – 120 Graphs.





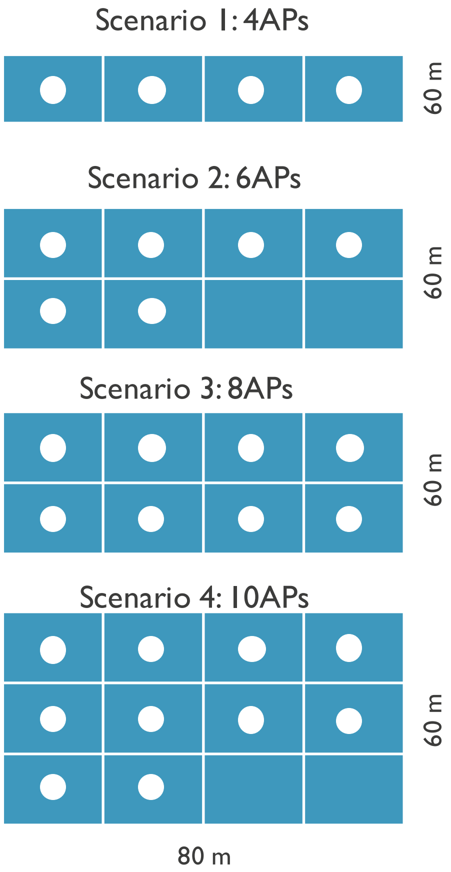
UNIVERSITEIT GENT
Universiteit Antwerpen

publicd

Test Dataset

Characteristics

- Four testing scenarios.
- Different spatial distribution than training.
- 50 random deployments per scenario.



Hands – On

Link

Notebook: Building an NDT for next-generation WLANs using ML/DL

https://github.com/miguelhdo/ndt-latincom-tutorial

```
conda create -n ndt-tutorial-latincom python==3.10

conda activate ndt-tutorial-latincom

conda install -c conda-forge scikit-learn  jupyterlab matplotlib

conda install tensorflow==2.12 pandas gdown

conda install pytorch==2.4.1 torchvision==0.19.1 torchaudio==2.4.1 -c pytorch

conda install pyg -c pyg

conda install pytorch-scatter -c pyg
```

https://docs.anaconda.com/anaconda/install/

Link

Notebook: Building an NDT for next-generation WLANs using ML/DL

Google Colab

This tutorial can also run in Google Colab. There are two main notebooks, one for building the NDT - GNN and another to build the NDT - ML.

To access the notebook regarding the NDT - ML, please enter here.

To access the notebook regarding the NDT - GNN, please enter here.

Link

Notebook: Building an NDT for next-generation WLANs using ML/DL

https://github.com/miguelhdo/ndt-latincom-tutorial

```
conda create -n ndt-tutorial-latincom python==3.10
conda activate ndt-tutorial-latincom
conda install -c conda-forge scikit-learn  jupyterlab matplotlib
conda install tensorflow==2.12 pandas gdown
conda install pytorch==2.4.1 torchvision==0.19.1 torchaudio==2.4.1 -c pytorch
conda install pyg -c pyg
conda install pytorch-scatter -c pyg
```

You can also use pyenv to build your virtual environment.

Google Colab

This tutorial can also run in Google Colab. There are two main notebooks, one for building the NDT - GNN and

To access the notebook regarding the NDT - ML, please enter here.

To access the notebook regarding the NDT - GNN, please enter here.

https://docs.anaconda.com/anaconda/install/

imec

embracing a better life