



# The (Smart) Cyber-physical Revolution: Challenges and Opportunities

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# The Cyber-physical Systems

Cyber Domain

Physical Sensing

Actuation and Control

Object Domain

Physical Domain



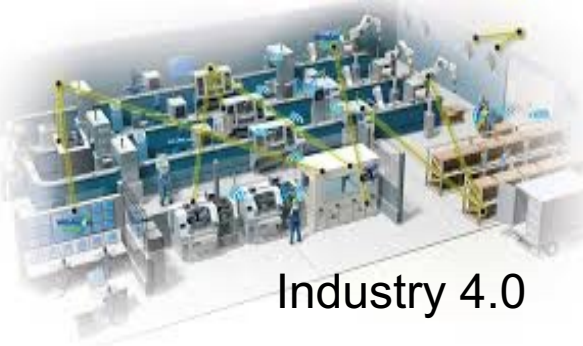


# Cyber-physical Systems: the application scenarios

E-health



Smart Car



Industry 4.0

Cyber-physical Systems



Smart Cities

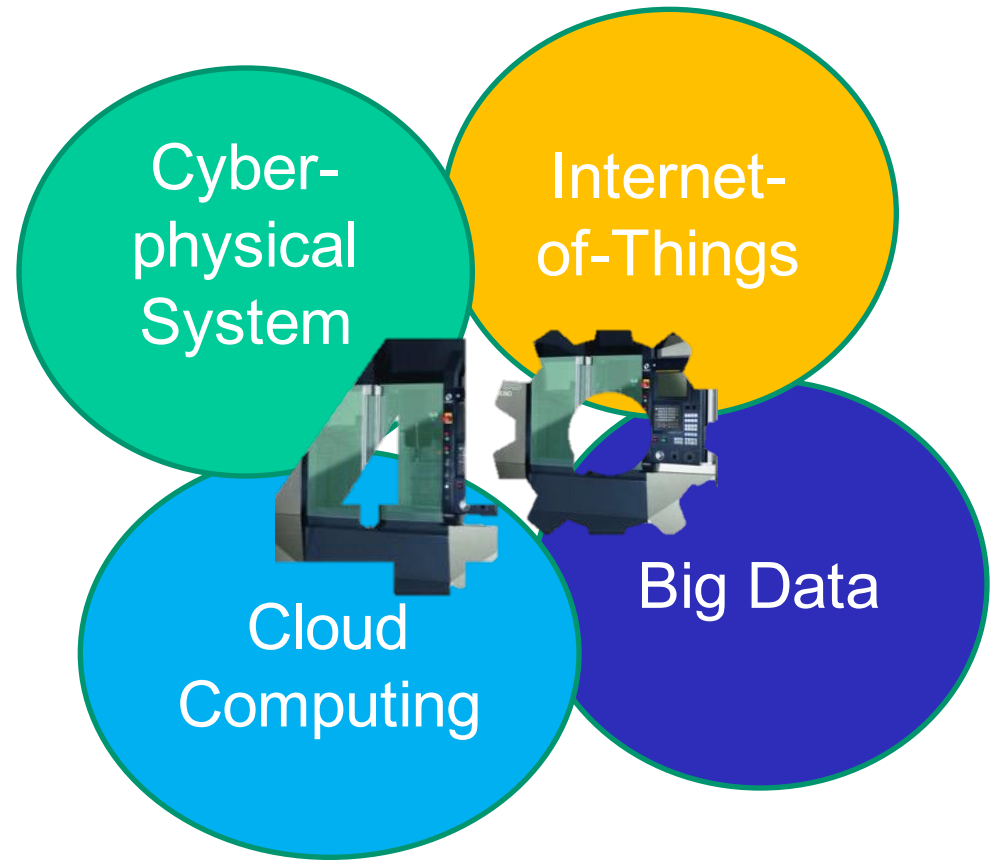


Smart Home/Building

...



# The application case of Industry 4.0



...





# Applications, Systems and World

Applications



Cyber-physical  
Systems

Physical World





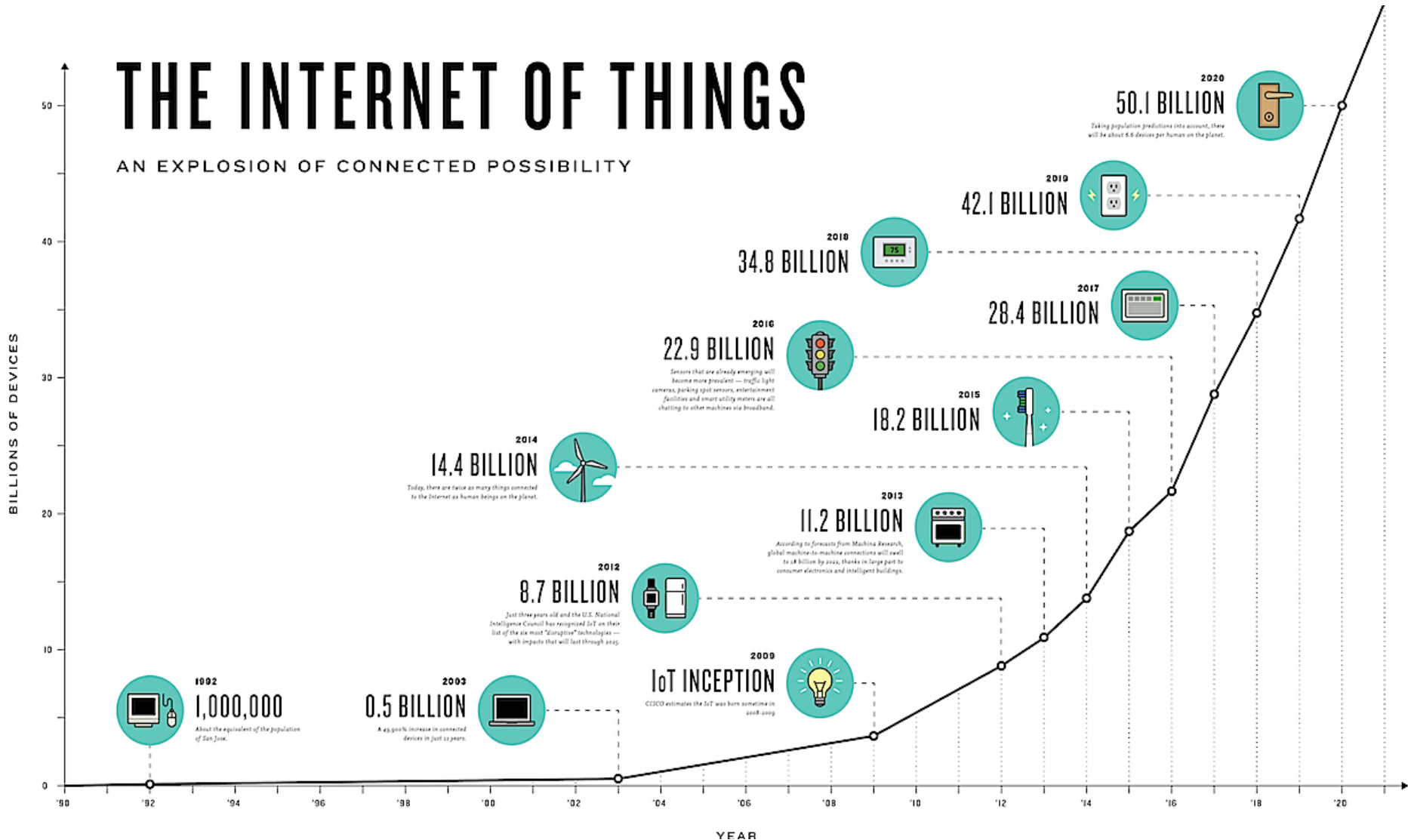
# The Challenges



# The ever-growing number of devices

## THE INTERNET OF THINGS

AN EXPLOSION OF CONNECTED POSSIBILITY



Fonte: <https://www.ncta.com>



## Complex systems in remote and harsh environments







# ... Faults, Errors and Changes in the Environment

Applications



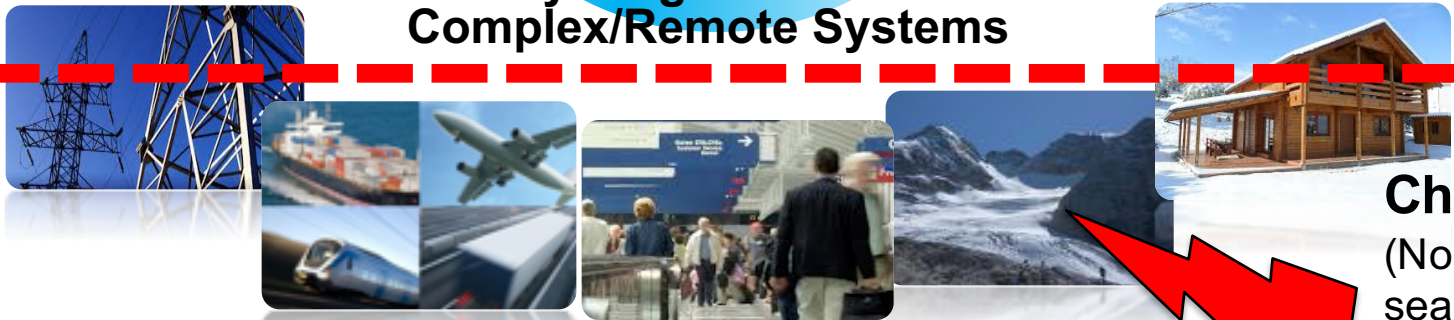
Cyber-physical Systems

Faults, Errors, Uncertainty, Malfunctionings



Very Large-scale and Complex/Remote Systems

Physical World



Changes (Nonstationary, seasonality, periodicity)





# The effects on the considered applications

Applications



Performance reduction, cascade effects

Faults, Errors, Uncertainty, Malfunctionings



Cyber-physical Systems

Very Large-scale and Complex/Remote Systems

Physical World



Changes (Nonstationary, seasonality, periodicity)



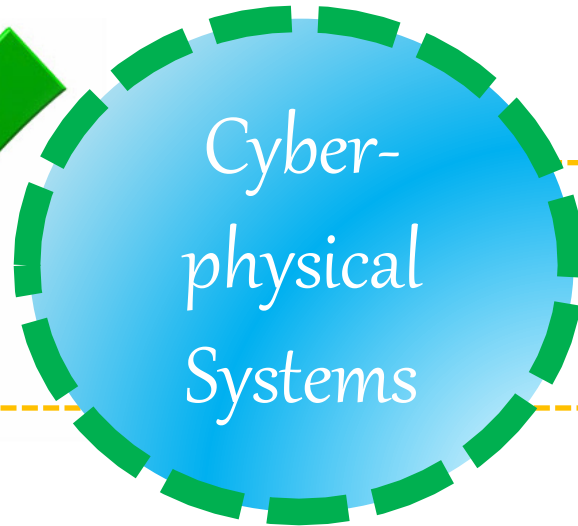


**How to deal with that?**



# Intelligence for cyber-physical systems

Applications



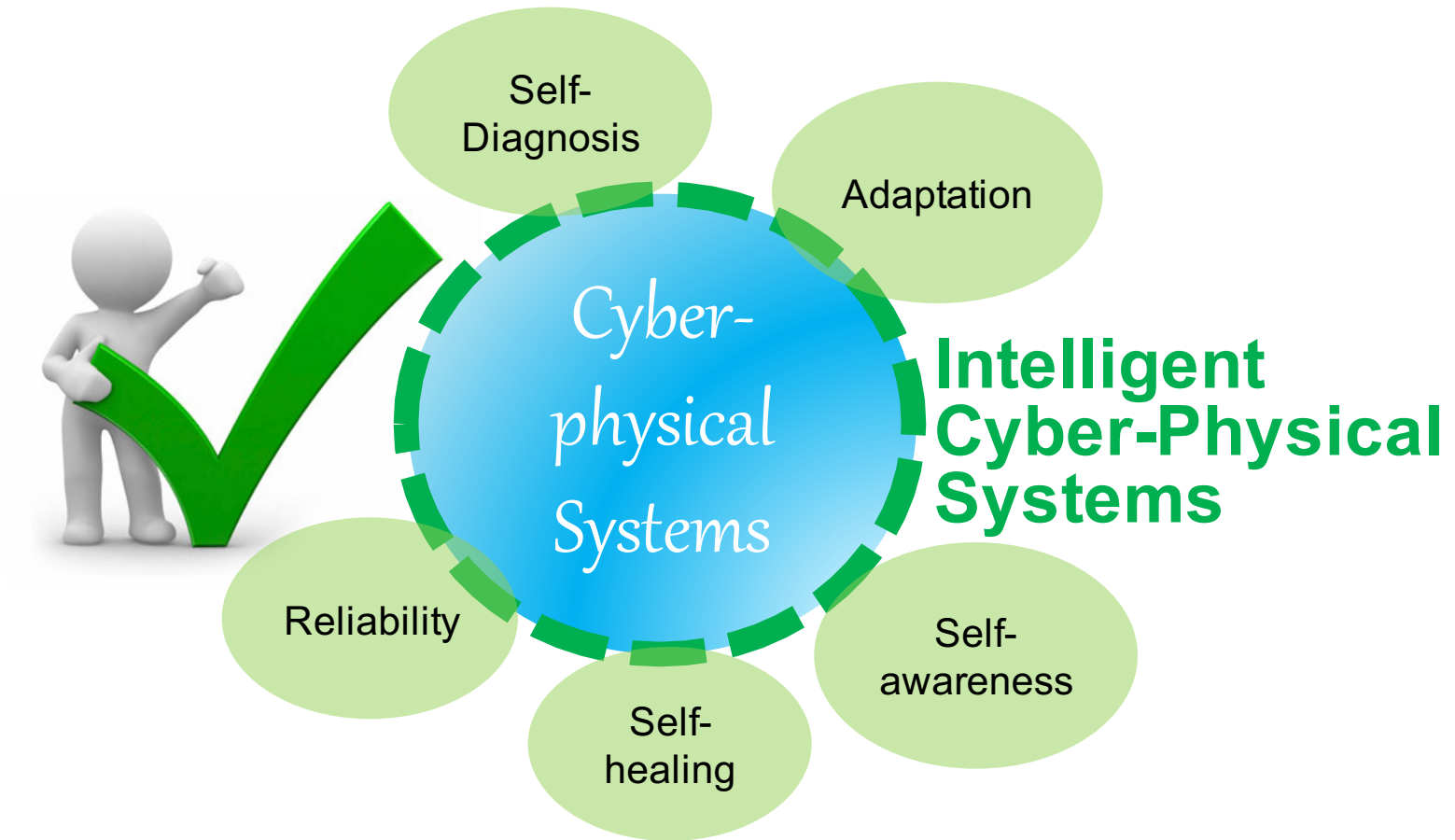
## Intelligent Cyber-Physical Systems

Physical World





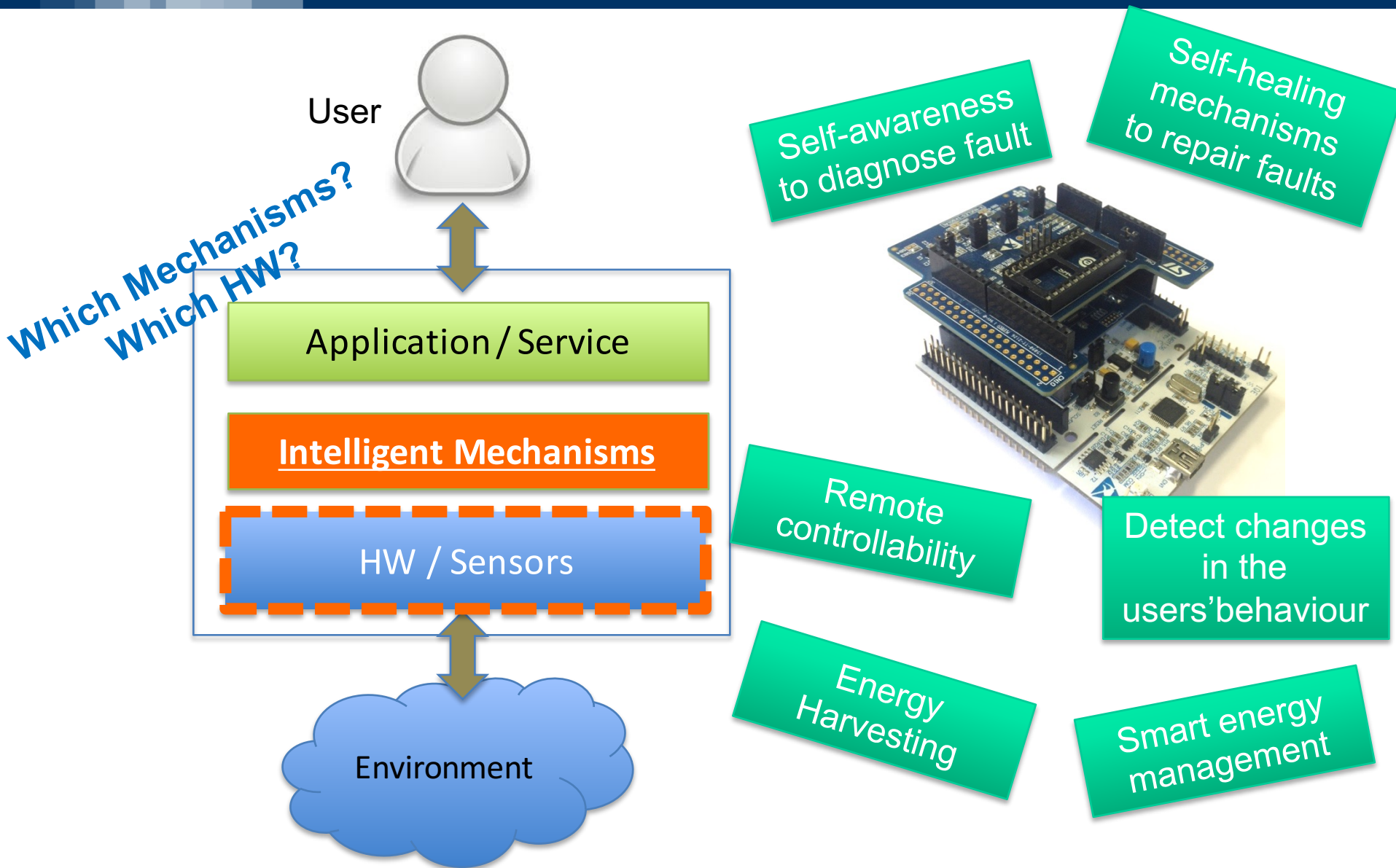
# Intelligence for cyber-physical systems





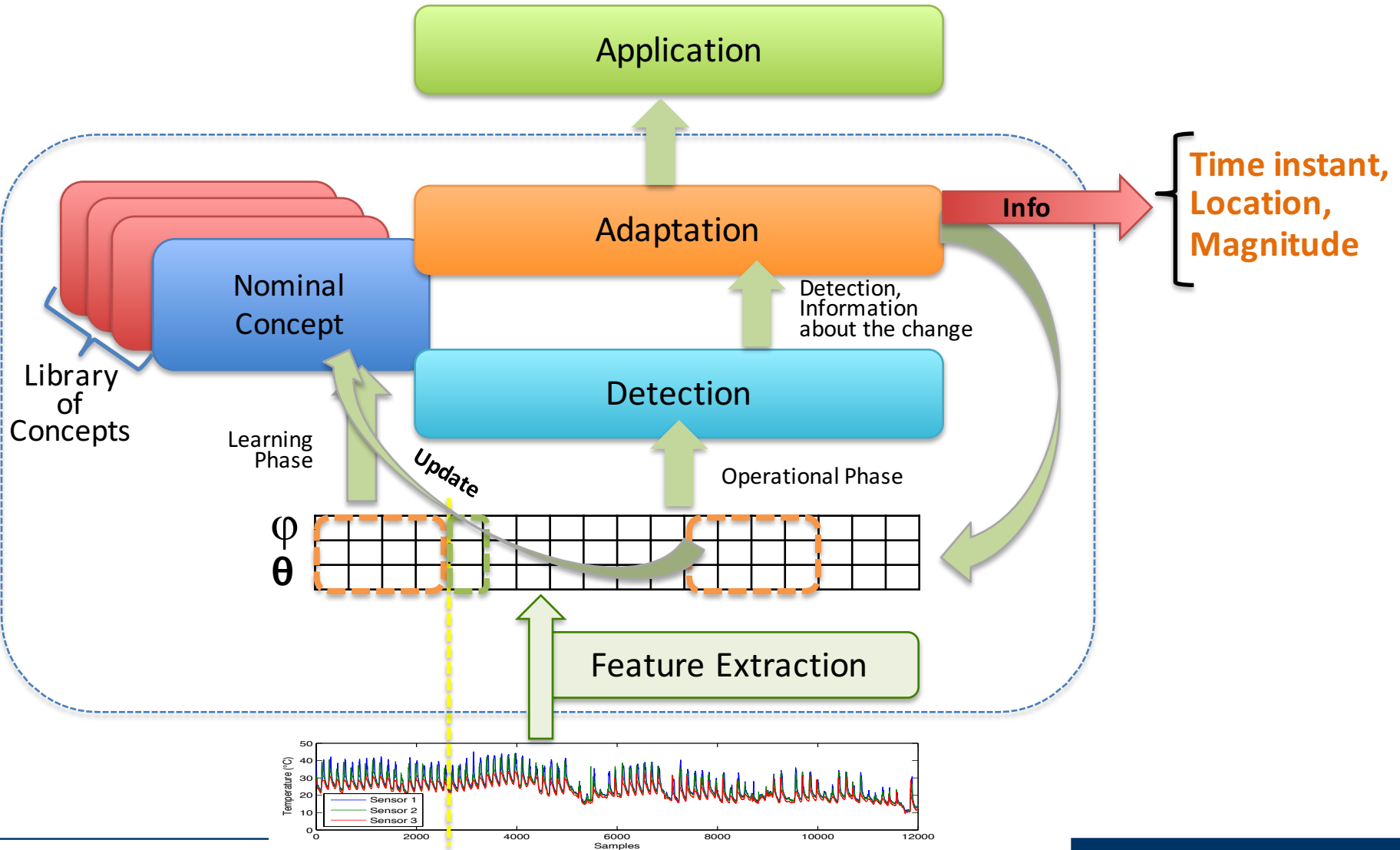


# Intelligent Objects/Devices



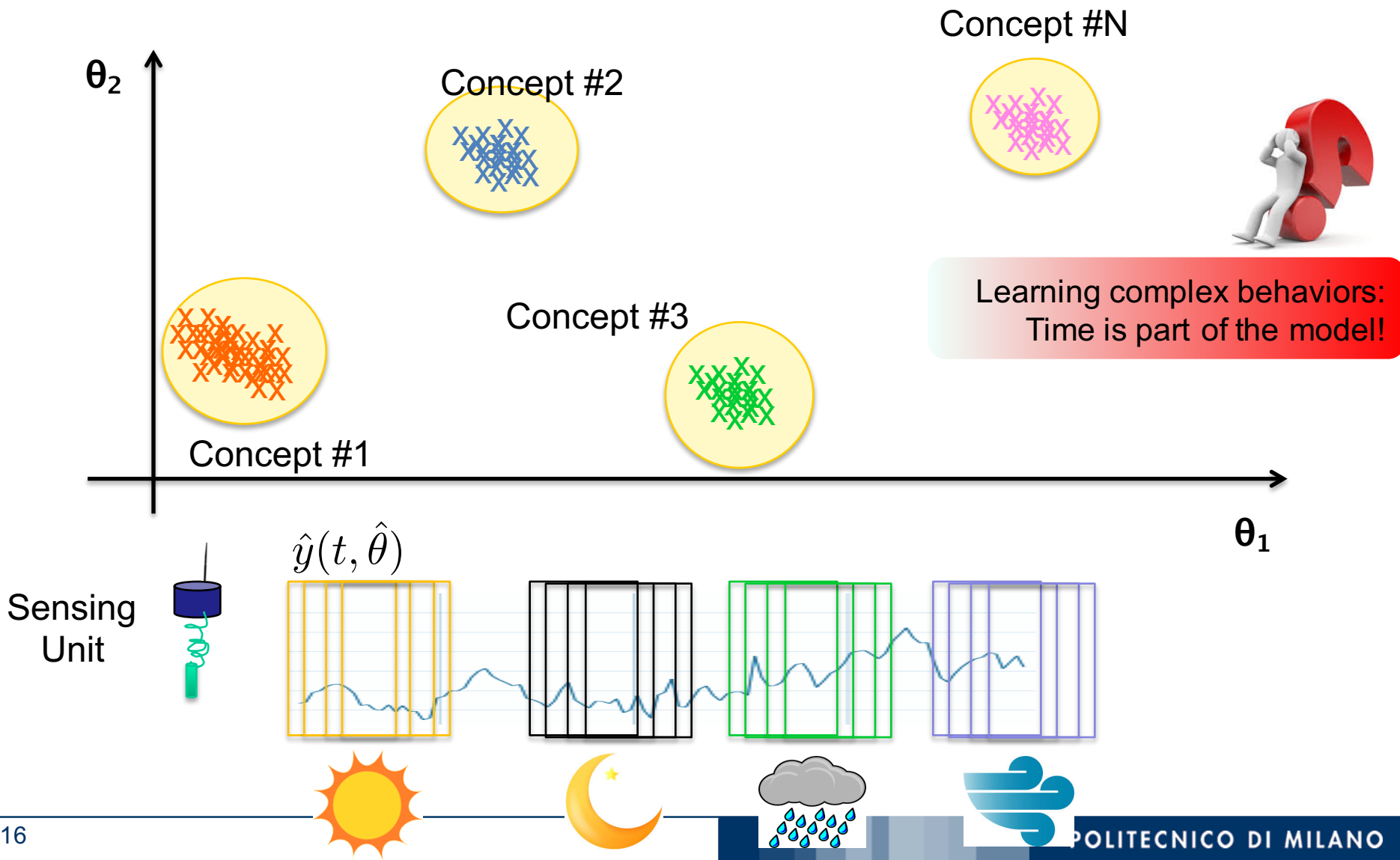


# .... up to the Unit Layer .....



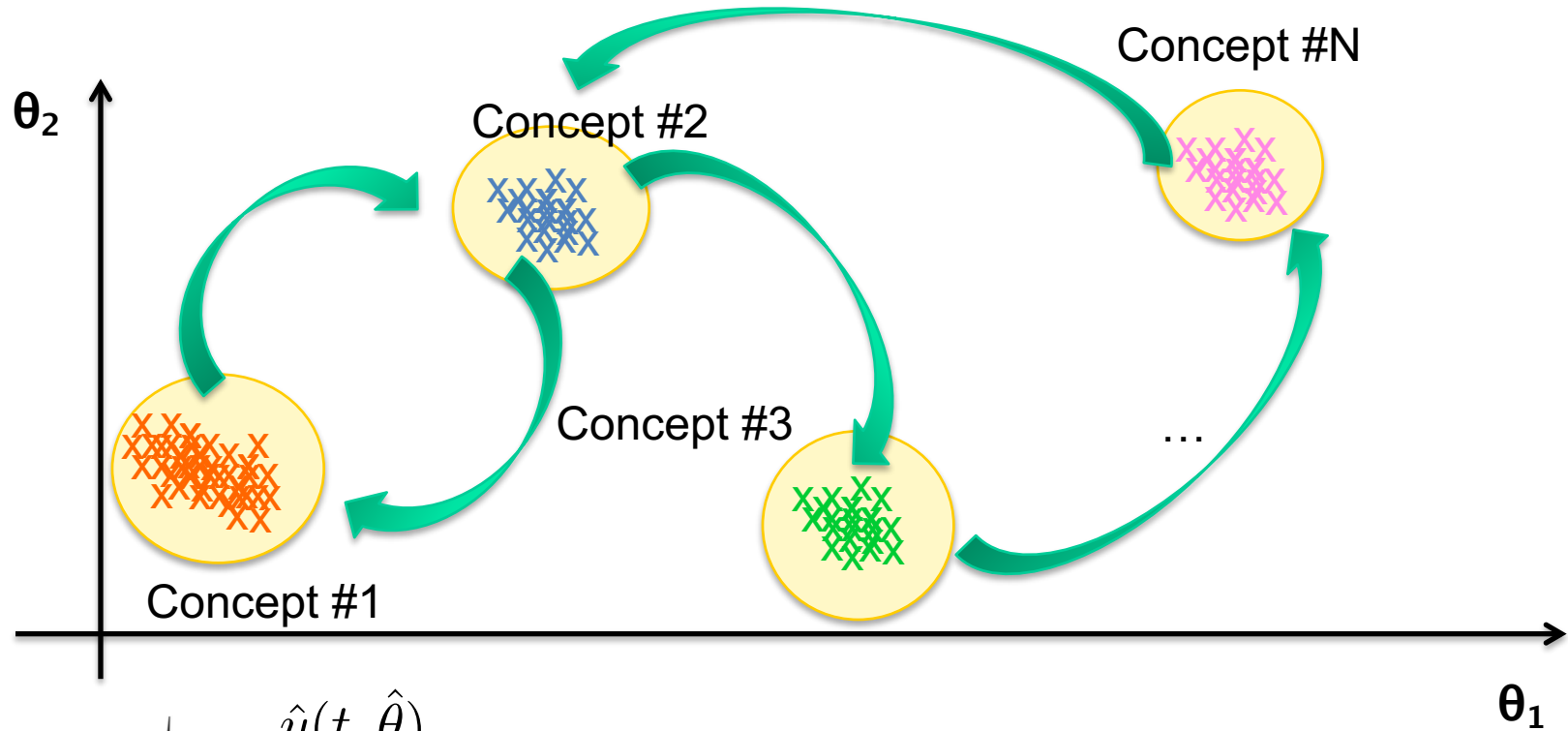


# Continuously Learning Complex Behaviors

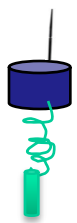




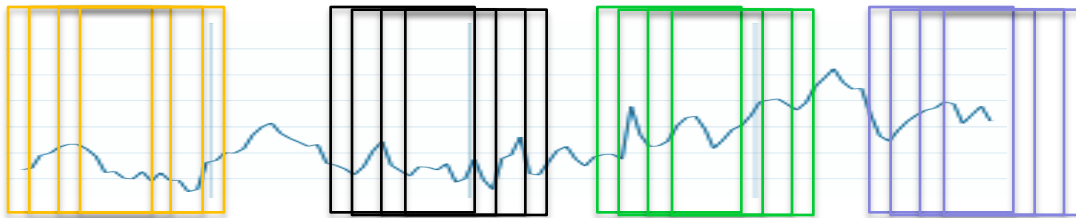
# Continuously Learning Complex Behaviors



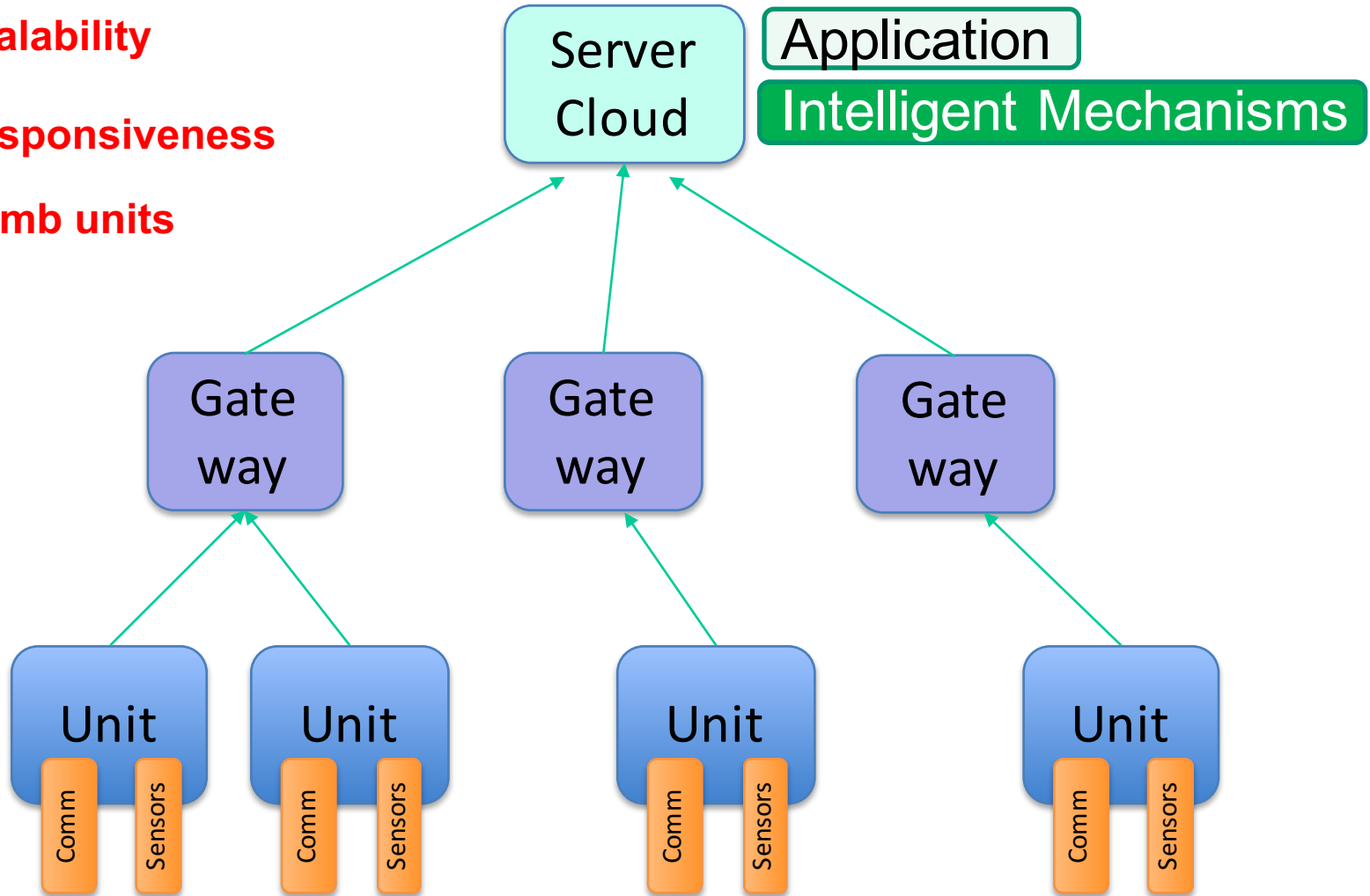
Sensing Unit



$$\hat{y}(t, \hat{\theta})$$



- ↓ Scalability
- ↓ Responsiveness
- ↓ Dumb units



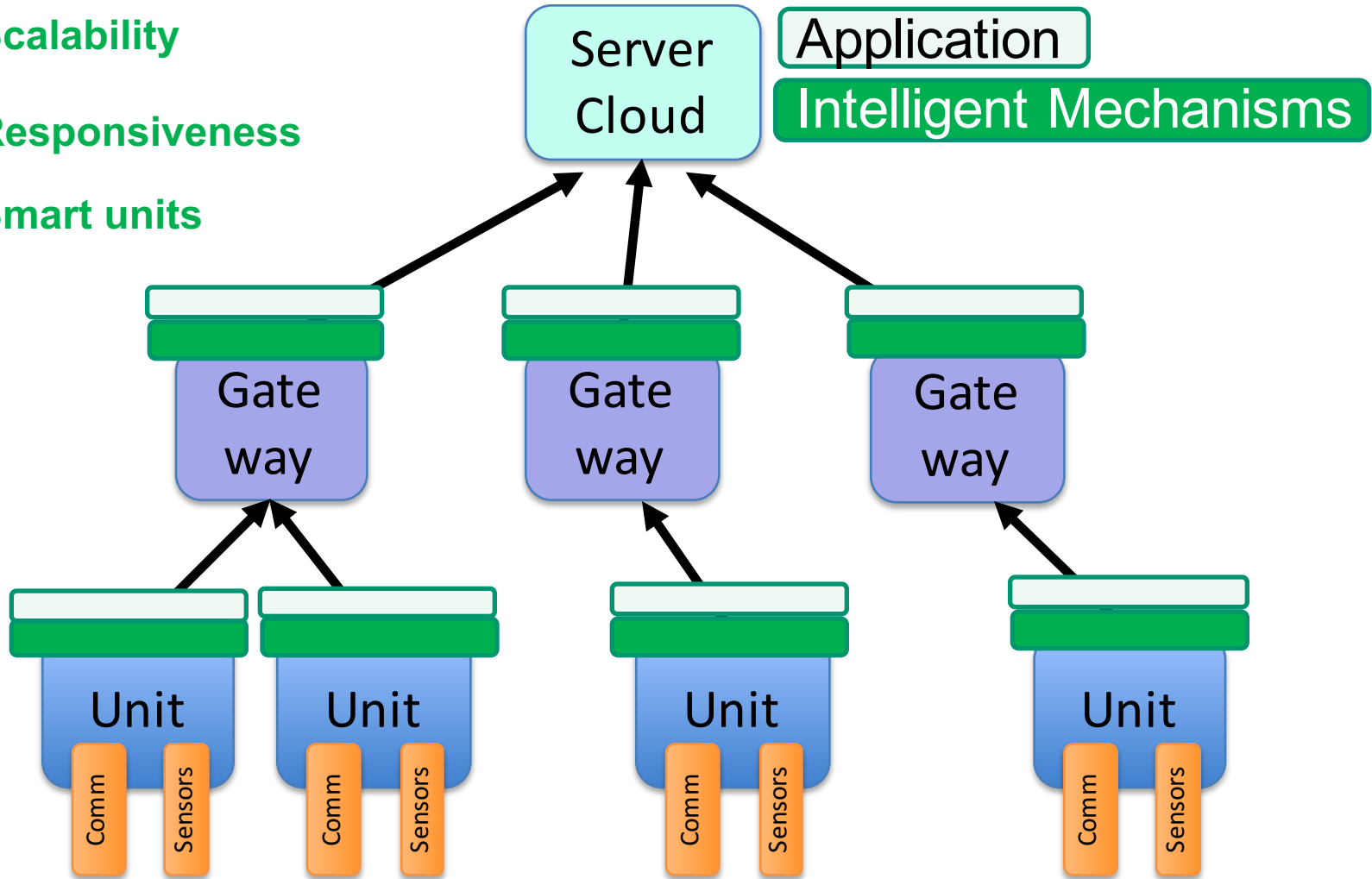




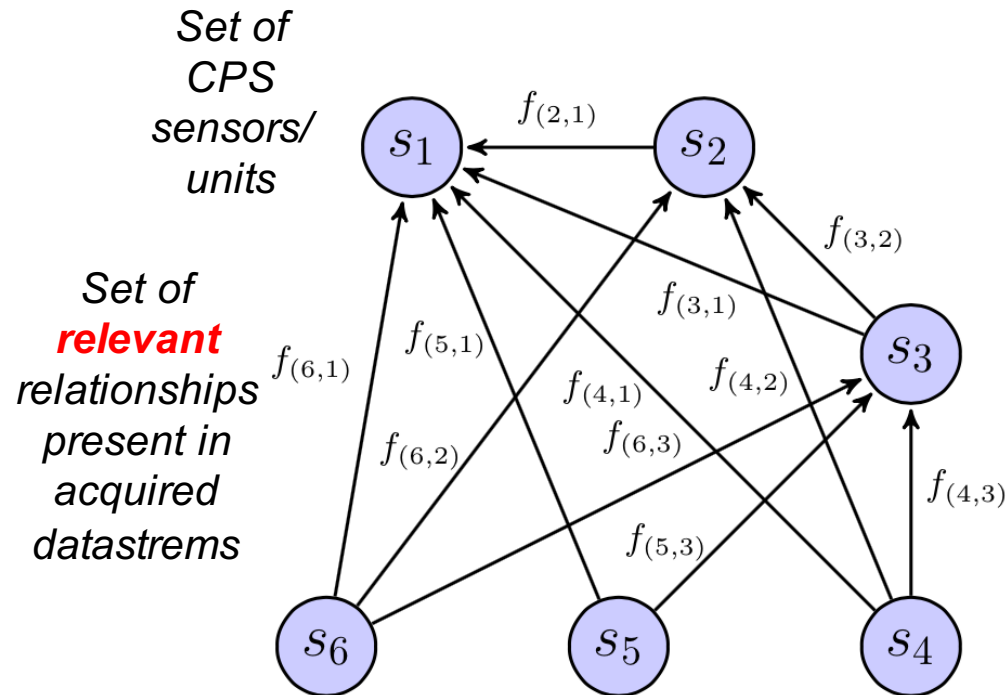
# Designing Intelligent CPSs: ....to distributed intelligent systems



- ↑ Scalability
- ↑ Responsiveness
- ↑ Smart units

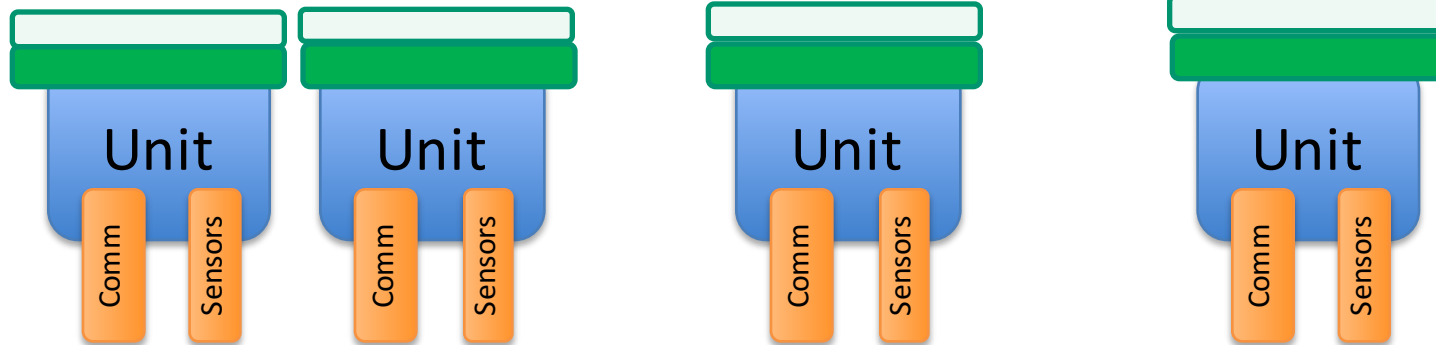


# Capturing the relationships among the sensors ...



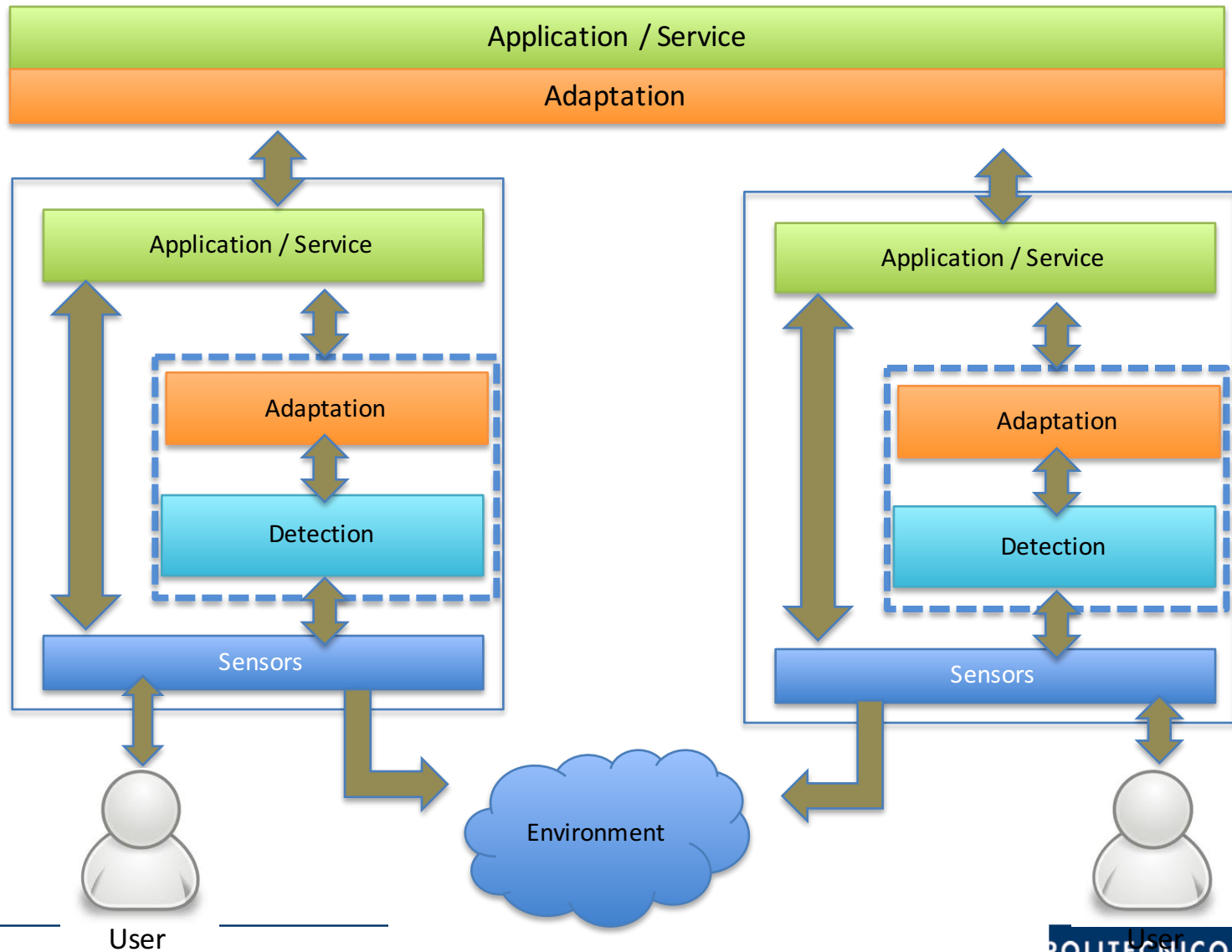
Dependency Graph

$$\mathcal{G} = (V, E)$$





# Distributing Intelligence among the Units



# Distributing Intelligence among the Units





## Intelligent Cyber-Physical Systems: an active joint project

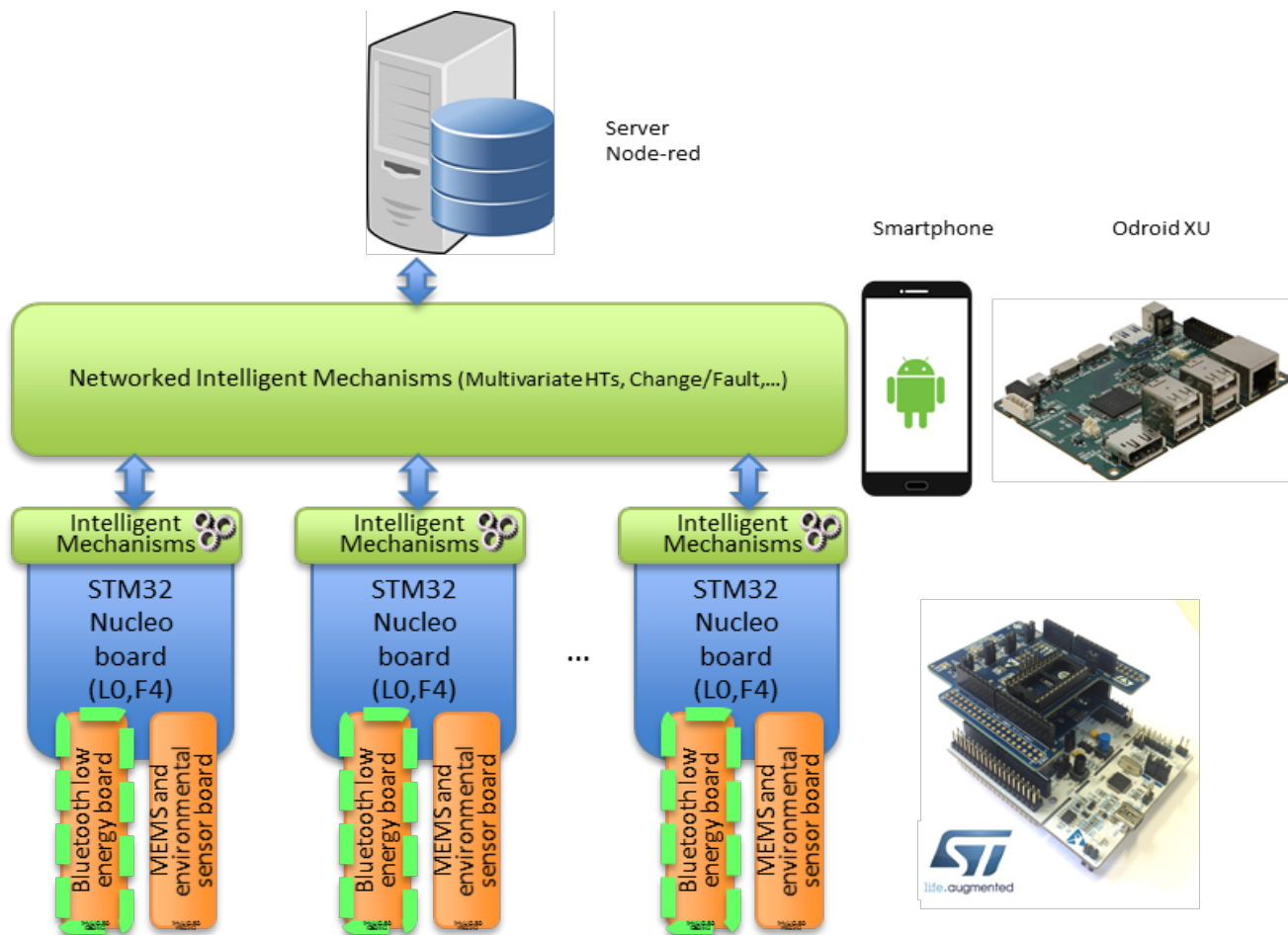






# Aim of the project

- Design and develop a network of intelligent units based on **STMicroelectronics NUCLEO boards** endowed with STM32, Bluetooth, heterogeneous sensors (e.g., MEMS, humidity, temperature, pressure, microphones etc), **coordinator** (e.g., smartphone/tablet), and **remote server**

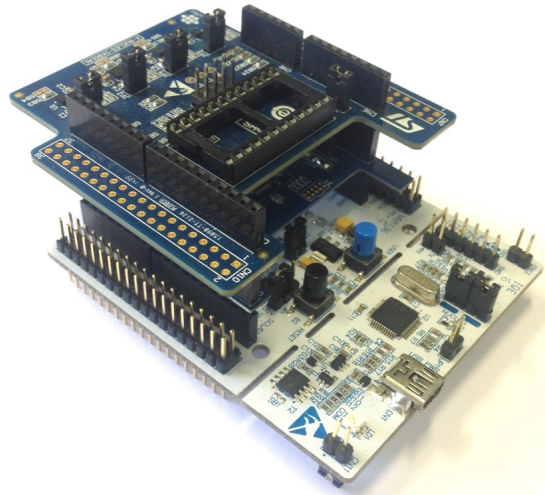




## The designed Intelligent Cyber-Physical System

- Ability **to interact with the environment** in which the system is operating and **adapt to new working conditions** at different layers
  - Single unit
  - Group of units (cluster-level intelligence, multiple-sensors);
  - Network of units
- The **intelligent mechanisms** are based on:
  - Statistical techniques
  - Machine learning/computational intelligence techniques
  - Cognitive and distributed mechanisms able to exploit the spatial and temporal relationships in datastreams

# Intelligent Mechanisms on ST Nucleo Systems



Intelligent Mechanisms 

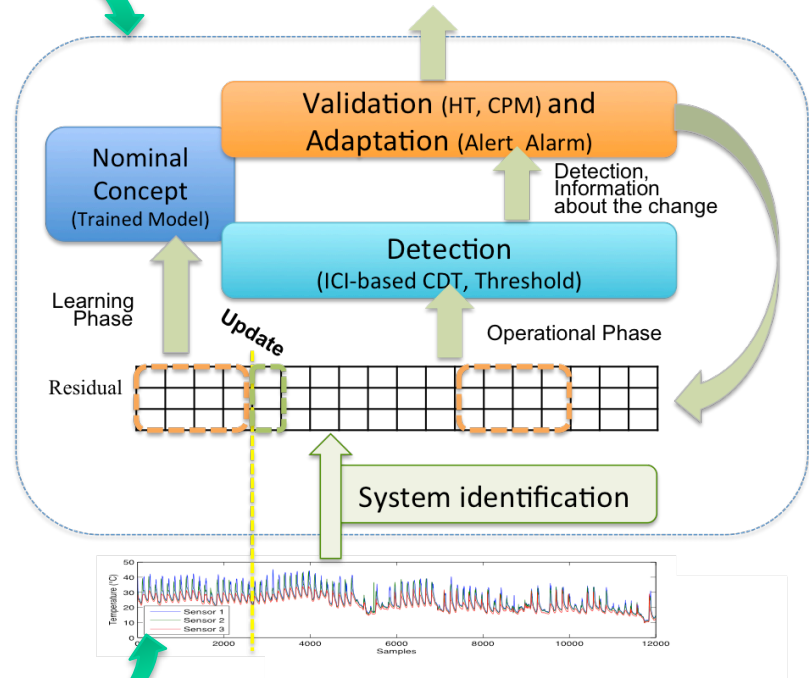
STM32  
Nucleo board  
(L0,F4)

Bluetooth low  
energy board

X-NUCLEO  
1DB04A1

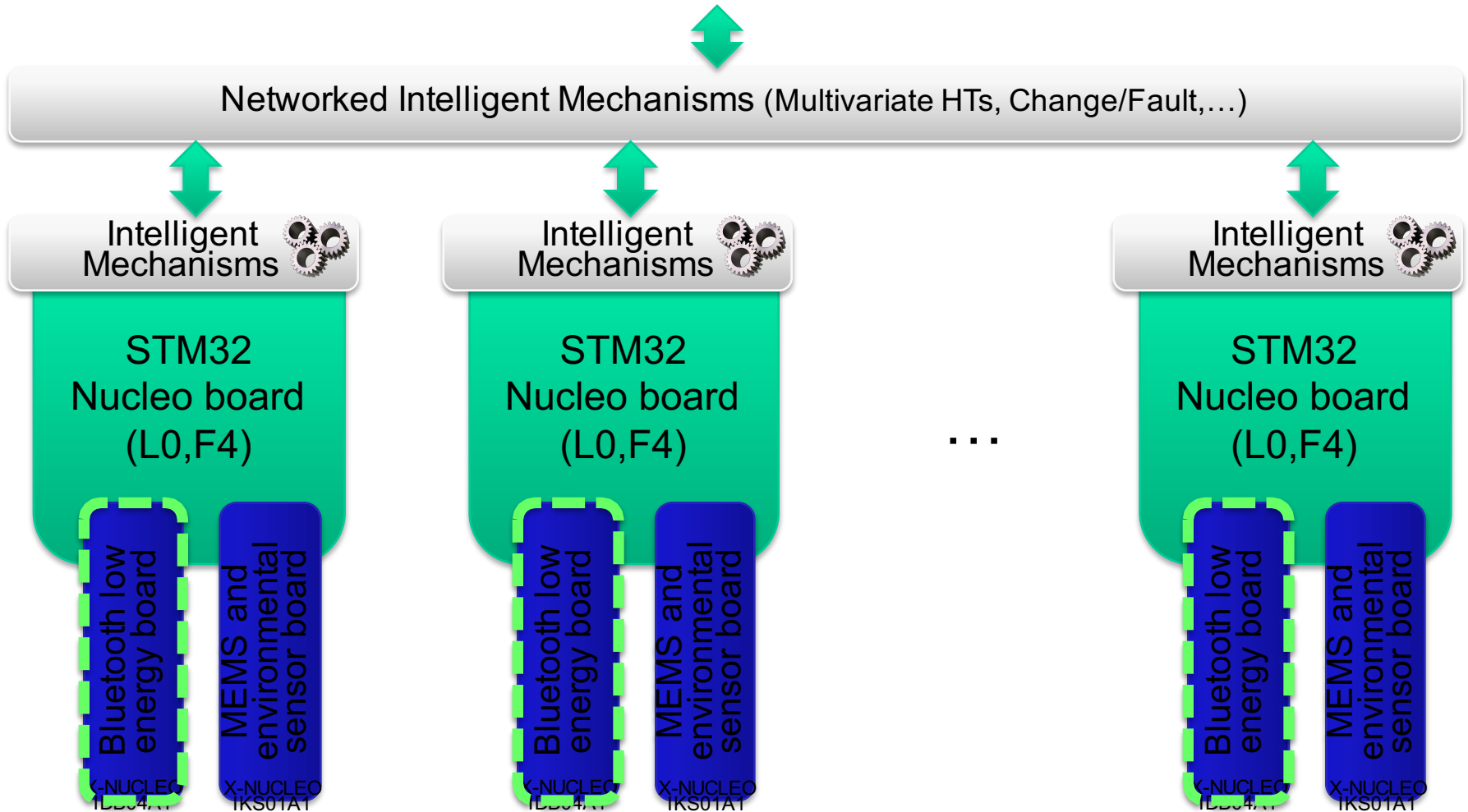
MEMS and  
environmental  
sensor board

X-NUCLEO  
1KS01A1

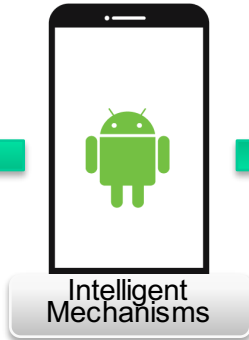
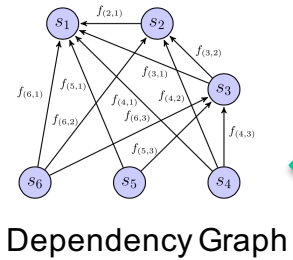




# Intelligent Mechanisms on ST Nucleo Systems



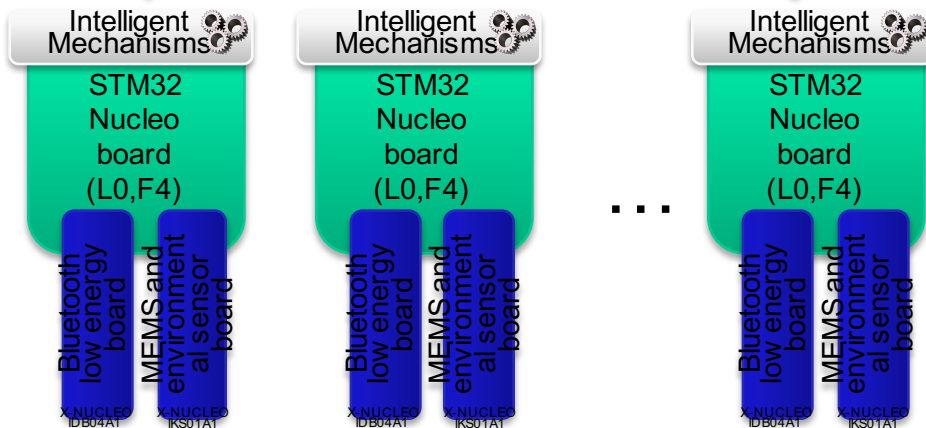
# Intelligent Mechanisms on ST Nucleo Systems



05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 0 and 0: 1.0
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 0 and 1: -0.789314562284707
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	0 3
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 1 and 0: -0.7893145622847069
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 1 and 1: 1.0
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 1 and 2: 0.41231110371116747
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	1 7
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 2 and 1: 0.4123111037111675
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	correlation between 2 and 2: 1.0
05-13 13:19:25	5810	5810	com.example.bluetooth	debug	2 6

Correlation Analysis (CrossCorr, Granger)

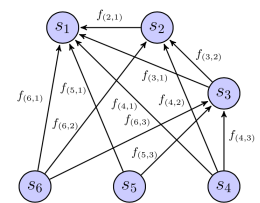
Registration  
(Data Set)



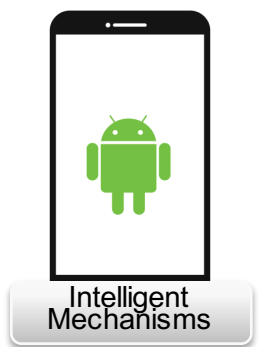




# Intelligent Mechanisms on ST Nucleo Systems



Dependency Graph

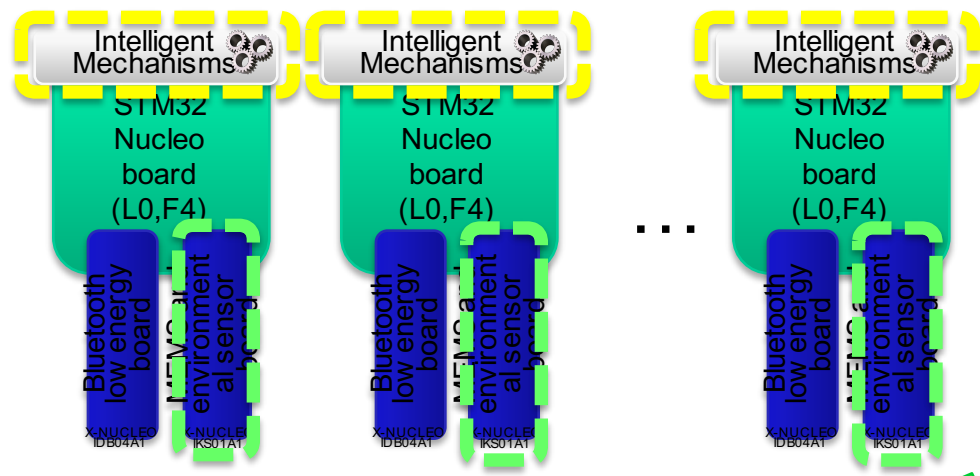


```

x - □ /dev/ttyACM0 - PuTTY
Time: 12:52:29 - Last val: 27.160000, Predicted: 27.195967, e = -0.035966
Time: 12:52:34 - Last val: 27.129999, Predicted: 27.202652, e = -0.072653
Time: 12:52:39 - Last val: 27.090000, Predicted: 27.193714, e = -0.103715
Change at time: 12:52:24
Error confidence interval: -0.177840 - 0.177840
Soglia change: 0.118560.
Coefficients (6):
0.659481
0.252999
-0.028602
0.287361
0.161935
-0.310781

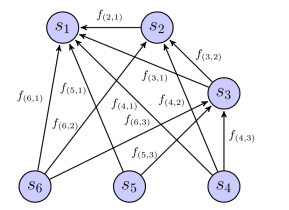
Time: 12:52:44 - Last val: 27.139999, Predicted: 27.186205, e = -0.046206
Time: 12:52:49 - Last val: 27.200001, Predicted: 27.212433, e = -0.012432
Time: 12:52:54 - Last val: 27.250000, Predicted: 27.236588, e = 0.013412
Time: 12:52:59 - Last val: 27.230000, Predicted: 27.251547, e = -0.021547
Time: 12:53:4 - Last val: 27.320000, Predicted: 27.342178, e = -0.022179
Time: 12:53:9 - Last val: 27.340000, Predicted: 27.387257, e = -0.047256
Time: 12:53:14 - Last val: 27.250000, Predicted: 27.314091, e = -0.064091
Time: 12:53:19 - Last val: 27.209999, Predicted: 27.271454, e = -0.061455
Time: 12:53:24 - Last val: 27.209999, Predicted: 27.290445, e = -0.080446
Time: 12:53:29 - Last val: 27.280001, Predicted: 27.287159, e = -0.007159
Time: 12:53:34 - Last val: 27.340000, Predicted: 27.312155, e = 0.027846
Time: 12:53:39 - Last val: 27.370001, Predicted: 27.366610, e = 0.003392
Time: 12:53:44 - Last val: 27.420000, Predicted: 27.438004, e = -0.018004
Time: 12:53:49 - Last val: 27.480000, Predicted: 27.517941, e = -0.037942
Time: 12:53:54 - Last val: 27.500000, Predicted: 27.541462, e = -0.041463
Time: 12:53:59 - Last val: 27.370001, Predicted: 27.459654, e = -0.089653
Time: 12:54:4 - Last val: 27.370001, Predicted: 27.442207, e = -0.072206
Time: 12:54:9 - Last val: 27.410000, Predicted: 27.472229, e = -0.062229
Time: 12:54:14 - Last val: 27.410000, Predicted: 27.429585, e = -0.019584
Time: 12:54:19 - Last val: 27.459999, Predicted: 27.434145, e = -0.025853
Time: 12:54:24 - Last val: 27.459999, Predicted: 27.498692, e = -0.038692
Time: 12:54:29 - Last val: 27.480000, Predicted: 27.516928, e = -0.036929
Time: 12:54:34 - Last val: 27.530001, Predicted: 27.556900, e = -0.026899
Time: 12:54:39 - Last val: 27.549999, Predicted: 27.590263, e = -0.040264
Time: 12:54:44 - Last val: 27.480000, Predicted: 27.537937, e = -0.057938
Time: 12:54:49 - Last val: 27.459999, Predicted: 27.524073, e = -0.064074
Time: 12:54:54 - Last val: 27.459999, Predicted: 27.528643, e = -0.068644
Time: 12:54:59 - Last val: 27.496999, Predicted: 27.496799, e = -0.036800
  
```

Anomaly in Data





# Intelligent Mechanisms on ST Nucleo Systems



Dependency Graph

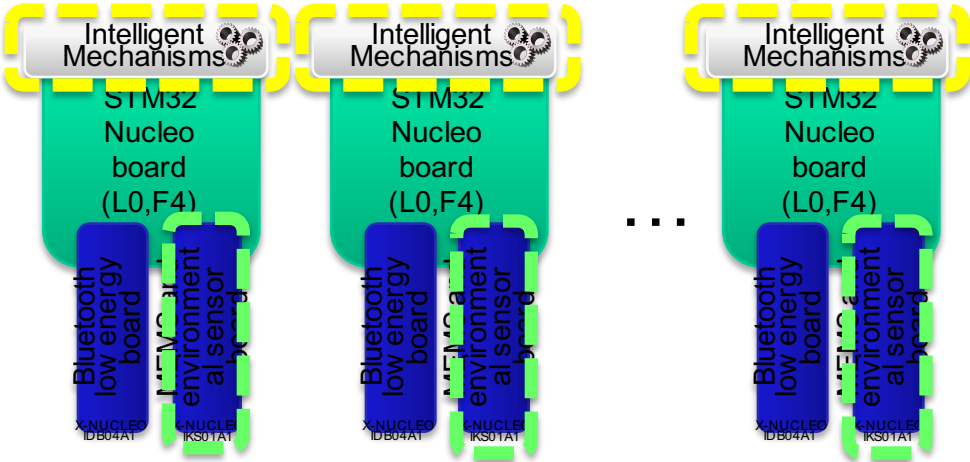


Alarm  
(Change Time Instant)

```

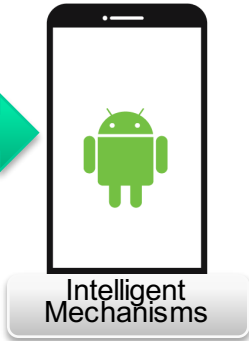
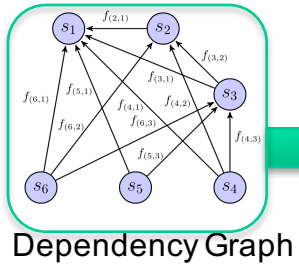
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Time: 12:54:39 - Last val: 27.549999, Predicted: 27.590263, e = -0.040264
Time: 12:54:44 - Last val: 27.480000, Predicted: 27.537937, e = -0.057938
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```

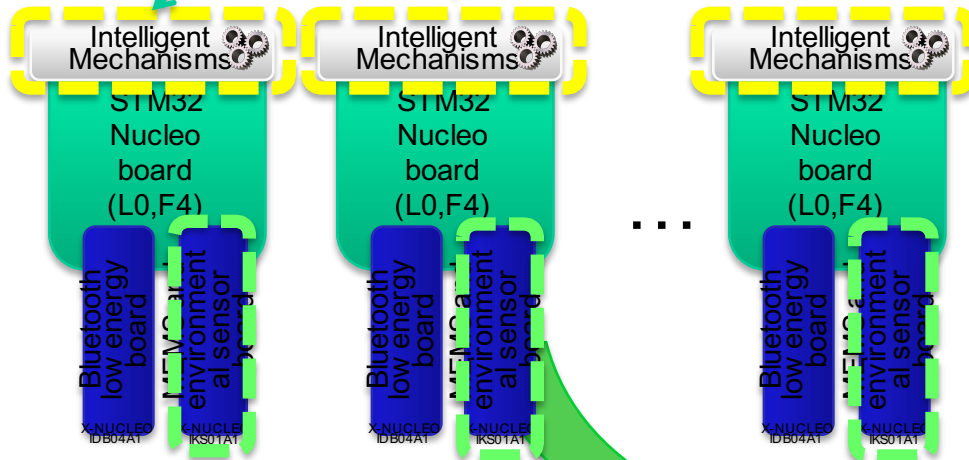


Anomaly in Data

# Intelligent Mechanisms on ST Nucleo Systems



Analysis Request  
(Change Time Instant)

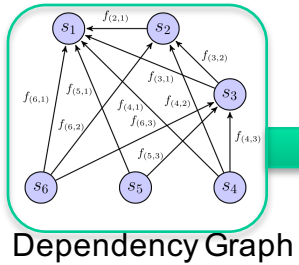


```

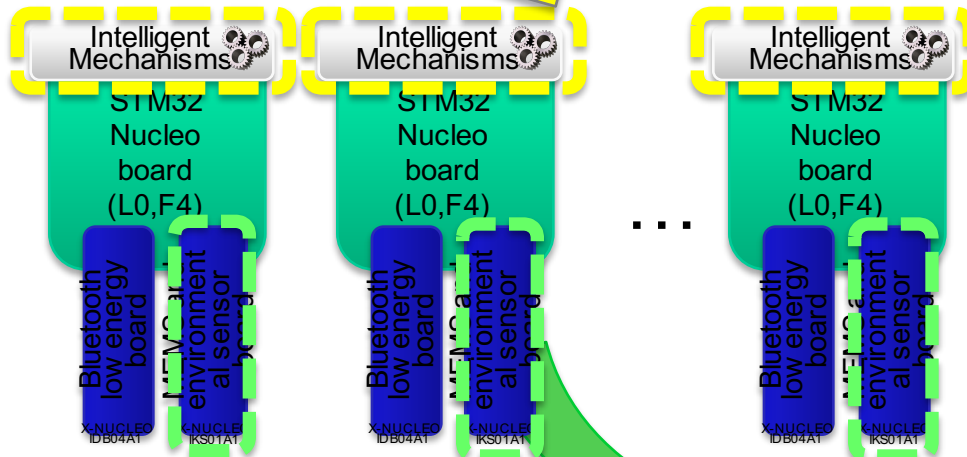
/dev/ttyACM0 - PuTTY
24 misure: 990,991943, Predicted: 991,008118, e = -0,016203
22 misure: 27,129999, Predicted: 27,080629, e = 0,049369
T-test(22): 1,952609 - 2,059537, 25, 5
23 misure: 64,570000, Predicted: 64,258430, e = 0,311569
24 misure: 991,001221, Predicted: 991,012817, e = -0,011612
22 misure: 27,160000, Predicted: 26,808958, e = 0,351041
T-test(22): 1,630853 - 2,059537, 25, 6
23 misure: 64,110001, Predicted: 63,954815, e = 0,155186
24 misure: 991,103027, Predicted: 991,113525, e = -0,010502
22 misure: 27,230000, Predicted: 27,127447, e = 0,102553
T-test(22): 1,973669 - 2,059537, 25, 7
23 misure: 63,939999, Predicted: 63,967365, e = -0,027367
24 misure: 991,036865, Predicted: 991,050232, e = -0,013349
22 misure: 27,299999, Predicted: 27,268515, e = 0,031485
23 misure: 63,740002, Predicted: 63,862926, e = -0,122925
24 misure: 991,220215, Predicted: 991,214172, e = 0,006044
22 misure: 27,340000, Predicted: 27,331074, e = 0,008926
23 misure: 63,180000, Predicted: 63,167015, e = 0,012983
24 misure: 991,275391, Predicted: 991,272217, e = 0,003148
22 misure: 27,410000, Predicted: 27,387569, e = 0,022430
23 misure: 63,060001, Predicted: 63,078163, e = -0,018162
24 misure: 991,106445, Predicted: 991,096191, e = 0,010282
  
```

Hypothesis Tests, CPMs  
(Hotelling, Mann-Whitney)

# Intelligent Mechanisms on ST Nucleo Systems



Local validation



```

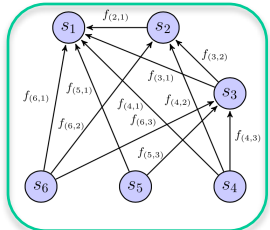
/dev/ttyACM0 - PuTTY
24 misure: 990,991943, Predicted: 991,008118, e = -0,016203
...
23 misure: 27,129999, Predicted: 27,080629, e = 0,049369
24 misure: 1,952609 - 2,059537, 25, 5
...
23 misure: 64,570000, Predicted: 64,258430, e = 0,311569
24 misure: 991,001221, Predicted: 991,012817, e = -0,011612
...
22 misure: 27,160000, Predicted: 26,808958, e = 0,351041
T-test(22): 1,630853 - 2,059537, 25, 6
...
23 misure: 64,110001, Predicted: 63,954815, e = 0,155186
24 misure: 991,103027, Predicted: 991,113525, e = -0,010502
...
22 misure: 27,230000, Predicted: 27,127447, e = 0,102553
T-test(22): 1,973669 - 2,059537, 25, 7
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23 misure: 63,939999, Predicted: 63,967365, e = -0,027367
24 misure: 991,036865, Predicted: 991,050232, e = -0,013349
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22 misure: 27,299999, Predicted: 27,268515, e = 0,031485
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...
22 misure: 27,340000, Predicted: 27,331074, e = 0,008926
23 misure: 63,180000, Predicted: 63,167015, e = 0,012983
24 misure: 991,275391, Predicted: 991,272217, e = 0,003148
...
22 misure: 27,410000, Predicted: 27,387569, e = 0,022430
23 misure: 63,060001, Predicted: 63,078163, e = -0,018162
24 misure: 991,106445, Predicted: 991,096191, e = 0,010282

```

Hypothesis Tests, CPMs (Hotelling, Mann-Whitney)



# Intelligent Mechanisms on ST Nucleo Systems

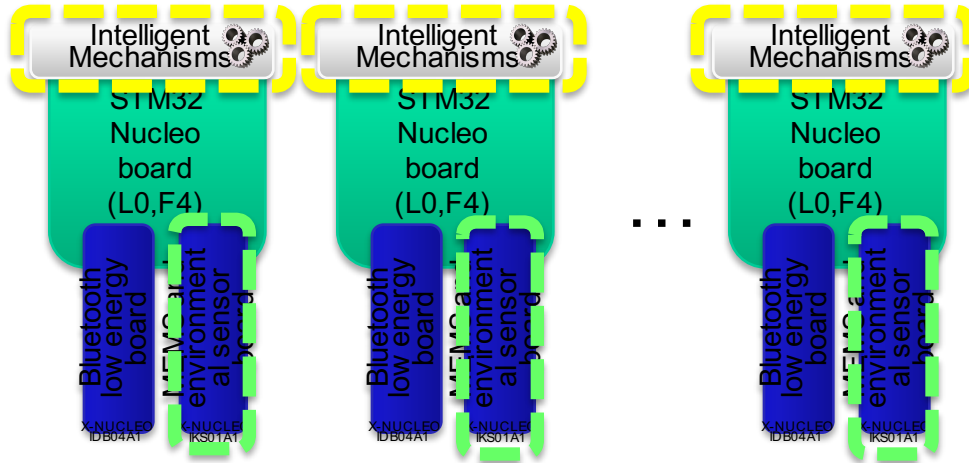


Dependency Graph

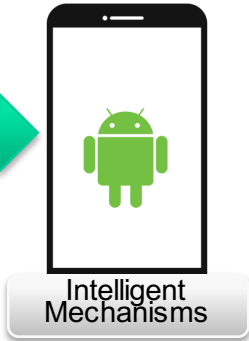
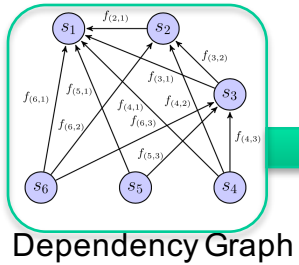


Intelligent Mechanisms

Response  
(change/  
no change)



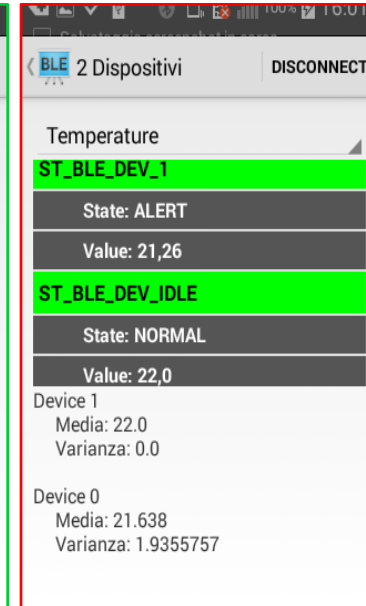
# Intelligent Mechanisms on ST Nucleo Systems



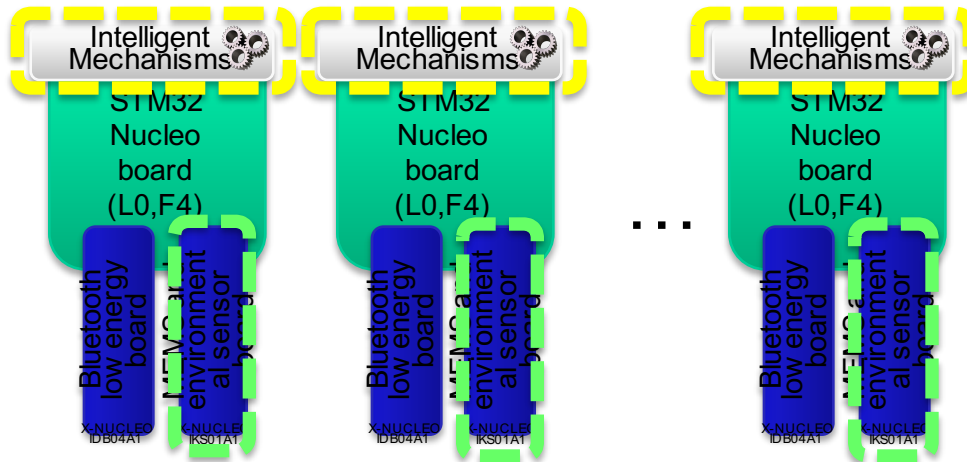
Aggregation



Normal

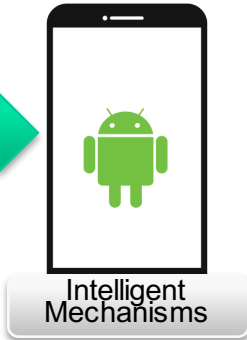
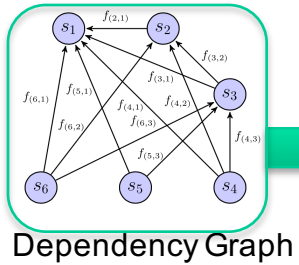


Alert





# Intelligent Mechanisms on ST Nucleo Systems



Aggregation



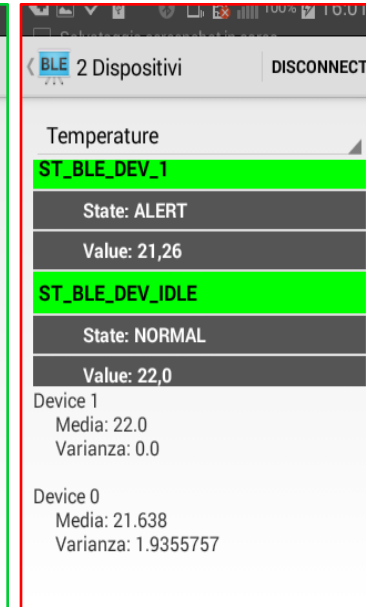
BLE 2 Dispositivi DISCONNECT

Humidity	ST_BLE_DEV_1	State: NORMAL	Value: 68,8
	ST_BLE_DEV_IDLE	State: NORMAL	Value: 65,0

Device 1  
Media: 65.0  
Varianza: 0.0

Device 0  
Media: 69.59599  
Varianza: 1.4731656

Normal



BLE 2 Dispositivi DISCONNECT

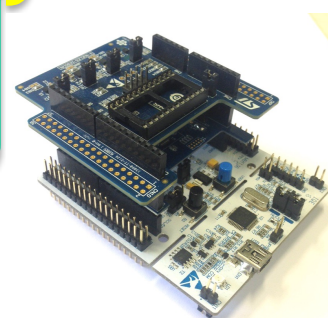
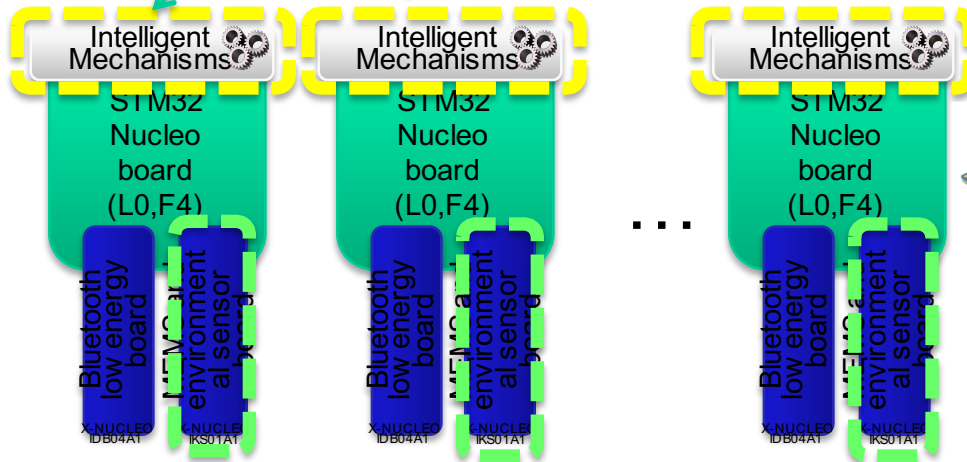
Temperature	ST_BLE_DEV_1	State: ALERT	Value: 21,26
	ST_BLE_DEV_IDLE	State: NORMAL	Value: 22,0

Device 1  
Media: 22.0  
Varianza: 0.0

Device 0  
Media: 21.638  
Varianza: 1.9355757

Alert

Notification,  
Adaptation,  
Retraining





**What's next?**

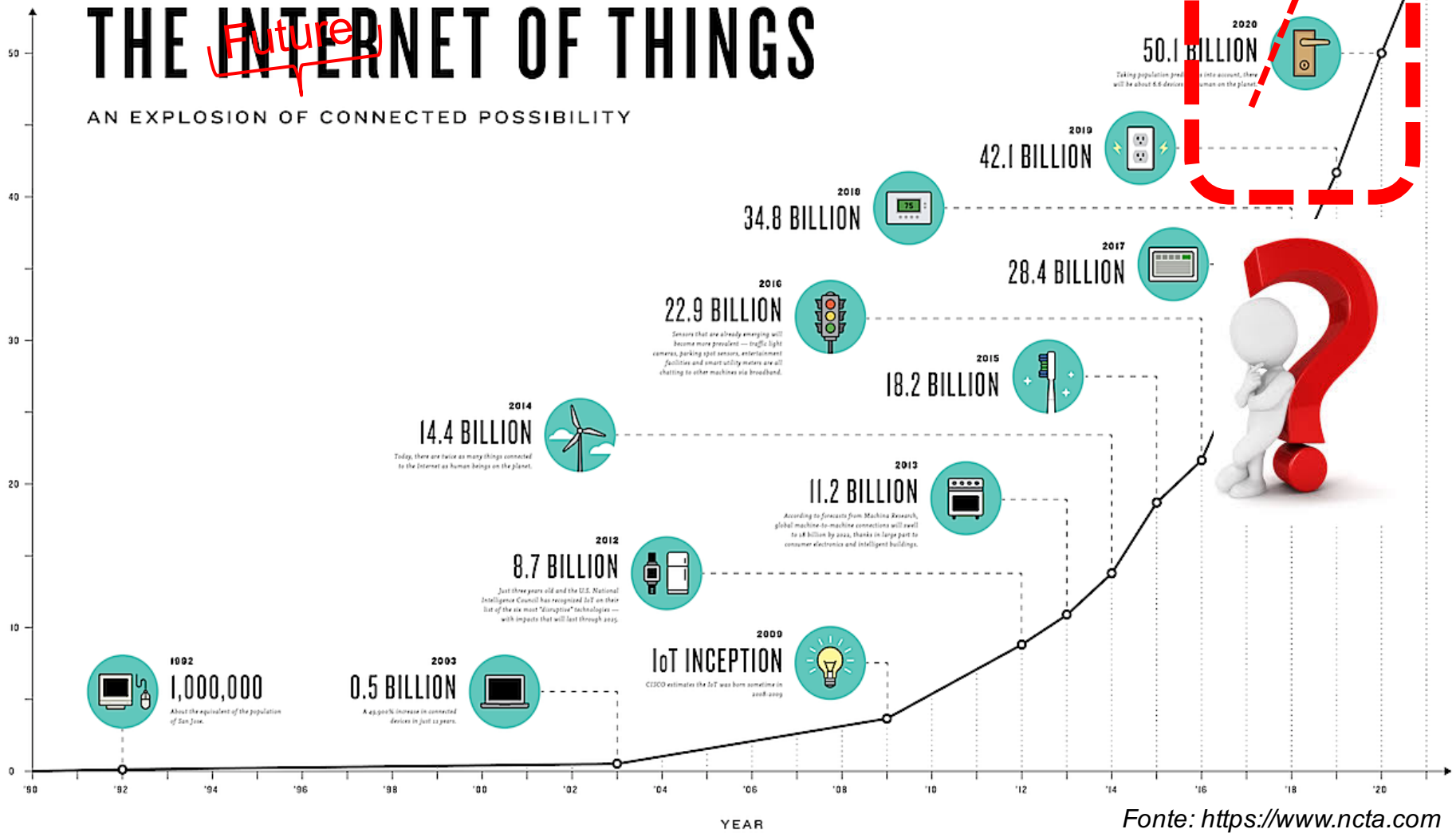


# THE INTERNET OF THINGS

Future

AN EXPLOSION OF CONNECTED POSSIBILITY

BILLIONS OF DEVICES



Fonte: <https://www.ncta.com>



# The Sensor-swarm Revolution ...





Questions?



**KEEP  
CALM  
AND  
DESIGN  
INTELLIGENT  
CYBER-PHYSICAL  
SYSTEMS**