Advanced Research Intelligent Embedded Systems

Politecnico di Milano

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

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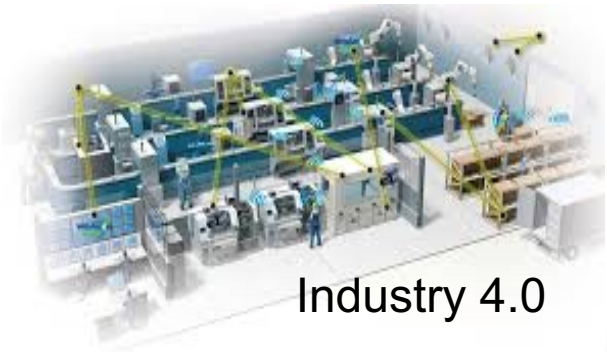
# The Cyber-physical Systems

# Cyber-physical Systems: the application scenarios

E-health

Smart Car



Industry 4.0

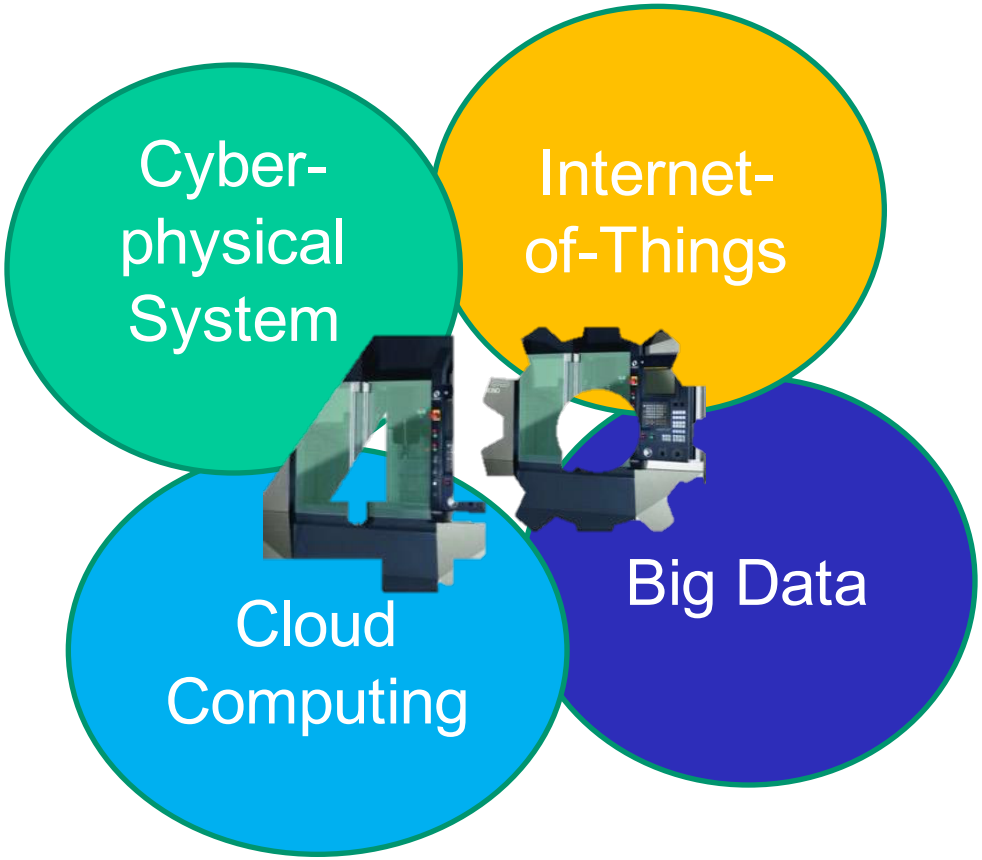
Cyber-physical Systems

Smart Cities

...

Smart Home/Building

# The application case of Industry 4.0

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# Applications, Systems and World

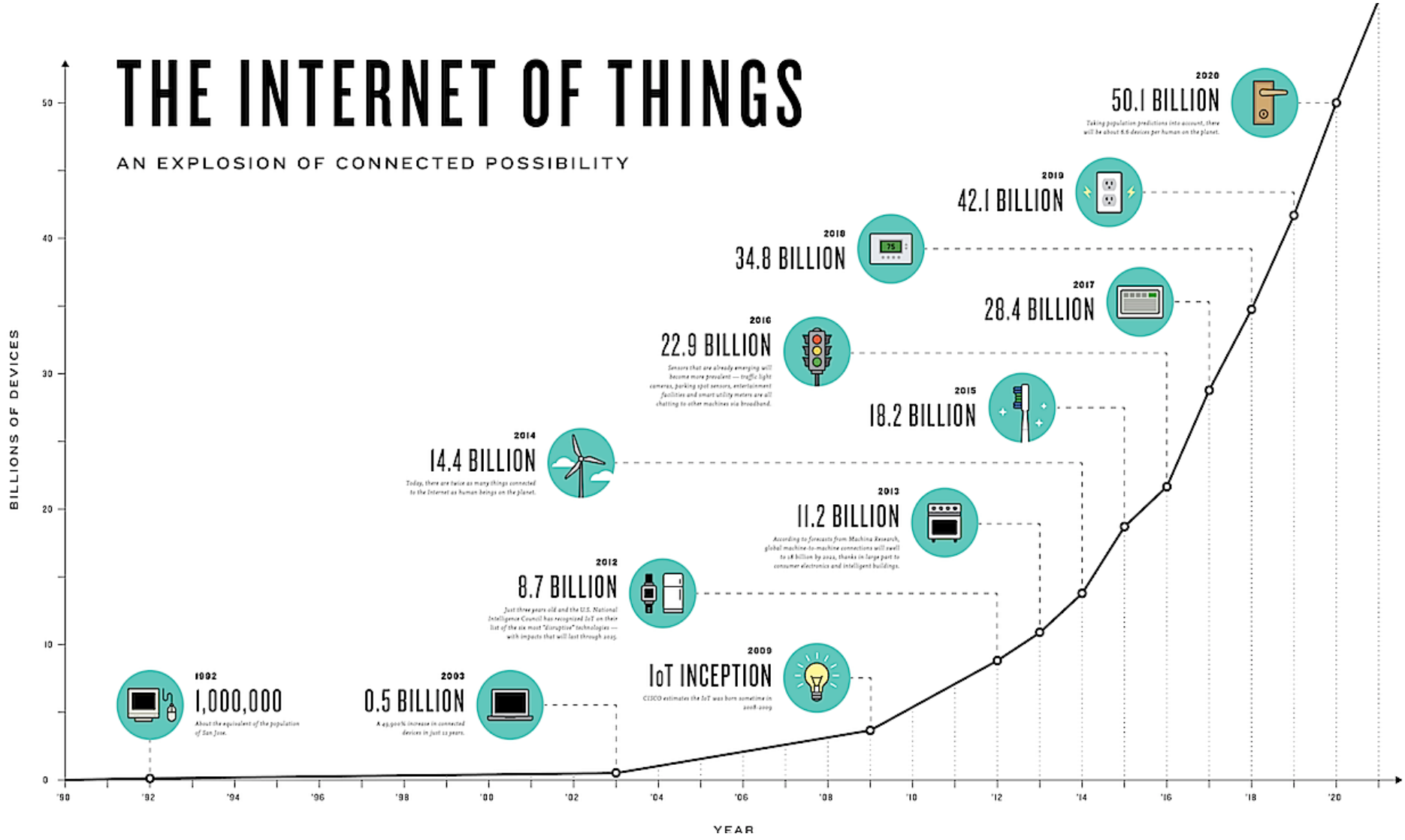
Applications

Cyber-physical Systems

Physical World

# The Challenges

# The ever-growing number of devices




*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

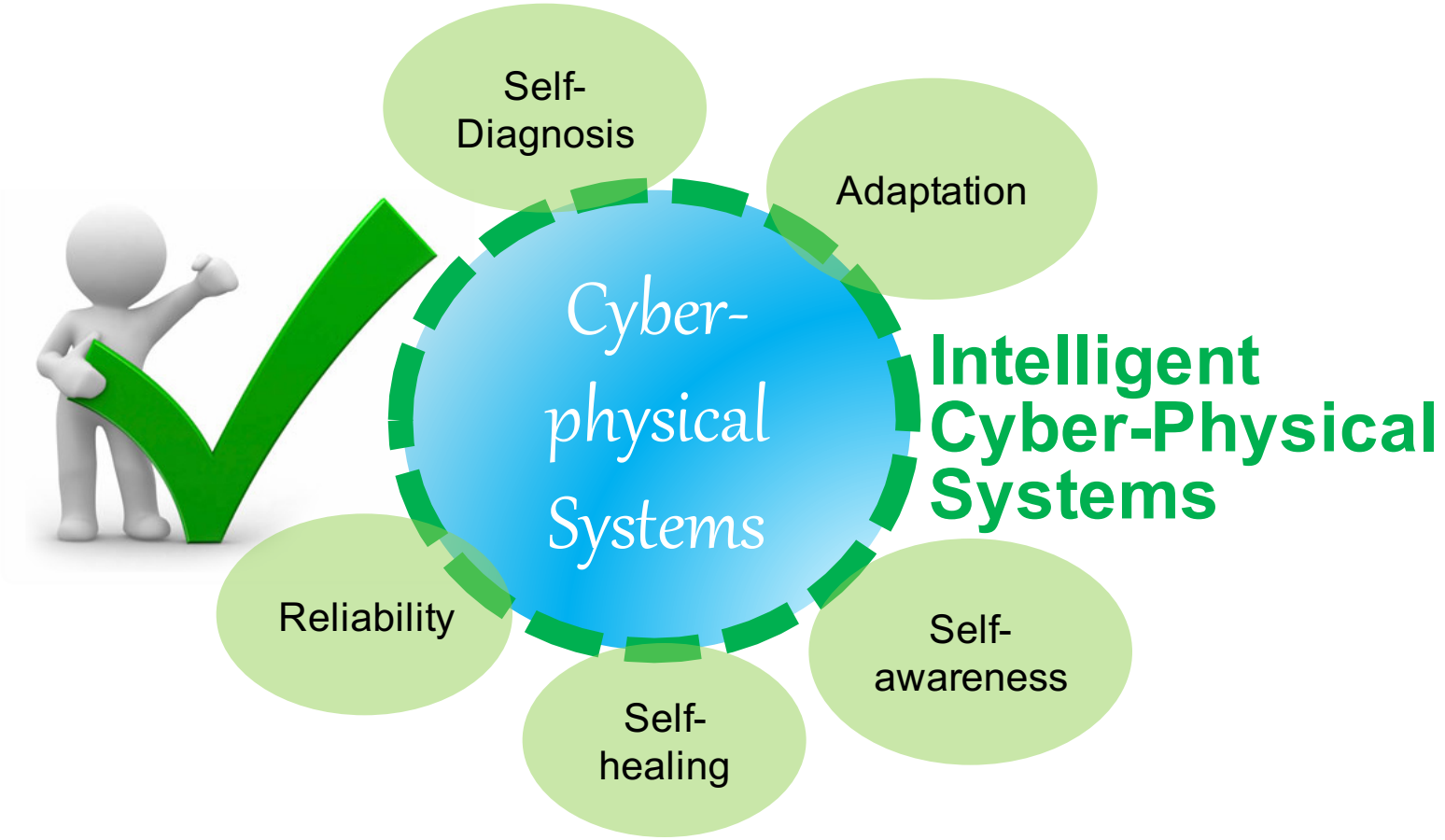
Applications

Cyber-physical Systems

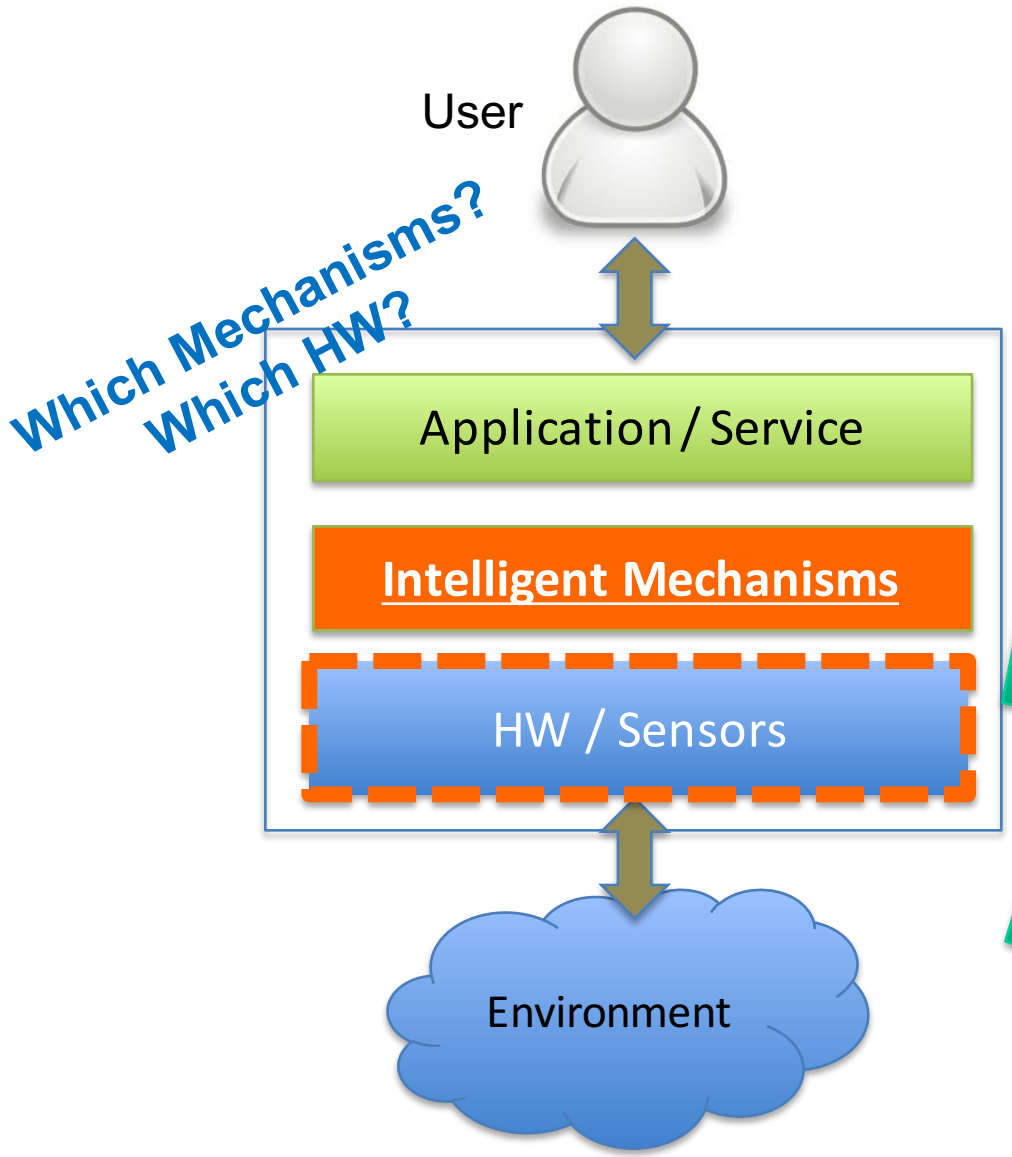
**Intelligent Cyber-Physical Systems**

Physical World

# Intelligence for cyber-physical systems

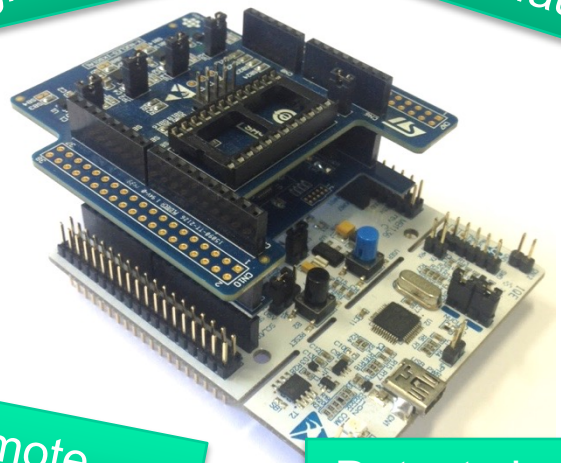


# Intelligent Objects/Devices




Self-awareness to diagnose fault

Self-healing mechanisms to repair faults



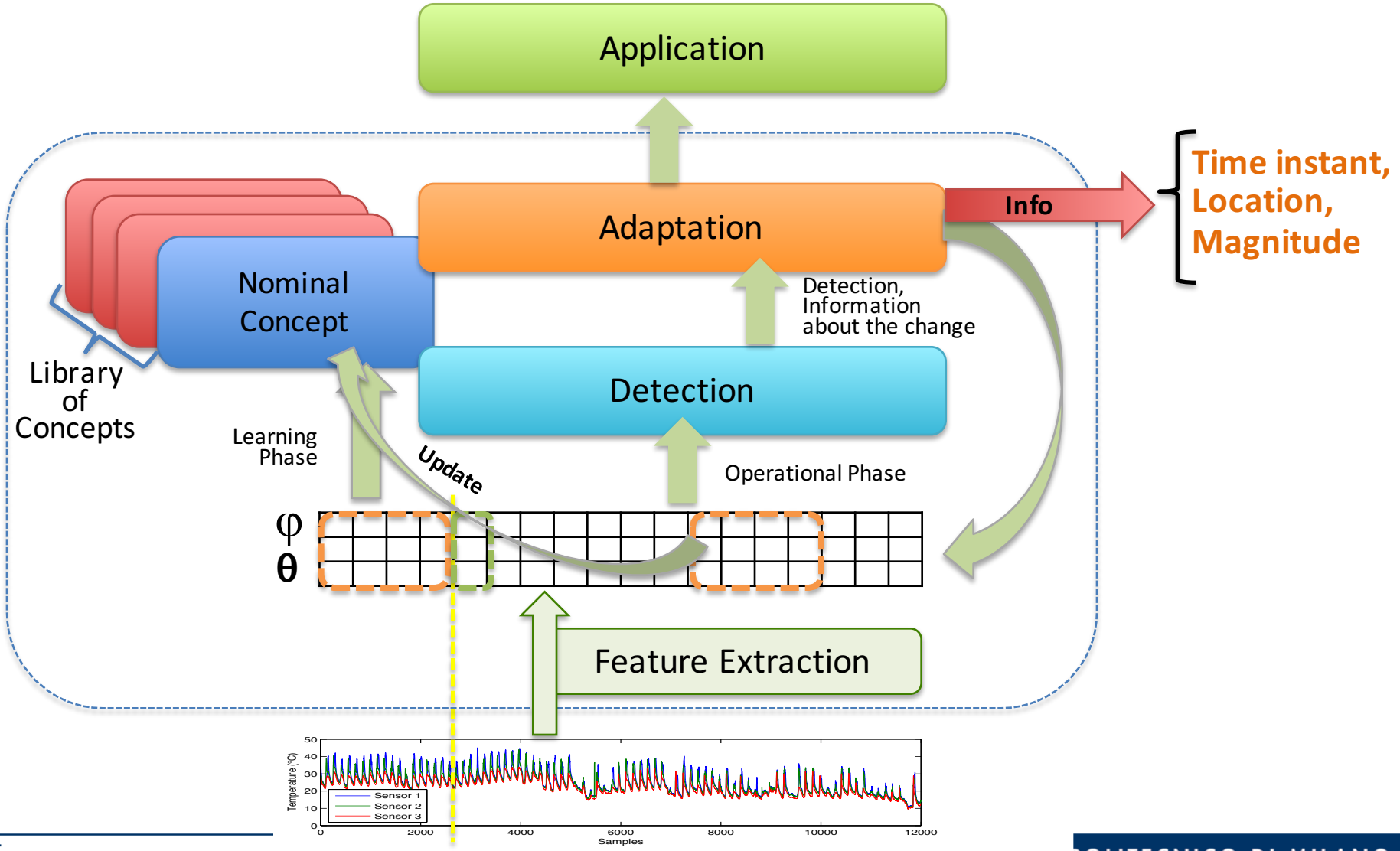
Remote controllability

Detect changes in the users'behaviour

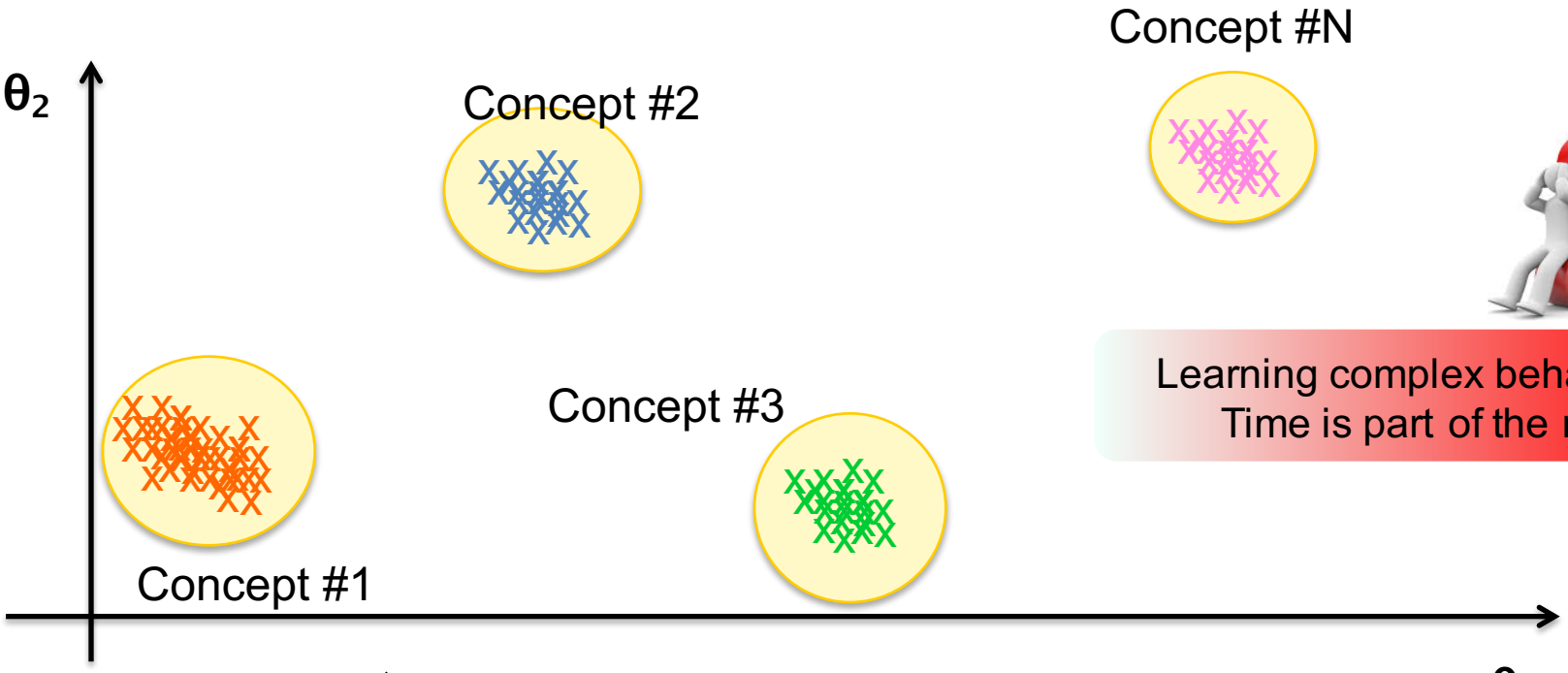
Energy Harvesting

Smart energy management

# …. up to the Unit Layer …..

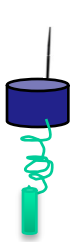


# Continuously Learning Complex Behaviors

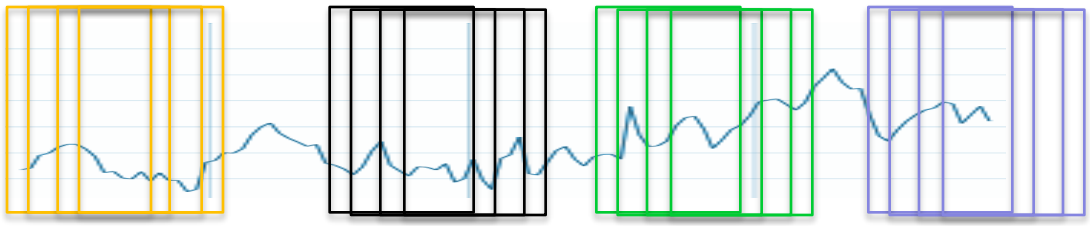



Learning complex behaviors:
Time is part of the model!

Sensing Unit



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



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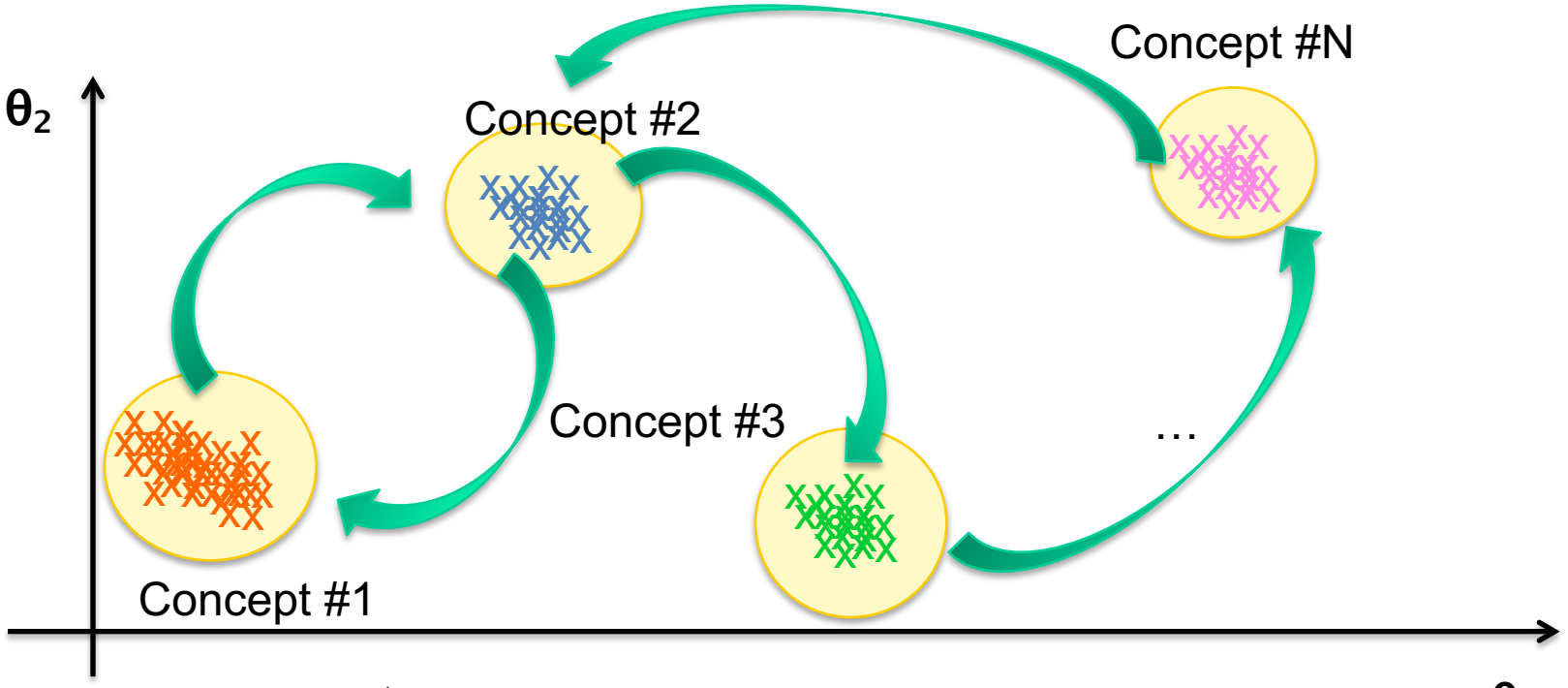
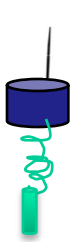



Sensing Unit



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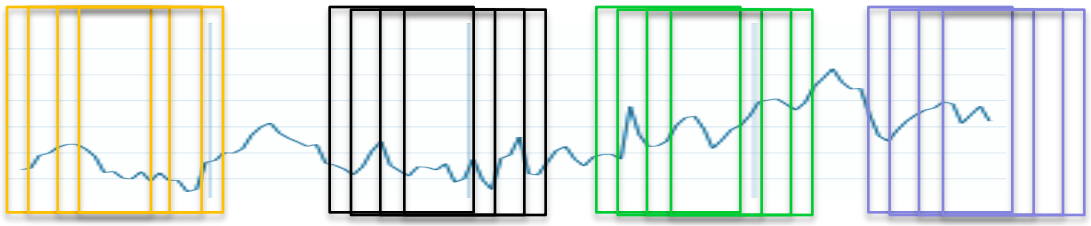
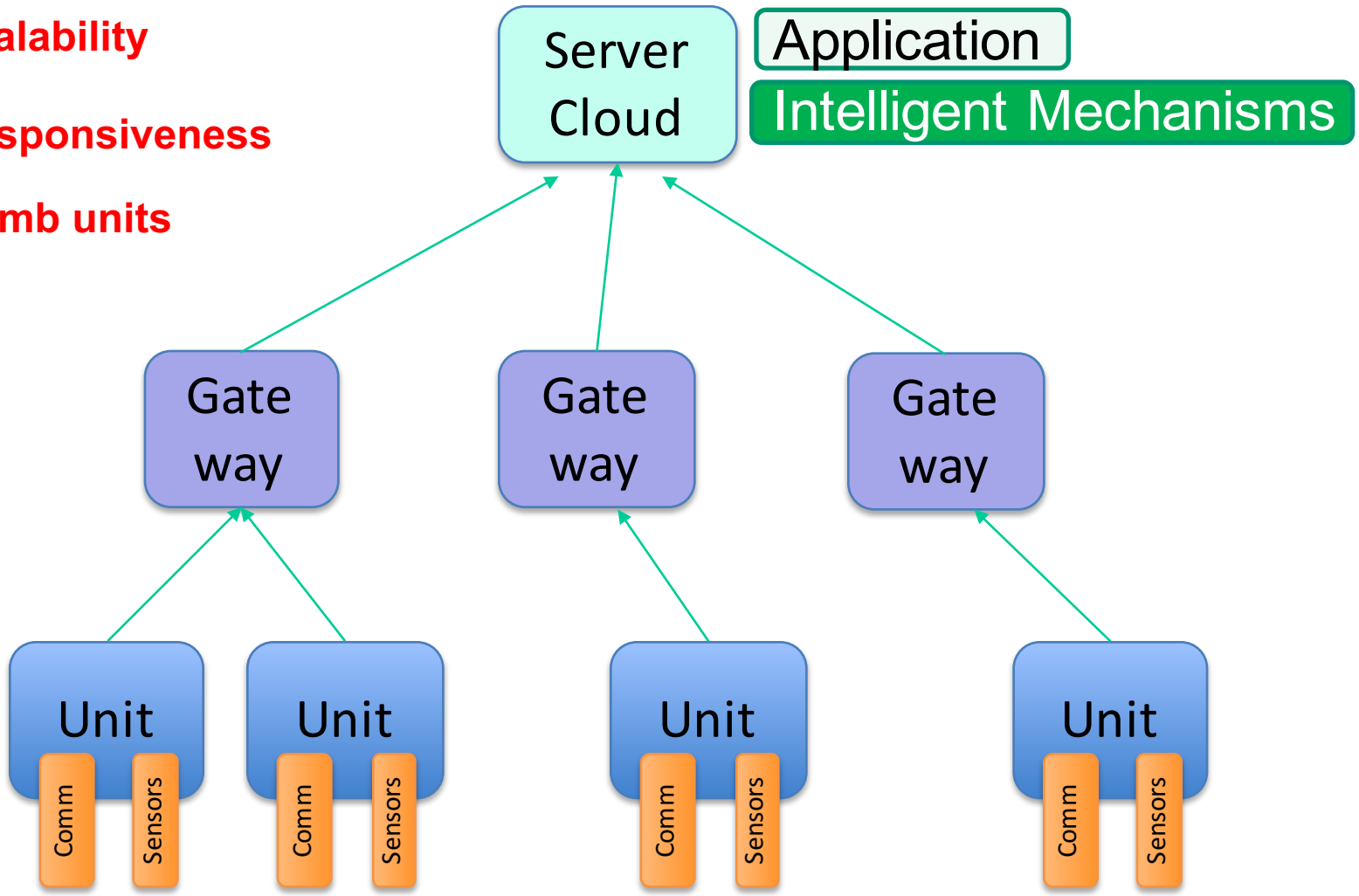


# Designing Intelligent CPES: from centralized ….



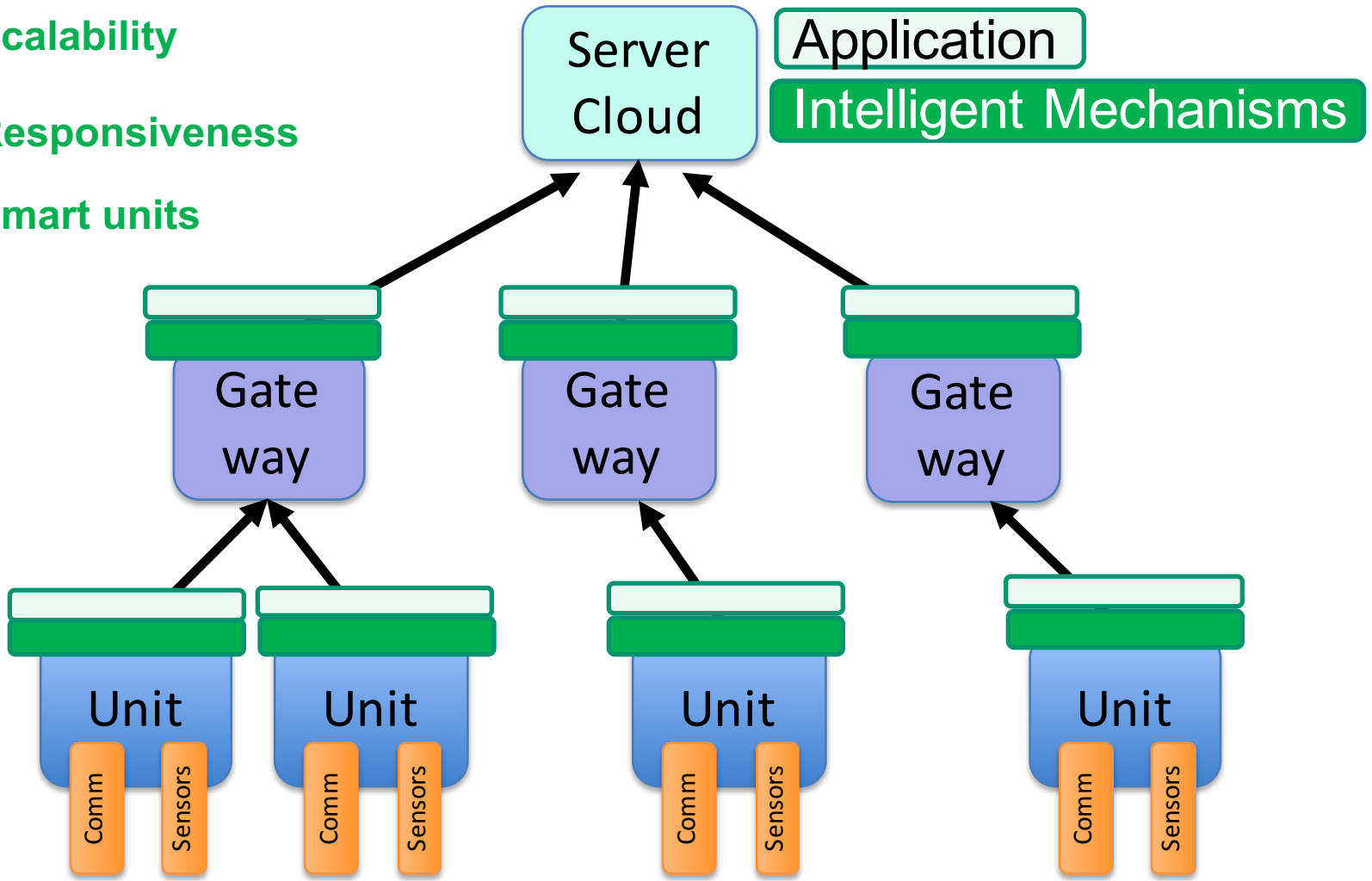
- Scalability
- Responsiveness
- Dumb units



# Designing Intelligent CPSs: ….to distributed intelligent systems



- Scalability
- Responsiveness
- Smart units

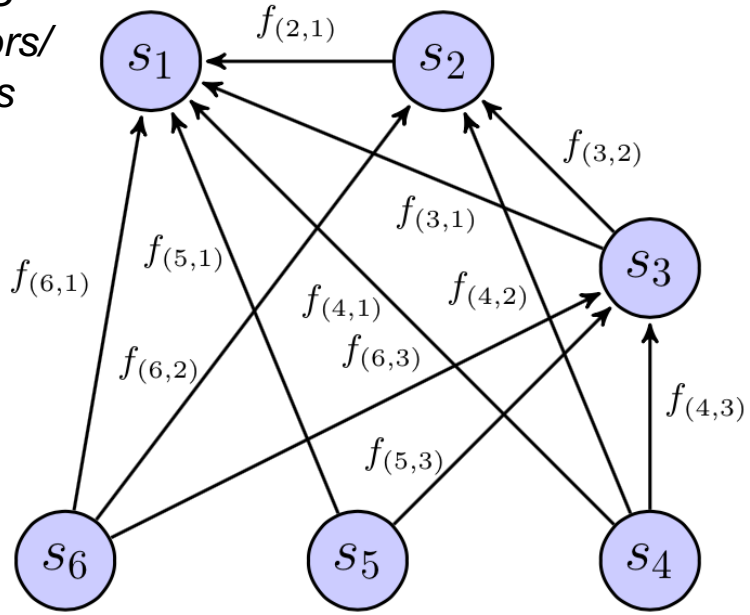


# Capturing the relationships among the sensors …



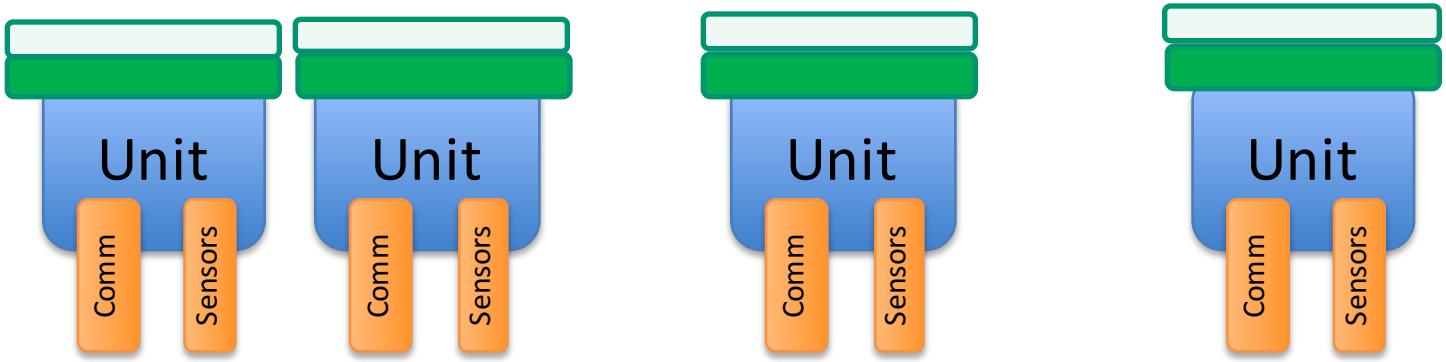
*Set of CPS sensors/ units*

*Set of **relevant** relationships present in acquired datastrems*

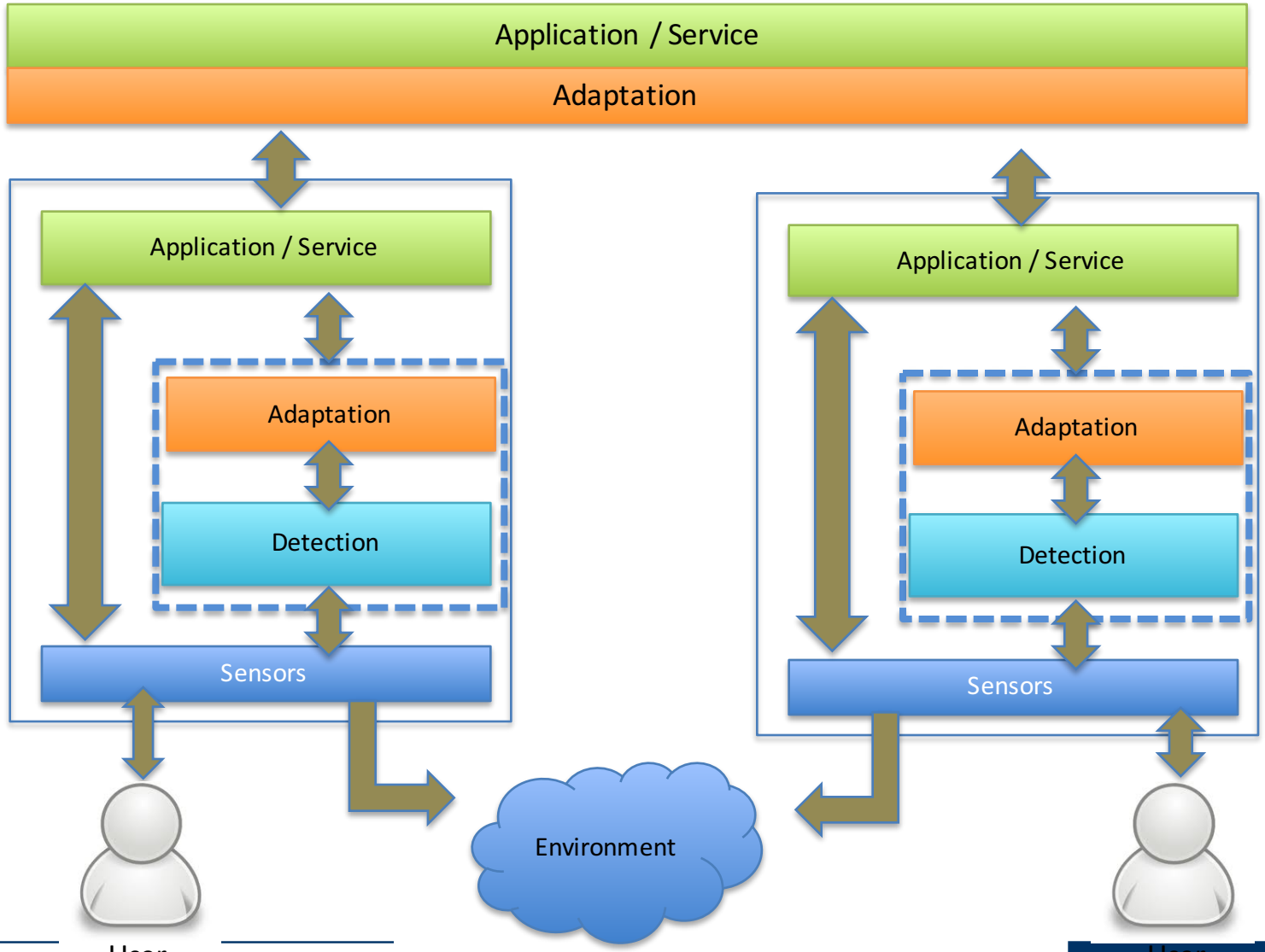



**Dependency Graph**

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



# Distributing Intelligence among the Units

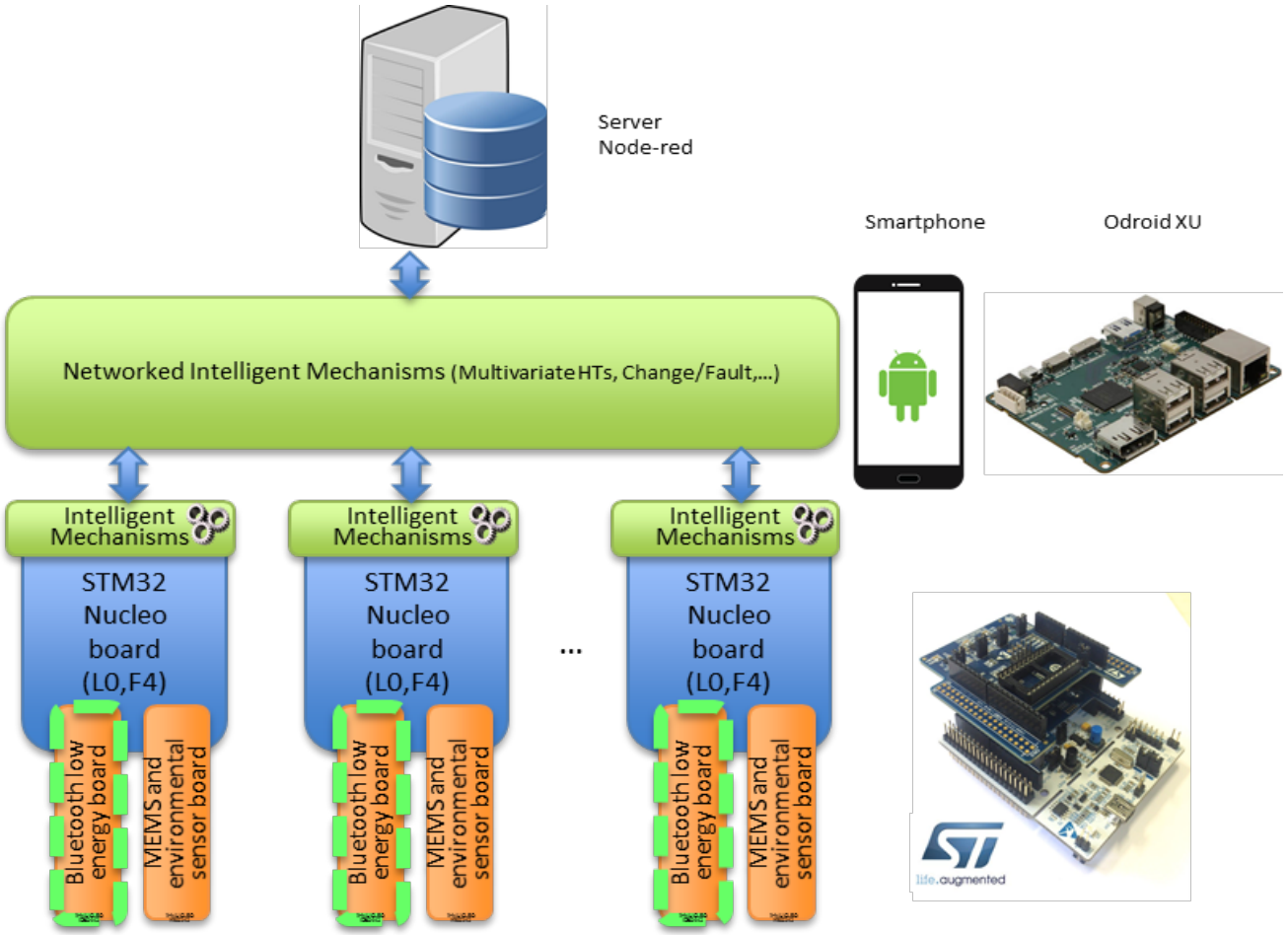


# Distributing Intelligence among the Units

# Intelligent Cyber-Physical Systems: an active joint project


# Aim of the project

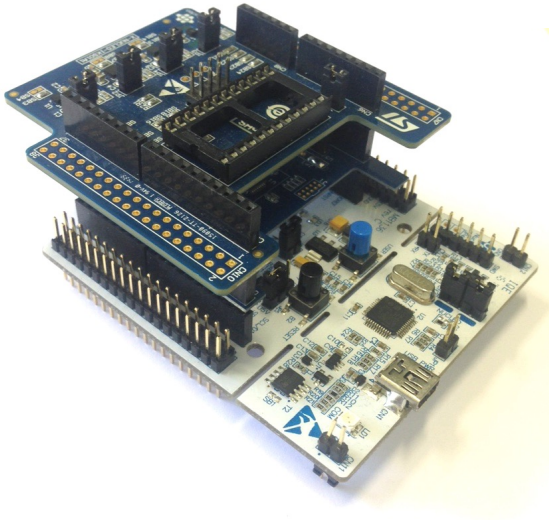
- Design and develop **a network of intelligent units based on STMicroelectronics NUCLEO boards** endowed with STM32, Bluetooth, heterogeneous sensors (e.g., MEMS, humidity, temperature, pressure, microphones etc), **coordinator** (e.g., smartphone/tablet), **and remote server**

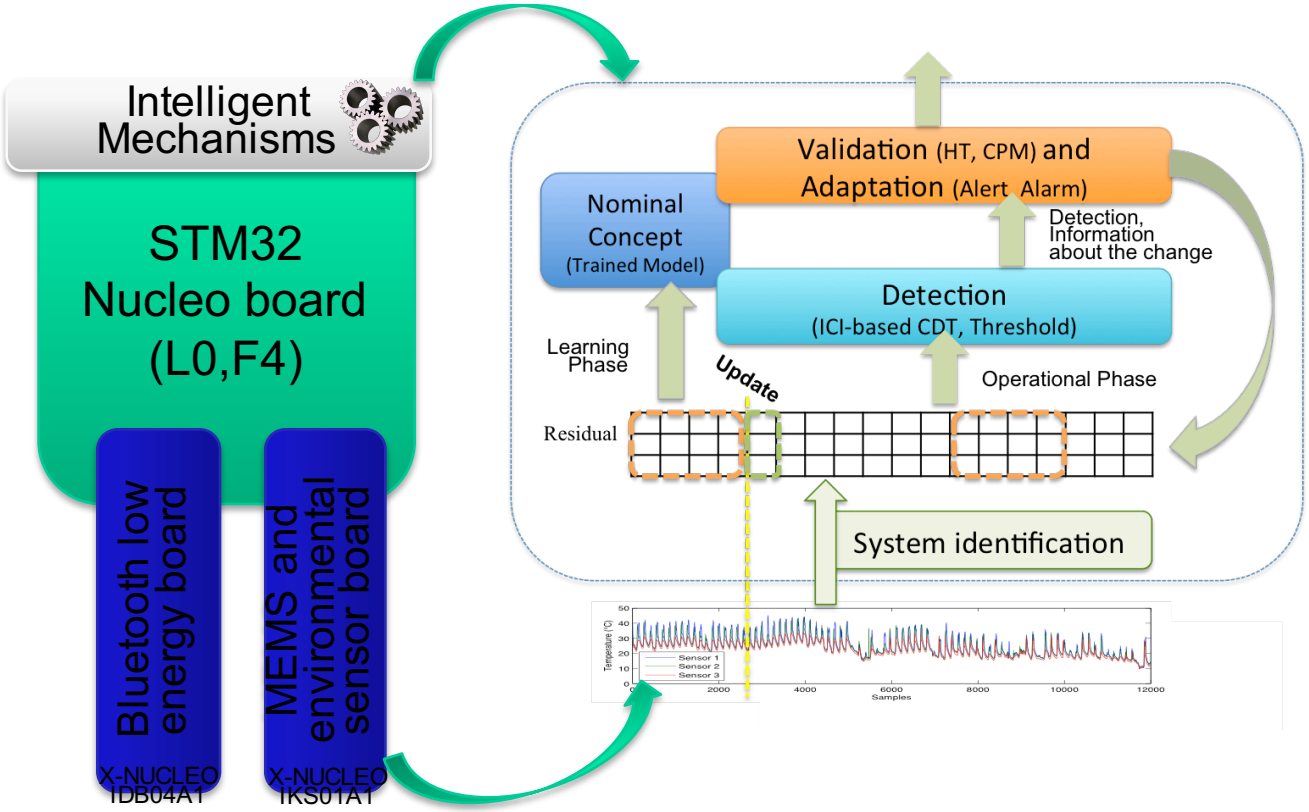


# The designed Intelligent Cyber-Physical System

- 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





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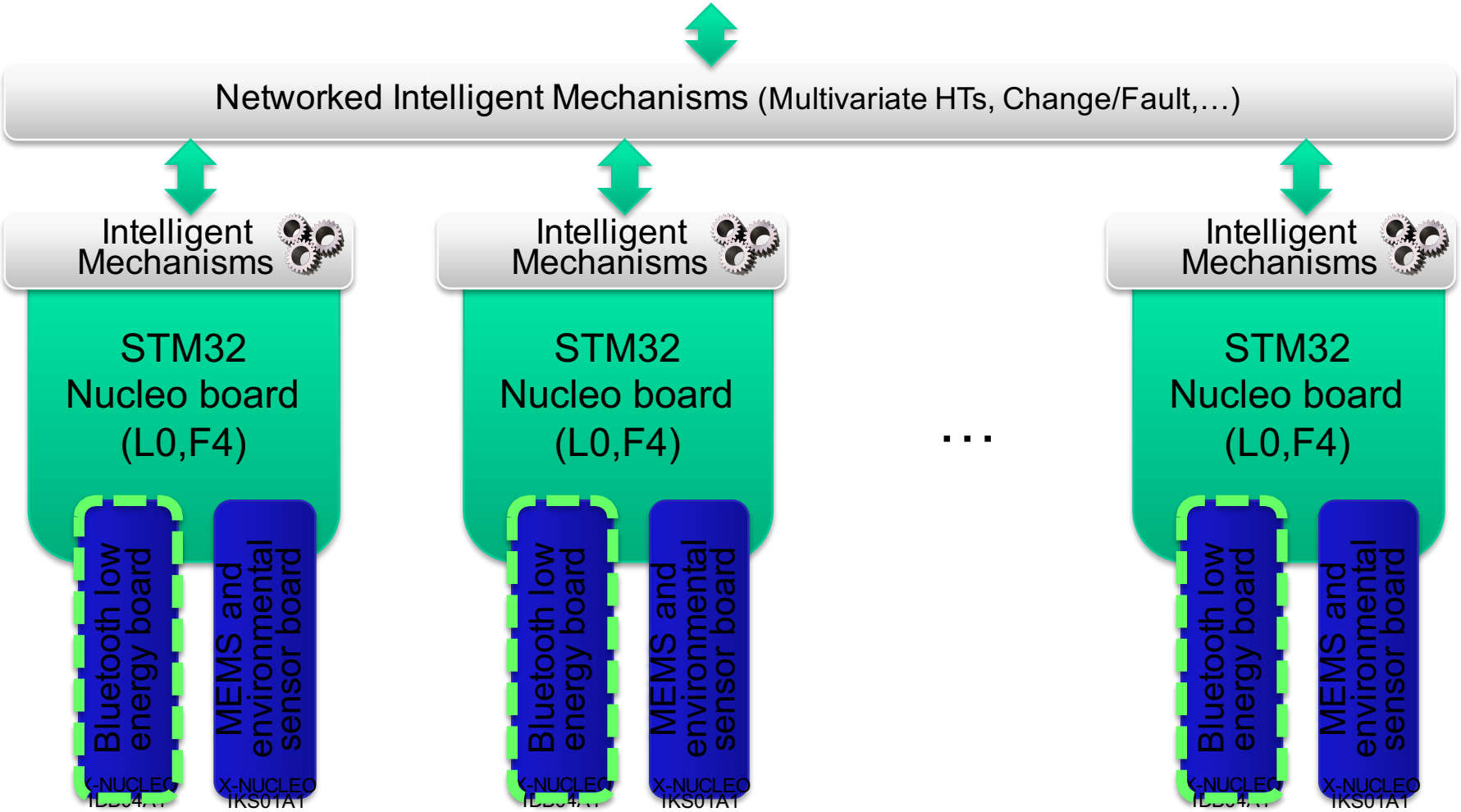

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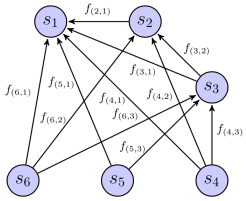


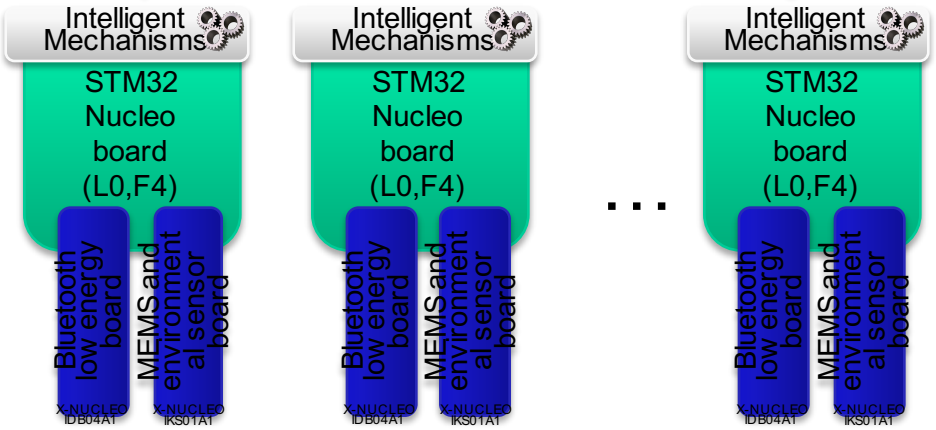

Dependency Graph

Intelligent Mechanisms

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

Correlation Analysis (CrossCorr, Granger)

Registration
(Data Set)



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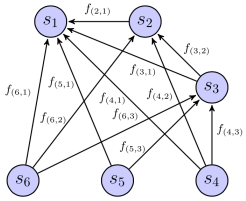
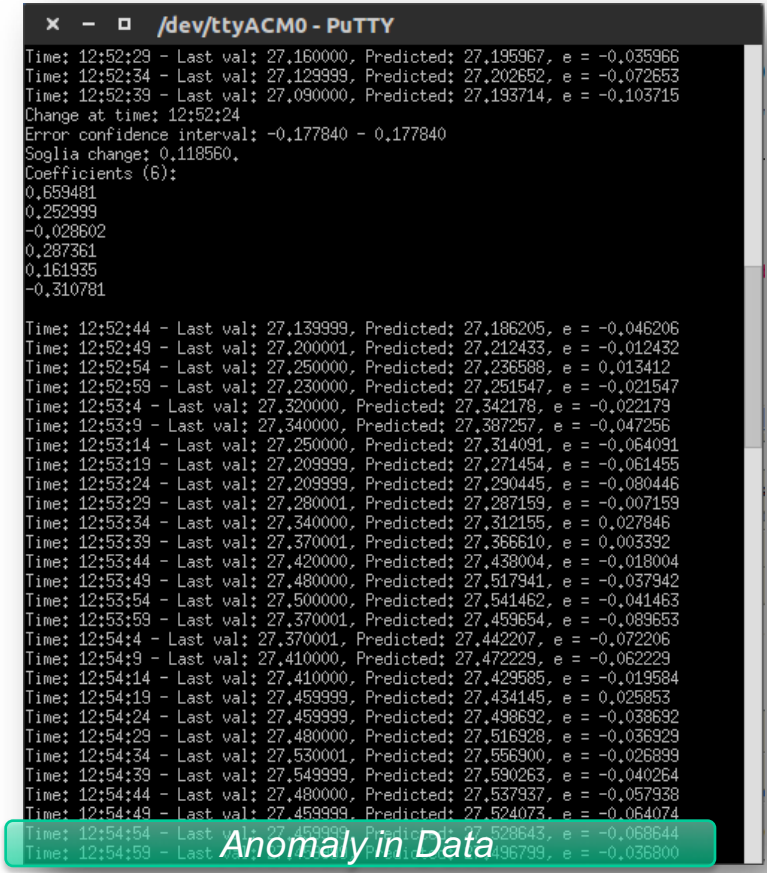
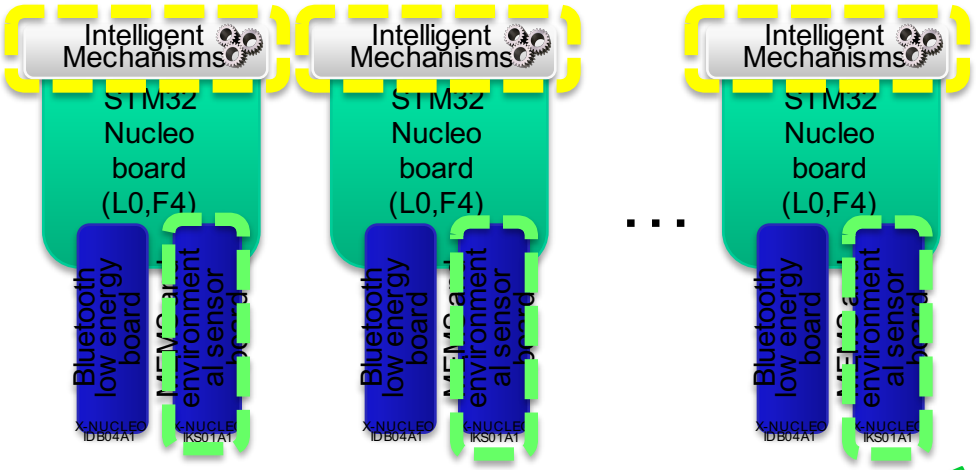


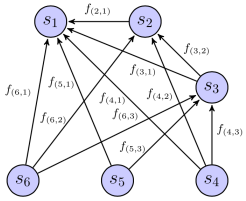

Dependency Graph

Intelligent Mechanisms



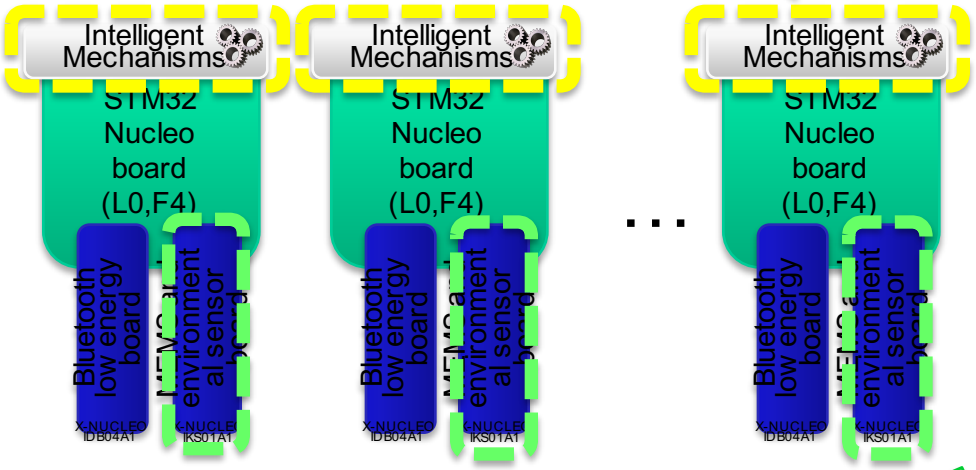
# Intelligent Mechanisms on ST Nucleo Systems

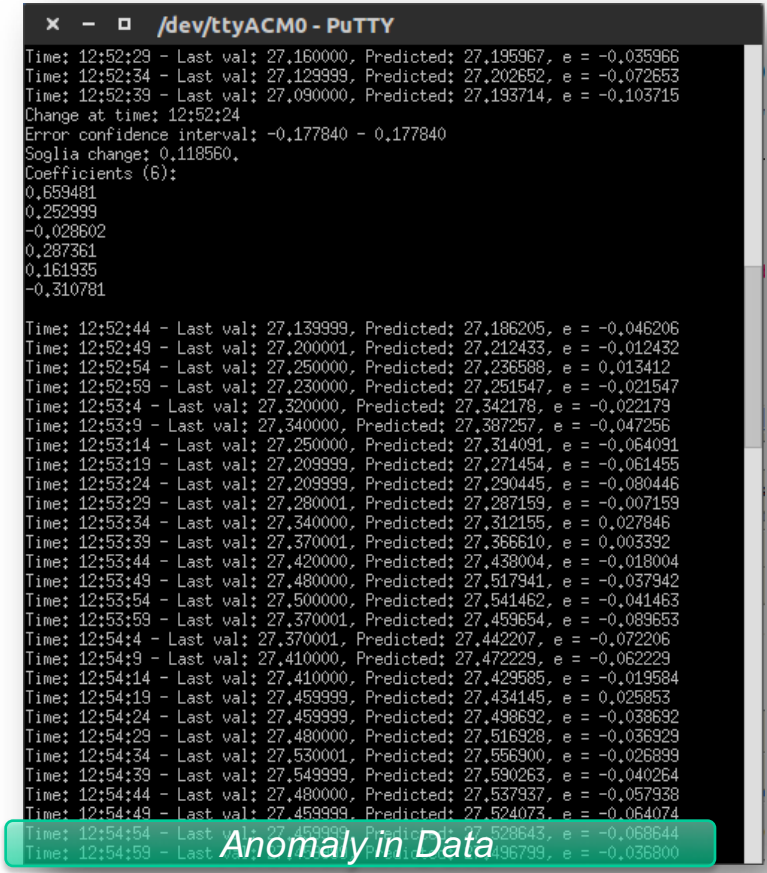



Dependency Graph

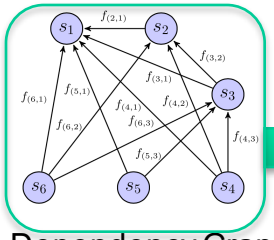
Intelligent Mechanisms

Alarm
(Change Time Instant)



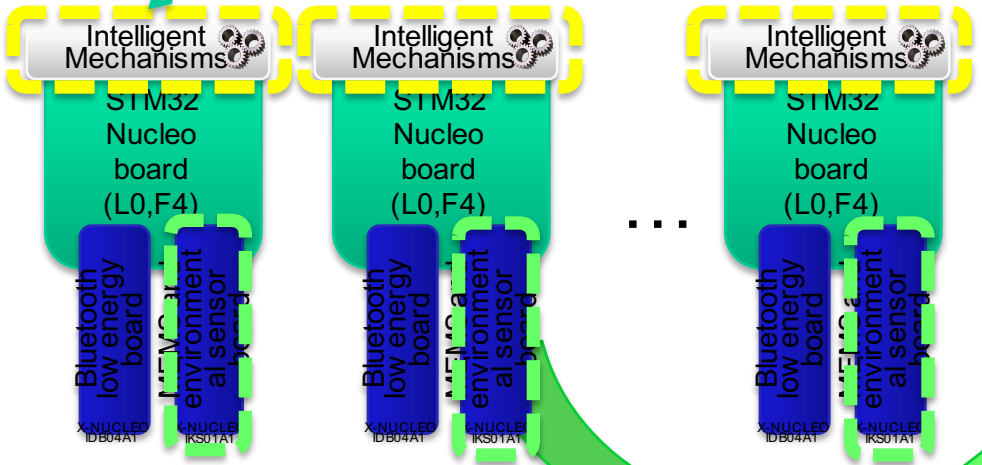
# Intelligent Mechanisms on ST Nucleo Systems

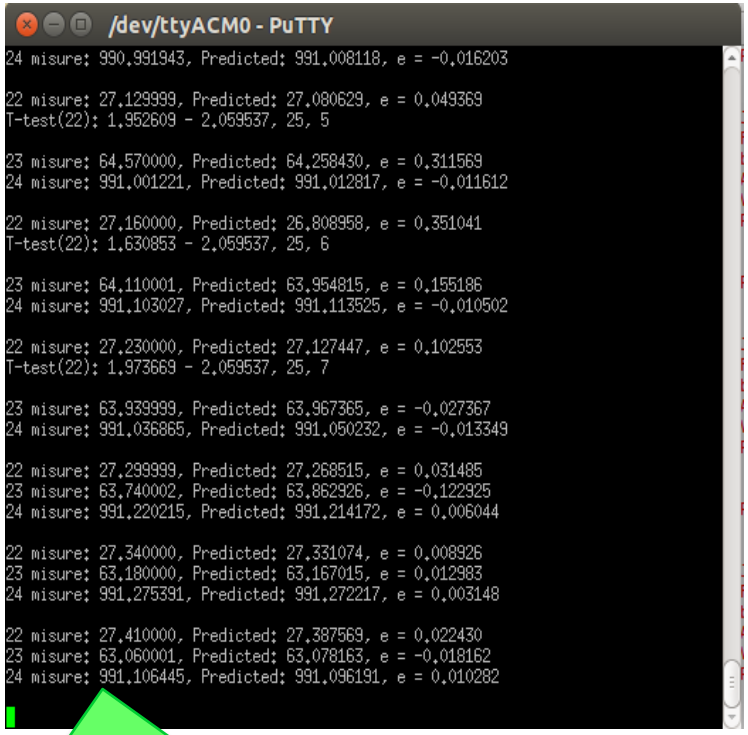



Dependency Graph

Intelligent Mechanisms

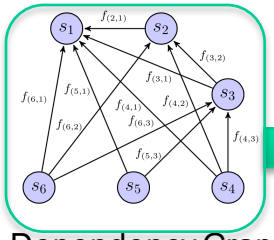
Analysis Request
(Change Time Instant)




Hypothesis Tests,CPMs
(Hotelling,Mann-Whitney)

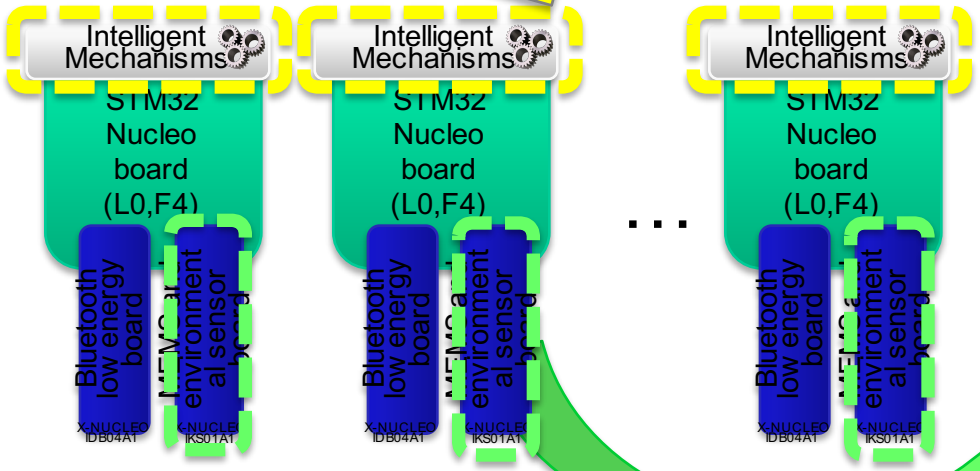
# Intelligent Mechanisms on ST Nucleo Systems

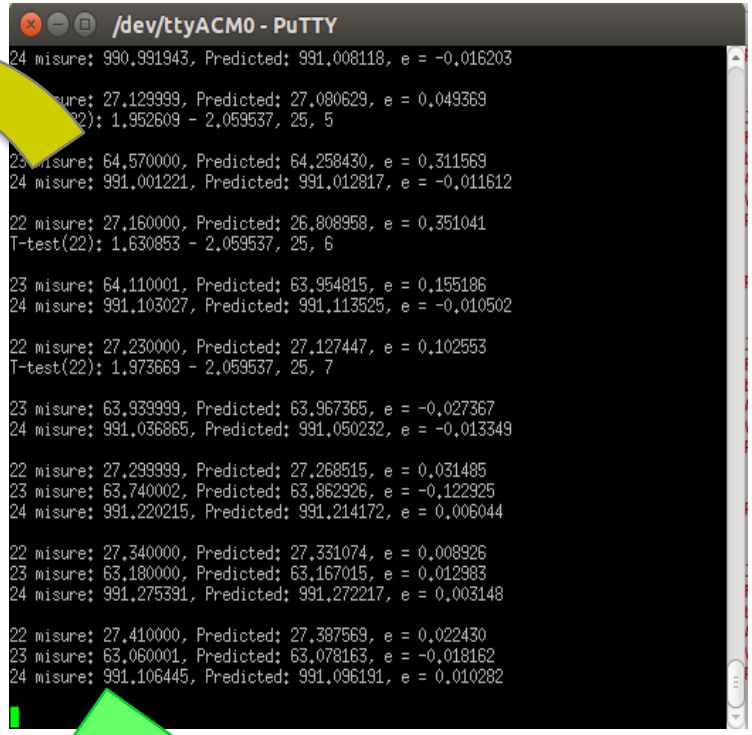



Dependency Graph

Intelligent Mechanisms

Local validation




Hypothesis Tests,CPMs
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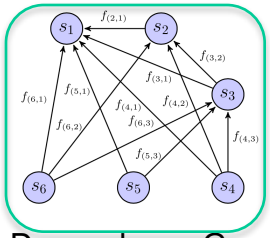
# Intelligent Mechanisms on ST Nucleo Systems




Dependency Graph

Intelligent Mechanisms

Response
(change/
no change)

Intelligent Mechanisms

STM32 Nucleo board (L0,F4)

Bluetooth low energy board

X-NUCLEO IDB04A1

Intelligent Mechanisms

STM32 Nucleo board (L0,F4)

Bluetooth low energy board

X-NUCLEO IDB04A1

...

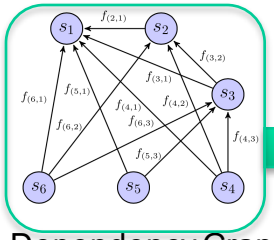
Intelligent Mechanisms

STM32 Nucleo board (L0,F4)

Bluetooth low energy board

X-NUCLEO IDB04A1

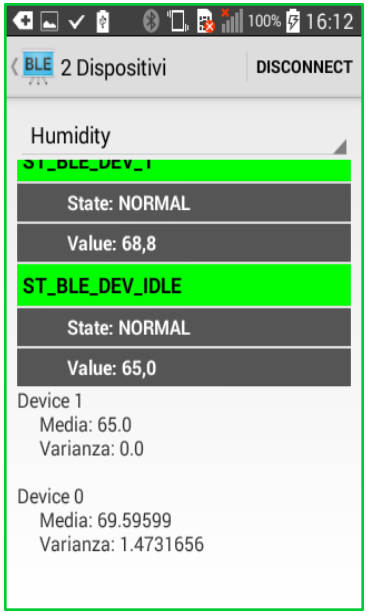
# Intelligent Mechanisms on ST Nucleo Systems



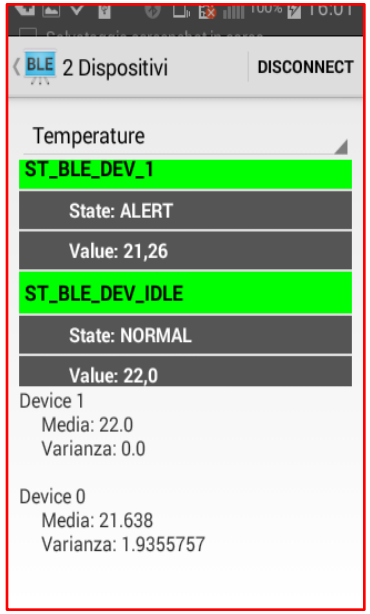

Dependency Graph

Intelligent Mechanisms

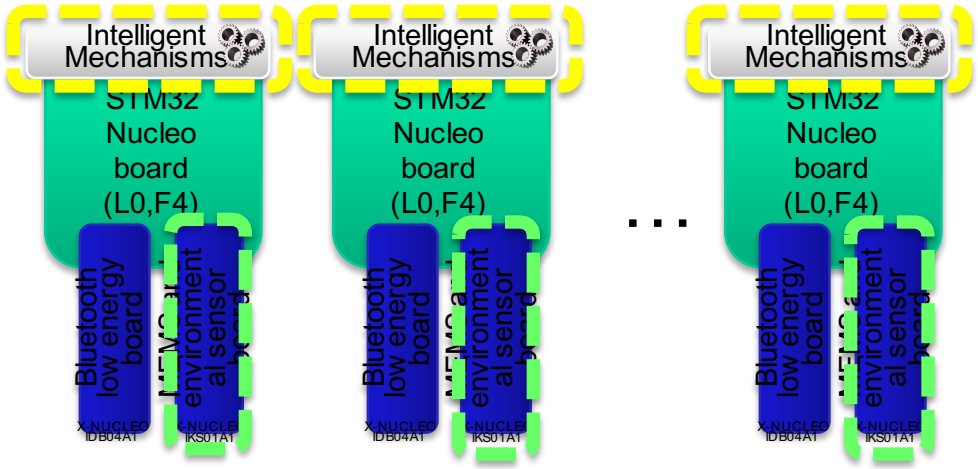
Aggregation



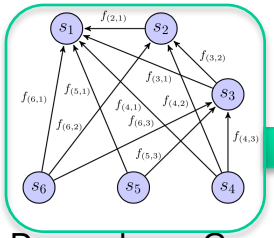

Normal




Alert



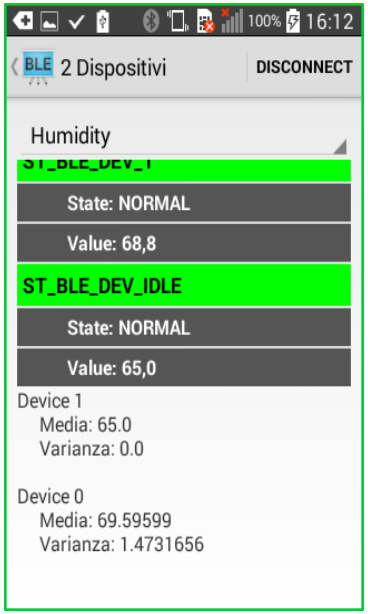
# Intelligent Mechanisms on ST Nucleo Systems




Dependency Graph

Intelligent Mechanisms

Aggregation

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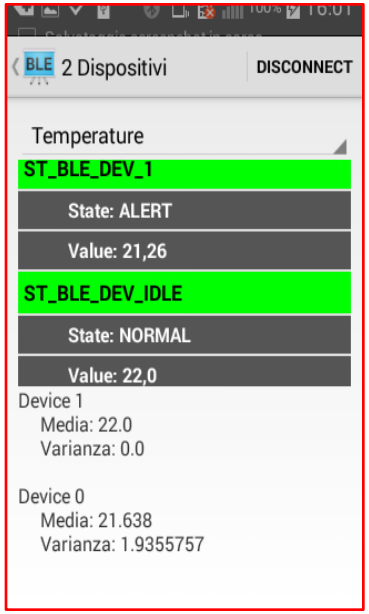
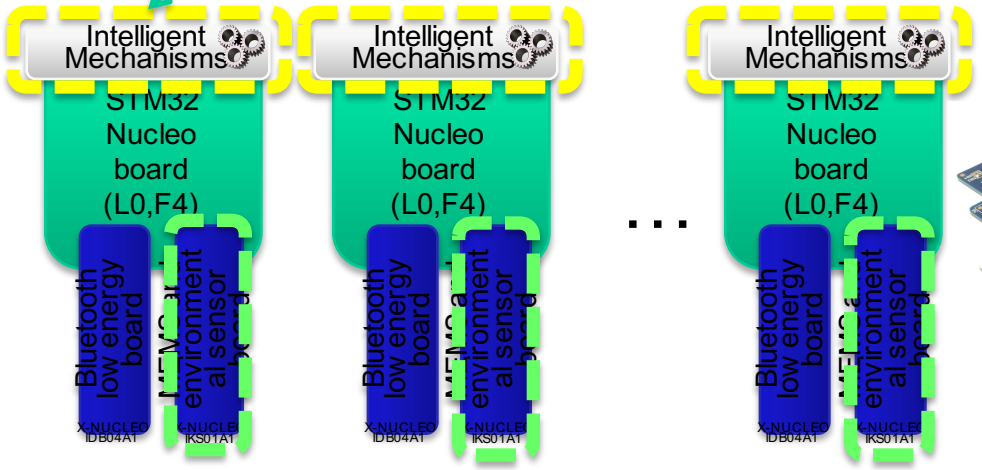
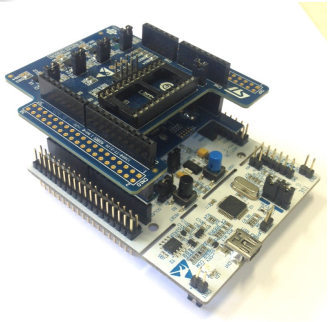


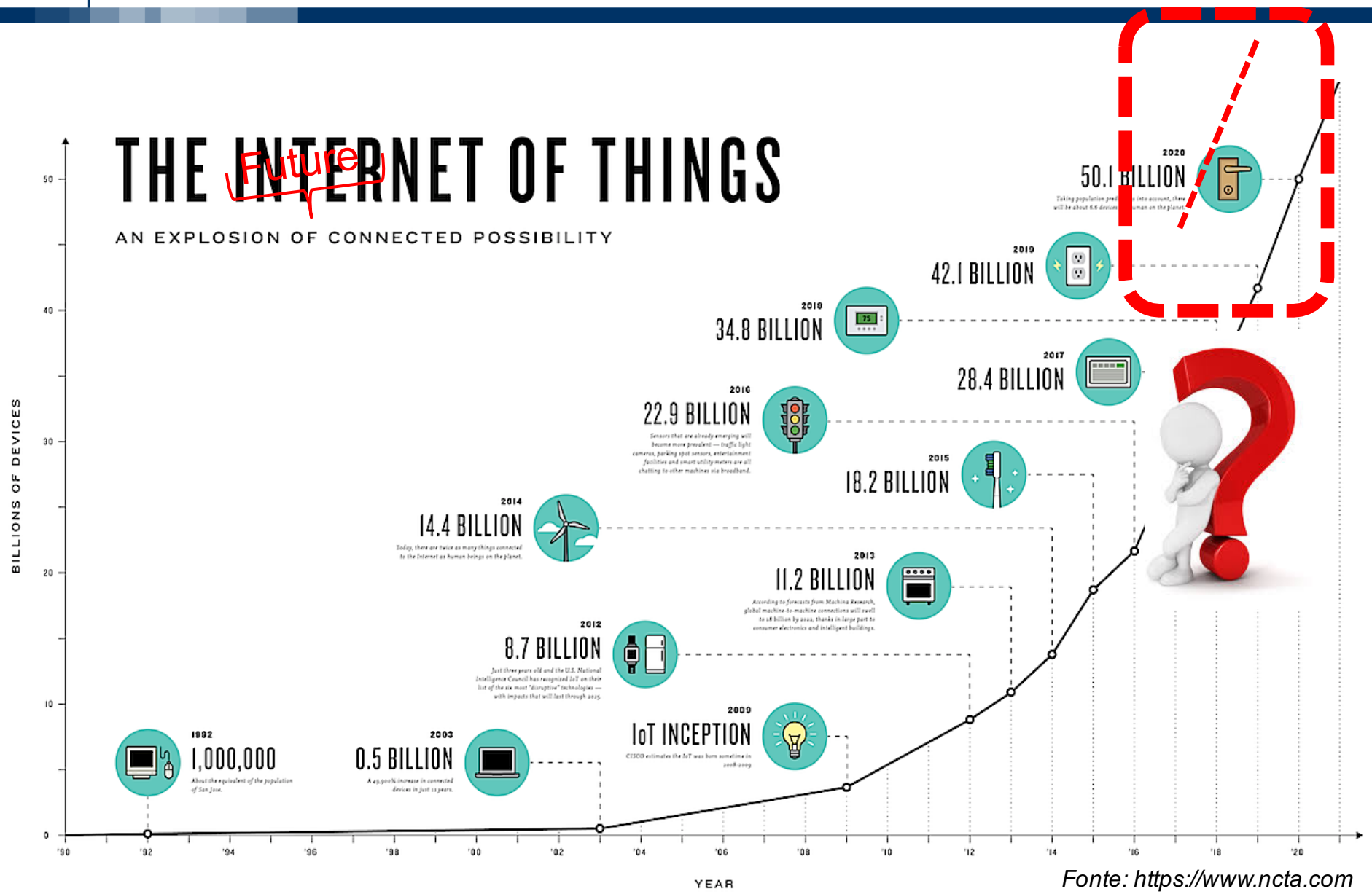

Alert

*Notification, Adaptation, Retraining*



# What’s next?




Fonte: https://www.ncta.com

# The Sensor-swarm Revolution …

# Questions?