Introduction to industrial agents:
fundamentals, research challenges and alignment with Industry 4.0

Paulo Leitão
pleitao@ipb.pt
http://www.ipb.pt/~pleitao

INSTITUTO POLITÉCNICO DE BRAGANÇA

CeDRI
Centro de Investigação em Digitalização e Robótica Inteligente

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Summary and objectives

1. Need for distributed and reconfigurable systems
2. Fundamentals of MAS
3. MAS to develop Cyber-Physical Systems
4. Standards, tools and frameworks to develop agent-based solutions
5. Examples of industrial applications
6. Research challenges and alignment with Industry 4.0

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Evolution of complexity

Spirit of St. Louis,
National Air and Space Museum,
Smithsonian Institution

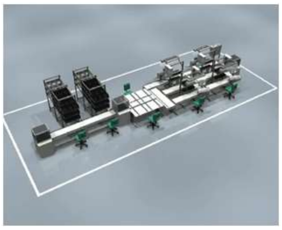
Airbus A380

The traditional approaches

- Customization of products, fast response to demand, and quality and diversity of products

Mass production → Mass customization → Unique products

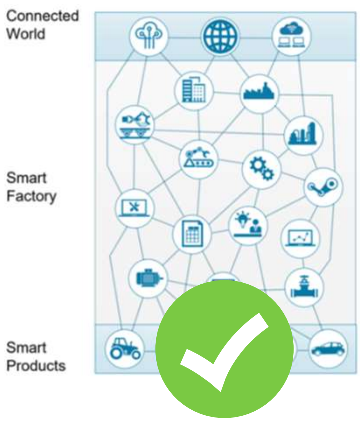
- Reduction of the reconfiguration time
- Time in the market versus time to the market



The new approaches

Tradicional: centralized na monolithic structures

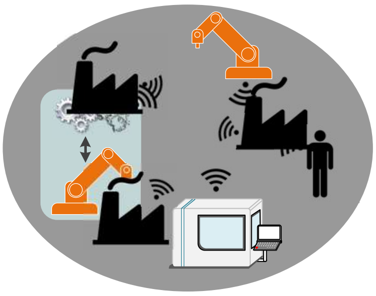
Challenge: distributed and decentralized structures



Fonte: Plattform Industrie 4.0, "Reference Architectural Model Industrie 4.0 (RAMI 4.0) - An Introduction," vol. 0, p. 21, 2016.

Cyber-physical systems

- Intelligent, dynamic and adaptive systems, characterized by:
  - Coexistence of cyber and physical elements
  - Organized in network
  - Interact to reach a common objective

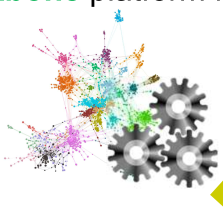


- High decision capability, in two aspects:
  - autonomous with self-decision processes
  - collaborative with decision processes based on negotiation

Data as a pillar in Industry 4.0

- **CPS** as the **backbone** platform for Industry 4.0

Internet of Things →



← **Artificial Intelligence**

extract value and knowledge

- **Huge volume of data is** real time collected
  - **Heterogeneous** data sources
  - Need to be managed in real time
- AI for descriptive, predictive and prescriptive analytics

90% of data were collected in the last years, but only 0,5% is analyzed

IBM, 2013

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Multi-agent systems

- Derived from Distributed AI
- Suitable to implement large-scale CPS
- Society of agents

FBI agent

super agent

agent Smith

insurance agent

What is an agent?

- Not a unique nor consensual definition!

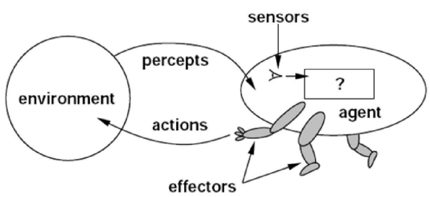
[Russel and Norvig, 1995]:
"As something autonomous that perceives and acts in an environment, being its choice depends on its own experience rather than on kno

[Wooldridge and Jennings, 1995]:
"An encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet its design objectives."

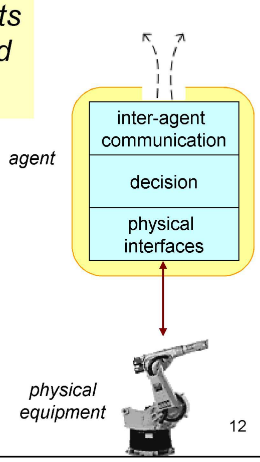
[Ferber, 1995]
"A physical or virtual entity whic environment, (2) can communic has autonomous behaviour, (4) has only a partial representation of this environment, (5) may be able to reproduce itself, and (6) possesses skills and can offer services."

What is an agent?

Autonomous component that represents physical or logical objects in the system, capable to act to achieve its goals and to interact with other agents when it doesn't possess enough knowledge and skills to reach alone its objectives



Source: Russel and Norvig 1995



Main characteristics (properties)

- Autonomy (capability to perform their own decisions)
- Cooperation (ability to cooperate with other agents to achieve a desired goal)
- Other characteristics [Wooldridge and Jennings, 1995]:
  - Reactivity: perception of the environment and quick response to changes
  - Proactivity: able to take the initiative
  - Social capabilities: able to interact with other agents (and possibly humans) via a communication language.
- Other properties: mobility, Intelligence, learning, truth, …

Agents versus objects

	Objects	Agents
Passive/ active	Passive, acting in reaction to an external stimuli.	Passive but may also exhibit a pro-active behaviour taking the initiative.
Decision & autonomy	Encapsulate a set of attributes and services, without capacity to decide about the execution of the requested services.	Able to accept or to reject the execution of the service, based on its knowledge and skills.
Type of messages	Related to the invocation of object's services (methods).	Related to the request to execute services or to provide information.

"Objects do it for free; agents do it for money"

From an agent to a MAS

- Rare applications consider agents in an isolated manner
- Need to work with other agents to solve complex problems → **MAS**

Society of agents that represent the objects of a system, capable of interacting to achieve their individual goals when they have not enough knowledge and/or skills to achieve individually their objectives

- System behavior emerges from interaction among agents

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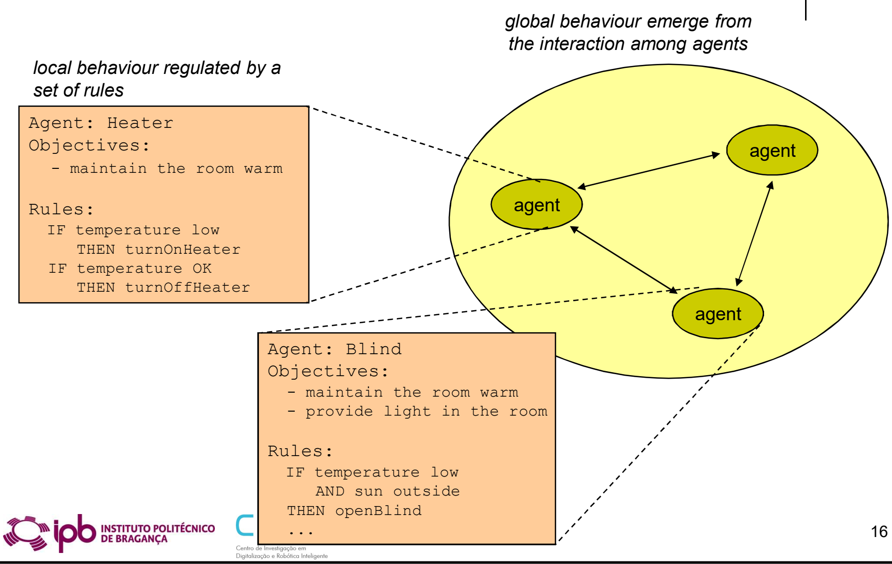
Local and global behaviors



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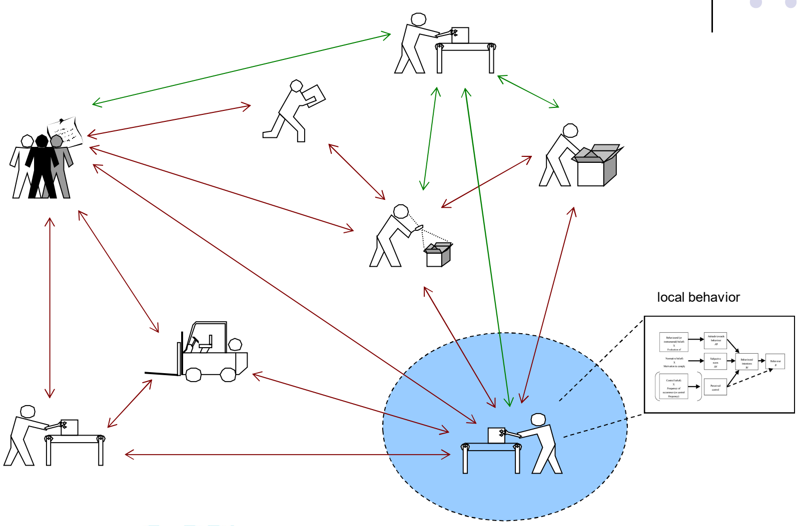
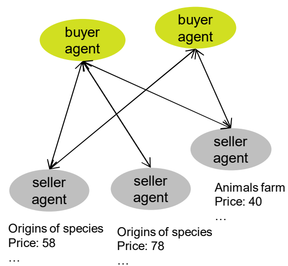
MAS working in practice



Book seller - buyer problem

- Consider a **problem** where
  - Some entities (book sellers) are selling books and others are buying books (customers)
  - Sellers sell at least one book and has a price for each one
  - Buyers want to buy books spending the less money possible
- Using **MAS approach to solve this problem**:
  - **Each seller or buyer is an agent** (need to create two different agent classes since each one has different behavior!)
  - Use the **CNP protocol** to support the negotiation between agents

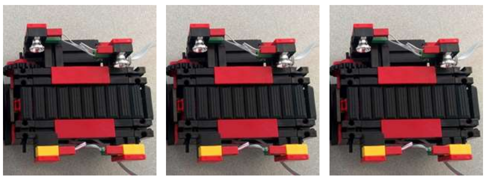


Why agent technology is a fascinating topic?

- Suitable to **build complex systems** with autonomous building blocks each incorporating the capability to take decisions **without hierarchy** but contributing for **the best of the system**
- System behavior emerges from interaction among agents
- **MAS as potential enabler** for Industry 4.0
  - to distribute intelligence
  - to manage long-term alliances and short-term coalitions

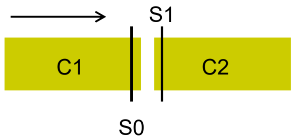
Need of MAS in practice

- System comprising a sequence of modular conveyors



- Individual conveyor comprises:
  - 1 motor
  - 2 light sensors

- Transfer a part from an input to an output location



- C1 only stops when the part arrives to S1
- C2 starts when the part arrives to S0

How to implement the control system?

Using the traditional solution

- Use a centralized logical control approach
- Programmed using IEC 61131-3 running in a PLC

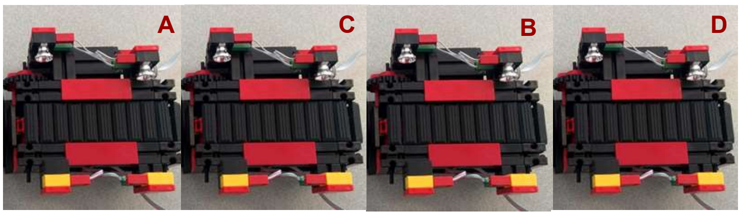
Fonte: Schneider Electric

- Simple to program
- Industrial adopted

- Lack in supporting scalability and re-configuration of the conveyor system
- Interdependencies between conveyors increases development effort and time!

Particularly, what happen if we need to …

- Switch the order of the conveyors?
- Add a new conveyor?



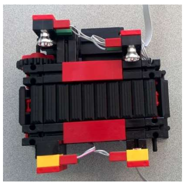
We need an alternative design approach to support the easy reconfiguration on-the-fly!!!

Using the MAS solution

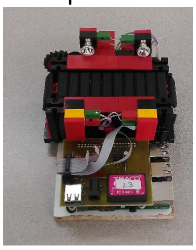
☞ Create cyber-physical components

agent

single-board computer



physical platform



cyber-physical component

Intelligent MAS solution

agent

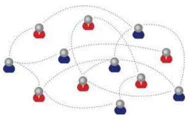
FIPA-ACL messages

☞ *plugability and reconfigurability on-the-fly!*

Important notes

- MAS technology is used to implement an industrial CPS
- Agents are **deployed in single board computers**
  - Low cost
  - Located at edge computing
- MAS introduces **self-organization to the system**, and particularly on-the-fly reconfiguration
- **No intelligent algorithm is used**!

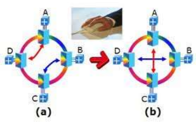
What multi-agents can offer



Distributed thinking
a complex problem can be divided into several small problems

Modularity
building the system by pieces like using LEGO

Robustness
losing one decision node doesn't implies the system failure



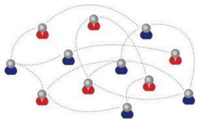
Reconfigurability
changes can be performed on the fly

Reusability
old components can be re-used to develop new components or new systems

Smooth migration
from old technologies to new ones

Road-blockers

investment



distributed thinking

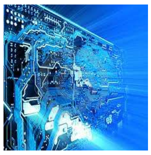
interoperability

scalability

standardization

real-time constraints

integration with physical devices



supporting technologies and methodologies

Traditional systems versus MAS

Conventional approach	MAS approach
Hierarchies of large programs	Large network of small agents
Sequential execution of operations	Parallel execution of operations
Instruction from top to bottom	Negotiation
Centralized decision	Distributed decisions
Data driven	Knowledge driven
Predictability	Self-organization
Stability	Evolution
Striving to reduce the complexity	Striving to thrive with the complexity
Total control	Support for growth
Weak response to perturbations	High response to perturbations
Rigid and static architecture	Flexible, programmable and dynamic architecture
More efficient to high volume and small variability	Indicated for high-medium volume and medium-high variability

Usual misunderstandings

A **simple agent based application** is not a MAS application!

An application where the **distributed components are not autonomous** is not a MAS application!

An application where agents executes a pre-defined sequence of actions without negotiation or cooperation is not a MAS application!

An application using **agents that are not interacting** is not a MAS application!

MAS is not the solution for everything!

MAS development frameworks have **central bottlenecks**

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Agent typologies

- Several approaches to classify the agents
- [Wooldridge and Jennings, 1995]:
  - Deliberative, reactive and hybrid
- [Ferber, 1999]:
  - Reactive and cognitive
- [Nwana, 1996]:
  - Mobility (static or mobile)
  - Capacity of response (reactive or deliberative)
  - Ideal attributes (autonomy, co-operation, learning and versatility)

Architectures of agents

Deliberative ⟷ Reactive

reasoning — *reflexive*

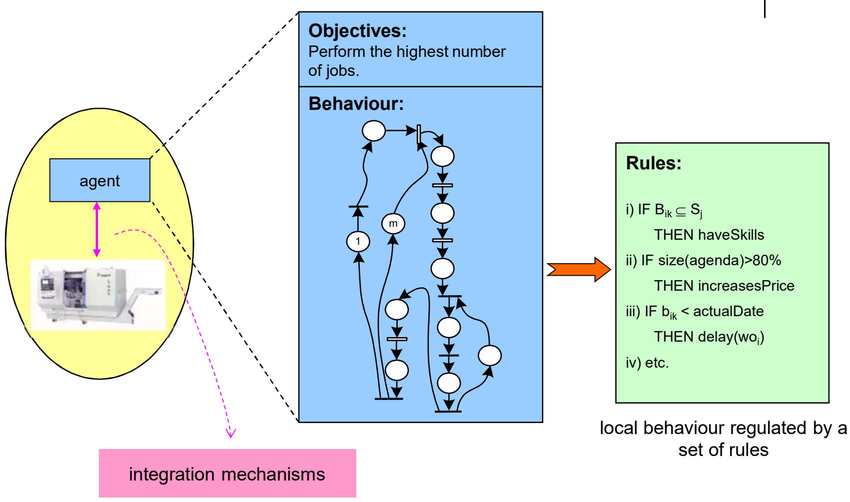
speed of response →

← *predictive capabilities*

← *dependence on complete model*

Deliberative	Reactive
• Goal-oriented behavior • Requires full knowledge about the environment • Frequent updating of the model • Optimized solutions • Slow reaction to change & uncertainty	• Stimulus response operation • Incapable of foreseeing the future (no memory) • Robust, fault-tolerant and fast response to unforeseen situations • Non-optimized solutions

Implementation of MAS, step 1: local agents' behaviors



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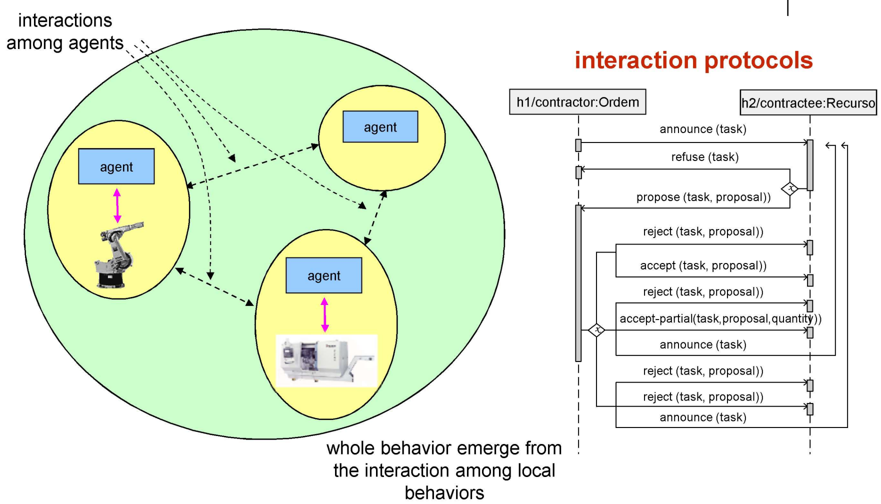
Implementation of MAS, step 2: interaction among agents



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Interaction in MAS

- Each agent needs to interact with other agents
- Different types and forms of interaction:
  - cooperation, competition, coordination, collaboration & negotiation

- For discussion: candidates preparing (together) an interview to get a job

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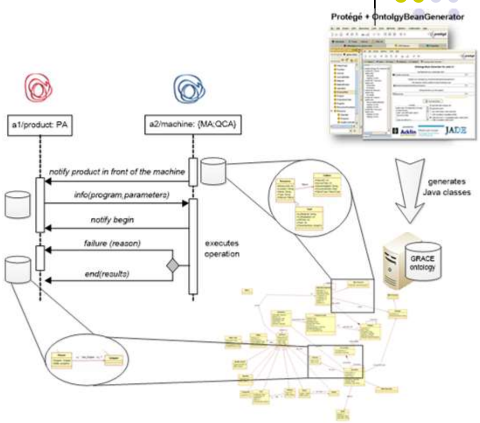
Ontologies to represent knowledge

- Knowledge sharing problem:
  - Each agent has its own knowledge structure
  - Lack of understanding of shared knowledge
  - Inter-operability, reuse and share the knowledge



use of ontologies to represent the structure of the shared knowledge!

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Definition of ontology

- Create shared understanding, enabling the exchange of knowledge and the capability to reuse that knowledge
- Defines the vocabulary that is used in the communication between agents, and knowledge relating to these terms
- This knowledge includes the definition of the:
  - Concepts (objects or classes)
  - Terms of each concept
  - Predicates (relationships between the concepts)
- An ontology together with a set of individual instances of classes constitutes a knowledge base

Where to run the agents?

- Using only the cloud?
  - Storing big amount of data
  - Execution of complex and demanding algorithms

Cloud technology is n
solution f
Send, storing and
processing data in the
cloud can be e
Some data need to be
proces d as close and as fast
as ir source
Communication latency
(u lly low bandwidth)
What happen if the
connection fails?

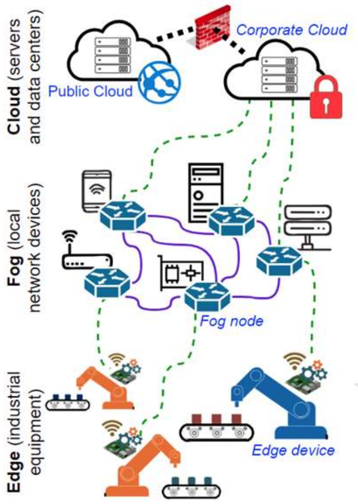
"We should not send all collected data to be processed in the cloud but instead to make analysis in the edge"

James Truchard, National Instruments @IFAC IMS'16

"Analysing data close to the device that collected the data can make the difference between averting disaster and a cascading system failure"

Cisco, White paper, 2015

Agents to distribute intelligence in cloud, fog and edge continum



- Centralized aggregation of data and data analysis performed offline
- Extraction of knowledge for decision-making, prediction, optimization and planning
- Historic data analysis

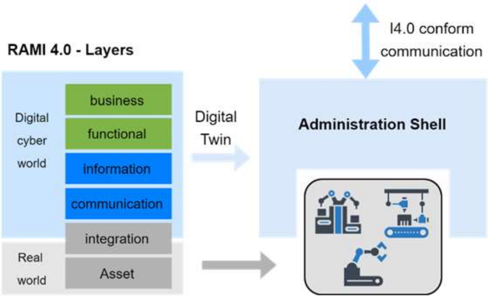
- Data analysis performed online and near the data source
- Process monitoring and fast response
- Pre-processing and filtering

Industrial agents

- Inherit software agent principles, e.g., intelligence, autonomy and cooperation
- Applied to industrial applications and facing industrial requirements:
  - hardware integration, reliability, fault-tolerance, scalability, industrial standard compliance, quality assurance, resilience, manageability, and maintainability
- These requirements may have varying degrees of importance
  - however, the focus is on well-established, stable, and proven approaches rather than experimental and not fully tested features

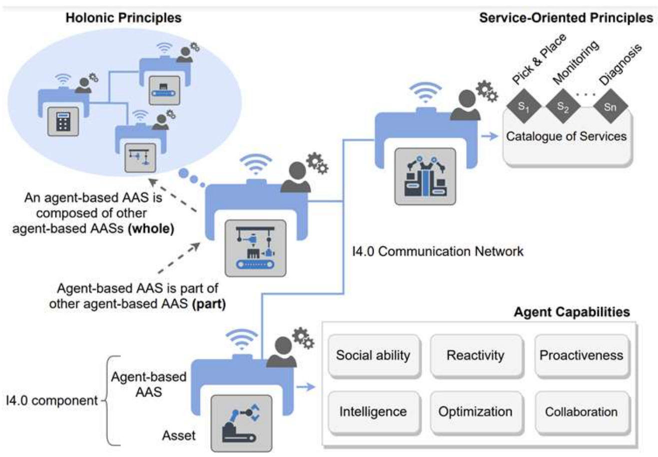
Matching digitalization defined by RAMI4.0

- Industrial agents can implement **AAS**
- Particularly developing **AAS type 3**
  - Ability to **represent and interact** with physical assets
  - Provide **intelligence** for simulation and data-driven analytics
  - Implement **collaboration models to interact** with other agents or AASs



Source: V. Melo, F. Prieta, P. Leitão, "Alignment of Digital Twin Systems with the RAMI 4.0 Model using Multi-agent Systems", SOHOMA'22.

MAS based AAS Type 3



Source: L. Sakurada, P. Leitao, F. De la Prieta (2022), "Agent-Based Asset Administration Shell Approach for Digitizing Industrial Assets", 14th IFAC Workshop on Intelligent Manufacturing Systems (IMS'22), pp. 193-198 (DOI: 10.1016/j.ifacol.2022.04.192)

Key challenges in industrial CPS

Table 2
Key challenges in Industrial CPS.

Area	Key Challenges	Difficulty	Priority	Maturity in
CPS Capabilities	Real-time control of CPS systems	High	High	4–7 years
	Real-time CPS SoS	High	Medium	3–5 years
	Optimization in CPS and their application	High	Medium	4–7 years
	On-CPS advanced analytics	Medium	High	3–5 years
	Modularization and servification of CPS	low	High	3–5 years
	Energy efficient CPS	Medium	Medium	3–5 years
CPS Management	Lifecycle management of CPS	Medium	Medium	5–8 years
	Management of (very) large scale CPS and CPS-SoS	High	High	5–8 years
	Security and trust management for heterogeneous CPS	High	High	5–8 years
CPS Engineering	Safe programming and validation of CPS SoS	High	High	5–10+ years
	Resilient risk-mitigating CPS	High	High	5–10+ years
	Methods and tools for CPS lifecycle support	High	High	3–7 years
	New operating systems and programming languages for CPS and CPS SoS	Medium	Low	3–6 years
	Simulation of CPS and of CPS-SoS	Medium	High	3–6 years
CPS Infrastructures	Interoperable CPS services	Medium	High	2–5 years
	Migration solutions to emerging CPS infrastructures	Medium	High	3–6 years
	Integration of heterogeneous/mobile hardware and software technologies in CPS	Low	Medium	2–4 years
	Provision of ubiquitous CPS services	Medium	Medium	3–5 years
	Economic impact of CPS Infrastructure	High	High	3–6 years
CPS Ecosystems	Autonomic and self-* CPS	High	Medium	7–10+ years
	Emergent behavior of CPS	High	Medium	7–10+ years
	CPS with humans in the loop	High	High	2–5 years
	Collaborative CPS	Medium	Medium	5–8 years
CPS Information Systems	Artificial intelligence in CPS	High	High	7–10+ years
	Cross-domain large-scale information integration to CPS infrastructures	Medium	Low	6–9 years
	Transformation of CPS data and information analytics to actionable knowledge	High	High	4–8 years
	Knowledge-driven decision making/management	High	Medium	6–10+ years

Source: P. Leitão, S. Karnouskos, A.W. Colombo (2016), "Industrial Automation based on Cyber-Physical Systems Technologies: Prototype Implementations and Challenges", Computers in Industry, vol. 81, pp. 11-25 (DOI: 10.1016/j.compind.2015.08.004).

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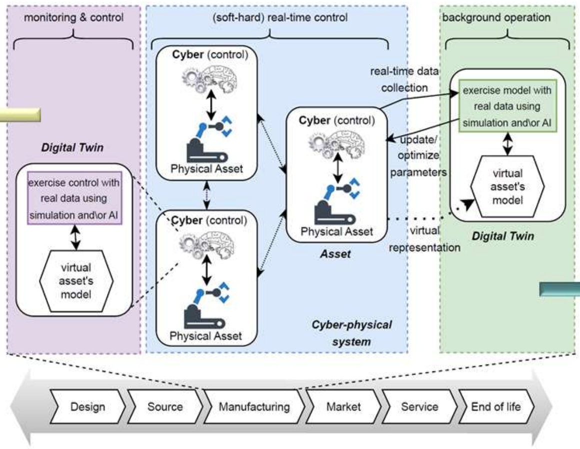
Convergence of CPS and DT

DT as the cyber part of CPS



DT improving the CPS operation

Source: F. Pires, V. Melo, J. Queiroz, A.P. Moreira, F. de la Prieta, E. Estévez, P. Leitão (2024), "Positioning Cyber-Physical Systems and Digital Twin in Industry 4.0", IEEE Int. Conference Industrial Cyber-Physical Systems.

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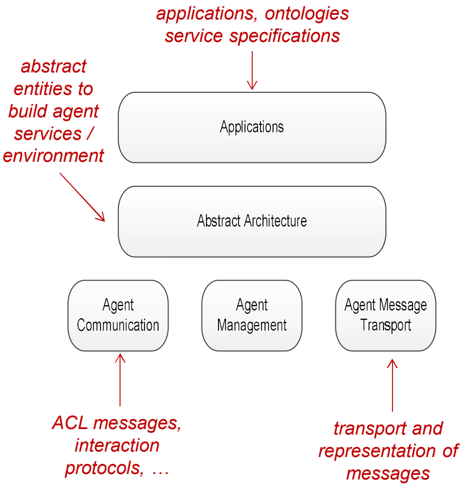
FIPA (Foundation for Intelligent Physical Agents)

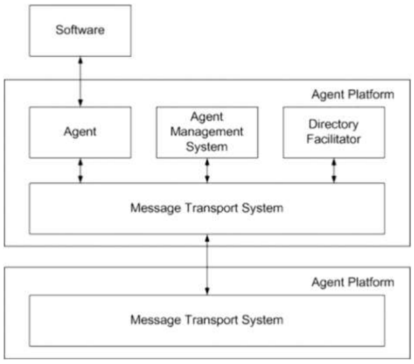
- Originally formed in 1996 to **produce specifications for agent-oriented software engineering**
- Specifies the reference model that defines the basic structure of a MAS
- The only standard for the development of MAS
  - Highly adopted mainly due to high popularity of JADE
- IEEE Computer Society standard since 2005
- Now seems to be **dead with no maintenance**!
- See: http://www.fipa.org

FIPA Specifications

FIPA Categories



FIPA Agent Management Reference Model



- *AP: provides physical infrastructure to deploy agents*
- *AMS: controls access to AP and provides services e.g., white pages*
- *MTS: supports the transport of msgs between agents*
- *DF: provides yellow pages services*

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Standards related to interoperability

- Interoperability and contents interpretation during the cooperation processes are important aspects
- Ontologies for representation of shared knowledge:
  - Several standards defined by W3C and OASIS
  - Examples: RDF and OWL
- Content of the messages:
  - Example: FIPA SL
- Communication language:
  - Examples: KQML and FIPA-ACL

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Standards related to industrial automation

IEC 61131
(industrial practice of PLCs)

IEC 61499
(distributed control and automation based on FB)

ANSI/ISA 88
(design philosophy for describing equipment and procedures, for batch process control)

ISO 15531
(representation of data captured by manufacturing control and stored and handled at the manufacturing management)

ANSI/ISA 95
(automated interfaces between enterprise and control systems, applied for all industries and sort of processes)

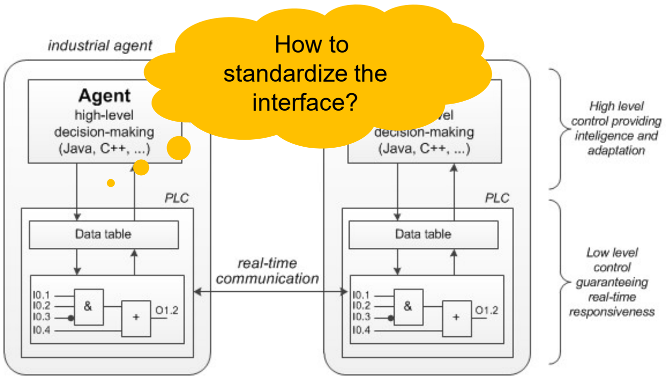
IEC 62264
(enterprise control systems integration, based on ANSI/ISA 95)

ISO 15704
(requirements for enterprise reference architectures regarding frameworks, languages and modules

ISO/IEC 15288
(system life-cycle process management, comprising the requirements analysis, architectural design, verification and validation)

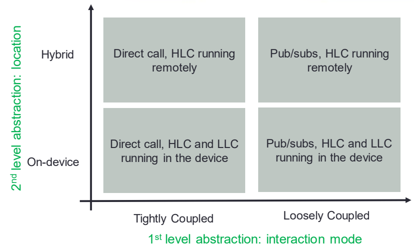
Agents in CPS context

- MAS usually misses real-time constraints
- Preserve low-level control to ensure responsiveness



IEEE 2660.1-2020

- Recommended practices to solve the interface problem
  - integrating software agents with low-level real-time automation control devices
  - in the context of cyber-physical systems
  - allowing the reuse and transparency



Source: P. Leitão, S. Karnouskos, L. Ribeiro, P. Moutis, J. Barbosa, T. Strasser (2018), "Integration Patterns for Interfacing Software Agents with Industrial Automation Systems", IECON'18, pp. 2908-2913

Application 1: digitize a robot that is being produced

Definition of the context:

- **Function:** monitoring
- **Parameters:** response time (50%) and reusability (50%)
- **Location:** robot asset cannot run agents locally

Results						
Recomended interface practice						
Id practice	Location	Interaction mode	API client	Channel	Broker	Score
HT-5	**Hybrid**	**Tightly coupled**	**Apache Milo**	**OPC-UA**		**4.00**
Details						
Id practice	Location	Interaction mode	API client	Channel	Broker	Score
HT-5	Hybrid	Tightly coupled	Apache Milo	OPC-UA		4.00
HT-6	Hybrid	Tightly coupled	Java	Ethernet/IP		3.50
HT-7	Hybrid	Tightly coupled	Java	OPC UA		3.20
HT-4	Hybrid	Tightly coupled	C/C++/SQL	Sockets		3.20
HL-1	Hybrid	Loosely coupled	Apache Paho	MQTT	Eclipse Mosquitto	3.20
HT-2	Hybrid	Tightly coupled	Java	Sockets		3.10
HT-3	Hybrid	Tightly coupled	Java	DPWS		2.80
HL-2	Hybrid	Loosely coupled	Java	OPC-UA		2.72
HL-4	Hybrid	Loosely coupled	Apache Paho	MQTT		2.40
HL-3	Hybrid	Loosely coupled	C/C++/SQL	Sockets	DBMS	2.40
HT-1	Hybrid	Tightly coupled	Java	Modbus		1.92

Source: P. Leitão, S. Karnouskos, T. I. Strasser, X. Jia, J. Lee, A. W. Colombo (2023), "Alignment of the IEEE industrial agents recommended practice standard with the reference architectures RAMI4.0, IIRA, and SGAM," IEEE OJIES, vol. 4, p. 98–111 (DOI: 10.1109/OJIES.2023.3262549).

Application 2: digitize a robot that is placed in a production line

Definition of the context:

- **Function:** control
- **Parameters:** response time (80%) and reusability (20%)
- **Location:** robot asset can run agents locally

Results

Recomended interface practice

Id practice	Location	Interaction mode	API client	Channel	Broker	Score
OT-1	On-device	Tightly coupled	Java			3.77

Details

Id practice	Location	Interaction mode	API client	Channel	Broker	Score
OT-1	On-device	Tightly coupled	Java			3.77
HT-7	Hybrid	Tightly coupled	Java	OPC UA		3.20
HT-5	Hybrid	Tightly coupled	Apache Milo	OPC-UA		3.20
OT-2	On-device	Tightly coupled	C/C++	Sockets		3.09
HT-6	Hybrid	Tightly coupled	Java	Ethernet/IP		2.56
HT-3	Hybrid	Tightly coupled	Java	DPWS		2.56
OL-1	On-device	Loosely coupled	REST/JSON	MQTT	Eclipse Mosquitto	2.56
OL-2	On-device	Loosely coupled	C/C++/SQL	DBMS	DBMS	1.92
OT-3	On-device	Tightly coupled	C/C++/SQL	DBMS		1.92
HT-2	Hybrid	Tightly coupled	Java	Sockets		1.82
HT-4	Hybrid	Tightly coupled	C/C++/SQL	Sockets		1.63
HL-1	Hybrid	Loosely coupled	Apache Paho	MQTT	Eclipse Mosquitto	1.63
HT-1	Hybrid	Tightly coupled	Java	Modbus		1.56
HL-2	Hybrid	Loosely coupled	Java	OPC-UA		1.45

Source: P. Leitão, S. Karnouskos, T. I. Strasser, X. Jia, J. Lee, A. W. Colombo (2023), "Alignment of the IEEE industrial agents recommended practice standard with the reference architectures RAMI4.0, IIRA, and SGAM," IEEE OJIES, vol. 4, p. 98–111 (DOI: 10.1109/OJIES.2023.3262549).

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How to implement MAS concepts?

- Using usual object-oriented languages, e.g. C++ or Java
- Specific features required by MAS:
  - Message transport
  - Encoding and parsing
  - Yellow and white pages services
  - Ontologies for common understanding
  - Agent life-cycle management services
- Features **not provided** by usual programming languages

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Existing Development Frameworks

- Several commercial or open platforms, addressing different agent models

Features provided by these frameworks

- Compliant with FIPA specifications (preferable)
- Set of services to manage the agent platform
- Language, protocols and semantics for the exchange of messages
- Set of graphical tools to:
  - Monitor the agents state
  - Support the debugging and testing phases
- Documentation and (usually) active forum groups

Implementation of industrial agents

- **More complex** than the traditional software agents
- Besides technical requirements, the **physical hardware integration is a challenge**
- FIPA is not suitable for industry, missing important industrial requirements, namely:
  - Security and privacy
  - Hardware and legacy systems integration
  - Real-time interaction protocols for large-scale systems ensuring scalability and latency
  - Light ACL protocol to support scalability in large-scale systems
  - Distributed yellow pages and discovery mechs to improve robustness

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Agent Based Modelling (ABM)

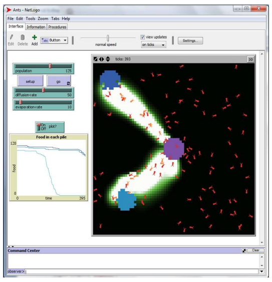
- Modeling of a system or process by using a MAS system, and posterior simulation in presence of complex phenomena
- During the design phase and before its deployment

TABLE I – CHARACTERISTICS OF SOME ABM PLATFORMS

	MASON	NetLogo	Swarm	Repast
Availability (free)	✓	✓	✓	✓
Maturity	Poor	Fair	Good	Fair
Programming effort	Poor	Good	Fair	Poor
Change of properties	Poor	Fair	Poor	Good
User interface	Poor	Good	Poor	Good
Simulation speed	Good	Fair	Fair	Good
Documentation	Good	Good	Fair	Fair

Legend: Good; Fair; Poor

Source: . Barbosa, P. Leitão (2011), "Simulation of Multi-agent Manufacturing Systems using Agent-based Modelling Platforms", IEEE Int. Conf. on Industrial Informatics (INDIN'11), (DOI: 10.1109/INDIN.2011.6034926)



stationary agents (or patches) and mobile agents (or turtles)

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Summary and objectives

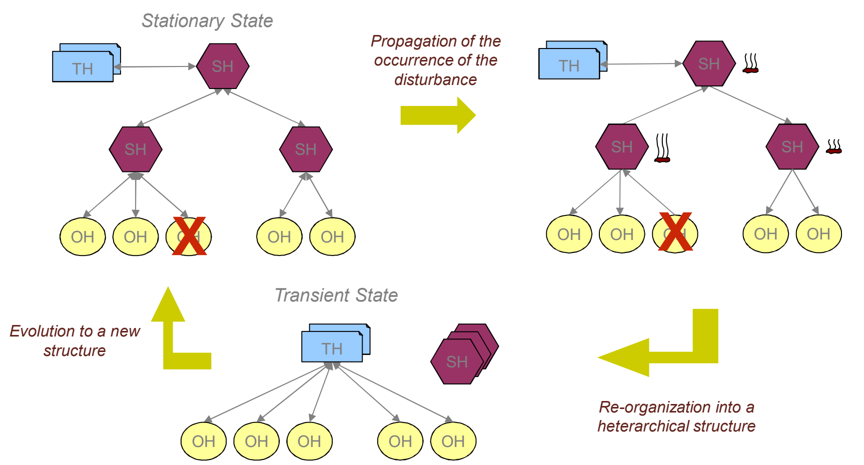
1. Need for distributed and reconfigurable systems
2. Fundamentals of MAS
3. MAS to develop Cyber-Physical Systems
4. Standards, tools and frameworks to develop agent-based solutions
5. Examples of industrial applications
6. Research challenges and alignment with Industry 4.0

ADACOR Holonic Control Architecture

- Built upon a set of **autonomous and co-operative holons**, each one representing a manufacturing component
- Defines four holon classes: product, task, operational and supervisor
- **Supervisor holon** introduce hierarchy in decentralized systems
- **Dynamic adaptive production control** that:
  - evolves dynamically between a more **centralized** and a more **decentralized** approach, supported by the self-organization associated to ADACOR holons
  - allows the **re-configurability of the system**, combining the agility with the production optimization

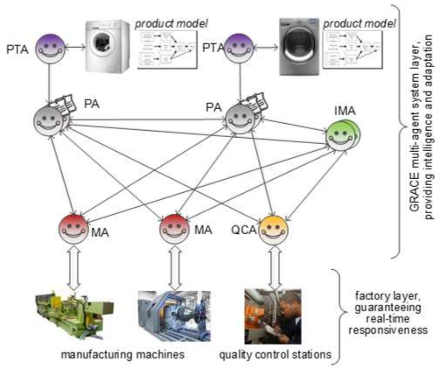
Source: P. Leitão and F. Restivo (2006), "ADACOR: A Holonic Architecture for Agile and Adaptive Manufacturing Control", Computers in Industry, vol. 57, nº 2, pp. 121-130, Elsevier (DOI: 10.1016/j.compind.2005.05.005).

Re-configurability in ADACOR Control System



Example of application

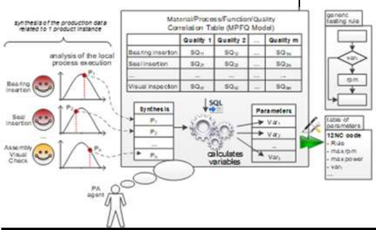
- Integrate quality control and process
- Improve efficiency, quality and customization
- Preserving the low-level control
- MAS for:
  - Collect data
  - Perform real-time data analysis
  - Correlate operating variables



Source: P. Leitao, N. Rodrigues, C. Turrin, A. Pagani (2015), "Multi-agent System Integrating Process and Quality Control in a Factory Producing Laundry Washing Machines", IEEE Transactions on Industrial Informatics, vol. 11, n. 4, pp. 879 - 886 (DOI: 10.1109/TII.2015.2431232)

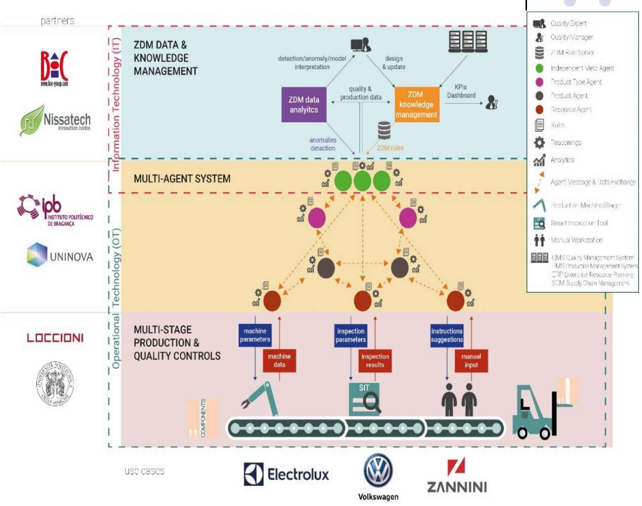
Examples of intelligence

- Customize functional tests
  - Remove unnecessary tests
  - Adjust tests
- Customization of parameters of the machine controller
- Early detection of products that never reach the desired quality
- Dynamic adaptation of the process performance



ZDM at multi-stage production

- Integration of quality & process control in real-time
- MAS for:
  - Data collection
  - Real-time data analysis
  - Correlation of operating variables

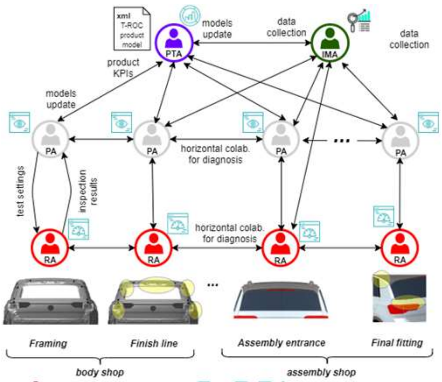


Implementation

GOØDMAN
AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

Volkswagen

Jade OPC UA



- 1 PTA representing the T-ROC car model
- 4 RAs representing inspection stations, deployed at edge
- > 200k PAs, each one associated to a T-ROC car

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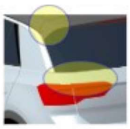
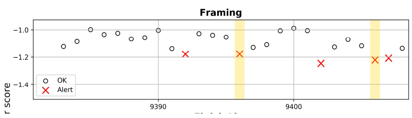
Data Analysis Deployed in RAs

GOØDMAN
AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

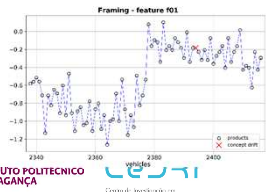
- **Objective:** monitoring deviations in the rear part of the vehicle (alignment and gaps between the frame and tailgate)
  - Detection of anomalies in inspection stations





- Algorithms:
  - Nelson rules
  - Local Outlier Factor (LOF)

  - Detection of changes in the process



- Concept Drift Page-Hinkley algorithm

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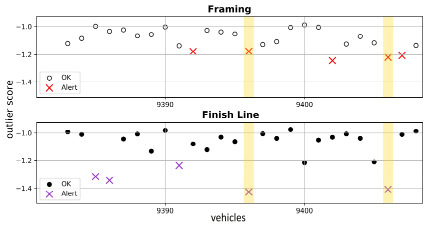
Data Analysis Deployed in PAs

GOØDMAN
AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

- **Objective:** correlate product data along the different stations
  - Detection of anomalies in multi-stage inspection stations



- Composed condition rules
  IF x1>σ1 AND x2>σ2 THEN warning1
- Control limits updated by IMA

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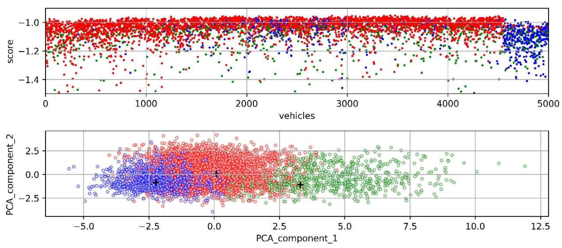
Data Analysis Deployed in IMA

GOØDMAN
AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

- **Objective:** keeping up-to-date the monitoring and control settings of the lower level agents
  - Support the identification of similar groups of cars



BIRCH (Balanced Iterative Reducing and Clustering using Hierarchies) algorithm

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Innovation Radar

Source: https://www.innoradar.eu/innovation/34921

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Summary and objectives

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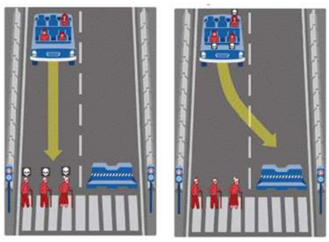
Organizational, social, ethical perspectives

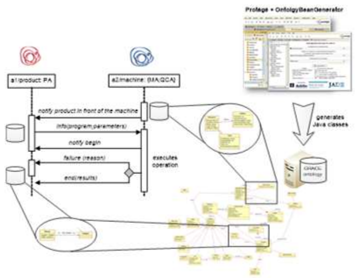
- Need to **look beyond technology**
  - draw important ethical, human and philosophical considerations
- Which social-organizational, legal and ethical frameworks are needed to support AI and MAS?
- Consider **legal issues**,
  - e.g., General Data Protection Regulation (GDPR)
- **Ethics** assumes important role in AI



Source: Moral machine - what should the self-driving car do?

Interoperability

- Use of **standardized** IoT and M2M technologies
- **Standardized** data models for knowledge sharing and re-use
  - AutomationML, B2MML, STEP, FIWARE, etc.



- How to remove barriers between business and operational data?
- **5G** will boost communication & collaboration mechanisms

Security and trust

- High levels of security to cope with privacy requirements
  - Inside factory
  - Between companies
- How to assure the security of the system and their components?
  - Encryption, privacy, … techniques
  - **ML to identify attack vectors**
- **Trust and reputation**

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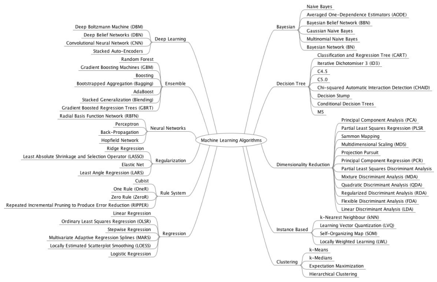
Which AI algorithms to select?

- None algorithm is adequate for all problems



- **Select the most appropriate ML algorithm**, depending:
  - Available volume, type of data
  - Computational resources
  - Response time

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Emergence and self-organization

- Which **inter-organization collaboration relationships** will emerge?
- How to ensure that only desired **behaviours and properties will emerge**?
- How to assure the proper system **behaviour and self-organization**?
- How to control the **system nervousness**?
- How such systems are **created, maintained and evolve**?
- …

Thank you!

Paulo Leitão
e-mail: pleitao@ipb.pt
http:// www.ipb.pt/~pleitao