Industrial Agents as a Key Enabler Technology Towards Smart, Digital and Sustainable Transition: Ultimate Driving-Forces

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

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INSTITUTO POLITÉCNICO DE BRAGANÇA

CeDRI
Research Centre in
Digitalization and Intelligent Robotics

Agenda

- Contextualization
- Multi-agent Systems as a key enabler for CPS engineering
- Industrial applications and road blockers
- Next stage in the AI era
- Takeaway messages

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Evolution of complexity

Ferrari D50
Fangio's 1956 Silverstone Grand Prix winner

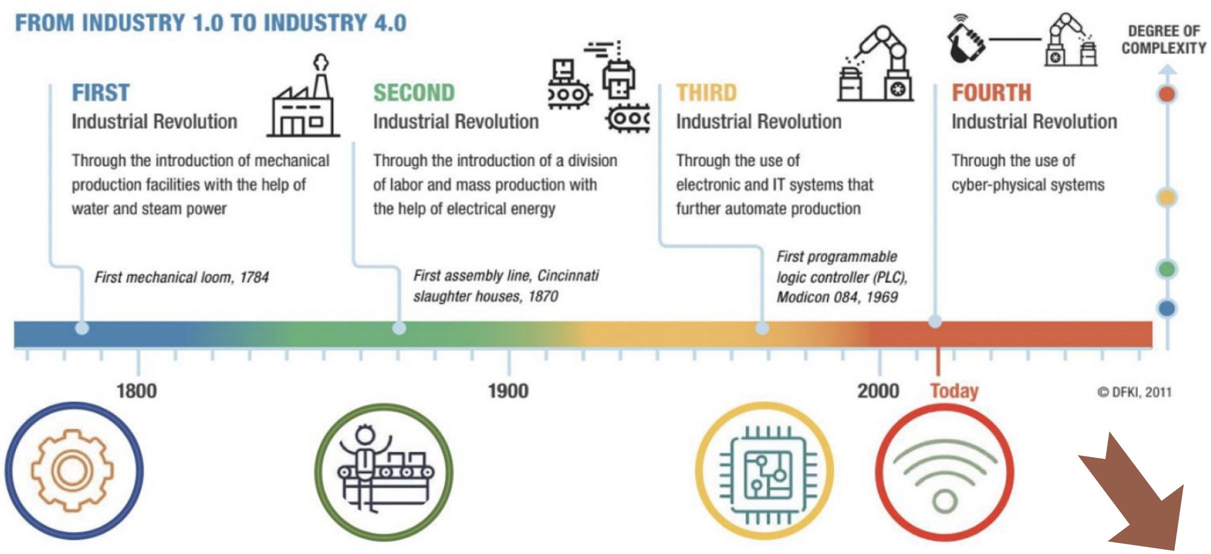
Ferrari SF-25
Formula 1 World Championship (Leclerc / Hamilton)

Motorola DynaTAC
April 1973

Apple iPhone 17
September 2025

Industry 4.0

- Re-shaping the way **machines, processes and systems operate**

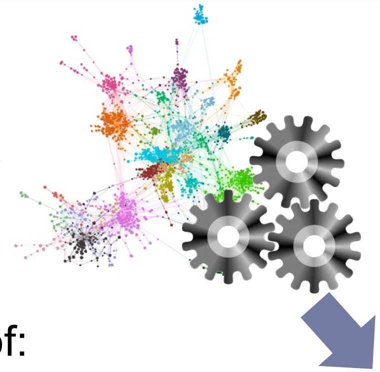


Source: https://www.momenta.one/industry5.0

intelligent, digital and connected automation!

Realizing Industry 4.0

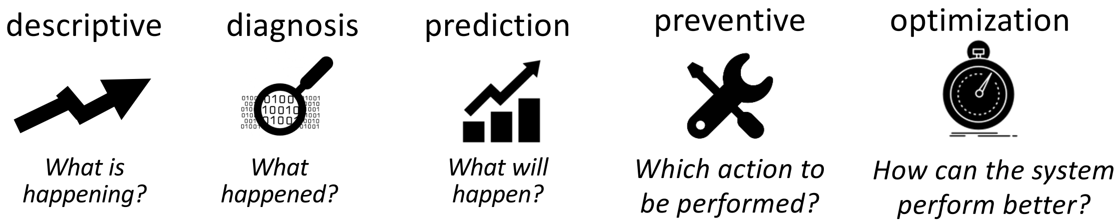
CPS as the **backbone platform** to realize Industry 4.0 applications complemented with **emergent digital technologies**

Internet of Things →  ← **Artificial Intelligence**

Collection and transmission of:

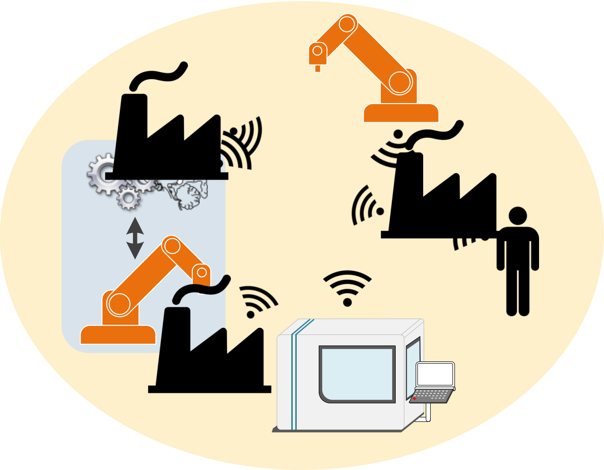
- (volume) huge amount of data
- (variety) heterogeneous data sources
- (velocity) real-time collected and managed

analyze and extract value and knowledge



Cyber-Physical Systems

- Intelligent, dynamic and adaptive systems, characterized by:
  - Tight combination of computational and physical elements
  - Distributed network manner
  - Interaction to reach a common goal
- Forming **Systems of Systems** (SoS)
- High decision capability at two levels:
  - autonomous with self-decision processes
  - collaborative with decision processes based in negotiation



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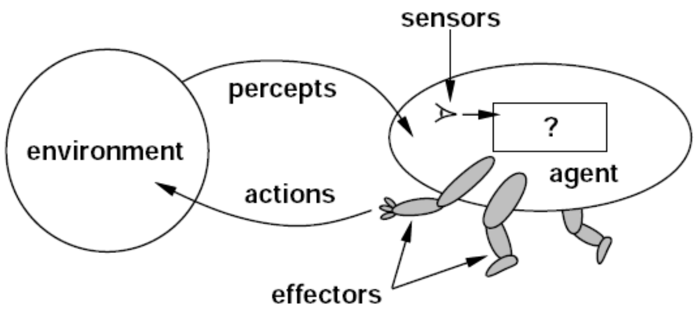
What is an agent?

- 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 knowledge of the environment."

[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 which: (1) is capable of acting in an environment, (2) can communicate directly with other agents, (3) 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."



Source: Russel and Norvig 1995

[Leitao, 2009]:
"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 does not possess enough knowledge and skills to reach alone its objectives."

Source: https://doi.org/10.1016/j.engappai.2008.09.005

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, …

Agent typologies: Reactive versus Deliberative

Deliberative ⟷ **Reactive**

reasoning — *reflexive*

speed of response →

← *predictive capabilities*

← *dependence on complete model*

Deliberative

- Goal-oriented behavior
- Requires full knowledge of the environment
- Frequent updating of the model
- Optimized solutions
- Slow reaction to change & uncertainty

Reactive

- Stimulus-response operation
- Incapable of foreseeing the future (no memory)
- Robust, fault-tolerant and fast response to unforeseen situations
- Non-optimized solutions

From an agent to a Multi-agent System

- Rare applications consider agents in an isolated manner
- Work with other agents to solve complex problems
- **Infrastructure** to distribute intelligence, implementing large-scale CPS

> ***Society of autonomous agents*** *representing the system objects,* ***capable of interacting*** *to achieve their individual goals when they have not enough knowledge and/or skills to achieve their objectives individually*

- System behavior emerges from the interaction among agents allowing to reach **self-organization on-the-fly**

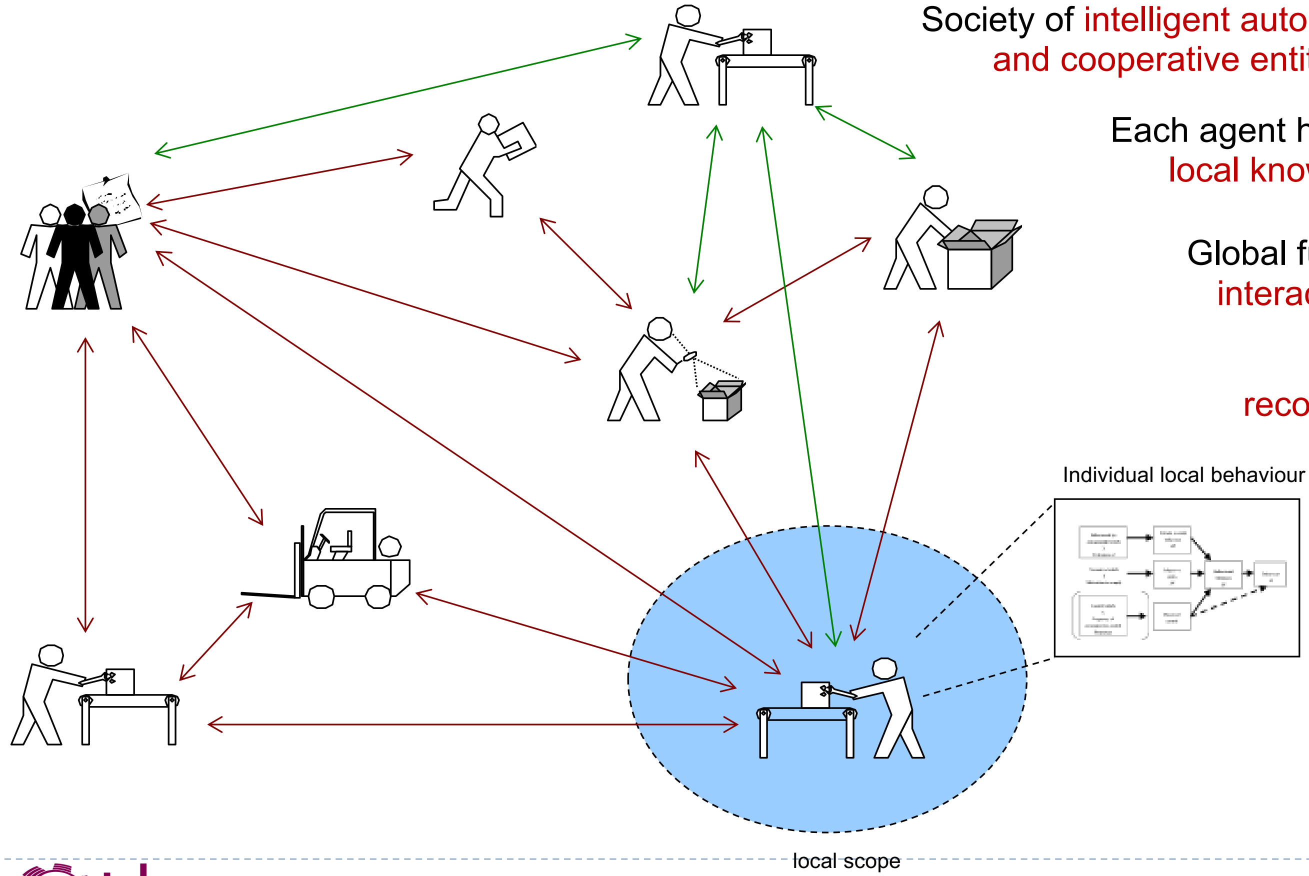
MAS working in practice

Society of intelligent autonomous and cooperative entities

Each agent has a set a skills and local knowledge (myopia)

Global function emerges from interaction among entities

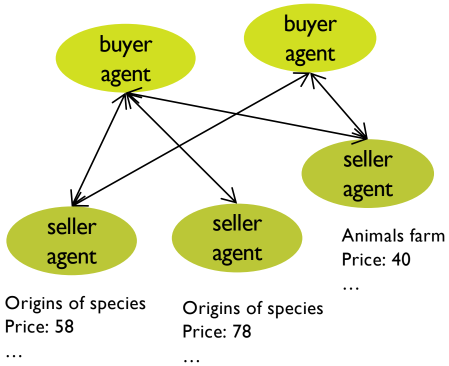
Modularity and reconfiguration is easy!



Other examples

Book seller-buyer problem

- Some entities are selling books and others are buying books
- Sellers sell at least one book and have a price for each one
- Buyers want to buy books spending the less money as possible



- Agents use the **CNP protocol** to support the negotiation between them

Collision avoidance problem

- Some entities (cars, ships, flights, etc.) are moving with the possibility of colliding each other

- Agents need to collaborate, negotiate and synchronise their actions to avoid collision

Emergence and self-organization

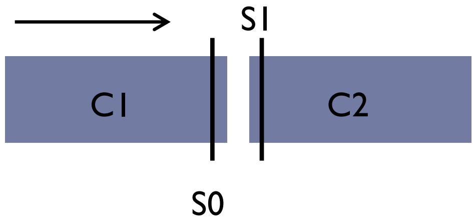
- Supports **collective intelligence** towards **emergence and self-organisation**
- **Complexity** comes from:
  - **Non-linear interactions** among components involving amplification and cooperation
  - Achieved behavior is **more complex** than the individuals from which they emerge
  - **Sensitivity to initial conditions** (butterfly effect)
- Some challenges:

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**?	How to adapt the **emergent behavior using learning**?

Example of MAS in practice

- System comprising a sequence of modular conveyors
- Individual conveyor comprises:
  - 1 motor
  - 2 light sensors

- **Objective:** 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

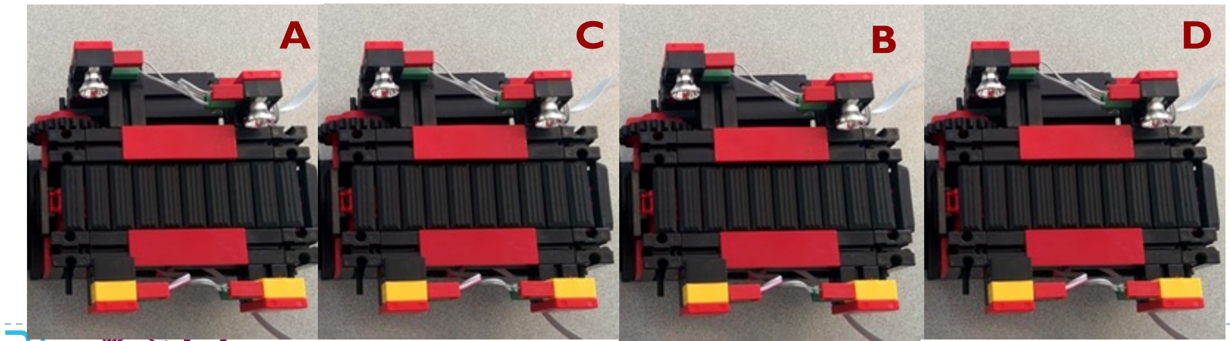
- Use a centralized logical control approach
- Programmed using IEC 61131-3 running in a PLC

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 happens if we need to …



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

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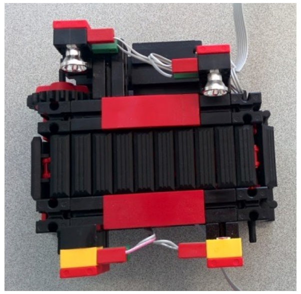
Using the MAS based CPS solution

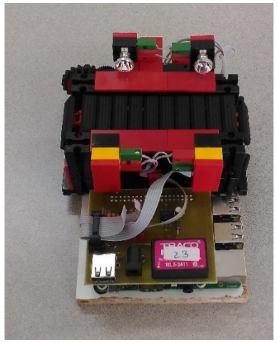
☞ Create cyber-physical components

agent

single-board
computer



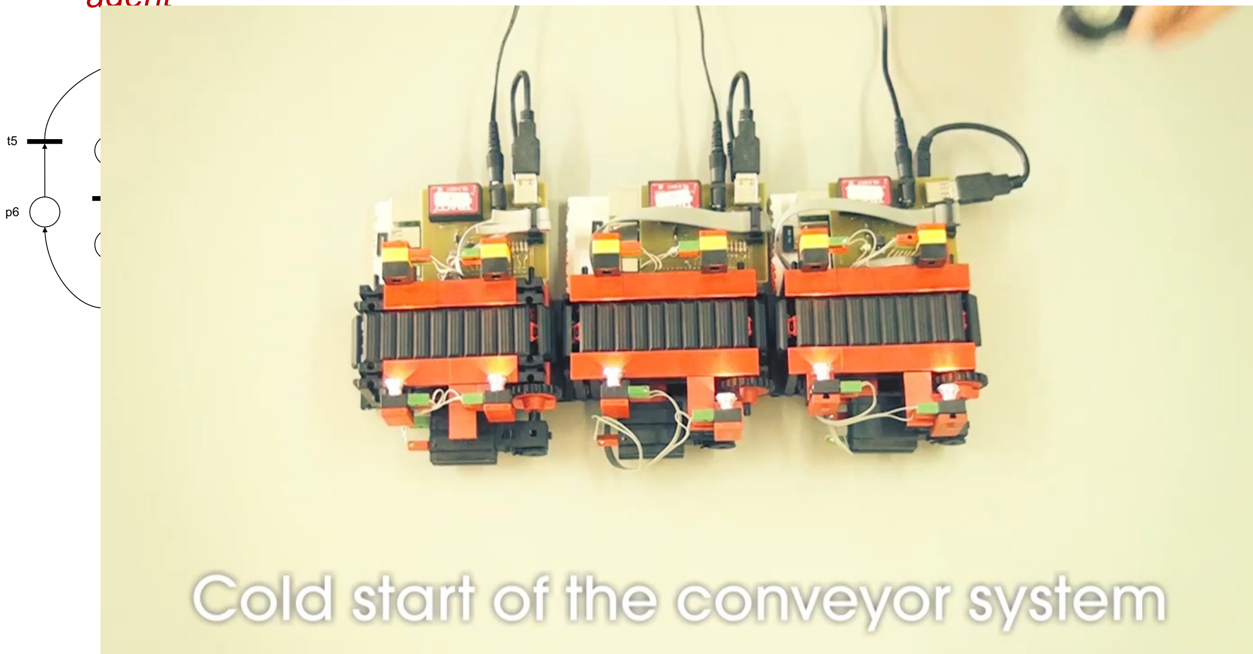
physical
platform



cyber-physical component

Intelligent MAS solution

agent



FIPA-ACL messages

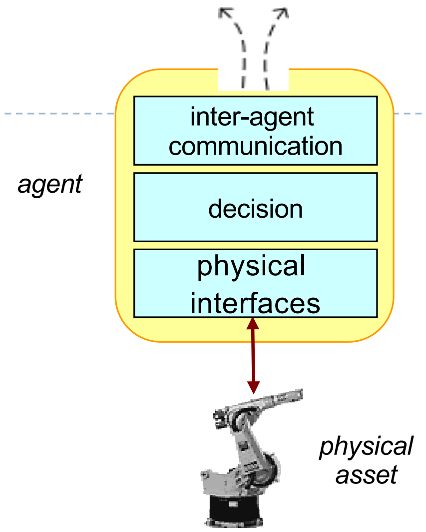
plugability and reconfigurability on-the-fly!

Important notes in this example

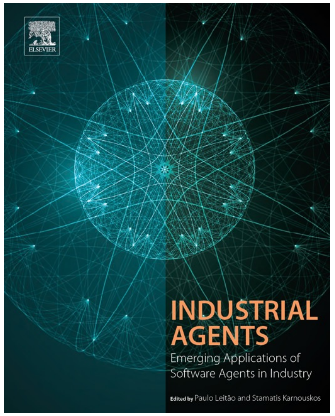
- MAS technology is used to implement an industrial CPS
- Agents are **deployed in single board computers**
  - Low cost
  - Located at edge computing
- MAS introduces **self-organization to the system**, and particularly on-the-fly reconfiguration
- **No intelligent algorithm is used**!
- System will perform even better if **intelligence is embedded in individual nodes**!

Industrial agents

- Inherit software agent principles, e.g., intelligence, autonomy and cooperation
- Facing industrial requirements:
  - hardware integration, reliability, fault-tolerance, scalability, industrial standard compliance, quality assurance, resilience, manageability, and maintainability

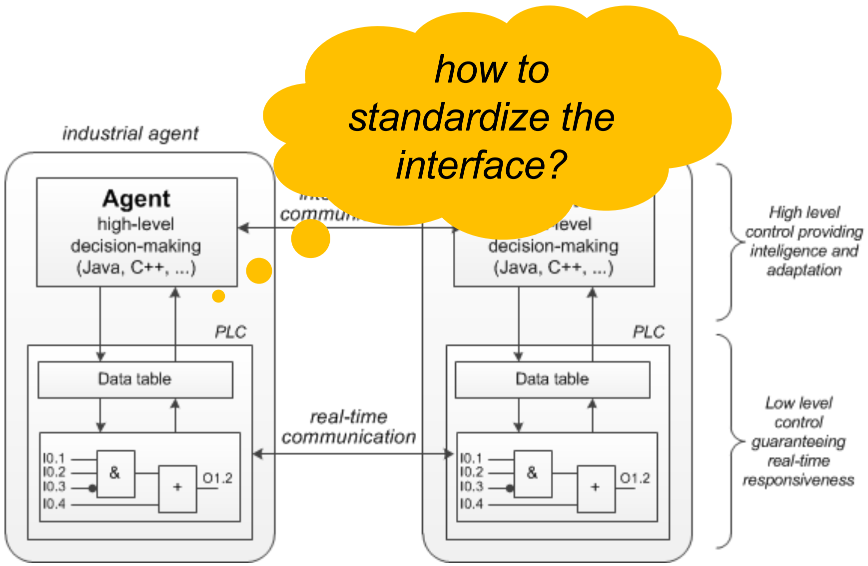


*"An **Industrial Agent** is an agile and robust software entity that intelligently represents and manages the functionalities and capabilities of an industrial unit. While it reveals the common features of an advanced agent, it also has some specifics. It understands and efficiently handles the interface and functionality of (low-level) industrial devices. Usually, it belongs to an agent-based industrial application system within which it acts and communicates in an efficient, intelligent, collaborative, and goal-oriented way. In principle, it is an autonomous and self-sustained unit. Nevertheless, it accepts and follows company guidelines, codes of conduct, general laws, and relevant directives from higher levels. Moreover, especially in emergency and real-time scenarios, its autonomy may be compromised in order to permit fast and efficient reactions."* Source: [Unland, 2015]



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

source: https://standards.ieee.org/ieee/2660.1/6264/

Source: http://dx.doi.org/10.1109/OJIES.2023.3262549

Why agent technology is a fascinating topic?

- Suitable to **build complex systems** with connected autonomous building blocks, each incorporating the capability to make decisions **without hierarchy**
- System behaviour emerges from interaction among agents, allowing to exhibit **emergence and self-organisation** features
- Capability to **distribute intelligence** among the edge-cloud continuum
- Provide **modularity**, **robustness**, **adaptability** and **reusability**

Agent technology is a potential **key enabler** of **smart, digital, and sustainable transformation**!

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MAS applications in industrial domain

Application of Agents in Smart Production

Name	ISA95 level	Scope	Year
BHP Billiton	L2	Process control [23]	1995
Yokogawa	L1	Machinery control [24]	1998
MASCADA (Daimler-Benz pilot)	L2	Manufacturing control [25]	1999
Daimler Chrysler	L2	Manufacturing control [26]	2001
LIAZ	L3	Production planning [27]	2002
Skoda	L3	Production planning [27]	2002
Cambridge packing cell	L2	Manufacturing control [28]	2003
Watchdog Agent	L1	Machinery monitoring [29]	2003
FABMAS	L2	Process control [30]	2003
PABADIS	L1–L4	Manufacturing control [31]	2004
ABAS	L2	Manufacturing simulation and control [32]	2005
Saarstahl	L3	Production process planning and monitoring [33]	2005
SOCRADES	L1–L4	SOA-ready devices, SOA-based cross-layer integration (device-to-ERP) [34–36]	2007
NovaFlex	L2	Manufacturing control [37]	2007
AGP	L2	Manufacturing execution system [38]	2008
ADACOR-FMS	L2	Manufacturing control, and reconfiguration [39]	2008
Axion-Holding	L3	Manufacturing scheduling [40]	2010
IMC-AESOP	L1–L4	SOA-ready devices, cloud-based SCADA/DCS, SOA & cloud -based services [12, 36, 41]	2010
Kuznetsov	L3	Manufacturing scheduling [42]	2013
GRACE (Whirlpool pilot)	L2	Self-adaptation [43]	2013
IDEAS	L2	Reconfiguration and plug-and-produce [44]	2013
ARUM (Airbus and IHF pilots)	L3	Production planning and scheduling [45]	2015
ADACOR2	L2	Manufacturing control and reconfiguration [46]	2015
PRIME	L2	Manufacturing plug-and-produce [47]	2015

Application of Agents in Smart Electric Grids

Name	Automation functions	Year
CRISP	Active Control, Distributed Control and Monitoring [50]	2005
GridAgents	Distributed Control and Monitoring, Demand Response [51]	2008
Fenix	Demand Response, Distributed Control and Monitoring, Active Control [52]	2008
IDAPS	Distributed Control and Monitoring, Demand Side Management [53]	2009
SmartHouse/ SmartGrid	Demand Side Management, Demand Response, Distributed Control and Monitoring, Active Control [19, 50, 54, 55]	2009
OPTIMATE	Distributed Control and Monitoring [56]	2010
More Microgrids	Demand Side Management, Distributed Control and Monitoring, Active Control [19, 54, 57]	2010
Integral	Distributed Control and Monitoring, Active Control [58]	2011
MASGrid	Distributed Control and Monitoring, Active control, Self-Optimization [59]	2011
BeyWatch	Demand Side Management, Demand Response, Distributed Control and Monitoring [60]	2011
EcoGrid	Demand Side Management, Self-optimization [61]	2012
UNLV pilot	Demand Side Management, Peak Load Management [62]	2012
GRID4EU	Demand Side Management, Peak Load Management [63]	2013
NOBEL	User-bidding in Energy Marketplace [64, 65]	2013
E2SG	Distributed Control and Monitoring, Network Reconfiguration [66, 67]	2014

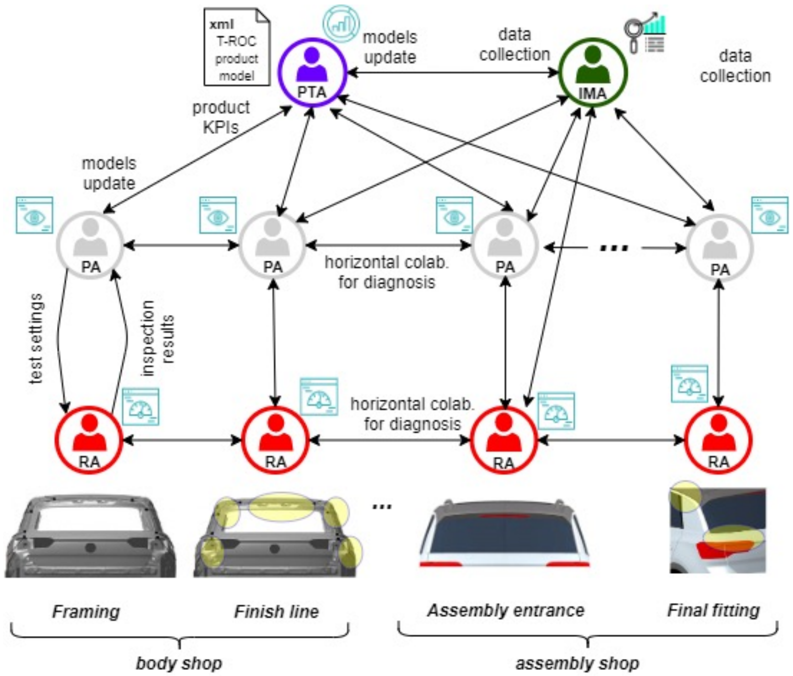
Application of Agents in Logistics

Name	Scope	Year
Southwest Airlines	Ground floor operations optimization [73]	2001
ABX Logistics	Real-time transport optimization [74]	2005
Tankers International	Real-time scheduling [75]	2006
GIST	Real-time routing and scheduling [75]	2007
Air Liquide America	Logistics optimization [76]	2008
Airport ground services operations	Planning and scheduling [77]	2008
Addison Lee	Real-time taxi scheduling [78]	2009
Avis	Rent a car optimization [79]	2009
Ciudad Real Central Airport	Airport ground handling management [80]	2012
Prologics	Real-time truck scheduling and routing [81]	2012
RusGlobal	Real-time truck scheduling and routing [81]	2012
Lego	Real-time scheduling [82]	2013
MASDIMA	Monitoring & real-time adaption in airline operations [83]	2014
Russian railways	Real-time train scheduling [84]	2015

Source: http://dx.doi.org/10.1109/jproc.2016.2521931 (Proceedings of the IEEE | Vol. 104,No. 5, 2016)

ZDM at multi-stage production

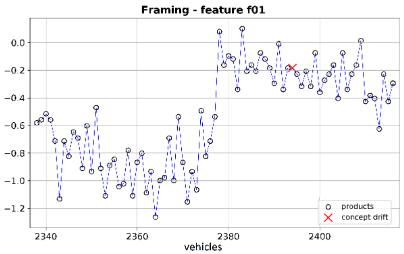
Volkswagen



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

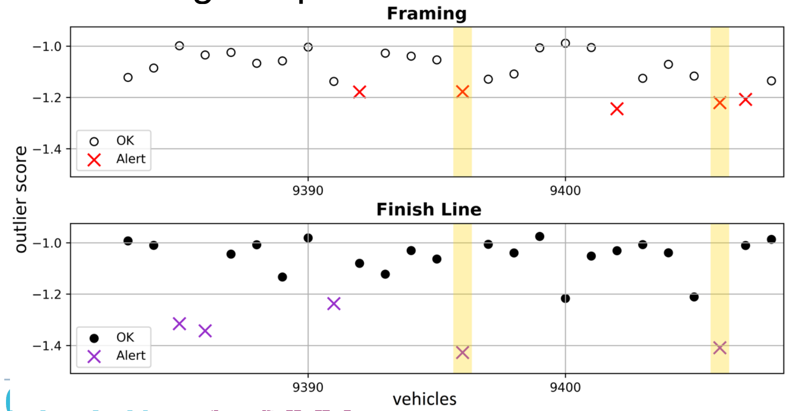
Examples of Data Analysis Deployed in Agents

RAs: Detection of changes in the process

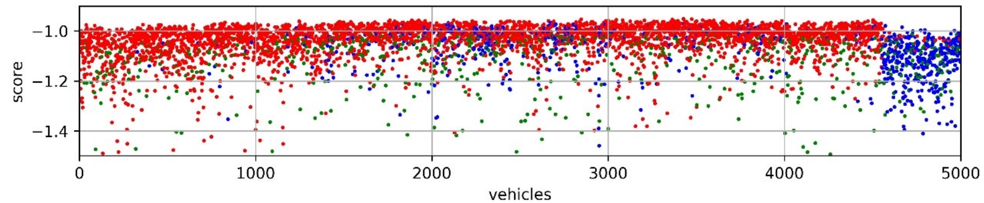


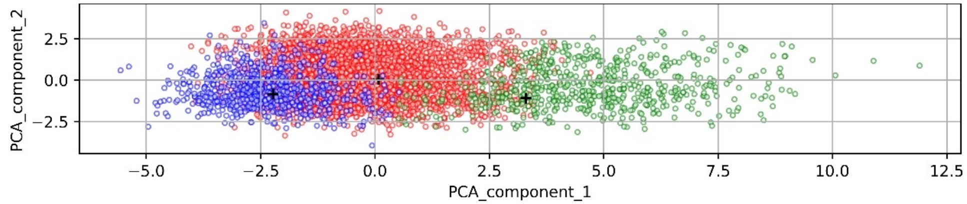
Concept Drift
Page-Hinkley algorithm

PAs: Detection of anomalies in multi-stage inspection stations



IMAs: keeping up-to-date the monitoring and control settings of the lower-level agents, e.g., identification of similar groups of cars





BIRCH (Balanced Iterative Reducing and Clustering using Hierarchies) algorithm

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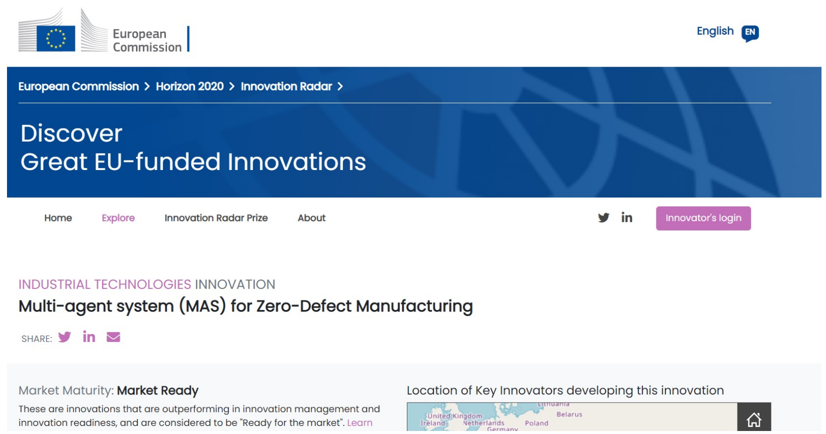
GOODMAN AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

Benefits

- Technological perspective: Effectiveness, robustness and scalability
  - In operation > 1 year, > 200 k agents
  - No breakdown or need for maintenance intervention
- Operational perspective
  - Reduction of cars needing to be aligned (± 10%)
  - Reduction of production costs, due to unnecessary alignment operations (± 15%)
  - Reduction of the inspection time (± 50%)

Source: J. Queiroz, P. Leitão, J. Barbosa, E. Oliveira, G. Garcia, "Agent-based Distributed Data Analysis in Industrial Cyber-Physical Systems", JESTIE, 2021; *http://dx.doi.org/10.1109/JESTIE.2021.3100775*

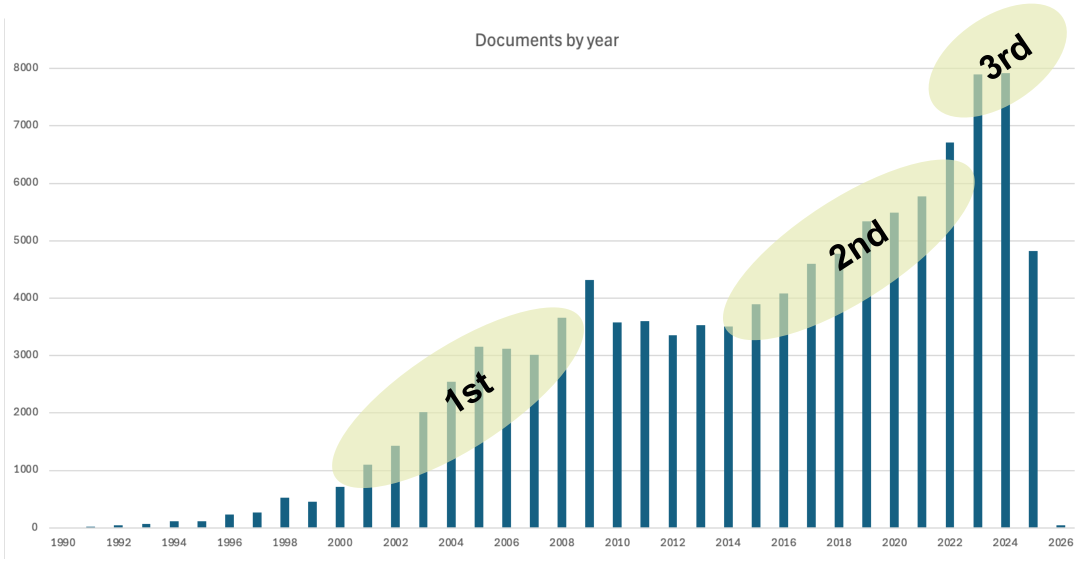


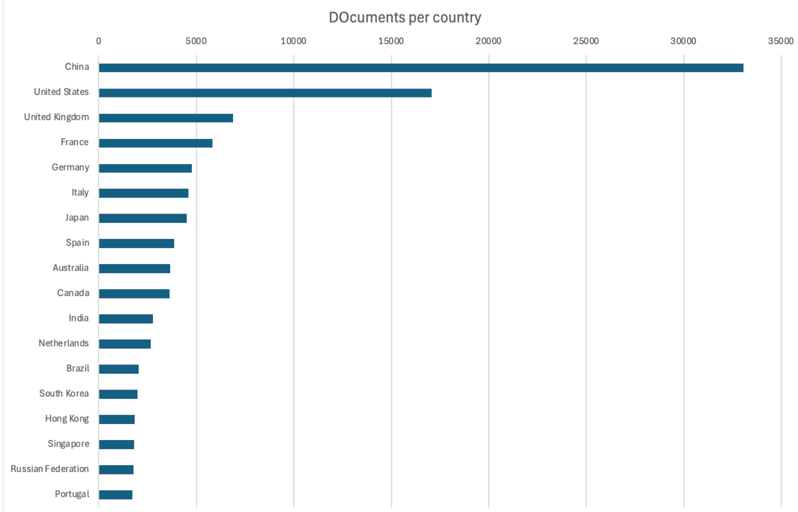
Source: https://www.innoradar.eu/innovation/34921

Weak adoption in industrial practice

- **In theory**, a promising approach!
- However, in practice, **several roadblocks arise**, e.g.,
  - Lack of understanding of applying **distributed thinking** to industrial problems
  - Lack of **standards** (FIPA is somehow abandoned)
  - Lack of **mature and industrial-oriented (open-source) agent development frameworks**
  - Biggest **learning curve** for deploying and maintaining when compared with other technologies
  - Lack of **interoperability** (i.e. the easy integration with physical assets and/or legacy systems)
  - **Improper application** of agent concepts and **overselling expectations** (e.g., is not the solution for all problems)
  - **Application in inadequate scenarios** (e.g., real-time control)
  - Lack of **conviction of stakeholders**

Analysis of MAS documents in literature





query in Scopus: *(TITLE-ABS-KEY(("multi-agent system" OR "multiagent system" OR "industrial agents")))*

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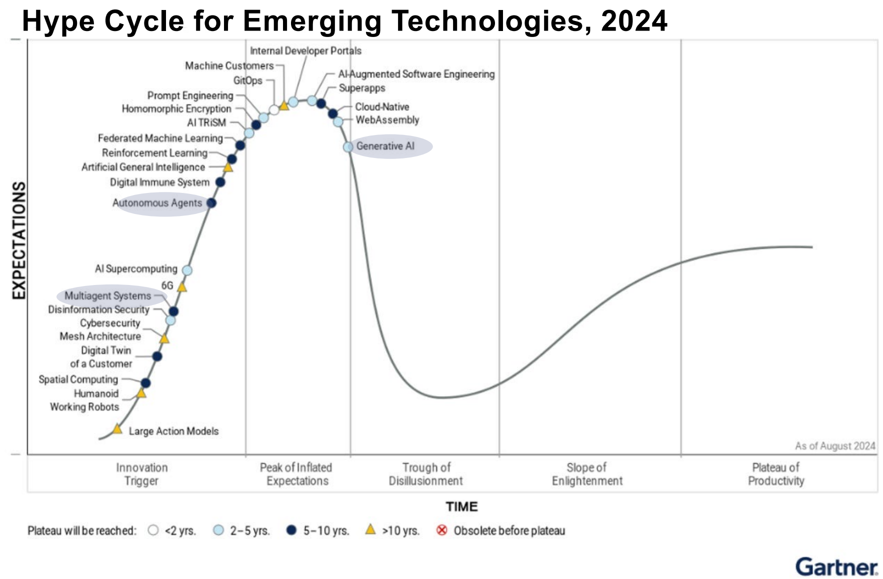
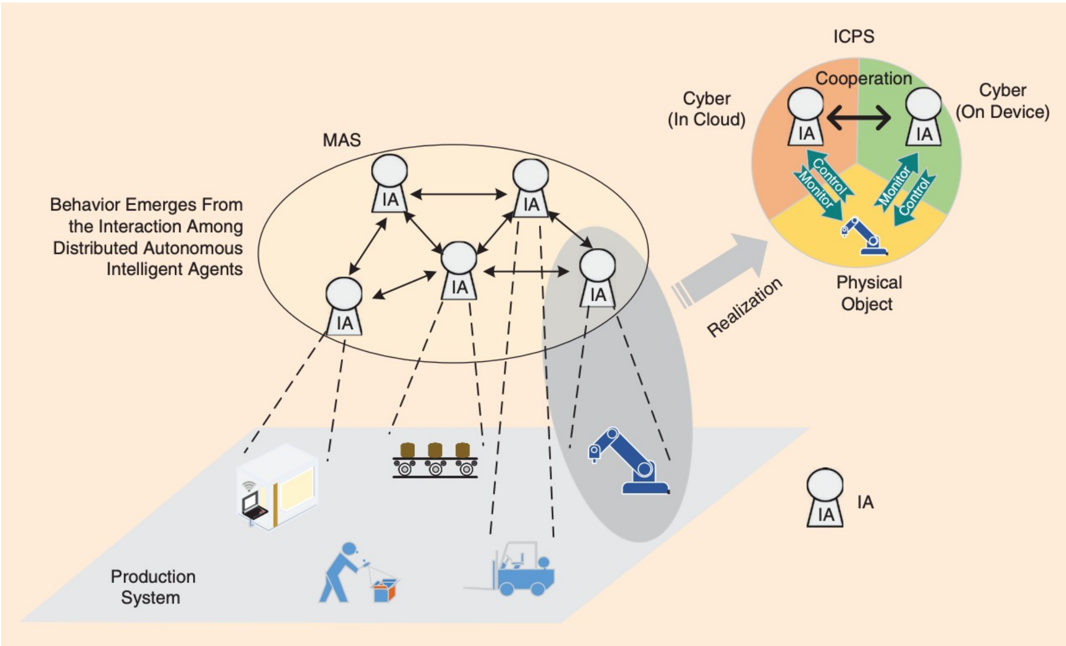
New boost for the (finally) mass adoption of agent-based systems?

- **Virtualisation**, **connectivity** and **AI** can boost the wider adoption of agent-based systems
- In the scope of:
  - **physical–digital integration**, e.g.,
    - Cyber-Physical Systems
    - Digital Twins
    - AAS Type 3
  - Combining with **Generative AI** (and **Agentic AI)**



Agents to implement Cyber-physical Systems

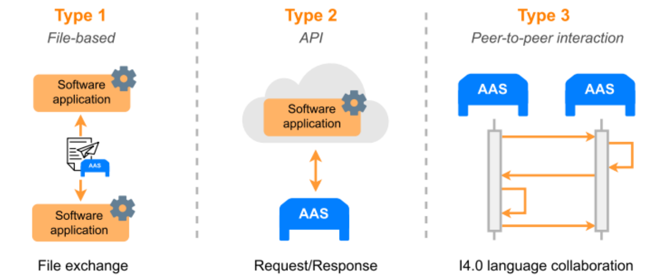


Source: http://dx.doi.org/10.1109/MIE.2019.2962225

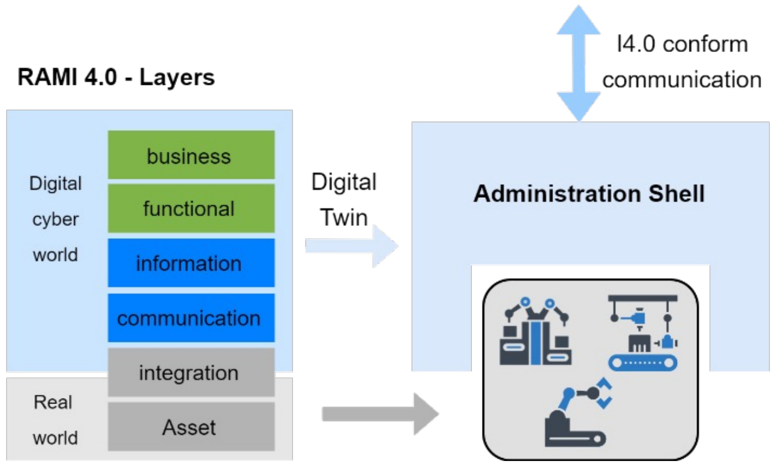
- Each agent can take control of different industrial resources
- Aligning its **cyber actuation boundaries with those of the physical system**
- Agents can run in cloud-edge continuum

Matching digitalization defined by RAMI4.0

- Industrial agents can implement **digital twins** and **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

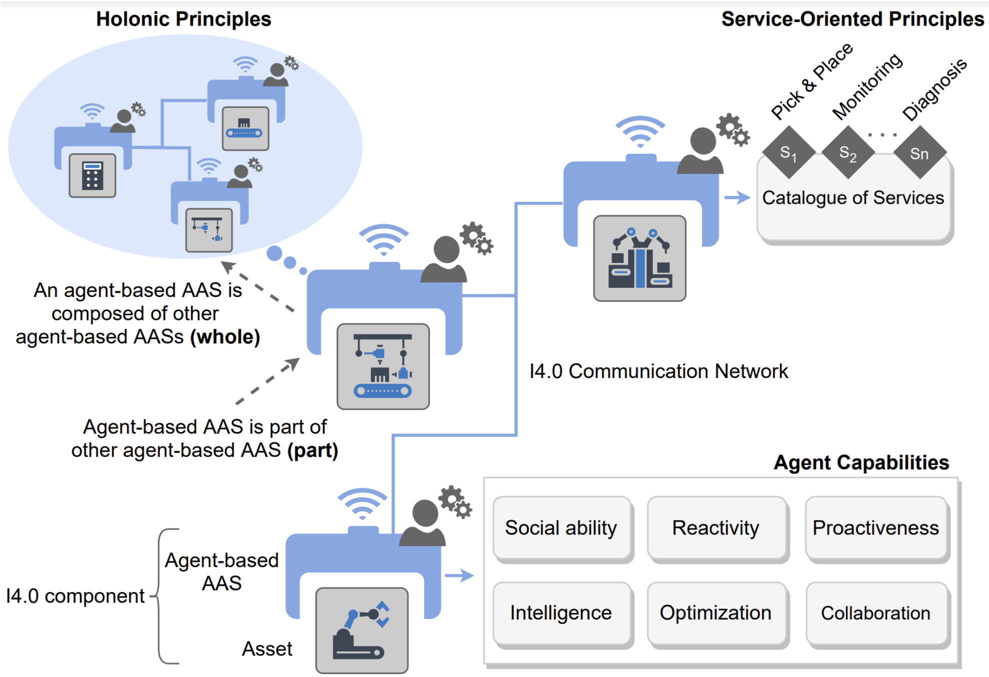


Source: http://dx.doi.org/10.1109/ACCESS.2025.3586716

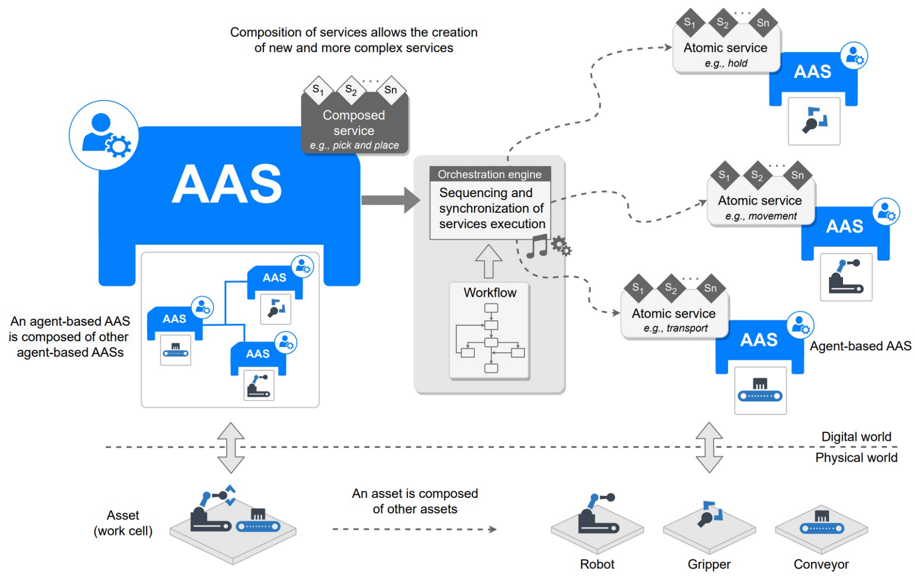


Source: V. Melo et al. 2023, https://doi.org/10.1007/978-3-031-24291-5_2

Holonic agent-based AAS Type 3



Source: L. Sakurada et al. (2022), https://doi.org/10.1016/j.ifacol.2022.04.192



Source: L. Sakurada et al. (2025), https://doi.org/10.3390/fi17070270

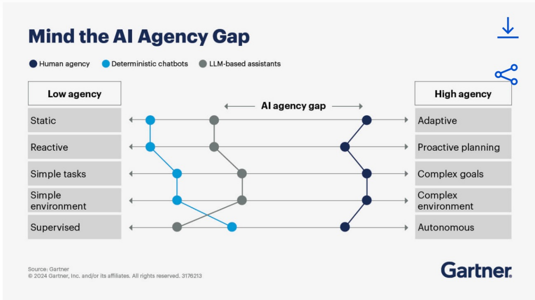
GenAI is a new boost for MAS

- Generative AI, and particularly LLMs, are **re-shaping everything**!

Intelligent Agents in AI Really Can Work Alone. Here's How.

AI systems are gaining agency to create plans and act autonomously, driving automation and workplace productivity.

By **Tom Coshow** | October 1, 2024



Intelligent agents in AI will make your AI more useful

Today's AI models perform tasks such as generating text, but these are "prompted" — the AI isn't acting by itself. That is about to change with agentic AI, or AI with agency. By 2028, 33% of enterprise software applications will include agentic AI, up from less than 1% in 2024, enabling 15% of day-to-day work decisions to be made autonomously.

Intelligent agents in AI are goal-driven software entities that use AI techniques to complete tasks and achieve goals. They don't require explicit inputs and don't produce predetermined outputs. Instead, they can receive instructions, create a plan and use tooling to complete tasks, and produce dynamic outputs. Examples include AI agents, **machine customers** and multiagent systems.

Current AI agency is low, but expect it to grow

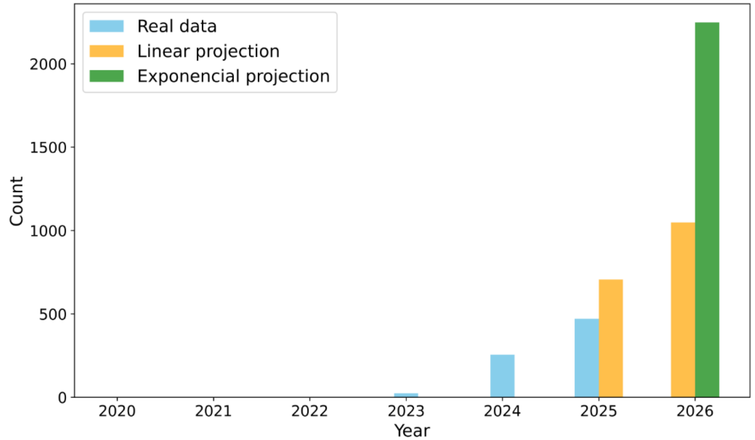
AI agency is a spectrum. At one end are traditional systems with limited ability to perform specific tasks under defined conditions. At the other end are future agentic AI systems with full ability to learn from their environment, make decisions and perform tasks independently. A big gap exists between current LLM-based assistants and full-fledged **AI agents**, but this gap will close as we learn how to build, govern and trust agentic AI solutions.

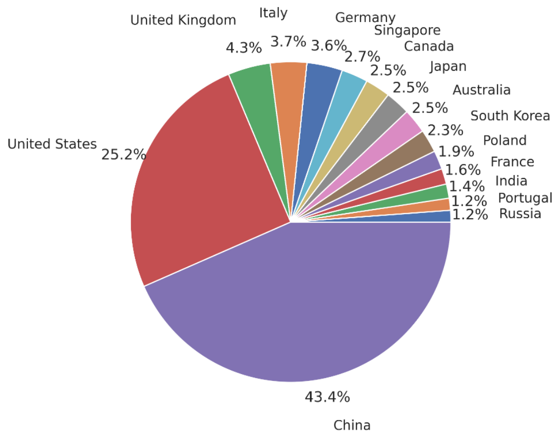
AI agents can help drive business model innovation

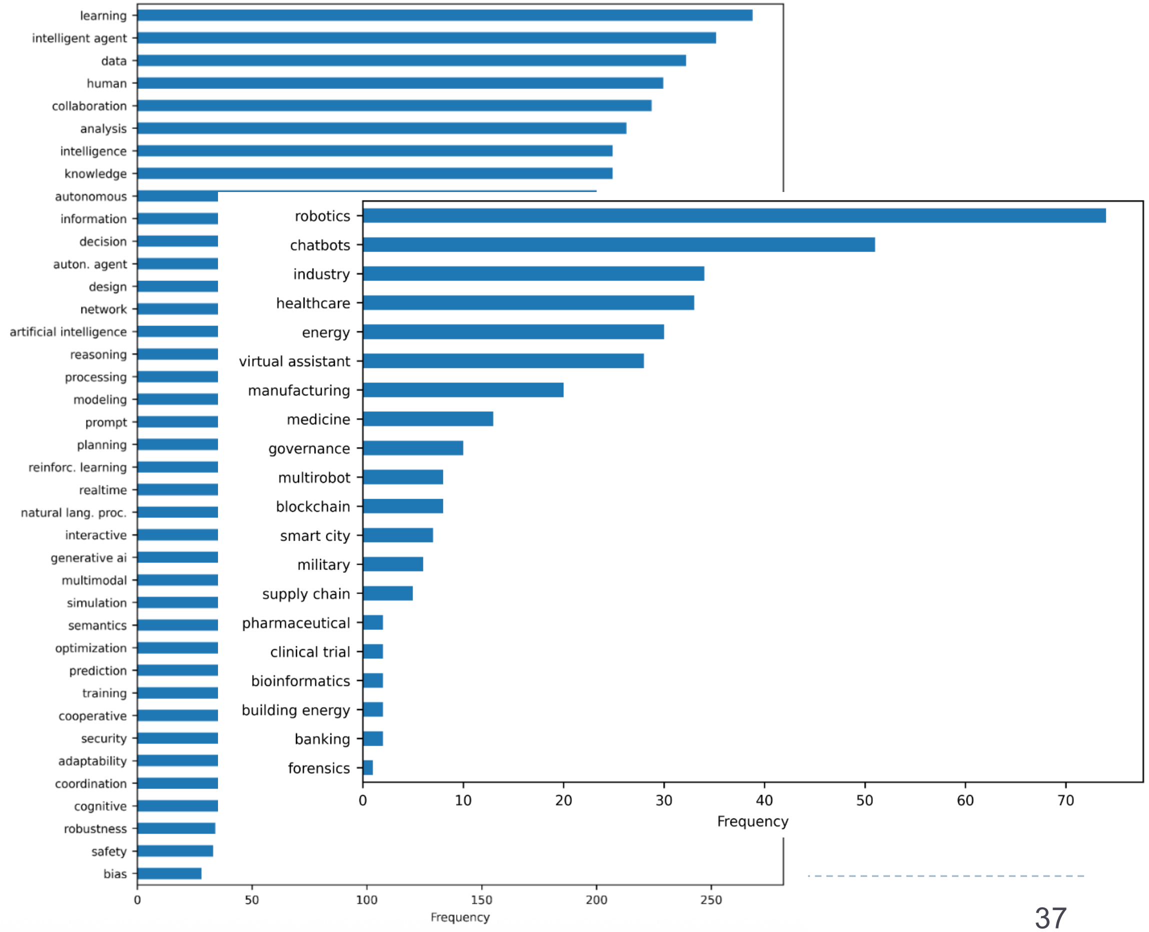
Though **generative AI** (GenAI) has captured headlines with its meteoric rise to popularity, **AI agents** are quickly becoming the "next big thing." By 2028, Gartner predicts that 33% of enterprise software applications will include agentic AI, up from less than 1% in 2024, with at least 15% of day-to-day work decisions being made autonomously through AI agents.

But AI agents are also being piloted more strategically to innovate business models, in particular to autonomously address pain points in customer journeys and capitalize on emerging opportunities.

SLR for MAS with Generative AI







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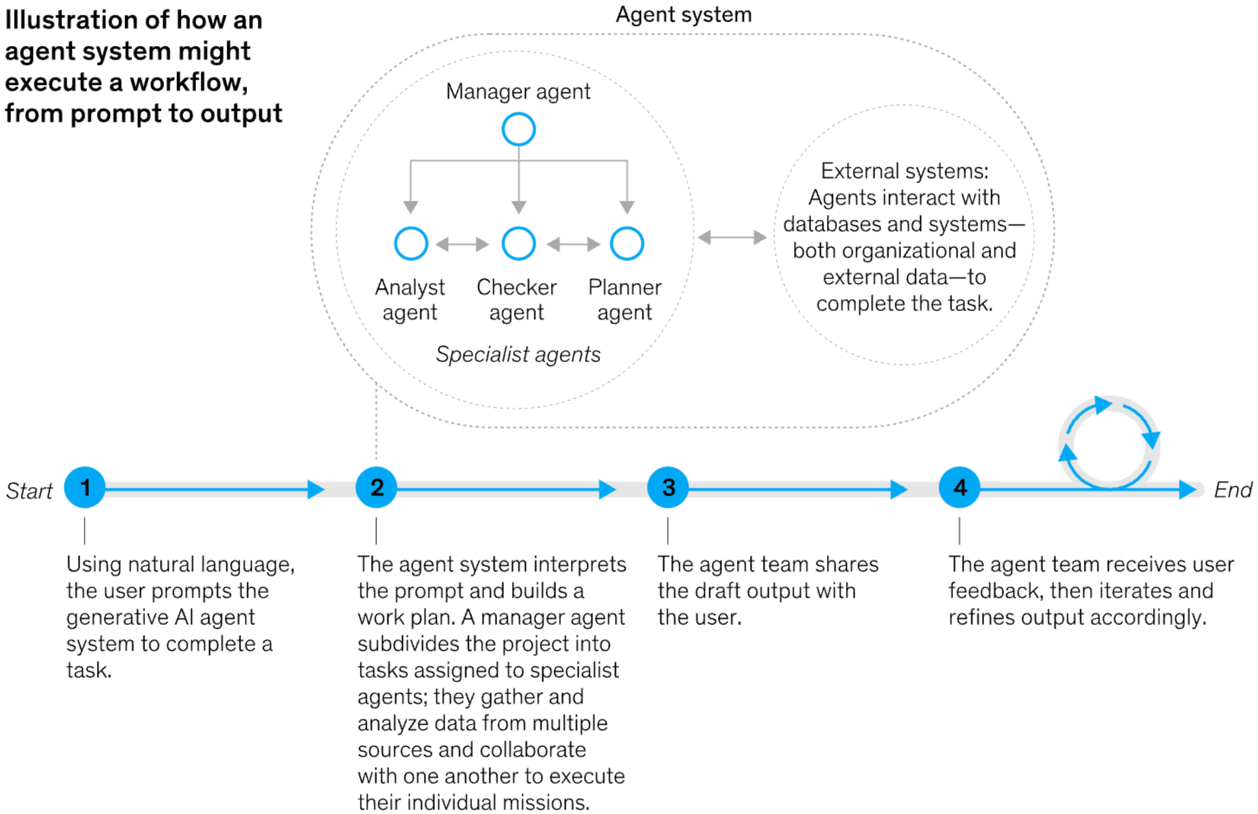
Example of agents enabled by generative AI

Illustration of how an agent system might execute a workflow, from prompt to output



McKinsey & Company

Agentic AI is reshaping the agents technology

- Also known as **autonomous AI agents**
- Remember (*source: https://www.ibm.com/think/topics/agent-communication-protocol*):
  - *"An **AI agent** is a system or program that is capable of autonomously performing tasks on behalf of a user or another system."*
  - *"**Multi-agent systems consist of multiple AI agents** working collectively to perform tasks on behalf of a user or another system."*

IBM

Top Strategic Technology Trends for 2025: Agentic AI

Gartner recently published the *Top Strategic Technology Trends for 2025 report*, reporting how, autonomous AI agents (i.e. agentic AI) "will dramatically upskill workers and teams, enabling them to manage complicated processes, projects and initiatives through natural language."

Furthermore, Gartner states, "Until now, AI models such as large language models (LLMs) have performed tasks including generating text and summarizing documents, but they haven't been able to take action by themselves on their own 'initiative.' Instead, they've acted on your prompts. Agentic AI is changing that."

- **What is Agentic AI**?
  - AI agent is an agent enhanced with LLMs, typically designed to perform a specific task without human intervention
  - Agentic AI leverages multiple AI agents working collaboratively to handle complex workflows
  - Operates as a MAS that coordinates, orchestrates, and optimizes individual agents

Agentic AI vs traditional AI

- Traditional AI operate within **predefined constraints and require human intervention**, but **Agentic AI exhibits autonomy, goal-driven behaviour and adaptability**

Feature	Agentic AI	Generative AI	Traditional AI
Primary Function	Goal-oriented action & decision-making	Content generation (text, code, images, etc.)	Focused on automating repetitive tasks
Autonomy	High – Operates with minimal human oversight	Variable – May require user prompts or guidance	Low – Relies on specific algorithms and set rules
Learning	Reinforced Learning – Improves through experience	Data-driven learning – Learns from existing data	Relies on predefined rules and human intervention

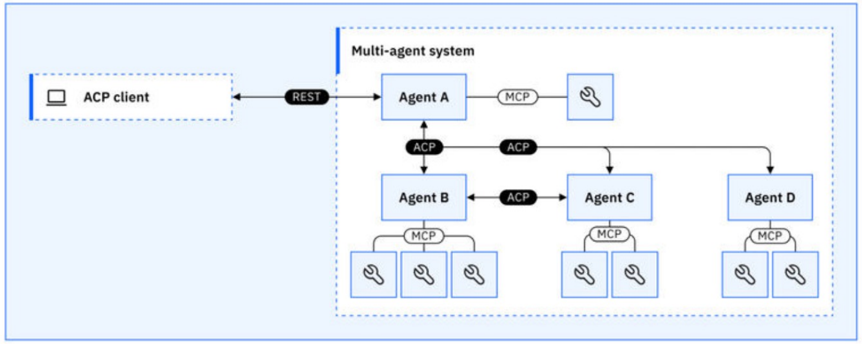
source: https://aisera.com/blog/agentic-ai/

- "***agentic***" refers to their capability to act independently and goal-oriented

Agent-to-agent communication protocols

Agent Communication Protocol (ACP)

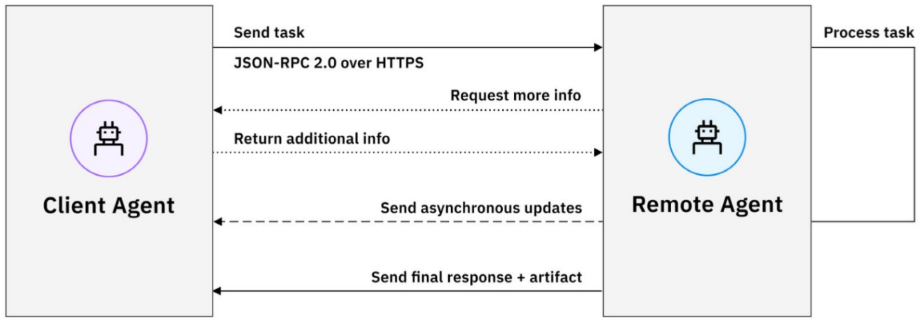
- Open standard, introduced by IBM's BeeAI
- Key features:
  - **REST**-based communication
  - **No SDK required** (or any specialised libraries)
  - **Offline discovery**
  - **Async-first** (as default), sync supported



source: https://www.ibm.com/think/topics/agent-communication-protocol

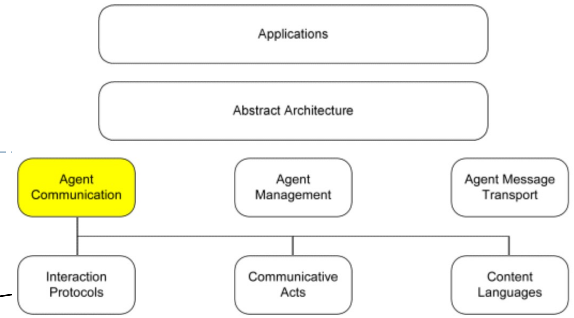
Agent2Agent (A2A) protocol

- Open standard, introduced by Google on April 25
- Key features:
  - **Client-server** architecture
  - **JSON-RPC 2.0** over HTTP(S) (for transport and format)
  - **Discovery mechanisms** (**Agent Cards**)
  - **Task management workflows**
  - Support for **various data modalities**
  - **Async first**

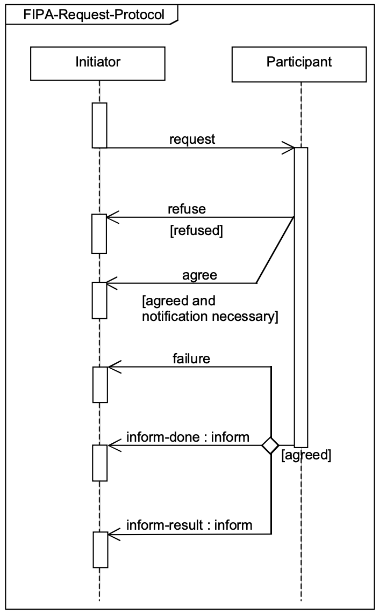


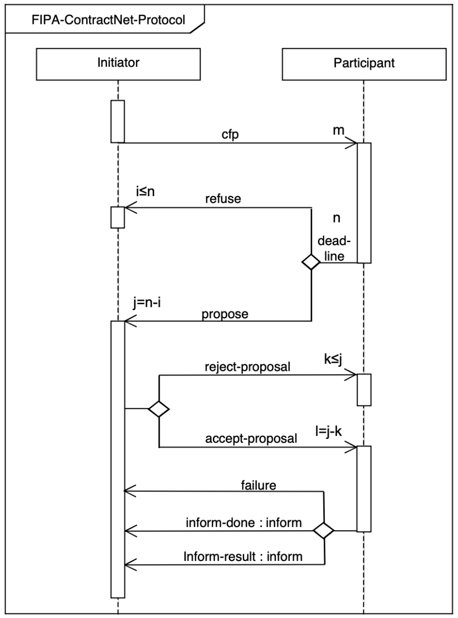
source: https://www.ibm.com/think/topics/agent2agent-protocol

Get inspiration from FIPA?



examples of interaction protocols





example of communication act

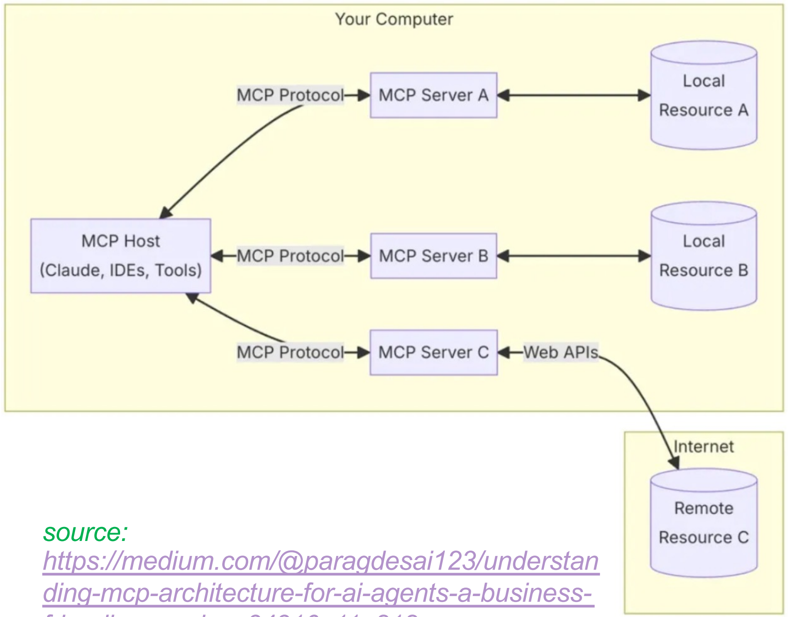
Summary	The sender informs the receiver that a given proposition is true.
Message Content	A proposition.
Description	`inform` indicates that the sending agent: · holds that some proposition is true, · intends that the receiving agent also comes to believe that the proposition is true, and, · does not already believe that the receiver has any knowledge of the truth of the proposition. The first two properties defined above are straightforward: the sending agent is sincere, and has (somehow) generated the intention that the receiver should know the proposition (perhaps it has been asked). The last property is concerned with the semantic soundness of the act. If an agent knows already that some state of the world holds (that the receiver knows proposition *p*), it cannot rationally adopt an intention to bring about that state of the world, that is, that the receiver comes to know *p* as a result of the `inform` act. Note that the property is not as strong as it perhaps appears. The sender *is not* required to establish whether the receiver knows *p*. It is only the case that, in the case that the sender already happens to know about the state of the receiver's beliefs; it should not adopt an intention to tell the receiver something it already knows. From the receiver's viewpoint, receiving an `inform` message entitles it to believe that: · the sender believes the proposition that is the content of the message, and, · the sender wishes the receiver to believe that proposition also. Whether or not the receiver does, indeed, adopt belief in the proposition will be a function of the receiver's trust in the sincerity and reliability of the sender.
Formal Model	<*i*, inform (*j*, f)> FP: B$_i$f Ù Ø B$_i$(Bif$_j$f Ú Uif$_j$f) RE: B$_j$f

Examples	Agent *i* informs agent *j* that (it is true that) it is raining today.
	
	`(inform`
	`:sender (agent-identifier :name i)`
	`:receiver (set (agent-identifier :name j))`
	`:content`
	`"weather (today, raining)"`
	`:language Prolog)`

Source: http://www.fipa.org/repository/aclspecs.html

Model Context Protocol (MCP)

- Open standard for connecting AI agents to external services, e.g., data sources and tools
- Client-Server architecture
- Key architectural components:
  - **MCP Hosts**: AI application, e.g., LLM (like Claude Desktop or IDEs), that initiate connections through clients
  - **MCP Clients**: multiple clients can exist with a singular MCP host, but each client has a 1:1 relationship with an MCP server
  - **MCP Servers**: external service that provides the context, tools, and prompts to clients



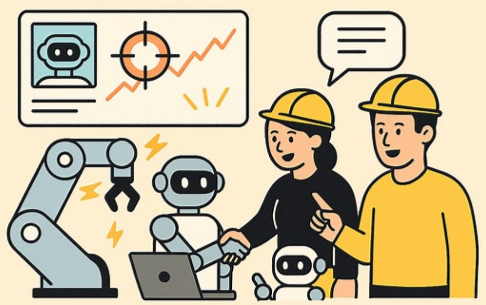
source: https://medium.com/@paragdesai123/understanding-mcp-architecture-for-ai-agents-a-business-friendly-overview-34316a11e818

Examples of industrial applications

Explainable predictive maintenance

Current: prediction of future failures or defects based on real-time analysis of collected data.

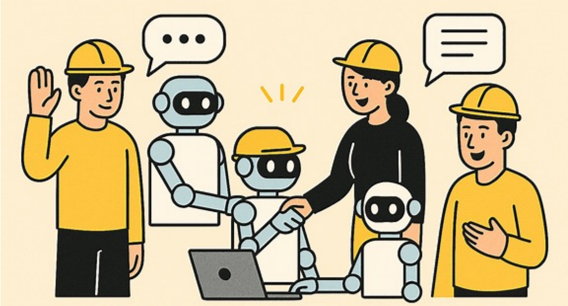
New features: capability to explain the elaborated predictions to users and to get feedback that are used for better predictions in the future.



Collaborative robots

Current: Cobots typically focus on the physical collaboration between robots and humans (shared space).

New features: a transformative role in enabling robots to communicate, reason, and collaborate more effectively with humans (extends physical collaboration to the cognitive level).



Logistics / supply chain

Current: complex processes are managed centrally with powerful algorithms or distributed with simpler algorithms.

New features: capability to enhance powerful AI algorithms to specialised agents, allowing to combine optimisation with fast response to uncertainty, and to interpret incomplete human instructions.

Take away messages

- **MAS** is suitable for implementing distributed intelligence in CPS, enabling the **smart, digital and sustainable transformation**
  - **Hide complexity, reveal functionality**
  - **Think globally, act locally**
- **Emergence of AI**, and particularly GenAI, can boost the (finally) **mass adoption of agent-based systems**
- In the scope of **physical–digital integration** (Digital Twins and AAS Type 3) and combining with **GenAI / Agentic AI**

e-mail: pleitao@ipb.pt

URL: http://www.ipb.pt/~pleitao

http:// cedri.ipb.pt @cedri.ipb.pt @cedri_pt

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