industrial internet CONSORTIUM


# Industrial Artificial Intelligence

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## AUTOMATION ORIGINS

The dream of mechanical automation goes back to the beginnings of human history[1]. Water flow and hydraulics were used to control movement as far back as 1500 BCE, and steam was leveraged as an automation force in 300 BCE. Leonardo Da Vinci designed and implemented his Robot Knight in 1495 using pulley and cables. In the 17$^{th}$ century, automation was used to play musical instruments and animate what appeared to be living things. Mechanical computation to support automation was introduced with the Analytical Engine in 1842, and these techniques have evolved into our modern digital computers.

Artificial Intelligence (AI) is our attempt to replicate human cognitive function. Just like we strived to duplicate the function and value from animal and human labor, the vision of machines and programs with greater autonomy has driven research and experimentation. Stanford University has records[2] on AI dating back to the 1960s. Back then a new programming language called LISP (LISt Processor)[3] supported representing structured programs and their data in the same list format. Could a computer program modify and extend itself? Certainly, at a minimum we can accomplish this today with discovery and tuning of configuration parameters, and runtime code patching is used in adaptive programming.

## ACADEMIC ORIGINS

AI for industrial applications bridged from academic research. Edward Feigenbaum from Stanford collaborated with the University of Michigan, University of Pittsburgh and Rockefeller University on DENDRAL[4], an expert system for scientific hypothesis formulation. This provided the basis for MYCIN[5] where the techniques were applied in medicine. Expert systems were an attractive approach because the pruned search of the solution space could be explained.

Neural networks, on the other hand, stemmed from neurological science and attempted to replicate how our brains worked. At Cornell University, Frank

[1] Spaeth, D., "From Single-Task Machines to Backflipping Robots: The Evolution of Robots", Cutting Tool Engineering (January 2018). https://www.ctemag.com/news/articles/evolution-of-robots

[2] The History of Artificial Intelligence, Stanford Libraries. https://exhibits.stanford.edu/ai

[3] Berkeley, E.C., "The Programming Language LISP: An Introduction and Appraisal", Computers and Automation (September 1964). https://archive.org/details/bitsavers_computersA_6908895/page/n15

[4] Lindsay, R.K., Buchanan, B.G., Feigenbaum, E.A., Lederberg, J., "DENDRAL: a case study of the first expert system for scientific hypothesis formulation", Artificial Intelligence vol. 61, Elsevier (1993).

[5] Buchanan, B.G., Shortliffe, E.D. "Rule-based expert systems: the MYCIN experiments of the Stanford Heuristic Programming Project" (1984).

Rosenblatt's Perceptron[6] had three layers with the middle set of neurons called the association layer. In 1969 Marvin Minsky and Seymour Papert from MIT wrote a book[7] stating that a multi-layered approach to neural networks would not be successful, which effectively eliminated funding for that kind of AI. Tell that to the folks creating amazing results with Convolution Neural Network (CNN) image recognition. It took twenty years for the innovation to get started again.

## EARLY INDUSTRIAL AI

Applications of AI in industry extended the ideas for pruned searches of the solution space, especially with the focus on product design, production planning and logistics. Mark Fox from Carnegie Mellon University summarized[8] the advances within two AI categories: Knowledge Representation and Search. He framed the driving forces as shown in Table 1.

| Force | Description |
| --- | --- |
| Expertise | Scarcity is endemic to many corporations |
| Decision complexity | Large number of alternatives from which to choose, exacerbated by flexible manufacturing systems |
| Decision support | Information is becoming more complex, reduce to only what is necessary for an individual to decide |
| Decision timelines | Deadline to plan and decide is decreasing |
| Coordination | How can designs help optimize the down-stream activities? |

*Table 1: Issues in Manufacturing*

These motivations drove specific applications of AI, especially expert systems, in the 1970s and 80s. Table 2 [8] below summarizes those early applications.

## INDUSTRIAL AI TODAY

The ground-breaking innovations in the last century are having a dramatic impact on many aspects of our lives. In addition, there is benefit from revisiting those solutions

[6] Rosenblatt, F., "The Perceptron: A Probabilistic Model for Information Storage and Organization in the Brain", Cornell Aeronautical Laboratory, Psychological Review, v65 (1958).

[7] Minsky, M., Papert, S., "Perceptrons: an introduction to computational geometry", The MIT Press, Second Edition (1972).

[8] Fox, M.S., "Industrial Applications of Artificial Intelligence", Robotics, Vol. 2, Issue 4, Elsevier (December 1986).

because the stakeholder concerns, expected value and associated requirements have not changed in all these decades. We have evolved significant increases in computing, storage and communication capacity that make the earlier applications seem like toys today.

| **Category** | **Summary** | **Examples** |
|---|---|---|
| Configuration | Combine components to form a final product | R1 / Xcon - knowledge-based configuration of VAX-11 computer systems<br>XSEL - artificial Intelligence applied to the acquisition and analysis of specifications<br>VT - elevator configuration |
| Extrapolation | Alter an existing product to meet the customer's specifications | ALADIN - engineering design altered to meet the customer's specifications |
| Discovery | Combine components to produce interesting functional systems | EURISCO - design of VLSI circuitry<br>TALIB - electronic circuitry design |
| Validation | Confirm design behaves as defined by the functional specification | CONSTRAINTS - infers functionality from the form of an electronic circuitry<br>CORA - thermal and hydraulic transient analysis of reactor core assemblies |
| Project Management | Manage product definition and activities performed to design products | CALLISTO - project scheduling, control and configuration problems |
| Production Planning | Forecast customer demand, plan the process, lay out the facilities, specifies maintenance and trains the workers. | ROME - analysis of resource plans<br>GREASE - select cutting fluids for machining operations<br>FADES - methodology for factory design |
| Production | Plan, schedule, manage the shop floor, control cells, inspect product and maintain of processes | ISIS - factory scheduling<br>IMACS / PTRANS - flow shop scheduling<br>IDT - detect faults in PDP 11/03 computers<br>IPWBIS - inspect inner layers of printed wire boards |
| Distribution and Field Service | Manage final phases of the manufacturing product life cycle | INET - simulation to model organization structures and analyze automatically the results |
| Diagnosis and Repair | Perform diagnosis of industrial assets using sensor input | GENAID - diagnosis of steam turbines and generators<br>ACE - diagnosis of cable problems for telephone wiring<br>DELTA - diagnosis of diesel locomotives<br>DART - diagnoses computers based upon their structure |

*Table 2: Early Industrial AI Applications*

The Industrial Analytics Task Group in the Industrial Internet Consortium (IIC) was renamed in 2018 to the Industrial Artificial Intelligence (IAI) Task Group to reflect member interests and to provide best practices for applying machine learning and AI technology to industrial settings. At the time of this article, the IAI Task Group is in the process of collaboratively authoring an AI white paper with the plan to publish the white paper by IoT Solutions World Congress in October. If you are interested in working on the white paper, please contact the IAI Task Group co-chairs. An earlier accomplishment of this Task Group is the Industrial IoT Analytics Framework published in October 2017, with a chapter dedicated to AI and Big Data. The IAI Task Group consists of experts from around the world and meets bi-weekly via conference calls to share perspectives and move their collaborative activities forward. At the IIC quarterly meetings, the IAI Task Group hosts sessions that often include executive panels exploring the challenges and future of AI.

We invite you to explore the rest of this Journal of Innovation issue dedicated to Artificial Intelligence and encourage you to engage with others on these topics and continue the advancement of industrial IoT, analytics and artificial intelligence.

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