Supply Chain 4.0 -Introduction

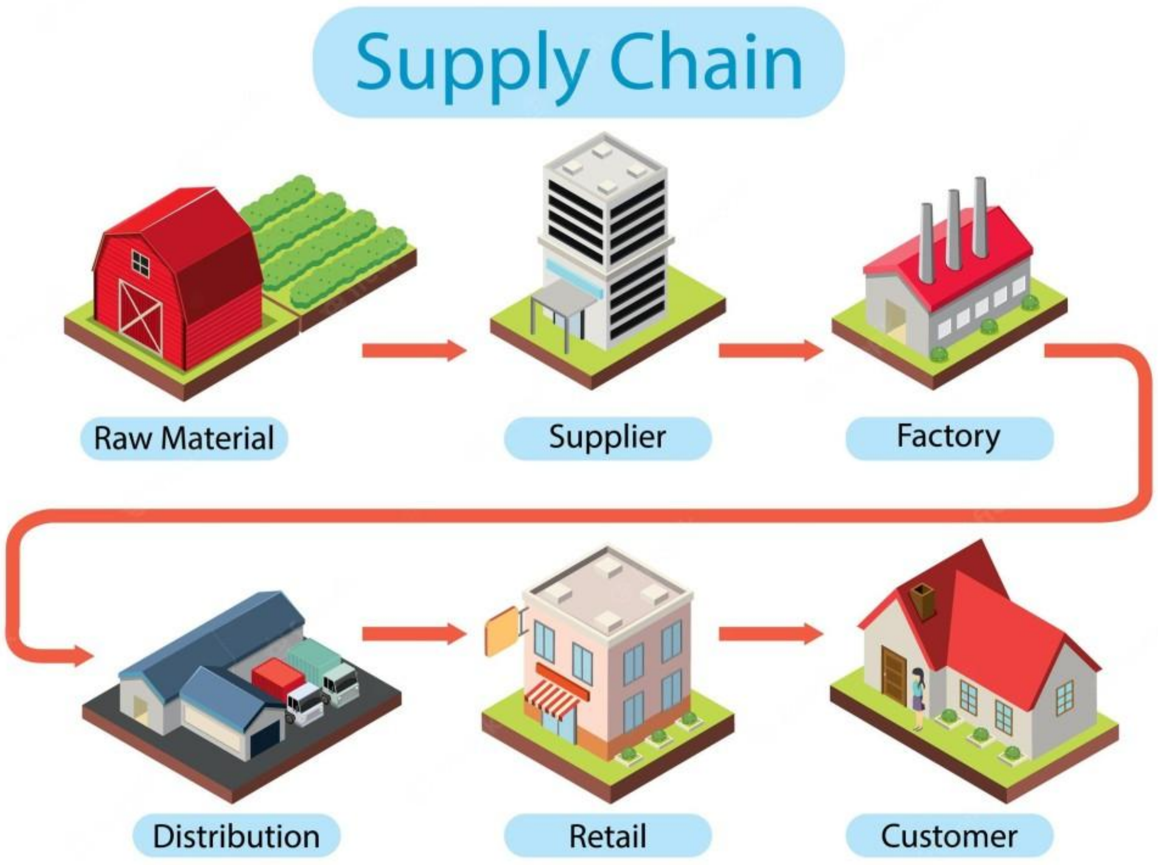
Instructor: Asst Prof Wang Pei

Definition of Supply Chain

Definition of a Supply Chain

- A supply chain is a network that moves a product from supplier to customer.

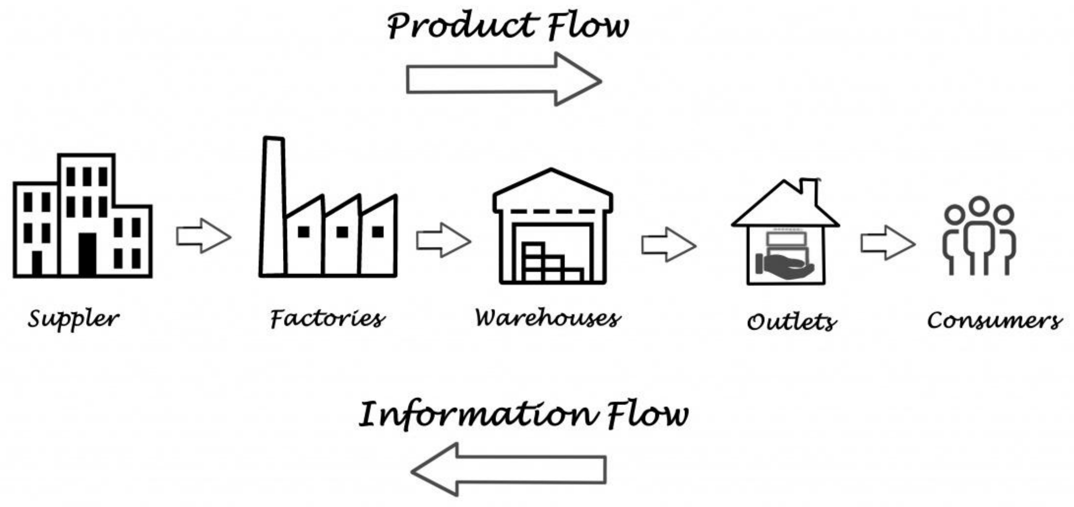
- It includes organizations, people, activities, information, and resources.



[(12) Supply Chain Management - Definition and importance of its strategies | LinkedIn]()

Key Components of a Supply Chain

- Suppliers: Initiate the chain by providing raw materials.
- Manufacturers: Transform these materials into finished products.
- Warehousing: Manages stock storage until distribution.
- Distribution: Delivers goods to retailers or directly to consumers.
- Retailers: Sell the products to the end user.



[Supply chain management: optimize and minimize risk - iXtenso – retail trends]

Importance of Supply Chains

- Economic Impact: They reduce costs and enhance productivity, enabling global competition.
- Global Reach: Connect markets, facilitating international business and economic integration.
- Innovation Driver: Adopt new technologies to improve services and products.

Challenges in Supply Chain Management

- Complexity: Involves coordinating many activities, often internationally.
- Risk Management: Vulnerable to disruptions like natural disasters and market volatility.
- Visibility: Crucial for effective operations management and timely delivery.
- Adaptability: Must be flexible to respond to market, technology, and regulatory changes.

Role of Technology in Modern Supply Chains

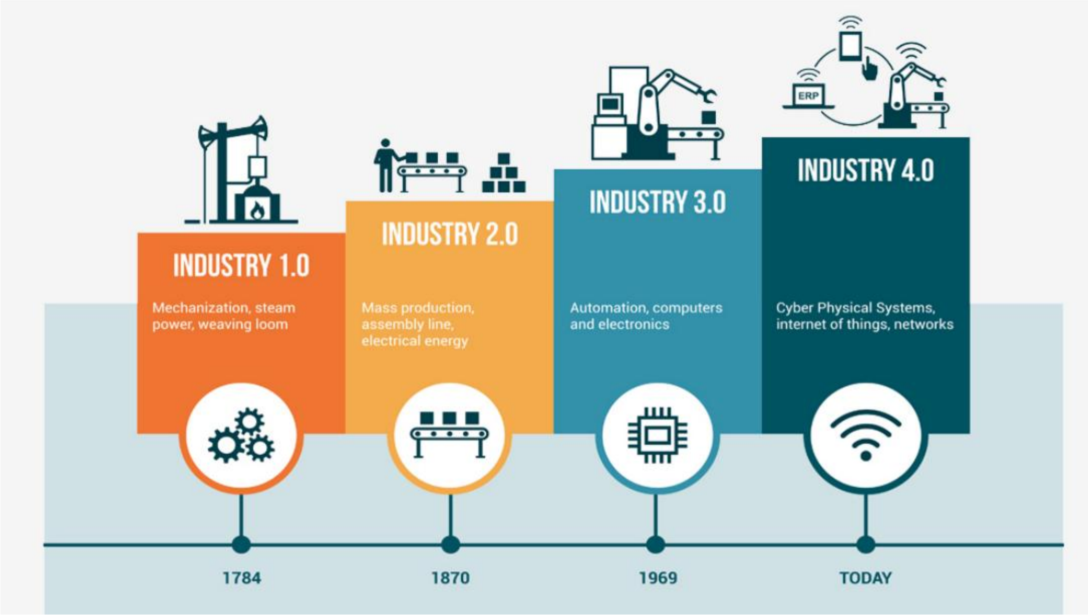
Historical Overview

- The Rise of Globalization: Post-World War II economic policies and advancements in transportation and communication expanded supply chains internationally.
- Traditional Supply Chains: Originated in the early industrial era, focused on linear, local production and distribution models with limited technology.

Technological Advancements

- 1980s and 1990s: Introduction of Enterprise Resource Planning (ERP) systems that integrated various business processes.
- 2000s: Adoption of the Internet and ecommerce transformed how companies managed supply and demand.
- 2010s: Emergence of Industry 4.0 technologies like IoT, AI, and big data analytics began reshaping supply chain management into what is now known as Supply Chain 4.0.

Evolution of Industry Technologies



https://dx.doi.org/10.55708/js0105012

Evolution of Industrial Technologies

Definition and Overview

- Supply Chain 4.0 is the integration of advanced digital technologies of Industry 4.0 into every aspect of the supply chain.
- It represents the convergence of the physical and digital worlds, creating highly efficient, automated, and data-driven networks.

Key Features

- Interconnectivity: All elements of the supply chain are connected and communicate seamlessly, enhancing collaboration and information sharing.

- Agility: Enhanced ability to respond quickly to market changes and customer demands, thanks to advanced analytics and flexible manufacturing techniques.

- Transparency: Real-time tracking of materials and products ensures accurate inventory management and improved quality control.

Benefits

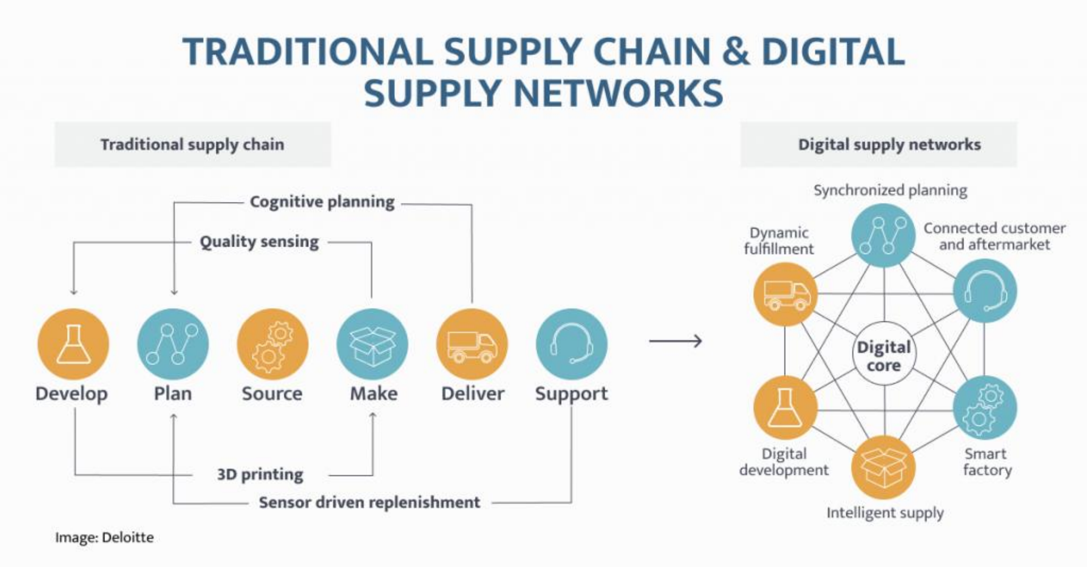
- Efficiency and Cost Reduction: Automation and optimized resource management lead to significant cost savings.
- Improved Customer Satisfaction: Faster delivery times and higher product quality meet customer expectations more effectively.
- Sustainability: Advanced technologies enable more sustainable practices by reducing waste and optimizing energy use.

Impact of Industry 4.0

- Connectivity and Real-Time Data: IoT and cloud computing enable real-time data collection and analysis, enhancing decision-making and responsiveness.

- Automation and Efficiency: Robotics and automation technologies have replaced many manual processes, increased speed and reducing errors.

- Customization and Customer Focus: AI and advanced analytics allow for more personalized production and predictive modeling to better meet customer demands.



[What Is Supply Chain 4.0 and Where Does It Drive Value? (agistix.com)]

Digital Supply Chains

Traditional Supply Chain

- Manual Processes: Heavy reliance on human intervention for inventory management, order processing, and logistics.
- Limited Data Use: Decision-making based on historical data without real-time insights.
- Linear Operations: Operations follow a linear sequence with little flexibility for changes.
- Siloed Functions: Limited communication and data sharing between departments like procurement and distribution.
- Inventory Management: Managed through periodic reviews, leading to potential excess or shortages.
- Lower Visibility: Limited ability to track products through the supply chain stages.
- Limited Customer Interaction: Minimal and reactive interactions, focused on order fulfilment.

Digital Supply Chain (Supply Chain 4.0)

- Automation and Integration: Use of IoT, robotics, and AI to enhance efficiency.
- Advanced Analytics and Real-Time Data: Real-time decision-making and predictive capabilities.
- Networked and Agile: Seamless collaboration across all stages and stakeholders.
- Collaborative Ecosystems: Facilitates collaboration through digital platforms.
- Optimized Inventory Management: Just-in-time inventory practices using AI and machine learning.
- Enhanced Visibility and Traceability: End-to-end visibility using blockchain and IoT.
- Customer-Centric Approaches: High levels of interaction and personalization with digital tools.

Key Benefits of Digital over Traditional

- Efficiency: Reduction in delays and errors through automated processes.
- Adaptability: Ability to quickly adapt to market conditions and customer needs.
- Cost-Effectiveness: Reduced costs through optimized inventory and forecasting.
- Customer Satisfaction: Improved service and satisfaction through enhanced visibility and personalization.

Introduction to Technological Drivers

Introduction to Technological Drivers

- Technological advancements are the backbone of Supply Chain 4.0, enabling unprecedented efficiency, accuracy, and responsiveness across global networks.

Internet of Things (IoT)

- IoT devices enable real-time tracking and monitoring of goods and assets in the supply chain.
- IoT devices use Sensors and RFID tags to collect data on location, temperature, humidity, and other variables.
- IoT facilitates predictive maintenance, inventory management, and supply chain visibility.
- IoT enhances inventory management, reduces downtime through predictive maintenance, and improves the responsiveness of supply chain operations.

Internet of Things (IoT)

Blockchain Technology

- Blockchain is a distributed ledger technology that provides a decentralized, transparent, and immutable record of transactions across the supply chain.

- Blockchain enhances traceability, authenticity, and transparency by securely recording and validating transactions, contracts, and product provenance.

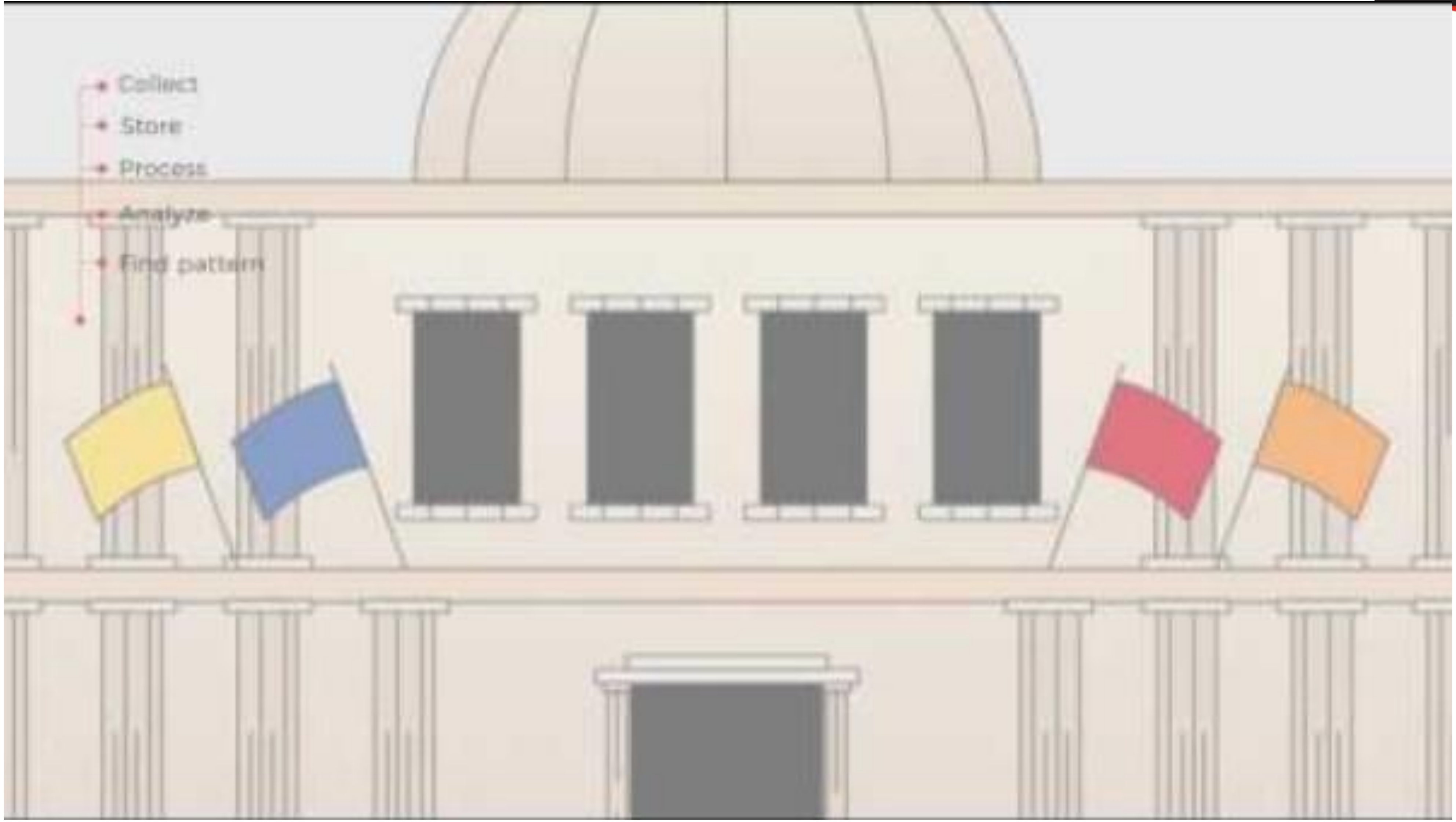
- Blockchain applications include traceability of goods, smart contracts, supply chain finance, and combating counterfeiting and fraud.

Blockchain

Big Data Analytics

- Big data analytics tools process and analyze vast amounts of structured and unstructured data from multiple sources across the supply chain.
- Advanced analytics techniques uncover hidden patterns, correlations, and trends to support data-driven decision-making and strategic planning.
- Big data analytics optimize inventory management, route optimization, customer segmentation, and supply chain performance measurement.
- Collects and analyses extensive data sets to inform strategic decision-making.
- Enables complex decision-making by providing insights into customer behaviour, market trends, and operational efficiencies.

Big Data Analytics



Cloud Computing

- Cloud computing provides scalable and flexible computing resources, storage, and services over the internet.
- Cloud-based supply chain platforms enable real-time collaboration, data sharing, and integration across multiple stakeholders and systems.
- Cloud computing supports the deployment of Software-as-a-Service (SaaS) applications, such as supply chain management systems, predictive analytics, and digital twins.

Cloud Computing

Artificial Intelligence (AI) and Machine Learning (ML)

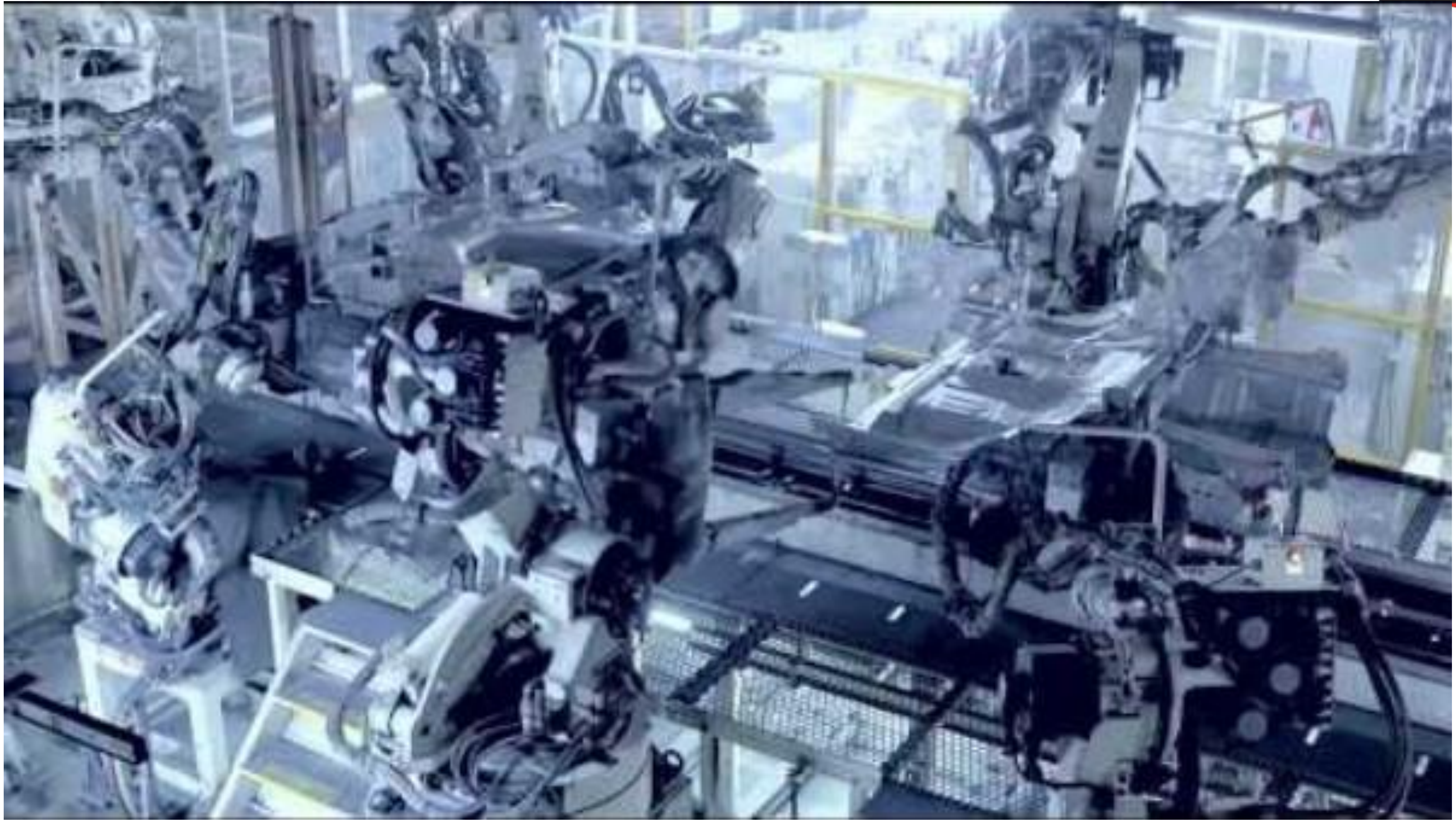
- AI and ML algorithms analyse large volumes of data generated by IoT sensors, historical data, and external sources to derive actionable insights.
- AI algorithms analyse large datasets to predict trends, automate decision-making, and optimize logistics.
- AI-driven predictive analytics enhance demand forecasting, inventory optimization, and supply chain risk management.
- ML algorithms enable autonomous decision-making, anomaly detection, and optimization of supply chain processes.

Artificial Intelligence (AI) and Machine Learning (ML)

Robotics and Automation

- Robots automate repetitive tasks in manufacturing, warehousing, and logistics,
- Autonomous vehicles and drones optimize transportation and delivery processes.
- Improving speed and precision in manufacturing and warehousing operations.
- Reduces labor costs, minimizes human error, and increases production efficiency, improves safety in the supply chain.

Robotics and Automation



Advanced Manufacturing Technologies

- Advanced manufacturing technologies, such as additive manufacturing (3D printing), computer numerical control (CNC) machining, and advanced robotics,
- enable more flexible, efficient, and customized production processes.
- These technologies allow for on-demand and batch production, reducing lead times and inventory costs.
- Advanced manufacturing technology facilitates the production of complex and customized products, contributing to greater product innovation and differentiation within the supply chain.

Advanced Manufacturing Technologies

Benefits of Supply Chain 4.0:

Enhanced Efficiency

- Decreases operational costs and enhances productivity
- Automation and real-time data analytics streamline operations
- Minimizes delays and reduces redundancy
- Optimizes resource allocation and logistics

Increased Transparency

- Technologies like IoT and blockchain provide endto-end visibility
- Improves inventory management and customer trust
- Ensures product authenticity and tracking

Improved Customer Satisfaction

- Results in higher service levels and faster delivery times
- Data-driven insights allow for better forecasting and personalization
- Leads to customized products and greater customer loyalty
- Closely aligns supply with consumer demand

Agility and Responsiveness

- AI and machine learning enable rapid responses to market changes
- Allows quick adaptation to seize opportunities
- Mitigates risks in volatile markets

Enhanced Collaboration

- Strengthens partnerships across the supply chain
- Shared digital platforms facilitate communication and cooperation
- Streamlines product development and go-to-market strategies

Sustainability Improvements

- Advanced technologies optimize routes and loads
- Reduces energy consumption and waste
- Supports corporate social responsibility goals

Challenges and Solutions

Integration Complexity

- Integrating new digital tools with legacy systems presents technical and managerial challenges.
- Can lead to disruptions in current operations and increased initial costs.

Data Security and Privacy Concerns

- Increased use of digital systems elevates the risks of data breaches and privacy issues.
- Requires robust cybersecurity measures, potentially increasing costs and complexity.

Skilled Workforce Shortage

- Shortage of skilled professionals equipped to manage new technologies like AI and IoT.
- Limits the ability to fully leverage technology investments without additional training or hiring.

High Initial Investment

- Upfront cost of adopting cutting-edge technologies can be prohibitively high, particularly for SMEs.
- Financial constraints can delay or deter the adoption of Supply Chain 4.0 innovations.

Resistance to Change

- Organizational resistance to change can hinder the adoption of new technologies and processes.
- Slows down transformation efforts and can lead to a competitive disadvantage.

Regulatory and Compliance Issues

- Navigating the complex landscape of international regulations and standards can be challenging.
- May result in compliance risks and restrict the ability to operate efficiently across borders.

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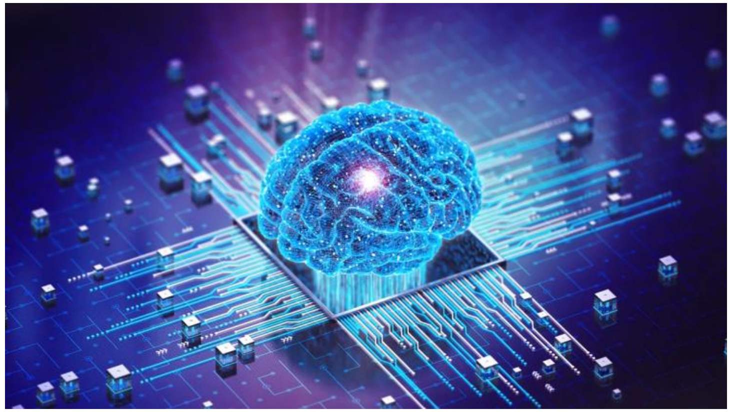
Supply Chain 4.0
- Artificial Intelligence

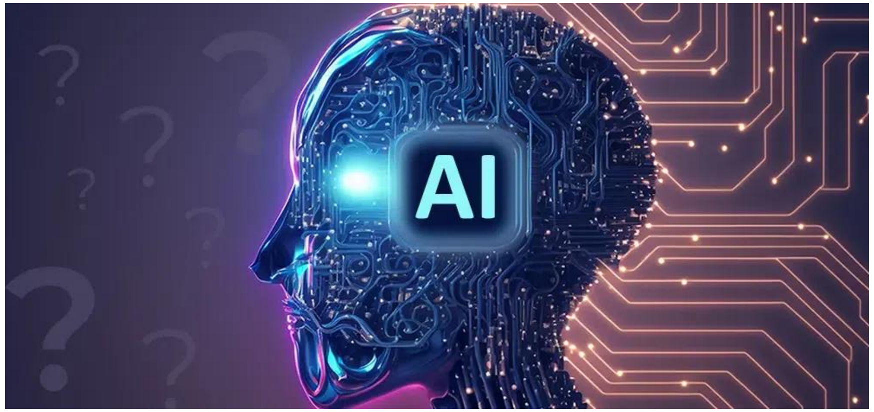
Instructor: Asst Prof Wang Pei

Artificial Intelligence - Introduction

What is Artificial Intelligence?

- Artificial Intelligence (AI) is the simulation of human intelligence processes by machines, particularly computer systems.



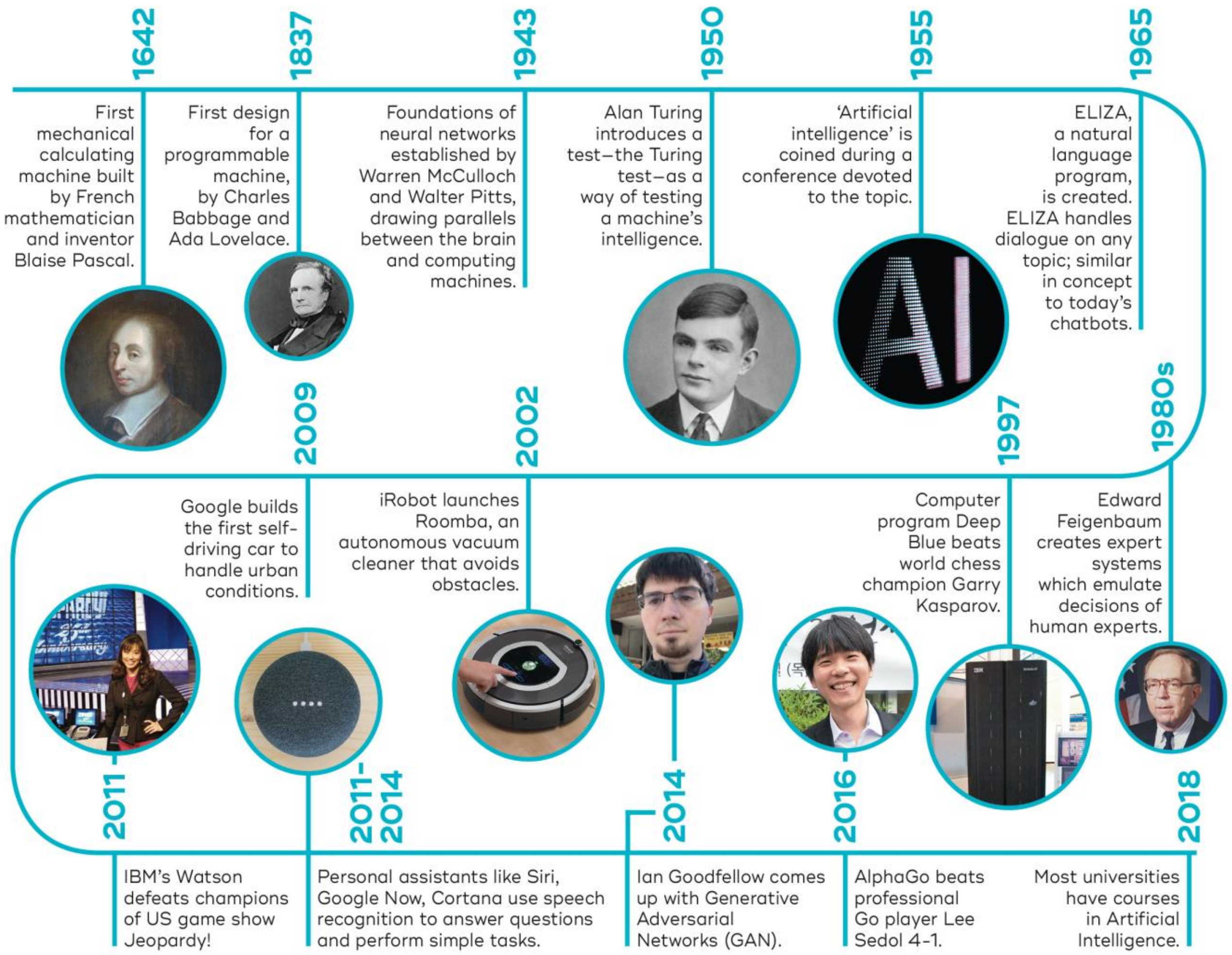


Why people use brains represent AI?

Russell, S. J., & Norvig, P. (2016). *Artificial intelligence: a modern approach*. Pearson.

Historical Perspectives in AI

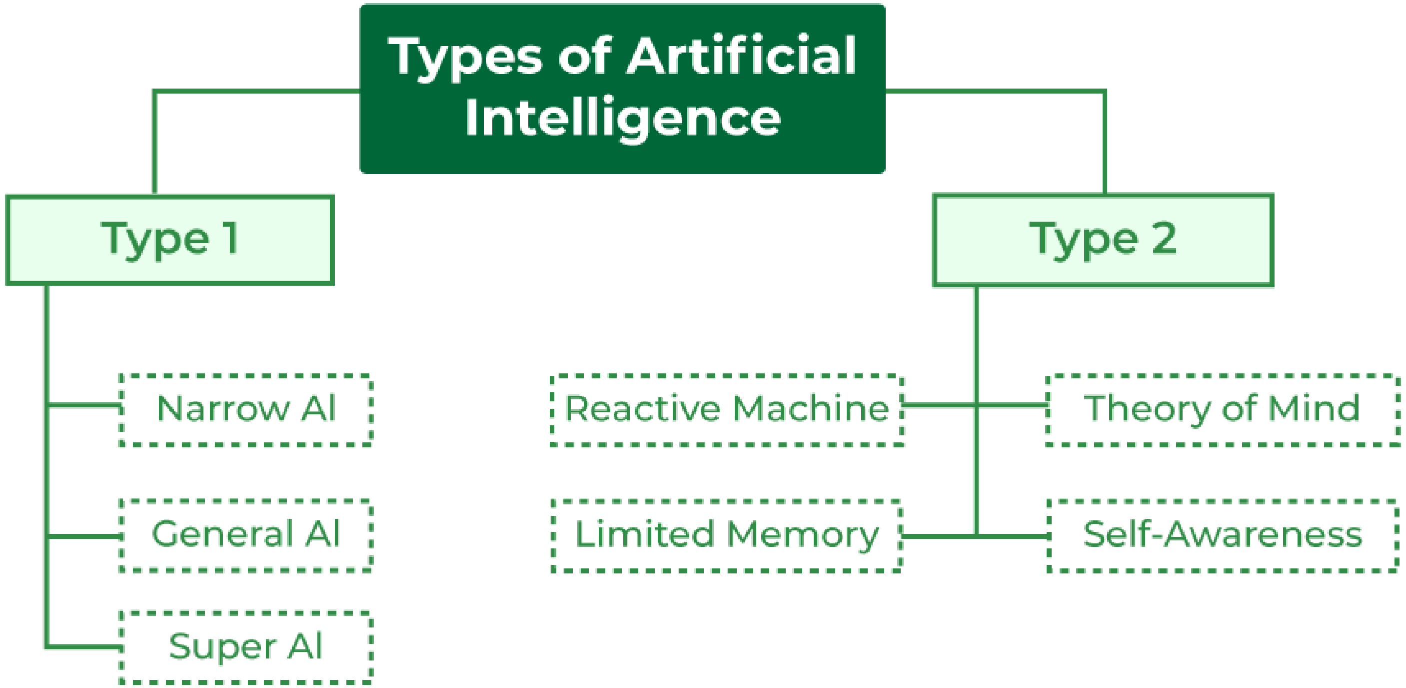
- 1940s-1950s:
  - Initial theories around neural networks; Alan Turing develops the Turing Test to measure machine intelligence.
- 1960s:
  - AI research is institutionalized; programs like ELIZA are developed.
- 1980s-1990s:
  - AI becomes a mainstream technology; major advancements in algorithms, including the development of backpropagation for neural networks.
- 2000s-Present:
  - AI dominates with innovations in deep learning, big data, and computational power, influencing every sector from healthcare to automotive.



Types of AI

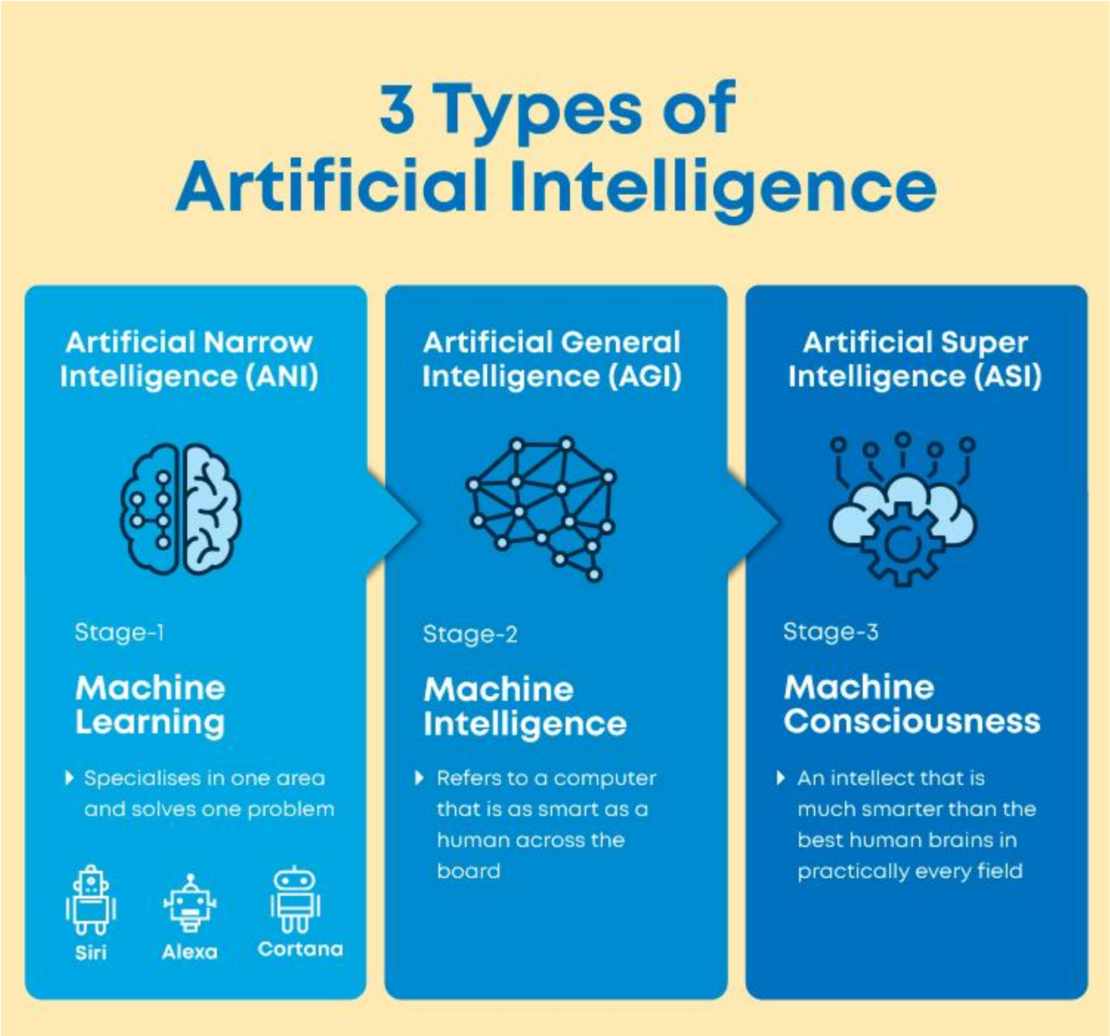
Types of AI

- Type 1: based on capabilities of AI
- Type 2: based on functionality of AI



[Types of Artificial Intelligence - GeeksforGeeks]

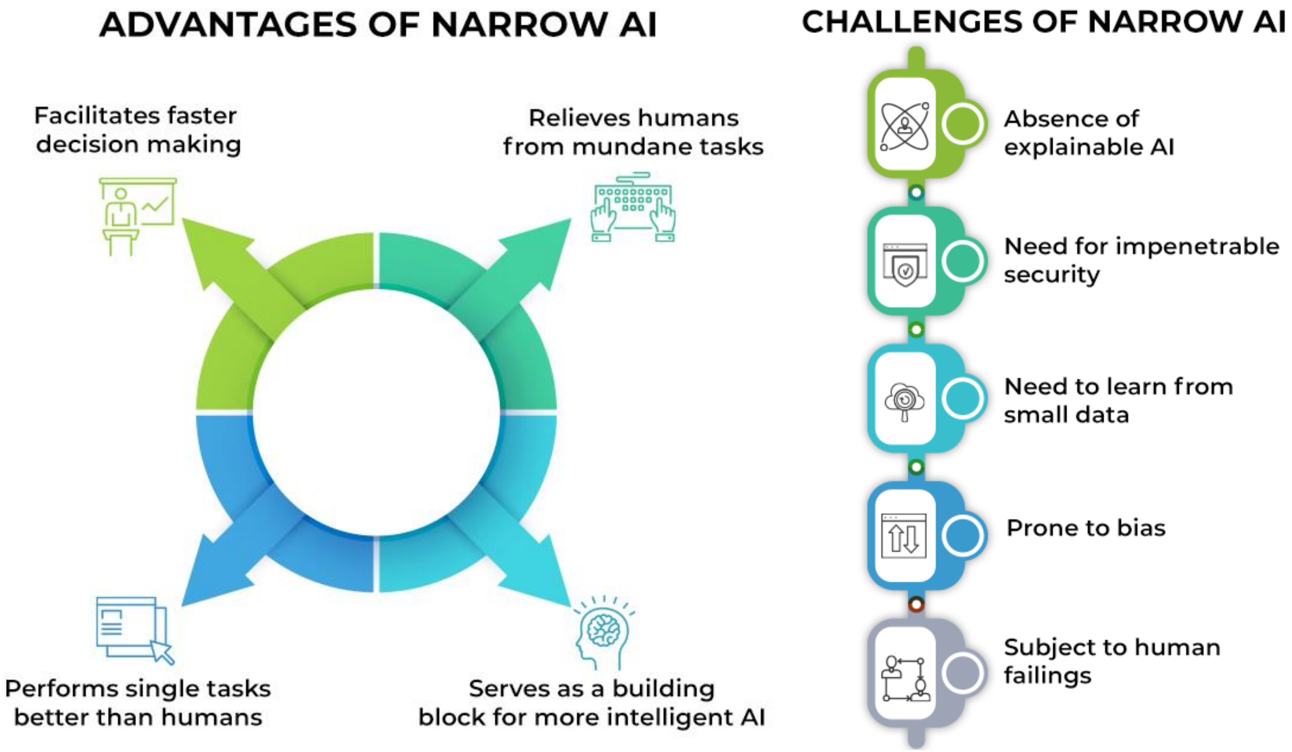
Type 1 AI



3 Types of
Artificial Intelligence
Artificial Narrow Intelligence (ANI)
Stage-1
Machine Learning
Specialises in one area and solves one problem
Siri
Alexa
Cortana
Artificial General Intelligence (AGI)
Stage-2
Machine Intelligence
Refers to a computer that is as smart as a human across the board
Artificial Super Intelligence (ASI)
Stage-3
Machine Consciousness
An intellect that is much smarter than the best human brains in practically every field

Type 1 AI

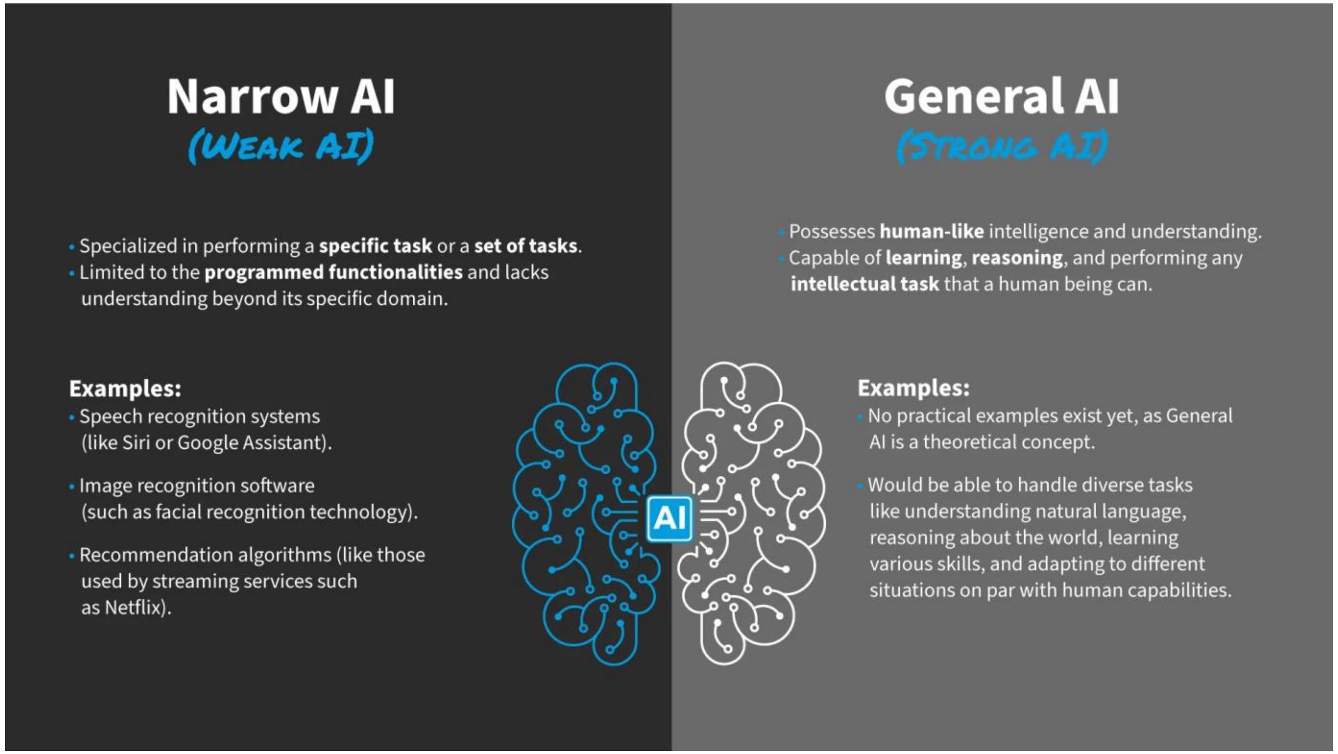
- Artificial Narrow Intelligence (Narrow AI or ANI):
  - Narrow AI is built for very specific tasks, such as playing a game, keeping spam out of your inbox, helping you find a nearby restaurant with your smartphone, or driving your car.



[Narrow Artificial Intelligence Definition, Challenges, Best Practices (spiceworks.com)]

Type 1 AI

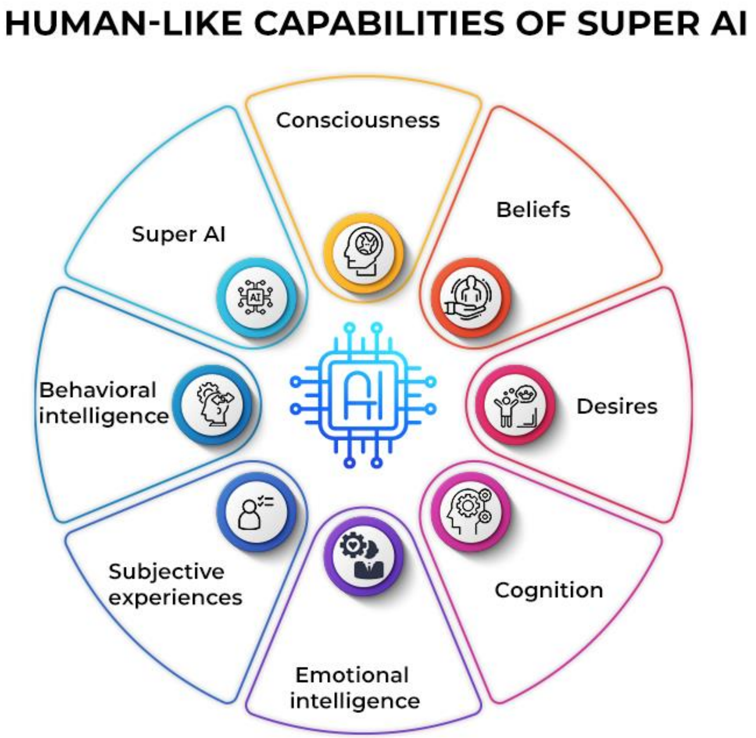
- Artificial General Intelligence (General AI or AGI):
  - With more resemblance to human capabilities, General AI is a more advanced form that can involve visual and language processing, contextual understanding, and the ability to adapt to a range of tasks. It's considered to be far off in the future.



[What Is General AI? — updated 2024 | IxDF (interaction-design.org)]

Type 1 AI

- Artificial super intelligence (Super AI or ASI)
  - Super AI is a form of AI that is capable of surpassing human intelligence by manifesting cognitive skills and developing thinking skills of its own.



[What Is Super Artificial Intelligence (AI)? Definition, Threats, and Trends - Spiceworks]

Type 2 AI

- **Reactive Machine AI**
  - Reactive machines are just that — reactionary. They can respond to immediate requests and tasks, but they aren't capable of storing memory, learning from past experiences or improving their functionality through experiences. Additionally, reactive machines can only respond to a limited combination of inputs. Reactive machines are the most fundamental type of AI.
  - In practice, reactive machines are useful for performing basic autonomous functions, such as filtering spam from your email inbox or recommending items based on your shopping history. But beyond that, reactive AI can't build upon previous knowledge or perform more complex tasks.
- **Reactive Machine AI Examples**
  - **IBM Deep Blue:** IBM's reactive AI machine Deep Blue was able to read real-time cues in order to beat Russian chess grandmaster Garry Kasparov in a 1997 chess match.
  - **Netflix Recommendation Engine:** Media platforms like Netflix often utilize AI-powered recommendation engines, which process data from a user's watch history to determine and suggest what they would be most likely to watch next.

Type 2 AI

- **Limited Memory AI**
  - Limited memory AI can store past data and use that data to make predictions. This means it actively builds its own limited, short-term knowledge base and performs tasks based on that knowledge.
  - The core of limited memory AI is deep learning, which imitates the function of neurons in the human brain. This allows a machine to absorb data from experiences and "learn" from them, helping it improve the accuracy of its actions over time.
  - Today, the limited memory model represents the majority of AI applications. It can be applied in a broad range of scenarios, from smaller scale applications, such as chatbots, to self-driving cars and other advanced use cases.
- **Limited Memory AI Examples**
  - **Chatbots and Virtual Assistants:** Chatbots and virtual assistants are forms of limited memory AI that use deep learning to mimic human conversation. As users interact more with these systems, they learn from this data and remember details about the user, allowing them to provide relevant and personalized responses.
  - **Self-Driving Cars:** Self-driving cars continually observe and process environmental data around them as they travel on the road. This helps them predict when they need to turn, stop or avoid an obstacle.

Type 2 AI

- **Theory of Mind AI**
  - Theory of mind refers to the concept of AI that can perceive and pick up on the emotions of others. The term is borrowed from psychology, describing humans' ability to read the emotions of others and predict future actions based on that information. Theory of mind hasn't been fully realized yet, and stands as the next substantial milestone in AI's development.
  - Theory of mind could bring plenty of positive changes to the tech world, but it also poses its own risks. Since emotional cues are so nuanced, it would take a long time for AI machines to perfect reading them, and could potentially make big errors while in the learning stage. Some people also fear that once technologies are able to respond to emotional signals as well as situational ones, the result could mean automation of some jobs.
- **Theory of Mind AI Example**
  - Rafael Tena, senior AI researcher at insurance company Acrisure, provided an example to illustrate how a successful theory of mind application would revolutionize the technology: A self-driving car may perform better than a human driver the majority of the time because it won't make the same human errors. But if you, as a driver, know that your neighbor's kid tends to play close to the street after school, you'll know instinctively to slow down while passing that neighbor's driveway — something an AI vehicle equipped with basic limited memory wouldn't be able to do.

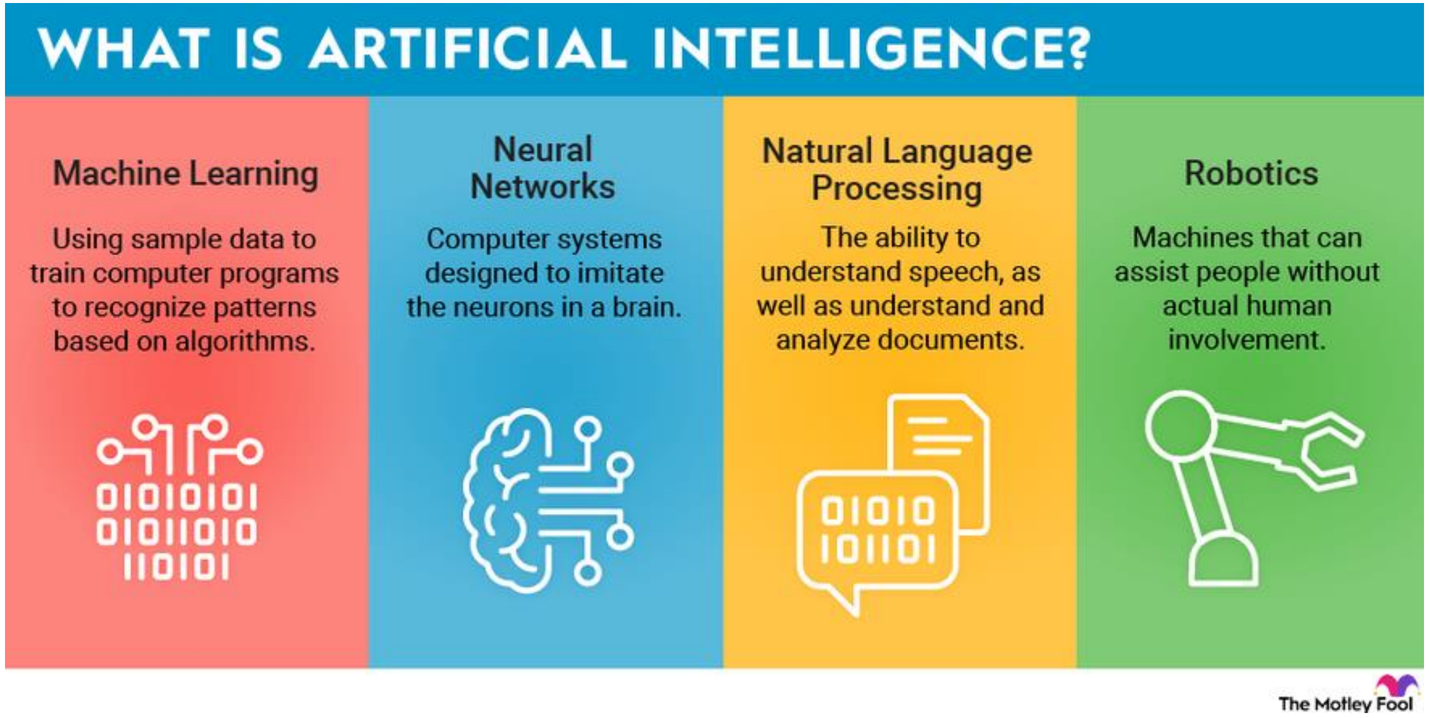
Type 2 AI

- **Self-Aware AI**
  - Self-aware AI describes artificial intelligence that possesses self-awareness. Referred to as the AI point of singularity, self-aware AI is the stage beyond theory of mind and is one of the ultimate goals in AI development. It's thought that once self-aware AI is reached, AI machines will be beyond our control, because they'll not only be able to sense the feelings of others, but will have a sense of self as well.
- **Self-Aware AI Example**
  - Perhaps one of the most famous of these is Sophia, a robot developed by robotics company Hanson Robotics. While not technically self-aware, Sophia's advanced application of current AI technologies provides a glimpse of AI's potentially self-aware future. It's a future of promise as well as danger — and there's debate about whether it's ethical to build sentient AI at all.

AI Technologies

AI Technologies Explained

- Machine Learning (ML): AI systems that improve over time from data.
- Neural Networks: computer systems designed to imitate the neurons in a brain.
- Natural Language Processing (NLP): AI that processes human language.
- Robotics: AI integrated to perform real-world tasks.



AI, ML and Deep Learning

Artificial Intelligence

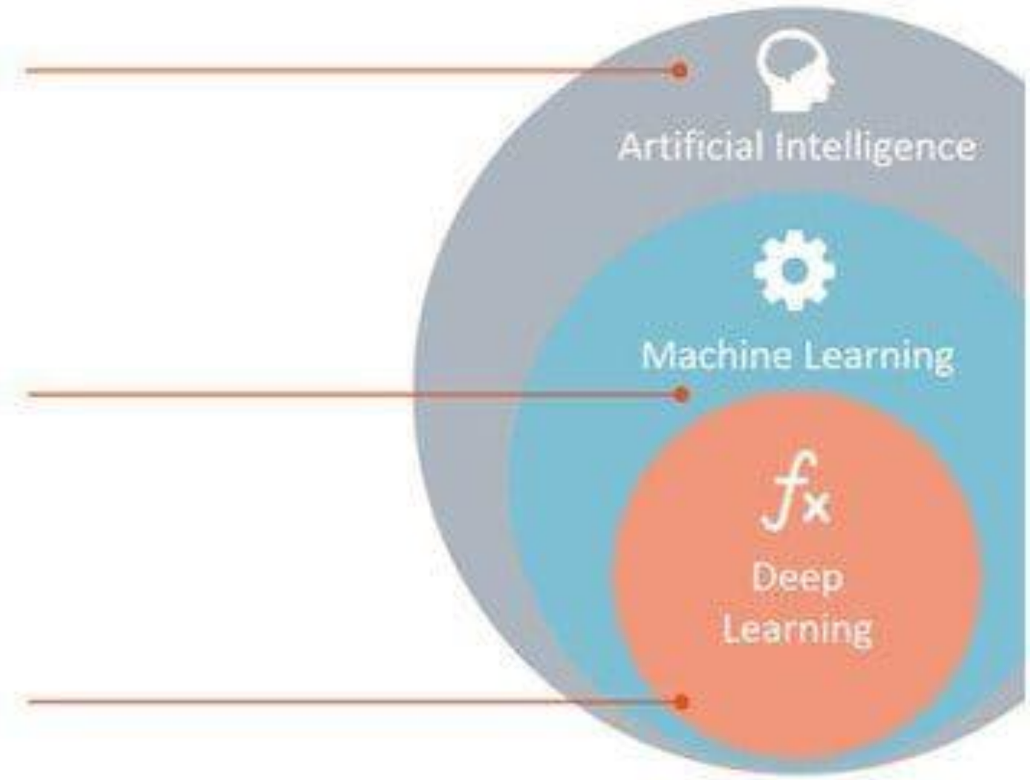
Any technique which enables computers to mimic human behavior.

Machine Learning

Subset of AI techniques which use statistical methods to enable machines to improve with experiences.

Deep Learning

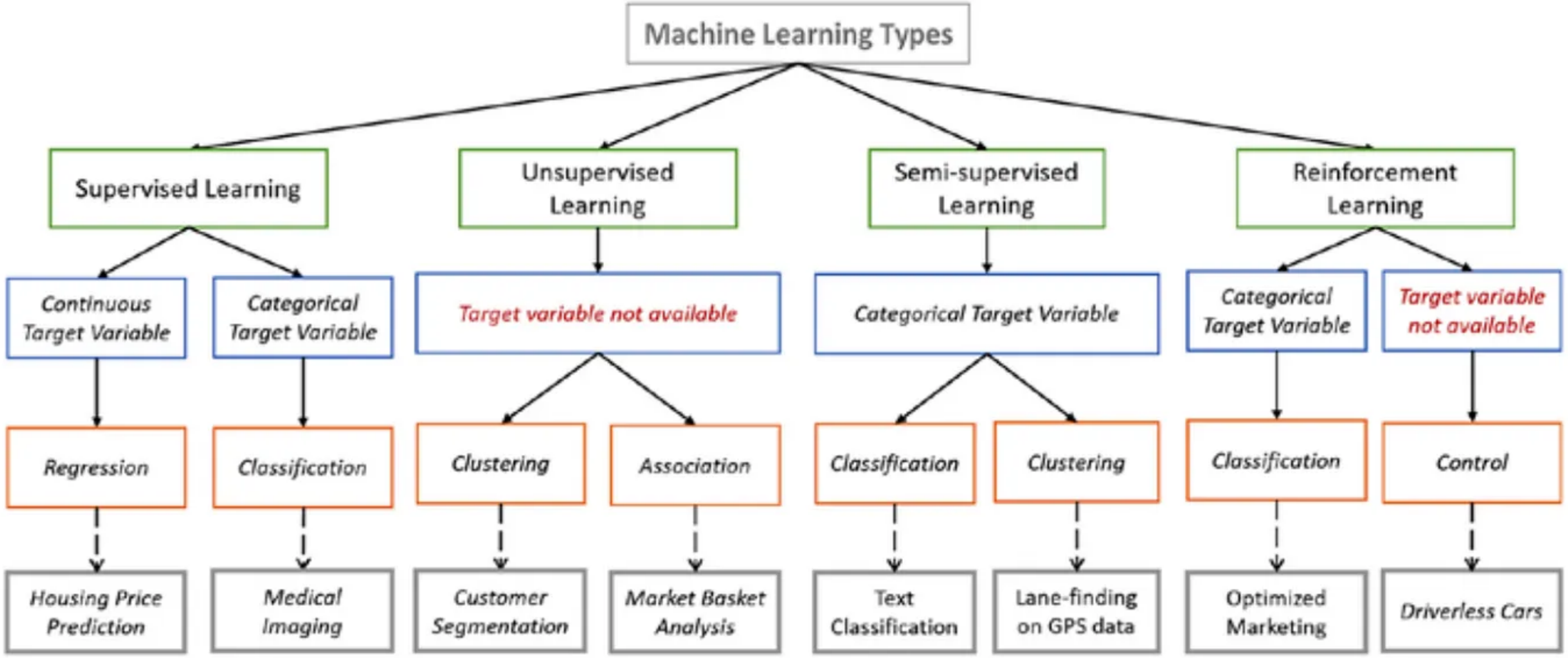
Subset of ML which make the computation of multi-layer neural networks feasible.



[What Are Artificial Intelligence, Machine Learning, and Deep Learning? - KDnuggets]

Machine Learning

- Machine learning (ML)
  - To use sample data to train computer programs to recognize patterns based on algorithms. Machine learning programs allow computers to do things without being programmed. The efficiency of machine learning generally depends on the algorithm.



Neural Networks

- Neural networks
  - A neural network is a method in artificial intelligence that teaches computers to process data in a way that is inspired by the human brain.
  - It is a type of machine learning process, called deep learning, that uses interconnected nodes or neurons in a layered structure that resembles the human brain.

Natural Language processing (NLP)

- Natural language processing (NLP)
  - A branch of AI involving the ability of computers to understand spoken language and text.
  - Natural language processing is often confused with simple speech recognition. It certainly includes the ability to understand speech, but it involves more than simple audio-to-text (and vice versa) translations.
  - One of the goals of natural language processing is the design of a computer to fully understand and analyse documents.

Robotics

- Robotics
  - The use of robots dates back hundreds of years, but machines that could assist people without actual human involvement are considerably newer.
  - One of the first autonomous robots was installed in 1961 and used to lift hot pieces of metal from a machine. Since then, robots have become far more common. They're used in applications ranging from space exploration to vacuuming your carpet.
  - Robotics has evolved beyond industrial uses and are used in a wide range of applications, including medicine.
- AI robotics
  - integrating AI technologies into robotic systems to enhance their capabilities and enable them to perform more complex tasks.
  - AI robotics allows robots to learn from experience, adapt to new situations, and make decisions based on data from sensors.

AI vs AI

Artificial Intelligence	Augmented Intelligence
AI replaces humans and operates with high accuracy.	Augmentation does not replace people but creates systems that help in manufacturing.
Replaces human decision making	Augments human decision making
Robots/Industrial IoT: Robots will replace all humans on the factory floor.	Robots/Industrial IoT: Collaborative robots work along with humans to handle tasks that are hard and repetitive.
Real-Time Applications of AI in Customer Success1. Automated Customer Support and Chatbots2. Virtual Assistants Automated Workflows	Real-Time Applications of IA in Customer Success1. IA-enabled customer analytics2. Discover high-risk/high-potential customers3. Forecasts Sales

Measuring Criteria for AI

How do we measure if Artificial Intelligence is acting like a human?

- Turing Test
- The Cognitive Modelling Approach
- The Law of Thought Approach
- The Rational Agent Approach

Turing Test in AI

- The basis of the Turing Test is that the Artificial Intelligence entity should be able to hold a conversation with a human agent. The human agent ideally should not be able to conclude that they are talking to Artificial Intelligence. To achieve these ends, the AI needs to possess these qualities:
  - Natural Language Processing to communicate successfully.
  - Knowledge Representation acts as its memory.
  - Automated Reasoning uses the stored information to answer questions and draw new conclusions.
  - Machine Learning to detect patterns and adapt to new circumstances.

Cognitive Modelling Approach

- As the name suggests, this approach tries to build an Artificial Intelligence model based on Human Cognition. To distil the essence of the human mind, there are 3 approaches:
  - Introspection: observing our thoughts, and building a model based on that
  - Psychological Experiments: conducting experiments on humans and observing their behaviour
  - Brain Imaging: Using MRI to observe how the brain functions in different scenarios and replicating that through code.

Laws of Thought Approach

- Laws of Thought Approach
  - The "laws of thought" approach concerned with correct inferences. Making correct inferences is sometimes part of being a rational agent, because one way to act rationally is to reason logically to the conclusion that a given action will achieve one's goals, and then act on that conclusion.
  - A set of rules that help us think, which can also be used to program artificial intelligence.
  - It’s hard to apply these rules to real-world problems, which need more than just fixed rules to solve.
  - AI might struggle to mimic human actions when there’s a lot of uncertainty.

Rational Agent Approach

- Rational Agent Approach

  - A strategy where an AI tries to make the best decision based on its current situation, rather than just following fixed rules.
  - The Rational Agent in AI operates through a cycle of perception, reasoning and action. It perceives its surroundings gathers relevant information, analyses available options, and ultimately takes action based on its programmed objectives.
  - Sometimes, there’s no single best choice and the AI has to decide among many options, each with its own pros and cons. This requires the AI to be very flexible.

How AI Processes Information

- Data Acquisition: AI systems gather data through sensors or human input.
- Data Processing: AI uses algorithms to analyze and process the data.
- Decision Making: Based on its analysis, AI makes decisions or predictions.

AI in Supply Chain

Applications of AI in SCM

- Warehousing: Autonomous robots for inventory and order fulfillment.
- Logistics: AI models for optimizing shipping and delivery.
- Inventory Management: AI for accurate demand forecasting, minimizing overstock and understock.

AIoT for supply chain

- Artificial intelligence of things (AIoT),
  - Artificial intelligence (AI) in the Internet of Things (IoT)
  - AIoT breaks the static streams of data and recognizes patterns that do not scale easily.
  - The AIoT in addition to being a revolutionary technology for all industries has also shown its potential in processes (e.g., supply chain), management, forecasting, and monitoring applications help the managers improve their company's distribution operational efficiency and increase transparency in their decisions.

Benefits of AI in SCM

- Increased Efficiency and Reduced Costs: Streamlining processes and minimizing errors.
- Enhanced Decision-Making Capabilities: Providing real-time insights and data-driven recommendations.

Conclusion and Future Outlook

- Summary of AI’s Impact on SCM: Transformative effects on efficiencies, cost reduction, and data-driven operations.
- Encouragement for Ongoing Education and Adaptation: Importance of staying updated with AI advancements for future success in SCM.

Thank you!

Introduction to Automation and Advanced Robotics in Supply Chain Management

Instructor: Asst Prof Wang Pei

SINGAPORE INSTITUTE OF TECHNOLOGY

Content

- Automation Overview
- Automation in Supply Chain Management
- Advanced Robotics Overview
- Advanced Robotics in Supply Chain Management
- Case Studies in Supply Chain 4.0

Automation

Introduction to Automation

- Automation
  - Refers to the use of technology to perform tasks without human intervention.
  - It involves the application of mechanical, electrical, and computer-based systems to operate processes or machinery.
- Historical perspective
  - Early Automation:

    The concept of automation dates to ancient times, with the use of simple mechanical devices such as water wheels and windmills.

  - Industrial Revolution:

    The first significant leap in automation occurred during the Industrial Revolution in the 18th and 19th centuries, with the introduction of steam engines and mechanized manufacturing.

  - 20th Century:

    The development of electronic control systems, computers, and robotics in the 20th century further advanced automation capabilities.

Types of automation

- **Fixed Automation:**
  - Also known as hard automation, it involves the use of specialized equipment to perform a specific set of tasks. Examples include assembly lines and conveyor systems.
- **Programmable Automation:**
  - This type of automation allows for the reprogramming of machines to perform different tasks. Examples include CNC (Computer Numerical Control) machines and robotic arms.
- **Flexible Automation:**
  - Also known as soft automation, it involves the use of computer-controlled machines that can be easily reconfigured for different tasks. Examples include flexible manufacturing systems and automated guided vehicles (AGVs).

Benefits of automation

- **Increased Efficiency:** Automation can significantly increase production rates and throughput.
- **Enhanced Accuracy:** Automated systems can perform tasks with high precision and consistency, reducing errors.
- **Cost Reduction:** Automation can lower labour costs and reduce waste, leading to overall cost savings.
- **Improved Safety:** Automation can perform dangerous tasks, reducing the risk of injury to workers.

Key industries using automation

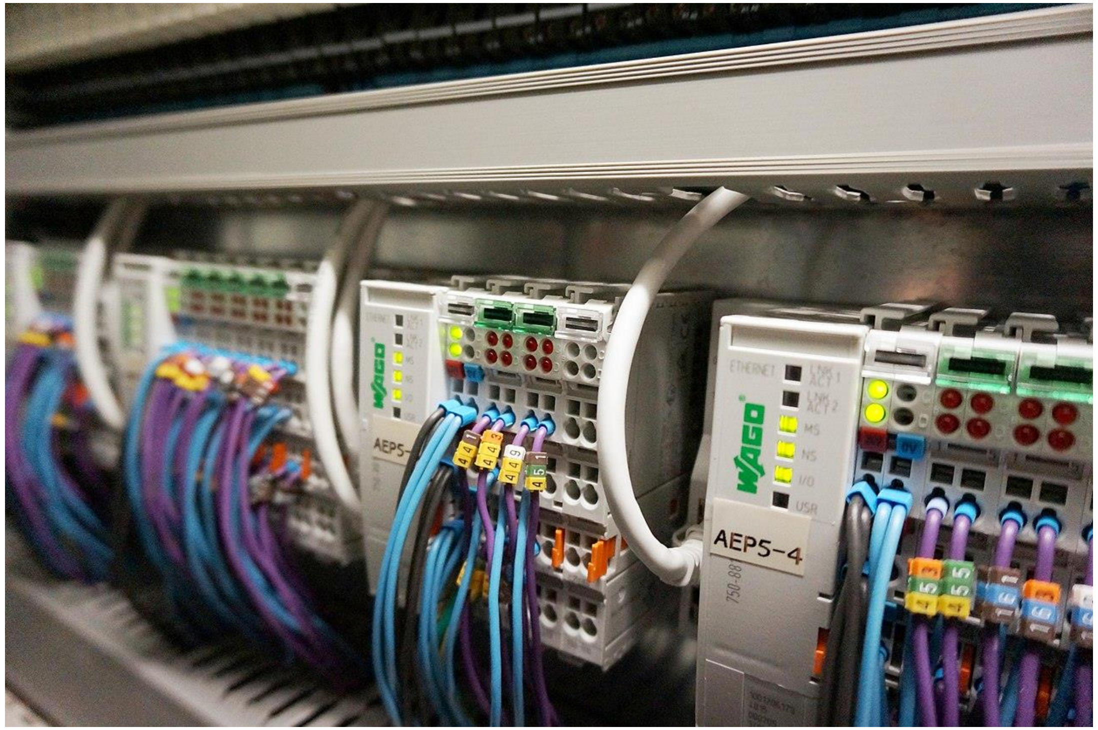
- **Manufacturing:** Automation is widely used in manufacturing for tasks such as assembly, machining, and packaging.
- **Logistics and Warehousing:** Automated systems are used for sorting, picking, and transporting goods.
- **Healthcare:** Automation is used in medical diagnostics, laboratory testing, and surgery.
- **Agriculture:** Automated machinery is used for planting, harvesting, and processing crops.

Automation Technologies

- PLCs (Programmable Logic Controllers)
- SCADA (Supervisory Control and Data Acquisition)
- CNC (Computer Numerical Control)
- Robotics

Programmable Logic Controllers (PLCs)

- PLCs are industrial digital computers designed for controlling manufacturing processes. They are highly reliable and can withstand harsh environments.
- Functions: PLCs monitor inputs, make decisions based on a custom program, and control outputs to automate machinery and processes.
- Applications: Widely used in assembly lines, robotics, and machinery control.



Supervisory Control and Data Acquisition (SCADA)

- **Definition:** SCADA systems are used for controlling and monitoring industrial processes. They collect data from various sensors and machines and provide real-time data visualization.
- **Components:** SCADA systems consist of hardware (sensors, controllers) and software (data acquisition, HMI).
- **Applications:** Commonly used in power plants, water treatment facilities, and manufacturing processes for monitoring and controlling operations.

Computer Numerical Control (CNC)

- **Definition:** CNC machines are automated milling devices that use programmed commands to control machinery. They can perform tasks such as cutting, drilling, and shaping materials.
- **Advantages:** High precision, repeatability, and ability to produce complex shapes.
- **Applications:** Used in manufacturing industries for producing metal and plastic parts, automotive components, and aerospace parts.

Robotics

- **Definition:** Robots are programmable machines capable of carrying out a series of actions autonomously or semi-autonomously. They are equipped with sensors, actuators, and controllers.
- Types of Robots:
  - **Industrial Robots:** Used in manufacturing for tasks such as welding, painting, and assembly.
  - **Collaborative Robots (Cobots):** Designed to work alongside humans safely.
  - **Autonomous Mobile Robots (AMRs):** Used for material transport and logistics within facilities.

Artificial Intelligence (AI) and Machine Learning (ML)

- **Definition:** AI and ML are technologies that enable machines to learn from data and make decisions. AI involves simulating human intelligence, while ML is a subset of AI focused on training algorithms to improve performance over time.
- **Advantages:** Enhanced decision-making, predictive maintenance, and process optimization.
- **Applications:** Used in quality control, predictive maintenance, supply chain optimization, and customer service.

Challenges of Automation

- High initial cost
  - Investment in Equipment: Automation requires significant upfront investment in hardware such as robots, sensors, and control systems.
  - Software and Integration Costs: Implementing automation involves costs for software licenses, custom programming, and system integration.
- Maintenance and skill requirements
  - Regular Maintenance: Automated systems require regular maintenance to ensure they operate efficiently and to prevent downtime.
  - Skilled Workforce: Maintaining and troubleshooting automated systems requires a workforce with specialized technical skills.
- Integration with existing systems
  - Regular Maintenance: Automated systems require regular maintenance to ensure they operate efficiently and to prevent downtime.
  - Skilled Workforce: Maintaining and troubleshooting automated systems requires a workforce with specialized technical skills.

Challenges of Automation

- Cybersecurity risks
  - Compatibility Issues: Integrating new automation technologies with existing systems can be complex due to compatibility issues.
  - Data Interoperability: Ensuring seamless data flow between different systems and technologies is crucial for efficient automation.
- Workforce Displacement and Adaptation
  - Job Displacement: Automation can lead to the displacement of workers, particularly in roles that are repetitive and easily automated.
  - Need for Reskilling: Workers need to be reskilled or upskilled to manage, maintain, and operate automated systems.
- Complexity in Programming and Customization
  - Advanced Programming Requirements: Customizing and programming automated systems can be complex and time-consuming.
  - Tailored Solutions: Each automated solution often needs to be tailored to specific tasks and environments.
- Ethical and Legal Concerns
  - Ethical Considerations: The use of automation raises ethical questions about job displacement, worker rights, and the digital divide.
  - Regulatory Compliance: Automated systems must comply with industry regulations and standards, which can vary by region and sector.

Future of Automation

- Advances in AI and machine learning
  - Enhanced Decision-Making: AI and ML will enable more sophisticated decision-making processes, allowing automated systems to learn from data, optimize operations, and predict outcomes.
  - Predictive Maintenance: AI-powered predictive maintenance can foresee equipment failures before they happen, reducing downtime and maintenance costs.
  - Example: AI-driven quality control systems can detect defects in products more accurately and in real-time.
- IoT (Internet of Things) integration
  - Connected Devices: IoT will connect a vast network of devices, sensors, and machinery, allowing for seamless communication and data exchange.
  - Real-Time Monitoring: IoT-enabled automation systems will provide real-time monitoring and analytics, enhancing operational efficiency.
  - Example: Smart factories use IoT to monitor production lines, manage inventory, and track equipment performance.
- Autonomous systems
  - Self-Driving Vehicles: Autonomous vehicles and drones will revolutionize logistics, transportation, and delivery services, making them faster and more efficient.
  - Robotic Process Automation (RPA): RPA will handle repetitive tasks across various industries, improving accuracy and freeing up human workers for more complex tasks.
  - Example: Companies like Tesla and Google are developing autonomous vehicles for commercial and consumer use.

Future of Automation

- Human-Robot Collaboration
  - Self-Driving Vehicles: Autonomous vehicles and drones will revolutionize logistics, transportation, and delivery services, making them faster and more efficient.
  - Robotic Process Automation (RPA): RPA will handle repetitive tasks across various industries, improving accuracy and freeing up human workers for more complex tasks.
  - Example: Companies like Tesla and Google are developing autonomous vehicles for commercial and consumer use.
- Smart Manufacturing and Industry 4.0
  - Digital Twins: The concept of digital twins involves creating virtual replicas of physical assets, systems, and processes to simulate and optimize operations.
  - Advanced Analytics: Big data analytics will drive insights and innovations, enabling more efficient and flexible manufacturing processes.
  - Example: Industry 4.0 initiatives focus on integrating advanced technologies into manufacturing, creating smart factories that are highly automated and interconnected.
- Ethical and Social Implications
  - Job Transformation: While automation may displace some jobs, it will also create new opportunities, requiring a shift in workforce skills and education.
  - Regulation and Policy: Governments and organizations will need to develop policies and regulations to address the ethical and social implications of automation.
  - Example: Policies promoting reskilling and upskilling of workers will be essential to manage the transition to an automated workforce.

Future of Automation

- Sustainability and Green Technologies
  - Energy Efficiency: Automation can improve energy efficiency and reduce waste in various industries.
  - Sustainable Practices: Automated systems can support sustainable practices by optimizing resource use and minimizing environmental impact.
  - Example: Automated energy management systems in buildings can optimize heating, cooling, and lighting to reduce energy consumption.

Automation in Supply Chain Management

Automation in Supply Chain Management

- Role of Automation:
  - Automation in SCM enhances efficiency, accuracy, and speed across various supply chain processes, from procurement and production to distribution and logistics.
- Key Areas of Automation in SCM
  - Inventory Management
  - Warehouse Automation
  - Transportation and Logistics

Automation in Inventory Management

- **Automated Inventory Tracking:** Using RFID, barcodes, and IoT sensors to monitor inventory levels in real-time.
- **Benefits:** Reduces stockouts and overstock situations, improves order accuracy, and optimizes inventory turnover.
- **Example:** Amazon uses automated inventory tracking systems in its warehouses to manage millions of products efficiently.

Warehouse Automation

- **Automated Storage and Retrieval Systems (AS/RS):** Systems that automatically place and retrieve goods from storage locations.
- **Robotic Process Automation (RPA):** Robots and cobots performing tasks like picking, packing, and sorting.
- **Benefits:** Increases storage density, reduces labor costs, and improves order fulfillment speed and accuracy.
- **Example:** Automated warehouses like those operated by Ocado use robots to handle the majority of the picking and packing processes.

Automation in Transportation and Logistics

- **Automated Guided Vehicles (AGVs) and Drones:** Used for moving goods within warehouses and for last-mile delivery.
- **Fleet Management Systems:** Use of GPS and telematics for real-time tracking and optimization of delivery routes.
- **Benefits:** Enhances delivery speed, reduces transportation costs, and improves supply chain visibility.
- **Example:** Companies like DHL use drones for quick and efficient delivery in remote areas.

Advanced Technologies in SCM Automation

- Artificial Intelligence (AI) and Machine Learning (ML)
- Blockchain Technology
- Internet of Things (IoT)

Artificial Intelligence (AI) and Machine Learning (ML)

- **Predictive Analytics:** AI and ML algorithms predict demand patterns, optimize stock levels, and forecast supply chain disruptions.
- **Benefits:** Improves demand planning, reduces excess inventory, and enhances overall supply chain resilience.
- **Example:** Retailers like Walmart use AI-driven predictive analytics to manage inventory and ensure products are available when and where they are needed.

Internet of Things (IoT)

- **Connected Devices:** IoT sensors and devices monitor and transmit data on goods and processes in real-time.
- **Benefits:** Provides real-time visibility, improves asset tracking, and enhances decision-making.
- **Example:** IoT-enabled temperature sensors monitor the conditions of perishable goods during transit, ensuring they are stored and transported at the correct temperatures.

Blockchain Technology

- **Transparency and Traceability:** Blockchain provides an immutable ledger for recording transactions, ensuring transparency and traceability in the supply chain.
- **Benefits:** Enhances trust, reduces fraud, and ensures compliance with regulations.
- **Example:** IBM's Food Trust blockchain platform helps track food products from farm to table, ensuring food safety and quality.

Benefits of Automation in SCM

- **Cost Reduction:** Automation reduces labor costs, minimizes errors, and optimizes resource utilization.
- **Efficiency and Speed:** Automated systems streamline processes, leading to faster production and delivery times.
- **Accuracy and Precision:** Automation improves the accuracy of inventory management, order processing, and demand forecasting.
- **Scalability:** Automated systems can easily scale to meet increased demand without proportional increases in labor costs.
- **Customer Satisfaction:** Faster and more accurate order fulfillment leads to higher customer satisfaction and loyalty.

Challenges and Considerations

- **Implementation Costs:** High initial investment in technology and infrastructure.
- **Integration with Existing Systems:** Ensuring new automated systems work seamlessly with legacy systems.
- **Workforce Impact:** Need for retraining and reskilling employees to work with automated systems.
- **Data Security:** Protecting automated systems from cyber threats and ensuring data integrity.
- **Regulatory Compliance:** Adhering to industry regulations and standards when implementing automated solutions.

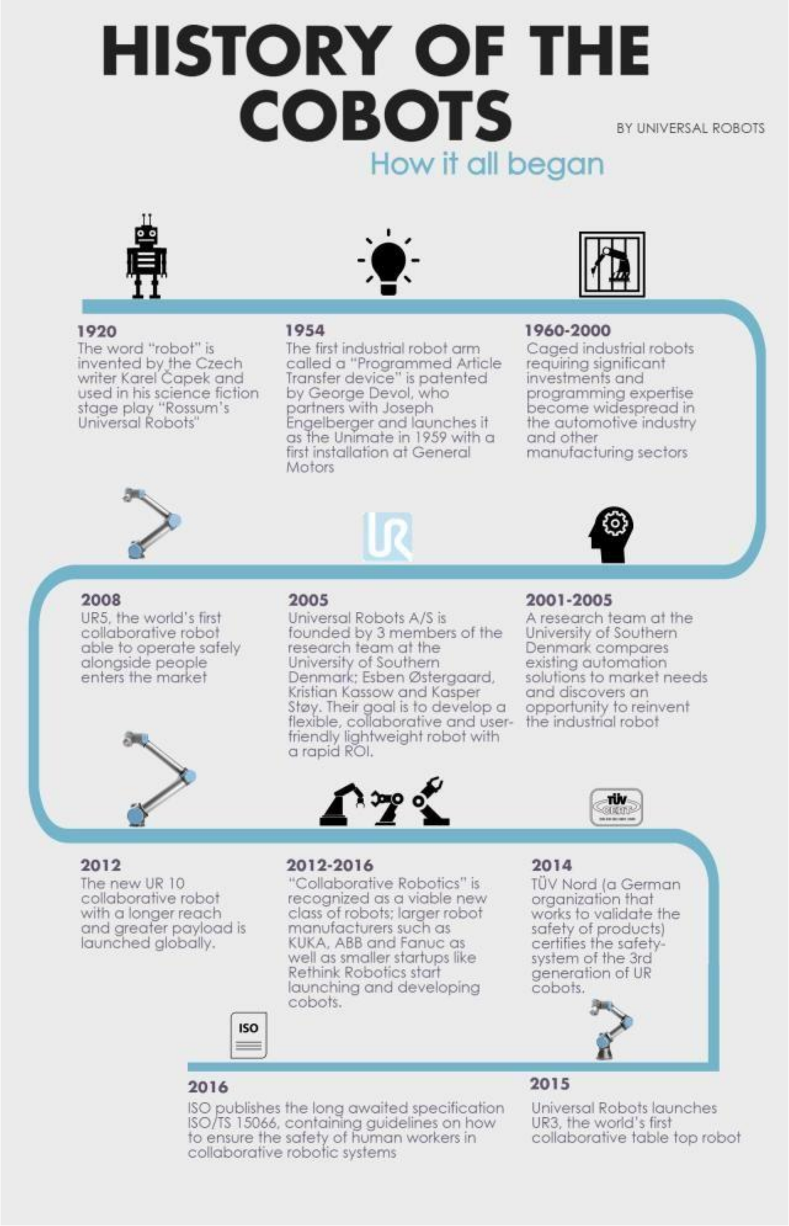
Advanced Robotics

Introduction to Advanced Robotics

- **Advanced Robotics:**
  - Advanced robotics involves the development and use of robots that can perform complex tasks autonomously or semi-autonomously, often with a high degree of precision and adaptability.
- **Key Characteristics:**
  - These robots are equipped with sophisticated sensors, artificial intelligence (AI), and machine learning (ML) algorithms, allowing them to interact with their environment, learn from experiences, and improve their performance over time.

Historical Development of Robotics

- **Early Robots:** The concept of robots dates back to ancient civilizations with automata, simple mechanical devices designed to perform specific tasks.
- **Industrial Revolution:** The development of powered machinery and early control systems during the Industrial Revolution laid the groundwork for modern robotics.
- **20th Century Innovations:** The introduction of electronic control systems, computers, and the first programmable robots in the mid-20th century marked significant milestones in robotics development.
- **21st Century Advances:** Recent advancements in AI, ML, and sensor technology have propelled robotics into new applications and capabilities.



Key Technologies in Advanced Robotics

- Sensors and Actuators
  - Sensors: Provide robots with data about their environment, including vision sensors (cameras), touch sensors, proximity sensors, and more.
  - Actuators: Mechanisms that enable robots to move and interact with their environment, such as motors, hydraulic systems, and pneumatic systems.
- Artificial Intelligence (AI)
  - Machine Learning (ML): Allows robots to learn from data and experiences, improving their decision-making and performance over time.
  - Computer Vision: Enables robots to interpret and understand visual information from the surrounding environment.
- Control Systems
  - Feedback Control: Systems that adjust robot actions based on feedback from sensors to achieve desired outcomes.
  - Path Planning and Navigation: Algorithms that allow robots to determine optimal paths and navigate complex environments.

Types of Advanced Robots

- **Industrial Robots:** Used primarily in manufacturing and production settings for tasks such as welding, painting, assembly, and material handling.
- **Collaborative Robots (Cobots):** Designed to work alongside humans, enhancing human capabilities and improving safety. Cobots are often used in manufacturing, healthcare, and logistics.

Types of Advanced Robots

- **Autonomous Mobile Robots (AMRs):** Capable of navigating and performing tasks without human intervention. AMRs are commonly used in warehousing, logistics, and agriculture.
- **Service Robots:** Robots designed to assist humans in various services, including healthcare (surgical robots, rehabilitation robots), hospitality (hotel service robots), and domestic tasks (cleaning robots, lawn mowing robots).

Applications of Advanced Robotics

- **Manufacturing:** Advanced robots are used for precision assembly, quality control, and hazardous material handling.
- **Healthcare:** Robots assist in surgeries, rehabilitation, patient care, and drug delivery.
- **Logistics and Warehousing:** Robots are used for sorting, picking, packing, and transporting goods.
- **Agriculture:** Robots perform tasks such as planting, harvesting, and monitoring crop health.
- **Service Industries:** Robots provide customer service, cleaning, and maintenance in various settings.

Benefits of Advanced Robotics

- Increased Efficiency and Productivity
- Enhanced Safety
- Cost Savings:
- Precision and Accuracy:
- Flexibility and Adaptability
- Improved Data Collection and Analysis
- Innovation and Competitive Advantage:

Challenges of Advanced Robotics

- High Initial Costs
- Complex Implementation:
- Technical Challenges:
- Workforce Impact:
- Cybersecurity Risks:
- Ethical and Social Concerns:
- Adaptation and Change Management:

Advanced Robotics in Supply Chain Management

Advanced Robotics in Supply Chain Management

- Advanced robotics in supply chain management (SCM) refers to the use of sophisticated robotic systems to automate and optimize various supply chain processes, from procurement and production to distribution and logistics.
- Significance: The integration of advanced robotics enhances efficiency, accuracy, and scalability, leading to more responsive and resilient supply chains.
- Key Applications:
  - Warehouse Automation:
  - Automated Sorting and Packaging:
  - Inventory Management:
  - Transportation and Logistics:
  - Quality Control and Inspection:

Warehouse Automation

- Automated Storage and Retrieval Systems (ASRS): Robots that automatically store and retrieve goods, increasing storage density and reducing picking times.
- Autonomous Mobile Robots (AMRs): Mobile robots that navigate warehouses to transport goods, streamline order fulfillment, and reduce labor costs.
- Example: Companies like Amazon and Ocado use AS/RS and AMRs to enhance their warehouse operations, ensuring fast and accurate order processing.

Automated Sorting and Packaging:

- Robotic Sorters: High-speed robotic systems that sort products based on size, weight, and destination, improving throughput and accuracy.
- Robotic Packaging: Robots that handle packaging tasks, from assembling boxes to wrapping and labeling, ensuring consistency and reducing manual labor.
- Example: FedEx and UPS use robotic sorters to handle large volumes of packages efficiently during peak seasons.

Inventory Management:

- Real-Time Inventory Tracking: Robots equipped with RFID and IoT sensors monitor inventory levels in real-time, providing accurate stock data and reducing stockouts.
- Automated Cycle Counting: Robots perform regular inventory audits, ensuring inventory accuracy and reducing the need for manual counts.
- Example: Walmart uses drones to perform inventory checks in its distribution centers, significantly reducing the time required for inventory audits.

Transportation and Logistics

- Autonomous Delivery Vehicles: Self-driving trucks and drones that transport goods from warehouses to distribution centers and end customers, reducing delivery times and costs.
- Fleet Management: Advanced robotics integrated with fleet management systems optimize delivery routes, monitor vehicle conditions, and improve fuel efficiency.
- Example: Companies like Tesla and Google are developing autonomous delivery vehicles to revolutionize last-mile delivery logistics.

Quality Control and Inspection

- Vision Systems: Robots with advanced vision systems inspect products for defects and ensure compliance with quality standards, reducing waste and rework.
- Predictive Maintenance: Robots equipped with sensors monitor equipment health, predict maintenance needs, and prevent unexpected breakdowns.
- Example: In the automotive industry, robots inspect parts and assemblies for defects, ensuring high quality and consistency in production.

Benefits of Advanced Robotics in SCM

- Increased Efficiency: Automation of repetitive and time-consuming tasks leads to faster processing times and higher throughput.
- Improved Accuracy: Robots perform tasks with high precision, reducing errors in picking, packing, and inventory management.
- Cost Savings: Reduction in labor costs, improved resource utilization, and optimized logistics result in significant cost savings.
- Scalability: Advanced robotics systems can scale operations up or down based on demand, providing flexibility in supply chain management.
- Enhanced Safety: Robots handle hazardous tasks, reducing the risk of workplace injuries and improving overall safety in supply chain operations.

Challenges and Considerations

- High Initial Investment: Significant capital expenditure is required to develop and deploy advanced robotic systems.
- Integration with Existing Systems: Ensuring compatibility and seamless integration with existing supply chain management systems can be complex.
- Maintenance and Support: Regular maintenance and technical support are essential to keep robotic systems operational and efficient.
- Workforce Impact: Adoption of advanced robotics may lead to job displacement, necessitating reskilling and upskilling of the workforce.
- Data Security: Protecting robotic systems and the data they generate from cyber threats is crucial for maintaining supply chain integrity.

Future Trends

- AI and Machine Learning Integration: Enhanced AI and ML capabilities will make robots more autonomous, intelligent, and capable of handling complex tasks.
- IoT and Connectivity: Increased connectivity through IoT will enable real-time monitoring, analytics, and decision-making across the supply chain.
- Collaborative Robots (Cobots): Growing use of cobots will facilitate human-robot collaboration, enhancing productivity and safety in supply chain operations.
- Sustainable Robotics: Development of energy-efficient and eco-friendly robotic systems will support sustainable supply chain practices.
- Example: Emerging trends such as smart factories and digital twins will further revolutionize supply chain management, providing end-to-end visibility and control.

Case Studies

Case Study - DHL

- Challenges Faced by DHL:
  - Operational Efficiency: Need to improve operational efficiency and handle increasing volumes of shipments due to the growth of e-commerce.
  - Accuracy and Speed: Requirement to enhance the accuracy and speed of order fulfillment to meet customer expectations.
  - Labor Shortages: Addressing labor shortages and reducing the reliance on manual labor in warehouse operations.
  - Cost Reduction: Need to reduce operational costs while maintaining high service levels and reliability.

Case Study - DHL

- Implementation of Advanced Robotics:
  - Automated Guided Vehicles (AGVs):
    - Function: AGVs are used to transport goods within warehouses, reducing manual handling and increasing throughput.
  - Robotic Picking Systems:
    - Function: Robots equipped with vision systems and AI are used to pick and place items in the order fulfillment process.
  - Collaborative Robots (Cobots):
    - Function: Cobots work alongside human workers, assisting with tasks such as packing, sorting, and palletizing.
  - Automated Sorting Systems:
    - Function: High-speed sorting systems automatically sort parcels based on destination, size, and weight.

Class Discussion and Presentation

Introduction to Digital Manufacturing

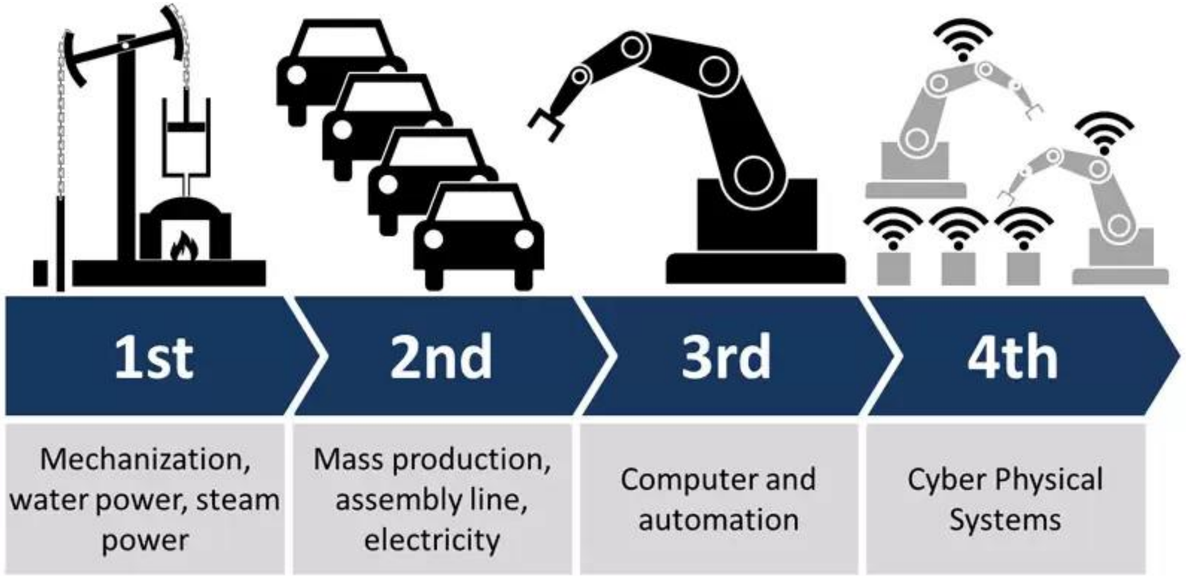
Instructor: Asst Prof Wang Pei

Content

- Overview of digital manufacturing
- Core Technologies in Digital Manufacturing
- Impact of Digital Manufacturing on Supply Chains
- Case studies

Overview of Manufacturing Evolution

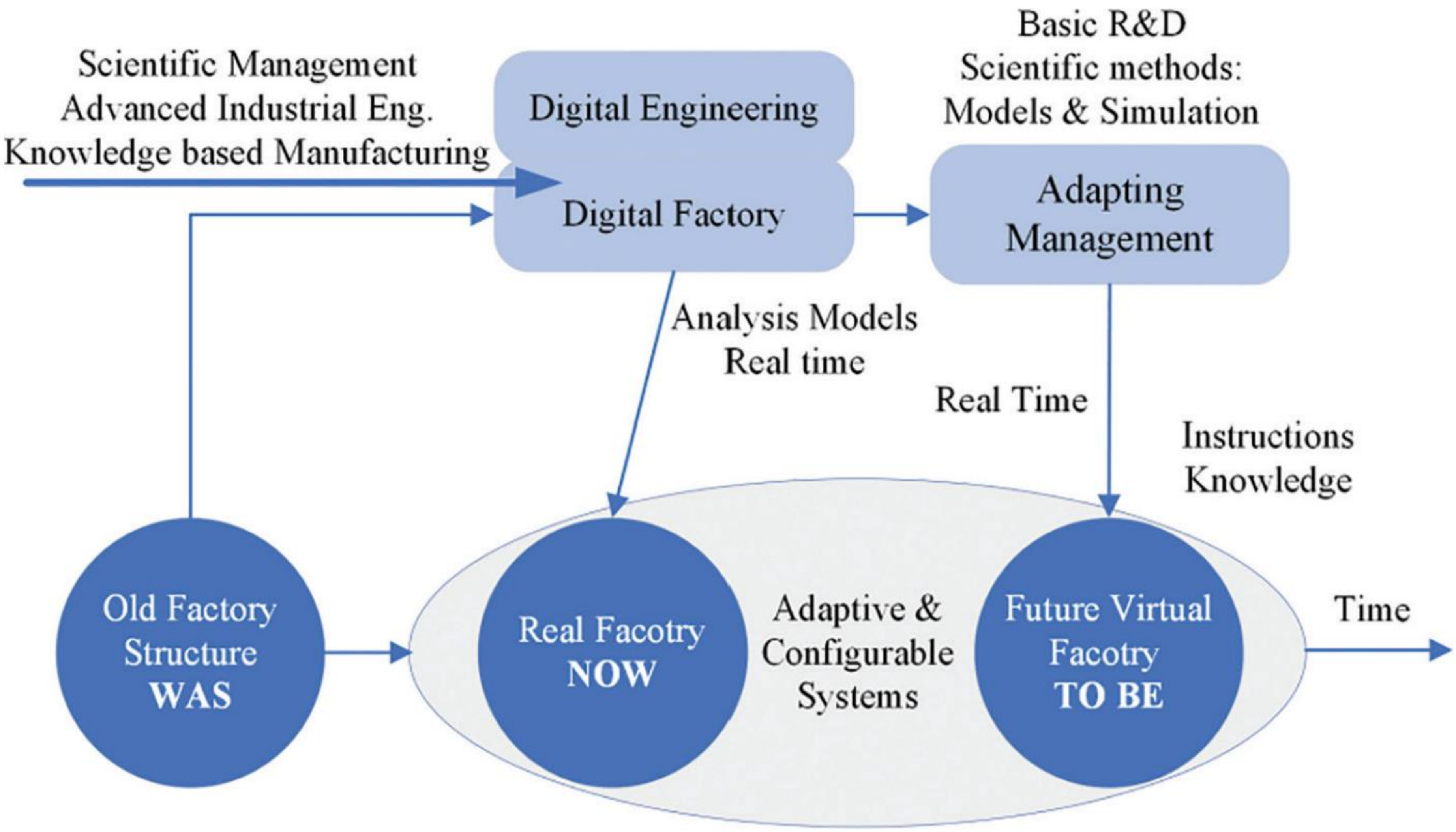
- From Industry 1.0 (mechanization) to Industry 4.0 (cyber-physical systems)
- Industry 1.0: Mechanization
- Industry 2.0: Mass production
- Industry 3.0: Automation and computers
- Industry 4.0: Cyber-physical systems and IoT



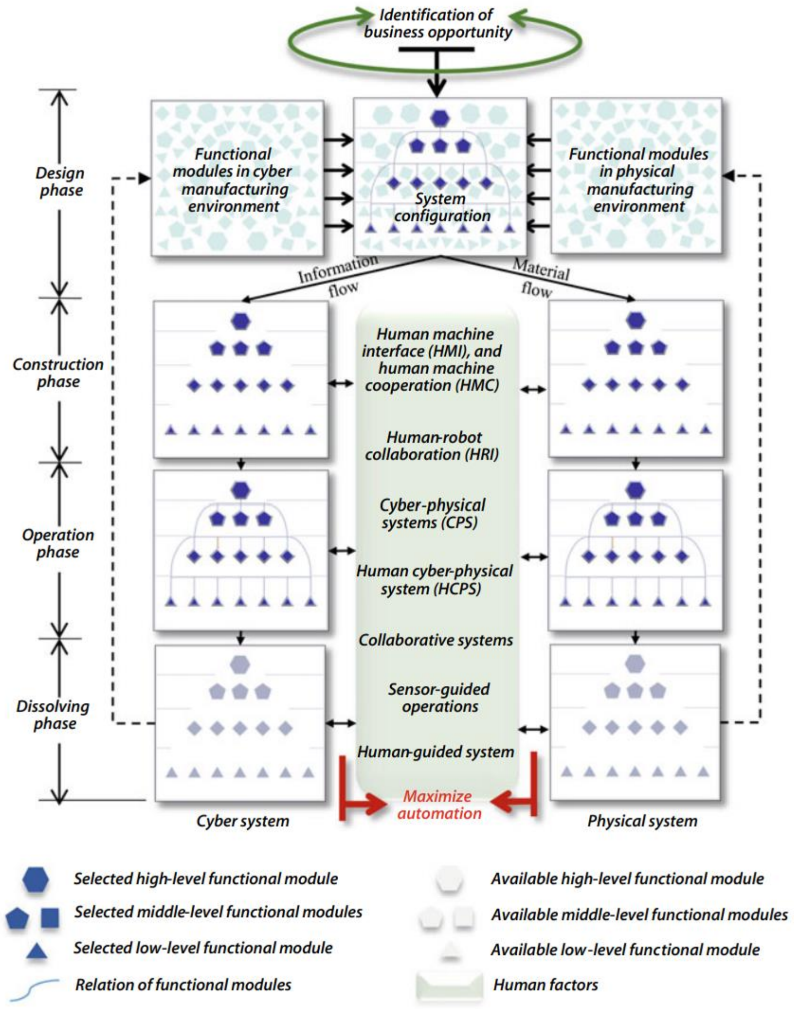
What is Digital Manufacturing?

- Integration of advanced digital technologies into manufacturing processes
- Use of computer systems for process control and data management
- Examples: CAD, CAM, ERP systems

A generic digital manufacturing framework

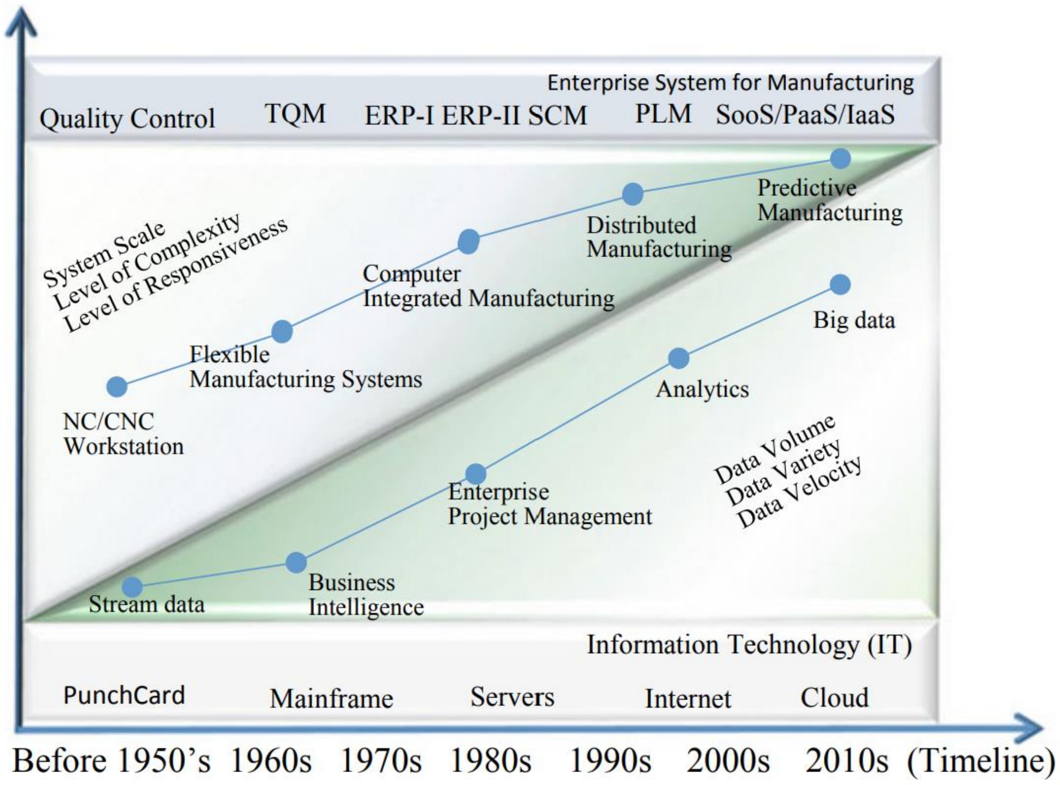


Computers for the automation in modern manufacturing system



- Activities in the information flow,
  - Computers are used to support decision-making activities at all phases of manufacturing systems' lifecycles from design, construction, operation, to the dissolve phase.
- Activities in the material flow,
  - computers are used to mechanize and automate manufacturing operations;
  - intelligent machines such as computer numerical control (CNC) machines and automated guided vehicles (AGVs) are widely used to replace human operations.

Evolution of computer-aided technologies in manufacturing



- ERP: enterprise resource planning
  - software system that helps you run your entire business, supporting automation and processes in finance, human resources, manufacturing, supply chain, services, procurement, and more.
- SCM?
- PLM: product lifecycle management
  - set of processes and technologies used to manage the entire lifecycle of a product, from conception to disposal.
- SaaS: software as a service
- PaaS: platform as a service
- IaaS: Infrastructure as a service

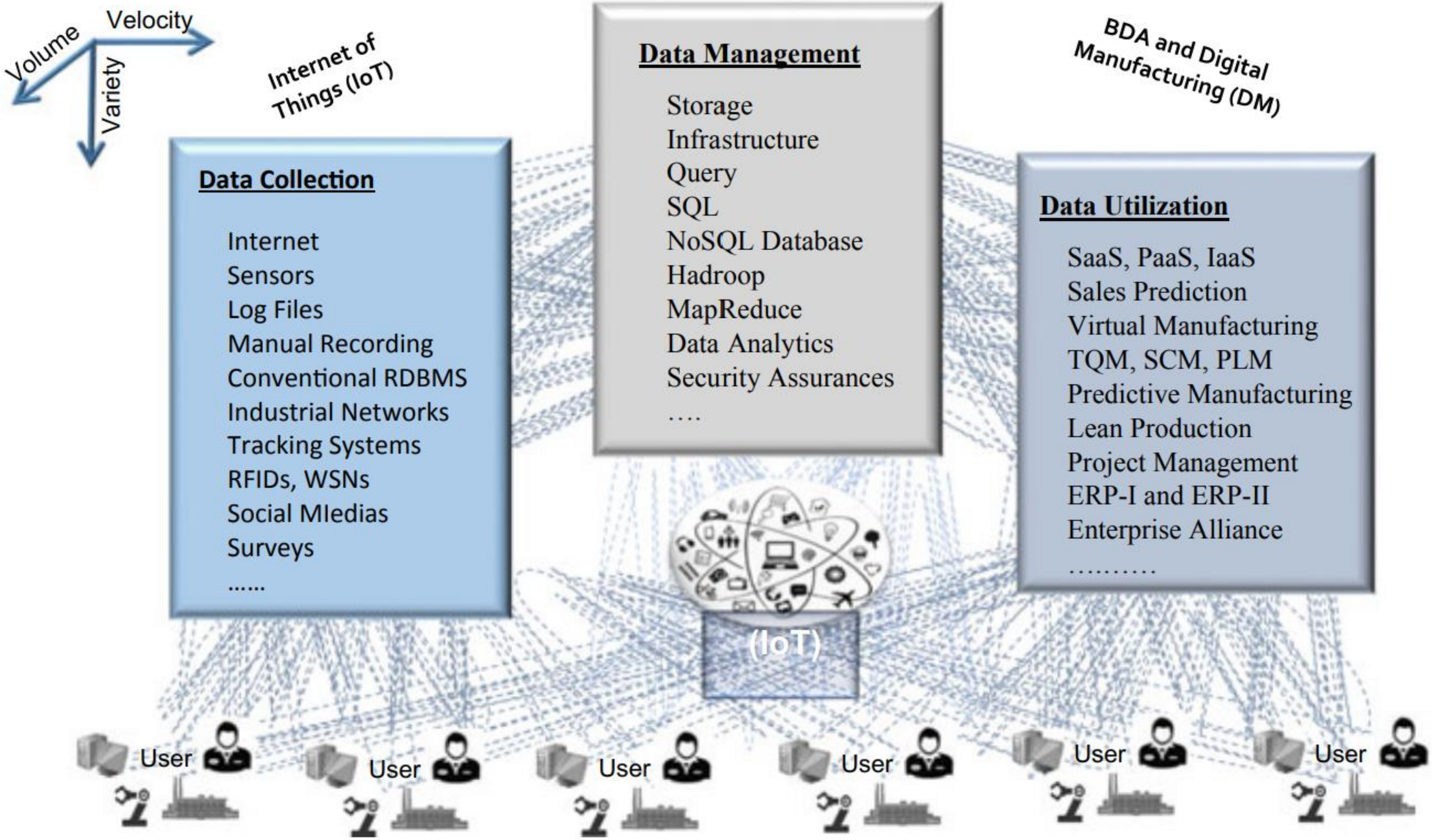
Core Technologies in Digital Manufacturing

- Internet of Things (IoT)
- Big Data and Analytics
- Artificial Intelligence (AI)
- Cyber-Physical Systems (CPS)

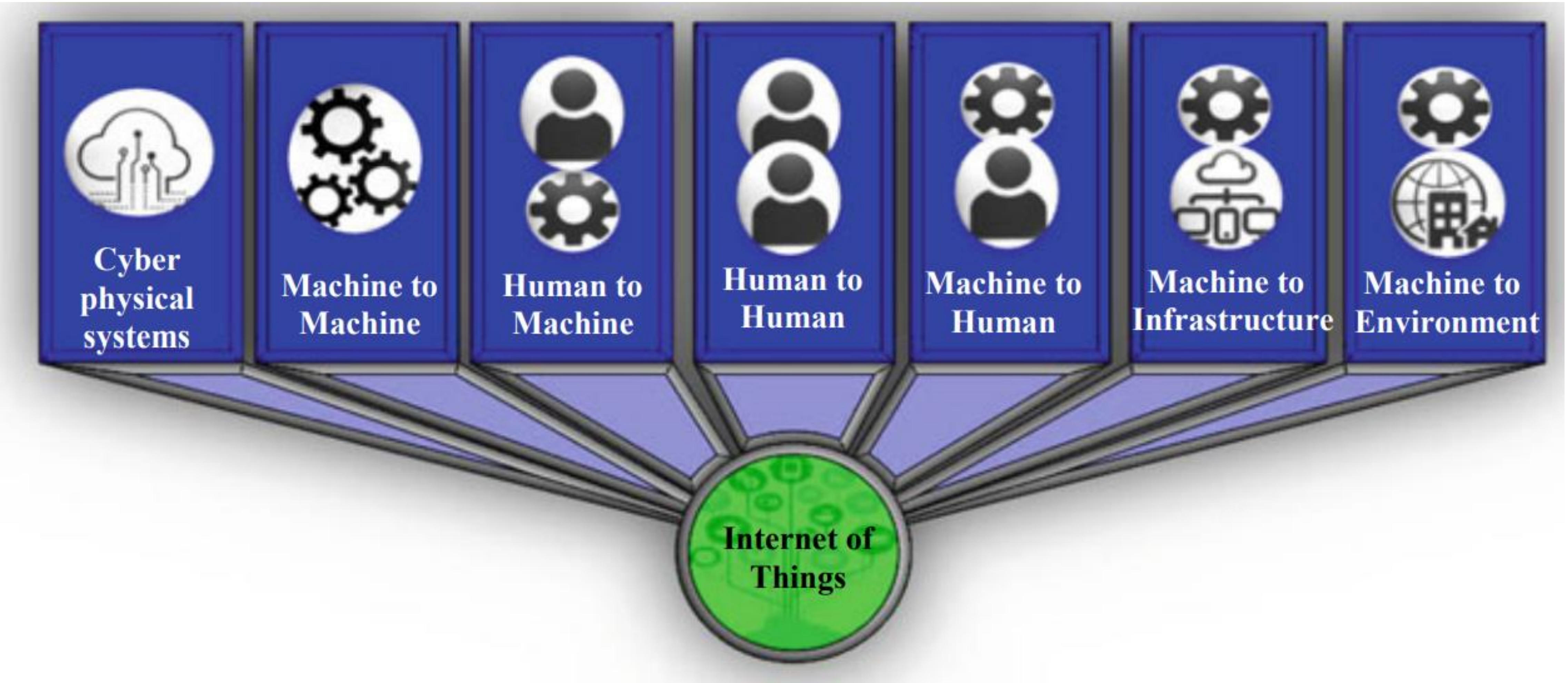
Internet of Things (IoT)

- Network of interconnected devices
- Real-time data collection and communication
- Applications: Smart factories, remote monitoring, and asset tracking

Internet of Things (IoT) in enterprise systems



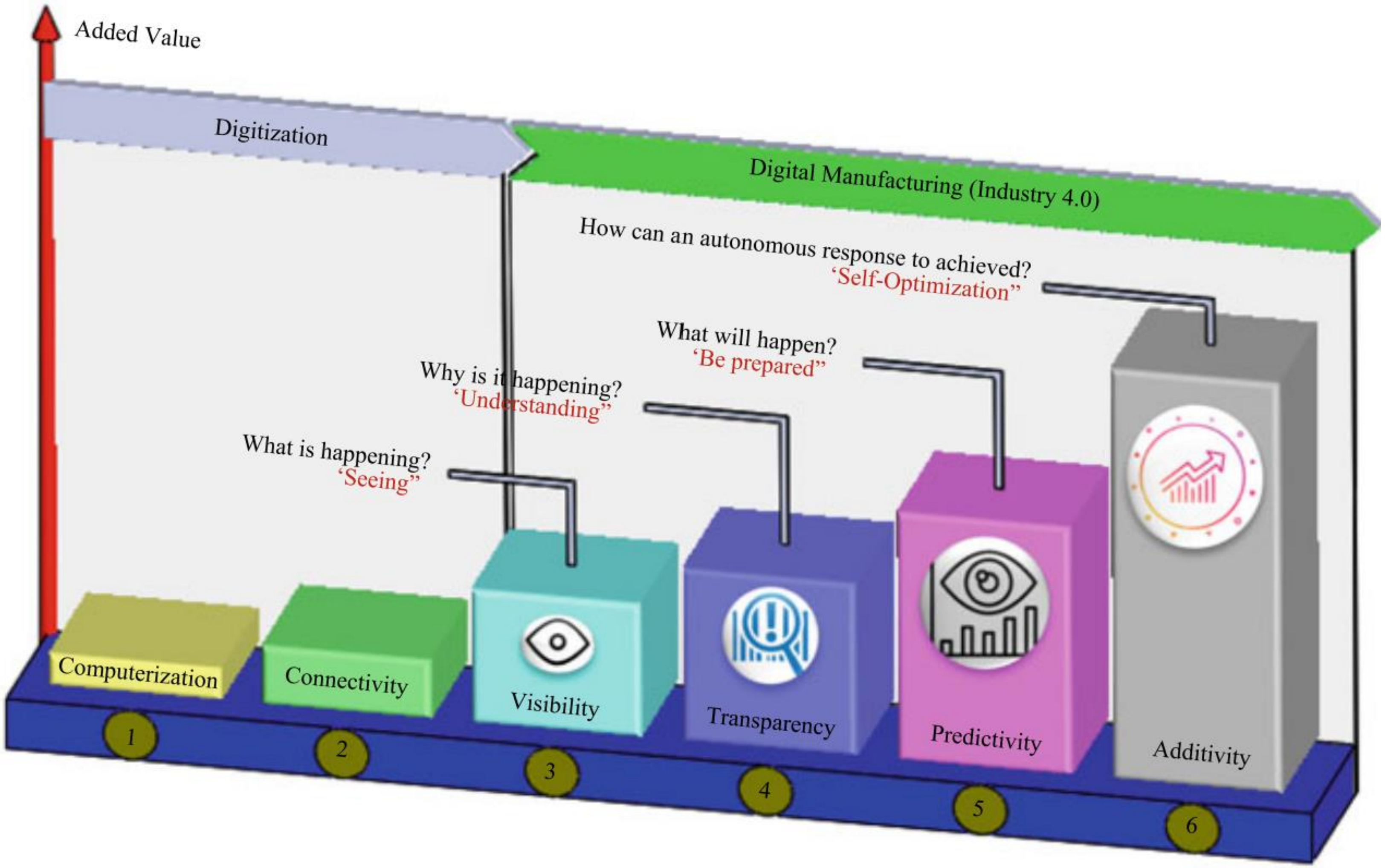
IoT makes any interaction possible



Big Data and Analytics (BDA)

- Collection and analysis of large data sets
- Enhancing decision-making and operational efficiency
- Examples: Predictive maintenance, quality control, supply chain optimization

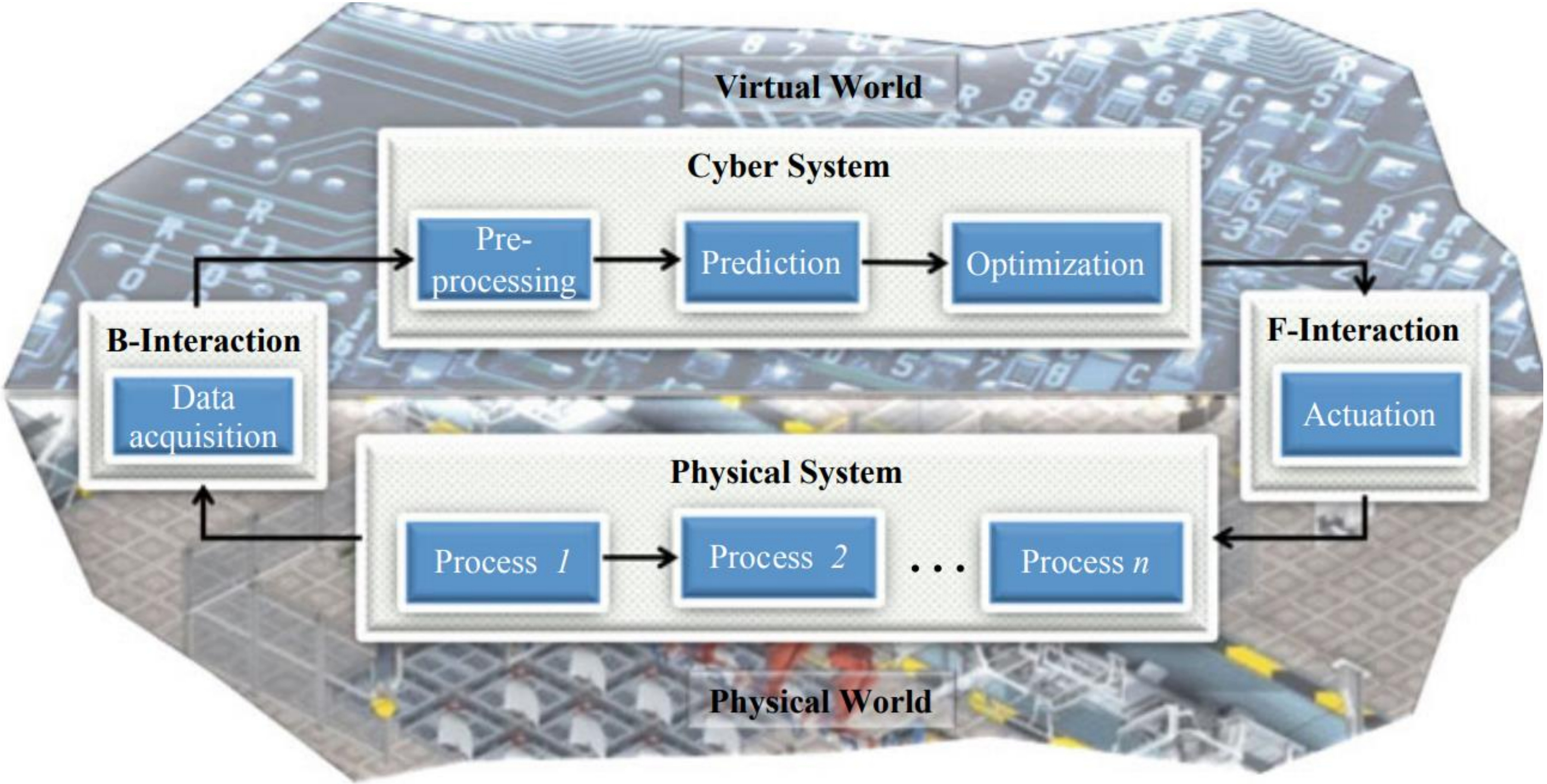
The goals of BDA in digital manufacturing



Cyber-Physical Systems (CPS)

- Integration of physical processes with digital control systems
- Real-time data exchange between systems
- Applications: Autonomous systems, real-time monitoring, process optimization

Main components in CPS

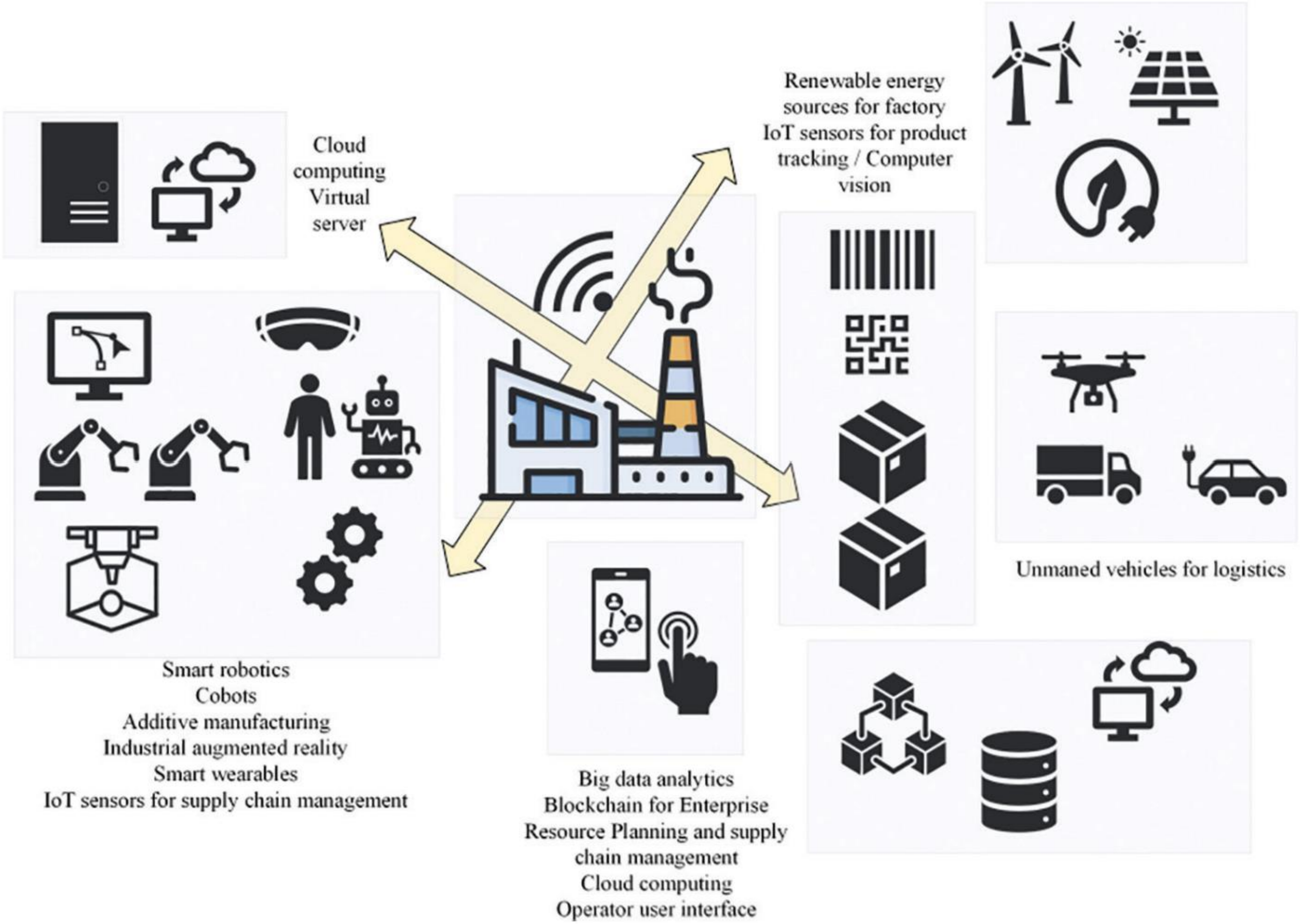


Artificial Intelligence (AI)

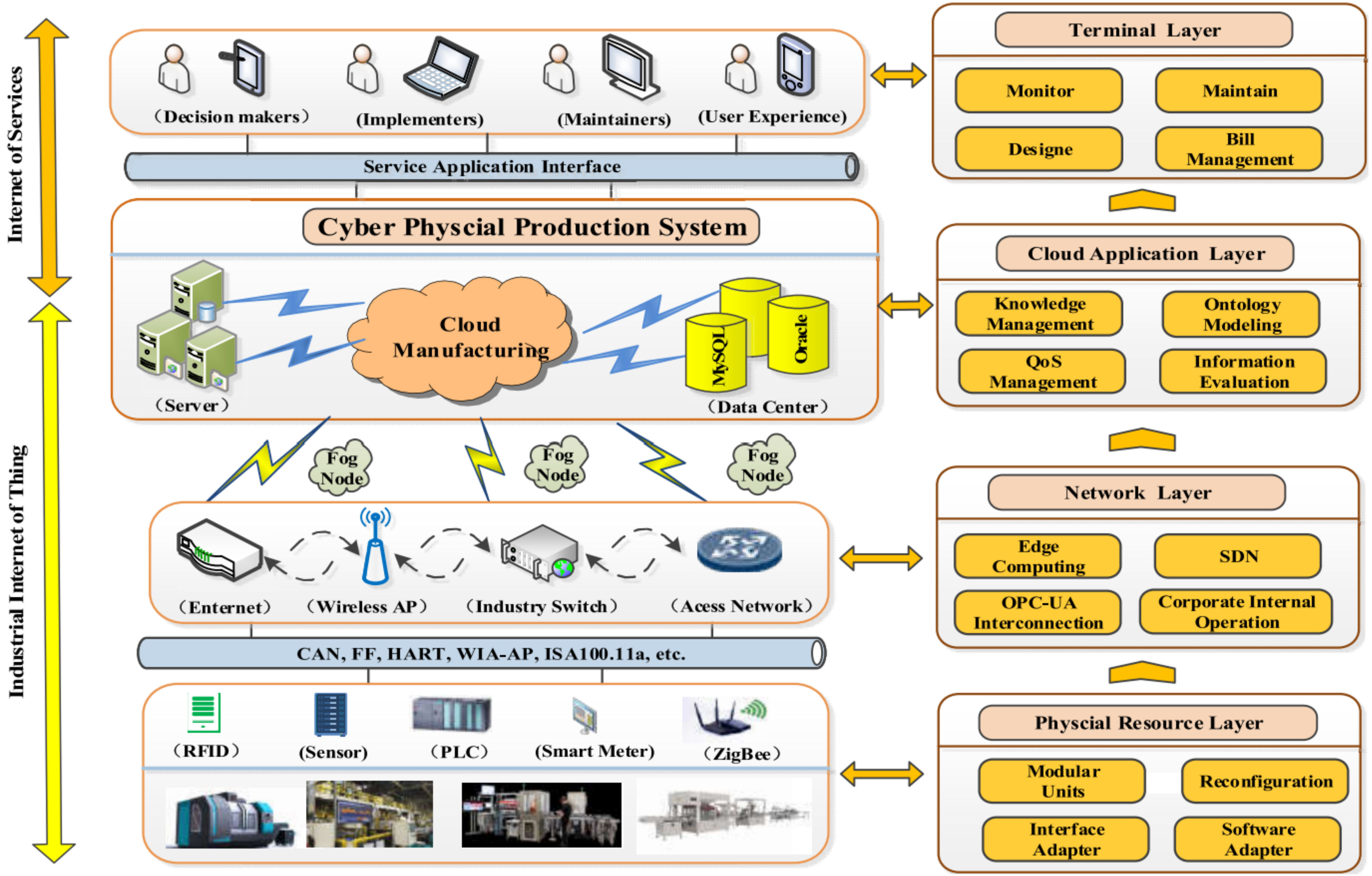
- Automation of complex tasks
- Machine learning for predictive analytics
- Examples: Robotics control, quality inspection, demand forecasting

Elements of a smart factory

The aim of digital manufacturing is to take advantage of new technologies to make processes more economical and productive.



Hierarchical architecture of smart factory



Impact of Digital Manufacturing on Supply Chains

- Enhanced efficiency and reduced costs
- Real-time tracking and monitoring
- Improved demand forecasting and inventory management

Infineon’s smart factory

- Which Industry 4.0 technologies did they use?

Xiaomi’s smart factory

- What is “light off factory”?

Midea's Smart Factory

- Which Industry 4.0 technologies did they use?

Challenges in Implementing Smart Factory

- Intelligent Requirements of Equipment
  - Data acquisition is the basis of big data analytics, where physical resource should:
    - support fine-grained and efficient data acquisition, and achieve visibility of manufacturing process
    - integrate heterogeneous data in a unified system by generic protocols (e.g., RFID, ZigBee, and NFC)
    - improve extensibility of controller for access to the core industrial networks

Challenges in Implementing Smart Factory

- Deep Integration Networks
  - IIoT (Industrial Internet of Things) facilitates deep integration of information and industrialization.
    - Advanced IIoT technology is crucial for implementing smart factories.
  - Requirement
    - Data transmission must be reliable and real-time in complex electromagnetic environments.
    - High transmission rates, low duty cycles, and IP network availability are essential for ubiquitous communication in smart factories.

Challenges in Implementing Smart Factory

- Knowledge-driven Manufacturing
  - Manufacturing data in smart factories requires semantic definition through a manufacturing glossary due to its high dimensionality, variable metrics, and noise.
  - Smart factories require to integrate various data resources (supply chains, product data, logistic data) into service platforms for functions like sales forecasting and quality analysis.

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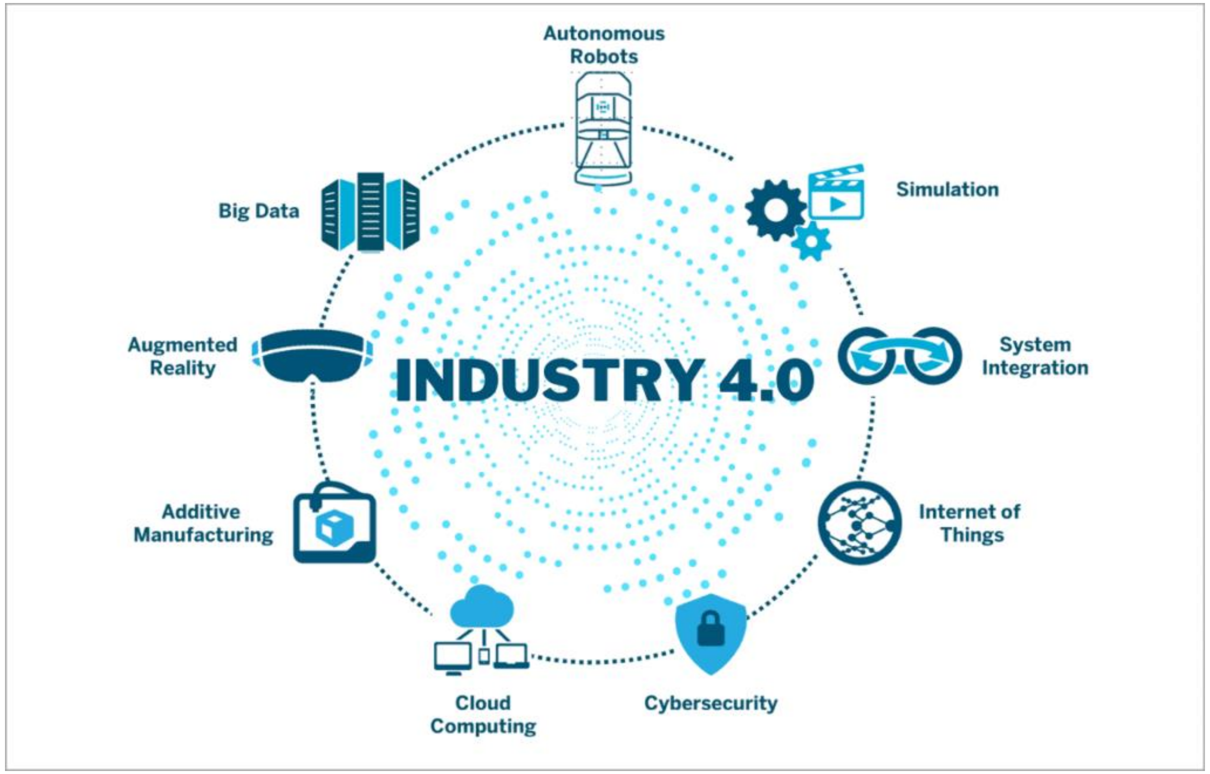
SINGAPORE INSTITUTE OF TECHNOLOGY

Smart Manufacturing – 3D Printing and Impact on Supply Chain Reformation – part 1

Instructor: Asst Prof Wang Pei

Industry 4.0

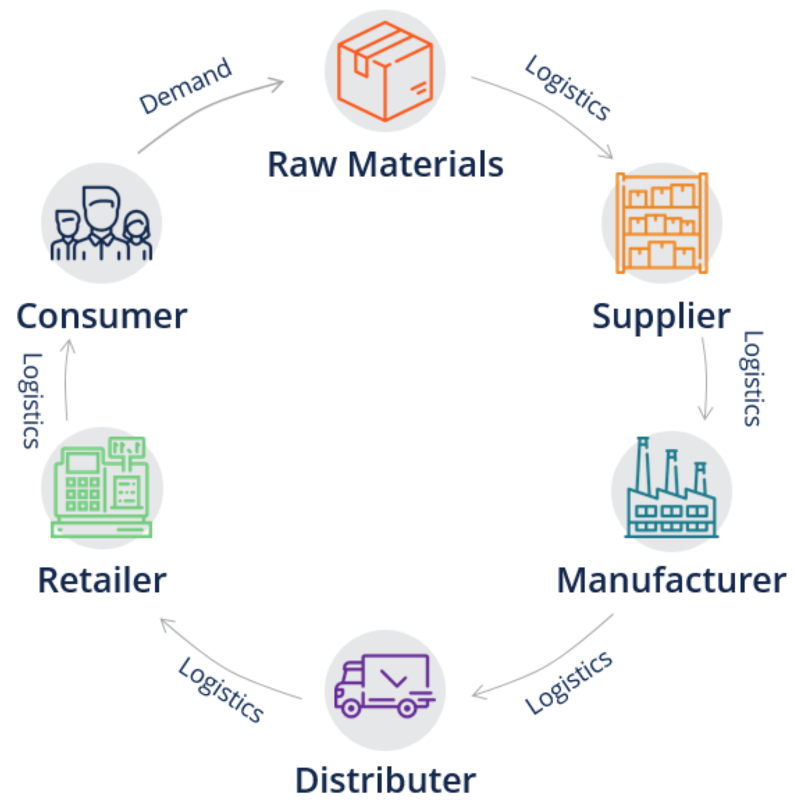
- Industry 4.0
  - Originated in early 2000
  - Government-backed initiative in Germany
  - Several related innovation technologies
  - Design principles for the wider applications of Industry 4.0
    - Interoperability
    - Virtualization
    - Decentralization
    - Real-time capabilities
    - Service orientation
    - Modularity



Aktas E, Bourlakis M, Minis I, Zeimpekis V. Supply Chain 4.0 Enabling market-driven strategies. Supply Chain 4 0 : Improving Supply Chains with Analytics and Industry 40 Technologies. 1st ed: Kogan Page; 2021.

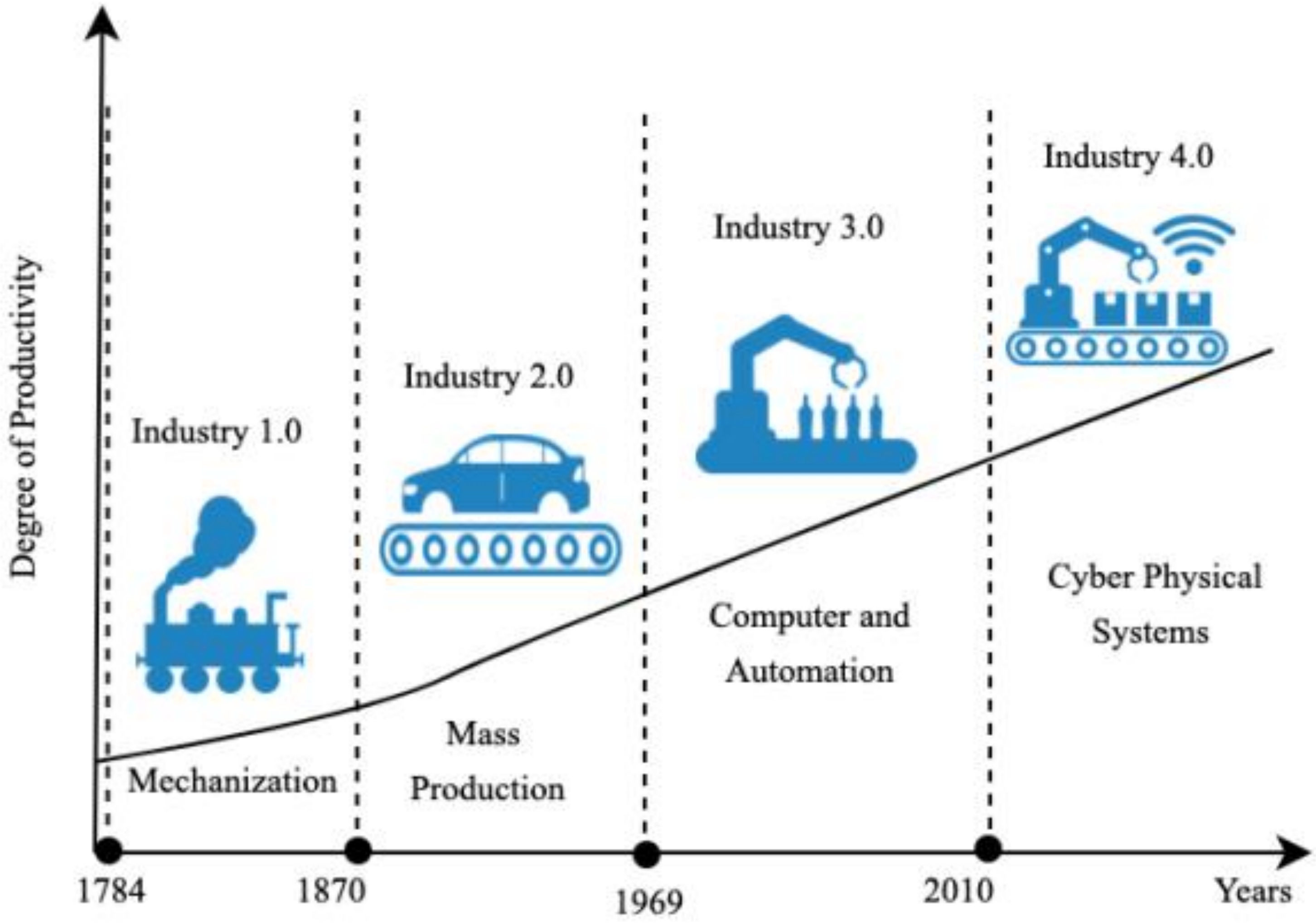
Supply Chain 4.0

- Supply Chain 4.0
  - Induced by Industry 4.0 for creating of supply/demand network.
  - Respond in short timescales to an ever-changing business environment
  - The changing shape of customer demand
  - From mass markets to ‘segments of one’
  - Transitioning from ‘forecast-driven’ to ‘demand-driven’
  - Digitalization of the supply chain allows
    - Faster
    - More flexible
    - More granular
    - More accurate
    - More efficient
  - Features
    - Manufacturing
    - Product shipping
    - Information flows



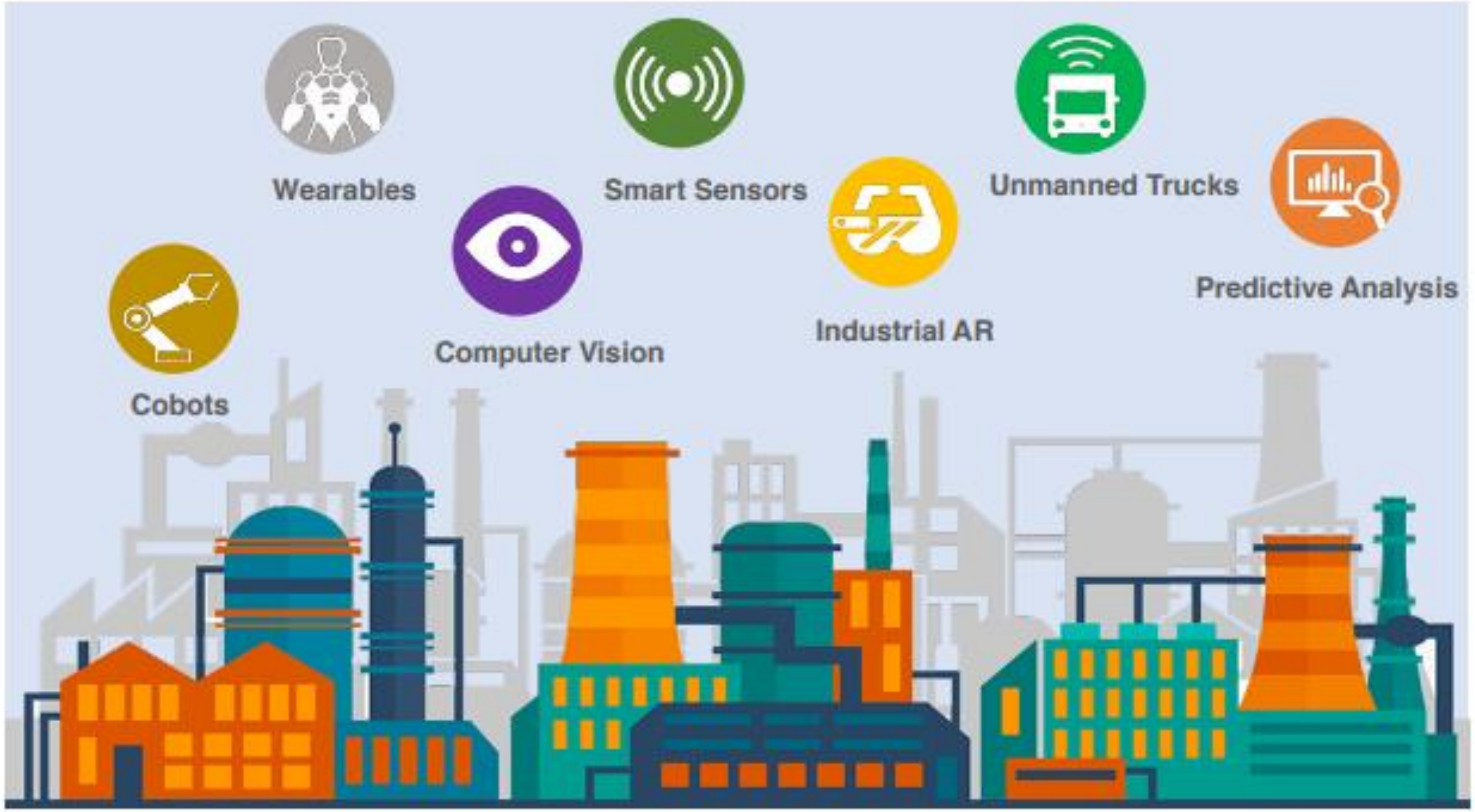
Generic Supply Chain

Evolution of Smart Manufacturing Systems (SMS)

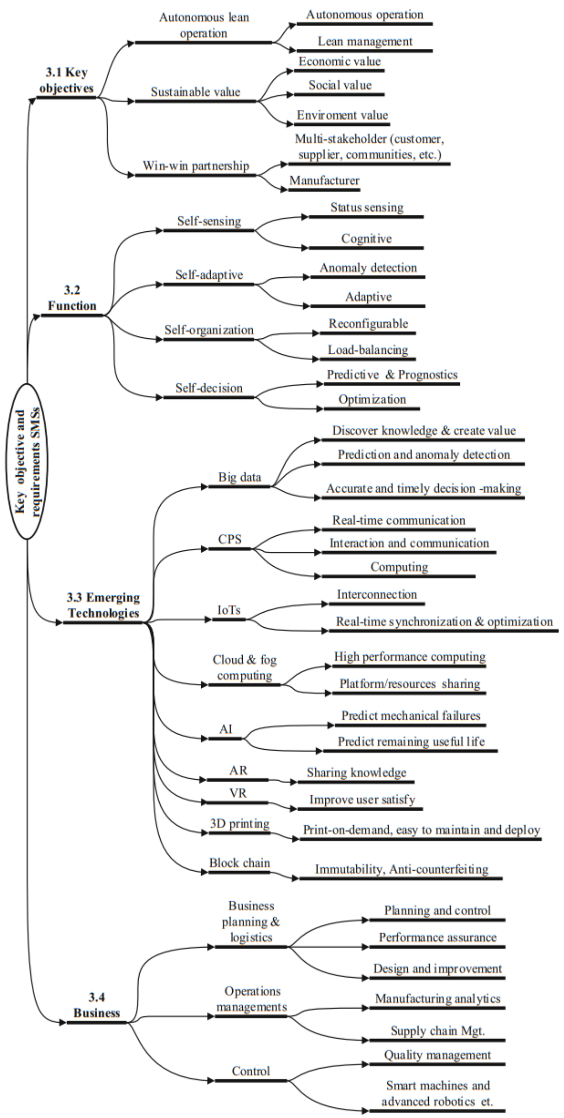


Qu YJ, Ming XG, Liu ZW, Zhang XY, Hou ZT. Smart manufacturing systems: state of the art and future trends. The International Journal of Advanced Manufacturing Technology. 2019;103(9-12):3751-68.

Components of SMSs



Mind-Map for SMSs Key Objective and Requirement



Qu YJ, Ming XG, Liu ZW, Zhang XY, Hou ZT. Smart manufacturing systems: state of the art and future trends. The International Journal of Advanced Manufacturing Technology. 2019;103(9-12):3751-68.

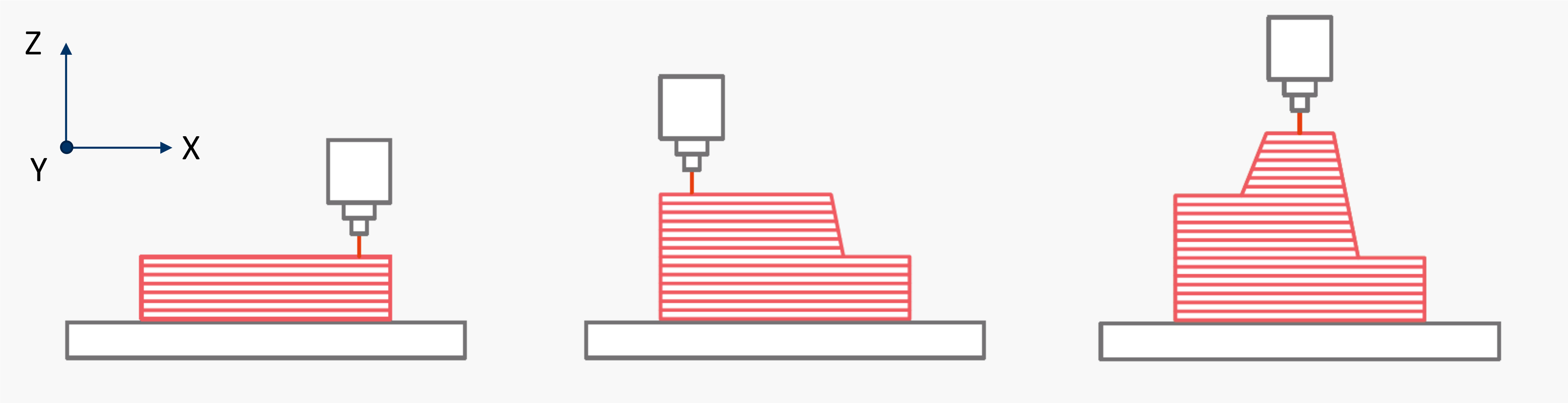
Recent Advances on Manufacturing – 3D printing

Process	Traditional manufacting	3D Printing
Geometry	Limitations	No limitations, flexible and complex parts, infill options
Nº of processes needed to get to final shape	One or more	One
Stocks needed	Yes	No
Profitability	Based on large batches	Indipendent of number of units
Goal	Mass production	Mass customization

Basic Principles of 3D Printing / Additive Manufacturing

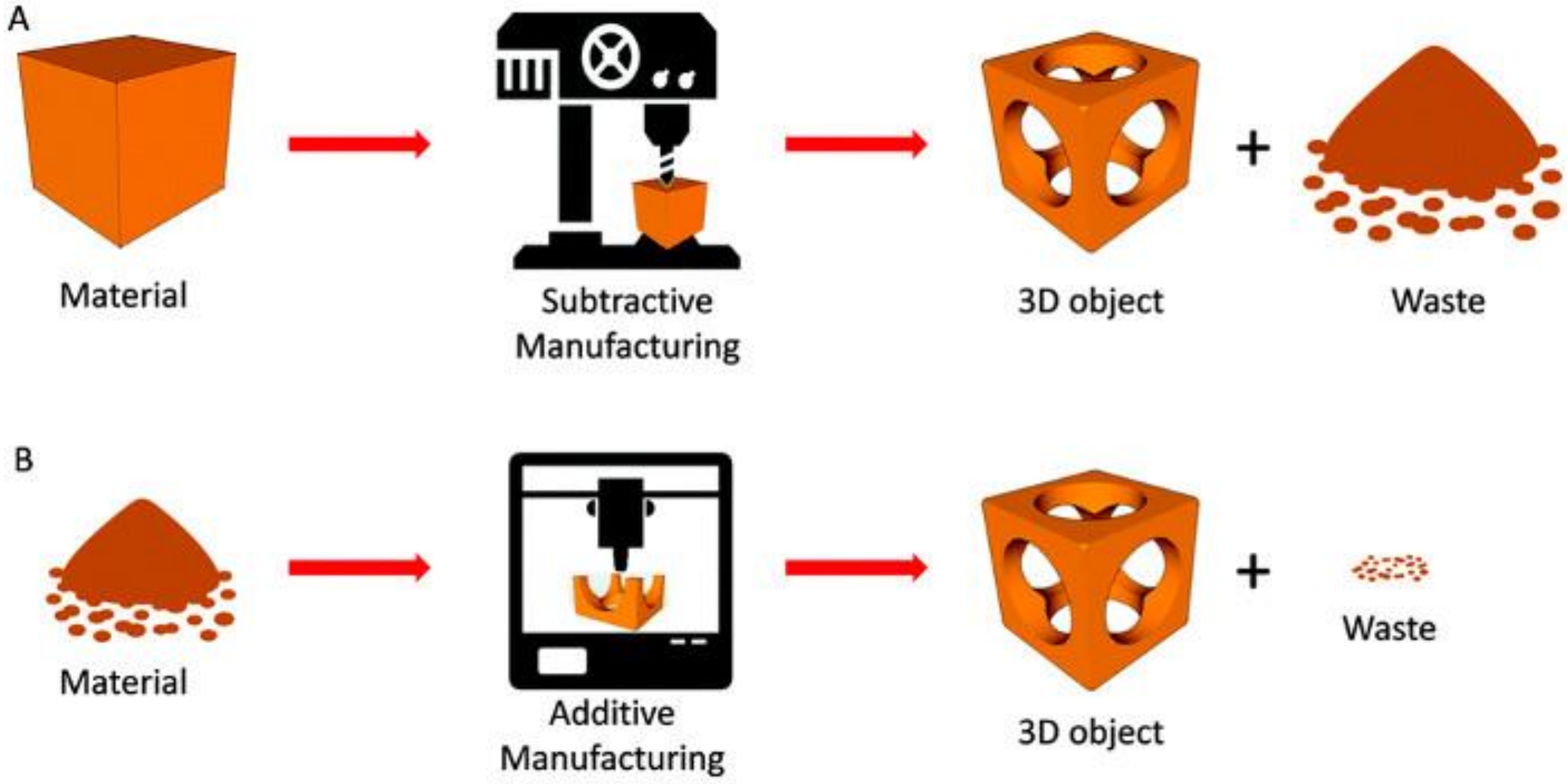
Additive Manufacturing (AM)

- AM Process: incrementally creating objects from computer model data using layer-by-layer.



https://www.hubs.com/knowledge-base/3d-printing-vs-cnc-machining/

Comparison between Subtractive and Additive



https://www.3dnatives.com/en/3d-printing-vs-cnc-160320184/#!

AM evolution history

- **Rapid prototyping**: production of prototype in a very short lead time.
- **Rapid tooling**: production of tooling to be used in other process: e.g. jigs and fixtures for machining, and/or production process
- **Direct-digital manufacturing**: manufacture of finished products directly from a computer file with no intervening tooling.
- **Rapid manufacturing**: upsurge of start-up companies for rapid manufacturing components.

Advantages of AM

- **Flexibility**: free-form fabrication and freedom of design
- **Economics**: heavily favour low-volume production
  - Relevant industries?
- **Buy-to-fly ratio**: mass ratio between the input materials and the final product
  - Subtractive manufacturing: 10:1 to 40:1 in aerospace application
  - AM: close to 1 (debatable)
  - Higher materials usages rate, low waste

Subtractive manufacturing (CNC)

https://youtu.be/HGyFhN01M4M

Additive manufacturing

https://youtu.be/EHvO-MlzAIM

Subtractive VS Additive manufacturing

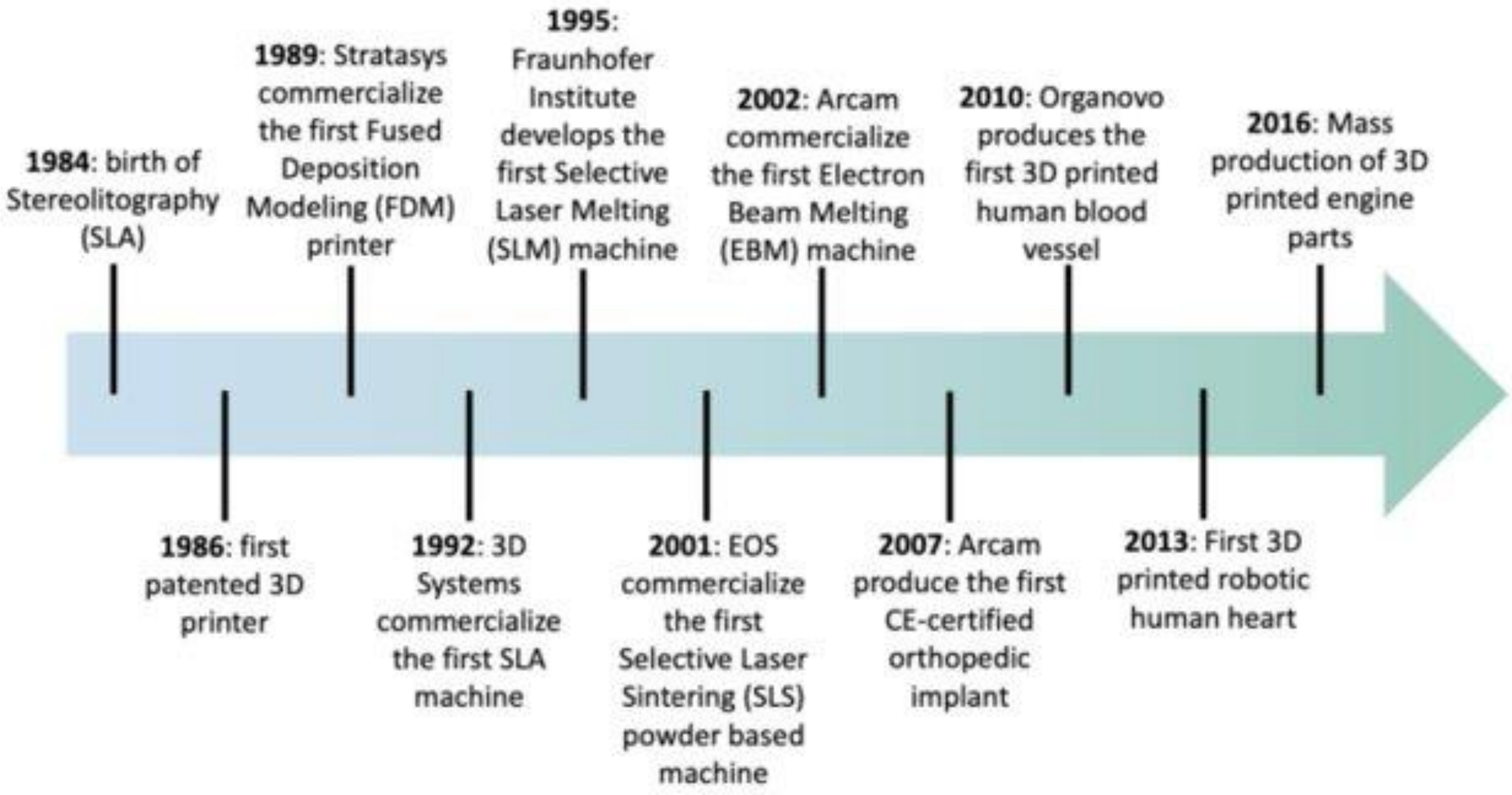
- Subtractive
  - Parts with simple geometry
  - Production in medium volumes
  - high dimension accuracy
  - Good surface finishing
  - Shorter time for a single part but longer time for batch production
  - Excellent part properties
  - High buy-to-fly ratio
    - Buy-to-fly ratio: the ratio of the starting billet of materials to the mass of the final, finished parts

- Additive
  - Complex part geometry
  - Production in low to medium volumes
  - Low dimension accuracy
  - Rough surface finishing, post processing required
  - Longer time for a single part but shorter time for batch production
  - Structural weakness in parts
  - Low buy-to-fly ratio

Advantages of AM

- **Flexibility**: free-form fabrication and freedom of design
- **Economics**: heavily favour low-volume production
  - Relevant industries?
- **Buy-to-fly ratio**: mass ratio between the input materials and the final product
  - Subtractive manufacturing: 10:1 to 40:1 in aerospace application
  - AM: close to 1 (debatable)
  - Higher materials usages rate, low waste

History of metal AM

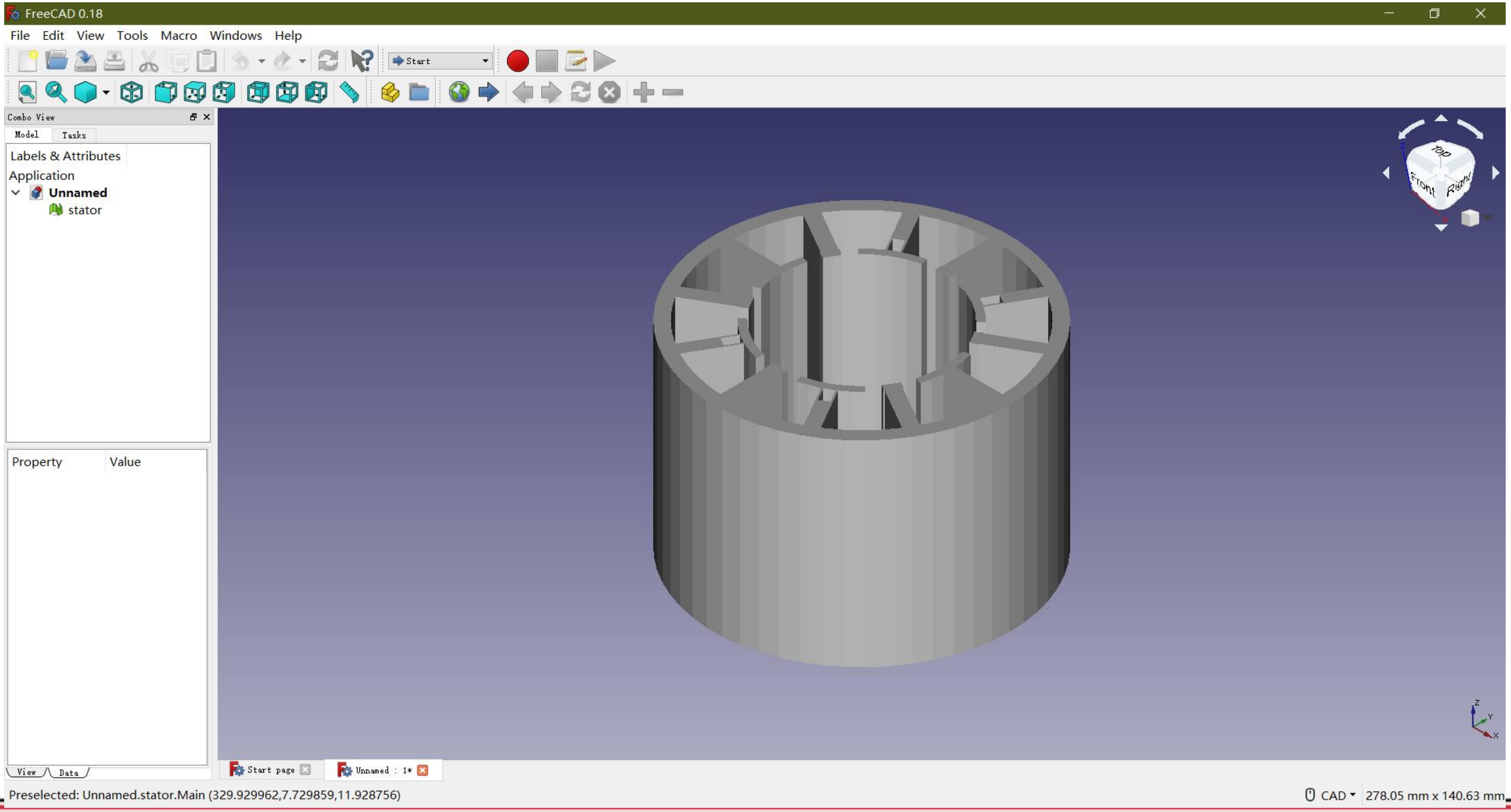


Procedures for metal AM fabrication

- 3D Geometric Model Construction
- Model parameter setting
- Model Slicing
- Machine printing
- Final finishing

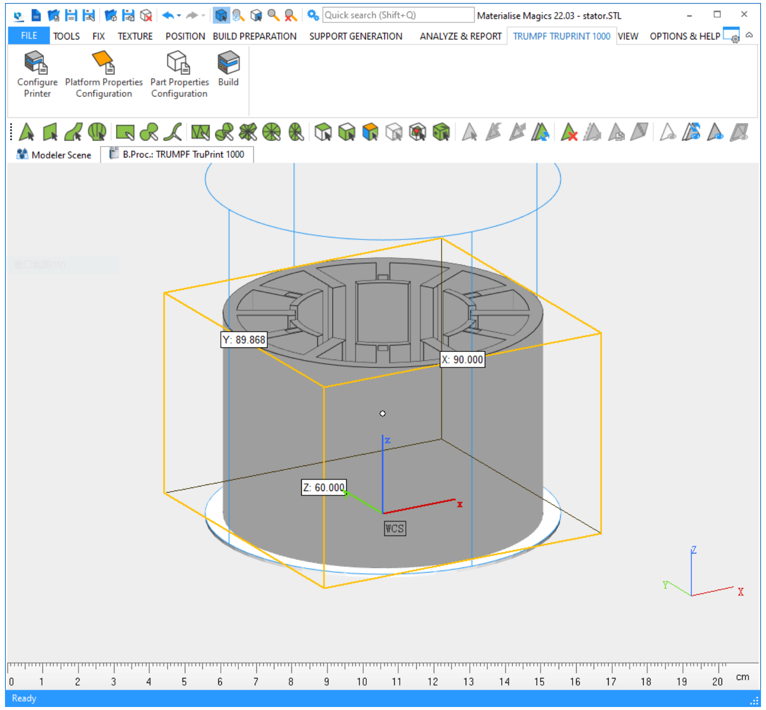
3D Geometric Model Construction

Software
1. AutoCAD
2. Solidworks
3. FreeCAD
4. etc.

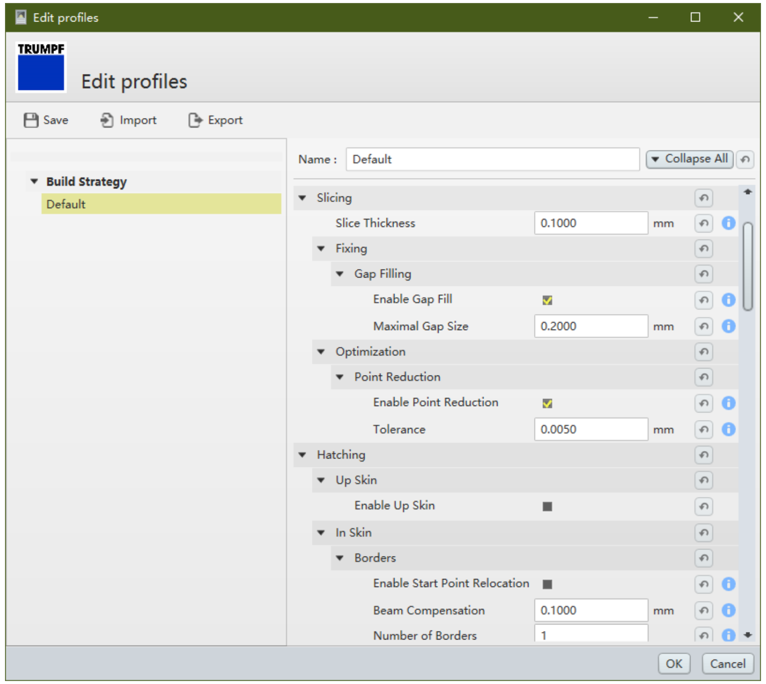


Model Parameter Setting

Allocate the model on the simulated platform



Assign the printing parameters to model

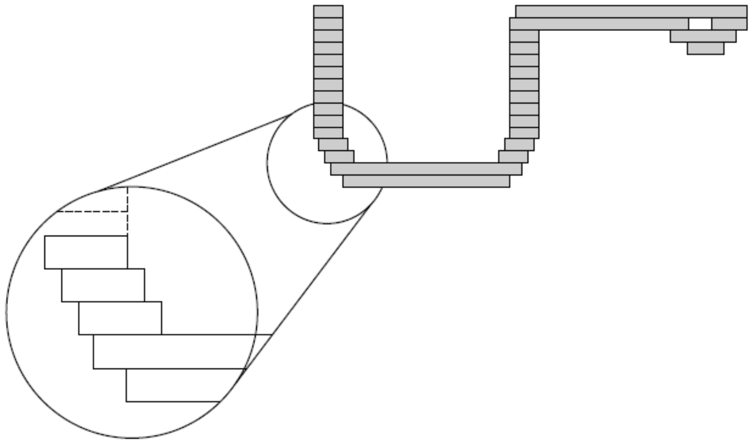


Software

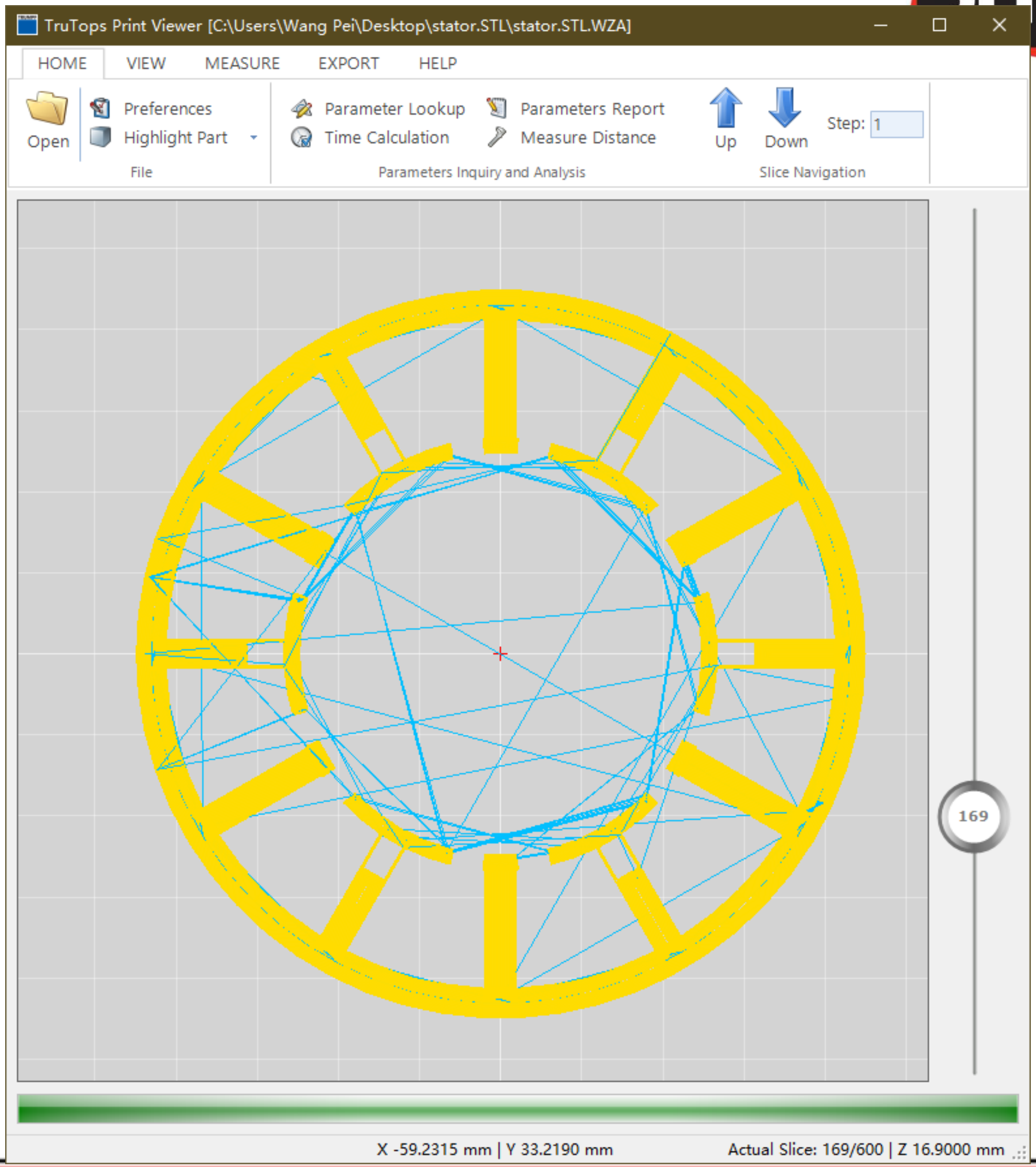
1. Materialize Magics
2. 3DXpert
3. Etc.

Model Slicing

Slicing the model based on its location on the simulated platform and assigned printing parameters.



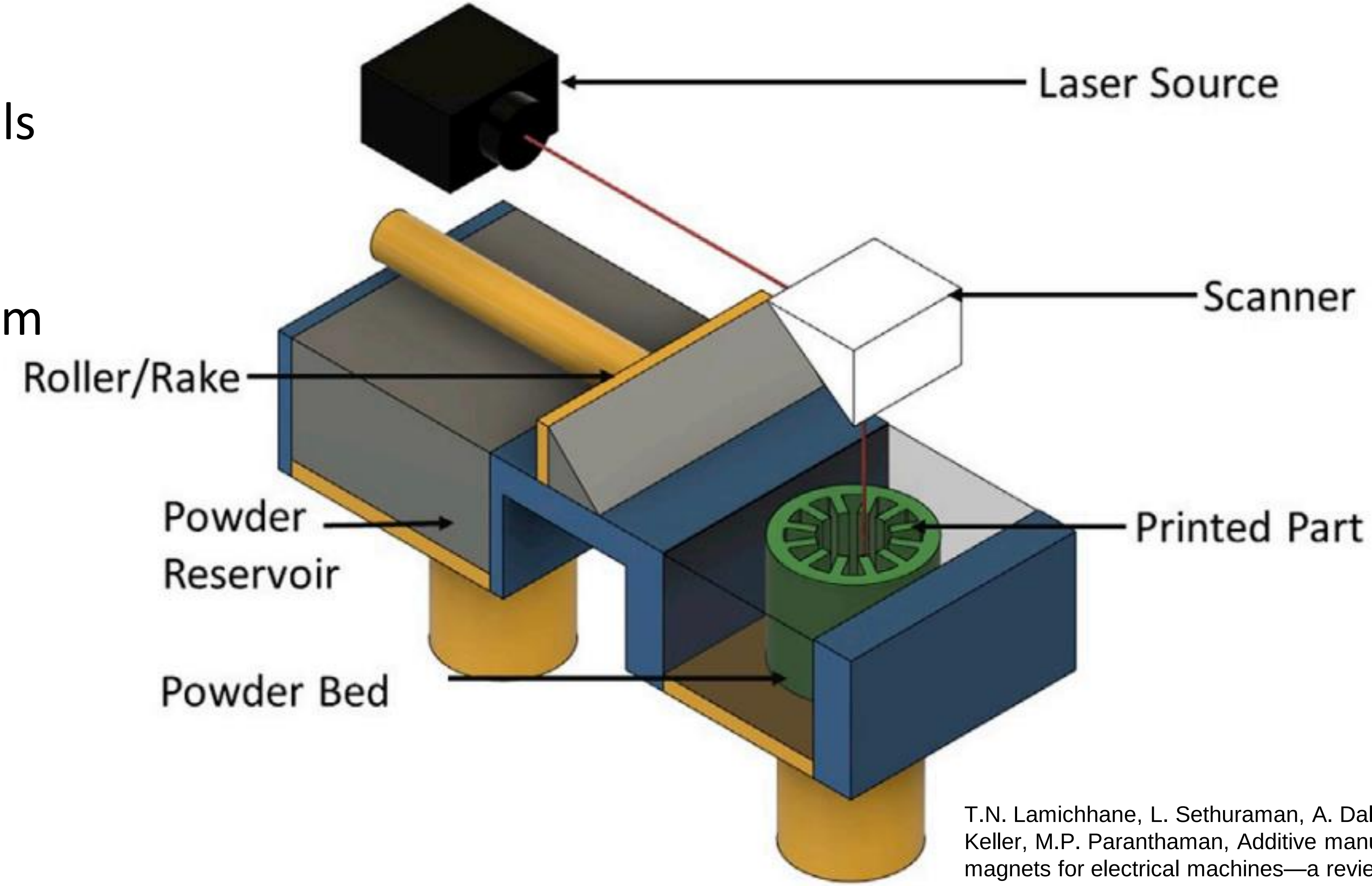
Software
1. Materialize Magics
2. 3DXpert
3. Etc.



Machine printing

Procedures

1. Load the materials
2. Load the sliced model
3. Set up gas/vacuum conditions
4. Set up machine parameters
5. Go

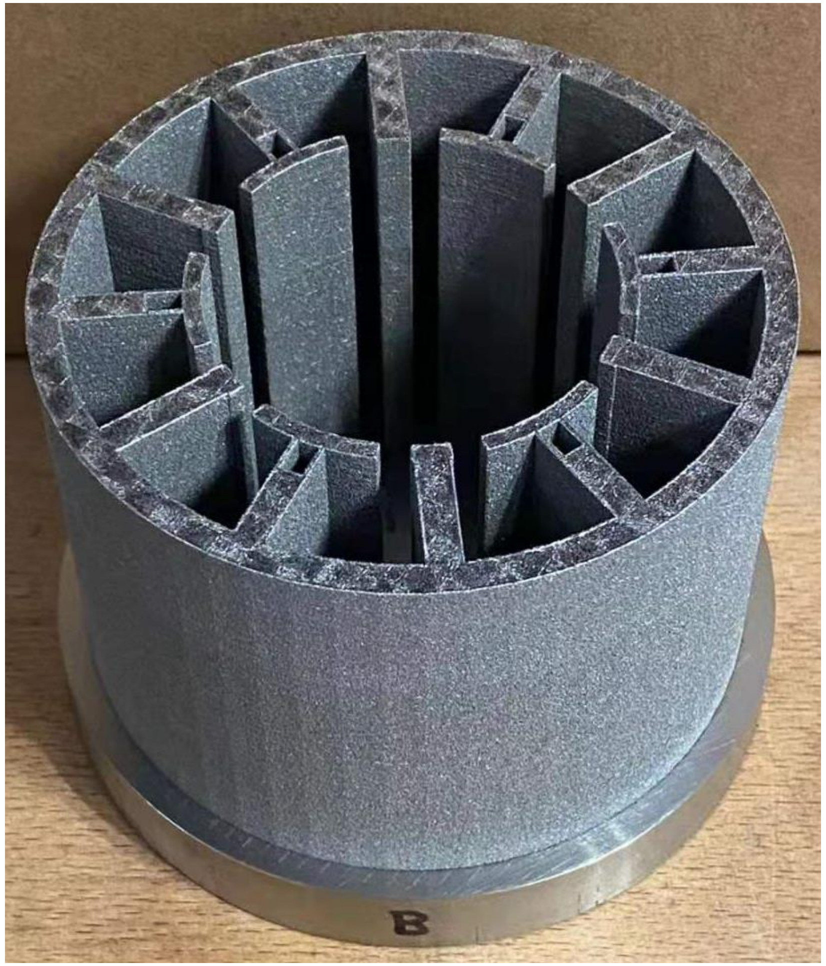


T.N. Lamichhane, L. Sethuraman, A. Dalagan, H. Wang, J. Keller, M.P. Paranthaman, Additive manufacturing of soft magnets for electrical machines—a review, Materials Today Physics 15 (2020).

Final Finishing

Post processing

1. Parts removal from substrate
2. Surface polishing
3. Dimension modification
4. Internal channel polishing
5. Post heat treatment



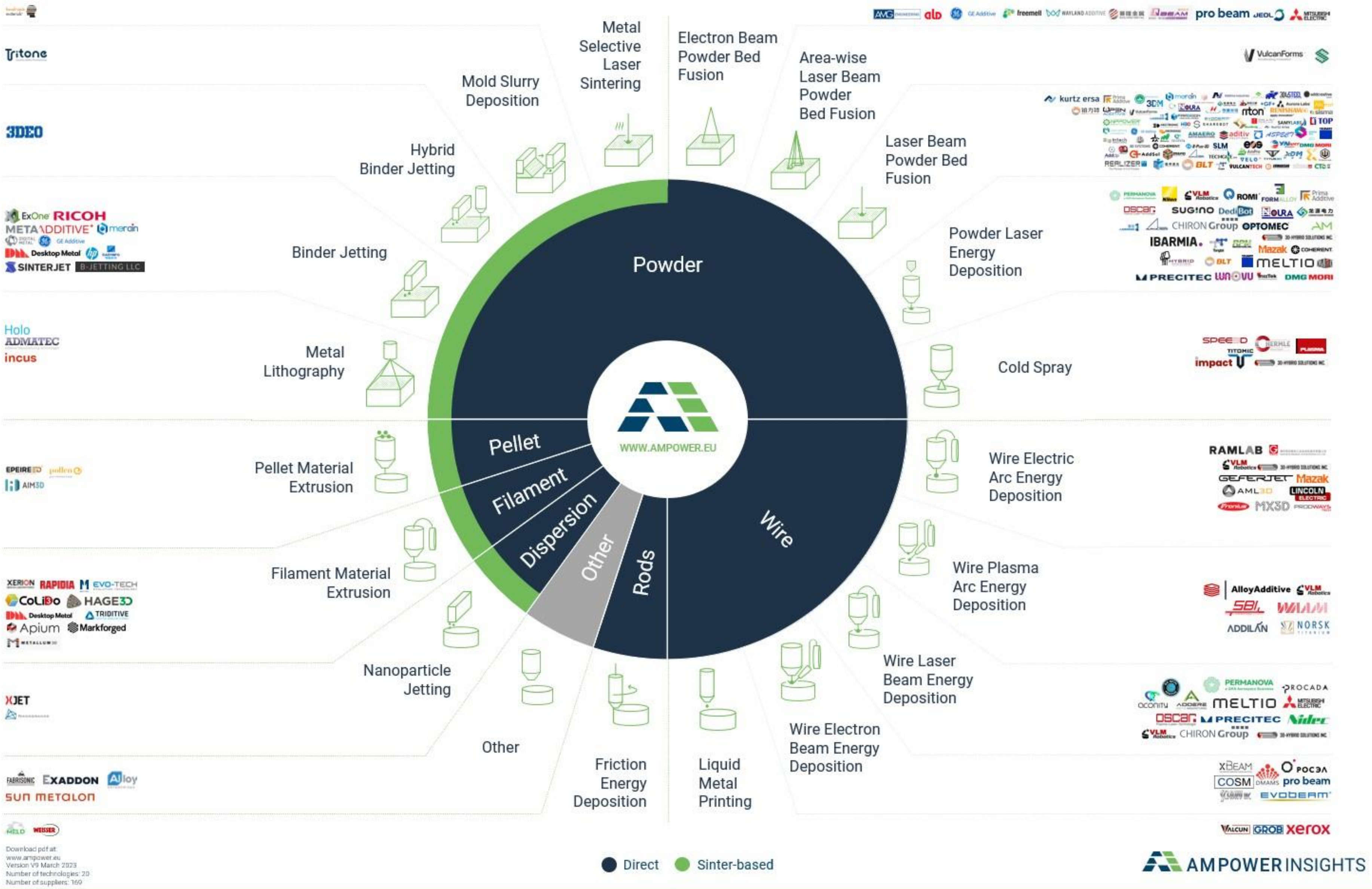
What else?

- **Recycle** and **Reuse** the remaining materials for next printing
- **AM Process**
  - **Clean** Manufacturing
    - Reduced processing time
    - Reduced energy consumption
  - **Green** Manufacturing
    - Materials can be recycled and reused.
    - Buy-to-fly ratio close to 1.

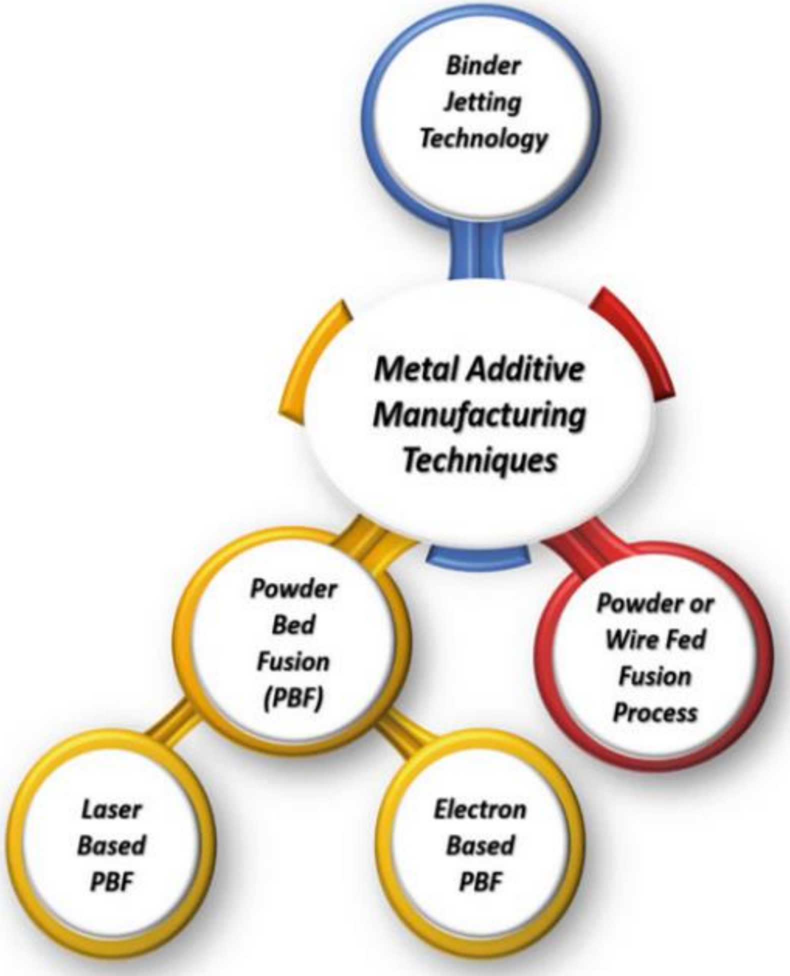
Clean and collect the remaining powder from a SLM process

Metal 3D Printing / Additive Manufacturing

Metal Additive Manufacturing technology landscape

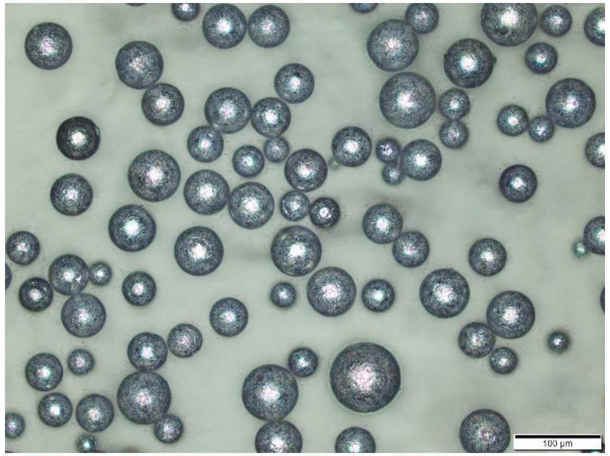


Category of metal AM technologies



Powder-based AM Systems

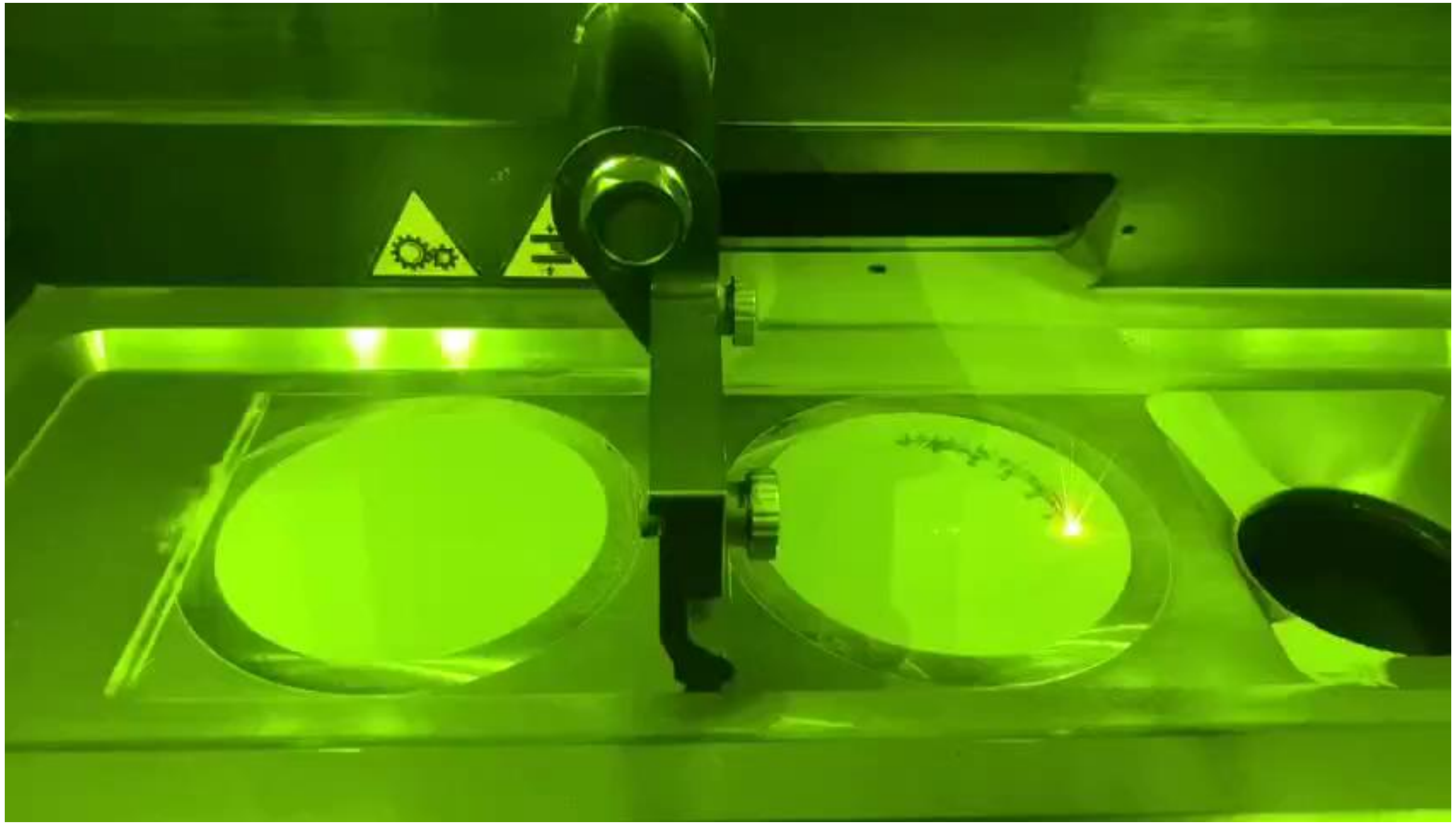
- Including
  - Laser Powder Bed Fusion (LPBF)
  - Laser Directed Energy Deposition (LDED)
  - Electron Beam Melting (EBM)
  - Binder Jetting Technology (BJT)
- Advantages
  - Powders
    - Readily available compared to other materials
    - Easy to produce in large quantity, transportation, and storage
  - Machine
    - Energy source is readily available
    - High energy efficiency



Pictures of Metal Powder

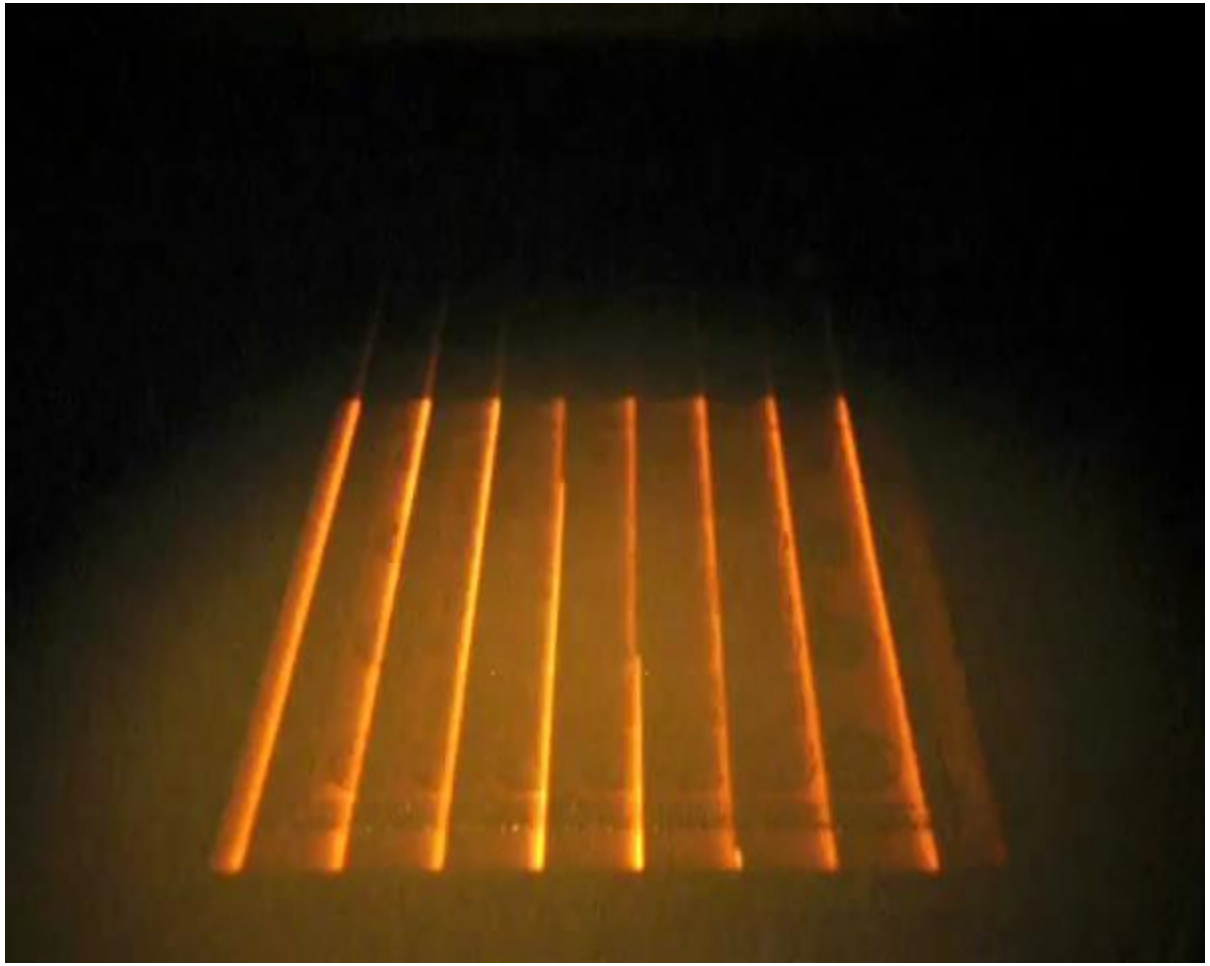
Laser Powder Bed Fusion

- Materials: metal powders
- Energy source used: high power laser
- Product: direct forming metal parts
- Industries: aerospace, medical implants, tooling industry, etc.



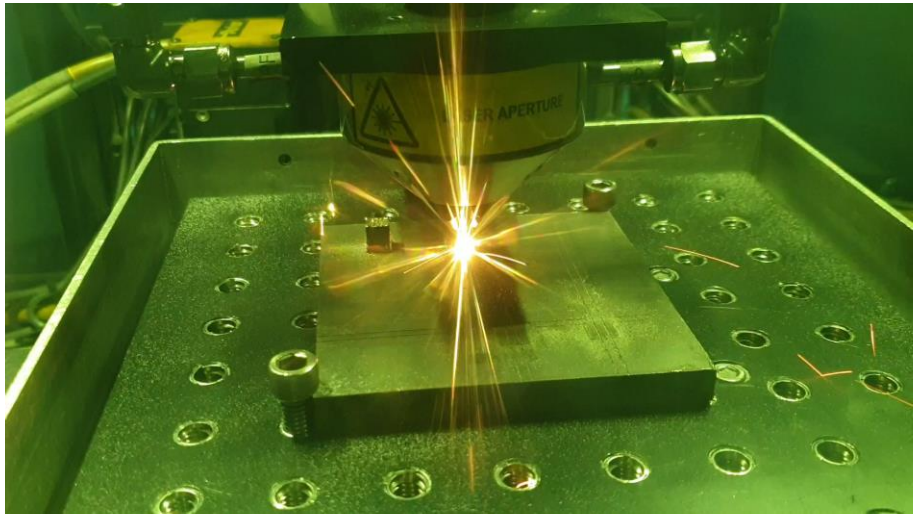
Electron Beam Melting (EBM)

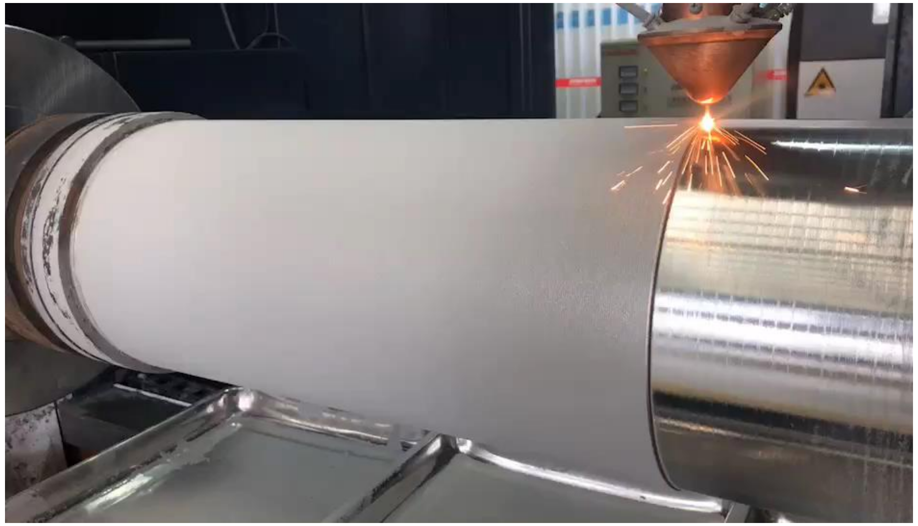
- Materials: metal powders
- Energy source used: high power electron beams
- Product: direct forming metal parts
- Industries: aerospace, medical implants, tooling industry, etc.



Laser Directed Energy Deposition

- Materials: metal powders
- Energy source used: high power laser
- Product: direct forming metal parts
- Industries: aerospace, marine,





Binder Jetting

- Materials: metal powders
- Forming source used: liquid glues
- Product: indirect forming of metal parts
- Industries: electronics, medical implants, consumer products, etc.

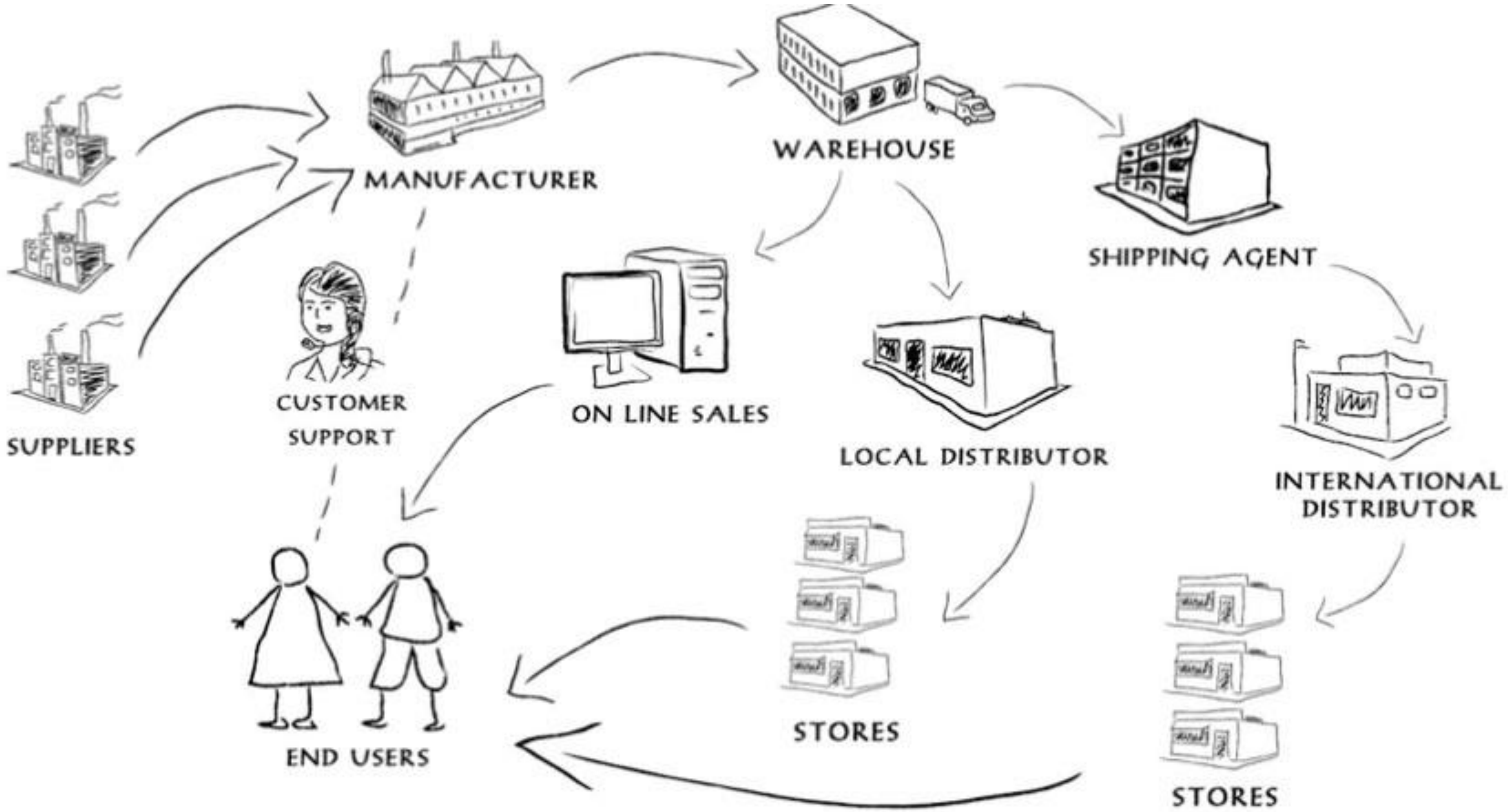
https://youtu.be/hjIoGPZPNjU

Case studies and Class discussion

Class Discussion

- Analyse the current supply chain for the metal products, including the sources of raw materials, the manufacturing processes, the distribution channels, and the end customers.
- Evaluate the feasibility and benefits of using 3D printing for the metal products, considering the technical, economic, environmental, and social factors.
- Propose a new supply chain model for the 3D printed metal products, incorporating the Industry 4.0 components such as smart sensors, cloud computing, big data analytics, and cyber-physical systems.
- Metal product list
  - Turbine blades for jet engines
  - cranial implants
  - Necklace
  - Metal molds and fixtures for manufacturing process
  - Artistic sculptures
  - Prosthetic arms
  - Firearms
  - Motor engine parts

Example: a supply chain map for shoes



End

Smart Manufacturing – 3D Printing and Impact on Supply Chain Reformation – part 2

Instructor: Asst Prof Wang Pei

Polymer Additive Manufacturing technology landscape

SINGAPORE INSTITUTE OF TECHNOLOGY

Fused Deposition Modelling (FDM) / Fused Filament Fabrication (FFF)

- Materials: plastic filament
- Forming source used: heat
- Product: direct forming of plastic parts
- Industries: electronics, medical implants, consumer products, etc.

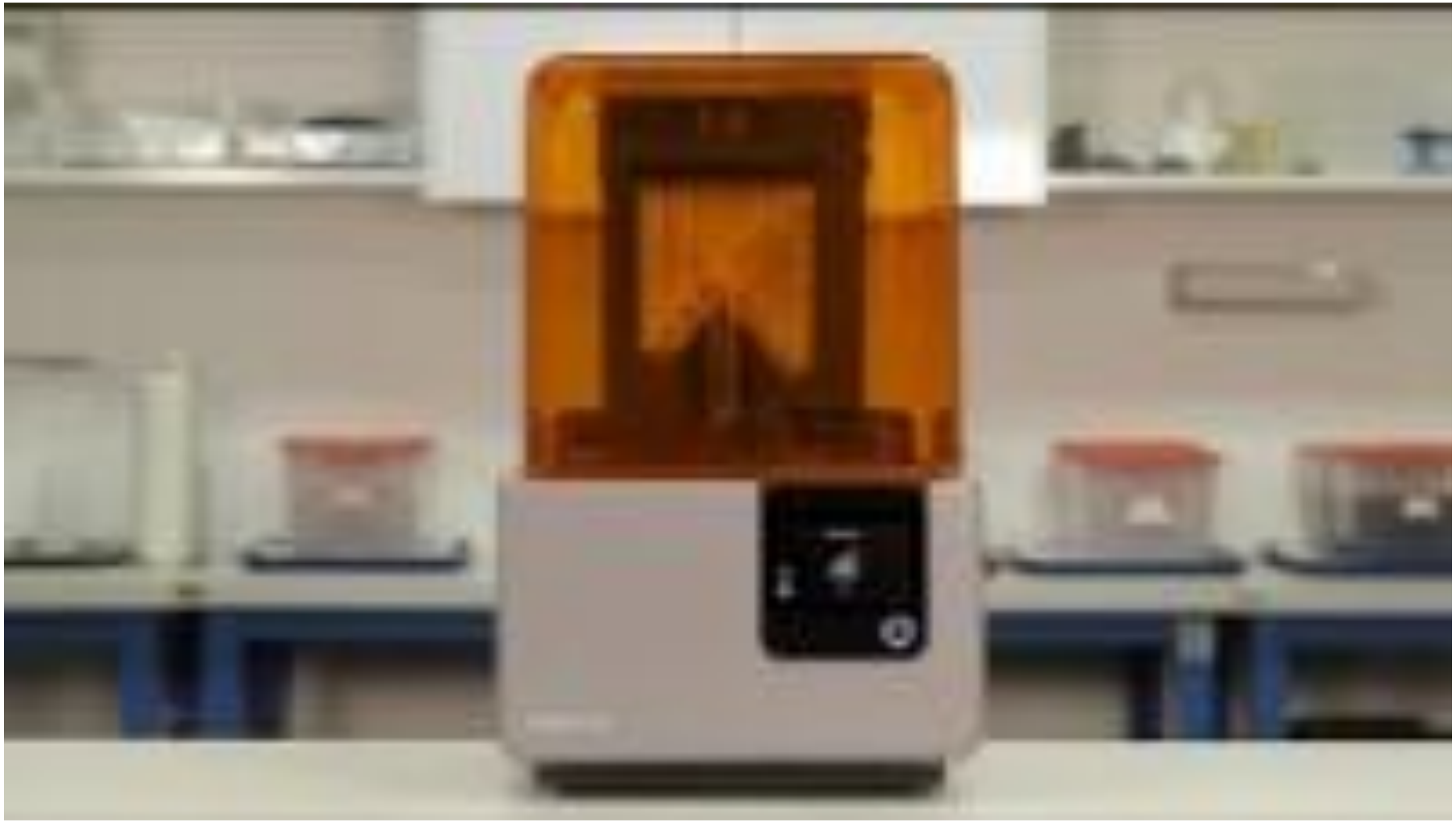
Any application Scenario in mind?

https://youtu.be/GxLjDNrQBgs

Stereolithography (SLA)

SINGAPORE INSTITUTE OF TECHNOLOGY

- Materials: liquid resin
- Forming source used: heat
- Product: direct forming of resin parts
- Industries: dental, jewellery, medical, etc.



Any application Scenario in mind?

https://youtu.be/8a2xNaAkvLo

Selective Laser Sintering (SLS)

- Materials: plastic powders
- Forming source used: laser
- Product: direct forming of plastic parts
- Industries: dental, jewellery, medical, etc.

https://youtu.be/sdBBhHvKD_8

Food 3D Printing / Additive Manufacturing

Fused Deposition Modelling for Food

- Materials: protein and food ingredients
- Forming source used: extrusion and solidification
- Product: direct forming food
- Industries: Food

Any application Scenario in mind?

https://youtu.be/B0Ty6wgM8KE

Case studies and Class discussion

Case Study 1

GE Leap engine fuel nozzle produced by SLM

Motivation?

- Reducing weight
- Improved efficiency

Benifits?

- Reduced pieces of parts from 20 to 1
- Reduced weight by 25%
- Improved lifetime due to desgin freedom

Outcome

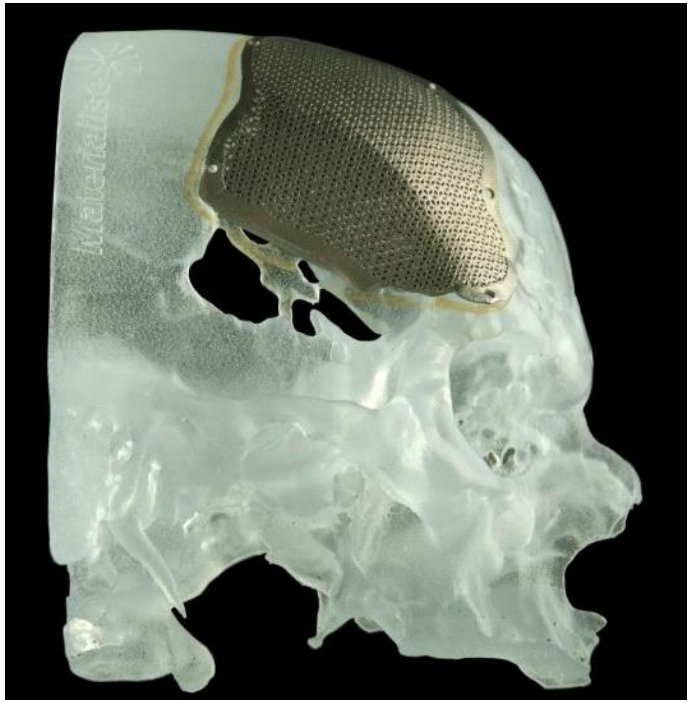
- 40,000/year by 2018
- Reduced cost by reducing the supply chain

Impact on supply chain?

https://www.industrial-lasers.com/welding/article/16485564/additive-manufacturing-at-ge-aviation

Case study 2

Patient specific implants to replace damaged bones



Motivation?

- Time consuming to find a correct shape from the off-the-shelf parts
- Plastic surgey using patient spacific implants

Benifits?

- Help patient look as close to nomal as possible
- Reducing pain to the patients

Impact on supply chain?

https://www.ge.com/news/reports/bone-machine-3d-printing-revolutionizing-plastic-surgery

https://youtu.be/jcp-aaa1PBk

Case study 3

3D printed customized footwear

Motivation?

- No limiation on design
- Customer centric product

Benifits?

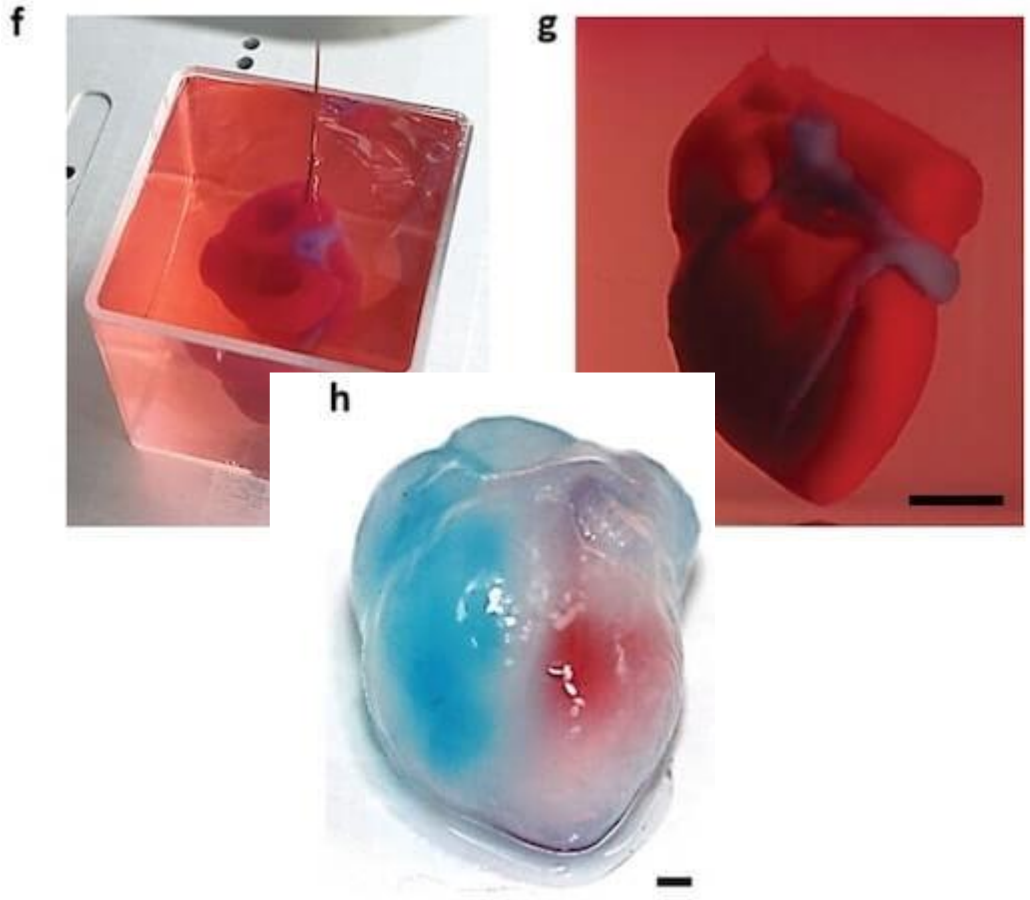
- TPU materials are fully reusable
- Less material usage
- Futuristic looking design

Impact on supply chain?

https://3dprinting.com/news/recyclable-tpu-shoes-3d-printed-by-peak-wanhua/

Case study 4

3D printing of human tissues



Motivation?

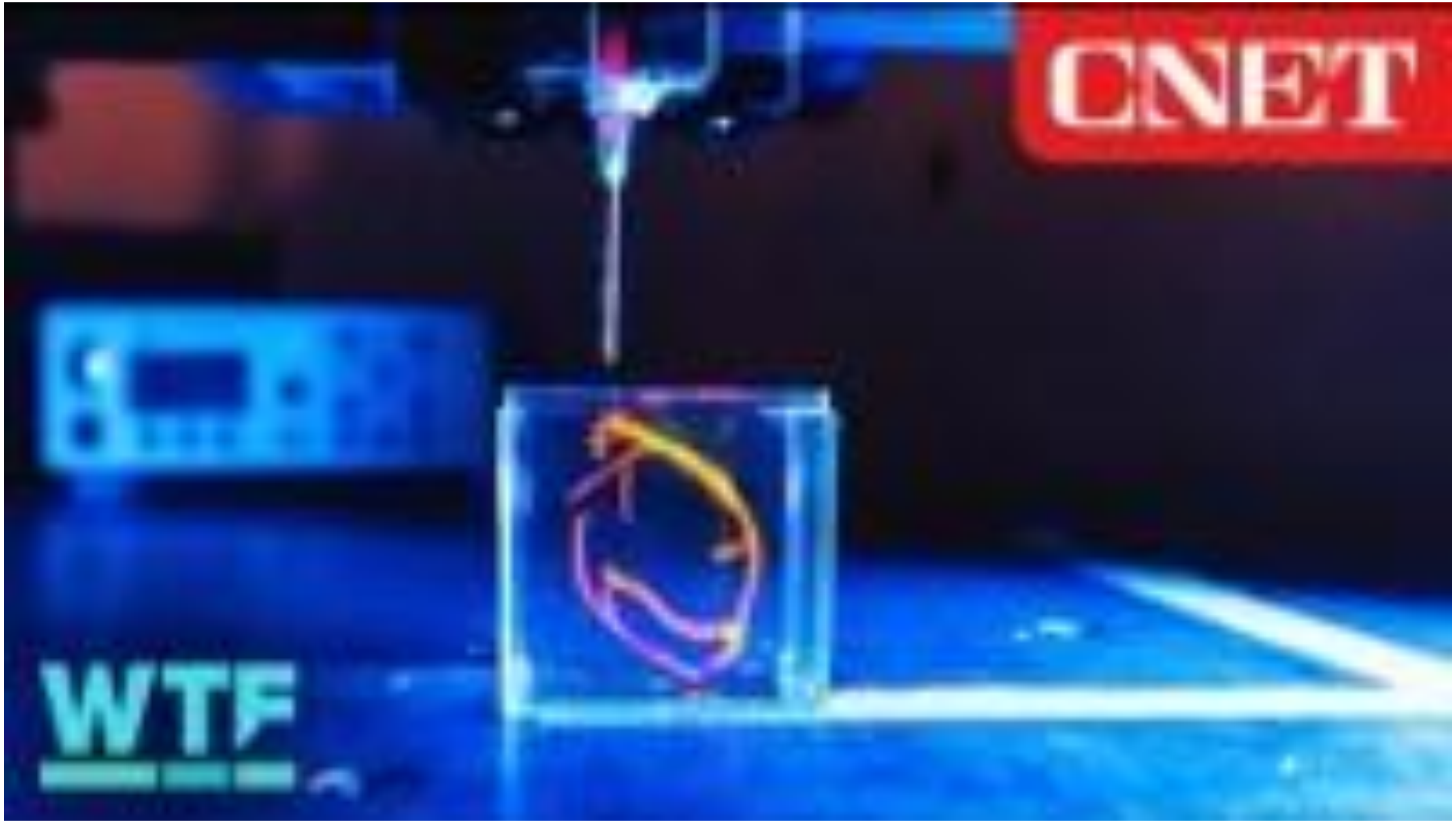
- 3D printing of organs
- Rapid and customized organs

Benifits?

- No need to wait for organ transplants
- Printing using patient' own stem cell
- Reduce the resk of organ rejection
- Increase human lifespan

Impact on supply chain?

Conti…



https://youtu.be/mMeOjwH4NVU

Case study 5

3D printing of house

Motivation?

- Faster, greener, durable buildings
- Design freedom

Benifits?

- Near to zero materials wastage
- Faster completion of the project
- Reduced cost
- Complex architectural design

Impact on supply chain?

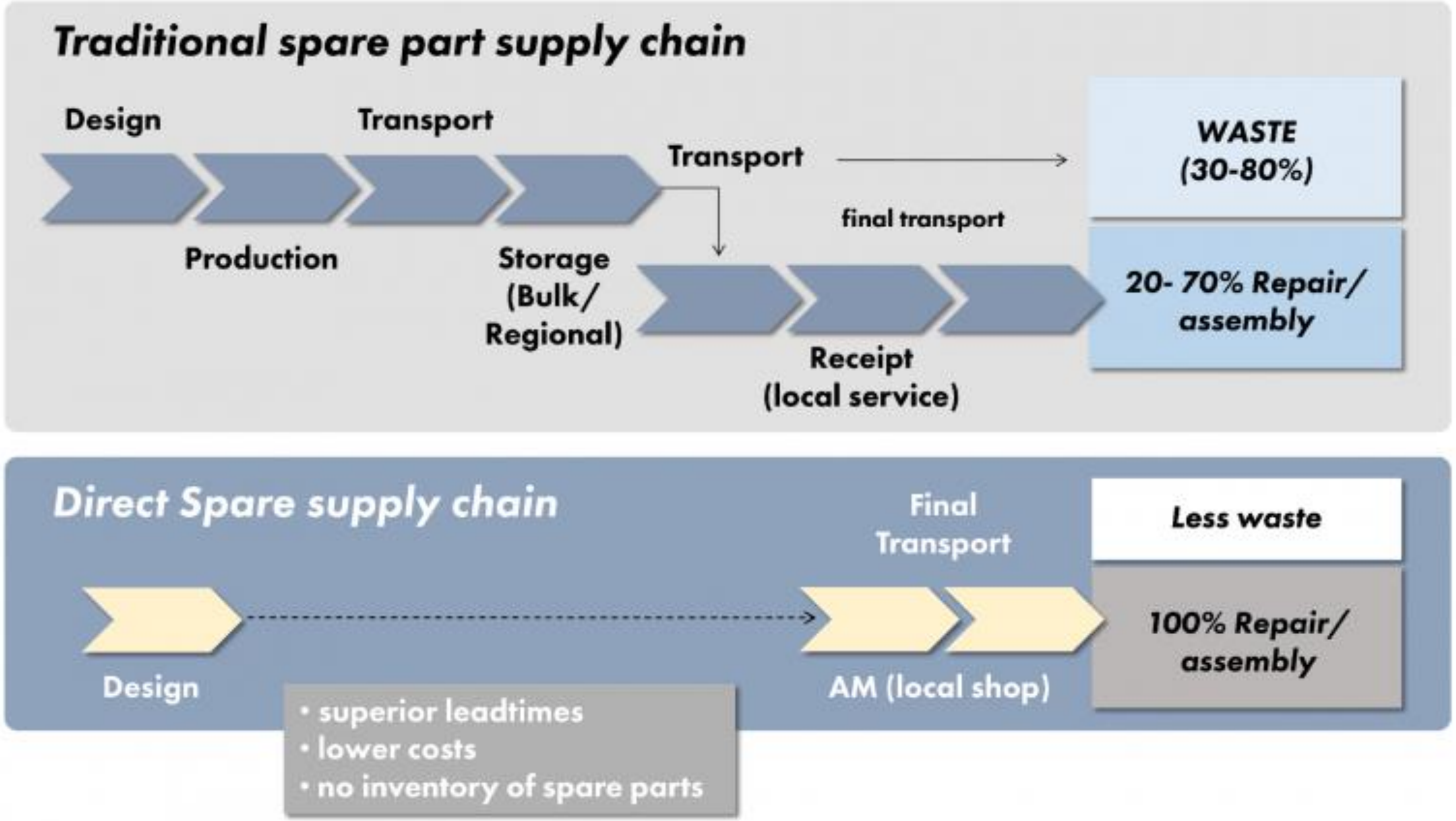
Conti…

https://youtu.be/lZh8E6zZdzk

What are the scenarios when AM could be applied in a business case?

- Product
  - Complex shape
  - Highly customized
  - Low volume
  - High value
  - Short lead time

- Supply Chain
  - Significantly shorter supply chain



[Understanding the business cases for entering Additive Manufacturing (metal-am.com)](metal-am.com)

Impact on Supply Chains

Five ways 3D printing will have a massive impact on the supply chain and drive competitive advantage

- Decentralized production
- Drive product customization
- Reduce complexity and improve time-to-market
- Improve resource efficiency
- Rationalize inventory and logistics

Total supply chain cost

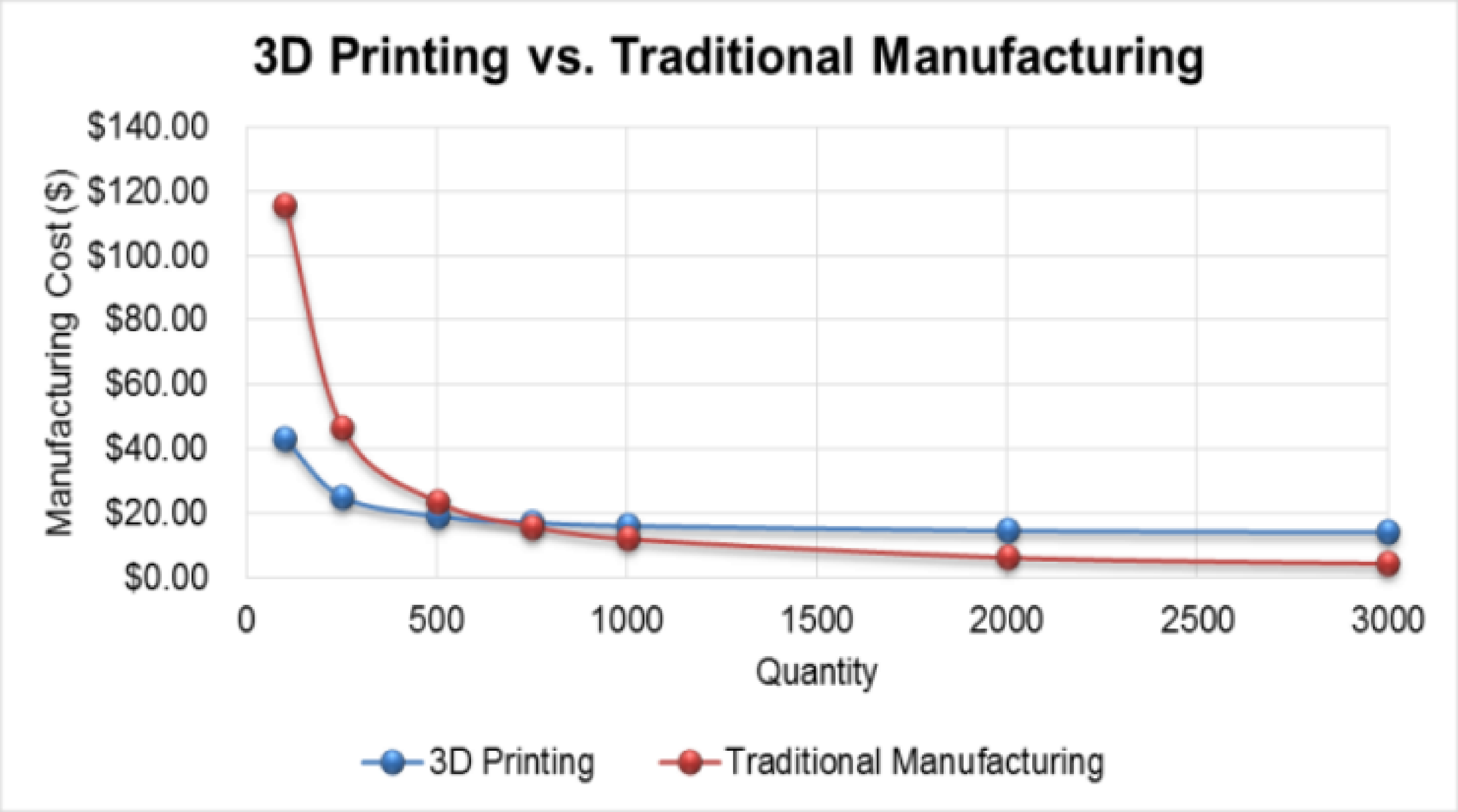
Total Supply Chain Cost

A Product Cost + B Order Cost + C Transportation Cost + D Inventory Holding Cost + E Pipeline Inventory Cost + F Stock Out Cost

- **A** Product Cost = Cost Of Manufacturing
- **B** Order Cost = Order Cost x (Demand/Order Quantity)
- **C** Transportation Cost = Demand x (Cost/Mile) x Distance in Miles
- **D** Inventory Holding Cost = Product Cost x Holding Rate x (Cycle Stock + Safety Stock)
- **E** Pipeline Inventory Cost = Product Cost x Holding Rate x (Demand over Lead Time)
- **F** Stock Out Cost = Stock Out Penalty x No. of Orders x Probability of Stock Out Per Cycle

Bhasin, V. and M.R. Bodla. 2014, Massachusetts Institute of Technology.

Product cost of 3D printing versus Traditional Manufacturing



Class Discussion

Class Discussion

- Compare the total supply chain cost of the following products from 3D printing and conventional manufacturing.
- Explain the possible impacts of 3D printing on supply cost.
- Propose Industry 4.0 technologies that can reduce the supply chain cost

- Product list
  - Dental implants
  - Jewellery
  - Organ transplants (heart)
  - Shoes
  - Chocolates
  - Motor engine parts
  - Costumes
  - Sports helmets

End