Building Informatics and Smart Building

- Informatics [Definition]
  - Study of computational systems, especially for data storage and retrieval （特别对于数据存储和检索系统）
  - US: about Data science
  - Europe: information technology / computer science [central: transformation of information]
  - Other: health / medical domain try to define Informatics
    - Cross- training field of study
    - **Informatics** is a fundamental theorem / technique improves any task
- Building informatics [Definition]
  - leveraging information technology, computer science, and related data science technologies → to improve building operation efficiency & user comfort in buildings.
  - No clear consensus & definition
  - Most: dealing with collecting, managing, and analysing building data → improve building efficiency & user comfort.

- Smart Building [Definition]
  - **digitally connected structures**: combine optimized building & operational automation with intelligent space management → user experience, increase productivity, reduce costs, mitigate physical & cybersecurity risks
  - **converges** various **building-wide systems** (E.g. HVAC, lighting, alarms, electrical, fire safety, plumbing and drainage, security&access control) into a single IT managed network infrastructure.
  - **integrate & account** for intelligence, enterprise, control, and materials and construction as an entire building system
  - Core: **adaptability, not reactivity （核心为适应性，而不是反应性）**
  - → to meet the drivers for building progression: 1. energy and efficiency, 2. longevity,（寿命） 3. and comfort and satisfaction.
  - The increased amount of information → wider range of sources will allow these systems to become adaptable, & enable a Smart Building to prepare itself for context and change over all timescales.

- Smart Building V.S. Intelligent Building
  - Often used interchangeably
  - "Intelligent Building" was popular in 1980's/90's
  - Intelligent Building [Definition]

creates an environment that **maximizes** the efficiency of the occupants of the building & allowing effective management of resources with **minimum life-time costs**

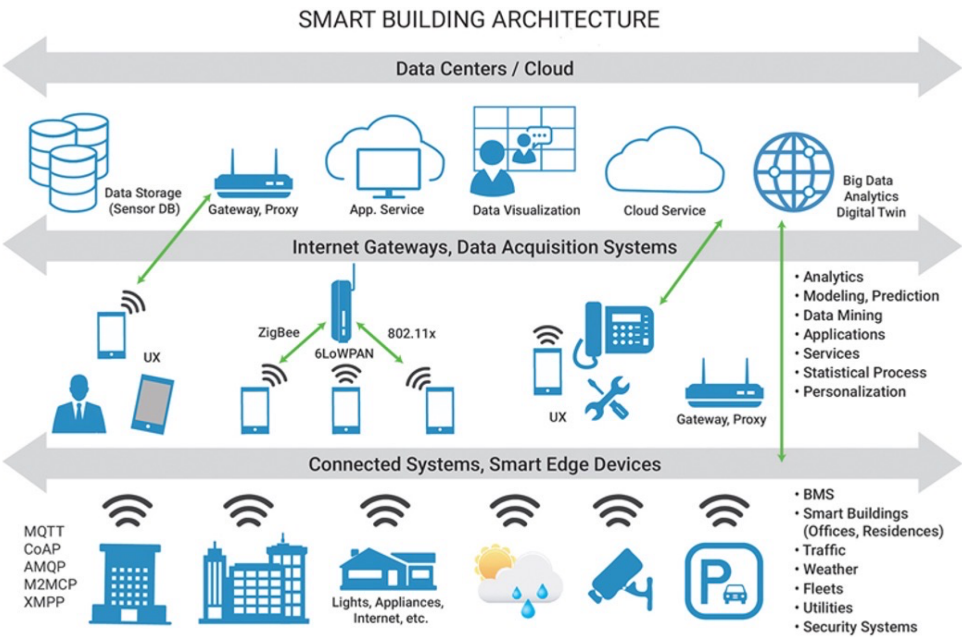
- Similar:
  - Focus on creating **integrated system** interrelates various subsystems → single control frame work
  - Use information technology and data generated by building
- Difference:
  - Smart Building also **includes wider integration** with utilities and city infrastructure to realize smart city （Smart Building 有公共设施和城市基建，实现 Smart city）
  - Smart Building includes use of emerging **machine learning and AI** for advanced control and diagnostics （Smart Building 有 AI 和 ML）
  - Smart Building considers interaction of users with building and surrounding environment → improve comfort of users apart from building operations.
  - Smart Building encompasses the use of emerging IoT, wireless communication, and other related technologies (technologies were not developed when Intelligent building concept was proposed) （Smart Building 会用一些 Intelligent Building 时期未开发的技术）

- Smart Building - Characteristic （特征）
  - Climate Response: buildings to adapt to external climate conditions
  - Grid Response: buildings to adapt the information coming from grid （电网） → **maximize** the energy/economic efficiency at district/city scale
  - User Response: enable a real-time interaction between users and technologies → optimized performance & user comfort
  - Monitoring and Supervision: enable real-time monitoring of building operations and users' behaviour.

- Smart Building - Benefits
  - **Lower Operational costs** – use emerge tech [Building System] → save time, space, money
  - **Lower Energy cost** – emission saving → achieve *net zero energy buildings*
  - **Greater Flexibility** – **dynamically adapt** the buildings according to external and internal changes by real-time monitoring using sensors

- **Improved user comfort, efficiency, and wellbeing** – improve health, comfort, efficiency of users by adjusting the surrounding environment & providing collaboration opportunities （协作机会）

- **Smart Building - Framework**



  - The bottom layer: systems and devices: HVAC, lighting, security and access control, water, elevator, drainage, etc.
  - The middle layer: **gateways** to acquire & transmit data from different building systems
  - The upper layer: services supported by cloud including storage, visualization, and data analytics.
  - E.g. Deloitte: 1. Physical 2. Digital 3. Use case
  - A smart building framework can be analysed from three aspects:
    - Different systems/devices within the smart buildings
    - Different technologies used within the smart buildings
    - Different use cases/features supported within the smart buildings

- Smart Building - Underlying Systems
  - Building Automation Systems (BAS) / BMS (Management): computerized, integrated, and intelligent network of hardware and software installed in a building → monitors and controls the building's mechanical and electrical equipment.
    - Integrates advanced technologies: Information Technology (IT), Internet of Things (IoT), Big Data, Artificial Intelligence (AI), modern control, etc.
    - Major Components:
      - Network (wired / wireless)

        - Controllers (programmable)
        - Actuator （执行器）
        - Sensors
        - Computers / Servers
        - Software
    - Typical Functions:
        - Air conditioning and ventilation system monitoring and control

    (on/off control of major equipment, control temperature and humidity, thermal comfort, etc.)
- Lighting control

    (dimming （调光）, special lighting effects, motion sensor, daylight, etc.)
- Fire detection and alarm

    (smoke detector, heat detector, fire alarm, etc.)
- Security and access control

    (monitoring camera, password, key, finger print, iris, bio-features, etc.)
- Lift control

    (destination control, up peak, down peak, etc.) （目的地控制、上峰、下峰等）
- Utility management interface （设施管理界面）

    (historical data analysis, cost management, etc.)

- Smart Building - Certification （认证）
    - One popular certification - provided by ***Smart Building Collective***
        - Smart Building Certification → to award buildings that *have the IT infrastructure* in place to measure a building and behavior.
        - Includes measures: optimization & innovation in buildings.
        - Imp. **Considers how the building data is being utilized.**
        - **4 - level** of certifications:
            - Bronze
            - Silver
            - Gold
            - Platinum
    - Certification is provided for both build phase and operation phase of buildings （在建造和运营阶段认证）

- In Design | Core & Shell: Certify the technical infrastructure in place → give a clear view on what is possible with the building
- In Operation:
  - Goes **beyond** only the technical infrastructure and looks

    （超越技术基础设施）

  - How the technical infrastructure is being used to optimize, improve, and manage the efficiency of the building

○ 6 - themes （六个主题）

- Building Usage: effective usage（有效使用）of building for users.
- Building Performance: optimization of investment, improved efficiencies, consumption, minimization of environmental impact.
- Building Environment: measures the health of the physical environment
- Health, Safety, and Security: if compliant with health and safety standards.
- User Behavior & Collaboration: explores how the building empowers user behavior and collaboration, supporting the maximization of

  value and purpose of the space（空间价值最大化）.

- Interactive Design & Connectivity: measures how well integrated with one another and the building

○ Other Certifications

- Also provided by some government organizations and other third-party organizations
- Government level certification E.g. *Smart Readiness Indicator* (SRI), [European Union (EU)]
- SRI rates 3 key functionalities:
  - optimise energy efficiency and overall in-use performance
  - adapt their operation to the needs of the occupant
  - adapt to signals from the grid (for example energy flexibility)
- **Beam Plus [HK]**

comprehensive set of **performance criteria** for a wide range of sustainability issues relating to the planning, design, construction, commissioning, fitting out, management, operation and maintenance of a building.

- Categories: new buildings (NB), existing buildings (EB), data centers (DC), Interiors (BI), Neighbourhood (ND), and existing schools (ES).

- Smart Building Acceleration Act [USE]
- Third-party organisation E.g. ***SmartScore provided by WiredScore company***
- LEED, BREEAM etc.

- Smart Building - Challenges
    - Limited interoperability due to heterogeneity of sensors, devices, and data （传感器，设备和数据的异构性→互操作性有限）
    - Complex dependency of different systems
    - Large scale of devices and data
    - Limited integration across systems and technologies （跨系统和技术的集成有限）
    - Lack of standardized technologies and solutions
    - Security & Privacy concerns
- Concept:
    - **Integration** can be defined as the ability to group intelligent, standalone systems into a cohesive building management system.
    - **Interoperability** is defined as the ability to link multiple standalone building services systems from variety of manufacturers (such as those for air conditioning, fire safety, lighting and access control) into a comprehensive system.

- Smart Building - Future
    - Will plug into **"smart" urban infrastructure** & cater to an increasingly dense and technology-savvy urban population （应合日益密集和精通技术的城市人口）
    - Skyscrapers will be continuously adapting & made from materials that from filtering air to producing energy

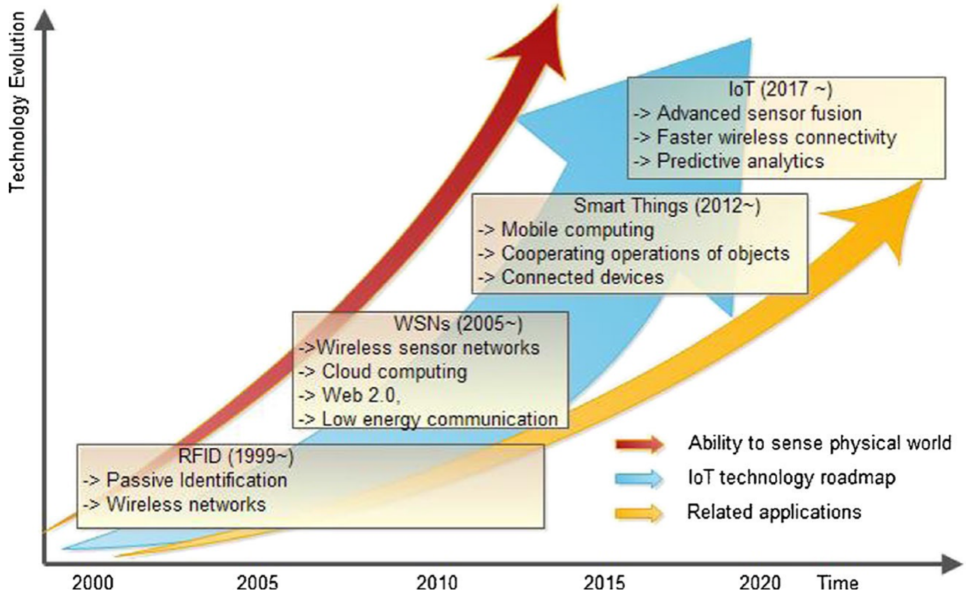
Internet of Things (IoT) in Smart Building

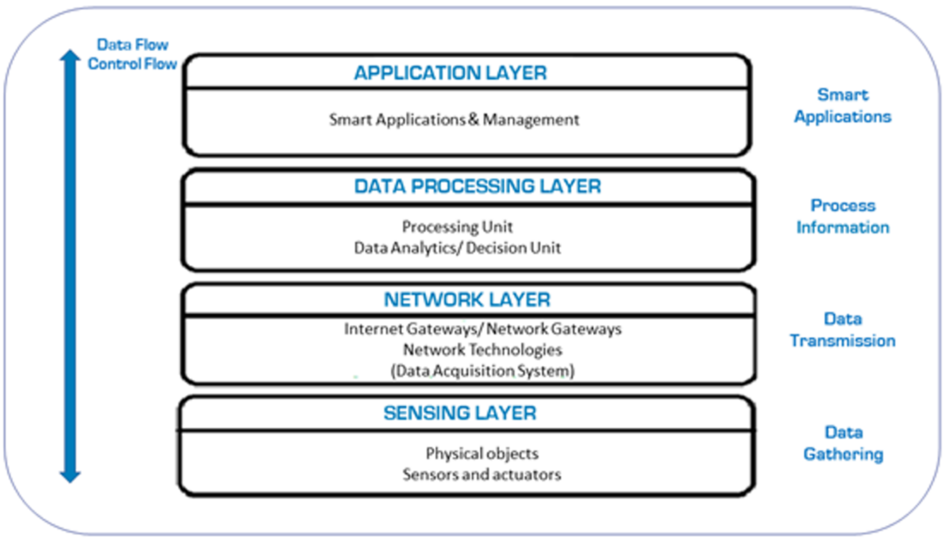
- Brief History of IoT
    - Kevin Ashton, co-founder of Auto-ID lab at MIT, in a presentation given to Proctor & Gamble in **1999** [RFID at first]

- IoT Definition
    - Physical objects (or groups of such objects) with sensors, processing ability, software and other technologies → connect and exchange data with other

devices and systems → over the <u>Internet or other communications networks</u>.

- ○ Connecting any device (so long as it has an on/off switch) → Internet and to other connected devices.
- ○ The IoT is a giant network of connected things and people – all of which collect and share data about the <u>way they are used</u> and about <u>the environment around them</u>.



- IoT Architecture
- 

  - ○ Sensing Layer (/Perception Layer/Device Layer) - [collecting, accepting, and processing data <u>over the network</u>]
    - Include:
      - ▪ IoT devices - sensors & actuators
    - Do:
      - ▪ Sensors: sense surrounding & transmit data
      - ▪ Actuators: receive the control signal & perform action

        - Each IoT device is also associated with an identity → enable **monitoring & management**.
        - IoT devices at *sensing layer* can have different form factors (ranging nanoscale low-power devices to autonomous vehicles and satellites)

          （在 Sensing Layer 的 IoT 设备可以有**不同的外形尺寸**）

        - In recent years due to improvement in technology → IoT devices have begun to **have computation and storage resources** → enabling local data processing
      - Network Layer (/Communication Layer) - [transmitting and processing the data collected by sensor devices]
        - Include:
          - Gateway
          - Routers

          → **transmit & process** data collected by sensors
  - Data acquiring systems (DAS):

    performing data aggregation and conversion functions (**collecting and aggregating** data from sensors, then **converting analog data to digital data**, etc.)
  - Data Processing Layer (/Middleware Layer) - [**processing, analyzing, storing data**]
    - Processing: done by cloud / edge devices
    - Include:
      - Different types of *data processing functionalities* （数据处理功能）
        - Data **accumulation**
        - Data **abstraction**
        - Etc.
      - Privacy & Security functions etc.
  - Application Layer
    - cloud / data centers, data is managed & is used by end-user applications from various sectors
    - Include:
      - **Different interface**
        - Graphical user interface (GUIs)
        - Command-line user interfaces (GUIs)

        → enable user interaction and provide application services to users
  - Management services:
    - Remote device monitoring & management
    - Security control…

- IoT Benefits

- Efficient resource monitoring and utilization
- Minimize human effort by enabling automation
- Save time and money
- Enhance real-time data collection
- Improve security and efficiency
- Enable new analytic insights by connecting different systems
- Add value by creating new business opportunities

- IoT Challenges
  - Heterogeneity （异质性）
  - Scalability （可扩展性）
  - Integration of devices from different systems and vendors （集成来自不同系统/供应商设备）
  - Dynamic and intermittent（间歇性） wireless networks
  - Energy concerns - due to low-cost and low-power devices
  - Reliability concerns due to device failures
  - Remote device management and diagnosis
  - Lack of standardized protocols （缺少标准化协议）
  - Privacy and security concerns

- Enabling Technologies for IoT
  - Low-cost and low-power sensing
  - Low-power and high data rate networking
  - Interoperability of different protocols （不同协议的互操作性）
  - Cloud/Edge computing platforms
  - AI/ML analytics enabling valuable insights and business solutions
  - Novel security and privacy solutions （新颖的安全和隐私解决方案）

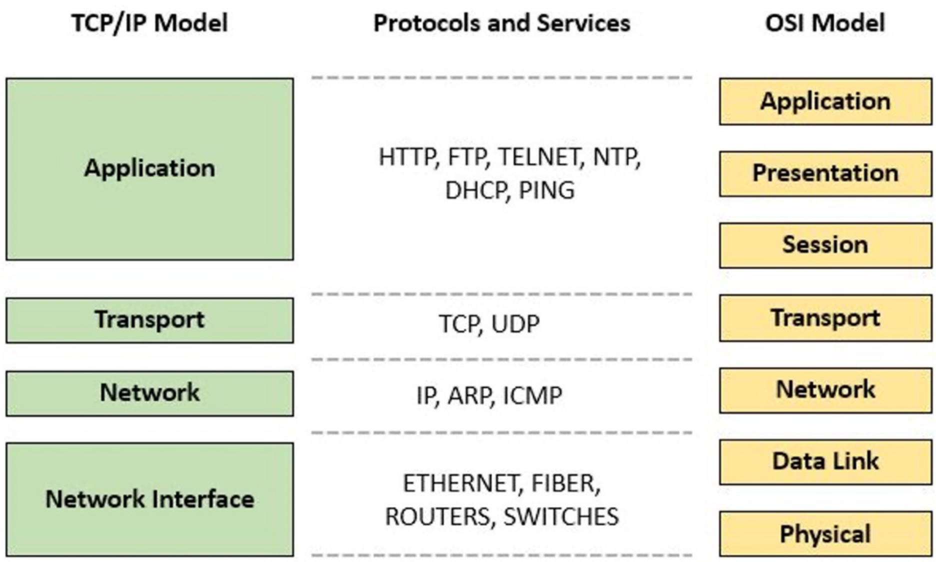
- OSI Model
  - Conceptual model → **coordination of [ISO] standards** （协调 ISO 标准）

    → systems interconnection
  - **Layer:**
    1. Physical Layer - Transmits raw bit stream over physical medium

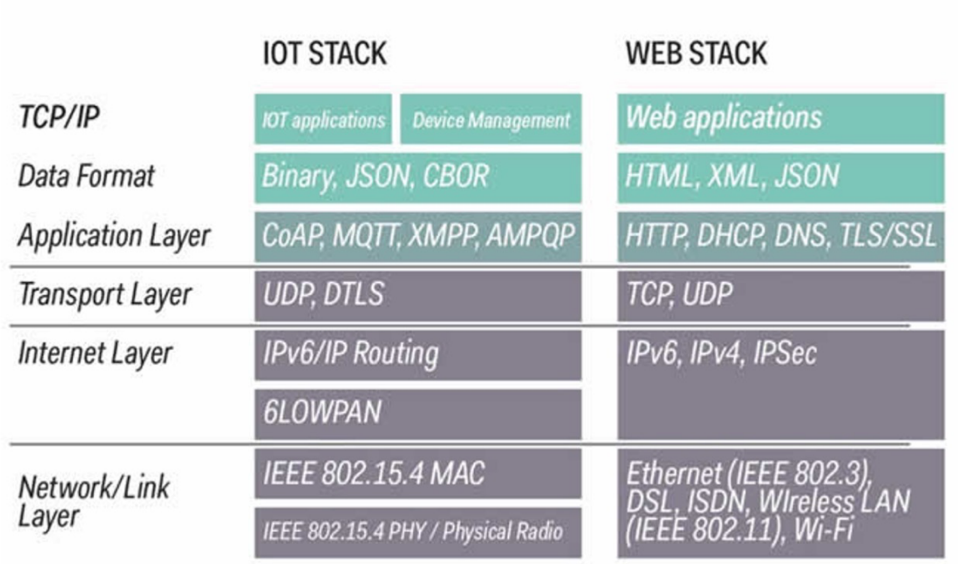
       （在 device 之间传递 raw bit stream）

2. Datalink Layer - Defines the *format of data* on the network
3. Network Layer - Decides which *physical path* the data take
4. Transport Layer - Transmits data *using transmission protocols* [TCP & UDP]
5. Session Layer - Maintains connections & controlling ports and sessions
6. Presentation Layer - Ensures data is in *usable format* & *data encryption* occurs （数据加密）
7. Application Layer - *Human - computer interaction* layer

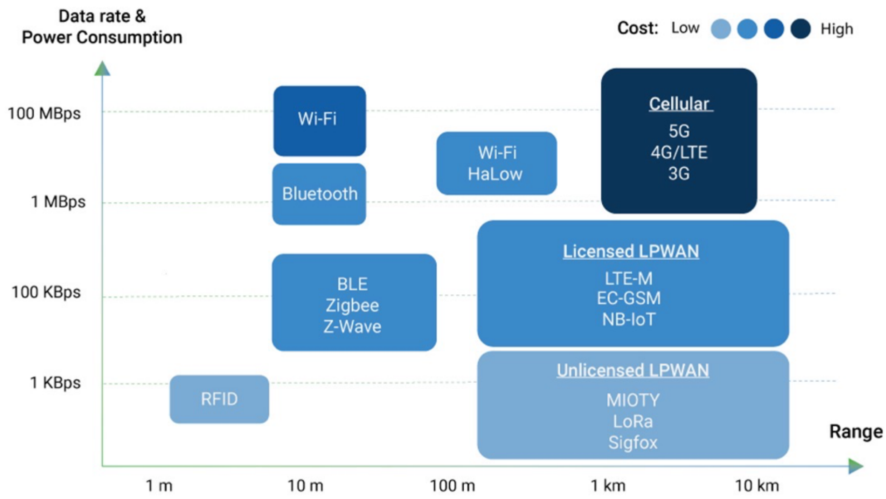
- **TCP/IP Model (Very IMP!!!)**



- IoT Stack



- Network Protocols for Buildings（网络协议） [communication mudiums used in IoT - Wire & Wireless]
    - Wired Protocols: BACnet, KNX, LonWorks, DALI, Ethernet
    - Wireless Protocols: WiFi, Bluetooth, ZigBee, Z-wave, 6LoWPAN, NB-IoT, 3G/4G/5G



- Wired V.S. Wireless Protocols:

PARAMETER	WIRED	WIRELESS
Communication Medium	Copper, Fiber etc.	Air
Standard	IEEE 802.3	802.11 family
Mobility and Roaming	Limited	Higher
Security	High	Lower than Wired. Also easy to hack
Speed / Bandwidth	High Speed upto 1 Gbps	Lower speed than Wired Network.
Access to Network	Physical Access Required	Proximity Required
Delay	Low	High
Reliability	High	Lower than Wired
Flexibility to change	Less flexible to changes	More flexible configuration
Working principle	CSMA/CD, operates by detecting the occurrence of a collision.	CSMA/CA , hence reduces possibility of collision be avoiding collision from happening
Interference and Fluctuations vulnerability	Very Less	High
Installation activity	Cumbersome and manpower intensive	Less labor intensive and easy
Installation Time	Takes longer time to perform	Very less deployment time
Dedicated / Shared Connection	Dedicated	Shared
Installation Cost	High	Low
Maintenance (Upgrade) cost	High	Low
Related equipment	Router, Switch , Hub	Wireless Router, Access Point
Benefits	• Greater Speed • Higher noise immunity • Highly reliable • Greater Security	• No Hassles of Cable • Best for mobile devices • Greater mobility • Easy installation and management

- IoT Solutions for Smart Building
  - **Localization for occupants & resources tracking** （本地化&资源追求）
    - Enable navigation inside the building for new occupants
    - Enable new applications E.g. personalized experience in museums
    - Automate/Predict user requirements based on location information
    - Enable building managers to locate equipment or facilities needing repair
    - Understand occupant's behaviour and predict unique events inside buildings by dynamically localizing occupants.
  - **Energy management**
    - Use smart meters/sensors to monitor and predict the *building environment and energy usage*
    - Provide a context-aware solution to control HVAC, lighting and other systems inside building based on **dynamic occupant behaviour**
    - Enable **dynamic adjustment** of supply and demand of electricity/energy by leveraging real-time information from smart meters
  - **Facility management**
    - Enable **timely preventive maintenance and malfunction detection** of building equipment to ensure the facility's optimal condition.
    - Provide adaptive and real-time access to building facilities for relevant personnel
    - Enable integration and remote monitoring and management of different system
    - Enable predictive maintenance and fault diagnosis by using large amount of collected data
  - **Indoor comfort enhancement**
    - Enable robust monitoring and control of the indoor built environment to maximize comfort
    - Enable automatic adjustment of indoor setting based on real-time data
    - **Joint control** of HVAC, lighting, and other systems
    - Enable learning of occupant's preference based on collected historical data
  - **Occupant safety and health security**
    - Use real-time data from wearable sensors, smartphone, and other sensor → detect safety & health-related emergency situations
  - **Efficient resource management for convenience**
    - Use IoT for smart parking → optimize space usage & reduce time wastage
    - Use real-time occupancy data → optimal space utilization in office

- **Building health control**
  - Integrate data from multiple sensors → structural health monitoring, fire hazard…

Big Building Data and Cloud/Edge Computing

- Big Data [Definition]
  - **Primarily**（主要是）refers to data sets that are too large / complex to be deal with by traditional data-processing application software
- Big Data Features (5V's / 4V's)
  - Value （不必须有 not all Big Data have value）
  - Velocity (data inflow high velocity E.g. IoT have high velocity)
  - Veracity
  - Variety
  - Volume
- Big Data Source in Building （一切和 Building 相关的量化数据都可以被称作是 Big Data）
  - Energy consumption/production
  - building management systems
  - asset management data
  - building stock auditing
  - weather and climate data
  - social media data
  - socioeconomic data
  - energy end-user's characteristics and comfort levels
  - open source data
  - etc.
- Big Data Challenges:
  - Data Challenges: Volume, variety, veracity, velocity, variability, visualization, value, etc.
  - Data **Processing** Challenges:

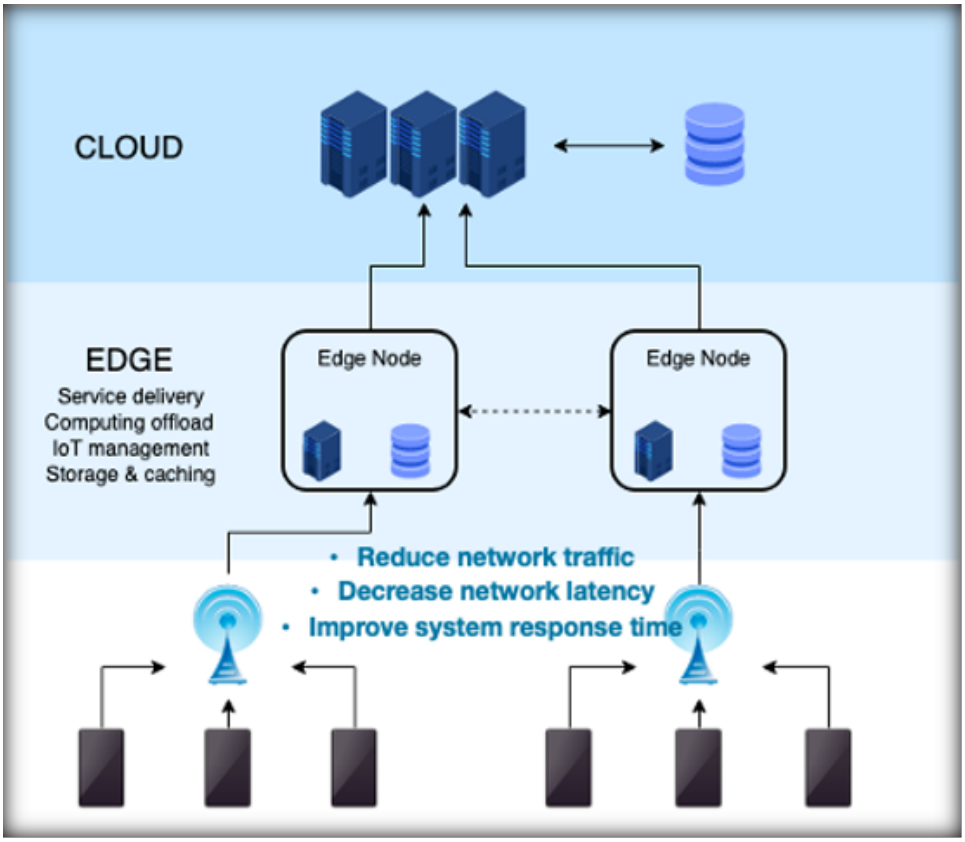
    - **Data Acquisition and Warehousing:** acquiring data from diverse sources and storing for value generation purpose （数据采集和仓储）
    - **Data Mining and Cleansing:** extracting and cleaning data from a collected pool of large scale structured/unstructured data （数据挖掘和清理）
    - **Data Aggregation and Integration:** aggregating and integrating clean data mined *from large **unstructured** data* （数据聚合和集成）
    - **Data Analysis and Modelling:** centers around solving the intricacy of relationships between different data and providing valuable insights （数据分析和建模）
    - **Data Interpretation:** visualising data and making data understandable for users （数据解释）
  - Data **Management** challenge
    - Privacy
    - Security
    - Data Governance
    - Data and Information sharing
    - Cost/Operational Expenditures （成本/运营支出）
    - Data Ownership （数据所有权）

- Power of Cloud
  - Cloud has become mainstream for business & many organizations (in last decade)
  - Cloud Computing includes providing on-demand services (database, servers, storage, applications, etc.) for users *via internet*

- The Great Cloud Bottleneck （巨大的 cloud 的瓶颈）
  - Cloud has many applications but not enough for IoT application
  - Drawbacks:
    - High Cost

- High Response time (Large delay - sending and receiving data from remote cloud servers that are <u>*located far from sensors/actuators*</u>)
- Bandwidth Congestion （带宽拥挤）
- Limited Scalability （可扩展性有限）
- Privacy Leakage

- Edge Computing
  - Edge Computing pushes the computation, storage, and other services <u>*close to the data sources*</u>



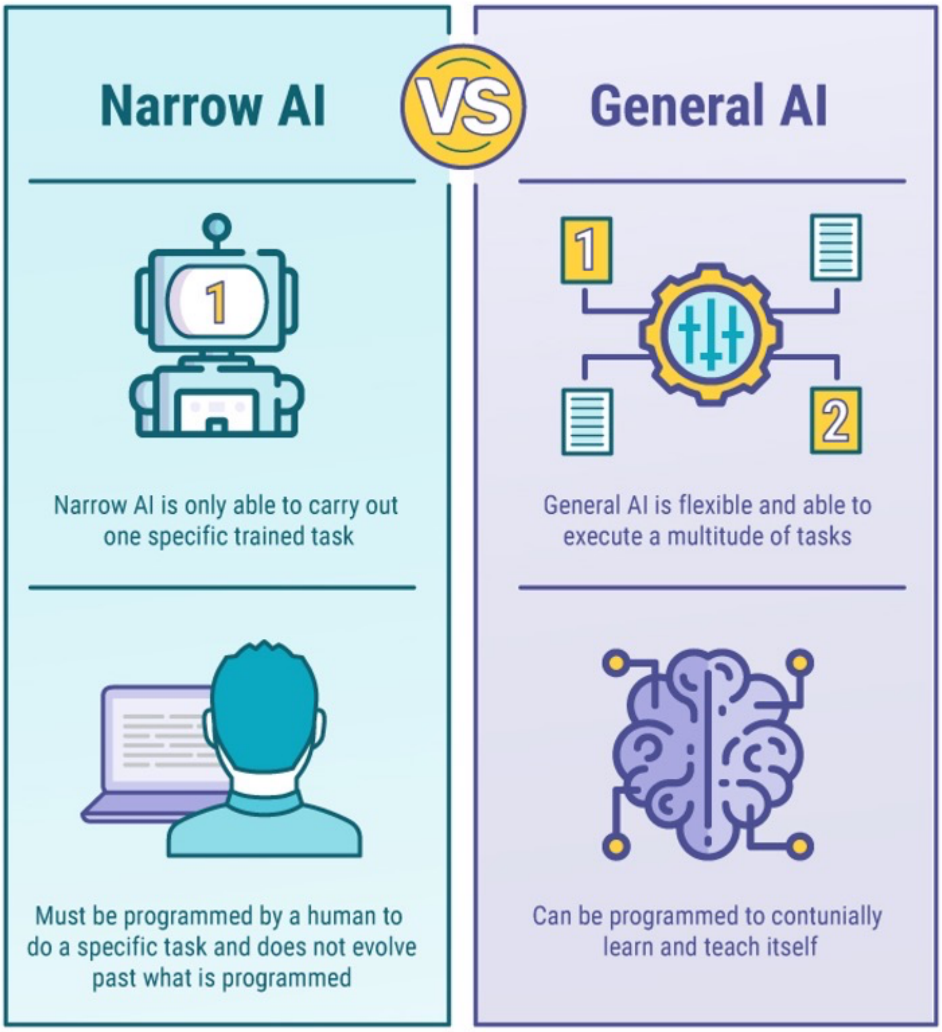
  - Component
    - <u>Local Devices</u>
    - Localized Data Centre
    - Regional Data Centre
  - Functionality
    - Caching （缓存）
    - Storage
    - Processing
    - Decision making
    - Security
    - …

- Benefits
    - Faster response time
    - Reliable Operations with intermittent Connectivity （具有间歇性链接的可靠操作）
    - Security & Compliance （安全和服从性）
    - Cost - Effective solutions
    - Interoperability between Legacy & Modern Devices （新老设备间的互操作性）
- Platforms
    - Extend cloud services to edge for data preprocessing: （将云服务扩展到 Edge 进行预处理）
        - Intelligent EdgeFabric
        - Azure IoT Edge
        - Cloud IoT Edge
        - AWS IoT Greengrass
    - Extend native Kubernetes to support edge computing seamlessly: （扩展原生 Kubernetes 来无缝支持 Edge computing）
        - KubeEdge
        - Baetyl
        - Openyurt
    - **Features**
        - on-demand services
        - broad network access
        - resource pooling
        - rapid elasticity
        - measured service
- Challenges
    - Resource-constraint devices with limited resources （资源有限）
    - Heterogeneity of network, compute, and storage resources at edge devices
    - Dynamic network with intermittent network connectivity and device/link failures （间歇性动态网络连接故障）

- Sharing and management of resources in distributed network （分布式网络的资源共享&管理）
- Extreme scale of devices
- Security and privacy concerns

AI and ML

- AI:
  - **processes and algorithms** that are able to simulate human intelligence, including mimicking cognitive functions such as perception, learning and problem solving.
  - Goal
    - To **Create Expert Systems** − exhibit intelligent behavior, learn, demonstrate, explain, and advice its users.
    - To **Implement Human Intelligence in Machines** − Creating systems that understand, think, learn, and behave like humans.
- Narrow V.S. General AI

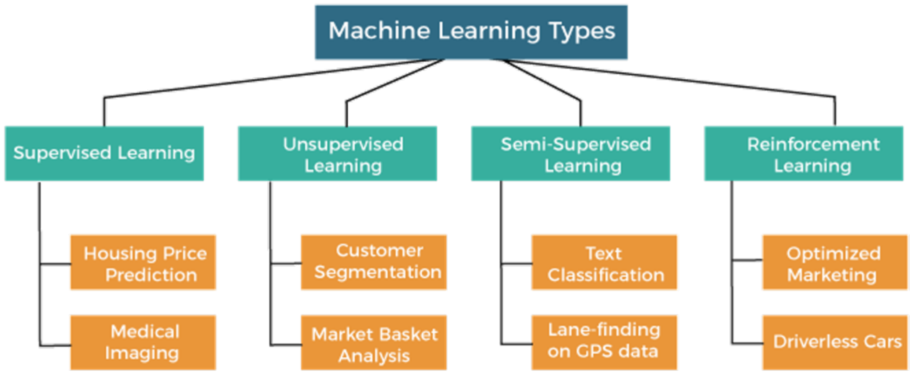


- Benefits of AI
  - High Accuracy with less errors
  - High-Speed
  - High reliability
  - Useful for risky areas （适用于危险区域）
  - Digital Assistant
  - Useful as a public utility
- Applications of AI
  - Data Security
  - Finance
  - Gaming
  - Astronomy
  - Healthcare
  - Transport
  - Agriculture

- Etc.

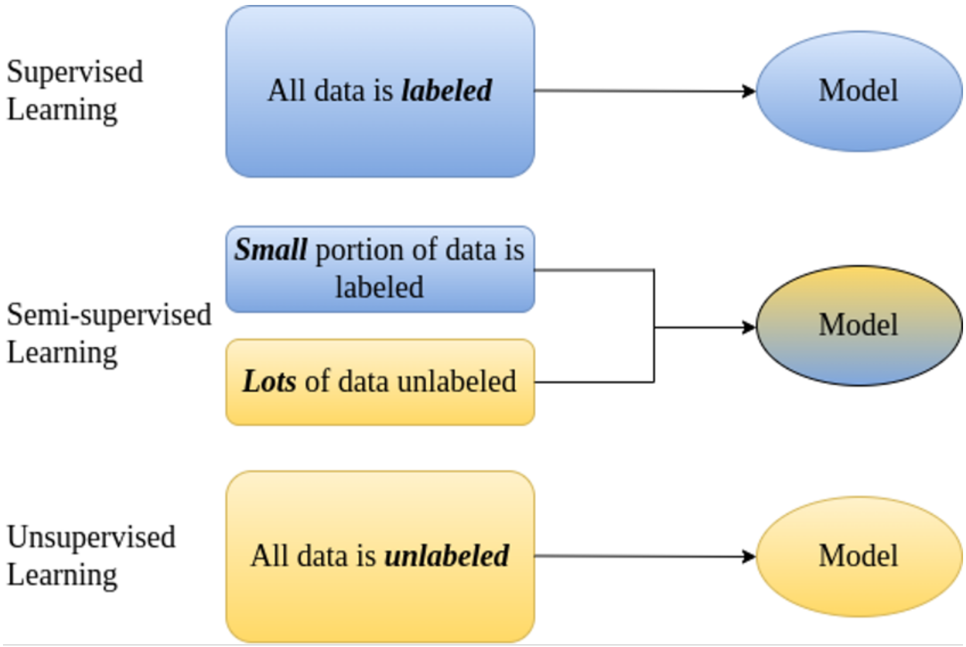
- Challenges / Disadvantages of AI
  - High Cost
  - Can't think out of the box
  - No feelings and emotions
  - Increase dependency on machines
  - No Original Creativity
  - Ethical concerns

- Machine Leaning (ML) - **Part of AI**
  - **studying** how computer agents can improve their perception, knowledge, thinking, or actions based on experience or data.
  - Type



- Supervised Learning
  - [input data & **labelled** output data]
  - Main Goal: map the input variable (x) with the output variable (y)（将输入与输出变量映射）
  - E.g. Risk Assessment, Fraud Detection, Spam filtering, etc.
  - **Classified into two types problem**
    - Classification
    - Regression
- Unsupervised Learning
  - [**not include labelled data**]
    - Trained with data *neither classified nor labelled* - model acts on data without any supervision
  - Main Goal: group / categories the unsorted dataset according to the *similarities, patterns and differences* - find the **hidden patterns** from the input dataset
  - Discover similarities & differences in information. E.g.exploratory data analysis, cross-selling strategies, customer segmentation, and image and pattern recognition.

- **Classified into:**
  - Clustering
  - Dimensionality reduction
  - Association
- Semi-Supervised Leaning
  - [both **labelled & unlabelled** data]
  - Solve: not having enough labeled data for a supervised learning algorithm & helps if it's too costly to label enough data.
  - Conjunction with a small amount of labeled data & unlabelled data → improvement in learning accuracy.
  - Variety of problems from ***classification and regression to clustering and association*** for different application domains such as medical, smart buildings, etc.



- Reinforcement Learning
  - Involves agents that learn to take suitable action → **maximize reward** in a particular situation.
  - **Not aware** of the correct output/label instead the agent learns to take optimal action based on experience of which action results in maximum reward.
  - **Similar to human being**
  - Employ: Game theory, Operation Research, Information theory, multi-agent systems.

- ML Algorithms

1. Regression Problem: model the relationship between a dependent (target) & independent (predictor) variables with one/more independent variables → **predicting** continuous/real values of dependent variable

- Linear regression: linear relationship between the independent variable (X-axis) and the dependent variable (Y-axis) **[Linear problem]**
    - Simple linear regression: if there is only one input variable (x)
    - Multiple linear regression: more than one input variable
    - Objective: Learn value of parameters **w** and **b** → hyperplane in linear regression is as **close to all training examples as possible**

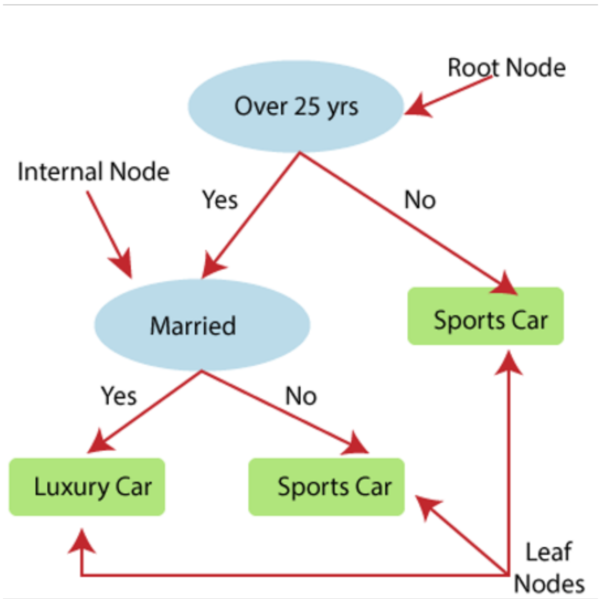
      （尽可能接近若有训练样本）

$$f_{\mathbf{w},b}(\mathbf{x}) = \mathbf{w}\mathbf{x} + b,$$

- Formal definition: To *minimize the squared error loss* （最小化平方误差）

$$\frac{1}{N}\sum_{i=1\ldots N}(f_{\mathbf{w},b}(\mathbf{x}_i) - y_i)^2.$$

- Decision Trees [**supervised learning algorithm**]
    - Solve:
        - Both Classification & Regression
        - Both categorical & numerical （解决分类和数据问题）
    - Build a tree-like structure
        - Each internal node represents the "test" for attribute （每个内部节点表示属性的"测试"）
        - Each branch represent the **result** of test （每个分支表示测试结果）
        - Each leaf node represents the **final decision / result** （每个叶节点表示最终决策/结果）



2. Classification Problem: program learns from the given dataset or observations → classifies new observation into a number of classes or groups
    - Binary Classifier: classification problem has only two possible outcomes
    - Multi-class Classifier: classification problem have more than two outcomes
    - Logistic Regression: predicts the output of a *categorical dependent variable*.

      （分类因变量的输出）

        - Outcome: categorical / discrete value

      E.g. 0 or 1; true or false; yes or no

- Imp. It is not giving the exact value as 0 and 1 → give the probabilistic values which **lie between 0 and 1**.
- Sigmoid function (to get probability value between 0-1)

$$f(x) = \frac{1}{1+e^{-x}},$$

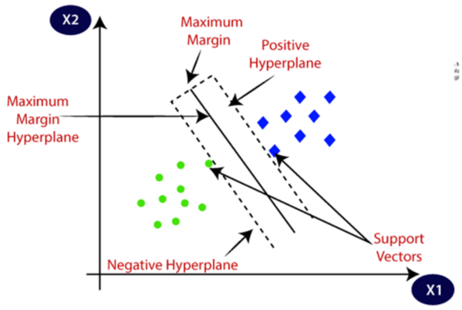
Plug in linear regression:

$$f_{\mathbf{w},b}(\mathbf{x}) \stackrel{\text{def}}{=} \frac{1}{1+e^{-(\mathbf{wx}+b)}}.$$

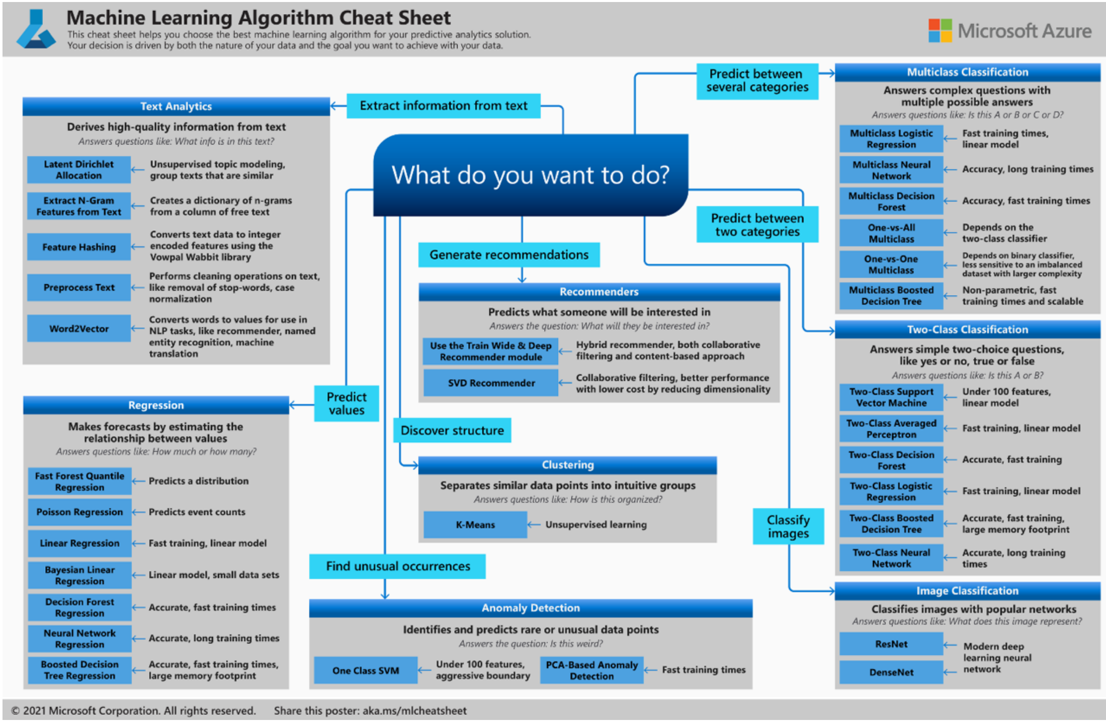
- Objective: **maximize the log-likelihood** of out training set
- Support Vector Machines (SVM)
    - Objective: create best line / decision boundary → can segregate（分开）

      n-dimensional space into classes → we can easily put the new data point in the correct category in future
    - **Hyperplane**: Best decision boundary
    - Maximum Margin （最大的距离）→ Maximum Margin Hyperplane

- Support Vectors - 距离 Positive Hyperplane / Negative Hyperplane 最近的一个点



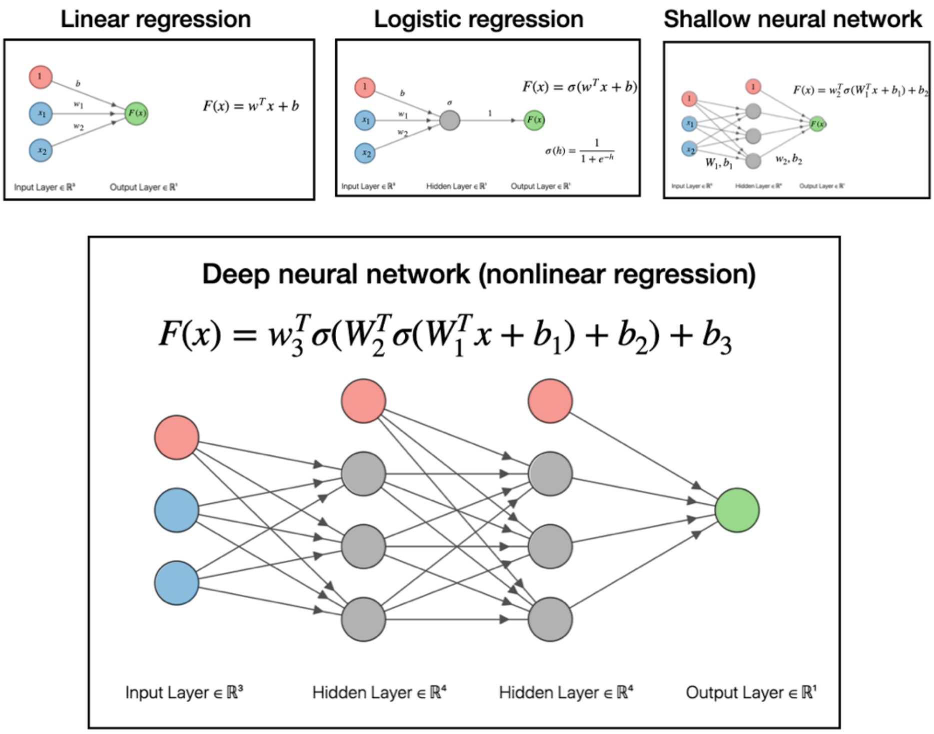
3. Clustering Problem: divide the population / data points into a number of groups [more similar to point in <u>same group</u> & dissimilar to point in <u>other group</u>]
    - Collection of object - similarity & dissimilarity between them
    - K-means Clustering: partitions n observations into k clusters [each observation belongs to the cluster]
        - Prototype: observation with nearest cluster mean
        - Steps for K-means clustering:
            - First, we <u>initialize random k points</u>, called <u>means / cluster centroids</u>
            - We <u>categorize each item to its closest mean</u> and we <u>update the mean's coordinates</u>（更新均值坐标） [averages of the items *categorized in that cluste*r so far]
            - We **repeat the process** for a given number of iterations and at the end → we have our clusters. （不断迭代重复）



Deep Neural Networks

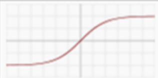
- Artificial Neural Network (ANNs) / neural networks (NNs)
  - computing systems inspired by the biological *neural networks that constitute animal brains*.

- Deep Neural Network (DNN)
  - [**a class of machine learning algorithms**] - uses multiple layers to *progressively extract higher-level features* from the raw input. （使用多个层 - 逐步提取较高级别的特征）
    - E.g. in image processing
      - Lower layers: identify edges
      - Higher layers: identify concepts relevant to human (digits/letters/faces)
  - Hidden Layer:
    - 1 - in shallow neural network
    - Many - in deep neural network
  - DNN is an ANN with multiple hidden layers [between **input and output layers**]

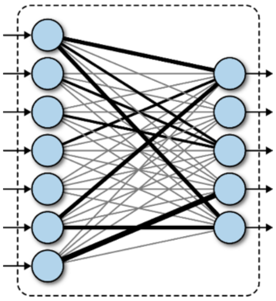


- Multilayer Perceptron (MLP)
  - Fully connected class of feedforward artificial neural network (ANN) （**完全连接的前馈人工神经系统**）（向前的 和 Recurrent 相对）
  - MLP consists **at least 3 layers of nodes**:
    - Input layer
    - Hidden layer
    - Output layer
  - Each node is a **neuron** [use nonlinear activation function]

- **Activation Functions in Neural Networks**

Name	Plot	Equation
Identity		$f(x) = x$
Binary step		$f(x) = \begin{cases} 0 & \text{for } x < 0 \\ 1 & \text{for } x \geq 0 \end{cases}$
Logistic (a.k.a Soft step)		$f(x) = \frac{1}{1+e^{-x}}$
TanH		$f(x) = \tanh(x) = \frac{2}{1+e^{-2x}} - 1$
ArcTan		$f(x) = \tan^{-1}(x)$
Rectified Linear Unit (ReLU)		$f(x) = \begin{cases} 0 & \text{for } x < 0 \\ x & \text{for } x \geq 0 \end{cases}$

- Fully Connected Neural Network (FCNN)
    - Consist of a series of *fully connected layers* [Connect every neuron in one layer to other layer]



- Major advantages: "structure agnostic"（与结构无关）- there are **no special assumptions** needed to be made about the input
- Drawback: tend to have weaker performance than *special-purpose networks* tuned to the structure of a problem space
- There are large number of weight parameters to be learned in Fully Connected Neural Network (Due to fully connected layers)
- **Fully connected neural networks cannot be applied for image data**

    E.g. for image of size 64*64*3, need 12288 weights（直接将 size 相乘，就是一个 neuron 的 first hidden layer 的 weights） for just one neuron in first hidden layer

- Convolutional Neural Network （卷轴神经） (CNN)

- Specialized **type of ANN** - use a mathematical operation called <u>convolution</u> in place of general matrix multiplication in at least one of their layers （在它们的至少一层中代替一般的矩阵乘法）
- Not all nodes in neuron are <u>connected to output nodes</u> → ***<u>number of weight</u>*** << FCNN
- 3 main types of layers
    - Convolutional layer

    Performing convolution operation <u>to input matrix</u> (with <u>stride</u> 2)

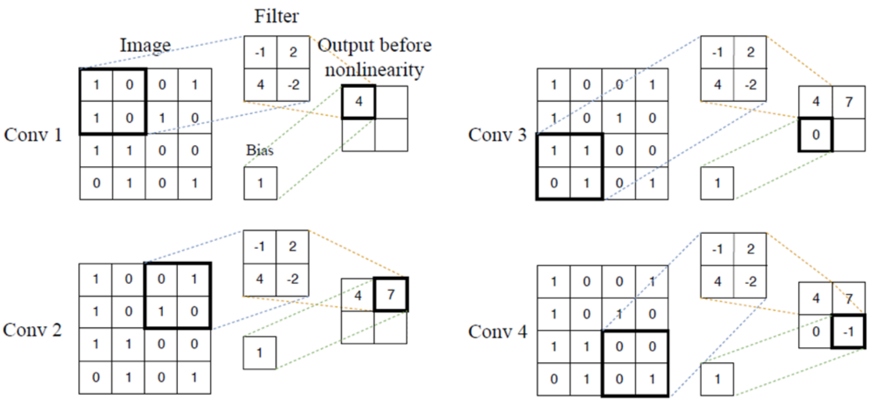


Figure 6.5: Convolution with stride 2.

- 图中的计算就是将 Filter 和 Image 中的格一一对应相乘得数 → +bias → output 中的数字
- Convolution operation using padding (stride 2 and padding1)

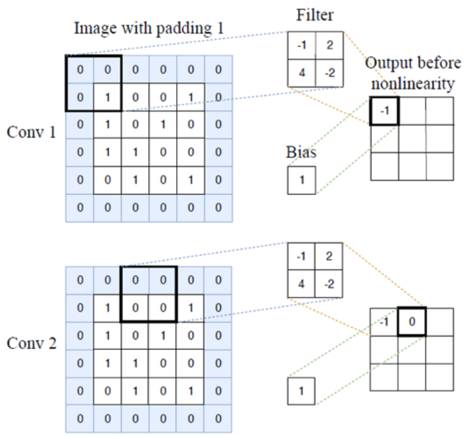


Figure 6.6: Convolution with stride 2 and padding 1.

- Polling layer

    Apply a fixed operator - <u>**usually max / average**</u> （下图中就是用的 max）

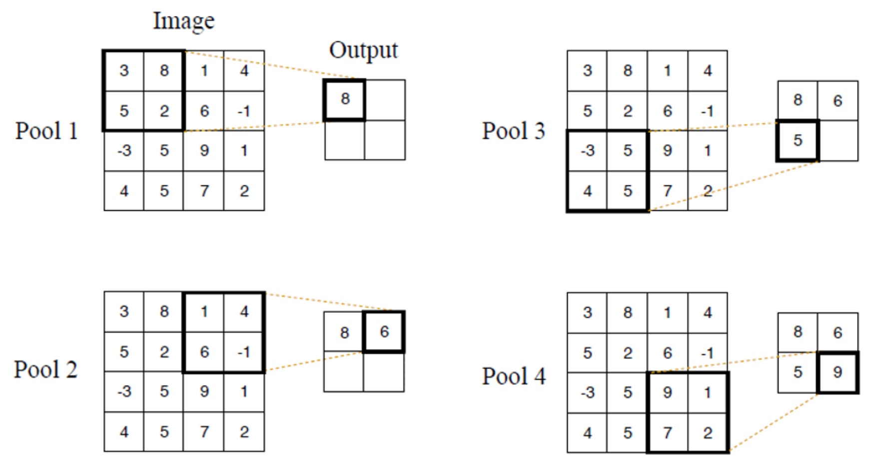
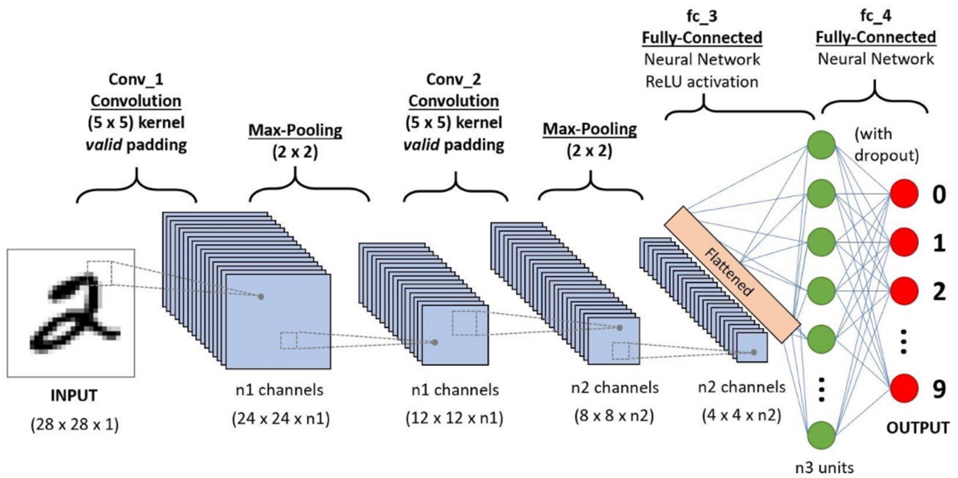
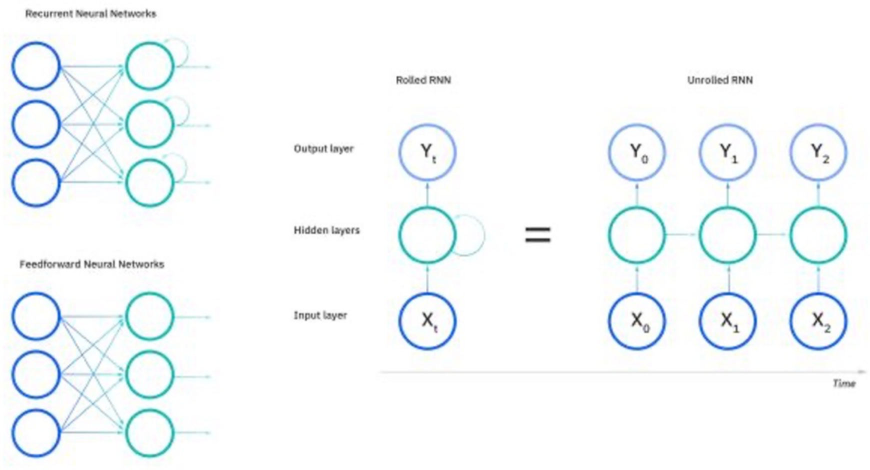


Figure 6.8: Pooling with filter of size 2 and stride 2.

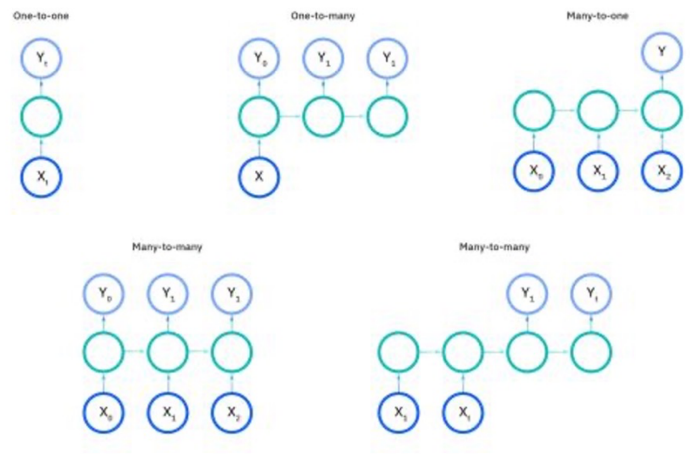
- Fully-connected (FC) layer
  - CNN architectures make the explicit assumption that the inputs are images - CNN architectures are able to successfully **capture the spatial and temporal（时间与空间）dependencies in the input image data**.



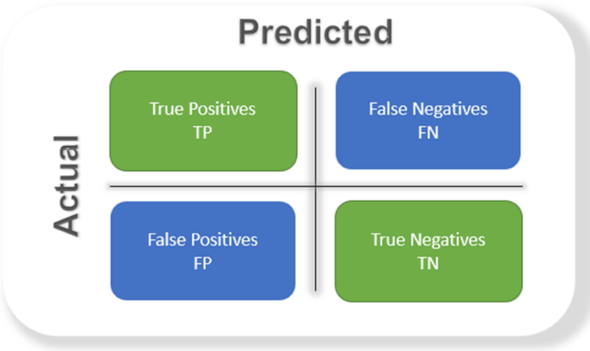
- Recurrent Nerual Network （递归神经） (RNN)
  - Type of NN - output from the previous step are fed as input to current step （上一步的输出作为当前步骤的输入馈送到当前步骤）
  - Use: *sequential data / time series data*



- <u>Output in RNN can vary in length</u>
- Different types of RNNs → Different use cases



- Performance Metrics （性能指标）
  - Model is trained → evaluate on <u>*test data*</u>
  - Regression:
    - Mean squared error
    - Root mean
    - Square error
    - Mean absolute error
  - Widely metrics & tools for **classification model**:
    - Confusion matrix - a table summarizes successful classification model [<u>*predicting examples - various class*</u>]



- **Binary** Classification

	spam (predicted)	not_spam (predicted)
spam (actual)	23 (TP)	1 (FN)
not_spam (actual)	12 (FP)	556 (TN)

- **Multiclass** Classification

Perceived vowel / Vowel produced	i	e	a	o	u
i	**15**		1		
e	1		1		
a			**79**	5	
o			4	**15**	3
u				2	**2**

Confusion matric → <u>further calculate precision & recall↓</u>

- Precision/Recall
  - **Precision:** ratio of correct positive predictions (TP) / overall number of positive prediction (TP+FP) [fraction of predictions as a <u>positive class were actually positive</u>.]

    E.g. precision is the <u>proportion</u> of **relevant documents** in the list of <u>*all returned documents*</u>

$$\text{precision} \stackrel{\text{def}}{=} \frac{\text{TP}}{\text{TP} + \text{FP}}.$$

- **Recall:** ratio of correct positive predictions (TP) / overall number of positive examples <u>(TP+FN)</u> [fraction of all positive samples were <u>correctly predicted as positive</u> by the classifier.]

  E.g. recall is the <u>ratio</u> of the **relevant documents** returned by the search engine to the <u>*total number of the relevant documents*</u> that could have been returned

$$\text{recall} \stackrel{\text{def}}{=} \frac{\text{TP}}{\text{TP} + \text{FN}}.$$

- In the case of the spam（垃圾邮件）detection problem, we want to have **high precision** (we want to *avoid making mistakes by detecting that a legitimate message is spam*) and we are ready to **tolerate lower recall** (we tolerate some spam messages in our inbox). （precision 与 recall 是相反的，如果想要更高的 precision 就会带来较低的 recall）

- Specificity
  - proportion of actual negatives correctly identified (TN) / all negatives (TN+FP) [跟 recall 相反]

$$\frac{TN}{TN+FP}$$

- F1-score
  - Calculate **harmonic mean** → find balance between precision & recall

$$F_1\text{–score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} = \frac{2\text{TP}}{2\text{TP} + \text{FP} + \text{FN}}$$

- Accuracy
  - correctly classified examples (TP+TN) / total number of classified examples (TP+TN+FP+FN)

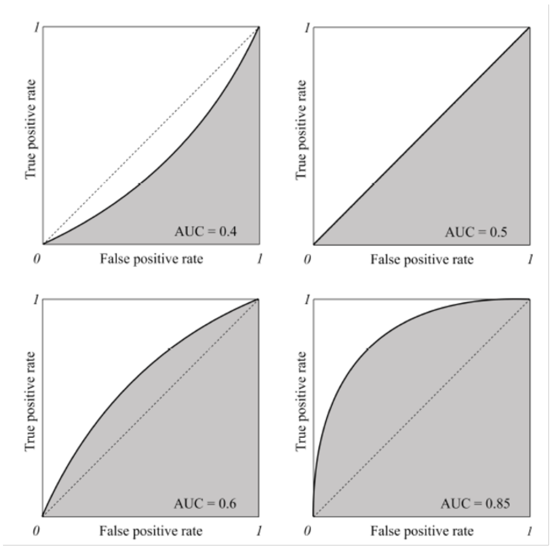
$$\text{accuracy} \stackrel{\text{def}}{=} \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}.$$

- When errors in predicting all classes are **equally important** → Accuracy is useful
  E.g. spam/not spam is not this case ← this is not equal (false positives less than false negative)

- Area under the ROC curve
  - ROC stands for operating characteristic; graph is plotted against TPR (TP Recall) & FPR (FP Recall) [various threshold values]
  - ROC curves can **only assess** classifiers that *return some confidence score / a probability* of prediction（只能用于评估返回预测的置信分数/概率的 classifier)

$$\text{TPR} \stackrel{\text{def}}{=} \frac{\text{TP}}{\text{TP} + \text{FN}} \text{ and } \text{FPR} \stackrel{\text{def}}{=} \frac{\text{FP}}{\text{FP} + \text{TN}}.$$

- ROC AUS is area under the curve [higher its number → better]

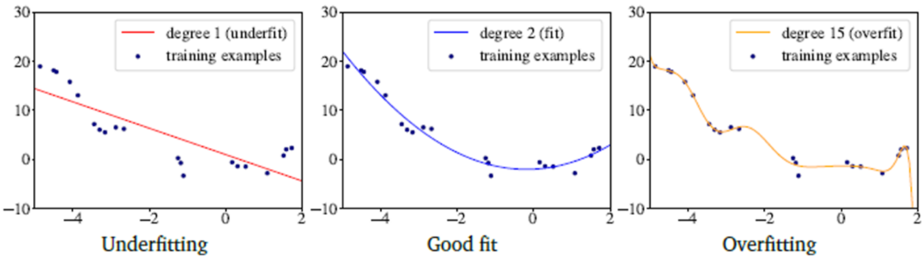


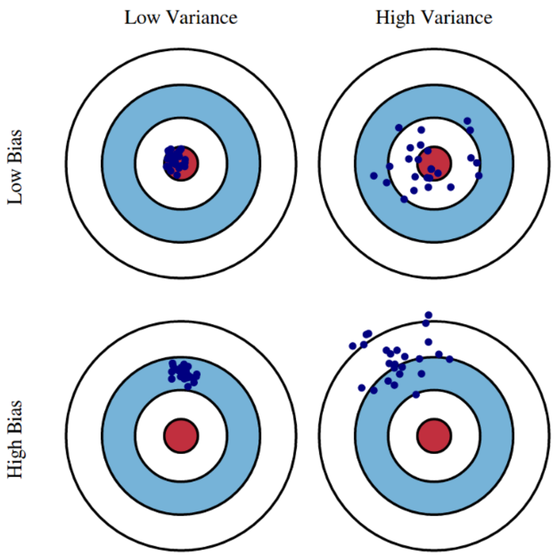
- Overfitting & Underfitting

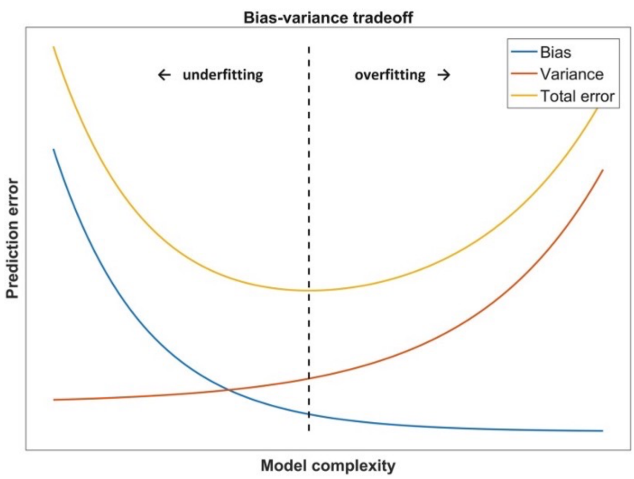
  If model is good ML model → generalizes any new input data <u>from problem domain in proper way</u>

  - Bias:
    - Assumptions function actually the <u>*error rate of training data*</u>
    - Error rate: high - High Bias; low - Low Bias
  - Variance:
    - Difference between the <u>error rate</u> of training data & testing data
    - **Difference of errors high** - high variance
    - **Difference of errors low** - low variance
    - Goal: usually want to make **low variance** for generalized out model
  - Underfitting: model/algorithm <u>cannot capture the underlying trend</u> of data （无法捕捉数据基本趋势）
    - Model/algorithm <u>**not fit**</u> the data well enough - have fewer data to build accurate model & we want to build a linear model with fewer non-linear data （Model 和 algorithm 都有）
    - Not perform well <u>**both**</u> on training data & new data
    - **Reasons for Underfitting:**
      - High bias & low variance
      - Size of training dataset is not enough
      - Model is too simple
      - Training data not clean - contain noise in it
  - Overfitting: model does not make accurate predictions on <u>**testing data （只有model）**</u>

- When model trained with so much data ← model start to learn from noise & inaccurate data entries
- Evaluation of ML algorithms on training data is different from unseen data (new data)
- Reasons for Overfitting:
    - High variance & low bias
    - The model is too complex
    - The size of training data is too small （容易被一些 noise 影响）







- Address Overfitting / Underfitting
    - Reduce underfitting:
        - Increase model complexity
        - Increase the number of features, performing feature engineering
        - Remove noise from data
        - Increase the number of epochs（周期）/ increase the duration of training（增加训练时间） → get better result
    - Reduce overfitting
        - Increase training data
        - Reduce model complexity
        - Early stopping during the training phase (loss begins increase → stop training)
        - **Ridge Regularization and Lasso Regularization**
        - Use dropout for neural networks