Introduction to Pattern Recognition

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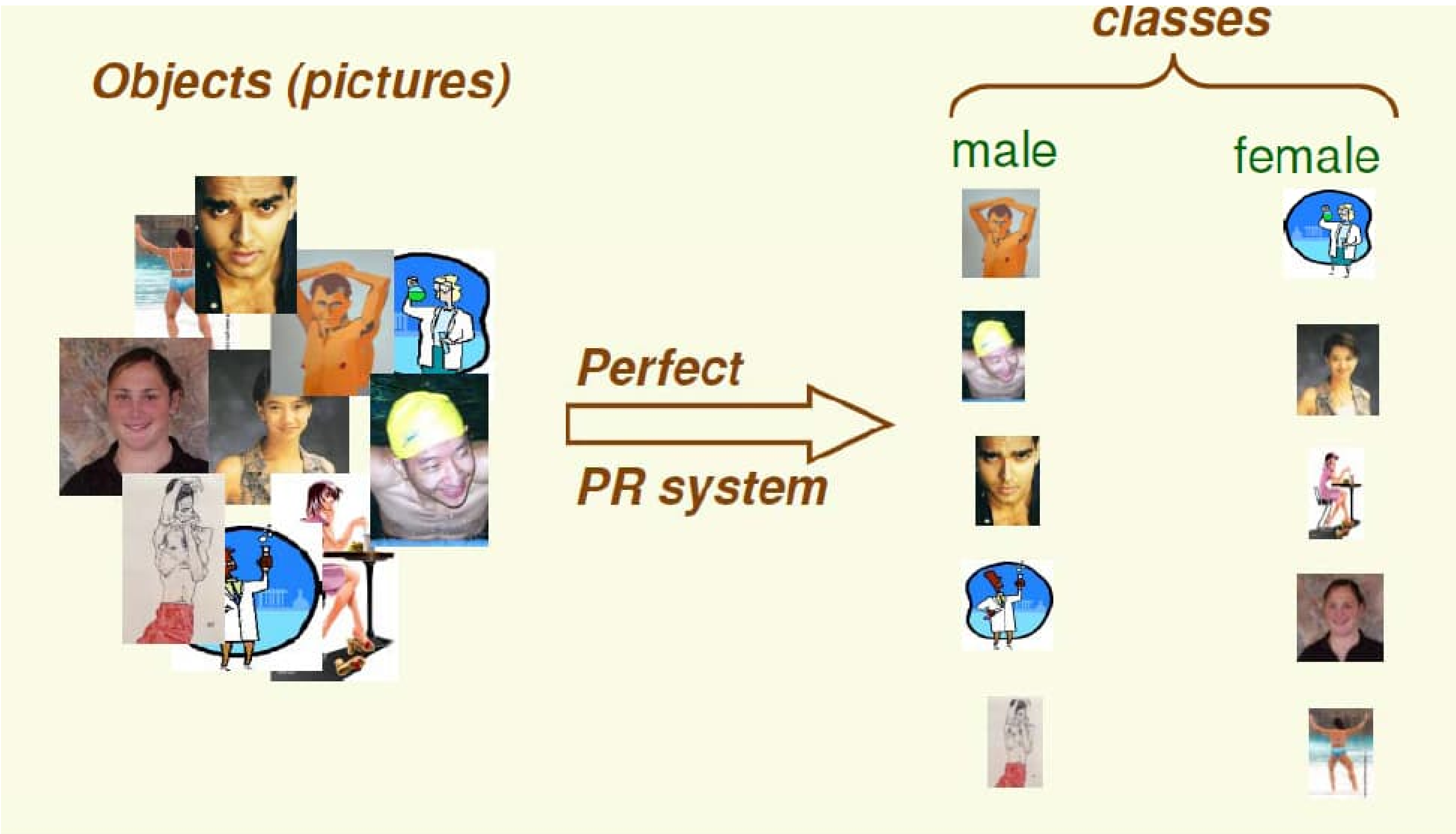
What is Pattern Recognition (PR)?

- Assign an unknown pattern to one of several known categories (or classes)

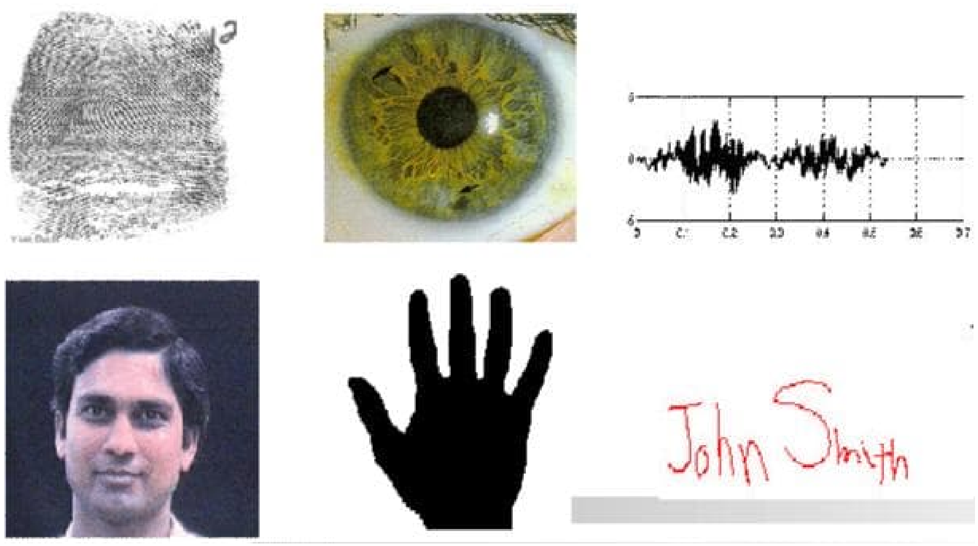


What is a Pattern?

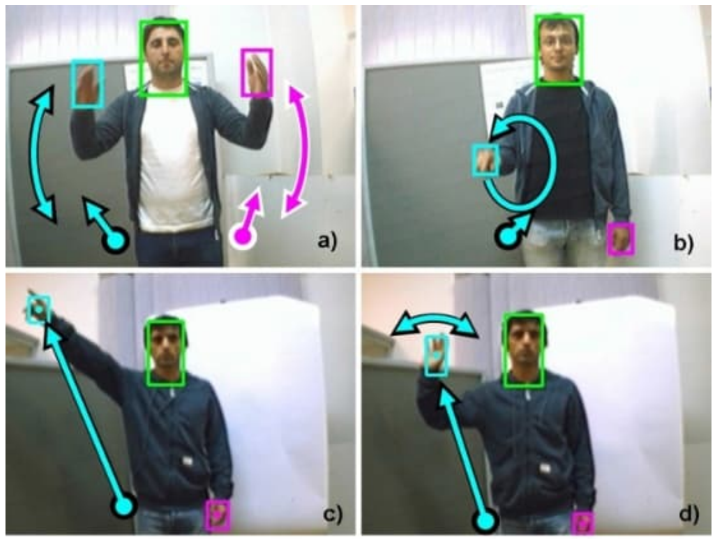
- A pattern could be an object or event.

An example:

biometric patterns



hand gesture patterns



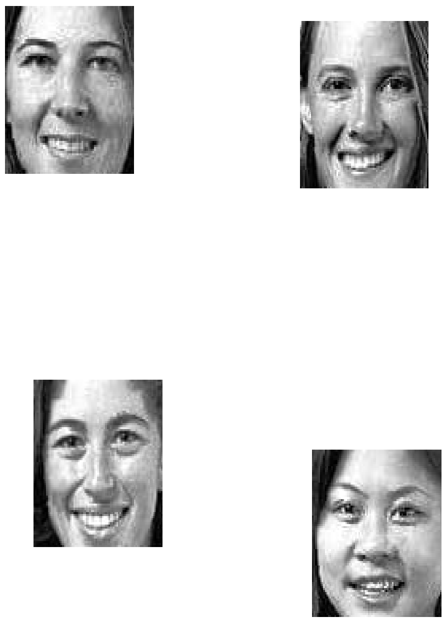
What is a Pattern?

- Loan/Credit card applications
  - Income, # of dependents, mortgage amount → credit worthiness classification
- Dating services
  - Age, hobbies, income → "desirability" classification
- Web documents retrieval
  - Key-word based descriptions → document classification

What is a Class?

- A collection of “similar” objects.

Female

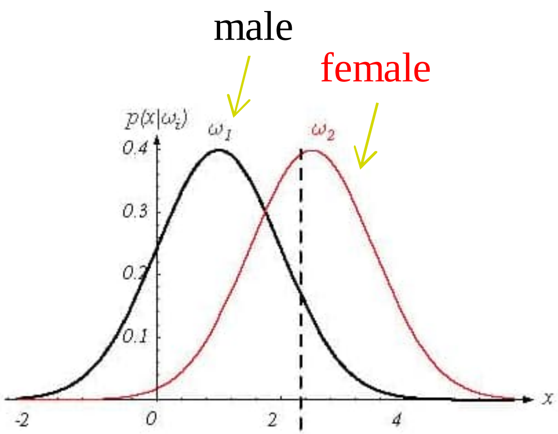


Male

How Do We Model a Pattern Class?

- Typically, with a statistical model.
  - Probability Density Function (PDF) (e.g., Gaussian)
  - A pattern class can be modelled using a PDF.

Gender Classification

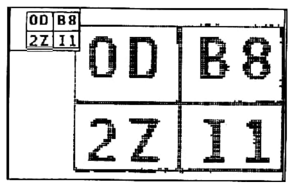


How Do We Model a Pattern Class?

- Key challenges:
  - Intra-class variability

The letter “T” in different typefaces

  - Inter-class variability



Letters/Numbers that look similar

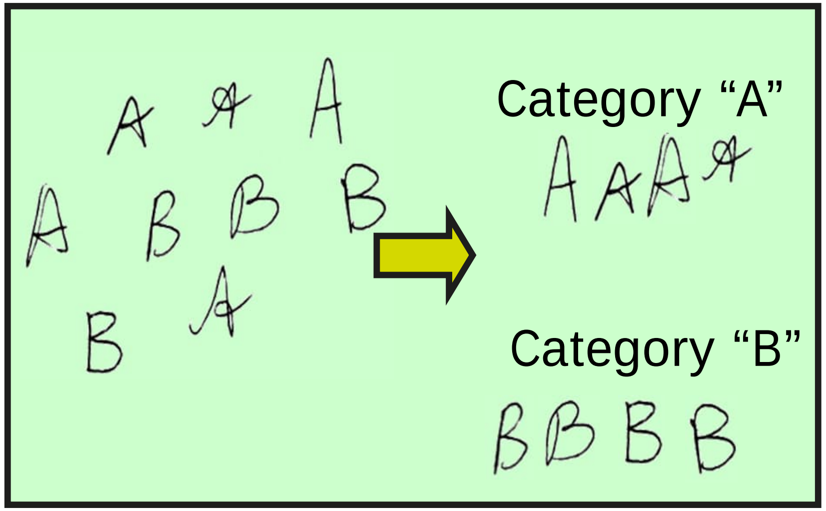
Pattern Recognition: Two Main Objectives

- Hypothesize the models that describe pattern classes, e.g., recover the processes that previously generated the existing patterns.

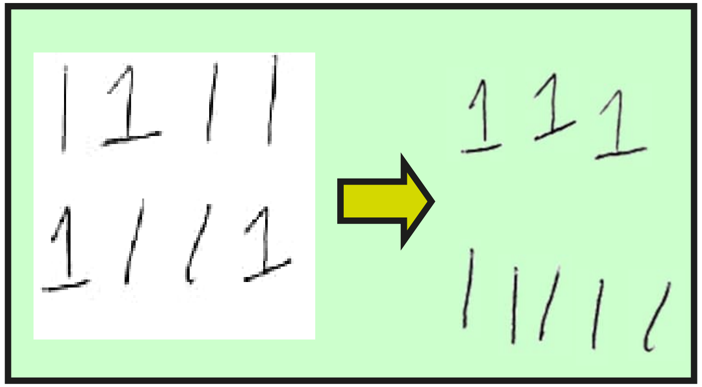
- Given a novel pattern, choose the best-fitting model for it, and then assign it to the pattern class associated with the model.

Classification vs. Clustering

- Classification (known categories)
- Clustering (unknown categories)



Classification (Recognition)
(Supervised Classification)

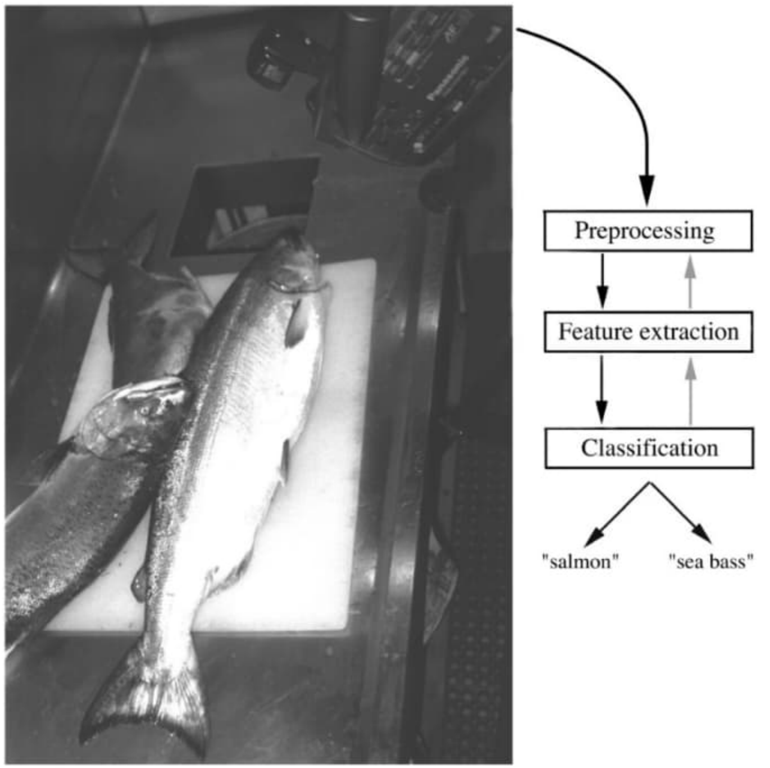


Clustering
(Unsupervised Classification)

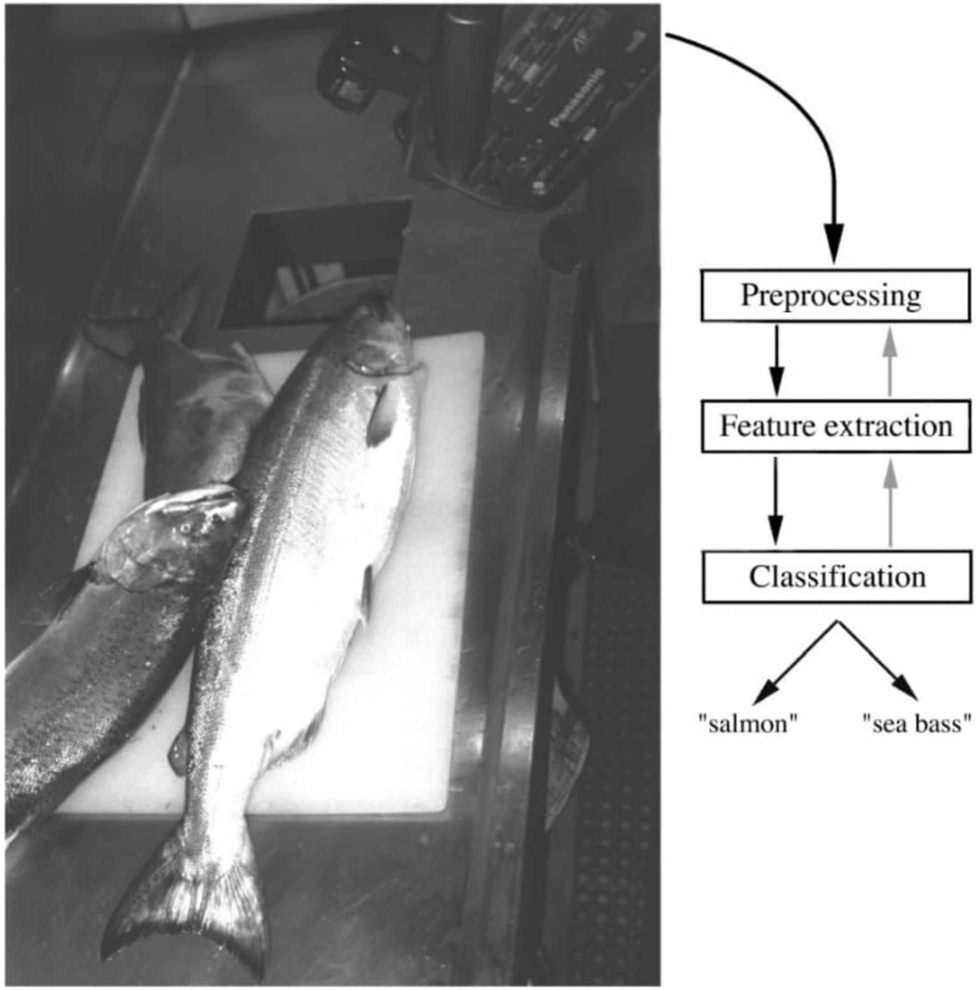
An Example of Pattern Recognition

Problem: Sorting incoming fish on a convey or belt.

Assumption: Two kinds of fish:
(1) sea bass
(2) salmon



Pre-processing Step



Example of Preprocessing

(1) Image enhancement.

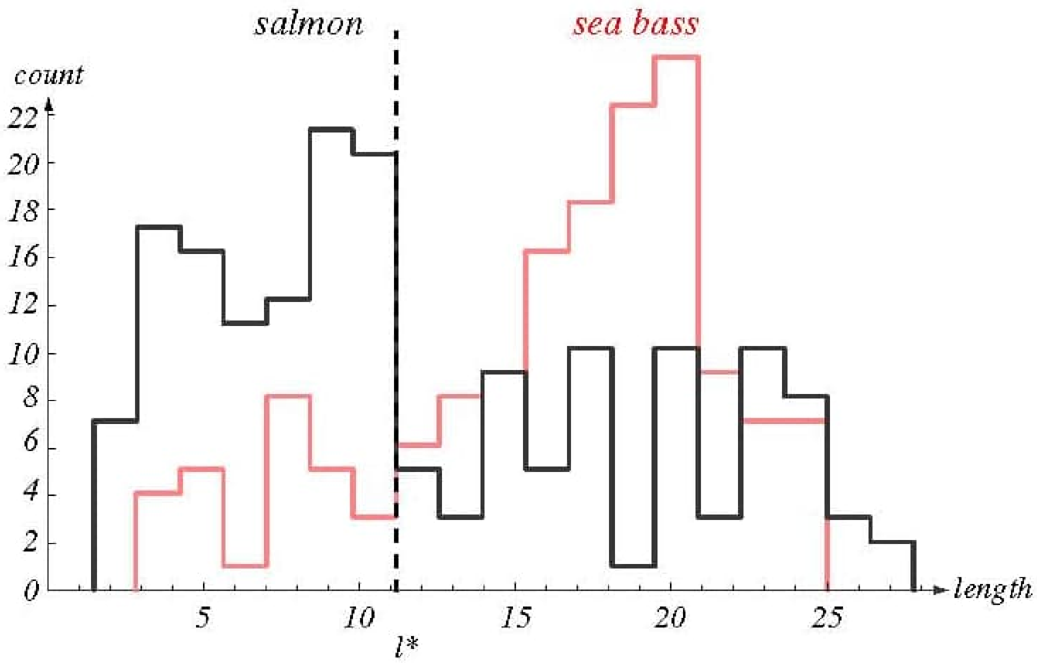
(2) Separate touching or occluding fish.

(3) Find the boundary of each fish.

Feature Extraction

- Assume a fisherman has told us that a sea bass is generally longer than a salmon.
- We can use length as a feature, and decide between sea bass and salmon according to a threshold on the length.
- How should we choose the threshold?

“Length” Histograms

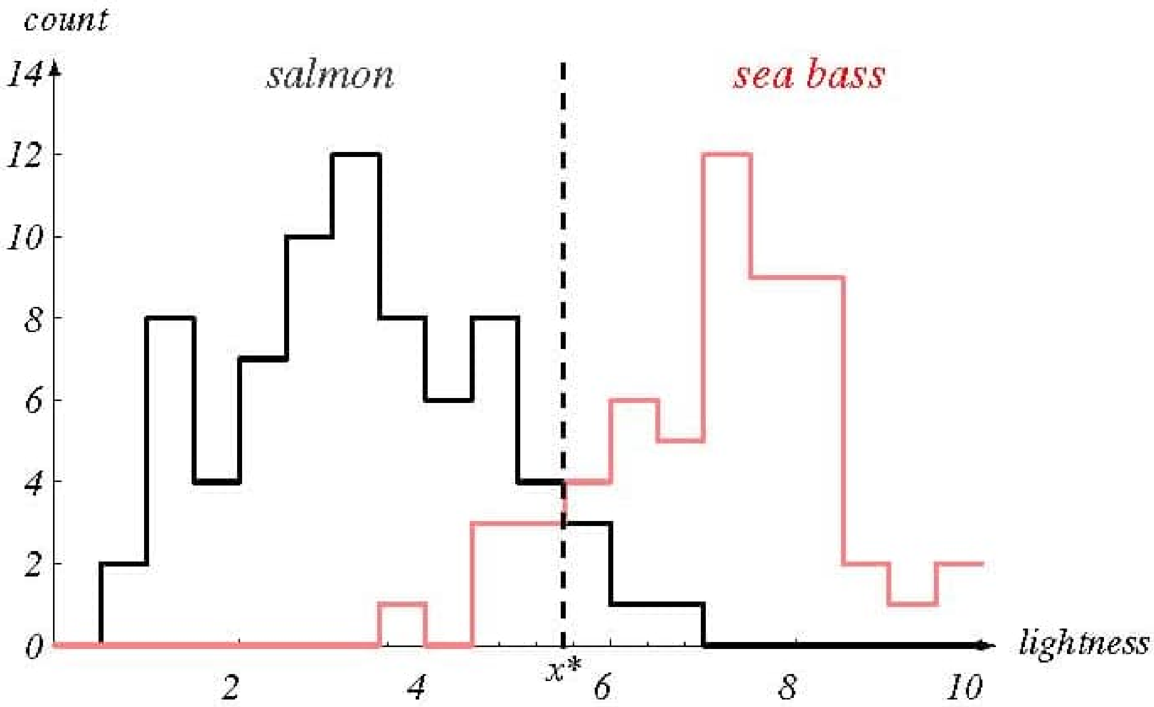


threshold *l**

- Even though sea bass is longer than salmon on the *average*, there are still many examples of fish, where this observation does not hold.

"Lightness" Histograms

- Consider a different feature, such as "lightness".



threshold *x**

Multiple Features

- To improve recognition accuracy, we may have to use more than one feature at a time.
  - Single features might not yield the best performance.
  - Using combinations of features could provide better performances.

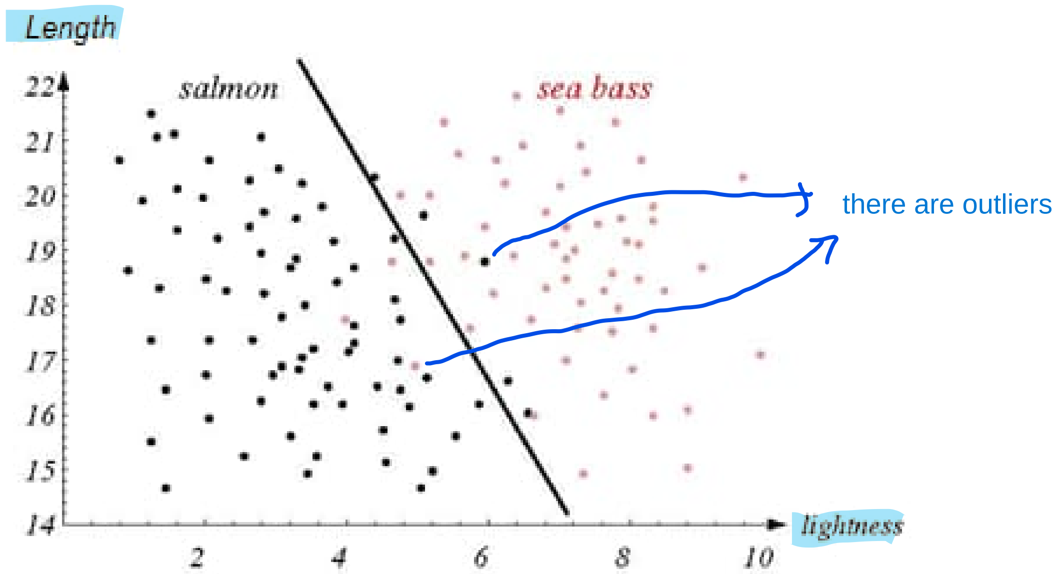
$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

- x_1 Length
- x_2 Lightness

- How many (optimal?) features should we choose?

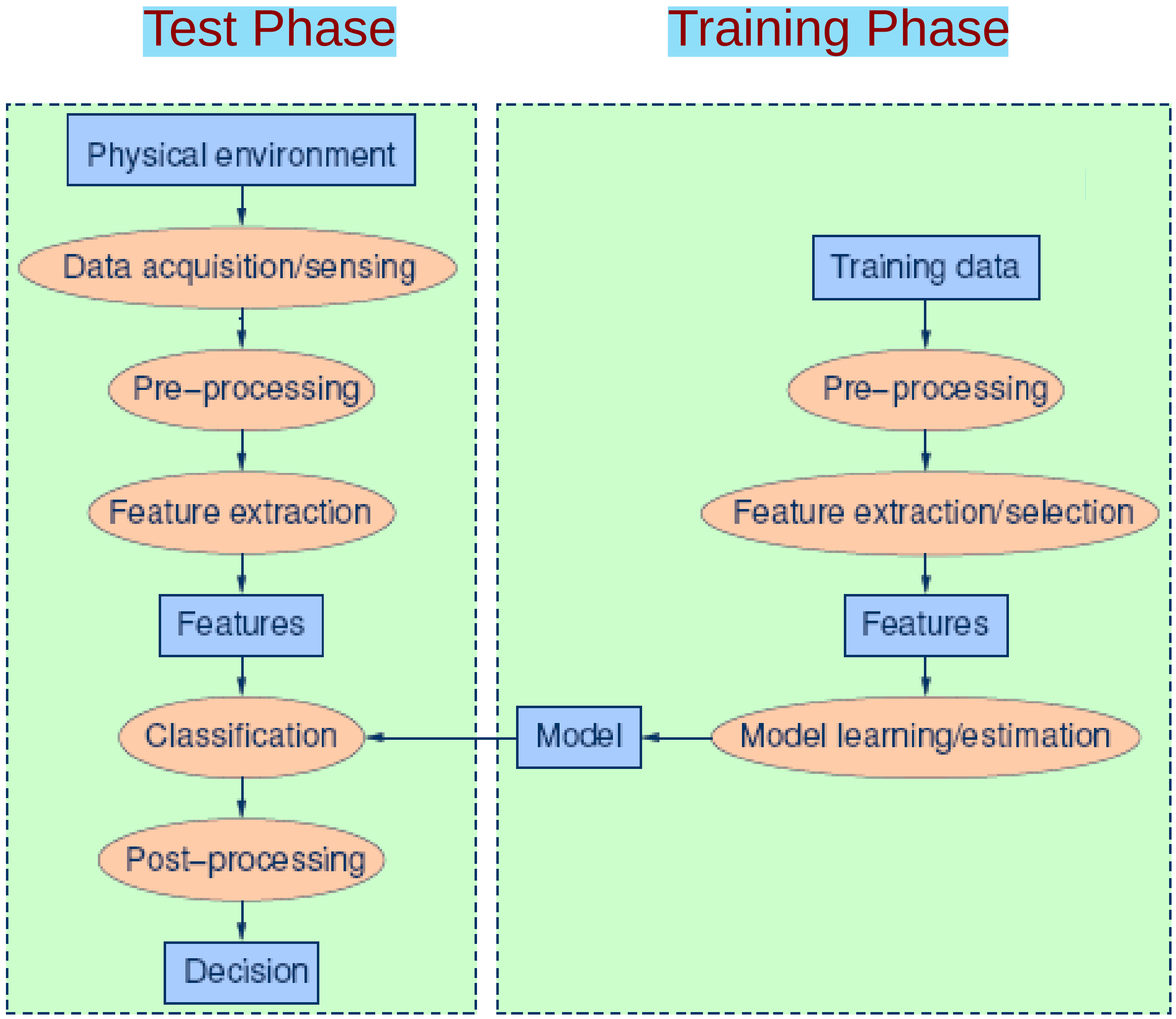
Classification

- Partition the whole *feature space* into two separate regions (salmon and sea bass) by finding the decision boundary that minimizes the classification error.



- How should we find the optimal decision boundary?

Pattern Recognition System – Two Major Phases



Sensors & Preprocessing

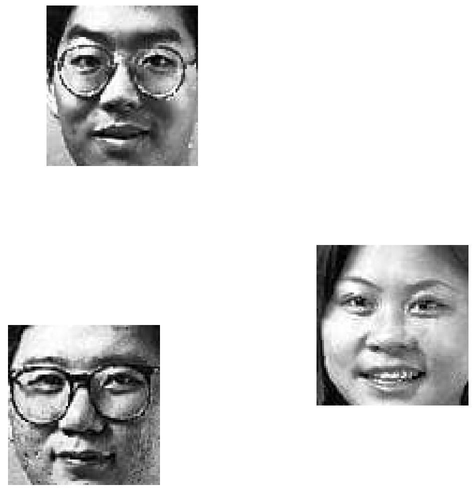
- Sensing:
  - Use a sensor (camera, microphone, velocity encoder, etc.) for data capture.
  - Pattern recognition performance depends on bandwidth, resolution, sensitivity, and distortion of the sensor.
- Pre-processing:
  - Removal of noise in data.
  - Segmentation (isolation of patterns of interest from background).

Training/Testing data

- How do we know that we have collected an adequately large and representative set of examples for training/testing the system?

Training Set?

Testing Set?



Feature Extraction

- How to choose a good set of features?
  - Discriminative features

  - Invariant features (not dependent on translation, rotation, scaling, etc.)
- Are there any ways to automatically learn which features are the best?

How Many Features?

- Does adding more features always improve the pattern recognition performance? no
  - It might be difficult and computationally expensive to extract certain features.
  - similar
    Correlated features might not improve the pattern recognition performance.
  - "Curse" of dimensionality problem.

Missing Features

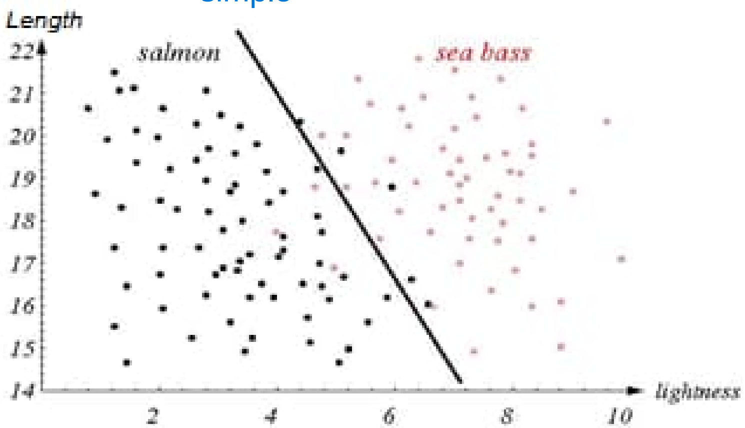
- Certain features may be missing (e.g., due to information occlusion).
- How should we train the pattern recognition systems with missing features?
- How should the pattern recognition systems make the best decision with missing features?

Model Complexity

- We can always get perfect classification performance on the *training* data by choosing over-complex models.
- Complex models are tuned to the particular training samples, rather than on the characteristics of the 'true' model.

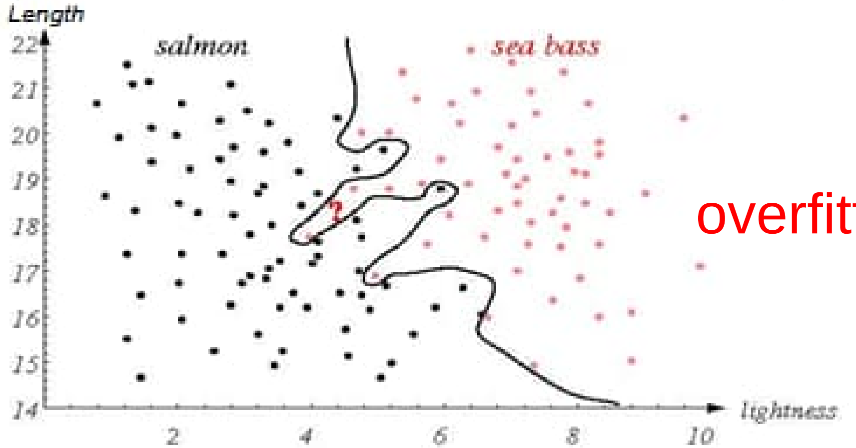
simple

better at testing data?



complex

better at training



overfitting

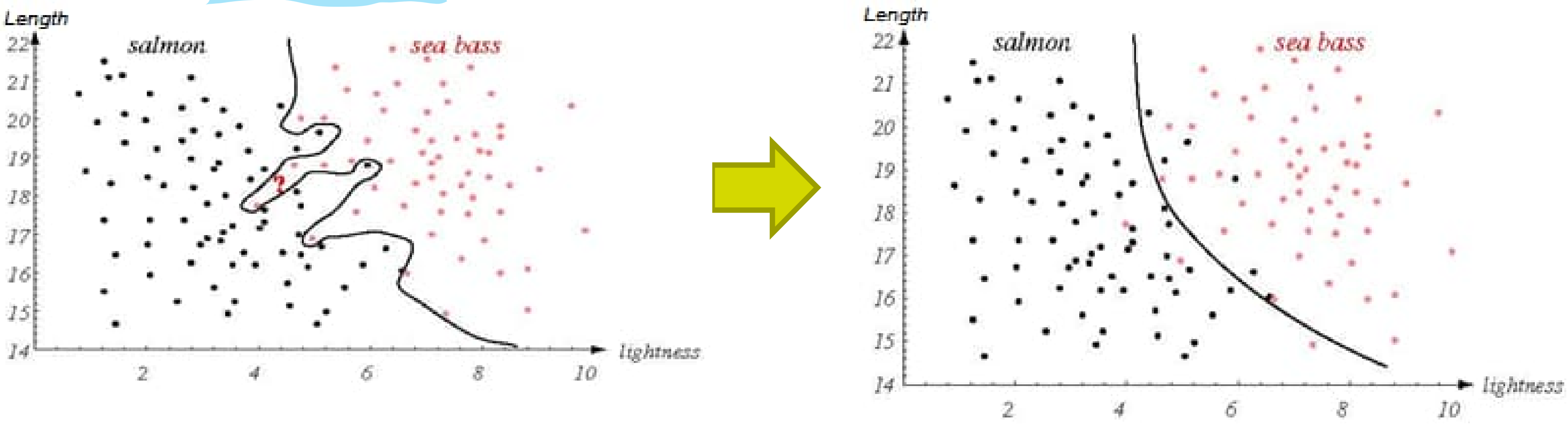
How well can the model generalize to unknown samples?

Generalization

- Generalization is defined as the ability of a classifier to produce correct results on novel/fresh patterns.
- How can we improve generalization performance?
  - More training examples.
  - Simpler models usually yield better performances.

complex model

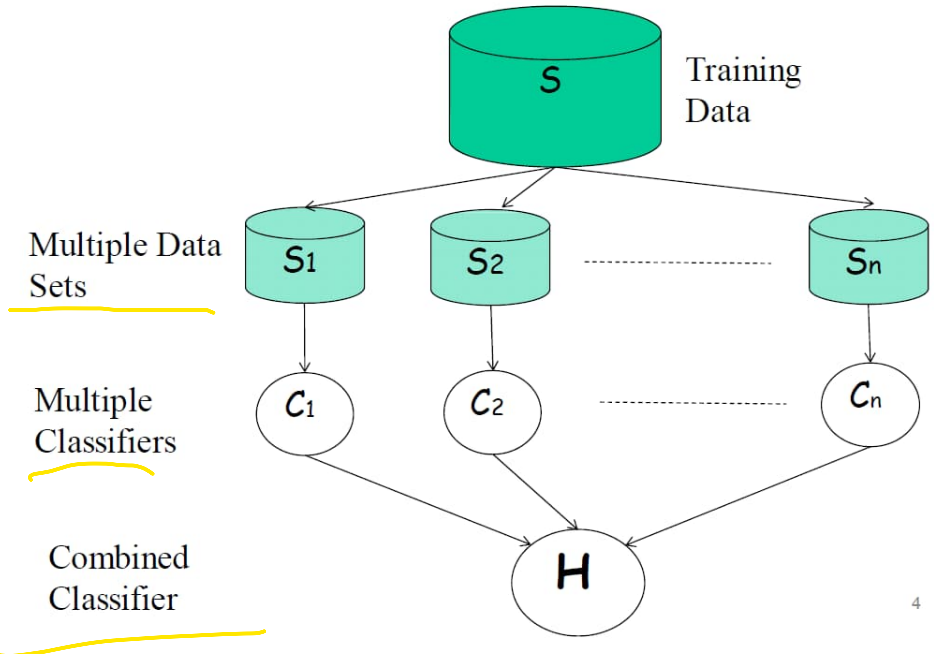
simpler model



Ensembles of Classifiers

- Performance can be improved using a "pool" of various classifiers.

- How should we build and combine different classifiers?



Computational Complexity

- How does a pattern recognition algorithm scale with the number of:
  - features
  - patterns
  - categories
- Consider trade-offs between computational complexities and performances of pattern recognition systems.

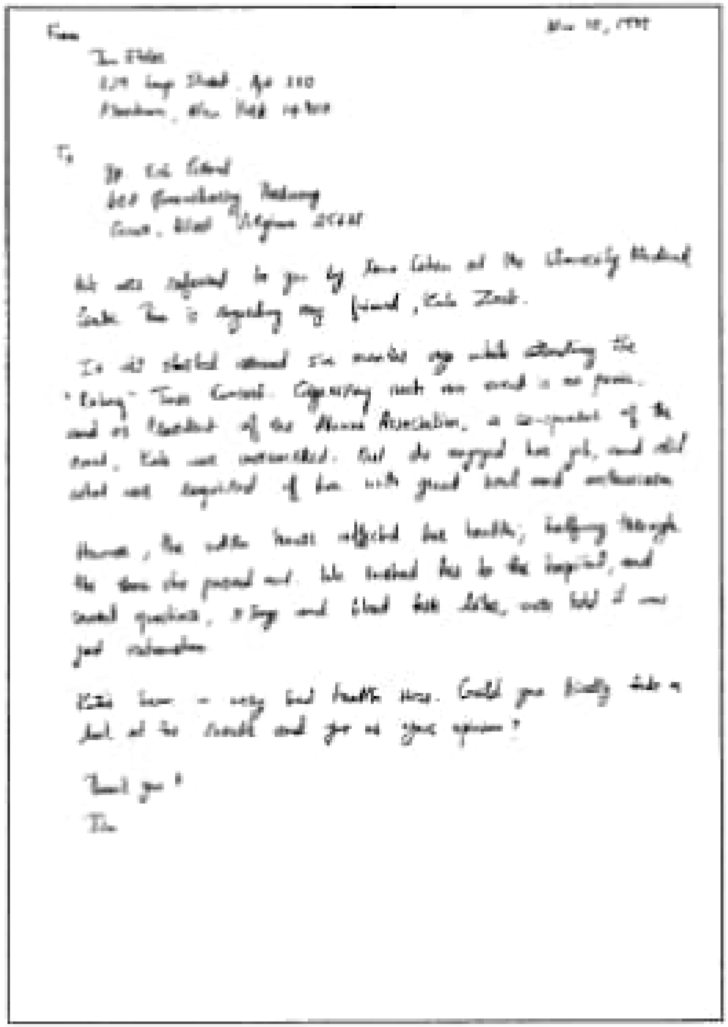
“General Purpose” Pattern Recognition System?

- Humans have the ability of switching rapidly and seamlessly between different pattern recognition tasks.
- It is very difficult, if not impossible, to design a universal system that is capable of performing a large variety of classification tasks.
  - Different decision tasks may require different features.
  - Different features might yield different solutions.
  - Different trade-offs exist for different tasks.

Pattern Recognition Applications

Problem Domain	Application	Input Pattern	Pattern Classes
Document image analysis	Optical character recognition	Document image	Characters, words
Document classification	Internet search	Text document	Semantic categories
Document classification	Junk mail filtering	Email	Junk/non-junk
Multimedia database retrieval	Internet search	Video clip	Video genres
Speech recognition	Telephone directory assistance	Speech waveform	Spoken words
Natural language processing	Information extraction	Sentences	Parts of speech
Biometric recognition	Personal identification	Face, iris, fingerprint	Authorized users for access control
Medical	Computer aided diagnosis	Microscopic image	Cancerous/healthy cell
Military	Automatic target recognition	Optical or infrared image	Target type
Industrial automation	Printed circuit board inspection	Intensity or range image	Defective/non-defective product
Industrial automation	Fruit sorting	Images taken on a conveyor belt	Grade of quality
Remote sensing	Forecasting crop yield	Multispectral image	Land use categories
Bioinformatics	Sequence analysis	DNA sequence	Known types of genes
Data mining	Searching for meaningful patterns	Points in multidimensional space	Compact and well-separated clusters

Handwriting Recognition



From Nov 10, 1999
Jim Elder
829 Loop Street, Apt 300
Allentown, New York 14707

To
Dr. Bob Grant
602 Queensberry Parkway
Omar, West Virginia 25638

We were referred to you by Xena Cohen at the University Medical Center. This is regarding my friend, Kate Zack.

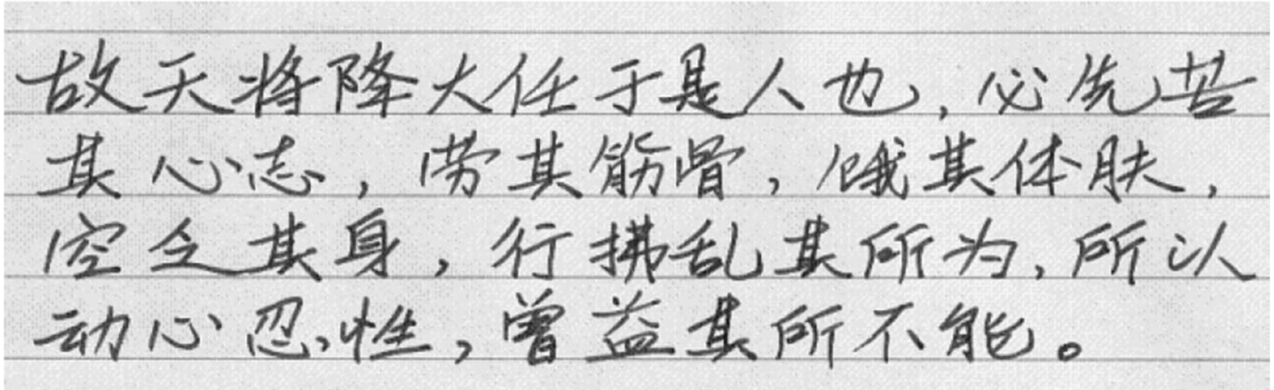
It all started around six months ago while attending the "Rubeq" Jazz Concert. Organizing such an event is no picnic, and as President of the Alumni Association, a co-sponsor of the event, Kate was overworked. But she enjoyed her job, and did what was required of her with great zeal and enthusiasm.

However, the extra hours affected her health; halfway through the show she passed out. We rushed her to the hospital, and several questions, x-rays and blood tests later, were told it was just exhaustion.

Kate's been in very bad health since. Could you kindly take a look at the results and give us your opinion?

Thank you!
Jim

Handwriting Recognition



故天将降大任于是人也，必先苦
其心志，劳其筋骨，饿其体肤，
空乏其身，行拂乱其所为，所以
动心忍性，曾益其所不能。

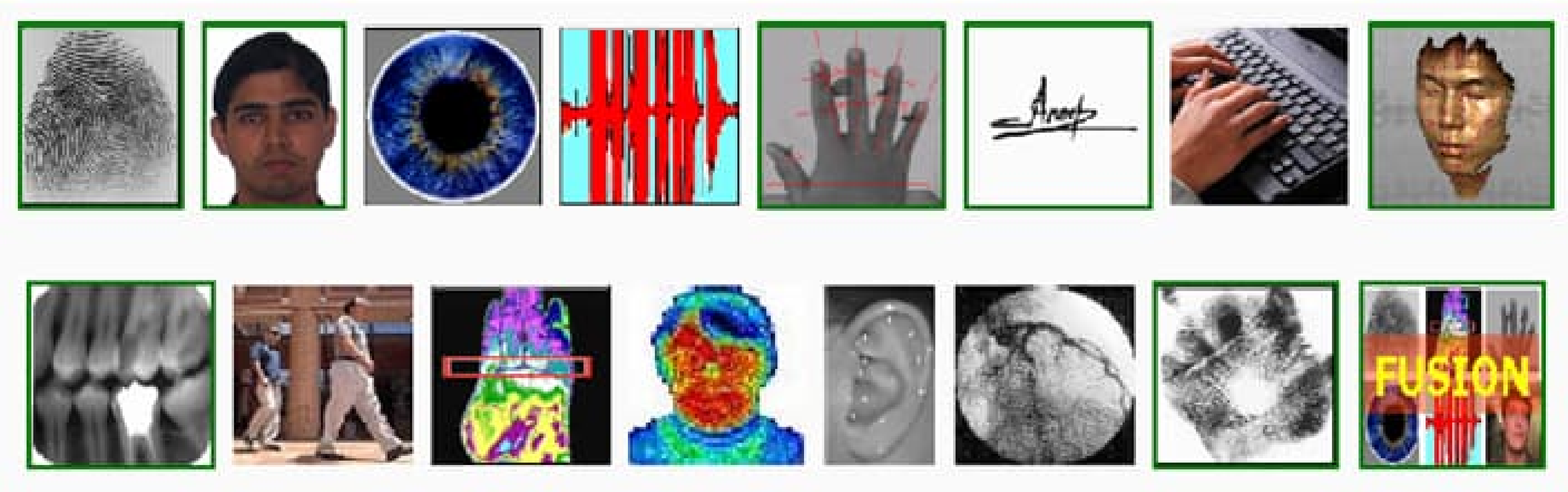
(a) Handwriting

故天将降大任于是人也，必先苦
其心志，劳其筋骨，饿其体肤，
空乏其身，行拂乱其所为，所以
动心忍性，曾益其所不能。

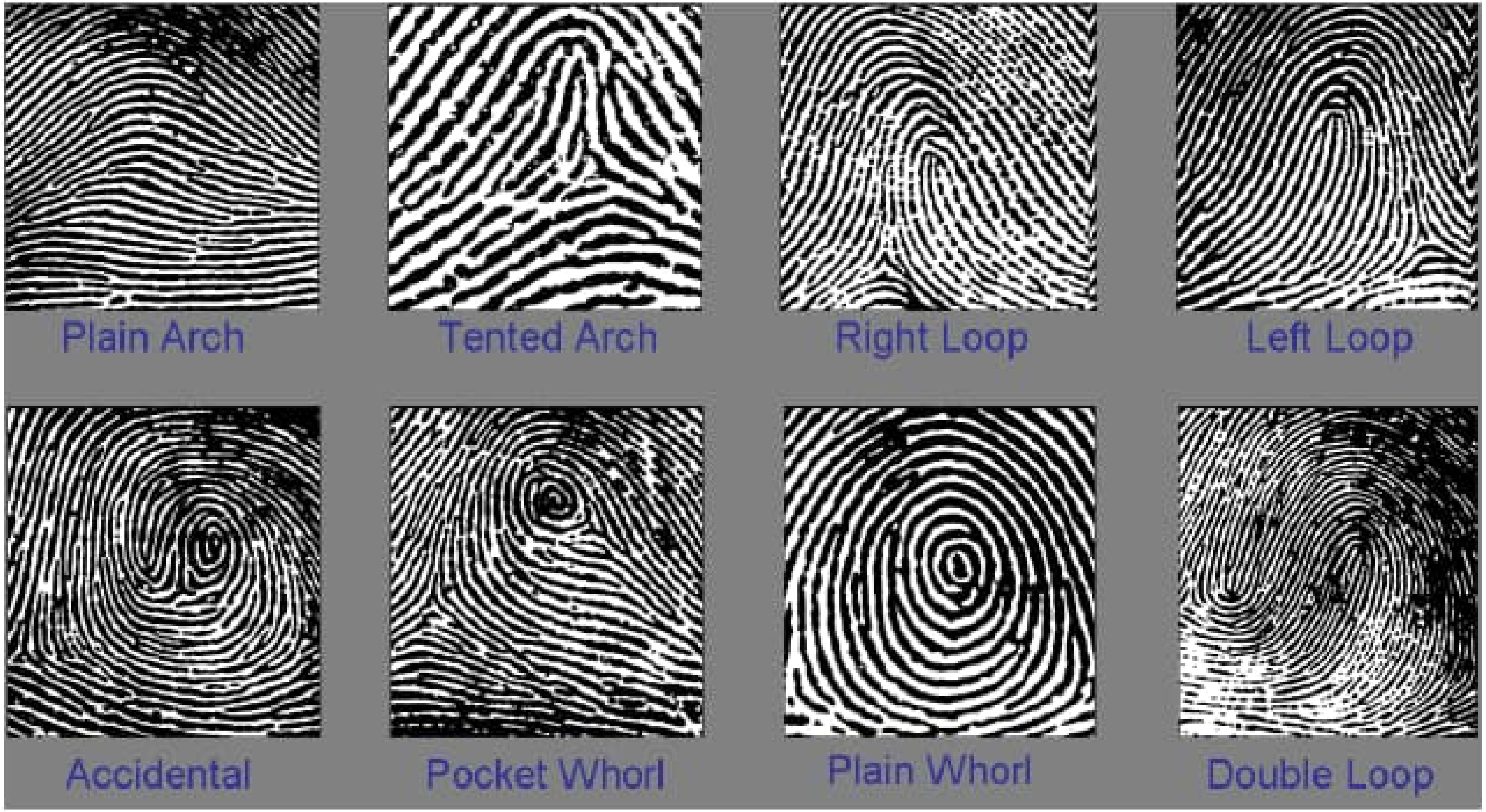
(b) Corresponding Machine Print

License Plate Recognition

Biometric Recognition

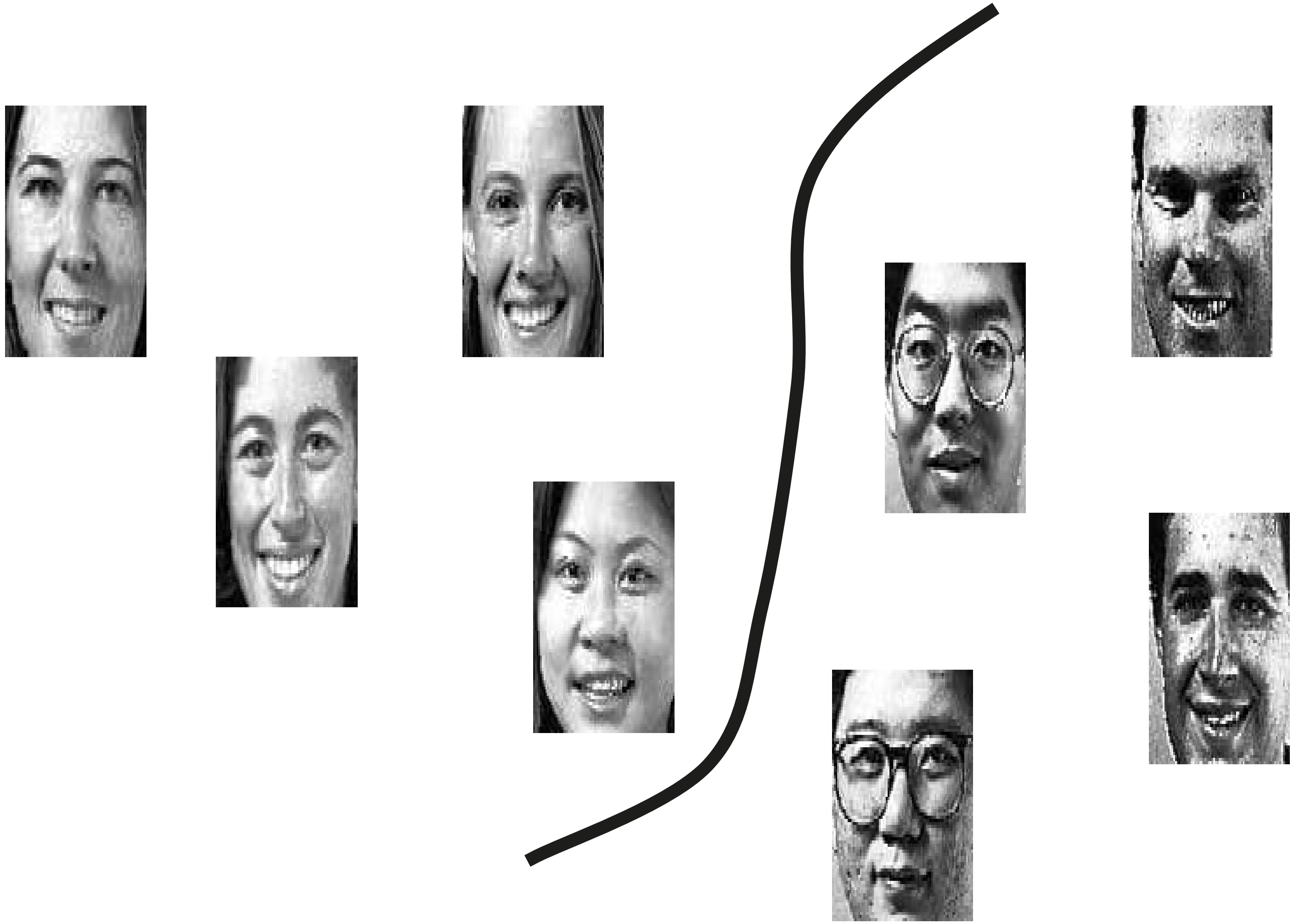


Fingerprint Classification



Face Detection

Gender Classification

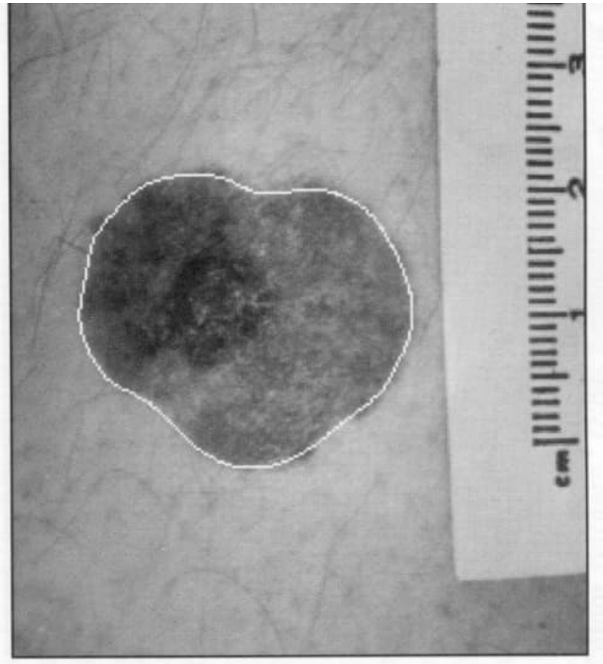


Balanced classes (i.e., male vs, female)

Autonomous Systems

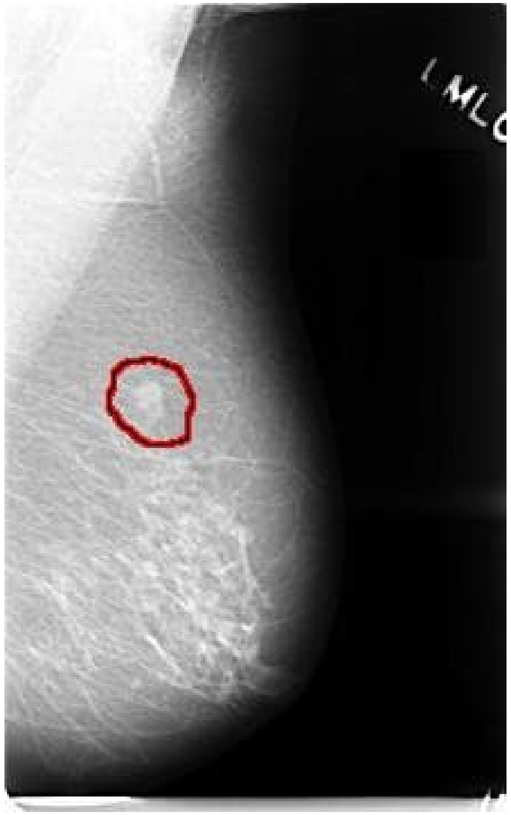
Medical Applications

Skin Cancer Detection



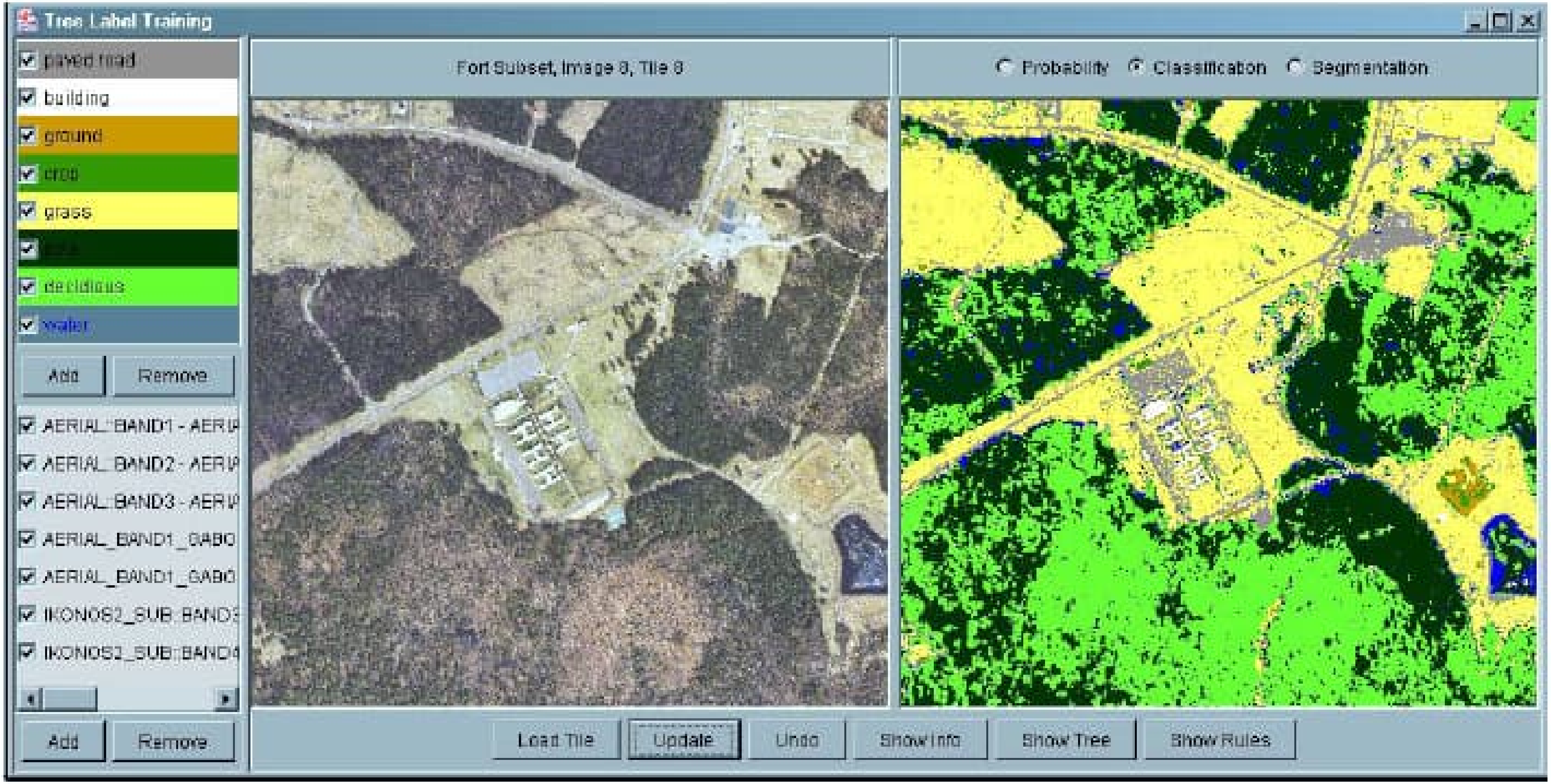
Visual examination

Breast Cancer Detection



Mammogram examination

Land Classification (Aerial and Satellite Images)



“Hot” Applications

- Recommendation systems
  - Amazon, Netflix, etc.
- Targeted advertising
  - Google, etc.

The Netflix Prize

- Predict how much someone is going to enjoy a movie based on their movie preferences.
  - $ 1M awarded in September 2009
- Can software recommend suitable movies to customers?
  - For example:
    - Not ‘Rambo’ to Woody Allen fans
    - Not ‘Saw VI’, if you’ve seen all previous Saw movies

Appendix I: Introduction to Industrial Internet

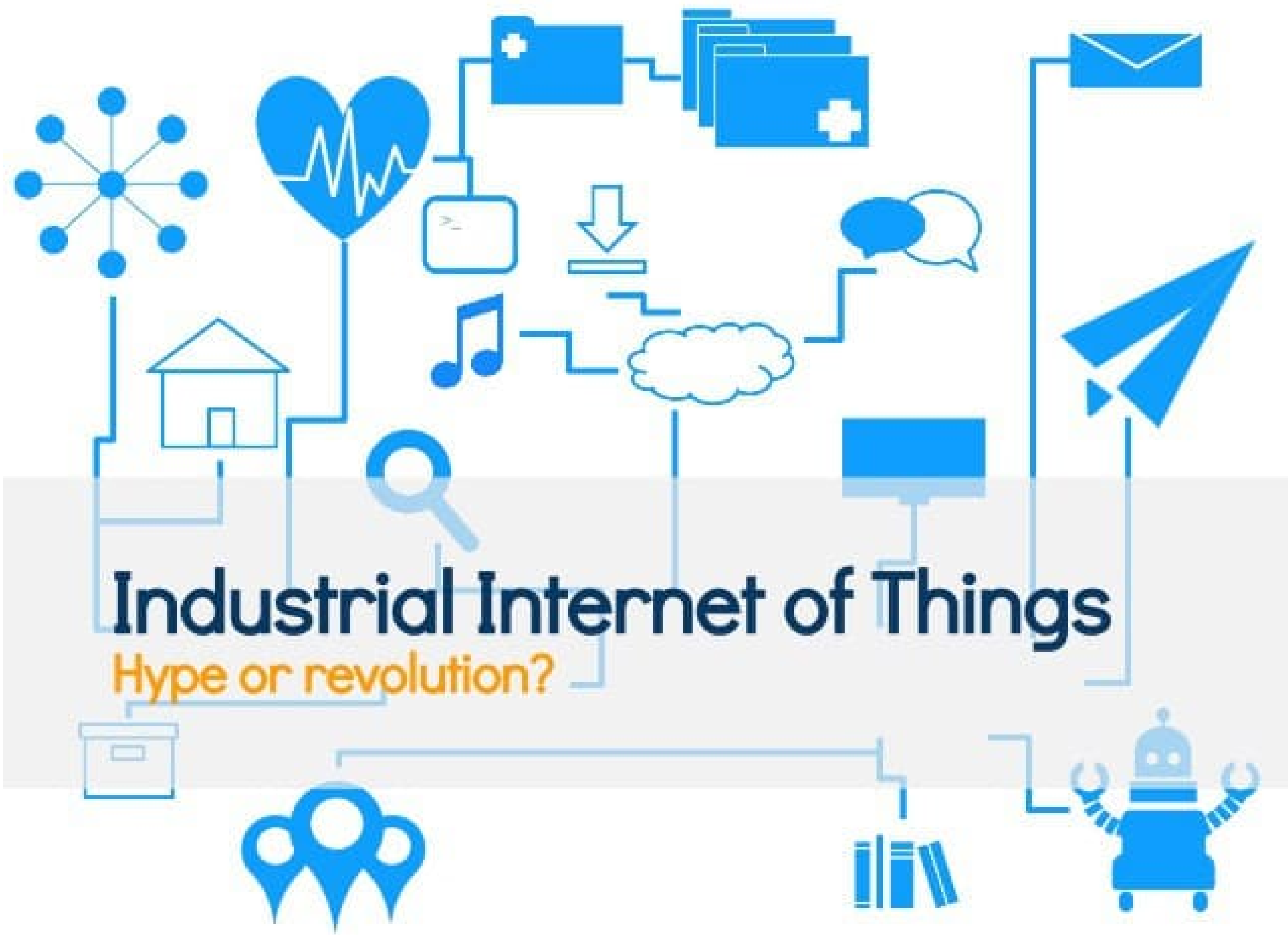
What is Industrial Internet?

- Industrial Internet, also known as Industrial Internet of Things (IIoT), is the use of Internet of Things (IoT) technologies in manufacturing.
  - A concept firstly proposed by GE.
- Internet of Things (IoT) is the network of physical objects enabling these objects to collect and exchange data.
- Industrial Internet is 'an integration of complex physical machinery with networked sensors and software'.
  - *Industrial Internet draws together fields, e.g., machine learning, big data, IoT, and machine-to-machine communication, to ingest data from machines, analyze and use it to adjust operations* (an unofficial definition).

Internet

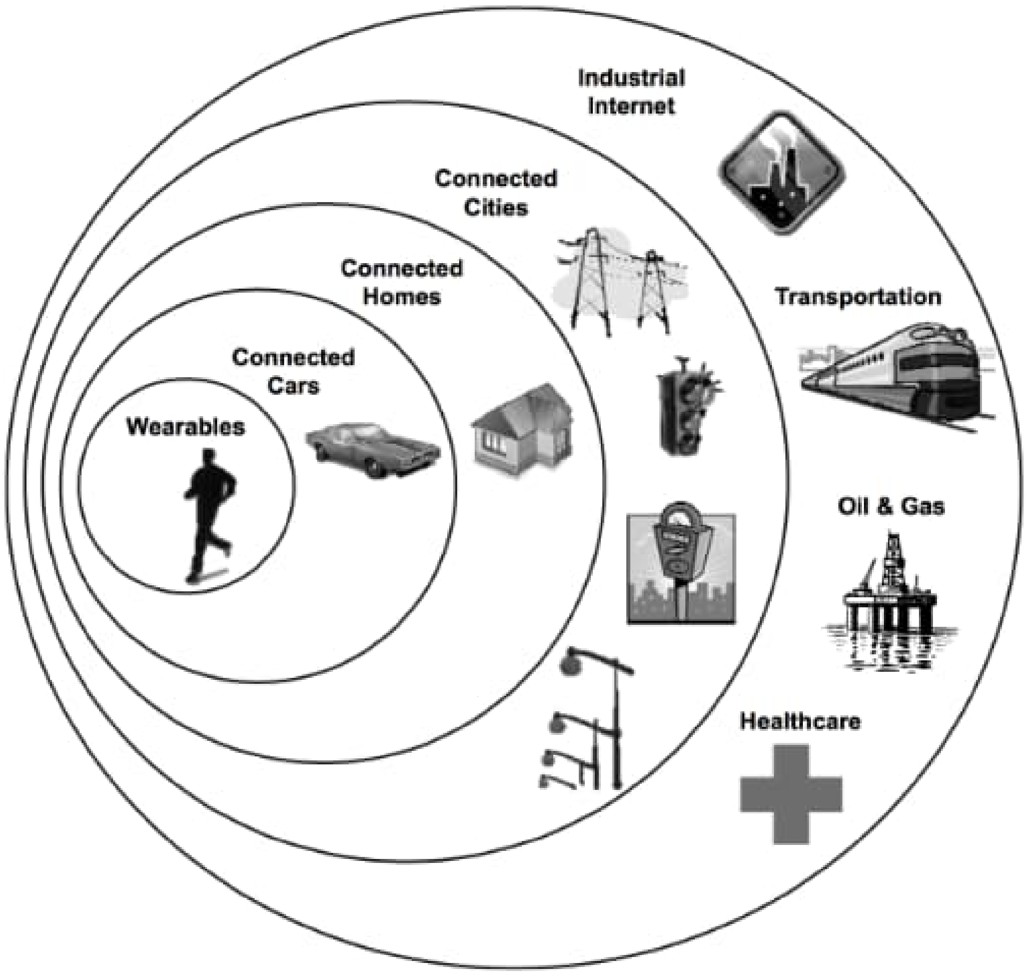
Internet of Things (IoT)

Industrial Internet



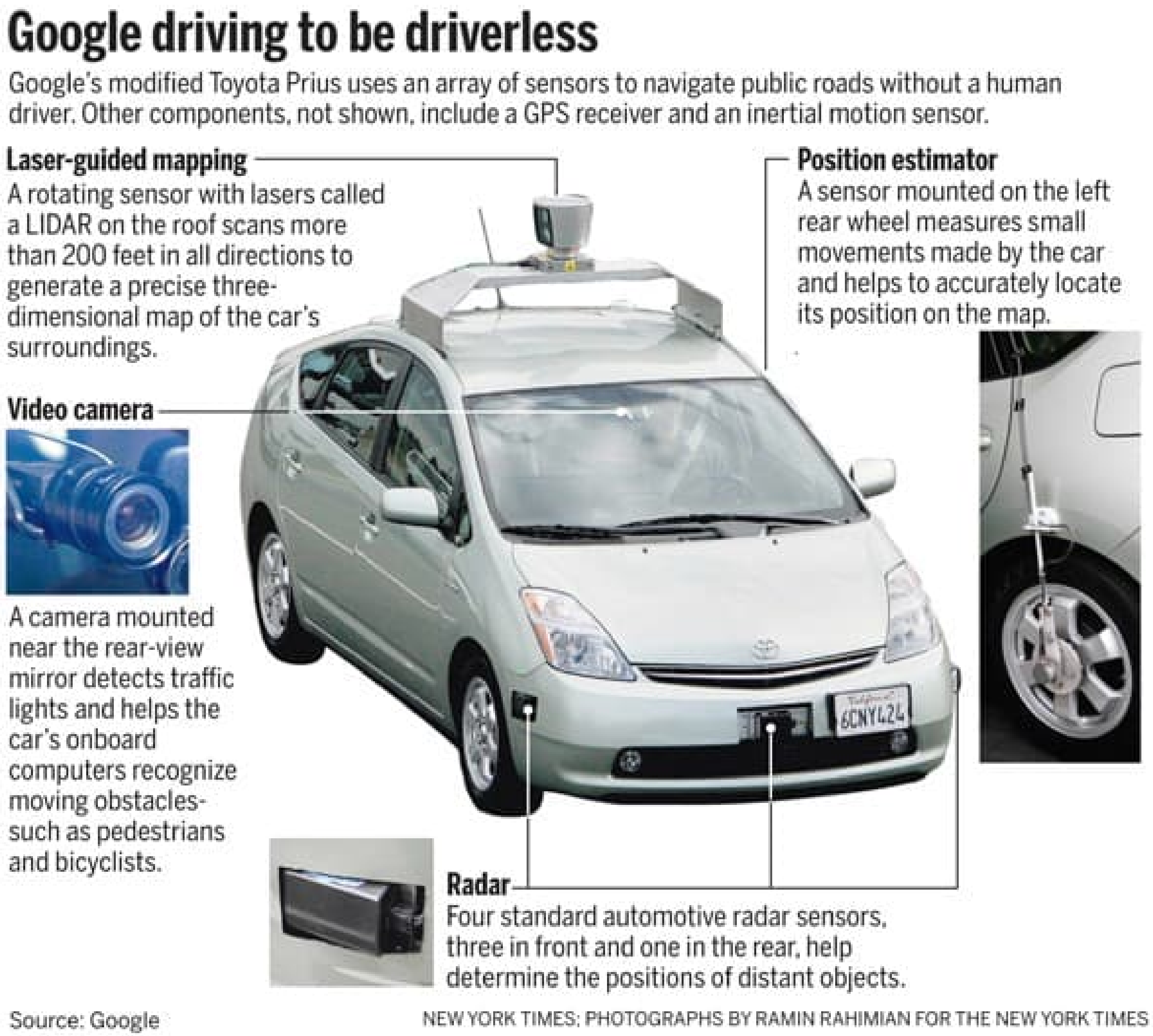
Landscape of IoT

Exhibit 2: The IoT landscape



Source: Goldman Sachs Global Investment Research.

An Example of Industrial Internet



Google self-driving car hits a bus

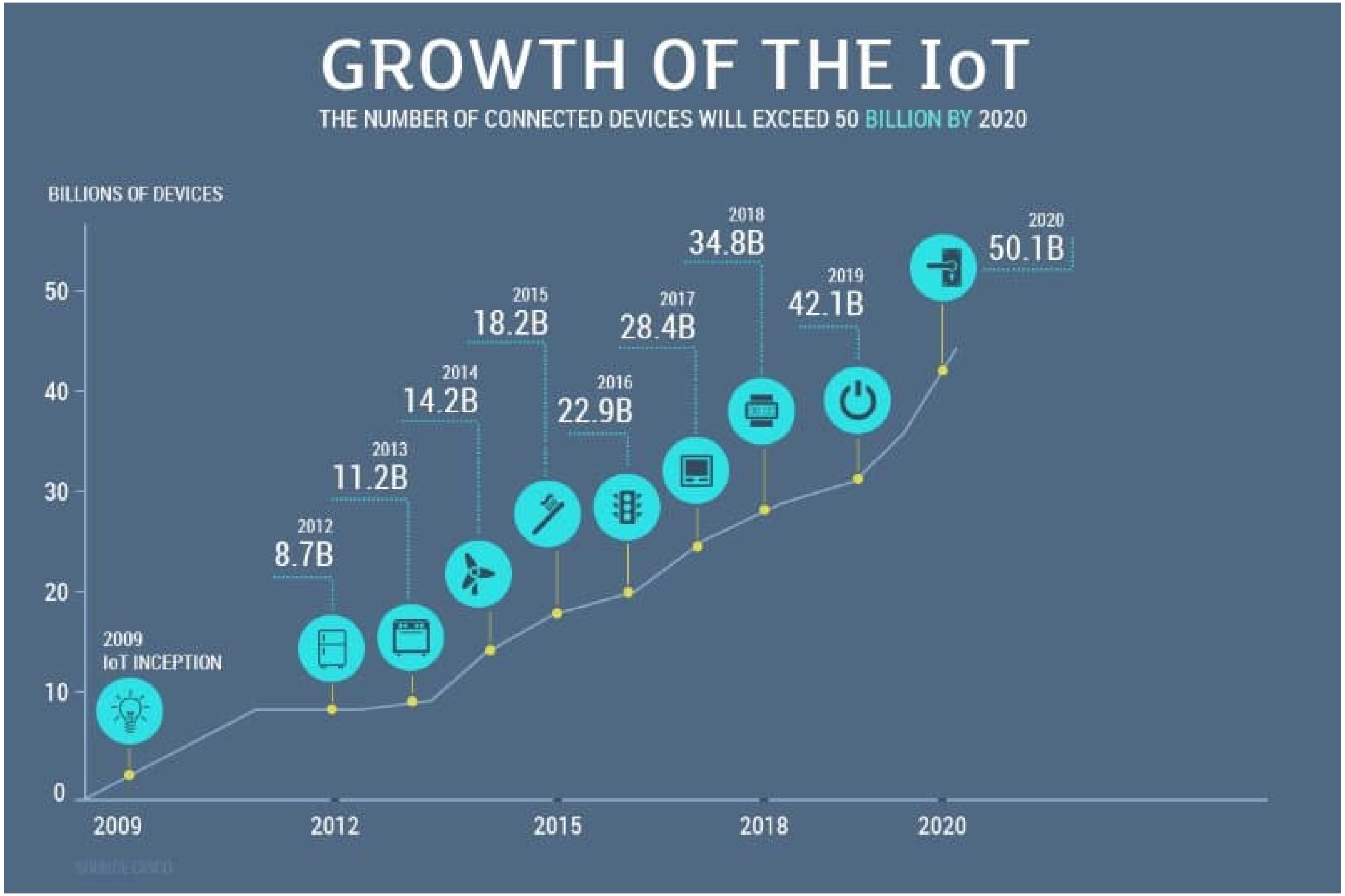
Dave Lee
North America technology reporter

29 February 2016 | Technology | 465

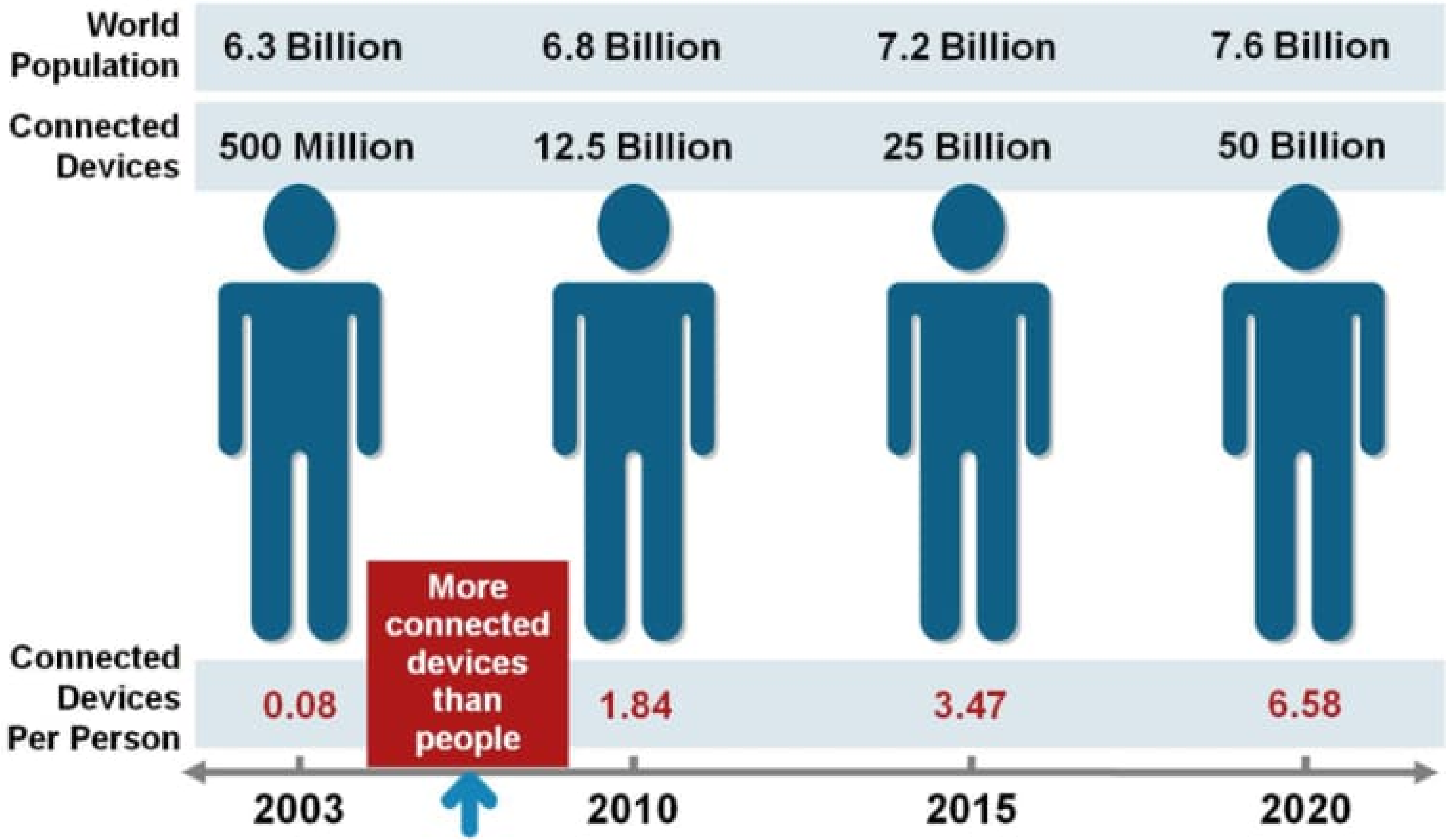
Google cars have clocked up over one million miles on public roads

One of Google's self-driving cars crashed into a bus in California last month. There were no injuries.

Growth of IoT

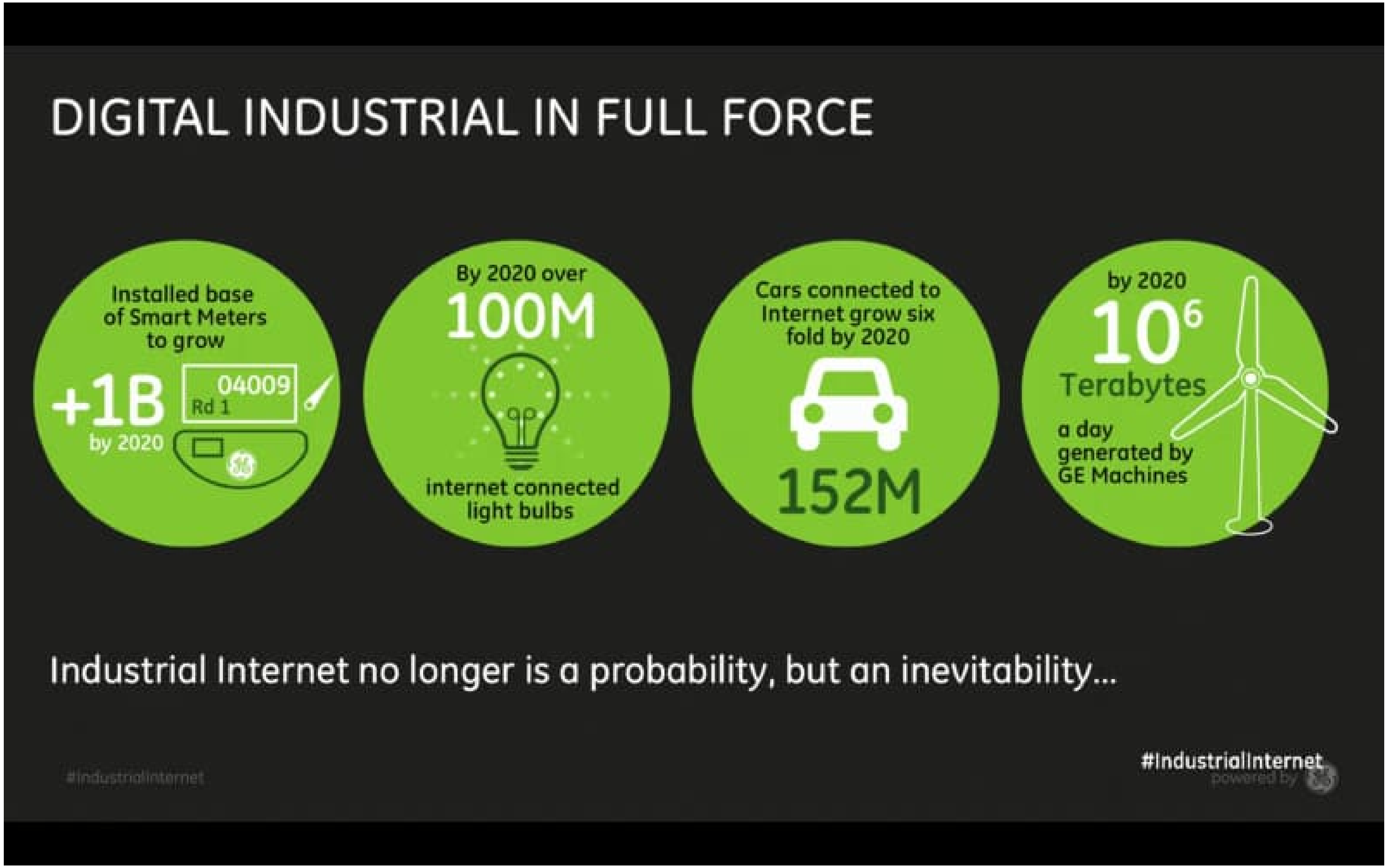


Connected Devices vs. World Population



Source: Cisco IBSG, April 2011

Conneced Devices in Industrial Internet



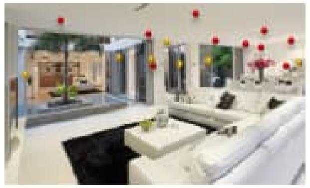
Driving Forces of Industrial Internet

- Cheaper sensors
  - Average price has dropped from 1.3 USD to 0.6 USD in 10 years.
- Cheaper bandwidth
  - Average price has dropped by 40 X in 10 years.
- Cheaper data processing
  - Average price has dropped by 60 X in 10 years.
- Smart phones
  - Personal gateway to industrial Internet.
- Wireless coverage
  - Free/low-cost WiFI connections almost everywhere.

Applications of Industrial Internet

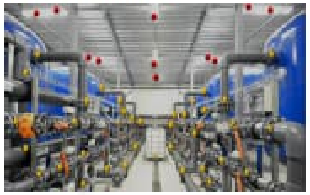
Wearables
- Entertainment
- Fitness
- Smart watch
- Location and tracking

Building & Home Automation
- Access control
- Light & temp control
- Energy optimization
- Predictive maintenance
- Connected appliances



Smart Cities
- Residential E-meters
- Smart street lights
- Pipeline leak detection
- Traffic control
- Surveillance cameras
- Centralized and integrated system control

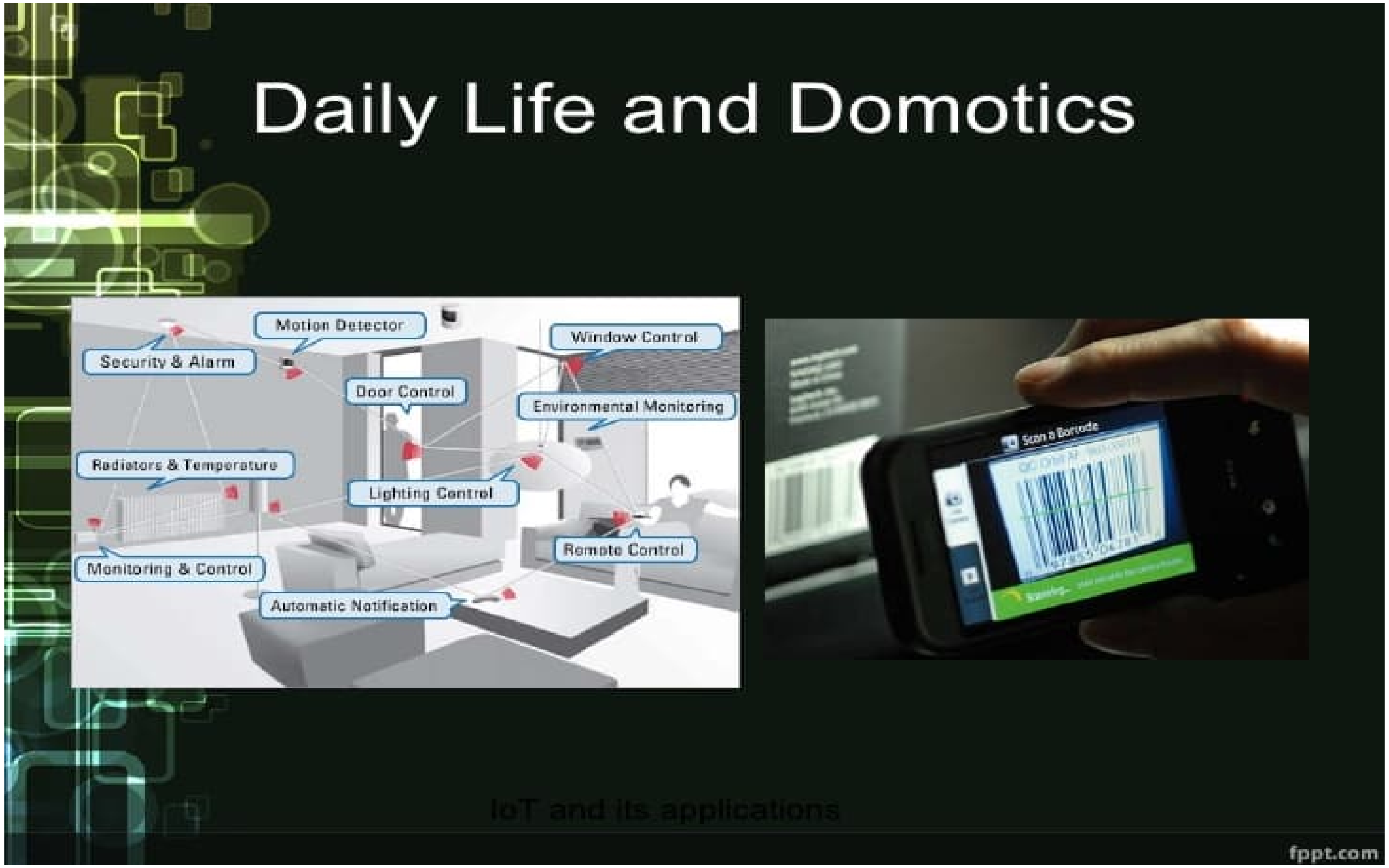
Smart Manufacturing
- Flow optimization
- Real time inventory
- Asset tracking
- Employee safety
- Predictive maintenance
- Firmware updates



Health Care
- Remote monitoring
- Ambulance telemetry
- Drugs tracking
- Hospital asset tracking
- Access control
- Predictive maintenance

Automotive
- Infotainment
- Wire replacement
- Telemetry
- Predictive maintenance
- C2C and C2I

An Application Example: Smart Home



Devices connected allowing homeowner to control, customize, and monitor their environments

Reference: Industrial Internet Consortium

- Industrial Internet Consortium (IIC) was founded by AT&T, Cisco, GE, IBM, and Intel in March 2014.
- IIC is an open membership organization with 237 members so far.
- IIC aims at accelerating the development, adoption, and widespread use of industrial Internet.

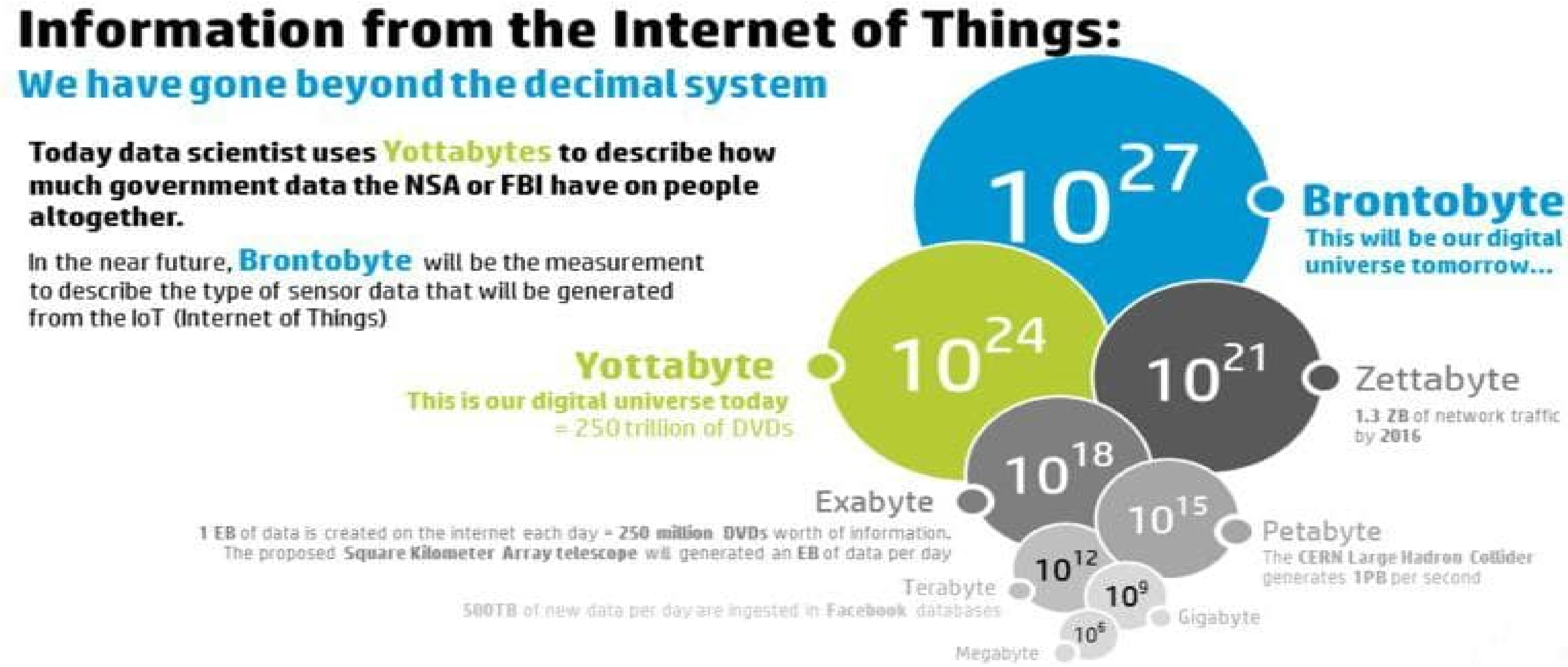
industrial internet CONSORTIUM

www.iiconsortium.org

Big Data and Machine Learning in Industrial Internet

- Big data refer to databases containing an extremely large amount of data.
- Big data are generated by numerous measurement devices, meters, and machines in industrial Internet.
- How to effectively collect, store, and process big data for modeling, simulation, and design of controllers in industrial Internet is a demanding issue.
- Modern machine learning is utilized to extract features from big data for control under circumstance of industrial Internet.

Big Data of IoT/Industrial Internet

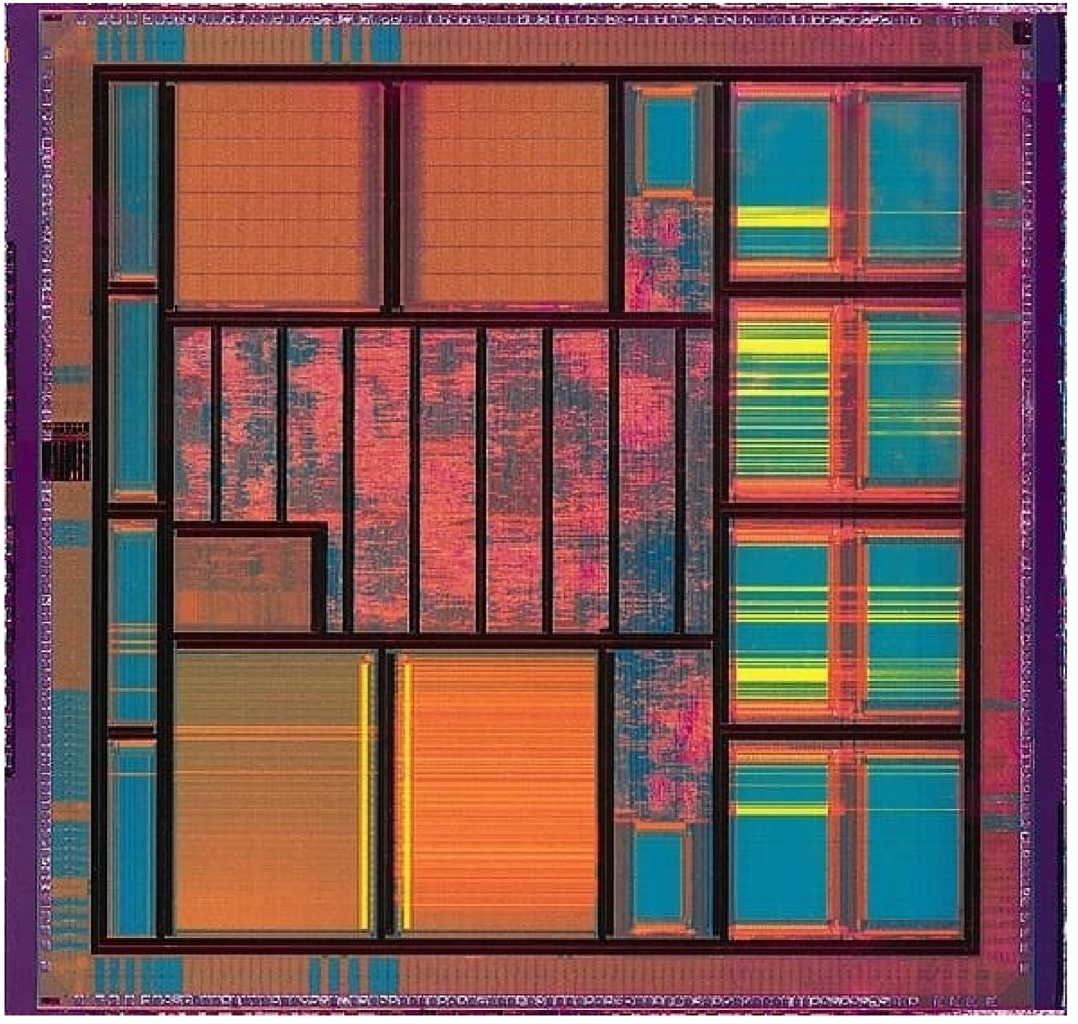


Appendix II: Introduction to VHDL

What is VHDL?

- VHDL stands for VHSIC Hardware Description Language.
  - VHSIC (Very High Speed Integrated Circuit).
- VHSIC was firstly proposed by US DoD (Department of Defense) to push the research and development in the *state-of-the-art* VLSI technology.
  - VLSI (Very-Large-Scale Integration): aims at creating an Integrated Circuit (IC) by combining numerous transistors into a single chip.
  - Was launched in 1980.
  - More than 1 billion USD in total spent in VHSIC program.

An Example of VLSI IC Die



What is VHDL?

- VHSIC resulted in advances in the IC materials, lithography, packaging, testing, algorithms, and CAD tools.
  - There was a need for a common descriptive language from industry, government, and academia.
- VHDL can be considered as a product of US government to promote a new means for describing digital hardware.
- VHDL is one of the best known contributions made by the VHSIC program.
  - 17 million USD spent on direct VHDL.
  - 16 million USD spent on VHDL design tools.

What is VHDL?

- A brief history of VHDL
  - The frist contract was given to IBM and Texas Instruments to develop VHDL in 1983.
  - The final version of VHDL (VHDL Version 7.2) was released in 1985.
  - VHDL became IEEE Standard 1076-1987 in 1987.
  - VHDL became ANSI standard in 1988.
  - VHDL was re-standardized to be IEEE Standard 1076-1993 in 1993.
    - VHDL was further clarified and enhanced.

What is the Purpose of VHDL?

- Why should we use VHDL?
  - VHDL is an international IEEE standard specification language for describing digital hardware used by industry worldwide.
  - VHDL can enable hardware modeling from the gate level to system level.
  - VHDL provides a useful mechanism for digital design and reusable design documentation.
  - VHDL has the functions of documentation-based modeling, simulation-based testing and validation, performance prediction, and automatic synthesis.

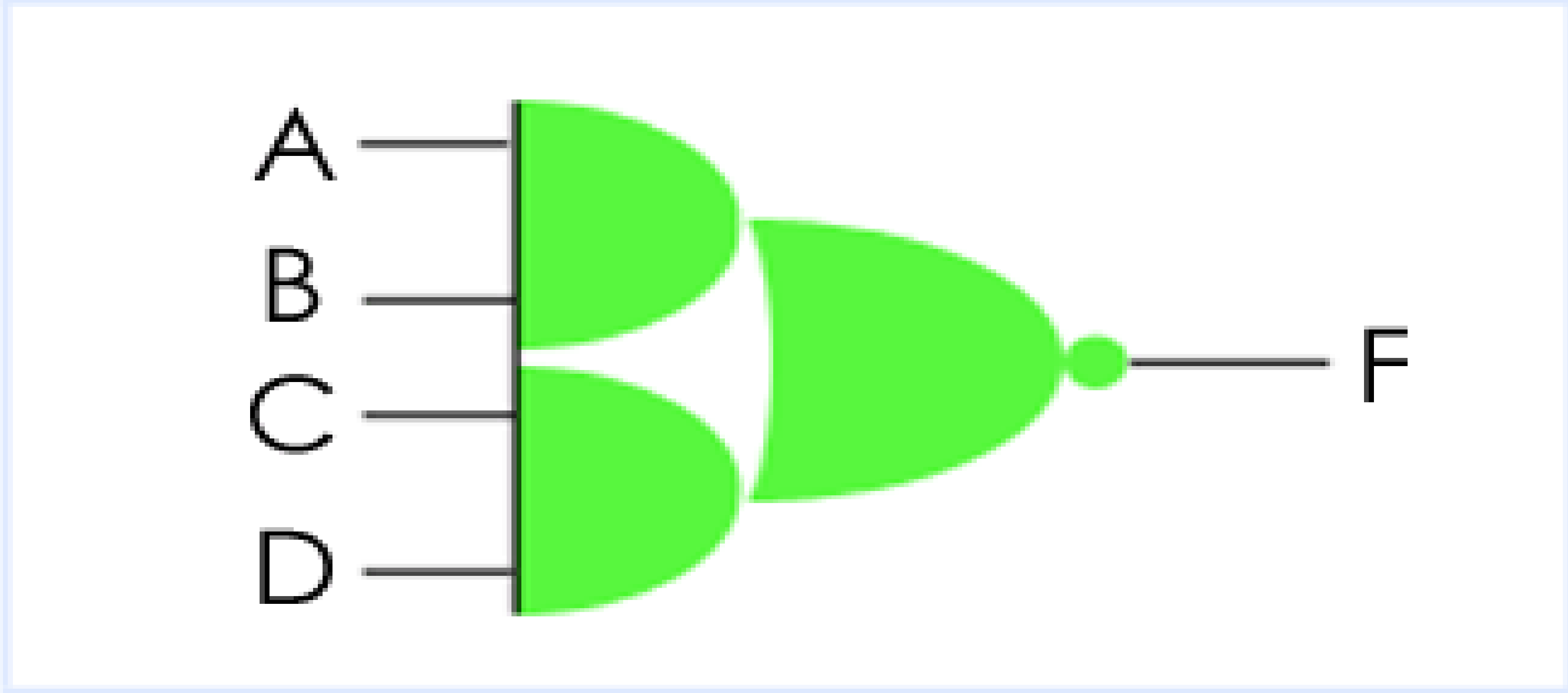
What is the Purpose of VHDL?

- Benefits of VHDL
  - Allows for a large variety of design methodologies.
    - Top-down, bottom-up, delay of detail, etc.
    - Very flexible in describing digital hardware.
  - Provides technology independence.
    - VHDL is independent of any technology or process, such as ASIC (Application-Specific Integrated Circuit), FPGA (Field-Programmable Gate Array), etc.
    - VHDL codes can be written and targeted for different technologies.
  - Describes various digital hardware.
    - On different levels of design.
    - Mixed descriptions: behavioral with gate level description

What is the Purpose of VHDL?

- Benefits of VHDL
  - Can ease communication through standard design language.
    - Efficient communications among different designers and different design tools.
    - Easier documentation of design.
    - Runs the same code under various development environments.
  - Allows for a better design management.
    - Use of VHDL including packages and libraries allows common elements sharing among digital hardware designs.
  - VHDL has already led to many derivative standards.
    - For example, WAVES (WAveform and Vector Exchange Standard), VITAL (VHDL Initiative Towards ASIC Libraries), Analog VHDL.

An And-Or-Invert (AOI) Gate



$$F = \overline{(A \wedge B) \vee (C \wedge D)}$$

VHDL Codes

- -- VHDL code for AND-OR-INVERT gate
- library IEEE;
- use IEEE.STD_LOGIC_1164.all;
- entity AOI is
- port (
- A, B, C, D: in STD_LOGIC;
- F : out STD_LOGIC
-);
- end AOI;
- architecture V1 of AOI is
- begin
- F <= not ((A and B) or (C and D));
- end V1;
- -- end of VHDL code

Applications of VHDL

- VHDL has been widely used in the design and analysis of digital/analog circuits.
  - Electronics systems (power electronics, industrial electronics, home appliances, etc.).
  - Mobile communications systems.
  - Signal filters.
  - Process controllers.
  - Chips (CPU, FPU, memory etc.) design.
  - Instrumentation and measurement.
  - High performance computing.
  - etc.