Five Decades of Pattern Recognition Research

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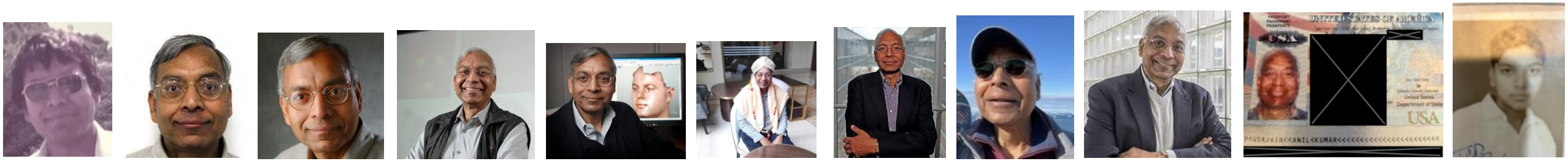
Michigan State University
December 11, 2025



Threshold=0.54 @FAR=0.1%

Pattern Recognition

By pattern recognition we mean the extraction of the significant features from a background of irrelevant detail. ... it is the kind of thing that brains seem to do very well....that computing machines do not do very well yet. O. G. Selfridge, **1955**

My first course in P.R.: March 1970. Also known as Data mining, Data science, Machine learning,..

Selfridge, “Pattern recognition and modern computers." In Proceedings of the Western Joint Computer Conf, pp. 91-93. March 1-3, 1955.

Model-driven Approach: Linear Discriminant (1936)

Fisher (1890-1962)

Input: Features $(\mathbf{x_1}, \mathbf{x_2}, \ldots, \mathbf{x_n})$
Labeled data (by pattern class) for 2 classes
Statistical model: $\mathbf{N}(\boldsymbol{\mu_1}, \boldsymbol{\Sigma})$ and $\mathbf{N}(\boldsymbol{\mu_2}, \boldsymbol{\Sigma})$

Output: Class label of the input

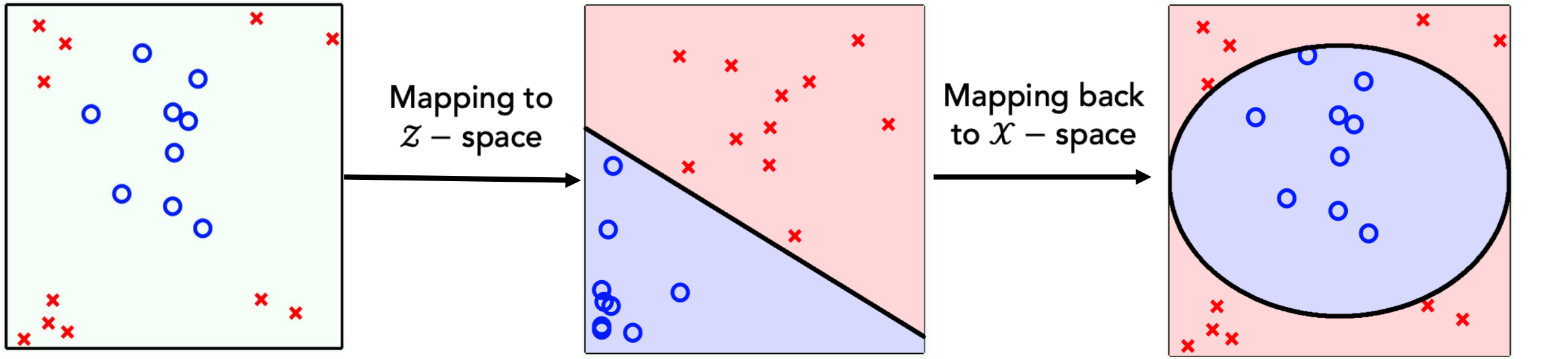
Learning: Estimate model parameters $(\boldsymbol{\mu_1}, \boldsymbol{\mu_2}, \boldsymbol{\Sigma})$

R.A. Fisher, The Use of Multiple Measurements in Taxonomic Problems, Annals of Eugenics, 1936

Linear to Quadratic Classifiers (1960) and SVM(1990)

Statistical model: $N(\mu_1, \Sigma_1)$ and $N(\mu_2, \Sigma_2)$

Nonlinear kernel: Transform data to linearly separable space



Original feature space $\mathcal{X}$

Decision boundary after non-linear transformation $z - \phi(\mathbf{x})$

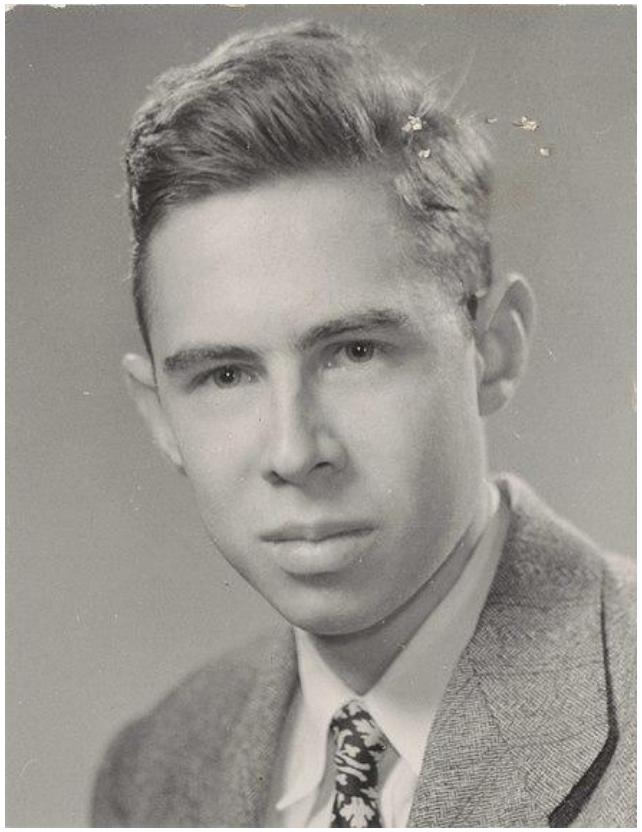
Non-linear decision boundary in the original space

Abu-Mostafa, Magdon-Ismail, Lin, "Learning from Data", AML Book, 2012

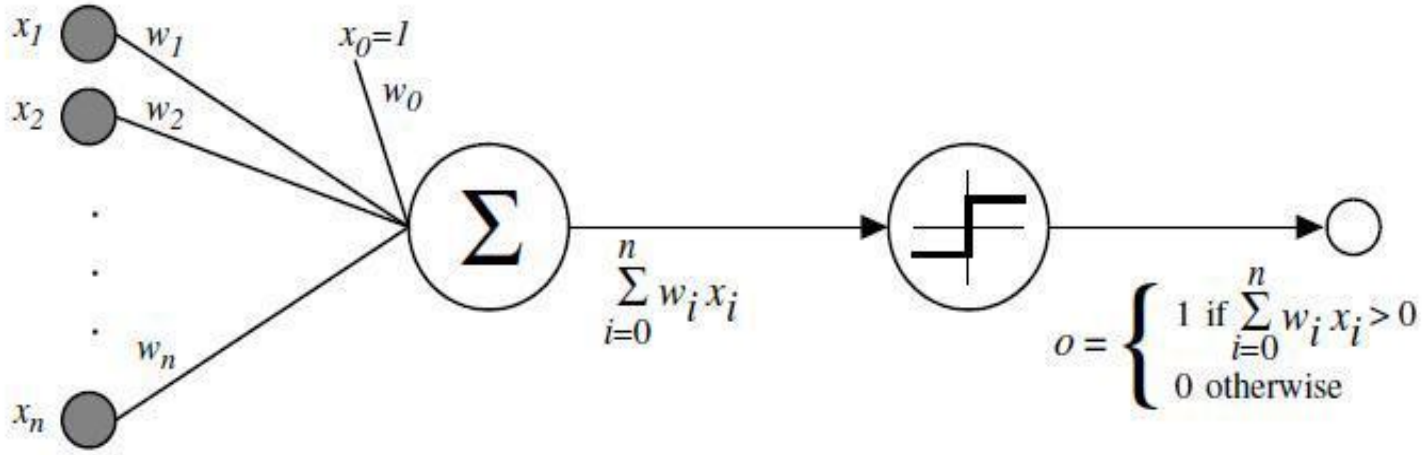
T. W. Anderson, "Classification into Multivariate Normal Distributions with Unequal Covariance Matrices, JASA, 1960

Data-Driven Approach: Perceptron (1958)

First biologically motivated network that learns to classify patterns



Rosenblatt (1928-1971)



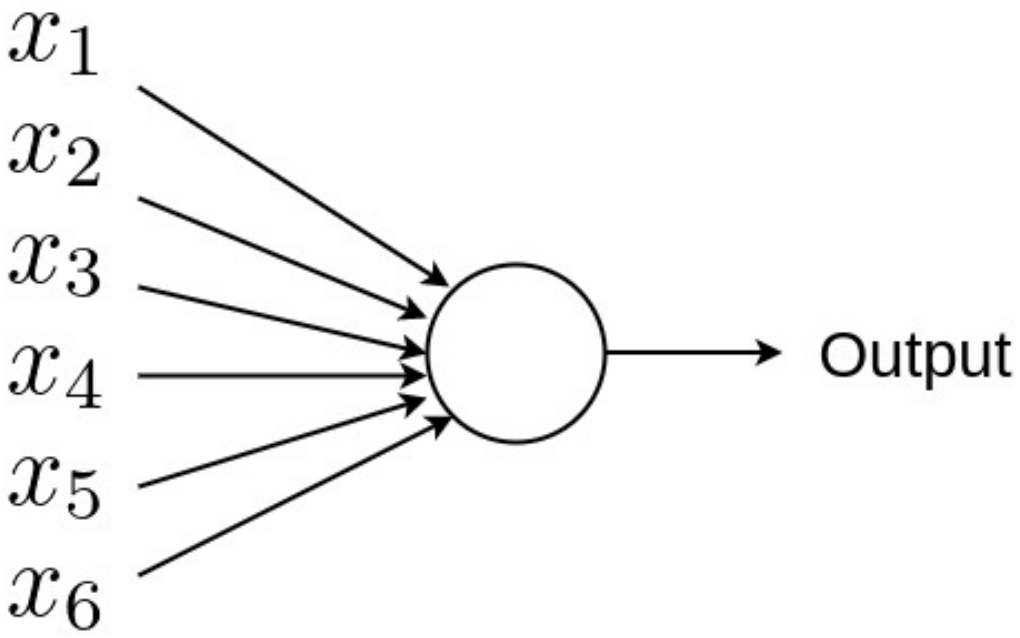
Input: Features $(\mathbf{x_1}, \mathbf{x_2}, \ldots, \mathbf{x_n})$
Labeled data

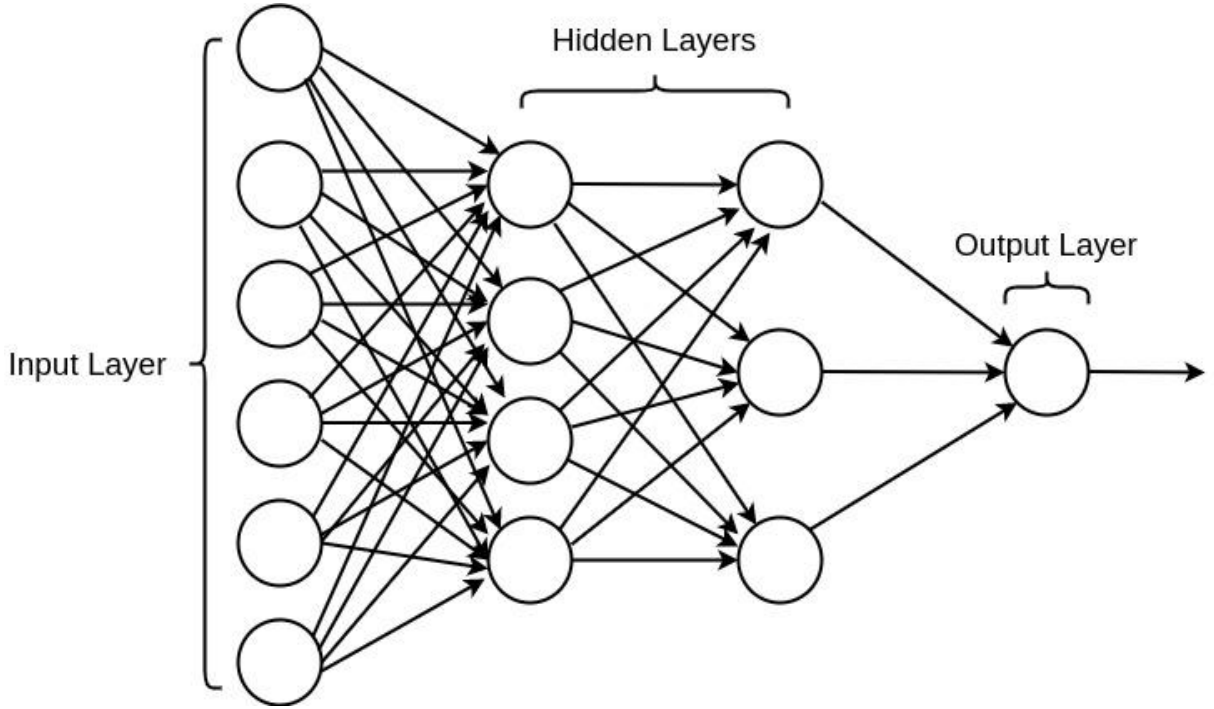
Output: Class label of the input

Learning: Network weights $(\mathbf{w_0}, \mathbf{w_1}, \ldots, \mathbf{w_n})$

F. Rosenblatt. The perceptron, a perceiving and recognizing automaton Project Para. Cornell Aeronautical Laboratory, 1957

Perceptron to Multi-layer Neural Networks (1986)





Perceptron

(7 parameters to learn)

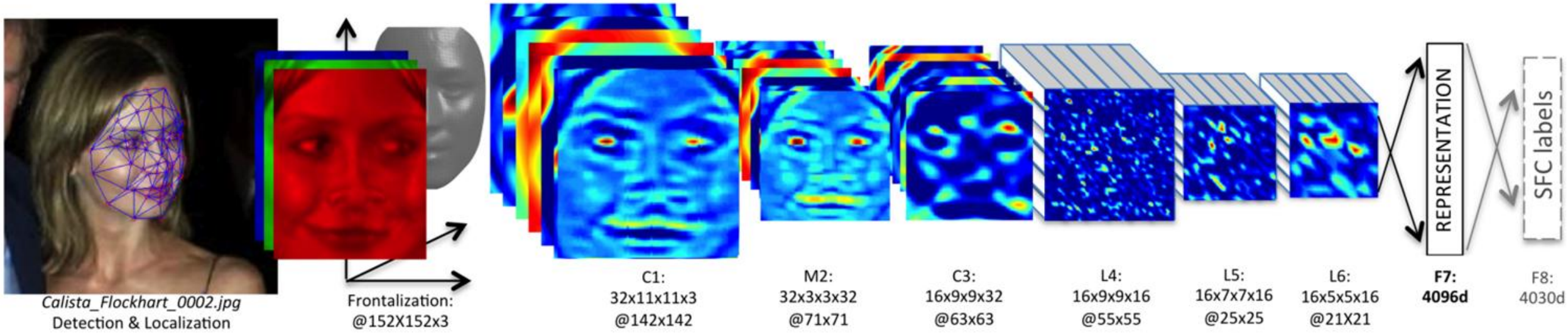
Rosenblatt's Perceptron learning algorithms

2-Hidden layer neural network

(47 parameters to learn)

Backpropagation learning algorithm:
Werbos, 1974; Rumelhart, Hinton & Williams, 1986

Deep Networks (2012)



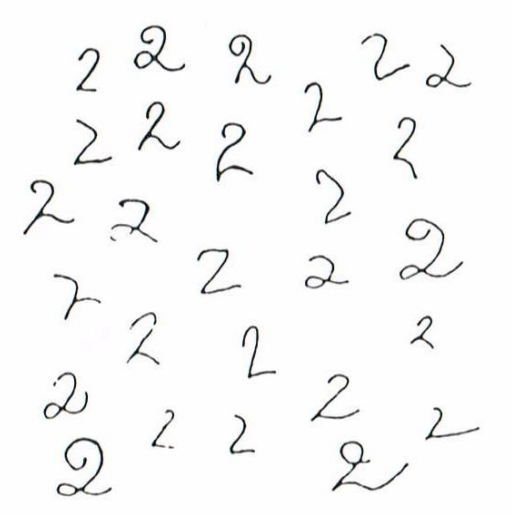
Multiple layers of neurons stacked together and connected to a small area in previous layer (120M parameters); standard stochastic gradient descent (SGD) with backpropagation and softmax cross-entropy loss.

Taigman, Yaniv, Ming Yang, Marc'Aurelio Ranzato, and Lior Wolf. "Deepface: Closing the gap to human-level performance in face verification." CVPR, 2014.

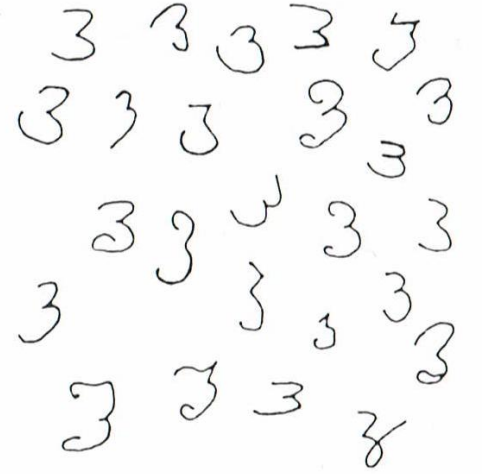
Intra-class Variability





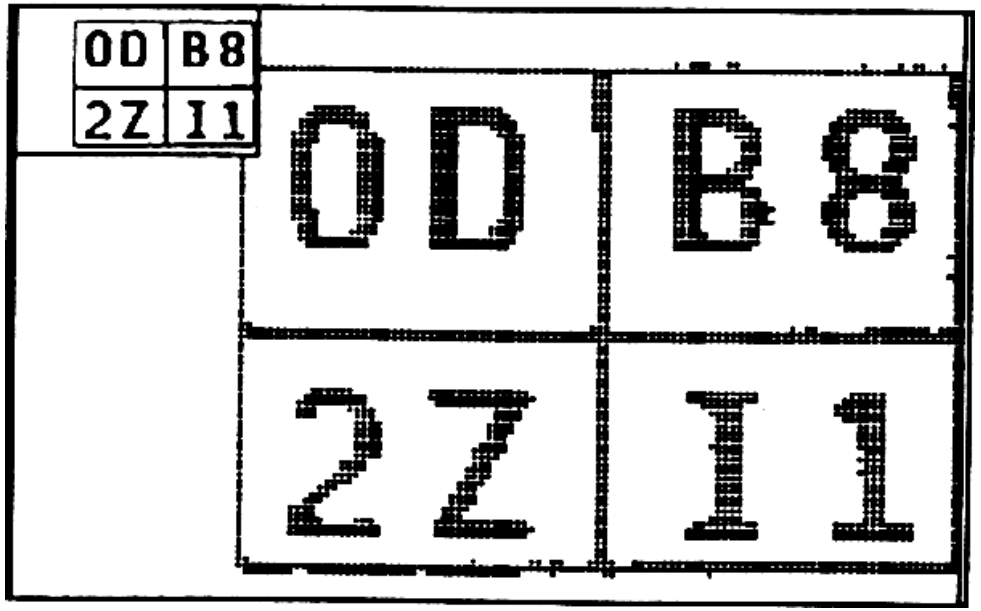




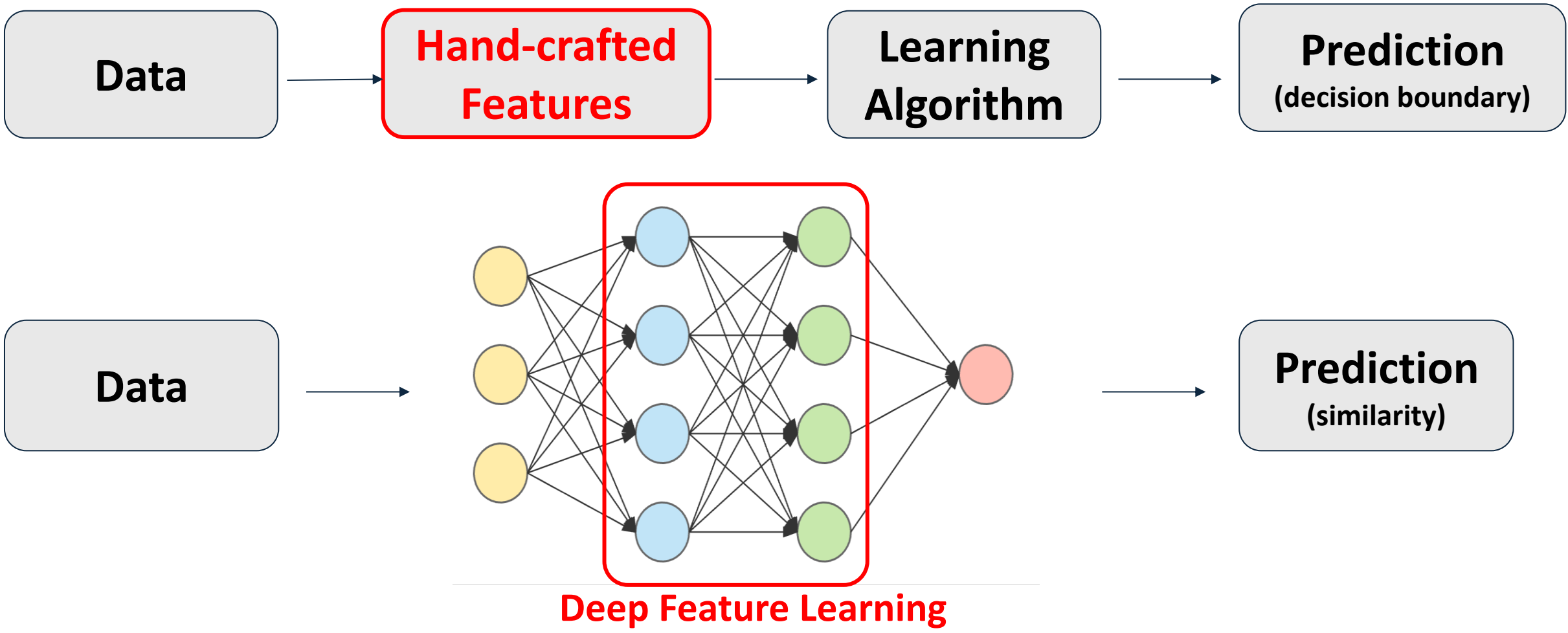
Inter-Class Similarity

~3 in 1000 live births are identical twins



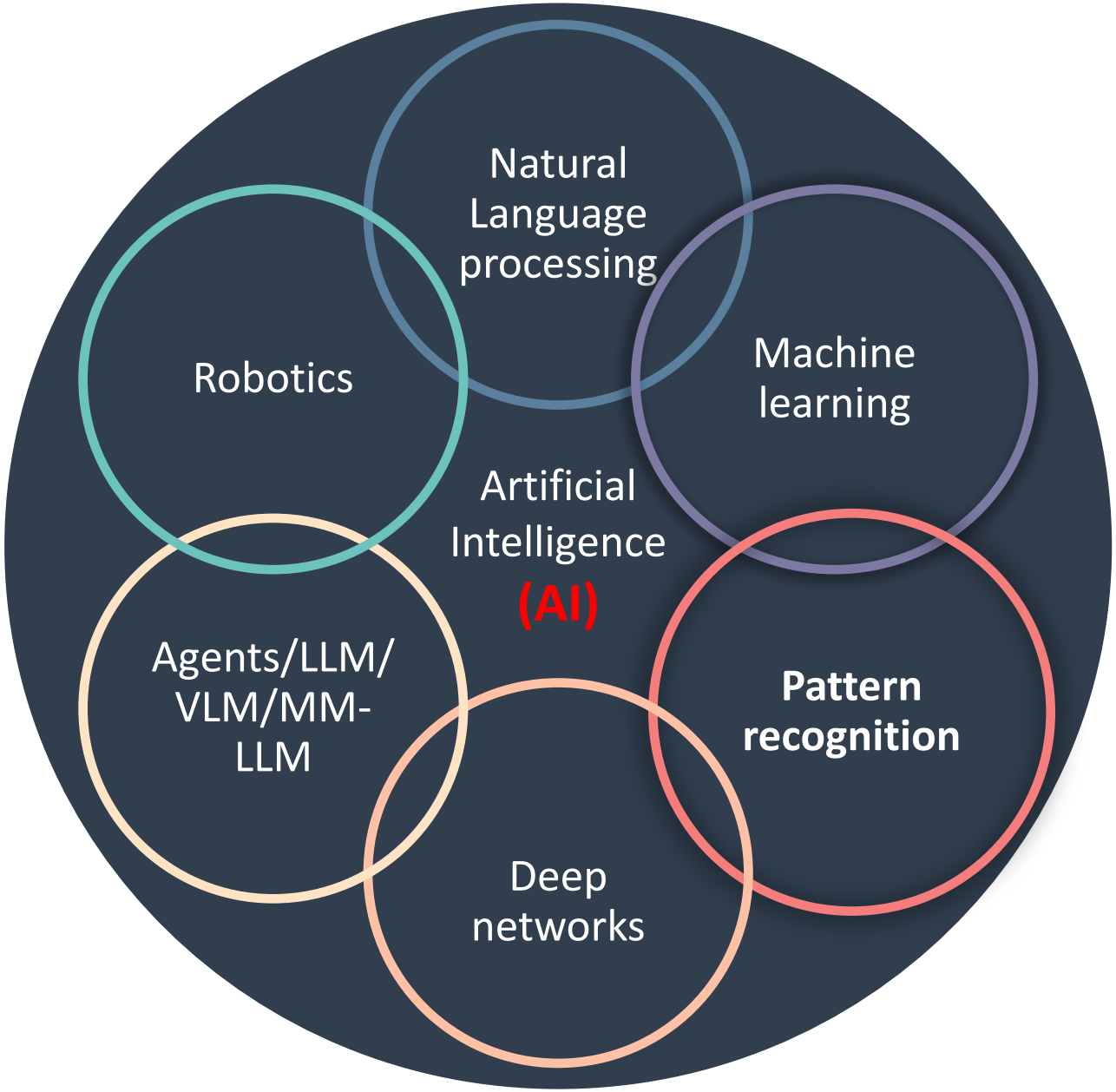
Characters that look similar

Central Problem: Representation & Prediction



Training & test data requirements, interpretability of features, generalization

AI Boom



- **Utilize domain knowledge**
- **Understand problem requirements**
- **Learn from failure cases**

IIT Kanpur (1964-1969)

DESIGN OF 3-PHASE, 60 CPS, POWER SUPPLY
USING PARALLEL INVERTER CIRCUITS

Undergraduate Project

A Project report presented to the
Faculty of Electrical Engineering in partial
fulfilment of the requirements of the degree
of Bachelor of Technology

Anil Kumar Jain
(64025)

Indian Institute of Technology
Kanpur
May, 1969

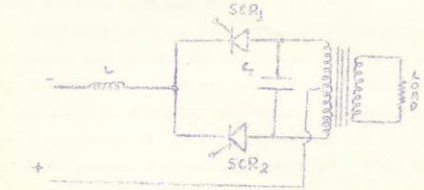


Fig 21 Conventional parallel Inverter

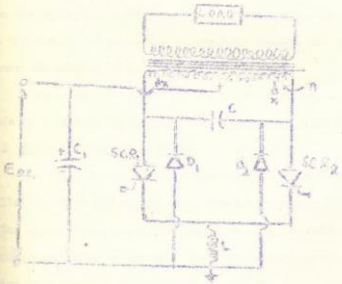
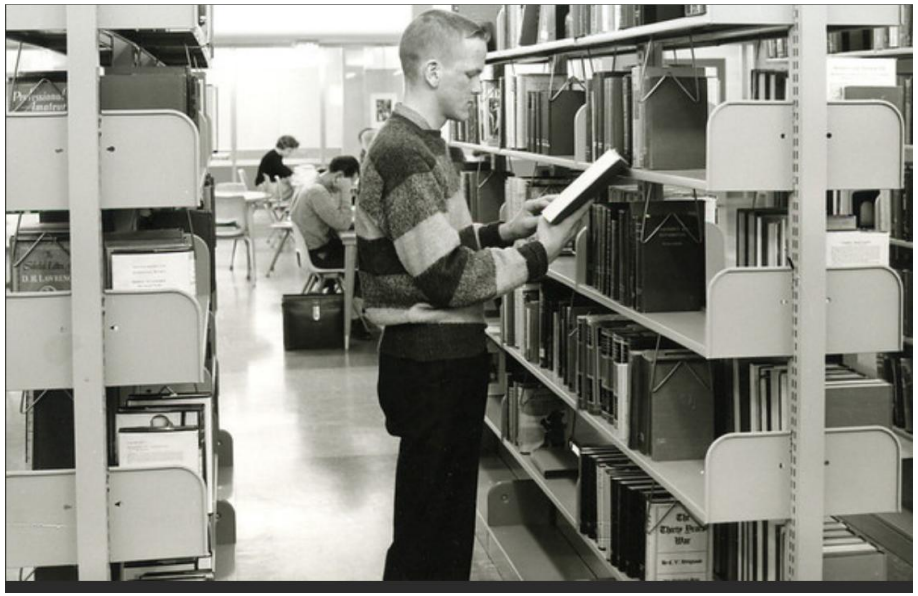


Fig 22 Improved Parallel Inverter

Ohio State University (1969-1972)

- 1970 (M.S.): Thesis on *"Regularly Realizable gait matrices"* in *Mathematical Biosciences, 1972. Reprinted in "On Natural Computation", MIT Press.*
- 1973 (Ph.D.): First conf. paper *"Quantization Complexity...", in IEEE Int'l Symp. Info. Th. (1972); IEEE Trans. Information Th. 1973.*

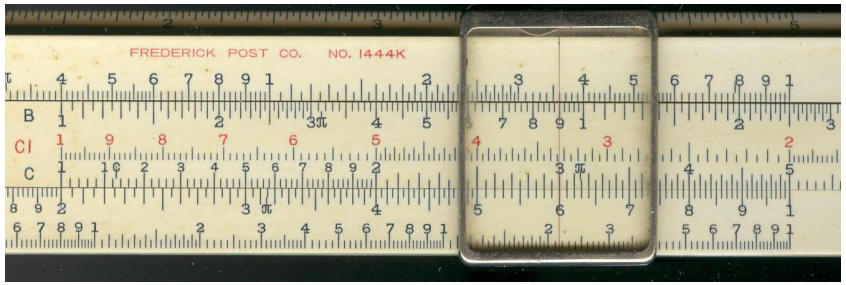


First IDD:1975; PAMI (1979); Copy machine:1980; PC (1980); CVPR (1983); GPS:1990; mobile: 1990; WWW: 1993; Google Scholar (2004); h index (2005).

Computing Environment

Property of Museum of History & Industry, Seattle

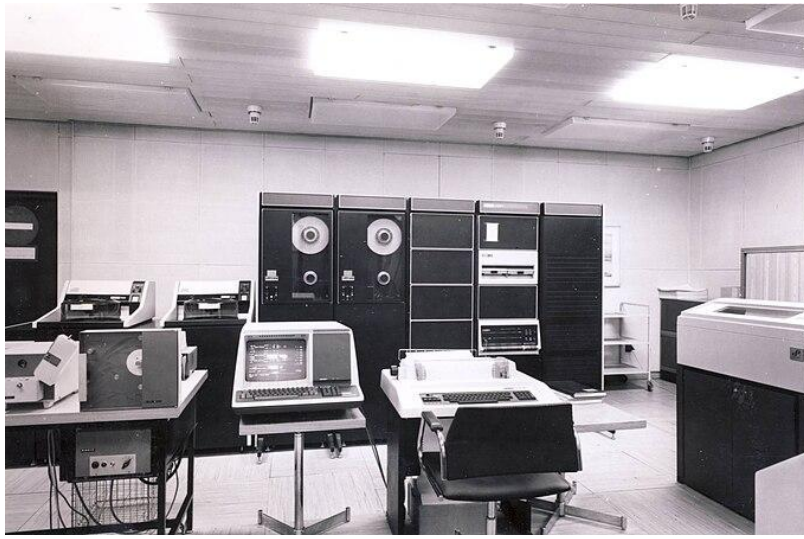
IBM 1620 (IITK), 1968



Slide rule, IITK (1964-69)

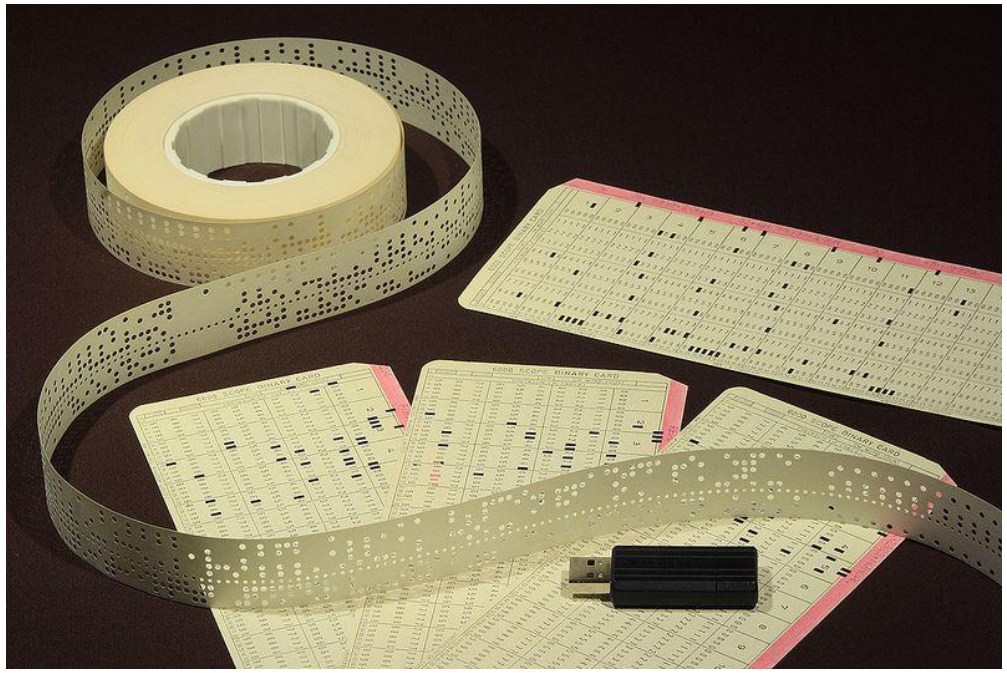
CDC 6500 (MSU),1974

HP calculator (1972)

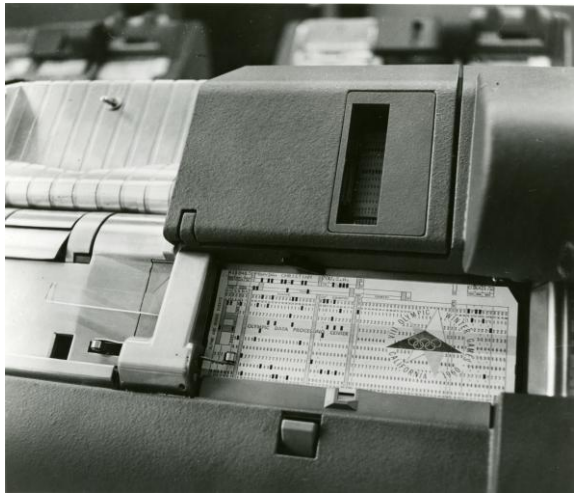


DEC PDP 11/34 minicomputer, 1976

I/O: Paper Tapes & Punched cards



Punched card & Tape with USB stick



Card punch

Card Reader

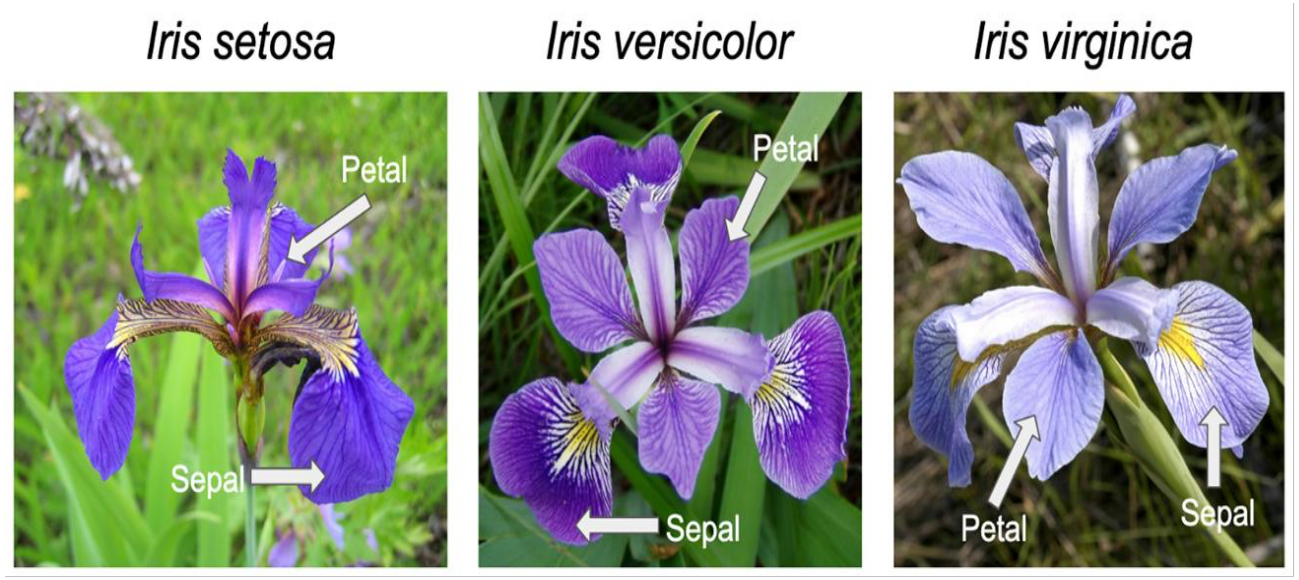
Deck of punched cards

Paper tape punch/ reader

IBM 1403 Printer

Datasets

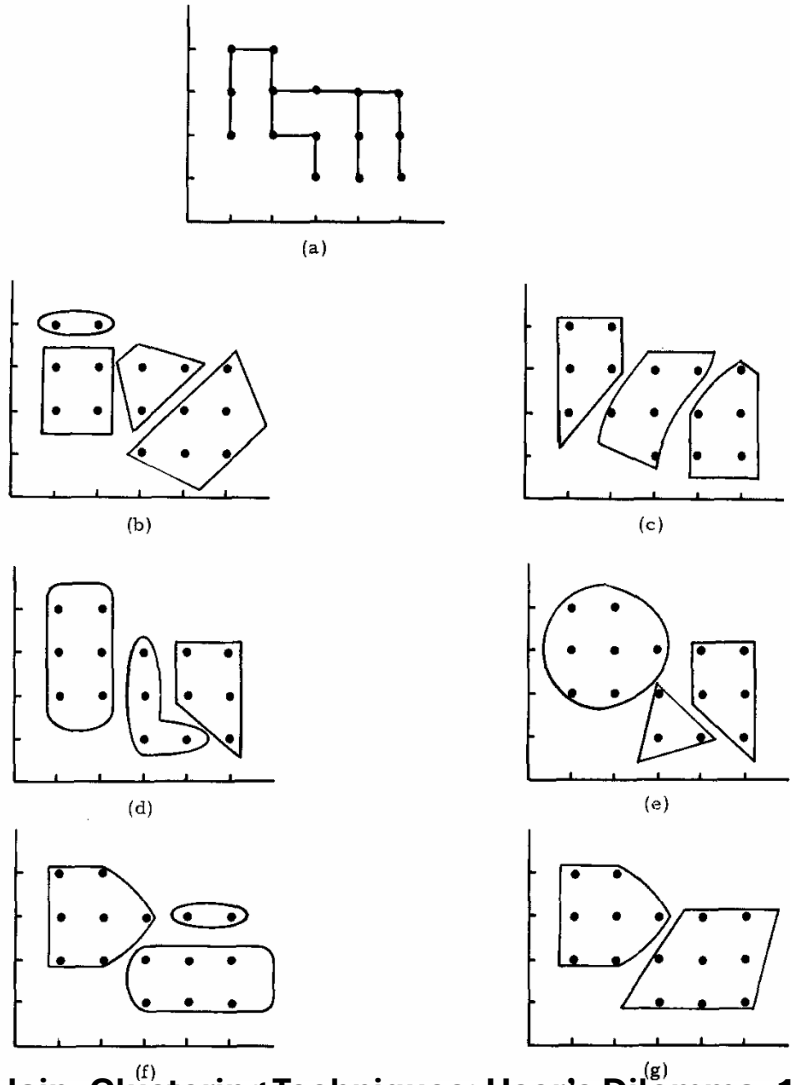
MNIST dataset: 70K images (60K for train;10K for test) of handwritten digits:0 to 9



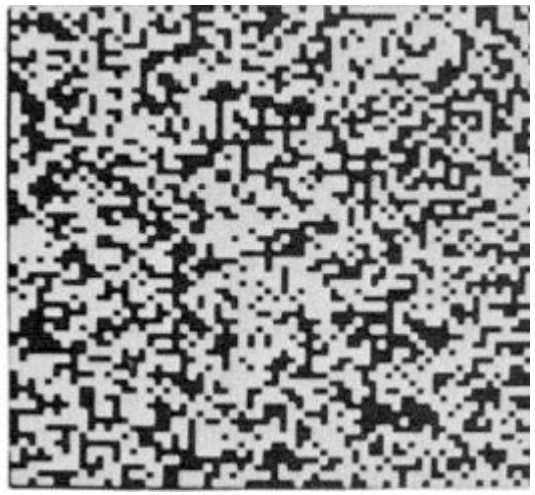
Fisher's Iris data

On My Own (1972-)

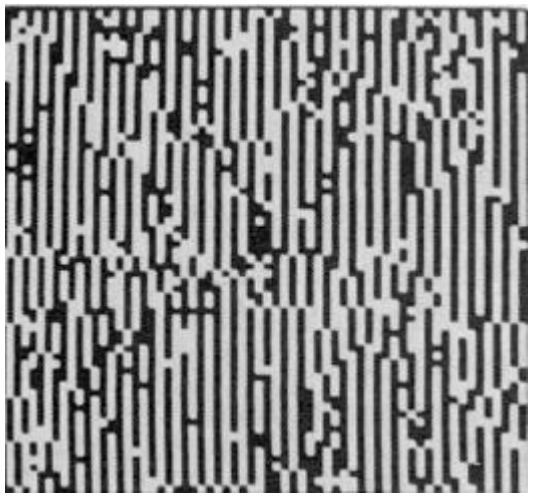
- **Clustering: Given n d-dim points, find C clusters. Notion of cluster validity.**
- **Models for texture synthesis, classification & segmentation. MRF model.**



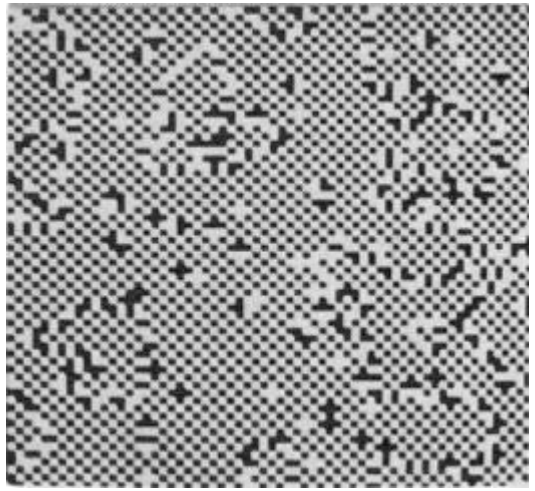
Dubes & Jain, Clustering Techniques: User's Dilemma, 1976 (538 cites)



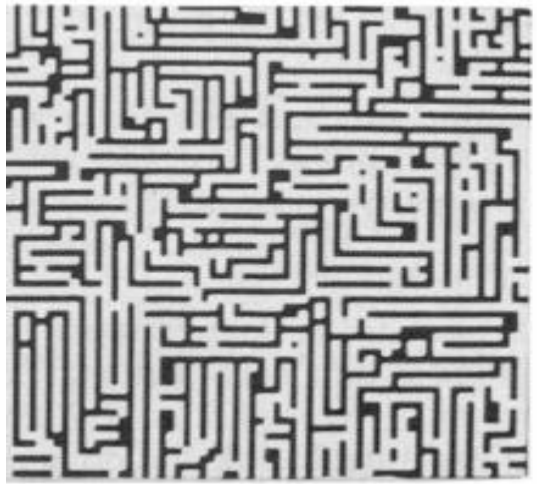
Isotropic first-order texture



Anisotroic line texture

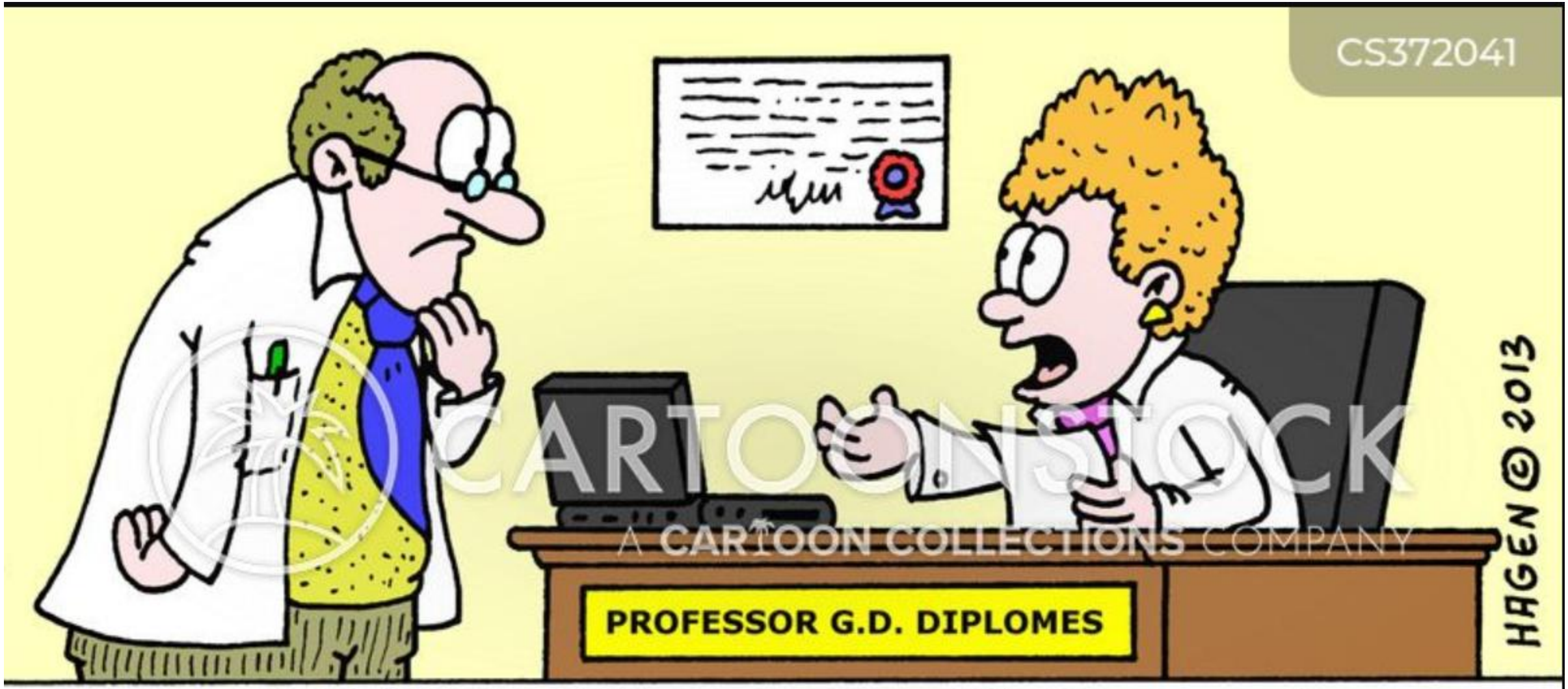


Ordered pattern



Diagonal inhibition texture

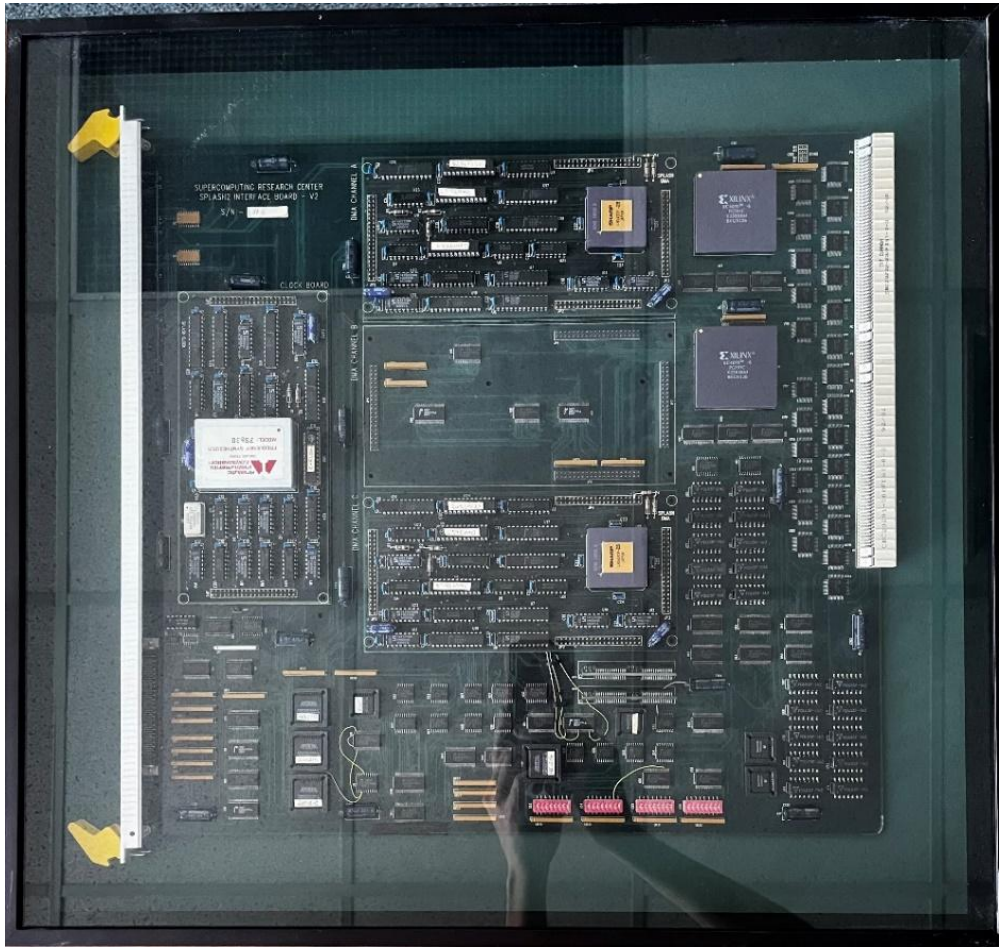
Cross & Jain, Markov random Field texture models, TPAMI 1983 (2374 cites)

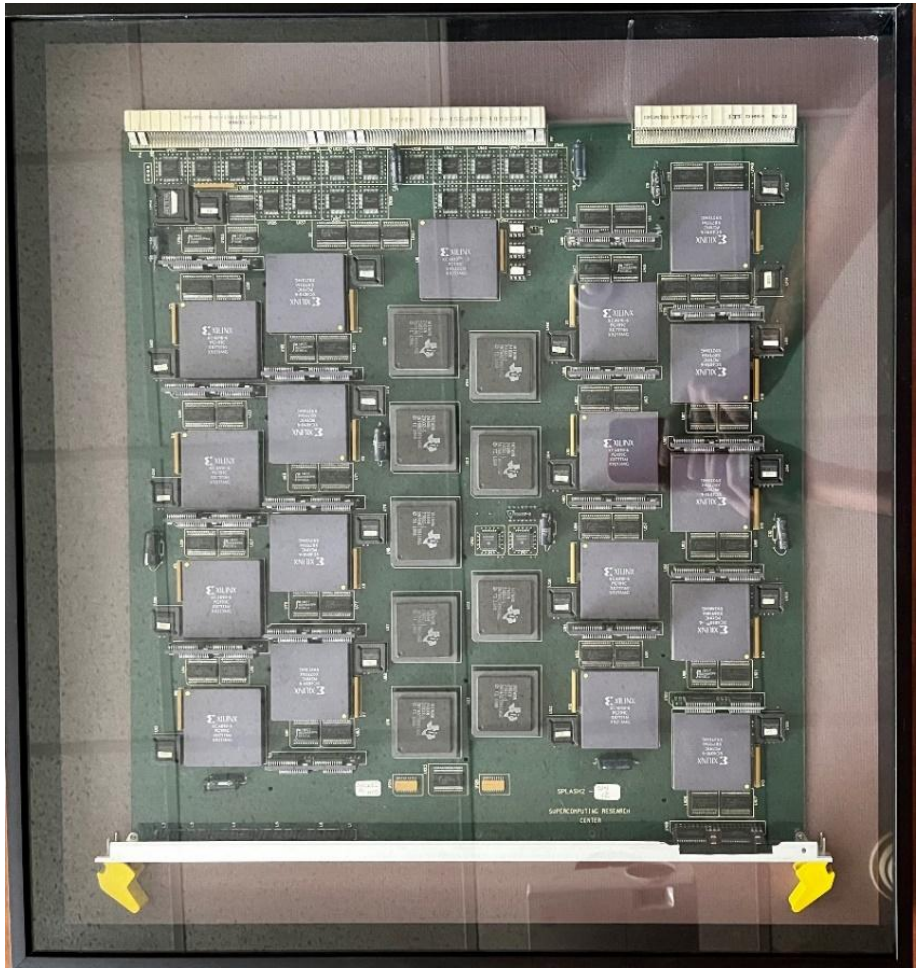


It's kind of depressing: We've spent three years on this research paper, and probably only ten people in the World will ever read it...

Luck Strikes (1991)

"Luck favors the prepared mind.” (Hamming)

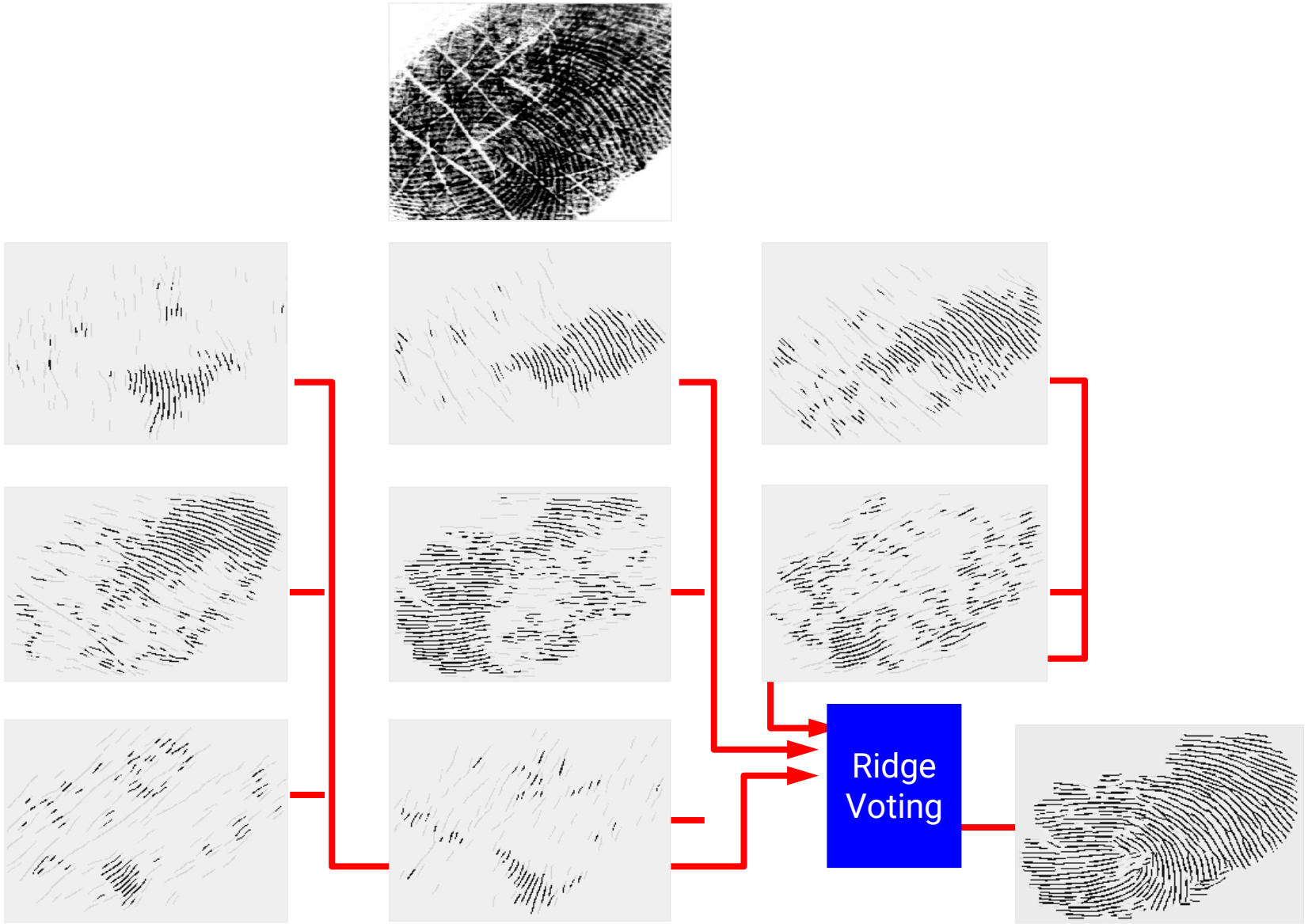




Splash 2 was the first computer to use FPGAs. Front-end board controlled data flowing to/from processing boards. Call from Duncan Buell, Inst. For Supercomputing Applications Center.

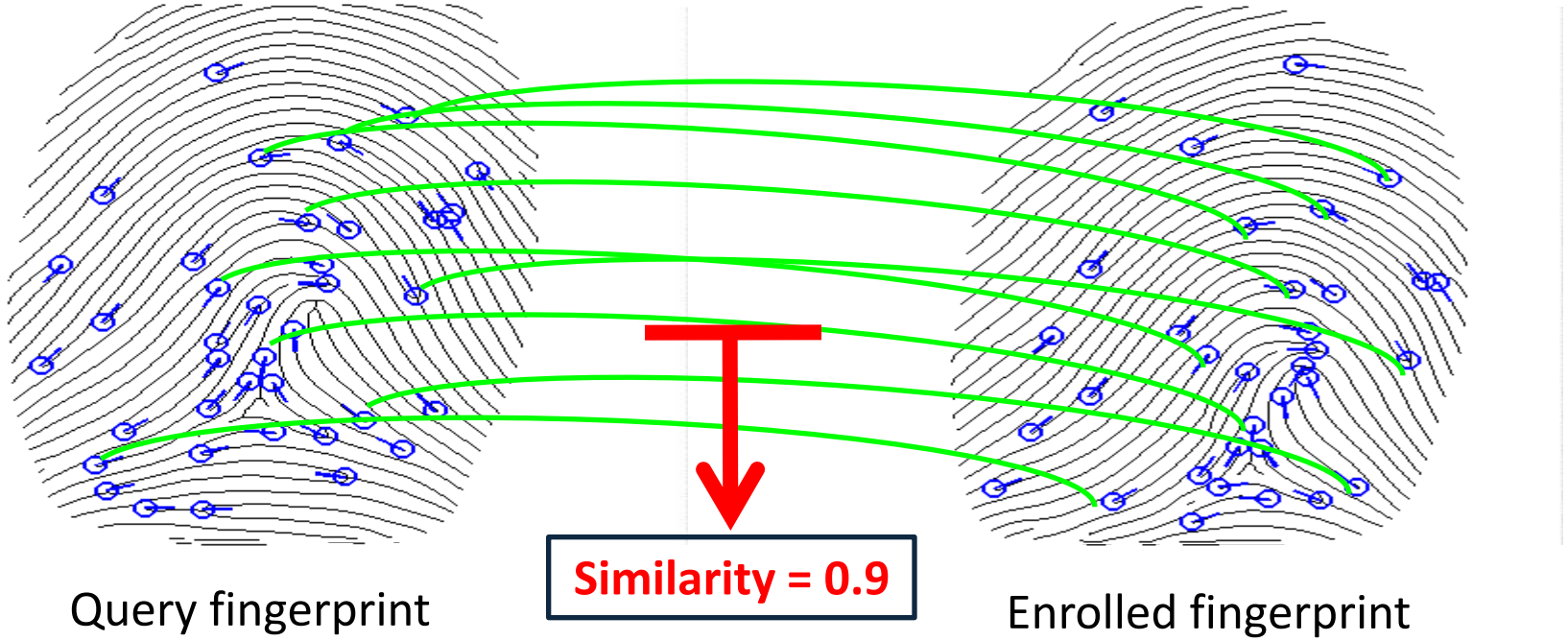
Arnold et al., "The Splash 2 processor and applications," Proc. ICCD’93

Fingerprint Enhancement using Gabor Filters



Hong, Wang & Jain, Fingerprint image enhancement: algorithm and performance evaluation IEEE TPAMI, 1998 (**3642 cites**).

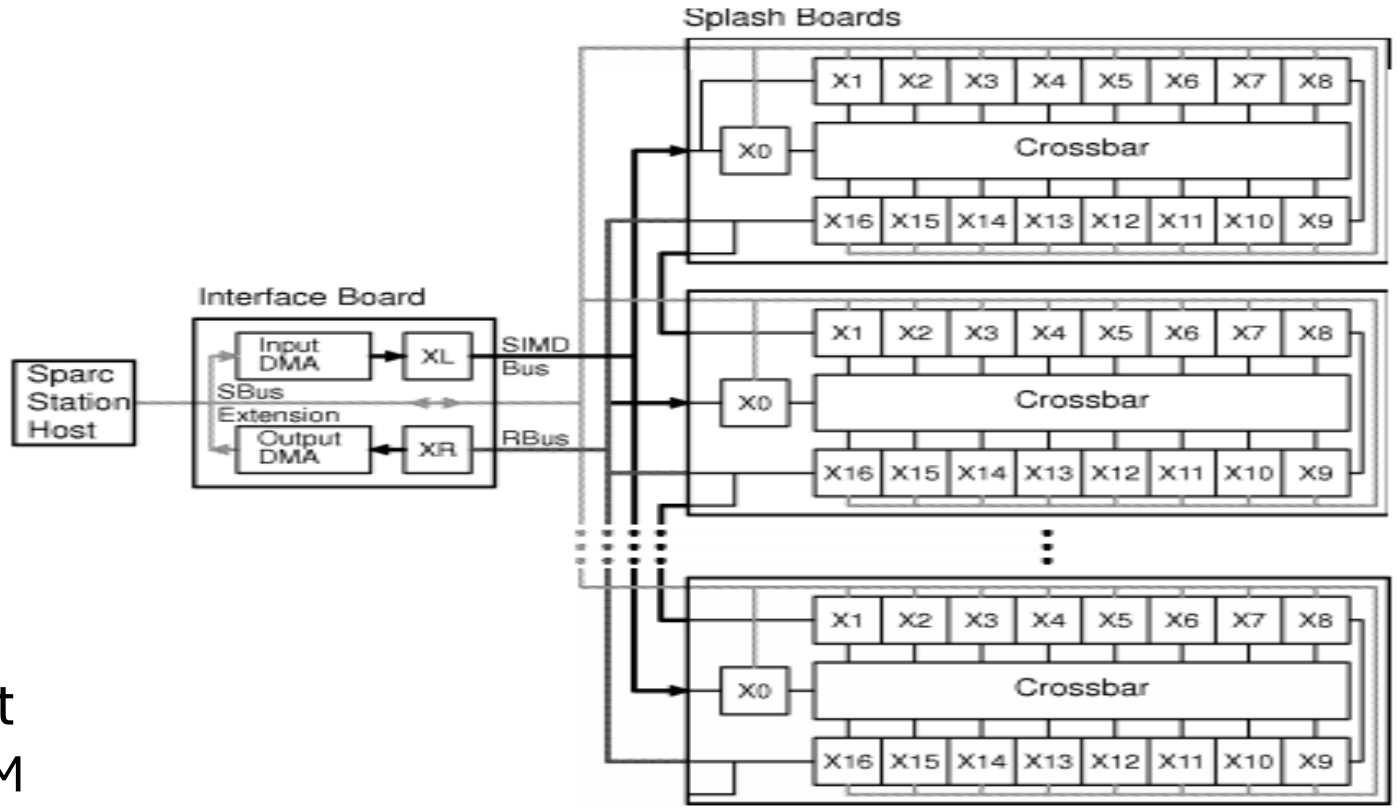
Fingerprint Minutiae Correspondence



Jain, Hong & Bolle, On-line Fingerprint Recognition, TPAMI, 1997 (**2344 cites**)

Fingerprint Matching on Splash 2

Sun SPARCstation host
~100 MHz CPU; 512 MB RAM

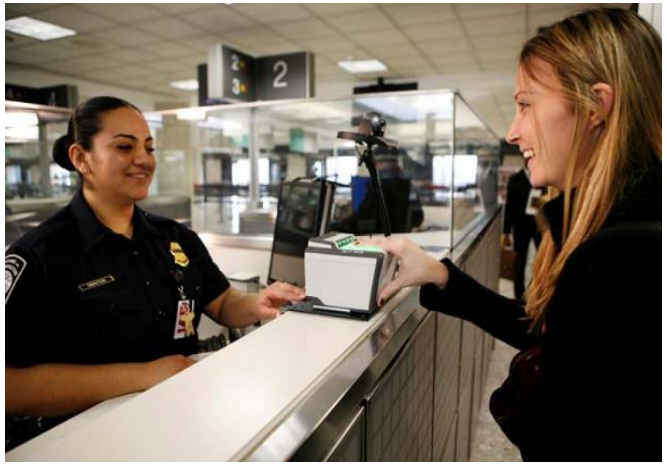


Each board has 16 Xilinx 4010s as PEs (**512 KB memory**); X0 controls data flow into the board

- 100 times speedup over sequential matcher on the host
- Licensed 6 patents to IBM (1998)

Ratha, Rover and Jain, "An FPGA-Based Point pattern Matching Processor with application to Fingerprint Matching", *CAMP ` 95*, Italy

We Were Ready for Emerging Applications!!

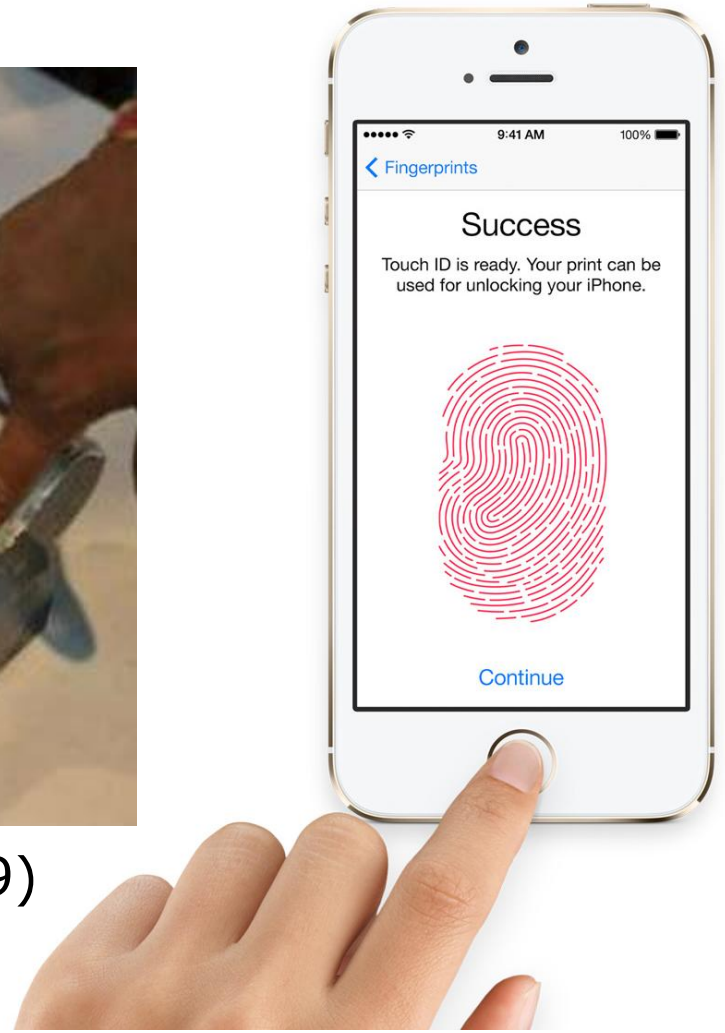


US-VISIT (2004)

Disney Parks (2006)

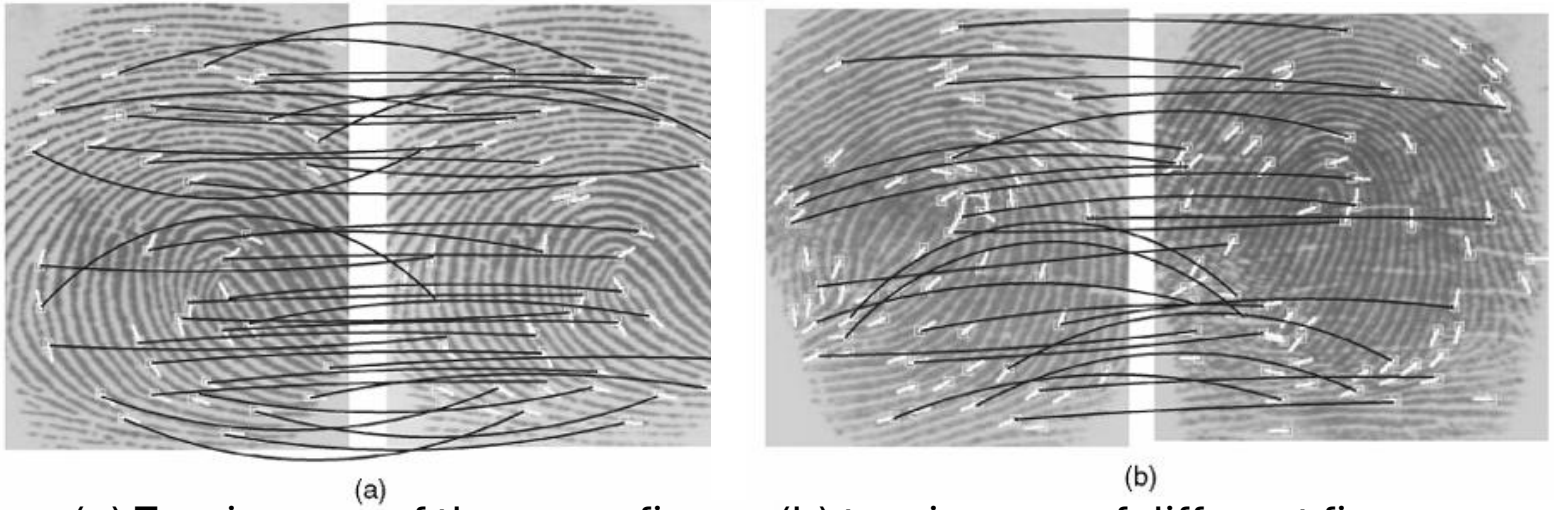
Aadhaar authentication (2009)

Lack of trust in credentials



iPhone 5s: Touch ID (2013)

Fundamental Premise of Fingerprints

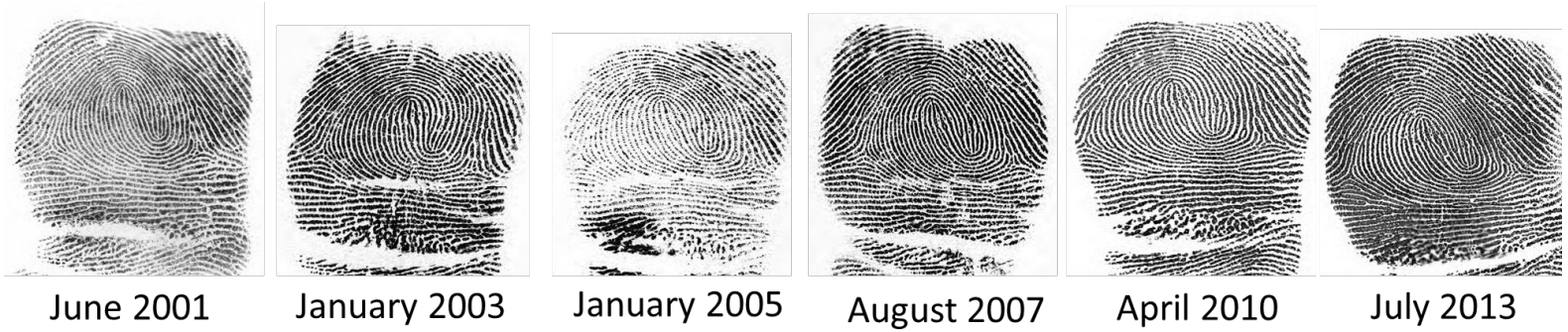


(a) Two images of the same finger; (b) two images of different fingers

Pankanti, Prabhakar, Jain, "On the Individuality of Fingerprints", CVPR, 2001.

1. Individuality: *Probability of two fingerprints, one with m minutia and other with n minutia sharing q points.*

2. Persistence: Longitudinal model to predict accuracy over time.

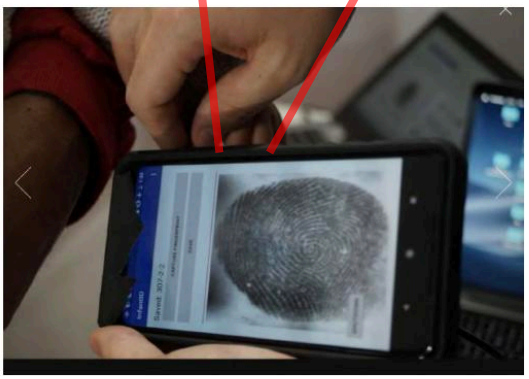


Yoon & Jain, Longitudinal study on fingerprint recognition, PNAS, 2015.

3. Can fingerprints separate **Identical twins**?

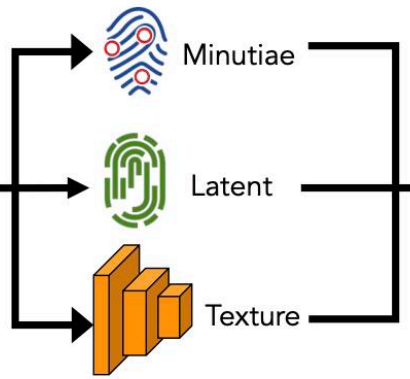
Jain, Prabhakar, Pankanti, “Similarity of Identical Twin Fingerprints", PR 2002.

MSU Infant-Print Matcher



Fingerprint Capture

Age Transformed & Enhanced



Feature Extraction

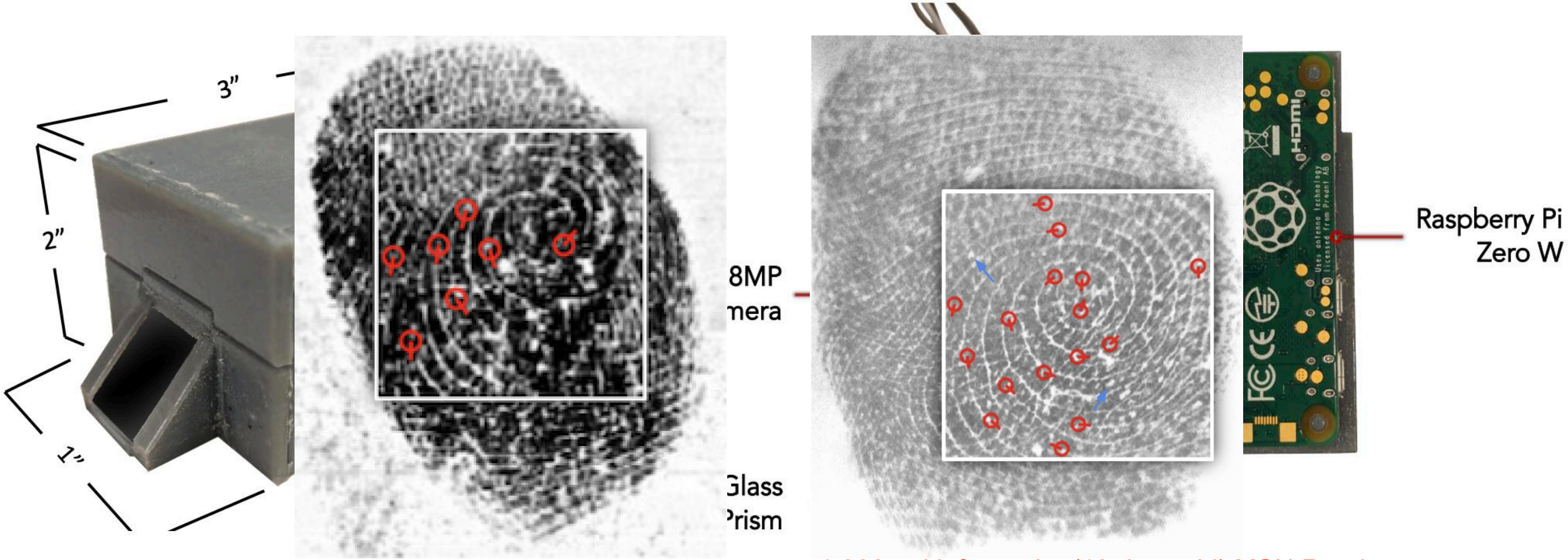
Search Gallery

InfantID App

- Image capture: 1900 ppi in-house reader to smartphone over blue tooth
- Preprocessing: Enhancement and aging
- Matching: Minutiae, latent and texture matchers

Engelsma, Deb, Cao, Bhatnagar, Sudhish & Jain, "Infant-ID: Fingerprints for Global Good", *TPAMI*, 2021.

MSU Infant-Print Reader



500 ppi infant-print (13 days old) DP UrUreader

1,900 ppi infant-print (13 days old) MSU Reader

Reader: 1,900 ppi; cost: $85; assembly time: < 2 hours

Open Source: *https://bit.ly/31s2TQT*

Challenges: Blur, distortion, small ridge gaps, wet/dry finger

Detection of Altered Fingerprints

Fingerprint of Gus Winkler (1933) before and after alteration; algorithm licensed to Idemia

S. Yoon, J. Feng and A. K. Jain, "Altered Fingerprints: Analysis and Detection", *IEEE Trans. Pattern Analysis and Machine Intelligence*, 2012.

Fingerprint Spoof Buster

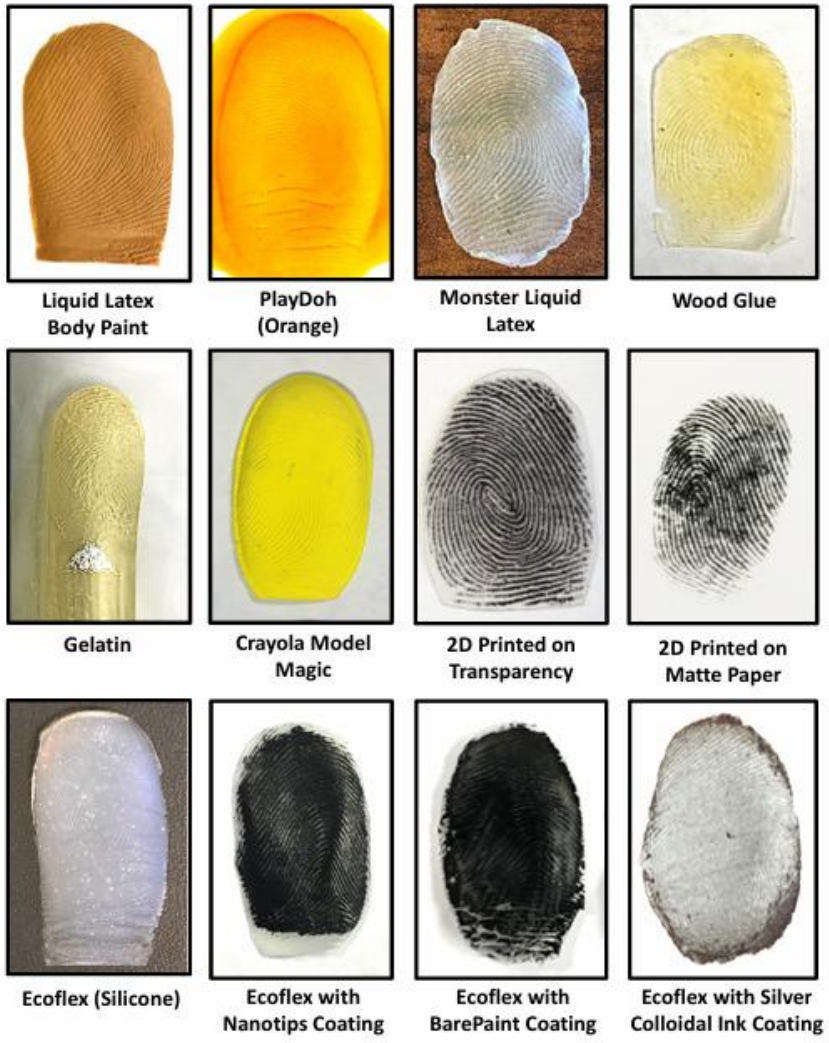
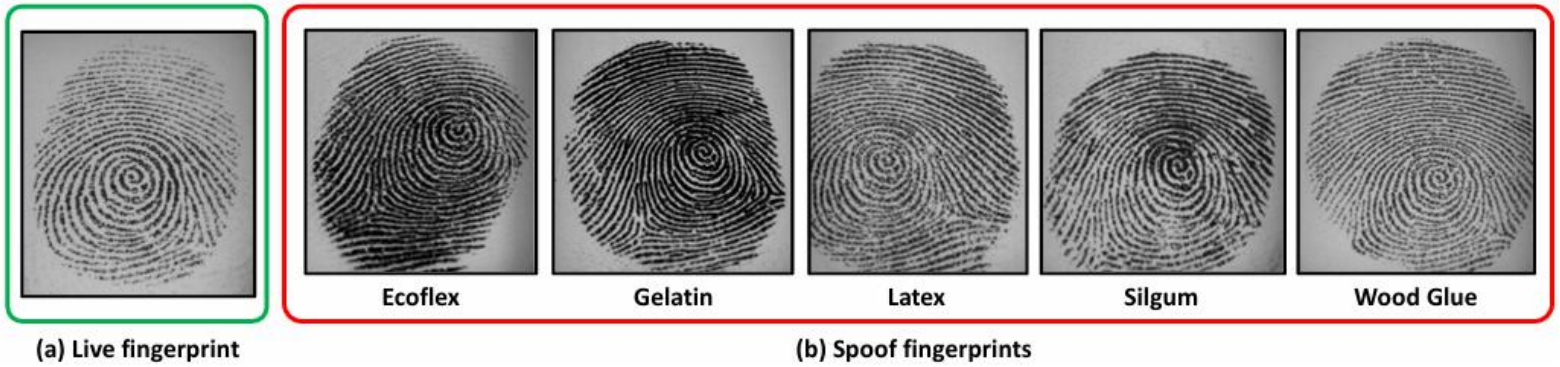
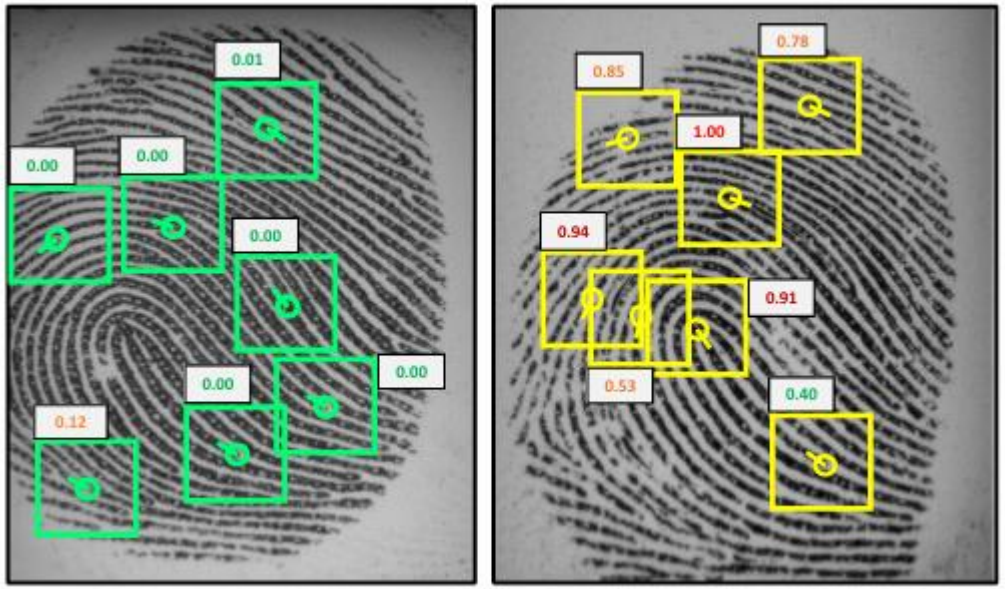


Fig. 1. Fingerprint spoof attacks can be realized using various readily available fabrication materials, such as PlayDoh, WoodGlue, Gelatin, etc.

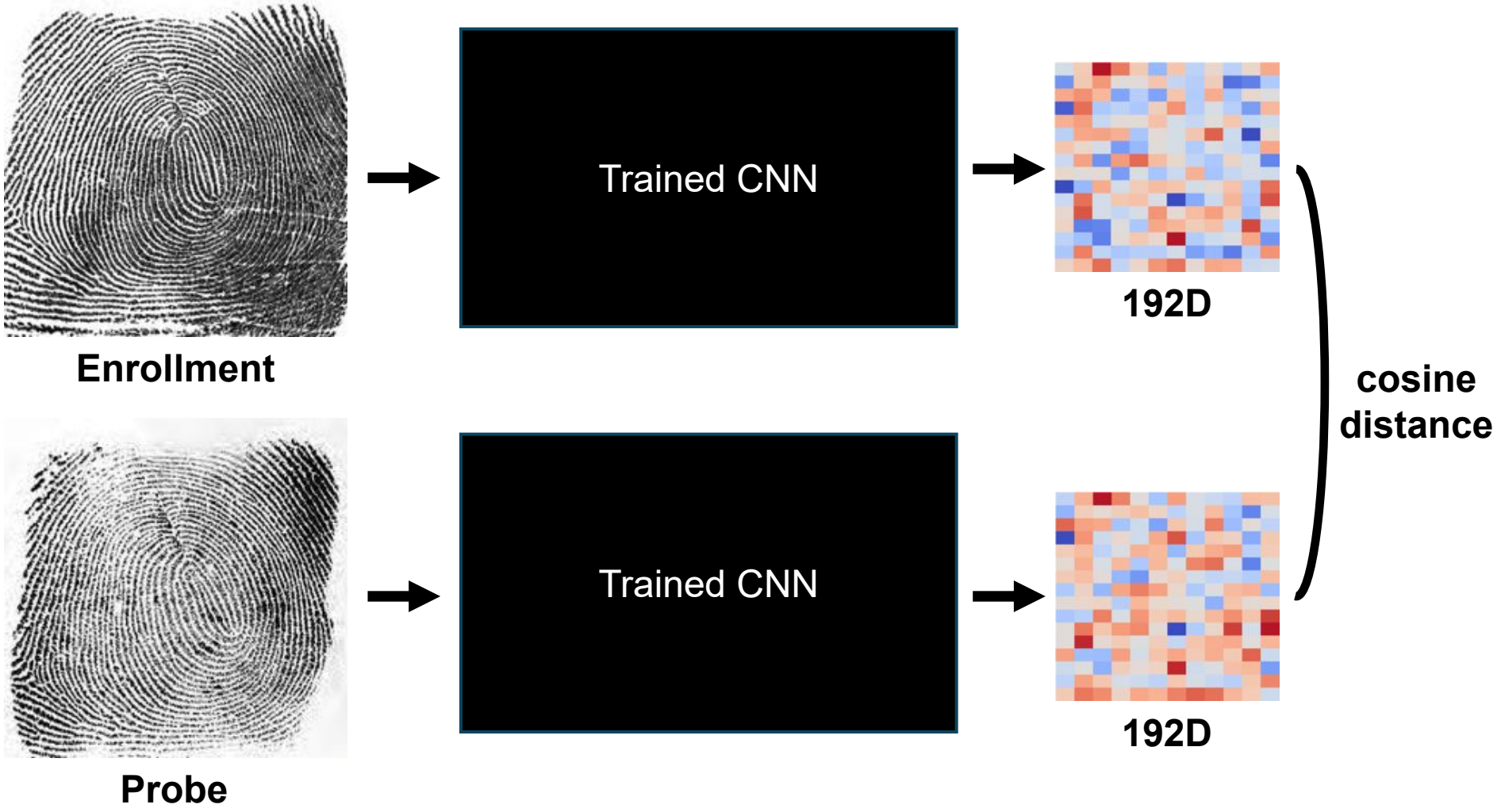




Real (left) and gelatin (right) fingerprints. Patch embeddings for centered at minutiae can separate real and spoof fingerprints.

Chugh, Cao and Jain, Fngerprint Spoof Buster, IEEE TIFS, 2019

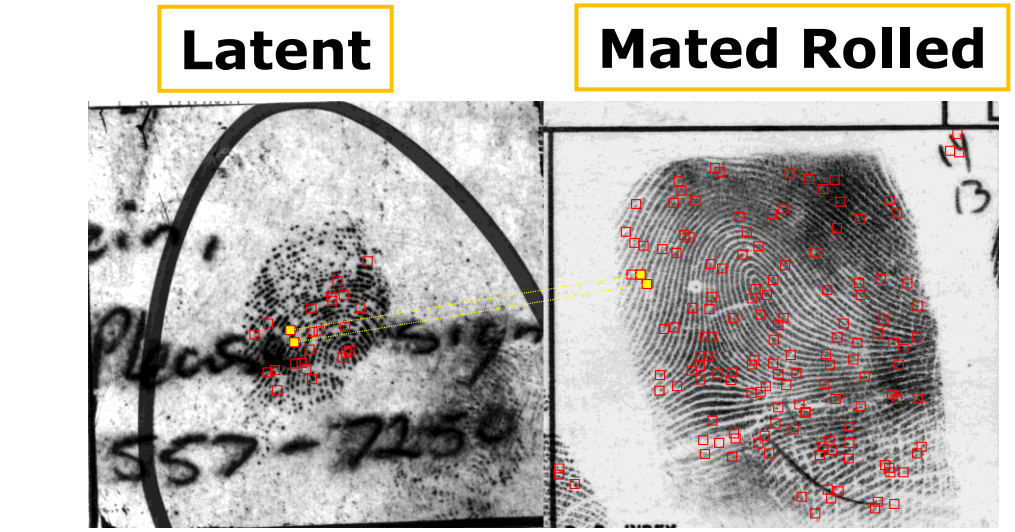
Fixed-Length Fingerprint Representation



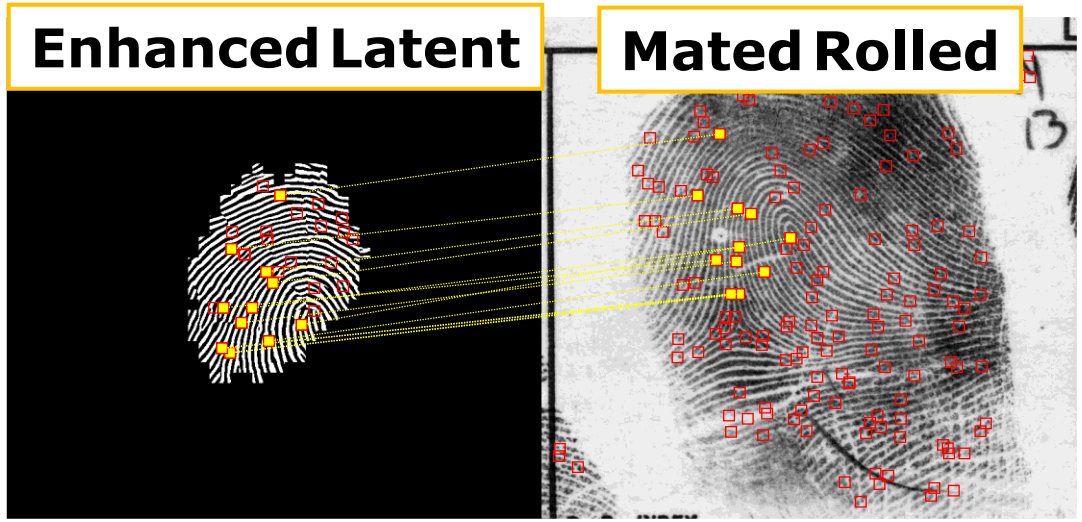
Fixed-length embedding is 3 times faster than point correspondence; licensed to NEC.

Engelsma, Cao, Jain, Learning a fixed-length fingerprint representation, TPAMI, 2019

Latent (crime scene) Fingerprint Matcher



Matched minutiae = 2
Similarity score = 3



Matched minutiae = 13
Similarity score = 38

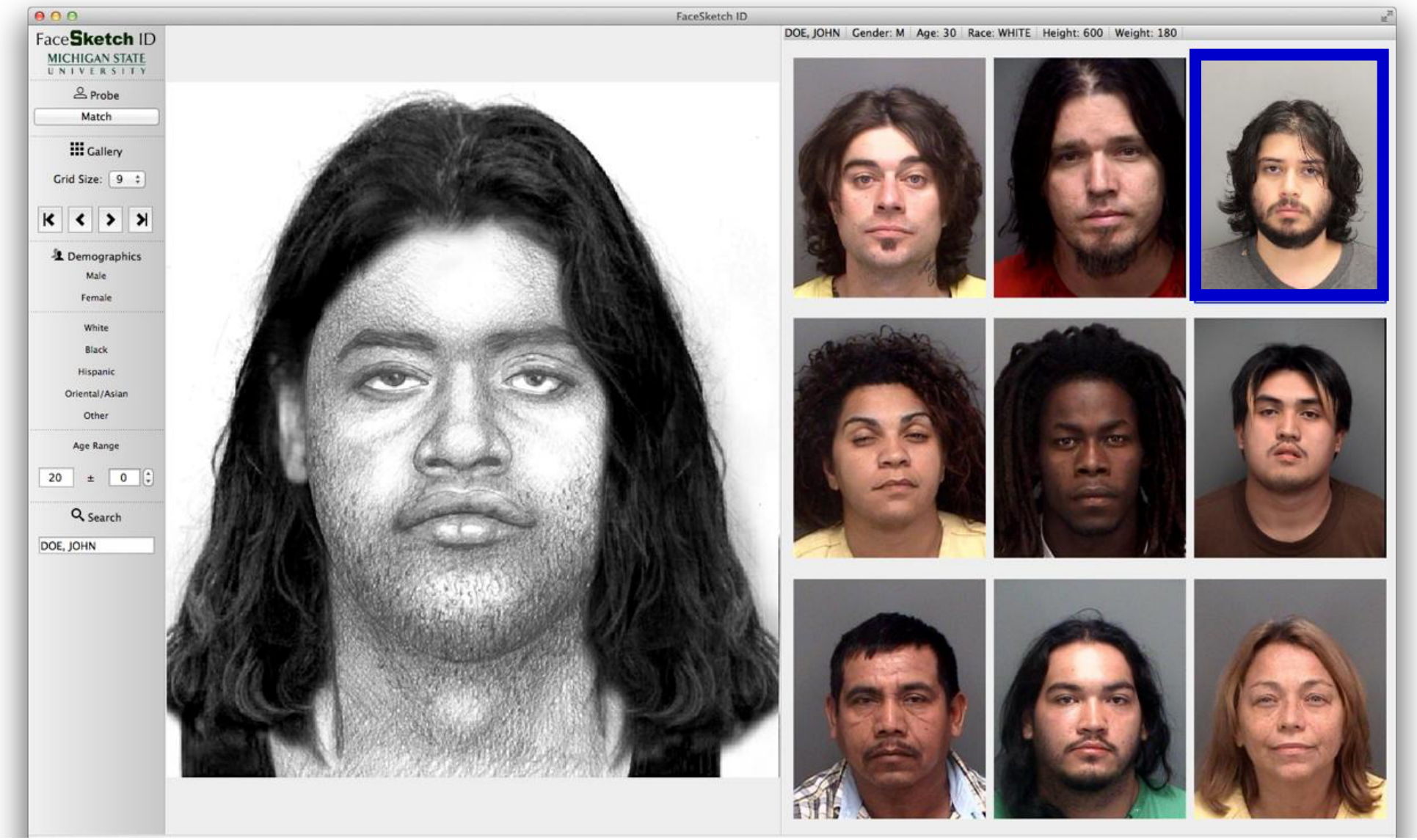
Grosz & Jain, IEEE TIFS, 2023. Licensed to Thales, 2024

Tattoo Image Matching & Retrieval

Gang tattoos of (a) Latin kings and (b) Family stones; (c) teardrop criminal tattoo (person has killed someone or had a friend killed in prison); (d) spider within a web tattoo (drug addict or a thief).

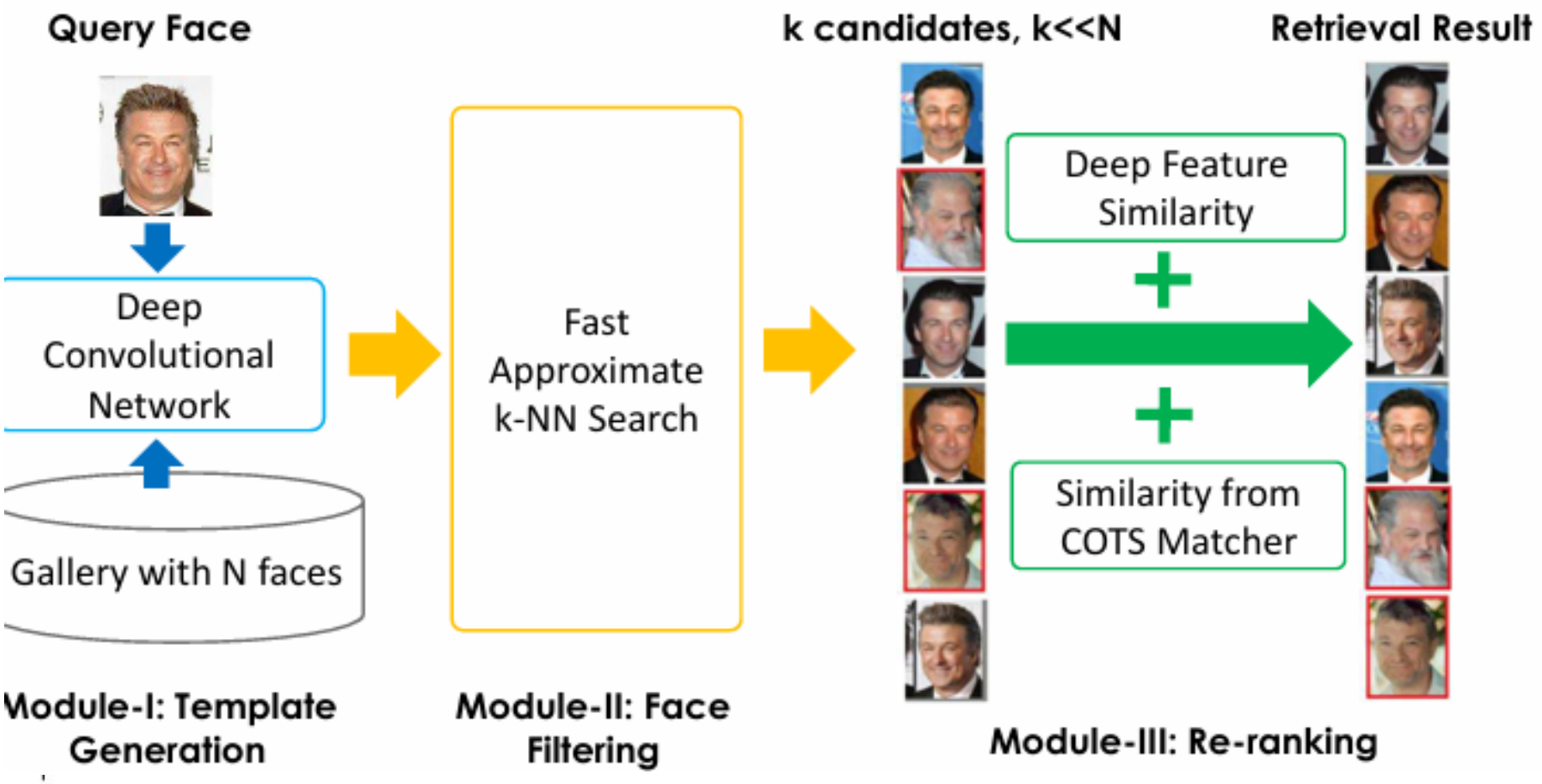
Jain, Lee, Jin, " Tattoo-ID: Automatic Tattoo Image Retrieval for Suspect & Victim Identification", *Proc. PCM*, 2007. **Licensed to Idemia.**

Face-Sketch ID System



Klare, Li and Jain, TPAMI. Licensed to Idemia, 2016

Large Scale Face search: 80 M Gallery



Query

Top-10 retrieved images from a gallery of 80 million images

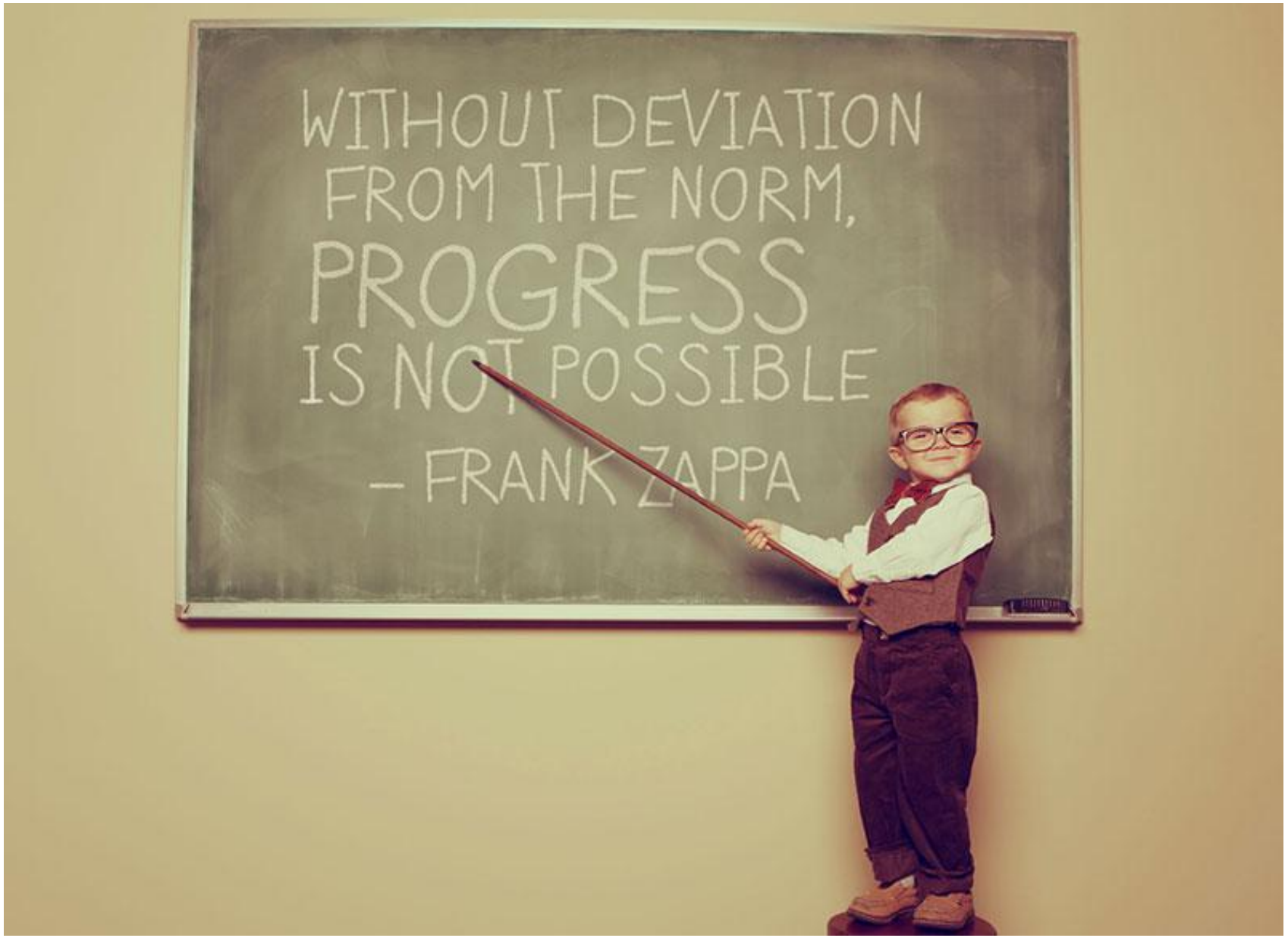
Wang, Otto, Jain, Face search at Scale, TPAMI, 2016. **Licensed to NEC 2016.**

Joys of Research

- *As PhD advisor, my job is like that of a "diamond cutter & polisher": take a rough diamond and make it glow and valuable.*
- *A sense of satisfaction in training students and see them flourish in academia/industry.*
- *Chance to travel the world, make friends and learn different cultures (extended stays in Indonesia, S. Korea, Portugal, Norway, Turkey, China and Hong Kong).*
- *Assisting in national policies (National Academy of Engineering, Defense Science Board, Forensic Science Board).*
- *Mentoring young colleagues.*

Take Home Message

- *"If you don't work on important problems, it's unlikely you will do important work." (Hamming)*
- *"It is better to do the right problem the wrong way than the wrong problem the right way." (Hamming)*
- Read, listen & talk with peers smarter than you; find an "opening".
- Success requires preparation/initiative/resources/perseverance.
- Pick "low-hanging fruits".
- Publication vs. impact; breadth vs. depth.
- Learn to write/speak clearly & concisely (2-min. elevator pitch)
- Research can be stressful; physical & mental fitness is essential.



Frank Zappa, an American composer, guitarist, and satirist (1940-1993).