Machine Learning

Artificial Intelligence

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Machine Learning

- What is the Machine Learning?

  - **Herbert Simon**: "Leaning is any process by which a system improves performance from experience."

  - **Tom Mitchell** (1998):

    Machine Learning is the study of algorithms that

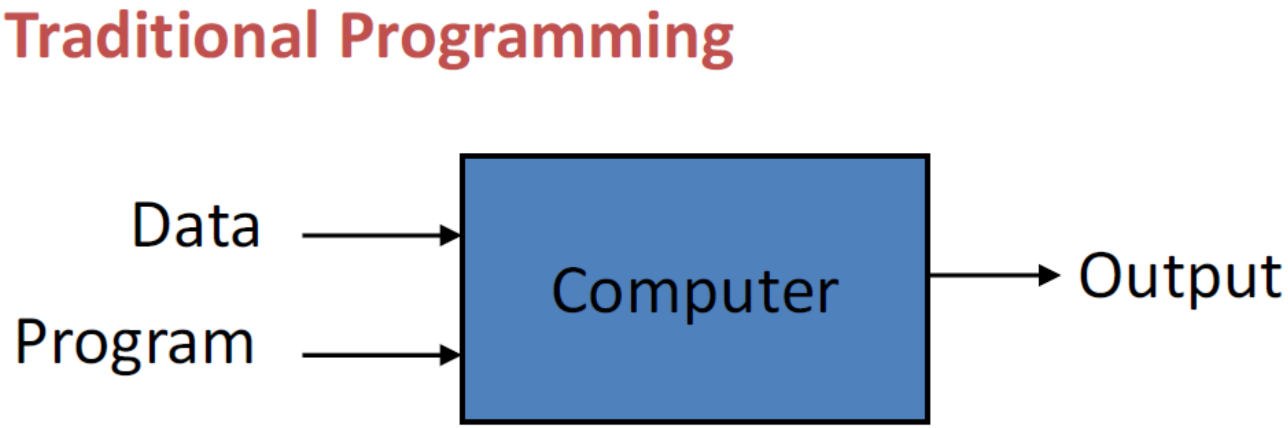
    - improve their performance, ***P***
    - at some task, ***T***
    - with experience, ***E***

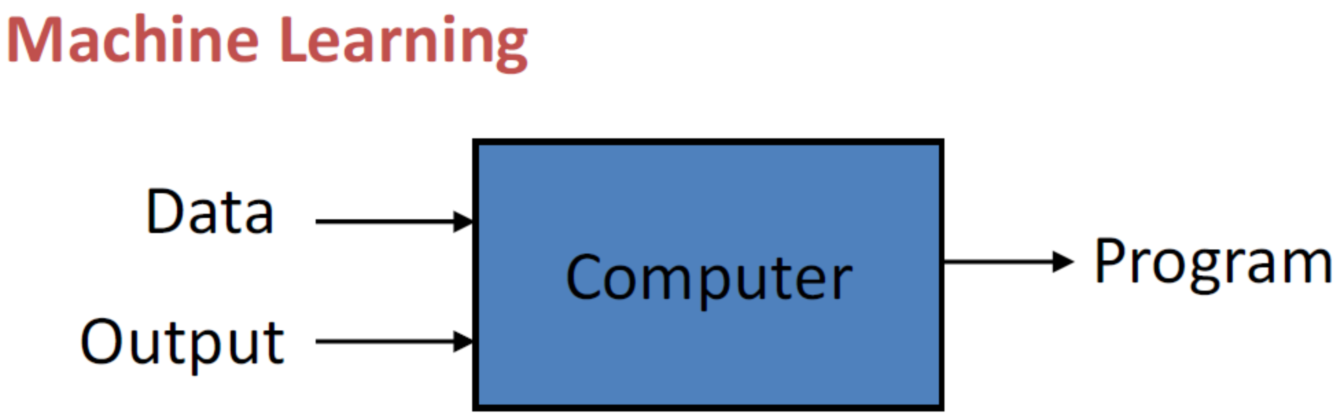
    A well-defined learning task is given by {***P, T, E***}

Based on Slide by Eric Eaton

Machine Learning

- Traditional Programming vs. Machine Learning





Slide Credit by Pedro Domingos

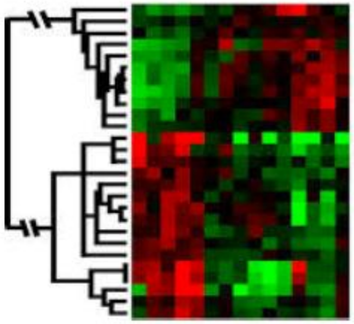
Machine Learning

❖ When do we use Machine Learning?

ML is used when:

- Human expertise does not exist (navigating on Mars)
- Humans can't explain their expertise (speech recognition)
- Models must be customized (personalized medicine)
- Models are based on huge amounts of data (genomics)



Learning isn't always useful:

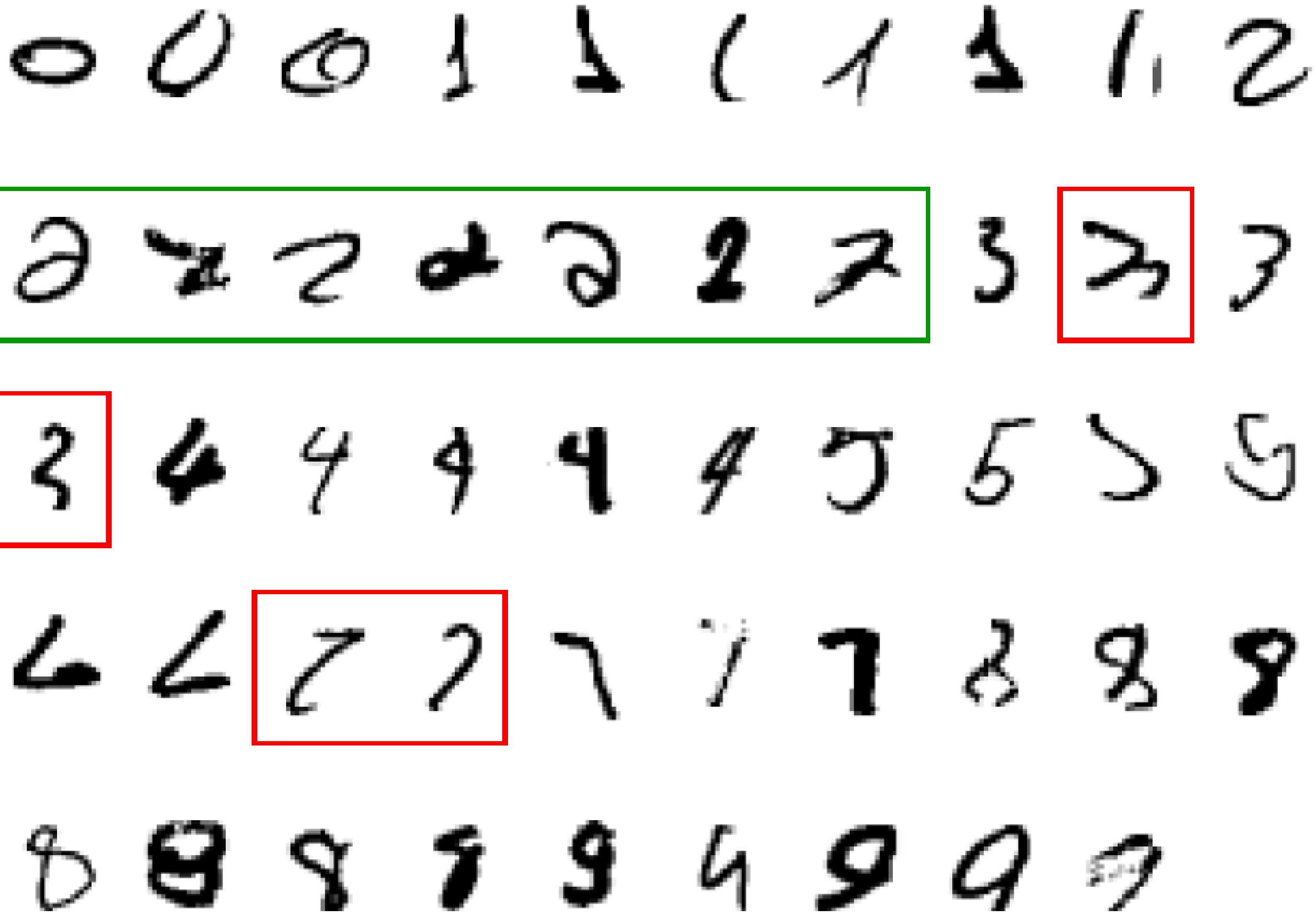
- There is no need to "learn" to calculate payroll

Based on Slide by E. Alpaydin

Machine Learning

A classic example of a task that requires machine learning:

It is very hard to say what makes a 2



Slide Credit by Geoffrey Hinton

Some more examples of tasks that are best solved by using a learning algorithm

- Recognizing patterns:
  - Facial identities or facial expressions
  - Handwritten or spoken words
  - Medical images
- Generating patterns:
  - Generating images or motion sequences
- Recognizing anomalies:
  - Unusual credit card transactions
  - Unusual patterns of sensor readings in a nuclear power plant
- Prediction:
  - Future stock prices or currency exchange rates

Slide Credit by Eric Eaton

Samuel's Checkers-Player

"Machine Learning: Field of study that gives computers the ability to learn without being explicitly programmed." -Arthur Samuel (1959)

Slide Credit by Eric Eaton

Machine Learning

- Defining the Learning Task

Improve on task T, with respect to performance metric P, based on experience E

T: Playing checkers
P: Percentage of games won against an arbitrary opponent
E: Playing practice games against itself

T: Recognizing hand-written words
P: Percentage of words correctly classified
E: Database of human-labeled images of handwritten words

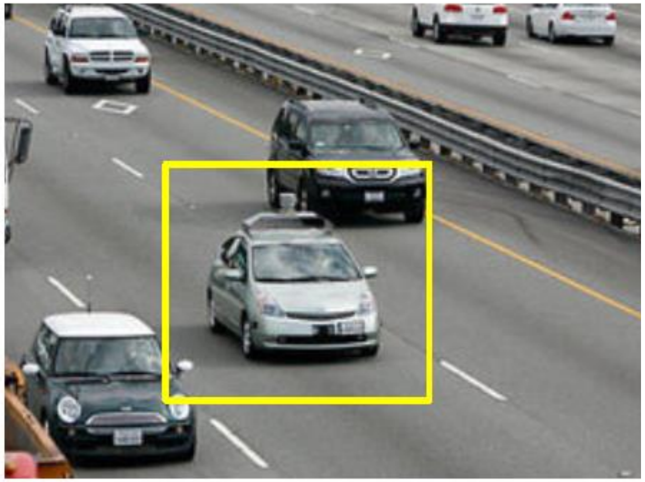
T: Driving on four-lane highways using vision sensors
P: Average distance traveled before a human-judged error
E: A sequence of images and steering commands recorded while observing a human driver.

T: Categorize email messages as spam or legitimate.
P: Percentage of email messages correctly classified.
E: Database of emails, some with human-given labels

Slide Credit by Ray Mooney

SOTA ML Applications

❖ Autonomous Cars



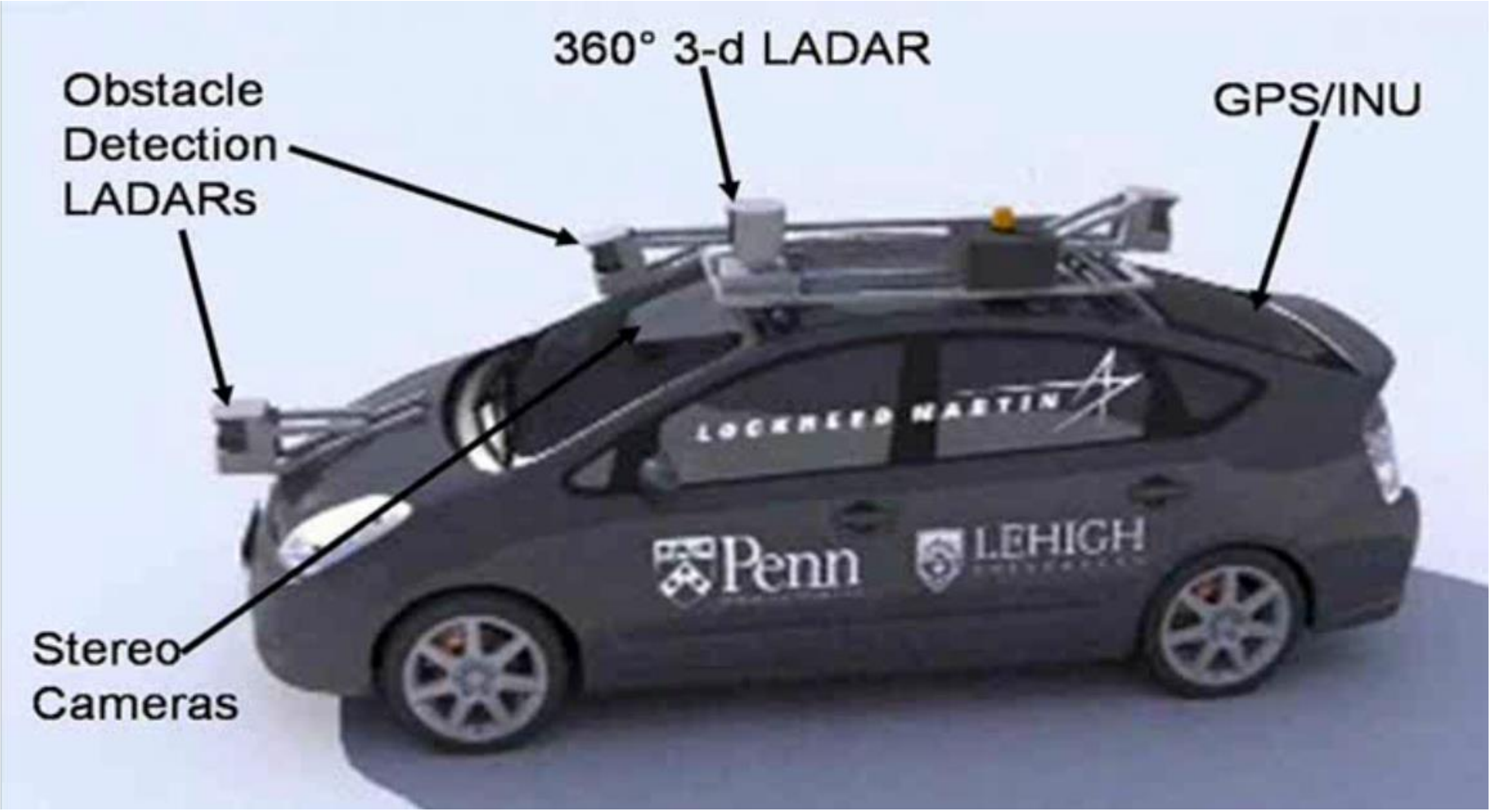
- Nevada made it legal for autonomous cars to drive on roads in June 2011
- As of 2013, four states (Nevada, Florida, California, and Michigan) have legalized autonomous cars

Penn's Autonomous Car →
(Ben Franklin Racing Team)

Slide Credit by Eric Eaton

SOTA ML Applications

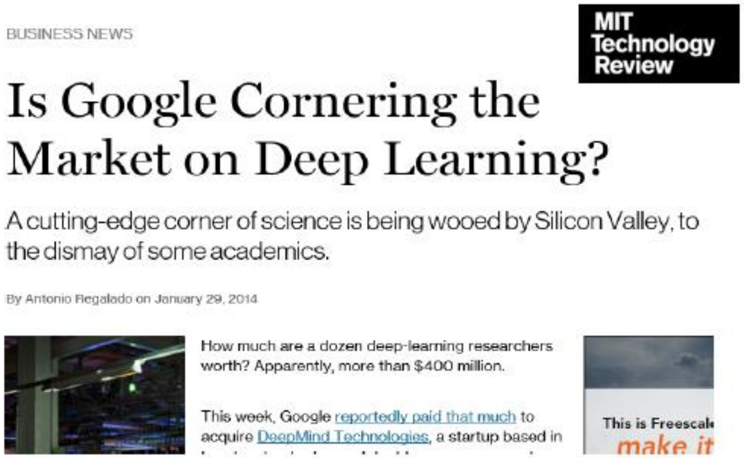
- Autonomous Car Sensors



Slide Credit by Eric Eaton

SOTA ML Applications

- Deep Learning in the Headlines



BUSINESS NEWS

MIT Technology Review

Is Google Cornering the Market on Deep Learning?

A cutting-edge corner of science is being wooed by Silicon Valley, to the dismay of some academics.

By Antonio Regalado on January 29, 2014

How much are a dozen deep-learning researchers worth? Apparently, more than $400 million.

This week, Google reportedly paid that much to acquire DeepMind Technologies, a startup based in

BloombergBusinessweek

Technology

Acquisitions

The Race to Buy the Human Brains Behind Deep Learning Machines

By Ashlee Vance | January 27, 2014

intelligence projects. "DeepMind is bona fide in terms of its research capabilities and depth," says Peter Lee, who heads Microsoft Research.

According to Lee, Microsoft, Facebook (FB), and Google find themselves in a battle for deep learning talent. Microsoft has gone from four full-time deep learning experts to 70 in the past three years. "We would have more if the talent was there to

WIRED GEAR SCIENCE ENTERTAINMENT BUSINESS SECURITY DESIGN

INNOVATION INSIGHTS community content featured

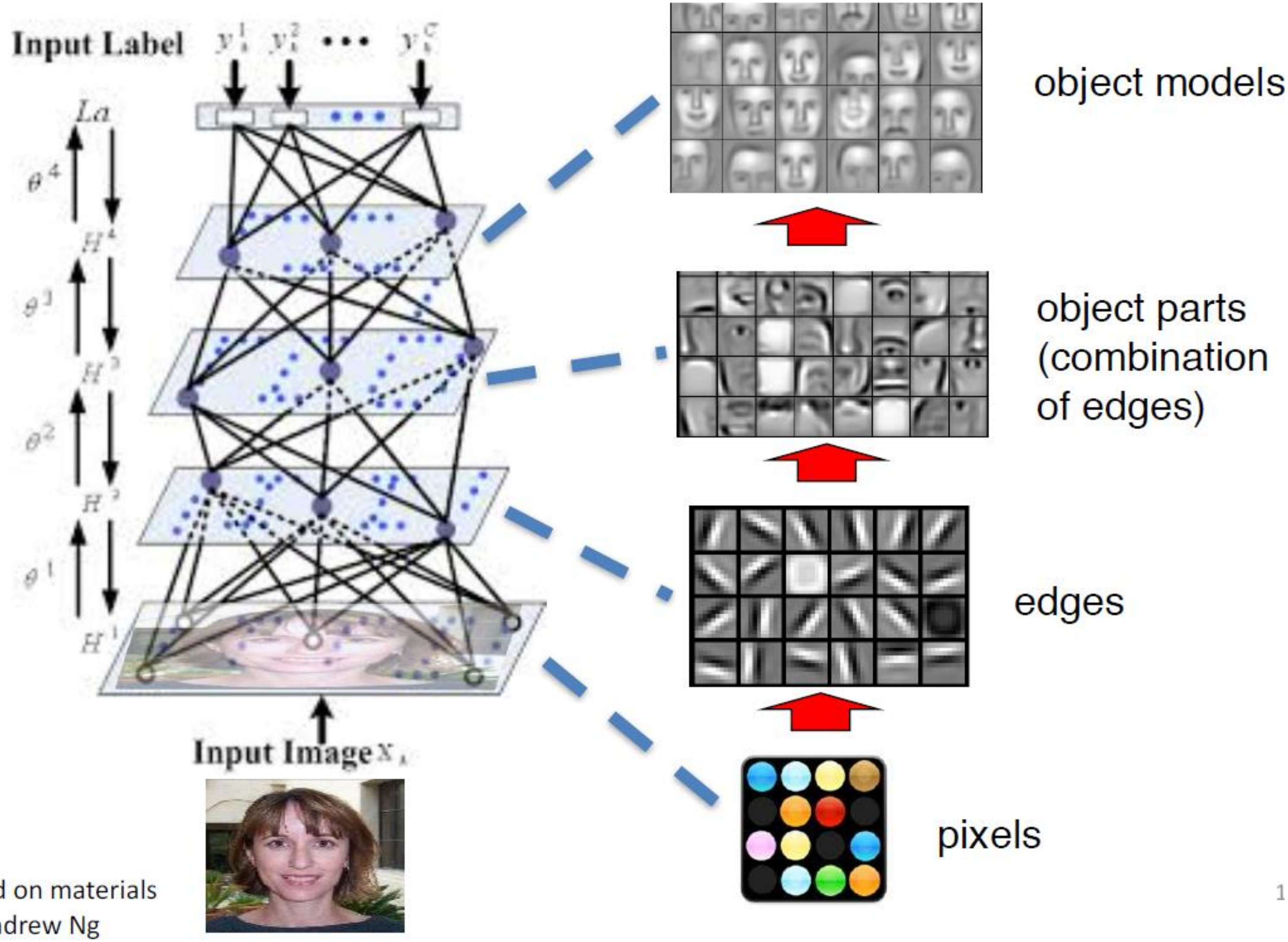
Deep Learning's Role in the Age of Robots

BY JULIAN GREEN, JETPAC 05.02.14 2:56 PM

Slide Credit by Eric Eaton

SOTA ML Applications

❖ Deep Belief Net on Face Images

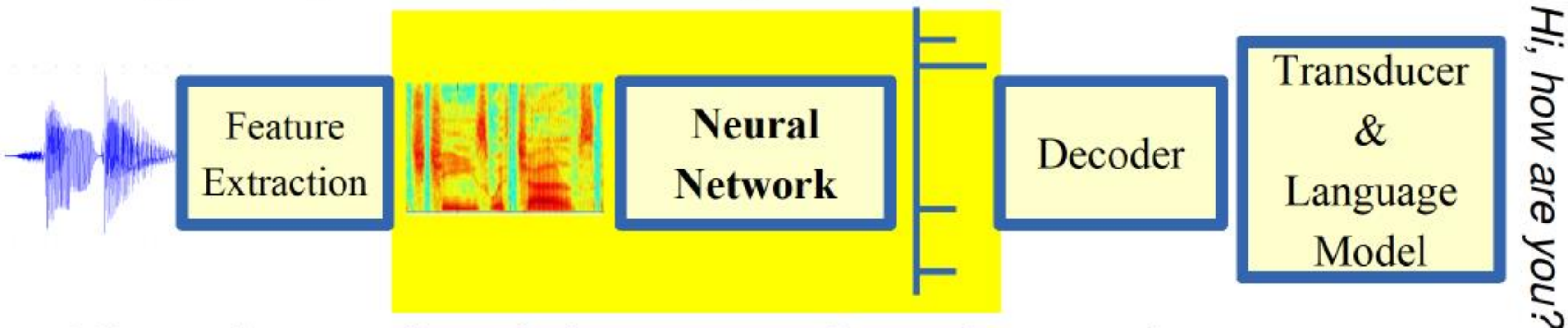


Based on materials
by Andrew Ng

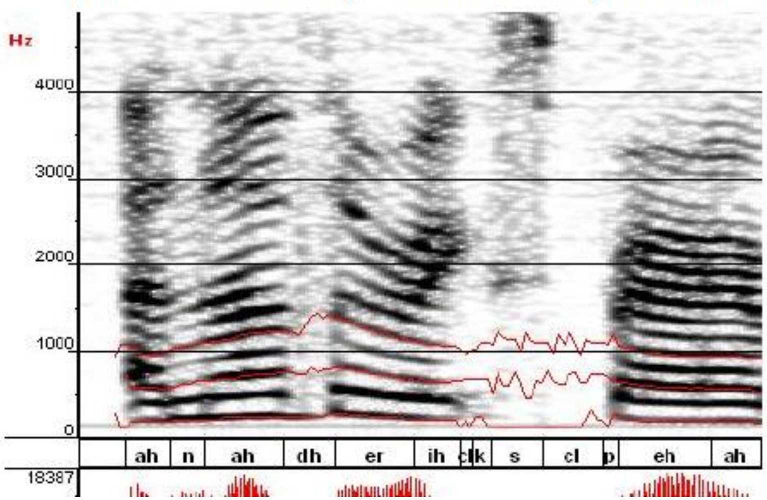
SOTA ML Applications

- Machine Learning in Automatic Speech Recognition

A Typical Speech Recognition System



ML used to predict of phone states from the sound spectrogram



Deep learning has state-of-the-art results

# Hidden Layers	1	2	4	8	10	12
Word Error Rate %	16.0	12.8	11.4	10.9	11.0	11.1

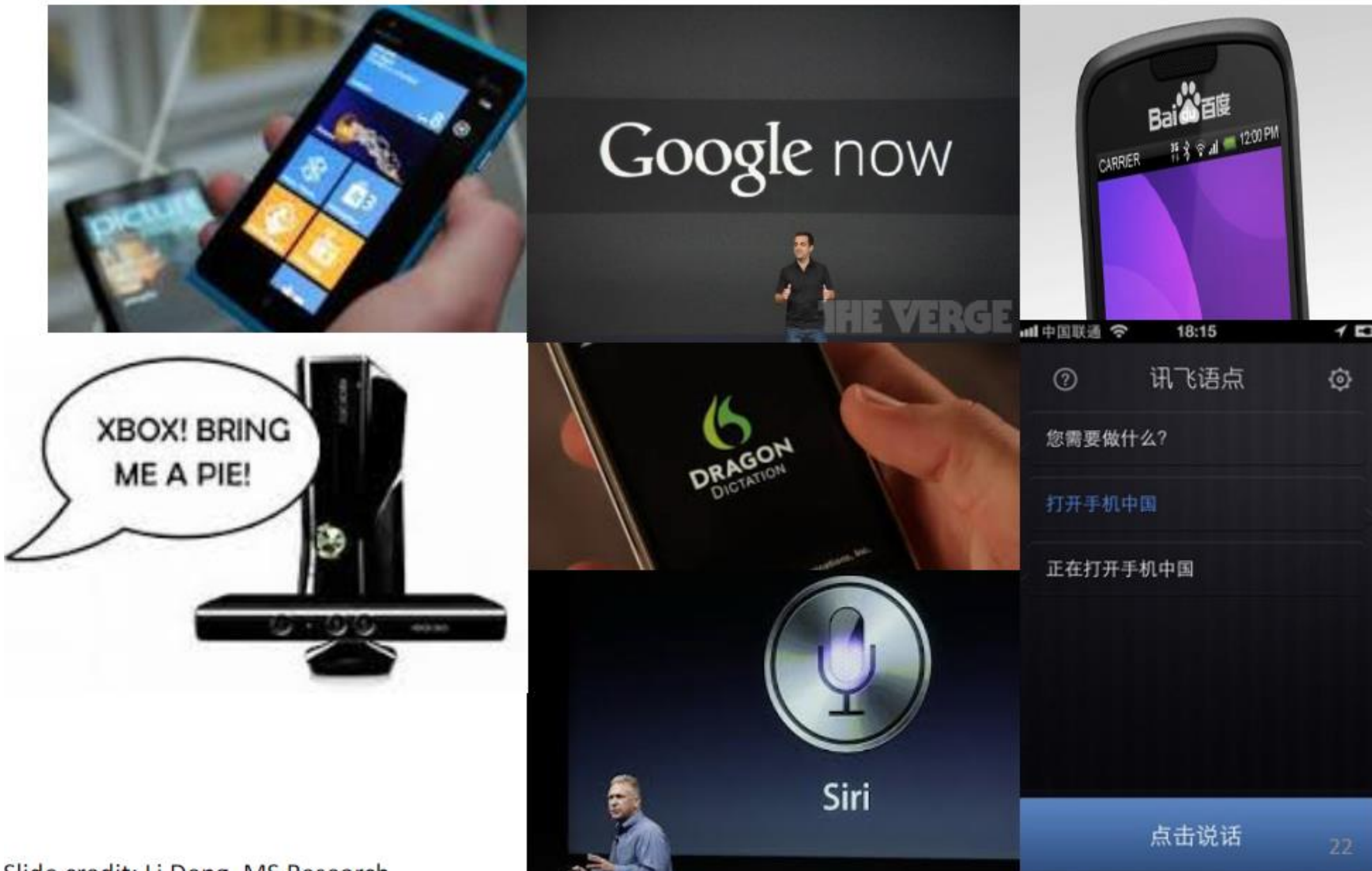
Baseline GMM performance = 15.4%

[Zeiler et al. "On rectified linear units for speech recognition" ICASSP 2013]

Slide Credit by Eric Eaton

SOTA ML Applications

❖ Impact of Deep Learning in Speech Technology



Slide credit: Li Deng, MS Research

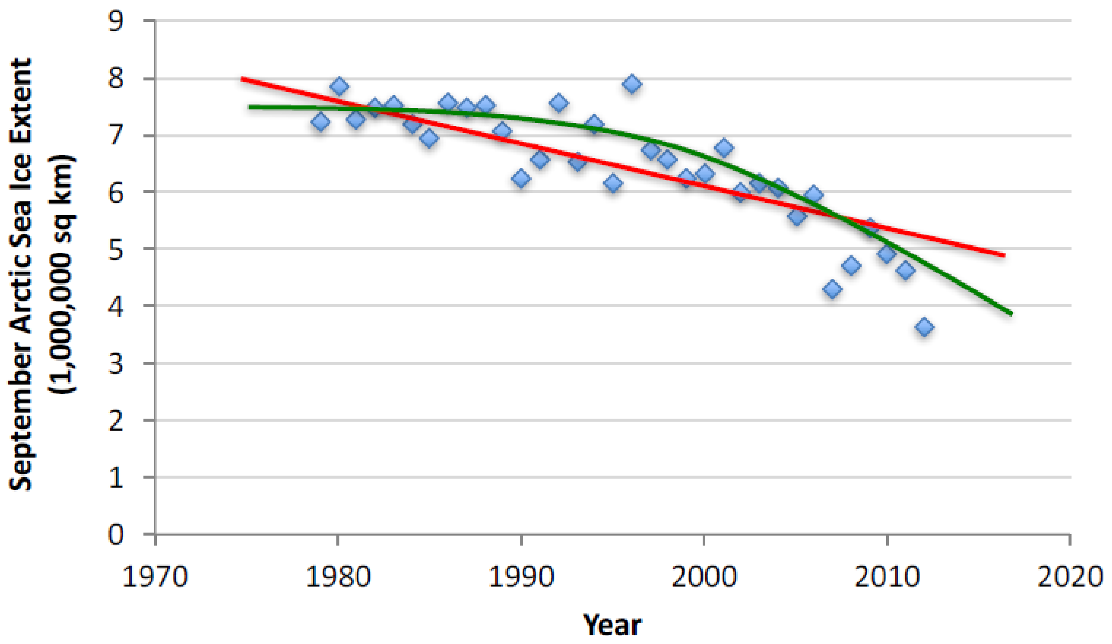
Learning Types

- **Supervised (inductive) learning**
  - Given: training data + desired outputs (labels)
- **Unsupervised learning**
  - Given: training data (without desired outputs)
- **Semi-supervised learning**
  - Given: training data + a few desired outputs
- **Reinforcement learning**
  - Rewards from sequence of actions

Slide Credit by Pedro Domingos

Learning Types

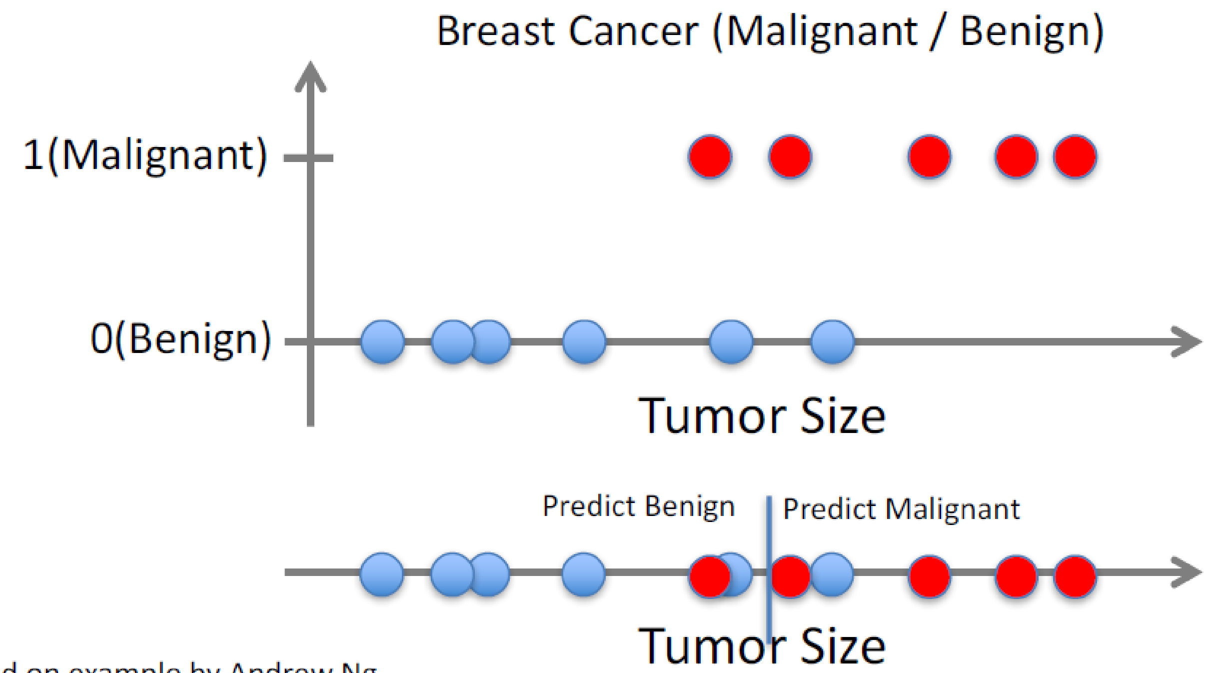
- Supervised Learning: Regression
  - Given $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$
  - Learn a function $f(x)$ to predict y given x
    - y is real-valued == regression



Data from G. Witt. Journal of Statistics Education, Volume 21, Number 1 (2013)

Learning Types

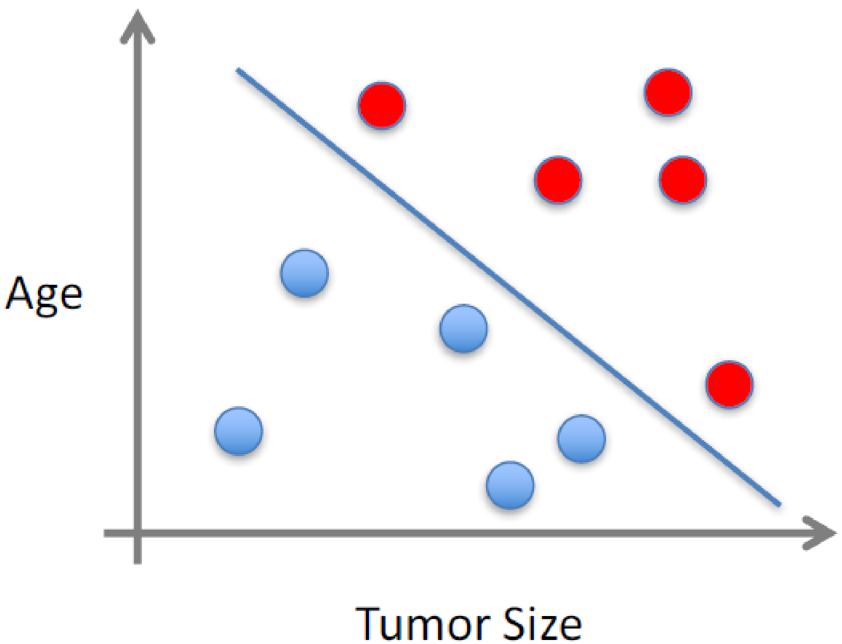
- Supervised Learning: Classification
  - Given $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$
  - Learn a function $f(x)$ to predict y given x
    - y is categorical == classification



Based on example by Andrew Ng

Learning Types

- Supervised Learning:
  - x can be multi-dimensional
    - Each dimension corresponds to an attribute



- Clump Thickness
- Uniformity of Cell Size
- Uniformity of Cell Shape

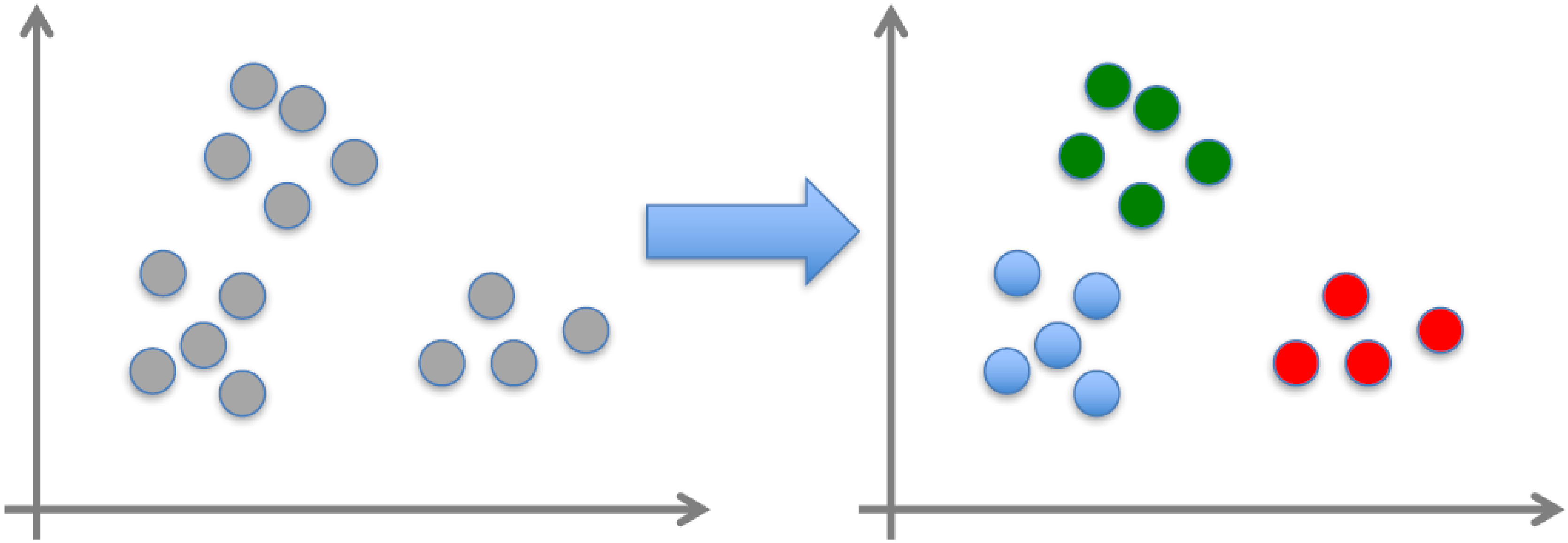
...

Based on example by Andrew Ng

Learning Types

❖ Unsupervised Learning

- Given x_1, x_2, …, x_n (without labels)
- Output hidden structure behind the x's
  - – E.g., clustering



Slide Credit by Eric Eaton

Learning Types

❖ Unsupervised Learning

- Independent component analysis – separate a combined signal into its original sources

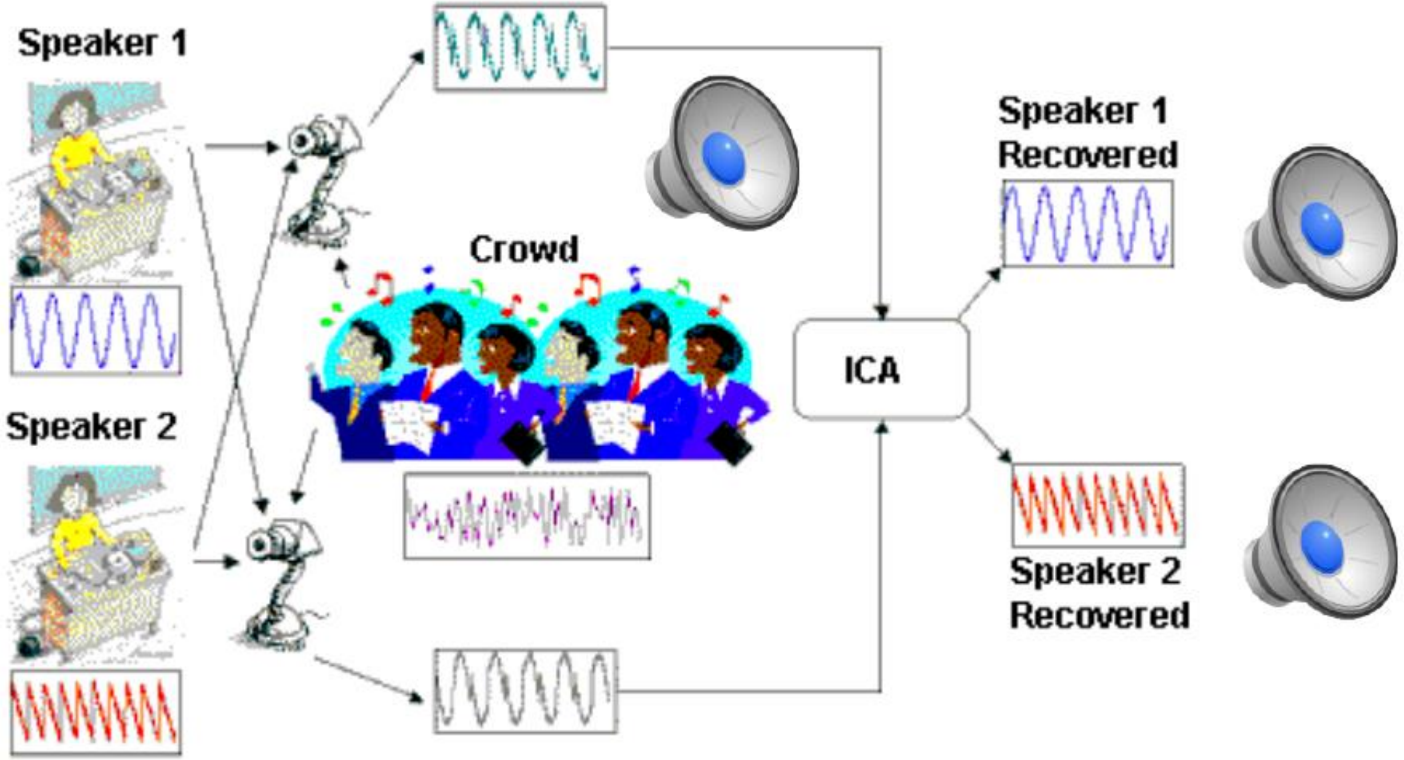


Image credit: statsoft.com Audio from http://www.ism.ac.jp/~shiro/research/blindsep.html

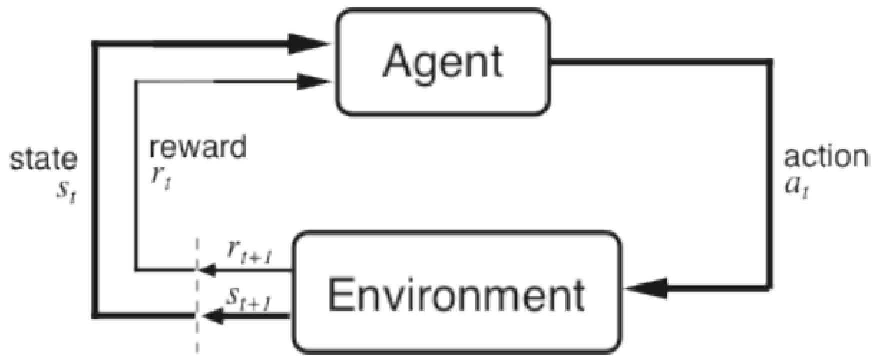
Learning Types

- Reinforcement Learning
  - Given a sequence of states and actions with (delayed) rewards, output a policy
    - Policy is a mapping from states → actions that tells you what to do in a given state
  - Examples:
    - Credit assignment problem
    - Game playing
    - Robot in a maze
    - Balance a pole on your hand

Slide Credit by Eric Eaton

Learning Types

- The Agent-Environment Interface



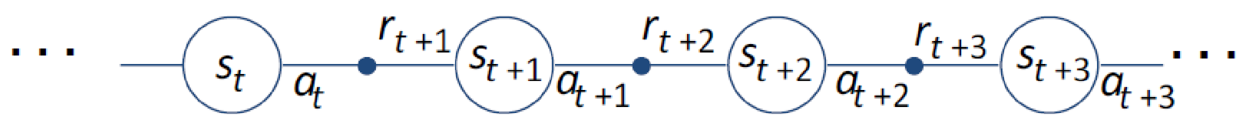
Agent and environment interact at discrete time steps : $t = 0, 1, 2, K$

Agent observes state at step t : $s_t \in S$

produces action at step t : $a_t \in A(s_t)$

gets resulting reward : $r_{t+1} \in \Re$

and resulting next state : s_{t+1}



Slide credit: Sutton & Barto

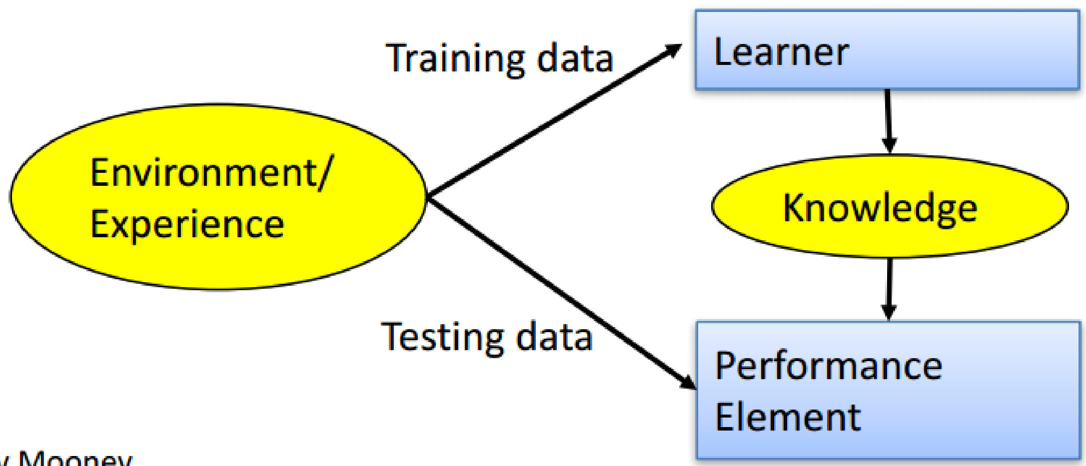
Learning Types

- Reinforcement Learning

https://www.youtube.com/watch?v=4cgWya-wjgY

Framing a Learning Problem

- Designing a Learning System
  - Choose the training experience
  - Choose exactly what is to be learned
    - i.e. the ***target function***
  - Choose how to represent the target function
  - Choose a learning algorithm to infer the target function from the experience



Based on slide by Ray Mooney

Framing a Learning Problem

- Training vs. Test Distribution
  - We generally assume that the training and test examples are independently drawn from the same overall distribution of data
    - We call this “i.i.d” which stands for “independent and identically distributed”
  - If test distribution is different, requires ***Transfer Learning***
- Tree Components in ML
  - **Representation**
  - **Optimization**
  - **Evaluation**

Framing a Learning Problem

❖ Various Function Representations

- Numerical functions
  - Linear regression
  - Neural networks
  - Support vector machines
- Symbolic functions
  - Decision trees
  - Rules in propositional logic
  - Rules in first-order predicate logic
- Instance-based functions
  - Nearest-neighbor
  - Case-based
- Probabilistic Graphical Models
  - Naïve Bayes
  - Bayesian networks
  - Hidden-Markov Models (HMMs)
  - Probabilistic Context Free Grammars (PCFGs)
  - Markov networks

Slide Credit by Ray Mooney

Framing a Learning Problem

❖ Various Search/Optimization Algorithms

- Gradient descent
  - Perceptron
  - Backpropagation
- Dynamic Programming
  - HMM Learning
  - PCFG Learning
- Divide and Conquer
  - Decision tree induction
  - Rule learning
- Evolutionary Computation
  - Genetic Algorithms (GAs)
  - Genetic Programming (GP)
  - Neuro-evolution

Slide Credit by Ray Mooney

Framing a Learning Problem

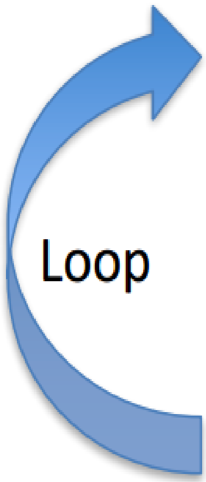
❖ Evaluation

- Accuracy
- Precision and recall
- Squared error
- Likelihood
- Posterior probability
- Cost / Utility
- Margin
- Entropy
- K-L divergence
- etc.

Slide Credit : Pedro Domingos

Framing a Learning Problem

❖ ML in Practice



- Understand domain, prior knowledge, and goals
- Data integration, selection, cleaning, pre-processing, etc.
- Learn models
- Interpret results
- Consolidate and deploy discovered knowledge

A Brief History of Machine Learning

- 1950s
  - Samuel's checker player
  - Selfridge's Pandemonium
- 1960s:
  - Neural networks: Perceptron
  - Pattern recognition
  - Learning in the limit theory
  - Minsky and Papert prove limitations of Perceptron
- 1970s:
  - Symbolic concept induction
  - Winston's arch learner
  - Expert systems and the knowledge acquisition bottleneck
  - Quinlan's ID3
  - Michalski's AQ and soybean diagnosis
  - Scientific discovery with BACON
  - Mathematical discovery with AM

Slide credit: Ray Mooney

A Brief History of Machine Learning

- 1980s:
  - Advanced decision tree and rule learning
  - Explanation-based Learning (EBL)
  - Learning and planning and problem solving
  - Utility problem
  - Analogy
  - Cognitive architectures
  - Resurgence of neural networks (connectionism, backpropagation)
  - Valiant's PAC Learning Theory
  - Focus on experimental methodology
- 1990s
  - Data mining
  - Adaptive software agents and web applications
  - Text learning
  - Reinforcement learning (RL)
  - Inductive Logic Programming (ILP)
  - Ensembles: Bagging, Boosting, and Stacking
  - Bayes Net learning

Slide credit: Ray Mooney

A Brief History of Machine Learning

- 2000s
  - Support vector machines & kernel methods
  - Graphical models
  - Statistical relational learning
  - Transfer learning
  - Sequence labeling
  - Collective classification and structured outputs
  - Computer Systems Applications (Compilers, Debugging, Graphics, Security)
  - E-mail management
  - Personalized assistants that learn
  - Learning in robotics and vision
- 2010s
  - Deep learning systems
  - Learning for big data
  - Bayesian methods
  - Multi-task & lifelong learning
  - Applications to vision, speech, social networks, learning to read, et
  - ???

Based on slide by Ray Mooney