CSCE 315: Introduction to Machine Learning

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- October 9, 2013

What Is Machine Learning?

- A subfield of AI that is rapidly growing in importance.
- Performance of a system increased based on learning experience.
- Learning from data.

Why Machine Learning?

- Abundance of data: the data deluge.
  - Scientific instruments.
  - Data acquisition devices.
  - Internet and the web.
  - All sectors of human society producing and digitizing data.
- Not enough human expertise or man power to make sense of such huge amounts of data.

Machine Learning in the News

IBM's Watson

- IBM's Watson beats human champions: Jeopardy (game show)
- Google detects cats from YouTube videos.
- Google Glass app recognizes people it sees.
- Legal, medical, financial applications.

What Does It Take to do ML?

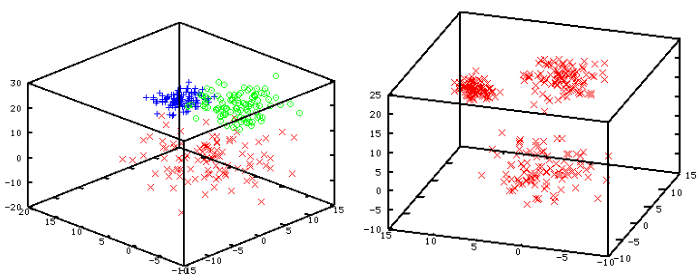
A lot of math:

- Linear algebra
- Calculus
- Probability and statistics
- Differential geometry
- Numerical methods

Types of Machine Learning

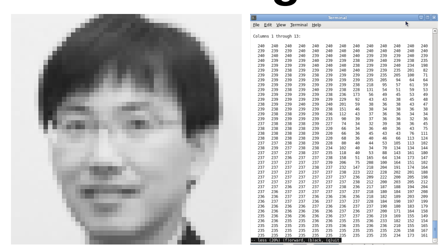
- Supervised learning
  - Input-Target pairs
  - $\{\langle \vec{x}_i, \vec{t}_i \rangle | i = 1, 2, .., n\}$
- Unsupervised learning
  - A bunch of inputs (unlabeled)
  - $\{\vec{x}_i | i = 1, 2, ..., n\}$
- Reinforcement learning
  - state$_1$ $\xrightarrow[\text{action}_1]{}$ state$_2$ $\xrightarrow[\text{action}_2]{}$ state$_3$, ... , reward
  - $s_{t+1} = \delta(s_t, a_t)$, $r_{t+1} = \rho(s_t, a_t)$

Example Data



- Left: supervised
- Right: unsupervised
- Typically very high dimensional (10,000, 1 million [or more]).

High-dimensional Data



$\longrightarrow \underbrace{[240, 240, ..., 232, ...]}_{\text{2,500-D vector}}$

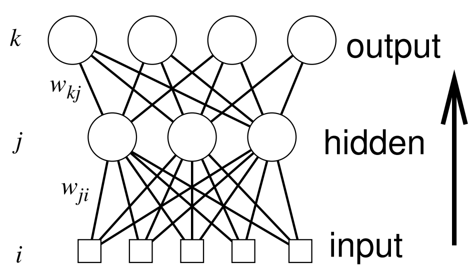
- Images: these are 2D images, but ...
- These are 50×50 = 2,500-dimensional vectors.
  - Each such image is a single point in 2,500-dimensional space.

Supervised Learning

Supervised Learning

- Regression: approximating $y = f(x)$
- Classification: face recognition, hand-written character recognition, credit risk assessment, etc.
- Techniques:
  - Neural networks
  - Decision tree learning
  - Support vector machines
  - Radial basis functions
  - Naive Bayes learning
  - k-nearest neighbor

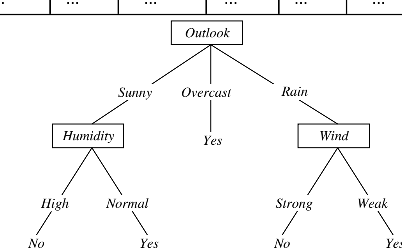
Neural Networks



- Input, hidden, and output units.
- Connection weights are adjusted based on $\langle \vec{x}_t, \vec{t}_t \rangle$ and error in the output.

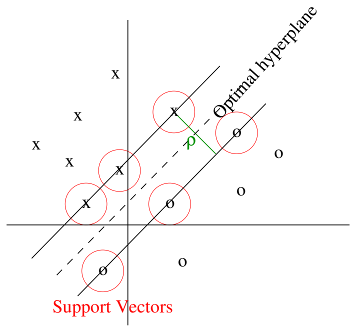
Decision Tree Learning

Ex Num	Outlook	Temp.	Humidity	Wind	Water	Forecast	Enjoy Sport?
1	Sunny	Warm	Normal	Strong	Warm	Same	Yes
2	Sunny	Warm	High	Strong	Warm	Same	Yes
3	Rainy	Cold	High	Strong	Warm	Change	No
...	...	...	...	...	...	...	...



- Building a tree from scratch, one attribute at a time.
- Maximized information gain (checking which attribute reduces uncertainty the most?).

Support Vector Machine

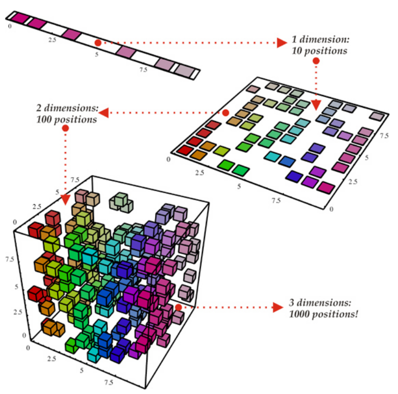


- Similar to a one-layer neural network.
- Learning rule is different.
- Nice optimality properties.

Supervised Learning Issues

- How well will it do on training inputs?
- How well will it do on novel inputs?
  - Generalization.
- How many samples needed for sufficient performance and generalization?
  - Sample complexity
  - Curse of dimensionality
  - Computational learning theory
- Catastrophic forgetting (online learning hard).

Addendum: Curse of Dimensionality



From: Yoshua Bengio's page

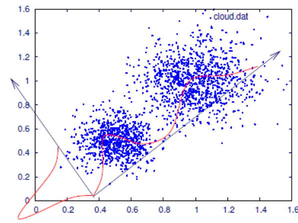
- Exponentially many points needed to achieve same density of training samples.

Unsupervised Learning

Unsupervised Learning

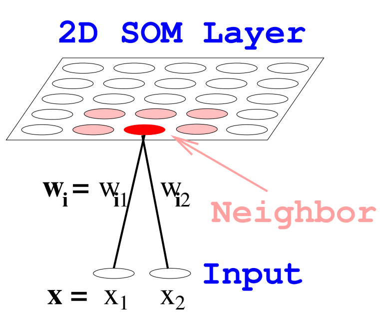
- Clustering, feature extraction, blind source separation, dimensionality reduction, etc.
- Techniques:
  - Principal Component Analysis (PCA)
  - Self-Organizing Maps (SOM)
  - Independent Component Analysis (ICA)
  - Multi-Dimensional Scaling (MDS)
  - ISOMAP, Locally Linear Embedding (LLE)

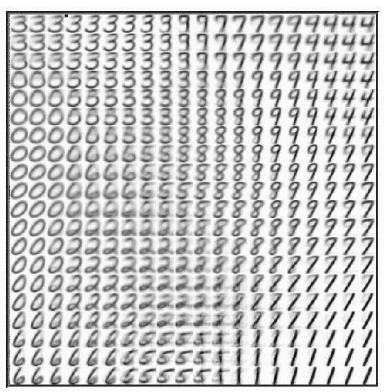
Principal Component Analysis



- Finding orthogonal axes that result in maximum variance when projected.
- Large portion of information resides in the first few principal components.
- Dimensionality reduction.

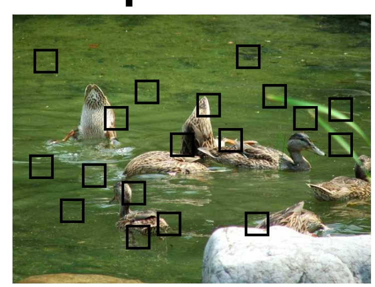
Self-Organizing Maps

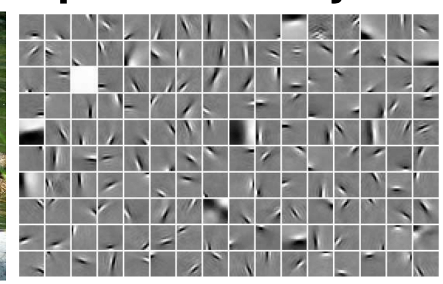




- Units occupy a regular grid (1D, 2D, 3D), with reference vector.
- Inputs matched to units with most similar reference vectors.
- Reference vectors adjusted based on match and neighbor on grid.
- Nearby units represent similar inputs.

Independent Component Analysis

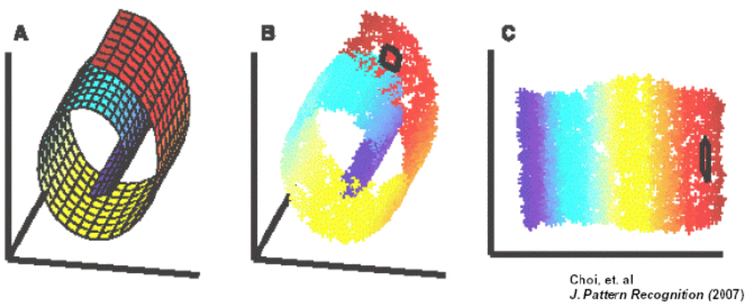




Hoyer and Hyvärinen (2000)

- Find additive sources (right) based on their mixtures (e.g., image patches to the left).
- Sources assumed to be statistically independent from each other and non-Gaussian.
- Feature extraction, blind source separation.

Manifold Learning: ISOMAP, etc.



- Low-dimensional manifold embedded in high-dimensional space.
- Recover the manifold. Geodesic distance a central concept.
- Dimensionality reduction, visualization, etc.

Unsupervised Learning Issues

- Discovering structure.
- Discovering features.
- Removing redundancy.
- How many clusters?
- What distance measures to use?

Reinforcement Learning

Reinforcement Learning

- Very different from supervised and unsupervised learning.
- Multi agent control, robot control, game playing, scheduling, etc.
- Techniques:
  - Value function-based: Q-learning, Temporal difference (TD) learning
  - Direct policy search: Neuroevolution, genetic algorithms.

Learning the Meaning of Neural Spikes

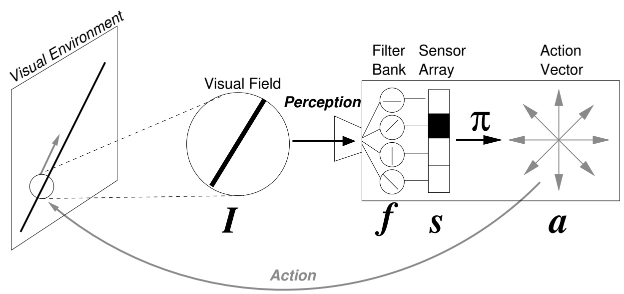
- What do these blinking lights mean? (Choe et al. 2007).

What If They Are Brain Responses to Something

They Are Visual Cortical Responses to Oriented Lines

This is a problem of *grounding*.

Use Reinforcement Learning



- Direct access to **encoded internal state** (sensory array) only.
- Action is enabled, which can **move the gaze**.
- How does this solve the grounding problem?

Action for Unchanging Internal State

- Diagonal motion causes the *internal state* to **remain unchanging** over time.
- Property of such a movement **exactly reflects** the property of the input I: Semantics figured out through action.

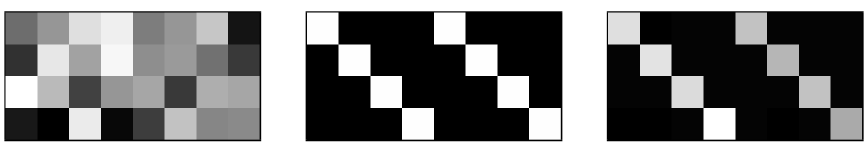
Reinforcement Learing

A: direction of motion

S: sensory state (orientation)	→	↗	↑	↖	←	↙	↓	↘
—	0.5	0	0	0	0.5	0	0	0
/	0	0.5	0	0	0	0.5	0	0
|	0	0	R(s ,a)	0	0	0	0.5	0
\	0	0	0	0.5	0	0	0	0.5

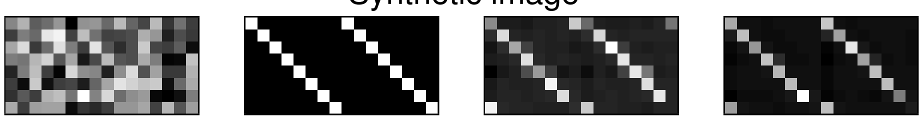
- Learn state-to-action mapping to maximize invariance in internal state.

Results: Learned $R(s, a)$



(a) Initial (b) Ideal (c) Final

Synthetic image

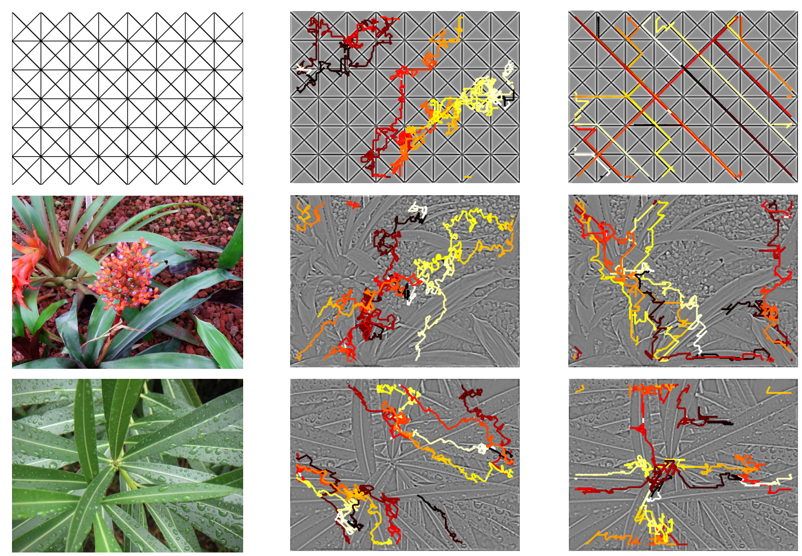


(a) Initial (b) Ideal (c) Plant (d) Oleander

Natural images

- Learned $R(s, a)$ close to ideal.

Results: Gaze Trajectory



(a) Input (b) Initial (c) Final

Brief Summary

- Decoding of encoded representation can be done **without** external reference.
- Action and changes in the internal representation induced by action is the key.
- Reinforcement learning plays a key role.

Reinforcement Learning Issues

- Discrete states and actions is a norm.
- Scalability an issue.
- Certain assumptions: state-action pair visited infinitely often.
- Online learning, safety, transfer, etc.

Wrap Up

Summary

- Machine learning is a rapidly developing field with great promise:
  - Big data
  - New theoretical insights (e.g., deep learning)
- Need to look beyond ML:
  - ML good at solving problems, but not posing problems (Choe and Mann 2012).