Machine Learning
CSCI 5622
Fall 2005

Greg Grudic

Admin Stuff 1

<table>
<thead>
<tr>
<th>Location:</th>
<th>Wednesdays 3:00pm-5:30pm ECCR 108</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor:</td>
<td>Professor Greg Grudic</td>
</tr>
<tr>
<td>Office:</td>
<td>ECOT 525</td>
</tr>
<tr>
<td>Office Hours:</td>
<td>Tuesday and Wednesday 10:00 to 11:00</td>
</tr>
<tr>
<td>Phone:</td>
<td>303-492-4419</td>
</tr>
<tr>
<td>Email:</td>
<td><a href="mailto:grudic@cs.colorado.edu">grudic@cs.colorado.edu</a></td>
</tr>
<tr>
<td>Course URL:</td>
<td><a href="http://www.cs.colorado.edu/~grudic/teaching/CSCI5622_2005">http://www.cs.colorado.edu/~grudic/teaching/CSCI5622_2005</a></td>
</tr>
</tbody>
</table>
Admin Stuff 2

• Course Textbook: There isn’t one….
  – However, if you plan to use ML after you finish the course, I recommend: *The Elements of Statistical Learning*, by Hastie, Tibshirani, Friedman

• Grading:
  – Homework 45%
  – Project 25%
  – Class participation 7%
  – Midterm exam 20%
  – Random Quizzes 3%

• Course workload outside of class?
  – 4 to 5 hours per week.

Admin Stuff 3

• **Homework**
  – N coding assignments (algorithm implementation). Essentially 3 big assignments but divide into sub-assignments.
  – **YOU MUST USE MATLAB!!**
  – Unless you have a very good excuse, each day your assignment is late will take 1% off what the assignment is worth.

• **Midterm** (Nov 9)
  – Test basic knowledge of ML. It will consist of general questions on the machine learning algorithms covered to date. You will *likely* not be required to derive algorithms or prove theorems.

• **Project** (Pick by Nov 2. Due Dec 7.)
  – Consists of building models from data I provide. Or a topic of your choice…

• **Class participation**
  – This consists of showing up for class and asking questions. Questions by email count as class participation!

• **Random Quizzes**
  – There will be about 5 of these. Based on material covered in class. If you pay attention, these will be trivial…
Goal of the Course

• A fundamental understanding of the basic concepts behind Machine Learning (ML)
  – What does it mean for a machine to learn?
• You will be able to read current research papers in ML after completing this course

Why is Machine Learning important?
  – ML algorithms are at the heart of many modern computer applications
    – ML is also at the heart of AI

Where can ML be found?

• Marketing
  – Who should a company target for advertising?
• Profiling
  – Is passenger 57 likely to hijack a plane?
• User interfaces
  – Making it easier to interact with a PC by anticipating what I am doing
• Document characterization
  – Searching the web (etc.) for things of interest
• Bioinformatics
  – Human genome project
    • Which gene is responsible for the cancer that runs in my family?
• Data mining
  – “Data doubles every year”, Dunham 2002
    – ML algorithms are used to make sense of this data
• Economics, medical diagnosis, robotics, computer vision, manufacturing, inventory control, elevator operation….
ML is part of Artificial Intelligence.
What is AI?

- “[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning” (Bellman, 1978)
- “The study of mental faculties through the use of computational models” (Charniak and McDermott, 1985)
- “The study of how to make computers do things at which, at the moment, people are better” (Rich and Knight, 1991)
- “The branch of computer science that is concerned with the automation of intelligent behavior” (Luger and Stubblefield, 1993)

My Personal View of AI

- I want to build a robot that will
  - Clean my house
  - Cook when I don’t want to
  - Wash my clothes
  - Cut my grass
  - Fix my car (or take it to be fixed)
  - i.e. do the things that I don’t feel like doing…
- Such activities are very different from games like chess!
  - They occur in a real and difficult to predict world
  - And they are much harder than chess
    - If they were easier than chess, I would have a robot butler by now…
- Therefore: AI is (to me) the science of building machines (agents) that act rationally in the real world with respect to a goal
What is a Rational Agent?

• An agent is an entity that perceives and acts
• A rational agent is one that does the right thing
  – The right thing: that which is expected to maximize goal achievement (*doing things I don’t feel like doing*), given the available information
• This is not a new idea:
  – Aristotle (Nicomachean Ethics): *Every art and every inquiry, and similarly every action and pursuit, is thought to aim at some good*

Elements of AI

- Representation
- Reasoning
- Learning

Greg Grudic  
Machine Learning
Why does learning encompass reasoning?

- How can I reason rationally about a world I know nothing about?
- How can I gain knowledge about a world without sampling it and learning from those samples?
- Fundamental lesson of AI (learned in the 1980’s):
  - It is not possible to hand code knowledge about anything but the most trivial problem domains!
  - Expert Systems: largely failed because an expert (e.g. doctor) doesn’t know how to formalize (code) what makes her an expert!
  - For example: I’m an expert on chairs but I can’t (and no one can!) write a program that identifies chairs in an image
  - **ML techniques can!**
What is Machine Learning?

• “The goal of machine learning is to build computer systems that can adapt and learn from their experience.”
  – Tom Dietterich

• What does this mean?
• When are ML algorithms NOT needed?

A Generic System

\[
\begin{align*}
\text{Input Variables: } \mathbf{x} &= (x_1, x_2, \ldots, x_N) \\
\text{Hidden Variables: } \mathbf{h} &= (h_1, h_2, \ldots, h_K) \\
\text{Output Variables: } \mathbf{y} &= (y_1, y_2, \ldots, y_M)
\end{align*}
\]
Another Definition of Machine Learning

- Machine Learning algorithms discover the relationships between the variables of a system (input, output and hidden) from direct samples of the system.

- These algorithms originate from many fields:
  - Statistics, mathematics, theoretical computer science, physics, neuroscience, etc.

When are ML algorithms NOT needed?

- When the relationships between all system variables (input, output, and hidden) is completely understood!

- This is NOT the case for almost any real system!
Main Subfields of Machine Learning

• Supervised learning
  – Classification
  – Regression
• Semi-Supervised (Transduction) learning
• Active learning
• Reinforcement Learning
• Unsupervised Learning

Supervised Learning

• Given: Training examples
  \[ \{(x_1,f(x_1)), (x_2,f(x_2)), ..., (x_P,f(x_P))\} \]
on of some unknown function (system) \( y = f(x) \)

• Find \( \hat{f}(x) \) (i.e. an approximation)
  – Predict \( y' = \hat{f}(x') \), where \( x' \) is not in the training set
Two Types of Supervised Learning

• **Classification**  \( y \in \{c_1, c_2, \ldots, c_N\} \)
  – Model output is a prediction that the input belongs to some class
  – If the input is an image, the output might be chair, face, dog, boat,… etc.

• **Regression**  \( y \in \mathbb{R} \)
  – The output has infinitely many values
  – If the input is stock features, the output could be a prediction of tomorrow’s stock price

Learning Classification Models

• Collect Training data
• Build Model: happy = F(feature space)
• Make a prediction
Learning Regression Models

- Collect Training data
- Build Model: stock value = F(feature space)
- Make a prediction

Examples of Supervised Learning

- Credit risk assessment
  \[ x \]: Properties of customer and proposed purchase
  \[ f(x) \]: Approve purchase (loan) or not

- Disease diagnosis
  \[ x \]: Properties of patient (symptoms, lab tests)
  \[ f(x) \]: Disease (or maybe, recommended therapy)
Examples of Supervised Learning (continued)

• Face recognition
  \( x \): Image of person's face
  \( f(x) \): Name of the person

• Automated Vehicle Driving
  \( x \): Image of the road
  \( f(x) \): Throttle, break, and steering commands

Appropriate Applications for Supervised Learning

• Situations where there is no human expert
  \( x \): Bond graph for a new molecule
  \( f(x) \): Predicted binding strength to AIDS protease molecule

• Situations where humans can perform the task but can't describe how they do it
  \( x \): Bitmap picture of hand-written character
  \( f(x) \): Ascii code of the character
Appropriate Applications for Supervised Learning (continued)

- Situations where the desired function is changing frequently
  \( x \): Description of stock prices
  \( f(x) \): Recommended stock transactions

- Situations where each user needs a customized function \( f \)
  \( x \): Incoming email message
  \( f(x) \): Importance score for presenting to user (or deleting without presenting)

Semi-Supervised Learning (Transduction)

- Given: Training examples
  \[ \{(x_1, f(x_1)), (x_2, f(x_2)), \ldots, (x_p, f(x_p))\} \]
  of some unknown function (system) \( y = f(x) \)

- And examples of inputs that require classification \( \{(x'_1), (x'_2), \ldots, (x'_k)\} \)

- Predict
  \[ \{(y'_1 = \hat{f}(x'_1)), (y'_2 = \hat{f}(x'_2)), \ldots, (y'_k = \hat{f}(x'_k))\} \]
Transduction 2
(from Learning with Local and Global Consistency
Dengyong Zhou, Olivier Bousquet, Thomas N. Lal, Jason Weston, Bernhard Schoelkopf, NIPS 2003)

Active Learning

- **Premise**: Data is expensive to collect (e.g. most experiments in biology)
- **Goal**: want to get the best possible model with the smallest dataset
- **Active learning** starts with a classifier and asks the following question
  - Where in the feature (input) space do I need to sample next to improve my classifier the most?
Reinforcement Learning (RL)

Autonomous agent learns to act “optimally” without human intervention

• Agent learns by stochastically interacting with its environment, getting infrequent rewards

• Goal: maximize infrequent reward

Reinforcement Learning

• Addresses the temporal credit assignment problem:
  – Delayed reward (HARD problem!)

• Successful RL applications:
  – TD gammon (Tesauro)
  – Packing containers (Moore)
  – Elevator dispatch (Crites and Barto)
RL in Robotics

- Hit an obstacle: get a **negative** reward
- Reach goal: get a **positive** reward
- Reach goal faster: get a **bigger positive** reward

A (simple?) Robotics Problem
Even Simple Robotic tasks are difficult to Program

Does ML work on Actual Robots?
Yes!

More Complex Example
Unsupervised Learning

- Studies how input patterns can be represented to reflect the statistical structure of the overall collection of input patterns
- No outputs are used (unlike supervised learning and reinforcement learning)
- Unsupervised learner brings to bear prior biases as to what aspects of the structure of the input should be captured in the output

Unsupervised Learning Example

- Collect Training data (e.g. consumer info)
- Build Model: things that a similar = M (feature space)
Conclusion

- How many people have I scared away?
  - Why?

- Class Schedule?

- Who’s in my class? Please email me the survey on the class web page by the end of the week (a text file please)