Admin

Assignment 3:
- how did it go?
- do the experiments help?

Assignment 4

Course feedback

Phishing
Setup
1. for 1 hour, google collects 1M e-mails randomly
2. they pay people to label them as “phishing” or “not-phishing”
3. they give the data to you to learn to classify e-mails as phishing or not
4. you, having taken ML, try out a few of your favorite classifiers
5. You achieve an accuracy of 99.997%

Should you be happy?

Imbalanced data
The phishing problem is what is called an imbalanced data problem
This occurs where there is a large discrepancy between the number of examples with each class label
E.g. for our 1M example dataset only about 30 would actually represent phishing e-mails
What is probably going on with our classifier?

Imbalanced data
Many classifiers are designed to optimize error/accuracy
This tends to bias performance towards the majority class
Anytime there is an imbalance in the data this can happen
It is particularly pronounced, though, when the imbalance is more pronounced
Imbalanced problem domains

Besides phishing (and spam) what are some other imbalanced problems domains?

Medical diagnosis

Predicting faults/failures (e.g. hard-drive failures, mechanical failures, etc.)

Predicting rare events (e.g. earthquakes)

Detecting fraud (credit card transactions, internet traffic)

Imbalanced data: current classifiers

All will do fine if the data can be easily separated/distinguished

Decision trees:
- explicitly minimizes training error
- when pruning pick “majority” label at leaves
- tend to do very poor at imbalanced problems

k-NN:
- even for small k, majority class will tend to overwhelm the vote

perceptron:
- can be reasonable since only updates when a mistake is made
- can take a long time to learn
Part of the problem: evaluation

Accuracy is not the right measure of classifier performance in these domains

Other ideas for evaluation measures?

“identification” tasks

View the task as trying to find/identify “positive” examples (i.e. the rare events)

Precision: proportion of test examples predicted as positive that are correct

Recall: proportion of test examples labeled as positive that are correct

precision = \frac{\# \text{ correctly predicted as positive}}{\# \text{ examples predicted as positive}}

recall = \frac{\# \text{ correctly predicted as positive}}{\# \text{ positive examples in test set}}

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
### Precision and Recall

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>(\frac{1}{2})</td>
<td>(\frac{2}{3})</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>(\frac{2}{4})</td>
<td>(\frac{2}{3})</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>(\frac{2}{4})</td>
<td>(\frac{2}{3})</td>
</tr>
</tbody>
</table>

**Data**
- # positive examples in test set
- # correctly predicted as positive
- # examples predicted as positive

**Label**
- # positive examples in test set
- # correctly predicted as positive

**Predicted**
- # positive examples in test set
- # correctly predicted as positive

**Why do we have both measures?**

**How can we maximize precision?**

**How can we maximize recall?**

---

### Maximizing Precision

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>(\frac{1}{2})</td>
<td>(\frac{2}{3})</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>(\frac{1}{2})</td>
<td>(\frac{2}{3})</td>
</tr>
</tbody>
</table>

**Don’t predict anything as positive!**

### Maximizing Recall

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>(\frac{1}{2})</td>
<td>(\frac{2}{3})</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>(\frac{1}{2})</td>
<td>(\frac{2}{3})</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>(\frac{1}{2})</td>
<td>(\frac{2}{3})</td>
</tr>
</tbody>
</table>

**Predict everything as positive!**
precision vs. recall

Often there is a tradeoff between precision and recall:

Increasing one tends to decrease the other.

For our algorithms, how might we increase/decrease precision/recall?

precision/recall tradeoff

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.90</td>
<td></td>
</tr>
</tbody>
</table>

- For many classifiers we can get some notion of the prediction confidence.
- Only predict positive if the confidence is above a given threshold.
- By varying this threshold, we can vary precision and recall.

precision/recall tradeoff

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.90</td>
<td></td>
</tr>
</tbody>
</table>

1/2 = 0.5
1/3 = 0.33
### precision/recall tradeoff

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>confidence</th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.20</td>
<td>3/5 = 0.6</td>
<td>3/3 = 1.0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### precision/recall tradeoff

<table>
<thead>
<tr>
<th>data</th>
<th>label</th>
<th>predicted</th>
<th>confidence</th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.90</td>
<td>3/7 = 0.43</td>
<td>3/3 = 1.0</td>
<td></td>
</tr>
</tbody>
</table>

### precision-recall curve

![Precision-Recall Curve](image-url)
Which is system is better?

Area under the curve

Area under the curve (AUC) is one metric that encapsulates both precision and recall.

Calculate the precision/recall values for all thresholding of the test set (like we did before).

Then calculate the area under the curve.

This can also be calculated as the average precision for all the recall points.

Any concerns/problems?

For real use, often only interested in performance in a particular range.

Eventually, need to deploy. How do we decide what threshold to use?
We’d like a compromise between precision and recall

A combined measure: $F$

Combined measure that assesses precision/recall tradeoff is $F$ measure (weighted harmonic mean):

$$F = \frac{1}{\alpha \frac{1}{P} + (1-\alpha) \frac{1}{R}} = \frac{(\beta^2 + 1)PR}{\beta^2 P + R}$$

F1-measure

Most common $\alpha = 0.5$: equal balance/weighting between precision and recall:

$$F = \frac{1}{\alpha \frac{1}{P} + (1-\alpha) \frac{1}{R}} = \frac{(\beta^2 + 1)PR}{\beta^2 P + R}$$

$$F1 = \frac{1}{0.5 \frac{1}{P} + 0.5 \frac{1}{R}} = \frac{2PR}{P + R}$$

Why harmonic mean?
Why not normal mean (i.e. average)?
**F₁ and other averages**

<table>
<thead>
<tr>
<th>Combined Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic</td>
</tr>
</tbody>
</table>

Harmonic mean encourages precision/recall values that are similar!

**Evaluation summarized**

Accuracy is often NOT an appropriate evaluation metric for imbalanced data problems.

Precision/recall capture different characteristics of our classifier.

AUC and F1 can be used as a single metric to compare algorithm variations (and to tune hyperparameters).

---

**Phishing – imbalanced data**

---

**Black box approach**

Abstraction: we have a generic binary classifier, how can we use it to solve our new problem?

Can we do some pre-processing/post-processing of our data to allow us to still use our binary classifiers?
Idea 1: subsampling

Create a new training data set by:
- including all \( k \) “positive” examples
- randomly picking \( k \) “negative” examples

Pros:
- Easy to implement
- Training becomes much more efficient (smaller training set)
- For some domains, can work very well

Cons:
- Throwing away a lot of data/information

Idea 2: oversampling

Create a new training data set by:
- including all \( m \) “negative” examples
- include \( m \) “positive examples:
  - repeat each example a fixed number of times, or
  - sample with replacement

Pros:
- Easy to implement
- Utilizes all of the training data
- Tends to perform well in a broader set of circumstances than subsampling

Cons:
- Computationally expensive to train classifier
Idea 2b: weighted examples

- Add costs/weights to the training set
  - “negative” examples get weight 1
  - “positive” examples get a much larger weight
- Change learning algorithm to optimize weighted training error

Pros:
- Achieves the effect of oversampling without the computational cost
- Utilizes all of the training data
- Tends to perform well in a broader set circumstances

Cons:
- Requires a classifier that can deal with weights

Cost/weights:

99.997/0.003 = 33332

weighted examples

Pros:
- Achieves the effect of oversampling without the computational cost
- Utilizes all of the training data
- Tends to perform well in a broader set circumstances

Cons:
- Requires a classifier that can deal with weights

Building decision trees

Otherwise:
- Calculate the “score” for each feature if we used it to split the data
- Pick the feature with the highest score, partition the data based on that data value and call recursively

We used the training error to decide on which feature to choose:
- use the weighted training error

In general, any time we do a count, use the weighted count (e.g. in calculating the majority label at a leaf)

Idea 3: optimize a different error metric

Train classifiers that try and optimize F1 measure or AUC or …

or, come up with another learning algorithm designed specifically for imbalanced problems

pros/cons?
Idea 3: optimize a different error metric

- Train classifiers that try and optimize F1 measure or AUC or …

  Challenge: not all classifiers are amenable to this

  or, come up with another learning algorithm designed specifically for imbalanced problems

  Don’t want to reinvent the wheel!

  That said, there are a number of approaches that have been developed to specifically handle imbalanced problems