Practical ML Advice

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Based on slides from Jude Shavlik and Tom Dietterich

Announcements

1. Assignment 4 is uploaded (elearning)
   - Nov 30th Due.
2. Finals on Dec 2nd.
3. Course - Evaluation.

Proper Experimental Methodology Can Have a Huge Impact:

Pure Sciences

A 2002 paper in *Nature* (a major journal) needed to be corrected due to “training on the testing set”

Original report : 95% accuracy (5% error rate)

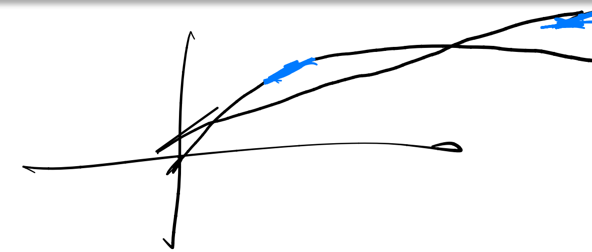
Corrected report (which still is buggy):

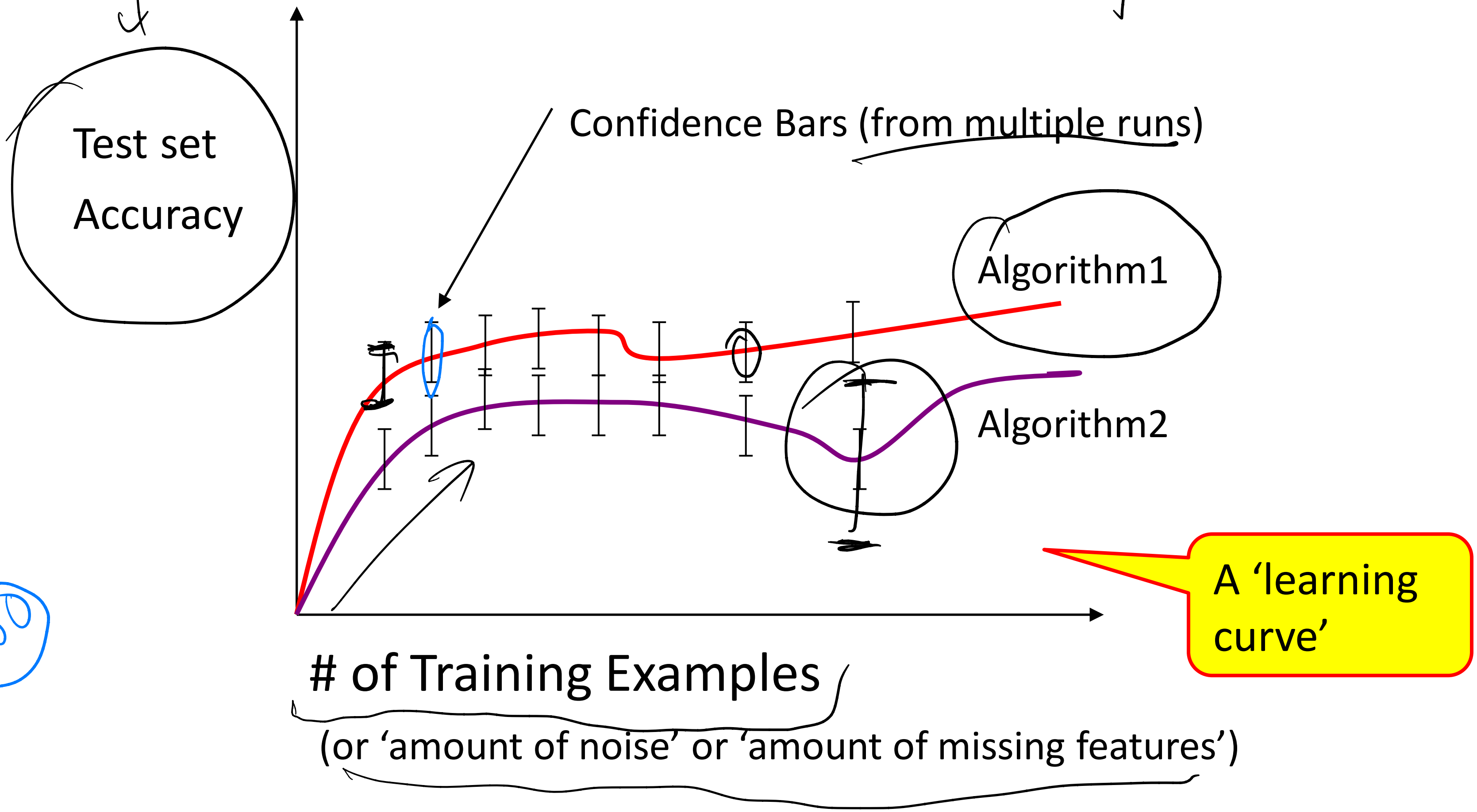
73% accuracy (27% error rate)

Error rate increased over 400%!!!

Some Typical ML Experiments

Not fraction Acc





1000

100

Typical Experiments

Ablation Study

	Test Set Performance
Full System (A, B, C, ..)	80%
Without Module A	75%
Without Module B	62%
Without Module C	79%

Experimental Methodology

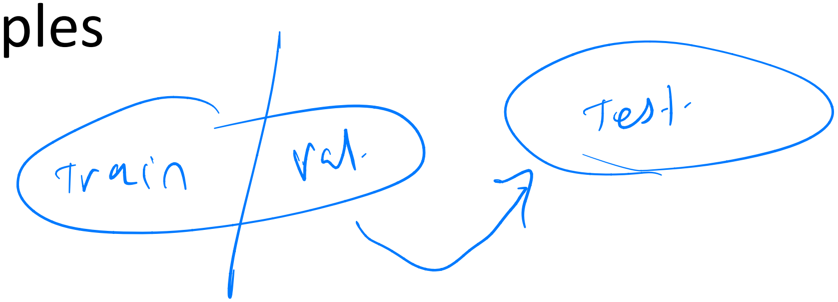
1) Start with a dataset of labeled examples
2) Randomly partition into *N* groups
3a) *N* times, combine *N* -1 groups into a train set
3b) Provide training set to learning system
3c) Measure accuracy on “left out” group (the test set)

Called *N*-fold cross validation

× 4 times.

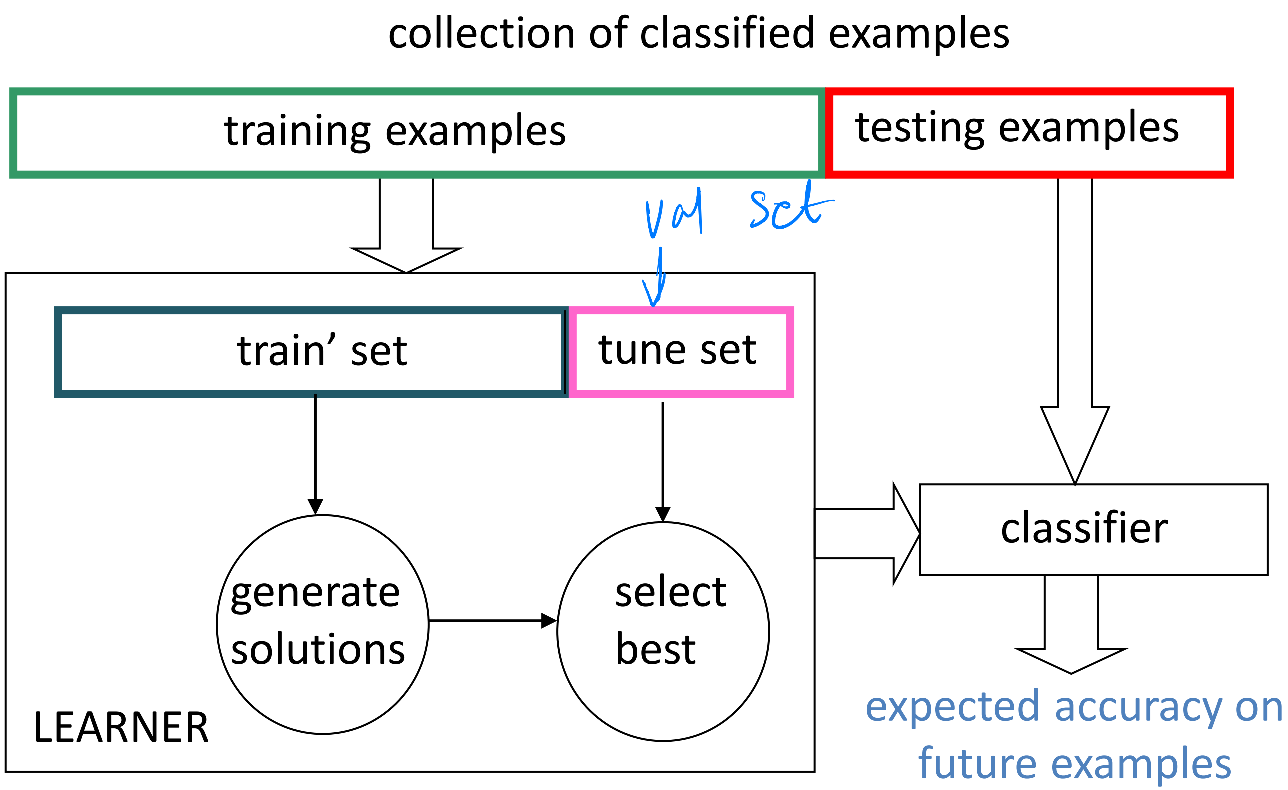
Validation Sets

- Often, an ML system has to choose when to stop learning, select among alternative answers, etc.
- One wants the model that produces the highest accuracy on **future** examples ("overfitting avoidance")
- It is a **"cheat"** to look at the **test** set while still learning
- Better method
  - Set aside part of the training set
  - Measure performance on this validation data to estimate future performance for a given set of hyperparameters
  - Use best hyperparameter settings, train with **all** training data (except **test** set) to estimate future performance on **new** examples



A typical Learning system

Statistical techniques such as 10-fold cross validation and *t*-tests are used to get meaningful results



Multiple Tuning sets

- Using a **single** tuning set can be unreliable predictor, plus some data “wasted”

1) For each possible set of hyperparameters

   a) Divide training data into **train** and **valid.** sets, using ***N*-fold cross validation**

   b) Score this set of hyperparameter values: average **valid.** set accuracy over the *N* folds

2) Use **best** set of hyperparameter settings and **all** (train + valid.) examples

3) Apply resulting model to **test** set

EVALUATING ML MODELS

Contingency Tables

(special case of 'confusion matrices')

$$Acc = \frac{n(1,1) + n(0,0)}{n}$$

		True Answer +	True Answer -
Algorithm Answer	+	n(1,1) [true pos]	n(1,0) [false pos]
	-	n(0,1) [false neg]	n(0,0) [true neg]

$n = n(1,1) + n(1,0) + n(0,1) + n(0,0)$.

Counts of occurrences

TPR and FPR

True

Pred	True +	True −
+	$n(1,1)$	$n(1,0)$
−	$n(0,1)$	$n(0,0)$

True Positive Rate (TPR) $= \; n(1,1)\, /\, (\, n(1,1) \; + \; n(0,1)\,)$

= correctly categorized +'s / total positives

~ P(algo outputs + | + is correct)

False Positive Rate (FPR) $= \; n(1,0)\, /\, (\, n(1,0) \; + \; n(0,0)\,)$

= incorrectly categorized –'s / total neg's

~ P(algo outputs + | - is correct)

Can similarly define False Negative Rate and True Negative Rate

$$\frac{n(0,1)}{n(1,1)+n(0,1)} \qquad\qquad \frac{n(0,0)}{n(1,0)+n(0,0)}$$

ROC Curves

10 % 90 %
positives negatives

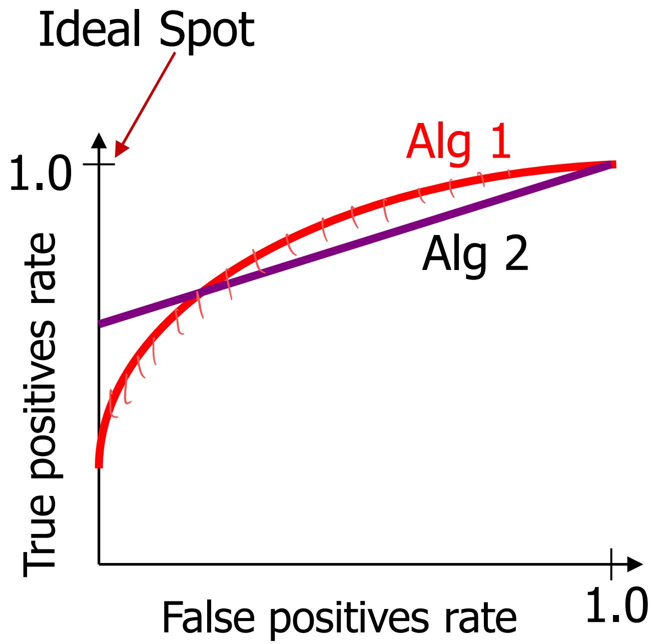
- ROC: *Receiver Operating Characteristics*
- Started for radar research during WWII
- Judging algorithms on accuracy alone may not be good enough when **getting a positive wrong** costs more than **getting a negative wrong** (or vice versa)
  - e.g., medical tests for serious diseases
  - e.g., a movie-recommender system

search / Ads

Algo 1: 100 % negatives (Acc: 90 %)

Algo 2: 5 % pos, 95 % Neg.

ROC Curves Graphically



Prob (alg outputs + | + is correct)

TP / # Pos

Prob (alg outputs + | - is correct)

FPs / # Neg

Different algorithms can work better in different parts of ROC space. This depends on cost of false + vs false -

Creating an ROC Curve

The Standard Approach:

- You need an ML algorithm that outputs NUMERIC results such as prob(example is +)   Alg Score $\in [0,1]$
- You can use ensemble methods to get this from a model that only provides Boolean outputs
  - e.g., have 100 models vote & count votes

Alg. for Creating ROC Curves

Step 1: Sort predictions on test set

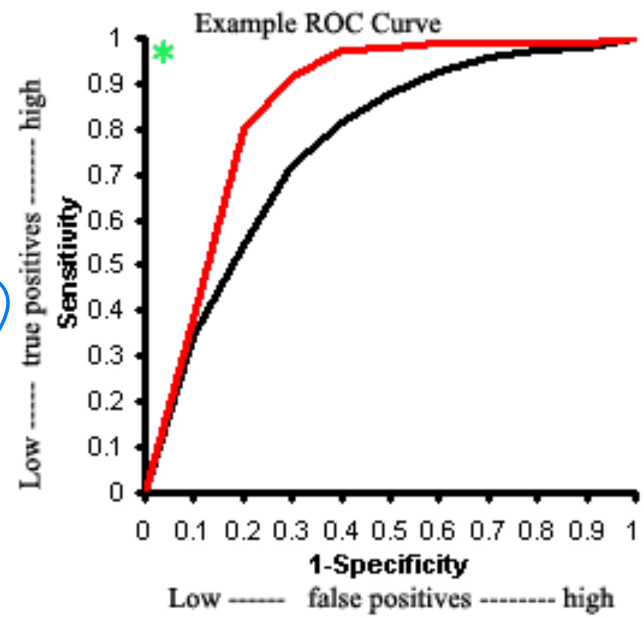
ex1
ex2
⋮
exN.

Step 2: Locate a *threshold* between examples with opposite categories

Step 3: Compute TPR & FPR for each threshold of Step 2

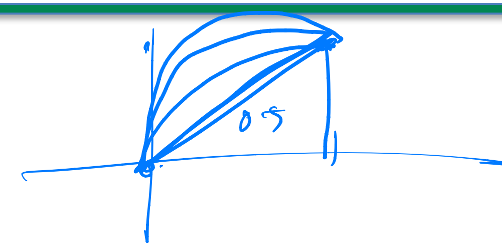
Step 4: Connect the dots

TPR.
(Recall)

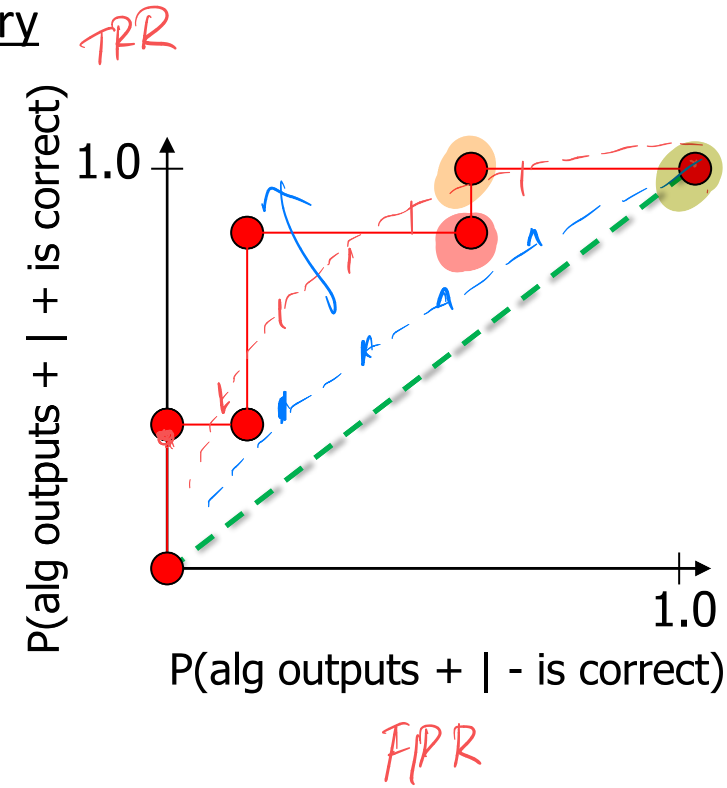


FPR.

Plotting ROC Curves - Example



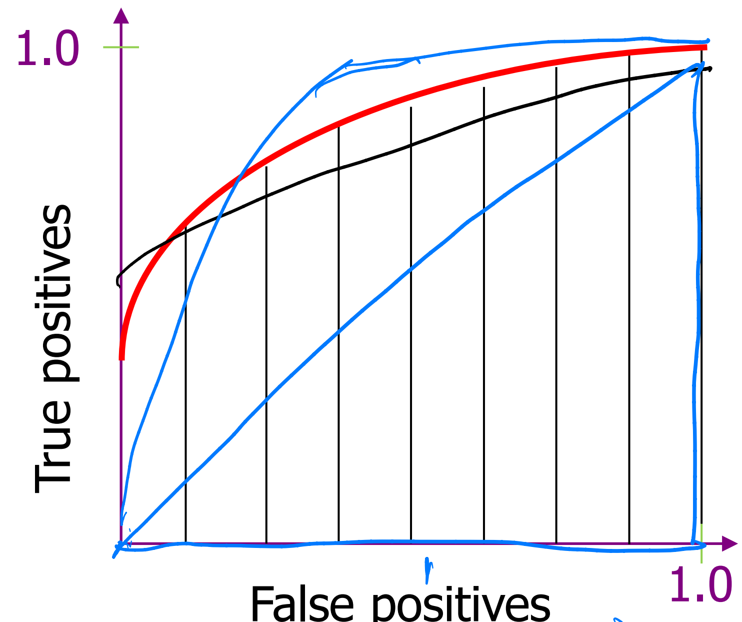
	ML Algo Output (Sorted)			Correct Category
+	Ex 9	.99		+
	Ex 7	.98	TPR=(2/5), FPR=(0/5)	+
	Ex 1	.72	TPR=(2/5), FPR=(1/5)	-
	Ex 2	.70		+
	Ex 6	.65	TPR=(4/5), FPR=(1/5)	+
	Ex 10	.51		-
0.25	Ex 3	.39	TPR=(4/5), FPR=(3/5)	-
	Ex 5	.24	TPR=(5/5), FPR=(3/5)	+
0.12	Ex 4	.11		-
0	Ex 8	.01	TPR=(5/5), FPR=(5/5)	-



Algorithm predicts + if its output is ≥ ~~0~~ thresh.

Area Under ROC Curve

- A common metric for experiments is to numerically integrate the ROC Curve
  - Usually called AUC
  - Probability that ML alg. will "rank" a randomly chosen positive instance higher than a randomly chosen negative one
  - Can summarize the curve **too much** in practice



$$AUC = \text{Prob}\left(\text{Score}_A(\text{Rand} +) \geq \text{Score}_A(\text{Rand} -)\right)$$

Asymmetric Error Costs

- Assume that cost(FP) ≠ cost(FN)
- You would like to pick a threshold that minimizes

$$E(total\ cost) = \boxed{cost(FP)} \times \mathrm{pr}(FP) \times (\#\ of\ neg\ ex's) + cost(FN) \times \mathrm{pr}(FN) \times (\#\ of\ pos\ ex's)$$

- You could also have (maybe negative) costs for TP and TN (assumed zero in above)

ROC's & Skewed Data

- One strength of ROC curves is that they are a good way to deal with skewed data (|+| >> |-|) since the axes are fractions (rates) independent of the # of examples

- You must be careful though!
  - Low FPR * (many negative ex) = sizable number of FP
  - Possibly more than # of TP

$TPR = \frac{TP}{\#Pos.}$

$FPR = \frac{FP}{\#Neg.}$

Precision vs. Recall (PR Curve)

- Think about search engines...

- **Precision** = (# of relevant items retrieved)
  / (total # of items retrieved)
  = n(1,1) / (n(1,1) + n(1,0))
  ≅ P(is pos | called pos)

$$\frac{TP}{TP + FP} = \text{Precision}$$

- **Recall** = (# of relevant items retrieved)
  / (# of relevant items that exist)
  = n(1,1) / (n(1,1) + n(0,1)) = TPR
  ≅ P(called pos | is pos)

$$\frac{TP}{TP + FN} = \text{Recall} = TPR$$

- Notice that n(0,0) is not used in either formula
  Therefore you get <u>no</u> credit for filtering out <u>i</u>rrelevant items

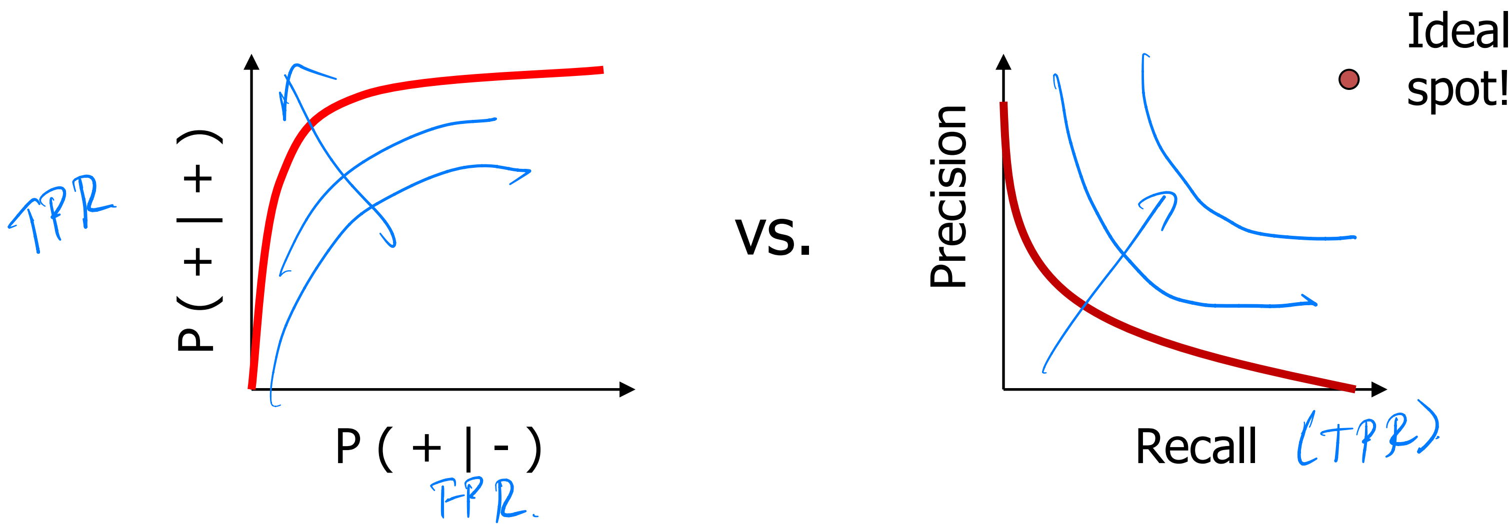
TN

$$FPR = \frac{FP}{FP + TN}.$$

(TN).

ROC vs. Precision-Recall

You can get very different visual results on the same data!



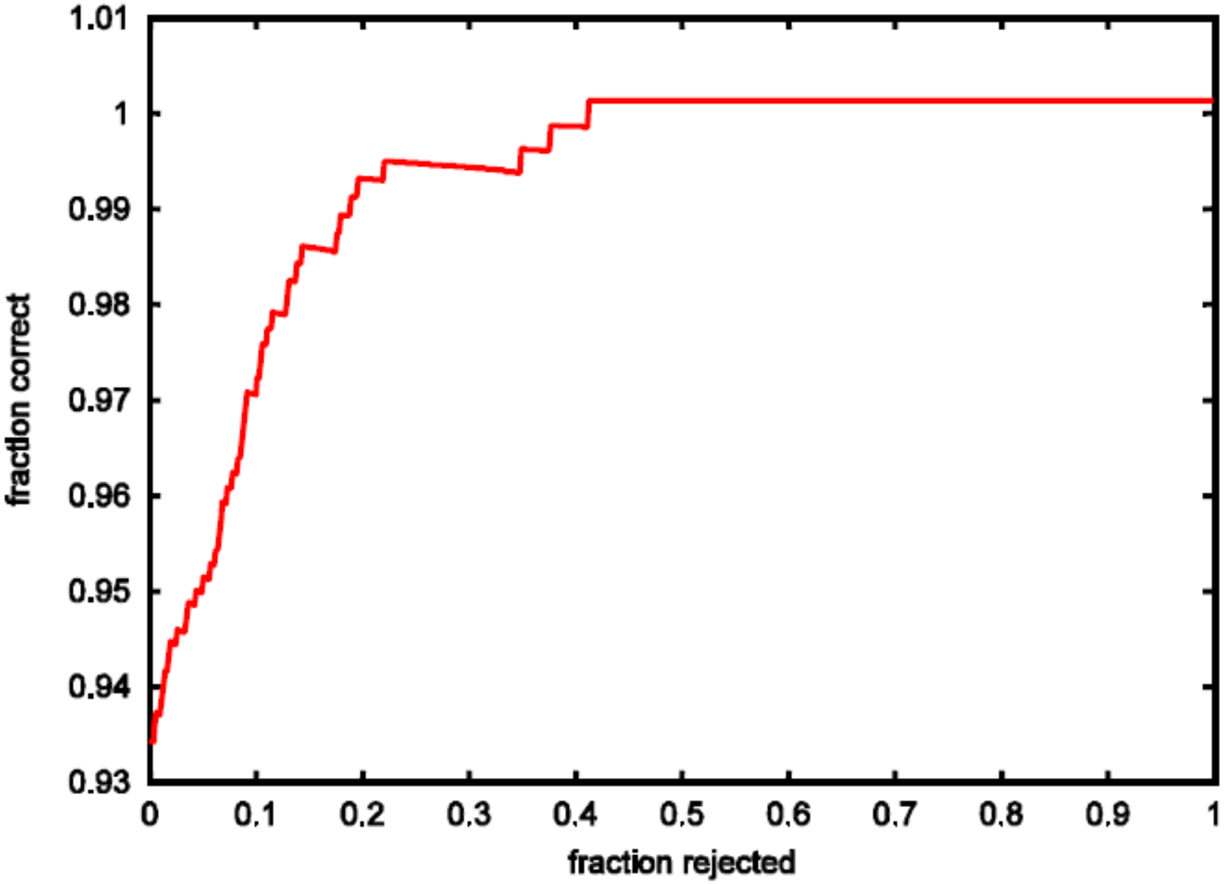
The reason for this is that there may be lots of – ex's
(e.g., might need to include 100 neg's to get 1 more pos)

Rejection Curves

- In most learning algorithms, we can specify a threshold for making a rejection decision
  - Probabilistic classifiers: adjust cost of rejecting versus cost of FP and FN
  - Decision-boundary method: if a test point $\boldsymbol{x}$ is within θ of the decision boundary, then reject
    - Equivalent to requiring that the "activation" of the best class is larger than the second-best class by at least θ

Rejection Curves

- Vary θ and plot fraction correct versus fraction rejected



The F1 Measure

- Figure of merit that combines precision and recall

(Assumes you have threshold)

$$F_1 = 2 \cdot \frac{P \cdot R}{P + R}$$

$$F_1 = \frac{2}{\frac{1}{P} + \frac{1}{R}}$$

where P = precision; R = recall. This is twice the harmonic mean of P and R.

- We can plot $F1$ as a function of the classification threshold θ

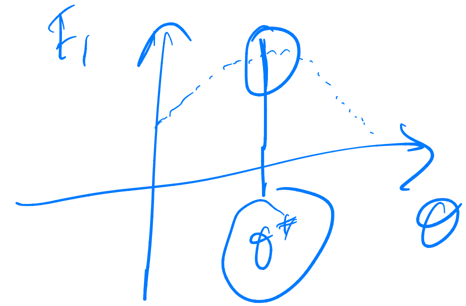
The F1 Measure

- Figure of merit that combines precision and recall

$\theta \approx 0$
$R = \text{High}$
$Pr = \text{Low}$

$\theta \to 1$
$R \simeq \text{Low}$
$Pr = \text{High}$

$$F_1 = 2 \cdot \frac{P \cdot R}{P + R}$$



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- We can plot $F1$ as a function of the classification threshold θ

Multi-Class

$F_1(y)$, $\forall y$.

Avg-F = Avg($F_1(y)$, $\forall y$)

1, 2, 3

$F_1(1)$: F_1(1 v/s 2-3)

$F_1(2)$: F_1(2 v/s 1-3)

$F_1(3)$ = F_1(3 v/s 1-2)

The F1 Measure

- Figure of merit that combines precision and recall

$$F_1 = 2 \cdot \frac{P \cdot R}{P + R}$$

where P = precision; R = recall. This is twice the harmonic mean of P and R.

- We can plot $F1$ as a function of the classification threshold θ