Resource report

March 30, 2016

1 'Stan' for statistical inference

Stan is a "probabilistic programming language" used to perform full Bayesian statistical inference. In many settings, especially natural language processing contexts, this type of full Bayesian inference is hard to implement and computationally intensive.

Stan offers a solution that is relatively easy to use and that runs efficiently. Stan is written in C++ for performance but can be accessed through various interfaces (Python, R, Matlab, etc). Today, I will go through a classification example using the Python interface, PyStan.

1.0.1 Document classification example

This example is adapted from Section 14.3 of the Stan reference manual available here and the Stan examples github available here.

We want to classify the topic of a document given its words. We also have a collection of topic-labeled documents and their words to train on. Let's use a Naive Bayes classifier. Then given a new document, we need to calculate the posterior probabilities:

$$p(topic|words) = \frac{p(topic) \times p(words|topic)}{p(words)}$$

and then pick the topic which maximizes this posterior. To do these calculations, we need to first infer $p(topic)$ and $p(words|topic)$.

Let's flesh this model out further. Assume the generative process is as follows. Fix the number of topics to be K. Our training data consists of M documents made up of a bag of words drawn from a vocabulary of V distinct words. A document m has N_m words indexed as $w_{m,1}, ..., w_{m,N_m}$. To keep this model simple, we will assume word order is not relevant.

For each document $m \in 1 : M$, a topic, $z_m \in 1 : K$ is chosen according to the categorical distribution $\boldsymbol{\theta}$. Where $\boldsymbol{\theta}$ is a K-dimension probability vector giving $p(\theta_k)$ for each topic $k \in K$. After the topic z_m is chosen, the words of the document are generated independently conditional on that topic. Specifically, word n of document m is chosen according to the categorical distribution $\boldsymbol{\phi_{z[m]}}$. Here, $\phi_{z[m]}$ gives the probability of each word of the vocabulary in documents belonging to topic z_m.

Then in the general language given above, $p(topic)$ is given by $\boldsymbol{\theta}$ and $p(words|topic)$ is given by $\boldsymbol{\phi_{z[m]}}$. Now, let's infer these values. Note that Stan will use a 'fully' Bayesian approach, that is, not an emprical one.

```
In [1]: # imports
        import pystan
        import scipy
        import numpy as np

In [2]: # model specification

        topic_model = """
        data {
```

```
// training data
int<lower=1> K; // num topics
int<lower=1> V; // num words
int<lower=0> M; // num docs
int<lower=0> N; // total word instances
int<lower=1,upper=K> z[M]; // topic for doc m
int<lower=1,upper=V> w[N]; // word n
int<lower=1,upper=M> doc[N]; // doc ID for word n
// hyperparameters
vector<lower=0>[K] alpha; // topic prior
vector<lower=0>[V] beta; // word prior
}

parameters {
simplex[K] theta; // topic prevalence
simplex[V] phi[K]; // word dist for topic k
}

model {
theta ~ dirichlet(alpha);
for (k in 1:K)
phi[k] ~ dirichlet(beta);
for (m in 1:M)
z[m] ~ categorical(theta);
for (n in 1:N)
w[n] ~ categorical(phi[z[doc[n]]]);
}
"""
```

In [3]:
```
# simulated data

# K is number of topics
# V is the vocabulary
# M is number of documents
# N is total word instances
# z[M] gives topic for doc m
# w{N} gives word n
# doc[N] gives doc ID for word n

sim_data = {
    "K":4, "V":10, "M": 200, "N": 1955,
    "z": [1L, 1L, 2L, 1L, 1L, 3L, 2L, 3L, 1L, 1L, 1L, 1L, 2L, 1L, 1L,
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            "alpha": [1, 1, 1, 1], "beta": [0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1]
            }
```

In [6]:
```
# fit model
fit = pystan.stan(model_code=topic_model, data=sim_data, iter=1000, chains=4)
```

In [5]:
```
print fit
```

```
Inference for Stan model: anon_model_20e980a24ef3b0be928a8c38650f65e3.
4 chains, each with iter=1000; warmup=500; thin=1;
post-warmup draws per chain=500, total post-warmup draws=2000.

           mean se_mean     sd   2.5%    25%    50%    75%  97.5%  n_eff   Rhat
theta[0]   0.51  1.3e-3   0.03   0.45   0.49   0.51   0.54   0.58  668.0    1.0
theta[1]   0.23  1.2e-3   0.03   0.17   0.21   0.23   0.25   0.29  668.0    1.0
theta[2]   0.17  9.9e-4   0.03   0.12   0.15   0.17   0.18   0.22  668.0    1.0
theta[3]   0.09  7.5e-4   0.02   0.05   0.08   0.09    0.1   0.13  668.0    1.0
phi[0,0]   0.19  4.7e-4   0.01   0.17   0.18   0.19    0.2   0.22  668.0    1.0
phi[1,0]   0.02  2.7e-4 6.9e-3   0.01   0.02   0.02   0.03   0.04  668.0    1.0
phi[2,0]   0.05  4.7e-4   0.01   0.02   0.04   0.04   0.05   0.07  668.0    1.0
phi[3,0]    0.2  1.2e-3   0.03   0.14   0.18    0.2   0.23   0.27  668.0    1.0
phi[0,1]   0.02  1.7e-4 4.5e-3   0.01   0.02   0.02   0.02   0.03  668.0    1.0
phi[1,1]   0.18  7.1e-4   0.02   0.14   0.17   0.18   0.19   0.22  668.0    1.0
phi[2,1]   0.02  3.3e-4 8.4e-3 9.0e-3   0.02   0.02   0.03   0.04  668.0    1.0
phi[3,1]   0.47  1.5e-3   0.04   0.39   0.44   0.47    0.5   0.55  668.0    1.0
phi[0,2]   0.04  2.4e-4 6.2e-3   0.03   0.04   0.04   0.05   0.06  668.0    1.0
phi[1,2]   0.45  9.0e-4   0.02   0.41   0.44   0.45   0.47    0.5  668.0    1.0
phi[2,2]   0.14  7.5e-4   0.02   0.11   0.13   0.14   0.16   0.18  668.0    1.0
phi[3,2]   0.03  4.8e-4   0.01 6.9e-3   0.02   0.02   0.03   0.05  668.0    1.0
phi[0,3]   0.05  2.7e-4 6.9e-3   0.04   0.05   0.05   0.06   0.07  668.0    1.0
phi[1,3]   0.12  5.9e-4   0.02   0.09   0.11   0.12   0.13   0.15  668.0    1.0
phi[2,3]   0.03  3.5e-4 9.0e-3   0.01   0.02   0.02   0.03   0.05  668.0    1.0
phi[3,3]   0.04  6.3e-4   0.02   0.02   0.03   0.04   0.05   0.08  668.0    1.0
phi[0,4]   0.01  1.5e-4 3.8e-3 8.1e-3   0.01   0.01   0.02   0.02  668.0    1.0
phi[1,4]   0.01  2.2e-4 5.8e-3 4.9e-3 9.4e-3   0.01   0.02   0.03  668.0    1.0
phi[2,4]   0.46  1.1e-3   0.03    0.4   0.44   0.46   0.48   0.52  668.0    1.0
phi[3,4]   0.05  6.7e-4   0.02   0.02   0.04   0.05   0.06   0.09  668.0    1.0
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phi[0,5]   0.06  3.0e-4 7.8e-3   0.05   0.06   0.06   0.07   0.08  668.0    1.0
phi[1,5]   0.02  2.7e-4 7.0e-3   0.01   0.02   0.02   0.03   0.04  668.0    1.0
phi[2,5]   0.16  8.0e-4   0.02   0.12   0.14   0.16   0.17    0.2  668.0    1.0
phi[3,5]   0.03  5.1e-4   0.01   0.01   0.02   0.03   0.04   0.06  668.0    1.0
phi[0,6]   0.45  6.2e-4   0.02   0.41   0.43   0.44   0.46   0.48  668.0    1.0
phi[1,6]   0.05  4.1e-4   0.01   0.03   0.04   0.05   0.06   0.07  668.0    1.0
phi[2,6]   0.03  3.4e-4 8.9e-3   0.01   0.02   0.02   0.03   0.05  668.0    1.0
phi[3,6]   0.05  6.8e-4   0.02   0.02   0.04   0.05   0.06   0.09  668.0    1.0
phi[0,7]   0.03  1.9e-4 5.0e-3   0.02   0.02   0.03   0.03   0.04  668.0    1.0
phi[1,7]   0.03  3.1e-4 8.0e-3   0.02   0.02   0.03   0.03   0.05  668.0    1.0
phi[2,7]   0.05  5.0e-4   0.01   0.03   0.05   0.05   0.06   0.08  668.0    1.0
phi[3,7] 6.7e-3  2.5e-4 6.5e-3 1.9e-4 2.0e-3 4.7e-3 9.2e-3   0.02  668.0    1.0
phi[0,8]   0.12  3.9e-4   0.01    0.1   0.11   0.12   0.13   0.14  668.0    1.0
phi[1,8]   0.08  4.9e-4   0.01   0.06   0.08   0.08   0.09   0.11  668.0    1.0
phi[2,8]   0.04  4.0e-4   0.01   0.02   0.03   0.03   0.04   0.06  668.0    1.0
phi[3,8]   0.09  9.1e-4   0.02   0.05   0.08   0.09   0.11   0.15  668.0    1.0
phi[0,9]   0.02  1.5e-4 4.0e-3   0.01   0.02   0.02   0.02   0.03  668.0    1.0
phi[1,9]   0.03  3.1e-4 8.1e-3   0.02   0.03   0.03   0.04   0.05  668.0    1.0
phi[2,9]   0.03  3.7e-4 9.5e-3   0.01   0.02   0.03   0.03   0.05  668.0    1.0
phi[3,9]   0.03  4.5e-4   0.01 7.8e-3   0.02   0.02   0.03   0.05  668.0    1.0
lp__      -3617    0.23   4.47  -3626  -3619  -3616  -3613  -3609  375.0    1.0

Samples were drawn using NUTS(diag_e) at Tue Mar 15 16:36:56 2016.
For each parameter, n_eff is a crude measure of effective sample size,
and Rhat is the potential scale reduction factor on split chains (at
convergence, Rhat=1).
```

In [7]:
```
# Naive Bayes classifier function
# remember that we only need to maximize the numerator

def NaiveBayesClassifier(doc):
    posteriors = {}

    for theta in range(0,4):
        theta_prob = np.mean(fit.get_posterior_mean()[theta])
        likelihood = 1
        for word in doc:
            index = 4*(word+1)+theta
            conditional_prob = np.mean(fit.get_posterior_mean()[index])
            likelihood = likelihood*conditional_prob
        posterior = theta_prob*likelihood
        posteriors[theta] = posterior

    import operator
    topic_classify = max(posteriors.iteritems(), key=operator.itemgetter(1))[0]
    results = {}
    results['classification'] =  "document belongs to topic "+str(topic_classify)
    results['posteriors'] = posteriors
    return results
```

In [8]:
```
# make up a new document
new_doc = [1,4,5,6,6,7]
```

In [9]:
```
# run classifier
classification =  NaiveBayesClassifier(new_doc)
```

```
In [10]: # printn results
         print classification['posteriors']
         print classification['classification']
```

```
{0: 5.6794045254845436e-08, 1: 8.891995259587062e-10, 2: 1.0201984918600699e-08, 3: 1.0564556227521439e-
document belongs to topic 0
```

1.0.2 Conclusion

This is a very simple example but you can imagine this type of problem over a much larger dataset or this type of inference needed in more complex NLP settings.

Sources [Stan wikipedia page](https://en.wikipedia.org/wiki/Stan_(software)
Official Stan webpage
Stan reference manual
Blog post about Stan
Stan examples github