Bayes Test Practice 1

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# Instructions

DistNames <- c('Beta','Binomial','ChiSquare','Exponential','F','Gamma','Normal','LogNormal','t')

The following distributions are easy to simulate from in Excel (using the inverse CDF functions built-in): Beta, Binomial, ChiSquare, Exponential, F, Gamma, Normal, LogNormal, t.

1. For each of these distributions, pick interesting parameters and simulate a single sample of size 50. Put these numbers on a spreadsheet in a table of size 50 by 9, with headings in the first row, and save it.
2. Import your spreadsheet into R and give a summary table. Discuss whether the average of each column seems reasonable.
3. Use Stan to fit each distribution to its sample. You will need to specify some priors of your choosing here and there (e.g. for the t df). Thus you will be doing 9 fits in total. For each fit discuss the trace plot and convergence.
4. Obtain parameter estimates from your simulations and compare them to the parameters your chose, and discuss any meaningful differences.

100 marks for following the instructions properly, -50 for having too similar parameters and numbers to another person, -50 for handing in late.

# Example Solution

## Part 1

| Beta | Binomial | ChiSquare | Exponential | F | Gamma | Normal | LogNormal | t |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| =BETA.INV(RAND(), 3, 8) | =BINOM.INV(20, 0.4, RAND()) | =CHISQ.INV(RAND(), 7) | =LN(RAND())/(-1.5) | =F.INV(RAND(), 4, 35) | =GAMMA.INV(RAND(), 3, 2) | =NORM.INV(RAND(), 3.4, 2.5) | =LOGNORM.INV(RAND(), 1.2, 0.4) | =T.INV(RAND(), 4) |

## Part 2

Here we load the data and give a summary.

"Test1Practice2022Bayes.xlsx" |> openxlsx::read.xlsx("Numbers") -> d  
"Test1Practice2022Bayes.xlsx" |> openxlsx::read.xlsx("Parameters") -> pars

pars |> kable()

| Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- |
| 1 | Beta | 3.0 | 8.0 | NA | 0.2727273 |
| 2 | Binomial | 20.0 | 0.4 | NA | 8.0000000 |
| 3 | ChiSquare | 7.0 | NA | NA | 7.0000000 |
| 4 | Exponential | 1.5 | NA | NA | 0.6666667 |
| 5 | F | 4.0 | 35.0 | NA | 1.0606061 |
| 6 | Gamma | 3.0 | 0.5 | NA | 6.0000000 |
| 7 | Normal | 3.4 | 2.5 | NA | 3.4000000 |
| 8 | LogNormal | 1.2 | 0.4 | NA | 3.5966397 |
| 9 | t | 4.0 | 0.0 | 1 | 0.0000000 |

d |> summary() |> kable()

|  | Beta | Binomial | ChiSquare | Exponential | F | Gamma | Normal | LogNormal | t |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Min. :0.0540 | Min. : 4.00 | Min. : 1.657 | Min. :0.002765 | Min. :0.0999 | Min. : 0.6784 | Min. :-3.411 | Min. :1.407 | Min. :-3.21272 |
|  | 1st Qu.:0.1478 | 1st Qu.: 7.00 | 1st Qu.: 4.126 | 1st Qu.:0.156398 | 1st Qu.:0.6060 | 1st Qu.: 3.0841 | 1st Qu.: 2.064 | 1st Qu.:2.555 | 1st Qu.:-0.64272 |
|  | Median :0.2625 | Median : 8.00 | Median : 6.794 | Median :0.403495 | Median :0.9481 | Median : 4.2988 | Median : 3.308 | Median :3.476 | Median : 0.05910 |
|  | Mean :0.2618 | Mean : 8.02 | Mean : 6.971 | Mean :0.624252 | Mean :1.0871 | Mean : 5.0766 | Mean : 3.725 | Mean :3.629 | Mean :-0.04075 |
|  | 3rd Qu.:0.3578 | 3rd Qu.: 9.00 | 3rd Qu.: 8.626 | 3rd Qu.:0.941209 | 3rd Qu.:1.4348 | 3rd Qu.: 6.4401 | 3rd Qu.: 5.646 | 3rd Qu.:4.477 | 3rd Qu.: 0.53238 |
|  | Max. :0.6009 | Max. :13.00 | Max. :15.648 | Max. :2.849005 | Max. :3.0403 | Max. :14.8405 | Max. :10.305 | Max. :7.716 | Max. : 1.95351 |

The averages seem to be within a reasonable distance of the expected values, thus we conclude that the reparameterisations were done appropriately.

## Part 3

First we load Stan.

library(parallel)  
library(rstan)  
mycores <- max(1,floor(detectCores(logical = FALSE)\*0.75))  
options(mc.cores = mycores)  
rstan\_options(auto\_write = TRUE)

Then we define all the models.

// This Stan block defines a Beta model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real<lower=0, upper=1> y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real<lower=0> a;   
 real<lower=0> b;   
}  
model {  
 y ~ beta(a, b);   
}

// This Stan block defines a Binomial model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 int<lower=1> N; // Binomial upper limit  
 int<lower=0, upper=N> y[n]; // observations  
}  
parameters {  
 real<lower=0, upper=1> p;   
}  
model {  
 y ~ binomial(N, p);   
}

// This Stan block defines a ChiSquare model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real<lower=0> y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real<lower=0> m;   
}  
model {  
 y ~ chi\_square(m);   
}

// This Stan block defines a Exponential model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real<lower=0> y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real<lower=0> l;   
}  
model {  
 y ~ exponential(l);   
}

// This Stan block defines an F model, by Sean van der Merwe, UFS  
functions{  
 real f\_lpdf(real x, real d1, real d2){  
// return(beta\_lpdf(d1\*x/d2/(d1\*x/d2 + 1) | d1/2, d2/2));  
 return ( 0.5 \* (-d1 \* log(d1 \* x + d2) -  
 d2 \* log(d1 \* x + d2) + d1 \* log(x) + d1 \* log(d1) +  
 d2 \* log(d2) - 2 \* log(x)) - lbeta(d1/2, d2/2) );  
 }  
}  
data {  
 int<lower=1> n; // number of observations  
 real<lower=0> y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real<lower=0> d1;   
 real<lower=0> d2;   
}  
model {  
 for (i in 1:n) {  
 y[i] ~ f(d1, d2);  
 } // Stan doesn't have an F distribution  
 d1 ~ exponential(0.1);  
 d2 ~ exponential(0.1);  
}

// This Stan block defines a Gamma model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real<lower=0> y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real<lower=0> a;   
 real<lower=0> l;   
}  
model {  
 y ~ gamma(a, l);   
}

// This Stan block defines a Normal model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real m;   
 real<lower=0> s;   
}  
model {  
 y ~ normal(m, s);   
}

// This Stan block defines a LogNormal model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real<lower=0> y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real m;   
 real<lower=0> s;   
}  
model {  
 y ~ lognormal(m, s);   
}

// This Stan block defines a t model, by Sean van der Merwe, UFS  
data {  
 int<lower=1> n; // number of observations  
 real y[n]; // observations  
}  
// The parameters of the model  
parameters {  
 real m;   
 real<lower=0> s;  
 real<lower=0.5> v;  
}  
model {  
 y ~ student\_t(v, m, s);  
 target += log(v) - 3\*log(v+0.75) - 2\*log(s); // joint objective prior  
}

Then we save all the models. We mark all the models and the saving as ‘Do not evaluate’ meaning that we must run them manually every time we move to a new computer.

models <- list(Beta, Binomial, ChiSquare, Exponential, Fdist, Gamma, Normal, LogNormal, tdist)  
names(models) <- DistNames  
saveRDS(models, file = 'models.Rds')

And we load the models that we previously saved. This is generally bad practice, but saves a lot of time when knitting.

Finally, we run the models and look at the output.

n <- nrow(d)  
for (m in 1:(nrow(pars))) {  
 stan\_data <- list(n=nrow(d), y=d[[m]], N=20)  
 ModelFit <- sampling(models[[m]], stan\_data, chains = mycores)  
 ModelFit |> traceplot() |> print()  
 kable(round(summary(ModelFit)$summary, 3)) |> print()  
 kable(pars[m,]) |> print()  
}



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| a | 2.680 | 0.019 | 0.498 | 1.782 | 2.335 | 2.643 | 3.005 | 3.734 | 708.474 | 1.010 |
| b | 7.612 | 0.056 | 1.512 | 4.873 | 6.566 | 7.524 | 8.559 | 10.829 | 720.316 | 1.009 |
| lp\_\_ | 34.363 | 0.033 | 1.003 | 31.490 | 33.967 | 34.681 | 35.079 | 35.354 | 901.342 | 1.003 |

| Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- |
| 1 | Beta | 3 | 8 | NA | 0.2727273 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| p | 0.401 | 0.000 | 0.016 | 0.37 | 0.39 | 0.401 | 0.412 | 0.432 | 1461.630 | 1.001 |
| lp\_\_ | -675.370 | 0.019 | 0.764 | -677.55 | -675.53 | -675.084 | -674.895 | -674.842 | 1673.621 | 1.003 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 2 | 2 | Binomial | 20 | 0.4 | NA | 8 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| m | 7.067 | 0.012 | 0.497 | 6.118 | 6.732 | 7.058 | 7.398 | 8.061 | 1656.601 | 1.000 |
| lp\_\_ | 45.686 | 0.017 | 0.721 | 43.722 | 45.507 | 45.971 | 46.144 | 46.195 | 1769.178 | 1.001 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 3 | 3 | ChiSquare | 7 | NA | NA | 7 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| l | 1.636 | 0.006 | 0.237 | 1.198 | 1.471 | 1.626 | 1.791 | 2.130 | 1586.458 | 1.000 |
| lp\_\_ | -26.494 | 0.020 | 0.748 | -28.631 | -26.662 | -26.206 | -26.014 | -25.959 | 1432.971 | 1.005 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 4 | 4 | Exponential | 1.5 | NA | NA | 0.6666667 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| d1 | 6.438 | 0.042 | 1.769 | 3.862 | 5.207 | 6.158 | 7.343 | 10.542 | 1796.272 | 1.000 |
| d2 | 19.781 | 0.243 | 10.560 | 7.065 | 12.487 | 17.386 | 24.328 | 46.694 | 1886.883 | 1.000 |
| lp\_\_ | -44.541 | 0.025 | 1.011 | -47.280 | -44.942 | -44.224 | -43.826 | -43.557 | 1653.221 | 1.005 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 5 | 5 | F | 4 | 35 | NA | 1.060606 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| a | 3.151 | 0.020 | 0.572 | 2.121 | 2.740 | 3.134 | 3.526 | 4.341 | 800.799 | 1.001 |
| l | 0.623 | 0.004 | 0.123 | 0.405 | 0.535 | 0.620 | 0.703 | 0.881 | 812.637 | 1.001 |
| lp\_\_ | -118.992 | 0.028 | 0.976 | -121.610 | -119.400 | -118.691 | -118.275 | -118.016 | 1211.071 | 1.003 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 6 | 6 | Gamma | 3 | 0.5 | NA | 6 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| m | 3.717 | 0.007 | 0.402 | 2.922 | 3.438 | 3.713 | 3.984 | 4.508 | 3111.971 | 1 |
| s | 2.836 | 0.005 | 0.296 | 2.325 | 2.629 | 2.809 | 3.015 | 3.489 | 3242.427 | 1 |
| lp\_\_ | -75.222 | 0.025 | 1.020 | -77.920 | -75.636 | -74.890 | -74.499 | -74.237 | 1624.007 | 1 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 7 | 7 | Normal | 3.4 | 2.5 | NA | 3.4 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| m | 1.214 | 0.001 | 0.058 | 1.101 | 1.175 | 1.215 | 1.251 | 1.326 | 3145.011 | 1.000 |
| s | 0.409 | 0.001 | 0.043 | 0.335 | 0.379 | 0.406 | 0.435 | 0.502 | 3167.708 | 1.001 |
| lp\_\_ | 19.626 | 0.023 | 0.995 | 16.979 | 19.245 | 19.909 | 20.343 | 20.610 | 1824.392 | 1.000 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 8 | 8 | LogNormal | 1.2 | 0.4 | NA | 3.59664 |



|  | mean | se\_mean | sd | 2.5% | 25% | 50% | 75% | 97.5% | n\_eff | Rhat |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| m | 0.004 | 0.003 | 0.142 | -0.272 | -0.092 | 0.002 | 0.100 | 0.275 | 2408.876 | 1.001 |
| s | 0.848 | 0.004 | 0.161 | 0.545 | 0.734 | 0.842 | 0.960 | 1.165 | 1794.026 | 1.000 |
| v | 13.318 | 1.947 | 72.702 | 1.565 | 2.859 | 4.399 | 7.945 | 62.641 | 1394.136 | 1.003 |
| lp\_\_ | -48.677 | 0.036 | 1.327 | -52.112 | -49.299 | -48.352 | -47.706 | -47.143 | 1367.831 | 1.003 |

|  | Num | Desc | Par1 | Par2 | Par3 | Ex |
| --- | --- | --- | --- | --- | --- | --- |
| 9 | 9 | t | 4 | 0 | 1 | 0 |

## Part 4

Comparing the posterior mean estimates from the summaries to the selected parameters we see good agreement in all cases.