

Simulate data with Jags

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Motivation

Recently, I have been struggling with simulating data from complex hierarchical models. After several unsuccessful attempts in **R**, I remembered the good old times when I was using **WinBUGS** (more than 10 years already!) and the possibility to simulate data with it. I'm using **Jags** now, and a quick search in Google with 'simulating data with jags' led me to a complex example and a simple example.

Here, I illustrate the possibility to use Jags to simulate data with two examples that might be of interest to population ecologists: first a linear regression, second a Cormack-Jolly-Seber capture-recapture model to estimate animal survival (formulated as a state-space model).

Simulating data with **Jags** is convenient because you can use (almost) the same code for simulation and inference, and you can carry out simulation studies (bias, precision, interval coverage) in the same environment (namely **Jags**).

Linear regression example

We first load the packages we will need for this tutorial:

```
library(R2jags)
library(runjags)
library(mcmcplots)
```

Then straight to the point, let's generate data from a linear regression model. The trick is to use a **data** block, have the simplest **model** block you could think of and pass the parameters as if they were data. Note that it'd be possible to use only a model block, see comment [here](#).

```
txtstring <- '
data{
# Likelihood:
for (i in 1:N){
y[i] ~ dnorm(mu[i], tau) # tau is precision (1 / variance)
mu[i] <- alpha + beta * x[i]
}
}
model{
fake <- 0
}
'
```

Here, **alpha** and **beta** are the intercept and slope, **tau** the precision or the inverse of the variance, **y** the response variable and **x** the explanatory variable.

We pick some values for the model parameters that we will use as data:

```
# parameters for simulations
N = 30 # nb of observations
x <- 1:N # predictor
alpha = 0.5 # intercept
beta = 1 # slope
sigma <- .1 # residual sd
```

```
tau <- 1/(sigma*sigma) # precision
# parameters are treated as data for the simulation step
data<-list(N=N,x=x,alpha=alpha,beta=beta,tau=tau)
```

Now call jags; note that we monitor the response variable instead of parameters as we would do when conducting standard inference:

```
# run jags
out <- run.jags(txtstring, data = data,monitor=c("y"),sample=1, n.chains=1, summarise=FALSE)
```

```
## Compiling rjags model...
## Calling the simulation using the rjags method...
## Note: the model did not require adaptation
## Burning in the model for 4000 iterations...
## Running the model for 1 iterations...
## Simulation complete
## Finished running the simulation
```

The output is a bit messy and needs to be formatted appropriately:

```
# reformat the outputs
Simulated <- coda::as.mcmc(out)
Simulated
```

```
## Markov Chain Monte Carlo (MCMC) output:
## Start = 5001
## End = 5001
## Thinning interval = 1
##      y[1]      y[2]      y[3]      y[4]      y[5]      y[6]      y[7]
## 5001 1.355851 2.480367 3.425027 4.578603 5.525765 6.298718 7.621059
##      y[8]      y[9]      y[10]     y[11]     y[12]     y[13]     y[14]     y[15]
## 5001 8.494814 9.655313 10.4964   11.51941 12.53202 13.51177 14.5584   15.43556
##      y[16]     y[17]     y[18]     y[19]     y[20]     y[21]     y[22]
## 5001 16.45084 17.44733 18.46348 19.52666 20.56731 21.4828   22.47064
##      y[23]     y[24]     y[25]     y[26]     y[27]     y[28]     y[29]     y[30]
## 5001 23.55256 24.55051 25.34902 26.60908 27.41689 28.56847 29.334    30.4805
```

```
dim(Simulated)
```

```
## [1] 1 30
```

```
dat = as.vector(Simulated)
dat
```

```
## [1] 1.355851 2.480367 3.425027 4.578603 5.525765 6.298718 7.621059
## [8] 8.494814 9.655313 10.496402 11.519409 12.532017 13.511767 14.558405
## [15] 15.435565 16.450844 17.447325 18.463480 19.526658 20.567306 21.482796
## [22] 22.470638 23.552561 24.550510 25.349022 26.609079 27.416889 28.568473
## [29] 29.333996 30.480498
```

Now let's fit the model we used to simulate to the data we just generated. I won't go into the details and assume that the reader is familiar with Jags and linear regression.

```
# specify model in BUGS language
model <-
paste("
model {
# Likelihood:
for (i in 1:N){
```

```

y[i] ~ dnorm(mu[i], tau) # tau is precision (1 / variance)
mu[i] <- alpha + beta * x[i]
}
# Priors:
alpha ~ dnorm(0, 0.01) # intercept
beta ~ dnorm(0, 0.01) # slope
sigma ~ dunif(0, 100) # standard deviation
tau <- 1 / (sigma * sigma)
}
")
writeLines(model,"lin_reg.jags")

# data
jags.data <- list(y = dat, N = length(dat), x = x)

# initial values
inits <- function(){list(alpha = rnorm(1), beta = rnorm(1), sigma = runif(1,0,10))}

# parameters monitored
parameters <- c("alpha", "beta", "sigma")

# MCMC settings
ni <- 10000
nt <- 6
nb <- 5000
nc <- 2

# call JAGS from R
res <- jags(jags.data, inits, parameters, "lin_reg.jags", n.chains = nc, n.thin = nt, n.iter = ni, n.burnin = nb)

## module glm loaded

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 30
##   Unobserved stochastic nodes: 3
##   Total graph size: 130
##
## Initializing model

Let's have a look to the results and compare with the parameters we used to simulate the data (see above):

# summarize posteriors
print(res, digits = 3)

## Inference for Bugs model at "lin_reg.jags", fit using jags,
## 2 chains, each with 10000 iterations (first 5000 discarded), n.thin = 6
## n.sims = 1668 iterations saved
##          mu.vect sd.vect   2.5%    25%    50%    75%   97.5%  Rhat
## alpha      0.494  0.034   0.430   0.472   0.495   0.516   0.562 1.001
## beta       1.000  0.002   0.996   0.999   1.000   1.001   1.004 1.001
## sigma      0.092  0.013   0.070   0.082   0.090   0.100   0.122 1.001
## deviance -60.083  2.652 -63.147 -62.087 -60.781 -58.822 -53.343 1.005

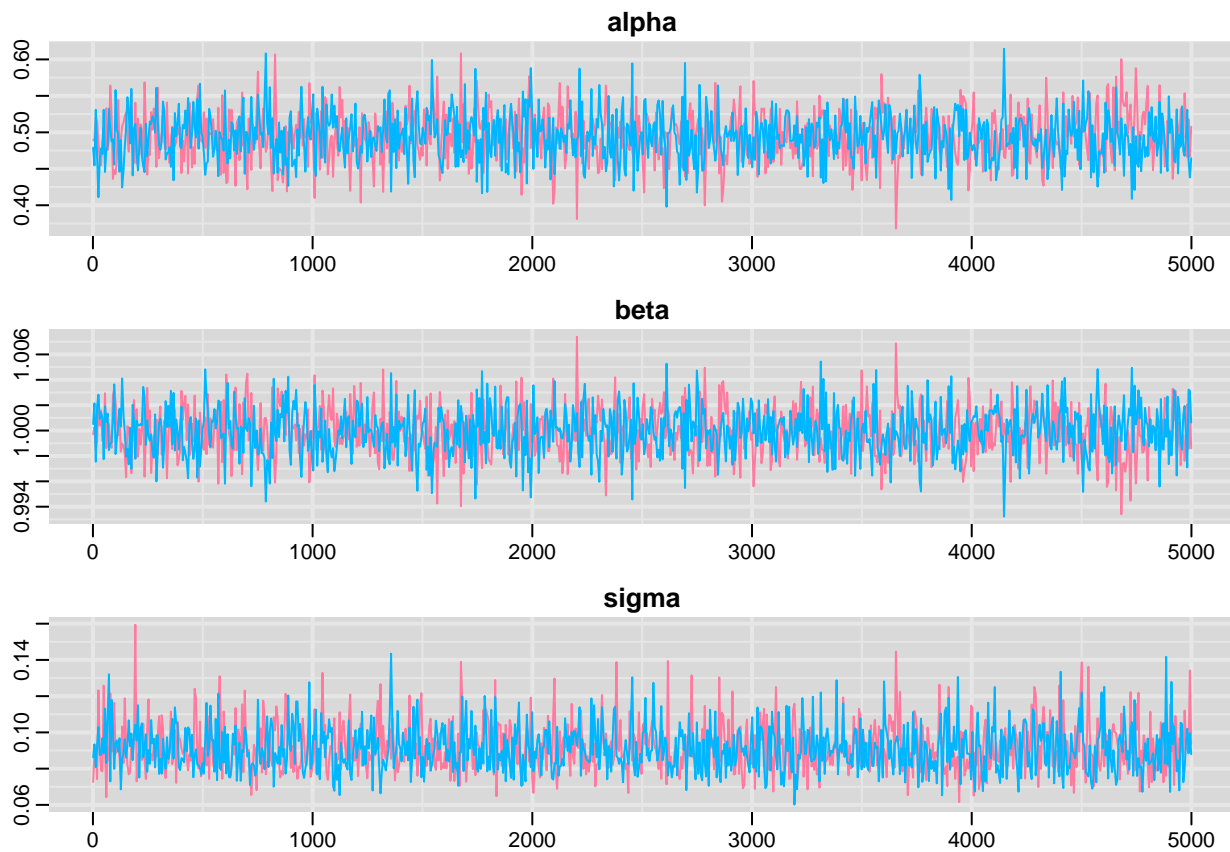
```

```
##           n.eff
## alpha    1700
## beta     1700
## sigma    1400
## deviance 1500
##
## For each parameter, n.eff is a crude measure of effective sample size,
## and Rhat is the potential scale reduction factor (at convergence, Rhat=1).
##
## DIC info (using the rule,  $pD = \text{var}(\text{deviance})/2$ )
##  $pD = 3.5$  and  $DIC = -56.6$ 
## DIC is an estimate of expected predictive error (lower deviance is better).
```

Pretty close!

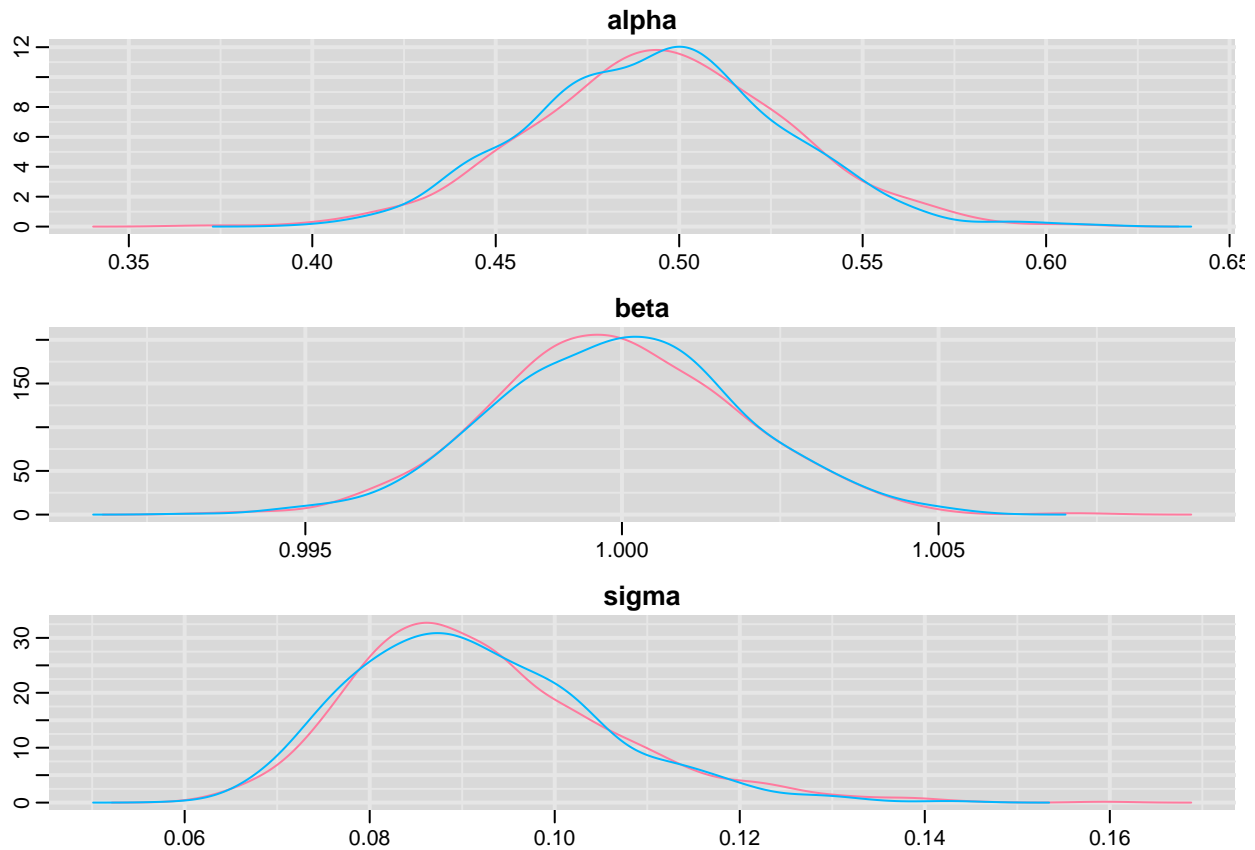
Check convergence:

```
# trace plots
traplot(res, c("alpha", "beta", "sigma"))
```



Plot the posterior distribution of the regression parameters and residual standard deviation:

```
# posterior distributions
denplot(res, c("alpha", "beta", "sigma"))
```



Capture-recapture example

I now illustrate the use of *Jags* to simulate data from a Cormack-Jolly-Seber model with constant survival and recapture probabilities. I assume that the reader is familiar with this model and its formulation as a state-space model.

Let's simulate!

```
txtstring <- '
data{
# Constant survival and recapture probabilities
for (i in 1:nind){
  for (t in f[i]:(n.occasions-1)){
    phi[i,t] <- mean.phi
    p[i,t] <- mean.p
  } #t
} #i
# Likelihood
for (i in 1:nind){
  # Define latent state and obs at first capture
  z[i,f[i]] <- 1
  mu2[i,1] <- 1 * z[i,f[i]] # detection is 1 at first capture ("conditional on first capture")
  y[i,1] ~ dbern(mu2[i,1])
  # then deal w/ subsequent occasions
  for (t in (f[i]+1):n.occasions){
    # State process
    z[i,t] ~ dbern(mu1[i,t])
  }
}
```

```

    mu1[i,t] <- phi[i,t-1] * z[i,t-1]
    # Observation process
    y[i,t] ~ dbern(mu2[i,t])
    mu2[i,t] <- p[i,t-1] * z[i,t]
  } #t
} #i
}
model{
fake <- 0
}
'

```

Let's pick some values for parameters and store them in a data list:

```

# parameter for simulations
n.occasions = 10 # nb of occasions
nind = 100 # nb of individuals
mean.phi <- 0.8 # survival
mean.p <- 0.6 # recapture
f = rep(1,nind) # date of first capture
data<-list(n.occasions = n.occasions, mean.phi = mean.phi, mean.p = mean.p, f = f, nind = nind)

```

Now run Jags:

```
out <- run.jags(txtstring, data = data,monitor=c("y"),sample=1, n.chains=1, summarise=FALSE)
```

```

## Compiling rjags model...
## Calling the simulation using the rjags method...
## Note: the model did not require adaptation
## Burning in the model for 4000 iterations...
## Running the model for 1 iterations...
## Simulation complete
## Finished running the simulation

```

Format the output:

```

Simulated <- coda::as.mcmc(out)
dim(Simulated)

```

```
## [1] 1 1000
```

```

dat = matrix(Simulated,nrow=nind)
head(dat)

```

```

##      [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
## [1,] 1    0    1    1    1    1    1    0    1    0
## [2,] 1    1    1    0    0    0    0    0    0    0
## [3,] 1    0    1    1    0    0    0    0    0    0
## [4,] 1    0    1    1    0    0    0    0    0    0
## [5,] 1    0    1    1    1    1    0    0    0    0
## [6,] 1    1    0    0    0    0    0    0    0    0

```

Here I monitored only the detections and non-detections, but it is also possible to get the simulated values for the states, i.e. whether an individual is alive or dead at each occasion. You just need to amend the call to Jags with `monitor=c("y","x")` and to amend the output accordingly.

Now we fit a Cormack-Jolly-Seber model to the data we've just simulated, assuming constant parameters:

```

model <-
paste("
model {
# Priors and constraints
for (i in 1:nind){
  for (t in f[i]:(n.occasions-1)){
    phi[i,t] <- mean.phi
    p[i,t] <- mean.p
  } #t
} #i
mean.phi ~ dunif(0, 1)          # Prior for mean survival
mean.p ~ dunif(0, 1)           # Prior for mean recapture
# Likelihood
for (i in 1:nind){
  # Define latent state at first capture
  z[i,f[i]] <- 1
  for (t in (f[i]+1):n.occasions){
    # State process
    z[i,t] ~ dbern(mu1[i,t])
    mu1[i,t] <- phi[i,t-1] * z[i,t-1]
    # Observation process
    y[i,t] ~ dbern(mu2[i,t])
    mu2[i,t] <- p[i,t-1] * z[i,t]
  } #t
} #i
}
")
writeLines(model,"cjs.jags")

```

Prepare the data:

```

# vector with occasion of marking
get.first <- function(x) min(which(x!=0))
f <- apply(dat, 1, get.first)
# data
jags.data <- list(y = dat, f = f, nind = dim(dat)[1], n.occasions = dim(dat)[2])

```

```

# Initial values
known.state.cjs <- function(ch){
  state <- ch
  for (i in 1:dim(ch)[1]){
    n1 <- min(which(ch[i,]==1))
    n2 <- max(which(ch[i,]==1))
    state[i,n1:n2] <- 1
    state[i,n1] <- NA
  }
  state[state==0] <- NA
  return(state)
}
inits <- function(){list(mean.phi = runif(1, 0, 1), mean.p = runif(1, 0, 1), z = known.state.cjs(dat))}

```

We'd like to carry out inference about survival and recapture probabilities:

```

parameters <- c("mean.phi", "mean.p")

```

Standard MCMC settings:

```
ni <- 10000
nt <- 6
nb <- 5000
nc <- 2
```

Ready to run Jags!

```
# Call JAGS from R (BRT 1 min)
```

```
cjs <- jags(jags.data, inits, parameters, "cjs.jags", n.chains = nc, n.thin = nt, n.iter = ni, n.burnin
```

```
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 900
##   Unobserved stochastic nodes: 902
##   Total graph size: 3707
##
## Initializing model
```

Summarize posteriors and compare to the values we used to simulate the data:

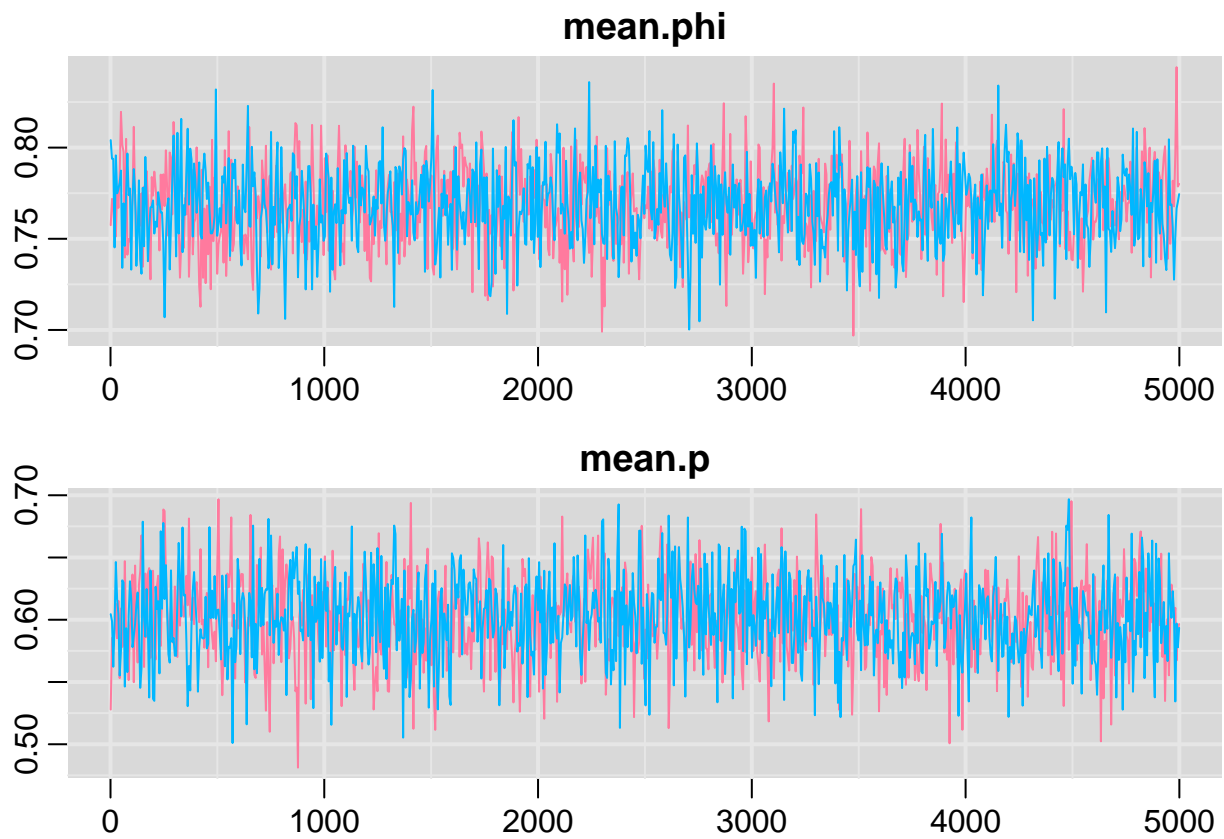
```
print(cjs, digits = 3)
```

```
## Inference for Bugs model at "cjs.jags", fit using jags,
## 2 chains, each with 10000 iterations (first 5000 discarded), n.thin = 6
## n.sims = 1668 iterations saved
##      mu.vect sd.vect   2.5%   25%   50%   75%  97.5%  Rhat
## mean.p    0.602   0.034   0.533   0.580   0.602   0.625   0.670 1.001
## mean.phi   0.768   0.022   0.724   0.753   0.768   0.784   0.809 1.000
## deviance 410.572  18.366 374.262 397.625 410.574 423.151 446.610 1.001
##      n.eff
## mean.p    1700
## mean.phi   1700
## deviance   1700
##
## For each parameter, n.eff is a crude measure of effective sample size,
## and Rhat is the potential scale reduction factor (at convergence, Rhat=1).
##
## DIC info (using the rule, pD = var(deviance)/2)
## pD = 168.7 and DIC = 579.3
## DIC is an estimate of expected predictive error (lower deviance is better).
```

Again pretty close!

Trace plots

```
trapplot(cjs,c("mean.phi", "mean.p"))
```

Posterior distribution plots:

```
denplot(cjs,c("mean.phi", "mean.p"))
```

