JAGS: Just Another Gibbs Sampler

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Outline

1. Why JAGS?
2. Extending JAGS
3. Differences between JAGS and BUGS
4. rjags
5. Conclusions

BUGS

Bayesian inference Using Gibbs Sampling

"Classic" BUGS (1992-1996); WinBUGS (1996-); OpenBUGS (2002-)

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BUGS

Bayesian inference Using Gibbs Sampling

"Classic" BUGS (1992-1996); WinBUGS (1996-); OpenBUGS (2002-)

- A **language** for defining Bayesian hierarchical models
- A **library** of sampling routines
- A **user interface** for running the sampler
- An **output processor** to interpret the results

JAGS

Just Another Gibbs Sampler

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Just Another Gibbs Sampler

- JAGS is an open-source engine for the BUGS language written in C++.
- It is not a port of WinBUGS, but has a completely independent code base.

Motivations for JAGS

1. To have an alternative BUGS language engine that
   - is extensible,
   - runs on Unix/Linux,
   - can interface to R.
2. To create a platform for exploring ideas in Bayesian modelling

Why C++?

C++ is an object oriented language, which easily allows creation of a *virtual graphical model*: an internal representation of the BUGS model in computer memory.

In contrast, OpenBUGS is written in component pascal and is built on the black box component framework.

Advantages of C++

- Interface to existing software written in C, C++, or Fortran
  - Linear algebra routines for matrix operations
    - BLAS, LAPACK, mkl, acml, ...
  - R math library for statistical functions
    - dnorm, pnorm, qnorm, rnorm
  - Random number generators
  - Sampling methods
- Portability: every platform has a C++ compiler and standard library.
- Popularity: there are more experienced developers

Current structure of JAGS

1. **A shared library** containing
   - A compiler for turning a BUGS-language description of a model into an internal graph.
   - Abstract base classes for elements of the BUGS language (functions, distributions), and objects that act on the graph (samplers, RNGs).
2. Dynamically loadable **modules** containing concrete classes for the above.
3. **User interfaces**
   - Command-line interface
   - Experimenal R package (rjags).

JAGS Modules

Modules can be dynamically loaded at runtime to extend the functionality of JAGS. A module can define five kinds of objects:

1. Function
2. Distribution
3. SamplerFactory
4. RNGFactory
5. MonitorFactory

Functions and Distributions

These are the building blocks of the BUGS language

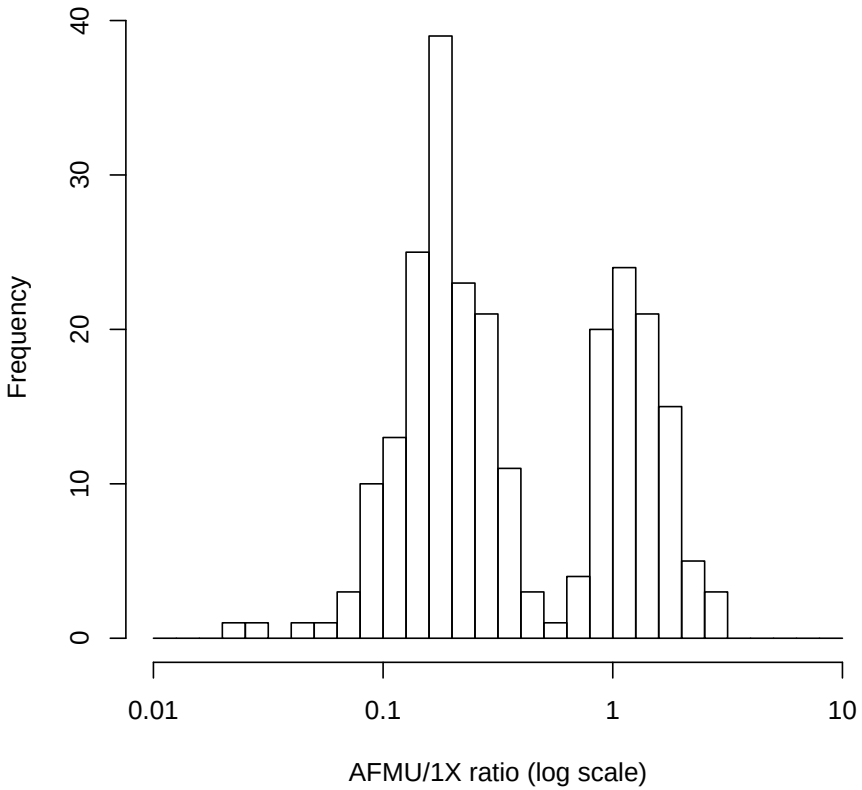
```
y <- exp(x) #Deterministic relation
x ~ dnorm(mu, tau) #Stochastic relation
```

Modules may define novel functions and distributions

```
Y <- mexp(X) #Matrix exponential
z ~ dnormmix(mu, tau, p) #Normal mixture
```

Novel distributions may require novel samplers.

Example: Enzyme data



- The figure shows the results of a biomarker experiment designed to distinguish "fast" and "slow" acetylator phenotype.
- Acetylator phenotype is related to polymorphisms in the NAT2 gene.
- This example was used by Richardson and Green (1997)

Finite mixture models

The enzyme data can be represented by a finite mixture model:

$$\begin{aligned} p\left(y_i \mid x_i, \boldsymbol{\mu}, \boldsymbol{\sigma}\right) &= \phi\left(\frac{y_i - \mu_{x_i}}{\sigma_{x_i}}\right) \\ P\left(X_i = x \mid \boldsymbol{\pi}\right) &= \pi_x \end{aligned}$$

where

- X_i is a latent indicator variable for the group to which individual i belongs
- $\phi(.)$ is the standard normal density

Alternative representation of finite mixture models

It is computationally simpler to marginalize over the latent variables $X_1 \ldots X_n$.

$$p\left(y_i \mid \boldsymbol{\pi}, \boldsymbol{\mu}, \boldsymbol{\sigma}\right) = \sum_{g=1}^{G} \pi_g \, \phi\left(\frac{Y_i - \mu_g}{\sigma_g}\right)$$

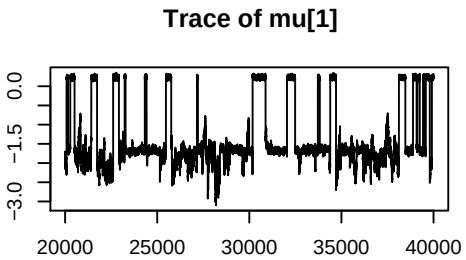
The `mix` module of JAGS defines the novel distribution `dnormmix`

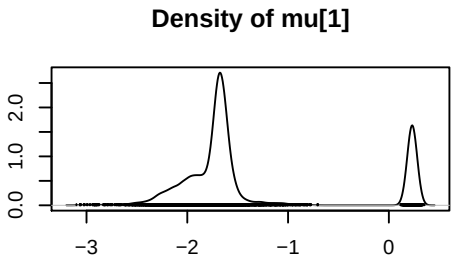
```
for (i in 1:N) {
  y[i] ~ dnormmix(pi, mu, tau)
}
sigma <- sqrt(1/tau)
```

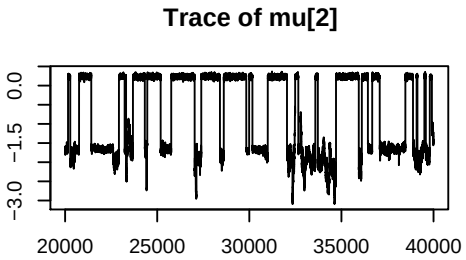
Analyzing mixture models with MCMC

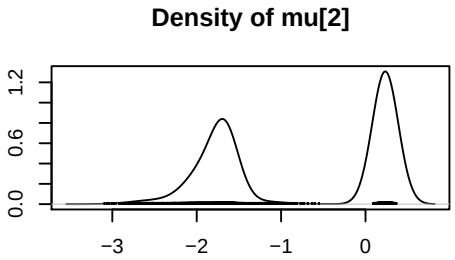
- Mixture models are notoriously hard to analyze by MCMC.
- We use *tempered transitions* (Neal, 1996) to jump between nodes of the multimodal posterior.
- This technique is implemented in the `mix` module of JAGS.

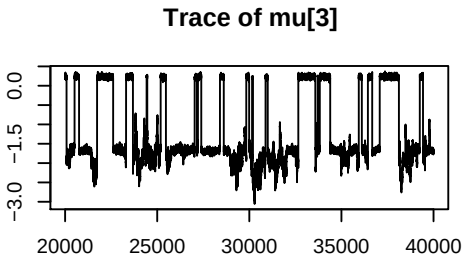
A 3-component mixture model

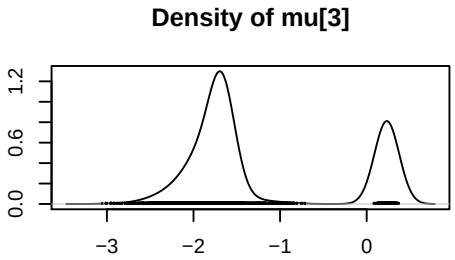












- Jumps in the traceplot represent label switching, in which (μ_1, μ_2, μ_3) are permuted.
- The marginal posterior distributions of μ_1, μ_2, μ_3 should be the same in the long run.

Incompatible differences betwen JAGS and BUGS

I have deliberately chosen to make JAGS incompatible with BUGS in four areas.

- Scripting language
- Data format
- Censoring
- Data transformations

The JAGS scripting language

Syntax borrowed from Stata.

```
model in blocker.bug
data in blocker-data.R
compile
parameters in blocker-ninit.R
initialize
update 3000
monitor set d, thin(10)
monitor set delta.new, thin(10)
monitor set sigma, thin(10)
update 30000
coda *
exit
```

Data format

- JAGS uses the R `dump()` format for data and initial values.
- No need to transpose matrices before dumping
  - JAGS uses column major ordering of arrays, like R and Fortran.
- JAGS can parse any numeric vector or array dumped from R.
  - Attributes can be parsed by JAGS but are ignored

Censoring and truncation

- The `I(,)` construct is used in WinBUGS to represent censoring (*a posteriori* restriction)
- Confusingly, it is also used to represent truncation of top-level parameters (*a priori* restriction).
- It is invalid to use `I(,)` for truncation for any distribution with unobserved parameters.

JAGS does not have the `I(,)` construct

- JAGS uses the `T(,)` construct for truncation
- Censoring is represented by the novel distribution `dinterval`

Interval censoring in JAGS

An example of a right-censored failure time:

```
is.censored[i] ~ dinterval(t[i], t.censor[i]);
t[i] ~ dweib(r,mu[i]);
```

where

- `t.censor[i]` is a censoring time
- `is.censored[i]` is a censoring indicator
- `t[i]` is a failure time
  - missing (NA) if censored.

Data transformations

Data transformations must be in a separate data block

BUGS

```
model {
  for (i in 1:N) {
    z[i] <- log(y[i])
    z[i] ~ dnorm(mu[i], tau)
  }
}
```

JAGS

```
data {
  z <- log(y)
}
model {
  for (i in 1:N) {
    z[i] ~ dnorm(mu[i], tau)
  }
}
```

The data block can also be used to simulate data from a model.

Compatible differences between JAGS and BUGS

- JAGS uses a dialect of the BUGS language that is slightly different from WinBUGS
- Most of these changes reflect my experience as a BUGS and R user
- The general trend is to make BUGS more "S-like" while still allowing WinBUGS code to run on JAGS.

Querying data objects

JAGS allows you to query the size of vectors and arrays supplied in the data file.

BUGS

```
for (i in 1:N) {
  y[i] ~ dnorm(mu[i], tau)
}
```

JAGS

```
for (i in 1:length(y)) {
   y[i] ~ dnorm(mu[i], tau)
}
```

No need to supply `N` in the data file

- There is also a dim function for array dimensions

Initial values

- WinBUGS generates initial values from the prior distribution
  - But diffuse priors generate initial values incompatible with the data
- JAGS tries to provide sensible initial values:

  fixed effects A deterministic typical value from the prior distribution (mean, median, mode ...)

  random effects A random sample from the prior.

Vectorization

Scalar functions with scalar arguments are automatically vectorized

BUGS

```
for (i in 1:N) {
  for (j in 1:M) {
    D[i,j] <- a + b * C[i,j]
  }
}
```

JAGS

```
D <- a + b * C
```

Use vectorization with caution

R users may be tempted to vectorize everything. But be careful not to create bottlenecks in the model

Fast

```
for (i in 1:N) {
  y[i] ~ dnorm(mu[i], tau)
  mu[i] <- lp[i] + e[i]
  e[i] ~ dnorm(0, tau.e)
}
```

Slow

```
for (i in 1:N) {
  y[i] ~ dnorm(mu[i], tau)
  e[i] ~ dnorm(0, tau.e)
}
mu <- lp + e
```

The right hand side recalculates the whole of `mu` every time `e[i]` is updated!

Vector-valued functions

JAGS has more vector- and array-valued functions

BUGS

```
for (i in 1:N) {
  for (j in 1:M) {
    ip <- a[i] * B[i,j] * c[j]
  }
}
```

JAGS

```
ip <- t(a) %*% B %*% c
```

Embedding expressions

Deterministic nodes can be embedded inside other expressions

BUGS

```
y[i,j] ~ dnorm(mu[i,j], tau)
mu[i,j] <- a[i] + b[j]
```

JAGS

```
y[i,j] ~ dnorm(a[i]+b[j], tau)
```

A JAGS package for R

JAGS has an experimental R interface "rjags". It will be released (uploaded to CRAN) after JAGS 1.0.0.

```
> library(rjags)
> m <- jags.model("line.bug", data=line.data)
Compiling model graph
Resolving undeclared variables
Allocating nodes
Checking graph
Graph Size: 37
```

JAGS model objects

- A `jags.model` is not a *fitted* model object.
- It is an object that we can query to get (dependent) random samples for the parameters.
- *In the long run*, these samples will be from the posterior distribution.

Drawing Samples

To get samples from the posterior distribution

```
x <- model.samples(m, variable.names=c("alpha, "beta", "tau"),
                   n.iter=1000)
```

The return value `x` is a list containing sampled values for the requested variables.

Burn-in

A model can be updated without drawing samples

```
m$update(1000)
```

This changes the state of the object `m`, and makes it more likely to generate samples close to the posterior distribution.

A `jags.model` has an object-oriented interface.

`m$ptr()`	A pointer to an external C++ object created by the
`m$data()`	A copy of the model data
`m$model()`	A character vector defining the BUGS model
`m$state()`	The current parameter values
`m$update(n)`	Updates the sampler by n iterations
`m$recompile()`	Recompiles the model

Current status and future plans

- The JAGS library is complete and documented
  - JAGS 1.0.0 to be released before end 2007.
- Developer manual required to show other users how to write modules.
- R package rjags to be released after JAGS 1.0.0.

Help wanted on Windows

JAGS runs on Windows. But I am not a habitual Windows user and it needs better support.

- Windows users expect an installer (*e.g* innosetup).
- Needs a better GUI than the DOS console.

Further information

- JAGS home page: `http://mcmc-jags.sourceforge.net`
- Source code repository:
  `http://sourceforge.net/projects/mcmc-jags`