# USING COMPILED CODE IN POMP

AARON A. KING

Contents

1. A two-dimensional Ornstein-Uhlenbeck process. 1
2. The .C interface 1
3. The .Call interface 3

## 1. A two-dimensional Ornstein-Uhlenbeck process.

Let's look again at our example of the discrete-time 2-D Ornstein-Uhlenbeck process with normal measurement error. Recall that the unobserved Ornstein-Uhlenbeck (OU) process $X_t \in \mathbb{R}^2$ satisfies

$$X_t = A\,X_{t-1} + \xi_t.$$

The observation process is

$$Y_t = B\,X_t + \varepsilon_t.$$

In these equations, $A$ and and $B$ are $2\times2$ constant matrices; $\xi_t$ and $\varepsilon_t$ are mutually-independent families of i.i.d. bivariate normal random variables. We let $\sigma\sigma^T$ be the variance-covariance matrix of $\xi_t$, where $\sigma$ is lower-triangular; likewise, we let $\tau\tau^T$ be that of $\varepsilon_t$.

Since many of the methods we will use require us to simulate the process and/or measurement models many times, it is a good idea to use native (compiled) codes for the computational heavy lifting. The package includes some C codes that were written to implement the OU example. Read the source (file 'ou2.c') for details.

## 2. The .C interface

```
> ou2.rprocess <- function(xstart, times, params,
+     ...) {
+     nvar <- nrow(xstart)
+     npar <- nrow(params)
+     nrep <- ncol(xstart)
+     ntimes <- length(times)
+     parindex <- match(c("alpha.1", "alpha.2",
+         "alpha.3", "alpha.4", "sigma.1", "sigma.2",
+         "sigma.3"), rownames(params)) - 1
+     array(.C("ou2_adv", X = double(nvar * nrep *
+         ntimes), xstart = as.double(xstart), par = as.double(params),
+         times = as.double(times), n = as.integer(c(nvar,
+             npar, nrep, ntimes)), parindex = as.integer(parindex),
+         DUP = FALSE, NAOK = TRUE, PACKAGE = "pomp.devel")$X,
```

```
+         dim = c(nvar, nrep, ntimes), dimnames = list(rownames(xstart),
+             NULL, NULL))
+ }
> ou2.dprocess <- function(x, times, params, log,
+     ...) {
+     nvar <- nrow(x)
+     npar <- nrow(params)
+     nrep <- ncol(x)
+     ntimes <- length(times)
+     parindex <- match(c("alpha.1", "alpha.2",
+         "alpha.3", "alpha.4", "sigma.1", "sigma.2",
+         "sigma.3"), rownames(params)) - 1
+     array(.C("ou2_pdf", d = double(nrep * (ntimes -
+         1)), X = as.double(x), par = as.double(params),
+         times = as.double(times), n = as.integer(c(nvar,
+             npar, nrep, ntimes)), parindex = as.integer(parindex),
+         give_log = as.integer(log), DUP = FALSE,
+         NAOK = TRUE, PACKAGE = "pomp.devel")$d,
+         dim = c(nrep, ntimes - 1))
+ }
> bvnorm.dmeasure <- function(y, x, times, params,
+     log = TRUE, ...) {
+     measindex <- match(c("tau"), rownames(params)) -
+         1
+     nvar <- dim(x)[1]
+     nrep <- dim(x)[2]
+     ntimes <- dim(x)[3]
+     npar <- nrow(params)
+     nobs <- 2
+     array(.C("normal_dmeasure", n = as.integer(c(nvar,
+         npar, nrep, ntimes, nobs)), X = as.double(x),
+         par = as.double(params), index = as.integer(measindex),
+         Y = as.double(y), f = double(nrep * ntimes),
+         give_log = as.integer(log), DUP = FALSE,
+         NAOK = TRUE, PACKAGE = "pomp.devel")$f,
+         dim = c(nrep, ntimes))
+ }
> bvnorm.rmeasure <- function(x, times, params,
+     ...) {
+     nvar <- dim(x)[1]
+     nrep <- dim(x)[2]
+     ntimes <- dim(x)[3]
+     npar <- dim(params)[1]
+     nobs <- 2
+     measindex <- match(c("tau"), rownames(params)) -
+         1
+     array(.C("normal_rmeasure", n = as.integer(c(nvar,
+         npar, nrep, ntimes, nobs)), X = as.double(x),
+         par = as.double(params), index = as.integer(measindex),
+         obs = double(nobs * nrep * ntimes), DUP = FALSE,
+         NAOK = TRUE, PACKAGE = "pomp.devel")$obs,
+         dim = c(nobs, nrep, ntimes), dimnames = list(c("y1",
```

```
+             "y2"), NULL, NULL))
+ }
> ou2 <- pomp(times = seq(1, 100), data = rbind(y1 = rep(0,
+     100), y2 = rep(0, 100)), t0 = 0, rprocess = ou2.rprocess,
+     dprocess = ou2.dprocess, rmeasure = bvnorm.rmeasure,
+     dmeasure = bvnorm.dmeasure)
```

We'll specify some parameters:

```
> p <- c(alpha.1 = 0.9, alpha.2 = 0, alpha.3 = 0,
+     alpha.4 = 0.99, sigma.1 = 1, sigma.2 = 0,
+     sigma.3 = 2, tau = 1, x1.0 = 50, x2.0 = -50)

> tic <- Sys.time()
> ou2 <- simulate(ou2, params = p, nsim = 1000,
+     seed = 800733088)[[1]]
> toc <- Sys.time()
> print(toc - tic)

Time difference of 2.541154 secs
```

## 3. The .Call interface

The following wrapper functions make use of the above compiled codes.

```
> ou2.rprocess <- function(xstart, times, params,
+     ...) .Call("ou2_simulator", xstart, times,
+     params)
> ou2.dprocess <- function(x, times, params, log = FALSE,
+     ...) .Call("ou2_density", x, as.numeric(times),
+     params, log)
> bvnorm.dmeasure <- function(y, x, times, params,
+     log = FALSE, ...) .Call("bivariate_normal_dmeasure",
+     y, x, as.numeric(times), params, log)
> bvnorm.rmeasure <- function(x, times, params,
+     ...) .Call("bivariate_normal_rmeasure", x,
+     as.numeric(times), params)
```

To take advantage of the compiled functions, we need to reconstruct the `pomp` object.

```
> ou2 <- pomp(times = seq(1, 100), data = rbind(y1 = rep(0,
+     100), y2 = rep(0, 100)), t0 = 0, rprocess = ou2.rprocess,
+     dprocess = ou2.dprocess, rmeasure = bvnorm.rmeasure,
+     dmeasure = bvnorm.dmeasure, ivpnames = c("x1.0",
+         "x2.0"), parnames = c("alpha.1", "alpha.2",
+         "alpha.3", "alpha.4", "sigma.1", "sigma.2",
+         "sigma.3", "tau"))
```

Notice that we have added two objects, `ivpnames` and `parnames` to the `pomp` object. These character vectors are placed into the `userdata` slot of the `pomp` object and will be passed to each of the process and measurement model functions. They will come in handy later when we do particle filtering.

We'll fill the data slot with simulated data:

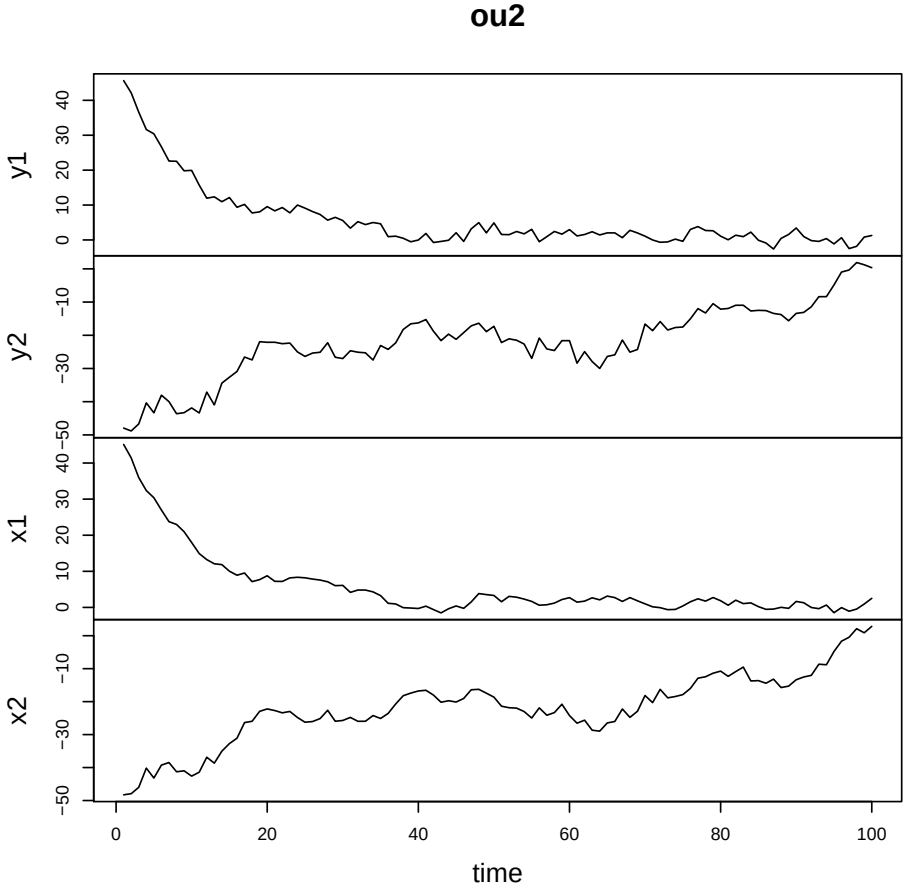


FIGURE 1. One realization of the two-dimensional OU process.

```
> tic <- Sys.time()
> ou2 <- simulate(ou2, params = p, nsim = 1000,
+     seed = 800733088)[[1]]
> toc <- Sys.time()
> print(toc - tic)
```

```
Time difference of 2.487309 secs
```

Fig. 1 plots the data.

The `pomp` object we just created is included in the package: use `data(ou2)` to retrieve it.

A. A. KING, DEPARTMENTS OF ECOLOGY & EVOLUTIONARY BIOLOGY AND MATHEMATICS, UNIVERSITY OF MICHIGAN, ANN ARBOR, MICHIGAN 48109-1048 USA

*E-mail address*: `kingaa at umich dot edu`

*URL*: `http://www.umich.edu/~kingaa`