Continuous character models

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07 March, 2018

First get packages we need

```
# install.packages("yearn")
# yearn::yearn(ape) #utility fns
# yearn::yearn(geiger) #utilty fns
# yearn::yearn(OUwie)
library(ape)
library(phytools)
```

```
## Loading required package: maps
```

```
##
##  # ATTENTION: maps v3.0 has an updated 'world' map.        #
##  # Many country borders and names have changed since 1990. #
##  # Type '?world' or 'news(package="maps")'. See README_v3. #
```

```
library(geiger)
library(OUwie)
```

```
## Loading required package: nloptr
```

```
## Loading required package: lattice
```

Now get the tree and data. For these exercises, knowing uncertainty in your measurements can also be important. (remember for homework to change `eval=FALSE` to `eval=TRUE`).

```
tree <- read.tree("bacterial_tree.tre")
continuous.data <- read.csv(file="ftsy_expression.csv", stringsAsFactors=FALSE,header=F,row.names=1) #d
continuous.data[,1] <- continuous.data[,1]
```

A function to clean data, make sure taxon names match between tree and data, etc.

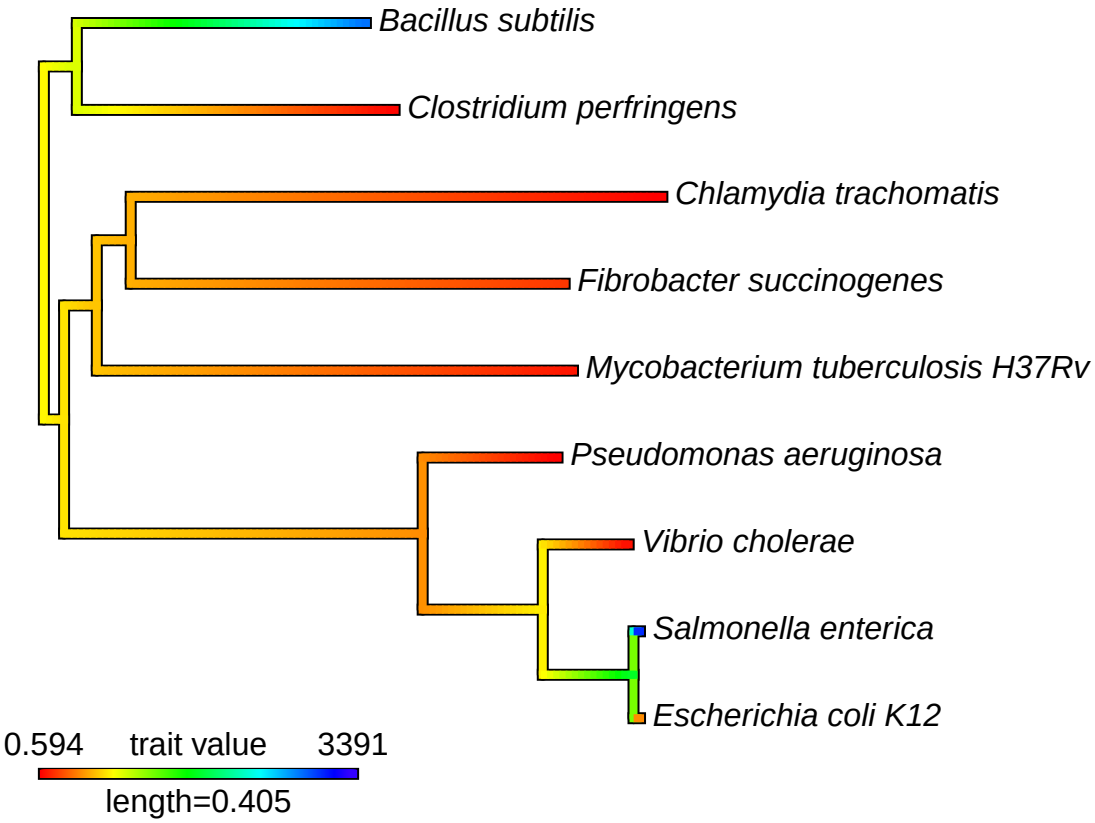
```
CleanData <- function(phy, data) {
    cleaned <- treedata(phy,data,warnings=F)# in Geiger is probably my favorite function in R.
    return(cleaned)
}

cleaned.cont <- CleanData(tree,continuous.data)

# Now write the code to use CleanData() to actually clean your data
```

A function to plot data. Look at `phytools::contMap()`. This is all part of checking: do your data all seem sensible? **LOOK AT IT**.

```
VisualizeData <- function(phy, data) {
    contMap(phy,data)
}
x<-c(cleaned.cont$data)
names(x)<-row.names(cleaned.cont$data)
VisualizeData(cleaned.cont$phy,x)
```



First, start basic. What is the rate of evolution of your trait on the tree?

```
BM1 <- geiger::fitContinuous(cleaned.cont$phy, cleaned.cont$data, model="BM")
print(paste("The rate of evolution is",BM1$opt$sigsq, "in units of", "RPKM^2/MY"))
```

```
## [1] "The rate of evolution is 71634238.4984637 in units of RPKM^2/MY"
```

Important: What are the rates of evolution? In what units?

```
OU1 <- geiger::fitContinuous(cleaned.cont$phy, cleaned.cont$data, model="OU")
```

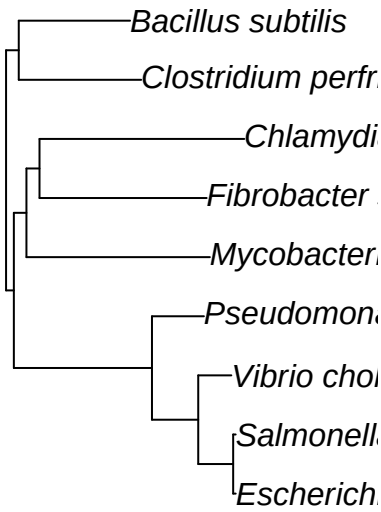
```
## Warning in geiger::fitContinuous(cleaned.cont$phy, cleaned.cont$data, model
## = "OU"): Non-ultrametric tree with OU model, using VCV method.
```

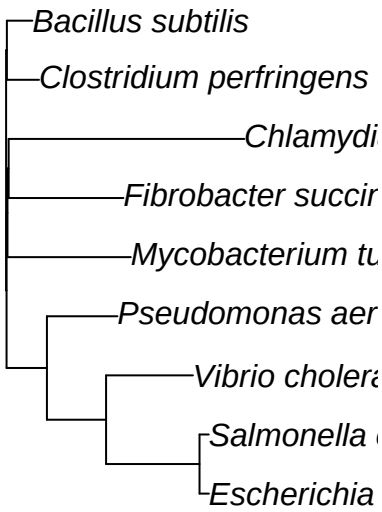
```
## Warning in cache$dat - mu: Recycling array of length 1 in vector-array arithmetic is deprecated.
##   Use c() or as.vector() instead.
```

```
## Warning in cache$dat - mu: Recycling array of length 1 in vector-array arithmetic is deprecated.
##   Use c() or as.vector() instead.
```

```
## Warning in geiger::fitContinuous(cleaned.cont$phy, cleaned.cont$data, model = "OU"): Parameter estima
##  alpha
```

```
par(mfcol=c(1,2))
plot(cleaned.cont$phy, show.tip.label=T)
ou.tree <- rescale(cleaned.cont$phy, model="OU", OU1$opt$alpha)
plot(ou.tree)
```





How are the trees different? The OU tree indicates shorter branch lengths for the divergences of B. subtillis, C. perfringens, C. trachomatis, F. succinogenes, and M. tuberculosis. It almost looks like a polytomy.

Compare trees

```
AIC.BM1 <- BM1$opt$aic
AIC.OU1 <- OU1$opt$aic
delta.AIC.BM1 <-AIC.BM1 - AIC.OU1
delta.AIC.OU1 <- AIC.OU1 - AIC.BM1

cat(paste0("Delta.AIC.BM1: ",delta.AIC.BM1,"\nDelta.AIC.OU1: ",delta.AIC.OU1,"\n"))
```

```
## Delta.AIC.BM1: 6.16407188682413
## Delta.AIC.OU1: -6.16407188682413
```

OUwie runs

This takes longer than you may be used to.

We're a bit obsessive about doing multiple starts and in general performing a thorough numerical search. It took you 3+ years to get the data, may as well take an extra five minutes to get an accurate answer

First, we need to assign regimes. The way we do this is with ancestral state estimation of a discrete trait. We can do this using ace() in ape, or similar functions in corHMM or diversitree. Use only one discrete char.

```
one.discrete.char.orig <- read.table("discrete_traits.csv",sep=",",header=F,stringsAsFactors = F,row.nar
one.discrete.char <- one.discrete.char.orig[cleaned.cont$phy$tip.label,] ##reorder traits to match orde
reconstruction.info <- ace(one.discrete.char, cleaned.cont$phy, type="discrete", method="ML", CI=TRUE)
best.states <- colnames(reconstruction.info$lik.anc)[apply(reconstruction.info$lik.anc, 1, which.max)]
```

Now add these labels to your tree.

```
cleaned.cont$phy$node.label <- best.states
labeled.tree <-cleaned.cont$phy
trait <- data.frame( cleaned.cont$phy$tip.label,one.discrete.char.orig[cleaned.cont$phy$tip.label,],cont
colnames(trait) <- c("Genus_species","Reg","X")
nodeBased.OUMV <- OUwie(labeled.tree,trait,model="OUMV", simmap.tree=FALSE, diagn=FALSE,root.age=0.8099
```

```
## Warning: You might not have enough data to fit this model well

## Initializing...
```

```
## Finished. Begin thorough search...
## Finished. Summarizing results.
```

```r
print(nodeBased.OUMV)
```

```
##
## Fit
##        lnL      AIC     AICc model ntax
##  -77.97533 165.9507 185.9507  OUMV    9
##
##
## Rates
##                      0            1
## alpha    1.005840e+01 1.005840e+01
## sigma.sq 4.851652e+08 4.851652e+08
##
## Optima
##                    0         1
## estimate -2191.7260 2834.9616
## se         267.3273   98.3159
##
## Arrived at a reliable solution
```

What do the numbers mean? The lnL, AIC, and AICc are measures of model fit to the data. Sigma^2 is the rate of wiggle towards state 0 or state 1 and alpha represent the rate at which a continuous trait is being pulled towards the optimal value. The optima estimate represents the theta values. Now run all OUwie models:

```r
models <- c("BM1","BMS","OU1","OUM","OUMV","OUMA","OUMVA")
results <- lapply(models, OUwie, phy=labeled.tree, data=trait,root.age=0.80994)
```

```
## Warning: You might not have enough data to fit this model well

## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.

## Warning: You might not have enough data to fit this model well

## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.

## Warning: You might not have enough data to fit this model well

## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.

## Warning: You might not have enough data to fit this model well

## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.

## Warning: You might not have enough data to fit this model well

## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.
```

```
## Warning: You might not have enough data to fit this model well
```

```
## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.
```

```
## Warning: You might not have enough data to fit this model well
```

```
## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.
```

```
AICc.values<-sapply(results, "[[", "AICc")
names(AICc.values)<-models
AICc.values<-AICc.values-min(AICc.values)


print(AICc.values) #The best model is the one with smallest AICc score
```

```
##       BM1       BMS       OU1       OUM      OUMV      OUMA     OUMVA
## 10.744203 18.570007  2.682899  0.000000 12.000000 12.000000 36.000000
```

```
best<-results[[which.min(AICc.values)]] #store for later

print(best) #prints info on best model
```

```
##
## Fit
##        lnL      AIC     AICc model ntax
##  -77.97533 163.9507 173.9507   OUM    9
##
##
## Rates
##                      0           1
## alpha    1.005876e+01 1.005876e+01
## sigma.sq 4.851652e+08 4.851652e+08
##
## Optima
##                    0          1
## estimate -2191.6841 2834.96821
## se         267.2862   98.30063
##
## Arrived at a reliable solution
```

We get SE for the optima (see nodeBased.OUMV$theta) but not for the other parameters. Let's see how hard they are to estimate. First, look at ?OUwie.fixed to see how to calculate likelihood at a single point.

```
?OUwie.fixed
```

Next, keep all parameters but alpha at their maximum likelihood estimates (better would be to fix just alpha and let the others optimize given this constraint, but this is harder to program for this class). Try a range of alpha values and plot the likelihood against this.

```
alpha.values<-seq(from= 10, to=425 , length.out=200)
```

Keep it simple (and slow) and do a for loop:

```
likelihood.values <- rep(NA, length(alpha.values))
for (iteration in sequence(length(alpha.values))) {
```

```
    likelihood.values[iteration] <- OUwie.fixed(labeled.tree, trait, model="OUMV", alpha=rep(alpha.valu
}
```

```
## Calculating likelihood using fixed parameter values: 10 10 485165195 485165195 -2191.684 2834.968
## Calculating likelihood using fixed parameter values: 12.08543 12.08543 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 14.17085 14.17085 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 16.25628 16.25628 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 18.34171 18.34171 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 20.42714 20.42714 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 22.51256 22.51256 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 24.59799 24.59799 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 26.68342 26.68342 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 28.76884 28.76884 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 30.85427 30.85427 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 32.9397 32.9397 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 35.02513 35.02513 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 37.11055 37.11055 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 39.19598 39.19598 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 41.28141 41.28141 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 43.36683 43.36683 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 45.45226 45.45226 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 47.53769 47.53769 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 49.62312 49.62312 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 51.70854 51.70854 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 53.79397 53.79397 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 55.8794 55.8794 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 57.96482 57.96482 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 60.05025 60.05025 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 62.13568 62.13568 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 64.22111 64.22111 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 66.30653 66.30653 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 68.39196 68.39196 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 70.47739 70.47739 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 72.56281 72.56281 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 74.64824 74.64824 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 76.73367 76.73367 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 78.8191 78.8191 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 80.90452 80.90452 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 82.98995 82.98995 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 85.07538 85.07538 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 87.1608 87.1608 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 89.24623 89.24623 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 91.33166 91.33166 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 93.41709 93.41709 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 95.50251 95.50251 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 97.58794 97.58794 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 99.67337 99.67337 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 101.7588 101.7588 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 103.8442 103.8442 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 105.9296 105.9296 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 108.0151 108.0151 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 110.1005 110.1005 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 112.1859 112.1859 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 114.2714 114.2714 485165195 485165195 -2191.684
```

```
## Calculating likelihood using fixed parameter values: 116.3568 116.3568 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 118.4422 118.4422 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 120.5276 120.5276 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 122.6131 122.6131 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 124.6985 124.6985 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 126.7839 126.7839 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 128.8693 128.8693 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 130.9548 130.9548 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 133.0402 133.0402 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 135.1256 135.1256 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 137.2111 137.2111 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 139.2965 139.2965 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 141.3819 141.3819 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 143.4673 143.4673 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 145.5528 145.5528 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 147.6382 147.6382 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 149.7236 149.7236 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 151.809 151.809 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 153.8945 153.8945 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 155.9799 155.9799 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 158.0653 158.0653 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 160.1508 160.1508 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 162.2362 162.2362 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 164.3216 164.3216 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 166.407 166.407 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 168.4925 168.4925 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 170.5779 170.5779 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 172.6633 172.6633 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 174.7487 174.7487 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 176.8342 176.8342 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 178.9196 178.9196 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 181.005 181.005 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 183.0905 183.0905 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 185.1759 185.1759 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 187.2613 187.2613 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 189.3467 189.3467 485165195 485165195 -2191.684
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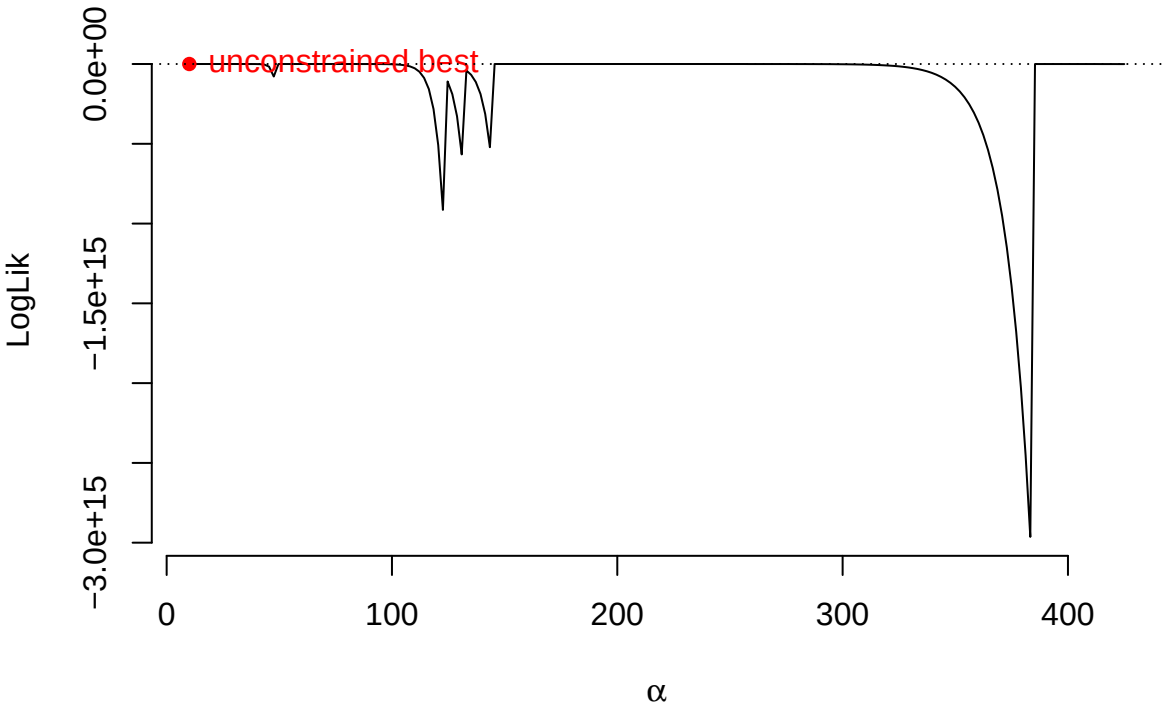
## Calculating likelihood using fixed parameter values: 193.5176 193.5176 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 195.603 195.603 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 197.6884 197.6884 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 199.7739 199.7739 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 201.8593 201.8593 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 203.9447 203.9447 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 206.0302 206.0302 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 208.1156 208.1156 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 210.201 210.201 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 212.2864 212.2864 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 214.3719 214.3719 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 216.4573 216.4573 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 218.5427 218.5427 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 220.6281 220.6281 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 222.7136 222.7136 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 224.799 224.799 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 226.8844 226.8844 485165195 485165195 -2191.684
```

```
## Calculating likelihood using fixed parameter values: 228.9698 228.9698 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 231.0553 231.0553 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 233.1407 233.1407 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 235.2261 235.2261 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 237.3116 237.3116 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 239.397 239.397 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 241.4824 241.4824 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 243.5678 243.5678 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 245.6533 245.6533 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 247.7387 247.7387 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 249.8241 249.8241 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 251.9095 251.9095 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 253.995 253.995 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 256.0804 256.0804 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 258.1658 258.1658 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 260.2513 260.2513 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 262.3367 262.3367 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 264.4221 264.4221 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 266.5075 266.5075 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 268.593 268.593 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 270.6784 270.6784 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 272.7638 272.7638 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 274.8492 274.8492 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 276.9347 276.9347 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 279.0201 279.0201 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 281.1055 281.1055 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 283.191 283.191 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 285.2764 285.2764 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 287.3618 287.3618 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 289.4472 289.4472 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 291.5327 291.5327 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 293.6181 293.6181 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 295.7035 295.7035 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 297.7889 297.7889 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 299.8744 299.8744 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 301.9598 301.9598 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 304.0452 304.0452 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 306.1307 306.1307 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 308.2161 308.2161 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 310.3015 310.3015 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 312.3869 312.3869 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 314.4724 314.4724 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 316.5578 316.5578 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 318.6432 318.6432 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 320.7286 320.7286 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 322.8141 322.8141 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 324.8995 324.8995 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 326.9849 326.9849 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 329.0704 329.0704 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 331.1558 331.1558 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 333.2412 333.2412 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 335.3266 335.3266 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 337.4121 337.4121 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 339.4975 339.4975 485165195 485165195 -2191.684
```

```
## Calculating likelihood using fixed parameter values: 341.5829 341.5829 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 343.6683 343.6683 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 345.7538 345.7538 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 347.8392 347.8392 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 349.9246 349.9246 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 352.0101 352.0101 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 354.0955 354.0955 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 356.1809 356.1809 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 358.2663 358.2663 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 360.3518 360.3518 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 362.4372 362.4372 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 364.5226 364.5226 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 366.608 366.608 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 368.6935 368.6935 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 370.7789 370.7789 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 372.8643 372.8643 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 374.9497 374.9497 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 377.0352 377.0352 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 379.1206 379.1206 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 381.206 381.206 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 383.2915 383.2915 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 385.3769 385.3769 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 387.4623 387.4623 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 389.5477 389.5477 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 391.6332 391.6332 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 393.7186 393.7186 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 395.804 395.804 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 397.8894 397.8894 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 399.9749 399.9749 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 402.0603 402.0603 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 404.1457 404.1457 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 406.2312 406.2312 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 408.3166 408.3166 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 410.402 410.402 485165195 485165195 -2191.684 28
## Calculating likelihood using fixed parameter values: 412.4874 412.4874 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 414.5729 414.5729 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 416.6583 416.6583 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 418.7437 418.7437 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 420.8291 420.8291 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 422.9146 422.9146 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 425 425 485165195 485165195 -2191.684 2834.968
```

```
plot(x= alpha.values , y= likelihood.values, xlab=expression(alpha), ylab="LogLik", type="l", bty="n")
points(x=best$solution[1,1], y=best$loglik, pch=16, col="red")
text(x=best$solution[1,1], y=best$loglik, "unconstrained best", pos=4, col="red")
abline(h=(best$loglik - 2), lty="dotted") #Two log-likelihood
```



A rule of thumb for confidence for likelihood is all points two log likelihood units worse than the best value. Draw a dotted line on the plot to show this

Now, let's try looking at both theta parameters at once, keeping the other parameters at their MLEs

```
require("akima")
```

```
## Loading required package: akima
```

```
nreps<-400
theta1.points<-c(best$theta[1,1], rnorm(nreps-1, best$theta[1,1], 5*best$theta[1,2] + 0.1)) #center on
theta2.points<-c(best$theta[2,1], rnorm(nreps-1, best$theta[2,1], 5*best$theta[2,2])) #center on optima
likelihood.values<-rep(NA,nreps)

for (iteration in sequence(nreps)) {
    likelihood.values[iteration] <- OUwie.fixed(labeled.tree, trait, model="OUMV", alpha=best$solution[
}
```

```
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2191.684
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 370.1171 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3605.543
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2869.246
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1005.849
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1895.446
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -396.4208
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2316.801
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2036.921
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3889.934
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2568.231
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4109.022
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1671.346
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1395.862
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -906.5372
```

```
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 96.83195 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -576.7011
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2234.545
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3398.621
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1636.417
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2509.886
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1768.198
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2975.266
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4.121442
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2448.47 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1855.866
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1725.758
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1584.583
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2658.64 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -5234.522
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3366.294
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1023.808
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1453.344
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2741.357
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1678.836
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3347.304
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3621.491
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1222.862
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -344.5391
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1457.345
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4471.314
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2135.074
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4175.745
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2592.834
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -343.9362
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3398.663
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2836.696
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2021.598
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1906.466
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -202.3953
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3054.092
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2359.807
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3913.195
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -426.5717
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1437.668
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1665.139
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2093.037
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1303.468
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -220.6397
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1549.875
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -345.2953
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1933.172
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2640.873
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -441.9592
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1609.178
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2911.035
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 791.1557 3
```

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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -653.8629
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4874.735
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3107.188
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3994.1 2
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1791.839
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2152.215
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3092.449
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3305.896
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2195.796
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4445.14 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1068.555
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3003.003
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2584.128
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -690.1451
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1506.945
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1080.223
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1053.133
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 1078.104 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -589.5935
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2417.406
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1223.449
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -659.359 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4646.004
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4654.569
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2751.626
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1257.708
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1448.246
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2128.879
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 624.39 21
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2869.433
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2930.543
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4737.91 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1430.358
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3638.841
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2518.885
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2957.167
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3774.884
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 49.78498 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -801.9747
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4062.336
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2582.239
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1041.73 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 673.6732 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3179.39 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1496.335
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2437.935
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2311.426
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1013.353
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3065.399
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -5988.708
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3115.763
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2269.839
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2420.366
```

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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3611.403
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2220.876
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1607.525
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2571.182
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2068.736
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2171.662
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2182.378
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3892.7 20
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2068.617
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1068.49 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -675.846 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3329.76 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1578.374
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2467.08 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -107.9289
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4120.544
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4660.4 19
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2009.726
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3251.65 1
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3130.518
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1173.903
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3602.327
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1760.954
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2054.468
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3054.21 3
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1727.259
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3000.112
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2064.97 1
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -901.4983
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3473.245
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2381.901
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2824.9 34
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1418.819
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -511.4305
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2823.001
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -321.8628
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1075.614
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3856.091
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1806.919
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2342.385
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2678.523
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -444.6123
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3738.697
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2020.71 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1146.5 29
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1015.129
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -5033.819
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 283.1128 3
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3811.311
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2806.584
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4273.095
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1818.36 1
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2690.332
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -4339.448
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1387.724
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2027.28 1
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1664.744
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```

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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1425.374
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -1475.311
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 179.8172 3
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## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2579.694
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -3151.673
## Calculating likelihood using fixed parameter values: 10.05876 10.05876 485165195 485165195 -2388.691
```

Think of how long that took to do 400 iterations. Now remember how long the search took (longer).

```
likelihood.differences<-(-(likelihood.values-max(likelihood.values)))
```

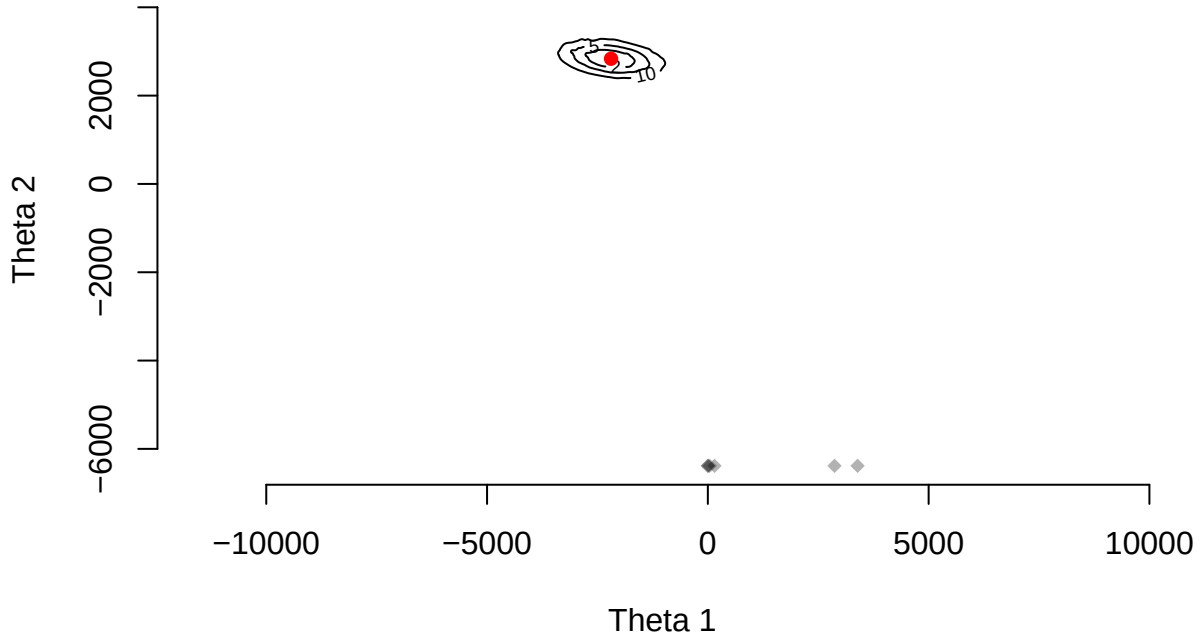
We are interpolating here: contour wants a nice grid. But by centering our simulations on the MLE values, we made sure to sample most thoroughly there

```
interpolated.points<-interp(x=theta1.points,y=theta2.points, z= likelihood.differences, linear=F, extrap

contour(interpolated.points, xlim=range(c(theta1.points, theta2.points)),ylim=range(c(theta1.points, the

points(x=best$theta[1,1], y=best$theta[2,1], col="red", pch=16)

points(x=trait$X[which(trait$Reg==1)],y=rep(min(c(theta1.points, theta2.points)), length(which(trait$Reg
points(y=trait$X[which(trait$Reg==2)],x=rep(min(c(theta1.points, theta2.points)), length(which(trait$Reg
```



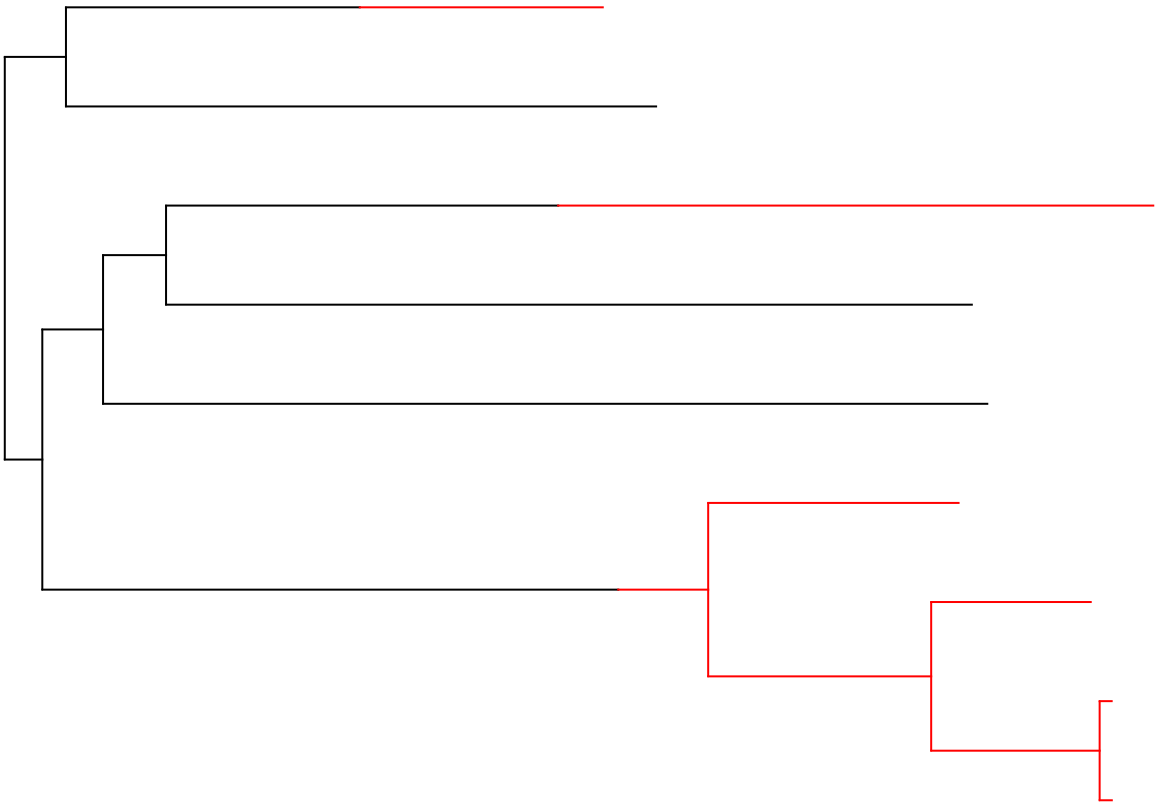
The below only works if the discrete trait rate is low, so you have a good chance of estimating where the state is. If it evolves quickly, hard to estimate where the regimes are, so some in regime 1 are incorrectly mapped in regime 2 vice versa. This makes the models more similar than they should be. See Revell 2013, DOI:10.1093/sysbio/sys084 for an exploration of this effect.

```
yearn::yearn(phytools)
trait.ordered<-data.frame(trait[,2],trait[,3],row.names=trait[,1])
trait.ordered<- trait.ordered[cleaned.cont$phy$tip.label,]
z<-trait.ordered[,1]
names(z)<-rownames(trait.ordered)
tree.mapped<-make.simmap(cleaned.cont$phy,z,model="ER",nsim=1)
```

```
## make.simmap is sampling character histories conditioned on the transition matrix
##
## Q =
##           0         1
## 0 -1.380484  1.380484
## 1  1.380484 -1.380484
## (estimated using likelihood);
## and (mean) root node prior probabilities
## pi =
##   0   1
## 0.5 0.5
```

```
## Done.
```

```
leg<-c("black","red")
names(leg)<-c(0,1)
plotSimmap(tree.mapped,leg,pts=FALSE,ftype="off", lwd=1)
```



```
simmapBased<-OUwie(tree.mapped,trait,model="OUMV", simmap.tree=TRUE, diagn=FALSE,root.age=0.80994)
```

```
## Warning: You might not have enough data to fit this model well
```

```
## Initializing...
## Finished. Begin thorough search...
## Finished. Summarizing results.
```

```
print(simmapBased)
```

```
##
## Fit
##        lnL      AIC     AICc model ntax
```

```
##  -72.96016 155.9203 175.9203  OUMV    9
##
##
## Rates
##                      0            1
## alpha    6.415409e+00 6.415409e+00
## sigma.sq 5.777721e+05 4.851652e+08
##
## Optima
##                 0         1
## estimate 25.11674 5392.9703
## se       21.24008  980.6098
##
## Arrived at a reliable solution
```

```
print(best)
```

```
##
## Fit
##        lnL      AIC     AICc model ntax
##  -77.97533 163.9507 173.9507   OUM    9
##
##
## Rates
##                      0            1
## alpha    1.005876e+01 1.005876e+01
## sigma.sq 4.851652e+08 4.851652e+08
##
## Optima
##                   0          1
## estimate -2191.6841 2834.96821
## se         267.2862   98.30063
##
## Arrived at a reliable solution
```

How does this compare to our best model from above? Should they be directly comparable? Based on the AICc, the best model is the OUM model estimated without performing stochastic mapping of the character traits. It seems to me these models are directly comparable. The make.simmap and ace approaches both attempt to estimate the history of a discrete character trait, with the difference being the latter allows for the the character history to vary along the length of the branch. Maybe this is an oversimplification, but it seems to me that the ace approach to estimating the character history is nested within the make.simmap approach of allowing these traits to vary along a branch.