```
knitr::opts_knit$set(root.dir = '~/Desktop/bio_modelling_course/mod5/proj5/')
```

Code for question 2

```
library(tidyverse)
```

```
## ── Attaching packages ─────────────────────────────────────────────────────── tidyverse 1.2.1 ──
```

```
## ✔ ggplot2 2.2.1     ✔ purrr   0.2.4
## ✔ tibble  1.4.2     ✔ dplyr   0.7.4
## ✔ tidyr   0.8.0     ✔ stringr 1.3.0
## ✔ readr   1.1.1     ✔ forcats 0.3.0
```

```
## ── Conflicts ────────────────────────────────────────────────────────── tidyverse_conflicts() ──
## ✖ dplyr::filter() masks stats::filter()
## ✖ dplyr::lag()    masks stats::lag()
```

```
library(gridExtra)
```

```
##
## Attaching package: 'gridExtra'
```

```
## The following object is masked from 'package:dplyr':
##
##     combine
```

```
bkv <- 0.02
bgv <- 0.30
bgc <- 0.32
fv <- 0.25
fc <- 0.07
la <- 0.05
lb <- 0.025
h1 <- 0.5
h4 <- 0.4

aV <- h1*bkv + h4*bgv
bV <- (fv + la)
aBC <- h4*bgc
bBC <- lb

g1 <- function(x) 1 - exp(-0.5*x)

f <- function(now) {
  dV <- aV - bV*now[1]
  dBC <- aBC - bBC*now[2] - fc*g1(now[2]/now[1])*now[2]
  c(dV,dBC)
}

find_equib <- function (init) {
  list(init,
       nlm(function(now) sum(f(now)**2), init)$estimate)
}
equibs <- map(map(1:10, function(x) rnorm(2, sd = 10)**2),
              find_equib)

equibs
```

```
## [[1]]
## [[1]][[1]]
## [1] 450.1387 243.2018
##
## [[1]][[2]]
## [1]  0.4333313 -1.0027958
##
##
## [[2]]
## [[2]][[1]]
## [1]  1.080837 48.322038
##
## [[2]][[2]]
## [1] 0.4333353 1.5393659
##
##
## [[3]]
## [[3]][[1]]
## [1]  67.08876 129.56966
##
## [[3]][[2]]
## [1]  0.4333304 -1.0027926
##
##
## [[4]]
## [[4]][[1]]
## [1] 21.610532  5.467587
##
## [[4]][[2]]
## [1] 0.4333328 1.5393737
##
##
## [[5]]
## [[5]][[1]]
## [1] 72.408838  9.545054
##
## [[5]][[2]]
## [1] 0.4333327 1.5393772
##
##
## [[6]]
## [[6]][[1]]
## [1] 167.2968 472.5032
##
## [[6]][[2]]
## [1] 0.4333329 1.5393769
##
##
## [[7]]
## [[7]][[1]]
## [1] 331.05052  23.89905
##
## [[7]][[2]]
## [1] 0.4333328 1.5393768
##
##
## [[8]]
## [[8]][[1]]
## [1]  2.867073 92.946316
##
## [[8]][[2]]
## [1] 0.4333335 1.5393799
##
##
## [[9]]
## [[9]][[1]]
## [1]  2.900686 11.447281
##
## [[9]][[2]]
## [1] 0.4333292 1.5393858
##
##
## [[10]]
## [[10]][[1]]
## [1]  8.162693 18.269167
##
## [[10]][[2]]
## [1] 0.4333327 1.5393769
```

```
equib <- equibs[[1]][[2]]
equib
```

```
## [1]  0.4333313 -1.0027958
```

```
-(fv + la)
```

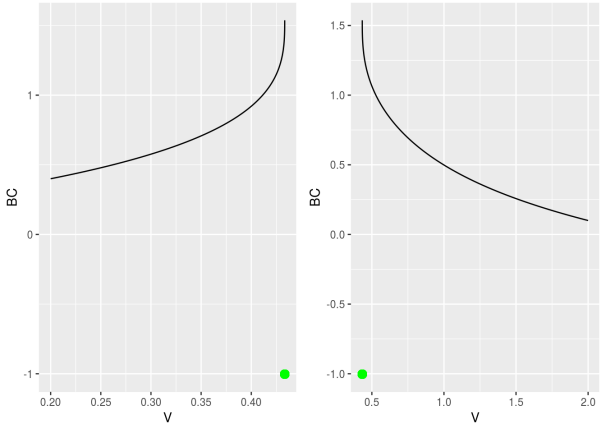
```
## [1] -0.3
```

```
-fc/2*((equib[1]/equib[2])**2)*exp(equib[1]/equib[2])
```

```
## [1] -0.004242428
```

```
euler_auton <- function(diff, x0,
                        n, h, improv = T,
                        names) {
  xs <- matrix(nrow = n, ncol = 2)
  xs[1,] <- x0
  for (i in 2:n) {
    xstar <- xs[i-1,] + diff(xs[i-1,])*h
    if (improv) {
      xs[i,] <- xs[i-1,] + (diff(xs[i-1,]) + diff(xstar))*h/2
    }
    else {
      xs[i,] <- xstar
    }
  }
  colnames(xs) <- names
  data.frame(xs)
}

sim1 <- euler_auton(f, c(0.2, 0.4),
                    1500, 1/24, T, c('V', 'BC'))
sim2 <- euler_auton(f, c(2, 0.1),
                    1500, 1/24, T, c('V', 'BC'))
grid.arrange(grobs = list(sim1 %>%
                            ggplot(aes(V, BC)) +
                            geom_path() +
                            geom_point(aes(x = equib[1], y = equib[2]), color='green', size=3),
                          sim2 %>%
                            ggplot(aes(V, BC)) +
                            geom_path() +
                            geom_point(aes(x = equib[1], y = equib[2]), color='green', size=3)),
             nrow=1)
```



Code for question 3

```
setwd('~/Desktop/bio_modelling_course/mod5/proj5/')

library(tidyverse)
library(xtable)

a <- 2
b <- 0.001
c <- 0.1
d <- 0.01
e <- 0.2
f <- 0.7

Geq <- function(alpha, beta) {

  b_temp <- a*(1-b/beta)
  dis <- b_temp**2 + 4*a*alpha

  c(0,
    1/alpha,
    1/d,
    (b_temp + sqrt(dis))/(2*a*alpha),
    (b_temp - sqrt(dis))/(2*a*alpha))
}

Feq <- function(alpha, beta) {
  c(0,
    0,
    (d-alpha)/(d*b),
    1/beta,
    1/beta)
}

Ueq <- function(G4, G5) {
  c(0,
    0,
    0,
    (d*G4 - 1)/e,
    (d*G5 - 1)/e)
}

find_equibs <- function(alpha, beta) {
  Geqs <- Geq(alpha, beta)
  Feqs <- Feq(alpha, beta)
  Ueqs <- Ueq(Geqs[4], Geqs[5])
  eqs <- matrix(c(Geqs, Feqs, Ueqs),
                nrow = 5)
  colnames(eqs) <- c('G', 'F', 'U')
  rownames(eqs) <- c('L1', 'L2', 'L3', 'L4', 'L5')
  eqs
}

find_equibs(0.002, 0.005)
```

```
##             G   F        U
## L1   0.0000000   0  0.000000
## L2 500.0000000   0  0.000000
## L3 100.0000000 800  0.000000
## L4 400.6240265 200 15.031201
## L5  -0.6240265 200 -5.031201
```

```
find_equibs(0.002, 0.0008)
```

```
##             G    F          U
## L1    0.000000    0   0.000000
## L2  500.000000    0   0.000000
## L3  100.000000  800   0.000000
## L4    1.968985 1250  -4.901551
## L5 -126.968985 1250 -11.348449
```

```
find_equibs(0.02, 0.0008)
```

```
##             G     F         U
## L1   0.000000     0  0.000000
## L2  50.000000     0  0.000000
## L3 100.000000 -1000  0.000000
## L4   1.753905  1250 -4.912305
## L5 -14.253905  1250 -5.712695
```

```
print(xtable(find_equibs(0.002, 0.005)), file='eq_t1.tex')
print(xtable(find_equibs(0.002, 0.0008)), file='eq_t2.tex')
print(xtable(find_equibs(0.02, 0.0008)), file='eq_t3.tex')

dF <- function(Geq,Feq,Ueq, alpha,beta) {
  matrix(c(a*(1-2*alpha*Geq-b*Feq),
           c*d*Feq,
           0,
           -a*b*Geq,
           c*(d*Geq-1-e*Ueq),
           -c*e*Feq,
           0,
           f*beta*Ueq,
           f*(beta*Feq - 1)),
         nrow=3
         )
}

L4 <- find_equibs(0.002, 0.005)[4,]
eigen(dF(L4[1], L4[2], L4[3], 0.002, 0.005))$values
```

```
## [1] -1.5077112+0.0000000i -0.0486405+0.4707959i -0.0486405-0.4707959i
```