Introduction

Scuba package (developed by Adrian Badderley from University of Western Australia) supports creation, manipulation and visualization of dive profiles, as well as running decompression models and gas toxicity calculations against them.

DIVE PROFILES

Dive Profile Creation

Dive profile is a piecewise line function with diver's depth on vertical axis and time on horizontal axis. To make it visually intuitive, the axis is filpped, so greater depth values are plotted lower on the graph.

To create a dive profile we use the `dive` function, which can take a series of vectors of length 2 with first value representing the depth (in meters) and the second value the duration at that depth (in minutes). Thus, they are sequentially used to describe the entire dive:

```
library(scuba) # load the scuba package
myDiveProfile = dive(c(18, 45),c(5,3)) # create the dive profile
plot(myDiveProfile) # plot the profile
```

Plotted graph shows us a piecewise linear function, that represents the diver descending to 18 metres, staying at that depth for 45 minutes, ascending to 5 metres, doing a 3 minute safety stop, and surfacing.

```
myDiveProfile # print the dive profile
```

```
Dive profile
gas: air
   time depth
1  0:00     0
2  0:36    18
3 45:36    18
4 46:19     5
5 49:19     5
6 49:36     0
```

Notice that we don't reach 18 meters until 36 seconds. Since we have not specified the ascent and descent rates, default ones are used. `ascent` and `descent` functions let us specify either the speed (in metres per minute) or time (in minutes) between the appropriate depths. Let's modify the above profile:

```
myDiveProfile = dive(descent(time=1), c(18, 45), ascent(speed=10), c(5,3),
ascent(speed=5))
plot(myDiveProfile)
myDiveProfile
```

```
Dive profile
gas: air
   time depth
1  0:00     0
2  1:00    18
```

```
3 46:00    18
4 47:18     5
5 50:18     5
6 51:18     0
```

Now we have explicitely stated that the initial descent will take 1 minute, the ascent to safety stop will be at 10 metres per minute, and after the diver will finally ascend to surface at 5 metres per minute.

We can get the dive duration and some other dsecriptive statistics with the `summary` command:

```
summary(myDiveProfile)
```

```
Dive to 18 metres on air
Total dive time: 51.3 minutes
Stages:
  depth time
1    18   45
2     5    3
Mean depth 16.6 metres
```

Dive Profile Manipulation

`dive` function can also combined multiple dives into a single profile:

```
myFirstDive = dive(c(18, 45), ascent(speed=10), c(5,3), ascent(speed=5))
mySecondDive = dive(c(12, 35), ascent(speed=5), c(5,3.5), ascent(speed=7))
bothDives = dive(myFirstDive, c(0, 90), mySecondDive)
plot(bothDives)
bothDives
```

```
Dive profile
gas: air
     time depth
1    0:00     0
2    0:36    18
3   45:36    18
4   46:54     5
5   49:54     5
6   50:54     0
7  140:54     0
8  140:54     0
9  141:18    12
10 176:18    12
11 177:42     5
12 181:12     5
13 181:54     0
```

We have just added a 90 minute surface interval between the two dives.

Conversely, `chop.dive` can be used to pull out a desired time interval into a separate dive profile.

```
first51Minutes = chop.dive(bothDives, 0, 51) # 0 <= t <= 51
everythingElse = chop.dive(bothDives, 51) # t >= 51
```

DECOMPRESSION THEORY

Decompression Sickness

The main reason why we need to keep track of dive profiles is to minimize the risk of decompression sickness (also called DCS or the bends for short). Not to be confused with barotrauma (bodily injury due to excess pressure of *actual* gasses, typically in divers' lungs, ears or sinuses) DCS deals with the bodily damage caused by excess pressure of *inert gasses* in any tissue (human body is around 60% water), including blood, skin and bones.

Any liquid may contain inert gasses in form of micronuclei or microbubbles. When the pressure of the inert gas becomes sufficiently greater than the atmospheric pressure (supersaturation) these microbubbles grow in size until they eventually surface. As they become too large they can cause physical damage to human tissue.

Decompression Models

Decompression theory deals with modeling the inert gas uptake and elimination in bodily tissue and estimating limits of supersaturation, beyond which DCS is likely to develop.

Decompression models can be divided into two types:
1. **Bubble models** model the size of a single microbubble and the probability that it will exceed the critical size at any point in time for a given dive profile. These include RGBM and VPM, neither of which is included by the scuba package.

2. **Gas content models** model the partial pressure of a given gas (typically nitrogen) in the given type of tissue at any point in time during the dive profile. Many are supported by the scuba package and are often called Haldane type models after John Scott Haldane, who came up with the first gas content model in 1908.

Haldane was comissioned by the British navy to determine how to prevent the bends in divers, and he experimented on himself, his sons and goats until he came up with the first decompression model. He divided the body into 5 different tissue groups (called compartments) that he treated independently, and for each one he empirically determined the *tissue half time*, during which the pressure of the inert gasses in that tissue will change so that the difference between it and atmospheric pressure is halfed.

In scuba package `pickmodel` lets us pick the gas content model to use in relevant calculations:

```
pickmodel("Haldane")
```

```
Haldane type decompression model
Name: Haldane
5 compartments
inert gas: N2
  N2.HalfT N2.M0 N2.dM
1        5  1.58  1.58
2       10  1.58  1.58
3       20  1.58  1.58
4       40  1.58  1.58
5       75  1.58  1.58
```

We can see that in Haldane's original 1908 model the half times for 5 compartments range from 5 minutes (this is mostly blood) to 75 minutes (mostly ligaments and cartiilage). M-value is the magnitude of supersaturation that a given tissue type can take before critically sized bubble formation are likely to form.

N2.M0 is the pressure at which it is safe to surface at 1 atm air pressure (in this model it is 1.58 for all tissue types), and N2.dM specifies by how much the inert gas pressure is allowed to increase with every additional atm of atmospheric pressure at different depths:
*maxToleratedN2Pressure = N2.M0 + (atmosphericPressureAtCurrentDepth-1) * N2.dM*

Haldane's general model is still in use today, but it has been refined many times since then. Swiss physician Dr Albert Bühlmann published a 16 compartment version in 1983:

```
pickmodel("ZH-L16A")
```

```
Haldane type decompression model
Name: Buehlmann ZH-L16A
17 compartments
inert gases: N2, He
   N2.HalfT    N2.M0    N2.dM He.HalfT    He.M0    He.dM
1       4.0 3.240098 1.980198     1.51 4.098113 2.355713
1b      5.0 2.962357 1.792757     1.88 3.715336 2.096436
2       8.0 2.535155 1.535155     3.02 3.123038 1.740038
3      12.5 2.246458 1.384658     4.72 2.723997 1.532097
4      18.5 2.034155 1.277955     6.99 2.430266 1.384466
5      27.0 1.897318 1.230618    10.21 2.240913 1.318913
6      38.3 1.778977 1.185677    14.48 2.077255 1.256755
7      54.3 1.678551 1.150351    20.53 1.938375 1.207875
8      77.0 1.592434 1.122334    29.11 1.819380 1.169180
9     109.0 1.518568 1.099868    41.20 1.736944 1.141944
10    146.0 1.464163 1.084363    55.19 1.677717 1.123217
11    187.0 1.422777 1.073077    70.69 1.644782 1.111482
12    239.0 1.385790 1.063490    90.34 1.621071 1.102171
13    305.0 1.352286 1.055186   115.29 1.614351 1.096251
14    390.0 1.321479 1.047779   147.42 1.607994 1.090394
15    498.0 1.293750 1.041450   188.24 1.602152 1.084952
16    635.0 1.268647 1.035947   240.03 1.590998 1.079098
```

N2 is usually the main concern is because its partial pressure is typically the greatest and because oxygen gets metabolized by the body. Bühlmann's ZH-L16A model also accounts for helium which is important for technical divers that breathe trimix.

PADI certified divers are trained to use PADI's recreational dive planner table, which is based on DSAT model:

```
pickmodel("DSAT")
```

For an interactive visualization of partial pressures in various compartments for any Haldane type model, showstates function can be used:

```
showstates(bothDives, "DSAT")
```

This will display the dive profile passed in as the first argument on the right hand side. When any point on this graph is selected by a mouse click, the left hand side will display a histogram showing partial pressure of N2 in each of the compartments tracked by the model at the selected time.

Try a different model:

```
showstates(bothDives, "ZH-L16A")
```

This time the histogram will show 16 bars. Once done interacting, press 'finish' button on the top right.

To get the same information in plain text, `haldane` function can be used. To get the desired point in time, we can use the previously mentioned `chop.dive` function. The following will show N2 pressures for all compartments 20 minutes into the dive:

```
haldane(chop.dive(bothDives, 0, 20), "ZH-L16A")

          N2 He
1  2.1651702  0
2  2.1193241  0
3  1.9539748  0
4  1.7350242  0
5  1.5322449  0
6  1.3544420  0
7  1.2164482  0
8  1.1061730  0
9  1.0210779  0
10 0.9574340  0
11 0.9169656  0
12 0.8901356  0
13 0.8689669  0
14 0.8522594  0
15 0.8389266  0
16 0.8284610  0
17 0.8202521  0
```

Note that we are breathing regular air (default), so He pressure stays at 0.

No Decompression Limit

No decompression limit is the maximum duration of time at which a diver can stay at a given depth in their current state (in other words with the current pressures in various compartments) without having to do step-wise decompression at different depths. Exceeding this duration is known as 'going into deco'.

Let us say we are planning a dive where the points of interest are at 30 meters depth, and we need to determine how long we can stay there without going into deco. `ndl` function lets us do that.

```
# Make a profile where we descend to 30m in 2 minutes
# end=0 means do not automatically finish the profile with an ascent to 0
noDecoProfile = dive(descent(time=2), c(30, 0), end=NA)

# save the diver state at the end of the profile according to a given model
diverStateAfter1min = haldane(noDecoProfile, model="DSAT")

# calculate the no decompression limit for 30 minutes after gradually
descending there in 2 minutes:
ndl(30, prevstate=diverStateAfter1min, model="DSAT")

[1] 18.18637
attr(,"controlling")
[1] 2
```

We can stay there for little over 18 minutes. The second returned value is the number of the controlling compartment, which is the number of the compartment which would exceed the m-value if we overstay the no decompression limit.

WORD OF CAUTION

Decompression sickness is probabilistic in nature, and although less likely, it is possible to develop even in people who drive within the limits of decompression models. Other, unmeasured factors come into play, such as diver's physiology (which changes every day), heat, dehydration, exercise state, and many others.

Many people like to further increase the odds by using various 'gradient factors' which amount to only allowing themselves to reach a fraction of the M-value, but the only sure way to not get decompression illness is to not dive.

SOURCES

Scuba Package CRAN documentation:
https://cran.r-project.org/web/packages/scuba/scuba.pdf
https://cran.r-project.org/web/packages/scuba/vignettes/intro.pdf

Adrian Baddeley, the package author and maintainer:
http://staffhome.ecm.uwa.edu.au/~00025879/

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http://www.nigelhewitt.co.uk/diving/maths/deco.html
http://www.rsc.org/chemistryworld/Issues/2010/August/HaldanesBloodGasAnalyser.asp

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