Graunt and US 1993 Life Table

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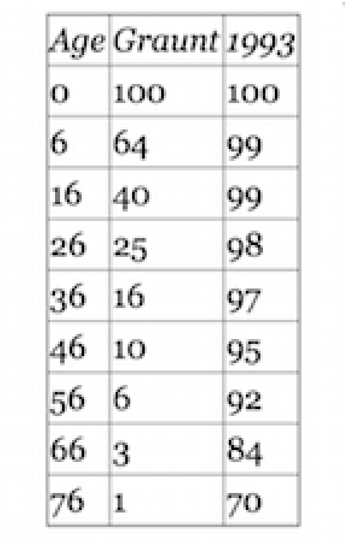
Source of Data

```
knitr::include_graphics("../pics/graunt_table.png")
```



Age	Graunt	1993
0	100	100
6	64	99
16	40	99
26	25	98
36	16	97
46	10	95
56	6	92
66	3	84
76	1	70

Data Input

- Graunt's Life Table

```
graunt <- data.frame(x = c(0, seq(6, 76, by = 10)),
                     xPo_g = c(100, 64, 40, 25, 16, 10, 6, 3, 1))
```

More data

- US 1993 life table for the same age group

```
us93 <- data.frame(x = graunt$x,
                   xPo_us = c(100, 99, 99, 98, 97, 95, 92, 84, 70))
```

Data Extraction

There are many ways to extract part of `us93` data frame.

```
us93["xPo_us"]
```

```
##   xPo_us
## 1    100
## 2     99
## 3     99
## 4     98
## 5     97
## 6     95
## 7     92
## 8     84
## 9     70
```

```
us93["xPo_us"][[1]]
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93["xPo_us"]$xPo_us
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93["xPo_us"]$xPo
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93[2]
```

```
##   xPo_us
## 1    100
## 2     99
## 3     99
## 4     98
## 5     97
## 6     95
## 7     92
## 8     84
## 9     70
```

```
us93[2][[1]]
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93[2]$xPo_us
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93[ , "xPo_us"]
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93[ , 2]
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93$xPo_us
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

```
us93$xPo
```

```
## [1] 100  99  99  98  97  95  92  84  70
```

Into one single data frame

Combine two data frames into one single data frame, compare the results.

```
(graunt_us <- data.frame(graunt, xPo_us = us93$xPo))
```

```
##    x xPo_g xPo_us
## 1  0   100    100
## 2  6    64     99
## 3 16    40     99
## 4 26    25     98
## 5 36    16     97
## 6 46    10     95
## 7 56     6     92
## 8 66     3     84
## 9 76     1     70
```

```
(graunt_us_2 <- data.frame(graunt, us93[2]))
```

```
##    x xPo_g xPo_us
## 1  0   100    100
## 2  6    64     99
## 3 16    40     99
## 4 26    25     98
## 5 36    16     97
## 6 46    10     95
## 7 56     6     92
## 8 66     3     84
## 9 76     1     70
```

```
(graunt_us_3 <- data.frame(graunt, us93[, 2]))
```

```
##    x xPo_g us93...2.
## 1  0   100       100
## 2  6    64        99
## 3 16    40        99
## 4 26    25        98
## 5 36    16        97
## 6 46    10        95
## 7 56     6        92
## 8 66     3        84
## 9 76     1        70
```

Life Expectancy

The basic principle is that the area under the survival function is the life expectancy.

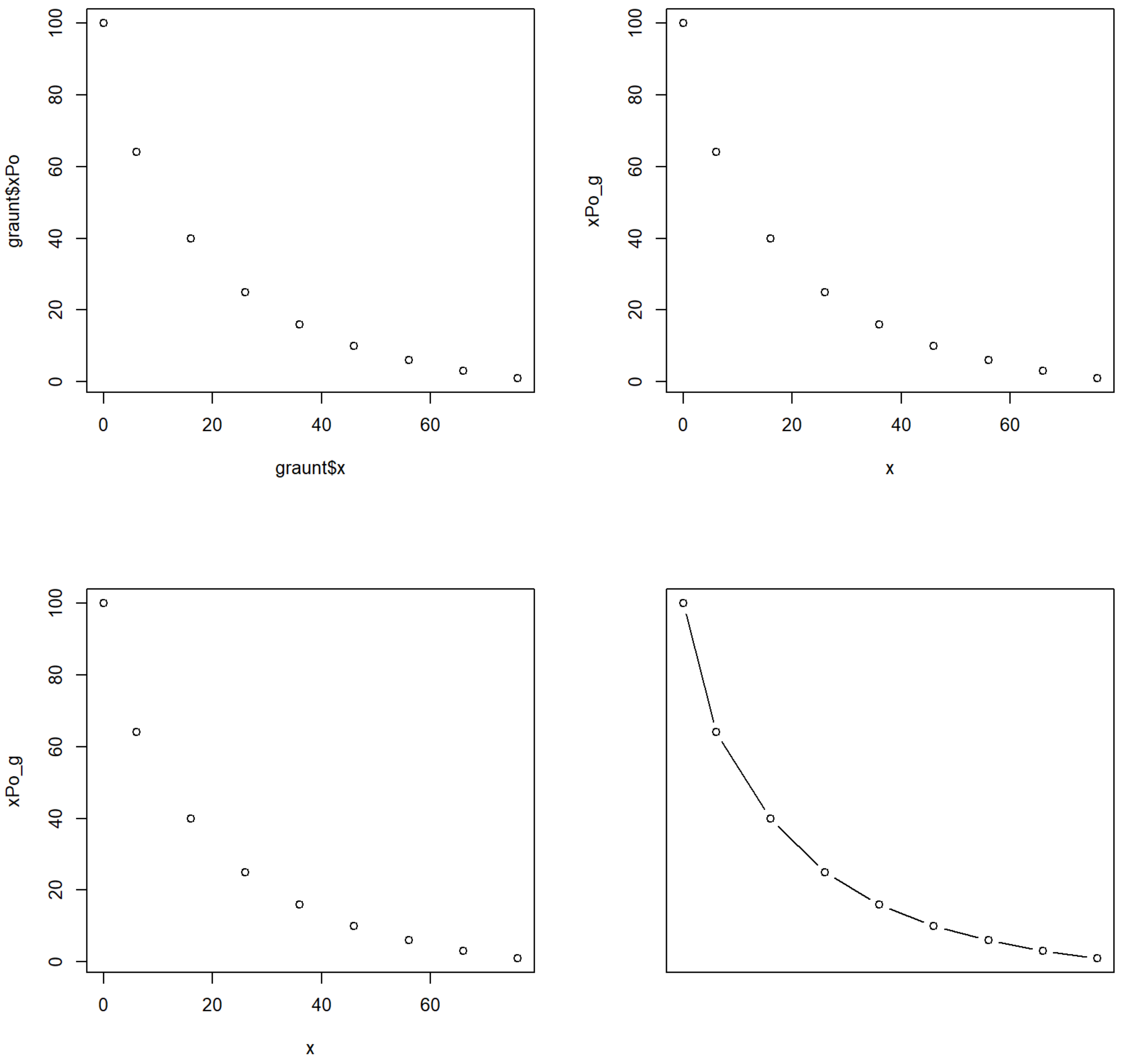
$X \geq 0, X \sim F(x)$ => $X \equiv F^{-1}(U), U \sim U(0,1)$, therefore,

$E(X) = E\{F^{-1}(U)\} = \int_0^1 F^{-1}(u)du = \int_0^\infty 1 - F(x)dx = \int_0^\infty S(x)dx$

Step by step approach to draw survival function plot

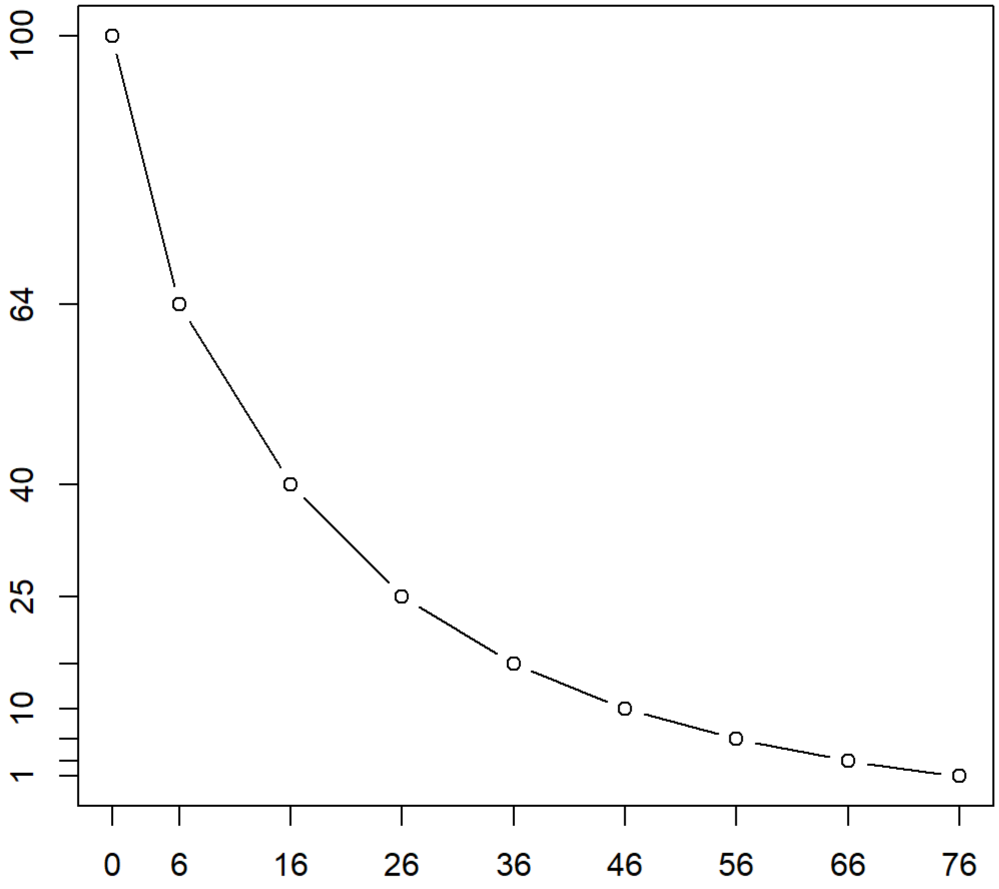
1. Basic plot with points and lines, compare the following threes methods

```
par(mfrow = c(2, 2))
plot(x = graunt$x, y = graunt$xPo)
plot(xPo_g ~ x, data = graunt)
plot(graunt)
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
```



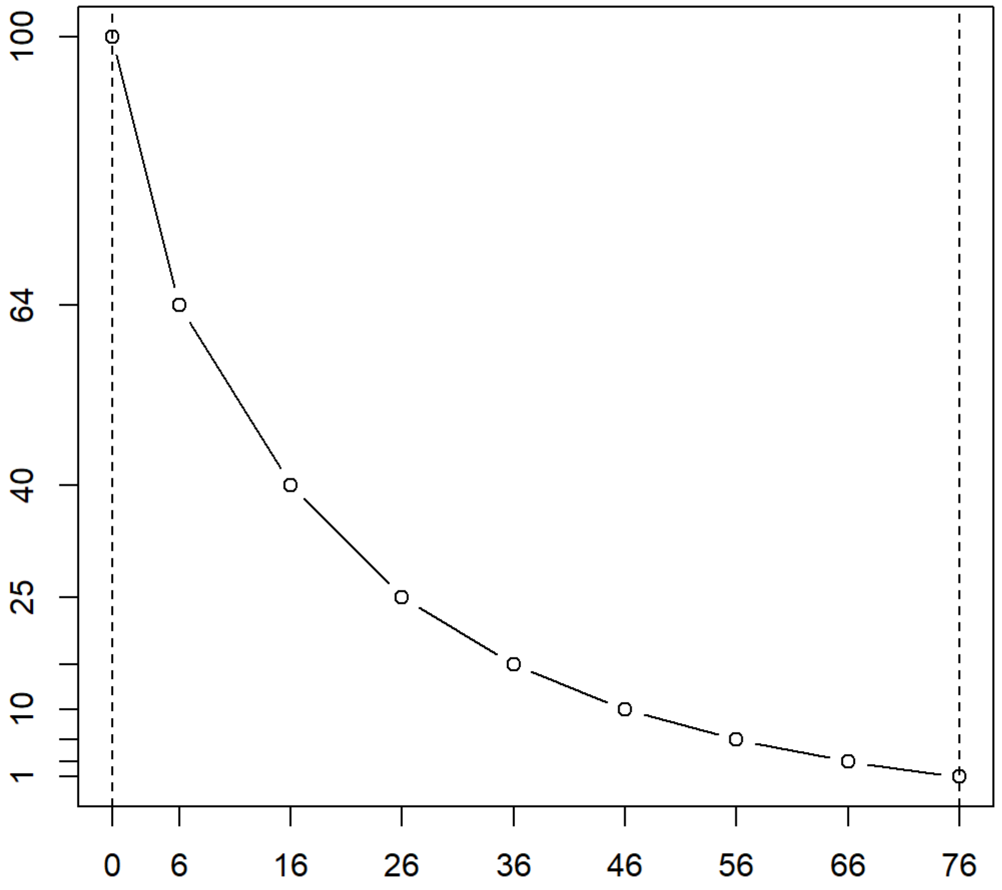
2. Denote the ages and observed survival rates on the axes

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo_g, labels = graunt$xPo_g)
```



3. Denote the age 0 and 76 by dotted lines

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo_g, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
```



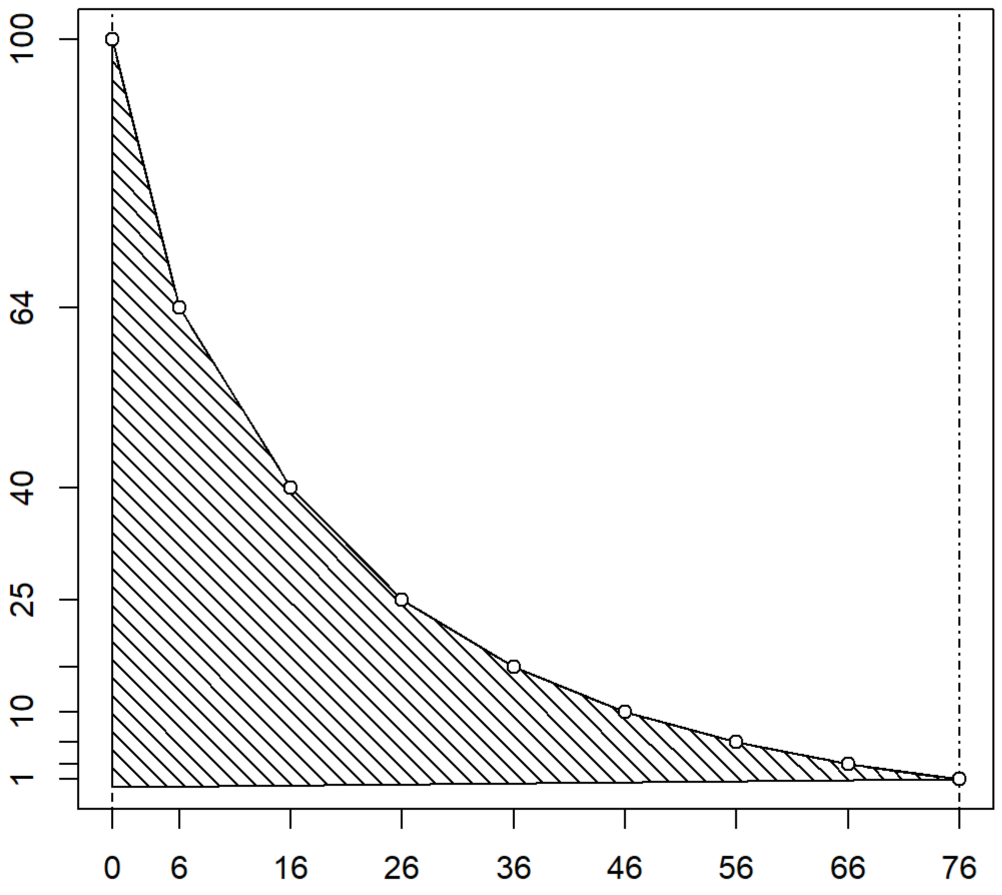
Setting up coordinates for `polygon()` (Clockwise)

```
graunt_x <- c(graunt$x, 0)
graunt_y <- c(graunt$xPo_g, 0)
graunt_poly <- data.frame(x = graunt_x, y = graunt_y)
```

4. Shading

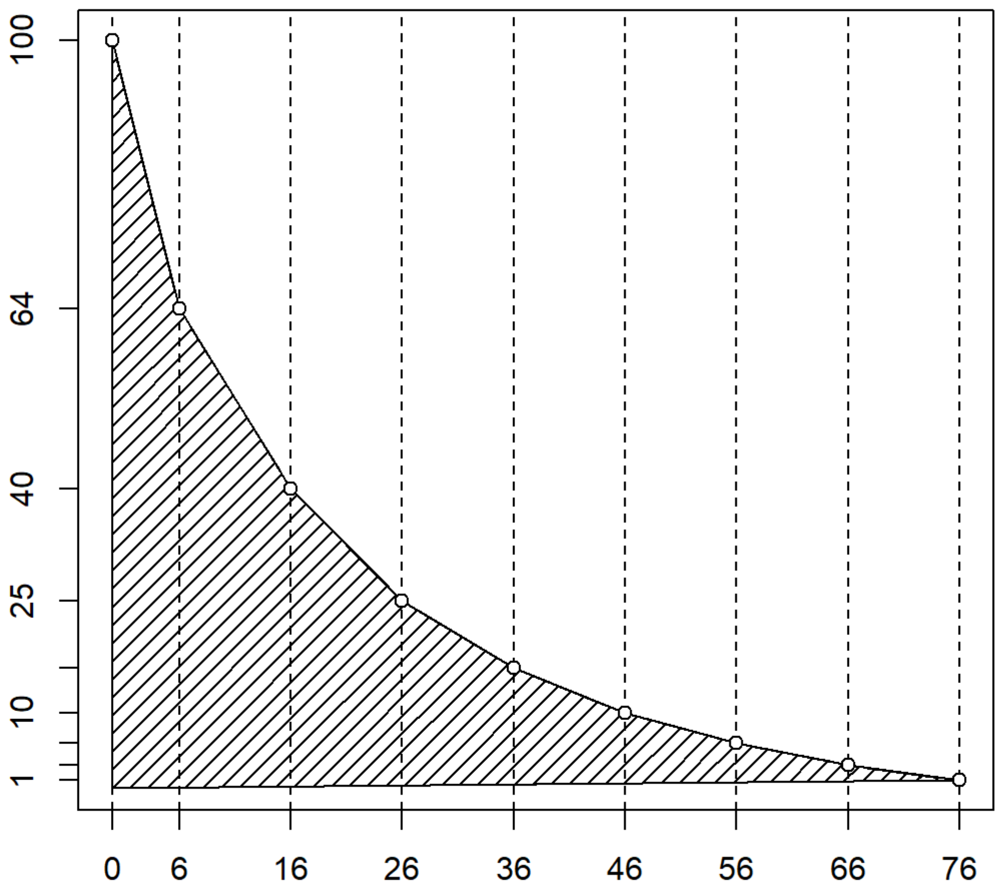
Note the effect of the last line of code.

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo_g, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 4)
polygon(graunt_poly, density = 15, angle = 135)
points(graunt, pch = 21, col = "black", bg = "white")
```



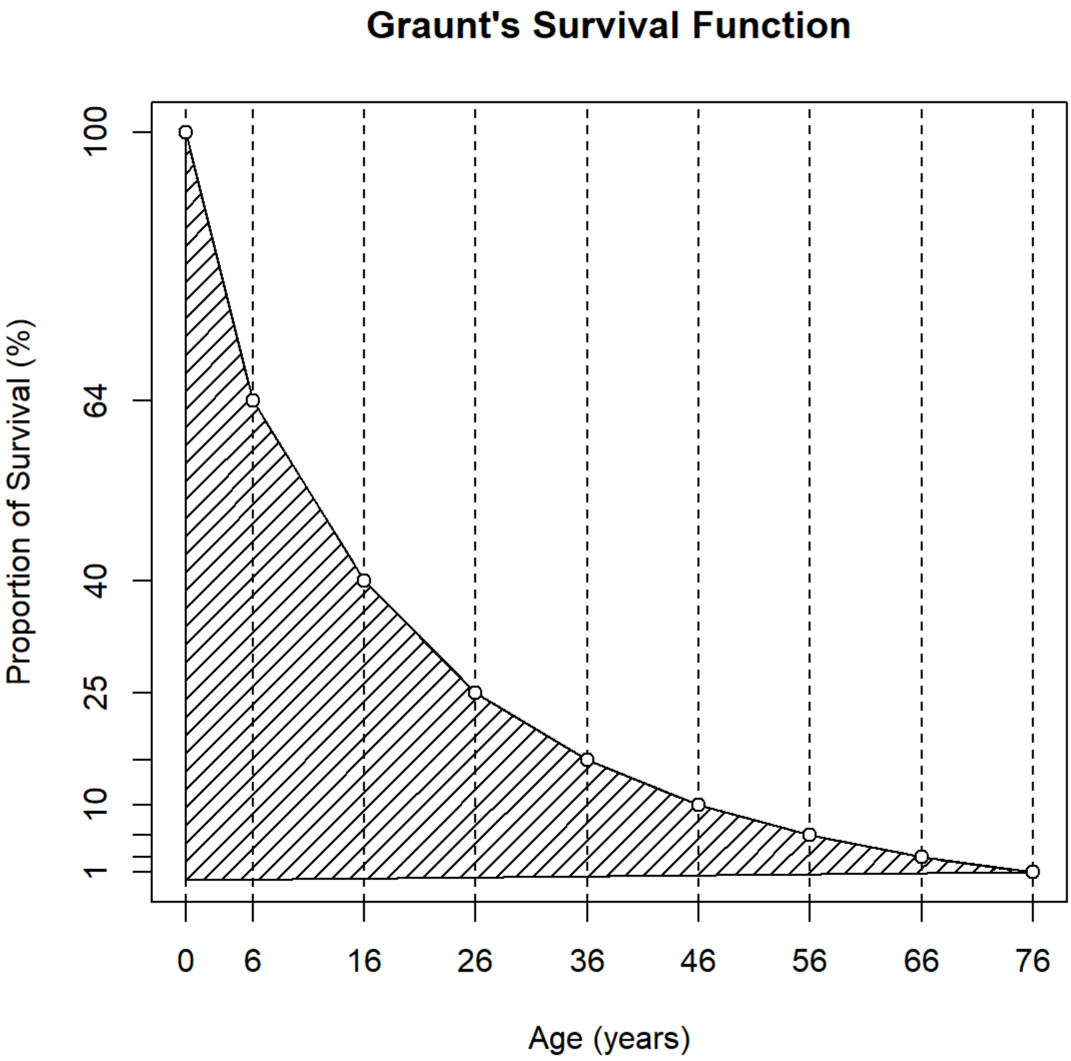
5. Grids

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo_g, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
polygon(graunt_poly, density = 15)
abline(v = graunt$x, lty = 2)
points(graunt, pch = 21, col = "black", bg = "white")
```



6. Title, x-axis label, and y-axis label

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo_g, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
polygon(graunt_poly, density = 15)
abline(v = graunt$x, lty = 2)
points(graunt, pch = 21, col = "black", bg = "white")
main_title <- "Graunt's Survival Function"
x_lab <- "Age (years)"
y_lab <- "Proportion of Survival (%)"
title(main = main_title, xlab = x_lab, ylab = y_lab)
```



Area under the curve

The area under the curve can be approximated by the sum of the areas of trapezoids, therefore the area is $\sum_{i=1}^{n-1}(x_{i+1} - x_i) \times \frac{1}{2}(y_i + y_{i+1})$.

- `diff()` , `head()` , and `tail()` can be used to write a function to compute the area easily.

```
area.R <- function(x, y) {
  sum(diff(x) * (head(y, -1) + tail(y, -1))/2)
  }
area.R(graunt$x, graunt$xPo_g)/100
```

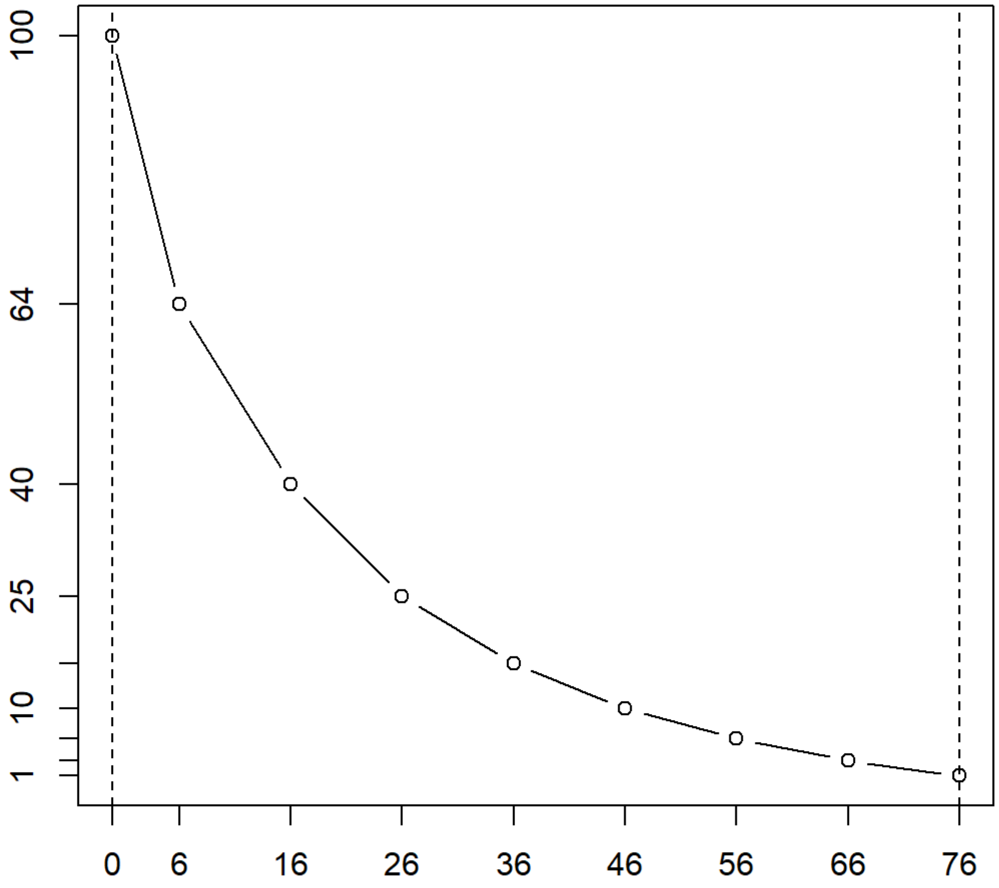
```
## [1] 18.17
```

Comparison with US 1993 life table

The shaded area between the survival function of Graunt and that of US 1993 represents the difference of life expectancies.

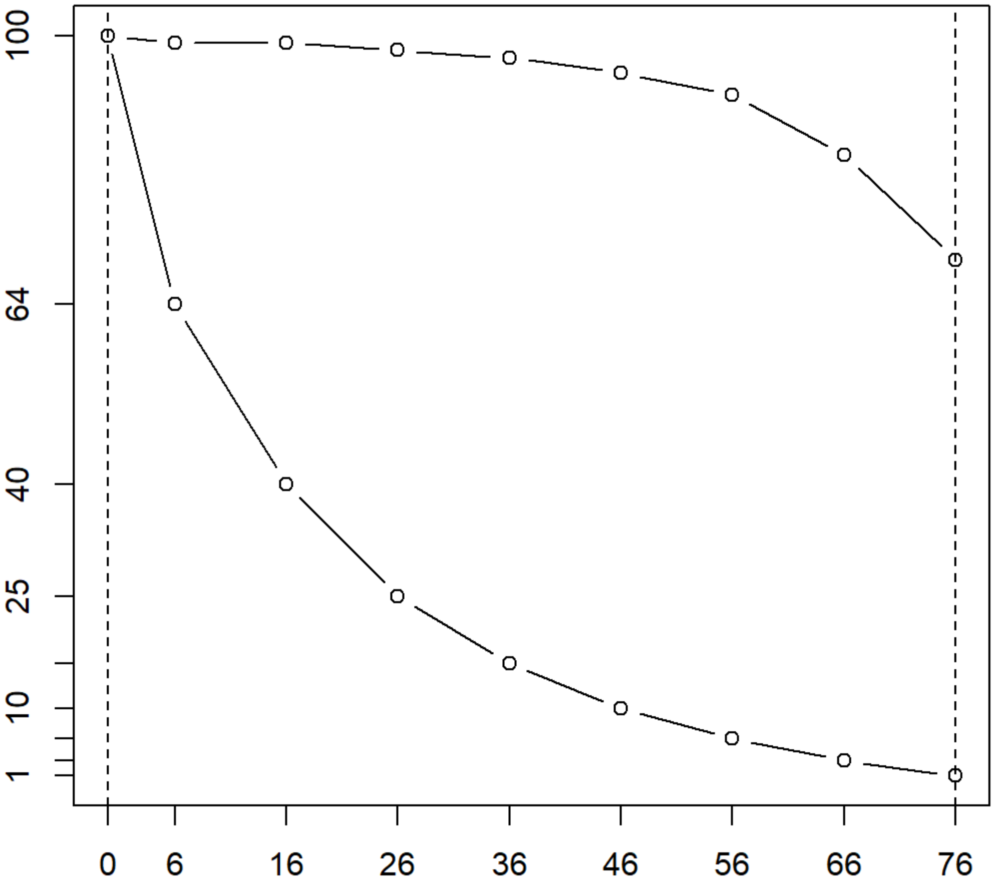
1. Draw Graunt's first with axes, lower and upper limits. Check what happens if you place `abline(...)` right after `plot(...)` .

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
```



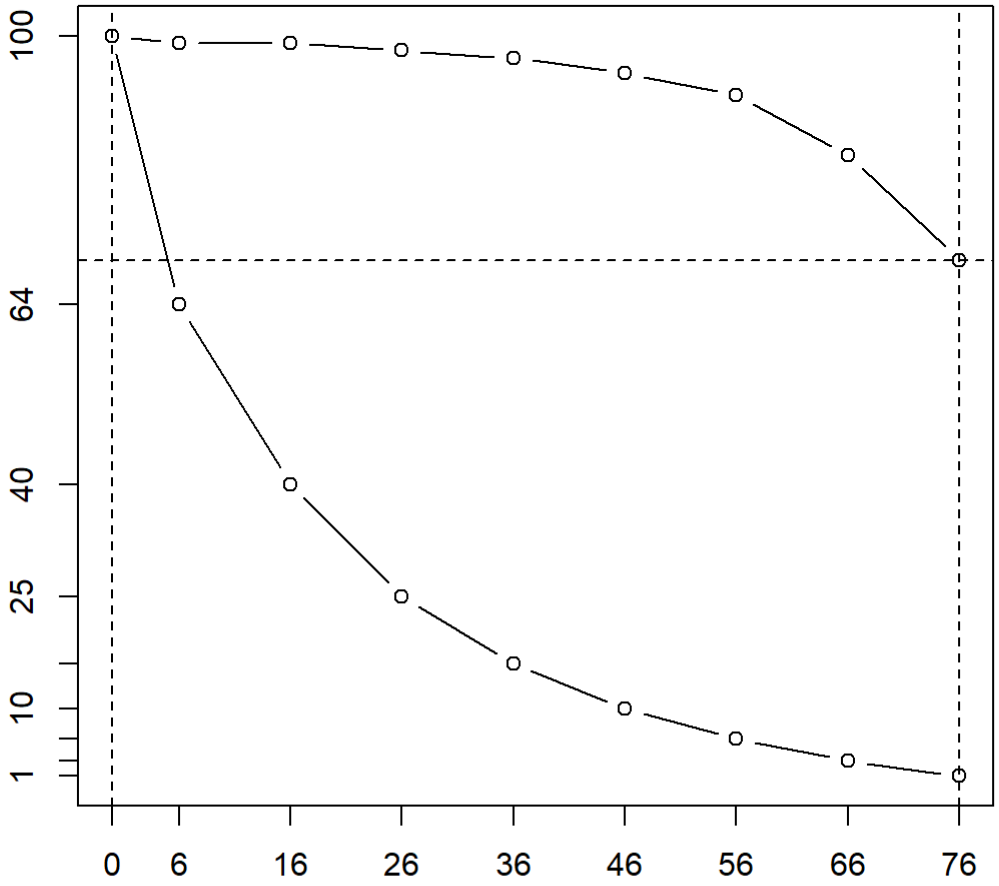
2. Add US 1993 survival function

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
lines(us93, type = "b")
```



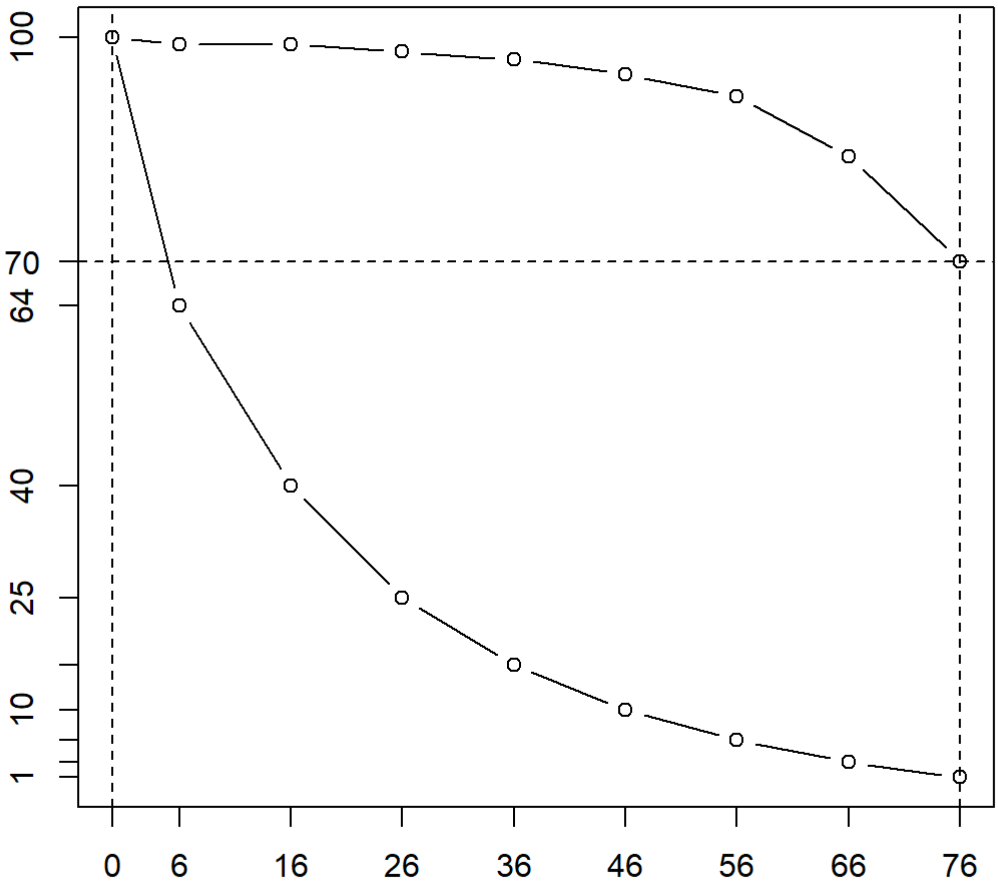
3. Actually, US 1993 life table is truncated at the age 76. Specify that point.

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
lines(us93, type = "b")
abline(h = 70, lty = 2)
```



4. Using `las = 1` to specify 70%.

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
lines(us93, type = "b")
abline(h = 70, lty = 2)
axis(side = 2, at = 70, labels = 70, las = 1)
```



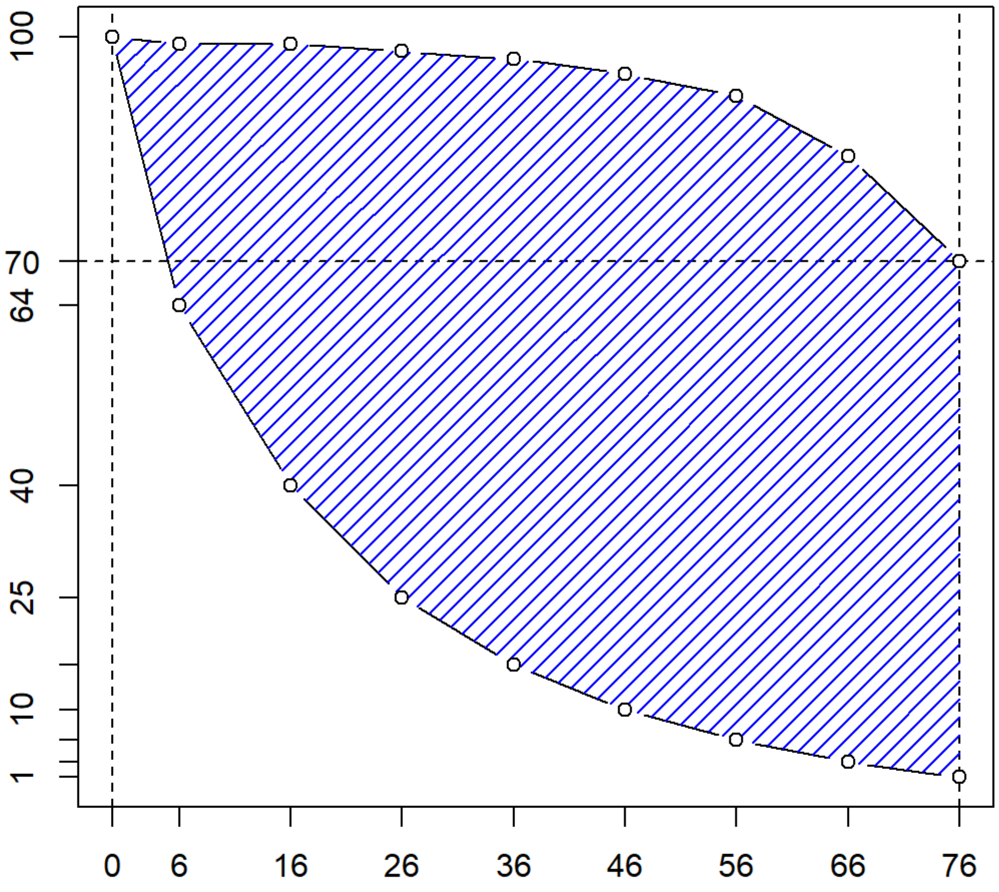
Setting coordinates for `polygon()`

```
us_graunt_x <- c(us93$x, rev(graunt$x))
us_graunt_y <- c(us93$xPo_us, rev(graunt$xPo_g))
us_graunt <- data.frame(x = us_graunt_x, y = us_graunt_y)
```

5. Shading

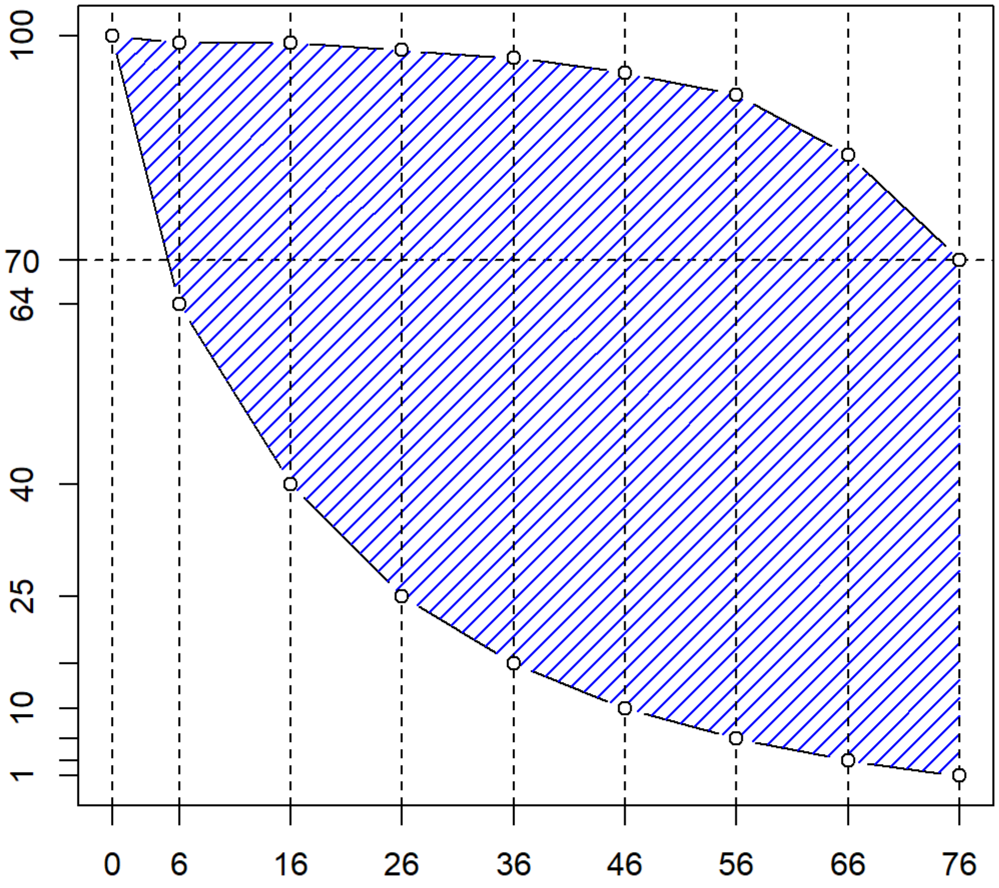
What is the effect of `border = NA`, the last line of code?

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
lines(us93, type = "b")
abline(h = 70, lty = 2)
axis(side = 2, at = 70, labels = 70, las = 1)
polygon(us_graunt, density = 15, col = "blue", border = NA)
points(us_graunt, pch = 21, col = "black", bg = "white")
```



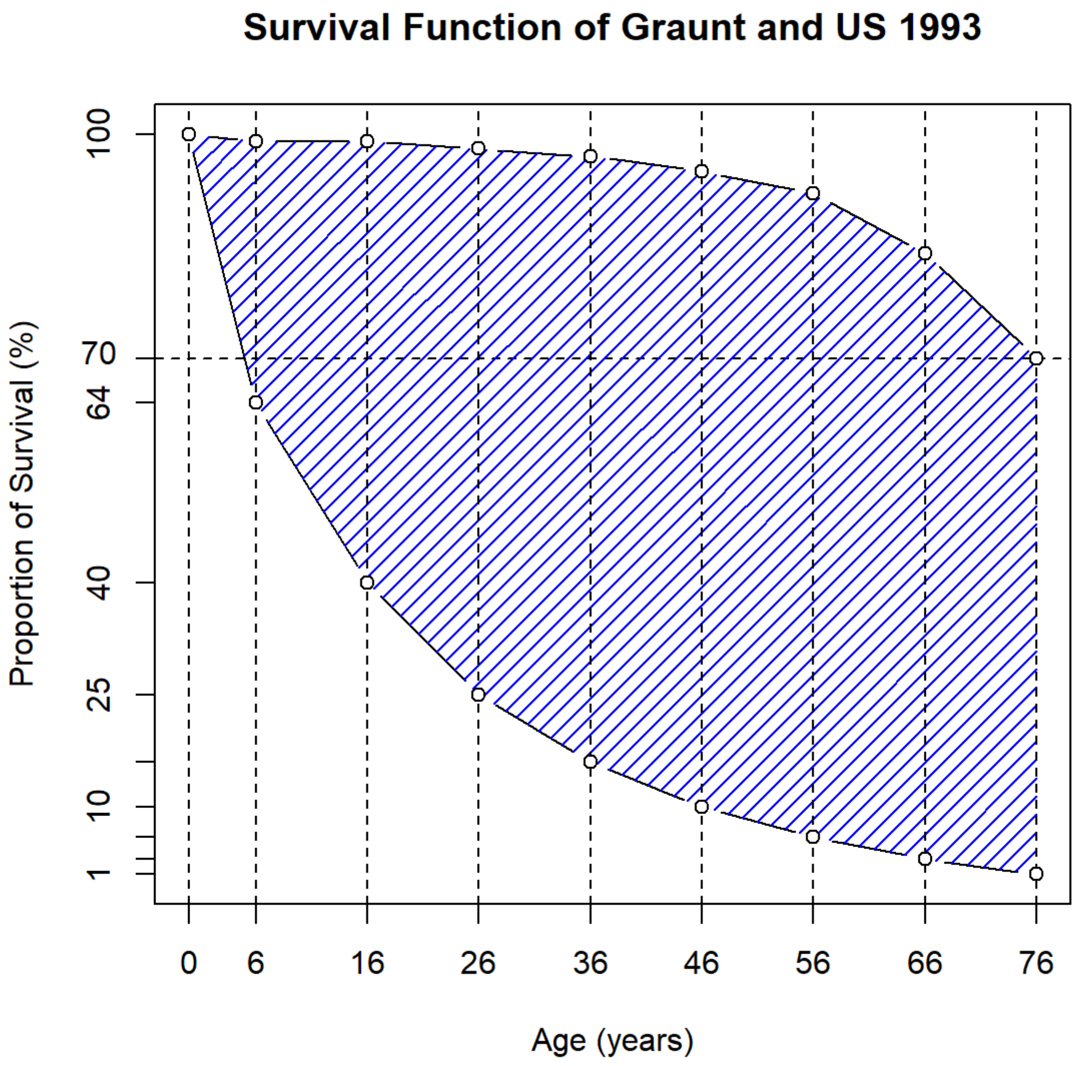
6. Grids

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
lines(us93, type = "b")
abline(h = 70, lty = 2)
axis(side = 2, at = 70, labels = 70, las = 1)
polygon(us_graunt, density = 15, col = "blue", border = NA)
abline(v = graunt$x, lty = 2)
points(us_graunt, pch = 21, col = "black", bg = "white")
```



7. Title, x-axis and y-axis labels

```
plot(graunt, ann = FALSE, xaxt = "n", yaxt = "n", type = "b")
axis(side = 1, at = graunt$x, labels = graunt$x)
axis(side = 2, at = graunt$xPo, labels = graunt$xPo_g)
abline(v = c(0, 76), lty = 2)
lines(us93, type = "b")
abline(h = 70, lty = 2)
axis(side = 2, at = 70, labels = 70, las = 1)
polygon(us_graunt, density = 15, col = "blue", border = NA)
abline(v = graunt$x, lty = 2)
points(us_graunt, pch = 21, col = "black", bg = "white")
main_title_g_us <- "Survival Function of Graunt and US 1993"
title(main = main_title_g_us, xlab = x_lab, ylab = y_lab)
```



```
dev.copy(device = png, file = "../pics/graunt_us93.png")
```

```
## png
##   3
```

```
dev.off()
```

```
## png
##   2
```

Life expectancy

The area under the US 1993 survival function is

```
area.R(us93$x, us93$xPo_us)/100
```

```
## [1] 70.92
```

The area of shaded region is

```
area.R(us93$x, us93$xPo_us)/100 - area.R(graunt$x, graunt$xPo_g)/100
```

```
## [1] 52.75
```

ggplot

```
library(ggplot2)
```

Data Reshape

Attach `reshape2` package to change wide format to long format

```
library(reshape2)
```

How `melt()` works

```
graunt_us_melt <- melt(graunt_us,
                       id.vars = "x",
                       measure.vars = c("xPo_g", "xPo_us"),
                       value.name = "xPo",
                       variable.name = "times")
graunt_us_melt
```

```
##     x  times xPo
## 1   0  xPo_g 100
## 2   6  xPo_g  64
## 3  16  xPo_g  40
## 4  26  xPo_g  25
## 5  36  xPo_g  16
## 6  46  xPo_g  10
## 7  56  xPo_g   6
## 8  66  xPo_g   3
## 9  76  xPo_g   1
## 10  0 xPo_us 100
## 11  6 xPo_us  99
## 12 16 xPo_us  99
## 13 26 xPo_us  98
## 14 36 xPo_us  97
## 15 46 xPo_us  95
## 16 56 xPo_us  92
## 17 66 xPo_us  84
## 18 76 xPo_us  70
```

```
str(graunt_us_melt)
```

```
## 'data.frame':    18 obs. of  3 variables:
##  $ x    : num  0 6 16 26 36 46 56 66 76 0 ...
##  $ times: Factor w/ 2 levels "xPo_g","xPo_us": 1 1 1 1 1 1 1 1 1 2 ...
##  $ xPo  : num  100 64 40 25 16 10 6 3 1 100 ...
```

- Change factor levels of `times`

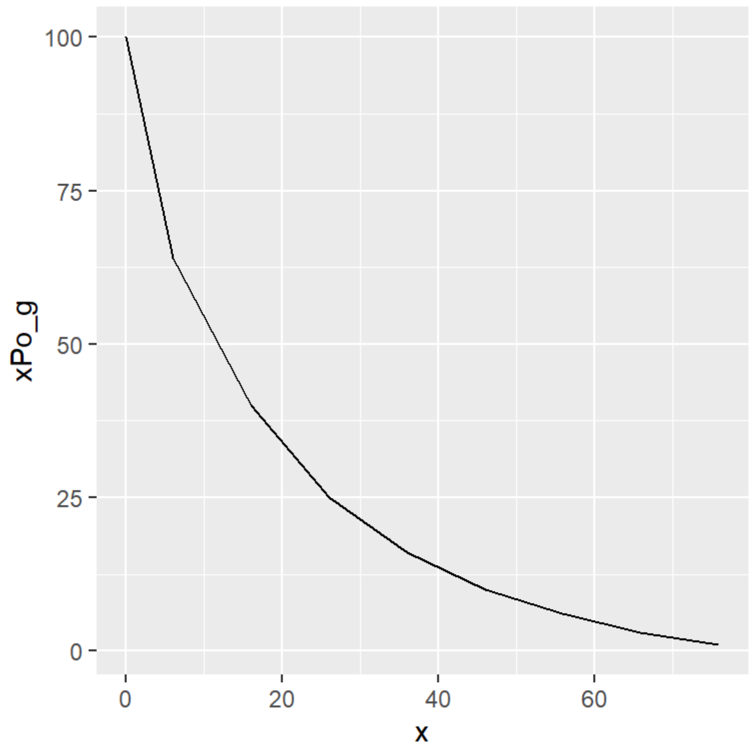
```
levels(graunt_us_melt$times) <- c("Graunt", "US1993")
graunt_us_melt
```

```
##     x  times xPo
## 1   0 Graunt 100
## 2   6 Graunt  64
## 3  16 Graunt  40
## 4  26 Graunt  25
## 5  36 Graunt  16
## 6  46 Graunt  10
## 7  56 Graunt   6
## 8  66 Graunt   3
## 9  76 Graunt   1
## 10  0 US1993 100
## 11  6 US1993  99
## 12 16 US1993  99
## 13 26 US1993  98
## 14 36 US1993  97
## 15 46 US1993  95
## 16 56 US1993  92
## 17 66 US1993  84
## 18 76 US1993  70
```

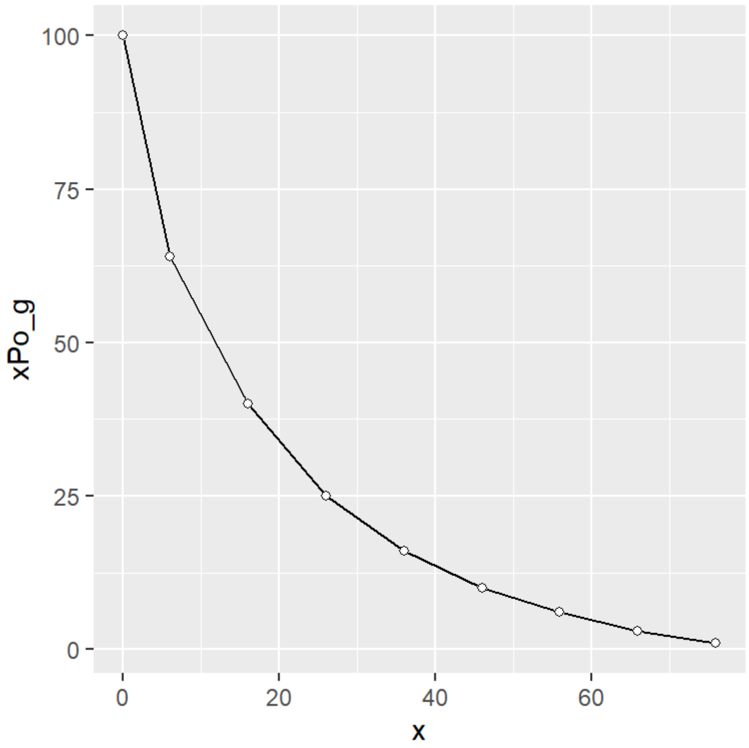
Graunt

Structure of ggplot

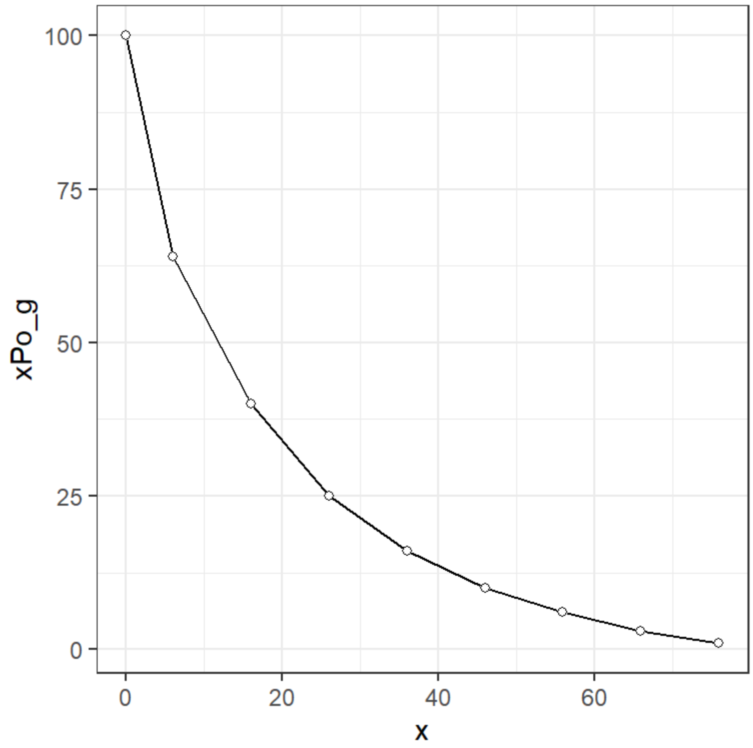
```
(g1 <- ggplot(data = graunt,
              mapping = aes(x = x, y = xPo_g)) +
   geom_line())
```



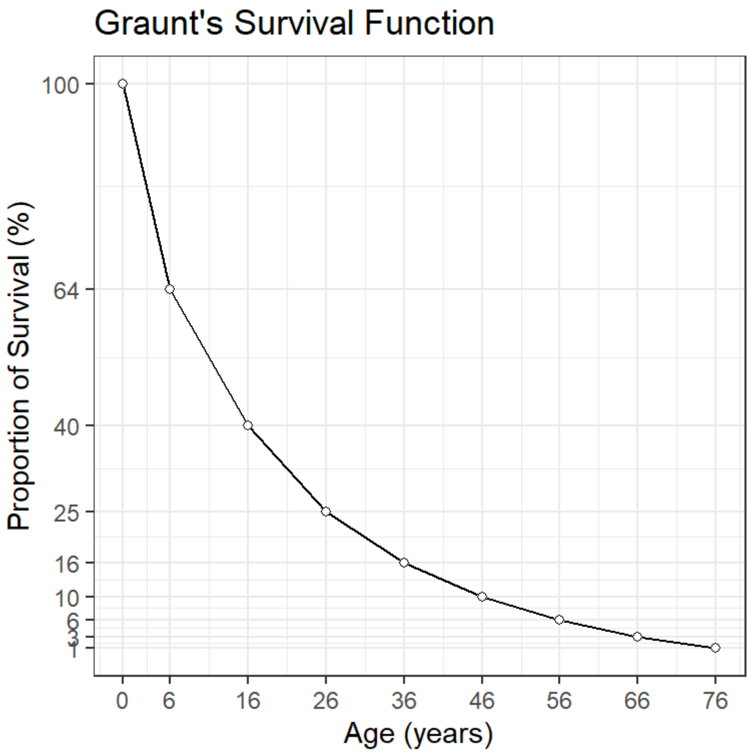
```
(g2 <- g1 +
  geom_point(shape = 21, fill = "white"))
```



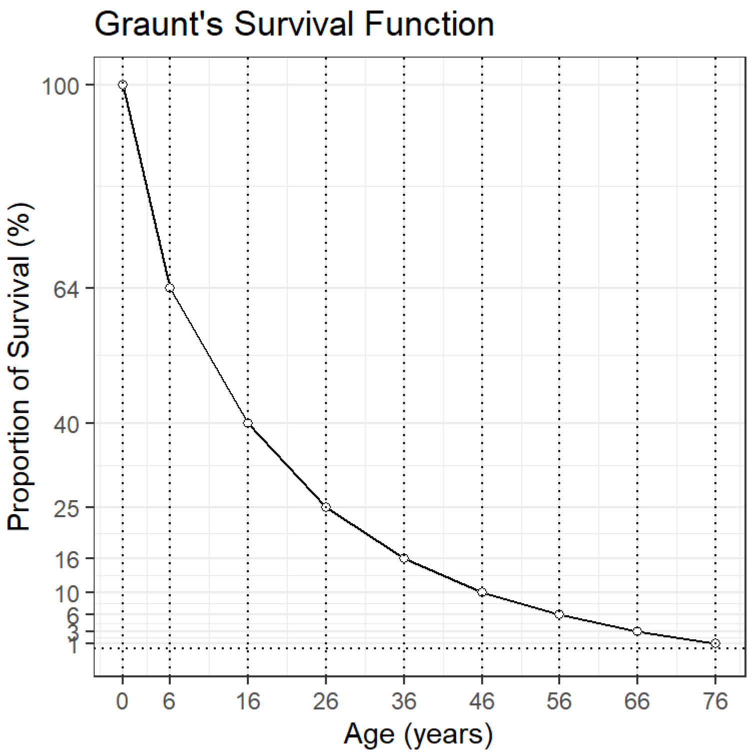
```
(g3 <- g2 +
  theme_bw())
```



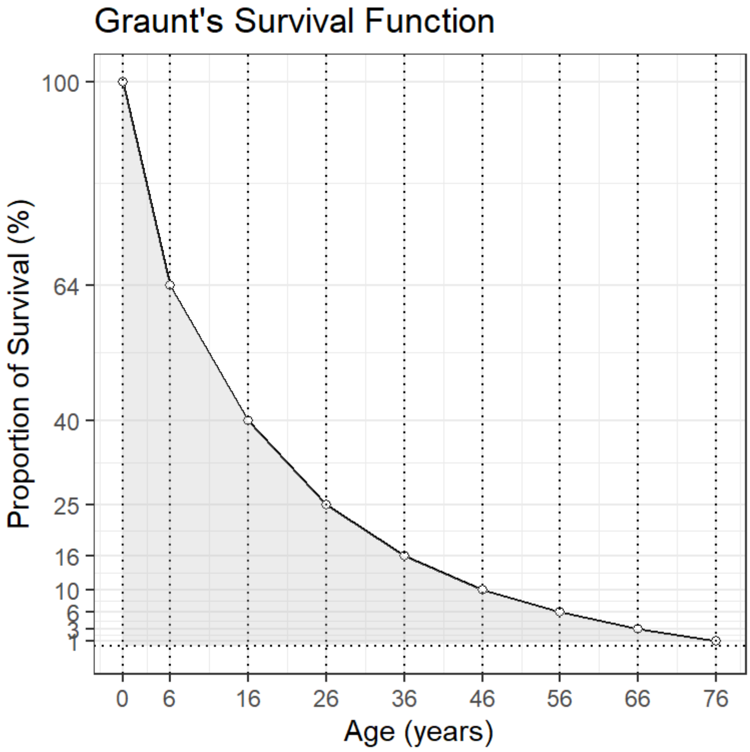
```
(g4 <- g3 +
   xlab(x_lab) +
   ylab(y_lab) +
   ggtitle(main_title) +
   scale_x_continuous(breaks = graunt$x) +
   scale_y_continuous(breaks = graunt$xPo_g))
```



```
(g5 <- g4 +
  geom_vline(xintercept = graunt$x, linetype = "dotted") +
  geom_hline(yintercept = 0, linetype = "dotted"))
```

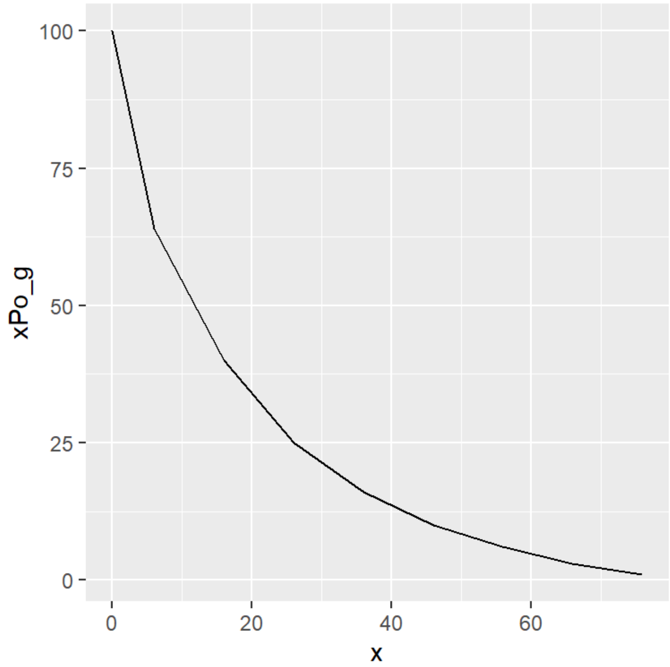


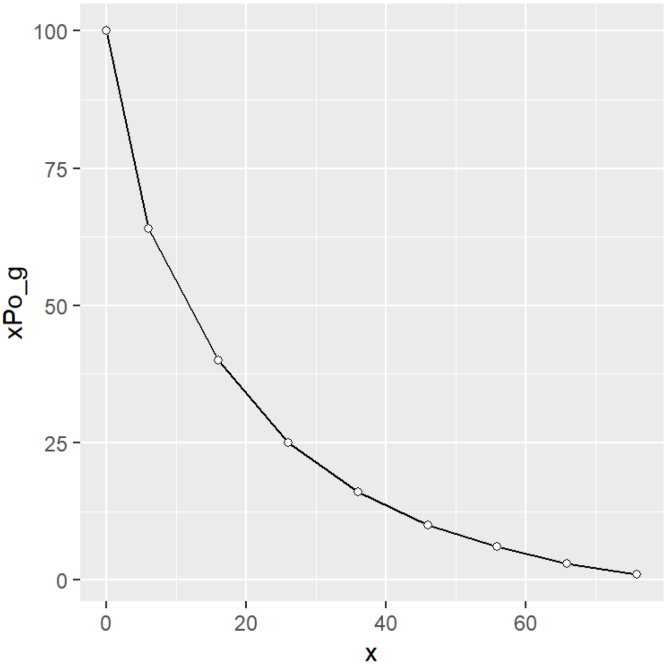
```
(pg5 <- g5 +
  geom_polygon(data = graunt_poly,
               mapping = aes(x = x, y = y),
               alpha = 0.3, fill = "grey"))
```

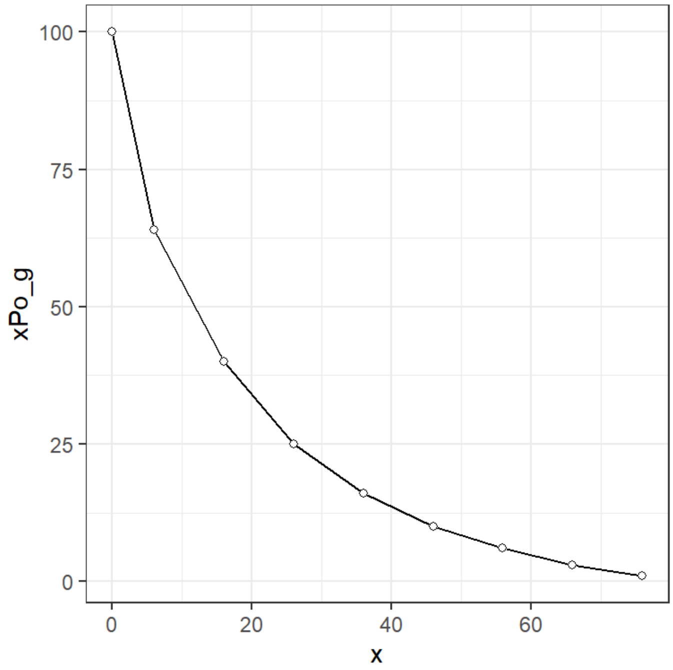


```
# ggsave("../pics/graunt_poly_ggplot.png", pg5)
```

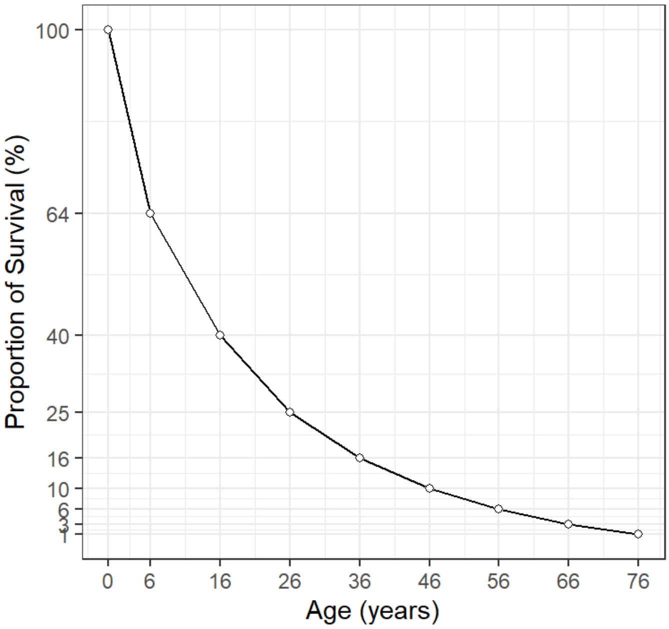
```
library(gridExtra)
g_graunt <- grid.arrange(g1, g2, g3, g4, g5, pg5, nrow = 3)
```



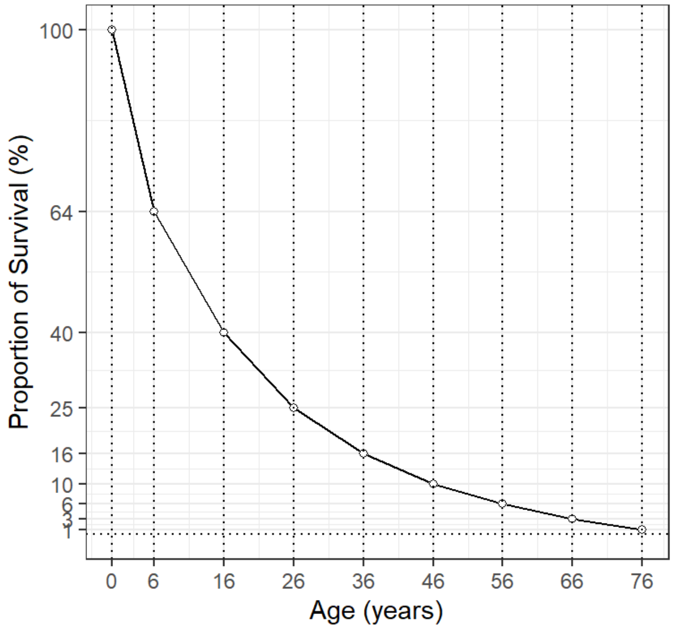




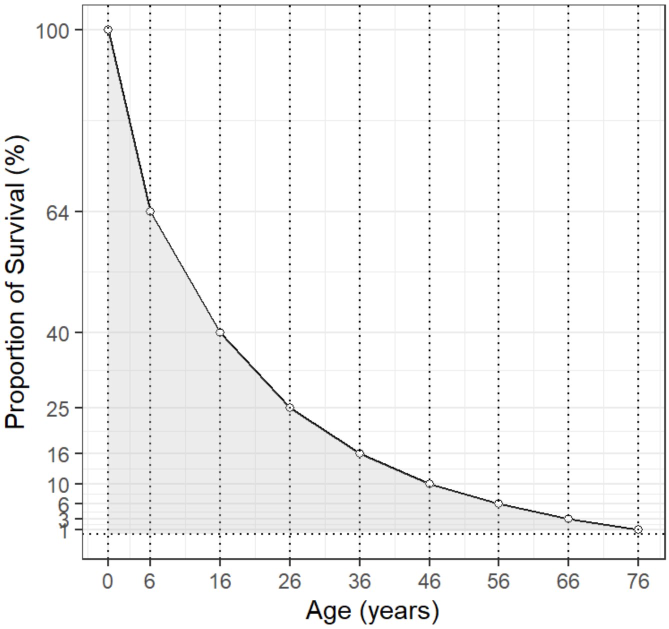
Graunt's Survival Function



Graunt's Survival Function



Graunt's Survival Function



```
# ggsave(g_graunt, file = "../pics/graunt_ggplots.png", width = 8, height = 12)
```

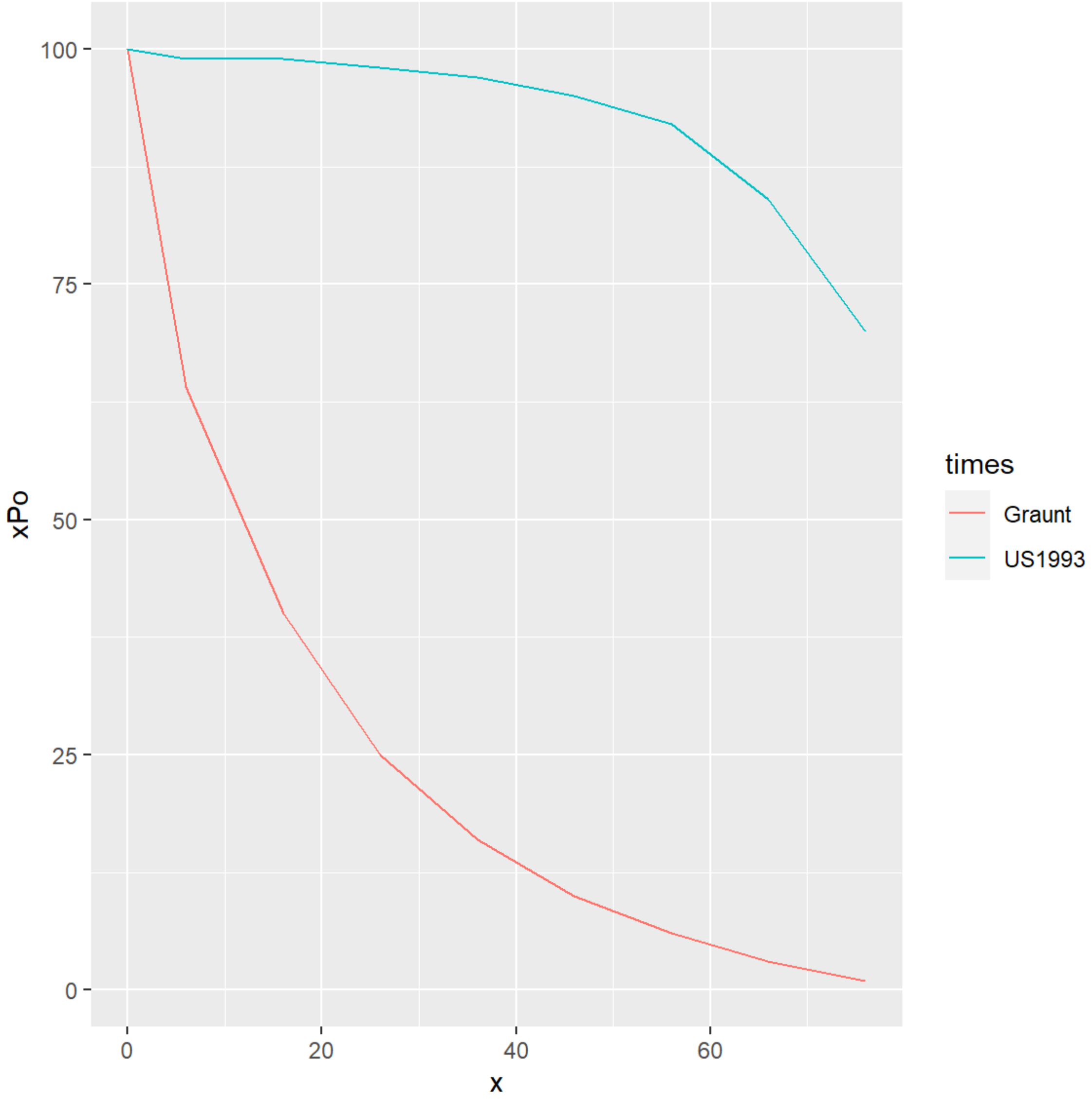
Graunt and US 1993

Points and Lines

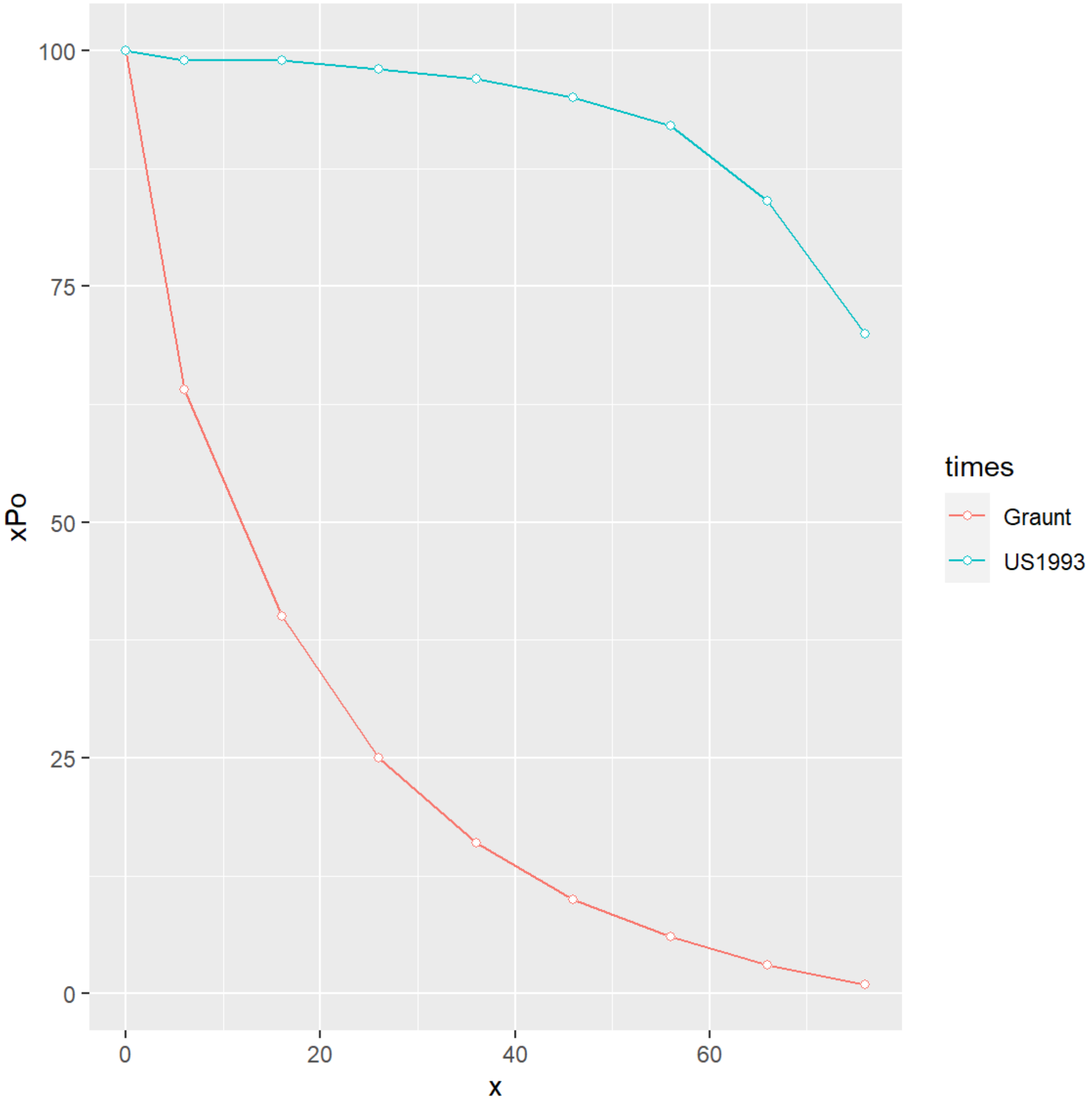
Step by step approach to understand the grammar of ggplot

- We set `ggplot()` to accept varying `data.frame()` and `aes()` in `geom_polygon`

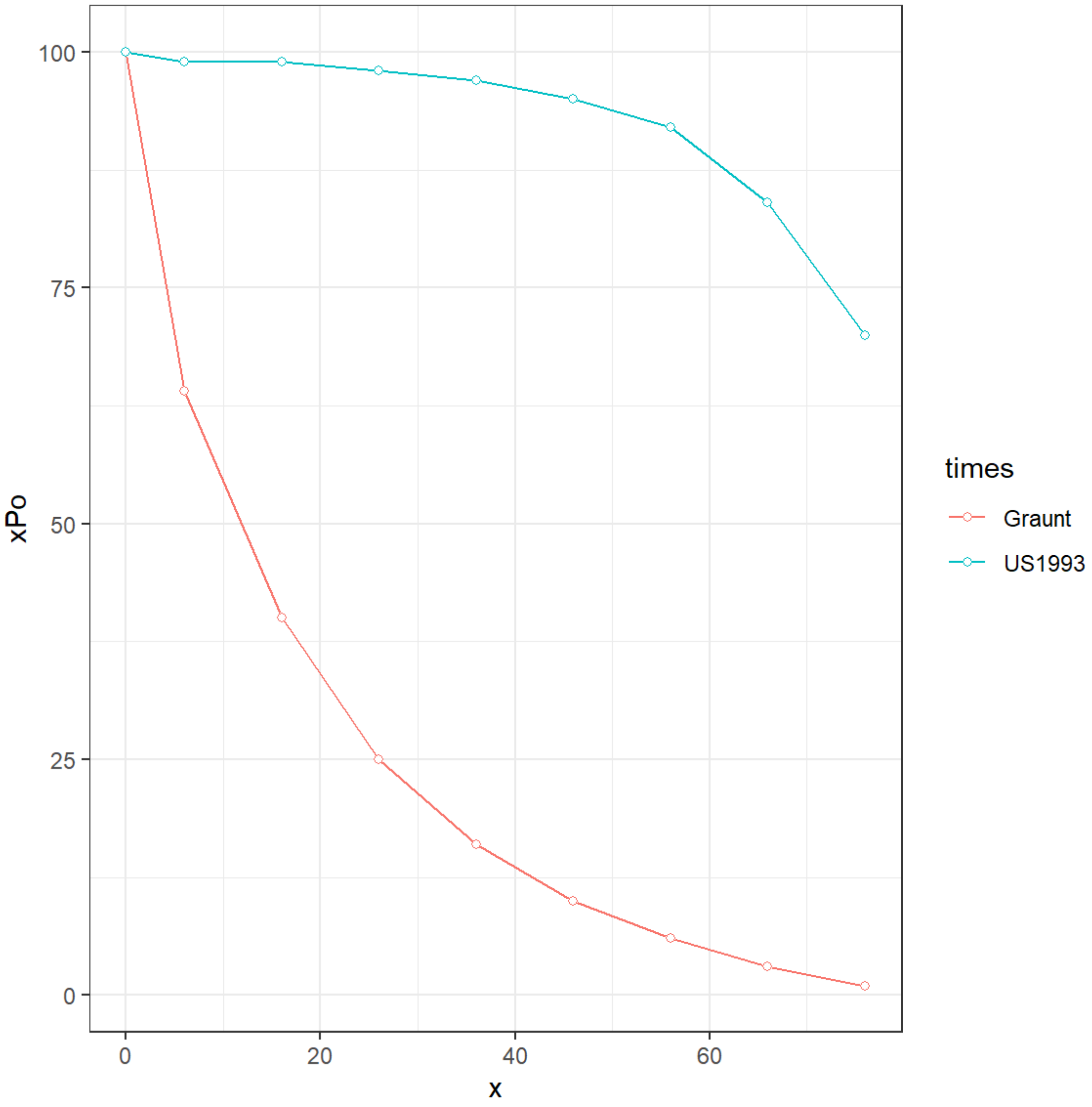
```
(gu1 <- ggplot() +
  geom_line(data = graunt_us_melt,
            mapping = aes(x = x, y = xPo, colour = times)))
```



```
(gu2 <- gu1 +
  geom_point(data = graunt_us_melt,
             mapping = aes(x = x, y = xPo, colour = times),
             shape = 21, fill = "white"))
```



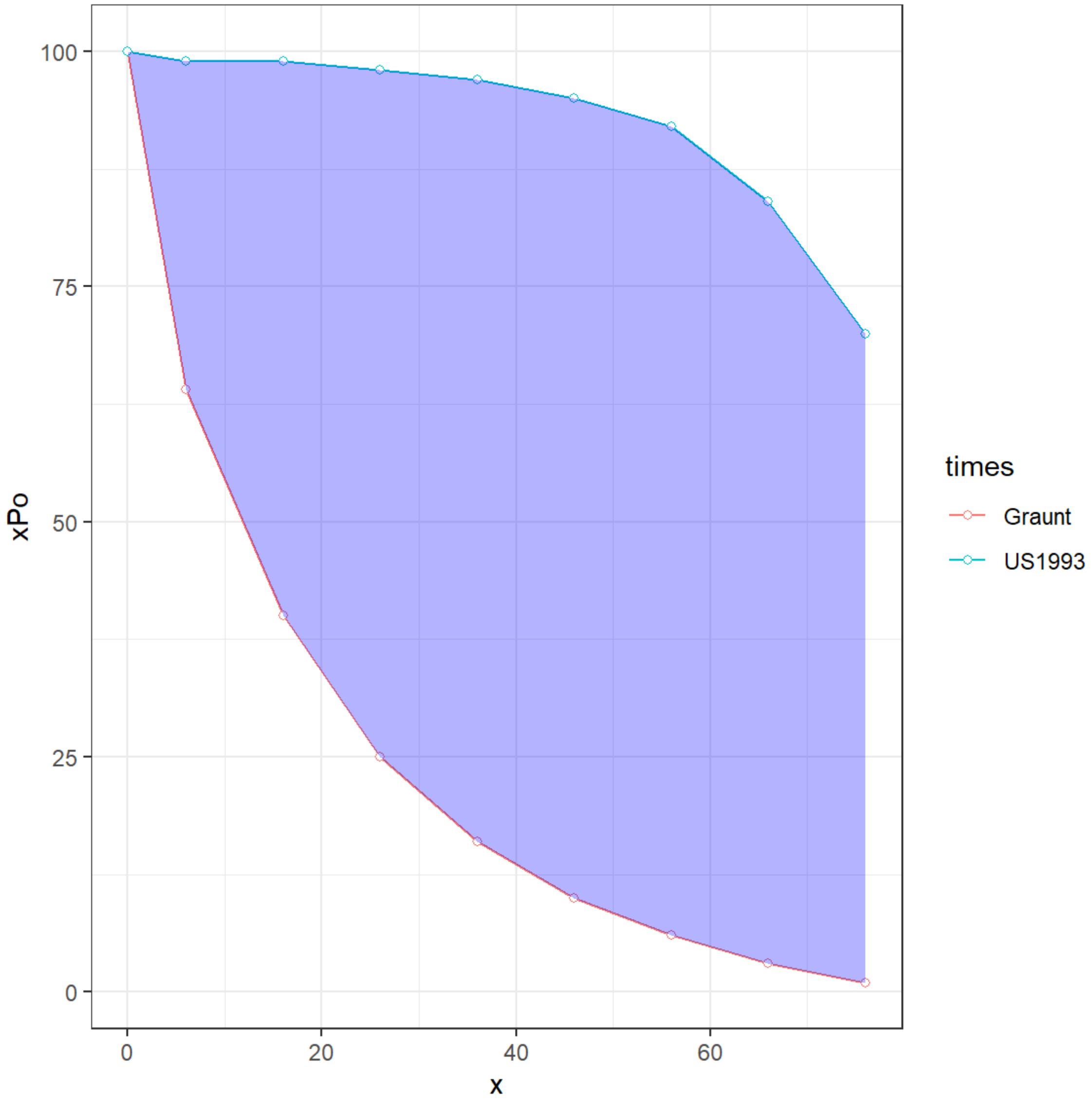
```
(gu3 <- gu2 +
  theme_bw())
```



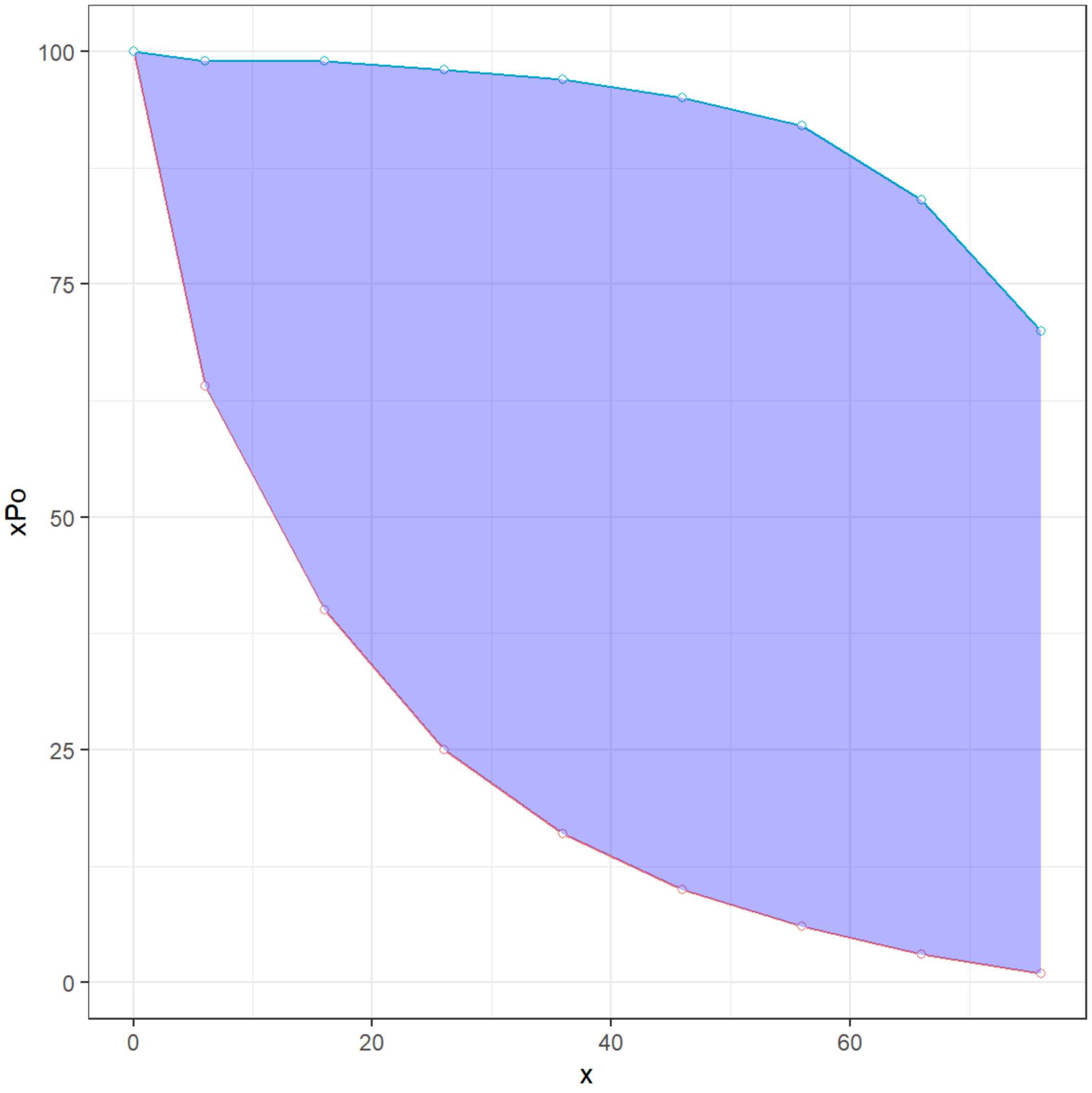
Polygon

Reuse `us_graunt` which contains `x = us_graunt_x` and `y = us_graunt_y` for `polygon()` . Note that we start with `gu3` , and also note how to remove default legends.

```
(gup3 <- gu3 +
  geom_polygon(data = us_graunt,
               mapping = aes(x = x, y = y),
               alpha = 0.3, fill = "blue"))
```



```
(gup4 <- gup3 +
  guides(colour = "none"))
```

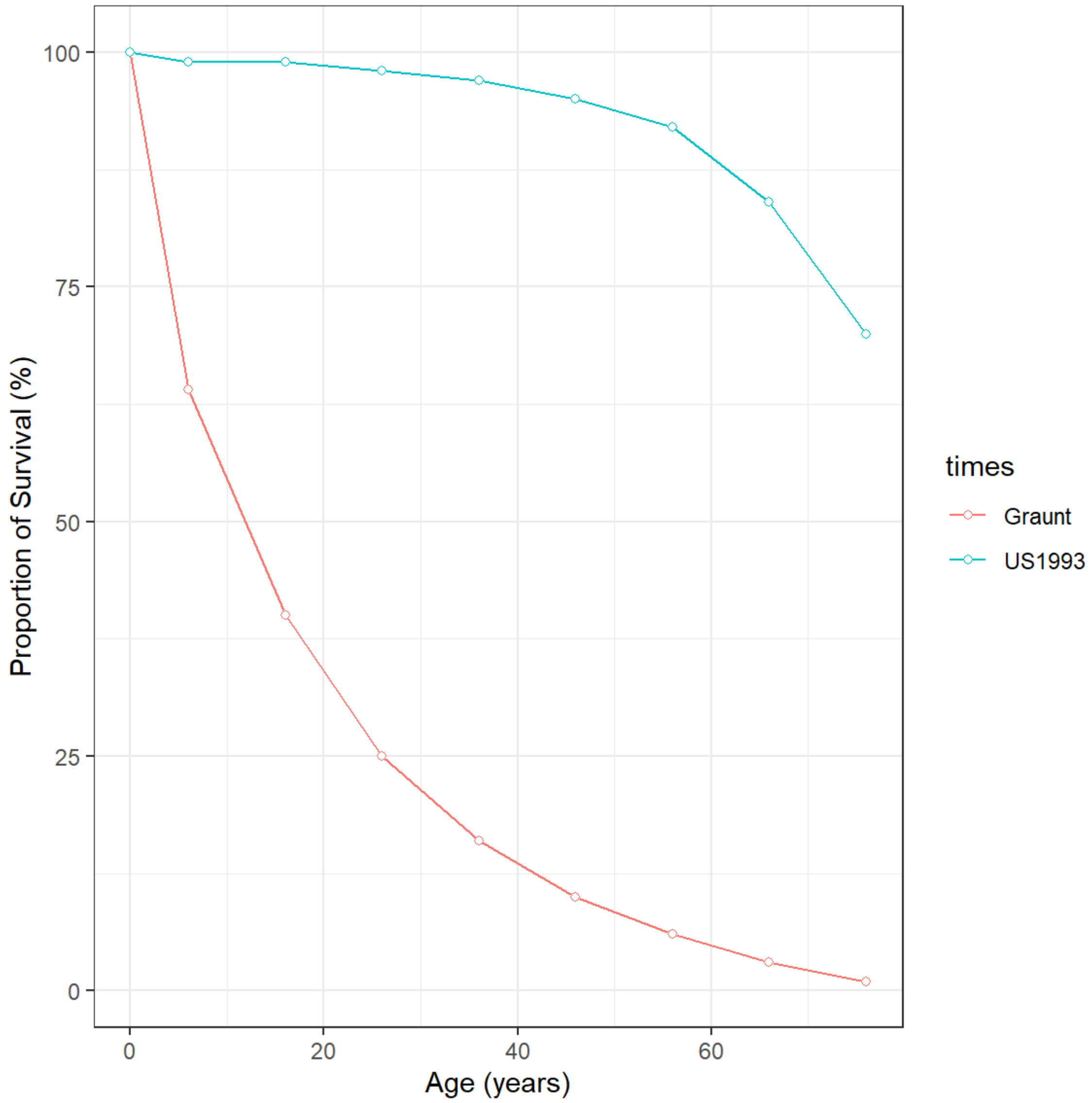


Change default annotations

Points and Lines

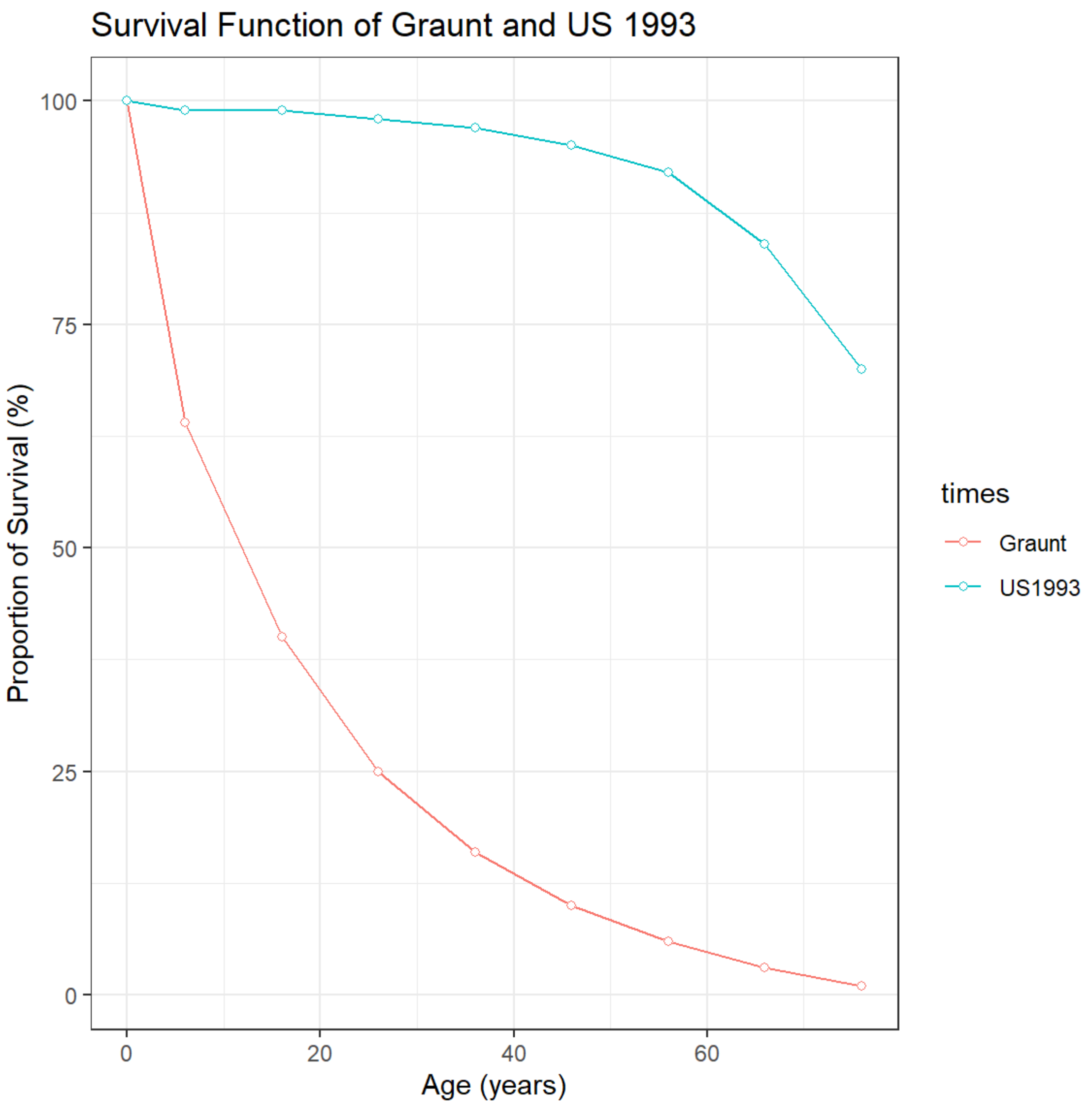
1. Change the x-axis and y-axis labels

```
(gu4 <- gu3 +
   xlab(x_lab) +
   ylab(y_lab))
```



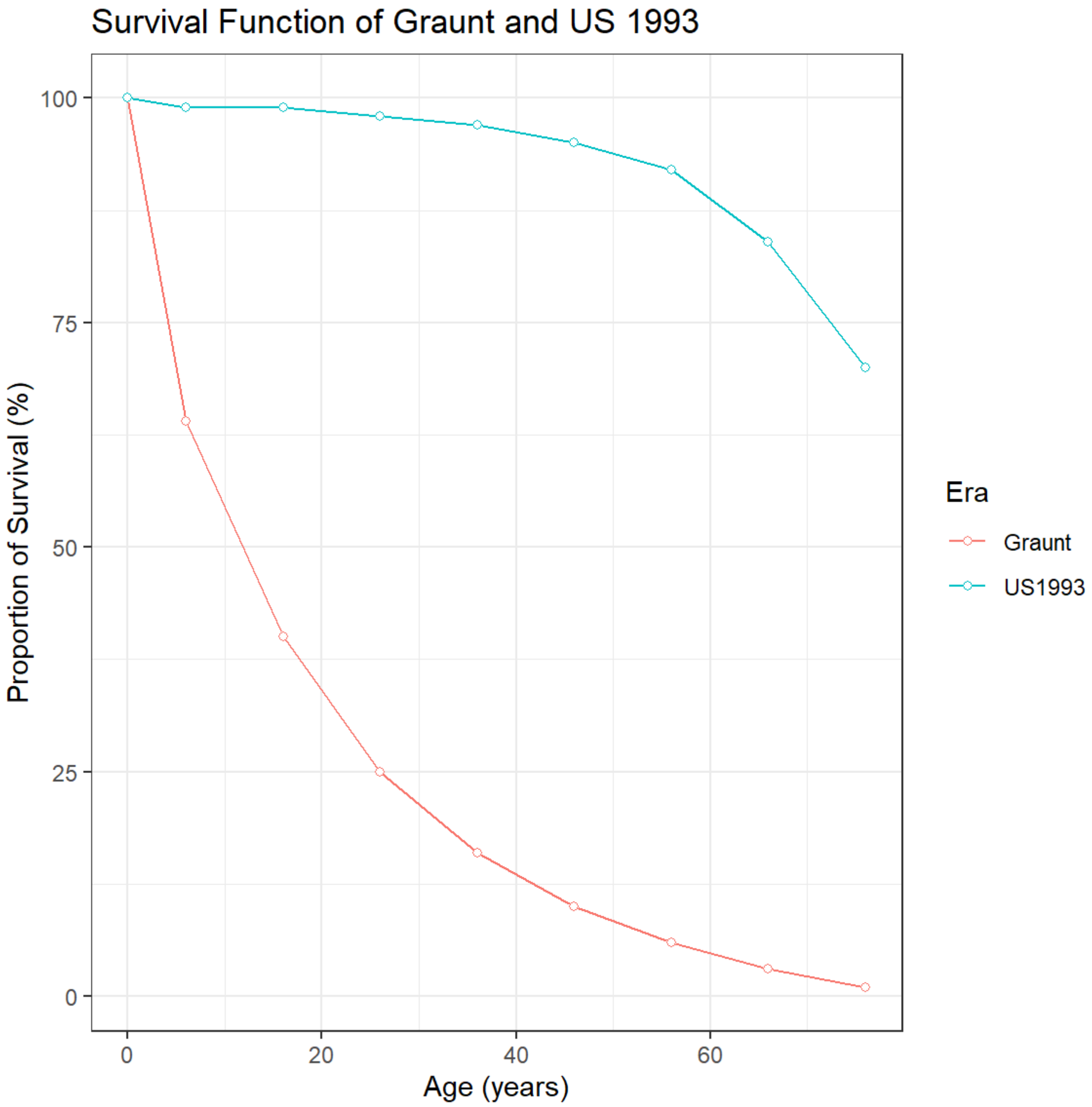
2. Add main title

```
(gu4 <- gu3 +
   xlab(x_lab) +
   ylab(y_lab) +
   ggtitle(main_title_g_us))
```



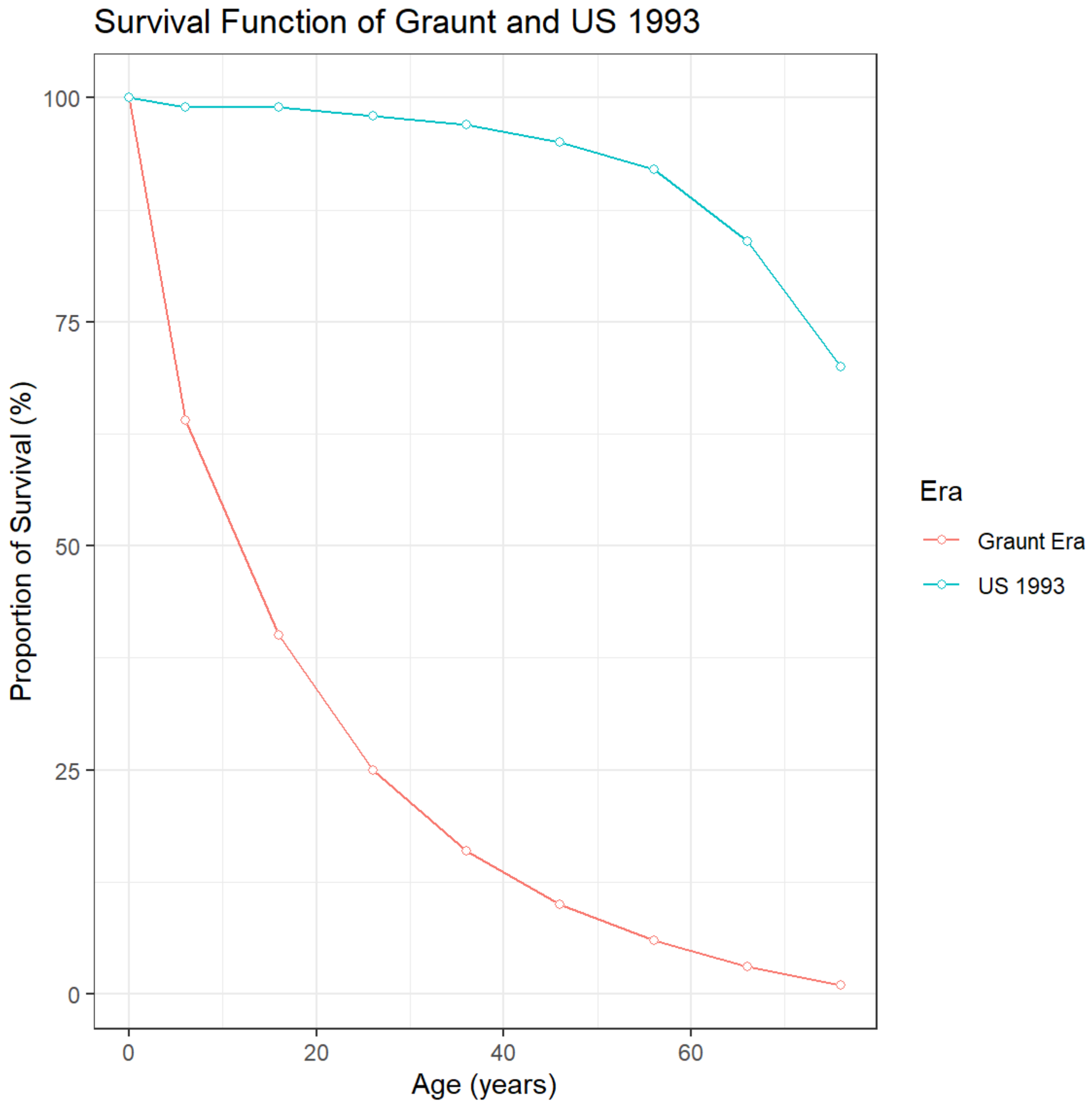
3. Change legend title

```
(gu4 <- gu3 +
   xlab(x_lab) +
   ylab(y_lab) +
   ggtitle(main_title_g_us) +
   labs(colour = "Era"))
```



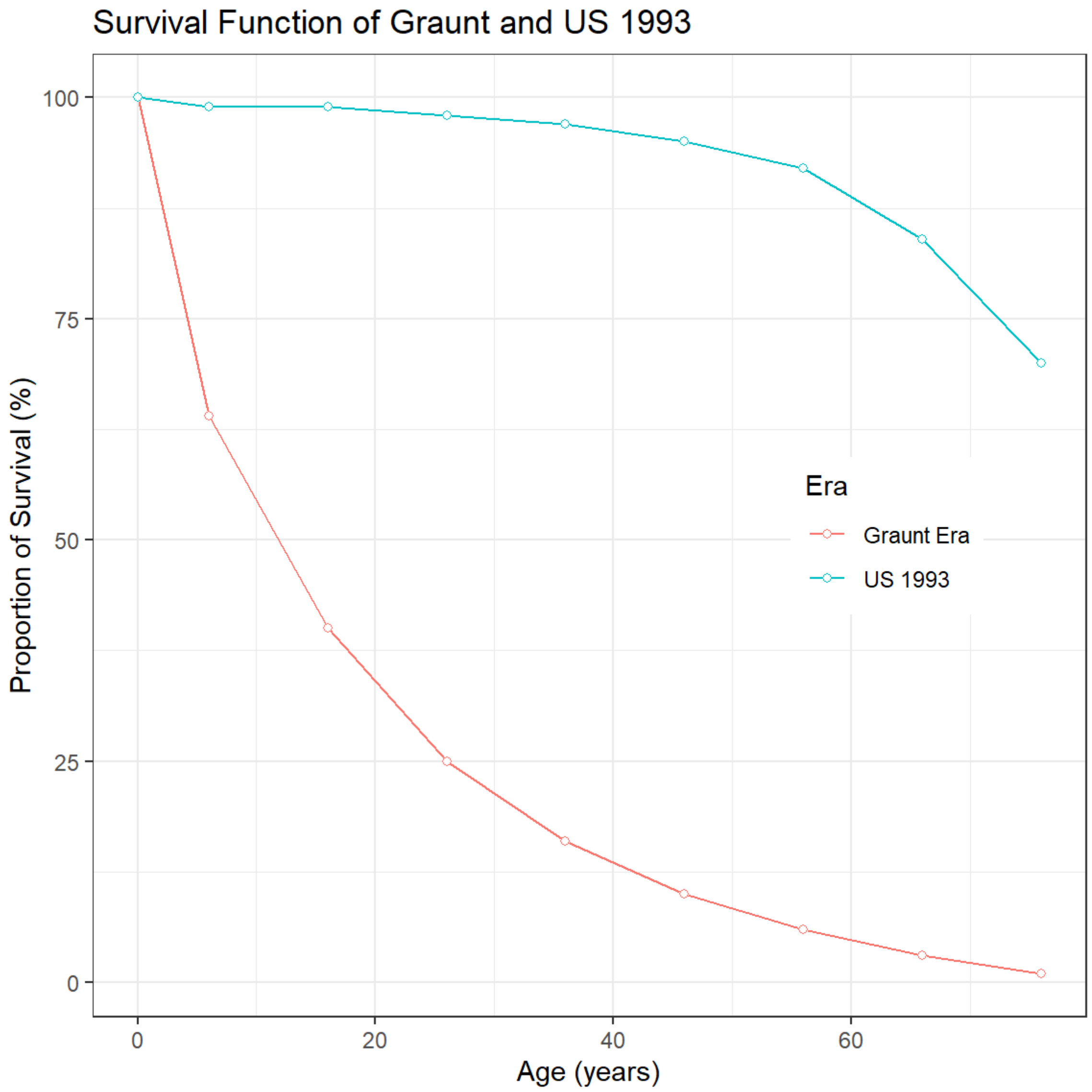
4. Change legends.

```
(gu4 <- gu3 +
   xlab(x_lab) +
   ylab(y_lab) +
   ggtitle(main_title_g_us) +
   labs(colour = "Era") +
   scale_colour_discrete(labels = c("Graunt Era", "US 1993")))
```



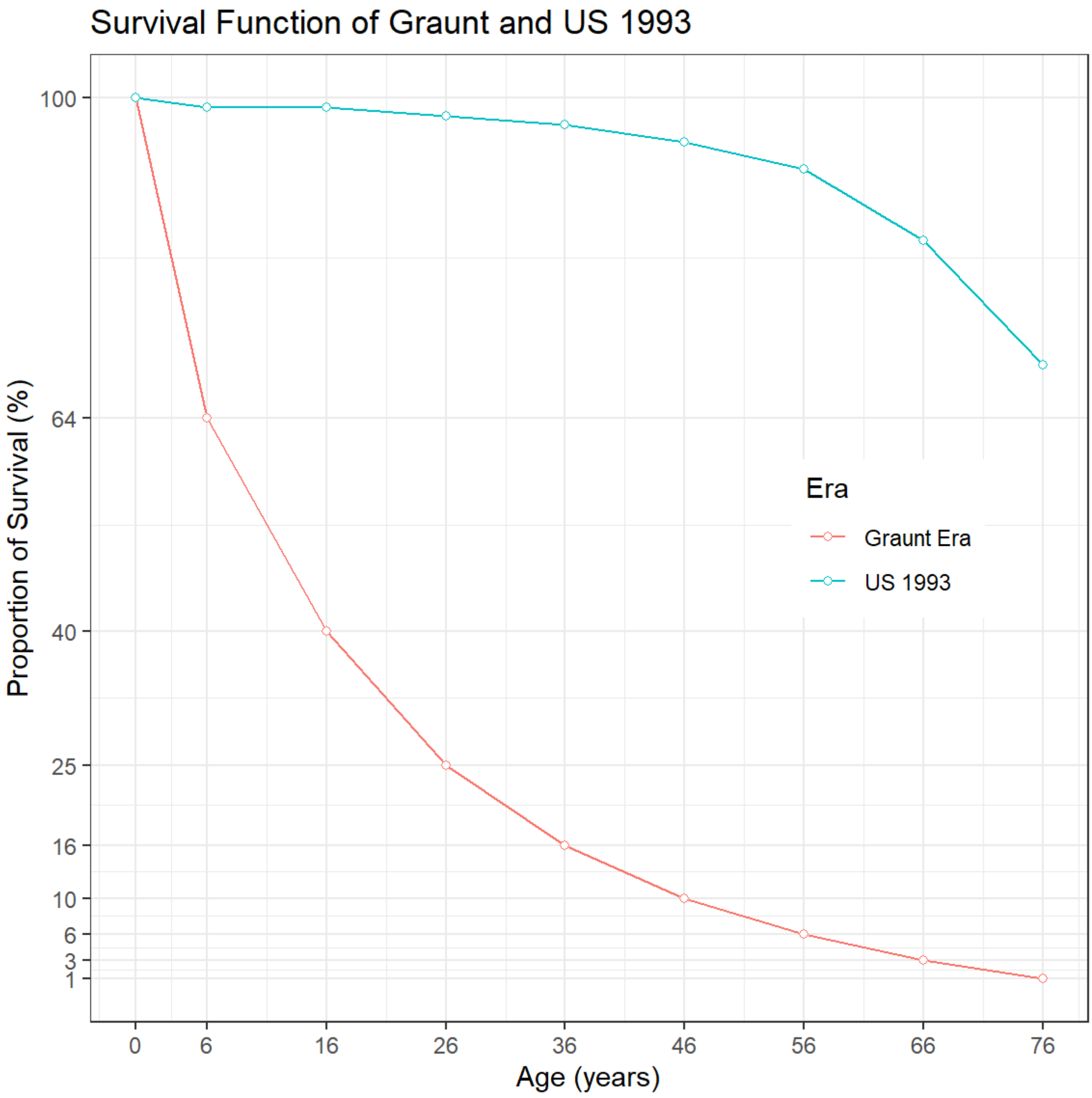
5. Place legends inside the plot

```
(gu5 <- gu4 +
   theme(legend.position = c(0.8, 0.5)))
```



6. Change x-axis and y-axis tick marks

```
(gu6 <- gu5 +
   scale_x_continuous(breaks = graunt$x) +
   scale_y_continuous(breaks = graunt$xPo_g))
```



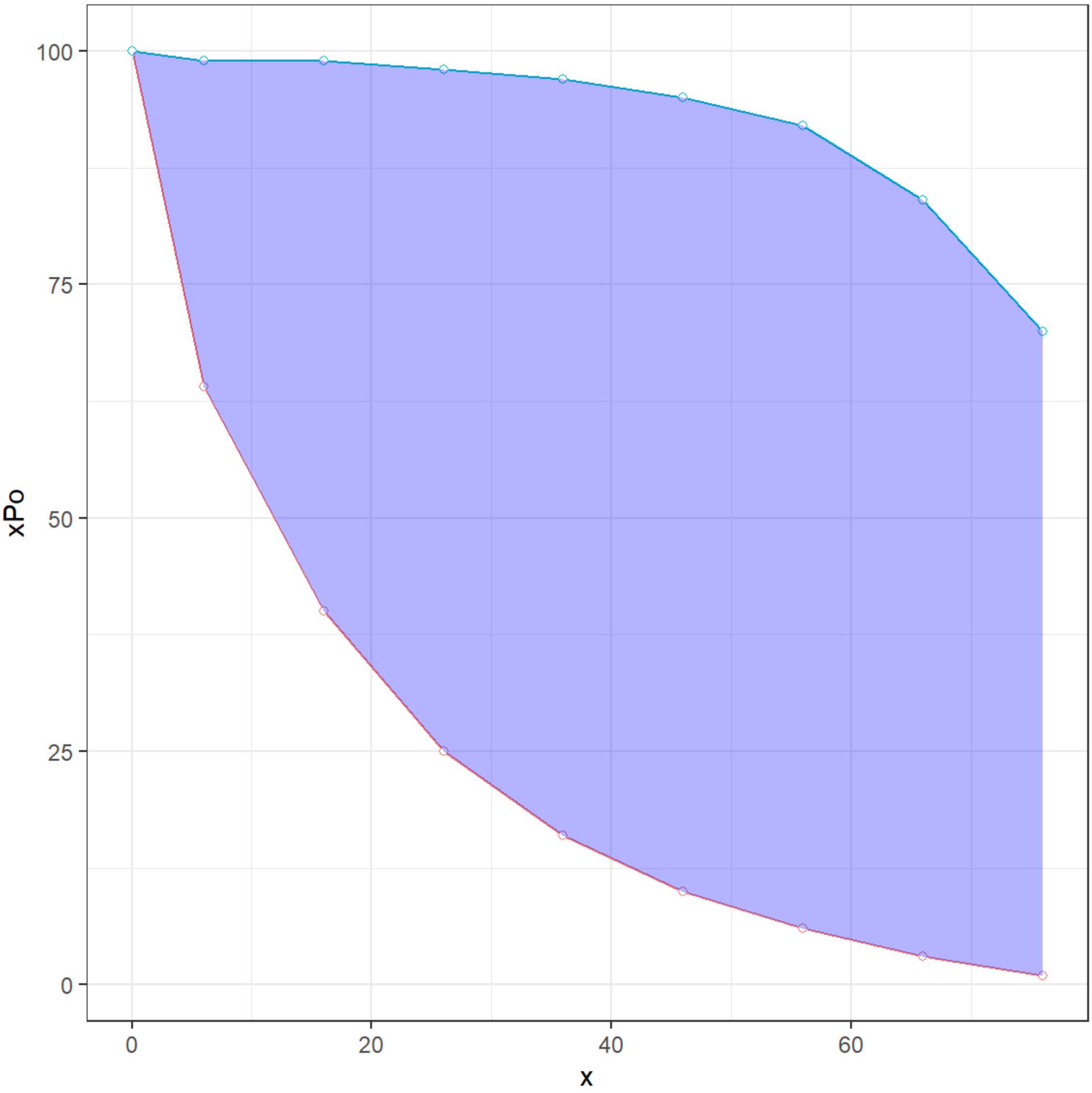
```
# ggsave("../pics/graunt_us_ggplot.png", gu6)
```

Polygon

Add information to the plot drawn with `polygon()`

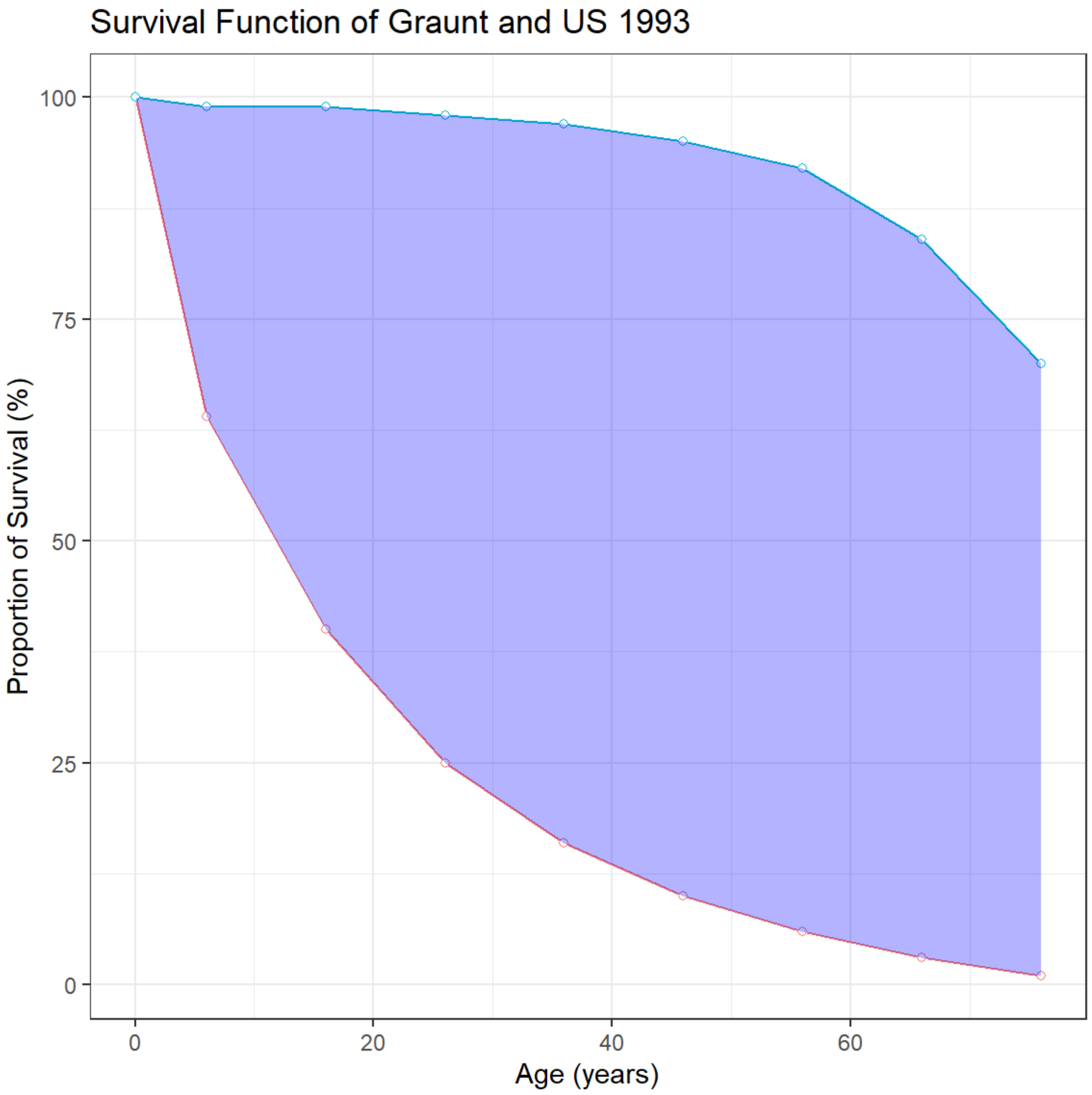
1. Start with `gup4`

```
gup4
```



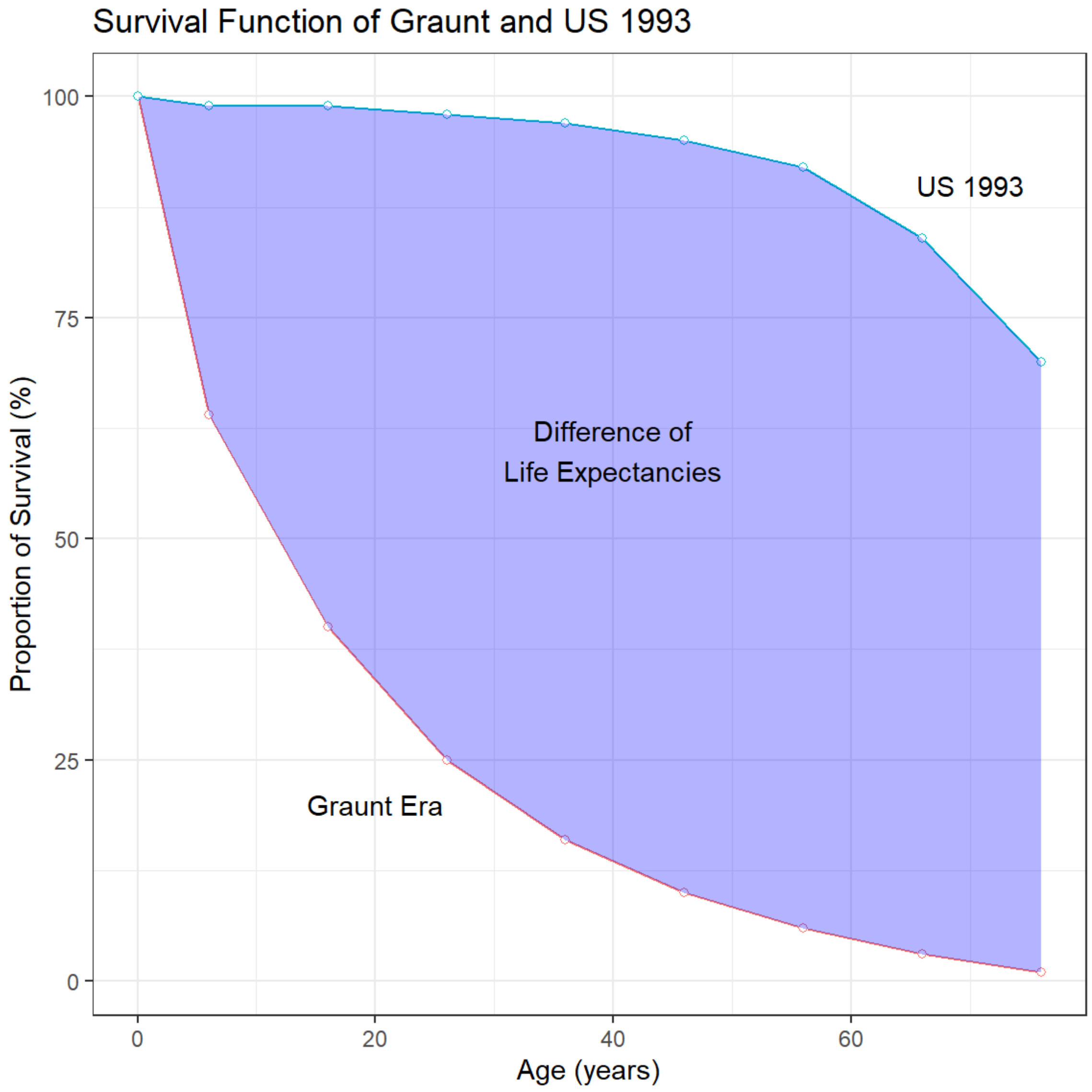
2. Main title, x-axis and y-axis labels

```
(gup5 <- gup4 +
   xlab(x_lab) +
   ylab(y_lab) +
   ggtitle(main_title_g_us))
```



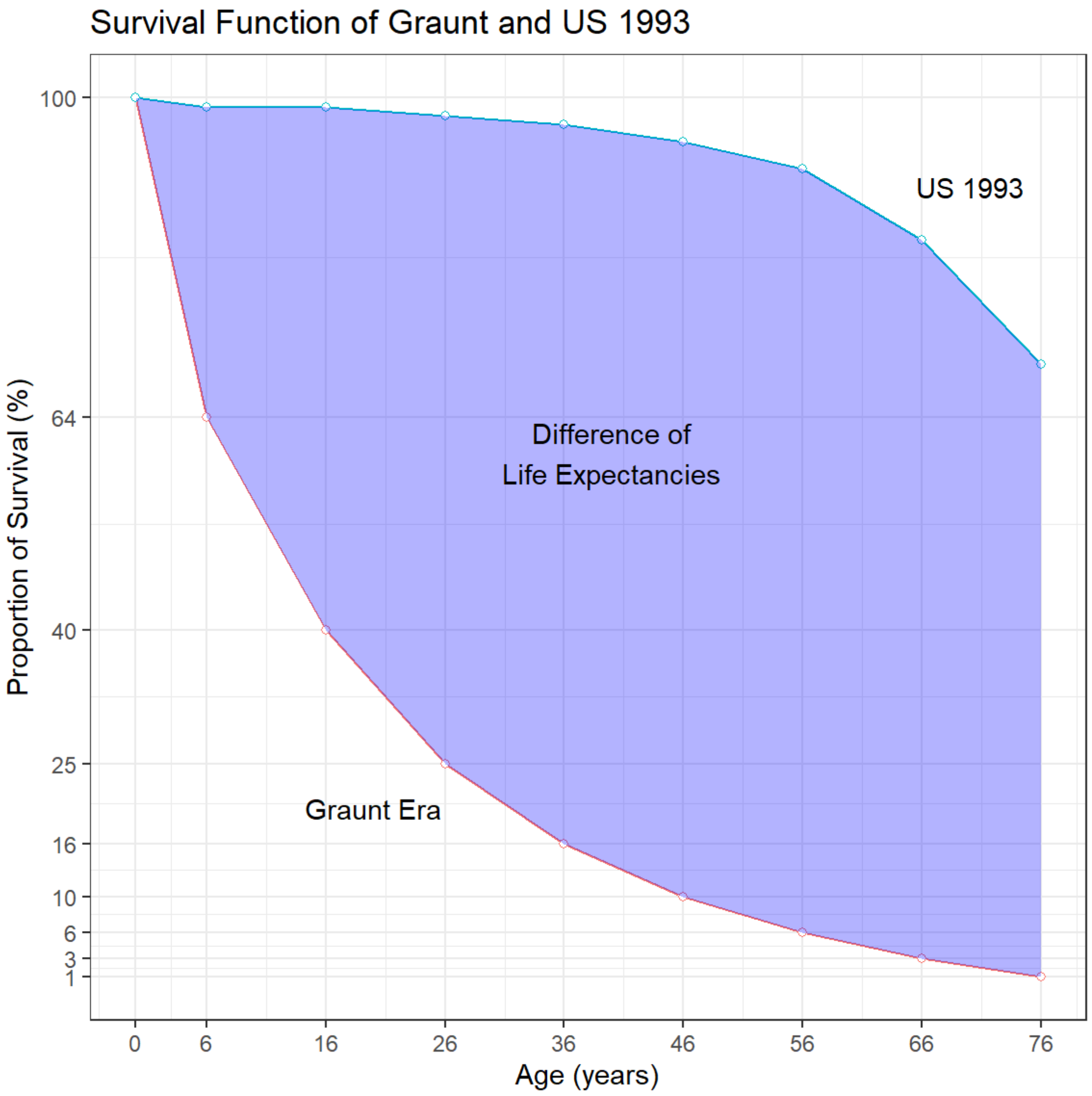
3. `"Graunt Era"` , `"US 1993"` , `"Difference of Life Expectancies"` at proper positions

```
(gup6 <- gup5 +
   annotate("text",
            x = c(20, 40, 70), y = c(20, 60, 90),
            label = c("Graunt Era", "Difference of\nLife Expectancies", "US 1993"),
            family = ""))
```



4. x-axis and y-axis tick marks

```
(gup7 <- gup6 +
   scale_x_continuous(breaks = graunt$x) +
   scale_y_continuous(breaks = graunt$xPo_g))
```



```
# ggsave("../pics/graunt_us_poly.png", gup7)
```

`dump()` and `source()`

- Check out how to save and retrieve. Use `source()` and `load()` for retrieval.

```
dump("area.R", file = "area.R")
save.image("./graunt_halley.RData")
```

Comments

존 그론트는 출생 사망표를 근거로 최초의 생명표를 작성하였다.생명표와 기대수명을 통해 전염병이 유행했을 때와 전염병이 유행하지 않았을 때의 기대 수명을 비교할 수 있다. 그리고 전염병이 돌 때 이 비교분석한 것을 참고자료로 쓸 수 있겠다는 생각을 했다. 지난 학기에 수강했던 수업의 과제에서 썼던 plot함수를 통해 포인트만 찍는 것이 아니라, 그래프를 그리고 각 포인트에 대한 x 그래프, 빗금의 각도를 설정하여 그래프의 면적을 구하는 것을 배워서 흥미로웠다. 그리고 1992년도의 그래프를 같은 그래프상에 그려 두 그래프 사이의 넓이를 통해 기대 수명의 차이를 알게 되었다. 직접 그래프를 그리는 것 말고 그동안 쓰였던 ggplot을 통해 다시 한번 그려봄으로써 그래프를 그릴 때 2가지 버전으로 그리고 다른 점을 비교하는 방법으로 쓰이면 좋을 것 같다.