R basics

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Todays concepts

- arithmetic calculations
- order of evaluation
- objects
- assignments
- the workspace
- indexing
- vectors
- vectorization
- data frames
- functions
- arguments
- logical comparisons

Todays operators

- `+`, `-`, `/`, `*`, `^`
- `[]`
- `<-`
- `>=`
- `:`

Todays functions

- `data.frame()`
- `plot()`, `lines()`
- `log()`, `exp()`
- `function()`
- `uniroot()`

When will 10 billion people live on earth?

In 2017 around 7.5 billion live on planet earth. Ten years earlier the number was 6.6 billion. We feed this information into R by *assigning* it to an *object* via the *assignment operator* `<-`.

```
N2017 <- 7.5e9
N2007 <- 6.6e9
```

We choose the names `N2017` and `N2007` for our objects. It is a good idea to pick a name which lets you remember the content of the object. Some mild restrictions apply to naming:

> "A syntactically valid name consists of letters, numbers and the dot or underline characters and starts with a letter or the dot not followed by a number. Names such as '.2way' are not valid, and neither are the reserved words." (from `?make.names`)

Arithmetic growth

Now that we know the world population at two points in time we can calculate the average absolute annual growth rate. Doing basic arithmetic in R feels much like using a desk calculator.

```
# an average annual growth of 90 million people
R <- (N2017-N2007)/10
```

Again, we assign the result of our calculation to a new object named `R`, the absolute annual growth rate.

We use absolute growth rates if we want to model linear growth, i.e. a situation where the population number N is a linear function of time:

$$N(t+n) = N(t) + nR$$

So our projections for the population numbers in 2018 and 2019 are

```
N2017+R # 2018
```

```
## [1] 7.59e+09
```

```
N2017+R*2 # 2019
```

```
## [1] 7.68e+09
```

What about the next 10 years? It would be tedious to type it out manually so we make use of Rs vector arithmetic.

```
# next 10 years
N2017+R*1:10
```

```
##  [1] 7.59e+09 7.68e+09 7.77e+09 7.86e+09 7.95e+09 8.04e+09 8.13e+09
##  [8] 8.22e+09 8.31e+09 8.40e+09
```

Using the `:` operator we have constructed an integer sequence from 1 to 10, i.e. a vector object. Multiplying a *scalar* (a vector with a single element) like `R` with a vector like `1:10` produces a vector with entries $R \cdot 1, R \cdot 2, \ldots, R \cdot 10$. Vector (and matrix) operations are at the heart of R. Usually we don't need to state what we want on an element-by-element basis but instead work with complete vectors. Writing R code in a way that makes use of the vector and matrix features in R is called *vectorization* – an important concept for writing efficient R code.

We want to get an estimate of when the world population will hit 10 million people. So we will linearly project 50 years into the future and store our results in a `data.frame` – think of it as a table.

```r
arith_growth <-
  data.frame(
    year = 2017 + 1:50,
    N = N2017 + R*1:50
  )
arith_growth
```

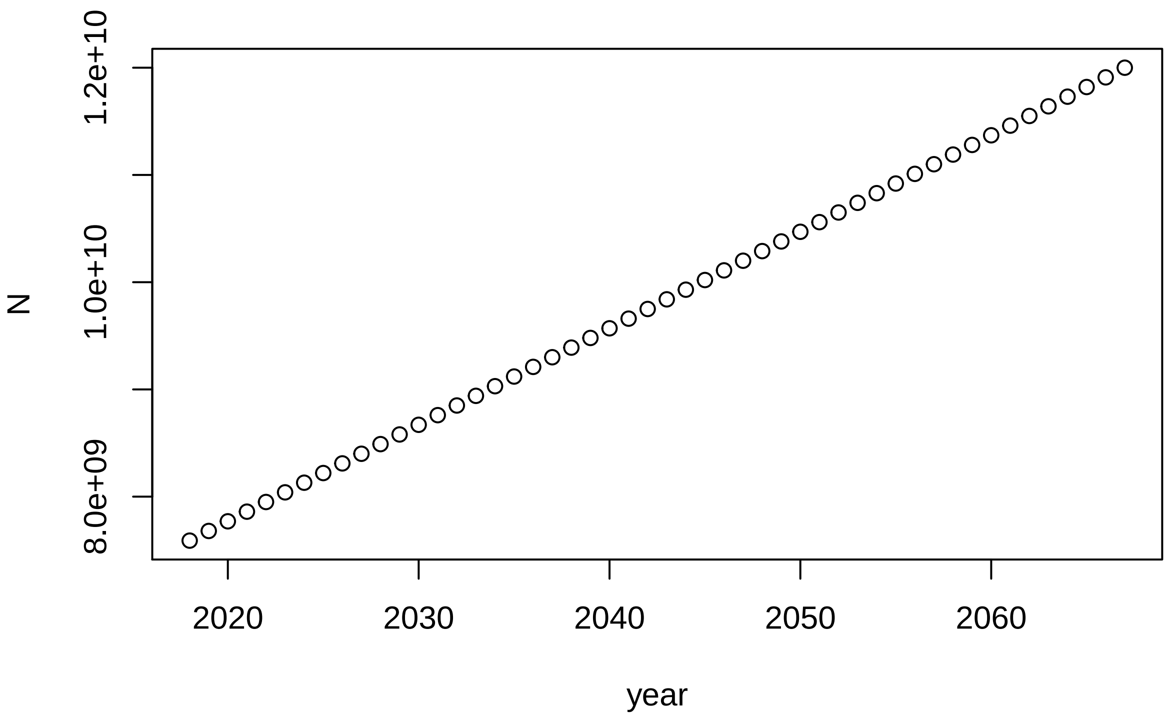
```
##    year         N
## 1  2018 7.590e+09
## 2  2019 7.680e+09
## 3  2020 7.770e+09
## 4  2021 7.860e+09
## 5  2022 7.950e+09
## 6  2023 8.040e+09
## 7  2024 8.130e+09
## 8  2025 8.220e+09
## 9  2026 8.310e+09
## 10 2027 8.400e+09
## 11 2028 8.490e+09
## 12 2029 8.580e+09
## 13 2030 8.670e+09
## 14 2031 8.760e+09
## 15 2032 8.850e+09
## 16 2033 8.940e+09
## 17 2034 9.030e+09
## 18 2035 9.120e+09
## 19 2036 9.210e+09
## 20 2037 9.300e+09
## 21 2038 9.390e+09
## 22 2039 9.480e+09
## 23 2040 9.570e+09
## 24 2041 9.660e+09
## 25 2042 9.750e+09
## 26 2043 9.840e+09
## 27 2044 9.930e+09
## 28 2045 1.002e+10
## 29 2046 1.011e+10
## 30 2047 1.020e+10
## 31 2048 1.029e+10
## 32 2049 1.038e+10
## 33 2050 1.047e+10
## 34 2051 1.056e+10
## 35 2052 1.065e+10
## 36 2053 1.074e+10
## 37 2054 1.083e+10
## 38 2055 1.092e+10
## 39 2056 1.101e+10
## 40 2057 1.110e+10
## 41 2058 1.119e+10
## 42 2059 1.128e+10
## 43 2060 1.137e+10
## 44 2061 1.146e+10
## 45 2062 1.155e+10
## 46 2063 1.164e+10
```

```
## 47 2064 1.173e+10
## 48 2065 1.182e+10
## 49 2066 1.191e+10
## 50 2067 1.200e+10
```

Our data frame has two columns and 50 rows. The columns have names `year` and `N`. The advantage of using a data frame to store your calculation results is the same advantage as using a table: all your results in a single place. Note that in order to "see" (`print` in R lingo) the table we have to explicitly call the object we stored the table in (`arith_growth`).

The function `plot()`, if applied to a data frame with two numeric columns, plots the first column against the second.

```r
plot(arith_growth)
```




```r
# all rows with a value of N larger or equal to 10 billion
arith_growth[arith_growth$N >= 10e9,]
```

```
##    year         N
## 28 2045 1.002e+10
## 29 2046 1.011e+10
## 30 2047 1.020e+10
## 31 2048 1.029e+10
## 32 2049 1.038e+10
## 33 2050 1.047e+10
## 34 2051 1.056e+10
## 35 2052 1.065e+10
## 36 2053 1.074e+10
## 37 2054 1.083e+10
## 38 2055 1.092e+10
## 39 2056 1.101e+10
## 40 2057 1.110e+10
## 41 2058 1.119e+10
```

```
## 42 2059 1.128e+10
## 43 2060 1.137e+10
## 44 2061 1.146e+10
## 45 2062 1.155e+10
## 46 2063 1.164e+10
## 47 2064 1.173e+10
## 48 2065 1.182e+10
## 49 2066 1.191e+10
## 50 2067 1.200e+10
```

```
# all years of rows with a value of N larger or equal to 10 billion
arith_growth[arith_growth$N >= 10e9, 'year'][1]
```

```
## [1] 2045
```

```
# the first year where N gets larger or equal to 10 billion
arith_growth[arith_growth$N >= 10e9, 'year'][1]
```

```
## [1] 2045
```

Geometric growth

$$N(t+n) = N(t) \cdot (1+r)^n$$

```
# an average annual growth rate of ~1.3%
r <- (1+(N2017-N2007)/N2007)^(1/10) - 1

# next 10 years
N2007*(1+r)^(1:10) # what's with that: N0*(1+r)^1:10
```

```
##  [1] 6684911596 6770915612 6858026105 6946257308 7035623640 7126139705
##  [7] 7217820295 7310680391 7404735170 7500000000
```

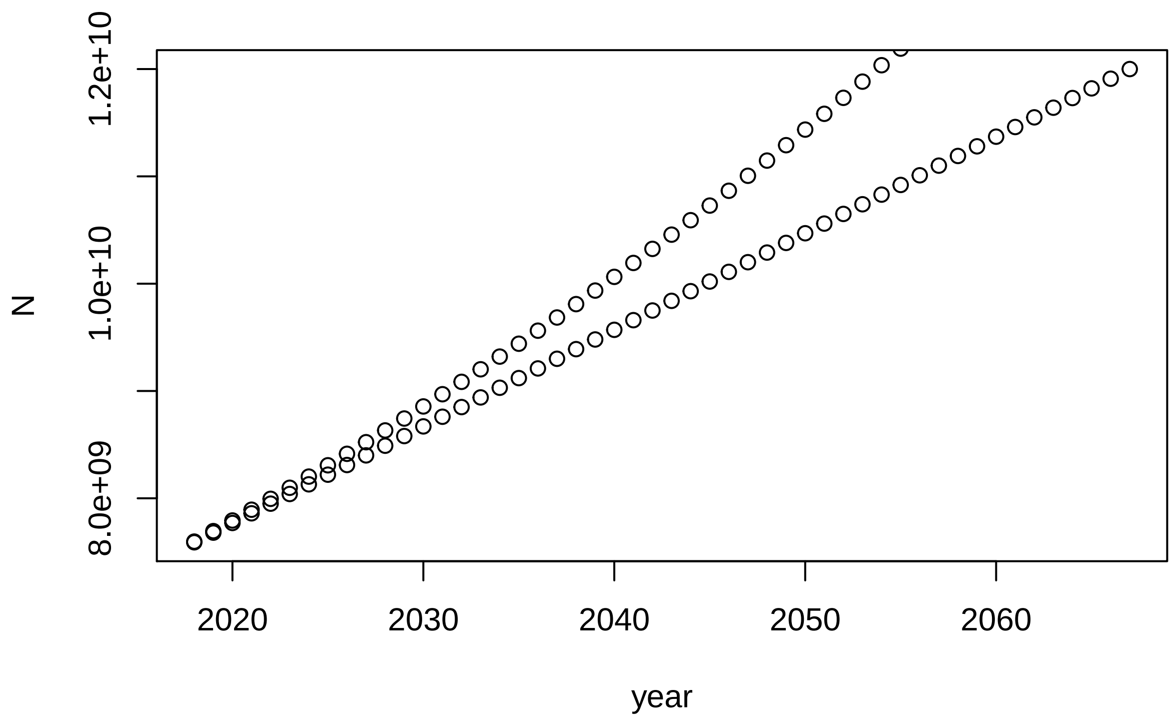
```
geom_growth <-
  data.frame(
    year = 2017 + 1:100,
    N = N2017*(1+r)^(1:100)
  )
geom_growth
```

```
##     year          N
## 1   2018 7596490450
## 2   2019 7694222287
## 3   2020 7793211483
## 4   2021 7893474213
## 5   2022 7995026863
## 6   2023 8097886028
## 7   2024 8202068517
## 8   2025 8307591354
## 9   2026 8414471784
## 10  2027 8522727273
## 11  2028 8632375511
## 12  2029 8743434417
## 13  2030 8855922139
## 14  2031 8969857060
## 15  2032 9085257799
```

```
## 16   2033   9202143214
## 17   2034   9320532405
## 18   2035   9440444720
## 19   2036   9561899754
## 20   2037   9684917355
## 21   2038   9809517626
## 22   2039   9935720928
## 23   2040  10063547886
## 24   2041  10193019387
## 25   2042  10324156590
## 26   2043  10456980925
## 27   2044  10591514097
## 28   2045  10727778091
## 29   2046  10865795176
## 30   2047  11005587904
## 31   2048  11147179121
## 32   2049  11290591964
## 33   2050  11435849870
## 34   2051  11582976576
## 35   2052  11731996125
## 36   2053  11882932869
## 37   2054  12035811474
## 38   2055  12190656922
## 39   2056  12347494518
## 40   2057  12506349891
## 41   2058  12667249001
## 42   2059  12830218141
## 43   2060  12995283943
## 44   2061  13162473382
## 45   2062  13331813778
## 46   2063  13503332806
## 47   2064  13677058493
## 48   2065  13853019230
## 49   2066  14031243770
## 50   2067  14211761239
## 51   2068  14394601137
## 52   2069  14579793342
## 53   2070  14767368117
## 54   2071  14957356116
## 55   2072  15149788385
## 56   2073  15344696370
## 57   2074  15542111924
## 58   2075  15742067306
## 59   2076  15944595193
## 60   2077  16149728681
## 61   2078  16357501292
## 62   2079  16567946979
## 63   2080  16781100133
## 64   2081  16996995586
## 65   2082  17215668619
## 66   2083  17437154966
## 67   2084  17661490823
## 68   2085  17888712848
## 69   2086  18118858174
```

```
## 70  2087 18351964410
## 71  2088 18588069650
## 72  2089 18827212477
## 73  2090 19069431969
## 74  2091 19314767711
## 75  2092 19563259794
## 76  2093 19814948825
## 77  2094 20069875935
## 78  2095 20328082782
## 79  2096 20589611562
## 80  2097 20854505012
## 81  2098 21122806421
## 82  2099 21394559632
## 83  2100 21669809056
## 84  2101 21948599672
## 85  2102 22230977039
## 86  2103 22516987302
## 87  2104 22806677199
## 88  2105 23100094070
## 89  2106 23397285865
## 90  2107 23698301150
## 91  2108 24003189114
## 92  2109 24311999582
## 93  2110 24624783018
## 94  2111 24941590536
## 95  2112 25262473908
## 96  2113 25587485570
## 97  2114 25916678635
## 98  2115 26250106898
## 99  2116 26587824847
## 100 2117 26929887670
```

```r
plot(arith_growth)
lines(geom_growth, type = 'p')
```




```
geom_growth[geom_growth$N >= 10e9, 'year'][1]
```

```
## [1] 2040
```

Exponential growth

$$N(t+n) = N(t) \cdot \exp(rn)$$

```
r = log(N2017/N2007)/10

N2007*exp(r*1:10)
```

```
##  [1] 6684911596 6770915612 6858026105 6946257308 7035623640 7126139705
##  [7] 7217820295 7310680391 7404735170 7500000000
```

```
ExpGrowth <- function (x, N0, r) {
  N0*exp(r*x)
}

years_until_10b <- uniroot(function (x) {ExpGrowth(x, N2007, r)-10e9}, interval = c(0, 100))
years_until_10b
```

```
## $root
## [1] 32.50446
##
## $f.root
## [1] -16.56351
##
## $iter
## [1] 7
##
## $init.it
```

```
## [1] NA
##
## $estim.prec
## [1] 6.103516e-05
```

Further reading

- Riffe etal. (2017). EDSD Computer Programming. Chapter 1. Basic R.
- Smith, D. P., & Keyfitz, N. (2013). Mathematical Demography. Chapter 1.1. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-35858-6