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R (programming language)

R is a programming language and free software environment for statistical computing and graphics. It is supported by the R Core Team and the R Foundation for Statistical Computing.[7] It is widely used among statisticians and data miners for developing statistical software and data analysis. Polls, data mining surveys, and studies of scholarly literature databases show that R is highly popular;[8] since August 2021, R ranks 14th in the TIOBE index, a measure of programming language popularity.[9]

The official R software environment is a GNU package. It is written primarily in C, Fortran, and R itself (partially self-hosting) and is available under the GNU General Public License. Precompiled executables are provided for various operating systems. It has a command line interface. Multiple third-party graphical user interfaces are available, such as RStudio, an integrated development environment; and Jupyter, a notebook interface.

Contents

R

R terminal

Paradigms	Multi-paradigm: procedural, object-oriented, functional, reflective, imperative, array[1]
Designed by	Ross Ihaka and Robert Gentleman
Developer	R Core Team
First appeared	August 1993
Stable release	4.1.2[2] / 1 November 2021
Typing discipline	Dynamic
License	GNU GPL v2
Filename extensions	.r[3] .rdata .rds .rda[4]
Website	www.r-project.org (https://www.r-project.org)
Influenced by	
Common Lisp[5] · S · Scheme · XLispStat	
Influenced	
Julia[6]	
R Programming at Wikibooks	

History

R is an implementation of the S programming language combined with lexical scoping semantics. It is inspired by Scheme.[1] S was created by John Chambers in 1976 while at Bell Labs. A commercial version of S was offered as S-PLUS starting in 1988. Many codes written for S-PLUS run unaltered in R.[10]

In 1991 Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand, embarked on an S implementation, independent of S-PLUS. They began publicizing it in 1993.[11] It was named partly after the first names of the first two R authors and partly as a play on the name of S.[12] In 1995, Martin Maechler convinced Ihaka and Gentleman to make R free and open-source software under the GNU General Public License.[13][14] The R Core Team was formed in 1997 to further develop the language.[12] As of 2021, it consisted of Gentleman, Ihaka, and Maechler, plus Douglas Bates, John Chambers, Peter Dalgaard, Kurt Hornik, Tomas Kalibera, Michael Lawrence, Friedrich Leisch, Uwe Ligges, Thomas Lumley, Martin Morgan, Paul Murrell, Martyn Plummer, Brian Ripley, Deepayan Sarkar, Duncan Temple Lang, Luke Tierney, and Simon Urbanek. Heiner Schwarte, Guido Masarotto, Stefano Iacus, Seth Falcon, and Duncan Murdoch were members.[15]

The first official release came in 1995.[11] The Comprehensive R Archive Network (CRAN) was officially announced 23 April 1997 with 3 mirrors and 12 contributed packages.[16] The first official "stable beta" version (v1.0) was released on 29 February 2000.[17][18]

Features

Statistics

R and its libraries implement various statistical and graphical techniques, including linear and nonlinear modeling, classical statistical tests, spatial and time-series analysis, classification, clustering, and others. R is easily extensible through functions and extensions, and its community is noted for contributing packages. Many of R's standard functions are written in R, which makes it easy for users to follow the algorithmic choices made. For computationally intensive tasks, C, C++, and Fortran code can be linked and called at run time. Advanced users can write C, C++,[19] Java,[20] .NET[21] or Python code to manipulate R objects directly.[22] R is highly extensible through the use of packages for specific functions and specific applications. Due to its S heritage, R has stronger object-oriented programming facilities than most statistical computing languages. Extending it is facilitated by its lexical scoping rules.[23]

Another of R's strengths is static graphics; it can produce publication-quality graphs that include mathematical symbols. Dynamic and interactive graphics are available through additional packages.[24]

Programming

R is an interpreted language; users typically access it through a command-line interpreter. If a user types 2+2 at the R command prompt and presses enter, the computer replies with 4.

Like languages such as APL and MATLAB, R supports matrix arithmetic. R's data structures include vectors, matrices, arrays, data frames (similar to tables in a relational database) and lists.[25] Arrays are stored in column-major order.[26] R's extensible object system includes objects for (among others): regression models, time-series and geo-spatial coordinates. R has no scalar data type.[27] Instead, a scalar is represented as a length-one vector.[28]

Many features of R derive from Scheme. R uses S-expressions to represent both data and code. Functions are first-class objects and can be manipulated in the same way as data objects, facilitating meta-programming that allows multiple dispatch. Variables in R are lexically scoped and dynamically typed.[29] Function arguments are passed by value, and are lazy—that is to say, they are only evaluated when they are used, not when the function is called.[30]

R supports procedural programming with functions and, for some functions, object-oriented programming with generic functions.[31] A generic function acts differently depending on the classes of the arguments passed to it. In other words, the generic function dispatches the method implementation specific to that object's class. For example, R has a generic `print` function that can print almost every class of object in R with `print(objectname)`[32]

Although used mainly by statisticians and other practitioners seeking an environment for statistical computation and software development, R can also operate as a general matrix calculation toolbox – with performance benchmarks comparable to GNU Octave or MATLAB.[33]

Packages

R's capabilities are extended through user-created[34] *packages*, which allow offer statistical techniques, graphical devices, import/export, reporting (RMarkdown, knitr, Sweave), etc. R's packages and the ease of installing and using them, has been cited as driving the language's widespread adoption in data science.[35][36][37][38][39] The packaging system is also used by researchers to create compendia to organise research data, code and report files in a systematic way for sharing and archiving.[40]

Multiple packages are included with the basic installation. As of September 2018 more than 15,000 additional packages were available at the Comprehensive R Archive Network (CRAN),[41] Bioconductor, Omegahat,[42] GitHub, and other repositories.[43][44][45]

The "Task Views" on the CRAN website[46] lists packages in fields including Finance, Genetics, High Performance Computing, Machine Learning, Medical Imaging, Social Sciences and Spatial Statistics. R has been identified by the FDA as suitable for interpreting data from clinical research.[47] Microsoft maintains a daily snapshot of CRAN that dates back to Sept. 17, 2014.[48]

Other R package resources include R-Forge,[49] a platform for the collaborative development of R packages. The Bioconductor project provides packages for genomic data analysis, including object-oriented data-handling and analysis tools for data from Affymetrix, cDNA microarray, and next-generation high-throughput sequencing methods.[50]

A group of packages called the Tidyverse, which can be considered a "dialect" of the R language, is increasingly popular among developers.[note 1] It strives to provide a cohesive collection of functions to deal with common data science tasks, including data import, cleaning, transformation and visualisation (notably with the ggplot2 package).

R is one of 5 languages with an Apache Spark API, along with Scala, Java, Python, and SQL.[51][52]

Milestones

A list of changes in R releases is maintained in various "news" files at CRAN.[53] Some highlights are listed below for several major releases.

Release	Date	Description
0.16		This is the last alpha version developed primarily by Ihaka and Gentleman. Much of the basic functionality from the "White Book" (see S history) was implemented. The mailing lists commenced on 1 April 1997.
0.49	1997-04-23	This is the oldest source release which is currently available on CRAN.[54] CRAN is started on this date, with 3 mirrors that initially hosted 12 packages.[55] Alpha versions of R for Microsoft Windows and the classic Mac OS are made available shortly after this version.
0.60	1997-12-05	R becomes an official part of the GNU Project. The code is hosted and maintained on CVS.
0.65.1	1999-10-07	First versions of update.packages and install.packages functions for downloading and installing packages from CRAN.[56]
1.0	2000-02-29	Considered by its developers stable enough for production use.[57]
1.4	2001-12-19	S4 methods are introduced and the first version for Mac OS X is made available soon after.
1.8	2003-10-08	Introduced a flexible condition handling mechanism for signalling and handling condition objects.
2.0	2004-10-04	Introduced lazy loading, which enables fast loading of data with minimal expense of system memory.
2.1	2005-04-18	Support for UTF-8 encoding, and the beginnings of internationalization and localization for different languages.
2.6.2	2008-02-08	Last version to support Windows 95, 98, Me and NT 4.0[58]
2.11	2010-04-22	Support for Windows 64-bit systems.
2.12.2	2011-02-25	Last version to support Windows 2000[59]
2.13	2011-04-14	Adding a new compiler function that allows speeding up functions by converting them to byte-code.
2.14	2011-10-31	Added mandatory namespaces for packages. Added a new parallel package.
2.15	2012-03-30	New load balancing functions. Improved serialisation speed for long vectors.
3.0.0	2013-04-03	Support for numeric index values 2^{31} and larger on 64-bit systems.
3.3.3	2017-03-06	Last version to support Microsoft Windows XP.
3.4.0	2017-04-21	Just-in-time compilation (JIT) of functions and loops to byte-code enabled by default.
3.5.0	2018-04-23	Packages byte-compiled on installation by default. Compact internal representation of integer sequences. Added a new serialisation format to support compact internal representations.
3.6.0	2019-04-26	Improved sampling from a discrete uniform distribution, which was noticeably non-uniform on large populations.[60] New serialisation format supported since 3.5.0 becomes the default.
4.0.0	2020-04-24	R now uses a `stringsAsFactors = FALSE` default, and hence by default no longer converts strings to factors in calls to `data.frame()` and `read.table()`. Reference counting is used for tracking object sharing, which reduces the need for copying objects. New syntax for raw string constants.
4.1.0	2021-05-18	Introduced `|>` as the pipe operator for base R syntax (similar to the %>% operator of the magrittr package) and the anonymous function shortcut syntax `\(x) x+1`

Interfaces

Various applications can be used to edit or run R code.[61]

Early developers preferred to run R via the command line console,[62] succeeded by those who prefer an IDE.[63] IDEs for R include (in alphabetical order) Rattle GUI, R Commander, RKWard, RStudio, and Tinn-R.[62] R is also supported in multi-purpose IDEs such as Eclipse via the StatET plugin,[64] and Visual Studio via the R Tools for Visual Studio.[65] Of these, Rstudio is the most commonly used.[63]

Editors that support R include Emacs, Vim (Nvim-R plugin),[66] Kate,[67] LyX,[68] Notepad++,[69] Visual Studio Code, WinEdt,[70] and Tinn-R.[71] Jupyter Notebook can also be configured to edit and run R code.[72]

R functionality is accessible from scripting languages including Python,[73] Perl,[74] Ruby,[75] F#,[76] and Julia.[77] Interfaces to other, high-level programming languages, like Java[78] and .NET C#[79][80] are available.

Implementations

The main R implementation is written in R, C, and Fortran.[81] Several other implementations aimed at improving speed or increasing extensibility. A closely related implementation is pqR (pretty quick R) by Radford M. Neal with improved memory management and support for automatic multithreading. Renjin and FastR (https://github.com/oracle/fastr) are Java implementations of R for use in a Java Virtual Machine. CXXR, rho, and Riposte[82] are implementations of R in C++. Renjin, Riposte, and pqR attempt to improve performance by using multiple cores and deferred evaluation.[83] Most of these alternative implementations are experimental and incomplete, with relatively few users, compared to the main implementation maintained by the R Development Core Team.

TIBCO built a runtime engine called TERR, which is part of Spotfire.[84]

Microsoft R Open (MRO) is a fully compatible R distribution with modifications for multi-threaded computations.[85][86] As of 30 June 2021, Microsoft started to phase out MRO in favor of the CRAN distribution. [87]

Communities

R has local communities worldwide for users to network, share ideas, and learn.[88][89]

A growing number of R events bring users together, such as conferences (e.g. useR!, WhyR?, conectaR, SatRdays),[90][91] meetups,[92] as well as R-Ladies groups[93] that promote gender diversity. The R Foundation taskforce focuses on women and other under-represented groups.[94]

useR! conferences

The official annual gathering of R users is called "useR!".[95] The first such event was useR! 2004 in May 2004, Vienna, Austria.[96] After skipping 2005, the useR! conference has been held annually, usually alternating between locations in Europe and North America.[97] History:[95]

- useR! 2006, Vienna, Austria

- useR! 2007, Ames, Iowa, USA
- useR! 2008, Dortmund, Germany
- useR! 2009, Rennes, France
- useR! 2010, Gaithersburg, Maryland, USA
- useR! 2011, Coventry, United Kingdom
- useR! 2012, Nashville, Tennessee, USA
- useR! 2013, Albacete, Spain
- useR! 2014, Los Angeles, California, USA
- useR! 2015, Aalborg, Denmark
- useR! 2016, Stanford, California, USA
- useR! 2017, Brussels, Belgium
- useR! 2018, Brisbane, Australia
- useR! 2019, Toulouse, France
- useR! 2020, took place online due to COVID-19 pandemic
- useR! 2021, took place online due to COVID-19 pandemic

As of November 2021, no next event date has been set yet. [98]

The R Journal

The R Journal is an open access, refereed journal of the R project. It features short to medium length articles on the use and development of R, including packages, programming tips, CRAN news, and foundation news.

Comparison with alternatives

R is comparable to popular commercial statistical packages such as SAS, SPSS, and Stata. One difference is that R is available at no charge under a free software license.[99]

In January 2009, the *New York Times* ran an article charting the growth of R, the reasons for its popularity among data scientists and the threat it poses to commercial statistical packages such as SAS.[100] In June 2017 data scientist Robert Muenchen published a more in-depth comparison between R and other software packages, "The Popularity of Data Science Software".[101]

R is more procedural than either SAS or SPSS, both of which make heavy use of pre-programmed procedures (called "procs") that are built-in to the language environment and customized by parameters of each call. R generally processes data in-memory, which limits its usefulness in processing larger files.[102]

Commercial support

Although R is an open-source project, some companies provide commercial support and extensions.

In 2007, Richard Schultz, Martin Schultz, Steve Weston and Kirk Mettler founded Revolution Analytics to provide commercial support for Revolution R, their distribution of R, which includes components developed by the company. Major additional components include: ParallelR, the R Productivity Environment IDE, RevoScaleR (for big data analysis), RevoDeployR, web services framework, and the ability for reading and writing data in the SAS file format.[103] Revolution

Analytics offers an R distribution designed to comply with established IQ/OQ/PQ criteria that enables clients in the pharmaceutical sector to validate their installation of REvolution R.[104] In 2015, Microsoft Corporation acquired Revolution Analytics[105] and integrated the R programming language into SQL Server, Power BI, Azure SQL Managed Instance, Azure Cortana Intelligence, Microsoft ML Server and Visual Studio 2017.[106]

In October 2011, Oracle announced the *Big Data Appliance*, which integrates R, Apache Hadoop, Oracle Linux, and a NoSQL database with Exadata hardware.[107] As of 2012, Oracle R Enterprise[108] became one of two components of the "Oracle Advanced Analytics Option"[109] (alongside Oracle Data Mining).

IBM offers support for in-Hadoop execution of R,[110] and provides a programming model for massively parallel in-database analytics in R.[111]

TIBCO offers a runtime-version R as a part of Spotfire.[112]

Mango Solutions offers a validation package for R, ValidR,[113][114] to comply with drug approval agencies, such as the FDA. These agencies required the use of validated software, as attested by the vendor or sponsor.[115]

Examples

Basic syntax

The following examples illustrate the basic syntax of the language and use of the command-line interface. (An expanded list of standard language features can be found in the R manual, "An Introduction to R".[116])

In R, the generally preferred assignment operator is an arrow made from two characters <-, although = can be used in some cases.[117][118]

```
> x <- 1:6 # Create a numeric vector in the current environment
> y <- x^2 # Create vector based on the values in x.
> print(y) # Print the vector's contents.
[1]  1  4  9 16 25 36

> z <- x + y # Create a new vector that is the sum of x and y
> z # Return the contents of z to the current environment.
[1]  2  6 12 20 30 42

> z_matrix <- matrix(z, nrow=3) # Create a new matrix that turns the vector z into a 3x2 matrix object
> z_matrix
     [,1] [,2]
[1,]    2   20
[2,]    6   30
[3,]   12   42

> 2*t(z_matrix)-2 # Transpose the matrix, multiply every element by 2, subtract 2 from each element in
the matrix, and return the results to the terminal.
     [,1] [,2] [,3]
[1,]    2   10   22
[2,]   38   58   82

> new_df <- data.frame(t(z_matrix), row.names=c('A','B')) # Create a new data.frame object that contains
the data from a transposed z_matrix, with row names 'A' and 'B'
> names(new_df) <- c('X','Y','Z') # Set the column names of new_df as X, Y, and Z.
> print(new_df)  # Print the current results.
   X  Y  Z
A  2  6 12
B 20 30 42

> new_df$Z # Output the Z column
```

```
[1] 12 42

> new_df$Z==new_df['Z'] && new_df[3]==new_df$Z # The data.frame column Z can be accessed using $Z,
['Z'], or [3] syntax, and the values are the same.
[1] TRUE

> attributes(new_df) # Print attributes information about the new_df object
$names
[1] "X" "Y" "Z"

$row.names
[1] "A" "B"

$class
[1] "data.frame"

> attributes(new_df)$row.names <- c('one','two') # Access and then change the row.names attribute; can
also be done using rownames()
> new_df
     X  Y  Z
one  2  6 12
two 20 30 42
```

Structure of a function

One of R's strengths is the ease of creating new functions. Objects in the function body remain local to the function, and any data type may be returned.[119] Example:

```
# Declare function "f" with parameters "x", "y"
# that returns a linear combination of x and y.
f <- function(x, y) {
  z <- 3 * x + 4 * y
  return(z) ## the return() function is optional here
}
```

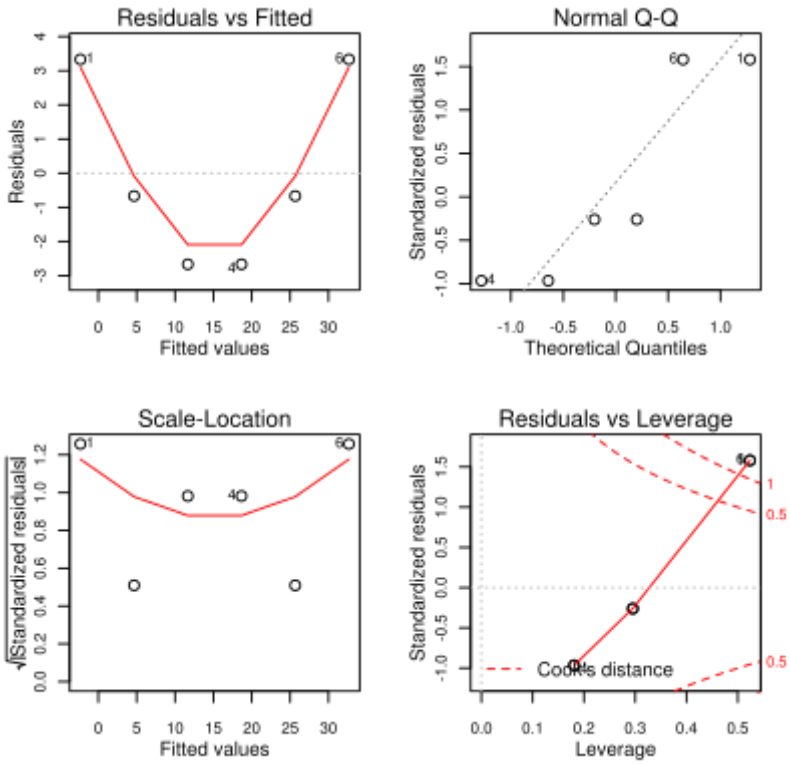
```
> f(1, 2)
[1] 11

> f(c(1,2,3), c(5,3,4))
[1] 23 18 25

> f(1:3, 4)
[1] 19 22 25
```

Modeling and plotting

The R language has built-in support for data modeling and graphics. The following example shows how R can easily generate and plot a linear model with residuals.

```
> x <- 1:6 # Create x and y values
> y <- x^2
> model <- lm(y ~ x)  # Linear
regression model y = A + B * x.
> summary(model)  # Display an in-
depth summary of the model.

Call:
lm(formula = y ~ x)

Residuals:
      1       2       3       4
5       6
 3.3333 -0.6667 -2.6667 -2.6667
-0.6667  3.3333

Coefficients:
```

```
            Estimate Std. Error t
value Pr(>|t|)
(Intercept)  -9.3333     2.8441
-3.282 0.030453 *
x             7.0000     0.7303
9.585 0.000662 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’
0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 3.055 on 4
degrees of freedom
Multiple R-squared:  0.9583, Adjusted
R-squared:  0.9478
F-statistic: 91.88 on 1 and 4 DF,  p-
value: 0.000662

> par(mfrow = c(2, 2))  # Create a 2
by 2 layout for figures.
> plot(model)  # Output diagnostic
plots of the model.
```



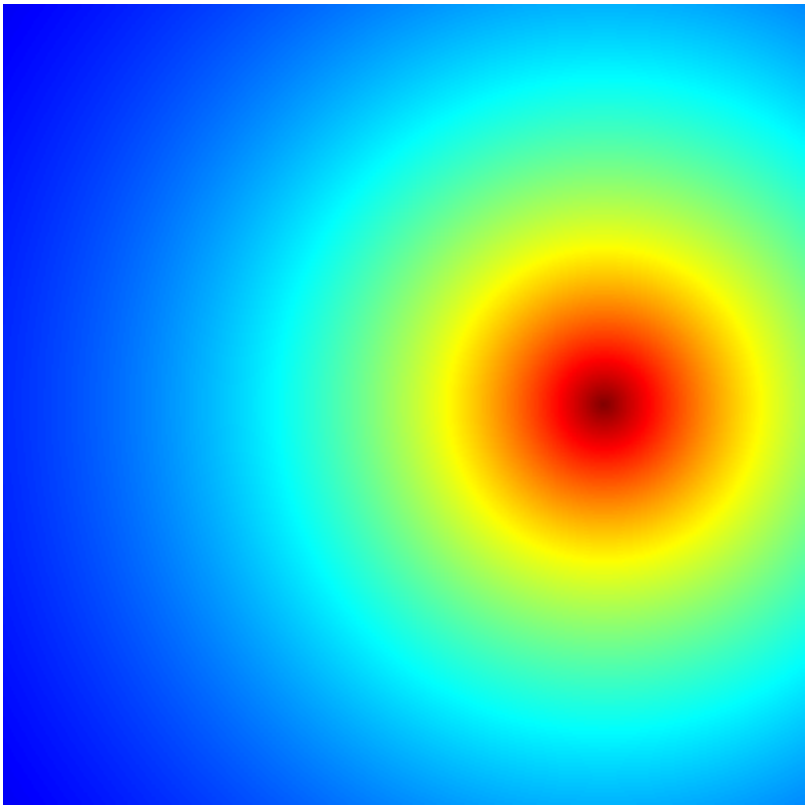
Diagnostic plots from plotting “model” (q.v. “plot.lm()” function). Notice the mathematical notation allowed in labels (lower left plot).

Mandelbrot set

Short R code calculating Mandelbrot set through the first 20 iterations of equation $z = z^2 + c$ plotted for different complex constants c. This example demonstrates:

- use of community-developed external libraries (called packages), in this case caTools package
- handling of complex numbers
- multidimensional arrays of numbers used as basic data type, see variables C, Z and X.

```
install.packages("caTools")  #
install external package
library(caTools)             #
external package providing write.gif
function
jet.colors <-
colorRampPalette(c("red", "blue",
"#007FFF", "cyan", "#7FFF7F",

"yellow", "#FF7F00", "red",
"#7F0000"))
dx <- 1500                   #
define width
dy <- 1400                   #
define height
C  <- complex(real = rep(seq(-2.2,
1.0, length.out = dx), each = dy),
              imag = rep(seq(-1.2,
1.2, length.out = dy), dx))
C <- matrix(C, dy, dx)       #
reshape as square matrix of complex
numbers
Z <- 0                       #
initialize Z to zero
X <- array(0, c(dy, dx, 20)) #
initialize output 3D array
for (k in 1:20) {            # loop
with 20 iterations
  Z <- Z^2 + C               # the
```



"Mandelbrot.gif" – graphics created in R with 14 lines of code in Example 2

```
  central difference equation
    X[, , k] <- exp(-abs(Z))   #
  capture results
  }
  write.gif(X, "Mandelbrot.gif", col =
  jet.colors, delay = 100)
```

See also

- S programming language
- R package
- Comparison of numerical-analysis software
- Comparison of statistical packages
- List of numerical-analysis software
- List of statistical software
- Rmetrics
- RStudio
- Tidyverse

Notes

1. As of 13 June 2020, Metacran (https://www.r-pkg.org/downloaded) listed 7 of the 8 core packages of the Tidyverse in the list of most download R packages.

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