

Introduction to Sage

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Jeudi SageMath au LaBRI

LaBRI

October 13th 2021

Outline

An History of Math Softwares

Sage

Community

Some functionalities

Development

Plan

An History of Math Softwares

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Development

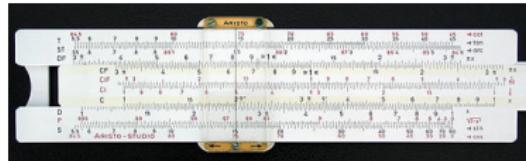
From Abacus to computers



Abacus (2000 BC)



Pascaline (1645)



Slide rule (1620)



HP-35 (1972)



IMB PC 5150 (1983)



TI-89 (1998)

Depuis 1960, au moins 45 logiciels de mathématiques
(32 à licence libre et 13 commerciaux) :

Axiom	FORM	Magnus	MuPAD	SyMAT
Cadabra	FriCAS	Maple	OpenAxiom	SymbolicC
Calcinator	FxSolver	Mathcad	PARI/GP	Symbolism
CoCoA-4	GAP	Mathematica	Reduce	Symengine
CoCoA-5	GiNaC	MathHandbook	Scilab	Sympy
Derive	KANT/KASH	Mathics	SageMath	TI-Nspire
DataMelt	Macaulay2	Mathomatic	SINGULAR	Wolfram A
Erable	Macsyma	Maxima	SMath	Xcas/Giac
Fermat	Magma	MuMATH	Symbolic	Yacas

Source : http://en.wikipedia.org/wiki/List_of_computer_algebra_systems

Quelques logiciels commerciaux :

- ▶ **Maple**, Waterloo Maple Inc., Maplesoft, since 1985.
- ▶ **Mathematica**, Wolfram Research, since 1988.
- ▶ **Matlab**, MathWorks, since 1989
- ▶ **Magma**, University of Sydney, since 1990



Quelques logiciels libres :

- ▶ **Maxima**, W. Schelter et coll., since 1967 : **symbolic operations**
- ▶ **Singular**, U. of Kaiserslautern, since 1984 : **polynomial comput.**
- ▶ **PARI/GP**, U. Bordeaux 1, since 1985 : **number theory computations**
- ▶ **GAP**, GAP Group, since 1986 : **computational group theory**
- ▶ **R**, U. of Auckland, New Zealand, since 1993 : **statistiques**

"You can read Sylow's Theorem and its proof in Huppert's book in the library . . . then you can use Sylow's Theorem for the rest of your life free of charge, but for many computer algebra systems license fees have to be paid regularly . . .

With this situation two of the most basic rules of conduct in mathematics are violated : In mathematics information is passed on free of charge and everything is laid open for checking."

—J. Neubüser (1993)

(il a fondé GAP en 1986)

Python scientifique



NumPy
Base N-dimensional
array package



SciPy library
Fundamental library
for scientific
computing



Matplotlib
Comprehensive 2D
Plotting



IPython
Enhanced Interactive
Console



Sympy
Symbolic
mathematics



pandas
Data structures &
analysis



- ▶ 1991 : première version de Python
- ▶ 2000-2001 : Matplotlib, IPython, SciPy
- ▶ 2006-2008 : NumPy, SymPy, pandas
- ▶ 2006 : Sage based on PARI, Maxima, Python, Singular, GAP.
- ▶ 2012-2014 : Julia, Jupyter
- ▶ 2015 : 70 000 librairies Python dans le *Python Package Index*
- ▶ 2020 : Sage 9.0 was released on 2020-01-01 using Python 3
- ▶ 2021 : 332 885 librairies Python dans le *Python Package Index*

Plan

An History of Math Softwares

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Some functionalities

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Mission

The Sage Project aims to create a viable high-quality and open-source alternative to Magma, Maple, Mathematica, Matlab and MuPAD, and to foster a friendly community of users and developers.

Sage is an *open source* software

Sage is distributed under the terms of the GNU General Public License version 2 (GPLv2) which guarantees four types of freedom :

- ▶ The freedom to **use** the software (it is free).
- ▶ The freedom to **read the source code**.
- ▶ The freedom to **improve the software**.
- ▶ The freedom to **redistribute the modified software to anyone**.

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Installation

- ▶ Use the Sage Debian Live USB key
- ▶ Via Linux package managers :
 - ▶ GNU/Linux Debian version ≥ 9
 - ▶ Ubuntu version ≥ 18.04
 - ▶ Arch Linux
- ▶ Install from Pre-built Binaries :
 - ▶ Linux
 - ▶ macOS
 - ▶ Microsoft Windows (Cygwin)
- ▶ Install from conda-forge
- ▶ Install from Source Code
- ▶ Or use it online :
 - ▶ Cocalc
 - ▶ Sage Cell Server

See <https://doc.sagemath.org/html/en/installation/>

Sage is . . .

a *distribution* of softwares

Sage is a free software : mutualization

Build the bike instead of reinventing the wheel :

Arbitrary precision arithmetic	MPIR (GMP), MPFR, MPFI, NTL
Algebra	GAP, Maxima, Singular, Givaro
Algebraic geometry	Singular, Macaulay2*
Arithmetic geometry	FLINT, PARI/GP, NTL, ecm
Courbes elliptiques et fonctions L	ECLib, mwrank, ratpoints, SYMPOW, Lca
Symbolic computation	Pynac, Maxima, Sympy, giac*
Exact linear algebra	Linbox, IML
Numerical calculations	Blas (Atlas), Numpy, LAPACK
Numerical calculations	GSL, Scipy
Combinatorics	Symmetria, Lrcalc, PALP, Coxeter 3, Che
Graph theory	NetworkX, Cliquer, Buckygen*, graphviz*,
	cvxopt, PPL, glpk, CBC*
Group theory	GAP
Game theory	Gambit*
Statistics	R, Rpy, pandas*
Cryptography	pycrypto, cryptominisat*

(* optional)

... and more!

```
> sage -gap
```

Information at: <http://www.gap-system.org>

Try '?help' for help. See also '?copyright' and '?authors'

Loading the library. Please be patient, this may take a while.
GAP4, Version: 4.4.10 of 02-Oct-2007, x86_64-unknown-linux-gnu-gcc

gap>

```
> sage -singular
```

```
          SINGULAR           / Development
A Computer Algebra System for Polynomial Computations / version 3-1-0
by: G.-M. Greuel, G. Pfister, H. Schoenemann      0<
FB Mathematik der Universitaet, D-67653 Kaiserslautern      \
>
```

```
> sage -maxima
```

```
Maxima 5.16.3 http://maxima.sourceforge.net
Using Lisp ECL 9.4.1
Distributed under the GNU Public License. See the file COPYING.
Dedicated to the memory of William Schelter.
The function bug_report() provides bug reporting information.
(%i1)
```

```
> sage -gp
```

```
GP/PARI CALCULATOR Version 2.3.3 (released)
amd64 running linux (x86-64/GMP-4.2.1 kernel) 64-bit version
compiled: Jul 10 2009, gcc-4.3.2 (Ubuntu 4.3.2-1ubuntu12)
(readline v5.2 enabled, extended help available)
```

```
Copyright (C) 2000-2006 The PARI Group
```

```
PARI/GP is free software, covered by the GNU General Public License, and
comes WITHOUT ANY WARRANTY WHATSOEVER.
```

```
Type ? for help, \q to quit.
```

```
Type ?12 for how to get moral (and possibly technical) support.
```

```
parisize = 8000000, primelimit = 500000
?
```

```
> sage -R
```

R version 2.6.1 (2007-11-26)

Copyright (C) 2007 The R Foundation for Statistical Computing
ISBN 3-900051-07-0

R is free software and comes with ABSOLUTELY NO WARRANTY.

You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

Natural language support but running in an English locale

R is a collaborative project with many contributors.

Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.

Type 'q()' to quit R.

```
>
```

Sage *combines* software.

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[These examples are from a presentation of William Stein]

Sage combines software

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Construct an elliptic curve using *John Cremona's table* :

```
sage: E = EllipticCurve('389a')
```

Sage combines software

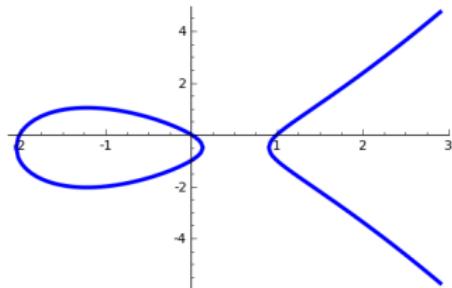
[These examples are from a presentation of William Stein]

Construct an elliptic curve using *John Cremona's table* :

```
sage: E = EllipticCurve('389a')
```

Use *matplotlib* to plot it :

```
sage: plot(E, thickness=3)
```



Sage combines software

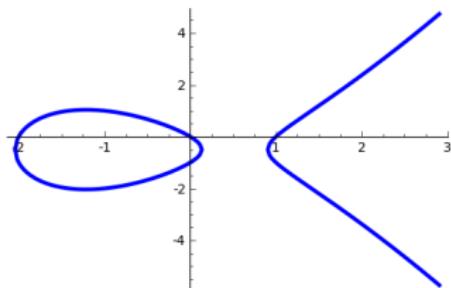
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```

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sage: plot(E, thickness=3)
```



mwrank to do a 2-descent :

```
sage: E.mwrank()  
Curve [0,1,1,-2,0] : Rank = 2
```

Sage *combines* software

PARI to compute Fourier coefficients a_n :

```
sage: E.anlist(15)
```

```
[0, 1, -2, -2, 2, -3, 4, -5, 0, 1, 6, -4, -4, -3, 10, 6]
```

Sage combines software

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```
[0, 1, -2, -2, 2, -3, 4, -5, 0, 1, 6, -4, -4, -3, 10, 6]
```

lcalc to compute zeros in the critical strip of the L-series :

```
sage: E.lseries().zeros(5)
```

```
[0.000000000, 0.000000000, 2.87609907, 4.41689608, 5.79]
```

Sage *combines* software

PARI to compute Fourier coefficients a_n :

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[0.000000000, 0.000000000, 2.87609907, 4.41689608, 5.79]
```

sympow to compute the modular degree :

```
sage: E.modular_degree()
```

```
40
```

Sage combines software

PARI to compute Fourier coefficients a_n :

```
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```
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```

sympow to compute the modular degree :

```
sage: E.modular_degree()
```

```
40
```

Magma to compute the rank of the 3-selmer group :

```
sage: magma(E).ThreeSelmerGroup()
```

```
Abelian Group isomorphic to Z/3 + Z/3
```

```
Defined on 2 generators
```

Sage combines software

Let's integrate $\int \cos(x^2)dx$:

```
sage: integrate(cos(x^2), x)
-1/8*((I + 1)*sqrt(2)*erf((1/2*I - 1/2)*sqrt(2)*x) +
(I - 1)*sqrt(2)*erf((1/2*I + 1/2)*sqrt(2)*x))*sqrt(pi)
```

Software **used** for this computation :

```
sage: from sage.misc.citation import get_systems
sage: get_systems("integrate(cos(x^2), x)")
['MPFI', 'ginac', 'GMP', 'Maxima']
```

```
sage: m = matrix(3,range(9))
sage: m.determinant?
Docstring:
    Return the determinant of this matrix.
```

INPUT:

* "algorithm"

- * "'default'" -- use "flint"
- * "'flint'" -- let flint do the determinant
- * "'padic'" - uses a p-adic / multimodular algorithm that relies
on code in IML and linbox
- * "'linbox'" - calls linbox det (you ***must*** set proof=False to
use this!)
- * "'ntl'" - calls NTL's det function
- * "'pari'" - uses PARI

...

```
sage: m.determinant??
[... prints the source code ...]
```

Sage uses *Python*
as its programming language.

Sage uses *Python*

- ▶ Sage \approx Python + a huge Python library
- ▶ Sage may be the first successful math software system **to not invent its own new language** just for mathematics.
- ▶ Tens of thousands of **third party Python packages** are immediately available for use with Sage !
- ▶ Easy to **write and read** :

math :
$$\left\{ 17x \mid x \in \{0, 1, \dots, 9\} \text{ et } x \text{ est impair} \right\}$$

python : [17*x for x in range(10) if x % 2 == 1]

Sage Important Philosophy : Elements have parent

```
sage: m = matrix(ZZ, 3, [2,3,4,2,4,6,8,8,5])
sage: m.parent()
Full MatrixSpace of 3 by 3 dense matrices over Integer Ring
sage: m.echelon_form()
[2 0 1]
[0 1 2]
[0 0 3]

sage: m = matrix(QQ, 3, [2,3,4,2,4,6,8,8,5])
sage: m.parent()
Full MatrixSpace of 3 by 3 dense matrices over Rational Field
sage: m.echelon_form()
[1 0 0]
[0 1 0]
[0 0 1]
```

Sage Optional Packages (spkg)

<http://www.sagemath.org/packages/optional/>

Fokko Ducloux's Coxeter 3 C++ library

```
sage -i coxeter3-1.1.spkg
```

Gnuplot.py is a Python package that interfaces to gnuplot

```
sage -i gnuplotpy-1.8.spkg
```

Ore Polynomials in Sage

http://www.risc.jku.at/research/combinat/software/ore_algebra/

```
sage -i ore_algebra-0.1.spkg  
sage: from ore_algebra import *
```

SageManifolds : Differential geometry and tensor calculus

<http://sagemanifolds.obspm.fr/>

```
sage -i http://sagemanifolds.obspm.fr/spkg/manifolds-0.2.spkg  
sage: from manifolds.all import *
```

Plan

An History of Math Softwares

Sage

Community

Some functionalities

Development

Community

You are not alone!

Working together with internet

Development :

- ▶ <http://groups.google.com/group/sage-devel>
- ▶ <http://groups.google.com/group/sage-release>
- ▶ http://trac.sagemath.org/sage_trac/
- ▶ <https://zulip.sagemath.org/login/>

Support :

- ▶ <http://groups.google.com/group/sage-support>
- ▶ <http://ask.sagemath.org/questions/>
- ▶ <http://wiki.sagemath.org/>

irc-channel

- ▶ #sage-devel on freenode.net

Sage Days

Sage Days are workshops aiming at

- ▶ fix bugs and develop new functionalities
- ▶ introduce new users and developers

Dozen of workshops are organized every year all around the world.

<https://wiki.sagemath.org/Workshops>

Sage Days in 2010

- ▶ Sage Days 19 : Seattle, USA (January 2010)
- ▶ Sage Days 20 : Marseille, France (February 2010)
- ▶ Sage Days 20.25 : Montreal, Canada (March 2010)
- ▶ Sage Days 20.5 : Toronto, Canada (May 2010)
- ▶ Sage Days 21 : Seattle, USA (June 2010)
- ▶ Sage-Combinat/Chevie : France (June 2010)
- ▶ Sage Days 22 : Berkeley, USA (July 2010)
- ▶ Sage Days 23 : Leiden, Netherlands (July 2010)
- ▶ Sage Days 23.5 : Kaiserslautern, Germany (July 2010)
- ▶ Sage Days 24 : Linz, Austria (July 2010)
- ▶ Sage Days 25 : Mumbai, India (August 2010)
- ▶ Sage Days 25.5 : Montreal, Canada (September 2010)
- ▶ Sage Days 26 : Seattle, USA (December 2010)

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Community

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Interfaces :

- ▶ Command line
- ▶ Jupyter Notebook
- ▶ Jupyterlab

Interfaces on internet :

- ▶ Sage Cell <http://sagecell.sagemath.org/>
- ▶ Sage Eval <http://www.sagemath.org/eval.html>
- ▶ Sage Cloud, CoCalc

Interesting features :

- ▶ Sagetex (Dan Drake, Corée du Sud)
- ▶ Interact and animations
- ▶ **Cython** : translates Python code \mapsto C code.

Command line interface

A screenshot of a terminal window titled "saliola@karkwa: ~". The window has a standard window title bar with icons for minimize, maximize, and close. Below the title bar is a menu bar with "File", "Edit", "View", "Terminal", "Tabs", and "Help". The main area of the terminal shows the command "sage" being run, followed by the SAGE version information and a welcome message. Then several Sage commands are entered and their results are displayed.

```
saliola@karkwa:~$ sage
| SAGE Version 3.1.2, Release Date: 2008-09-19
| Type notebook() for the GUI, and license() for information.

sage: 3 * 17
51
sage: [ 17 * x for x in range(10) if x % 2 == 1 ]
[17, 51, 85, 119, 153]
sage: Partitions(4).list()
[[4], [3, 1], [2, 2], [2, 1, 1], [1, 1, 1, 1]]
sage: █
```

Notebook interface (local)

The Sage Notebook (Sage) <localhost:8000/home/admin/3/>

SAGE The Sage Notebook Version 4.5.3

admin [Toggle](#) | [Home](#) | [Published](#) | [Log](#) | [Settings](#) | [Help](#) | [Report a Problem](#) | [Sign out](#)

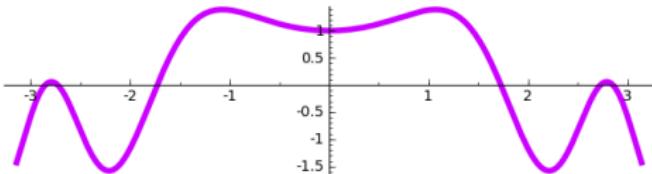
The Sage Notebook

last edited on November 27, 2010 01:03 PM by admin

[Save](#) [Save & quit](#) [Discard & quit](#)

File... Action Data... sage Typeset [Print](#) Worksheet Edit Text Undo Share Publish

```
plot(sin(x^2)+cos(x), -pi, pi, hue=0.8, thickness=4).show(figsize=[8,2])
```



plot

EXAMPLES: We plot the sin function:

```
sage: P = plot(sin, (0,10)); print P
Graphics object consisting of 1 graphics primitive
sage: len(P)      # number of graphics primitives
1
sage: len(P[0])   # how many points were computed (random)
225
sage: P          # render

sage: P = plot(sin, (0,10), plot_points=10); print P
Graphics object consisting of 1 graphics primitive
sage: len(P[0])   # random output
32
sage: P          # render
```

We plot with `randomize=False`, which makes the initial sample points evenly spaced (hence always the same). Adaptive plotting might insert other points, however, unless `adaptive_recursion=0`.

Sage Cell Server

<http://www.sagemath.org/eval.html>

v4.8 (2012-01-20) · [Like](#) 1.4k [+1](#) 459 [RSS](#) [Blog](#) [Trac](#) [Report Bugs](#) [Wiki](#) [Ask](#) [Feedback](#) [Search:](#) [Language](#)

open source mathematics software · Try Online: [sagenb](#) / KAIST or [Download](#)

Home Tour Support Library Download Development Links

Sage Cell Server

This web page contains an interactive Sage widget and a collection of 26 examples. You can edit it however you want. Interacts, graphics and plotting, etc., should all work.

Topic	Subtopic	Examples
Algebra	Basics	Funny Plot
Calculus	Multivariate	ODE Plot
Geometry	ODE	Simple Plot
Graph Theory	Plot	
Graphics		
Libs		

Calculus>Plot
Funny Plot: this is just a funny plot

```
1 plot(sin(x) / (2+cos(pi*x)), (-2*pi, 6*pi))
```

Evaluate

Permalink ([Alternative permalink](#); [Shortened temporary link](#))

LATEX

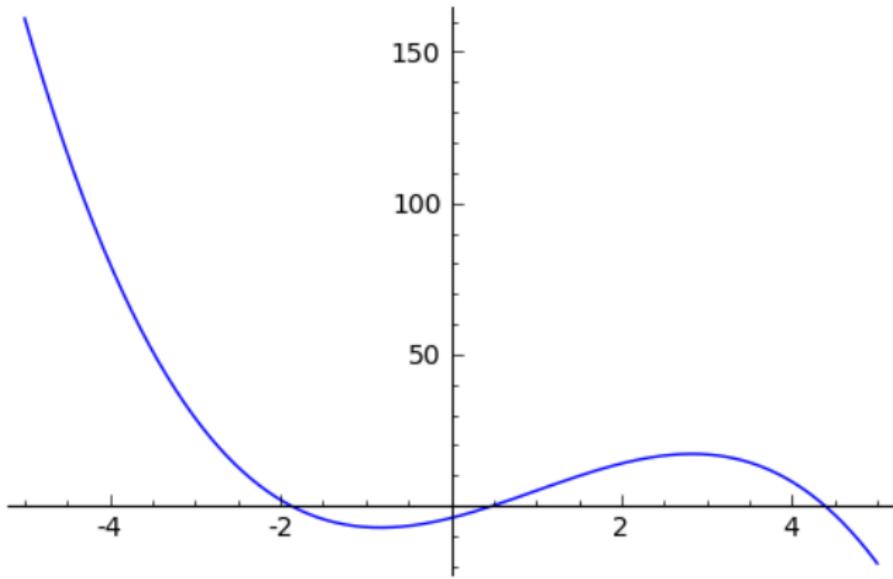
In this LATEXfile, I write

```
\sageplot{plot(-x^3+3*x^2+7*x-4,-5,5)}
```

In this L^AT_EXfile, I write

```
\sageplot{plot(-x^3+3*x^2+7*x-4,-5,5)}
```

and this is replaced by :



In this LATEXfile :

```
\begin{sagesilent}
sigma = Permutation([7,3,1,5,2,6,8,4])
P, Q = sigma.robinson_schensted()
\end{sagesilent}
```

Let $\sigma = \text{sage}\{\sigma\}$. The Robinson-Schensted-Knuth algorithm produces the tableaux:

```
\[\text{sage}\{P\} \quad \text{sage}\{Q\}\]
```

It got replaced with :

Let $\sigma = [7, 3, 1, 5, 2, 6, 8, 4]$. The Robinson-Schensted-Knuth algorithm produces the tableaux :

1	2	4	8
3	5	6	
7			

1	4	6	7
2	5	8	
3			

It got replaced with :

Let $\sigma = [7, 3, 1, 5, 2, 6, 8, 4]$. The Robinson-Schensted-Knuth algorithm produces the tableaux :

1	2	4	8
3	5	6	
7			

1	4	6	7
2	5	8	
3			

This is done with the **sagetex** package for LATEX, written by Dan Drake. Of course, the package is included with Sage.

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Development

> 900 Developers

```
$ git shortlog -n -s | wc  
    976    2832   20316  
$ git shortlog -n -s | head -20  
11656 Release Manager  
  5785 William Stein  
  4971 Frédéric Chapoton  
  4002 Travis Scrimshaw  
  3417 Jeroen Demeyer  
  2332 Matthias Koeppe  
  2242 Daniel Krenn  
  1799 Volker Braun  
  1756 Nathann Cohen  
  1392 mabshoff  
  1356 Vincent Delecroix  
  1161 Julian Rüth  
  1096 Erik M. Bray  
  1076 Martin Albrecht  
  1060 Clemens Heuberger  
  1048 David Coudert  
  1025 Dima Pasechnik  
  1008 Ralf Stephan  
   937 Robert Bradshaw
```

Versions 9.x (2020–)

- ▶ Sage 9.5 (current development cycle, 2021)
support for Python 3.10 planned
- ▶ Sage 9.4 (released Aug 22, 2021)
adds support for GCC 11, removes support for Python 3.6, major advances in symbolics, convex and differential geometry, knot theory
442 tickets (PRs) merged, **73 contributors**
- ▶ Sage 9.3 (released May 9, 2021)
adds support for macOS 11 "Big Sur"; major package upgrades
679 tickets (PRs) merged, **112 contributors**
- ▶ Sage 9.2 (released Oct 24, 2020)
Python 3 support expanded to 3.6, 3.7, 3.8, 3.9; Python 2 support dropped; major package upgrades;
727 tickets (PRs) merged, **134 contributors**
- ▶ Sage 9.1 (released May 21, 2020)
last release supporting both Python 2 and 3; major portability improvements
551 tickets (PRs) merged, **106 contributors**
- ▶ Sage 9.0 (released Jan 1, 2020)
first release that uses Python 3 by default;
348 tickets (PRs) merged, **116 contributors**

Current main development goals

Main goal is now to integrate Sage into the normal way of doing stuff in Python (which evolved greatly during the years).

Details explained in this talk :

- ▶ Modularization and pip-installability of the Sage library,
Matthias Koeppe (UC Davis), 30 Oct 2020, <https://researchseminars.org/talk/SageDays110/11/>

"Abstract : I will explain the ongoing project to modularize the Sage library into separate, pip-installable distributions."

and in this Meta-ticket :

- ▶ Meta-ticket : Modularize `sagelib` into separate distributions (pip-installable packages) `sagemath-`...
<https://trac.sagemath.org/ticket/29705>

The Python code inside SageMath



```
$ ls src/sage
algebras          docs           groups        misc          sandpiles
all_cmdline.py   doctest        homology     modular       sat
all_notebook.py  dynamics      __init__.py  modules      schemes
all.py            env.py        interacts    monoids      server
arith             ext           interfaces  numerical    sets
calculus          ext_data     knots         parallel    stats
categories        features     lfunctions  plot         structure
coding            finance      libs          probability symbolic
combinat          functions   logic         __pycache__ tensor
cpython           games        manifolds   quadratic_forms tests
crypto            game_theory matrix       quivers      typeset
databases         geometry    matroids    repl         version.py
data_structures  graphs      media        rings
```

Inside : now more than 300 packages



```
$ ls build/pkgs/ | wc  
323      323     3283
```

```
$ ls build/pkgs/  
4ti2  
alabaster  
appnope  
arb  
arch-bootstrap.txt  
...  
zeromq  
zipp  
zlib  
zn_poly  
zope_interface
```

Inside :



```
$ cd build/pkgs/singular
$ ls
checksums.ini    distros          patches        spkg-install.in  type
dependencies     package-version.txt spkg-check.in  SPKG.rst
$ ls distros/
freebsd.txt      nix.txt
$ cat dependencies
$(MP_LIBRARY) $(PYTHON) ntl flint readline mpfr cddlib
```

```
All lines of this file are ignored except the first.
It is copied by SAGE_ROOT/build/make/install into SAGE_ROOT/build/make/
$ cat type
standard
$ ls patches/
configure-no-ntl-header-check.patch  ntl-check-m4-no-ntl-header-check.p
fix-building-with-nodebug.patch      singular-ntl-error-handler.patch
```

For more information

- ▶ <http://sagemath.org/help.html>
- ▶ <http://sagemath.org/doc>
- ▶ <http://ask.sagemath.org/questions/>
- ▶ <http://wiki.sagemath.org>

Ressources in **French** :

- ▶ <http://sagemath.org/fr>
- ▶ <http://sagemath.org/fr/html/tutorial>

Le livre **Calcul mathématique avec Sage** :

- ▶ <http://sagebook.gforge.inria.fr/>