Elliptic Curves

(PARI-GP version 2.9.0)

An elliptic curve is initially given by 5-tuple $v = [a_1, a_2, a_3, a_4, a_6]$ attached to Weierstrass model or simply $[a_4, a_6]$. It must be converted to an *ell* struct.

Initialize *ell* struct over domain D	`E = ellinit`$(v, \{D = 1\})$
over $\mathbf{Q}$	$D = 1$
over $\mathbf{F}_p$	$D = p$
over $\mathbf{F}_q$, $q = p^f$	$D =$ `ffgen([`p, f`])`
over $\mathbf{Q}_p$, precision n	$D = O(p^n)$
over $\mathbf{C}$, current bitprecision	$D = 1.0$
over number field K	$D = nf$

Points are `[x,y]`, the origin is `[0]`. Struct members accessed as `E.`*member*:

- All domains: `E.a1,a2,a3,a4,a6`, `b2,b4,b6,b8`, `c4,c6`, `disc`, `j`
- E defined over $\mathbf{R}$ or $\mathbf{C}$

x-coords. of points of order 2	`E.roots`
periods / quasi-periods	`E.omega,E.eta`
volume of complex lattice	`E.area`

- E defined over $\mathbf{Q}_p$

residual characteristic	`E.p`
If $\lvert j\rvert_p > 1$: Tate's $[u^2, u, q, [a, b], \mathcal{L}]$	`E.tate`

- E defined over $\mathbf{F}_q$

characteristic	`E.p`
$\#E(\mathbf{F}_q)$/cyclic structure/generators	`E.no`, `E.cyc`, `E.gen`

- E defined over $\mathbf{Q}$

generators of $E(\mathbf{Q})$ (require `elldata`)	`E.gen`
$[a_1, a_2, a_3, a_4, a_6]$ from j-invariant	`ellfromj`(j)
cubic/quartic/biquadratic to Weierstrass	`ellfromeqn`(eq)
add points $P + Q$ / $P - Q$	`elladd`(E, P, Q), `ellsub`
negate point	`ellneg`(E, P)
compute $n \cdot z$	`ellmul`(E, z, n)
check if z is on E	`ellisoncurve`(E, z)
order of torsion point z	`ellorder`(E, z)
y-coordinates of point(s) for x	`ellordinate`(E, x)
point $[\wp(z), \wp'(z)]$ corresp. to z	`ellztopoint`(E, z)
complex z such that $p = [\wp(z), \wp'(z)]$	`ellpointtoz`(E, p)

Change of Weierstrass models, using $v = [u, r, s, t]$

change curve E using v	`ellchangecurve`(E, v)
change point z using v	`ellchangepoint`(z, v)
change point z using inverse of v	`ellchangepointinv`(z, v)

Twists and isogenies

quadratic twist	`elltwist`(E, D)
n-division polynomial $f_n(x)$	`elldivpol`$(E, n, \{x\})$
$[n]P = (\phi_n\psi_n\colon \omega_n\colon \psi_n^3)$; return (ϕ_n, ψ_n^2)	`ellxn`(E, n, v)
isogeny from E to E/G	`ellisogeny`(E, G)
apply isogeny to g (point or isogeny)	`ellisogenyapply`(f, g)

Formal group

formal exponential, n terms	`ellformalexp`$(E, \{n\}, \{v\})$
formal logarithm, n terms	`ellformallog`$(E, \{n\}, \{v\})$
$L(-x/y) \in \mathbf{Q}_p$; $P \in E(\mathbf{Q}_p)$	`ellpadiclog`(E, p, n, P)
$[x, y]$ in the formal group	`ellformalpoint`$(E, \{n\}, \{v\})$
$[f, g]$, $\omega = f(t)dt$, $x\omega = g(t)dt$	`ellformaldifferential`
$w = -1/y$ in parameter $-x/y$	`ellformalw`$(E, \{n\}, \{v\})$

Curves over finite fields, Pairings

random point on E	`random`(E)
$\#E(\mathbf{F}_q)$	`ellcard`(E)
$\#E(\mathbf{F}_q)$ with almost prime order	`ellsea`$(E, \{tors\})$
structure $\mathbf{Z}/d_1\mathbf{Z} \times \mathbf{Z}/d_2\mathbf{Z}$ of $E(\mathbf{F}_q)$	`ellgroup`(E)
is E supersingular?	`ellissupersingular`(E)
Weil pairing of m-torsion pts x, y	`ellweilpairing`(E, x, y, m)
Tate pairing of x, y; x m-torsion	`elltatepairing`(E, x, y, m)
Discrete log, find n s.t. $P = [n]Q$	`elllog`$(E, P, Q, \{ord\})$

Curves over Q

Reduction, minimal model

minimal model of $E/\mathbf{Q}$	`ellminimalmodel`$(E, \{\&v\})$
quadratic twist of minimal conductor	`ellminimaltwist`
multiple with good reduction	`ellnonsingularmultiple`(E, P)

Complex heights

canonical height of P	`ellheight`(E, P)
canonical bilinear form taken at P, Q	`ellheight`(E, P, Q)
height regulator matrix for pts in x	`ellheightmatrix`(E, x)

p-adic heights

cyclotomic p-adic height of $P \in E(\mathbf{Q})$	`ellpadicheight`(E, P, n)
...bilinear form at $P, Q \in E(\mathbf{Q})$	`ellpadicheight`(E, P, n, Q)
...matrix at vector of points	`ellpadicheightmatrix`(E, p, n, x)
Frobenius on $\mathbf{Q}_p \otimes H^1_{dR}(E/\mathbf{Q})$	`ellpadicfrobenius`(E, p, n)
slope of unit eigenvector of Frobenius	`ellpadics2`(E, p, n)

Isogenous curves

matrix of isogeny degrees for $\mathbf{Q}$-isog. curves	`ellisomat`(E)
a modular equation of prime degree N	`ellmodulareqn`(N)

L-function

p-th coeff a_p of L-function, p prime	`ellap`(E, p)
E supersingular at p?	`ellissupersingular`(E, p)
k-th coeff a_k of L-function	`ellak`(E, k)
$L(E, s)$ (using less memory than `lfun`)	`elllseries`(E, s)
$L^{(r)}(E, 1)$ (using less memory than `lfun`)	`ellL1`(E, r)
a Heegner point on E of rank 1	`ellheegner`(E)
order of vanishing at 1	`ellanalyticrank`$(E, \{eps\})$
root number for $L(E, .)$ at p	`ellrootno`$(E, \{p\})$
modular parametrization of E	`elltaniyama`(E)
degree of modular parametrization	`ellmoddegree`(E)
p-adic L-function of E at χ^s	`ellpadicL`$(E, p, n, \{s = 0\}$

Elldata package, Cremona's database:

db code `"11a1"` $\leftrightarrow [conductor, class, index]$	`ellconvertname`(s)
generators of Mordell-Weil group	`ellgenerators`(E)
look up E in database	`ellidentify`(E)
all curves matching criterion	`ellsearch`(N)
loop over curves with cond. from a to b	`forell`(E, a, b, seq)

Curves over number field K

coeff $a_\mathfrak{p}$ of L-function	`ellap`$(E, \mathfrak{p})$
Kodaira type of $\mathfrak{p}$-fiber of E	`elllocalred`$(E, \mathfrak{p})$
integral model of E/K	`ellintegralmodel`$(E, \{\&v\})$
minimal model of E/K	`ellminimalmodel`$(E, \{\&v\})$
cond, min mod, Tamagawa num `[`N, v, c`]`	`ellglobalred`(E)
$P \in E(K)$ n-divisible? $[n]Q = P$	`ellisdivisible`$(E, P, n, \{\&Q\})$

L-function

A domain $D = [c, w, h]$ in initialization mean we restrict $s \in \mathbf{C}$ to domain $|\Re(s) - c| < w$, $|\Im(s)| < h$; $D = [w, h]$ encodes $[1/2, w, h]$ and $[h]$ encodes $D = [1/2, 0, h]$ (critical line up to height h).

vector of first n a_k's in L-function	`ellan`(E, n)
init $L^{(k)}(E, s)$ for $k \le n$	`L = lfuninit`$(E, D, \{n = 0\})$
compute $L(E, s)$ (n-th derivative)	`lfun`$(L, s, \{n = 0\})$
torsion subgroup with generators	`elltors`(E)

Other curves of small genus

A hyperelliptic curve is given by a pair $[P, Q]$ ($y^2 + Qy = P$ with $Q^2 + 4P$ squarefree) or a single squarefree polynomial P ($y^2 = P$).

reduction of $y^2 + Qy = P$ (genus 2)	`genus2red`$([P, Q], \{p\})$
find a rational point on a conic, ${}^t xGx = 0$	`qfsolve`(G)
quadratic Hilbert symbol (at p)	`hilbert`$(x, y, \{p\})$
all solutions in $\mathbf{Q}^3$ of ternary form	`qfparam`(G, x)
$P, Q \in \mathbf{F}_q[X]$; char. poly. of Frobenius	`hyperellcharpoly`$([P, Q])$
matrix of Frobenius on $\mathbf{Q}_p \otimes H^1_{dR}$	`hyperellpadicfrobenius`

Elliptic & Modular Functions

$w = [\omega_1, \omega_2]$ or *ell* struct (`E.omega`), $\tau = \omega_1/\omega_2$.

arithmetic-geometric mean	`agm`(x, y)
elliptic j-function $1/q + 744 + \cdots$	`ellj`(x)
Weierstrass $\sigma/\wp/\zeta$ function	`ellsigma`(w, z), `ellwp`, `ellzeta`
periods/quasi-periods	`ellperiods`$(E, \{flag\})$, `elleta`(w)
$(2i\pi/\omega_2)^k E_k(\tau)$	`elleisnum`$(w, k, \{flag\})$
modified Dedekind η func. $\prod(1 - q^n)$	`eta`$(x, \{flag\})$
Dedekind sum $s(h, k)$	`sumdedekind`(h, k)
Jacobi sine theta function	`theta`(q, z)
k-th derivative at z=0 of `theta`(q, z)	`thetanullk`(q, k)
Weber's f functions	`weber`$(x, \{flag\})$
modular pol. of level N	`polmodular`$(N, \{inv = j\})$
Hilbert class polynomial for $\mathbf{Q}(\sqrt{D})$	`polclass`$(D, \{inv = j\})$

Based on an earlier version by Joseph H. Silverman

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