

Algebraic Number Theory

(PARI-GP version 2.11.0)

Binary Quadratic Forms

create $ax^2 + bxy + cy^2$ (distance d) `Qfb( $a, b, c, \{d\}$ )`
reduce x ($s = \sqrt{D}$, $l = \lfloor s \rfloor$) `qfbred( $x, \{flag\}, \{D\}, \{l\}, \{s\}$ )`
return $[y, g]$, $g \in \text{SL}_2(\mathbf{Z})$, $y = g \cdot x$ reduced `qfbreds12( $x$ )`
composition of forms $x*y$ or `qfbnucomp( $x, y, l$ )`
 n -th power of form x^n or `qfbnupow( $x, n$ )`
composition without reduction `qfbcomprow( $x, y$ )`
 n -th power without reduction `qfbpowrow( $x, n$ )`
prime form of disc. x above prime p `qfbprimeform( $x, p$ )`
class number of disc. x `qfbclassno( $x$ )`
Hurwitz class number of disc. x `qfbhclassno( $x$ )`
solve $Q(x, y) = p$ in integers, p prime `qfbsolve( $Q, p$ )`

Quadratic Fields

quadratic number $\omega = \sqrt{x}$ or $(1 + \sqrt{x})/2$ `quadgen( $x$ )`
minimal polynomial of ω `quadpoly( $x$ )`
discriminant of $\mathbf{Q}(\sqrt{x})$ `quaddisc( $x$ )`
regulator of real quadratic field `quadregulator( $x$ )`
fundamental unit in real $\mathbf{Q}(\sqrt{D})$ `quadunit( $D, \{w\}$ )`
class group of $\mathbf{Q}(\sqrt{D})$ `quadclassunit( $D, \{flag\}, \{t\}$ )`
Hilbert class field of $\mathbf{Q}(\sqrt{D})$ `quadhilbert( $D, \{flag\}$ )`
... using specific class invariant ($D < 0$) `polclass( $D, \{inv\}$ )`
ray class field modulo f of $\mathbf{Q}(\sqrt{D})$ `quadray( $D, f, \{flag\}$ )`

General Number Fields: Initializations

The number field $K = \mathbf{Q}[X]/(f)$ is given by irreducible $f \in \mathbf{Q}[X]$. We denote $\theta = \bar{X}$ the canonical root of f in K . A nf structure contains a maximal order and allows operations on elements and ideals. A bnf adds class group and units. A bnr is attached to ray class groups and class field theory. A rnf is attached to relative extensions L/K .

init number field structure nf `nfinit( $f, \{flag\}$ )`
known integer basis B `nfinit( $[f, B]$ )`
order maximal at $vp = [p_1, \dots, p_k]$ `nfinit( $[f, vp]$ )`
order maximal at all $p \leq P$ `nfinit( $[f, P]$ )`
certify maximal order `nfcertify( $nf$ )`

nf members:

a monic $F \in \mathbf{Z}[X]$ defining K $nf.pol$
number of real/complex places $nf.r1/r2/sign$
discriminant of nf $nf.disc$
 T_2 matrix $nf.t2$
complex roots of F $nf.roots$
integral basis of $\mathbf{Z}_K$ as powers of θ $nf.zk$
different/codifferent $nf.diff, nf.codiff$
index $[\mathbf{Z}_K : \mathbf{Z}[X]/(F)]$ $nf.index$
recompute nf using current precision `nfnewprec( $nf$ )`
init relative rnf $L = K[Y]/(g)$ `rnfinit( $nf, g$ )`
init bnf structure `bnfinit( $f, \{flag\}$ )`

bnf members:

same as nf , plus
underlying nf $bnf.nf$
classgroup $bnf.clgp$
regulator $bnf.reg$
fundamental/torsion units $bnf.fu, bnf.tu$

compress a bnf for storage `bnfcompress( $bnf$ )`
recover a bnf from compressed $bnfz$ `bnfinit( $bnfz$ )`
add S -class group and units, yield $bnfS$ `bnfsunit( $bnf, S$ )`
init class field structure bnr `bnrinit( $bnf, m, \{flag\}$ )`
bnr members: same as bnf , plus
underlying bnf $bnr.bnf$
big ideal structure $bnr.bid$
modulus $bnr.mod$
structure of $(\mathbf{Z}_K/m)^*$ $bnr.zkst$

Fields, subfields, embeddings

Defining polynomials, embeddings
smallest poly defining $f = 0$ (slow) `polredabs( $f, \{flag\}$ )`
small poly defining $f = 0$ (fast) `polredbest( $f, \{flag\}$ )`
random Tschirnhausen transform of f `poltschirnhaus( $f$ )`
 $\mathbf{Q}[t]/(f) \subset \mathbf{Q}[t]/(g)$? Isomorphic? `nfisincl( $f, g$ ), nfisom`
reverse polmod $a = A(t) \bmod T(t)$ `modreverse( $a$ )`
compositum of $\mathbf{Q}[t]/(f)$, $\mathbf{Q}[t]/(g)$ `polcompositum( $f, g, \{flag\}$ )`
compositum of $K[t]/(f)$, $K[t]/(g)$ `nfcompositum( $nf, f, g, \{flag\}$ )`
splitting field of K (degree divides d) `nfsplitting( $nf, \{d\}$ )`
signs of real embeddings of x `nfeltsign( $nf, x, \{pl\}$ )`
complex embeddings of x `nfeltembed( $nf, x, \{pl\}$ )`
 $T \in K[t]$, # of real roots of $\sigma(T) \in R[t]$ `nfpolsturm( $nf, T, \{pl\}$ )`

Subfields, polynomial factorization

subfields (of degree d) of nf `nfsubfields( $nf, \{d\}$ )`
 d -th degree subfield of $\mathbf{Q}(\zeta_n)$ `polsubcyclo( $n, d, \{v\}$ )`
roots of unity in nf `nfrootsof1( $nf$ )`
roots of g belonging to nf `nfroots( $nf, g$ )`
factor g in nf `nfactor( $nf, g$ )`
factor $g \bmod$ prime pr in nf `nfactormod( $nf, g, pr$ )`

Linear and algebraic relations

poly of degree $\leq k$ with root $x \in \mathbf{C}$ `algdep( $x, k$ )`
alg. dep. with pol. coeffs for series s `seralgdep( $s, x, y$ )`
small linear rel. on coords of vector x `lindep( $x$ )`

Basic Number Field Arithmetic (nf)

Number field elements are `t_INT`, `t_FRAC`, `t_POL`, `t_POLMOD`, or `t_COL` (on integral basis $nf.zk$).

Basic operations

$x + y$ `nfeltadd( $nf, x, y$ )`
 $x \times y$ `nfeltmul( $nf, x, y$ )`
 x^n , $n \in \mathbf{Z}$ `nfeltpow( $nf, x, n$ )`
 x/y `nfeltdiv( $nf, x, y$ )`
 $q = x \backslash y := \text{round}(x/y)$ `nfeltdiveuc( $nf, x, y$ )`
 $r = x \% y := x - (x \backslash y)y$ `nfeltmod( $nf, x, y$ )`
... $[q, r]$ as above `nfeltdivrem( $nf, x, y$ )`
reduce x modulo ideal A `nfeltreduce( $nf, x, A$ )`
absolute trace $\text{Tr}_{K/\mathbf{Q}}(x)$ `nfelttrace( $nf, x$ )`
absolute norm $N_{K/\mathbf{Q}}(x)$ `nfeltnorm( $nf, x$ )`

Multiplicative structure of K^* ; $K^*/(K^*)^n$

valuation $v_{\mathfrak{p}}(x)$ `nfeltval( $nf, x, \mathfrak{p}$ )`
... write $x = \pi^{v_{\mathfrak{p}}(x)}y$ `nfeltval( $nf, x, \mathfrak{p}, \&y$ )`
quadratic Hilbert symbol (at $\mathfrak{p}$) `nfhilbert( $nf, a, b, \{\mathfrak{p}\}$ )`
 b such that $xb^n = v$ is small `idealredmodpower( $nf, x, n$ )`

Maximal order and discriminant

integral basis of field $\mathbf{Q}[x]/(f)$ `nfbasis( $f$ )`
field discriminant of field $f = 0$ `nfdisc( $f$ )`
express x on integer basis `nfalgtobasis( $nf, x$ )`
express element x as a polmod `nfbasistoalg( $nf, x$ )`

Dedekind Zeta Function ζ_K , Hecke L series

$R = [c, w, h]$ in initialization means we restrict $s \in \mathbf{C}$ to domain $|\Re(s) - c| < w$, $|\Im(s)| < h$; $R = [w, h]$ encodes $[1/2, w, h]$ and $[h]$ encodes $R = [1/2, 0, h]$ (critical line up to height h).
 ζ_K as Dirichlet series, $N(I) < b$ `dirzetak( $nf, b$ )`
init $\zeta_K^{(k)}(s)$ for $k \leq n$ `L = lfunitinit( $bnf, R, \{n = 0\}$ )`
compute $\zeta_K(s)$ (n -th derivative) `lfun( $L, s, \{n = 0\}$ )`
compute $\Lambda_K(s)$ (n -th derivative) `lfunlambda( $L, s, \{n = 0\}$ )`

init $L_K^{(k)}(s, \chi)$ for $k \leq n$ `L = lfunitinit( $[bnr, chi], R, \{n = 0\}$ )`
compute $L_K(s, \chi)$ (n -th derivative) `lfun( $L, s, \{n\}$ )`
Artin root number of K `bnrrootnumber( $bnr, chi, \{flag\}$ )`
 $L(1, \chi)$, for all χ trivial on H `bnrL1( $bnr, \{H\}, \{flag\}$ )`

Class Groups & Units (bnf, bnr)

Class field theory data $a_1, \{a_2\}$ is usually bnr (ray class field), bnr, H (congruence subgroup) or bnr, χ (character on `bnr.clgp`). Any of these define a unique abelian extension of K .
remove GRH assumption from bnf `bnfcertify( $bnf$ )`
expo. of ideal x on class gp `bnfisprincipal( $bnf, x, \{flag\}$ )`
expo. of ideal x on ray class gp `bnrisprincipal( $bnr, x, \{flag\}$ )`
expo. of x on fund. units `bnfisunit( $bnf, x$ )`
as above for S -units `bnfissunit( $bnfs, x$ )`
signs of real embeddings of $bnf.fu$ `bnfsignunit( $bnf$ )`
narrow class group `bnfnarrow( $bnf$ )`

Class Field Theory

ray class number for modulus m `bnrclassno( $bnf, m$ )`
discriminant of class field `bnrdisc( $a_1, \{a_2\}$ )`
ray class numbers, l list of moduli `bnrclassnolist( $bnf, l$ )`
discriminants of class fields `bnrdisclist( $bnf, l, \{arch\}, \{flag\}$ )`
decode output from `bnrdisclist` `bnfdecodemodule( $nf, fa$ )`
is modulus the conductor? `bnrconductor( $a_1, \{a_2\}$ )`
is class field (bnr, H) Galois over K^G `bnrisgalois( $bnr, G, H$ )`
action of automorphism on $bnr.gen$ `bnrgaloismatrix( $bnr, aut$ )`
apply `bnrgaloismatrix` M to H `bnrgaloisapply( $bnr, M, H$ )`
characters on `bnr.clgp` s.t. $\chi(g_i) = e(v_i)$ `bnrchar( $bnr, g, \{v\}$ )`
conductor of character χ `bnrconductor( $bnr, chi$ )`
conductor of extension `bnrconductor( $a_1, \{a_2\}, \{flag\}$ )`
conductor of extension $K[Y]/(g)$ `rnfconductor( $bnf, g$ )`
Artin group of extension $K[Y]/(g)$ `rnfnormgroup( $bnr, g$ )`
subgroups of bnr , index $\leq b$ `subgrouplist( $bnr, b, \{flag\}$ )`
rel. eq. for class field def'd by sub `rnfkummer( $bnr, sub, \{d\}$ )`
same, using Stark units (real field) `bnrstark( $bnr, sub, \{flag\}$ )`
is a an n -th power in K_v ? `nfislocalpower( $nf, v, a, n$ )`
cyclic L/K satisf. local conditions `nfgrunwaldwang( $nf, P, D, pl$ )`

Logarithmic class group

logarithmic ℓ -class group `bnflog( $bnf, \ell$ )`
 $[\bar{e}(F_v/Q_p), \bar{f}(F_v/Q_p)]$ `bnflogef( $bnf, pr$ )`
 $\exp \deg_F(A)$ `bnflogdegree( $bnf, A, \ell$ )`
is ℓ -extension L/K locally cyclotomic `rnfislocalcyclo( $rnf$ )`

Ideals: elements, primes, or matrix of generators in HNF

is id an ideal in nf ?	<code>nfisideal(nf, id)</code>
is x principal in bnf ?	<code>bnfisprincipal(bnf, x)</code>
give $[a, b]$, s.t. $a\mathbf{Z}_K + b\mathbf{Z}_K = x$	<code>idealtwoelt(nf, x, {a})</code>
put ideal a ($a\mathbf{Z}_K + b\mathbf{Z}_K$) in HNF form	<code>idealhnf(nf, a, {b})</code>
norm of ideal x	<code>idealnrm(nf, x)</code>
minimum of ideal x (direction v)	<code>idealmin(nf, x, v)</code>
LLL-reduce the ideal x (direction v)	<code>idealred(nf, x, {v})</code>

Ideal Operations

add ideals x and y	<code>idealadd(nf, x, y)</code>
multiply ideals x and y	<code>idealmul(nf, x, y, {flag})</code>
intersection of ideals x and y	<code>idealintersect(nf, x, y, {flag})</code>
n -th power of ideal x	<code>idealpow(nf, x, n, {flag})</code>
inverse of ideal x	<code>idealinv(nf, x)</code>
divide ideal x by y	<code>idealdiv(nf, x, y, {flag})</code>
Find $(a, b) \in x \times y, a + b = 1$	<code>idealaddtoone(nf, x, {y})</code>
coprime integral A, B such that $x = A/B$	<code>idealnumden(nf, x)</code>

Primes and Multiplicative Structure

factor ideal x in $\mathbf{Z}_K$	<code>idealfactor(nf, x)</code>
expand ideal factorization in K	<code>idealfactorback(nf, f, {e})</code>
is ideal A an n -th power ?	<code>idealispower(nf, A, n)</code>
expand elt factorization in K	<code>nffactorback(nf, f, {e})</code>
decomposition of prime p in $\mathbf{Z}_K$	<code>idealprimedec(nf, p)</code>
valuation of x at prime ideal pr	<code>idealval(nf, x, pr)</code>
weak approximation theorem in nf	<code>idealchinese(nf, x, y)</code>
$a \in K$, s.t. $v_{\mathfrak{p}}(a) = v_{\mathfrak{p}}(x)$ if $v_{\mathfrak{p}}(x) \neq 0$	<code>idealappr(nf, x)</code>
$a \in K$ such that $(a \cdot x, y) = 1$	<code>idealcoprime(nf, x, y)</code>
give bid =structure of $(\mathbf{Z}_K/id)^*$	<code>idealstar(nf, id, {flag})</code>
structure of $(1 + \mathfrak{p})/(1 + \mathfrak{p}^k)$	<code>idealprincipalunits(nf, pr, k)</code>
discrete log of x in $(\mathbf{Z}_K/bid)^*$	<code>ideallog(nf, x, bid)</code>
idealstar of all ideals of norm $\leq b$	<code>ideallist(nf, b, {flag})</code>
add Archimedean places	<code>ideallistarch(nf, b, {ar}, {flag})</code>
init modpr structure	<code>nfmodprinit(nf, pr)</code>
project t to $\mathbf{Z}_K/pr$	<code>nfmodpr(nf, t, modpr)</code>
lift from $\mathbf{Z}_K/pr$	<code>nfmodprlift(nf, t, modpr)</code>

Galois theory over $\mathbf{Q}$

conjugates of a root θ of nf	<code>nfgaloisconj(nf, {flag})</code>
apply Galois automorphism s to x	<code>nfgaloisapply(nf, s, x)</code>
Galois group of field $\mathbf{Q}[x]/(f)$	<code>polgalois(f)</code>
initializes a Galois group structure G	<code>galoisinit(pol, {den})</code>
character table of G	<code>galoischartable(G)</code>
conjugacy classes of G	<code>galoisconjclasses(G)</code>
$\det(1 - \rho(g)T)$, χ character of ρ	<code>galoischarpoly(G, \chi, {o})</code>
$\det(\rho(g))$, χ character of ρ	<code>galoischarpoly(G, \chi, {o})</code>
action of p in nfgaloisconj form	<code>galoispermtpol(G, {p})</code>
identify as abstract group	<code>galoisidentify(G)</code>
export a group for GAP/MAGMA	<code>galoisexport(G, {flag})</code>
subgroups of the Galois group G	<code>galoissubgroups(G)</code>
is subgroup H normal?	<code>galoisisnormal(G, H)</code>
subfields from subgroups	<code>galoissubfields(G, {flag}, {v})</code>
fixed field	<code>galoisfixedfield(G, perm, {flag}, {v})</code>
Frobenius at maximal ideal P	<code>idealfrobenius(nf, G, P)</code>
ramification groups at P	<code>idealramgroups(nf, G, P)</code>
is G abelian?	<code>galoisisabelian(G, {flag})</code>
abelian number fields/ $\mathbf{Q}$	<code>galoissubcyclo(N, H, {flag}, {v})</code>

Algebraic Number Theory

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The galpol package

query the package: polynomial	<code>galoisgetpol(a, b, {s})</code>
... : permutation group	<code>galoisgetgroup(a, b)</code>
... : group description	<code>galoisgetname(a, b)</code>

Relative Number Fields (rnf)

Extension L/K is defined by $T \in K[x]$.	
absolute equation of L	<code>rnfequation(nf, T, {flag})</code>
is L/K abelian?	<code>rnfisabelian(nf, T)</code>
relative nfalgtobasis	<code>rnfalgtobasis(rnf, x)</code>
relative nfbasistoalg	<code>rnfbasistoalg(rnf, x)</code>
relative idealhnf	<code>rnfidealhnf(rnf, x)</code>
relative idealmul	<code>rnfidealmul(rnf, x, y)</code>
relative idealtwoelt	<code>rnfidealtwoelt(rnf, x)</code>

Lifts and Push-downs

absolute $\rightarrow$ relative representation for x	<code>rnfeltabstorel(rnf, x)</code>
relative $\rightarrow$ absolute representation for x	<code>rnfeltreltoabs(rnf, x)</code>
lift x to the relative field	<code>rnfeltup(rnf, x)</code>
push x down to the base field	<code>rnfeltdown(rnf, x)</code>
idem for x ideal: (rnfideal)reltoabs, abstorel, up, down	

Norms and Trace

relative norm of element $x \in L$	<code>rnfeltnrm(rnf, x)</code>
relative trace of element $x \in L$	<code>rnfelttrace(rnf, x)</code>
absolute norm of ideal x	<code>rnfidealnrmabs(rnf, x)</code>
relative norm of ideal x	<code>rnfidealnrmrel(rnf, x)</code>
solutions of $N_{K/\mathbf{Q}}(y) = x \in \mathbf{Z}$	<code>bnfisintnorm(bnf, x)</code>
is $x \in \mathbf{Q}$ a norm from K ?	<code>bnfisnorm(bnf, x, {flag})</code>
initialize T for norm eq. solver	<code>rnfisnorminit(K, pol, {flag})</code>
is $a \in K$ a norm from L ?	<code>rnfisnorm(T, a, {flag})</code>
initialize t for Thue equation solver	<code>thueinit(f)</code>
solve Thue equation $f(x, y) = a$	<code>thue(t, a, {sol})</code>
characteristic poly. of $a \bmod T$	<code>rnfcharpoly(nf, T, a, {v})</code>

Factorization

factor ideal x in L	<code>rnfidealfactor(rnf, x)</code>
$[S, T]: T_{i,j} \mid S_i; S$ primes of K above p	<code>rnfidealprimedec(rnf, p)</code>

Maximal order $\mathbf{Z}_L$ as a $\mathbf{Z}_K$ -module

relative polredbest	<code>rnfpolredbest(nf, T)</code>
relative polredabs	<code>rnfpolredabs(nf, T)</code>
relative Dedekind criterion, prime pr	<code>rnfdedekind(nf, T, pr)</code>
discriminant of relative extension	<code>rnfdisc(nf, T)</code>
pseudo-basis of $\mathbf{Z}_L$	<code>rnfpsseudobasis(nf, T)</code>

General $\mathbf{Z}_K$ -modules: $M = [\text{matrix, vec. of ideals}] \subset L$

relative HNF / SNF	<code>nfhnf(nf, M), nfsnf</code>
multiple of $\det M$	<code>nfdetint(nf, M)</code>
HNF of M where $d = nf\detint(M)$	<code>nfhnfmod(x, d)</code>
reduced basis for M	<code>rnflllgram(nf, T, M)</code>
determinant of pseudo-matrix M	<code>rnfdet(nf, M)</code>
Steinitz class of M	<code>rnfsteinitz(nf, M)</code>
$\mathbf{Z}_K$ -basis of M if $\mathbf{Z}_K$ -free, or 0	<code>rnfhnfbasis(bnf, M)</code>
n -basis of M , or $(n + 1)$ -generating set	<code>rnfbasis(bnf, M)</code>
is M a free $\mathbf{Z}_K$ -module?	<code>rnfisfree(bnf, M)</code>

Associative Algebras

A is a general associative algebra given by a multiplication table mt (over $\mathbf{Q}$ or $\mathbf{F}_p$); represented by al from **algtabinit**.
create al from mt (over $\mathbf{F}_p$) `algtabinit(mt, {p = 0})`
group algebra $\mathbf{Q}[G]$ (or $\mathbf{F}_p[G]$) `alggroup(G, {p = 0})`
center of group algebra `alggroupcenter(G, {p = 0})`

Properties

is (mt, p) OK for algtabinit?	<code>algisassociative(mt, {p = 0})</code>
multiplication table mt	<code>algmtable(al)</code>
dimension of A over prime subfield	<code>algdim(al)</code>
characteristic of A	<code>algchar(al)</code>
is A commutative?	<code>algiscommutative(al)</code>
is A simple?	<code>algissimple(al)</code>
is A semi-simple?	<code>algisemisimple(al)</code>
center of A	<code>algcenter(al)</code>
Jacobson radical of A	<code>algradical(al)</code>
radical J and simple factors of A/J	<code>algsimpledec(al)</code>

Operations on algebras

create $A/I, I$ two-sided ideal	<code>algquotient(al, I)</code>
create $A_1 \otimes A_2$	<code>algtensor(al1, al2)</code>
create subalgebra from basis B	<code>algsubalg(al, B)</code>
quotients by ortho. central idempotents e	<code>algcentralproj(al, e)</code>
isomorphic alg. with integral mult. table	<code>algmakeintegral(mt)</code>
prime subalgebra of semi-simple A over $\mathbf{F}_p$	<code>algprimesubalg(al)</code>
find isomorphism $A \cong M_d(\mathbf{F}_q)$	<code>algsplit(al)</code>

Operations on lattices in algebras

lattice generated by cols. of M	<code>alglathnf(al, M)</code>
... by the products $xy, x \in lat1, y \in lat2$	<code>alglatmul(al, lat1, lat2)</code>
sum $lat1 + lat2$ of the lattices	<code>alglatadd(al, lat1, lat2)</code>
intersection $lat1 \cap lat2$	<code>alglatinter(al, lat1, lat2)</code>
test $lat1 \subset lat2$	<code>alglatsubset(al, lat1, lat2)</code>
generalized index $(lat2 : lat1)$	<code>alglatindex(al, lat1, lat2)</code>
$\{x \in al \mid x \cdot lat1 \subset lat2\}$	<code>alglatlefttransporter(al, lat1, lat2)</code>
$\{x \in al \mid lat1 \cdot x \subset lat2\}$	<code>alglatrighttransporter(al, lat1, lat2)</code>
test $x \in lat$ (set c = coord. of x)	<code>alglatcontains(al, lat, x, {&c})</code>
element of lat with coordinates c	<code>alglatelement(al, lat, c)</code>

Operations on elements

$a + b, a - b, -a$	<code>algadd(al, a, b), algsub, algneg</code>
$a \times b, a^2$	<code>algmul(al, a, b), algsqrt</code>
a^n, a^{-1}	<code>algpow(al, a, n), alginv</code>
is x invertible ? (then set $z = x^{-1}$)	<code>alginv(al, x, {&z})</code>
find z such that $x \times z = y$	<code>algdivl(al, x, y)</code>
find z such that $z \times x = y$	<code>algdivr(al, x, y)</code>
does z s.t. $x \times z = y$ exist? (set it)	<code>algisdivl(al, x, y, {&z})</code>
matrix of $v \mapsto x \cdot v$	<code>algtomatrix(al, x)</code>
absolute norm	<code>algnorm(al, x)</code>
absolute trace	<code>algtrace(al, x)</code>
absolute char. polynomial	<code>algcharpoly(al, x)</code>
given $a \in A$ and polynomial T , return $T(a)$	<code>algpoleval(al, T, a)</code>
random element in a box	<code>algrandom(al, b)</code>

Based on an earlier version by Joseph H. Silverman

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Central Simple Algebras

A is a central simple algebra over a number field K ; represented by al from **alginit**; K is given by a nf structure.
create CSA from data **alginit**($B, C, \{v\}, \{maxord = 1\}$)
multiplication table over K $B = K, C = mt$
cyclic algebra ($L/K, \sigma, b$) $B = rnf, C = [sigma, b]$
quaternion algebra $(a, b)_K$ $B = K, C = [a, b]$
matrix algebra $M_d(K)$ $B = K, C = d$
local Hasse invariants over K $B = K, C = [d, [PR, HF], HI]$

Properties

type of al (mt, CSA) **algtype**(al)
dimension of A over $\mathbf{Q}$ **algdim**($al, 1$)
dimension of al over its center K **algdim**(al)
degree of A ($= \sqrt{\dim_K A}$) **algdegree**(al)
 al a cyclic algebra ($L/K, \sigma, b$); return σ **algaut**(al)
...return b **algb**(al)
...return L/K , as an rnf **algsplittingfield**(al)
split A over an extension of K **algsplittingdata**(al)
splitting field of A as an rnf over center **algsplittingfield**(al)
multiplication table over center **algrelmultable**(al)
places of K at which A ramifies **algramifiedplaces**(al)
Hasse invariants at finite places of K **alghassef**(al)
Hasse invariants at infinite places of K **alghassei**(al)
Hasse invariant at place v **alghasse**(al, v)
index of A over K (at place v) **algindex**($al, \{v\}$)
is al a division algebra? (at place v) **algisdivision**($al, \{v\}$)
is A ramified? (at place v) **algisramified**($al, \{v\}$)
is A split? (at place v) **algissplit**($al, \{v\}$)

Operations on elements

reduced norm **algnorm**(al, x)
reduced trace **algtrace**(al, x)
reduced char. polynomial **algcharpoly**(al, x)
express x on integral basis **algalgtobasis**(al, x)
convert x to algebraic form **algbasistoalg**(al, x)
map $x \in A$ to $M_d(L)$, L split. field **algtomatrix**(al, x)

Orders

Z-basis of order $\mathcal{O}_0$ **algbasis**(al)
discriminant of order $\mathcal{O}_0$ **algdisc**(al)
Z-basis of natural order in terms $\mathcal{O}_0$'s basis **alginvbasis**(al)