

Algebraic Number Theory

(PARI-GP version 2.15.5)

Binary Quadratic Forms

create $ax^2 + bxy + cy^2$ **Qfb**(a, b, c) or **Qfb**($[a, b, c]$)
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 **qfbnpow**(x, n)
composition **qfbcomp**(x, y)
... without reduction **qfbcomppraw**(x, y)
 n -th power **qfbpow**(x, n)
... without reduction **qfbpowraw**(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 $Q(x, y) = n$ in integers **qfbsolve**(Q, n)
solve $x^2 + Dy^2 = p$, p prime **qfbcornacchia**(D, p)
... $x^2 + Dy^2 = 4p$, p prime **qfbcornacchia**($D, 4 * p$)

Quadratic Fields

quadratic number $\omega = \sqrt{x}$ or $(1 + \sqrt{x})/2$ **quadgen**(x)
minimal polynomial of ω **quadpoly**(x)
discriminant of **Q**(\sqrt{x}) **quaddisc**(x)
regulator of real quadratic field **quadregulator**(x)
fundamental unit in O_D , $D > 0$ **quadunit**($D, \{ 'w \}$)
norm of fundamental unit in O_D **quadunitnorm**(D)
index of $O_{Df_2}^\times$ in O_D^\times **quadunitindex**(D, f)
class group of **Q**(\sqrt{D}) **quadclassunit**($D, \{flag\}, \{t\}$)
Hilbert class field of **Q**(\sqrt{D}) **quadhilbert**($D, \{flag\}$)
... using specific class invariant ($D < 0$) **polclass**($D, \{inv\}$)
ray class field modulo f of **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**
primes ramified in *nf* **nf.p**
 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**($f, 1$)

bnf members: same as *nf*, plus
 underlying *nf* **bnf.nf**
 class group, regulator **bnf.clgp**, **bnf.reg**
 fundamental/torsion units **bnf.fu**, **bnf.tu**
 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 m **bnr.mod**
 structure of $(\mathbf{Z}_K/m)^*$ **bnr.zkst**

Fields, subfields, embeddings

Defining polynomials, embeddings
(some) number fields with Galois group G **nflist**(G)
... and $|\text{disc}(K)| = N$ and s complex places **nflist**($G, N, \{s\}$)
... and $a \leq |\text{disc}(K)| \leq b$ **nflist**($G, [a, b], \{s\}$)
smallest poly defining $f = 0$ (slow) **polredabs**($f, \{flag\}$)
small poly defining $f = 0$ (fast) **polredbest**($f, \{flag\}$)
monic integral $g = Cf(x/L)$ **poltomonic**($f, \{\&L\}$)
random Tschirnhausen transform of f **poltschirnhaus**(f)
Q[t]/(f) \subset **Q**[t]/(g) ? Isomorphic? **nfisincl**(f, g), **nfisisom**
reverse polmod $a = A(t) \bmod T(t)$ **modreverse**(a)
compositum of **Q**[t]/(f), **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*, $\{d\}$)
maximal subfields of *nf* **nfsubfieldsmax**(*nf*)
maximal CM subfield of *nf* **nfsubfieldscm**(*nf*)
 $K_d \subset \mathbf{Q}(\zeta_n)$, using Gaussian periods **polsubcyclo**($n, d, \{v\}$)
... using class field theory **polsubcyclofast**(n, d)
roots of unity in *nf* **nfrootsof1**(*nf*)
roots of g belonging to *nf* **nfroots**(*nf*, g)
factor g in *nf* **nffactor**(*nf*, g)

Linear and algebraic relations

poly of degree $\leq k$ with root $x \in \mathbf{C}$ or \mathbf{Q}_p **algdep**(x, k)
alg. dep. with pol. coeffs for series s **seralgdep**(s, x, y)
diff. dep. with pol. coeffs for series s **serdiffdep**(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)
 $q = x \setminus y := \text{round}(x/y)$ **nfeltdiveuc**(*nf*, x, y)
 $r = x \setminus y := x - (x \setminus y)y$ **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)

is x a square? **nfeltissquare**(*nf*, $x, \{\&y\}$)
... an n -th power? **nfeltispower**(*nf*, $x, n, \{\&y\}$)

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 **Q**[x]/(f) **nfbasis**(f)
field discriminant of **Q**[x]/(f) **nfdisc**(f)
... and factorization **nfdiscfactors**(f)
express x on integer basis **nfalgtobasis**(*nf*, x)
express element x as a polmod **nfbasistoalg**(*nf*, x)

Hecke Grossencharacters

Let K be a number field and m a modulus. A *gchar* structure describes the group of Hecke Grossencharacters of K of modulus m and allows computations with these characters. A character χ is described by its components modulo *gc.cyc*.

init *gchar* structure *gc* for modulus m **gcharinit**(*bnf*, $m, \{cm\}$)

gc members:

 underlying *bnf* **gc.bnf**
 modulus **gc.mod**
 elementary divisors (including 0s) **gc.cyc**
recompute *gc* using current precision **gcharnewprec**(*gc*)
evaluate Hecke character *chi* at ideal *id* **gchareval**(*gc*, *chi*, *id*)
exponent column of *id* in \mathbf{R}^n **gcharideallog**(*gc*, *id*)
log representation of ideal *id* **gcharlog**(*gc*, *id*)
... of character χ **gcharduallog**(*gc*, *chi*)
exponent vector of χ in \mathbf{R}^n **gcharparameters**(*gc*, *chi*)
conductor of χ **gcharconductor**(*gc*, *chi*)
L-function of χ **lfuncreate**(*gc*, *chi*)
local component χ_v of χ **gcharlocal**(*gc*, *chi*, v)
 χ s.t. $\chi_v \approx L_{chiv}[i]$ for $v = Lv[Lchiv]$ **gcharidentify**(*gc*, $Lv, Lchiv$)
basis of group of algebraic characters **gcharalgebraic**(*gc*)
is χ algebraic? **gcharisalgebraic**(*gc*, *chi*)

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, $N(I) \leq b$ **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 .
units / S -units **bnfunits**(*bnf*, $\{S\}$)
remove GRH assumption from *bnf* **bnfcertify**(*bnf*)

expo. of ideal x on class gp `bnfisprincipal(bnf,x,{flag})`
...on ray class gp `bnrisprincipal(bnr,x,{flag})`
expo. of x on fund. units `bnfisunit(bnf,x)`
...on S -units, U is `bnfunits(bnf,S)` `bnfisunit(bnfs,x,U)`
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(a1,{a2})`
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? `bnrisconductor(a1,{a2})`
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(a1,{a2},{flag})`
conductor of extension $K[Y]/(g)$ `rnfconductor(bnf,g)`
canonical projection $\text{Cl}_F \rightarrow \text{Cl}_f$, $f \mid F$ `bnrmap`
Artin group of extension $K[Y]/(g)$ `rnfnormgroup(bnr,g)`
subgroups of bnr , index $\leq b$ `subgrouplist(bnr,b,{flag})`
compositum as `[bnr,H]` `bnrcompositum([bnr1,H1],[bnr2,H2])`
class field defined by $H \subset \text{Cl}_f$ `bnrclassfield(bnr,H)`
...low level equivalent, prime degree `rnfkummer(bnr,H)`
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)`

Cyclotomic and Abelian fields theory

An Abelian field F given by a subgroup $H \subset (Z/fZ)^*$ is described by an argument F , e.g. f (for $H = 1$, i.e. $Q(\zeta_f)$) or $[G,H]$, where G is `idealstar(f,1)`, or a minimal polynomial.
minus class number $h^-(F)$ `subcyclohminus(F)`
... p -part `subcyclohminus(F,p)`
minus part of Iwasawa polynomials `subcycloiwasawa(F,p)`
 p -Sylow of $\text{Cl}(F)$ `subcyclopclgp(F,p)`

Logarithmic class group

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

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

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

Ideal Operations

add ideals x and y `idealadd(nf,x,y)`
multiply ideals x and y `idealmul(nf,x,y,{flag})`
intersection of ideal x with Q `idealdown(nf,x)`
intersection of ideals x and y `idealintersect(nf,x,y,{flag})`
 n -th power of ideal x `idealpow(nf,x,n,{flag})`
inverse of ideal x `idealinv(nf,x)`
divide ideal x by y `idealdiv(nf,x,y,{flag})`

Algebraic Number Theory

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Find $(a,b) \in x \times y$, $a + b = 1$ `idealaddtoone(nf,x,{y})`
coprime integral A,B such that $x = A/B$ `idealnumden(nf,x)`

Primes and Multiplicative Structure

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

Galois theory over Q

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

The galpol package

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

Relative Number Fields (rnf)

Extension L/K is defined by $T \in K[x]$.

absolute equation of L `rnfequation(nf,T,{flag})`
is L/K abelian? `rnfisabelian(nf,T)`
relative `nfalttobasis` `rnfalttobasis(rnf,x)`
relative `nfbasistoalg` `rnfbasistoalg(rnf,x)`
relative `idealhnf` `rnfidealhnf(rnf,x)`
relative `idealmul` `rnfidealmul(rnf,x,y)`
relative `idealtwoelt` `rnfidealtwoelt(rnf,x)`

Lifts and Push-downs

absolute \rightarrow relative representation for x `rnfeltabstorel(rnf,x)`
relative \rightarrow absolute representation for x `rnfeltretloabs(rnf,x)`
lift x to the relative field `rnfeltup(rnf,x)`
push x down to the base field `rnfeltdown(rnf,x)`
idem for x ideal: `(rnfideal)reltoabs, abstorel, up, down`

Norms and Trace

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

Factorization

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

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

relative `polredbest` `rnfpolredbest(nf,T)`
relative `polredabs` `rnfpolredabs(nf,T)`
relative Dedekind criterion, prime pr `rnfdedekind(nf,T,pr)`
discriminant of relative extension `rnfdisc(nf,T)`
pseudo-basis of \mathbf{Z}_L `rnfpseudobasis(nf,T)`

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

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

Associative Algebras

A is a general associative algebra given by a multiplication table *mt* (over **Q** or **F_p**); represented by *al* from `algtableinit`.

create *al* from *mt* (over **F_p**) `algtableinit(mt, {p = 0})`
group algebra **Q**[*G*] (or **F_p**[*G*]) `alggroup(G, {p = 0})`
center of group algebra `alggrouppcenter(G, {p = 0})`

Properties

is (*mt*, *p*) OK for `algtableinit`? `algisassociative(mt, {p = 0})`
multiplication table *mt* `algmultable(al)`
dimension of *A* over prime subfield `algdim(al)`
characteristic of *A* `algchar(al)`
is *A* commutative? `algiscommutative(al)`
is *A* simple? `algissimple(al)`
is *A* semi-simple? `algissemisimple(al)`
center of *A* `algcenter(al)`
Jacobson radical of *A* `algradical(al)`
radical *J* and simple factors of *A*/*J* `algsimpledec(al)`

Operations on algebras

create *A*/*I*, *I* two-sided ideal `algquotient(al, I)`
create *A*₁ ⊗ *A*₂ `algtensor(al1, al2)`
create subalgebra from basis *B* `algsubalg(al, B)`
quotients by ortho. central idempotents *e* `algcentralproj(al, e)`
isomorphic alg. with integral mult. table `algmakeintegral(mt)`
prime subalgebra of semi-simple *A* over **F_p** `algprimesubalg(al)`
find isomorphism *A* ≅ *M_d*(**F_q**) `algsplit(al)`

Operations on lattices in algebras

lattice generated by cols. of *M* `alglathnf(al, M)`
... by the products *xy*, *x* ∈ *lat1*, *y* ∈ *lat2* `alglatmul(al, lat1, lat2)`
sum *lat1* + *lat2* of the lattices `alglatadd(al, lat1, lat2)`
intersection *lat1* ∩ *lat2* `alglatinter(al, lat1, lat2)`
test *lat1* ⊂ *lat2* `alglatsubset(al, lat1, lat2)`
generalized index (*lat2* : *lat1*) `alglatindex(al, lat1, lat2)`
{*x* ∈ *al* | *x* · *lat1* ⊂ *lat2*} `alglatlefttransporter(al, lat1, lat2)`
{*x* ∈ *al* | *lat1* · *x* ⊂ *lat2*} `alglatrighttransporter(al, lat1, lat2)`
test *x* ∈ *lat* (set *c* = coord. of *x*) `alglatcontains(al, lat, x, {&c})`
element of *lat* with coordinates *c* `alglatelement(al, lat, c)`

Operations on elements

a + *b*, *a* − *b*, −*a* `algadd(al, a, b), algsub, algneg`
a × *b*, *a*² `algmul(al, a, b), algsqr`
aⁿ, *a*^{−1} `algpow(al, a, n), alginv`
is *x* invertible ? (then set *z* = *x*^{−1}) `alginv(al, x, {&z})`
find *z* such that *x* × *z* = *y* `algdivl(al, x, y)`
find *z* such that *z* × *x* = *y* `algdivr(al, x, y)`
does *z* s.t. *x* × *z* = *y* exist? (set it) `algsdivl(al, x, y, {&z})`
matrix of *v* ↦ *x* · *v* `algtomatrix(al, x)`
absolute norm `algnorm(al, x)`
absolute trace `algtrace(al, x)`
absolute char. polynomial `algcharpoly(al, x)`
given *a* ∈ *A* and polynomial *T*, return *T*(*a*) `algpoleval(al, T, a)`
random element in a box `algrandom(al, b)`

Central Simple Algebras

A is a central simple algebra over a number field *K*; represented by *al* from `algininit`; *K* is given by a *nf* structure.

create CSA from data `algininit(B, C, {v}, {maxord = 1})`
multiplication table over *K* *B* = *K*, *C* = *mt*
cyclic algebra (*L*/*K*, *σ*, *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 **Q** `algdim(al, 1)`
dimension of *al* over its center *K* `algdim(al)`
degree of *A* (= √dim_{*K*} *A*) `algdegree(al)`
al a cyclic algebra (*L*/*K*, *σ*, *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*) `algsdivision(al, {v})`
is *A* ramified? (at place *v*) `algsramified(al, {v})`
is *A* split? (at place *v*) `algsisplit(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* ∈ *A* to *M_d*(*L*), *L* split. field `algtomatrix(al, x)`

Orders

Z-basis of order *O*₀ `algbasis(al)`
discriminant of order *O*₀ `algdisc(al)`
Z-basis of natural order in terms *O*₀'s basis `alginvbasis(al)`