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Chapter 1

Resolutions of the ground ring

`ResolutionAbelianGroup(L, n)` `ResolutionAbelianGroup(G, n)` Inputs a list $L := [m_1, m_2, \dots, m_d]$ of nonnegative integers and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionAlmostCrystalGroup(G, n)` Inputs a positive integer n and an almost crystallographic pcg group G . It returns a ZG -resolution of $Z[G]$.

`ResolutionAlmostCrystalQuotient(G, n, c)` `ResolutionAlmostCrystalQuotient(G, n, c, false)` An almost crystallographic pcg group G and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionArtinGroup(D, n)` Inputs a Coxeter diagram D and an integer $n > 1$. It returns n terms of a free ZG -resolution of $Z[G]$.

`ResolutionAsphericalPresentation(F, R, n)` Inputs a free group F , a set R of words in F which constitute an aspherical presentation of $G = F/R$, and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionBieberbachGroup(G)` `ResolutionBieberbachGroup(G, v)` Inputs a Bieberbach group G (represented using `AffineCrystGroupOnRight`) and a positive integer v . Returns a ZG -resolution of $Z[G]$.

`ResolutionDirectProduct(R, S)` `ResolutionDirectProduct(R, S, "internal")` Inputs a ZG -resolution R of $Z[G]$ and a ZH -resolution S of $Z[H]$. Returns a $Z[G \times H]$ -resolution of $Z[G \times H]$.

`ResolutionExtension(g, R, S)` `ResolutionExtension(g, R, S, "TestFiniteness")` `ResolutionExtension(g, R, S, true)` Inputs a ZG -resolution R of $Z[G]$, a ZH -resolution S of $Z[H]$, and a group g . Returns a ZG -resolution of $Z[G]$.

`ResolutionFiniteDirectProduct(R, S)` `ResolutionFiniteDirectProduct(R, S, "internal")` Inputs a ZG -resolution R of $Z[G]$ and a ZH -resolution S of $Z[H]$. Returns a $Z[G \times H]$ -resolution of $Z[G \times H]$.

`ResolutionFiniteExtension(gensE, gensG, R, n)` `ResolutionFiniteExtension(gensE, gensG, R, n, true)` Inputs a ZG -resolution R of $Z[G]$, a list $gensE$ of generators of E , a list $gensG$ of generators of G , and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionFiniteGroup(gens, n)` `ResolutionFiniteGroup(gens, n, true)` `ResolutionFiniteGroup(gens, n, false)` Inputs a list $gens$ of generators of G and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionFiniteSubgroup(R, K)` `ResolutionFiniteSubgroup(R, gensG, gensK)` Inputs a ZG -resolution R of $Z[G]$ and a subgroup K of finite index $|G : K|$. Returns a ZK -resolution of $Z[K]$.

`ResolutionGraphOfGroups(D, n)` `ResolutionGraphOfGroups(D, n, L)` Inputs a graph of groups D and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionNilpotentGroup(G, n)` `ResolutionNilpotentGroup(G, n, "TestFiniteness")` Inputs a nilpotent group G and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionNormalSeries(L, n)` `ResolutionNormalSeries(L, n, true)` `ResolutionNormalSeries(L, n, false)` Inputs a list L of subgroups of G and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionPrimePowerGroup(P, n)` `ResolutionPrimePowerGroup(G, n, p)` Inputs a p -group P and integer $n > 0$. Returns a ZG -resolution of $Z[G]$.

`ResolutionSmallFpGroup(G, n)` `ResolutionSmallFpGroup(G, n, p)` Inputs a small finitely presented group G and a positive integer n . Returns a ZG -resolution of $Z[G]$.

`ResolutionSubgroup(R, K)` Inputs a ZG -resolution for an (infinite) group G and a subgroup K of finite index $|G : K|$. Returns a ZK -resolution of $Z[K]$.

`ResolutionSubnormalSeries(L, n)` Inputs a positive integer n and a list $L = [L_1, \dots, L_k]$ of subgroups L_i of a finite group G . Returns a ZG -resolution of $Z[G]$.

`TwistedTensorProduct(R, S, EhomG, GmapE, NhomE, NEhomN, EltsE, Mult, InvE)` Inputs a ZG -resolution R , a ZN -resolution S , and a twisted tensor product of ZG and ZN .

Chapter 2

Resolutions of modules

| `ResolutionFpGModule(M, n)` Inputs an FpG -module M and a positive integer n . It returns n terms of a minimal free F

Chapter 3

Induced equivariant chain maps

| `EquivariantChainMap(R, S, f)` Inputs a ZG -resolution R , a ZG' -resolution S , and a group homomorphism $f : G \rightarrow G'$

Chapter 4

Functors

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`HomToIntegers(X)` Inputs either a ZG -resolution $X = R$, or an equivariant chain map $X = (F : R \rightarrow S)$. It returns the

`HomToIntegersModP(R)` Inputs a ZG -resolution R and returns the cochain complex obtained by applying $Hom_{ZG}(Z, Z)$

`HomToIntegralModule(R, f)` Inputs a ZG -resolution R and a group homomorphism $f : G \rightarrow GL_n(Z)$ to the group of

`LowerCentralSeriesLieAlgebra(G)` `LowerCentralSeriesLieAlgebra(f)` Inputs a pcp group G . If each quo

`TensorWithIntegers(X)` Inputs either a ZG -resolution $X = R$, or an equivariant chain map $X = (F : R \rightarrow S)$. It retu

`TensorWithIntegersModP(X, p)` Inputs either a ZG -resolution $X = R$, or an equivariant chain map $X = (F : R \rightarrow S)$

`TensorWithRationals(R)` Inputs a ZG -resolution R and returns the chain complex obtained by tensoring with the tri

Chapter 5

Chain complexes

`ChevalleyEilenbergComplex(X, n)` Inputs either a Lie algebra $X = A$ (over the ring of integers Z or over a field K)
`LeibnizComplex(X, n)` Inputs either a Lie or Leibniz algebra $X = A$ (over the ring of integers Z or over a field K) or

Chapter 6

Homology and cohomology groups

`Cohomology(X)` Inputs either a cochain complex $X = C$ or a cochain map $X = (C \rightarrow D)$ over the integers Z . If $X = C$

`CohomologyPrimePart(C, n, p)` Inputs a cochain complex C in characteristic 0, a positive integer n , and a prime p . It re

`GroupCohomology(X, n)` `GroupCohomology(X, n, p)` Inputs a positive integer n and either a finite group $X = G$ or a t

`GroupHomology(X, n)`

`GroupHomology(X, n, p)` Inputs a positive integer n and either a finite group $X = G$ or a Coxeter diagram $X = D$ represe

`Homology(X, n)` Inputs either a chain complex $X = C$ or a chain map $X = (C \rightarrow D)$. If $X = C$ then the torsion coefficient

`HomologyPb(C, n)` This is a back-up function which might work in some instances where `Homology(C, n)` fails. It is mo

`HomologyPrimePart(C, n, p)` Inputs a chain complex C in characteristic 0, a positive integer n , and a prime p . It returns

`LeibnizAlgebraHomology(A, n)` Inputs a Lie or Leibniz algebra $X = A$ (over the ring of integers Z or over a field K), t

`LieAlgebraHomology(A, n)` Inputs a Lie algebra A (over the integers or a field) and a positive integer n . It returns the h

`PrimePartDerivedFunctor(G, R, F, n)` Inputs a finite group G , a positive integer n , at least $n + 1$ terms of a ZP -resolut

`RankHomologyPGroup(G, n)` `RankHomologyPGroup(R, n)` `RankHomologyPGroup(G, n, "empirical")` Inputs a (sm

`RankPrimeHomology(G, n)` Inputs a (smallish) p -group G together with a positive integer n . It returns a function `dim(k)`

Chapter 7

Poincare series

EfficientNormalSubgroups (G)

EfficientNormalSubgroups (G, k) Inputs a prime-power group G and, optionally, a positive integer k . The default is $k=1$.

ExpansionOfRationalFunction (f, n) Inputs a positive integer n and a rational function $f(x) = p(x)/q(x)$ where the denominator $q(x)$ is a product of linear factors.

PoincareSeries (G, n) PoincareSeries (R, n)

PoincareSeries (L, n)

PoincareSeries (G) Inputs a finite p -group G and a positive integer n . It returns a quotient of polynomials $f(x) = P(x)/Q(x)$.

PoincareSeriesPrimePart (G, p, n) Inputs a finite group G , a prime p , and a positive integer n . It returns a quotient of polynomials $f(x) = P(x)/Q(x)$.

Prank (G) Inputs a p -group G and returns the rank of the largest elementary abelian subgroup.

Chapter 8

Cohomology ring structure

`IntegralCupProduct (R, u, v, p, q)`
`IntegralCupProduct (R, u, v, p, q, P, Q, N)` (Various functions used to construct the cup product are also *CRfunctions*)
`IntegralRingGenerators (R, n)` Inputs at least $n + 1$ terms of a ZG -resolution and integer $n > 0$. It returns a minimal
`ModPCohomologyGenerators (G, n)`
`ModPCohomologyGenerators (R)` Inputs either a p -group G and positive integer n , or else n terms of a minimal $Z_p G$ -
`ModPCohomologyRing (G, n)`
`ModPCohomologyRing (G, n, level)`
`ModPCohomologyRing (R)`
`ModPCohomologyRing (R, level)` Inputs either a p -group G and positive integer n , or else n terms of a minimal $Z_p G$ -
`ModPRingGenerators (A)` Inputs a mod p cohomology ring A (created using the preceding function). It returns a mi

Chapter 9

Commutator and nonabelian tensor computations

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BaerInvariant(G, c) Inputs a nilpotent group G and integer $c > 0$. It returns the Baer invariant $M^{(c)}(G)$ defined as follows.
Coclass(G) Inputs a group G of prime-power order p^n and nilpotency class c say. It returns the integer $r = n - c$.
EpiCentre(G, N)
EpiCentre(G) Inputs a finite group G and normal subgroup N and returns a subgroup $Z^*(G, N)$ of the centre of N . The
NonabelianExteriorProduct(G, N) Inputs a finite group G and normal subgroup N . It returns a record E with the following
NonabelianTensorProduct(G, N) Inputs a finite group G and normal subgroup N . It returns a record E with the following
NonabelianTensorSquare(G)
NonabelianTensorSquare(G, m) Inputs a finite or nilpotent infinite group G and returns a record T with the following
RelativeSchurMultiplier(G, N) Inputs a finite group G and normal subgroup N . It returns the homology group $H_2(G/N)$.
TensorCentre(G) Inputs a group G and returns the largest central subgroup N such that the induced homomorphism $G/N \rightarrow G/N$ is
ThirdHomotopyGroupOfSuspensionB(G)
ThirdHomotopyGroupOfSuspensionB(G, m) Inputs a finite or nilpotent infinite group G and returns the abelian invariant $\beta_3(G)$.
UpperEpicentralSeries(G, c) Inputs a nilpotent group G and an integer c . It returns the c -th term of the upper epicentral series of G .

Chapter 10

Lie commutators and nonabelian Lie tensors

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All functions on this page were implemented by Hamid Mohammadzadeh.

`LieCoveringHomomorphism(L)` Inputs a finite dimensional Lie algebra L over a field, and returns a surjective Lie homomorphism ϕ such that $\phi(L)$ is a covering Lie algebra of L .

`LieEpiCentre(L)` Inputs a finite dimensional Lie algebra L over a field, and returns an ideal $Z^*(L)$ of the centre of L .

`LieExteriorSquare(L)` Inputs a finite dimensional Lie algebra L over a field. It returns a record E with the following fields:

`LieTensorSquare(L)` Inputs a finite dimensional Lie algebra L over a field and returns a record T with the following fields:

`TensorCentre(L)` Inputs a finite dimensional Lie algebra L over aq field and returns the largest ideal N such that the quotient L/N is a tensor Lie algebra.

Chapter 11

Generators and relators of groups

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CayleyGraphDisplay(G, X)

CayleyGraphDisplay($G, X, \text{"mozilla"}$) Inputs a finite group G together with a subset X of G . It displays the corresponding Cayley graph.

IsAspherical(F, R) Inputs a free group F and a set R of words in F . It performs a test on the 2-dimensional CW-space $K(F, R)$.

PresentationOfResolution(R) Inputs at least two terms of a reduced ZG -resolution R and returns a record P with the following fields:

TorsionGeneratorsAbelianGroup(G) Inputs an abelian group G and returns a generating set $[x_1, \dots, x_n]$ where no proper subset of $\{x_1, \dots, x_n\}$ generates G .

Chapter 12

Orbit polytopes and fundamental domains

`FundamentalDomainAffineCrystGroupOnRight(v, G)` Inputs a crystallographic group G (represented using AffineC

`OrbitPolytope(G, v, L)` Inputs a permutation group or matrix group G of degree n and a rational vector v of length n .
The function uses Polymake software.

`PolytopalComplex(G, v)`

`PolytopalComplex(G, v, n)`

Inputs a permutation group or matrix group G of degree n and a rational vector v of length n . In both cases there is a natural action of G on v . Let $P(G, v)$ be the convex polytope arising as the convex hull of the Euclidean points in the orbit of v under the action of G . The cellular chain complex $C_* = C_*(P(G, v))$ is an exact sequence of (not necessarily free) ZG -modules. The function returns a component object R with components:

- $R!.dimension(k)$ is a function which returns the number of G -orbits of the k -dimensional faces in $P(G, v)$. If each k -face has trivial stabilizer subgroup in G then C_k is a free ZG -module of rank $R!.dimension(k)$.
- $R!.stabilizer(k, n)$ is a function which returns the stabilizer subgroup for a face in the n -th orbit of k -faces.
- If all faces of dimension $< k + 1$ have trivial stabilizer group then the first k terms of C_* constitute part of a free ZG -resolution. The boundary map is described by the function $boundary(k, n)$. (If some faces have non-trivial stabilizer group then C_* is not free and no attempt is made to determine signs for the boundary map.)
- $R!.elements, R!.group, R!.properties$ are as in a ZG -resolution.

If an optional third input variable n is used, then only the first n terms of the resolution C_* will be computed.

The function uses Polymake software.

`PolytopalGenerators(G, v)`

Inputs a permutation group or matrix group G of degree n and a rational vector v of length n . In both cases there is a natural action of G on v , and the vector v must be chosen so that it has trivial stabilizer subgroup in G . Let $P(G, v)$ be the convex polytope arising as the convex hull of the Euclidean points in the orbit of v under the action of G . The function returns a record P with components:

- *P.generators* is a list of all those elements g in G such that $g \cdot v$ has an edge in common with v . The list is a generating set for G .
- *P.vector* is the vector v .
- *P.hasseDiagram* is the Hasse diagram of the cone at v .

The function uses Polymake software. The function is joint work with Seamus Kelly.

`VectorStabilizer(G, v)`

Inputs a permutation group or matrix group G of degree n and a rational vector of degree n . In both cases there is a natural action of G on v and the function returns the group of elements in G that fix v .

Chapter 13

Cocycles

`CocycleCondition(R, n)` Inputs a resolution R and an integer $n > 0$. It returns an integer matrix M with the following
`StandardCocycle(R, f, n)`
`StandardCocycle(R, f, n, q)` Inputs a ZG -resolution R (with contracting homotopy), a positive integer n and an integer q .
`Syzygy(R, g)` Inputs a ZG -resolution R (with contracting homotopy) and a list $g = [g[1], \dots, g[n]]$ of elements in G . It returns

Chapter 14

Words in free ZG -modules

`AddFreeWords(v, w)` Inputs two words v, w in a free ZG -module and returns their sum $v + w$. If the characteristic of Z is p , the result is reduced modulo p .

`AddFreeWordsModP(v, w, p)` Inputs two words v, w in a free ZG -module and the characteristic p of Z . It returns the sum $v + w$ reduced modulo p .

`AlgebraicReduction(w)` Inputs a word w in a free ZG -module and returns a reduced version of the word in which no two adjacent letters are inverses of each other.

`Multiply Word(n, w)` Inputs a word w and integer n . It returns the scalar multiple $n \cdot w$.

`Negate([i, j])` Inputs a pair $[i, j]$ of integers and returns $[-i, j]$.

`NegateWord(w)` Inputs a word w in a free ZG -module and returns the negated word $-w$.

`PrintZGword(w, elts)` Inputs a word w in a free ZG -module and a (possibly partial but sufficient) listing `elts` of the elements of G . It prints the word w in terms of the elements of G .

`TietzeReduction(S, w)` Inputs a set S of words in a free ZG -module, and a word w in the module. The function returns a reduced version of w in which no two adjacent letters are inverses of each other, and no two adjacent letters are in S .

Chapter 15

FpG -modules

`DirectSumOfFpGModules (M, N)`
`DirectSumOfFpGModules ([M[1], M[2], ..., M[k]])` Inputs two FpG -modules M and N with common group G .
`FpGModule (A, P)`
`FpGModule (A, G, p)` Inputs a p -group P and a matrix A whose rows have length a multiple of the order of G . It returns an FpG -module.
`FpGModuleDualBasis (M)` Inputs an FpG -module M . It returns a record R with two components: $R.freeModule$ is the free module and $R.dualBasis$ is a dual basis.
`FpGModuleHomomorphism (M, N, A)`
`FpGModuleHomomorphismNC (M, N, A)` Inputs FpG -modules M and N over a common p -group G . Also inputs a list A of matrices.
`DesuspensionFpGModule (M, n)`
`DesuspensionFpGModule (R, n)` Inputs a positive integer n and an FpG -module M . It returns an FpG -module $D^n M$.
`RadicalOfFpGModule (M)` Inputs an FpG -module M with G a p -group, and returns the Radical of M as an FpG -module.
`GeneratorsOfFpGModule (M)` Inputs an FpG -module M and returns a matrix whose rows correspond to a minimal generating set.
`ImageOfFpGModuleHomomorphism (f)` Inputs an FpG -module homomorphism $f : M \rightarrow N$ and returns its image $f(M)$.
`IntersectionOfFpGModules (M, N)` Inputs two FpG -modules M, N arising as submodules in a common free module.
`IsFpGModuleHomomorphismData (M, N, A)` Inputs FpG -modules M and N over a common p -group G . Also inputs a list A of matrices.
`MultipleOfFpGModule (w, M)` Inputs an FpG -module M and a list $w := [g_1, \dots, g_t]$ of elements in the group $G = M!.g$.
`ProjectedFpGModule (M, k)` Inputs an FpG -module M of ambient dimension $n|G|$, and an integer k between 1 and n .
`RandomHomomorphismOfFpGModules (M, N)` Inputs two FpG -modules M and N over a common group G . It returns a random homomorphism.
`Rank (f)` Inputs an FpG -module homomorphism $f : M \rightarrow N$ and returns the dimension of the image of f as a vector space.
`SumOfFpGModules (M, N)` Inputs two FpG -modules M, N arising as submodules in a common free module $(FG)^n$ where n is the ambient dimension.
`SumOp (f, g)` Inputs two FpG -module homomorphisms $f, g : M \rightarrow N$ with common source and common target. It returns their sum.
`VectorsToFpGModuleWords (M, L)` Inputs an FpG -module M and a list $L = [v_1, \dots, v_k]$ of vectors in M . It returns a list of words.

Chapter 16

Meataxe modules

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DesuspensionMtxModule(M) Inputs a meataxe module M over the field of p elements and returns an FpG-module DM .

FpG_to_MtxModule(M) Inputs an FpG-module M and returns an isomorphic meataxe module.

GeneratorsOfMtxModule(M) Inputs a meataxe module M acting on, say, the vector space V . The function returns a m

Chapter 17

Coxeter diagrams and graphs of groups

`CoxeterDiagramComponents(D)` Inputs a Coxeter diagram D and returns a list $[D_1, \dots, D_d]$ of the maximal connected components of D .

`CoxeterDiagramDegree(D, v)` Inputs a Coxeter diagram D and vertex v . It returns the degree of v (i.e. the number of neighbors of v in D).

`CoxeterDiagramDisplay(D)` Inputs a Coxeter diagram D and displays it as a .gif file. It uses the `GraphOfGroupsDisplay` function.

`CoxeterDiagramDisplay(D, "web browser")` Inputs a Coxeter diagram D and displays it as a .gif file. It uses the `GraphOfGroupsDisplay` function.

`CoxeterDiagramFpArtinGroup(D)` Inputs a Coxeter diagram D and returns the corresponding finitely presented Artin group.

`CoxeterDiagramFpCoxeterGroup(D)` Inputs a Coxeter diagram D and returns the corresponding finitely presented Coxeter group.

`CoxeterDiagramIsSpherical(D)` Inputs a Coxeter diagram D and returns "true" if the associated Coxeter groups is spherical.

`CoxeterDiagramMatrix(D)` Inputs a Coxeter diagram D and returns a matrix representation of it. The matrix is given by (m_{ij}) where m_{ij} is the order of $s_i s_j$.

`CoxeterSubDiagram(D, V)` Inputs a Coxeter diagram D and a subset V of its vertices. It returns the full sub-diagram of D with vertices V .

`CoxeterDiagramVertices(D)` Inputs a Coxeter diagram D and returns its set of vertices.

`EvenSubgroup(G)` Inputs a group G and returns a subgroup G^+ . The subgroup is that generated by all products xy where $x, y \in G$.

`GraphOfGroupsDisplay(D)` Inputs a graph of groups D and displays it as a .gif file. It uses the `GraphOfGroupsDisplay` function.

`GraphOfGroupsDisplay(D, "web browser")` Inputs a graph of groups D and displays it as a .gif file. It uses the `GraphOfGroupsDisplay` function.

`GraphOfGroupsTest(D)` Inputs an object D and tries to test whether it is a Graph of Groups. However, it DOES NOT work.

Chapter 18

Some functions for accessing basic data

`BoundaryMap(C)` Inputs a resolution, chain complex or cochain complex C and returns the function $C!.boundary$.

`BoundaryMatrix(C,n)` Inputs a chain or cochain complex C and integer $n>0$. It returns the n -th boundary map of C .

`Dimension(C)`

`Dimension(M)` Inputs a resolution, chain complex or cochain complex C and returns the function $C!.dimension$. Also returns the dimension of the complex.

`EvaluateProperty(X,"name")` Inputs a component object X (such as a ZG -resolution or chain map) and a string "name". Returns the value of the property "name" of X .

`GroupOfResolution(R)` Inputs a ZG -resolution R and returns the group G .

`Length(R)` Inputs a resolution R and returns its length (i.e. the number of terms of R that HAP has computed).

`Map(f)` Inputs a chain map, or cochain map or equivariant chain map f and returns the mapping function (as opposed to the map itself).

`Source(f)` Inputs a chain map, or cochain map, or equivariant chain map, or FpG -module homomorphism f and returns the source of f .

`Target(f)` Inputs a chain map, or cochain map, or equivariant chain map, or FpG -module homomorphism f and returns the target of f .

Chapter 19

Parallel Computation - Core Functions

ChildProcess ()

ChildProcess ("computer.ac.wales") This starts a GAP session as a child process and returns a stream to the child p

- open a shell on thishost
- cd .ssh
- ls
- *! if id_dsa, id_rsaet cexists, skip thenexttwo steps!*
- ssh-keygen -t rsa
- ssh-keygen -t dsa
- scp *.pub user@remotehost: /
- ssh remotehost -l user
- cat id_rsa.pub >> .ssh/authorized_kkeys
- cat id_dsa.pub >> .ssh/authorized_kkeys
- rm id_rsa.pub id_dsa.pub
- exit

You should now be able to connect from "thishost" to "remotehost" without a password prompt.)

ChildClose(s) This closes the stream s to a child GAP process.

ChildCommand("cmd"; s) This runs a GAP command "cmd;" on the child process accessed by the stream s. Here "cm

NextAvailableChild(L) Inputs a list L of child processes and returns a child in L which is ready for computation (as

IsAvailableChild(s) Inputs a child process s and returns true if s is currently available for computations, and false o

ChildPut(A, "B", s) This copies a GAP object A on the parent process to an object B on the child process s. (The cop

ChildGet("A", s) This functions copies a GAP object A on the child process s and returns it on the parent process. (T

Chapter 20

Parallel Computation - Extra Functions

`ChildFunction("function(arg);", s)` This runs the GAP function "function(arg);" on a child process accessed by the string `s`.

`ChildRead(s)` This returns, as a string, the output of the last application of `ChildFunction("function(arg);", s)`.

`ChildReadEval(s)` This returns, as an evaluated string, the output of the last application of `ChildFunction("function(arg);", s)`.

`ParallelList(I, fn, L)` Inputs a list `I`, a function `fn` such that `fn(x)` is defined for all `x` in `I`, and a list of children `L`. It returns a list of results.

Chapter 21

Topological Data Analysis

`MatrixToTopologicalSpace(A, n)` Inputs an integer matrix A and an integer n . It returns a 2-dimensional topological space.

`ReadImageAsTopologicalSpace("file.png", n)` `ReadImageAsTopologicalSpace("file.png", [m, n])` Reads an image file ("file.png") and returns a topological space.

`ReadImageAsMatrix("file.png")` Reads an image file ("file.png", "file.eps", "file.bmp" etc) and returns an integer matrix.

`WriteTopologicalSpaceAsImage(T, "filename", "ext")` Inputs a 2-dimensional topological space T , and a filename "filename" and an extension "ext".

`ViewTopologicalSpace(T)` `ViewTopologicalSpace(T, "mozilla")` Inputs a topological space T , and optionally a browser name "mozilla".

`BettiNumbers(T, n)` `BettiNumbers(T)` Inputs a topological space T and a non-negative integer n . It returns the n -th Betti number of T .

`PathComponent(T, n)` Inputs a topological space T and an integer n in the range $0, \dots, \text{BettiNumbers}(T, 0)$. It returns the n -th path component of T .

`SingularChainComplex(A)` Inputs a topological space T and returns a (usually very large) integral chain complex that computes the homology of T .

`ContractTopologicalSpace(T)` Inputs a topological space T of dimension d and removes d -dimensional cells from T .

`BoundaryTopologicalSpace(T)` Inputs a topological space T and returns its boundary as a topological space.

`BoundarySingularities(T)` Inputs a topological space T and returns the subspace of points in the boundary where the boundary is singular.

`ThickenedTopologicalSpace(T)` `ThickenedTopologicalSpace(T, n)` Inputs a topological space T and returns a thickened version of T .

`ComplementTopologicalSpace(T)` Inputs a topological space T and returns a topological space S . A euclidean point x is in S if and only if x is not in T .

`ConcatenatedTopologicalSpace(L)` Inputs a list L of topological spaces whose underlying arrays of numbers all have the same length.

Chapter 22

Pseudo lists

`Add(L, x)` Let L be a pseudo list of length n , and x an object compatible with the entries in L . If x is not in L then this operation adds x to the end of L .

`Append(L, K)` Let L be a pseudo list and K a list whose objects are compatible with those in L . This operation appends the elements of K to the end of L .

`ListToPseudoList(L)` Inputs a list L and returns the pseudo list representation of L .

Chapter 23

Miscellaneous

`BigStepLCS(G, n)` Inputs a group G and a positive integer n . It returns a subseries $G = L_1 > L_2 > \dots > L_k = 1$ of the lower central series of G .

`Compose(f, g)` Inputs two FpG -module homomorphisms $f : M \rightarrow N$ and $g : L \rightarrow M$ with $Source(f) = Target(g)$.

`HAPcopyright()` This function provides details of HAP'S GNU public copyright licence.

`IsLieAlgebraHomomorphism(f)` Inputs an object f and returns true if f is a homomorphism $f : A \rightarrow B$ of Lie algebras.

`IsSuperperfect(G)` Inputs a group G and returns "true" if both the first and second integral homology of G is trivial.

`MakeHAPManual()` This function creates the manual for HAP from an XML file.

`PermToMatrixGroup(G, n)` Inputs a permutation group G and its degree n . Returns a bijective homomorphism $f : G \rightarrow GL(n, F)$.

`SolutionsMatDestructive(M, B)` Inputs an $m \times n$ matrix M and a $k \times n$ matrix B over a field. It returns a $k \times m$ matrix C such that $CM = B$.

`TestHap()` This runs a representative sample of HAP functions and checks to see that they produce the correct output.

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