DESIGN

A Package for GAP

by

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This manual describes the DESIGN 1.7 package for GAP. The DESIGN package is for constructing, classifying, partitioning, and studying block designs.

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Please reference your use of the DESIGN package in a published work as follows:
L.H. Soicher, The DESIGN package for GAP, Version 1.7, 2019,
https://gap-packages.github.io/design

Any comments or bug reports should go to L.H.Soicher@qmul.ac.uk.

1.1 Installing the DESIGN Package

The DESIGN package is included in the standard GAP distribution. You only need to download and install DESIGN if you need to install the package locally or are installing an upgrade of DESIGN to an existing installation of GAP (see the main GAP reference section 76.1). If you do need to download DESIGN, you can find archive files for the package in various formats at http://www.gap-system.org/Packages/design.html, and then your archive file of choice should be downloaded and unpacked in the pkg subdirectory of an appropriate GAP root directory (see the main GAP reference section 9.2).

The DESIGN package is written entirely in GAP code, and requires no further installation. However, DESIGN makes use of the GRAPE package [Soi19], which must be fully installed.

1.2 Loading DESIGN

Before using DESIGN you must load the package within GAP by calling the statement

LoadPackage("design");
1.3 The structure of a block design in DESIGN

A block design is an ordered pair \((X, B)\), where \(X\) is a non-empty finite set whose elements are called points, and \(B\) is a non-empty finite multiset whose elements are called blocks, such that each block is a non-empty finite multiset of points.

DESIGN deals with arbitrary block designs. However, at present, some DESIGN functions only work for binary block designs (i.e. those with no repeated element in any block of the design), but these functions will check if an input block design is binary.

In DESIGN, a block design \(D\) is stored as a record, with mandatory components `isBlockDesign`, `v`, and `blocks`. The points of a block design \(D\) are always 1, 2, ..., \(D.v\), but they may also be given names in the optional component `pointNames`, with \(D.pointNames[i]\) the name of point \(i\). The `blocks` component must be a sorted list of the blocks of \(D\) (including any repeats), with each block being a sorted list of points (including any repeats).

A block design record may also have some optional components which store information about the design. At present these optional components include `isSimple`, `isBinary`, `isConnected`, \(r\), `blockSizes`, `blockNumbers`, `resolutions`, `autGroup`, `autSubgroup`, `tSubsetStructure`, `allTDesignLambdas`, `efficiency`, `id`, `statisticalPropertiesXML`, and `pointNames`.

A non-expert user should only use functions in the DESIGN package to create block design records and their components.

1.4 Example of the use of DESIGN

To give you an idea of the capabilities of this package, we now give an extended example of an application of the DESIGN package, in which a nearly resolvable non-simple 2-(21,4,3) design is constructed (for Donald Preece) via a pairwise-balanced design. All the DESIGN functions used here are described in this manual.

The program first discovers the unique (up to isomorphism) pairwise-balanced 2-(21,\{4,5\},1) design \(D\) invariant under \(H = \langle (1,2,\ldots,20) \rangle\), and then applies the *-construction of [MS07] to this design \(D\) to obtain a non-simple 2-(21,4,3) design \(D_{\text{star}}\) with automorphism group of order 80. The program then classifies the near-resolutions of \(D_{\text{star}}\) invariant under the subgroup of order 5 of \(H\), and finds exactly two such (up to the action of \(\text{Aut}(D_{\text{star}})\)). Finally, \(D_{\text{star}}\) is printed.

```gap
gap> H:=CyclicGroup(IsPermGroup,20);
Group([ (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20) ])
gap> D:=BlockDesigns(rec(v:=21,blockSizes:=[4,5],
> tSubsetStructure:=rec(t:=2,lambdas:=[1]),
> requiredAutSubgroup:=H ));;
gap> Length(D); 1
gap> D:=D[1];;
gap> BlockSizes(D); [ 4, 5 ]
gap> BlockNumbers(D); [ 20, 9 ]
gap> Size(AutGroupBlockDesign(D)); 80
gap> Dstar:=TDesignFromTBD(D,2,4);;
gap> AllTDesignLambdas(Dstar); [ 105, 20, 3 ]
gap> IsSimpleBlockDesign(Dstar); false
gap> Size(AutGroupBlockDesign(Dstar)); 80
```
Section 4. Example of the use of DESIGN

gap> near_resolutions:=PartitionsIntoBlockDesigns(rec(
    blockDesign:=Dstar,
    v:=21, blockSizes:=[4],
    tSubsetStructure:=rec(t:=0, lambdas:=[5]),
    blockIntersectionNumbers:=[[0]],
    requiredAutSubgroup:=SylowSubgroup(H, 5));

gap> Length(near_resolutions);
2

gap> List(near_resolutions, x-> Size(x.autGroup));
[5, 20]

gap> Print(Dstar, "\n")
rec(
    isBlockDesign := true,
    v := 21,
    blocks := [ [ 1, 2, 4, 15 ], [ 1, 2, 4, 15 ], [ 1, 2, 4, 15 ],
                [ 1, 3, 14, 20 ], [ 1, 3, 14, 20 ], [ 1, 5, 9, 13 ],
                [ 1, 5, 9, 17 ], [ 1, 5, 13, 17 ], [ 1, 6, 11, 16 ],
                [ 1, 6, 16, 21 ], [ 1, 7, 8, 10 ], [ 1, 7, 8, 10 ],
                [ 1, 9, 13, 17 ], [ 1, 11, 16, 21 ], [ 1, 12, 18, 19 ],
                [ 1, 12, 18, 19 ], [ 1, 12, 18, 19 ], [ 2, 3, 5, 16 ],
                [ 2, 3, 5, 16 ], [ 2, 3, 5, 16 ], [ 2, 6, 10, 14 ],
                [ 2, 6, 10, 14 ], [ 2, 6, 10, 14 ], [ 2, 7, 12, 17 ],
                [ 2, 7, 12, 17 ], [ 2, 7, 12, 17 ], [ 2, 8, 9, 11 ],
                [ 2, 8, 9, 11 ], [ 2, 8, 9, 11 ], [ 2, 10, 14, 18 ],
                [ 2, 10, 14, 18 ], [ 2, 12, 17, 21 ], [ 2, 12, 17, 21 ],
                [ 2, 13, 19, 20 ], [ 2, 13, 19, 20 ], [ 2, 13, 19, 20 ],
                [ 3, 4, 6, 17 ], [ 3, 4, 6, 17 ], [ 3, 7, 11, 15 ],
                [ 3, 7, 11, 19 ], [ 3, 7, 15, 19 ], [ 3, 8, 13, 18 ],
                [ 3, 8, 13, 21 ], [ 3, 8, 18, 21 ], [ 3, 9, 10, 12 ],
                [ 3, 9, 10, 12 ], [ 3, 9, 10, 12 ], [ 3, 11, 15, 19 ],
                [ 3, 11, 15, 19 ], [ 3, 13, 18, 21 ], [ 4, 5, 7, 18 ],
                [ 4, 5, 7, 18 ], [ 4, 5, 7, 18 ], [ 4, 5, 7, 18 ],
                [ 4, 8, 12, 16 ], [ 4, 8, 12, 16 ], [ 4, 8, 12, 20 ],
                [ 4, 8, 12, 20 ], [ 4, 8, 16, 20 ], [ 4, 9, 14, 19 ],
                [ 4, 9, 14, 19 ], [ 4, 9, 14, 19 ], [ 4, 9, 19, 21 ],
                [ 4, 9, 19, 21 ], [ 4, 10, 11, 13 ], [ 4, 10, 11, 13 ],
                [ 4, 10, 11, 13 ], [ 4, 12, 16, 20 ], [ 4, 12, 16, 20 ],
                [ 4, 14, 19, 21 ], [ 5, 6, 8, 19 ], [ 5, 6, 8, 19 ],
                [ 5, 6, 8, 19 ], [ 5, 6, 8, 19 ], [ 5, 9, 13, 17 ],
                [ 5, 9, 13, 17 ], [ 5, 10, 15, 20 ], [ 5, 10, 15, 20 ],
                [ 5, 10, 20, 21 ], [ 5, 10, 20, 21 ], [ 5, 11, 12, 14 ],
                [ 5, 11, 12, 14 ], [ 5, 11, 12, 14 ], [ 6, 7, 9, 20 ],
                [ 6, 7, 9, 20 ], [ 6, 7, 9, 20 ], [ 6, 10, 14, 18 ],
                [ 6, 10, 14, 18 ], [ 6, 11, 16, 21 ], [ 6, 12, 13, 15 ],
                [ 6, 12, 13, 15 ], [ 6, 12, 13, 15 ], [ 7, 11, 15, 19 ],
                [ 7, 11, 15, 19 ], [ 7, 12, 17, 21 ], [ 7, 13, 14, 16 ],
                [ 7, 13, 14, 16 ], [ 7, 13, 14, 16 ], [ 8, 12, 16, 20 ],
                [ 8, 12, 16, 20 ], [ 8, 14, 15, 17 ], [ 8, 14, 15, 17 ],
                [ 8, 14, 15, 17 ], [ 9, 14, 19, 21 ], [ 9, 15, 16, 18 ],
                [ 9, 15, 16, 18 ], [ 9, 15, 16, 18 ], [ 9, 15, 16, 18 ],
                [ 10, 15, 20, 21 ], [ 10, 15, 20, 21 ], [ 10, 16, 17, 19 ],
                [ 10, 16, 17, 19 ], [ 10, 16, 17, 19 ], [ 10, 16, 17, 19 ],
                [ 11, 17, 18, 20 ], [ 11, 17, 18, 20 ], [ 11, 17, 18, 20 ],
                [ 11, 17, 18, 20 ],
    autGroup := Group( [ ( 2,4,10,18)( 3,7,19,15)( 4,20, 8,12)( 5,13,17, 9),
                        ( 1,17, 5, 9)( 2,10,14, 6)( 4,16,12,20)( 7,15,19,11),
                        ( 1,18,19,12)( 2,11, 8, 9)( 3,4,17, 6)( 5,10,15,20)( 7,16,13,14) ] ),
    blockSizes := [4],
    isBinary := true,
    allTDesignLambdas := [ 105, 20, 3 ],
    isSimple := false )
2 Information from block design parameters

2.1 Information from t-design parameters

For \( t \) a non-negative integer and \( v, k, \lambda \) positive integers with \( t \leq k \leq v \), a \( t \)-design with parameters \( t, v, k, \lambda \), or a \( t-(v,k,\lambda) \) design, is a binary block design with exactly \( v \) points, such that each block has size \( k \) and each \( t \)-subset of the points is contained in exactly \( \lambda \) blocks.

\[ \text{TDesignLambdas}(t, v, k, \lambda) \]

A \( t-(v,k,\lambda) \) design is also an \( s-(v,k,\lambda_s) \) design for \( 0 \leq s \leq t \), where \( \lambda_s = \lambda \binom{v-s}{t-s} / \binom{k-s}{t-s} \).

Given a non-negative integer \( t \), and positive integers \( v, k, \lambda \), with \( t \leq k \leq v \), this function returns a length \( t+1 \) list whose \((s+1)\)-st element is \( \lambda_s \) as defined above, if all the \( \lambda_s \) are integers. Otherwise, \text{fail} is returned.

\[
\text{gap> TDesignLambdas(5,24,8,1);}
[759, 253, 77, 21, 5, 1]
\]

\[ \text{TDesignLambdaMin}(t, v, k) \]

Given a non-negative integer \( t \), and positive integers \( v \) and \( k \), with \( t \leq k \leq v \), this function returns the minimum positive \( \lambda \) such that \( \text{TDesignLambdas}(t, v, k, \lambda) \) does not return \text{fail}.

See 2.1.1.

\[
\text{gap> TDesignLambdaMin(5,24,8);}
1
\]

\[
\text{gap> TDesignLambdaMin(2,12,4);}
3
\]

\[ \text{TDesignIntersectionTriangle}(t, v, k, \lambda) \]

Suppose \( D \) is a \( t-(v,k,\lambda) \) design, let \( i \) and \( j \) be non-negative integers with \( i + j \leq t \), and suppose \( X \) and \( Y \) are disjoint subsets of the points of \( D \), such that \( X \) and \( Y \) have respective sizes \( i \) and \( j \). The \((i,j)\)-intersection number is the number of blocks of \( D \) that contain \( X \) and are disjoint from \( Y \) (this number depends only on \( t, v, k, \lambda, i \) and \( j \)).

Given a non-negative integer \( t \), and positive integers \( v, k \) and \( \lambda \), with \( t \leq k \leq v \), this function returns the \( t \)-design intersection triangle, which is a two dimensional array whose \((i+1,j+1)\)-entry is the \((i,j)\)-intersection number for a \( t-(v,k,\lambda) \) design (assuming such a design exists), such that \( i,j \geq 0, i+j \leq t \). This function returns \text{fail} if \( \text{TDesignLambdas}(t,v,k,\lambda) \) does. When \( \lambda = 1 \), then more information can be obtained using 2.1.4.
Chapter 2. Information from block design parameters

gap> TDesignLambdas(2,12,4,3);  
[ 33, 11, 3 ]
gap> TDesignIntersectionTriangle(2,12,4,3);  
[ [ 33, 22, 14 ], [ 11, 8 ], [ 3 ] ]
gap> TDesignLambdas(2,12,4,2);  
fail
gap> TDesignIntersectionTriangle(2,12,4,2);  
fail

C SteinerSystemIntersectionTriangle( t, v, k )

A Steiner system is a $t-(v,k,1)$ design, and in this case it is possible to extend the notion of intersection triangle defined in 2.1.3.

Suppose $D$ is a $t-(v,k,1)$ design, with $B$ a block of $D$, let $i$ and $j$ be non-negative integers with $i + j \leq k$, and suppose $X$ and $Y$ are disjoint subsets of $B$, such that $X$ and $Y$ have respective sizes $i$ and $j$. The $(i,j)$-intersection number is the number of blocks of $D$ that contain $X$ and are disjoint from $Y$ (this number depends only on $t, v, k, i$ and $j$). Note that when $i + j \leq t$, this intersection number is the same as that defined in 2.1.3 for the general $t$-design case.

Given a non-negative integer $t$, and positive integers $v$ and $k$, with $t \leq k \leq v$, this function returns the Steiner system intersection triangle, which is a two dimensional array whose $(i+1,j+1)$-entry is the $(i,j)$-intersection number for a $t-(v,k,1)$ design (assuming such a design exists), such that $i,j \geq 0, i+j \leq k$. This function returns fail if TDesignLambdas$(t,v,k,1)$ does.

See also 2.1.3.

gap> SteinerSystemIntersectionTriangle(5,24,8);  
[ [ 759, 506, 330, 210, 130, 78, 46, 30, 30 ],  
  [ 21, 16, 12, 8, 4, 0 ],  
  [ 77, 56, 40, 28, 20, 16, 0 ],  
  [ 5, 4, 4, 4, 4 ],  
  [ 1, 0, 0, 0 ], [ 1, 0, 0 ],  
  [ 1, 0 ], [ 1 ] ]
gap> TDesignIntersectionTriangle(5,24,8,1);  
[ [ 759, 506, 330, 210, 130, 78, 46, 30, 30 ],  
  [ 21, 16, 12, 8, 4, 0 ],  
  [ 77, 56, 40, 28, 20, 16 ],  
  [ 5, 4, 4, 4, 4 ],  
  [ 1, 0, 0, 0 ], [ 1, 0, 0 ],  
  [ 1, 0 ], [ 1 ] ]

D TDesignBlockMultiplicityBound( t, v, k, lambda )

Given a non-negative integer $t$, and positive integers $v, k$ and $\lambda$, with $t \leq k \leq v$, this function returns a non-negative integer which is an upper bound on the multiplicity of any block in any $t-(v,k,\lambda)$ design (the multiplicity of a block in a block design is the number of times that block occurs in the block list). In particular, if the value 0 is returned, then this implies that a $t-(v,k,\lambda)$ design does not exist.

Although our bounds are reasonably good, we do not claim that the returned bound $m$ is always achieved; that is, there may not exist a $t-(v,k,\lambda)$ design having a block with multiplicity $m$.

See also 2.1.6.

gap> TDesignBlockMultiplicityBound(5,16,7,5);  
2
gap> TDesignBlockMultiplicityBound(2,36,6,1);  
0
gap> TDesignBlockMultiplicityBound(2,36,6,2);  
2
gap> TDesignBlockMultiplicityBound(2,15,5,2);  
0
gap> TDesignBlockMultiplicityBound(2,15,5,4);  
2
gap> TDesignBlockMultiplicityBound(2,11,4,6);  
3
Section 2. Block intersection polynomials

6. \texttt{ResolvableTDesignBlockMultiplicityBound( t, v, k, lambda )}

A \textit{resolution} of a block design is a partition of the blocks into subsets, each of which forms a partition of the point set, and a block design is \textit{resolvable} if it has a resolution.

Given a non-negative integer \( t \), and positive integers \( v, k \) and \( \lambda \), with \( t \leq k \leq v \), this function returns a non-negative integer which is an upper bound on the multiplicity of any block in any resolvable \( t \)-(\( v,k,\lambda \)) design (the \textit{multiplicity} of a block in a block design is the number of times that block occurs in the block list). In particular, if the value 0 is returned, then this implies that a resolvable \( t \)-(\( v,k,\lambda \)) design does not exist.

Although our bounds are reasonably good, we do not claim that the returned bound \( m \) is always achieved; that is, there may not exist a resolvable \( t \)-(\( v,k,\lambda \)) design having a block with multiplicity \( m \).

See also 2.1.5.

\begin{verbatim}
gap> ResolvableTDesignBlockMultiplicityBound(5,12,6,1); 1
gap> ResolvableTDesignBlockMultiplicityBound(2,21,7,3); 0
gap> TDesignBlockMultiplicityBound(2,21,7,3); 1
gap> TDesignBlockMultiplicityBound(2,12,4,3); 0
\end{verbatim}

2.2 Block intersection polynomials

In [CS07], Cameron and Soicher introduce block intersection polynomials and their applications to the study of block designs. Here we give functions to construct and analyze block intersection polynomials.

\textbf{BlockIntersectionPolynomial}(x, m, lambdavec )

For \( k \) a non-negative integer, define the polynomial \( P(x, k) = x(x - 1) \cdots (x - k + 1) \). Let \( s \) and \( t \) be non-negative integers, with \( s \geq t \), and let \( m_0, \ldots , m_s \) and \( \lambda_0, \ldots , \lambda_s \) be rational numbers. Then the \textit{block intersection polynomial} for the sequences \([m_0, \ldots , m_s], [\lambda_0, \ldots , \lambda_s]\) is defined to be

\[
\sum_{j=0}^{t} \binom{t}{j} P(-x,t-j)[P(s,j)\lambda_j - \sum_{i=j}^{s} P(i,j)m_i],
\]

and is denoted by \( B(x, [m_0, \ldots , m_s], [\lambda_0, \ldots , \lambda_s]) \).

Now suppose \( x \) is an indeterminate over the rationals, and \( m \) and \( lambdavec \) are non-empty lists of rational numbers, such that the length of \( lambdavec \) is not greater than that of \( m \). Then this function returns the block intersection polynomial \( B(x, m, lambdavec) \).

The importance of a block intersection polynomial is as follows. Let \( D = (V, \mathcal{B}) \) be a block design, let \( S \subseteq V \), with \( s = |S| \), and for \( i = 0, \ldots , s \), suppose that \( m_i \) is a non-negative integer with \( m_i \leq n_i \), where \( n_i \) is the number of blocks intersecting \( S \) in exactly \( i \) points. Let \( t \) be a non-negative even integer with \( t \leq s \), and suppose that, for \( j = 0, \ldots , t \), we have \( \lambda_j = 1/{\binom{t}{j}} \sum_{T \subseteq S, |T| = j} \lambda_T \), where \( \lambda_T \) is the number of blocks of \( D \) containing \( T \). Then the block intersection polynomial \( B(x) = B(x, [m_0, \ldots , m_s], [\lambda_0, \ldots , \lambda_s]) \) is a polynomial with integer coefficients, and \( B(n) \geq 0 \) for every integer \( n \). (These conditions can be checked using the function 2.2.2.) In addition, if \( B(n) = 0 \) for some integer \( n \), then \( m_i = n_i \) for \( i \not\in \{n, n+1, \ldots , n+t-1\} \).

For more information on block intersection polynomials and their applications, see [CS07] and [Soi10].
Chapter 2. Information from block design parameters

\begin{verbatim}
gap> x := Indeterminate(Rationals, 1);
x_1
gap> m := [0, 0, 0, 0, 0, 0, 0, 1];;
gap> lambdavec := TDesignLambdas(6, 14, 7, 4);
[ 1716, 396, 165, 60, 18, 4 ]
gap> B := BlockIntersectionPolynomial(x, m, lambdavec);
1715*x_1^6 - 10269*x_1^5 + 34685*x_1^4 - 69615*x_1^3 + 84560*x_1^2 - 56196*x_1 + 15120
gap> Factors(B);
[ 1715*x_1 - 1715, x_1^5 - 1222/245*x_1^4 + 3733/245*x_1^3 - 6212/245*x_1^2 + 5868/245*x_1 - 432/49 ]
gap> Value(B, 1);
0

\textbf{BlockIntersectionPolynomialCheck}(m, lambdavec)

Suppose \( m \) is a list of non-negative integers, and \( \text{lambdavec} \) is a list of non-negative rational numbers, with the length of \( \text{lambdavec} \) odd and not greater than the length of \( m \).

Then, for \( x \) an indeterminate over the rationals, this function checks whether \( \text{BlockIntersectionPolynomial}(x, m, \text{lambdavec}) \) is a polynomial over the integers and has a non-negative value at each integer. The function returns \text{true} if this is so; else \text{false} is returned.

See also 2.2.1.

\begin{verbatim}
gap> m := [0, 0, 0, 0, 0, 0, 0, 1];;
gap> lambdavec := TDesignLambdas(6, 14, 7, 4);
[ 1716, 396, 165, 60, 18, 4 ]
gap> BlockIntersectionPolynomialCheck(m, lambdavec);
true
gap> m := [1, 0, 0, 0, 0, 0, 0, 1];;
gap> BlockIntersectionPolynomialCheck(m, lambdavec);
false
\end{verbatim}
\end{verbatim}
3 Constructing block designs

3.1 Functions to construct block designs

- BlockDesign( v, B )
- BlockDesign( v, B, G )

Let \( v \) be a positive integer and \( B \) a non-empty list of non-empty sorted lists of elements of \{1, \ldots, v\}.

The first version of this function returns the block design with point-set \{1, \ldots, v\} and block multiset \( C \), where \( C \) is SortedList(\( B \)).

For the second version of this function, we require \( G \) to be a group of permutations of \{1, \ldots, v\}, and the function returns the block design with point-set \{1, \ldots, v\} and block multiset \( C \), where \( C \) is the sorted list of the concatenation of the \( G \)-orbits of the elements of \( B \).

```gap
gap> BlockDesign( 2, [[1,2],[1],[1,2]] );
rec( isBlockDesign := true, v := 2, blocks := [ [ 1 ], [ 1, 2 ], [ 1, 2 ] ] )
gap> D:=BlockDesign(7, [[1,2,4]], Group((1,2,3,4,5,6,7)));
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 5, 6 ], [ 2, 3, 5 ],
        [ 2, 6, 7 ], [ 3, 4, 6 ], [ 4, 5, 7 ] ],
    autSubgroup := Group([ (1,2,3,4,5,6,7) ])
)
gap> AllTDesignLambdas(D);
[ 7, 3, 1 ]
```

- AGPointFlatBlockDesign( n, q, d )

Let \( n \) be a positive integer, \( q \) a prime-power, and \( d \) a non-negative integer less than or equal to \( n \). Then this function returns the block design whose points are the points of the affine space \( AG(n, q) \), and whose blocks are the \( d \)-flats of \( AG(n, q) \), considering a \( d \)-flat as a set of points.

Note that the affine space \( AG(n, q) \) consists of all the cosets of all the subspaces of the vector space \( V(n, q) \), with the points being the cosets of the 0-dimensional subspace and the \( d \)-flats being the cosets of the \( d \)-dimensional subspaces. As is usual, we identify the points with the vectors in \( V(n, q) \), and these vectors are given as the point-names.

```gap
gap> D:=AGPointFlatBlockDesign(2,4,1);
rec( isBlockDesign := true, v := 16,
    blocks := [ [ 1, 2, 3, 4 ], [ 1, 5, 9, 13 ], [ 1, 6, 11, 16 ],
        [ 1, 7, 12, 14 ], [ 1, 8, 10, 15 ], [ 2, 5, 12, 15 ], [ 2, 6, 10, 14 ],
        [ 2, 7, 9, 16 ], [ 2, 8, 11, 13 ], [ 3, 5, 10, 16 ], [ 3, 6, 12, 13 ],
        [ 3, 7, 11, 15 ], [ 3, 8, 9, 14 ], [ 4, 5, 11, 14 ], [ 4, 6, 9, 15 ],
        [ 4, 7, 10, 13 ], [ 4, 8, 12, 16 ], [ 5, 6, 7, 8 ], [ 9, 10, 11, 12 ],
        [ 13, 14, 15, 16 ]],
    autSubgroup := Group([ (5,9,13)(6,10,14)(7,11,15)(8,12,16),
        (2,5,6)(3,9,11)(4,13,16)(7,14,12)(8,10,15),
        (1,5)(2,6)(3,7)(4,8)(9,13)(10,14)(11,15)(12,16),
        (3,4)(7,8)(9,13)(10,14)(11,16)(12,15) ]),
```
Chapter 3. Constructing block designs

pointNames := [ [ 0*Z(2), 0*Z(2) ], [ 0*Z(2), Z(2)^0 ], [ 0*Z(2), Z(2^2) ],
                [ 0*Z(2), Z(2^2)^2 ], [ Z(2)^0, 0*Z(2) ], [ Z(2)^0, Z(2)^0 ],
                [ Z(2)^0, Z(2^2) ], [ Z(2)^0, Z(2^2)^2 ], [ Z(2^2), 0*Z(2) ],
                [ Z(2^2), Z(2)^0 ], [ Z(2^2), Z(2^2) ], [ Z(2^2), Z(2^2)^2 ],
                [ Z(2^2)^2, 0*Z(2) ], [ Z(2^2)^2, Z(2)^0 ], [ Z(2^2)^2, Z(2^2) ],
                [ Z(2^2)^2, Z(2^2)^2 ] ] )
gap> AllTDesignLambdas(D);
[ 20, 5, 1 ]

3 ▶ PGPointFlatBlockDesign( n, q, d )

Let \( n \) be a non-negative integer, \( q \) a prime-power, and \( d \) a non-negative integer less than or equal to \( n \). Then this function returns the block design whose points are the (projective) points of the projective space \( PG(n, q) \), and whose blocks are the \( d \)-flats of \( PG(n, q) \), considering a \( d \)-flat as a set of projective points.

Note that the projective space \( PG(n, q) \) consists of all the subspaces of the vector space \( V(n+1, q) \), with the projective points being the 1-dimensional subspaces and the \( d \)-flats being the \((d+1)\)-dimensional subspaces.

gap> D := PGPointFlatBlockDesign(3,2,1);
rec( isBlockDesign := true, v := 15,
    blocks := [ [ 1, 2, 3 ], [ 1, 4, 5 ], [ 1, 6, 7 ], [ 1, 8, 9 ],
               [ 1, 10, 11 ], [ 1, 12, 13 ], [ 1, 14, 15 ], [ 2, 4, 6 ], [ 2, 5, 7 ],
               [ 2, 8, 10 ], [ 2, 9, 11 ], [ 2, 12, 14 ], [ 2, 13, 15 ], [ 3, 4, 7 ],
               [ 3, 5, 6 ], [ 3, 8, 11 ], [ 3, 9, 10 ], [ 3, 12, 15 ], [ 3, 13, 14 ],
               [ 4, 8, 12 ], [ 4, 9, 13 ], [ 4, 10, 14 ], [ 4, 11, 15 ], [ 5, 8, 13 ],
               [ 5, 9, 12 ], [ 5, 10, 15 ], [ 5, 11, 14 ], [ 6, 8, 14 ], [ 6, 9, 15 ],
               [ 6, 10, 12 ], [ 6, 11, 13 ], [ 7, 8, 15 ], [ 7, 9, 14 ],
               [ 7, 10, 13 ], [ 7, 11, 12 ] ],
    autSubgroup := Group([ (8,12)(9,13)(10,14)(11,15),
                          (1,2,4,8)(3,6,12,9)(5,10)(7,14,13,11) ]),
    pointNames := [ <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)>,
                     <vector space of dimension 1 over GF(2)> ] )

gap> AllTDesignLambdas(D);
[ 35, 7, 1 ]

4 ▶ WittDesign( n )

Suppose \( n \in \{ 9, 10, 11, 12, 21, 22, 23, 24 \} \).

If \( n = 24 \) then this function returns the large Witt design \( W_{24} \), the unique (up to isomorphism) 5-(24,8,1) design. If \( n = 24 - i \), where \( i \in \{ 1, 2, 3 \} \), then the \( i \)-fold point-derived design of \( W_{24} \) is returned; this is the unique (up to isomorphism) \((5 - i)\)-(24 - i, 8 - i, 1) design.
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If \( n = 12 \) then this function returns the small Witt design \( W_{12} \), the unique (up to isomorphism) 5-(12,6,1) design. If \( n = 12 - i \), where \( i \in \{1, 2, 3\} \), then the \( i \)-fold point-derived design of \( W_{12} \) is returned; this is the unique (up to isomorphism) \((5 - i)\)-(12 - \( i \), \( 6 - i \), 1) design.

```gap
gap> W24:=WittDesign(24);;
gap> AllTDesignLambdas(W24);
[ 759, 253, 77, 21, 5, 1 ]
gap> DisplayCompositionSeries(AutomorphismGroup(W24));
G (3 gens, size 244823040)
  M(24)
  1 (0 gens, size 1)
gap> W10:=WittDesign(10);;
gap> AllTDesignLambdas(W10);
[ 30, 12, 4, 1 ]
gap> DisplayCompositionSeries(AutomorphismGroup(W10));
G (4 gens, size 1440)
  Z(2)
  S (4 gens, size 720)
  Z(2)
  S (3 gens, size 360)
  A(6) ~ A(1,9) = L(2,9) ~ B(1,9) = O(3,9) ~ C(1,9) = S(2,9) ~ 2A(1,9) = U(2,9)
  1 (0 gens, size 1)
```

5\* DualBlockDesign( \( D \) )

Suppose \( D \) is a block design for which every point lies on at least one block. Then this function returns the dual of \( D \), the block design in which the roles of points and blocks are interchanged, but incidence (including repeated incidence) stays the same. Note that, since the list of blocks of a block design is always sorted, the block list of the dual of the dual of \( D \) may not be equal to the block list of \( D \).

```gap
gap> D:=BlockDesign(4,[[1,3],[2,3,4],[3,4]]);;
gap> dualD:=DualBlockDesign(D);
rec( isBlockDesign := true, v := 3,
    blocks := [ [ 1 ], [ 1, 2, 3 ], [ 2 ], [ 2, 3 ] ],
    pointNames := [ [ 1, 3 ], [ 2, 3, 4 ], [ 3, 4 ] ] )
gap> DualBlockDesign(dualD).blocks;
[ [ 1, 2 ], [ 2, 3, 4 ], [ 2, 4 ] ]
```

6\* ComplementBlocksBlockDesign( \( D \) )

Suppose \( D \) is a binary incomplete-block design. Then this function returns the block design on the same point-set as \( D \), whose blocks are the complements of those of \( D \) (complemented with respect to the point-set).

```gap
gap> D:=PGPointFlatBlockDesign(2,2,1);
rec( isBlockDesign := true, v := 7,
    pointNames := [ <vector space of dimension 1 over GF(2)>,
                    <vector space of dimension 1 over GF(2)>,
                    <vector space of dimension 1 over GF(2)>,
                    <vector space of dimension 1 over GF(2)>,
                    <vector space of dimension 1 over GF(2)>,
                    <vector space of dimension 1 over GF(2)>,
                    <vector space of dimension 1 over GF(2)> ],
    blocks := [ [ 1, 2, 3 ], [ 1, 4, 5 ], [ 1, 6, 7 ], [ 2, 4, 6 ],
               [ 2, 5, 7 ], [ 3, 4, 7 ], [ 3, 5, 6 ] ] )
```
Chapter 3. Constructing block designs

gap> AllTDesignLambdas(D);
[ 7, 3, 1 ]
gap> C:=ComplementBlocksBlockDesign(D);
rec( isBlockDesign := true, v := 7,
   blocks := [ [ 1, 2, 4, 7 ], [ 1, 2, 5, 6 ], [ 1, 3, 4, 6 ], [ 1, 3, 5, 7 ],
   [ 2, 3, 4, 5 ], [ 2, 3, 6, 7 ], [ 4, 5, 6, 7 ] ],
   pointNames := [ <vector space of dimension 1 over GF(2)>,
   <vector space of dimension 1 over GF(2)>,
   <vector space of dimension 1 over GF(2)>,
   <vector space of dimension 1 over GF(2)>,
   <vector space of dimension 1 over GF(2)>,
   <vector space of dimension 1 over GF(2)> ] )
gap> AllTDesignLambdas(C);
[ 7, 4, 2 ]
7 ▶ DeletedPointsBlockDesign( D, Y )

Suppose D is a block design and Y is a proper subset of the point-set of D.

Then this function returns the block design DP obtained from D by deleting the points in Y from the point-set, and from each block. It is an error if the resulting design contains an empty block. The points of DP are relabelled 1, 2, ···, preserving the order of the corresponding points of D; the point-names of DP (listed in DP.pointNames) are those of these corresponding points of D.

gap> D:=BlockDesigns(rec(v:=11,blockSizes:=\{5\},
> tSubsetStructure:=rec(t:=2,lambdas:=\{2\}))[1];
rec( isBlockDesign := true, v := 11,
   blocks := [ [ 1, 2, 3, 4, 5 ], [ 1, 2, 9, 10, 11 ], [ 1, 3, 6, 7, 9 ],
   [ 1, 4, 7, 8, 10 ], [ 1, 5, 6, 8, 11 ], [ 2, 3, 6, 8, 10 ],
   [ 2, 4, 6, 7, 11 ], [ 2, 5, 7, 8, 9 ], [ 3, 4, 8, 9, 11 ],
   [ 3, 5, 7, 10, 11 ], [ 4, 5, 6, 9, 10 ] ],
   tSubsetStructure := rec( t := 2, lambdas := [ 2 ] ), isBinary := true,
   isSimple := true, blockSizes := [ 5 ], blockNumbers := [ 11 ], r := 5,
   autGroup := Group([ (2,4)(3,5)(7,11)(8,9), (1,3)(2,5)(7,9)(10,11),
   (1,5,3)(6,11,7)(8,10,9), (1,10,5,2,11,3)(4,9,7)(6,8) ] )
)

gap> AllTDesignLambdas(D);
[ 11, 5, 2 ]
gap> DP:=DeletedPointsBlockDesign(D,\{5,8\});
rec( isBlockDesign := true, v := 9,
   blocks := [ [ 1, 2, 3, 4 ], [ 1, 2, 7, 8, 9 ], [ 1, 3, 5, 6, 7 ],
   [ 1, 4, 6, 8 ], [ 1, 5, 9 ], [ 2, 3, 5, 8 ], [ 2, 4, 5, 6, 9 ],
   [ 2, 6, 7 ], [ 3, 4, 7, 9 ], [ 3, 6, 8, 9 ], [ 4, 5, 7, 8 ] ],
   pointNames := [ 1, 2, 3, 4, 6, 7, 9, 10, 11 ] )

gap> PairwiseBalancedLambda(DP); 2

8 ▶ DeletedBlocksBlockDesign( D, Y )

Suppose D is a block design, and Y is a proper sublist of the block-list of D (Y need not be sorted).

Then this function returns the block design obtained from D by deleting the blocks in Y (counting repeats) from the block-list of D.
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```gap
D:=BlockDesign(7,[[1,2,4],[1,2,4]],Group((1,2,3,4,5,6,7)));
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 3, 5 ], [ 2, 6, 7 ],
                [ 2, 6, 7 ], [ 3, 4, 6 ], [ 3, 4, 6 ], [ 4, 5, 7 ], [ 4, 5, 7 ] ],
    autSubgroup := Group([ (1,2,3,4,5,6,7) ])
) gap> DeletedBlocksBlockDesign(D,[[2,3,5],[2,3,5],[4,5,7]]);
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 6, 7 ], [ 2, 6, 7 ], [ 3, 4, 6 ],
                [ 3, 4, 6 ] ]
) AddedPointBlockDesign( D, Y )
```

Suppose \( D \) is a block design, and \( Y \) is a sublist of the block-list of \( D \) (\( Y \) need not be sorted).

Then this function returns the block design obtained from \( D \) by adding the new point \( D.v+1 \) to the point-set, and adding this new point (once) to each block of \( Y \) (where repeats count).

The optional parameter \( \text{pointname} \) specifies a point-name for the new point.

```gap
D:=BlockDesign(7,[[1,2,4],[1,2,4]],Group((1,2,3,4,5,6,7)));
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 3, 5 ], [ 2, 6, 7 ],
                [ 2, 6, 7 ], [ 3, 4, 6 ], [ 3, 4, 6 ], [ 4, 5, 7 ], [ 4, 5, 7 ] ],
    autSubgroup := Group([ (1,2,3,4,5,6,7) ])
) gap> AddedPointBlockDesign(D,[[2,3,5],[2,3,5],[4,5,7]],"infinity");
rec( isBlockDesign := true, v := 8,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 3, 5 ], [ 2, 6, 7 ],
                [ 2, 6, 7 ], [ 3, 4, 6 ], [ 3, 4, 6 ], [ 4, 5, 7 ], [ 4, 5, 7, 8 ] ],
    pointNames := [ 1, 2, 3, 4, 5, 6, 7, "infinity" ])
```

Suppose \( Y \) is a list of multisets of points of the block design \( D \). Then this function returns a new block design, whose point-set is that of \( D \), and whose block list is that of \( D \) with the elements of \( Y \) (including repeats) added.

```gap
D:=BlockDesign(7,[[1,2,4],[1,2,4]],Group((1,2,3,4,5,6,7)));
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 3, 5 ], [ 2, 6, 7 ],
                [ 2, 6, 7 ], [ 3, 4, 6 ], [ 3, 4, 6 ], [ 4, 5, 7 ], [ 4, 5, 7, 8 ] ],
    autSubgroup := Group([ (1,2,3,4,5,6,7) ])
) gap> AddedBlocksBlockDesign(D,D.blocks);
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 3, 5 ], [ 2, 6, 7 ],
                [ 2, 6, 7 ], [ 3, 4, 6 ], [ 3, 4, 6 ], [ 4, 5, 7 ], [ 4, 5, 7 ] ]
)```

Suppose \( D \) is a block design, and \( x \) is a point or block of \( D \). Then this function returns the derived design \( DD \) of \( D \), with respect to \( x \).

```gap
D:=BlockDesign(7,[[1,2,4],[1,2,4]],Group((1,2,3,4,5,6,7)));
rec( isBlockDesign := true, v := 7,
    blocks := [ [ 1, 2, 4 ], [ 1, 2, 4 ], [ 1, 3, 7 ], [ 1, 3, 7 ],
                [ 1, 5, 6 ], [ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 3, 5 ], [ 2, 6, 7 ],
                [ 2, 6, 7 ], [ 3, 4, 6 ], [ 3, 4, 6 ], [ 4, 5, 7 ], [ 4, 5, 7 ] ]
) gap> DerivedBlockDesign(D, x);
```

Suppose \( D \) is a block design, and \( x \) is a point or block of \( D \). Then this function returns the derived design \( DD \) of \( D \), with respect to \( x \).
If \( x \) is a point then \( DD \) is the block design whose blocks are those of \( D \) containing \( x \), but with \( x \) deleted from these blocks, and the points of \( DD \) are those which occur in some block of \( DD \).

If \( x \) is a block, then the points of \( DD \) are the points in \( x \), and the blocks of \( DD \) are the blocks of \( D \) other than \( x \) containing at least one point of \( x \), but with all points not in \( x \) deleted from these blocks. Note that any repeat of \( x \), but not \( x \) itself, is a block of \( DD \).

It is an error if the resulting block design \( DD \) has no blocks or an empty block.

The points of \( DD \) are relabelled \( 1, 2, \ldots \), preserving the order of the corresponding points of \( D \); the point-names of \( DD \) (listed in \( DD \).pointNames) are those of these corresponding points of \( D \).

Suppose \( D \) is a block design, and \( x \) is a point or block of \( D \). Then this function returns the residual design \( RD \) of \( D \), with respect to \( x \).

If \( x \) is a point then \( RD \) is the block design whose blocks are those of \( D \) not containing \( x \), and the points of \( RD \) are those which occur in some block of \( RD \).

If \( x \) is a block, then the points of \( RD \) are those of \( D \) not in \( x \), and the blocks of \( RD \) are the blocks of \( D \) (including repeats) containing at least one point not in \( x \), but with all points in \( x \) deleted from these blocks.

It is an error if the resulting block design \( RD \) has no blocks.

The points of \( RD \) are relabelled \( 1, 2, \ldots \), preserving the order of the corresponding points of \( D \); the point-names of \( RD \) (listed in \( RD \).pointNames) are those of these corresponding points of \( D \).
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\texttt{gap> D:=BlockDesigns(rec(v:=11, blockSizes:=[5],
> tSubsetStructure:=rec(t:=2,lambdas:=[2])))[1];
rec( isBlockDesign := true, v := 11,
blocks := [ [ 1, 2, 3, 4, 5 ], [ 1, 2, 9, 10, 11 ], [ 1, 3, 6, 7, 9 ],
[ 1, 4, 7, 8, 10 ], [ 1, 5, 6, 8, 11 ], [ 2, 3, 6, 8, 10 ],
[ 2, 4, 6, 7, 11 ], [ 2, 5, 7, 8, 9 ], [ 3, 4, 8, 9, 11 ],
[ 3, 5, 7, 10, 11 ], [ 4, 5, 6, 9, 10 ]],
tSubsetStructure := rec( t := 2, lambdas := [ 2 ] ), isBinary := true,
isSimple := true, blockSizes := [ 5 ], blockNumbers := [ 11 ], r := 5,
autGroup := Group([ (2,4)(3,5)(7,11)(8,9), (1,3)(2,5)(7,9)(10,11),
(1,5,3)(6,11,7)(8,10,9), (1,10,5,2,11,3)(4,9,7)(6,8) ])
)\texttt{gap> AllTDesignLambdas(D);
[ 11, 5, 2 ]\texttt{gap> RD:=ResidualBlockDesign(D,6);
rec( isBlockDesign := true, v := 10,
blocks := [ [ 1, 2, 3, 4, 5 ], [ 1, 2, 8, 9, 10 ], [ 1, 4, 6, 7, 9 ],
[ 2, 5, 6, 7, 8 ], [ 3, 4, 7, 8, 10 ], [ 3, 5, 6, 9, 10 ]],
pointNames := [ 1, 2, 3, 4, 5, 7, 8, 9, 10, 11 ])
\texttt{gap> AllTDesignLambdas(RD);
[ 6, 3 ]\texttt{gap> RD:=ResidualBlockDesign(D,D.blocks[6]);
rec( isBlockDesign := true, v := 6,
blocks := [ [ 1, 2, 3 ], [ 1, 2, 4 ], [ 1, 3, 6 ], [ 1, 4, 5 ],
[ 1, 5, 6 ], [ 2, 3, 5 ], [ 2, 4, 6 ], [ 2, 5, 6 ], [ 3, 4, 5 ],
[ 3, 4, 6 ]], pointNames := [ 1, 4, 5, 7, 9, 11 ])
\texttt{gap> AllTDesignLambdas(RD);
[ 10, 5, 2 ]}

13▶ \texttt{TDesignFromTBD( D, t, k )}

For \( t \) a non-negative integer, \( K \) a set of positive integers, and \( v, \lambda \) positive integers with \( t \leq v \), a \( t \)-\textit{wise balanced design}, or a \( t-(v,K,\lambda) \) design, is a binary block design with exactly \( v \) points, such that each block has size in \( K \) and each \( t \)-subset of the points is contained in exactly \( \lambda \) blocks.

Now let \( t \) and \( k \) be positive integers, \( D \) be a \( t-(v,K,\lambda) \) design (for some set \( K \)), and \( t \leq k \leq k_1 \), where exactly \( s \) distinct block-sizes \( k_1 < \cdots < k_s \) occur in \( D \). Then this function returns the \( t \)-design \( D^* = D^*(t,k) \) described and studied in [MS07].

The point set of \( D^* \) is that of \( D \), and the block multiset of \( D^* \) consists of, for each \( i = 1, \ldots, s \) and each block \( B \) of \( D \) of size \( k_i \) (including repeats), exactly \( n/(k_i^{-t}) \) copies of every \( k_i \)-subset of \( B \), where \( n := \text{lcm}(k_i^{-t}) : 1 \leq i \leq s \).

It is shown in [MS07] that \( D^* \) is a \( t-(v,k,n\lambda) \) design, that \( \text{Aut}(D) \subseteq \text{Aut}(D^*) \), and that if \( \lambda = 1 \) and \( t < k \), then \( \text{Aut}(D) = \text{Aut}(D^*) \).

\texttt{gap> D:=BlockDesigns(rec(v:=10, blockSizes:=[3,4],
> tSubsetStructure:=rec(t:=2,lambdas:=[1])))[1];
rec( isBlockDesign := true, v := 10,
blocks := [ [ 1, 2, 3, 4 ], [ 1, 5, 6, 7 ], [ 1, 8, 9, 10 ], [ 2, 5, 10 ],
[ 2, 6, 8 ], [ 2, 7, 9 ], [ 3, 5, 9 ], [ 3, 6, 10 ], [ 3, 7, 8 ],
[ 4, 5, 8 ], [ 4, 6, 9 ], [ 4, 7, 10 ]],
tSubsetStructure := rec( t := 2, lambdas := [ 1 ] ), isBinary := true,
isSimple := true, blockSizes := [ 3, 4 ], blockNumbers := [ 9, 3 ],
autGroup := Group([ (5,6,7)(8,9,10), (2,3)(5,7)(8,10),
(2,3,4)(5,7,6)(8,9,10), (2,3,4)(5,9,6,8,7,10), (2,6,9,3,7,10)(4,5,8) ]) )
Chapter 3. Constructing block designs

gap> PairwiseBalancedLambda(D);
1
gap> Dstar:=TDesignFromTBD(D,2,3);

rec( isBlockDesign := true, v := 10,
    blocks := [ [ 1, 2, 3 ], [ 1, 2, 4 ], [ 1, 3, 4 ], [ 1, 5, 6 ],
                [ 1, 5, 7 ], [ 1, 6, 7 ], [ 1, 8, 9 ], [ 1, 8, 10 ], [ 1, 9, 10 ],
                [ 2, 3, 4 ], [ 2, 5, 10 ], [ 2, 5, 10 ], [ 2, 6, 8 ], [ 2, 6, 8 ],
                [ 2, 7, 9 ], [ 2, 7, 9 ], [ 3, 5, 9 ], [ 3, 5, 9 ], [ 3, 6, 10 ],
                [ 3, 6, 10 ], [ 3, 7, 8 ], [ 3, 7, 8 ], [ 4, 5, 8 ], [ 4, 5, 8 ],
                [ 4, 6, 9 ], [ 4, 6, 9 ], [ 4, 7, 10 ], [ 4, 7, 10 ], [ 5, 6, 7 ],
                [ 8, 9, 10 ] ],
    autGroup := Group([ (5,6,7)(8,9,10), (2,3)(5,7)(8,10), (2,3,4)(5,7,6)(8,9,10), (2,3,4)(5,9,6,8,7,10), (2,6,9,3,7,10)(4,5,8) ] )

)
4 Determining basic properties of block designs

4.1 The functions for basic properties

1 ▶ IsBlockDesign( obj )
   This boolean function returns true if and only if obj, which can be an object of arbitrary type, is a block design.
   gap> IsBlockDesign(5);
   false
   gap> IsBlockDesign( BlockDesign(2,[[1],[1,2],[1,2]])) ;
   true

2 ▶ IsBinaryBlockDesign( D )
   This boolean function returns true if and only if the block design D is binary, that is, if no block of D has a repeated element.
   gap> IsBinaryBlockDesign( BlockDesign(2,[[1],[1,2],[1,2]])) ;
   true
   gap> IsBinaryBlockDesign( BlockDesign(2,[[1],[1,2],[1,2,2]])) ;
   false

3 ▶ IsSimpleBlockDesign( D )
   This boolean function returns true if and only if the block design D is simple, that is, if no block of D is repeated.
   gap> IsSimpleBlockDesign( BlockDesign(2,[[1],[1,2],[1,2]])) ;
   false
   gap> IsSimpleBlockDesign( BlockDesign(2,[[1],[1,2],[1,2,2]])) ;
   true

4 ▶ IsConnectedBlockDesign( D )
   This boolean function returns true if and only if the block design D is connected, that is, if its incidence graph is a connected graph.
   gap> IsConnectedBlockDesign( BlockDesign(2,[[1],[2]])) ;
   false
   gap> IsConnectedBlockDesign( BlockDesign(2,[[1,2]])) ;
   true

5 ▶ BlockDesignPoints( D )
   This function returns the set of points of the block design D, that is [1..D.v]. The returned result is immutable.
Chapter 4. Determining basic properties of block designs

\begin{verbatim}
gap> D := BlockDesign(3,[[1,2],[1,3],[2,3],[2,3]]);
rec(isBlockDesign := true, v := 3,
   blocks := [ [ 1, 2 ], [ 1, 3 ], [ 2, 3 ], [ 2, 3 ] ])
gap> BlockDesignPoints(D);
[ 1 .. 3 ]

 NrBlockDesignPoints( D )

This function returns the number of points of the block design \textit{D}.

\begin{verbatim}
gap> D := BlockDesign(3,[[1,2],[1,3],[2,3],[2,3]]);
rec(isBlockDesign := true, v := 3,
   blocks := [ [ 1, 2 ], [ 1, 3 ], [ 2, 3 ], [ 2, 3 ] ])
gap> BlockDesignBlocks(D);
[ [ 1, 2 ], [ 1, 3 ], [ 2, 3 ], [ 2, 3 ] ]

 NrBlockDesignBlocks( D )

This function returns the (sorted) list of blocks of the block design \textit{D}. The returned result is immutable.

\begin{verbatim}
gap> D := BlockDesign(3,[[1,2],[1,3],[2,3],[2,3]]);
rec(isBlockDesign := true, v := 3,
   blocks := [ [ 1, 2 ], [ 1, 3 ], [ 2, 3 ], [ 2, 3 ] ])
gap> BlockSizes(D);
[ 1, 3 ]
gap> BlockNumbers(D);
[ 3, 2 ]

 BlockSizes( D )

This function returns the set of sizes (actually list-lengths) of the blocks of the block design \textit{D}.

\begin{verbatim}
 gap> D := BlockDesign(3,[[1,2],[1,3],[2,3],[2,3]]);
 rec( isBlockDesign := true, v := 3,
       blocks := [ [ 1, 2 ], [ 1, 3 ], [ 2, 3 ], [ 2, 3 ] ] )
 gap> BlockNumbers(D);
[ 1, 3 ]

 BlockNumbers( D )

Let \textit{D} be a block design. Then this function returns a list of the same length as \textit{BlockSizes(D)}, such that the \(i\)-th element of this returned list is the number of blocks of \textit{D} of size \textit{BlockSizes(D)}[\(i\)].

\begin{verbatim}
 gap> D := BlockDesign(3,[[1,2],[1,2,2],[1,2,3],[2],[3]]);
 rec( isBlockDesign := true, v := 3,
       blocks := [ [ 1 ], [ 1, 2, 2 ], [ 1, 2, 3 ], [ 2 ], [ 3 ] ] )
 gap> BlockSizes(D);
[ 1, 3 ]
 gap> BlockNumbers(D);
[ 3, 2 ]

 ReplicationNumber( D )

If the block design \textit{D} is equireplicate, then this function returns its replication number; otherwise \textit{fail} is returned.
\end{verbatim}
\end{verbatim}
Section 1. The functions for basic properties

A block design $D$ is **equireplicate** with replication number $r$ if, for every point $x$ of $D$, $r$ is equal to the sum over the blocks of the multiplicity of $x$ in a block. For a binary block design this is the same as saying that each point $x$ is contained in exactly $r$ blocks.

```gap
gap> ReplicationNumber(BlockDesign(4,[[1],[1,2],[2,3],[4,4]]));
2
gap> ReplicationNumber(BlockDesign(4,[[1],[1,2],[2,3],[4,4]]));
fail
```

**PairwiseBalancedLambda** ($D$)

A binary block design $D$ is **pairwise balanced** if $D$ has at least two points and every pair of distinct points is contained in exactly $\lambda$ blocks, for some positive constant $\lambda$.

Given a binary block design $D$, this function returns `fail` if $D$ is not pairwise balanced, and otherwise the positive constant $\lambda$ such that every pair of distinct points of $D$ is in exactly $\lambda$ blocks.

```gap
gap> D:=BlockDesigns(rec(v:=10, blockSizes:=[3,4],
> tSubsetStructure:=rec(t:=2,lambdas:=[1])))[1];
rec( isBlockDesign := true, v := 10,
blocks := [ [ 1, 2, 3, 4 ], [ 1, 5, 6, 7 ], [ 1, 8, 9, 10 ], [ 2, 5, 10 ],
[ 2, 6, 8 ], [ 2, 7, 9 ], [ 3, 5, 9 ], [ 3, 6, 10 ], [ 3, 7, 8 ],
[ 4, 5, 8 ], [ 4, 6, 9 ], [ 4, 7, 10 ] ],
tSubsetStructure := rec( t := 2, lambdas := [ 1 ] ), isBinary := true,
isSimple := true, blockSizes := [ 3, 4 ], blockNumbers := [ 9, 3 ],
autGroup := Group([ (5,6,7)(8,9,10), (2,3)(5,7)(8,10),
(2,3,4)(5,7,6)(8,9,10), (2,3,4)(5,9,6,8,7,10), (2,6,9,3,7,10)(4,5,8) ]) )

gap> PairwiseBalancedLambda(D);
1
```

**TSubsetLambdasVector** ($D$, $t$)

Let $D$ be a block design, $t$ a non-negative integer, and $v=D.v$. Then this function returns an integer vector $L$ whose positions correspond to the $t$-subsets of $\{1, \ldots, v\}$. The $i$-th element of $L$ is the sum over all blocks $B$ of $D$ of the number of times the $i$-th $t$-subset (in lexicographic order) is contained in $B$. (For example, if $t=2$ and $B = [1,2,3,4]$, then $B$ contains $[1,2]$ twice, $[1,3]$ four times, $[1,4]$ twice, $[2,3]$ twice, $[2,4]$ once, and $[3,4]$ twice.) In particular, if $D$ is binary then $L[i]$ is simply the number of blocks of $D$ containing the $i$-th $t$-subset (in lexicographic order).

```gap
gap> D:=BlockDesign(3,[[1],[1,2],[1,2,3],[2],[3]]);
gap> TSubsetLambdasVector(D,0);
[ 5 ]
gap> TSubsetLambdasVector(D,1);
[ 3, 4, 2 ]
gap> TSubsetLambdasVector(D,2);
[ 3, 1, 1 ]
gap> TSubsetLambdasVector(D,3);
[ 1 ]
```

**AllTDesignLambdas** ($D$)

If the block design $D$ is not a $t$-design for some $t \geq 0$ then this function returns an empty list. Otherwise $D$ is a binary block design with constant block size $k$, say, and this function returns a list $L$ of length $T+1$, where $T$ is the maximum $t \leq k$ such that $D$ is a $t$-design, and, for $i = 1, \ldots, T+1$, $L[i]$ is equal to the (constant) number of blocks of $D$ containing an $(i-1)$-subset of the point-set of $D$. The returned result is immutable.

```gap
gap> AllTDesignLambdas(D);
```

12 ▶ PairwiseBalancedLambda( D )

13 ▶ TSubsetLambdasVector( D, t )

14 ▶ AllTDesignLambdas( D )
A block design is **affine resolvable** if the design is resolvable and any two blocks not in the same parallel class of a resolution meet in a constant number $\mu$ of points.

If the block design $D$ is affine resolvable, then this function returns its value of $\mu$; otherwise fail is returned.

The value 0 is returned if, and only if, $D$ consists of a single parallel class.
In this chapter we describe functions to calculate certain matrices associated with a block design, and the function `BlockDesignEfficiency` which determines certain statistical efficiency measures of a 1-design.

We also document the utility function `DESIGN_IntervalForLeastRealZero`, which is used in the calculation of E-efficiency measures, but has much wider application.

### 5.1 Matrices associated with a block design

1. **PointBlockIncidenceMatrix( D )**

   This function returns the point-block incidence matrix $N$ of the block design $D$. This matrix has rows indexed by the points of $D$ and columns by the blocks of $D$, with the $(i,j)$-entry of $N$ being the number of times point $i$ occurs in block $j$.

   The returned matrix $N$ is immutable.

   ```
   gap> D:=DualBlockDesign(AGPointFlatBlockDesign(2,3,1));;
   gap> BlockDesignBlocks(D);
   [ [ 1, 2, 3, 4 ], [ 1, 5, 6, 7 ], [ 1, 8, 9, 10 ], [ 2, 5, 8, 11 ],
   [ 2, 7, 9, 12 ], [ 3, 5, 10, 12 ], [ 3, 6, 9, 11 ], [ 4, 6, 8, 12 ],
   [ 4, 7, 10, 11 ] ]
   gap> PointBlockIncidenceMatrix(D);
   [ [ 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
   [ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ] ]
   ```

2. **ConcurrenceMatrix( D )**

   This function returns the concurrence matrix $L$ of the block design $D$. This matrix is equal to $NN^T$, where $N$ is the point-block incidence matrix of $D$ (see 5.1.1) and $N^T$ is the transpose of $N$. If $D$ is a binary block design then the $(i,j)$-entry of its concurrence matrix is the number of blocks containing points $i$ and $j$.

   The returned matrix $L$ is immutable.
Chapter 5. Matrices and efficiency measures for block designs

gap> D:=DualBlockDesign(AGPointFlatBlockDesign(2,3,1));;

ConcurrenceMatrix(D);

This function returns the information matrix $C$ of the block design $D$.

This matrix is defined as follows. Suppose $D$ has $v$ points and $b$ blocks, let $R$ be the $v \times v$ diagonal matrix whose $(i,i)$-entry is the replication number of the point $i$, let $N$ be the point-block incidence matrix of $D$ (see 5.1.1), and let $K$ be the $b \times b$ diagonal matrix whose $(j,j)$-entry is the length of $D.blocks[j]$. Then the information matrix of $D$ is $C := R - NK^{-1}N^T$. If $D$ is a $1-(v,k,r)$ design then this expression for $C$ simplifies to $rI - k^{-1}L$, where $I$ is the $v \times v$ identity matrix and $L$ is the concurrence matrix of $D$ (see 5.1.2).

The returned matrix $C$ is immutable.

InformationMatrix(D);

3 ▶ InformationMatrix(D)

This function returns the information matrix $C$ of the block design $D$.

This matrix is defined as follows. Suppose $D$ has $v$ points and $b$ blocks, let $R$ be the $v \times v$ diagonal matrix whose $(i,i)$-entry is the replication number of the point $i$, let $N$ be the point-block incidence matrix of $D$ (see 5.1.1), and let $K$ be the $b \times b$ diagonal matrix whose $(j,j)$-entry is the length of $D.blocks[j]$. Then the information matrix of $D$ is $C := R - NK^{-1}N^T$. If $D$ is a $1-(v,k,r)$ design then this expression for $C$ simplifies to $rI - k^{-1}L$, where $I$ is the $v \times v$ identity matrix and $L$ is the concurrence matrix of $D$ (see 5.1.2).

The returned matrix $C$ is immutable.
5.2 The function BlockDesignEfficiency

Let $D$ be a $1-(v, k, r)$ design with $v > 1$, let $eps$ be a positive rational number (default: $10^{-6}$), and let $includeMV$ be a boolean (default: false). Then this function returns a record $eff$ containing information on statistical efficiency measures of $D$. These measures are defined below. See [CDMS04], [BC09] and [BR97] for further details. All returned results are computed using exact algebraic computation.

The component $eff$.A contains the A-efficiency measure for $D$. $eff$.Dpowered contains the D-efficiency measure of $D$ raised to the power $v - 1$, and $eff$.Einterval is a list $[a, b]$ of non-negative rational numbers such that if $x$ is the E-efficiency measure of $D$ then $a \leq x \leq b$, $b - a \leq eps$, and if $x$ is rational then $a = x = b$. Moreover $eff$.CEFpolynomial contains the monic polynomial over the rationals whose zeros (counting multiplicities) are the canonical efficiency factors of the design $D$. If $includeMV$=true then additional work is done to compute the MV- (also called E' )-efficiency measure, and then $eff$.MV contains the value of this measure. (This component may be set even if $includeMV$=false, as a byproduct of other computation.)

We now define the canonical efficiency factors and the A-, D-, E-, and MV-efficiency measures of a 1-design.

Let $D$ be a $1-(v, k, r)$ design with $v \geq 2$, let $C$ be the information matrix of $D$ (see 5.1.3), and let $F := r^{-1}C$. The eigenvalues of $F$ are all real and lie in the interval $[0, 1]$. At least one of these eigenvalues is zero: an associated eigenvector is the all-1 vector. The remaining eigenvalues $\delta_1 \leq \delta_2 \leq \cdots \leq \delta_{v-1}$ of $F$ are called the canonical efficiency factors of $D$. These are all non-zero if and only if $D$ is connected (that is, the point-block incidence graph of $D$ is a connected graph).

If $D$ is not connected, then the A-, D-, E-, and MV-efficiency measures of $D$ are all defined to be zero. Otherwise, the A-efficiency measure is $(v - 1)/\sum_{i=1}^{v-1} 1/\delta_i$ (the harmonic mean of the canonical efficiency factors), the D-efficiency measure is $\prod_{i=1}^{v-1} \delta_i^{1/(v-1)}$ (the geometric mean of the canonical efficiency factors), and the E-efficiency measure is $\delta_1$ (the minimum of the canonical efficiency factors).

If $D$ is connected, and the MV-efficiency measure is required, then it is computed as follows. Let $F := r^{-1}C$ be as before, and let $P := v^{-1}J$, where $J$ is the $v \times v$ all-1 matrix. Set $M := (F + P)^{-1} - P$, making $M$ the “Moore-Penrose inverse” of $F$ (see [BC09]). Then the MV-efficiency measure of $D$ is the minimum value (over all $i, j \in \{1, \ldots, v\}$, $i \neq j$) of $2/(M_{ii} + M_{jj} - M_{ij} - M_{ji})$.

```gap
D := DualBlockDesign(AGPointFlatBlockDesign(2,3,1));
BlockDesignEfficiency(D);
```

```plaintext
rec(A := 33/41,
CEFpolynomial := x_1^11+9*x_1^10+147/4*x_1^9+18723/128*x_1^7+106797/512*x_1^6-
47/64*x_1^5+159813/2048*x_1^4+2067201/65536*x_1^3-556227/65536,
Efficiency := 6561/65536,
Einterval := [ 3/4, 3/4 ], MV := 3/4 )
```

5.3 Computing an interval for a certain real zero of a rational polynomial

We document a DESIGN package utility function used in the calculation of the $E_{\text{interval}}$ component above, but is more widely applicable.

```plaintext
DESIGN_IntervalForLeastRealZero( f, a, b, eps )
```

Suppose that $f$ is a univariate polynomial over the rationals, $a, b$ are rational numbers with $a \leq b$, and $eps$ is a positive rational number.

If $f$ has no real zero in the closed interval $[a, b]$, then this function returns the empty list. Otherwise, let $\alpha$ be the least real zero of $f$ such that $a \leq \alpha \leq b$. Then this function returns a list $[c, d]$ of rational numbers, with $c \leq \alpha \leq d$ and $d - c \leq eps$. Moreover, $c = d$ if and only if $\alpha$ is rational (in which case $\alpha = c = d$).

```plaintext
gap> x:=Indeterminate(Rationals,1);
x_1

gap> f:=(x+3)*(x^2-3);
x_1^3+3*x_1^2-3*x_1-9

gap> L:=DESIGN_IntervalForLeastRealZero(f,-5,5,10^(-3));
[ -3, -3 ]

gap> L:=DESIGN_IntervalForLeastRealZero(f,-2,5,10^(-3));
[ -14193/8192, -7093/4096 ]

gap> List(L,Float);
[ -1.73254, -1.73169 ]

gap> L:=DESIGN_IntervalForLeastRealZero(f,0,5,10^(-3));
[ 14185/8192, 7095/4096 ]

gap> List(L,Float);
[ 1.73157, 1.73218 ]

gap> L:=DESIGN_IntervalForLeastRealZero(f,0,5,10^(-5));
[ 454045/262144, 908095/524288 ]

gap> List(L,Float);
[ 1.73204, 1.73205 ]

gap> L:=DESIGN_IntervalForLeastRealZero(f,2,5,10^(-5));
[ ]
```
6 Automorphism groups and isomorphism testing for block designs

The functions in this chapter depend on *nauty* [McK90], [MP14] or *bliss* [JK07] via the GRAPE package, which must be fully installed in order for these functions to work.

### 6.1 Computing automorphism groups

This function returns the automorphism group of the block design $D$. The automorphism group $\text{Aut}(D)$ of $D$ is the group consisting of all the permutations of the points $\{1, \ldots, D.v\}$ which preserve the block-multiset of $D$.

This function is not yet implemented for non-binary block designs.

This function can also be called via `AutomorphismGroup(D)`.

```
gap> D:=PGPointFlatBlockDesign(2,3,1);; # projective plane of order 3
gap> Size(AutGroupBlockDesign(D));
5616
```

### 6.2 Testing isomorphism

This boolean function returns true if and only if block designs $D1$ and $D2$ are isomorphic, that is, there is a bijection from the point-set of $D1$ to that of $D2$ which maps the block-multiset of $D1$ to that of $D2$.

This function is not yet implemented for non-binary block designs.

For pairwise isomorphism testing for three or more binary block designs, see 6.2.2.

```
gap> D1:=BlockDesign(3,[[1],[1,2,3],[2]]);;
gap> D2:=BlockDesign(3,[[1],[1,2,3],[3]]);;
gap> IsIsomorphicBlockDesign(D1,D2); true
gap> D3:=BlockDesign(4,[[1],[1,2,3],[3]]);;
gap> IsIsomorphicBlockDesign(D2,D3); false
```

# block designs with different numbers of points are not isomorphic
Chapter 6. Automorphism groups and isomorphism testing for block designs

BlockDesignIsomorphismClassRepresentatives(L)

Given a list \( L \) of binary block designs, this function returns a list consisting of pairwise non-isomorphic elements of \( L \), representing all the isomorphism classes of elements of \( L \). The order of the elements in the returned list may differ from their order in \( L \).

\[
\text{gap> } D1:=\text{BlockDesign}(3,[[1],[1,2,3],[2]]);;
\text{gap> } D2:=\text{BlockDesign}(3,[[1],[1,2,3],[3]]);;
\text{gap> } D3:=\text{BlockDesign}(4,[[1],[1,2,3],[3]]);;
\text{gap> } \text{BlockDesignIsomorphismClassRepresentatives([D1,D2,D3]);}
\]

\[
[\text{rec( isBlockDesign := true, v := 4, blocks := [ [ 1 ], [ 1, 2, 3 ], [ 3 ] ],}
\text{ isBinary := true ),}
\text{ rec( isBlockDesign := true, v := 3, blocks := [ [ 1 ], [ 1, 2, 3 ], [ 2 ] ],}
\text{ isBinary := true ) }]
\]
Classifying block designs

This chapter describes the function `BlockDesigns` which can classify block designs with given properties. The possible properties a user can specify are many and varied, and are described below. Depending on the properties, this function can handle block designs with up to about 20 points (sometimes more and sometimes less, depending on the problem).

### 7.1 The function `BlockDesigns`

```plaintext
BlockDesigns( param )
```

This function returns a list `DL` of block designs whose properties are specified by the user in the record `param`. The precise interpretation of the output depends on `param`, described below. Only binary designs are generated by this function, if `param.blockDesign` is unbound or is a binary design.

The required components of `param` are `v`, `blockSizes`, and `tSubsetStructure`. `param.v` must be a positive integer, and specifies that for each block design in the list `DL`, the points are 1,...,`param.v`. `param.blockSizes` must be a set of positive integers, and specifies that the block sizes of each block design in `DL` will be contained in `param.blockSizes`. `param.tSubsetStructure` must be a record, having components `t`, `partition`, and `lambdas`. Let `t` be equal to `param.tSubsetStructure.t`, `partition` be `param.tSubsetStructure.partition`, and `lambdas` be `param.tSubsetStructure.lambdas`. Then `t` must be a non-negative integer, `partition` must be a list of non-empty sets of `t`-subsets of `[1..param.v]`, forming an ordered partition of all the `t`-subsets of `[1..param.v]`, and `lambdas` must be a list of distinct non-negative integers (not all zero) of the same length as `partition`. This specifies that for each design in `DL`, each `t`-subset in `partition[i]` will occur exactly `lambdas[i]` times, counted over all blocks of the design. For binary designs, this means that each `t`-subset in `partition[i]` is contained in exactly `lambdas[i]` blocks. The partition component is optional if `lambdas` has length 1. We require that `t` is less than or equal to each element of `param.blockSizes`, and `param.blockDesign` must contain at least `t` distinct elements. We require that `param.tSubsetStructure` is equal to `rec(t:=0,lambdas:=[b])`, for some positive integer `b`, then all that is being specified is that each design in `DL` must have exactly `b` blocks.

The optional components of `param` are used to specify additional constraints on the designs in `DL` or to change default parameter values. These optional components are `blockDesign`, `r`, `b`, `blockNumbers`, `blockIntersectionNumbers`, `blockMaxMultiplicities`, `isoGroup`, `requiredAutSubgroup`, and `isoLevel`. `param.blockDesign` must be a block design with `param.blockDesign.v` equal to `param.v`. Then each block multiset of a design in `DL` will be a submultiset of `param.blockDesign.blocks` (that is, each block of a design `D` in `DL` will be a block of `param.blockDesign`, and the multiplicity of a block of `D` will be less than or equal to that block’s multiplicity in `param.blockDesign`). The `blockDesign` component is useful for the computation of subdesigns, such as parallel classes.

`param.r` must be a positive integer, and specifies that in each design in `DL`, each point will occur exactly `param.r` times in the list of blocks. In other words, each design in `DL` will have replication number `param.r`.

`param.b` must be a positive integer, and specifies that each design in `DL` will have exactly `param.b` blocks.
param.blockNumbers must be a list of non-negative integers, the \(i\)-th element of which specifies the number of blocks whose size is equal to \(\text{param.blockSizes}[i]\) (for each design in DL). The length of \(\text{param.blockNumbers}\) must equal that of \(\text{param.blockSizes}\), and at least one entry of \(\text{param.blockNumbers}\) must be positive.

\(\text{param.blockIntersectionNumbers}\) must be a symmetric matrix of sets of non-negative integers, the \([i][j]\)-element of which specifies the set of possible sizes for the intersection of a block \(B\) of size \(\text{param.blockSizes}[i]\) with a different block (but possibly a repeat of \(B\)) of size \(\text{param.blockSizes}[j]\) (for each design in DL). In the case of multisets, we take the multiplicity of an element in the intersection to be the minimum of its multiplicities in the multisets being intersected; for example, the intersection of \([1,1,2,2,3]\) with \([1,1,2,2,2,4]\) is \([1,1,2,2]\), having size 4. The dimension of \(\text{param.blockIntersectionNumbers}\) must equal the length of \(\text{param.blockSizes}\).

\(\text{param.blockMaxMultiplicities}\) must be a list of non-negative integers, the \(i\)-th element of which specifies an upper bound on the multiplicity of a block whose size is equal to \(\text{param.blockSizes}[i]\) (for each design in DL). The length of \(\text{param.blockMaxMultiplicities}\) must equal that of \(\text{param.blockSizes}\).

Let \(G\) be the automorphism group of \(\text{param.blockDesign}\) if bound, and \(G\) be \(\text{SymmetricGroup}(\text{param.v})\) otherwise. Let \(H\) be the subgroup of \(G\) stabilizing \(\text{param.tSubsetStructure.partition}\) (as an ordered list of sets of sets) if bound, and \(H\) be equal to \(G\) otherwise.

\(\text{param.isoGroup}\) must be a subgroup of \(H\), and specifies that we consider two designs with the required properties to be equivalent if their block multisets are in the same orbit of \(\text{param.isoGroup}\) (in its action on multisets of multisets of \([1..\text{param.v}]\)). The default for \(\text{param.isoGroup}\) is \(H\). Thus, if \(\text{param.blockDesign}\) and \(\text{param.isoGroup}\) are both unbound, equivalence is the same as block-design isomorphism for the required designs.

\(\text{param.requiredAutSubgroup}\) must be a subgroup of \(\text{param.isoGroup}\), and specifies that each design in DL must be invariant under \(\text{param.requiredAutSubgroup}\) (in its action on multisets of multisets of \([1..\text{param.v}]\)). The default for \(\text{param.requiredAutSubgroup}\) is the trivial permutation group.

\(\text{param.isoLevel}\) must be 0, 1, or 2 (the default is 2). The value 0 specifies that DL will contain at most one block design, and will contain one block design with the required properties if and only if such a block design exists; the value 1 specifies that DL will contain (perhaps properly) a list of \(\text{param.isoGroup}\)-orbit representatives of the required designs; the value 2 specifies that DL will consist precisely of \(\text{param.isoGroup}\)-orbit representatives of the required designs.

For an example, we classify up to isomorphism the 2-(15,3,1) designs invariant under a semi-regular group of automorphisms of order 5, and then classify all parallel classes of these designs, up to the action of the automorphism groups of these designs.

```gap
gap> DL:=BlockDesigns(rec(
> v:=15,blockSizes:=[3],
> tSubsetStructure:=rec(t:=2,lambdas:=[1]),
> requiredAutSubgroup:=
> Group((1,2,3,4,5)(6,7,8,9,10)(11,12,13,14,15))));;
gap> List(DL,AllTDesignLambdas);
[ [ 35, 7, 1 ], [ 35, 7, 1 ], [ 35, 7, 1 ] ]
gap> List(DL,D->Size(AutGroupBlockDesign(D)));
[ 20160, 5, 60 ]
gap> parclasses:=List(DL,D->
> BlockDesigns(rec(
> blockDesign:=D,
> v:=15,blockSizes:=[3],
> tSubsetStructure:=rec(t:=1,lambdas:=[1]))));
[ [ rec( isBlockDesign := true, v := 15,
blocks := [ [ 1, 2, 6 ], [ 3, 4, 8 ], [ 5, 7, 14 ], [ 9, 12, 15 ],
[ 10, 11, 13 ]],
tSubsetStructure := rec( t := 1, lambdas := [ 1 ]),
isBinary := true, isSimple := true, blockSizes := [ 3 ],]...]```
blockNumbers := [ 5 ], r := 1,
autSubgroup := Group([ (2,6)(3,11)(4,10)(5,14)(8,13)(12,15),
  (2,6)(4,8)(5,12)(7,9)(10,13)(14,15),
  (2,6)(3,12)(4,9)(7,14)(8,15)(11,13),
  (3,12,5)(4,15,7)(8,9,14)(10,11,13),
  (1,6,2)(3,4,8)(5,7,14)(9,12,15)(10,11,13),
  (1,8,11,2,3,10)(4,13,6)(5,15,14,9,7,12) ] ),
rec( isBlockDesign := true, v := 15,
  blocks := [ [ 1, 7, 12 ], [ 2, 8, 13 ], [ 3, 9, 14 ],
    [ 4, 10, 15 ], [ 5, 6, 11 ] ],
tSubsetStructure := rec( t := 1, lambdas := [ 1 ] ),
isBinary := true, isSimple := true, blockSizes := [ 3 ],
blockNumbers := [ 5 ], r := 1,
autSubgroup := Group([ (1,5,4,3,2)(6,10,9,8,7)(11,15,14,13,12) ] ),
rec( isBlockDesign := true, v := 15, blocks := [ [ 1, 2, 6 ], [ 3, 10, 13 ],
  [ 4, 11, 12 ], [ 5, 7, 15 ], [ 8, 9, 14 ] ],
tSubsetStructure := rec( t := 1, lambdas := [ 1 ] ),
isBinary := true, isSimple := true, blockSizes := [ 3 ],
blockNumbers := [ 5 ], r := 1,
autSubgroup := Group([ (1,2)(3,5)(7,10)(8,9)(11,12)(13,15),
  (1,11,8)(2,12,9)(3,13,10)(4,14,6)(5,15,7) ] ),
rec( isBlockDesign := true, v := 15,
  blocks := [ [ 1, 8, 11 ], [ 2, 9, 12 ], [ 3, 10, 13 ],
    [ 4, 6, 14 ], [ 5, 7, 15 ] ],
tSubsetStructure := rec( t := 1, lambdas := [ 1 ] ),
isBinary := true, isSimple := true, blockSizes := [ 3 ],
blockNumbers := [ 5 ], r := 1,
autSubgroup := Group([ (1,2)(3,5)(7,10)(8,9)(11,12)(13,15),
  (1,3,4,2)(6,9,8,10)(11,13,14,12),
  (1,3,5,2,4)(6,8,10,7,9)(11,13,15,12,14),
  (1,11,8)(2,12,9)(3,13,10)(4,14,6)(5,15,7) ] ) ] }]
gap> List(parclasses,Length); [ 1, 1, 2 ]
gap> List(parclasses,L->List(L,parclass->Size(parclass.autSubgroup))); [ [ 360 ], [ 5 ], [ 6, 60 ] ]
This chapter describes the function \texttt{SemiLatinSquareDuals} which can classify semi-Latin squares with certain given properties, and return a list of their duals as block designs.

\subsection*{8.1 Semi-Latin squares and SOMAs}

Let \( n \) and \( k \) be positive integers. An \((n \times n)/k\) semi-Latin square is an \(n\times n\) array \(A\), whose entries are \(k\)-subsets of a \(kn\)-set \(X\) (the symbol-set), such that each element of \(X\) occurs exactly once in each row and exactly once in each column of \(A\). (Thus an \((n \times n)/1\) semi-Latin square is the same thing as a Latin square of order \(n\).) For extensive useful information on semi-Latin squares, see
\[ \text{http://www.maths.qmul.ac.uk/~rab/sls.html} \]

A SOMA\((k,n)\) is an \((n \times n)/k\) semi-Latin square \(A\), with \(n \geq 2\), in which no \(2\)-subset of the symbol-set is contained in more than one entry of \(A\). For extensive useful information on SOMAs, see
\[ \text{http://www.maths.qmul.ac.uk/~lsoicher/soma/} \]

Let \(A\) and \(B\) be \((n \times n)/k\) semi-Latin squares. We say that \(B\) is (weakly) isomorphic to \(A\) if \(B\) can be obtained from \(A\) by applying one or more of: a row permutation; a column permutation; transposing; renaming the symbols. If transposing is not allowed then we get the concept of strong isomorphism. More formally, \(B\) is strongly isomorphic to \(A\) if \(B\) can be obtained from \(A\) by applying one or more of: a row permutation; a column permutation; renaming the symbols.

Let \(A\) be an \((n \times n)/k\) semi-Latin square. Then the dual of \(A\) can be represented as a binary block design as follows. The point-set of \(D\) is taken to be the Cartesian square of \(\{1, \ldots, n\}\), with \([x, y]\) representing the \([x, y]\)-entry of \(A\). The blocks of \(D\) are in one-to-one correspondance with the symbols of \(A\), with the \(i\)-th block of \(D\) consisting of the ordered pairs \([x, y]\) such that the \(i\)-th symbol of \(A\) is contained in the \([x, y]\)-entry of \(A\). Given \(D\), the semi-Latin square \(A\) can be recovered, up to the naming of its symbols.

\subsection*{8.2 The function \texttt{SemiLatinSquareDuals}}

\begin{verbatim}
>> SemiLatinSquareDuals( n, k )
>> SemiLatinSquareDuals( n, k, maxmult )
>> SemiLatinSquareDuals( n, k, maxmult, blockintsizes )
>> SemiLatinSquareDuals( n, k, maxmult, blockintsizes, isolevel )
\end{verbatim}

Let \(n\) and \(k\) be positive integers. Then this function (which makes heavy use of the function \texttt{BlockDesigns}) returns a list \(DL\) of block designs which are the duals of the \((n \times n)/k\) semi-Latin squares whose properties are specified by the given parameters, described below. In practice, depending on the specified properties, this function can be useful for \(n\) up to about 6 or 7.

The parameter \texttt{maxmult}, if given, must be a positive integer or the string "default". If it is a positive integer, then \texttt{maxmult} specifies an upper bound on the multiplicity of each block in each semi-Latin square dual in \(DL\). The default value for \texttt{maxmult} (if omitted or if given as "default") is \(k\), which poses no constraint on the block multiplicities.

The parameter \texttt{blockintsizes}, if given, must be a set of non-negative integers or the string "default". If it is given as a set, then \texttt{blockintsizes} specifies, for each semi-Latin square dual in \(DL\), the set of possible sizes for the intersection of a block \(B\) with a different block (but possibly a repeat of \(B\)). The default value for \texttt{blockintsizes} (if omitted or if given
Section 2. The function SemiLatinSquareDuals

as "default") is \([0..n]\), which poses no constraint on the block intersection sizes. Note that block intersection sizes in the dual of a semi-Latin square correspond to concurrences of points in the semi-Latin square itself. Also note that if \(n \geq 2\) and blockintsizes is specified to be \([0,1]\) then the \((n \times n)/k\) semi-Latin squares being considered are SOMA\((k,n)\).

The parameter isolevel, if given, must be 0, 1, 2, 3, 4 or the string "default" (the default value is 2). The value 0 specifies that \(DL\) will contain at most one (semi-Latin square dual given as a) block design, and will contain one such block design if and only if a semi-Latin square with the required properties exists. The value 1 specifies that \(DL\) will contain a list of duals representing all weak isomorphism classes of semi-Latin squares with the required properties (possibly with some classes represented more than once) and the value 2 specifies that \(DL\) will contain precisely one dual semi-Latin square representative for each weak isomorphism class of semi-Latin squares with the required properties. The values 3 and 4 for isolevel play the roles of 1 and 2, respectively, but with weak isomorphism replaced by strong isomorphism. Thus, isolevel = 3 specifies that \(DL\) will contain a list of duals representing all strong isomorphism classes of semi-Latin squares with the required properties (possibly with some classes represented more than once) and isolevel = 4 specifies that \(DL\) will contain precisely one dual semi-Latin square representative for each strong isomorphism class of semi-Latin squares with the required properties.

For example, we determine the numbers of weak and strong isomorphism classes of \((4 \times 4)/k\) semi-Latin squares for \(k = 1,\ldots, 6\). (These numbers disagree with P. E. Chigbu’s classification for the cases \(k = 3,4\) [BC97].)

```gap
gap> List([1..6],k->Length(SemiLatinSquareDuals(4,k))); # weak
[ 2, 10, 40, 164, 621, 2298 ]
gap> List([1..6],k->Length(SemiLatinSquareDuals(4,k,"default","default",4))); # strong
[ 2, 11, 46, 201, 829, 3343 ]
```

Next, we determine one SOMA\((3,6)\).

```gap
gap> SemiLatinSquareDuals(6,3,"default",[0,1],0);
[ rec( isBlockDesign := true, v := 36,
  blocks := [ [ 1, 8, 15, 22, 29, 36 ], [ 1, 9, 16, 23, 30, 32 ],
    [ 1, 12, 14, 21, 28, 35 ], [ 2, 9, 17, 24, 25, 34 ],
    [ 2, 11, 18, 27, 31 ], [ 2, 12, 16, 19, 29, 33 ],
    [ 3, 10, 14, 24, 29, 31 ], [ 3, 11, 16, 20, 25, 36 ],
    [ 3, 12, 13, 26, 34 ], [ 4, 7, 14, 23, 27, 36 ],
    [ 4, 8, 17, 21, 30, 31 ], [ 4, 9, 18, 19, 26, 35 ],
    [ 5, 7, 15, 20, 30, 34 ], [ 5, 8, 13, 24, 28, 33 ],
    [ 5, 10, 18, 21, 25, 32 ], [ 6, 7, 17, 22, 26, 33 ],
    [ 6, 10, 13, 20, 27, 35 ], [ 6, 11, 15, 19, 28, 32 ],
  ],
  tSubsetStructure := rec( t := 1, lambdas := [ 3 ] ), isBinary := true,
  isSimple := true, blockSizes := [ 6 ], blockNumbers := [ 18 ], r := 3,
  autSubGroup := <permutation group of size 72 with 3 generators>,
  pointNames := [ [ 1, 1 ], [ 1, 2 ], [ 1, 3 ], [ 1, 4 ], [ 1, 5 ],
    [ 1, 6 ], [ 2, 1 ], [ 2, 2 ], [ 2, 3 ], [ 2, 4 ], [ 2, 5 ],
    [ 2, 6 ], [ 3, 1 ], [ 3, 2 ], [ 3, 3 ], [ 3, 4 ], [ 3, 5 ],
    [ 3, 6 ], [ 4, 1 ], [ 4, 2 ], [ 4, 3 ], [ 4, 4 ], [ 4, 5 ],
    [ 4, 6 ], [ 5, 1 ], [ 5, 2 ], [ 5, 3 ], [ 5, 4 ], [ 5, 5 ],
    [ 5, 6 ], [ 6, 1 ], [ 6, 2 ], [ 6, 3 ], [ 6, 4 ], [ 6, 5 ],
    [ 6, 6 ] ] ) ]
```
9 Partitioning block designs

This chapter describes the function `PartitionsIntoBlockDesigns` which can classify partitions of (the block multiset of) a given block design into (the block multisets of) block designs having user-specified properties. We also describe `MakeResolutionsComponent` which is useful for the special case when the desired partitions are resolutions.

9.1 Partitioning a block design into block designs

```plaintext
PartitionsIntoBlockDesigns(param)
```

Let $D$ equal `param.blockDesign`. This function returns a list $PL$ of partitions of (the block multiset of) $D$. Each element of $PL$ is a record with one component `partition`, and, in most cases, a component `autGroup`. The `partition` component gives a list $P$ of block designs, all with the same point set as $D$, such that the list of (the block multisets of) the designs in $P.partition$ forms a partition of (the block multiset of) $D$. The component `P.autGroup`, if bound, gives the automorphism group of the partition, which is the stabilizer of the partition in the automorphism group of $D$. The precise interpretation of the output depends on `param`, described below.

The required components of `param` are `blockDesign`, `v`, `blockSizes`, and `tSubsetStructure`. `param.blockDesign` is the block design to be partitioned. `param.v` must be a positive integer, and specifies that for each block design in each partition in $PL$, the points are $1,...,param.v$. It is required that $param.v$ be equal to $param.blockDesign.v$.

`param.blockSizes` must be a set of positive integers, and specifies that the block sizes of each block design in each partition in $PL$ will be contained in `param.blockSizes`.

`param.tSubsetStructure` must be a record, having components `t`, `partition`, and `lambdas`. Let $t$ be equal to `param.tSubsetStructure.t`, `partition` be `param.tSubsetStructure.partition`, and `lambdas` be `param.tSubsetStructure.lambdas`. Then $t$ must be a non-negative integer, `partition` must be a list of non-empty sets of $t$-subsets of $[1..param.v]$, forming an ordered partition of all the $t$-subsets of $[1..param.v]$, and `lambdas` must be a list of distinct non-negative integers (not all zero) of the same length as `partition`. This specifies that for each design in each partition in $PL$, each $t$-subset in `partition[i]` will occur exactly `lambdas[i]` times, counted over all blocks of the design. For binary designs, this means that each $t$-subset in `partition[i]` is contained in exactly `lambdas[i]` blocks. The `partition` component is optional if `lambdas` has length 1. We require that $t$ is less than or equal to each element of `param.blockSizes`, and that each block of `param.blockDesign` contains at least $t$ distinct elements.

The optional components of `param` are used to specify additional constraints on the partitions in $PL$, or to change default parameter values. These optional components are `r`, `b`, `blockNumbers`, `blockIntersectionNumbers`, `blockMaxMultiplicities`, `isoGroup`, `requiredAutSubgroup`, and `isoLevel`. Note that the last three of these optional components refer to the partitions and not to the block designs in a partition.

`param.r` must be a positive integer, and specifies that in each design in each partition in $PL$, each point must occur exactly `param.r` times in the list of blocks.

`param.b` must be a positive integer, and specifies that each design in each partition in $PL$ has exactly `param.b` blocks.

`param.blockNumbers` must be a list of non-negative integers, the $i$-th element of which specifies the number of blocks whose size is equal to `param.blockSizes[i]` (in each design in each partition in $PL$). The length of `param.blockNumbers` must equal that of `param.blockSizes`, and at least one entry of `param.blockNumbers` must be positive.
param.blockIntersectionNumbers must be a symmetric matrix of sets of non-negative integers, the \( [i][j]\)-element of which specifies the set of possible sizes for the intersection of a block \( B \) of size \( param.blockSizes[i] \) with a different block (but possibly a repeat of \( B \)) of size \( param.blockSizes[j] \) (in each design in each partition in \( PL \)). In the case of multisets, we take the multiplicity of an element in the intersection to be the minimum of its multiplicities in the multisets being intersected: for example, the intersection of \([1,1,1,2,2,3]\) with \([1,1,2,2,2,4]\) is \([1,1,2,2]\), having size 4. The dimension of \( param.blockIntersectionNumbers \) must equal the length of \( param.blockSizes \).

\( param.blockMaxMultiplicities \) must be a list of non-negative integers, the \( i \)-th element of which specifies an upper bound on the multiplicity of a block whose size is equal to \( param.blockSizes[i] \) (for each design in each partition in \( PL \)). The length of \( param.blockMaxMultiplicities \) must equal that of \( param.blockSizes \).

\( param.isoGroup \) must be a subgroup of the automorphism group of \( param.blockDesign \). We consider two elements of \( PL \) to be equivalent if they are in the same orbit of \( param.isoGroup \) (in its action on multisets of block multisets). The default for \( param.isoGroup \) is the automorphism group of \( param.blockDesign \).

\( param.requiredAutSubgroup \) must be a subgroup of \( param.isoGroup \), and specifies that each partition in \( PL \) must be invariant under \( param.requiredAutSubgroup \) (in its action on multisets of block multisets). The default for \( param.requiredAutSubgroup \) is the trivial permutation group.

\( param.isoLevel \) must be 0, 1, or 2 (the default is 2). The value 0 specifies that \( PL \) will contain at most one partition, and will contain one partition with the required properties if and only if such a partition exists; the value 1 specifies that \( PL \) will contain (perhaps properly) a list of \( param.isoGroup \) orbit-representatives of the required partitions; the value 2 specifies that \( PL \) will consist precisely of \( param.isoGroup \)-orbit representatives of the required partitions.

For an example, we first classify up to isomorphism the 2-(15,3,1) designs invariant under a semi-regular group of automorphisms of order 5, and then use PartitionsIntoBlockDesigns to classify all the resolutions of these designs, up to the actions of the respective automorphism groups of the designs.

```gap
gap> DL:=BlockDesigns(rec(  > v:=15,blockSizes:=[3],  > tSubsetStructure:=rec(t:=2,lambdas:=[1]),  > requiredAutSubgroup:=  > Group((1,2,3,4,5)(6,7,8,9,10)(11,12,13,14,15))));
gap> List(DL,D->Size(AutGroupBlockDesign(D)));
[ 20160, 5, 60 ]
gap> PL:=PartitionsIntoBlockDesigns(rec(  > blockDesign:=DL[1],  > v:=15,blockSizes:=[3],  > tSubsetStructure:=rec(t:=1,lambdas:=[1])));
[ rec(  > partition := [ rec( isBlockDesign := true, v := 15, blocks := [ [ 1, 2, 6 ], [ 3, 4, 8 ], [ 5, 7, 14 ], [ 9, 12, 15 ], [ 10, 11, 13 ] ] ),
  > rec( isBlockDesign := true, v := 15, blocks := [ [ 1, 3, 11 ], [ 2, 4, 12 ], [ 5, 6, 8 ], [ 7, 13, 15 ], [ 9, 10, 14 ] ] ),
  > rec( isBlockDesign := true, v := 15, blocks := [ [ 1, 4, 14 ], [ 2, 5, 15 ], [ 3, 10, 12 ], [ 6, 7, 11 ], [ 8, 9, 13 ] ] ),
  > rec( isBlockDesign := true, v := 15, blocks := [ [ 1, 5, 10 ], [ 2, 9, 11 ], [ 3, 14, 15 ], [ 4, 6, 13 ], [ 7, 8, 12 ] ] ),
  > rec( isBlockDesign := true, v := 15, blocks := [ [ 1, 7, 9 ], [ 2, 8, 10 ], [ 3, 5, 13 ], [ 4, 11, 15 ], [ 6, 12, 14 ] ] ) )
```
Chapter 9. Partitioning block designs

rec( isBlockDesign := true, v := 15, blocks :=
   [ [ 1, 8, 15 ], [ 2, 13, 14 ], [ 3, 6, 9 ], [ 4, 7, 10 ],
    [ 5, 11, 12 ] ] ),
rec( isBlockDesign := true, v := 15, blocks :=
   [ [ 1, 12, 13 ], [ 2, 3, 7 ], [ 4, 5, 9 ], [ 6, 10, 15 ],
    [ 8, 11, 14 ] ] ),
autGroup := Group([ (1,10)(2,11)(3,8)(6,13)(7,14)(12,15),
   (1,13)(2,11)(3,14)(4,5)(6,10)(7,8),
   (1,13,7)(2,11,5)(6,10,14)(9,12,15),
   (2,11,5,15,4,9,12)(3,10,8,14,7,13,6) ] ),
rec( partition := [ rec( isBlockDesign := true, v := 15,
     blocks := [ [ 1, 2, 6 ], [ 3, 4, 8 ], [ 5, 7, 14 ],
      [ 9, 12, 15 ] ),
     rec( isBlockDesign := true, v := 15,
      blocks := [ [ 1, 3, 11 ], [ 2, 4, 12 ], [ 5, 6, 8 ],
       [ 7, 9, 10 ] ] ),
     rec( isBlockDesign := true, v := 15,
      blocks := [ [ 1, 4, 14 ], [ 2, 5, 15 ], [ 3, 10, 12 ],
       [ 6, 7, 11 ] ] ),
     rec( isBlockDesign := true, v := 15,
      blocks := [ [ 1, 5, 10 ], [ 2, 13, 14 ], [ 3, 6, 9 ],
       [ 4, 11, 15 ] ] ),
     rec( isBlockDesign := true, v := 15,
      blocks := [ [ 1, 7, 9 ], [ 2, 8, 10 ], [ 3, 14, 15 ],
       [ 4, 6, 13 ] ] ),
     rec( isBlockDesign := true, v := 15,
      blocks := [ [ 1, 8, 15 ], [ 2, 9, 11 ], [ 3, 5, 13 ],
       [ 4, 7, 10 ] ] ),
     rec( isBlockDesign := true, v := 15,
      blocks := [ [ 1, 12, 13 ], [ 2, 3, 7 ], [ 4, 5, 9 ],
       [ 6, 10, 15 ] ] ) ] ),
autGroup := Group([ (1,15)(2,9)(3,4)(5,7)(6,12)(10,13),
   (1,12)(2,9)(3,5)(4,7)(6,15)(8,14),
   (1,14)(2,5)(3,8)(6,7)(9,12)(10,13),
   (1,8,10)(2,5,15)(3,14,13)(4,9,12) ] )
);
gap> List(PL,resolution->Size(resolution.autGroup));
[ 168, 168 ]
gap> PL:=PartitionsIntoBlockDesigns(rec(
   blockDesign:=DL[2],
   v:=15,blockSizes:=[3],
   tSubsetStructure:=rec(t:=1,lambdas:=[1]));
[ ]
gap> PL:=PartitionsIntoBlockDesigns(rec(
   blockDesign:=DL[3],
   v:=15,blockSizes:=[3],
   tSubsetStructure:=rec(t:=1,lambdas:=[1]));
[ ]
9.2 Computing resolutions

- \( \text{MakeResolutionsComponent}( D ) \)
- \( \text{MakeResolutionsComponent}( D, \text{isolevel} ) \)

This function computes resolutions of the block design \( D \), and stores the result in \( D . \text{resolutions} \). If \( D . \text{resolutions} \) already exists then it is ignored and overwritten. This function returns no value.

A resolution of a block design \( D \) is a partition of the blocks into subsets, each of which forms a partition of the point set. We say that two resolutions \( R \) and \( S \) of \( D \) are isomorphic if there is an element \( g \) in the automorphism group of \( D \), such that the \( g \)-image of \( R \) is \( S \). (Isomorphism defines an equivalence relation on the set of resolutions of \( D \).

The parameter \( \text{isolevel} \) (default 2) determines how many resolutions are computed: \( \text{isolevel}=2 \) means to classify up to isomorphism, \( \text{isolevel}=1 \) means to determine at least one representative from each isomorphism class, and \( \text{isolevel}=0 \) means to determine whether or not \( D \) has a resolution.

When this function is finished, \( D . \text{resolutions} \) will have the following three components:

- list: a list of distinct partitions into block designs forming resolutions of \( D \);
- \( \text{pairwiseNonisomorphic} \): true, false or "unknown", depending on the resolutions in list and what is known. If \( \text{isolevel}=0 \) or \( \text{isolevel}=2 \) then this component will be true;
- \( \text{allClassesRepresented} \): true, false or "unknown", depending on the resolutions in list and what is known. If \( \text{isolevel}=1 \) or \( \text{isolevel}=2 \) then this component will be true.

Note that \( D . \text{resolutions} \) may be changed to contain more information as a side-effect of other functions in the DESIGN package.

\[
\text{gap} \gg L := \text{BlockDesigns}(\text{rec}(v:=9,\text{blockSizes}:=[3], > \text{tSubsetStructure}: = \text{rec}(t:=2,\text{lambda}s:=[1])))); \\
\text{gap} \gg D := L[1];; \\
\text{gap} \gg \text{MakeResolutionsComponent}(D); \\
\text{gap} \gg D; \\
\text{rec}( \text{isBlockDesign} := \text{true}, v := 9, \\
\text{blocks} := [[ 1, 2, 3 ], [ 1, 4, 5 ], [ 1, 6, 7 ], [ 1, 8, 9 ], \\
[ 2, 4, 6 ], [ 2, 5, 8 ], [ 2, 7, 9 ], [ 3, 4, 9 ], [ 3, 5, 7 ], \\
[ 3, 6, 8 ], [ 4, 7, 8 ], [ 5, 6, 9 ]], \\
\text{tSubsetStructure} := \text{rec}( t := 2, \text{lambda}s := [ 1 ] ), \text{isBinary} := \text{true}, \\
\text{isSimple} := \text{true}, \text{blockSizes} := [ 3 ], \text{blockNumbers} := [ 12 ], r := 4, \\
\text{autGroup} := \text{Group}( [ (1,2)(5,6)(7,8), (1,3,2)(4,8,7)(5,6,9), (1,2)(4,7)(5,9), \\
(1,2)(4,9)(5,7)(6,8), (1,4,8,6,9,2)(3,5,7) ] ), \\
\text{resolutions} := \text{rec}( \text{list} := [ \text{rec}( \text{partition} := \\
\text{rec}( \text{isBlockDesign} := \text{true}, v := 9, \\
\text{blocks} := [[ 1, 2, 3 ], [ 4, 7, 8 ], [ 5, 6, 9 ] ] ), \\
\text{rec}( \text{isBlockDesign} := \text{true}, v := 9, \\
\text{blocks} := [[ 1, 4, 5 ], [ 2, 7, 9 ], [ 3, 6, 8 ] ] ), \\
\text{rec}( \text{isBlockDesign} := \text{true}, v := 9, \\
\text{blocks} := [[ 1, 6, 7 ], [ 2, 5, 8 ], [ 3, 4, 9 ] ] ), \\
\text{rec}( \text{isBlockDesign} := \text{true}, v := 9, \\
\text{blocks} := [[ 1, 8, 9 ], [ 2, 4, 6 ], [ 3, 5, 7 ] ] ) ], \\
\text{autGroup} := \text{Group}( [ (2,3)(4,5)(6,7)(8,9), (1,3,2)(4,8,7)(5,6,9), \\
(1,8,9)(2,4,6)(3,7,5), (1,2)(5,6)(7,8), (1,2)(4,7)(5,9), \\
(1,2,9,6,8,4)(3,7,5) ] ), \text{pairwiseNonisomorphic} := \text{true}, \\
\text{allClassesRepresented} := \text{true} ) ) \\
\]

This chapter describes functions to write and read lists of binary block designs in the
external representation XML-format (see [CDMS04]).

10.1 Writing lists of block designs and their properties in XML-format

- BlockDesignsToXMLFile( filename, designs )
- BlockDesignsToXMLFile( filename, designs, include )
- BlockDesignsToXMLFile( filename, designs, include, list_id )

This function writes a list of (assumed distinct) binary block designs (given in DESIGN package format) to a file in external representation XML-format (version 2.0).

The parameter filename is a string giving the name of the file, and designs is a record whose component list contains the list of block designs (designs can also be a list, in which case it is replaced by rec(list:=designs)).

The record designs should have the following components:

- list: the list of distinct binary block designs in DESIGN package format;
- pairwiseNonisomorphic (optional): should be true or false or the string "unknown", specifying the pairwise-nonisomorphism status of the designs in designs.list;
- infoXML (optional): should contain a string in XML format for the info element of the list_of_designs which is written.

The combinatorial and group-theoretical properties output for each design depend on include (default: empty list), which should be a list containing zero or more of the strings "indicators", "resolvable", "combinatorial_properties", "automorphism_group", and "resolutions". A shorthand for the list containing all these strings is "all". The strings "indicators", "combinatorial_properties", "automorphism_group", and "resolutions" are used to specify that those subtrees of the external representation of each design are to be expanded and written out. In the case of "resolutions" being in include, all resolutions up to isomorphism will be determined and written out. The string "resolvable" is used to specify that the resolvable indicator must be set (usually this is not forced), if the indicators subtree is written out, and also that if a design is resolvable but "resolutions" is not in include, then one and only one resolution should be written out in the resolutions subtree.

If list_id is given then the id's of the output designs will be list_id-0, list_id-1, list_id-2, ...

```gap
D:=[ BlockDesign(3, [[1,2],[1,3]]),
    BlockDesign(3, [[1,2],[1,2],[2,3]] ) ];
gap> designs:=rec(list:=D, pairwiseNonisomorphic:=true);
gap> BlockDesignsToXMLFile("example.xml",designs,[],"example");
```
10.2 Reading lists of block designs in XML-format

This function reads a file with name *filename*, containing a list of distinct binary block designs in external representation XML-format, and returns a record *designs* in DESIGN package format containing the essential information in this file.

The record *designs* contains the following components:

- **list**: a list of block designs in DESIGN package format of the list of block designs in the file (certain elements such as *statistical_properties* are stored verbatim as strings; certain other elements are not stored since it is usually easier and more reliable to recompute them – this can be done when the block designs are written out in XML format);
- **pairwiseNonisomorphic** is set according to the attribute `pairwise_nonisomorphic` of the XML element *list_of_designs*.
- **infoXML** is bound iff the *info* element occurs as a child of the XML *list_of_designs* element, and if bound, contains this *info* element in a string.

```gap
gap> BlockDesignsFromXMLFile("example.xml");
rec(
    infoXML := "<info>
        <software>
            [ DESIGN-1.7, GRAPE-4.8.2, GAPDoc-1.6.2, GAP-4.10.1 ]
        </software>
    </info>",
    list :=
    [ rec( blocks := [ [ 1, 2 ], [ 1, 3 ] ], id := "example-0",
        isBinary := true, isBlockDesign := true, v := 3 ),
      rec( blocks := [ [ 1, 2 ], [ 1, 2 ], [ 2, 3 ] ], id := "example-1",
        isBinary := true, isBlockDesign := true, v := 3 ) ],
    pairwiseNonisomorphic := true )
```
Bibliography


http://dx.doi.org/10.1016/j.disc.2004.10.027.


http://designtheory.org/library/extrep/.


http://dx.doi.org/10.1112/blms/bdm034.


[McK90] Brendan D. McKay. nauty user’s guide (version 1.5), Technical report TR-CS-90-02. Australian National University, Computer Science Department, 1990. nauty homepage:


http://dx.doi.org/10.1016/j.jcta.2010.03.005.


https://gap-packages.github.io/grape.
This index covers only this manual. A page number in *italics* refers to a whole section which is devoted to the indexed subject. Keywords are sorted with case and spaces ignored, e.g., “PermutationCharacter” comes before “permutation group”.

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