Open CASCADE Technology
7.7.0

Boolean Operations

November 2, 2022

Contents

1 Introduction

Boolean operations are used to create new shapes from the combinations of two groups of shapes. This document provides a comprehensive description of the algorithms in the Boolean Operations Component as it is implemented in Open CASCADE Technology. The Boolean Component contains:

- General Fuse Operator (GFA),
- Boolean Operator (BOA),
- Section Operator (SA),
- Splitter Operator (SPA).

GFA is the base algorithm for BOA, SPA, SA.

GFA has a history-based architecture designed to allow using OCAF naming functionality. The architecture of GFA is expandable, that allows creating new algorithms basing on it.

2 Overview

2.1 Operators

2.1.1 Boolean operator

The Boolean operator provides the following operations between two groups *Objects* and *Tools*:

- FUSE - Union of two groups;
- COMMON - Intersection of two groups;
- CUT - Difference between two groups.

Each group consists of an arbitrary number of arguments in terms of *TopoDS_Shape*.

The operator can be represented as:

$R_B = B_j (G_1, G_2)$,

where:

- R_B – result of the operation;
- B_j – operation of type *j* (Common, Fuse, Cut);
- $G_1 = \{S_{11}, S_{12} \ldots S_{1n1}\}$ group of arguments (Objects);
- $G_2 = \{S_{21}, S_{22} \ldots S_{2n2}\}$ group of arguments (Tools);
- n_1 – Number of arguments in *Objects* group;
- n_2 – Number of arguments in *Tools* group.

Note There is an operation *Cut21*, which is an extension for forward Cut operation, i.e *Cut21=Cut(G2, G1)*.

For more details see Boolean Operations Algorithm section.

2.1.2 General Fuse operator

The General fuse operator can be applied to an arbitrary number of arguments in terms of *TopoDS_Shape*.

The GFA operator can be represented as:

$R_{GF} = GF (S_1, S_2 \ldots S_n)$,

where

- R_{GF} – result of the operation,
- $S_1, S_2 \ldots S_n$ – arguments of the operation,
- n – number of arguments.

The result of the Boolean operator, R_B, can be obtained from R_{GF}.

For example, for two arguments S_1 and S_2 the result R_{GF} is

$R_{GF} = GF (S_1, S_2) = S_{p1} + S_{p2} + S_{p12}$

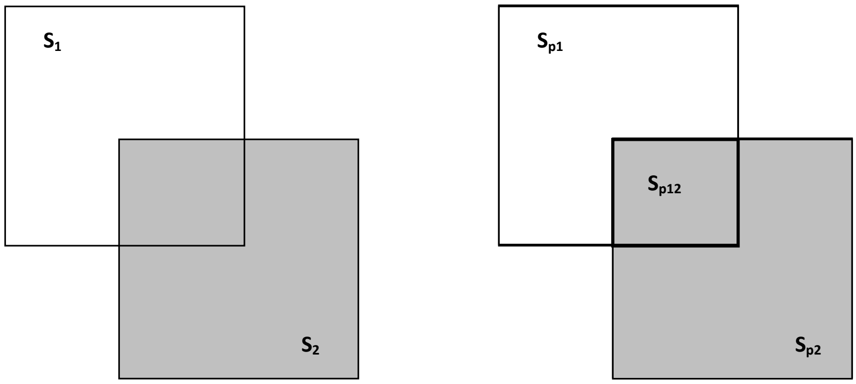


Figure 1: Operators

This Figure shows that

- B_{common} $(S_1, S_2) = S_{p12}$;
- B_{cut12} $(S_1, S_2) = S_{p1}$;
- B_{cut21} $(S_1, S_2) = S_{p2}$;
- B_{fuse} $(S_1, S_2) = S_{p1}+S_{p2}+S_{p12}$

R_{GF}=GF $(S_1, S_2) = B_{fuse} = B_{common}+ B_{cut12}+ B_{cut21}$.

The fact that R_{GF} contains the components of R_B allows considering GFA as the general case of BOA. So it is possible to implement BOA as a subclass of GFA.

For more details see General Fuse Algorithm section.

2.1.3 Splitter operator

The Splitter operator can be applied to an arbitrary number of arguments in terms of *TopoDS_Shape*. The arguments are divided into two groups: *Objects* and *Tools*. The result of *SPA* contains all parts that belong to the *Objects* but does not contain the parts that belong to the *Tools*.

The *SPA* operator can be represented as follows:

R_{SPA}=*SPA* (G_1, G_2), where:

- R_{SPA} – is the result of the operation;
- $G_1=\{S_{11}, S_{12} ... S_{1n1}\}$ group of arguments (*Objects*);
- $G_2=\{S_{21}, S_{22} ... S_{2n2}\}$ group of arguments (*Tools*);
- n_1 – Number of arguments in *Objects* group;
- n_2 – Number of arguments in *Tools* group.

The result R_{SPA} can be obtained from R_{GF} .

For example, for two arguments S_1 and S_2 the result R_{SPA} is

$R_{SPA}=SPA(S_1,S_2)=S_{p1}+S_{p12}$.

In case when all arguments of the *SPA* are *Objects* and there are no *Tools*, the result of *SPA* is equivalent to the result of *GFA*.

For example, when G_1 consists of shapes S_1 and S_2 the result of *SPA* is

R_{SPA}=$SPA(S_1, S_2) = S_{p1} + S_{p2} + S_{p12} = GF(S_1, S_2)$

The fact that the R_{GF} contains the components of R_{SPA} allows considering *GFA* as the general case of *SPA*. Thus, it is possible to implement *SPA* as a subclass of *GFA*.

For more details see Splitter Algorithm section.

2.1.4 Section operator

The Section operator *SA* can be applied to arbitrary number of arguments in terms of *TopoDS_Shape*. The result of *SA* contains vertices and edges in accordance with interferences between the arguments The SA operator can be represented as follows: R_{SA}=*SA(S1, S2... Sn)*, where

- R_{SA} – the operation result;
- *S1, S2 ... Sn* – the operation arguments;
- *n* – the number of arguments.

For more details see Section Algorithm section.

2.2 Parts of algorithms

GFA, BOA, SPA and SA have the same Data Structure (DS). The main goal of the Data Structure is to store all necessary information for input data and intermediate results.

The operators consist of two main parts:

- Intersection Part (IP). The main goal of IP is to compute the interferences between sub-shapes of arguments. The IP uses DS to retrieve input data and store the results of intersections.
- Building Part (BP). The main goal of BP is to build required result of an operation. This part also uses DS to retrieve data and store the results.

As it follows from the definition of operator results, the main differences between GFA, BOA, SPA and SA are in the Building Part. The Intersection Part is the same for the algorithms.

3 Terms and Definitions

This chapter provides the background terms and definitions that are necessary to understand how the algorithms work.

3.1 Interferences

There are two groups of interferences.

At first, each shape having a boundary representation (vertex, edge, face) has an internal value of geometrical tolerance. The shapes interfere with each other in terms of their tolerances. The shapes that have a boundary representation interfere when there is a part of 3D space where the distance between the underlying geometry of shapes is less or equal to the sum of tolerances of the shapes. Three types of shapes: vertex, edge and face – produce six types of **BRep interferences:**

- Vertex/Vertex,
- Vertex/Edge,
- Vertex/Face,
- Edge/Edge,
- Edge/Face and
- Face/Face.

At second, there are interferences that occur between a solid *Z1* and a shape *S2* when *Z1* and *S2* have no BRep interferences but *S2* is completely inside of *Z1*. These interferences are **Non-BRep interferences**. There are four possible cases:

- Vertex/Solid,
- Edge/Solid,
- Face/Solid and
- Solid/Solid.

3.1.1 Vertex/Vertex interference

For two vertices *Vi* and *Vj*, the distance between their corresponding 3D points is less than the sum of their tolerances *Tol(Vi)* and *Tol(Vj)*.

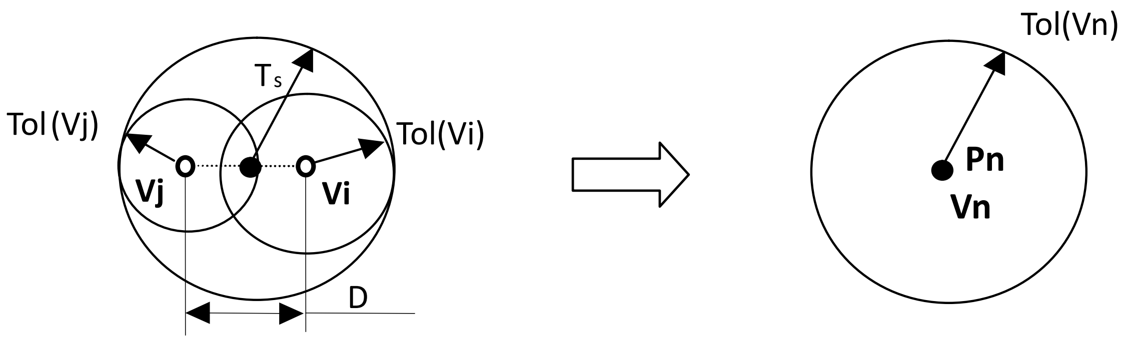


Figure 2: Vertex/vertex interference

The result is a new vertex *Vn* with 3D point *Pn* and tolerance value *Tol(Vn)*.

The coordinates of *Pn* and the value *Tol(Vn)* are computed as the center and the radius of the sphere enclosing the tolerance spheres of the source vertices *(V1, V2)*.

3.1.2 Vertex/Edge interference

For a vertex *Vi* and an edge *Ej*, the distance *D* between 3D point of the vertex and its projection on the 3D curve of edge *Ej* is less or equal than sum of tolerances of vertex *Tol(Vi)* and edge *Tol(Ej)*.

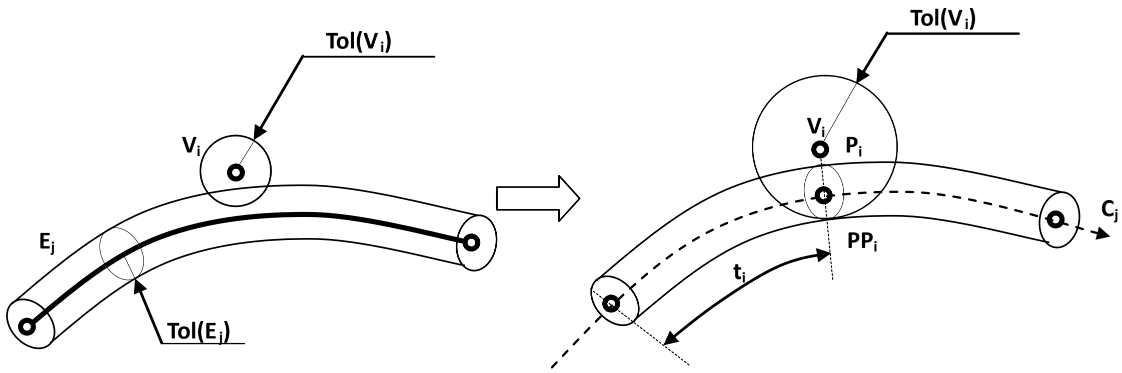


Figure 3: Vertex/edge interference

The result is vertex *Vi* with the corresponding tolerance value *Tol(Vi)=Max(Tol(Vi), D+Tol(Ej))*, where *D = distance (Pi, PPi)*;

and parameter t_i of the projected point *PPi* on 3D curve *Cj* of edge *Ej*.

3.1.3 Vertex/Face interference

For a vertex *Vi* and a face *Fj* the distance *D* between 3D point of the vertex and its projection on the surface of the face is less or equal than sum of tolerances of the vertex *Tol(Vi)* and the face *Tol(Fj)*.

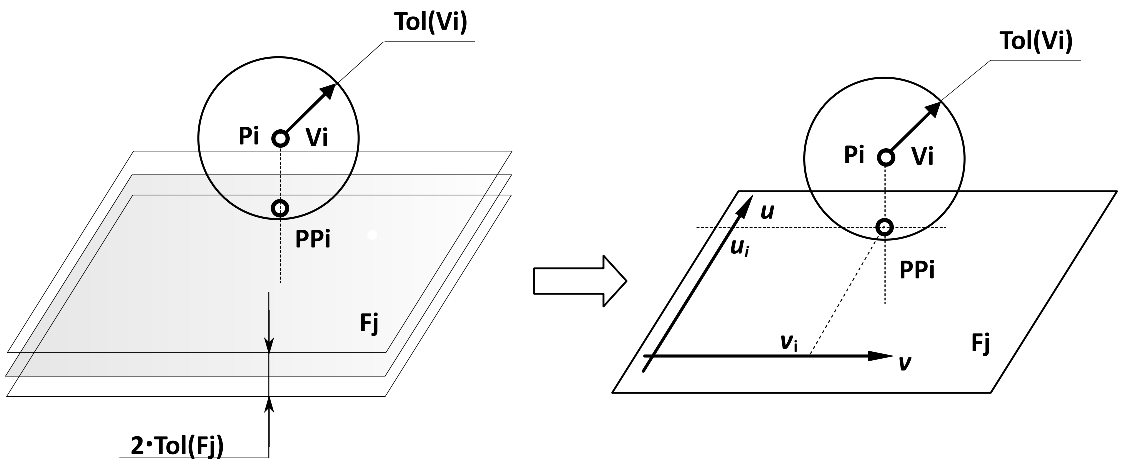


Figure 4: Vertex/face interference

The result is vertex *Vi* with the corresponding tolerance value *Tol(Vi)=Max(Tol(Vi), D+Tol(Fj))*, where *D = distance (Pi, PPi)* and parameters u_i, v_i of the projected point *PPi* on surface *Sj* of face *Fj*.

3.1.4 Edge/Edge interference

For two edges *Ei* and *Ej* (with the corresponding 3D curves *Ci* and *Cj*) there are some places where the distance between the curves is less than (or equal to) sum of tolerances of the edges.

Let us examine two cases:

In the first case two edges have one or several common parts of 3D curves in terms of tolerance.

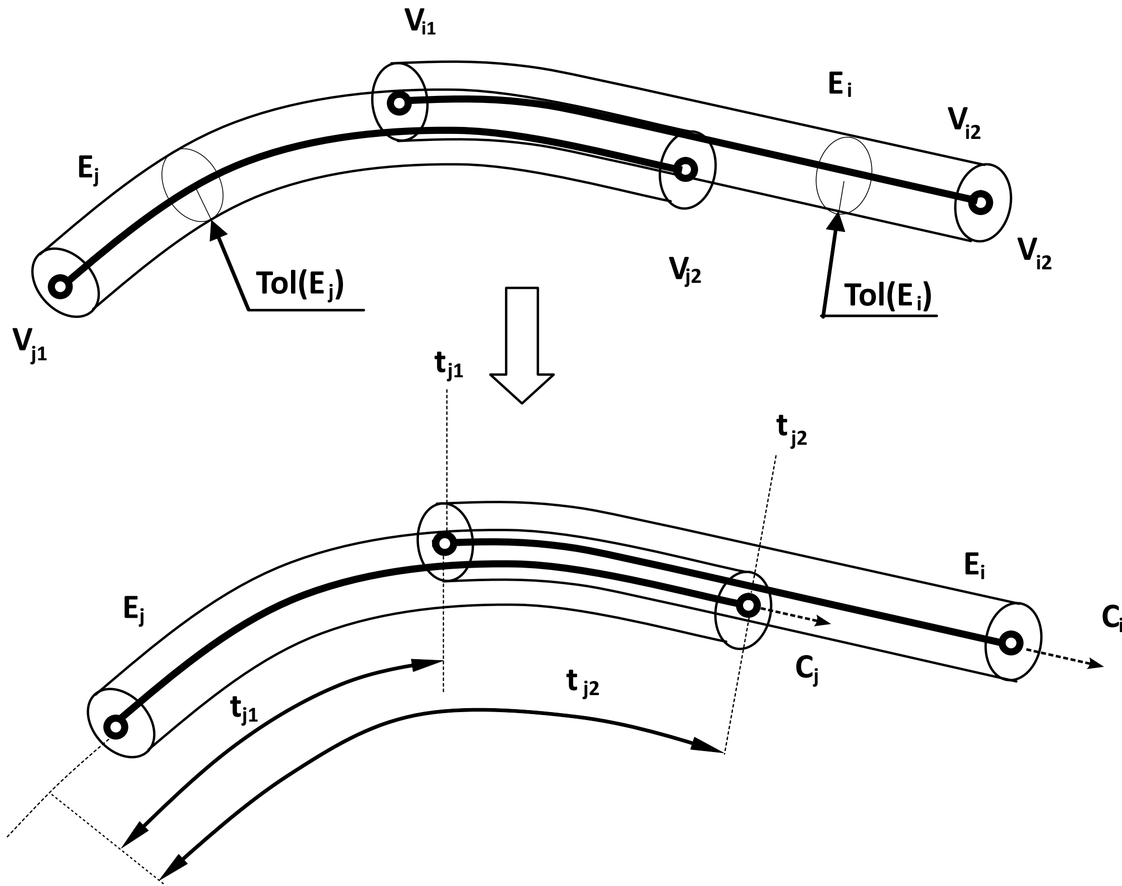


Figure 5: Edge/edge interference: common parts

The results are:

- Parametric range $[t_{i1}, t_{i2}]$ for 3D curve *Ci* of edge *Ei*.
- Parametric range $[t_{j1}, t_{j2}]$ for 3D curve *Cj* of edge *Ej*.

In the second case two edges have one or several common points in terms of tolerance.

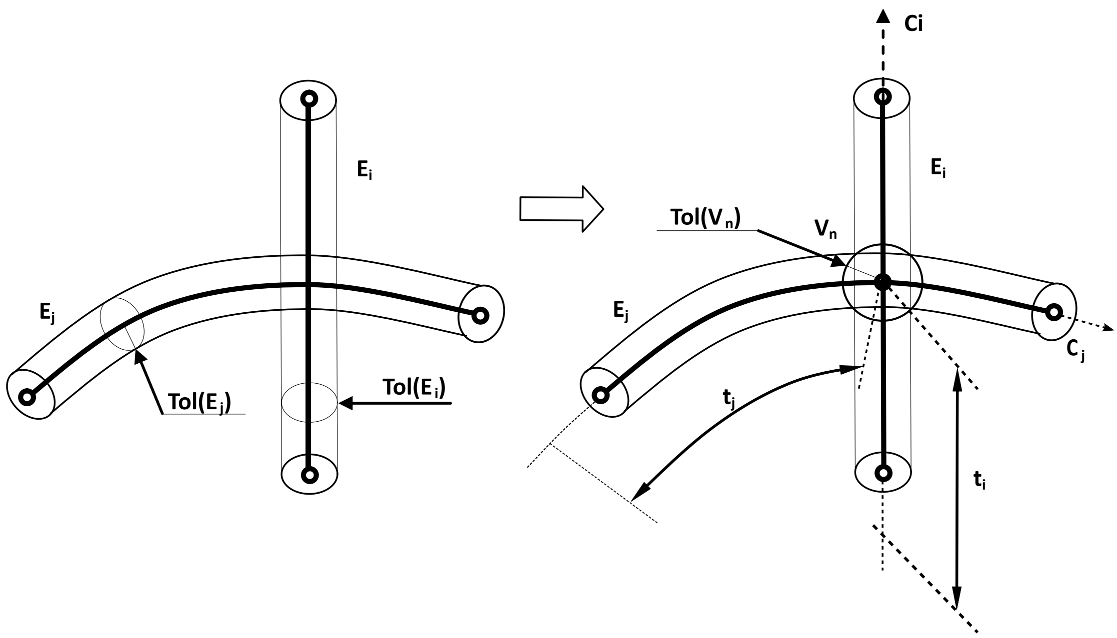


Figure 6: Edge/edge interference: common points

The result is a new vertex *Vn* with 3D point *Pn* and tolerance value *Tol(Vn)*.

The coordinates of *Pn* and the value *Tol(Vn)* are computed as the center and the radius of the sphere enclosing the tolerance spheres of the corresponding nearest points *Pi*, *Pj* of 3D curves *Ci*, *Cj* of source edges *Ei*, *Ej*.

- Parameter t_i of *Pi* for the 3D curve *Ci*.
- Parameter t_j of *Pj* for the 3D curve *Cj*.

3.1.5 Edge/Face interference

For an edge *Ei* (with the corresponding 3D curve *Ci*) and a face *Fj* (with the corresponding 3D surface *Sj*) there are some places in 3D space, where the distance between *Ci* and surface *Sj* is less than (or equal to) the sum of tolerances of edge *Ei* and face *Fj*.

Let us examine two cases:

In the first case Edge *Ei* and Face *Fj* have one or several common parts in terms of tolerance.

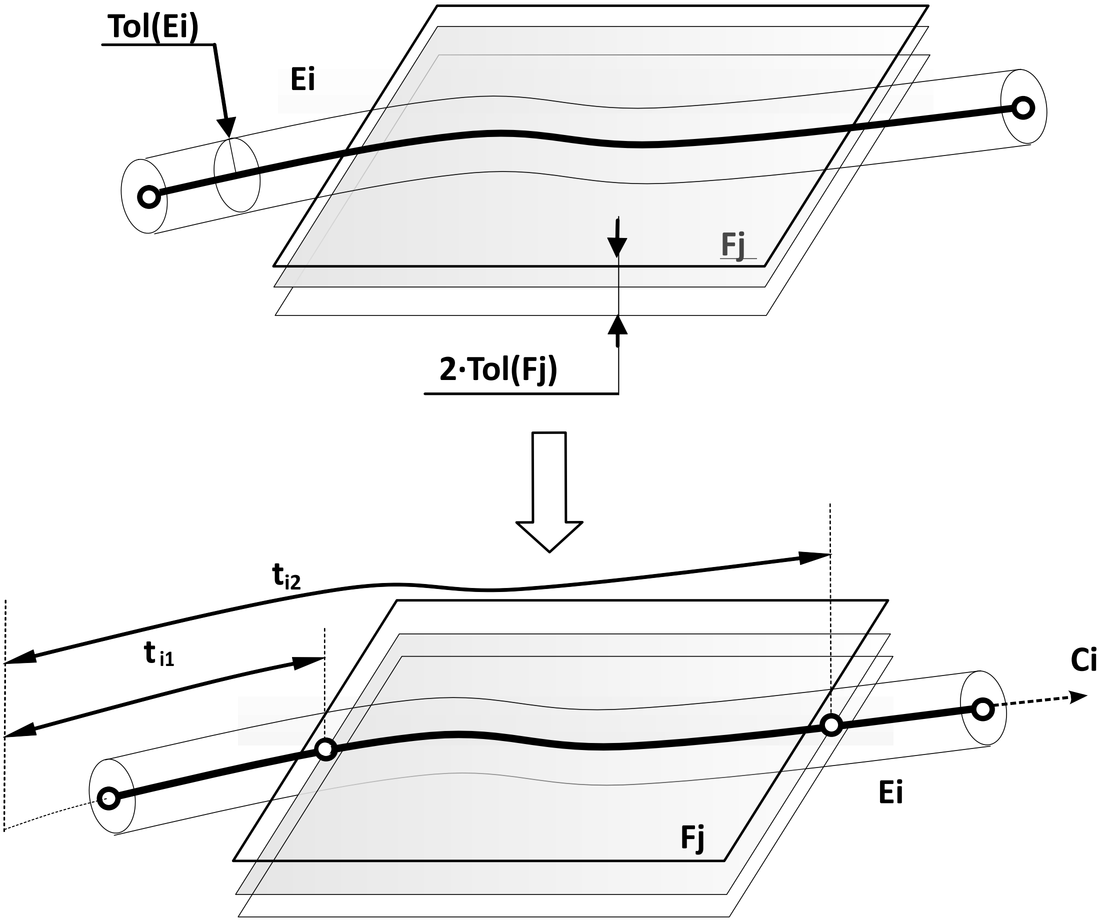


Figure 7: Edge/face interference: common parts

The result is a parametric range *[t_{i1}, t_{i2}]* for the 3D curve *Ci* of the edge *Ei*.

In the second case Edge *Ei* and Face *Fj* have one or several common points in terms of tolerance.

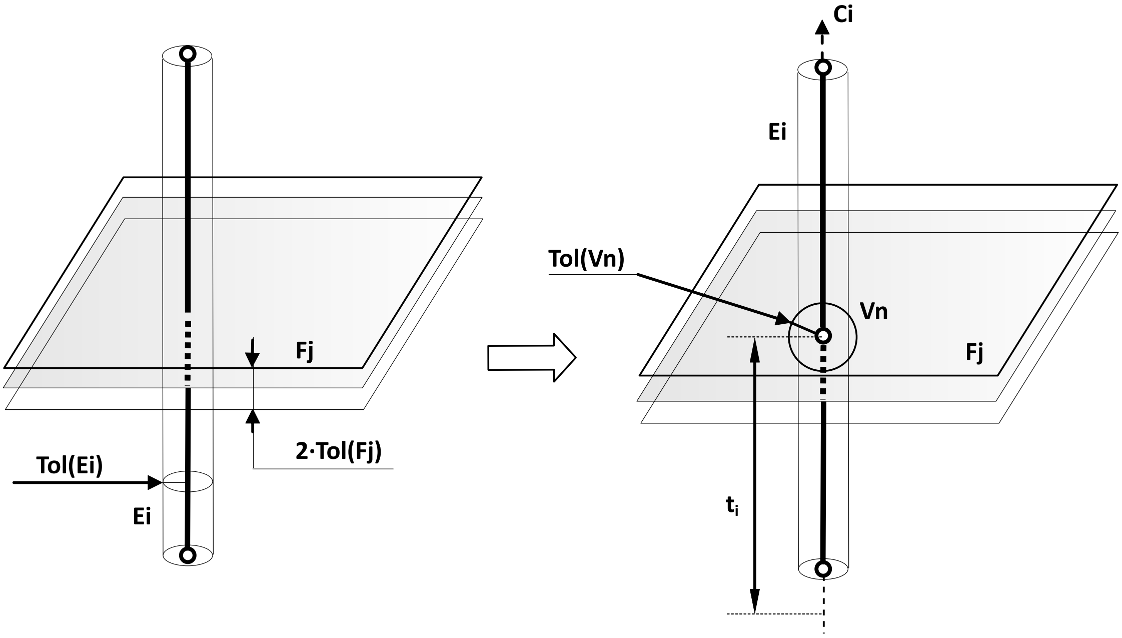


Figure 8: Edge/face interference: common points

The result is a new vertex *Vn* with 3D point *Pn* and tolerance value *Tol(Vn)*.

The coordinates of *Pn* and the value *Tol(Vn)* are computed as the center and the radius of the sphere enclosing the tolerance spheres of the corresponding nearest points *Pi*, *Pj* of 3D curve *Ci* and surface *Sj* of source edges *Ei*, *Fj*.

- Parameter t_i of *Pi* for the 3D curve *Ci*.
- Parameters u_i and v_i of the projected point *PPi* on the surface *Sj* of the face *Fj*.

3.1.6 Face/Face Interference

For a face *Fi* and a face *Fj* (with the corresponding surfaces *Si* and *Sj*) there are some places in 3D space, where the distance between the surfaces is less than (or equal to) sum of tolerances of the faces.

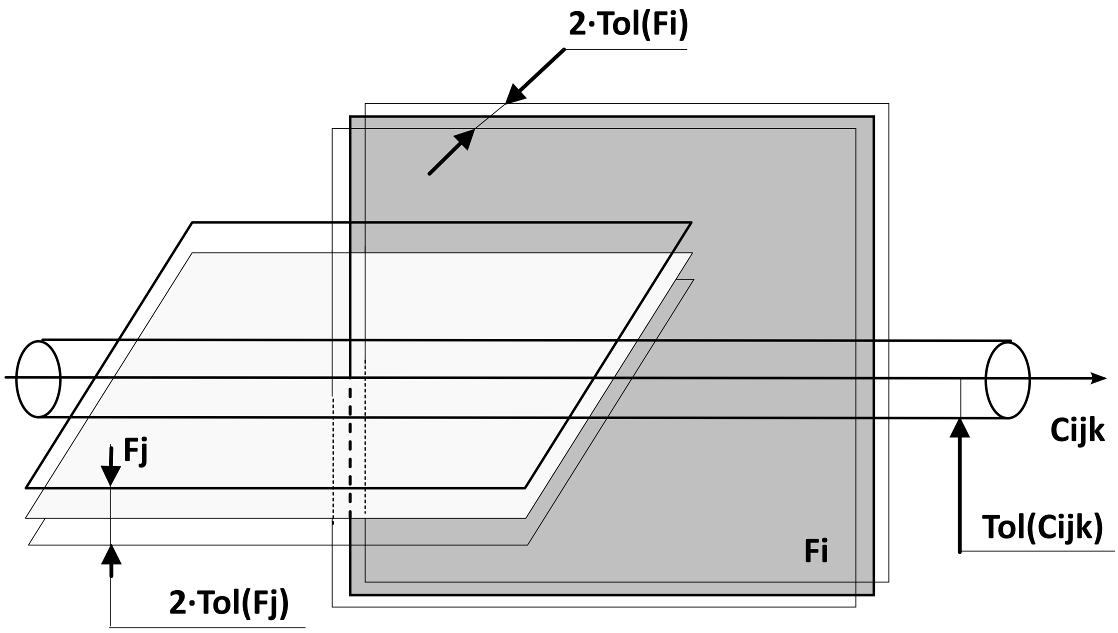


Figure 9: Face/face interference: common curves

In the first case the result contains intersection curves C_{ijk} *(k = 0, 1, 2... k_N,* where k_N is the number of intersection curves with corresponding values of tolerances *Tol(C_{ijk})*.

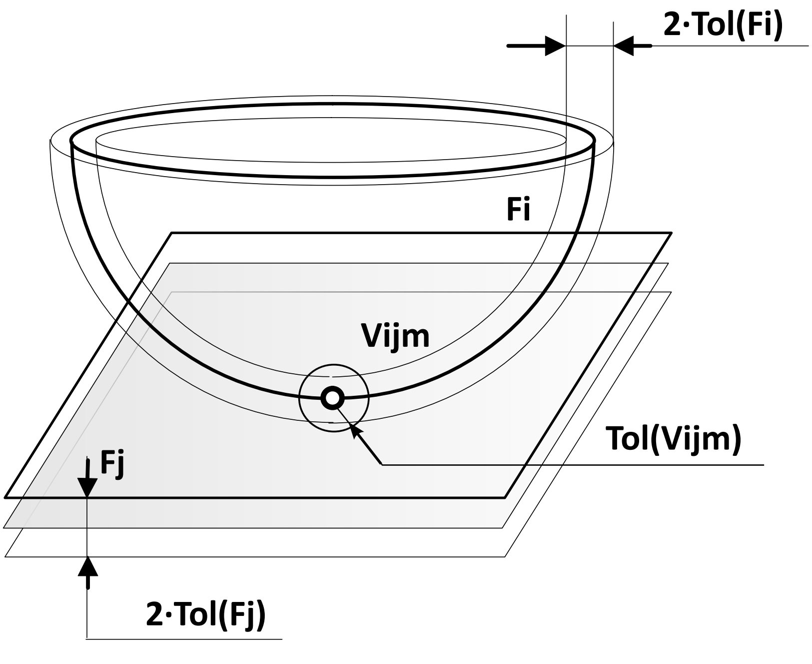


Figure 10: Face/face interference: common points

In the second case Face *Fi* and face *Fj* have one or several new vertices V_{ijm}, where *m=0,1,2, ... mN, mN* is the number of intersection points.

The coordinates of a 3D point P_{ijm} and the value *Tol(V_{ijm})* are computed as the center and the radius of the sphere enclosing the tolerance spheres of the corresponding nearest points *Pi*, *Pj* of the surface *Si*, *Sj* of source shapes *Fi*, *Fj*.

- Parameters u_j, v_j belong to point *PPj* projected on surface *Sj* of face *Fj*.
- Parameters u_i and v_i belong to point *PPi* projected on surface *Si* of face *Fi*.

3.1.7 Vertex/Solid Interference

For a vertex *Vi* and a solid *Zj* there is Vertex/Solid interference if the vertex *Vi* has no BRep interferences with any sub-shape of *Zj* and *Vi* is completely inside the solid *Zj*.

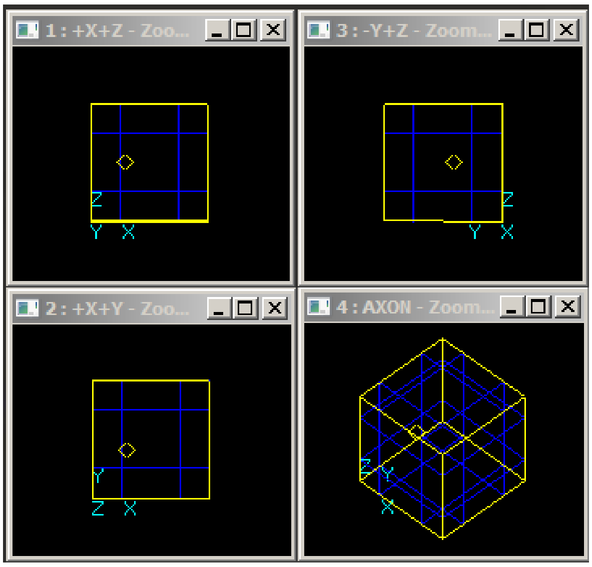


Figure 11: Vertex/Solid Interference

3.1.8 Edge/Soild Interference

For an edge *Ei* and a solid *Zj* there is Edge/Solid interference if the edge *Ei* and its sub-shapes have no BRep interferences with any sub-shape of *Zj* and *Ei* is completely inside the solid *Zj*.

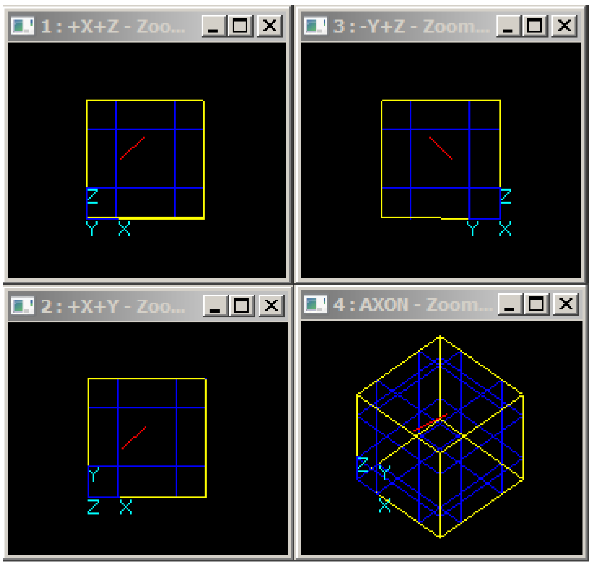


Figure 12: Edge/Solid Interference

3.1.9 Face/Soild Interference

For a face *Fi* and a solid *Zj* there is Face/Solid interference if the face *Fi* and its sub-shapes have no BRep interferences with any sub-shape of *Zj* and *Fi* is completely inside the solid *Zj*.

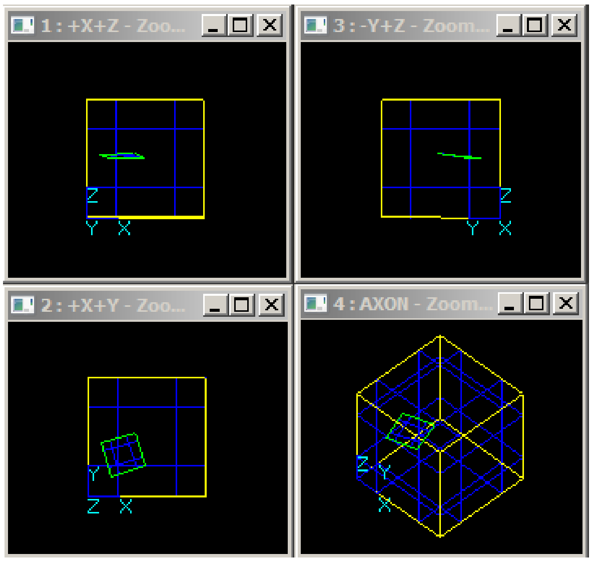


Figure 13: Face/Solid Interference

3.1.10 Solid/Soild Interference

For a solid *Zi* and a solid *Zj* there is Solid/Solid interference if the solid *Zi* and its sub-shapes have no BRep interferences with any sub-shape of *Zj* and *Zi* is completely inside the solid *Zj*.

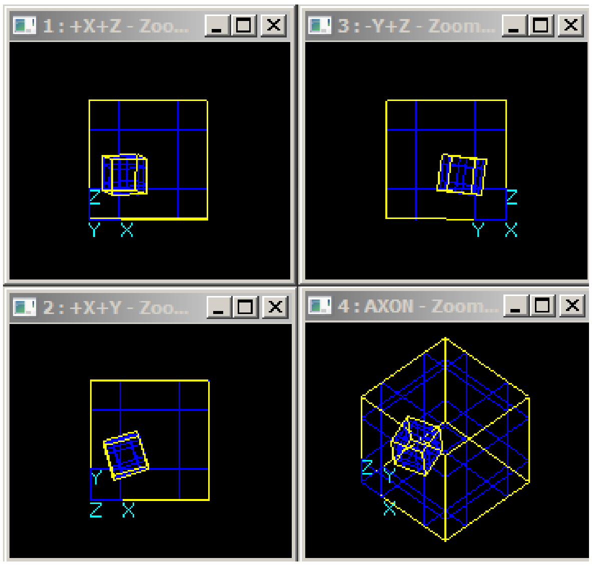


Figure 14: Solid/Solid Interference

3.1.11 Computation Order

The interferences between shapes are computed on the basis of increasing of the dimension value of the shape in the following order:

- Vertex/Vertex,
- Vertex/Edge,
- Edge/Edge,
- Vertex/Face,
- Edge/Face,
- Face/Face,
- Vertex/Solid,
- Edge/Solid,
- Face/Solid,
- Solid/Solid.

This order allows avoiding the computation of redundant interferences between upper-level shapes *Si* and *Sj* when there are interferences between lower sub-shapes *Sik* and *Sjm*.

3.1.12 Results

- The result of the interference is a shape that can be either interfered shape itself (or its part) or a new shape.
- The result of the interference is a shape with the dimension value that is less or equal to the minimal dimension value of interfered shapes. For example, the result of Vertex/Edge interference is a vertex, but not an edge.
- The result of the interference splits the source shapes on the parts each time as it can do that.

3.2 Paves

The result of interferences of the type Vertex/Edge, Edge/Edge and Edge/Face in most cases is a vertex (new or old) lying on an edge.

The result of interferences of the type Face/Face in most cases is intersection curves, which go through some vertices lying on the faces.

The position of vertex *Vi* on curve *C* can be defined by a value of parameter t_i of the 3D point of the vertex on the curve. Pave *PVi* on curve *C* is a structure containing the vertex *Vi* and correspondent value of the parameter t_i of the 3D point of the vertex on the curve. Curve *C* can be a 3D or a 2D curve.

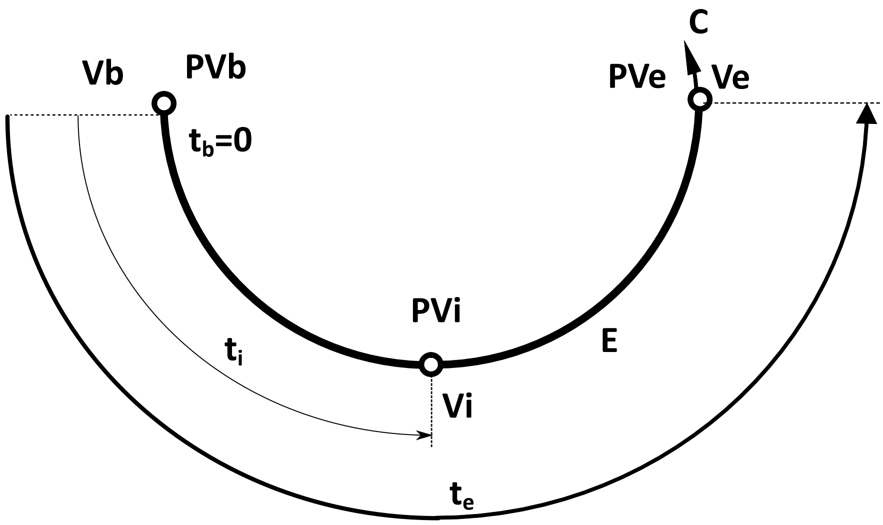


Figure 15: Paves

Two paves *PV1* and *PV2* on the same curve *C* can be compared using the parameter value

```
PV1 > PV2 if t1 > t2
```

The usage of paves allows binding of the vertex to the curve (or any structure that contains a curve: edge, intersection curve).

3.3 Pave Blocks

A set of paves *PVi (i=1, 2...nPV)*, where *nPV* is the number of paves] of curve *C* can be sorted in the increasing order using the value of parameter *t* on curve *C*.

A pave block *PBi* is a part of the object (edge, intersection curve) between neighboring paves.

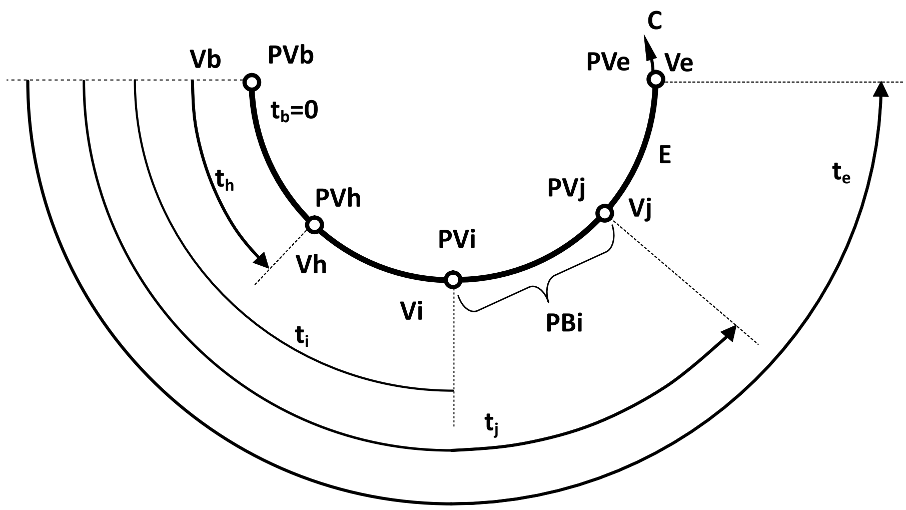


Figure 16: Pave Blocks

Any finite source edge *E* has at least one pave block that contains two paves *PVb* and *PVe*:

- Pave *PVb* corresponds to the vertex *Vb* with minimal parameter t_b on the curve of the edge.
- Pave *PVe* corresponds to the vertex *Ve* with maximal parameter t_e on the curve of the edge.

3.4 Shrunk Range

Pave block *PV* of curve *C* is bounded by vertices *V1* and *V2* with tolerance values *Tol(V1)* and *Tol(V2)*. Curve *C* has its own tolerance value *Tol(C)*:

- In case of edge, the tolerance value is the tolerance of the edge.
- In case of intersection curve, the tolerance value is obtained from an intersection algorithm.

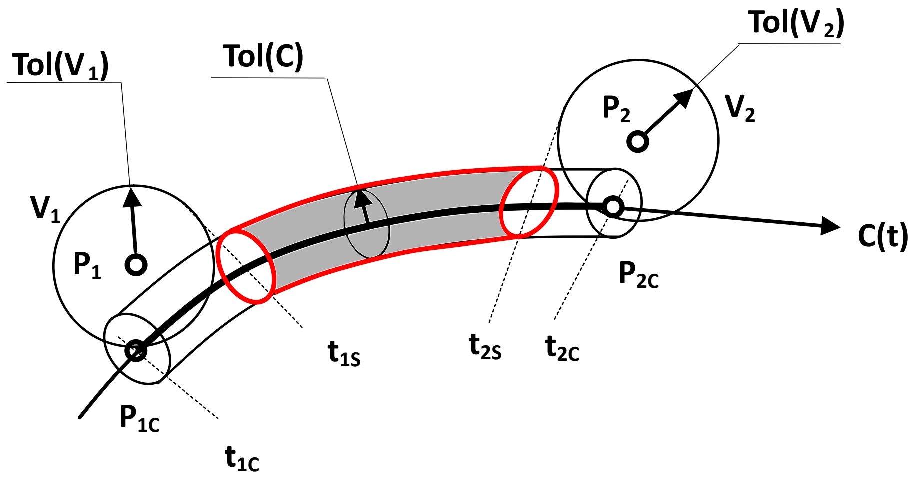


Figure 17: Shrunk Range

The theoretical parametric range of the pave block is *[t1C, t2C]*.

The positions of the vertices *V1* and *V2* of the pave block can be different. The positions are determined by the following conditions:

```
Distance (P1, P1c) is equal or less than Tol(V1) + Tol(C)
Distance (P2, P2c) is equal or less than Tol(V2) + Tol(C)
```

The Figure shows that each tolerance sphere of a vertex can reduce the parametric range of the pave block to a range *[t1S, t2S]*. The range *[t1S, t2S]* is the shrunk range of the pave block.

The shrunk range of the pave block is the part of 3D curve that can interfere with other shapes.

3.5 Common Blocks

The interferences of the type Edge/Edge, Edge/Face produce results as common parts.

In case of Edge/Edge interference the common parts are pave blocks that have different base edges.

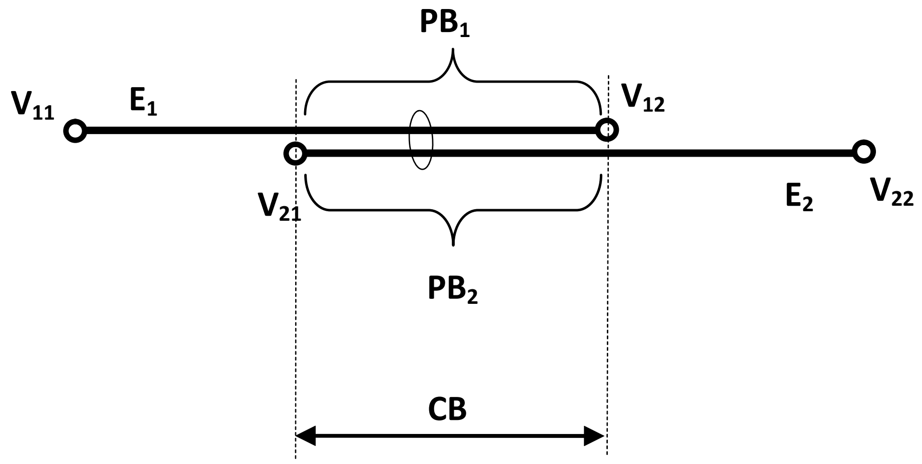


Figure 18: Common Blocks: Edge/Edge interference

If the pave blocks PB_1, PB_2. . . PB_{NbPB} , where *NbPB* is the number of pave blocks have the same bounding vertices and geometrically coincide, the pave blocks form common block *CB*.

In case of Edge/Face interference the common parts are pave blocks lying on a face(s).

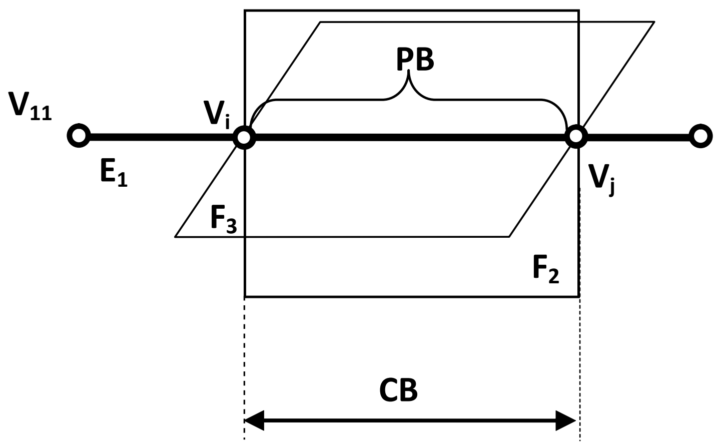


Figure 19: Common Blocks: Edge/Face interference

If the pave blocks *PBi* geometrically coincide with a face *Fj*, the pave blocks form common block *CB*.

In general case a common block *CB* contains:

- Pave blocks *PBi (i=0,1,2, 3. . . NbPB).*
- A set of faces *Fj (j=0,1... NbF), NbF* – number of faces.

3.6 FaceInfo

The structure *FaceInfo* contains the following information:

- Pave blocks that have state **In** for the face;

- Vertices that have state **In** for the face;
- Pave blocks that have state **On** for the face;
- Vertices that have state **On** for the face;
- Pave blocks built up from intersection curves for the face;
- Vertices built up from intersection points for the face.

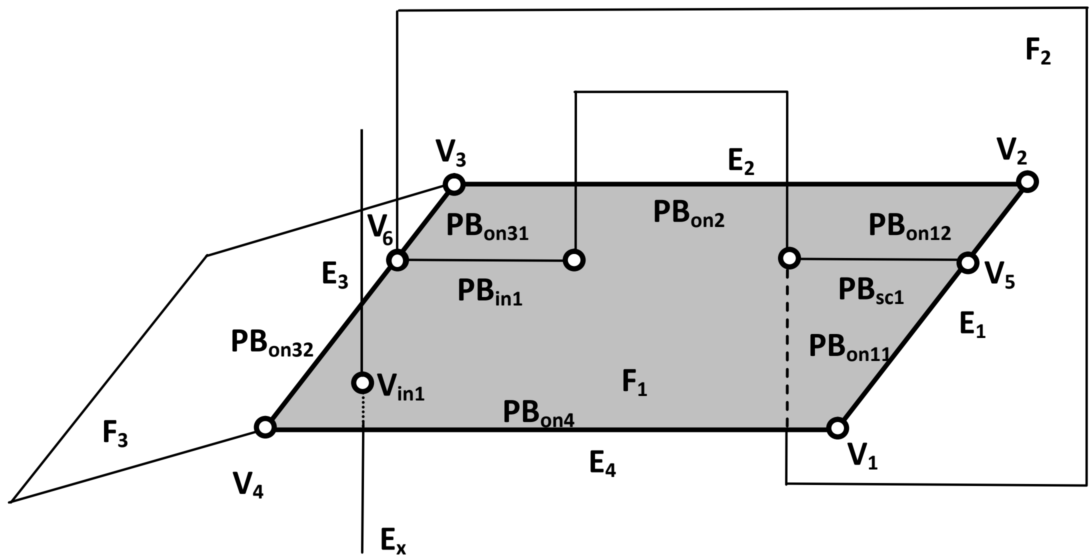


Figure 20: Face Info

In the figure, for face *F1*:

- Pave blocks that have state **In** for the face: PB_{in1}.
- Vertices that have state **In** for the face: V_{in1}.
- Pave blocks that have state **On** for the face: PB_{on11}, PB_{on12}, PB_{on2}, PB_{on31}, PB_{on32}, PB_{on4}.
- Vertices that have state **On** for the face: *V1, V2, V3, V4, V5, V6*.
- Pave blocks built up from intersection curves for the face: PB_{sc1}.
- Vertices built up from intersection points for the face: none

4 Data Structure

Data Structure (DS) is used to:

- Store information about input data and intermediate results;
- Provide the access to the information;
- Provide the links between the chunks of information.

This information includes:

- Arguments;
- Shapes;
- Interferences;
- Pave Blocks;
- Common Blocks.

Data Structure is implemented in the class *BOPDS_DS*.

4.1 Arguments

The arguments are shapes (in terms of *TopoDS_Shape*):

- Number of arguments is unlimited.
- Each argument is a valid shape (in terms of *BRepCheck_Analyzer*).
- Each argument can be of one of the following types (see the Table):

No	Type	Index of Type
1	COMPOUND	0
2	COMPSOLID	1
3	SOLID	2
4	SHELL	3
5	FACE	4
6	WIRE	5
7	EDGE	6
8	VERTEX	7

- The argument of type *0 (COMPOUND)* can include any number of shapes of an arbitrary type (0, 1...7).
- The argument should not be self-interfered, i.e. all sub-shapes of the argument that have geometrical coincidence through any topological entities (vertices, edges, faces) must share these entities.
- There are no restrictions on the type of underlying geometry of the shapes. The faces or edges of arguments S_i can have underlying geometry of any type supported by Open CASCADE Technology modeling algorithms (in terms of *GeomAbs_CurveType* and *GeomAbs_SurfaceType*).
- The faces or edges of the arguments should have underlying geometry with continuity that is not less than C1.

4.2 Shapes

The information about Shapes is stored in structure *BOPDS_ShapeInfo*. The objects of type *BOPDS_ShapeInfo* are stored in the container of array type. The array allows getting the access to the information by an index (DS index). The structure *BOPDS_ShapeInfo* has the following contents:

Name	Contents
myShape	Shape itself
myType	Type of shape
myBox	3D bounding box of the shape
mySubShapes	List of DS indices of sub-shapes
myReference	Storage for some auxiliary information
myFlag	Storage for some auxiliary information

4.3 Interferences

The information about interferences is stored in the instances of classes that are inherited from class *BOPDS_Interf*.

Name	Contents
BOPDS_Interf	Root class for interference
Index1	DS index of the shape 1
Index2	DS index of the shape 2
BOPDS_InterfVV	Storage for Vertex/Vertex interference
BOPDS_InterfVE	Storage for Vertex/Edge interference
myParam	The value of parameter of the point of the vertex on the curve of the edge
BOPDS_InterfVF	Storage for Vertex/Face interference
myU, myV	The value of parameters of the point of the vertex on the surface of the face
BOPDS_InterfEE	Storage for Edge/Edge interference
myCommonPart	Common part (in terms of *IntTools_CommonPart*)
BOPDS_InterfEF	Storage for Edge/Face interference
myCommonPart	Common part (in terms of *IntTools_CommonPart*)
BOPDS_InterfFF	Storage for Face/Face interference
myTolR3D, myTolR2D	The value of tolerances of curves (points) reached in 3D and 2D
myCurves	Intersection Curves (in terms of *BOPDS_Curve*)
myPoints	Intersection Points (in terms of *BOPDS_Point*)
BOPDS_InterfVZ	Storage for Vertex/Solid interference
BOPDS_InterfEZ	Storage for Edge/Solid interference
BOPDS_InterfFZ	Storage for Face/Solid interference
BOPDS_InterfZZ	Storage for Solid/Solid interference

The Figure shows inheritance diagram for *BOPDS_Interf* classes.

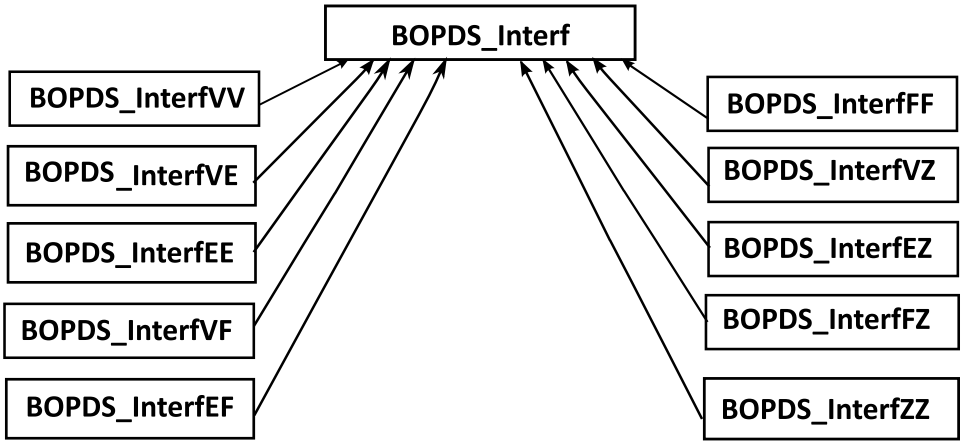


Figure 21: BOPDS_Interf classes

4.4 Pave, PaveBlock and CommonBlock

The information about the pave is stored in objects of type *BOPDS_Pave*.

Name	Contents
BOPDS_Pave	
myIndex	DS index of the vertex
myParam	Value of the parameter of the 3D point of vertex on curve.

The information about pave blocks is stored in objects of type *BOPDS_PaveBlock*.

Name	Contents
BOPDS_PaveBlock	
myEdge	DS index of the edge produced from the pave block
myOriginalEdge	DS index of the source edge
myPave1	Pave 1 (in terms of *BOPDS_Pave*)
myPave2	Pave 2 (in terms of *BOPDS_Pave*)
myExtPaves	The list of paves (in terms of *BOPDS_Pave*) that is used to store paves lying inside the pave block during intersection process
myCommonBlock	The reference to common block (in terms of *BOPDS_CommonBlock*) if the pave block is a common block
myShrunkData	The shrunk range of the pave block

- To be bound to an edge (or intersection curve) the structures of type *BOPDS_PaveBlock* are stored in one container of list type *(BOPDS_ListOfPaveBlock)*.
- In case of edge, all the lists of pave blocks above are stored in one container of array type. The array allows getting the access to the information by index of the list of pave blocks for the edge. This index (if exists) is stored in the field *myReference*.

The information about common block is stored in objects of type *BOPDS_CommonBlock*.

Name	Contents
BOPDS_CommonBlock	
myPaveBlocks	The list of pave blocks that are common in terms of Common Blocks
myFaces	The list of DS indices of the faces, on which the pave blocks lie.

4.5 Points and Curves

The information about intersection point is stored in objects of type *BOPDS_Point*.

Name	Contents
BOPDS_Point	
myPnt	3D point
myPnt2D1	2D point on the face1
myPnt2D2	2D point on the face2

The information about intersection curve is stored in objects of type *BOPDS_Curve*.

Name	Contents
BOPDS_Curve	
myCurve	The intersection curve (in terms of *IntTools_Curve*)
myPaveBlocks	The list of pave blocks that belong to the curve
myBox	The bounding box of the curve (in terms of *Bnd_Box*)

4.6 FaceInfo

The information about *FaceInfo* is stored in a structure *BOPDS_FaceInfo*. The structure *BOPDS_FaceInfo* has the following contents.

Name	Contents
BOPDS_FaceInfo	
myPaveBlocksIn	Pave blocks that have state In for the face
myVerticesIn	Vertices that have state In for the face
myPaveBlocksOn	Pave blocks that have state On for the face
myVerticesOn	Vertices that have state On for the face
myPaveBlocksSc	Pave blocks built up from intersection curves for the face
myVerticesSc	Vertices built up from intersection points for the face +

The objects of type *BOPDS_FaceInfo* are stored in one container of array type. The array allows getting the access to the information by index. This index (if exists) is stored in the field *myReference*.

5 Root Classes

5.1 Class BOPAlgo_Options

The class *BOPAlgo_Options* provides the following options for the algorithms:

- Set the appropriate memory allocator;
- Check the presence of the Errors and Warnings;
- Turn on/off the parallel processing;
- Set the additional tolerance for the operation;
- Break the operations by user request;
- Usage of Oriented Bounding boxes in the operation.

5.2 Class BOPAlgo_Algo

The class *BOPAlgo_Algo* provides the base interface for all algorithms:

- Perform the operation;
- Check the input data;
- Check the result.

6 Intersection Part

Intersection Part (IP) is used to

- Initialize the Data Structure;
- Compute interferences between the arguments (or their sub-shapes);
- Compute same domain vertices, edges;
- Build split edges;
- Build section edges;
- Build p-curves;
- Store all obtained information in DS.

IP is implemented in the class *BOPAlgo_PaveFiller*.

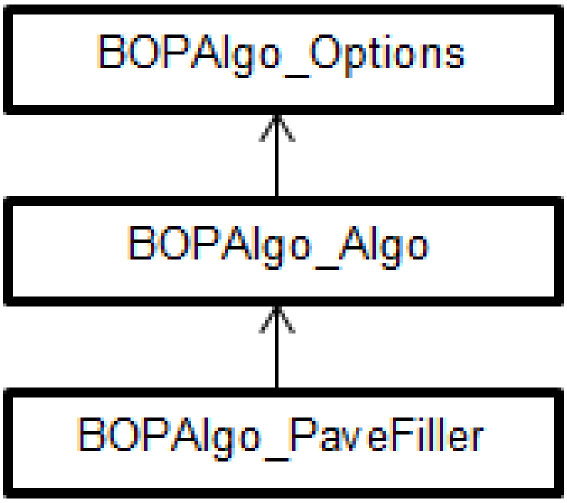


Figure 22: Diagram for Class BOPAlgo_PaveFiller

The description provided in the next paragraphs is coherent with the implementation of the method *BOPAlgo_PaveFiller::Perform()*.

6.1 Initialization

The input data for the step is the Arguments. The description of initialization step is shown in the Table.

No	Contents	Implementation
1	Initialization the array of shapes (in terms of Shapes). Filling the array of shapes.	*BOPDS_DS::Init()*
2	Initialization the array pave blocks (in terms of Pave, PaveBlock, CommonBlock)	*BOPDS_DS::Init()*
3	Initialization of intersection Iterator. The intersection Iterator is the object that computes intersections between sub-shapes of the arguments in terms of bounding boxes. The intersection Iterator provides approximate number of the interferences for given type (in terms of Interferences)	*BOPDS_Iterator*
4	Initialization of intersection Context. The intersection Context is an object that contains geometrical and topological toolkit (classifiers, projectors, etc). The intersection Context is used to cache the tools to increase the algorithm performance.	*IntTools_Context*

6.2 Compute Vertex/Vertex Interferences

The input data for this step is the DS after the Initialization. The description of this step is shown in the table :

No	Contents	Implementation
1	Initialize array of Vertex/Vertex interferences.	*BOPAlgo_PaveFiller::PerformVV()*
2	Access to the pairs of interfered shapes *(nVi, nVj)k, k=0, 1...nk*, where *nVi* and *nVj* are DS indices of vertices *Vi* and *Vj* and *nk* is the number of pairs.	*BOPDS_Iterator*
3	Compute the connexity chains of interfered vertices *nV1C, nV2C... nVnC)k, C=0, 1...nCs*, where *nCs* is the number of the connexity chains	*BOPAlgo_Tools::MakeBlocksCnx()*
4	Build new vertices from the chains *VNc. C=0, 1...nCs.*	*BOPAlgo_PaveFiller::PerformVV()*
5	Append new vertices in DS.	*BOPDS_DS::Append()*
6	Append same domain vertices in DS.	*BOPDS_DS::AddShapeSD()*
7	Append Vertex/Vertex interferences in DS.	*BOPDS_DS::AddInterf()*

- The pairs of interfered vertices are: *(nV11, nV12), (nV11, nV13), (nV12, nV13), (nV13, nV15), (nV13, nV14), (nV14, nV15), (nV21, nV22), (nV21, nV23), (nV22, nV23);*
- These pairs produce two chains: *(nV11, nV12, nV13, nV14, nV15)* and *(nV21, nV22, nV23);*
- Each chain is used to create a new vertex, *VN1* and *VN2*, correspondingly.

The example of connexity chains of interfered vertices is given in the image:

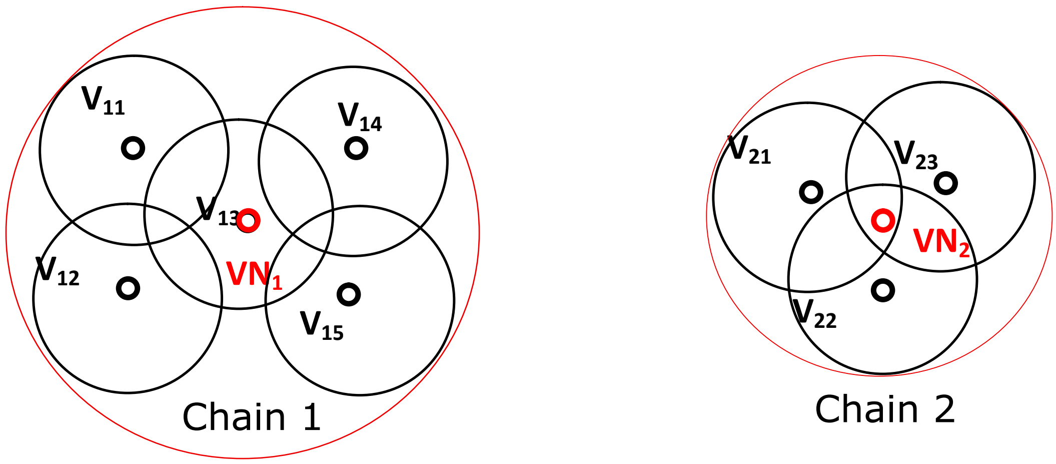


Figure 23: Connexity chains of interfered vertices

6.3 Compute Vertex/Edge Interferences

The input data for this step is the DS after computing Vertex/Vertex interferences.

No	Contents	Implementation
1	Initialize array of Vertex/Edge interferences	*BOPAlgo_PaveFiller::PerformVE()*
2	Access to the pairs of interfered shapes *(nVi, nEj)k k=0, 1...nk*, where *nVi* is DS index of vertex *Vi*, *nEj* is DS index of edge *Ej* and *nk* is the number of pairs.	*BOPDS_Iterator*
3	Compute paves. See Vertex/Edge Interference	*BOPInt_Context::ComputeVE()*

No	Contents	Implementation
4	Initialize pave blocks for the edges *Ej* involved in the interference	*BOPDS_DS:: ChangePaveBlocks()*
5	Append the paves into the pave blocks in terms of Pave, PaveBlock and CommonBlock	*BOPDS_PaveBlock:: AppendExtPave()*
6	Append Vertex/Edge interferences in DS	*BOPDS_DS::AddInterf()*

6.4 Update Pave Blocks

The input data for this step is the DS after computing Vertex/Edge Interferences.

No	Contents	Implementation
1	Each pave block PB containing internal paves is split by internal paves into new pave blocks *PBN1, PBN2... PBNn*. PB is replaced by new pave blocks *PBN1, PBN2... PBNn* in the DS.	*BOPDS_DS:: UpdatePaveBlocks()*

6.5 Compute Edge/Edge Interferences

The input data for this step is the DS after updating Pave Blocks.

No	Contents	Implementation
1	Initialize array of Edge/Edge interferences	*BOPAlgo_PaveFiller::PerformEE()*
2	Access to the pairs of interfered shapes *(nEi, nEj)k, k=0, 1...nk,* where *nEi* is DS index of the edge *Ei*, *nEj* is DS index of the edge *Ej* and *nk* is the number of pairs.	*BOPDS_Iterator*
3	Initialize pave blocks for the edges involved in the interference, if it is necessary.	*BOPDS_DS:: ChangePaveBlocks()*
4	Access to the pave blocks of interfered shapes: *(PBi1, PBi2...PBiNi)* for edge *Ei* and *(PBj1, PBj2...PBjNj)* for edge *Ej*	*BOPAlgo_PaveFiller::PerformEE()*
5	Compute shrunk data for pave blocks in terms of Pave, PaveBlock and CommonBlock, if it is necessary.	*BOPAlgo_PaveFiller::FillShrunkData()*
6	Compute Edge/Edge interference for pave blocks *PBix* and *PBiy*. The result of the computation is a set of objects of type *IntTools_CommonPart*	*IntTools_EdgeEdge*
7.1	For each *CommonPart* of type *VERTEX:* Create new vertices *VNi (i =1, 2...,NbVN),* where *NbVN* is the number of new vertices. Intersect the vertices *VNi* using the steps Initialization and compute Vertex/Vertex interferences as follows: a) create a new object *PFn* of type *BOPAlgo_PaveFiller* with its own DS; b) use new vertices *VNi (i=1, 2...,NbVN), NbVN* as arguments (in terms of *TopoDs_Shape*) of *PFn*; c) invoke method *Perform()* for *PFn*. The resulting vertices *VNXi (i=1, 2...,NbVNX)*, where *NbVNX* is the number of vertices, are obtained via mapping between *VNi* and the results of *PVn*.	*BOPTools_Tools::MakeNewVertex()*
7.2	For each *CommonPart* of type *EDGE:* Compute the coinciding connexity chains of pave blocks *(PB1C, PB2C... PNnC)k, C=0, 1...nCs,* where *nCs* is the number of the connexity chains. Create common blocks *(CBc. C=0, 1...nCs)* from the chains. Attach the common blocks to the pave blocks.	*BOPAlgo_Tools::PerformCommonBlocks()*

No	Contents	Implementation
8	Post-processing. Append the paves of *VNXi* into the corresponding pave blocks in terms of Pave, PaveBlock and CommonBlock	*BOPDS_PaveBlock:: AppendExtPave()*
9	Split common blocks CBc by the paves.	*BOPDS_DS:: UpdateCommonBlock()*
10	Append Edge/Edge interferences in the DS.	*BOPDS_DS::AddInterf()*

The example of coinciding chains of pave blocks is given in the image:

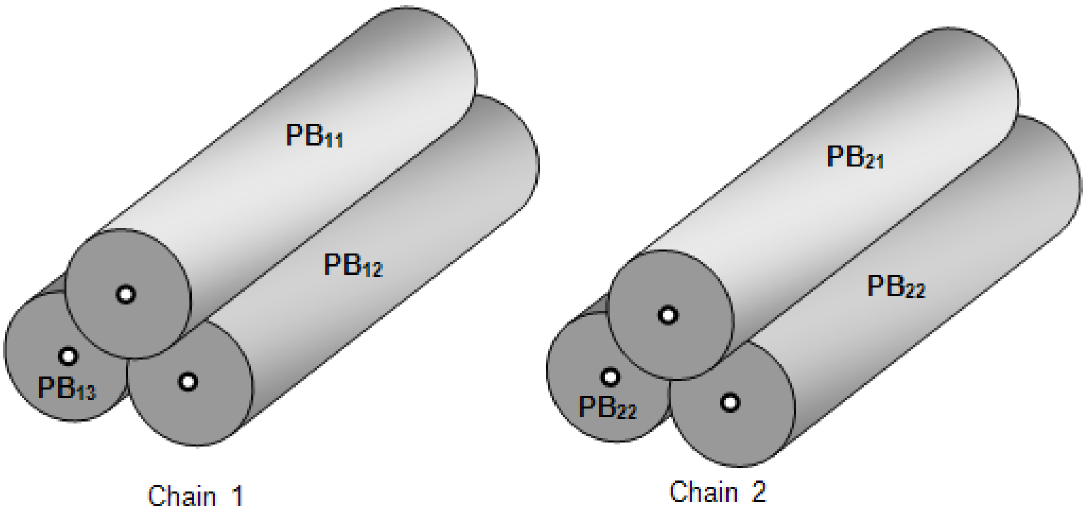


Figure 24: Coinciding chains of pave blocks

- The pairs of coincided pave blocks are: *(PB11, PB12), (PB11, PB13), (PB12, PB13), (PB21, PB22), (PB21, PB23), (PB22, PB23).*
- The pairs produce two chains: *(PB11, PB12, PB13)* and *(PB21, PB22, PB23).*

6.6 Compute Vertex/Face Interferences

The input data for this step is the DS after computing Edge/Edge interferences.

No	Contents	Implementation
1	Initialize array of Vertex/Face interferences	*BOPAlgo_PaveFiller::PerformVF()*
2	Access to the pairs of interfered shapes *(nVi, nFj)k, k=0, 1...nk,* where *nVi* is DS index of the vertex *Vi*, *nFj* is DS index of the edge *Fj* and *nk* is the number of pairs.	*BOPDS_Iterator*
3	Compute interference See Vertex/Face Interference	*BOPInt_Context::ComputeVF()*
4	Append Vertex/Face interferences in the DS	*BOPDS_DS::AddInterf()*
5	Repeat steps 2-4 for each new vertex *VNXi (i=1, 2...,NbVNX),* where *NbVNX* is the number of vertices.	*BOPAlgo_PaveFiller::TreatVerticesEE()*

6.7 Compute Edge/Face Interferences

The input data for this step is the DS after computing Vertex/Face Interferences.

No	Contents	Implementation
1	Initialize array of Edge/Face interferences	*BOPAlgo_PaveFiller::PerformEF()*
2	Access to the pairs of interfered shapes *(nEi, nFj)k, k=0, 1...nk,* where *nEi* is DS index of edge *Ei*, *nFj* is DS index of face *Fj* and *nk* is the number of pairs.	*BOPDS_Iterator*
3	Initialize pave blocks for the edges involved in the interference, if it is necessary.	*BOPDS_DS::ChangePaveBlocks()*
4	Access to the pave blocks of interfered edge *(PBi1, PBi2...PBiNi)* for edge *Ei*	*BOPAlgo_PaveFiller::PerformEF()*
5	Compute shrunk data for pave blocks (in terms of Pave, PaveBlock and CommonBlock) if it is necessary.	*BOPAlgo_PaveFiller::FillShrunkData()*
6	Compute Edge/Face interference for pave block *PBix*, and face *nFj*. The result of the computation is a set of objects of type *IntTools_CommonPart*	*IntTools_EdgeFace*
7.↩ 1	For each *CommonPart* of type *VERTEX:* Create new vertices *VNi (i=1, 2...,NbVN),* where *NbVN* is the number of new vertices. Merge vertices *VNi* as follows: a) create new object *PFn* of type *BOP↩ Algo_PaveFiller* with its own DS; b) use new vertices *VNi (i=1, 2...,NbVN), NbVN* as arguments (in terms of *TopoDs_Shape*) of *PFn*; c) invoke method *Perform()* for *PFn*. The resulting vertices *VNXi (i=1, 2...,NbVNX)*, where *NbVNX* is the number of vertices, are obtained via mapping between *VNi* and the results of *PVn*.	*BOPTools_Tools::MakeNewVertex()* and *BOP↩ Algo_PaveFiller::PerformVertices1()*
7.↩ 2	For each *CommonPart* of type *EDGE:* Create common blocks *(CBc. C=0, 1...nCs)* from pave blocks that lie on the faces. Attach the common blocks to the pave blocks.	*BOPAlgo_Tools::PerformCommonBlocks()*
8	Post-processing. Append the paves of *VNXi* into the corresponding pave blocks in terms of Pave, PaveBlock and CommonBlock.	*BOPDS_PaveBlock:: AppendExtPave()*
9	Split pave blocks and common blocks *CBc* by the paves.	*BOPAlgo_PaveFiller::PerformVertices1()*, *BOPD↩ S_DS:: UpdatePaveBlock()* and *BOPDS_DS:↩ : UpdateCommonBlock()*
10	Append Edge/Face interferences in the DS	*BOPDS_DS::AddInterf()*
11	Update *FaceInfo* for all faces having EF common parts.	*BOPDS_DS:: UpdateFaceInfoIn()*

6.8 Build Split Edges

The input data for this step is the DS after computing Edge/Face Interferences.

For each pave block *PB* take the following steps:

No	Contents	Implementation
1	Get the real pave block *PBR*, which is equal to *PB* if *PB* is not a common block and to PB_1 if *PB* is a common block. PB_1 is the first pave block in the pave blocks list of the common block. See Pave, PaveBlock and CommonBlock.	*BOPAlgo_PaveFiller::MakeSplitEdges()*
2	Build the split edge *Esp* using the information from *DS* and *PBR*.	*BOPTools_Tools::MakeSplitEdge()*
3	Compute *BOPDS_ShapeInfo* contents for Esp	*BOPAlgo_PaveFiller::MakeSplitEdges()*
4	Append *BOPDS_ShapeInfo* contents to the DS	*BOPDS_DS::Append()*

6.9 Compute Face/Face Interferences

The input data for this step is DS after building Split Edges.

No	Contents	Implementation
1	Initialize array of Face/Face interferences	*BOPAlgo_PaveFiller::PerformFF()*
2	Access to the pairs of interfered shapes *(nFi, nFj)k, k=0, 1...nk,* where *nFi* is DS index of edge *Fi*, *nFj* is DS index of face *Fj* and *nk* is the number of pairs.	*BOPDS_Iterator*
3	Compute Face/Face interference	*IntTools_FaceFace*
4	Append Face/Face interferences in the DS.	*BOPDS_DS::AddInterf()*

6.10 Build Section Edges

The input data for this step is the DS after computing Face/Face interferences.

No	Contents	Implementation
1	For each Face/Face interference *nFi, nFj*, retrieve FaceInfo. Create draft vertices from intersection points *VPk (k=1, 2..., NbVP)*, where *NbVP* is the number of new vertices, and the draft vertex *VPk* is created from an intersection point if *VPk Vm (m = 0, 1, 2... NbVm)*, where *Vm* is an existing vertex for the faces *nFi* and *nF,j* (*On* or *In* in terms of *TopoDs_Shape*), *NbVm* is the number of vertices existing on faces *nFi* and *nF,j* and – means non-coincidence in terms of Vertex/Vertex interference.	*BOPAlgo_PaveFiller::MakeBlocks()*
2	For each intersection curve *Cijk*	
2.↩1	Create paves PVc for the curve using existing vertices, i.e. vertices On or In (in terms of *FaceInfo*) for faces *nFi* and *nFj*. Append the paves *PVc*	*BOPAlgo_PaveFiller::PutPaveOnCurve()* and *BO↩PDS_PaveBlock::AppendExtPave()*
2.↩2	Create technological vertices *Vt*, which are the bounding points of an intersection curve (with the value of tolerance *Tol(Cijk)*). Each vertex *Vt* with parameter *Tt* on curve *Cijk* forms pave *PVt* on curve *Cijk*. Append technological paves.	*BOPAlgo_PaveFiller::PutBoundPaveOnCurve()*
2.↩3	Create pave blocks *PBk* for the curve using paves *(k=1, 2..., NbPB)*, where *NbPB* is the number of pave blocks	*BOPAlgo_PaveFiller::MakeBlocks()*
2.↩4	Build draft section edges *ESk* using the pave blocks *(k=1, 2..., NbES)*, where *NbES* is the number of draft section edges The draft section edge is created from a pave block *PBk* if *PBk* has state *In* or *On* for both faces *nFi* and *nF,j* and *PBk PBm (m=0, 1, 2... NbPBm)*, where *PBm* is an existing pave block for faces *nFi* and *nF,j* (*On* or *In* in terms of *FaceInfo*), *NbVm* is the number of existing pave blocks for faces *nFi* and *nF,j* and – means non-coincidence (in terms of Vertex/Face interference).	*BOPTools_Tools::MakeEdge()*

No	Contents	Implementation
3	Intersect the draft vertices *VPk (k=1, 2..., NbVP)* and the draft section edges *ESk (k=1, 2..., NbES)*. For this: a) create new object *PFn* of type *BOPAlgo_PaveFiller* with its own DS; b) use vertices *VPk* and edges *ESk* as arguments (in terms of Arguments) of *PFn*; c) invoke method *Perform()* for *PFn*. Resulting vertices *VPXk (k=1, 2... NbVPX)* and edges *ESXk (k=1, 2... NbESX)* are obtained via mapping between *VPk, ESk* and the results of *PVn*.	*BOPAlgo_PaveFiller::PostTreatFF()*
4	Update face info (sections about pave blocks and vertices)	*BOPAlgo_PaveFiller::PerformFF()*

6.11 Build P-Curves

The input data for this step is the DS after building section edges.

No	Contents	Implementation
1	For each Face/Face interference *nFi* and *nFj* build p-Curves on *nFi* and *nFj* for each section edge *ESXk*.	*BOPAlgo_PaveFiller::MakePCurves()*
2	For each pave block that is common for faces *nFi* and *nFj* build p-Curves on *nFi* and *nFj*.	*BOPAlgo_PaveFiller::MakePCurves()*

6.12 Process Degenerated Edges

The input data for this step is the DS after building P-curves.

No	Contents	Implementation
	For each degenerated edge *ED* having vertex *VD*	BOPAlgo_PaveFiller::ProcessDE()
1	Find pave blocks *PBi (i=1,2... NbPB)*, where *NbPB* is the number of pave blocks, that go through vertex *VD*.	*BOPAlgo_PaveFiller::FindPaveBlocks()*
2	Compute paves for the degenerated edge *ED* using a 2D curve of *ED* and a 2D curve of *PBi*. Form pave blocks *PBDi (i=1,2... NbPBD)*, where *NbPBD* is the number of the pave blocks for the degenerated edge *ED*	*BOPAlgo_PaveFiller::FillPaves()*
3	Build split edges *ESDi (i=1,2...NbESD)*, where *ESD* is the number of split edges, using the pave blocks *PBDi*	*BOPAlgo_PaveFiller:: MakeSplitEdge()*

7 General description of the Building Part

Building Part (BP) is used to

- Build the result of the operation
- Provide history information (in terms of *::Generated(), ::Modified()* and *::IsDeleted()*) BP uses the DS prepared by *BOPAlgo_PaveFiller* described at chapter 5 as input data. BP is implemented in the following classes:
- *BOPAlgo_Builder* – for the General Fuse operator (GFA).
- *BOPAlgo_BOP* – for the Boolean Operation operator (BOA).
- *BOPAlgo_Section* – for the Section operator (SA).
- *BOPAlgo_MakerVolume* – for the Volume Maker operator.
- *BOPAlgo_Splitter* – for the Splitter operator.
- *BOPAlgo_CellsBuilder* – for the Cells Builder operator.

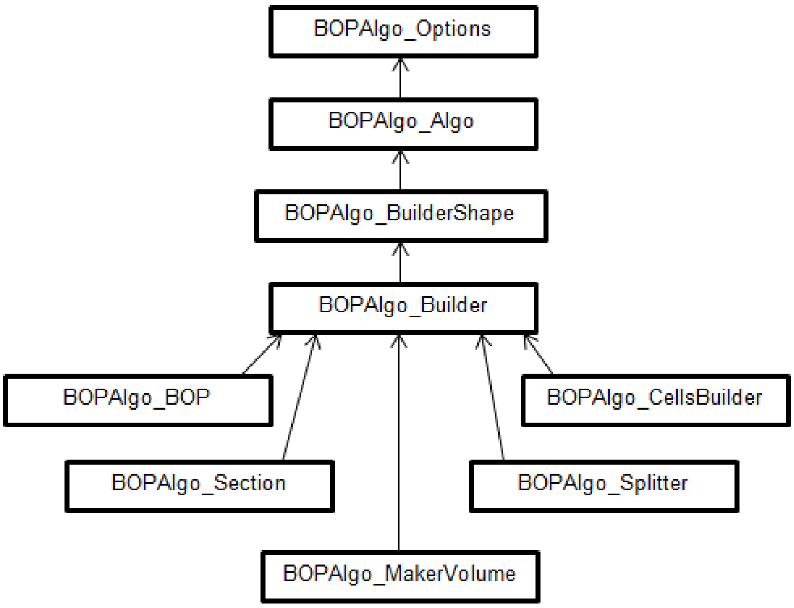


Figure 25: Diagram for BP classes

The class *BOPAlgo_BuilderShape* provides the interface for algorithms that have:

- A Shape as the result;
- History information (in terms of *::Generated(), ::Modified()* and *::IsDeleted()).*

8 General Fuse Algorithm

8.1 Arguments

The arguments of the algorithm are shapes (in terms of *TopoDS_Shape*). The main requirements for the arguments are described in Data Structure chapter.

8.2 Results

During the operation argument *Si* can be split into several parts *Si1, Si2... Si1NbSp*, where *NbSp* is the number of parts. The set *(Si1, Si2... Si1NbSp)* is an image of argument *Si*.

- The result of the General Fuse operation is a compound. Each sub-shape of the compound corresponds to the certain argument shape S1, S2...Sn and has shared sub-shapes in accordance with interferences between the arguments.
- For the arguments of the type EDGE, FACE, SOLID the result contains split parts of the argument.
- For the arguments of the type WIRE, SHELL, COMPSOLID, COMPOUND the result contains the image of the shape of the corresponding type (i.e. WIRE, SHELL, COMPSOLID or COMPOUND). The types of resulting shapes depend on the type of the corresponding argument participating in the operation. See the table below:

No	Type of argument	Type of resulting shape	Comments
1	COMPOUND	COMPOUND	The resulting COMPOUND is built from images of sub-shapes of type COMPOUND COMPSOLID, S↩ HELL, WIRE and VERTEX. Sets of split sub-shapes of type SOLID, FACE, EDGE.
2	COMPSOLID	COMPSOLID	The resulting COMPSOLID is built from split SOLIDs.
3	SOLID	Set of split SOLIDs	
4	SHELL	SHELL	The resulting SHELL is built from split FACEs
5	FACE	Set of split FACEs	
6	WIRE	WIRE	The resulting WIRE is built from split EDGEs
7	EDGE	Set of split EDGEs	
8	VERTEX	VERTEX	

8.3 Options

The General Fuse algorithm has a set of options, which allow speeding-up the operation and improving the quality of the result:

- Parallel processing option allows running the algorithm in parallel mode;
- Fuzzy option allows setting the additional tolerance for the operation;
- Safe input shapes option allows preventing modification of the input shapes;
- Gluing option allows speeding-up the intersection of the arguments;
- Possibility to disable the check for the inverted solids among input shapes;
- Usage of Oriented Bounding Boxes in the operation;
- History support.

For more detailed information on these options, see the Advanced options section.

8.4 Usage

The following example illustrates how to use the GF algorithm:

Usage of the GF algorithm on C++ level

```
BOPAlgo_Builder aBuilder;
// Setting arguments
TopTools_ListOfShape aLSObjects = ...; // Objects
aBuilder.SetArguments(aLSObjects);

// Setting options for GF

// Set parallel processing mode (default is false)
Standard_Boolean bRunParallel = Standard_True;
aBuilder.SetRunParallel(bRunParallel);

// Set Fuzzy value (default is Precision::Confusion())
Standard_Real aFuzzyValue = 1.e-5;
aBuilder.SetFuzzyValue(aFuzzyValue);

// Set safe processing mode (default is false)
Standard_Boolean bSafeMode = Standard_True;
aBuilder.SetNonDestructive(bSafeMode);

// Set Gluing mode for coinciding arguments (default is off)
BOPAlgo_GlueEnum aGlue = BOPAlgo_GlueShift;
aBuilder.SetGlue(aGlue);

// Disabling/Enabling the check for inverted solids (default is true)
Standard Boolean bCheckInverted = Standard_False;
aBuilder.SetCheckInverted(bCheckInverted);

// Set OBB usage (default is false)
Standard_Boolean bUseOBB = Standard_True;
aBuilder.SetUseOBB(buseobb);

// Perform the operation
aBuilder.Perform();

// Check for the errors
if (aBuilder.HasErrors())
{
  return;
}

// Check for the warnings
if (aBuilder.HasWarnings())
{
  // treatment of the warnings
  ...
}

// result of the operation
const TopoDS_Shape& aResult = aBuilder.Shape();
```

Usage of the GF algorithm on Tcl level

```
# prepare the arguments
box b1 10 10 10
box b2 3 4 5 10 10 10
box b3 5 6 7 10 10 10

# clear inner contents
bclearobjects; bcleartools;

# set the arguments
baddobjects b1 b2 b3

# setting options for GF

# set parallel processing mode (default is 0)
brunparallel 1

# set Fuzzy value
bfuzzyvalue 1.e-5

# set safe processing mode (default is 0)
bnondestructive 1

# set gluing mode (default is 0)
bglue 1

# set check for inverted (default is 1)
```

```
bcheckinverted 0

# set obb usage (default is 0)
buseobb 1

# perform intersection
bfillds

# perform GF operation
bbuild result
```

8.5 Examples

Have a look at the examples to better understand the definitions.

8.5.1 Case 1: Three edges intersecting at a point

Let us consider three edges: *E1, E2* and *E3* that intersect in one 3D point.

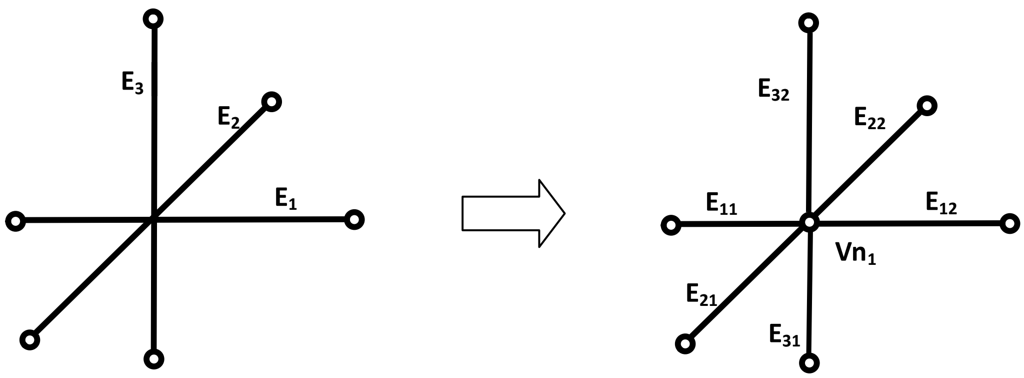


Figure 26: Three Intersecting Edges

The result of the GFA operation is a compound containing 6 new edges: *E11, E12, E21, E22, E31*, and *E32*. These edges have one shared vertex *Vn1*.

In this case:

- The argument edge *E1* has resulting split edges *E11* and *E12* (image of *E1*).
- The argument edge *E2* has resulting split edges *E21* and *E22* (image of *E2*).
- The argument edge *E3* has resulting split edges *E31* and *E32* (image of *E3*).

8.5.2 Case 2: Two wires and an edge

Let us consider two wires *W1 (Ew11, Ew12, Ew13)* and *W2 (Ew21, Ew22, Ew23)* and edge *E1*.

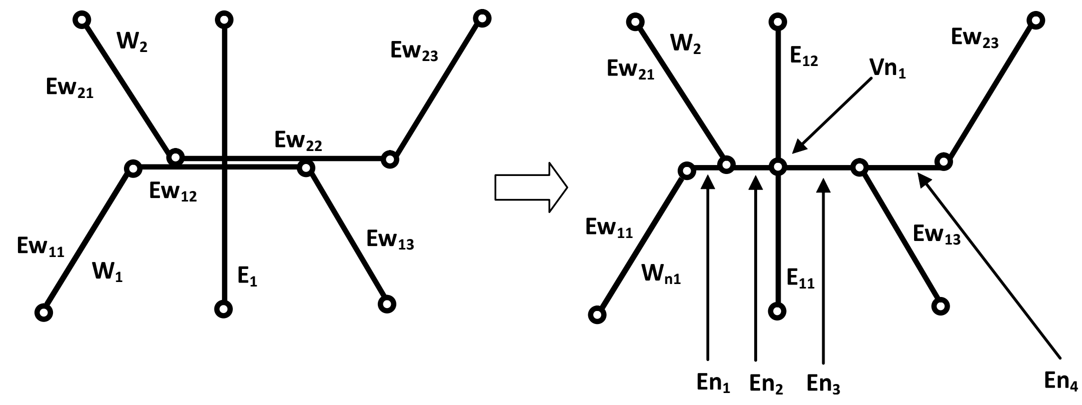


Figure 27: Two wires and an edge

The result of the GF operation is a compound consisting of 2 wires: *Wn1 (Ew11, En1, En2, En3, Ew13)* and *Wn2 (Ew21, En2, En3, En4, Ew23)* and two edges: *E11* and *E12*.

In this case :

- The argument *W1* has image *Wn1*.
- The argument *W2* has image *Wn2*.
- The argument edge *E1* has split edges *E11* and *E12*. (image of *E1*). The edges *En1, En2, En3, En4* and vertex *Vn1* are new shapes created during the operation. Edge *Ew12* has split edges *En1, En2* and *En3* and edge *Ew22* has split edges *En2, En3* and *En4*.

8.5.3 Case 3: An edge intersecting with a face

Let us consider edge *E1* and face *F2*:

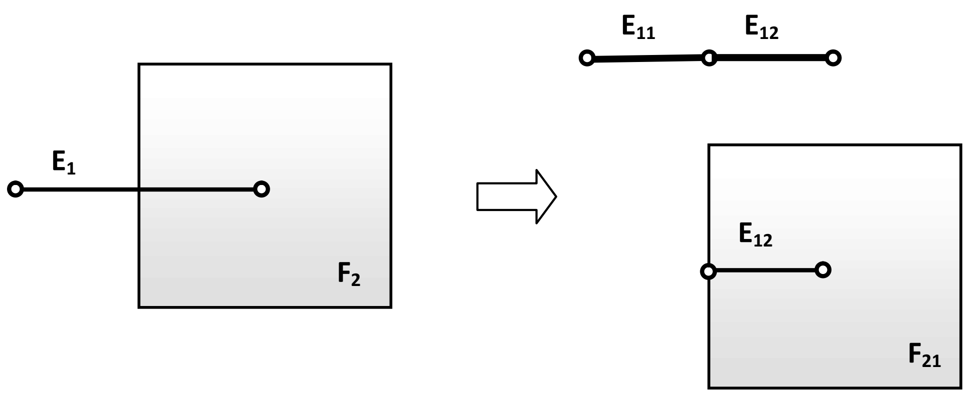


Figure 28: An edge intersecting with a face

The result of the GF operation is a compound consisting of 3 shapes:

- Split edge parts *E11* and *E12* (image of *E1*).
- New face *F21* with internal edge *E12* (image of *F2*).

8.5.4 Case 4: An edge lying on a face

Let us consider edge *E1* and face *F2*:

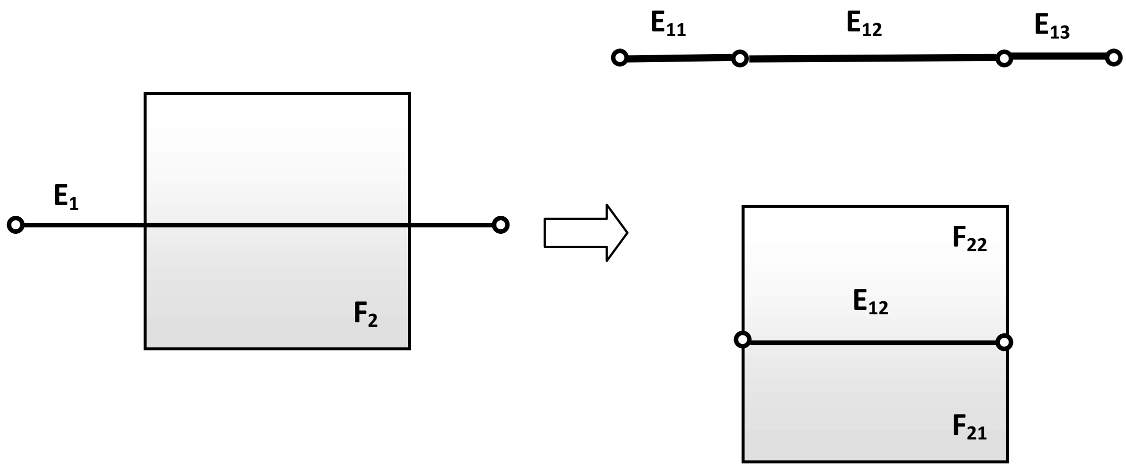


Figure 29: An edge lying on a face

The result of the GF operation is a compound consisting of 5 shapes:

- Split edge parts *E11, E12* and *E13* (image of *E1*).
- Split face parts *F21* and *F22* (image of *F2*).

8.5.5 Case 5: An edge and a shell

Let us consider edge *E1* and shell *Sh2* that consists of 2 faces: *F21* and *F22*

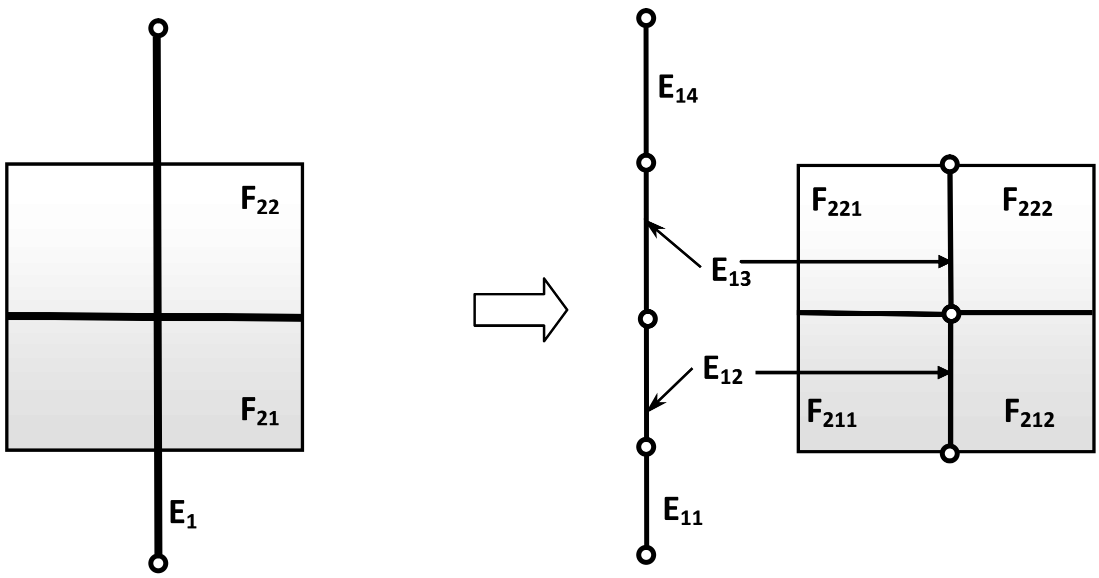


Figure 30: An edge and a shell

The result of the GF operation is a compound consisting of 5 shapes:

- Split edge parts *E11, E12 , E13* and *E14* (image of *E1*).

- Image shell *Sh21* (that contains split face parts *F211, F212, F221* and *F222*).

8.5.6 Case 6: A wire and a shell

Let us consider wire *W1 (E1, E2, E3, E4)* and shell *Sh2 (F21, F22)*.

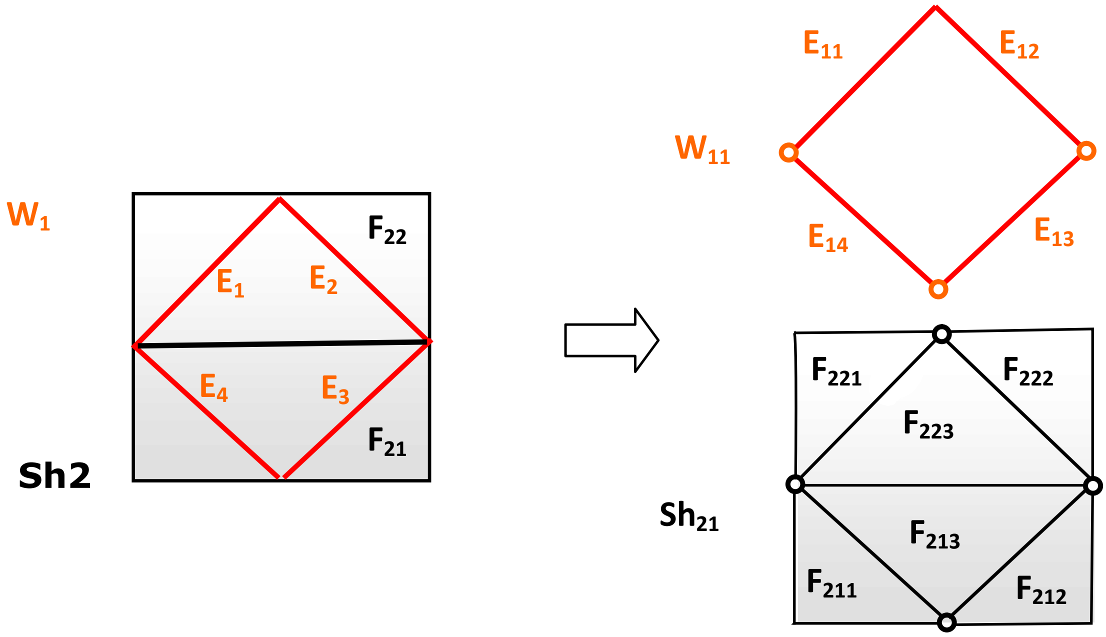


Figure 31: A wire and a shell

The result of the GF operation is a compound consisting of 2 shapes:

- Image wire *W11* that consists of split edge parts from wire *W1: E11, E12, E13* and *E14*.
- Image shell *Sh21* that contains split face parts: *F211, F212, F213, F221, F222* and *F223*.

8.5.7 Case 7: Three faces

Let us consider 3 faces: *F1, F2* and *F3*.

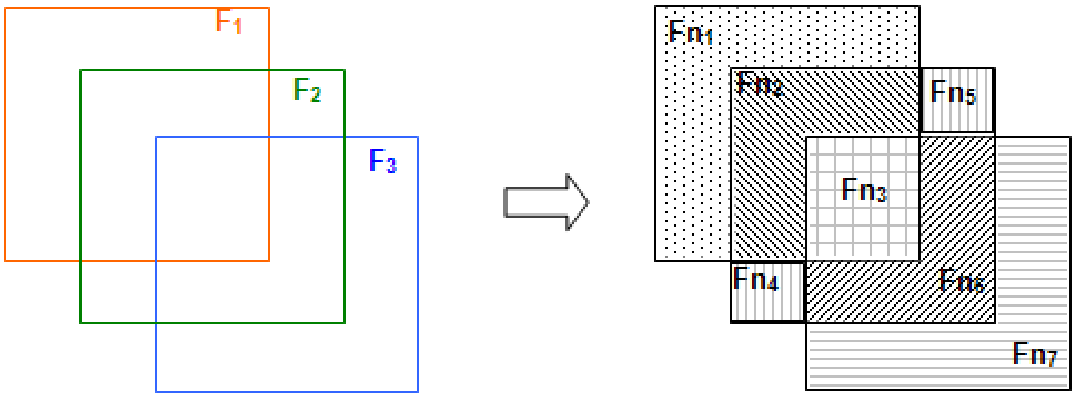


Figure 32: Three faces

The result of the GF operation is a compound consisting of 7 shapes:

- Split face parts: *Fn1, Fn2, Fn3, Fn4, Fn5, Fn6* and *Fn7*.

8.5.8 Case 8: A face and a shell

Let us consider shell *Sh1 (F11, F12, F13)* and face *F2*.

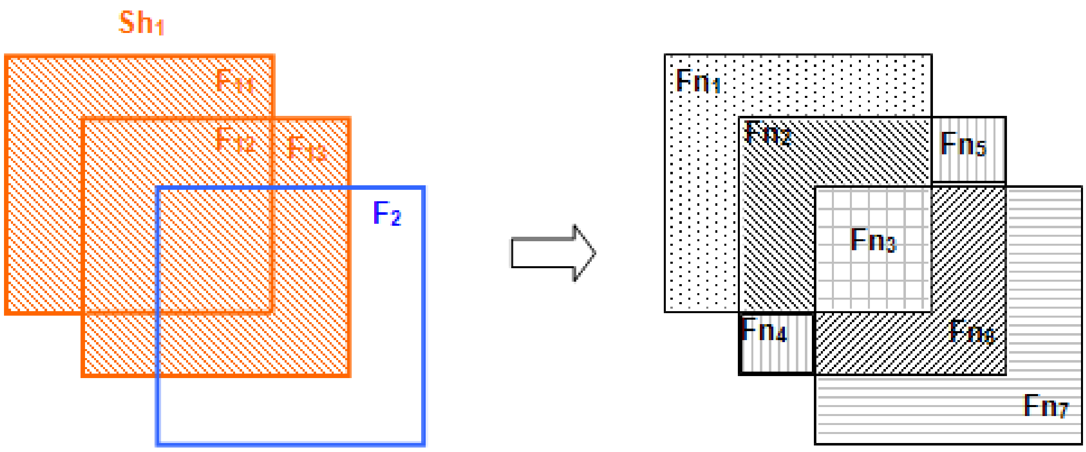


Figure 33: A face and a shell

The result of the GF operation is a compound consisting of 4 shapes:

- Image shell *Sh11* that consists of split face parts from shell *Sh1: Fn1, Fn2, Fn3, Fn4, Fn5* and *Fn6*.
- Split parts of face *F2: Fn3, Fn6* and *Fn7*.

8.5.9 Case 9: A shell and a solid

Let us consider shell *Sh1 (F11, F12. . . F16)* and solid *So2*.

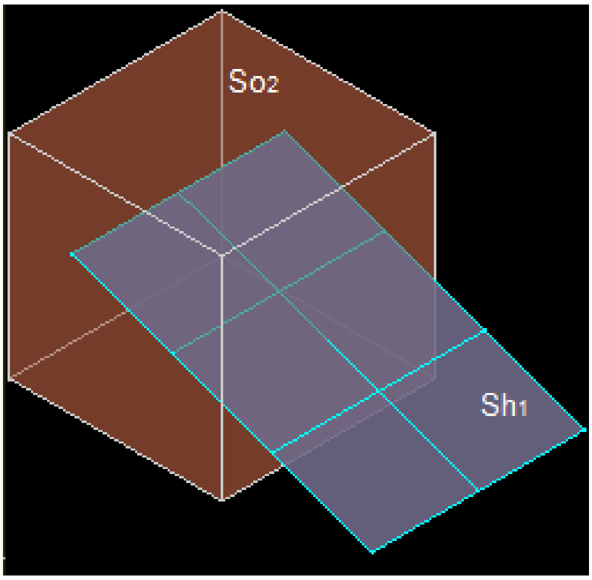


Figure 34: A shell and a solid: arguments

The result of the GF operation is a compound consisting of 2 shapes:

- Image shell *Sh11* consisting of split face parts of *Sh1: Fn1, Fn2 ... Fn8.*
- Solid *So21* with internal shell. (image of *So2*).

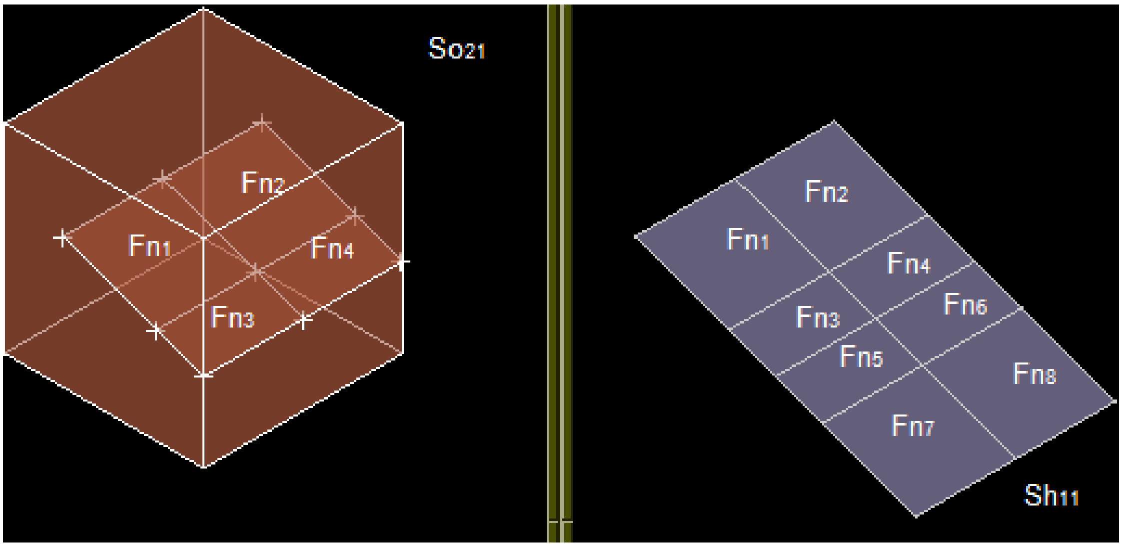


Figure 35: A shell and a solid: results

8.5.10 Case 10: A compound and a solid

Let us consider compound *Cm1* consisting of 2 solids *So11* and *So12*) and solid *So2*.

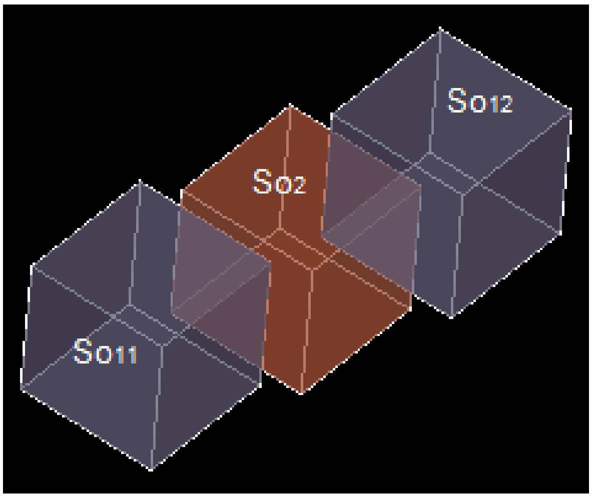


Figure 36: A compound and a solid: arguments

The result of the GF operation is a compound consisting of 4 shapes:

- Image compound *Cm11* consisting of split solid parts from *So11* and *So12 (Sn1, Sn2, Sn3, Sn4)*.
- Split parts of solid *So2 (Sn2, Sn3, Sn5)*.

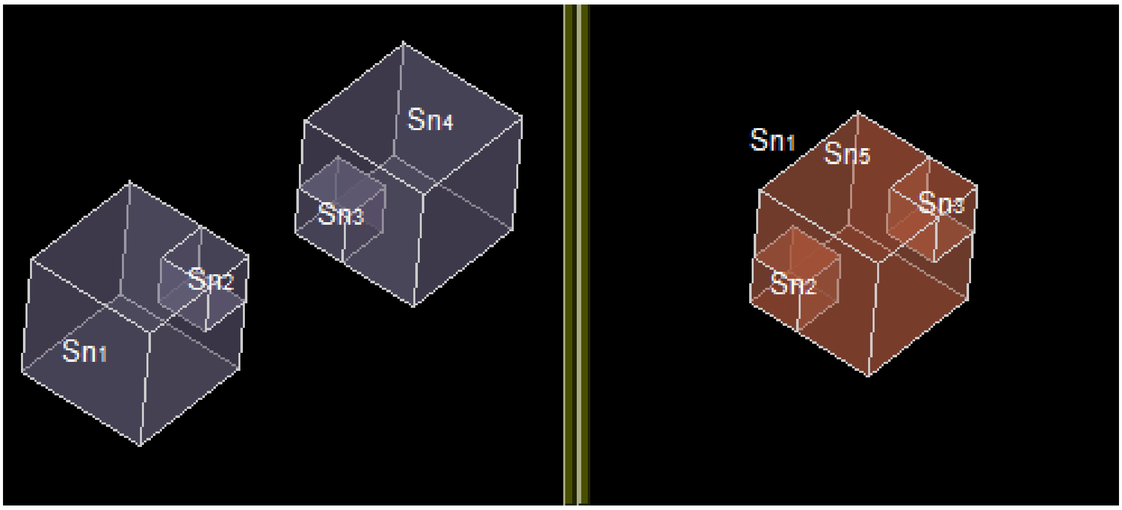


Figure 37: A compound and a solid: results

8.6 Class BOPAlgo_Builder

GFA is implemented in the class *BOPAlgo_Builder*.

8.6.1 Fields

The main fields of the class are described in the Table:

Name	Contents
myPaveFiller	Pointer to the *BOPAlgo_PaveFiller* object
myDS	Pointer to the *BOPDS_DS* object

Name	Contents
myContext	Pointer to the intersection Context
myImages	The Map between the source shape and its images
myShapesSD	The Map between the source shape (or split part of source shape) and the shape (or part of shape) that will be used in result due to same domain property.

8.6.2 Initialization

The input data for this step is a *BOPAlgo_PaveFiller* object (in terms of Intersection) at the state after Processing of degenerated edges with the corresponding DS.

No	Contents	Implementation
1	Check the readiness of the DS and *BOPAlgo_PaveFiller*.	*BOPAlgo_Builder::CheckData()*
2	Build an empty result of type Compound.	*BOPAlgo_Builder::Prepare()*

8.6.3 Build Images for Vertices

The input data for this step is *BOPAlgo_Builder* object after Initialization.

No	Contents	Implementation
1	Fill *myShapesSD* by SD vertices using the information from the DS.	*BOPAlgo_Builder::FillImagesVertices()*

8.6.4 Build Result of Type Vertex

The input data for this step is *BOPAlgo_Builder* object after building images for vertices and *Type*, which is the shape type (*TopAbs_VERTEX*).

No	Contents	Implementation
1	For the arguments of type *Type*. If there is an image for the argument: add the image to the result. If there is no image for the argument: add the argument to the result.	*BOPAlgo_Builder::BuildResult()*

8.6.5 Build Images for Edges

The input data for this step is *BOPAlgo_Builder object* after building result of type vertex.

No	Contents	Implementation
1	For all pave blocks in the DS. Fill *myImages* for the original edge *E* by split edges *ESPi* from pave blocks. In case of common blocks on edges, use edge *ESPSDj* that corresponds to the leading pave block and fill *myShapesSD* by the pairs *ESPi/ESPSDj*.	*BOPAlgo_Builder::FillImagesEdges()*

8.6.6 Build Result of Type Edge

This step is the same as Building Result of Type Vertex, but for the type *Edge*.

8.6.7 Build Images for Wires

The input data for this step is:

- *BOPAlgo_Builder* object after building result of type *Edge*;
- Original Shape – Wire
- *Type* – the shape type *(TopAbs_WIRE).*

No	Contents	Implementation
1	For all arguments of the type *Type*. Create a container C of the type *Type*.	*BOPAlgo_Builder::FillImagesContainers()*
2	Add to C the images or non-split parts of the *Original Shape*, taking into account its orientation.	*BOPAlgo_Builder::FillImagesContainers()* *BOP↩ Tools_Tools::IsSplitToReverse()*
3	Fill *myImages* for the *Original Shape* by the information above.	*BOPAlgo_Builder::FillImagesContainers()*

8.6.8 Build Result of Type Wire

This step is the same as Building Result of Type Vertex but for the type *Wire*.

8.6.9 Build Images for Faces

The input data for this step is *BOPAlgo_Builder* object after building result of type *Wire*.

No	Contents	Implementation
1	Build Split Faces for all interfered DS shapes *Fi* of type *FACE*.	
1.↩ 1	Collect all edges or their images of *Fi(ESPij)*.	*BOPAlgo_Builder::BuildSplitFaces()*
1.↩ 2	Impart to ESPij the orientation to be coherent with the original one.	*BOPAlgo_Builder::BuildSplitFaces()*
1.↩ 3	Collect all section edges *SEk* for *Fi*.	*BOPAlgo_Builder::BuildSplitFaces()*
1.↩ 4	Build split faces for *Fi (Fi1, Fi2... FiNbSp)*, where *NbSp* is the number of split parts (see Building faces from a set of edges for more details).	*BOPAlgo_BuilderFace*
1.↩ 5	Impart to *(Fi1, Fi2... FiNbSp)* the orientation coherent with the original face *Fi*.	*BOPAlgo_Builder::BuildSplitFaces()*
1.↩ 6	Fill the map mySplits with *Fi/(Fi1, Fi2... FiNbSp)*	*BOPAlgo_Builder::BuildSplitFaces()*
2	Fill Same Domain faces	*BOPAlgo_Builder::FillSameDomainFaces*
2.↩ 1	Find and collect in the contents of *mySplits* the pairs of same domain split faces *(Fij, Fkl)m*, where *m* is the number of pairs.	*BOPAlgo_Builder::FillSameDomainFaces* *BOP↩ Tools_Tools::AreFacesSameDomain()*
2.↩ 2	Compute the connexity chains 1) of same domain faces *(F1C, F2C... FnC)k, C=0, 1... nCs,* where *nCs* is the number of connexity chains.	*BOPAlgo_Builder::FillSameDomainFaces()*
2.↩ 3	Fill *myShapesSD* using the chains *(F1C, F2C... FnC)k*	*BOPAlgo_Builder::FillSameDomainFaces()*
2.↩ 4	Add internal vertices to split faces.	*BOPAlgo_Builder::FillSameDomainFaces()*
2.↩ 5	Fill *myImages* using *myShapesSD* and *mySplits*.	*BOPAlgo_Builder::FillSameDomainFaces()*

The example of chains of same domain faces is given in the image:

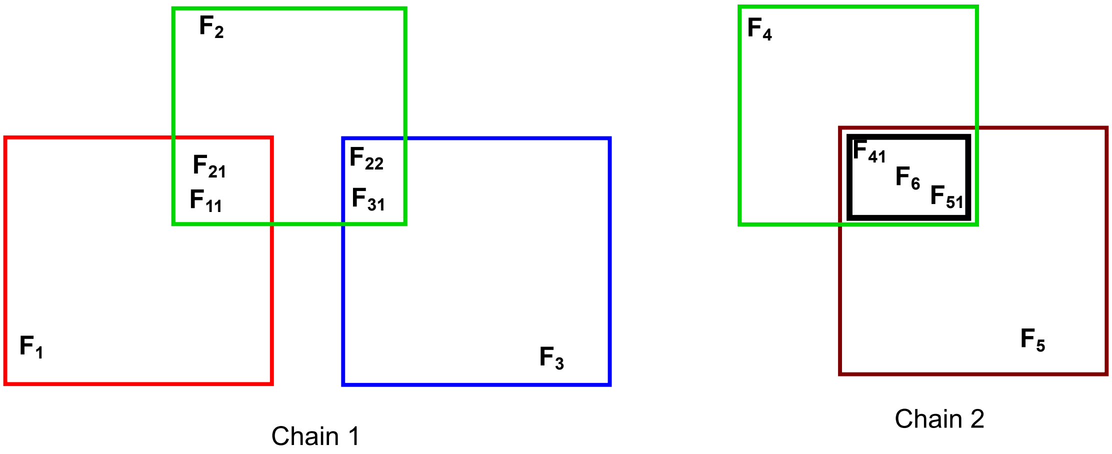


Figure 38: Chains of same domain faces

- The pairs of same domain faces are: *(F11, F21), (F22, F31), (F41, F51) , (F41, F6)* and *(F51, F6)*.
- The pairs produce the three chains: *(F11, F21), (F22, F31)* and *(F41, F51, F6)*.

8.6.10 Build Result of Type Face

This step is the same as Building Result of Type Vertex but for the type *Face*.

8.6.11 Build Images for Shells

The input data for this step is:

- *BOPAlgo_Builder* object after building result of type face;
- *Original Shape* – a Shell;
- *Type* – the type of the shape *(TopAbs_SHELL)*.

The procedure is the same as for building images for wires.

8.6.12 Build Result of Type Shell

This step is the same as Building Result of Type Vertex but for the type *Shell*.

8.6.13 Build Images for Solids

The input data for this step is *BOPAlgo_Builder* object after building result of type *Shell*.

The following procedure is executed for all interfered DS shapes *Si* of type *SOLID*.

No	Contents	Implementation
1	Collect all images or non-split parts for all faces *(FSPij)* that have 3D state *In Si*.	*BOPAlgo_Builder::FillIn3DParts ()*
2	Collect all images or non-split parts for all faces of *Si*	*BOPAlgo_Builder::BuildSplitSolids()*
3	Build split solids for *Si -> (Si1, Si2. . . SiNbSp)*, where *NbSp* is the number of split parts (see Building faces from a set of edges for more details)	*BOPAlgo_BuilderSolid*

No	Contents	Implementation
4	Fill the map Same Domain solids *myShapesSD*	*BOPAlgo_Builder::BuildSplitSolids()*
5	Fill the map *myImages*	*BOPAlgo_Builder::BuildSplitSolids()*
6	Add internal vertices to split solids	*BOPAlgo_Builder::FillInternalShapes()*

8.6.14 Build Result of Type Solid

This step is the same as Building Result of Type Vertex, but for the type Solid.

8.6.15 Build Images for Type CompSolid

The input data for this step is:

- *BOPAlgo_Builder* object after building result of type solid;
- *Original Shape* – a Compsolid;
- *Type* – the type of the shape *(TopAbs_COMPSOLID)*.

The procedure is the same as for building images for wires.

8.6.16 Build Result of Type Compsolid

This step is the same as Building Result of Type Vertex, but for the type Compsolid.

8.6.17 Build Images for Compounds

The input data for this step is as follows:

- *BOPAlgo_Builder* object after building results of type *compsolid*;
- *Original Shape* – a Compound;
- *Type* – the type of the shape *(TopAbs_COMPOUND)*.

The procedure is the same as for building images for wires.

8.6.18 Build Result of Type Compound

This step is the same as Building Result of Type Vertex, but for the type Compound.

8.6.19 Post-Processing

The purpose of the step is to correct tolerances of the result to provide its validity in terms of *BRepCheck_Analyzer.*

The input data for this step is a *BOPAlgo_Builder* object after building result of type compound.

No	Contents	Implementation
1	Correct tolerances of vertices on curves	*BOPTools_Tools::CorrectPointOnCurve()*
2	Correct tolerances of edges on faces	*BOPTools_Tools::CorrectCurveOnSurface()*

9 Splitter Algorithm

The Splitter algorithm allows splitting a group of arbitrary shapes by another group of arbitrary shapes.
It is based on the General Fuse algorithm, thus all options of the General Fuse (see GF Options) are also available in this algorithm.

9.1 Arguments

- The arguments of the Splitter algorithm are divided into two groups - *Objects* (shapes that will be split) and *Tools* (shapes, by which the *Objects* will be split);
- The requirements for the arguments (both for *Objects* and *Tools*) are the same as for the General Fuse algorithm - there can be any number of arguments of any type in each group, but each argument should be valid and not self-interfered.

9.2 Results

- The result of Splitter algorithm contains only the split parts of the shapes included into the group of *Objects*;
- The split parts of the shapes included only into the group of *Tools* are excluded from the result;
- If there are no shapes in the group of *Tools* the result of the operation will be equivalent to the result of General Fuse operation;
- The shapes can be split by other shapes from the same group (if these shapes are interfering).

9.3 Usage

9.3.1 API

On the low level the Splitter algorithm is implemented in class *BOPAlgo_Splitter*. The usage of this algorithm looks as follows:

```
BOPAlgo_Splitter aSplitter;
// Setting arguments and tools
TopTools_ListOfShape aLSObjects = ...; // Objects
TopTools_ListOfShape aLSTools = ...; // Tools
aSplitter.SetArguments(aLSObjects);
aSplitter.SetTools(aLSTools);

// Set options for the algorithm
// setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
...

// Perform the operation
aSplitter.Perform();
if (aSplitter.HasErrors()) { //check error status
  return;
}
//
const TopoDS_Shape& aResult = aSplitter.Shape(); // result of the operation
```

9.3.2 DRAW

The command *bsplit* implements the Splitter algorithm in DRAW. Similarly to the *bbuild* command for the General Fuse algorithm, the *bsplit* command should be used after the Pave Filler is filled.

```
# s1 s2 s3 - objects
# t1 t2 t3 - tools
bclearobjects
bcleartools
baddobjects s1 s2 s3
baddtools t1 t2 t3
bfillds
bsplit result
```

9.4 Examples

9.4.1 Example 1

Splitting a face by the set of edges:

```
# draw script for reproducing
bclearobjects
bcleartools

set height 20
cylinder cyl 0 0 0 0 0 1 10
mkface f cyl 0 2*pi -$height $height
baddobjects f

# create tool edges
compound edges

set nb_uedges 10
set pi2 [dval 2*pi]
set ustep [expr $pi2/$nb_uedges]
for {set i 0} {$i <= $pi2} {set i [expr $i + $ustep]} {
  uiso c cyl $i
  mkedge e c -25 25
  add e edges
}

set nb_vedges 10
set vstep [expr 2*$height/$nb_vedges]
for {set i -20} {$i <= 20} {set i [expr $i + $vstep]} {
  viso c cyl $i
  mkedge e c
  add e edges
}
baddctools edges

bfillds
bsplit result
```

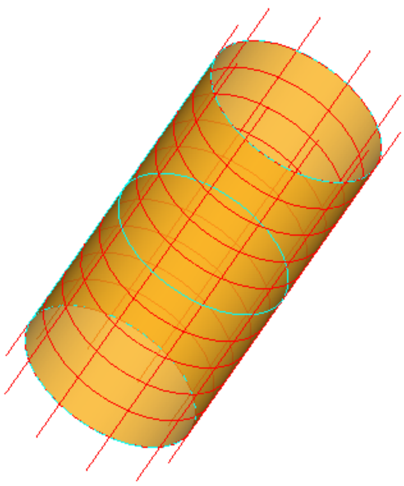


Figure 39: Arguments

9.4.2 Example 2

Splitting a plate by the set of cylinders:

```
# draw script for reproducing:
```

```
bclearobjects
bcleartools

box plate 100 100 1
baddobjects plate

pcylinder p 1 11
compound cylinders
for {set i 0} {$i < 101} {incr i 5} {
  for {set j 0} {$j < 101} {incr j 5} {
    copy p p1;
    ttranslate p1 $i $j -5;
    add p1 cylinders
  }
}
baddtools cylinders

bfillds
bsplit result
```

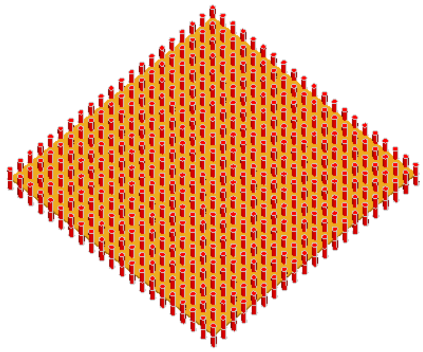


Figure 41: Arguments

9.4.3 Example 3

Splitting shell hull by the planes:

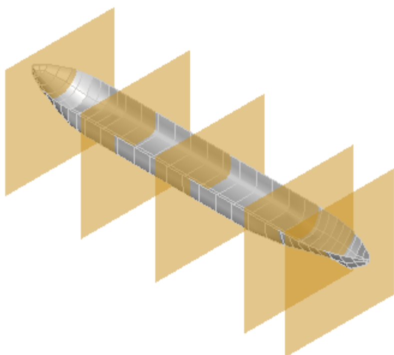


Figure 43: Arguments

10 Boolean Operations Algorithm

10.1 Arguments

- The arguments of BOA are shapes in terms of *TopoDS_Shape*. The main requirements for the arguments are described in the Data Structure
- There are two groups of arguments in BOA:
  - Objects *(S1=S11, S12, ...)*;
  - Tools *(S2=S21, S22, ...)*.
- The following table contains the values of dimension for different types of arguments:

No	Type of Argument	Index of Type	Dimension
1	COMPOUND	0	One of 0, 1, 2, 3
2	COMPSOLID	1	3
3	SOLID	2	3
4	SHELL	3	2
5	FACE	4	2
6	WIRE	5	1
7	EDGE	6	1
8	VERTEX	7	0

- For Boolean operation Fuse all arguments should have equal dimensions.
- For Boolean operation Cut the minimal dimension of *S2* should not be less than the maximal dimension of *S1*.
- For Boolean operation Common the arguments can have any dimension.

10.2 Results. General Rules

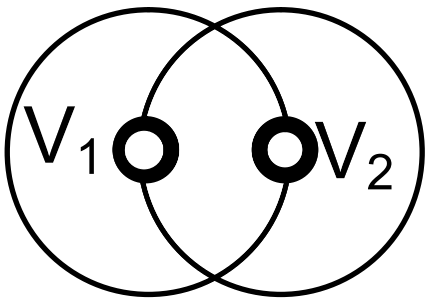
- The result of the Boolean operation is a compound (if defined). Each sub-shape of the compound has shared sub-shapes in accordance with interferences between the arguments.
- The content of the result depends on the type of the operation (Common, Fuse, Cut12, Cut21) and the dimensions of the arguments.
- The result of the operation Fuse is defined for arguments *S1* and *S2* that have the same dimension value : *Dim(S1)=Dim(S2)*. If the arguments have different dimension values the result of the operation Fuse is not defined. The dimension of the result is equal to the dimension of the arguments. For example, it is impossible to fuse an edge and a face.
- The result of the operation Fuse for arguments *S1* and *S2* contains the parts of arguments that have states **OUT** relative to the opposite arguments.
- The result of the operation Fuse for arguments *S1* and *S2* having dimension value 3 (Solids) is refined by removing all possible internal faces to provide minimal number of solids.
- The result of the operation Common for arguments *S1* and *S2* is defined for all values of the dimensions of the arguments. The result can contain shapes of different dimensions, but the minimal dimension of the result will be equal to the minimal dimension of the arguments. For example, the result of the operation Common between edges cannot be a vertex.
- The result of the operation Common for the arguments *S1* and *S2* contains the parts of the argument that have states **IN** and **ON** relative to the opposite argument.

- The result of the operation Cut is defined for arguments *S1* and *S2* that have values of dimensions *Dim(↩ S2)* that should not be less than *Dim(S1)*. The result can contain shapes of different dimensions, but the minimal dimension of the result will be equal to the minimal dimension of the objects *Dim(S1)*. The result of the operation *Cut12* is not defined for other cases. For example, it is impossible to cut an edge from a solid, because a solid without an edge is not defined.
- The result of the operation *Cut12* for arguments *S1* and *S2* contains the parts of argument *S1* that have state **OUT** relative to the opposite argument *S2*.
- The result of the operation *Cut21* for arguments *S1* and *S2* contains the parts of argument *S2* that have state **OUT** relative to the opposite argument *S1*.
- For the arguments of collection type (WIRE, SHELL, COMPSOLID) the type will be passed in the result. For example, the result of Common operation between Shell and Wire will be a compound containing Wire.
- For the arguments of collection type (WIRE, SHELL, COMPSOLID) containing overlapping parts the overlapping parts passed into result will be repeated for each container from the input shapes containing such parts. The containers completely included in other containers will be avoided in the result.
- For the arguments of collection type (WIRE, SHELL, COMPSOLID) the containers included into result will have the same orientation as the original containers from arguments. In case of duplication its orientation will be defined by the orientation of the first container in arguments. Each container included into result will have coherent orientation of its sub-shapes.
- The result of the operation Fuse for the arguments of collection type (WIRE, SHELL) will consist of the shapes of the same collection type. The overlapping parts (EDGES/FACES) will be shared among containers, but duplicating containers will be avoided in the result. For example, the result of Fuse operation between two fully coinciding wires will be one wire, but the result of Fuse operation between two partially coinciding wires will be two wires sharing coinciding edges.
- The result of the operation Fuse for the arguments of type COMPSOLID will consist of the compound containing COMPSOLIDs created from connexity blocks of fused solids.
- The result of the operation Common for the arguments of collection type (WIRE, SHELL, COMPSOLID) will consist of the unique containers containing the overlapping parts. For example, the result of Common operation between two fully overlapping wires will be one wire containing all splits of edges. The number of wires in the result of Common operation between two partially overlapping wires will be equal to the number of connexity blocks of overlapping edges.

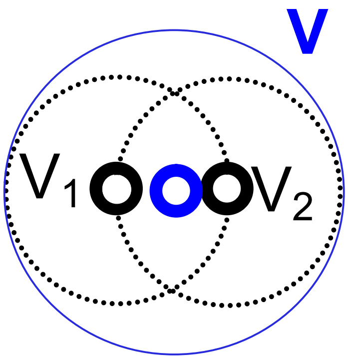
10.3 Examples

10.3.1 Case 1: Two Vertices

Let us consider two interfering vertices *V1* and *V2*:



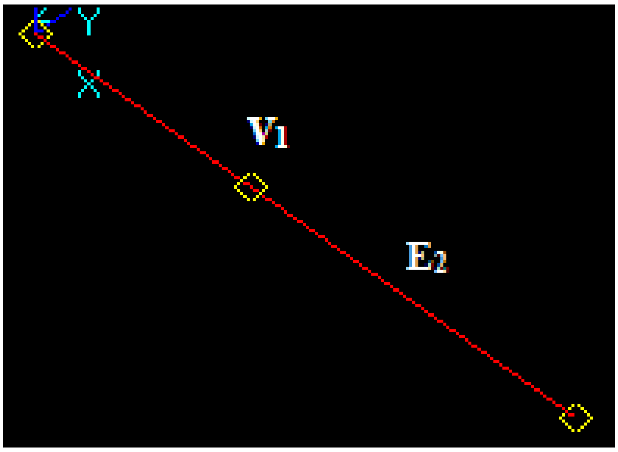
- The result of *Fuse* operation is the compound that contains new vertex *V*.



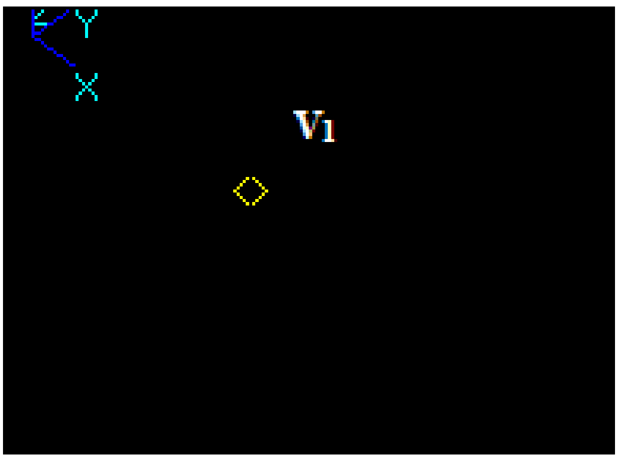
- The result of *Common* operation is a compound containing new vertex *V*.
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is an empty compound.

10.3.2 Case 2: A Vertex and an Edge

Let us consider vertex *V1* and the edge *E2*, that intersect in a 3D point:



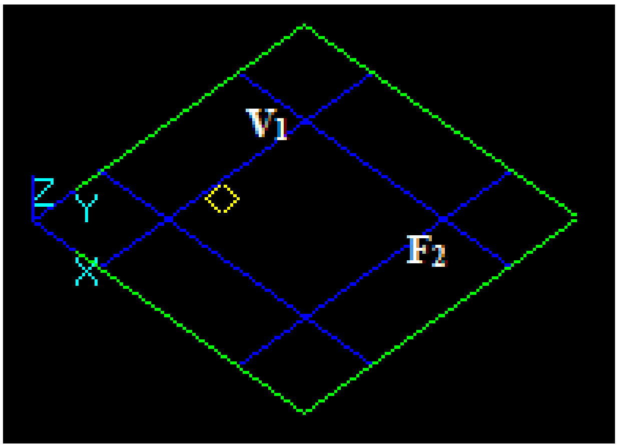
- The result of *Fuse* operation is result is not defined because the dimension of the vertex (0) is not equal to the dimension of the edge (1).
- The result of *Common* operation is a compound containing vertex V_1 as the argument V_1 has a common part with edge *E2*.



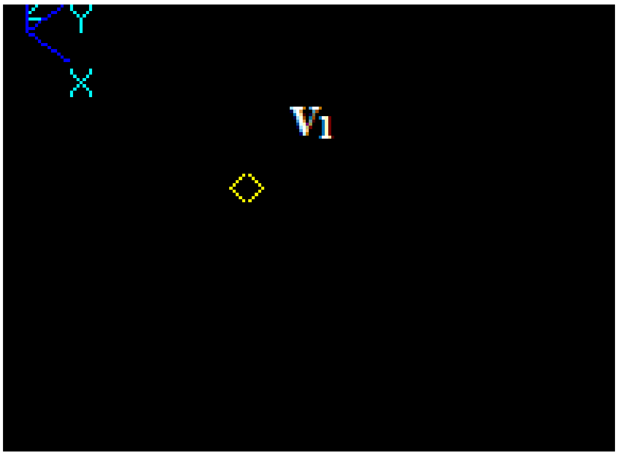
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is not defined because the dimension of the vertex (0) is less than the dimension of the edge (1).

10.3.3 Case 3: A Vertex and a Face

Let us consider vertex *V1* and face *F2*, that intersect in a 3D point:



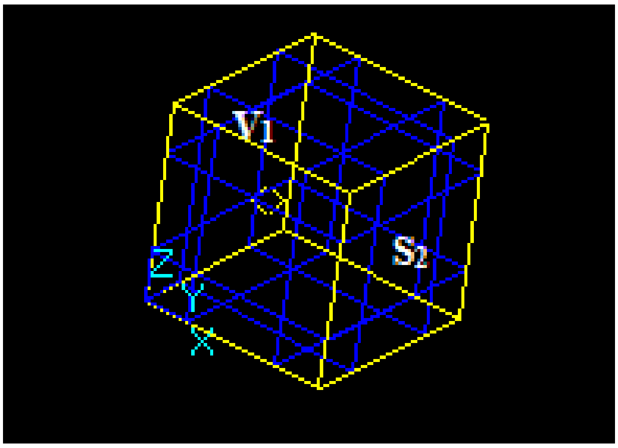
- The result of *Fuse* operation is not defined because the dimension of the vertex (0) is not equal to the dimension of the face (2).
- The result of *Common* operation is a compound containing vertex V_1 as the argument V_1 has a common part with face *F2*.



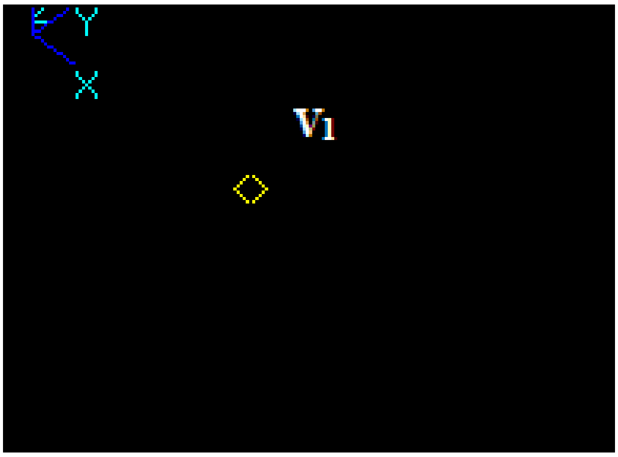
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is not defined because the dimension of the vertex (0) is less than the dimension of the face (2).

10.3.4 Case 4: A Vertex and a Solid

Let us consider vertex *V1* and solid *S2*, that intersect in a 3D point:



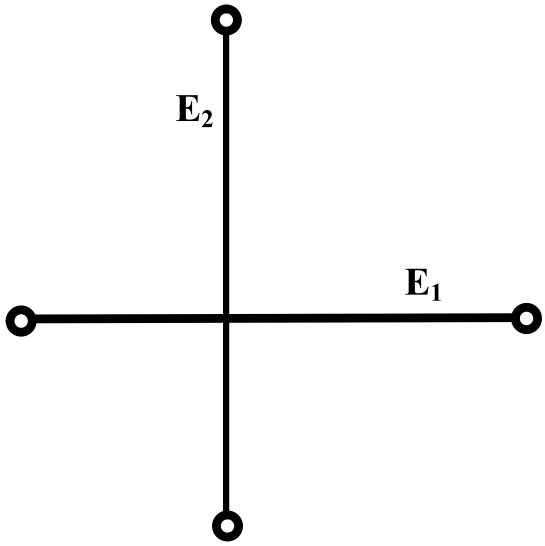
- The result of *Fuse* operation is not defined because the dimension of the vertex (0) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing vertex V_1 as the argument V_1 has a common part with solid *S2*.



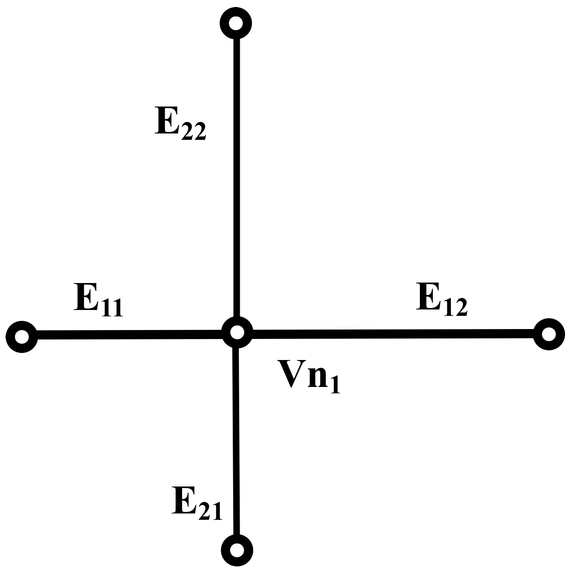
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is not defined because the dimension of the vertex (0) is less than the dimension of the solid (3).

10.3.5 Case 5: Two edges intersecting at one point

Let us consider edges *E1* and *E2* that intersect in a 3D point:

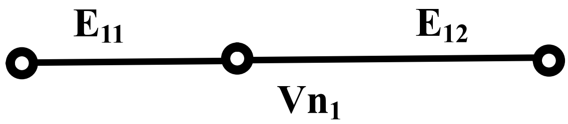


- The result of *Fuse* operation is a compound containing split parts of arguments i.e. 4 new edges *E11, E12, E21*, and *E22*. These edges have one shared vertex *Vn1*. In this case:
  - argument edge *E1* has resulting split edges *E11* and *E12* (image of *E1*);
  - argument edge *E2* has resulting split edges *E21* and *E22* (image of *E2*).



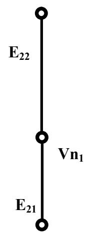
- The result of *Common* operation is an empty compound because the dimension (0) of the common part between the edges (vertex) is less than the dimension of the arguments (1).
- The result of *Cut12* operation is a compound containing split parts of the argument *E1*, i.e. 2 new edges *E11* and *E12*. These edges have one shared vertex *Vn1*.

In this case the argument edge *E1* has resulting split edges *E11* and *E12* (image of *E1*).



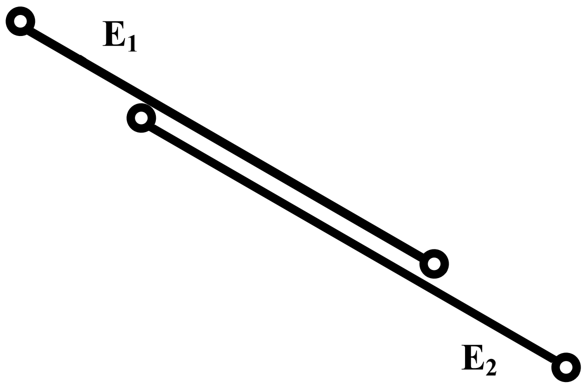
- The result of *Cut21* operation is a compound containing split parts of the argument *E2*, i.e. 2 new edges *E21* and *E12*. These edges have one shared vertex *Vn1*.

In this case the argument edge *E2* has resulting split edges *E21* and *E22* (image of *E2*).

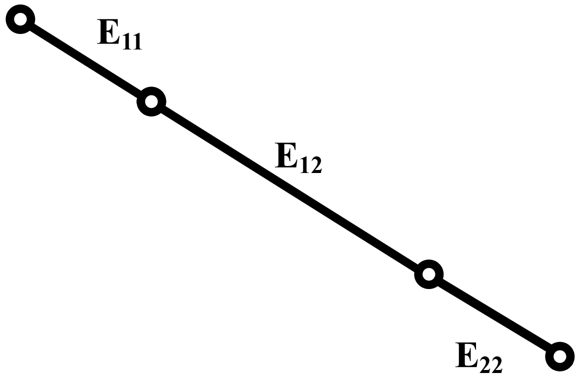


10.3.6 Case 6: Two edges having a common block

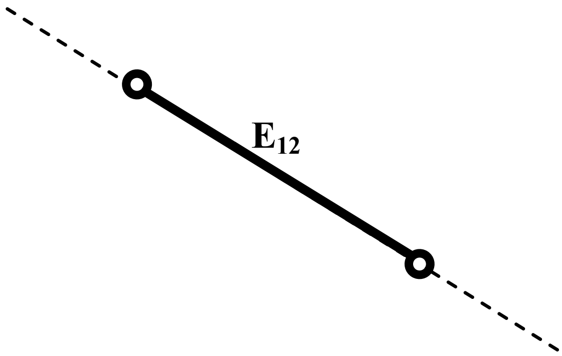
Let us consider edges *E1* and *E2* that have a common block:



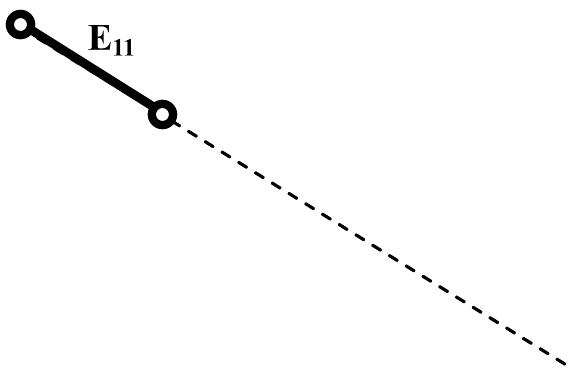
- The result of *Fuse* operation is a compound containing split parts of arguments i.e. 3 new edges *E11*, *E12* and *E22*. These edges have two shared vertices. In this case:
  - argument edge *E1* has resulting split edges *E11* and *E12* (image of *E1*);
  - argument edge *E2* has resulting split edges *E21* and *E22* (image of *E2*);
  - edge *E12* is common for the images of *E1* and *E2*.



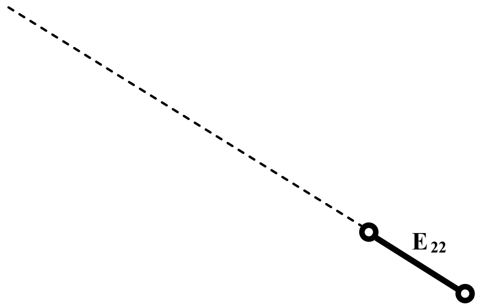
- The result of *Common* operation is a compound containing split parts of arguments i.e. 1 new edge *E12*. In this case edge *E12* is common for the images of *E1* and *E2*. The common part between the edges (edge) has the same dimension (1) as the dimension of the arguments (1).



- The result of *Cut12* operation is a compound containing a split part of argument *E1*, i.e. new edge *E11*.

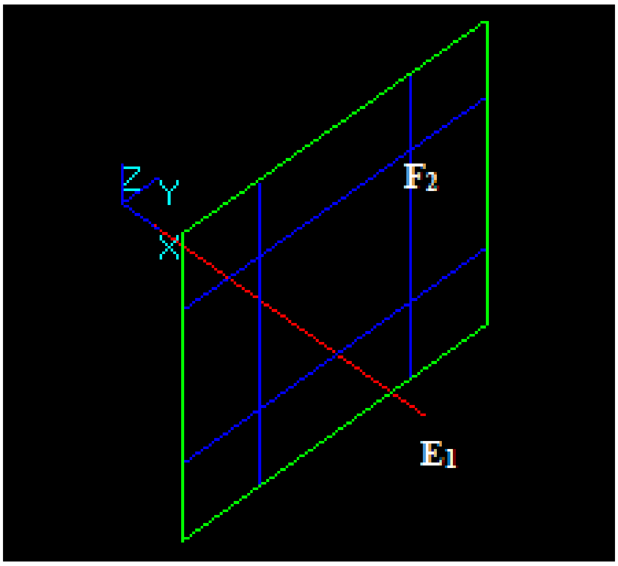


- The result of *Cut21* operation is a compound containing a split part of argument *E2*, i.e. new edge *E22*.



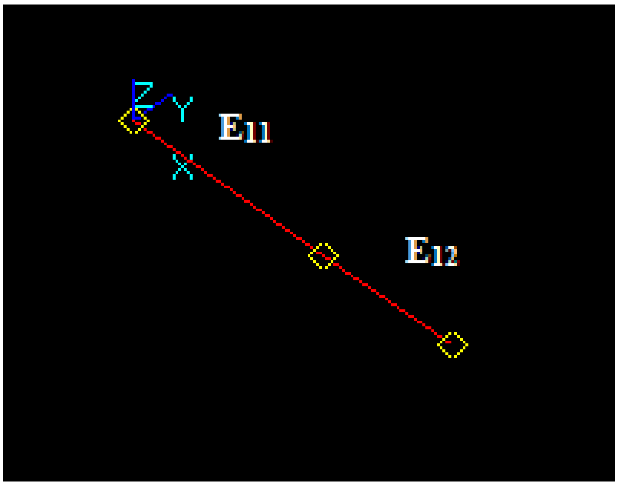
10.3.7 Case 7: An Edge and a Face intersecting at a point

Let us consider edge *E1* and face *F2* that intersect at a 3D point:



- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the face (2).
- The result of *Common* operation is an empty compound because the dimension (0) of the common part between the edge and face (vertex) is less than the dimension of the arguments (1).
- The result of *Cut12* operation is a compound containing split parts of the argument *E1*, i.e. 2 new edges *E11* and *E12*.

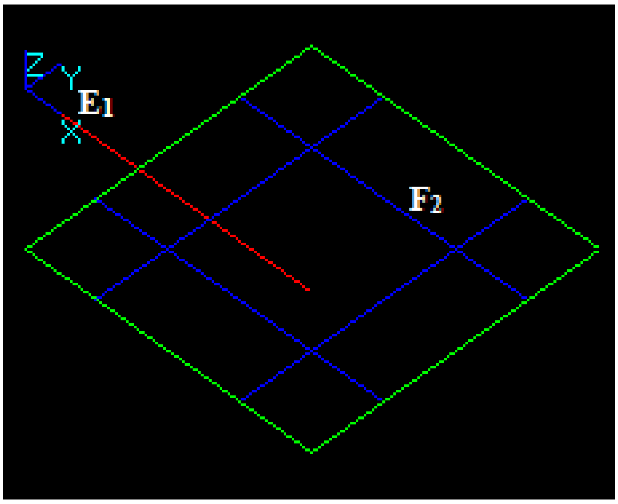
In this case the argument edge *E1* has no common parts with the face *F2* so the whole image of *E1* is in the result.



- The result of *Cut21* operation is not defined because the dimension of the edge (1) is less than the dimension of the face (2).

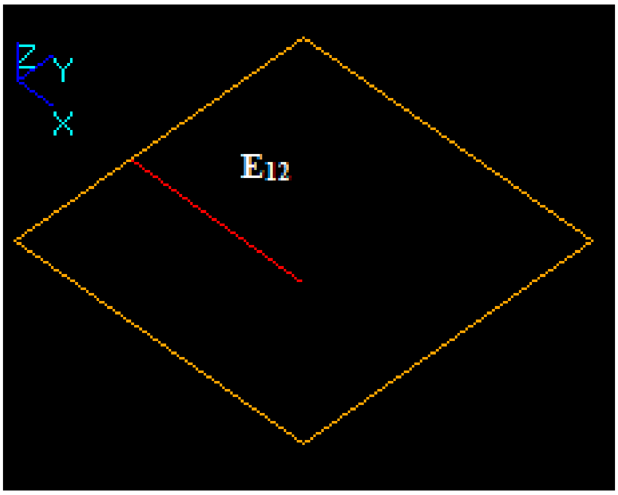
10.3.8 Case 8: A Face and an Edge that have a common block

Let us consider edge *E1* and face *F2* that have a common block:



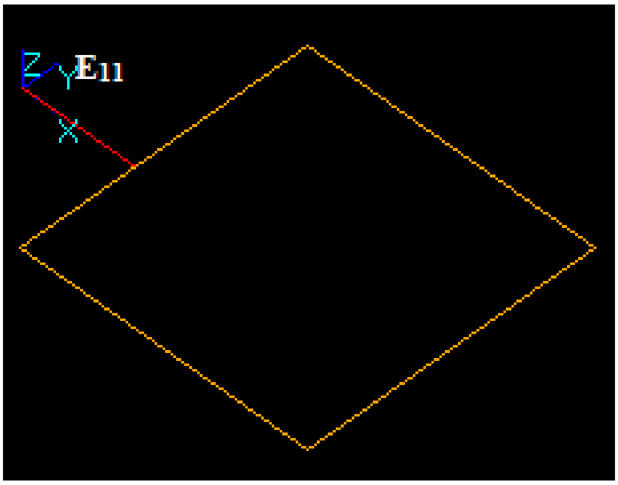
- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the face (2).
- The result of *Common* operation is a compound containing a split part of the argument *E1*, i.e. new edge *E12*.

In this case the argument edge *E1* has a common part with face *F2* so the corresponding part of the image of *E1* is in the result. The yellow square is not a part of the result. It only shows the place of *F2*.



- The result of *Cut12* operation is a compound containing split part of the argument *E1*, i.e. new edge *E11*.

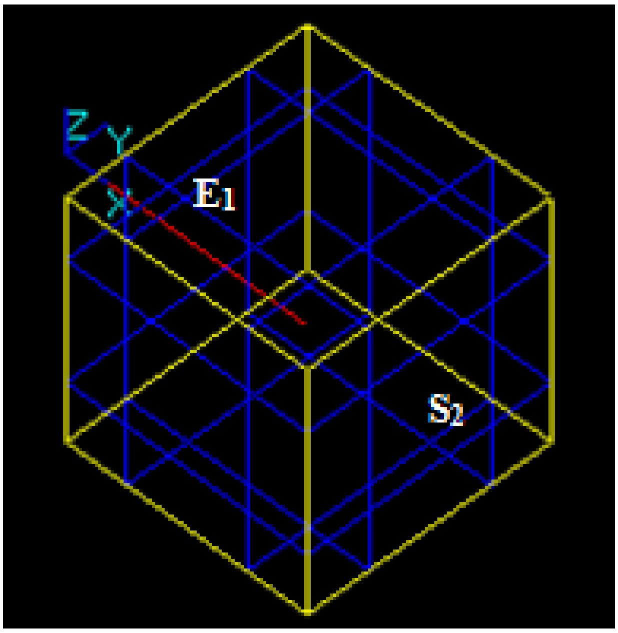
In this case the argument edge *E1* has a common part with face *F2* so the corresponding part is not included into the result. The yellow square is not a part of the result. It only shows the place of F2.



- The result of *Cut21* operation is not defined because the dimension of the edge (1) is less than the dimension of the face (2).

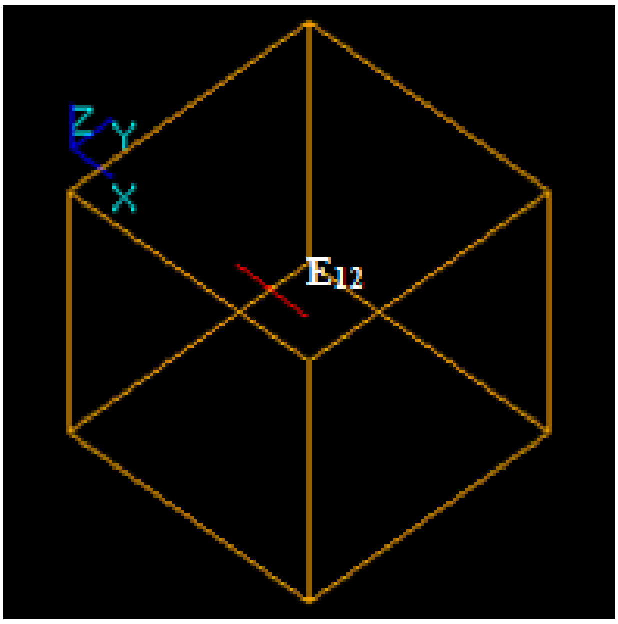
10.3.9 Case 9: An Edge and a Solid intersecting at a point

Let us consider edge *E1* and solid *S2* that intersect at a point:



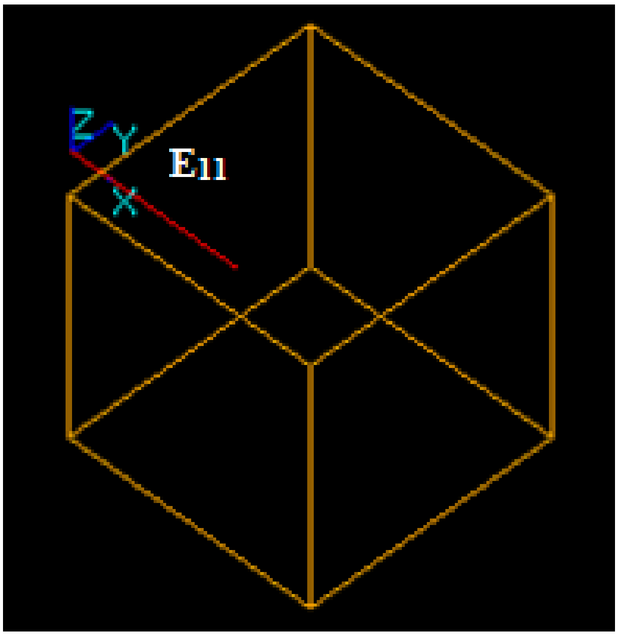
- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing a split part of the argument *E1*, i.e. new edge *E12*.

In this case the argument edge *E1* has a common part with solid *S2* so the corresponding part of the image of *E1* is in the result. The yellow square is not a part of the result. It only shows the place of *S2*.



- The result of *Cut12* operation is a compound containing split part of the argument *E1*, i.e. new edge *E11*.

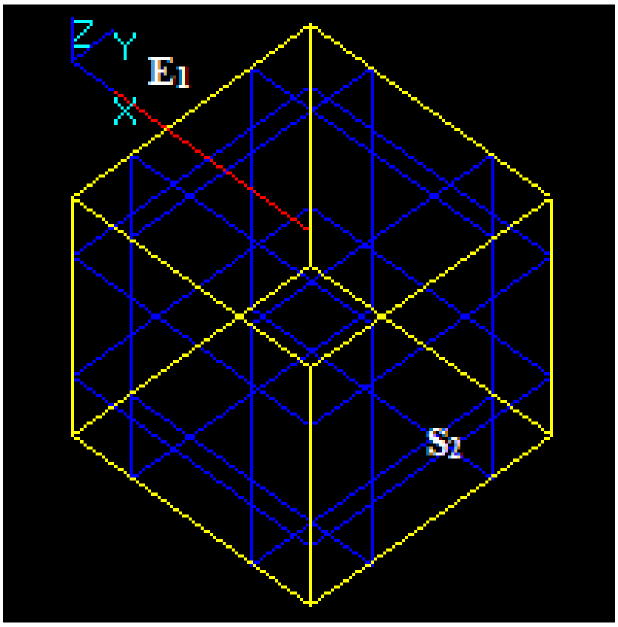
In this case the argument edge *E1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow square is not a part of the result. It only shows the place of *S2*.



- The result of *Cut21* operation is not defined because the dimension of the edge (1) is less than the dimension of the solid (3).

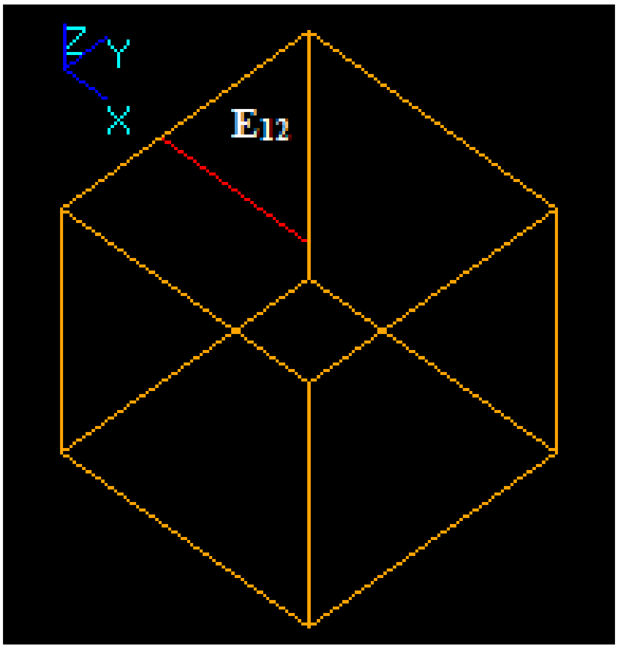
10.3.10 Case 10: An Edge and a Solid that have a common block

Let us consider edge *E1* and solid *S2* that have a common block:



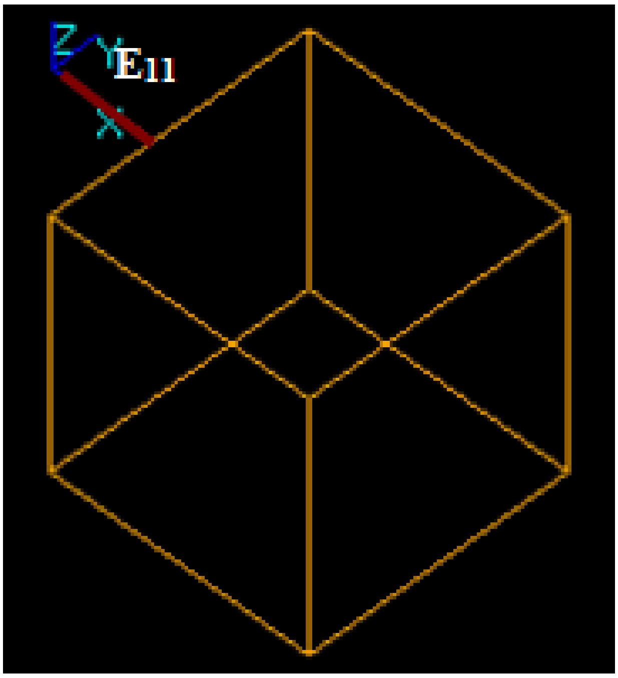
- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing a split part of the argument *E1*, i.e. new edge *E12*.

In this case the argument edge *E1* has a common part with solid *S2* so the corresponding part of the image of *E1* is in the result. The yellow square is not a part of the result. It only shows the place of *S2*.



- The result of *Cut12* operation is a compound containing split part of the argument *E1*, i.e. new edge *E11*.

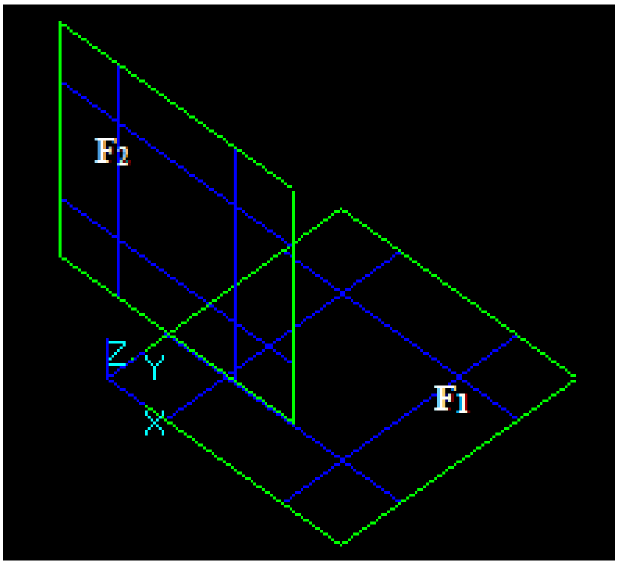
In this case the argument edge *E1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow square is not a part of the result. It only shows the place of *S2*.



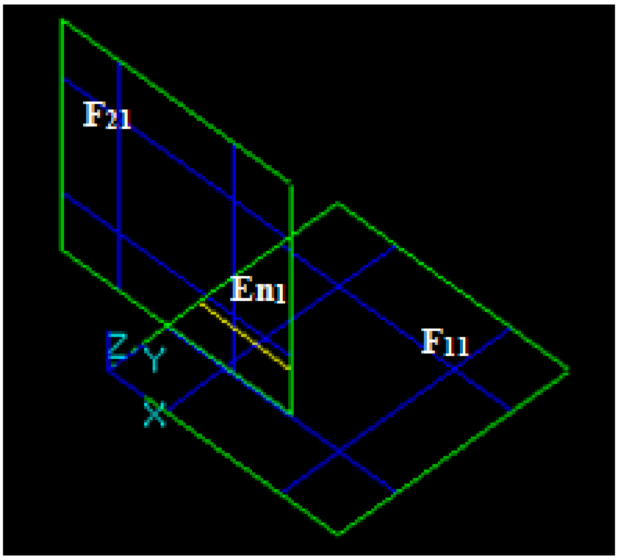
- The result of *Cut21* operation is not defined because the dimension of the edge (1) is less than the dimension of the solid (3).

10.3.11 Case 11: Two intersecting faces

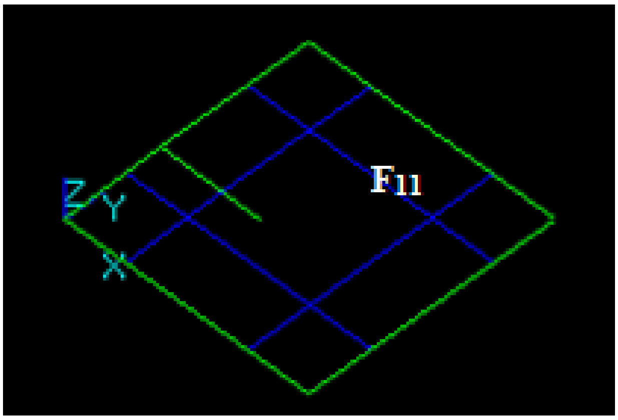
Let us consider two intersecting faces *F1* and *F2*:



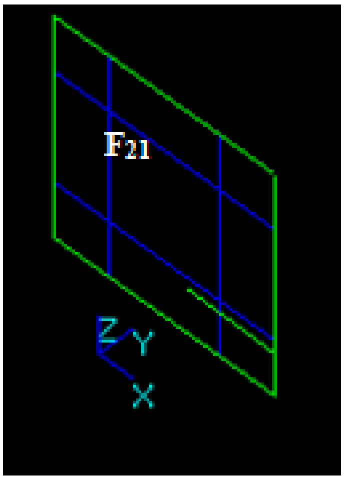
- The result of *Fuse* operation is a compound containing split parts of arguments i.e. 2 new faces *F11* and *F21*. These faces have one shared edge *En1*.



- The result of *Common* operation is an empty compound because the dimension (1) of the common part between *F1* and *F2* (edge) is less than the dimension of arguments (2).
- The result of *Cut12* operation is a compound containing split part of the argument *F1*, i.e. new face *F11*.

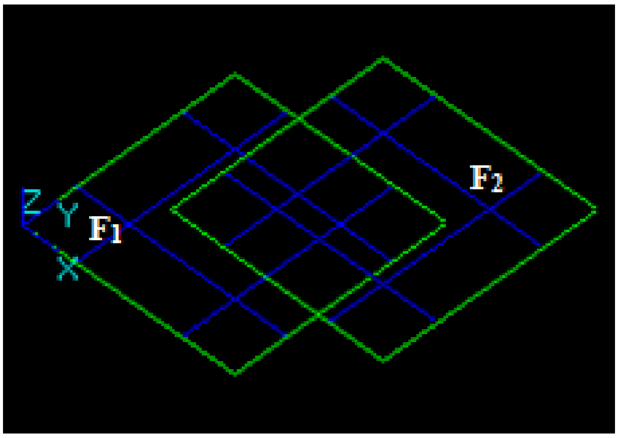


- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*.

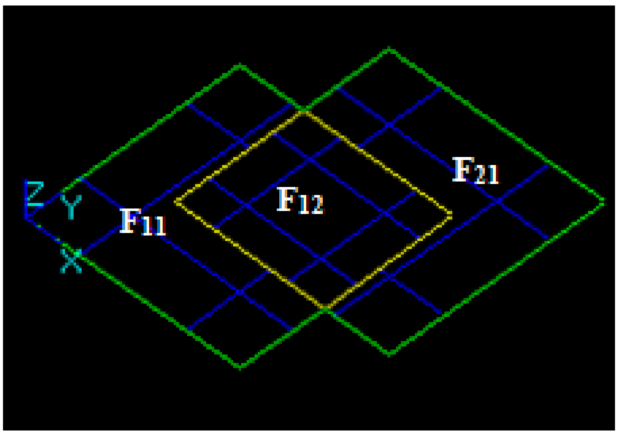


10.3.12 Case 12: Two faces that have a common part

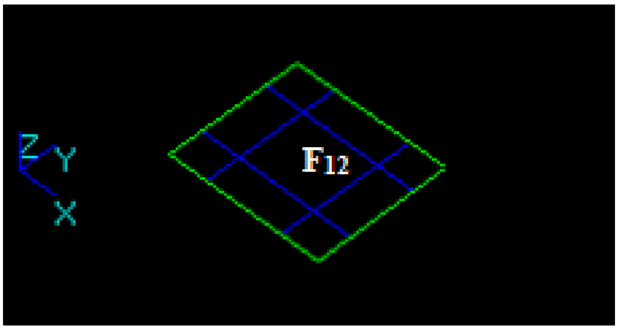
Let us consider two faces *F1* and *F2* that have a common part:



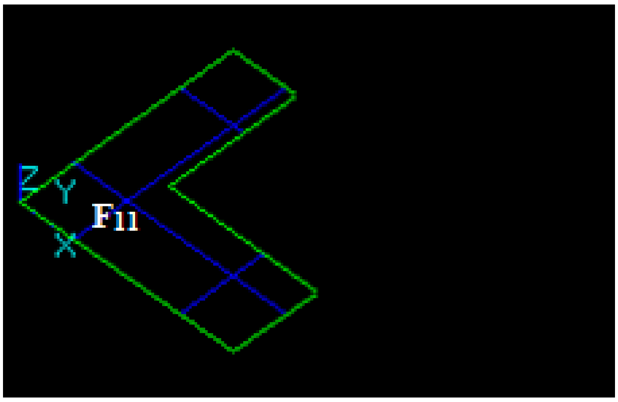
- The result of *Fuse* operation is a compound containing split parts of arguments, i.e. 3 new faces: *F11*, *F12* and *F22*. These faces are shared through edges In this case:
  - the argument edge *F1* has resulting split faces *F11* and *F12* (image of *F1*)
  - the argument face *F2* has resulting split faces *F12* and *F22* (image of *F2*)
  - the face *F12* is common for the images of *F1* and *F2*.



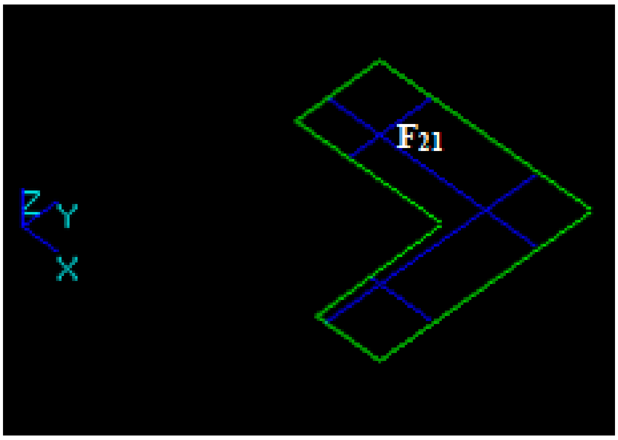
- The result of *Common* operation is a compound containing split parts of arguments i.e. 1 new face *F12*. In this case: face *F12* is common for the images of *F1* and *F2*. The common part between the faces (face) has the same dimension (2) as the dimension of the arguments (2).



- The result of *Cut12* operation is a compound containing split part of the argument *F1*, i.e. new face *F11*.

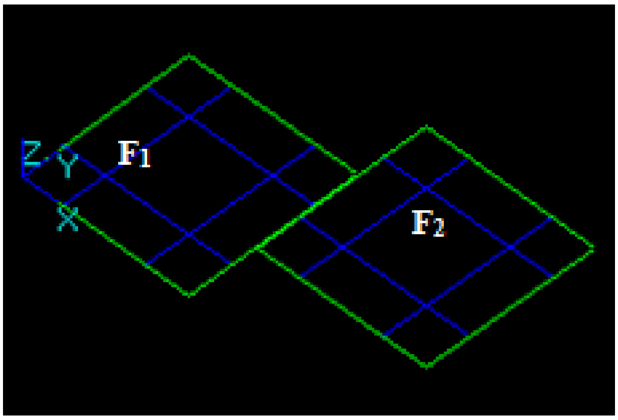


- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*.

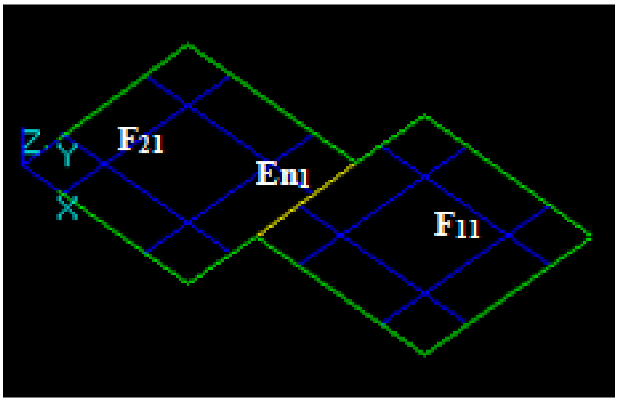


10.3.13 Case 13: Two faces that have a common edge

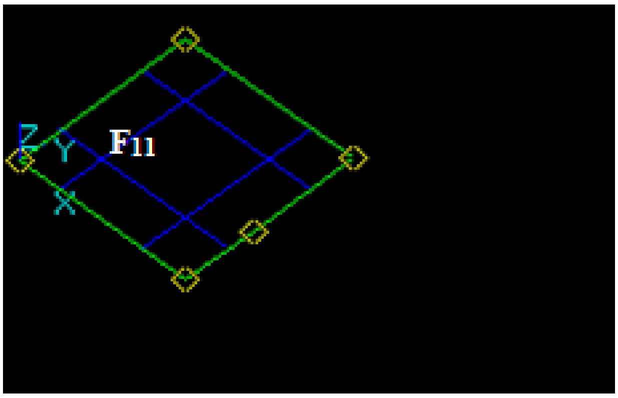
Let us consider two faces *F1* and *F2* that have a common edge:



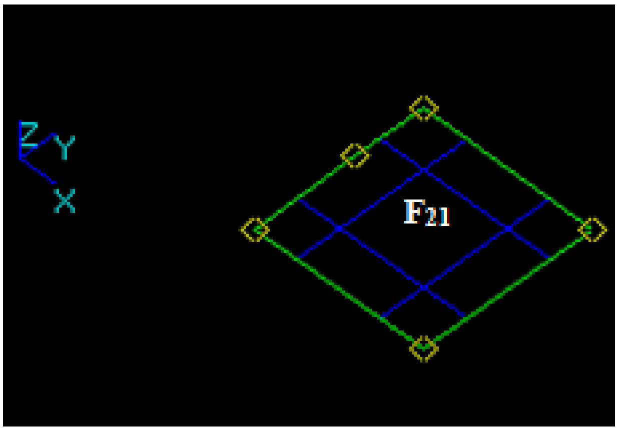
* The result of *Fuse* operation is a compound containing split parts of arguments, i.e. 2 new faces: *F11* and *F21*. These faces have one shared edge *En1*.



* The result of *Common* operation is an empty compound because the dimension (1) of the common part between *F1* and *F2* (edge)is less than the dimension of the arguments (2)
* The result of *Cut12* operation is a compound containing split part of the argument *F1*, i.e. new face *F11*. The vertices are shown just to clarify the fact that the edges are spitted.

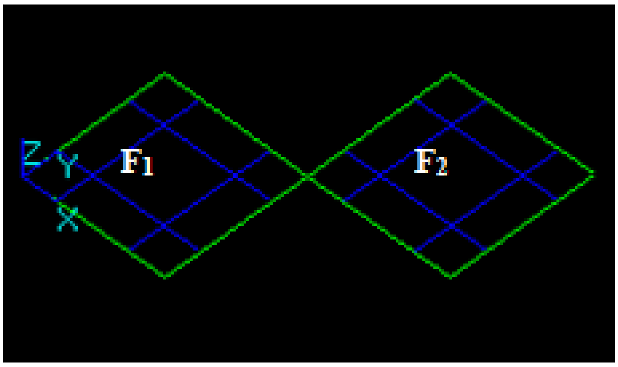


* The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*. The vertices are shown just to clarify the fact that the edges are spitted.

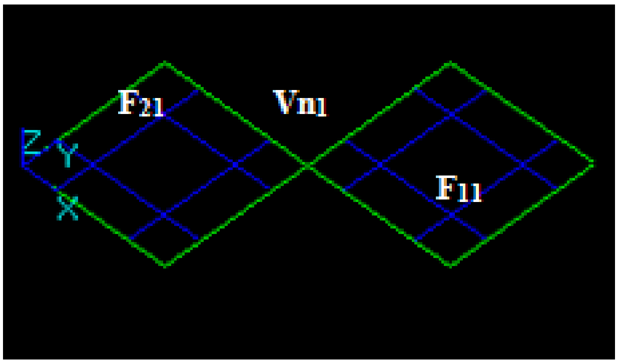


10.3.14 Case 14: Two faces that have a common vertex

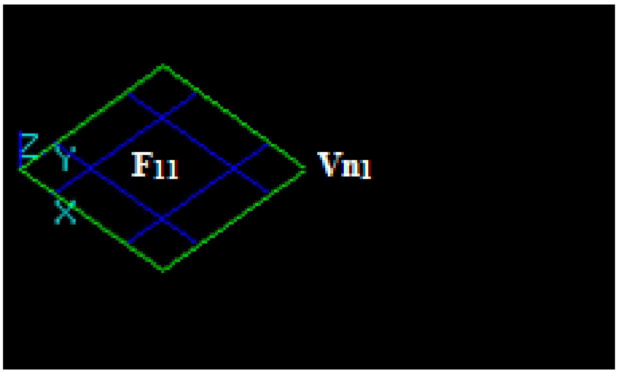
Let us consider two faces *F1* and *F2* that have a common vertex:



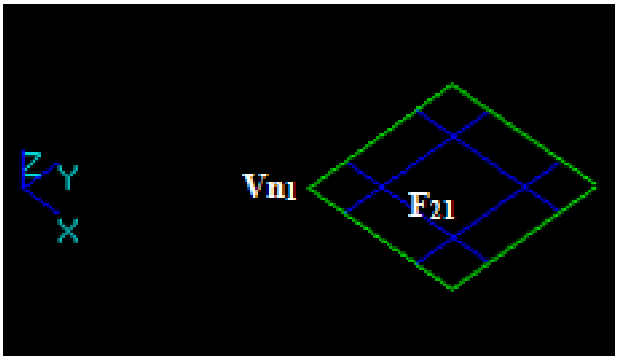
- The result of *Fuse* operation is a compound containing split parts of arguments, i.e. 2 new faces: *F11* and *F21*. These faces have one shared vertex *Vn1*.



- The result of *Common* operation is an empty compound because the dimension (0) of the common part between *F1* and *F2* (vertex) is less than the dimension of the arguments (2)
- The result of *Cut12* operation is a compound containing split part of the argument *F1*, i.e. new face *F11*.

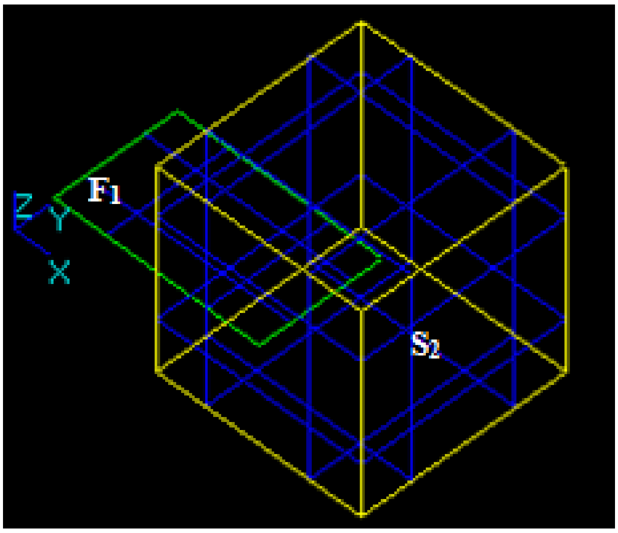


- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*.

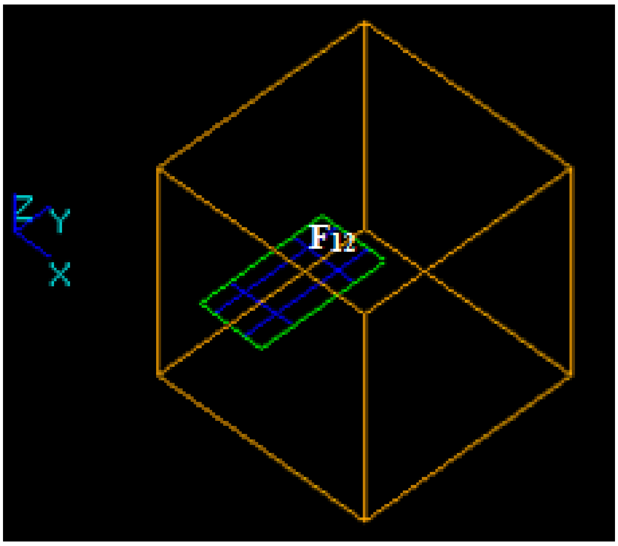


10.3.15 Case 15: A Face and a Solid that have an intersection curve.

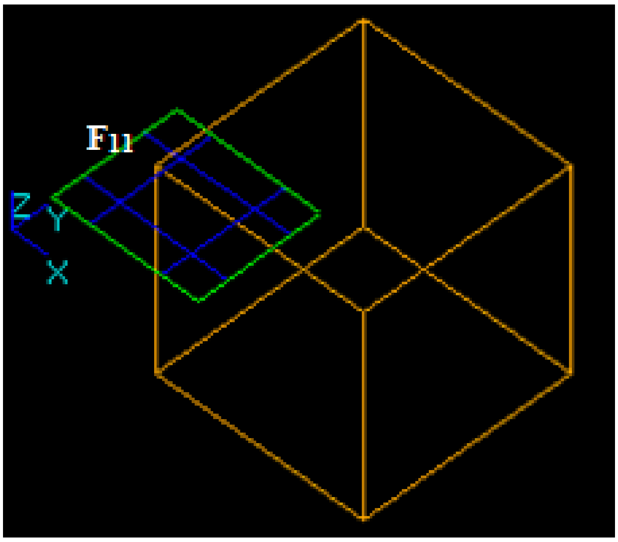
Let us consider face *F1* and solid *S2* that have an intersection curve:



- The result of *Fuse* operation is not defined because the dimension of the face (2) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing split part of the argument *F1*. In this case the argument face *F1* has a common part with solid *S2*, so the corresponding part of the image of *F1* is in the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



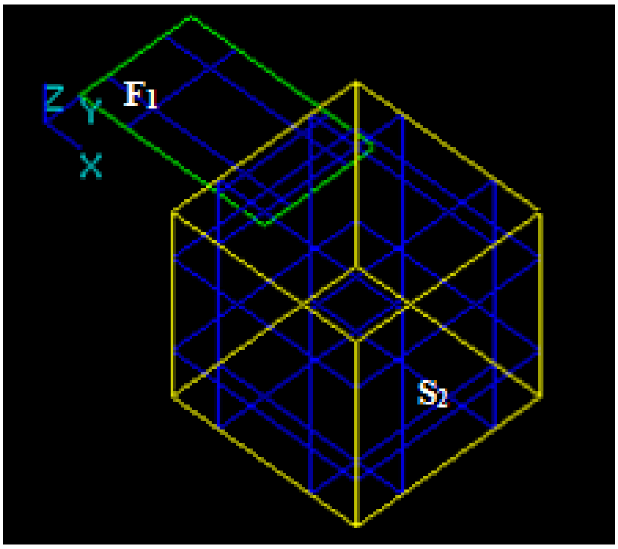
* The result of *Cut12* operation is a compound containing split part of the argument *F1*. In this case argument face *F1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



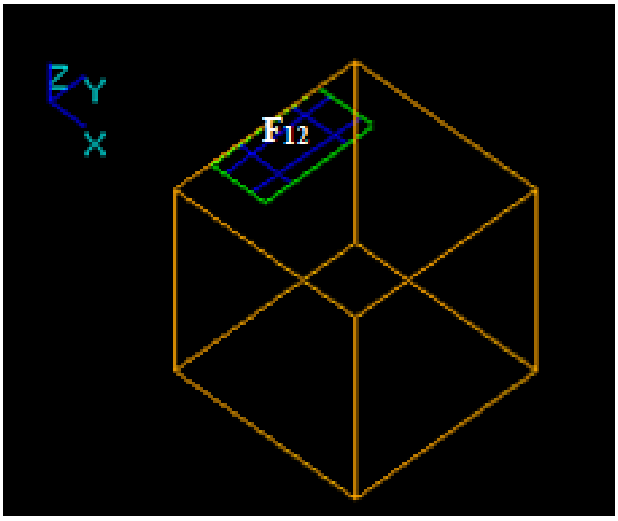
* The result of *Cut21* operation is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

10.3.16 Case 16: A Face and a Solid that have overlapping faces.

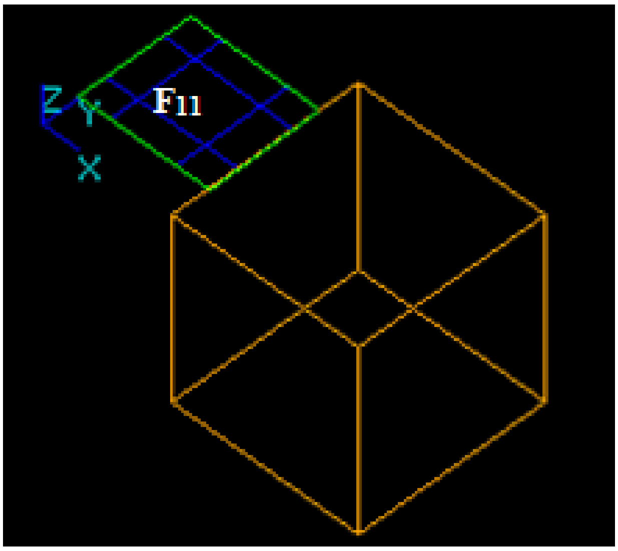
Let us consider face *F1* and solid *S2* that have overlapping faces:



- The result of *Fuse* operation is not defined because the dimension of the face (2) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing split part of the argument *F1*. In this case the argument face *F1* has a common part with solid *S2*, so the corresponding part of the image of *F1* is included in the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



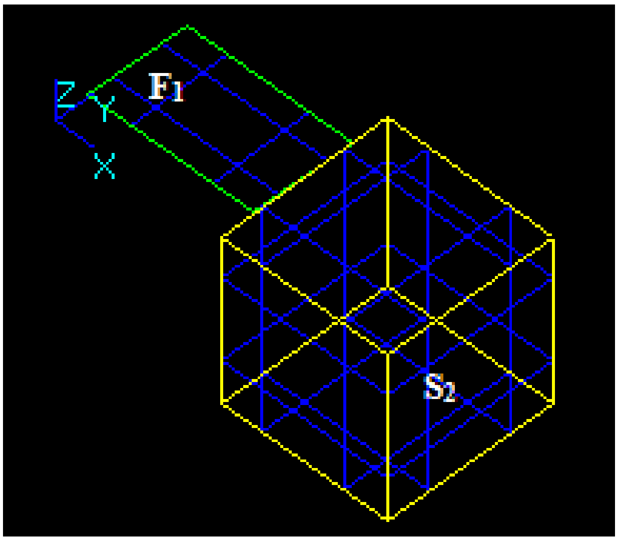
- The result of *Cut12* operation is a compound containing split part of the argument *F1*. In this case argument face *F1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



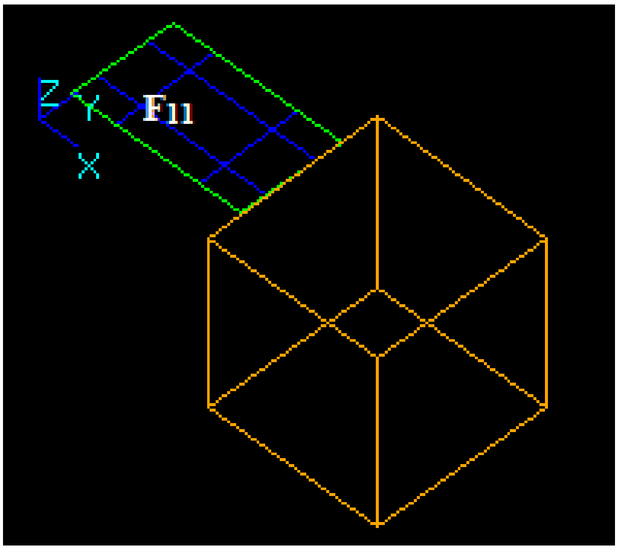
- The result of *Cut21* operation is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

10.3.17 Case 17: A Face and a Solid that have overlapping edges.

Let us consider face *F1* and solid *S2* that have overlapping edges:



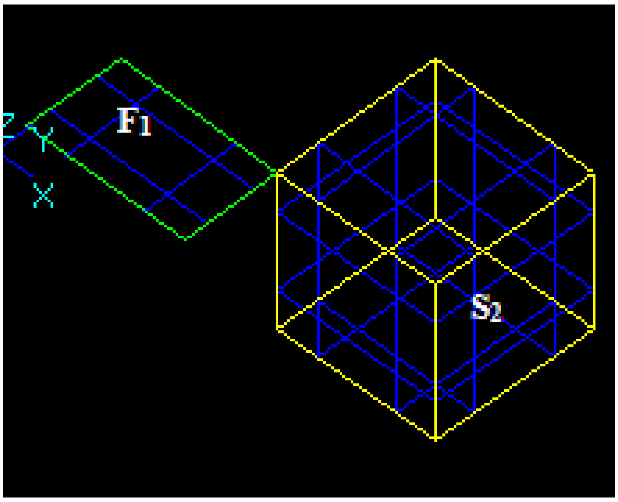
- The result of *Fuse* operation is not defined because the dimension of the face (2) is not equal to the dimension of the solid (3).
- The result of *Common* operation is an empty compound because the dimension (1) of the common part between *F1* and *S2* (edge) is less than the lower dimension of the arguments (2).
- The result of *Cut12* operation is a compound containing split part of the argument *F1*. In this case argument face *F1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



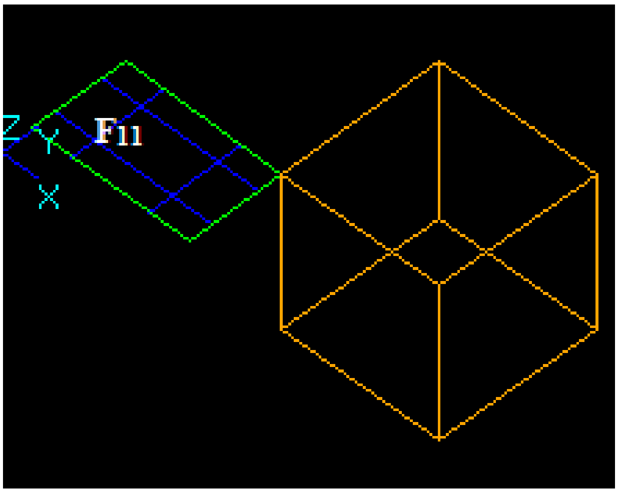
- The result of *Cut21* operation is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

10.3.18 Case 18: A Face and a Solid that have overlapping vertices.

Let us consider face *F1* and solid *S2* that have overlapping vertices:



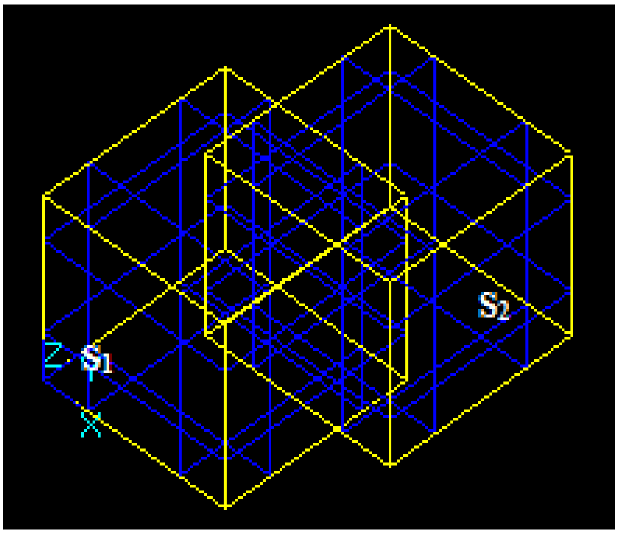
- The result of *Fuse* operation is not defined because the dimension of the face (2) is not equal to the dimension of the solid (3).
- The result of *Common* operation is an empty compound because the dimension (1) of the common part between *F1* and *S2* (vertex) is less than the lower dimension of the arguments (2).
- The result of *Cut12* operation is a compound containing split part of the argument *F1*. In this case argument face *F1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



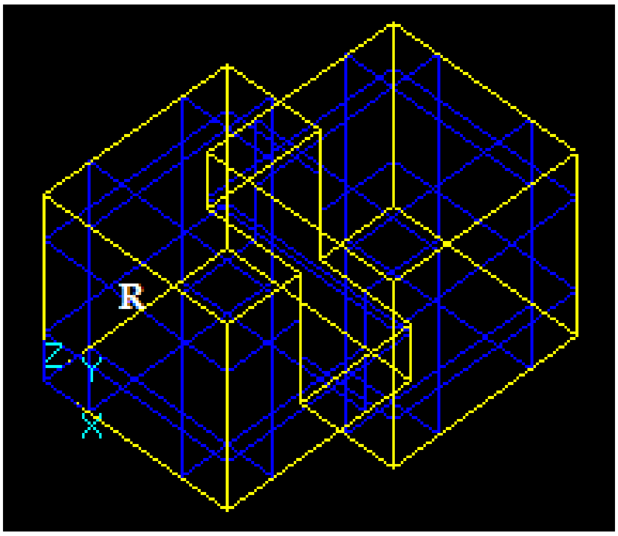
- The result of *Cut21* operation is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

10.3.19 Case 19: Two intersecting Solids.

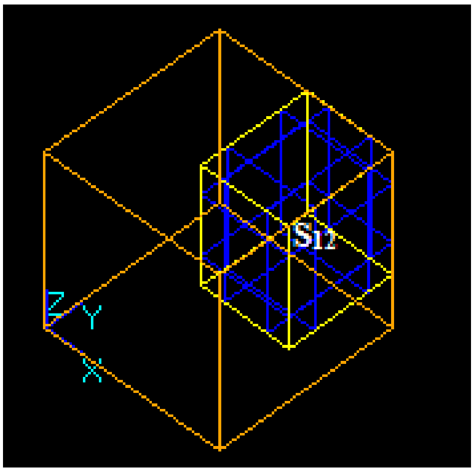
Let us consider two intersecting solids *S1* and *S2*:



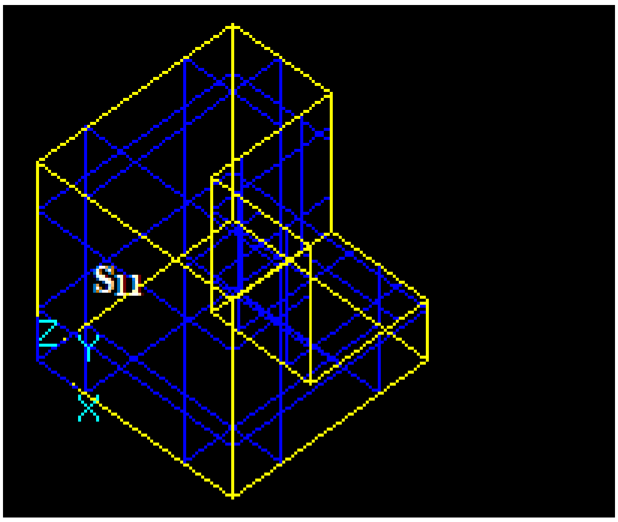
- The result of *Fuse* operation is a compound composed from the split parts of arguments *S11, S12* and *S22 (Cut12, Common, Cut21)*. All inner webs are removed, so the result is one new solid *R*.



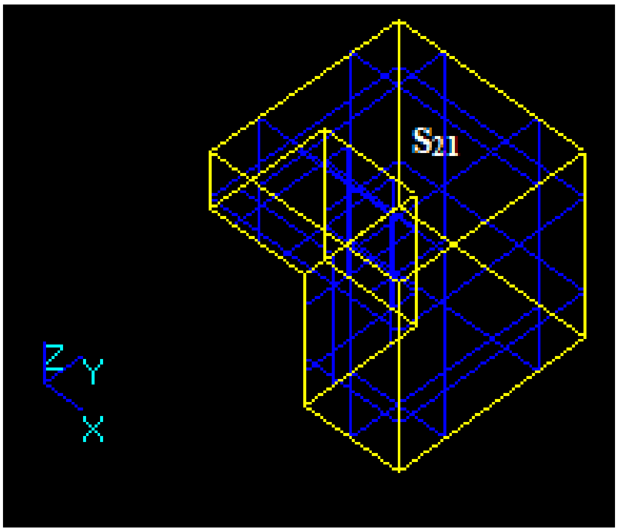
- The result of *Common* operation is a compound containing split parts of arguments i.e. one new solid *S12*. In this case solid *S12* is common for the images of *S1* and *S2*. The common part between the solids (solid) has the same dimension (3) as the dimension of the arguments (3). The yellow contour is not a part of the result. It only shows the place of *S1*.



- The result of *Cut12* operation is a compound containing split part of the argument *S1*, i.e. 1 new solid *S11*.

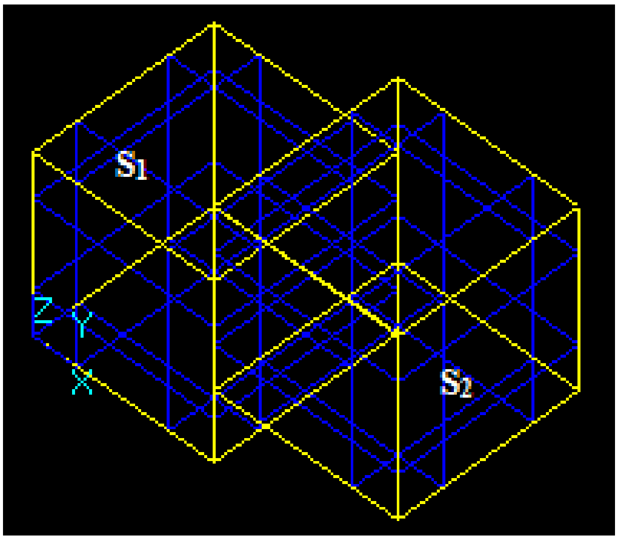


- The result of *Cut21* operation is a compound containing split part of the argument *S2*, i.e. 1 new solid *S21*.

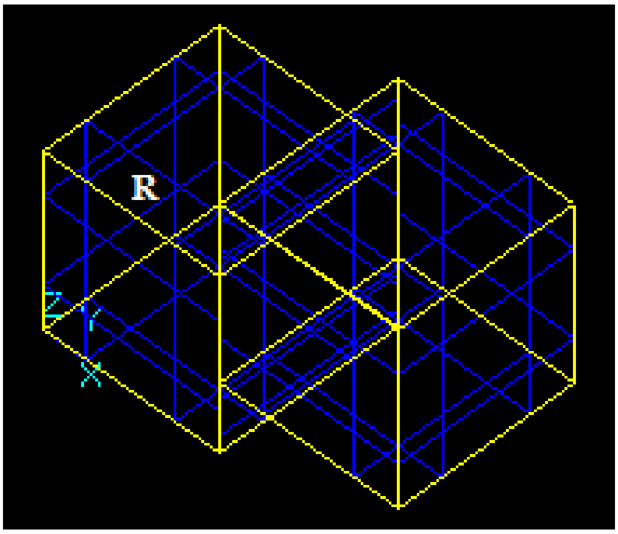


10.3.20 Case 20: Two Solids that have overlapping faces.

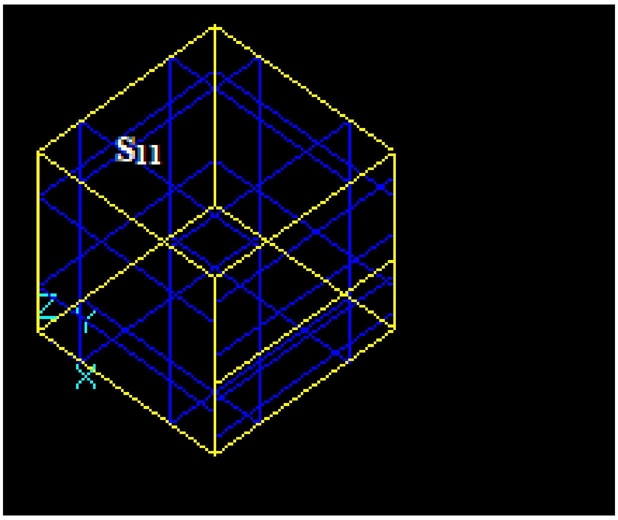
Let us consider two solids *S1* and *S2* that have a common part on face:



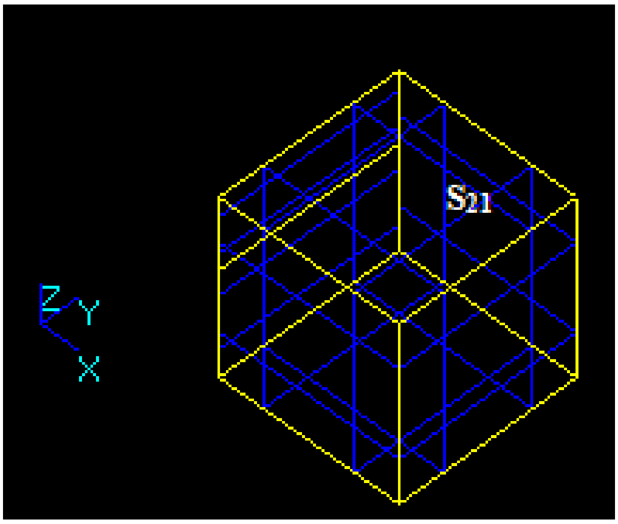
- The result of *Fuse* operation is a compound composed from the split parts of arguments *S11, S12* and *S22 (Cut12, Common, Cut21)*. All inner webs are removed, so the result is one new solid *R*.



* The result of *Common* operation is an empty compound because the dimension (2) of the common part between *S1* and *S2* (face) is less than the lower dimension of the arguments (3).
* The result of *Cut12* operation is a compound containing split part of the argument *S1*, i.e. 1 new solid *S11*.

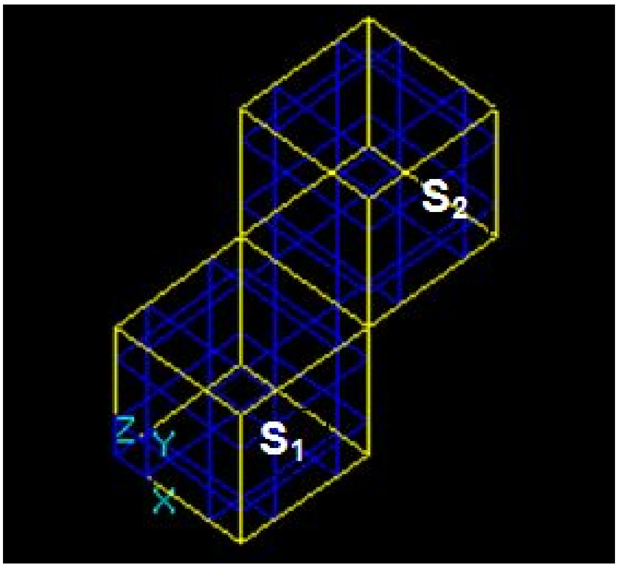


* The result of *Cut21* operation is a compound containing split part of the argument *S2*, i.e. 1 new solid *S21*.

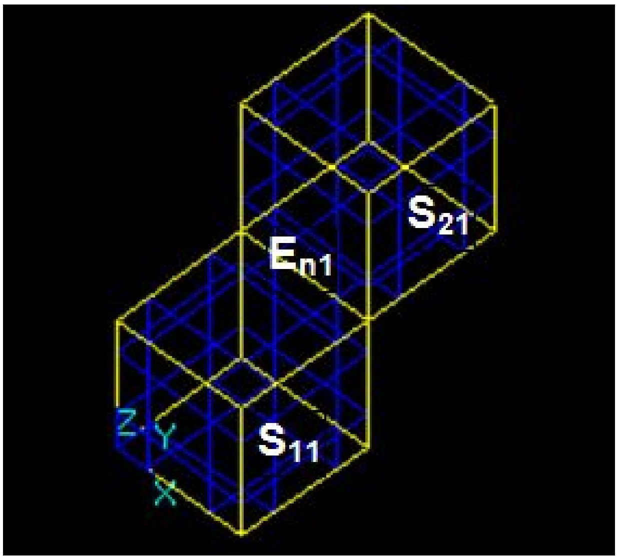


10.3.21 Case 21: Two Solids that have overlapping edges.

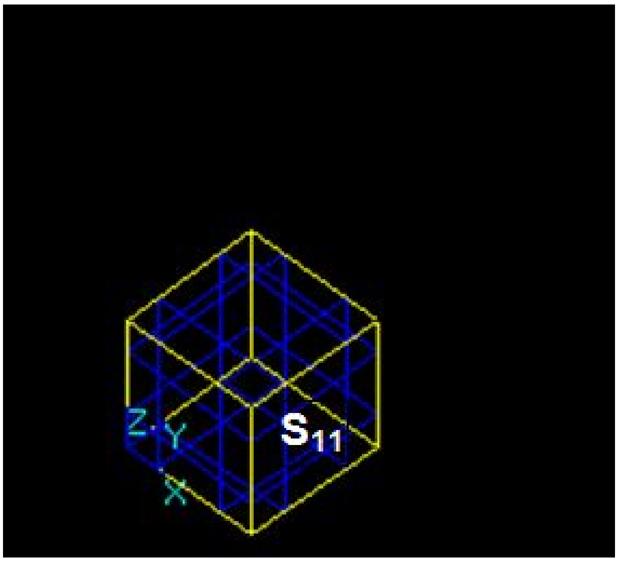
Let us consider two solids *S1* and *S2* that have overlapping edges:



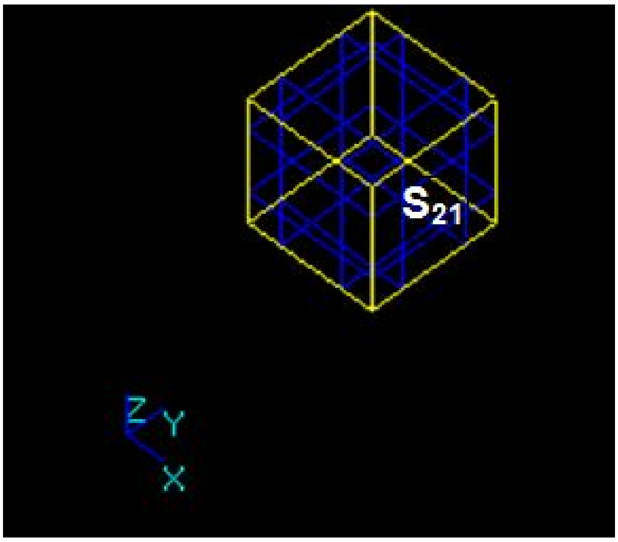
- The result of *Fuse* operation is a compound composed from the split parts of arguments i.e. 2 new solids *S11* and *S21*. These solids have one shared edge *En1*.



- The result of *Common* operation is an empty compound because the dimension (1) of the common part between *S1* and *S2* (edge) is less than the lower dimension of the arguments (3).
- The result of *Cut12* operation is a compound containing split part of the argument *S1*. In this case argument *S1* has a common part with solid *S2* so the corresponding part is not included into the result.

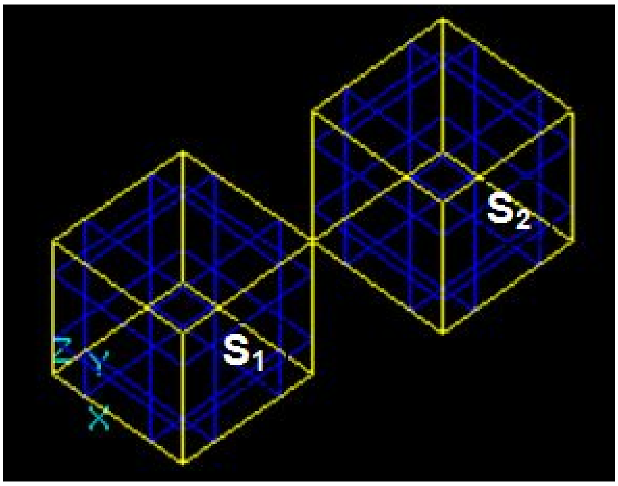


- The result of *Cut21* operation is a compound containing split part of the argument *S2*. In this case argument *S2* has a common part with solid *S1* so the corresponding part is not included into the result.

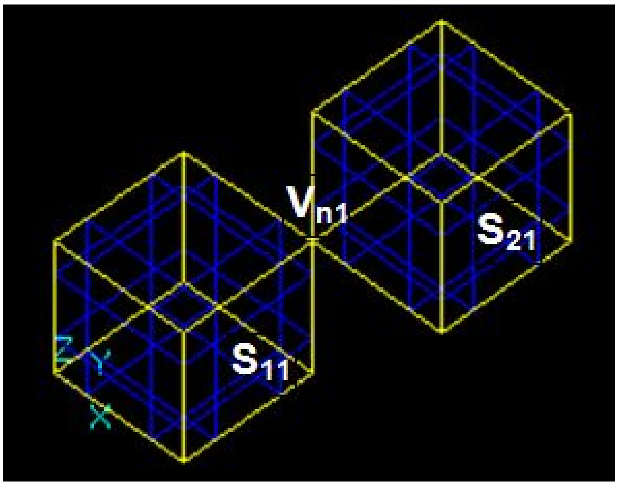


10.3.22 Case 22: Two Solids that have overlapping vertices.

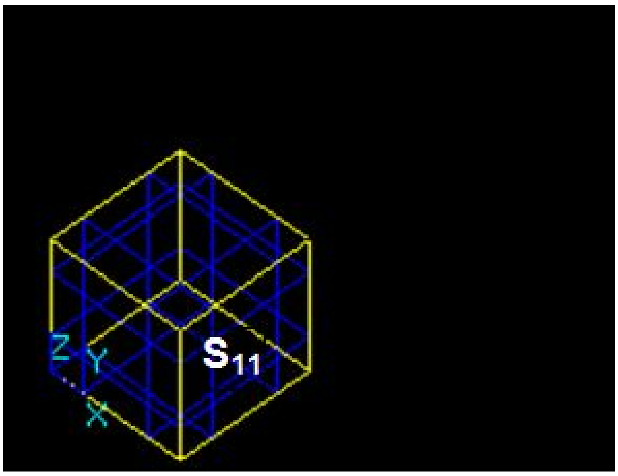
Let us consider two solids *S1* and *S2* that have overlapping vertices:



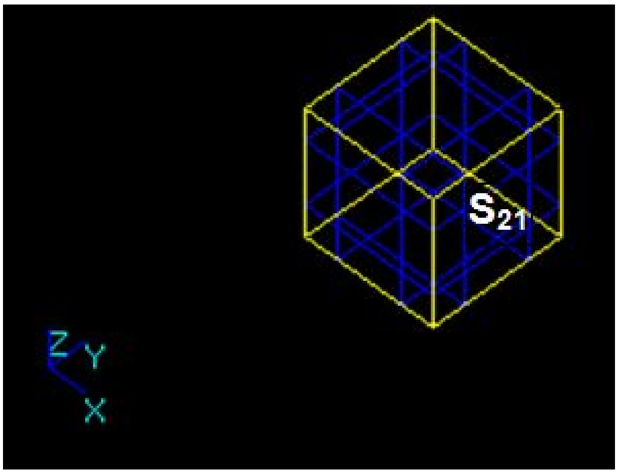
- The result of *Fuse* operation is a compound composed from the split parts of arguments i.e. 2 new solids *S11* and *S21*. These solids share *Vn1*.



- The result of *Common* operation is an empty compound because the dimension (0) of the common part between *S1* and *S2* (vertex) is less than the lower dimension of the arguments (3).
- The result of *Cut12* operation is a compound containing split part of the argument *S1*.

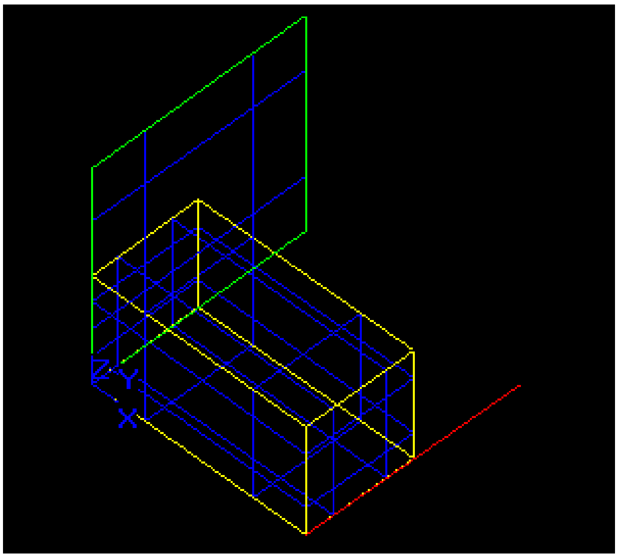


- The result of *Cut21* operation is a compound containing split part of the argument *S2*.

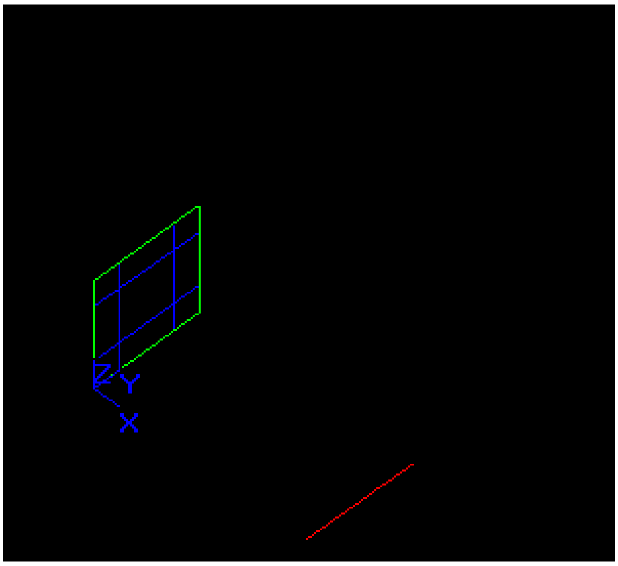


10.3.23 Case 23: A Shell and a Wire cut by a Solid.

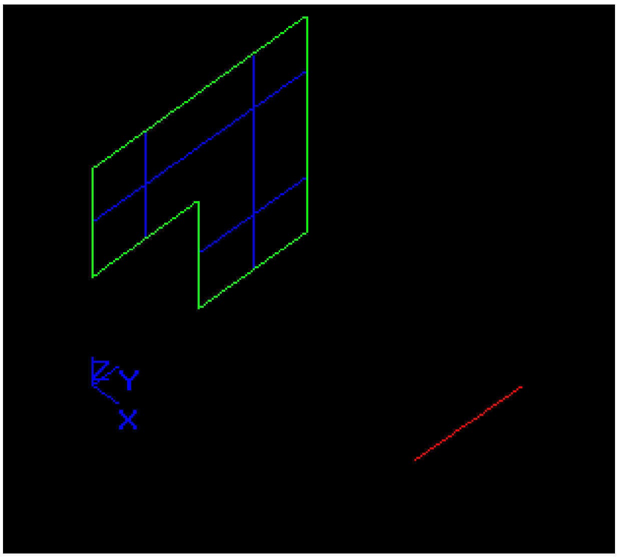
Let us consider Shell *Sh* and Wire *W* as the objects and Solid *S* as the tool:



- The result of *Fuse* operation is not defined as the dimension of the arguments is not the same.
- The result of *Common* operation is a compound containing the parts of the initial Shell and Wire common for the Solid. The new Shell and Wire are created from the objects.



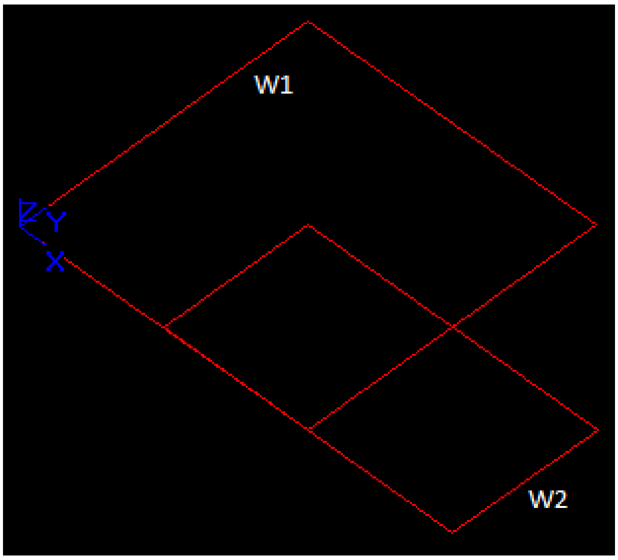
- The result of *Cut12* operation is a compound containing new Shell and Wire split from the arguments *Sh* and *W*. In this case they have a common part with solid *S* so the corresponding part is not included into the result.



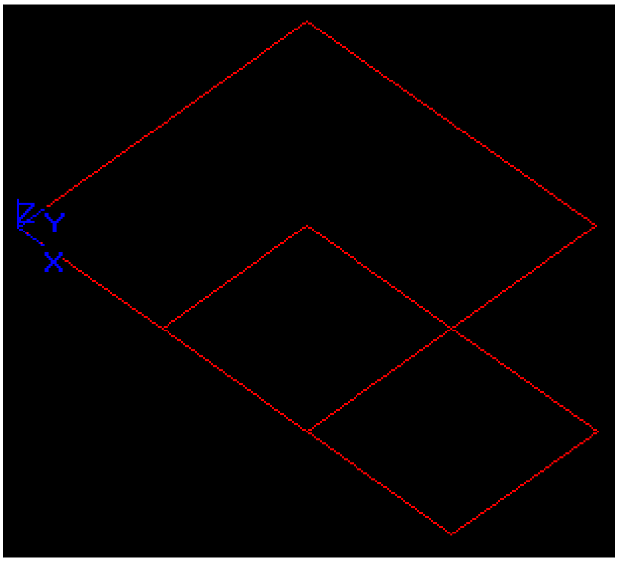
- The result of *Cut21* operation is not defined as the objects have a lower dimension than the tool.

10.3.24 Case 24: Two Wires that have overlapping edges.

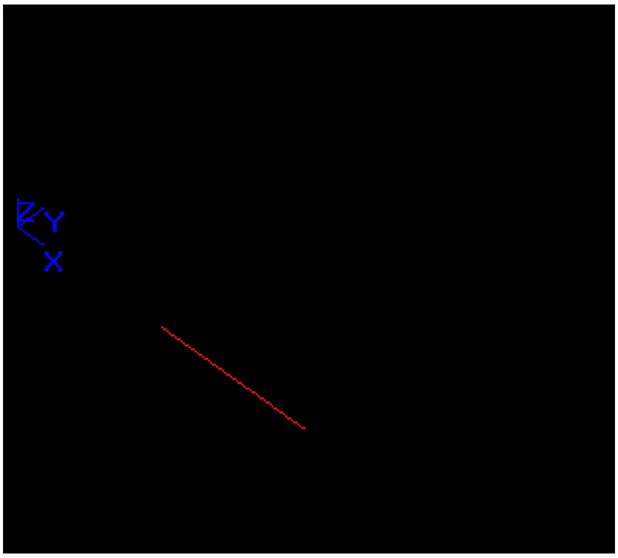
Let us consider two Wires that have overlapping edges, *W1* is the object and *W2* is the tool:



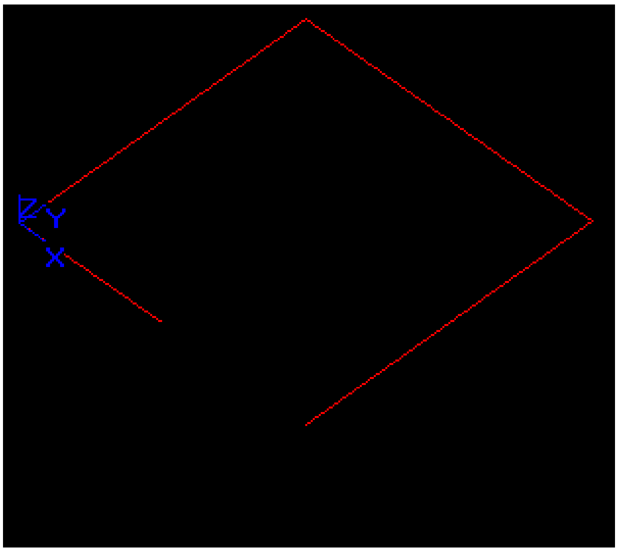
* The result of *Fuse* operation is a compound containing two Wires, which share an overlapping edge. The new Wires are created from the objects:



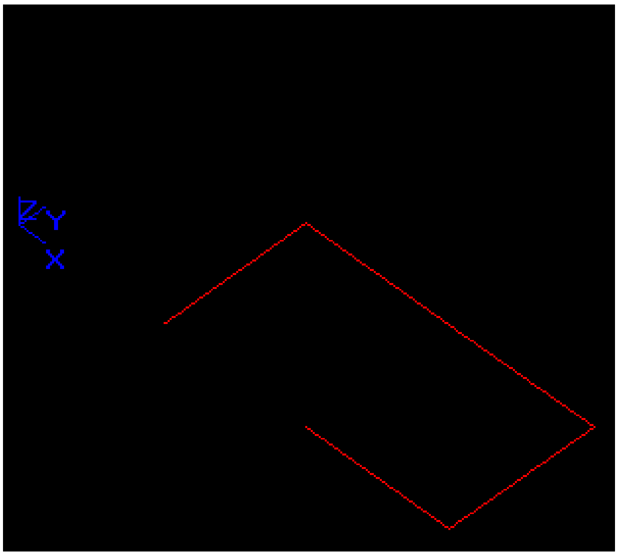
* The result of *Common* operation is a compound containing one Wire consisting of an overlapping edge. The new Wire is created from the objects:



- The result of *Cut12* operation is a compound containing a wire split from object *W1*. Its common part with *W2* is not included into the result.



- The result of *Cut21* operation is a compound containing a wire split from *W2*. Its common part with *W1* is not included into the result.



10.4 Class BOPAlgo_BOP

BOA is implemented in the class *BOPAlgo_BOP*. The main fields of this class are described in the Table:

Name	Contents
myOperation	The type of the Boolean operation (Common, Fuse, Cut)
myTools	The tools
myDims[2]	The values of the dimensions of the arguments
myRC	The draft result (shape)

The main steps of the *BOPAlgo_BOP* are the same as of BOPAlgo_Builder except for some aspects described in the next paragraphs.

10.5 Building Draft Result

The input data for this step is as follows:

- *BOPAlgo_BOP* object after building result of type *Compound*;
- *Type* of the Boolean operation.

No	Contents	Implementation
1	For the Boolean operation *Fuse* add to *myRC* all images of arguments.	*BOPAlgo_BOP::BuildRC()*
2	For the Boolean operation *Common* or *Cut* add to *myRC* all images of argument *S1* that are *Common* for the Common operation and are *Not Common* for the Cut operation	*BOPAlgo_BOP::BuildRC()*

10.6 Building the Result

The input data for this step is as follows:

- *BOPAlgo_BOP* object the state after building draft result.

No	Contents	Implementation
1	For the Type of the Boolean operation Common, Cut with any dimension and operation Fuse with *myDim[0]* $<$ *3*	
1.↩ 1	Find containers (WIRE, SHELL, COMPSOLID) in the arguments	*BOPAlgo_BOP:: BuildShape()*
1.↩ 2	Make connexity blocks from splits of each container that are in *myRC*	*BOPTools_Tools::MakeConnexityBlocks()*
1.↩ 3	Build the result from shapes made from the connexity blocks	*BOPAlgo_BOP:: BuildShape()*
1.↩ 4	Add the remaining shapes from *myRC* to the result	*BOPAlgo_BOP:: BuildShape()*
2	For the Type of the Boolean operation Fuse with *myDim[0] = 3*	
2.↩ 1	Find internal faces *(FWi)* in *myRC*	*BOPAlgo_BOP::BuildSolid()*
2.↩ 2	Collect all faces of *myRC* except for internal faces *(FWi) ->* *SFS*	*BOPAlgo_BOP::BuildSolid ()*
2.↩ 3	Build solids *(SDi)* from *SFS*.	*BOPAlgo_BuilderSolid*
2.↩ 4	Add the solids *(SDi)* to the result	

10.7 Boolean operations on open solids

The Boolean operations on open solids are tricky enough that the standard approach of Boolean operations for building the result, based on the splits of solids does not work. It happens because the algorithm for splitting solids (*BOPAlgo_BuilderSolid*) always tries to create the closed loops (shells) and make solids from them. But if the input solid is not closed, what can be expected from its splits? For performing Boolean Operations on open solids another approach is used, which does not rely on the splits of the solids to be correct, but tries to select the splits of faces, which are necessary for the given type of operation. The point here is that the type of Boolean operation clearly defines the states for the faces to be taken into result:

- For **COMMON** operation all the faces from the arguments located inside any solid of the opposite group must be taken;
- For **FUSE** operation all the faces from the arguments located outside of all solids of the opposite group must be taken;
- For **CUT** operation all the faces from the Objects located outside of all solids of the Tools and all faces from the Tools located inside any solid of the Objects must be taken;
- For **CUT21** operation all the faces from the Objects located inside any solid of the Tools and all faces from the Tools located outside of all solids of the Objects must be taken. From the selected faces the result solids are built. Please note, that the result may contain as normal (closed) solids as the open ones.

Even with this approach, the correct result of Boolean operation on open solids cannot be always guaranteed. This is explained by non-manifold nature of open solids: in some cases classification of a face depends on the point of the face chosen for classification.

11 Section Algorithm

11.1 Arguments

The arguments of BOA are shapes in terms of *TopoDS_Shape*. The main requirements for the arguments are described in the Algorithms.

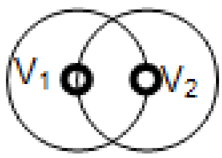
11.2 Results and general rules

- The result of Section operation is a compound. Each sub-shape of the compound has shared sub-shapes in accordance with interferences between the arguments.
- The result of Section operation contains shapes that have dimension that is less then 2 i.e. vertices and edges.
- The result of Section operation contains standalone vertices if these vertices do not belong to the edges of the result.
- The result of Section operation contains vertices and edges of the arguments (or images of the arguments) that belong to at least two arguments (or two images of the arguments).
- The result of Section operation contains Section vertices and edges obtained from Face/Face interferences.
- The result of Section operation contains vertices that are the result of interferences between vertices and faces.
- The result of Section operation contains edges that are the result of interferences between edges and faces (Common Blocks),

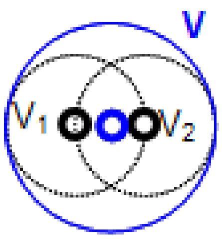
11.3 Examples

11.3.1 Case 1: Two Vertices

Let us consider two interfering vertices: *V1* and *V2*.

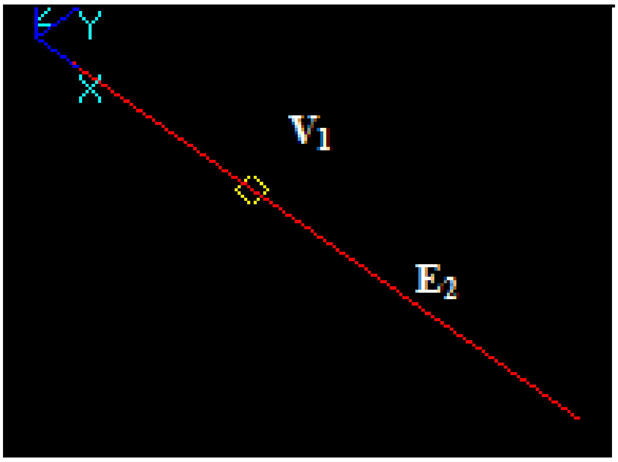


The result of *Section* operation is the compound that contains a new vertex *V*.

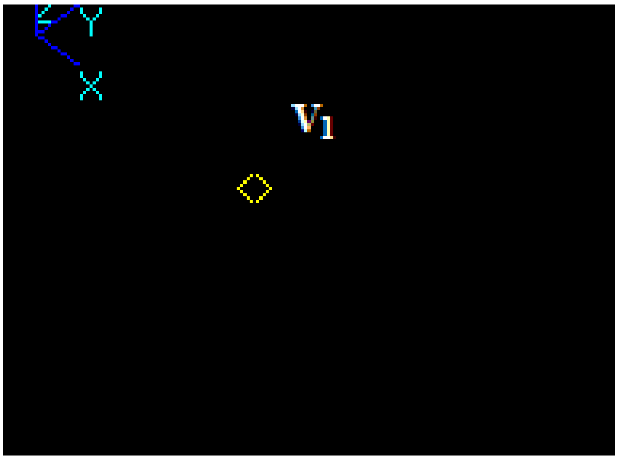


11.3.2 Case 1: Case 2: A Vertex and an Edge

Let us consider vertex *V1* and the edge *E2*, that intersect in a 3D point:

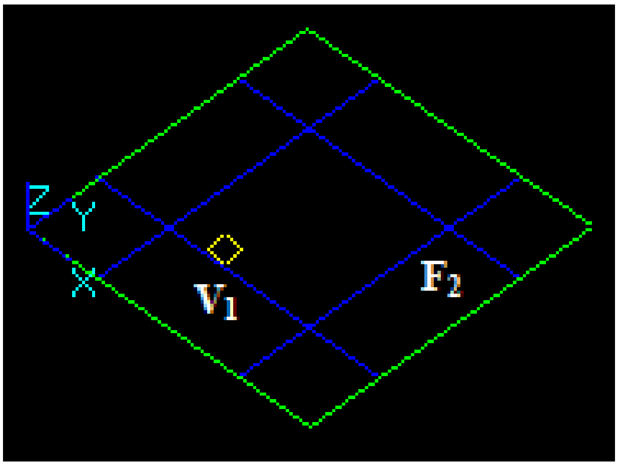


The result of *Section* operation is the compound that contains vertex *V1*.

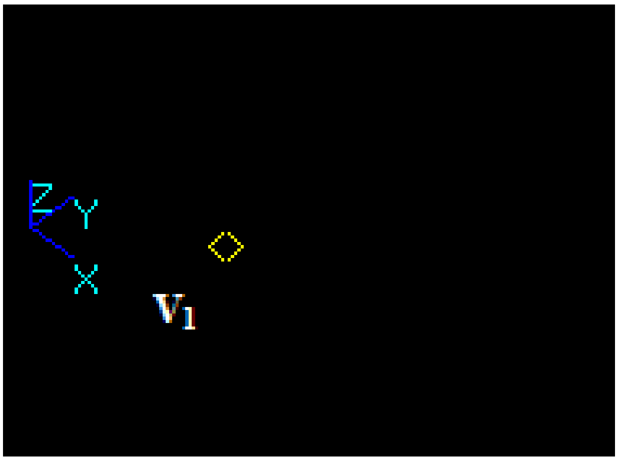


11.3.3 Case 1: Case 2: A Vertex and a Face

Let us consider vertex *V1* and face *F2*, that intersect in a 3D point:

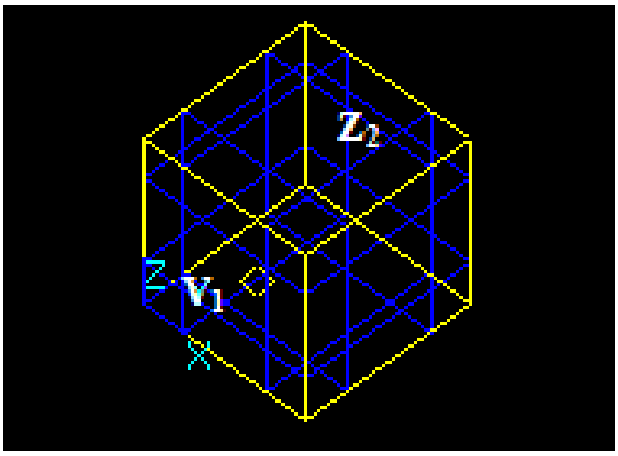


The result of *Section* operation is the compound that contains vertex *V1*.



11.3.4 Case 4: A Vertex and a Solid

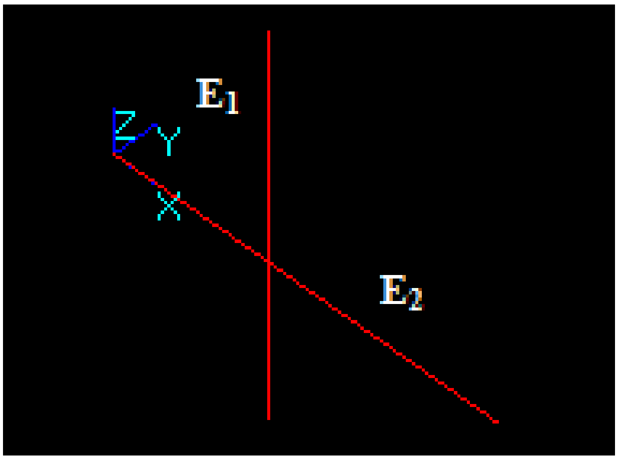
Let us consider vertex *V1* and solid *Z2*. The vertex *V1* is inside the solid *Z2*.



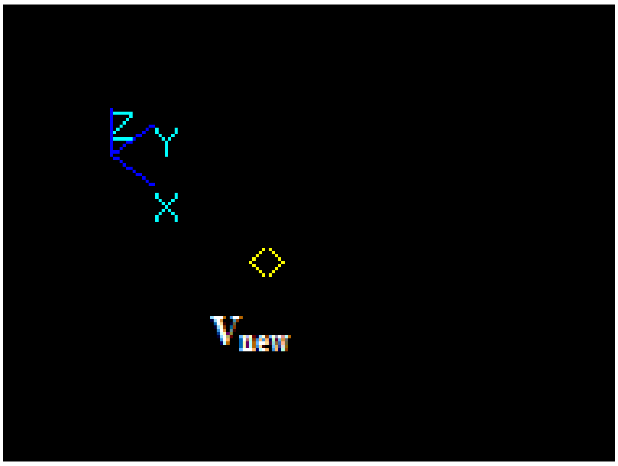
The result of *Section* operation is an empty compound.

11.3.5 Case 5: Two edges intersecting at one point

Let us consider edges *E1* and *E2*, that intersect in a 3D point:

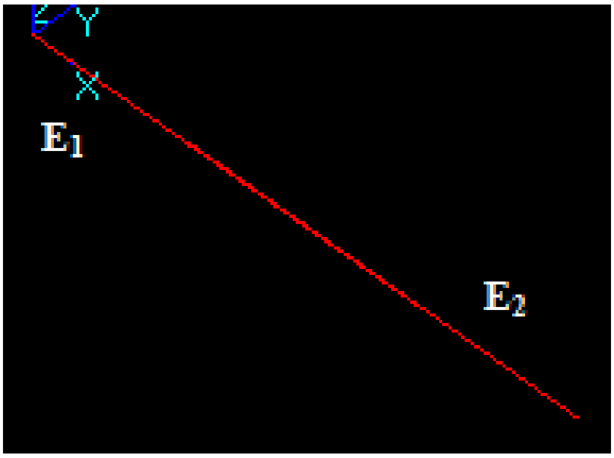


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

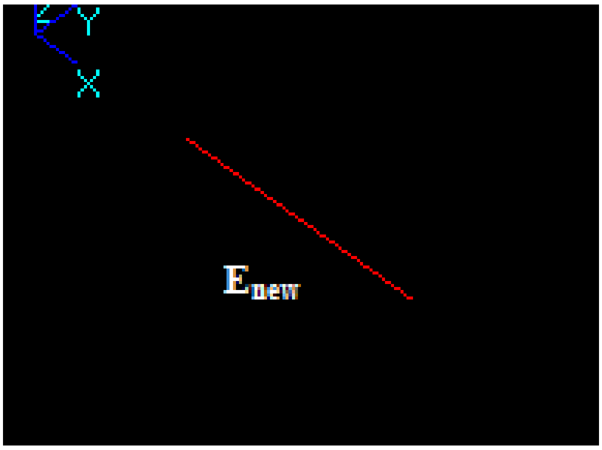


11.3.6 Case 6: Two edges having a common block

Let us consider edges *E1* and *E2*, that have a common block:

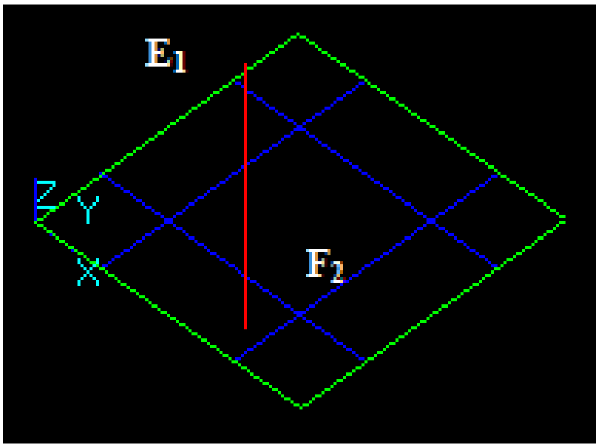


The result of *Section* operation is the compound that contains a new edge *Enew*.

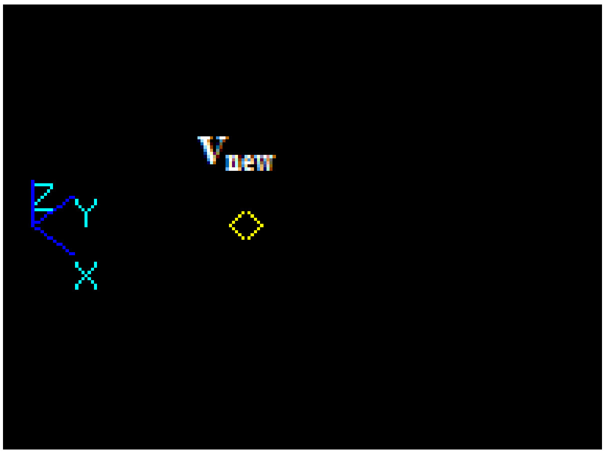


11.3.7 Case 7: An Edge and a Face intersecting at a point

Let us consider edge *E1* and face *F2*, that intersect at a 3D point:

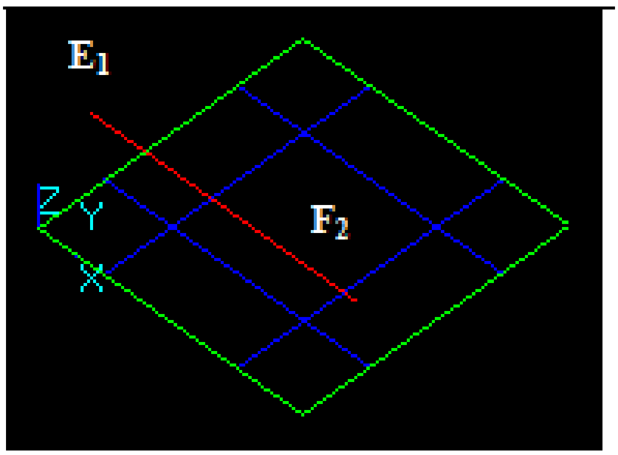


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

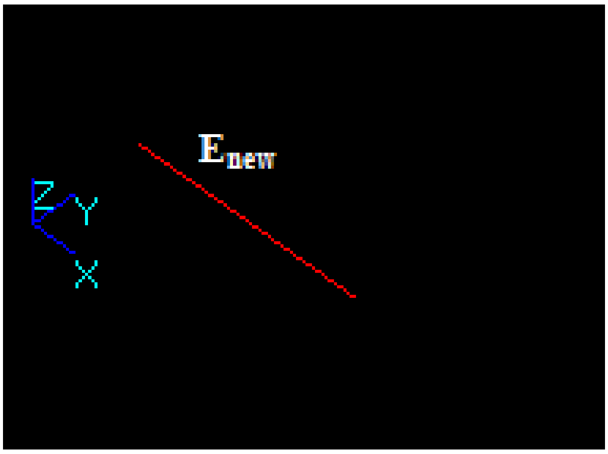


11.3.8 Case 8: A Face and an Edge that have a common block

Let us consider edge *E1* and face *F2*, that have a common block:

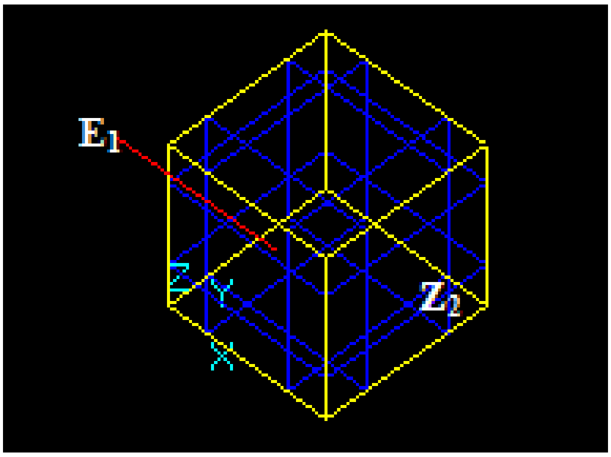


The result of *Section* operation is the compound that contains new edge *Enew*.

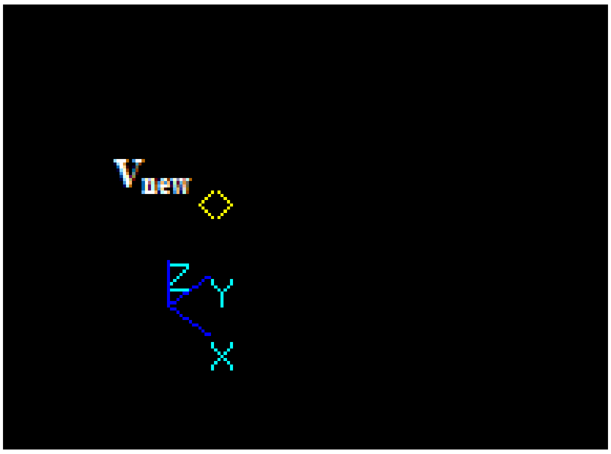


11.3.9 Case 9: An Edge and a Solid intersecting at a point

Let us consider edge *E1* and solid *Z2*, that intersect at a point:

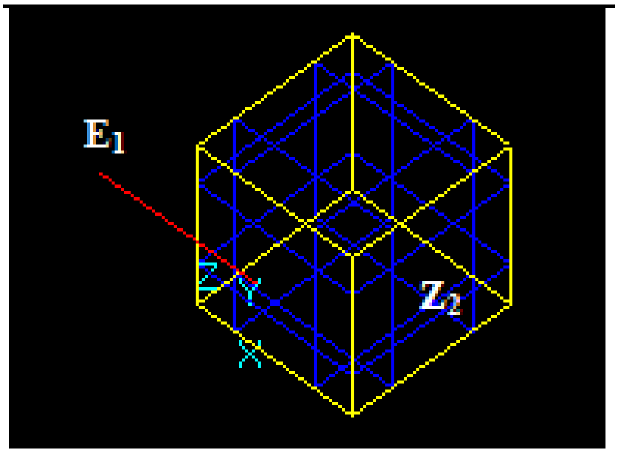


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

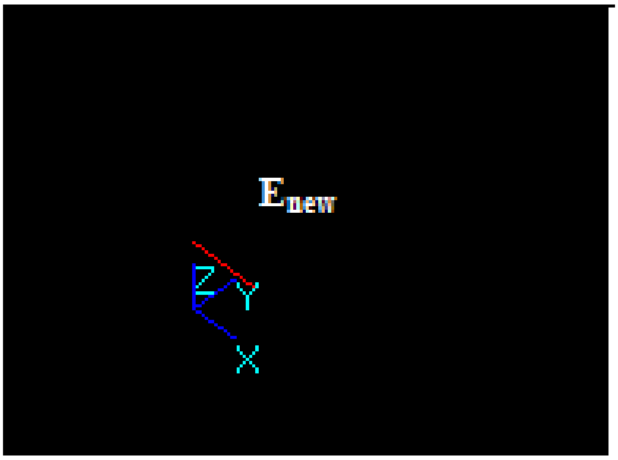


11.3.10 Case 10: An Edge and a Solid that have a common block

Let us consider edge *E1* and solid *Z2*, that have a common block at a face:

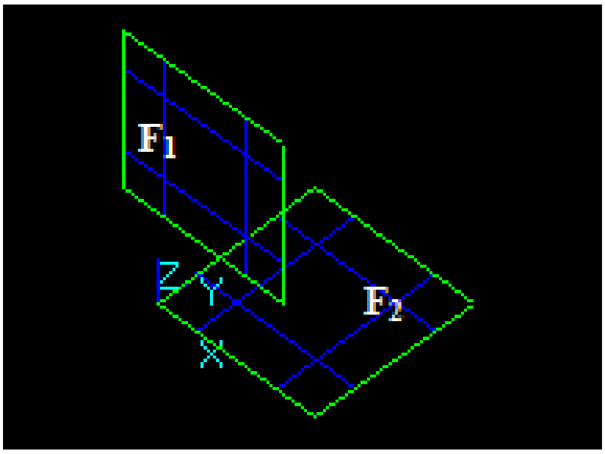


The result of *Section* operation is the compound that contains a new edge *Enew*.

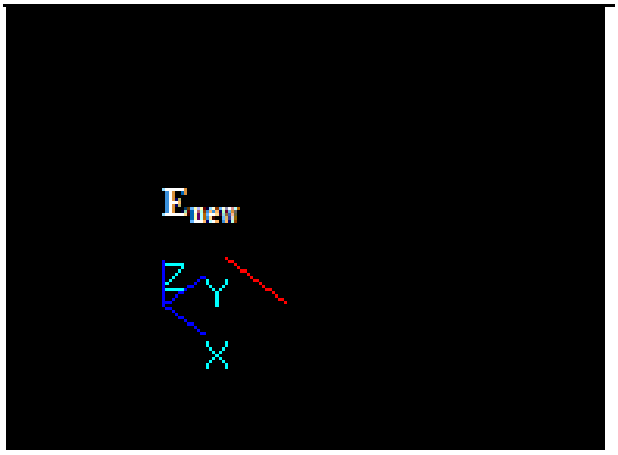


11.3.11 Case 11: Two intersecting faces

Let us consider two intersecting faces *F1* and *F2*:

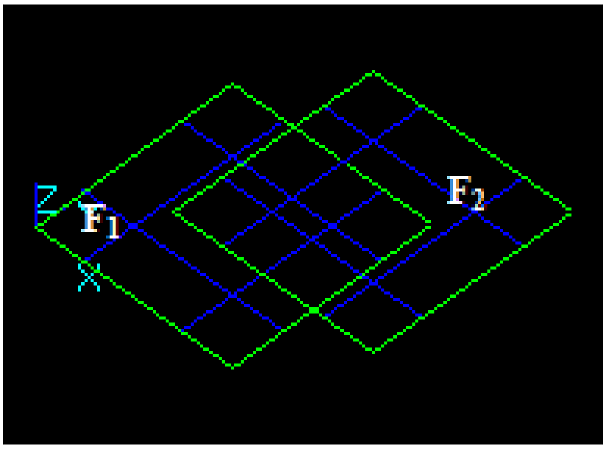


The result of *Section* operation is the compound that contains a new edge *Enew*.

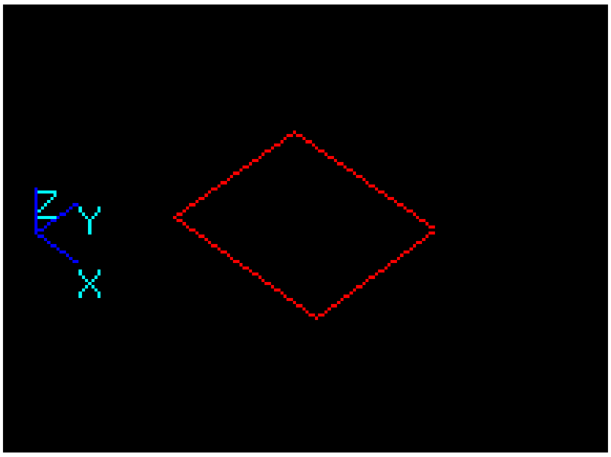


11.3.12 Case 12: Two faces that have a common part

Let us consider two faces *F1* and *F2* that have a common part:

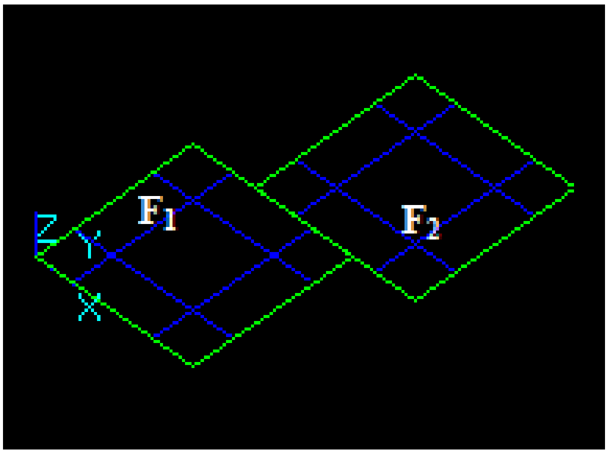


The result of *Section* operation is the compound that contains 4 new edges.

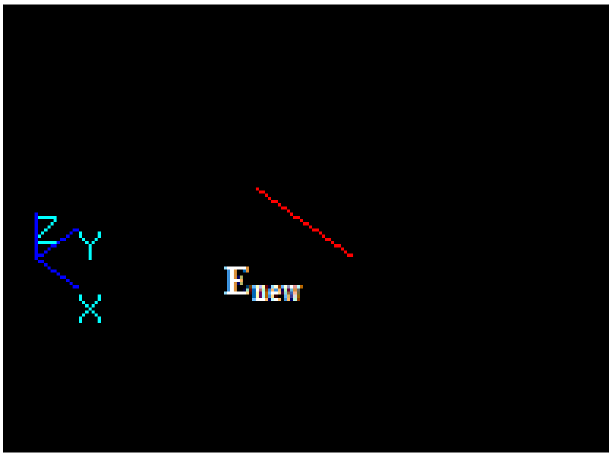


11.3.13 Case 13: Two faces that have overlapping edges

Let us consider two faces *F1* and *F2* that have a overlapping edges:

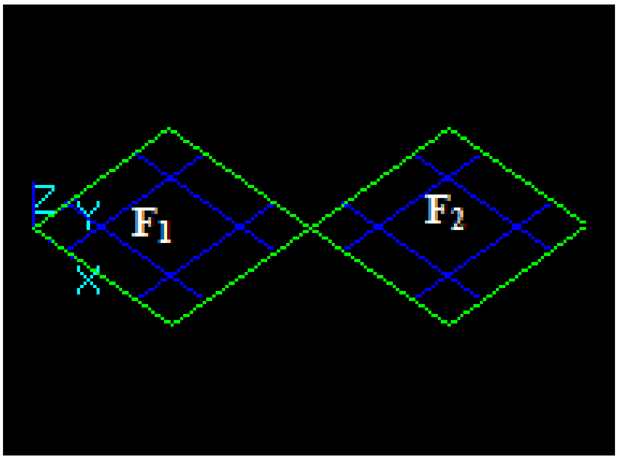


The result of *Section* operation is the compound that contains a new edge *Enew*.

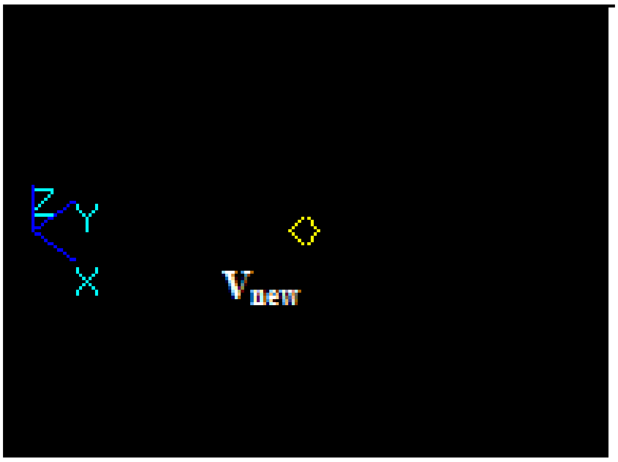


11.3.14 Case 14: Two faces that have overlapping vertices

Let us consider two faces *F1* and *F2* that have overlapping vertices:

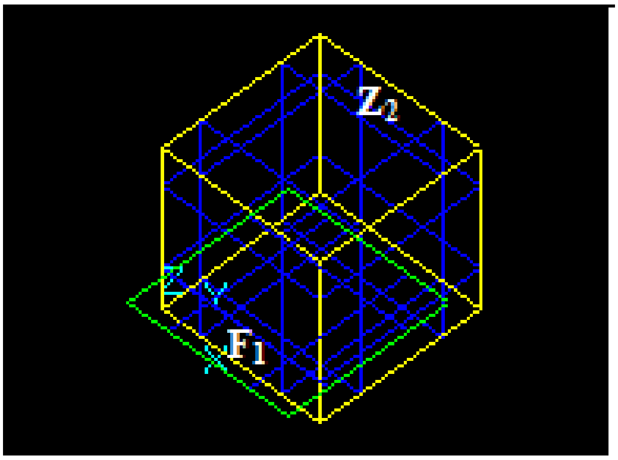


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

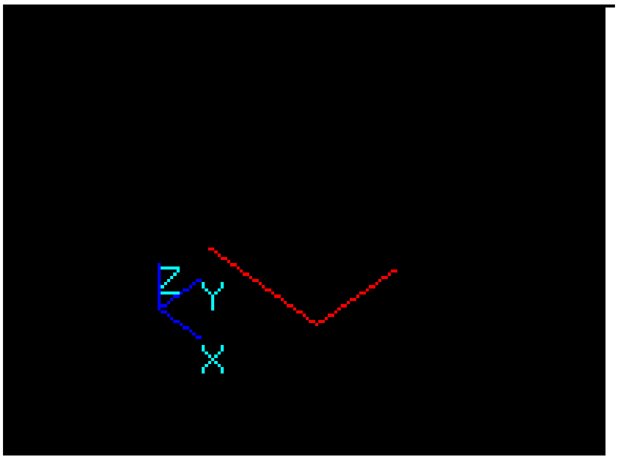


11.3.15 Case 15: A Face and a Solid that have an intersection curve

Let us consider face *F1* and solid *Z2* that have an intersection curve:

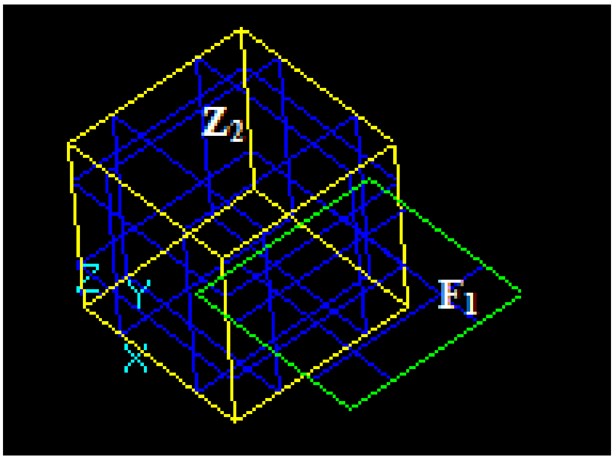


The result of *Section* operation is the compound that contains new edges.

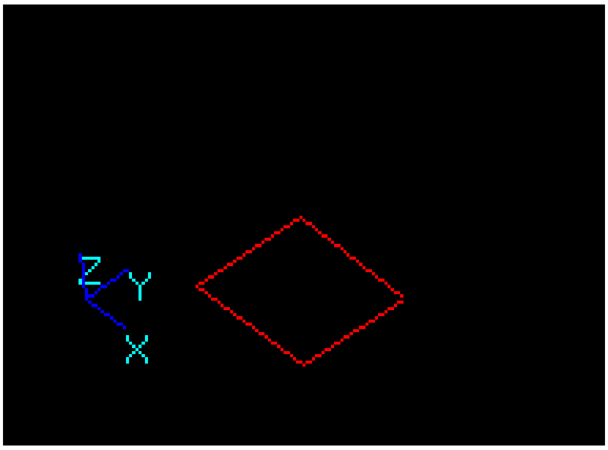


11.3.16 Case 16: A Face and a Solid that have overlapping faces.

Let us consider face *F1* and solid *Z2* that have overlapping faces:

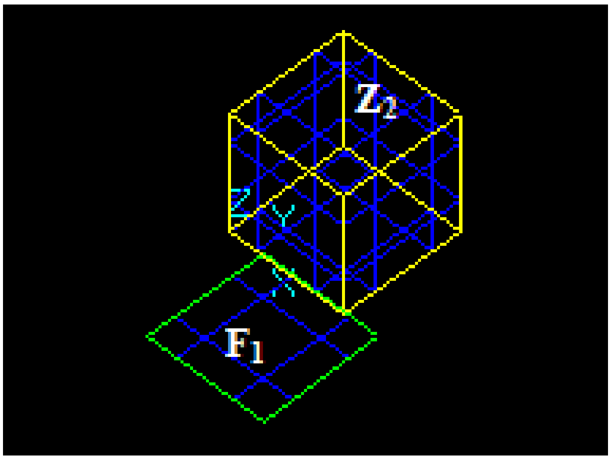


The result of *Section* operation is the compound that contains new edges

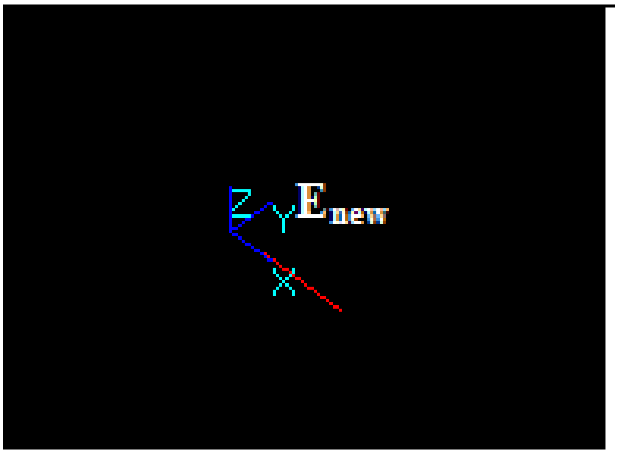


11.3.17 Case 17: A Face and a Solid that have overlapping edges.

Let us consider face *F1* and solid *Z2* that have a common part on edge:

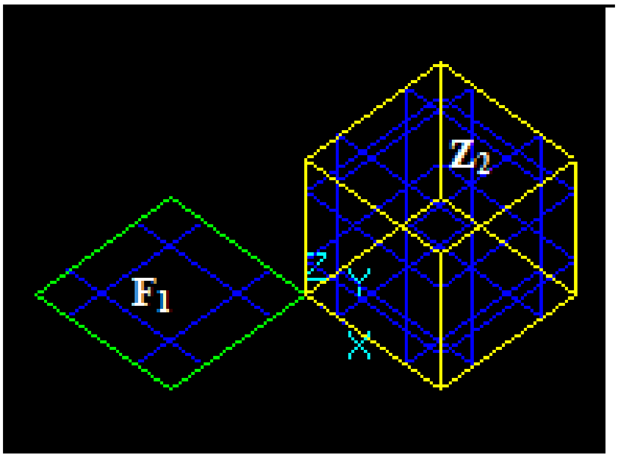


The result of *Section* operation is the compound that contains a new edge *Enew*.

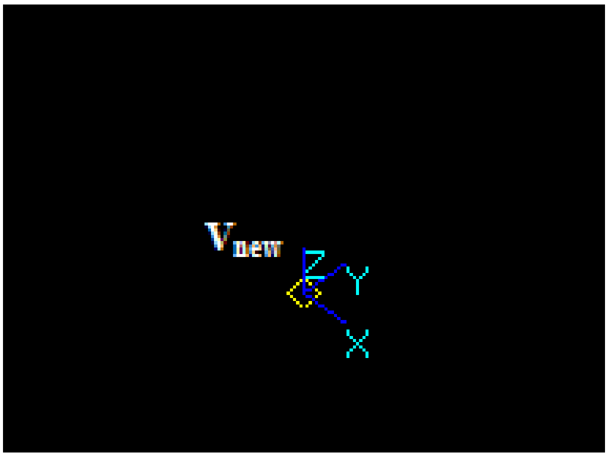


11.3.18 Case 18: A Face and a Solid that have overlapping vertices.

Let us consider face *F1* and solid *Z2* that have overlapping vertices:

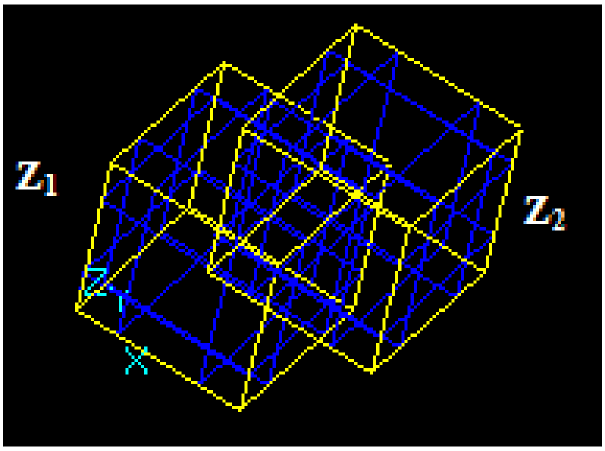


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

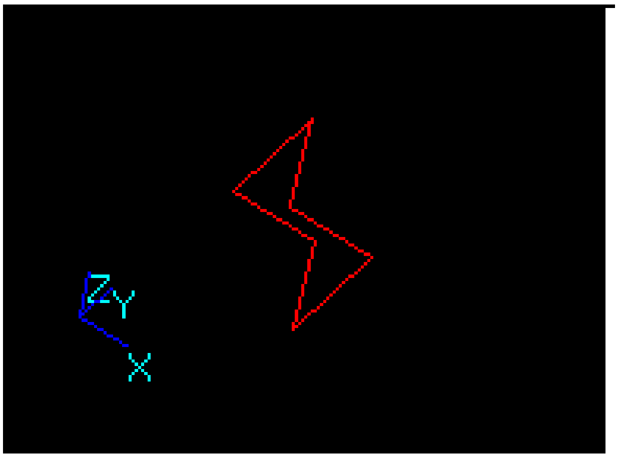


11.3.19 Case 19: Two intersecting Solids

Let us consider two intersecting solids *Z1* and *Z2*:

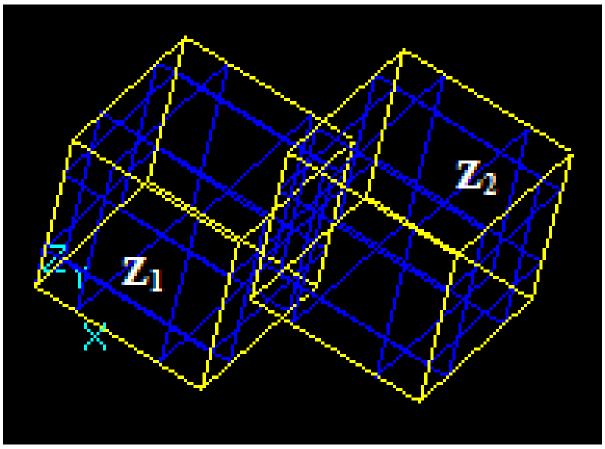


The result of *Section* operation is the compound that contains new edges.

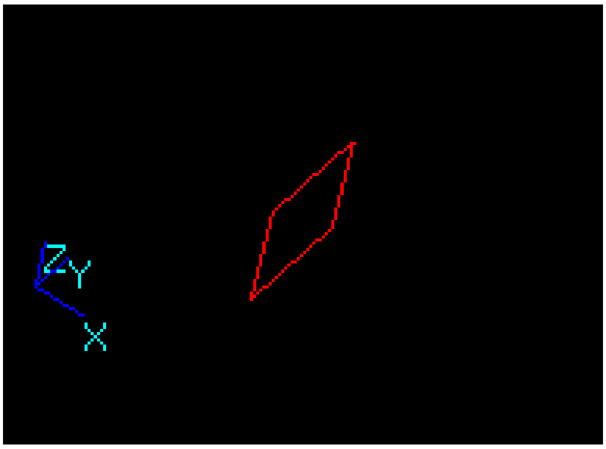


11.3.20 Case 20: Two Solids that have overlapping faces

Let us consider two solids *Z1* and *Z2* that have a common part on face:

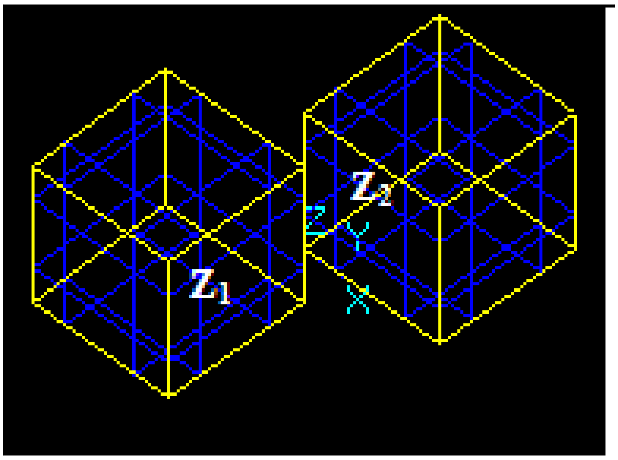


The result of *Section* operation is the compound that contains new edges.

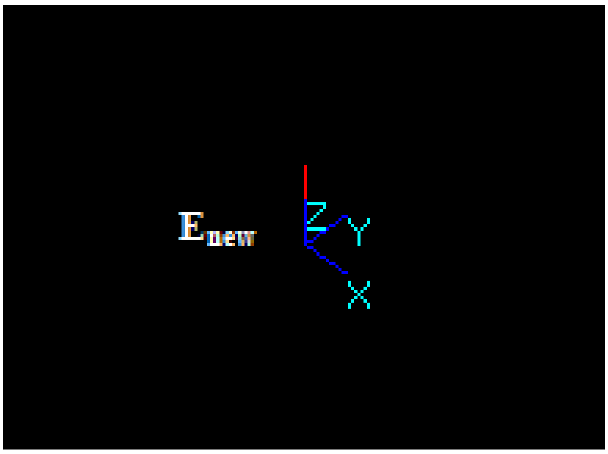


11.3.21 Case 21: Two Solids that have overlapping edges

Let us consider two solids *Z1* and *Z2* that have overlapping edges:

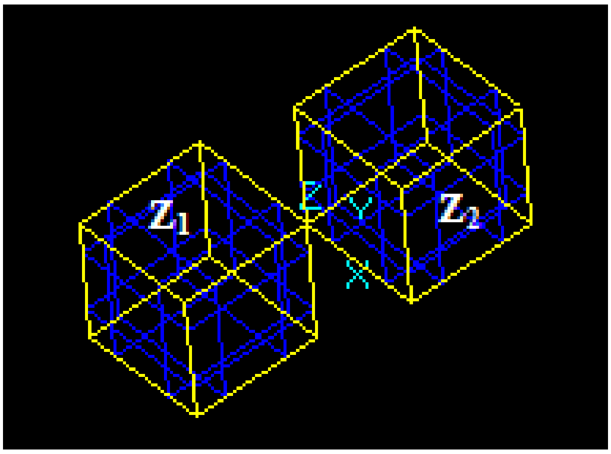


The result of *Section* operation is the compound that contains a new edge *Enew*.

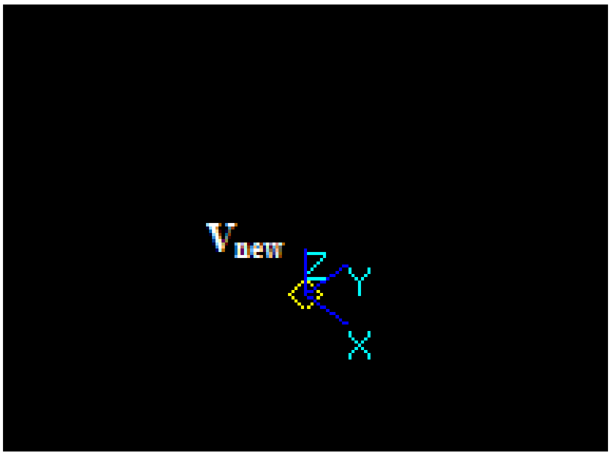


11.3.22 Case 22: Two Solids that have overlapping vertices

Let us consider two solids *Z1* and *Z2* that have overlapping vertices:



The result of *Section* operation is the compound that contains a new vertex *Vnew*.



11.4 Class BOPAlgo_Section

SA is implemented in the class *BOPAlgo_Section*. The class has no specific fields. The main steps of the *BOPAlgo_Section* are the same as of *BOPAlgo_Builder* except for the following steps:

- Build Images for Wires;
- Build Result of Type Wire;
- Build Images for Faces;
- Build Result of Type Face;
- Build Images for Shells;
- Build Result of Type Shell;
- Build Images for Solids;
- Build Result of Type Solid;
- Build Images for Type CompSolid;
- Build Result of Type CompSolid;
- Build Images for Compounds; Some aspects of building the result are described in the next paragraph

11.5 Building the Result

No	Contents	Implementation
1	Build the result of the operation using all information contained in *FaceInfo*, Common Block, Shared entities of the arguments, etc.	*BOPAlgo_Section:: BuildSection()*

12 Volume Maker Algorithm

The Volume Maker algorithm has been designed for building the elementary volumes (solids) from a set of connected, intersecting, or nested shapes. The algorithm can also be useful for splitting solids into parts, or constructing new solid(s) from set of intersecting or connected faces or shells. The algorithm creates only closed solids. In general case the result solids are non-manifold: fragments of the input shapes (wires, faces) located inside the solids are added as internal sub-shapes to these solids. But the algorithm allows preventing the addition of the internal for solids parts into result. In this case the result solids will be manifold and not contain any internal parts. However, this option does not prevent from the occurrence of the internal edges or vertices in the faces.
Non-closed faces, free wires etc. located outside of any solid are always excluded from the result.

The Volume Maker algorithm is implemented in the class BOPAlgo_MakerVolume. It is based on the General Fuse (GF) algorithm. All the options of the GF algorithm (see GF Options) are also available in this algorithm.

The requirements for the arguments are the same as for the arguments of GF algorithm - they could be of any type, but each argument should be valid and not self-interfered.

The algorithm allows disabling the calculation of intersections among the arguments. In this case the algorithm will run much faster, but the user should guarantee that the arguments do not interfere with each other, otherwise the result will be invalid (e.g. contain unexpected parts) or empty. This option is useful e.g. for building a solid from the faces of one shell or from the shapes that have already been intersected.

12.1 Usage

C++ Level

The usage of the algorithm on the API level:

```
BOPAlgo_MakerVolume aMV;
// Set the arguments
TopTools_ListOfShape aLS = ...; // arguments
aMV.SetArguments(aLS);

// Set options for the algorithm
// setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
...
// Additional option of the algorithm
Standard_Boolean bAvoidInternalShapes = Standard_False; // Set to True to exclude from the result any
       shapes internal to the solids
aMV.SetAvoidInternalShapes(bAvoidInternalShapes);

// Perform the operation
aMV.Perform();
if (aMV.HasErrors()) { //check error status
  return;
}
//
const TopoDS_Shape& aResult = aMV.Shape(); // result of the operation
```

Tcl Level

To use the algorithm in Draw the command mkvolume has been implemented. The usage of this command is following:

```
Usage: mkvolume r b1 b2 ... [-c] [-ni] [-ai]
Options:
-c - use this option to have input compounds considered as set of separate arguments (allows passing
      multiple arguments as one compound);
-ni - use this option to disable the intersection of the arguments;
-ai - use this option to avoid internal for solids shapes in the result.
```

12.2 Examples

Example 1

Creation of 9832 solids from sphere and set of 63 planes:

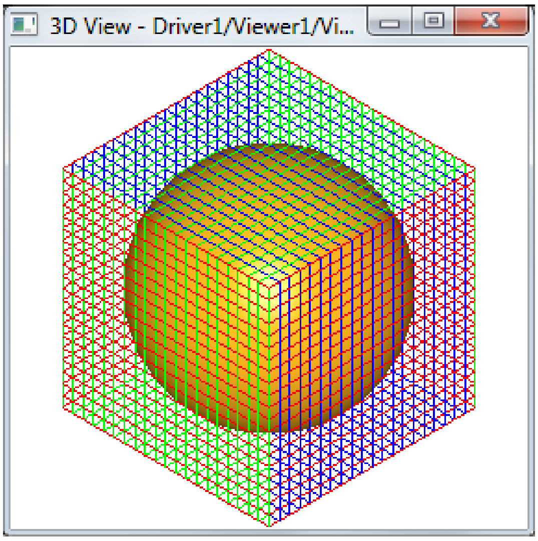


Figure 45: Arguments

Example 2

Creating compartments on a ship defined by hull shell and a set of planes. The ship is divided on compartments by five transverse bulkheads and a deck – six compartments are created:

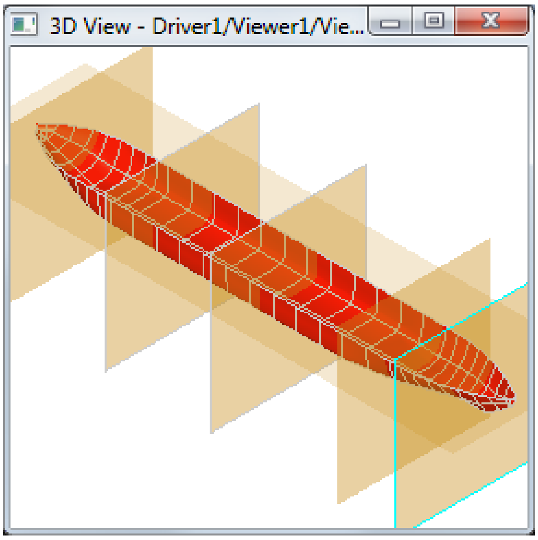


Figure 47: Arguments

13 Cells Builder algorithm

The Cells Builder algorithm is an extension of the General Fuse algorithm. The result of General Fuse algorithm contains all split parts of the arguments. The Cells Builder algorithm provides means to specify if any given split part of the arguments (referred to as Cell) can be taken or avoided in the result.

The possibility of selecting any Cell allows combining any possible result and gives the Cells Builder algorithm a very wide sphere of application - from building the result of any Boolean operation to building the result of any application-specific operation.

The algorithm builds Cells only once and then just reuses them for combining the result. This gives this algorithm the performance advantage over Boolean operations, which always rebuild the splits to obtain the desirable result.

Thus, the Cells Builder algorithm can be especially useful for simulating Boolean expressions, i.e. a sequence of Boolean operations on the same arguments. Instead of performing many Boolean operations it allows getting the final result in a single operation. The Cells Builder will also be beneficial to obtain the results of different Boolean operations on the same arguments - Cut and Common, for example.

The Cells Builder algorithm also provides the possibility to remove any internal boundaries between splits of the same type, i.e. to fuse any same-dimensional parts added into the result and to keep any other parts as separate. This possibility is implemented through the Cells material approach: to remove the boundary between two Cells, both Cells should be assigned with the same material ID. However, if the same material ID has been assigned to the Cells of different dimension, the removal of the internal boundaries for that material will not be performed. Currently, such case is considered a limitation for the algorithm.

The algorithm can also create containers from the connected Cells added into result - WIRES from Edges, SHELLS from Faces and COMPSOLIDS from Solids.

13.1 Usage

The algorithm has been implemented in the *BOPAlgo_CellsBuilder* class.

Cells Builder is based on the General Fuse algorithm. Thus all options of the General Fuse algorithm (see GF Options) are also available in this algorithm.

The requirements for the input shapes are the same as for General Fuse - each argument should be valid in terms of *BRepCheck_Analyzer* and *BOPAlgo_ArgumentAnalyzer*.

The result of the algorithm is a compound containing the selected parts of the basic type (VERTEX, EDGE, FACE or SOLID). The default result is an empty compound. It is possible to add any Cell by using the methods *AddTo↵ Ressult()* and *AddAllToResult()*. It is also possible to remove any part from the result by using methods *Remove↵ FromResult()* and *RemoveAllFromResult()*. The method *RemoveAllFromResult()* is also suitable for clearing the result.

The Cells that should be added/removed to/from the result are defined through the input shapes containing the parts that should be taken ∗(ShapesToTake)∗ and the ones containing parts that should be avoided (ShapesTo↵ Avoid). To be taken into the result the part must be IN all shapes from *ShapesToTake* and OUT of all shapes from *ShapesToAvoid*.

To remove Internal boundaries, it is necessary to set the same material to the Cells, between which the boundaries should be removed, and call the method *RemoveInternalBoundaries()*. The material should not be equal to 0, as this is the default material ID. The boundaries between Cells with this material ID will not be removed. The same Cell cannot be added with different materials. It is also possible to remove the boundaries when the result is combined. To do this, it is necessary to set the material for parts (not equal to 0) and set the flag *bUpdate* to TRUE. If the same material ID has been set for parts of different dimension, the removal of internal boundaries for this material will not be performed.

It is possible to create typed Containers from the parts added into result by using method *MakeContainers()*. The type of the containers will depend on the type of the input shapes: WIRES for EDGE, SHELLS for FACES and COMPSOLIDS for SOLIDS. The result will be a compound containing containers.

API usage

Here is the example of the algorithm use on the API level:

```
BOPAlgo_CellsBuilder aCBuilder;
// Set the arguments
TopTools_ListOfShape aLS = ...; // arguments
aCBuilder.SetArguments(aLS);

// Set options for the algorithm
// setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
      chapter)
...

aCBuilder.Perform(); // build splits of all arguments (GF)
if (aCBuilder.HasErrors()) { // check error status
  return;
}
//
// collecting of the cells into result
const TopoDS_Shape& anEmptyRes = aCBuilder.Shape(); // empty result, as nothing has been added yet
const TopoDS_Shape& anAllCells = aCBuilder.GetAllParts(); //all split parts
//
TopTools_ListOfShape aLSToTake = ...; // parts of these arguments will be taken into result
TopTools_ListOfShape aLSToAvoid = ...; // parts of these arguments will not be taken into result
//
Standard_Integer iMaterial = 1; // defines the material for the cells
Standard_Boolean bUpdate = Standard_False; // defines whether to update the result right now or not
// adding to result
aCBuilder.AddToResult(aLSToTake, aLSToAvoid, iMaterial, bUpdate);
aCBuilder.RemoveInternalBoundaries(); // removing of the boundaries
TopoDS_Shape aResult = aCBuilder.Shape(); // the result
// removing from result
aCBuilder.AddAllToResult();
aCBuilder.RemoveFromResult(aLSToTake, aLSToAvoid);
aResult = aCBuilder.Shape(); // the result
```

DRAW usage

The following set of new commands has been implemented to run the algorithm in DRAW Test Harness:

```
bcbuild          : Initialization of the Cells Builder. Use: *bcbuild r*
bcadd            : Add parts to result. Use: *bcadd r s1 (0,1) s2 (0,1) ... [-m material [-u]]*
bcaddall         : Add all parts to result. Use: *bcaddall r [-m material [-u]]*
bcremove         : Remove parts from result. Use: *bcremove r s1 (0,1) s2 (0,1) ...*
bcremoveall      : Remove all parts from result. Use: *bcremoveall*
bcremoveint      : Remove internal boundaries. Use: *bcremoveint r*
bcmakecontainers : Make containers from the parts added to result. Use: *bcmakecontainers r*
```

Here is the example of the algorithm use on the DRAW level:

```
psphere s1 15
psphere s2 15
psphere s3 15
ttranslate s1 0 0 10
ttranslate s2 20 0 10
ttranslate s3 10 0 0
bclearobjects; bcleartools
baddobjects s1 s2 s3
bfillds
# rx will contain all split parts
bcbuild rx
# add to result the part that is common for all three spheres
bcadd res s1 1 s2 1 s3 1 -m 1
# add to result the part that is common only for first and third spheres
bcadd res s1 1 s2 0 s3 1 -m 1
# remove internal boundaries
bcremoveint res
```

13.2 Examples

The following simple example illustrates the possibilities of the algorithm working on a cylinder and a sphere intersected by a plane:

```
pcylinder c 10 30
```

```
psphere s 15
ttranslate s 0 0 30
plane p 0 0 20 1 0 0
mkface f p -25 30 -17 17
```

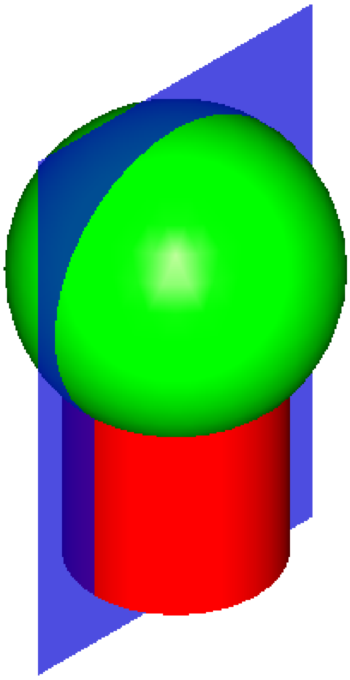


Figure 49: Arguments

```
bclearobjects
bcleartools
baddobjects c s f
bfillds
bcbuild r
```

1. Common for all arguments

```
bcremoveall
bcadd res c 1 s 1 f 1
```


Figure 50: The result of COMMON operation

2. Common between cylinder and face

```
bcremoveall
bcadd res f 1 c 1
```

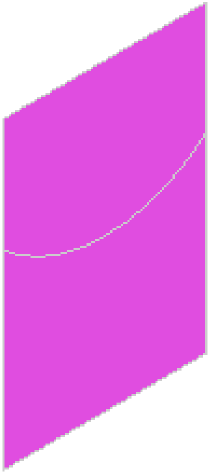


Figure 51: The result of COMMON operation between cylinder and face

3. Common between cylinder and sphere

```
bcremoveall
bcadd res c 1 s 1
```

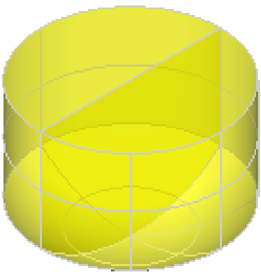


Figure 52: The result of COMMON operation between cylinder and sphere

4. Fuse of cylinder and sphere

```
bcremoveall
bcadd res c 1 -m 1
bcadd res s 1 -m 1
bcremoveint res
```

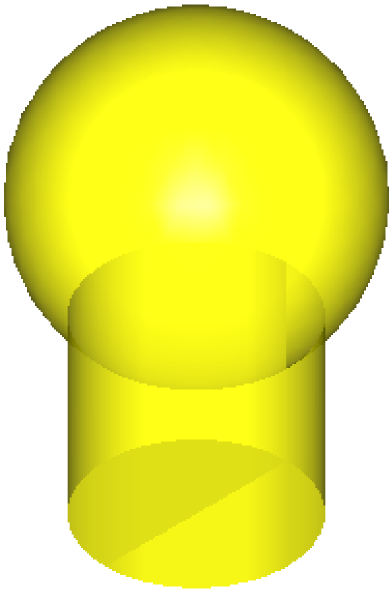


Figure 53: The result of FUSE operation between cylinder and sphere

5. Parts of the face inside solids - FUSE(COMMON(f, c), COMMON(f, s))

```
bcremoveall
bcadd res f 1 s 1 -m 1
bcadd res f 1 c 1 -m 1
```

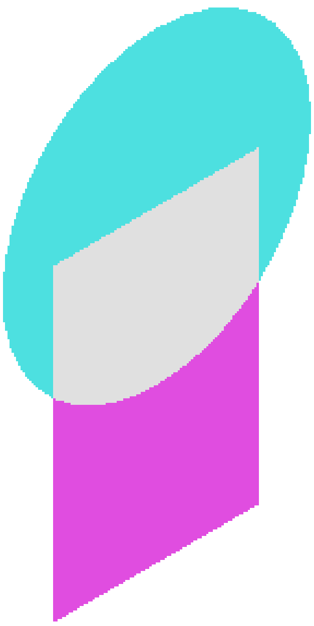


Figure 54: Parts of the face inside solids

```
bcremoveint res
```

Figure 55: Unified parts of the face inside solids

6. Part of the face outside solids

```
bcremoveall
bcadd res f 1 c 0 s 0
```

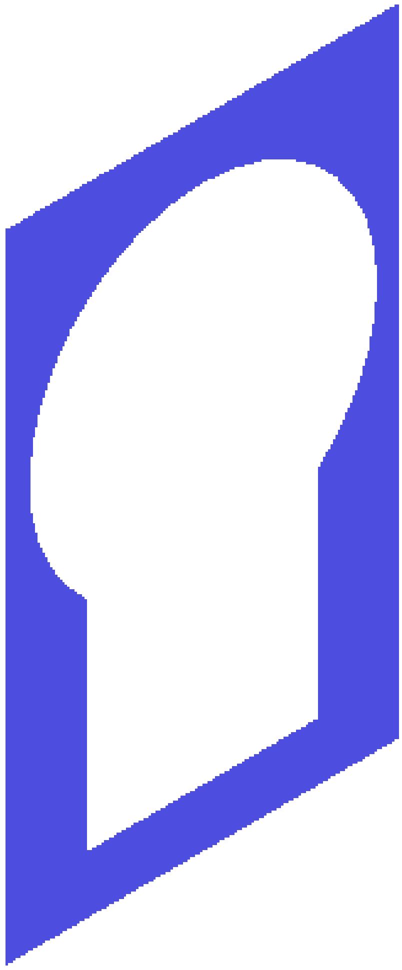


Figure 56: Part of the face outside solids

7. Fuse operation (impossible using standard Boolean Fuse operation)

```
bcremoveall
bcadd res c 1 -m 1
bcadd res s 1 -m 1
bcadd res f 1 c 0 s 0
bcremoveint res
```

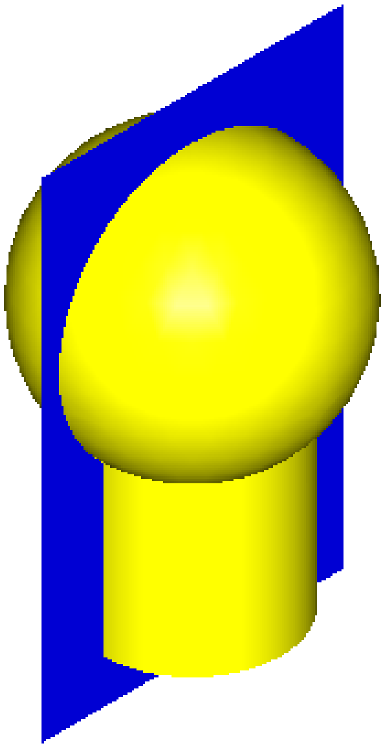


Figure 57: Fuse operation

These examples may last forever. To define any new operation, it is just necessary to define, which Cells should be taken and which should be avoided.

14 Algorithm Limitations

The chapter describes the problems that are considered as Algorithm limitations. In most cases an Algorithm failure is caused by a combination of various factors, such as self-interfered arguments, inappropriate or ungrounded values of the argument tolerances, adverse mutual position of the arguments, tangency, etc.

A lot of failures of GFA algorithm can be caused by bugs in low-level algorithms: Intersection Algorithm, Projection Algorithm, Approximation Algorithm, Classification Algorithm, etc.

- The Intersection, Projection and Approximation Algorithms are mostly used at the Intersection step. Their bugs directly cause wrong section results (i.e. incorrect section edges, section points, missing section edges or micro edges). It is not possible to obtain a correct final result of the GFA if a section result is wrong.
- The Projection Algorithm is used at the Intersection step. The purpose of Projection Algorithm is to compute 2D curves on surfaces. Wrong results here lead to incorrect or missing faces in the final GFA result.
- The Classification Algorithm is used at the Building step. The bugs in the Classification Algorithm lead to errors in selecting shape parts (edges, faces, solids) and ultimately to a wrong final GFA result.

The description below illustrates some known GFA limitations. It does not enumerate exhaustively all problems that can arise in practice. Please address cases of Algorithm failure to the OCCT Maintenance Service.

14.1 Arguments

14.1.1 Common requirements

Each argument should be valid (in terms of *BRepCheck_Analyzer*), or conversely, if the argument is considered as non-valid (in terms of *BRepCheck_Analyzer*), it cannot be used as an argument of the algorithm.

The class *BRepCheck_Analyzer* is used to check the overall validity of a shape. In OCCT a Shape (or its sub-shapes) is considered valid if it meets certain criteria. If the shape is found as invalid, it can be fixed by tools from *ShapeAnalysis, ShapeUpgrade* and *ShapeFix* packages.

However, it is important to note that class *BRepCheck_Analyzer* is just a tool that can have its own problems; this means that due to a specific factor(s) this tool can sometimes provide a wrong result.

Let us consider the following example:

The Analyzer checks distances between couples of 3D check-points *(Pi, PSi)* of edge *E* on face *F*. Point *Pi* is obtained from the 3D curve (at the parameter *ti*) of the edge. *PSi* is obtained from 2D curve (at the parameter *ti*) of the edge on surface *S* of face *F*. To be valid the distance should be less than *Tol(E)* for all couples of check-points. The number of these check-points is a predefined value (e.g. 23).

Let us consider the case when edge *E* is recognized valid (in terms of *BRepCheck_Analyzer*).

Further, after some operation, edge *E* is split into two edges *E1* and *E2*. Each split edge has the same 3D curve and 2D curve as the original edge *E*.

Let us check *E1* (or E2). The Analyzer again checks the distances between the couples of check-points points *(Pi, PSi)*. The number of these check-points is the same constant value (23), but there is no guarantee that the distances will be less than *Tol(E)*, because the points chosen for *E1* are not the same as for *E*.

Thus, if *E1* is recognized by the Analyzer as non-valid, edge *E* should also be non-valid. However *E* has been recognized as valid. Thus the Analyzer gives a wrong result for *E*.

The fact that the argument is a valid shape (in terms of *BRepCheck_Analyzer*) is a necessary but insufficient requirement to produce a valid result of the Algorithms.

14.1.2 Pure self-interference

The argument should not be self-interfered, i.e. all sub-shapes of the argument that have geometrical coincidence through any topological entities (vertices, edges, faces) should share these entities.

Example 1: Compound of two edges

The compound of two edges *E1* and *E2* is a self-interfered shape and cannot be used as the argument of the Algorithms.

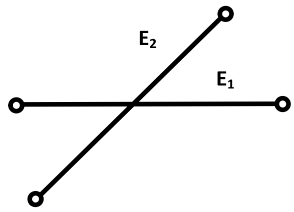


Figure 58: Compound of two edges

Example 2: Self-interfered Edge

The edge *E* is a self-interfered shape and cannot be used as an argument of the Algorithms.

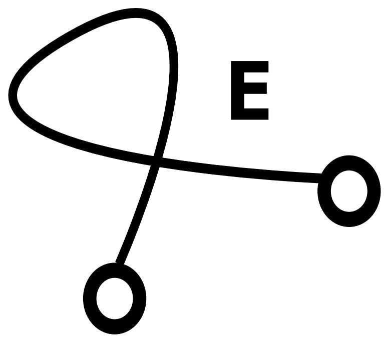


Figure 59: Self-interfered Edge

Example 3: Self-interfered Face

The face *F* is a self-interfered shape and cannot be used as an argument of the Algorithms.

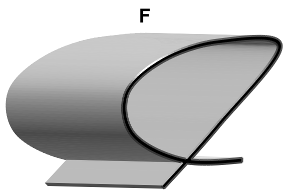


Figure 60: Self-interfered Face

Example 4: Face of Revolution

The face *F* has been obtained by revolution of edge *E* around line *L*.

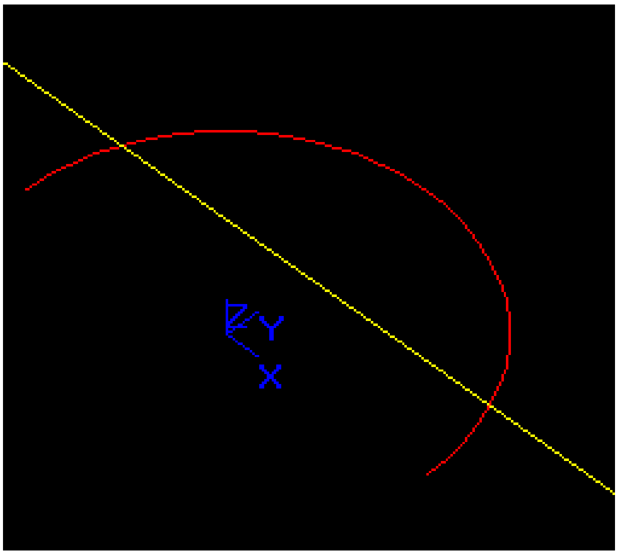


Figure 61: Face of Revolution: Arguments

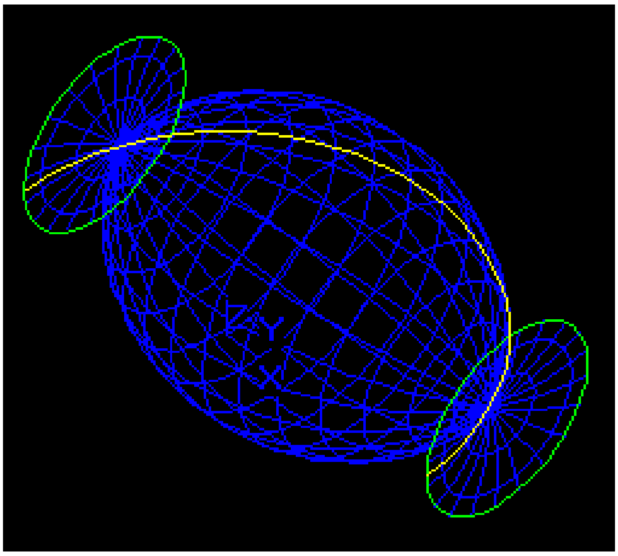


Figure 62: Face of Revolution: Result

In spite of the fact that face *F* is valid (in terms of *BRepCheck_Analyzer*) it is a self-interfered shape and cannot be used as the argument of the Algorithms.

14.1.3 Self-interferences due to tolerances

Example 1: Non-closed Edge

Let us consider edge *E* based on a non-closed circle.

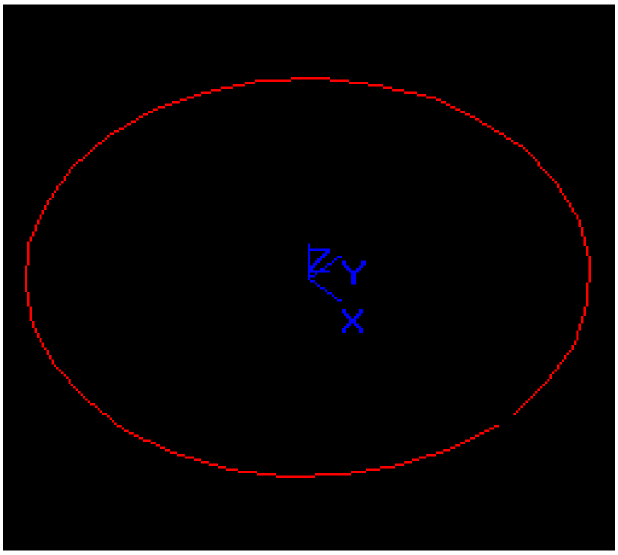


Figure 63: Edge based on a non-closed circle

The distance between the vertices of *E* is *D=0.69799*. The values of the tolerances *Tol(V1)=Tol(V2)=0.5*.

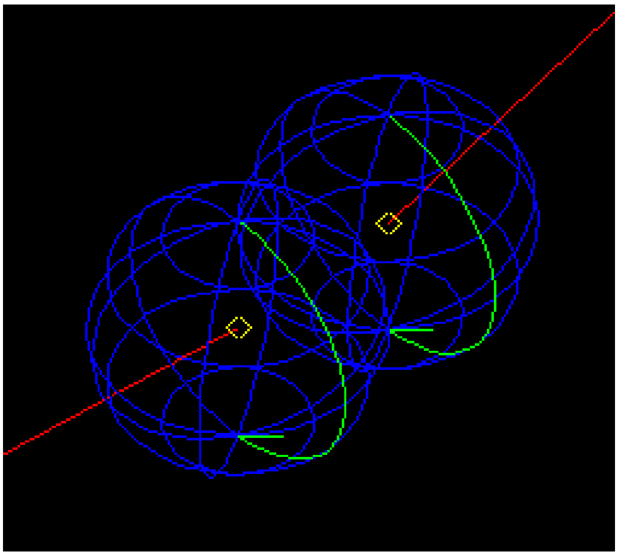


Figure 64: Distance and Tolerances

In spite of the fact that the edge *E* is valid in terms of *BRepCheck_Analyzer*, it is a self-interfered shape because its vertices are interfered. Thus, edge *E* cannot be used as an argument of the Algorithms.

Example 2: Solid containing an interfered vertex

Let us consider solid *S* containing vertex V.

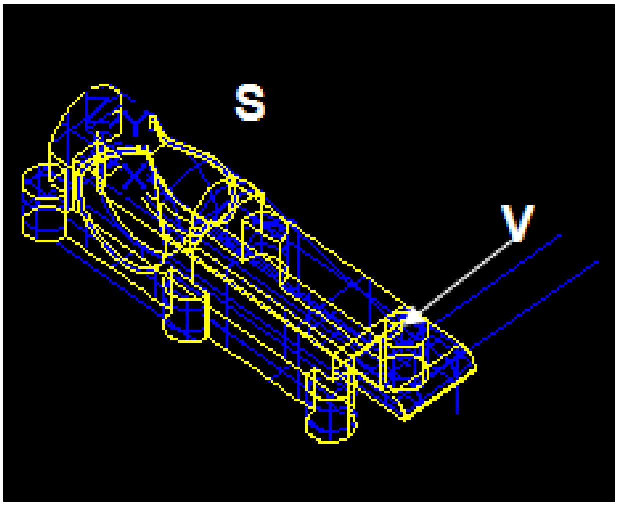


Figure 65: Solid containing an interfered vertex

The value of tolerance Tol(V)= 50.000075982061.

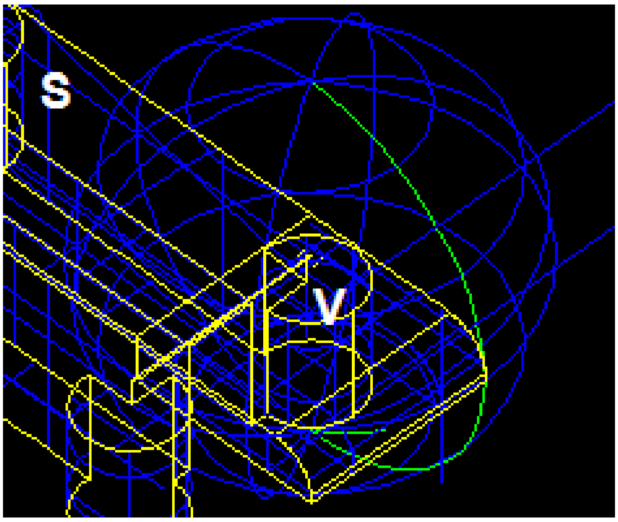


Figure 66: Tolerance

In spite of the fact that solid *S* is valid in terms of *BRepCheck_Analyzer* it is a self-interfered shape because vertex *V* is interfered with a lot of sub-shapes from *S* without any topological connection with them. Thus solid *S* cannot be used as an argument of the Algorithms.

14.1.4 Parametric representation

The parameterization of some surfaces (cylinder, cone, surface of revolution) can be the cause of limitation.

Example 1: Cylindrical surface

The parameterization range for cylindrical surface is:

$$U: [\,0, 2\pi]\,,\ V: [-\infty, +\infty]$$

The range of *U* coordinate is always restricted while the range of *V* coordinate is non-restricted.

Let us consider a cylinder-based *Face 1* with radii *R=3* and *H=6*.

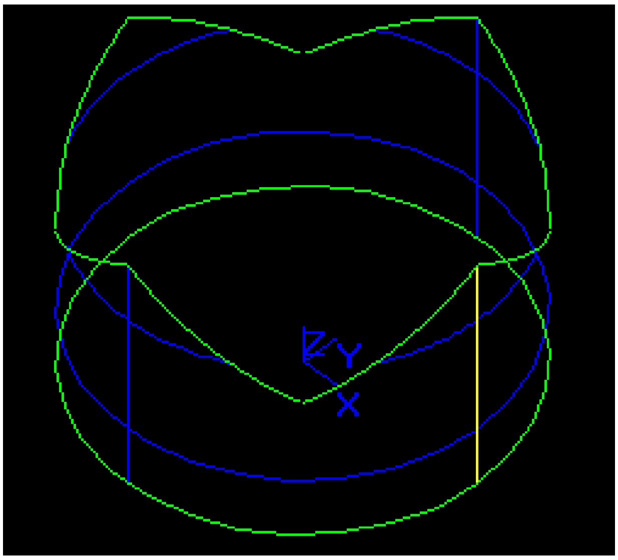


Figure 67: Face 1

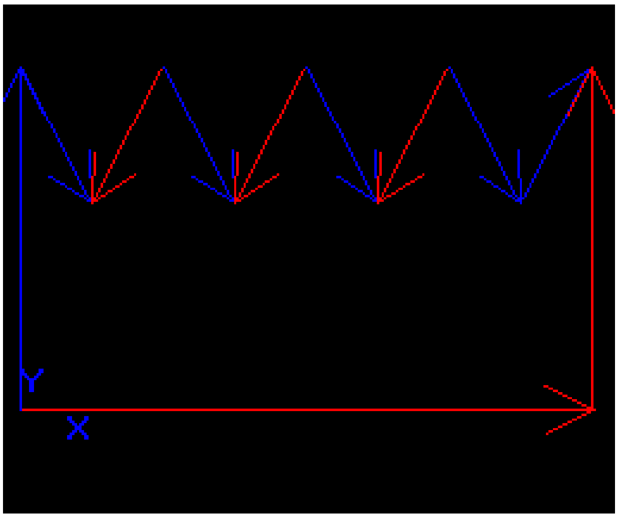


Figure 68: P-Curves for Face 1

Let us also consider a cylinder-based *Face 2* with radii *R=3000* and *H=6000* (resulting from scaling Face 1 with scale factor *ScF=1000*).

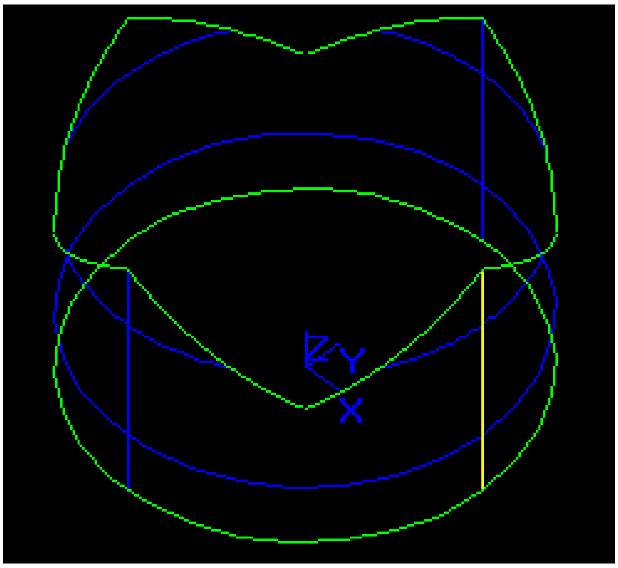


Figure 69: Face 2

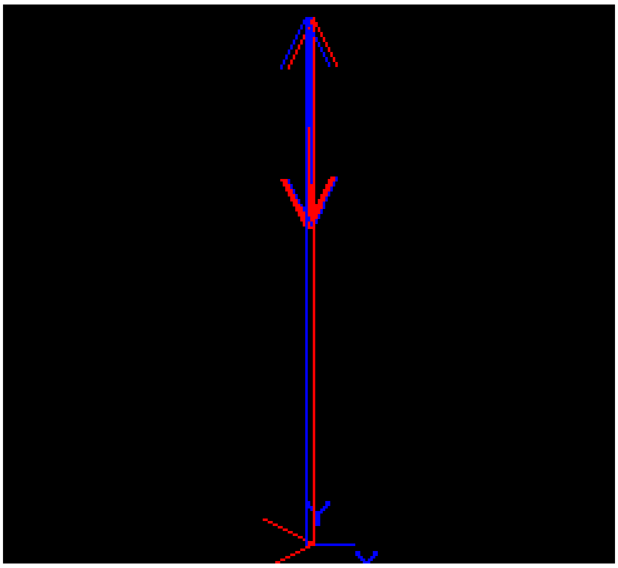


Figure 70: P-Curves for Face 2

Pay attention to the Zoom value of the Figures.

It is obvious that starting with some value of *ScF*, e.g. *ScF*>*1000000*, all sloped p-Curves on *Face 2* will be almost vertical. At least, there will be no difference between the values of angles computed by standard C Run-Time Library functions, such as *double acos(double x)*. The loss of accuracy in computation of angles can cause failure of some BP sub-algorithms, such as building faces from a set of edges or building solids from a set of faces.

14.1.5 Using tolerances of vertices to fix gaps

It is possible to create shapes that use sub-shapes of lower order to avoid gaps in the tolerance-based data model.

Let us consider the following example:

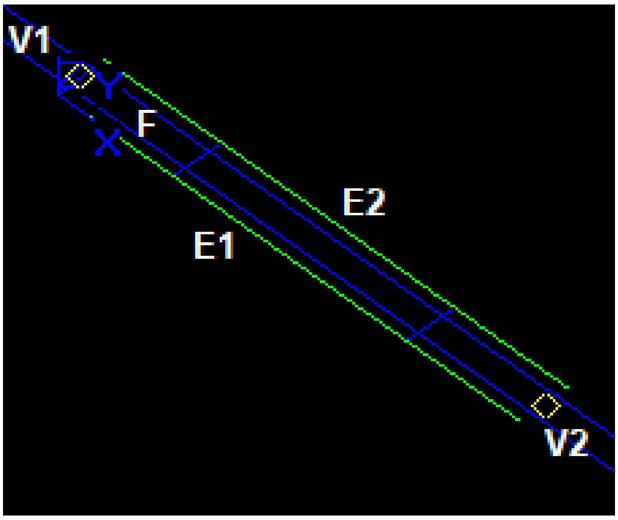


Figure 71: Example

- Face *F* has two edges *E1* and *E2* and two vertices, the base plane is *{0,0,0, 0,0,1}*;
- Edge *E1* is based on line *{0,0,0, 1,0,0}, Tol(E1) = 1.e-7;*
- Edge *E2* is based on line *{0,1,0, 1,0,0}, Tol(E2) = 1.e-7;*
- Vertex *V1*, point *{0,0.5,0}, Tol(V1) = 1;*
- Vertex *V2*, point *{10,0.5,0}, Tol(V2) = 1;*
- Face *F* is valid (in terms of *BRepCheck_Analyzer*).

The values of tolerances *Tol(V1)* and *Tol(V2)* are big enough to fix the gaps between the ends of the edges, but the vertices *V1* and *V2* do not contain any information about the trajectories connecting the corresponding ends of the edges. Thus, the trajectories are undefined. This will cause failure of some sub-algorithms of BP. For example, the sub-algorithms for building faces from a set of edges use the information about all edges connected in a vertex. The situation when a vertex has several pairs of edges such as above will not be solved in a right way.

14.2 Intersection problems

14.2.1 Pure intersections and common zones

Example: Intersecting Edges

Let us consider the intersection between two edges:

- *E1* is based on a line: *{0,-10,0, 1,0,0}, Tol(E1)=2.*
- *E2* is based on a circle: *{0,0,0, 0,0,1}, R=10, Tol(E2)=2.*

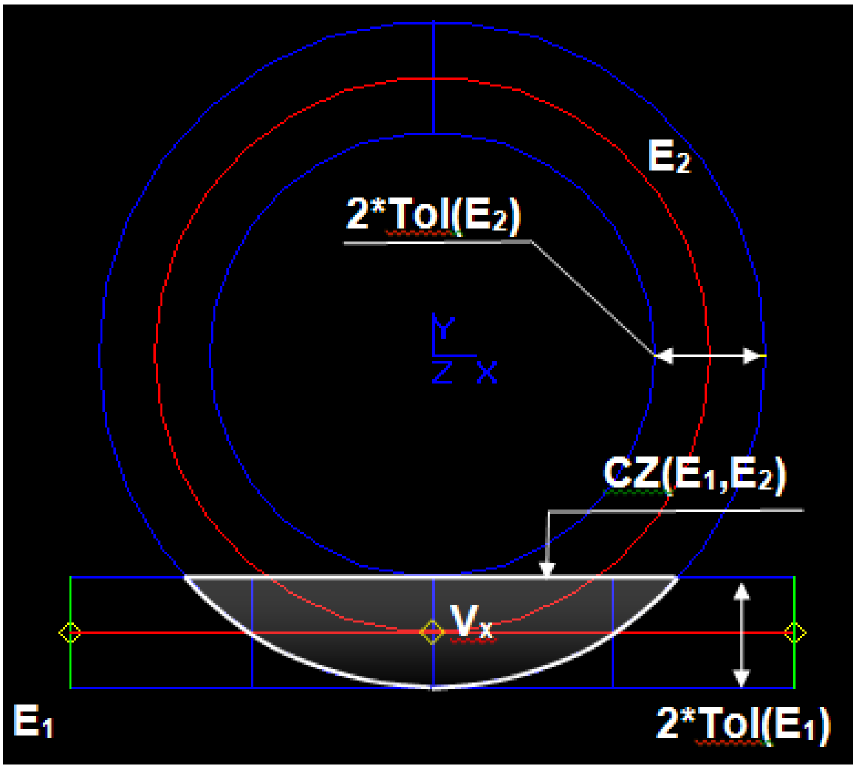


Figure 72: Intersecting Edges

The result of pure intersection between *E1* and *E2* is vertex *Vx {0,-10,0}*.

The result of intersection taking into account tolerances is the common zone *CZ* (part of 3D-space where the distance between the curves is less than or equals to the sum of edge tolerances.

The Intersection Part of Algorithms uses the result of pure intersection *Vx* instead of *CZ* for the following reasons:

- The Algorithms do not produce Common Blocks between edges based on underlying curves of explicitly different type (e.g. Line / Circle). If the curves have different types, the rule of thumb is that the produced result is of type **vertex**. This rule does not work for non-analytic curves (Bezier, B-Spline) and their combinations with analytic curves.
- The algorithm of intersection between two surfaces *IntPatch_Intersection* does not compute *CZ* of the intersection between curves and points. So even if *CZ* were computed by Edge/Edge intersection algorithm, its result could not be treated by Face/Face intersection algorithm.

14.2.2 Tolerances and inaccuracies

The following limitations result from modeling errors or inaccuracies.

Example: Intersection of planar faces

Let us consider two planar rectangular faces *F1* and *F2*.

The intersection curve between the planes is curve *C12*. The curve produces a new intersection edge *EC12*. The edge goes through vertices *V1* and *V2* thanks to big tolerance values of vertices *Tol(V1)* and *Tol(V2)*. So, two straight edges *E12* and *EC12* go through two vertices, which is impossible in this case.

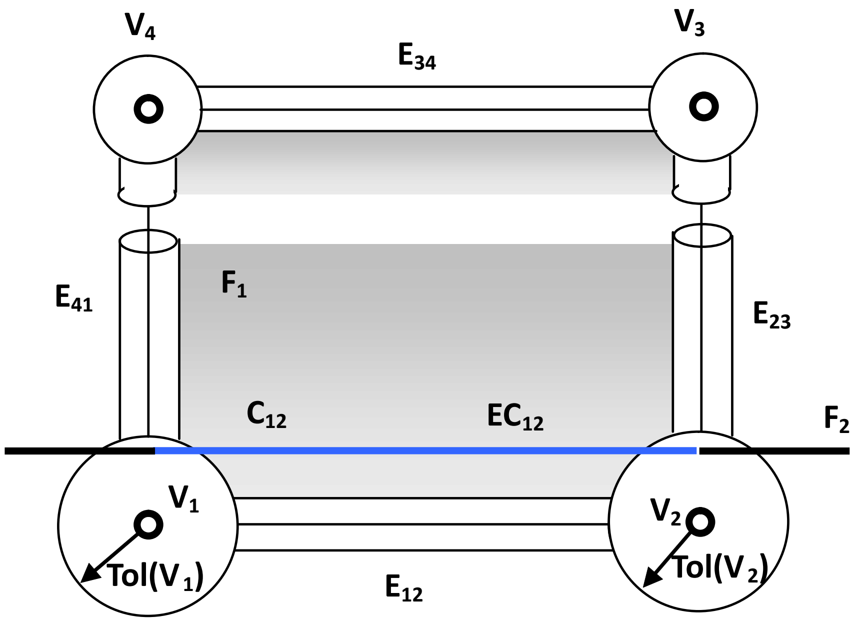


Figure 73: Intersecting Faces

The problem cannot be solved in general, because the length of *E12* can be infinite and the values of *Tol(V1)* and *Tol(V2)* theoretically can be infinite too.

In a particular case the problem can be solved in several ways:

- Reduce, if possible, the values of *Tol(V1)* and *Tol(V2)* (refinement of *F1*).
- Analyze the value of *Tol(EC12)* and increase *Tol(EC12)* to get a common part between the edges *EC12* and *E12*. Then the common part will be rejected as there is an already existing edge *E12* for face *F1*.

It is easy to see that if *C12* is slightly above the tolerance spheres of *V1* and *V2* the problem does not appear.

Example: Intersection of two edges

Let us consider two edges *E1* and *E2*, which have common vertices *V1* and *V2*. The edges *E1* and *E2* have 3D-curves *C1* and *C2*. *Tol(E1)=1.e*$^{-7}$, *Tol(E2)=1.e*$^{-7}$.

C1 practically coincides in 3D with *C2*. The value of deflection is *Dmax* (e.g. *Dmax=1.e*$^{-6}$).

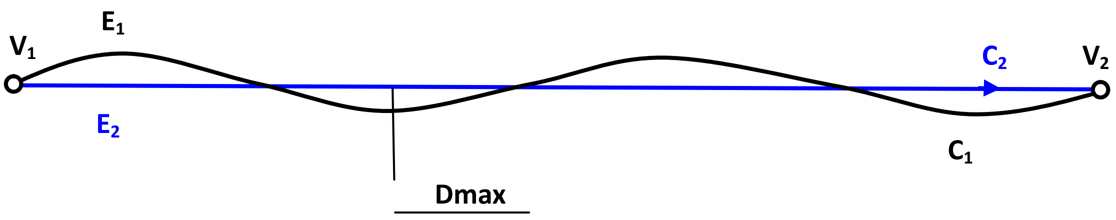


Figure 74: Intersecting Edges

The evident and prospective result should be the Common Block between *E1* and *E2*. However, the result of intersection differs.

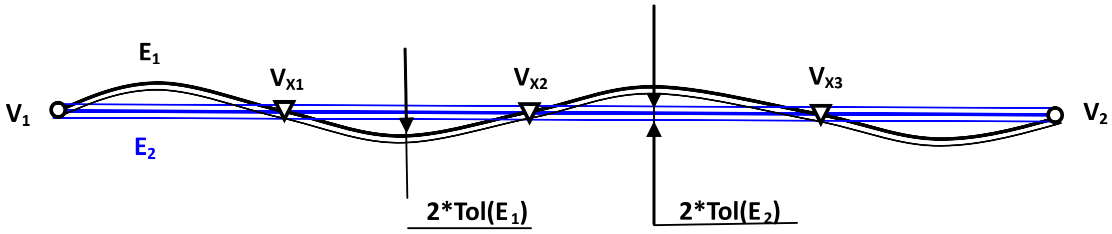


Figure 75: Result of Intersection

The result contains three new vertices *Vx1, Vx2* and *Vx3*, 8 new edges *(V1, Vx1, Vx2, Vx3, V2)* and no Common Blocks. This is correct due to the source data: $Tol(E1)=1.e^{-7}$, $Tol(E2)=1.e^{-7}$ and $Dmax=1.e^{-6}$.

In this particular case the problem can be solved by several ways:

- Increase, if possible, the values *Tol(E1)* and *Tol(E2)* to get coincidence in 3D between *E1* and *E2* in terms of tolerance.
- Replace *E1* by a more accurate model.

The example can be extended from 1D (edges) to 2D (faces).

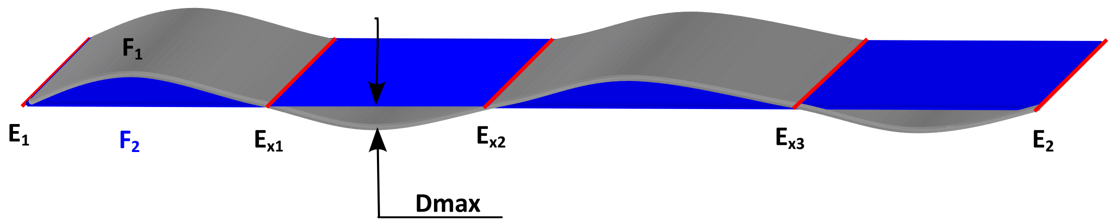


Figure 76: Intersecting Faces

The comments and recommendations are the same as for 1D case above.

14.2.3 Acquired Self-interferences

Example 1: Vertex and edge

Let us consider vertex *V1* and edge *E2*.

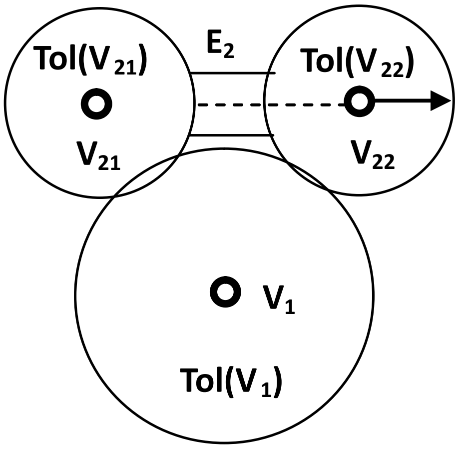


Figure 77: Vertex and Edge

Vertex *V1* interferes with vertices *V12* and *V22*. So vertex *V21* should interfere with vertex *V22*, which is impossible because vertices *V21* and *V22* are the vertices of edge *E2*, thus *V21* is not equal to *V22*.

The problem cannot be solved in general, because the length can be as small as possible to provide validity of *E2* (in the extreme case: *Length (E2) = Tol(V21) + Tol(V22) + e,* where *e-*> *0*).

In a particular case the problem can be solved by refinement of arguments, i.e. by decreasing the values of *Tol(V21)*, *Tol(V22)* and *Tol(V1)*.

Example 2: Vertex and wire

Let us consider vertex *V2* and wire consisting of edges *E11* and *E12*.

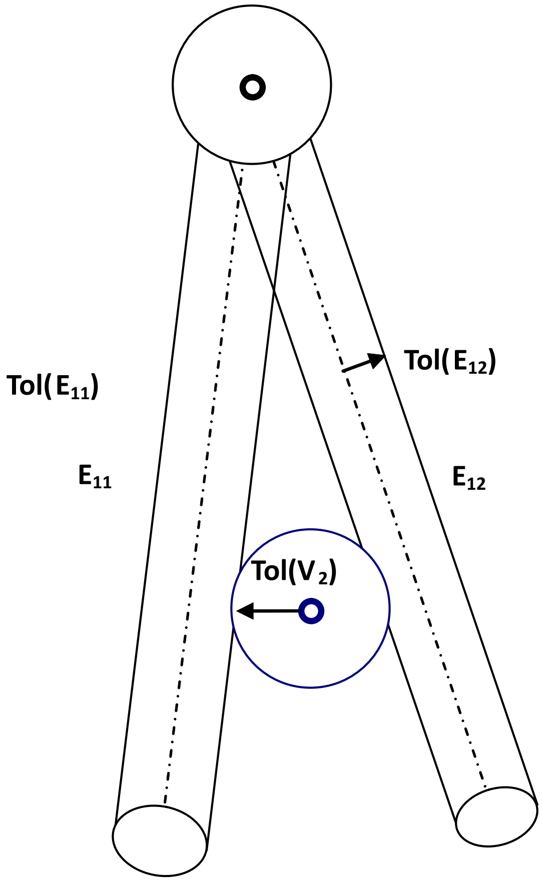


Figure 78: Vertex and Wire

The arguments themselves are not self-intersected. Vertex *V2* interferes with edges *E11* and *E12*. Thus, edge *E11* should interfere with edge *E22*, but it is impossible because edges *E11* and *E12* cannot interfere by the condition.

The cases when a non-self-interfered argument (or its sub-shapes) become interfered due to the intersections with other arguments (or their sub-shapes) are considered as limitations for the Algorithms.

15 Advanced Options

The previous chapters describe so called Basic Operations. Most of tasks can be solved using Basic Operations. Nonetheless, there are cases that can not be solved straightforwardly by Basic Operations. The tasks are considered as limitations of Basic Operations.

The chapter is devoted to Advanced Options. In some cases the usage of Advanced Options allows overcoming the limitations, improving the quality of the result of operations, robustness and performance of the operators themselves.

15.1 Fuzzy Boolean Operation

Fuzzy Boolean operation is the option of Basic Operations such as General Fuse, Splitting, Boolean, Section, Maker Volume and Cells building operations, in which additional user-specified tolerance is used. This option allows operators to handle robustly cases of touching and near-coincident, misaligned entities of the arguments.

The Fuzzy option is useful on the shapes with gaps or embeddings between the entities of these shapes, which are not covered by the tolerance values of these entities. Such shapes can be the result of modeling mistakes, or translating process, or import from other systems with loss of precision, or errors in some algorithms.

Most likely, the Basic Operations will give unsatisfactory results on such models. The result may contain unexpected and unwanted small entities, faulty entities (in terms of *BRepCheck_Analyzer*), or there can be no result at all.

With the Fuzzy option it is possible to get the expected result – it is just necessary to define the appropriate value of fuzzy tolerance for the operation. To define that value it is necessary to measure the value of the gap (or the value of embedding depth) between the entities of the models, slightly increase it (to make the shifted entities coincident in terms of their tolerance plus the additional one) and pass it to the algorithm.

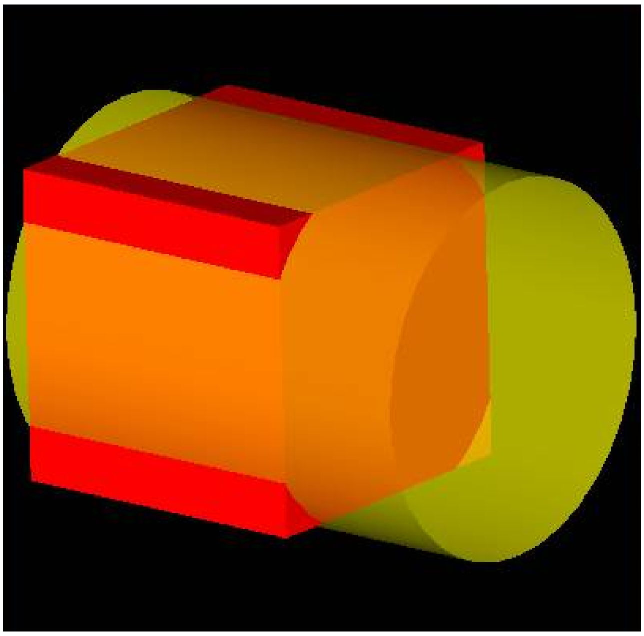
Fuzzy option is included in interface of Intersection Part (class *BOPAlgo_PaveFiller*) and application programming interface (class *BRepAlgoAPI_BooleanOperation*)

15.1.1 Examples

The following examples demonstrate the advantages of usage Fuzzy option operations over the Basic Operations in typical situations.

Case 1

In this example the cylinder (shown in yellow and transparent) is subtracted from the box (shown in red). The cylinder is shifted by $5e^{-5}$ relatively to the box along its axis (the distance between rear faces of the box and cylinder is $5e^{-5}$).



The following results are obtained using Basic Operations and the Fuzzy ones with the fuzzy value $5e^{-5}$:

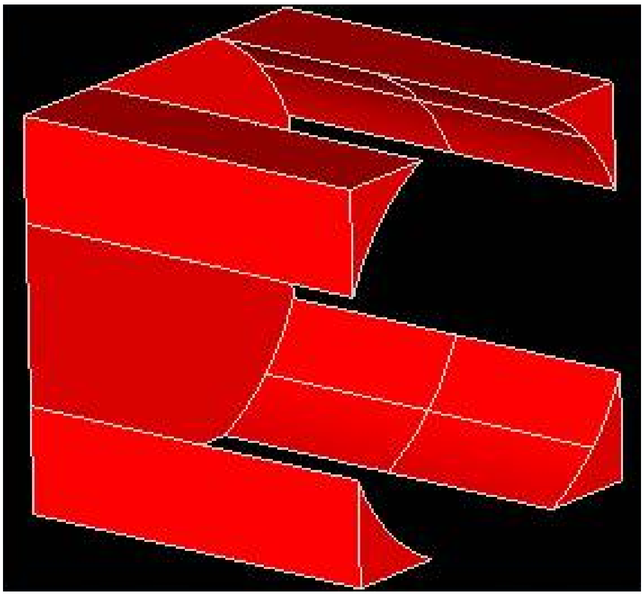


Figure 79: Result of CUT operation obtained with Basic Operations

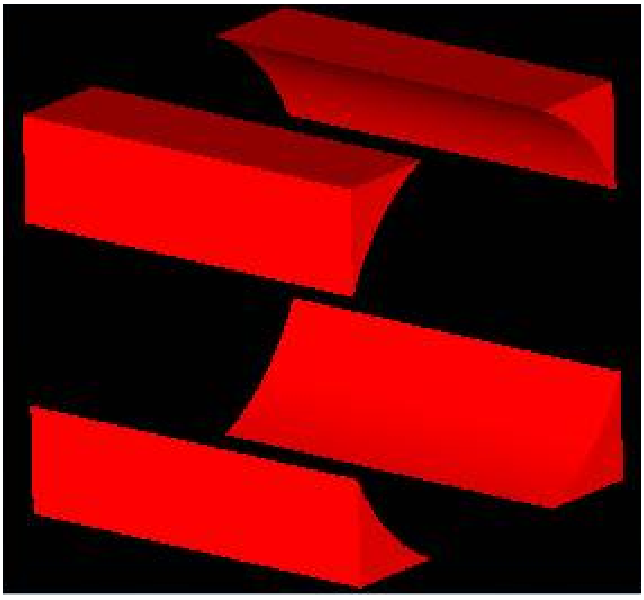
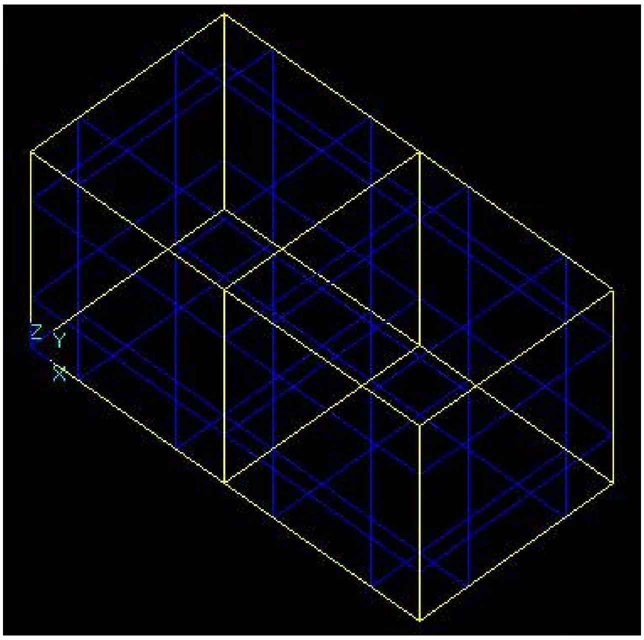


Figure 80: Result of CUT operation obtained with Fuzzy Option

In this example Fuzzy option allows eliminating a very thin part of the result shape produced by Basic algorithm due to misalignment of rear faces of the box and the cylinder.

Case 2

In this example two boxes are fused. One of them has dimensions 10∗10∗10, and the other is 10∗10.000001∗10.000001 and adjacent to the first one. There is no gap in this case as the surfaces of the neighboring faces coincide, but one box is slightly greater than the other.



The following results are obtained using Basic Operations and the Fuzzy ones with the fuzzy value $1e^{-6}$:

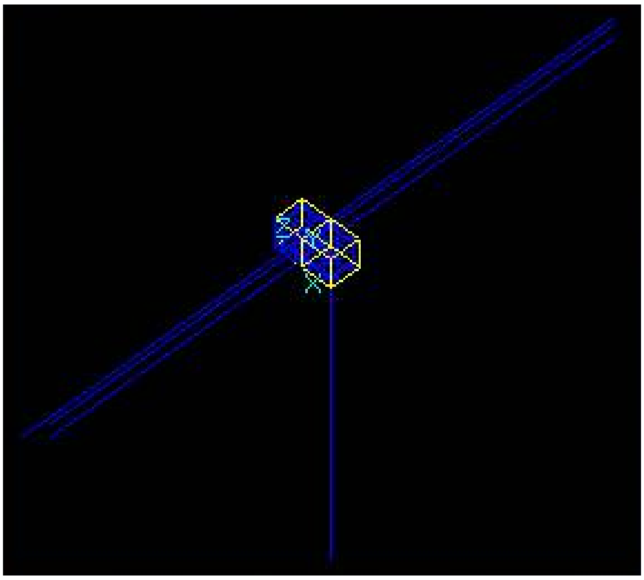


Figure 81: Result of CUT operation obtained with Basic Operations

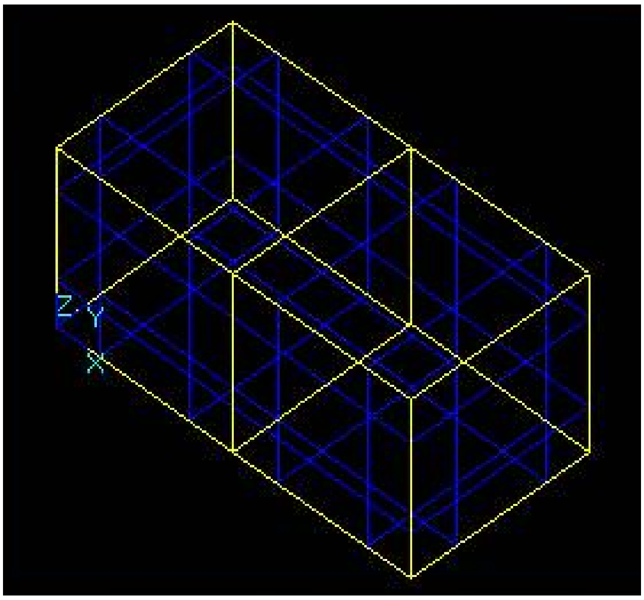
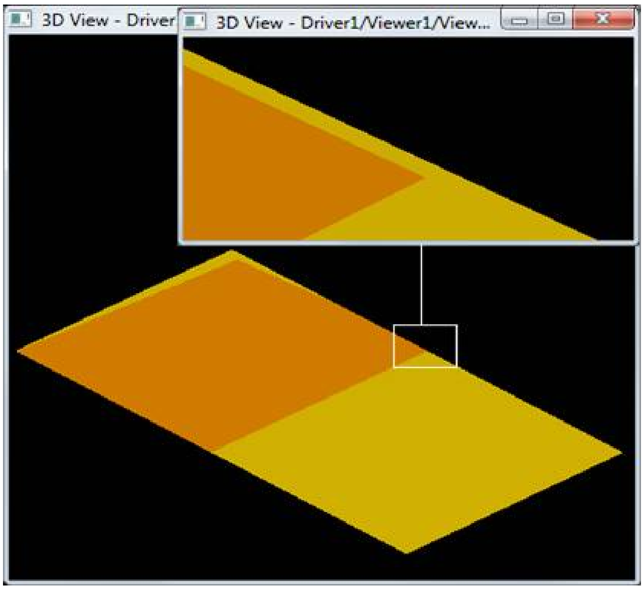


Figure 82: Result of CUT operation obtained with Fuzzy Option

In this example Fuzzy option allows eliminating an extremely narrow face in the result produced by Basic operation.

Case 3

In this example the small planar face (shown in orange) is subtracted from the big one (shown in yellow). There is a gap $1e^{-5}$ between the edges of these faces.



The following results are obtained using Basic Operations and the Fuzzy ones with the fuzzy value $1e^{-5}$:

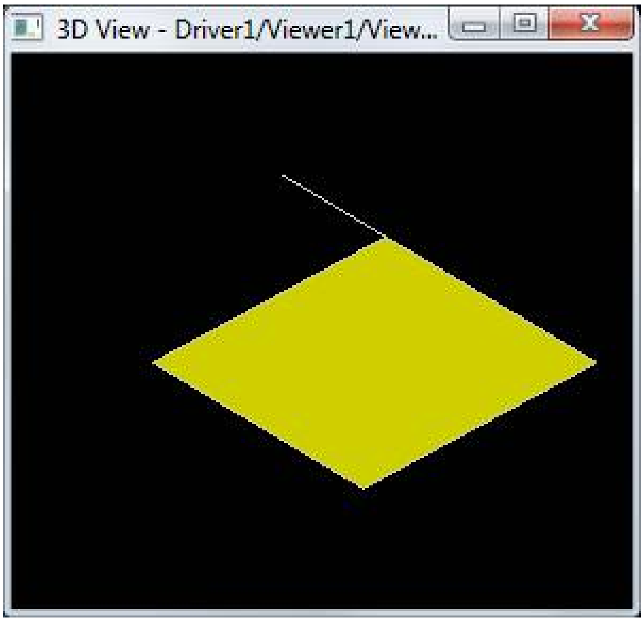


Figure 83: Result of CUT operation obtained with Basic Operations

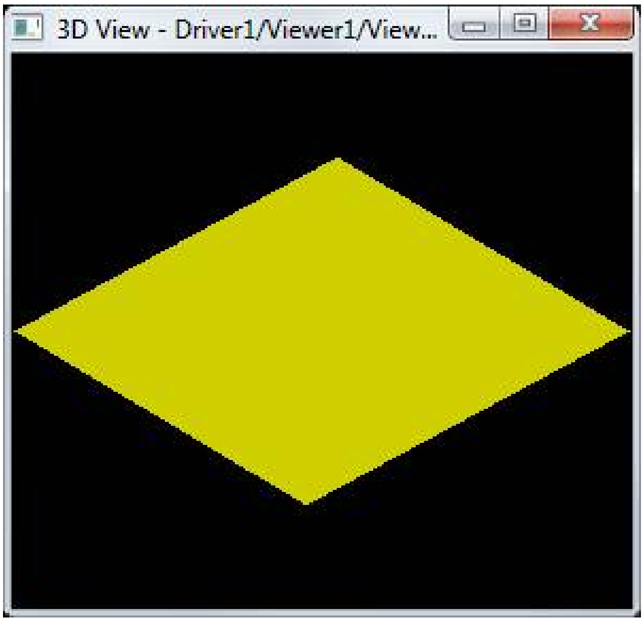
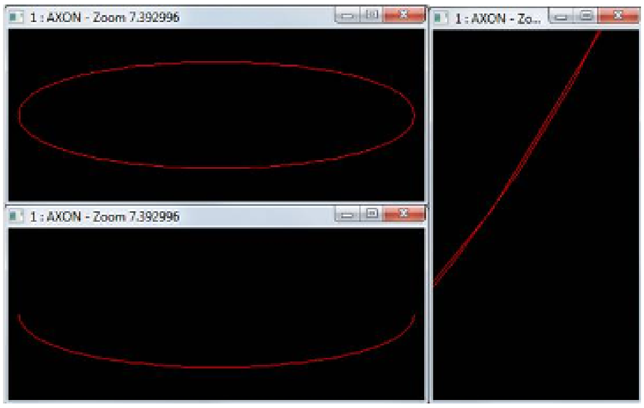


Figure 84: Result of CUT operation obtained with Fuzzy Option

In this example Fuzzy options eliminated a pin-like protrusion resulting from the gap between edges of the argument faces.

Case 4

In this example the small edge is subtracted from the big one. The edges are overlapping not precisely, with max deviation between them equal to 5.28004e^{-5}. We will use 6e^{-5} value for Fuzzy option.



The following results are obtained using Basic Operations and the Fuzzy ones with the fuzzy value 6e^{-5}:

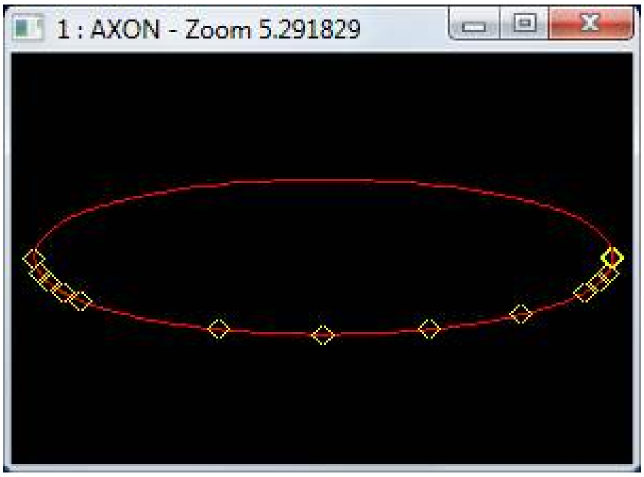


Figure 85: Result of CUT operation obtained with Basic Operations

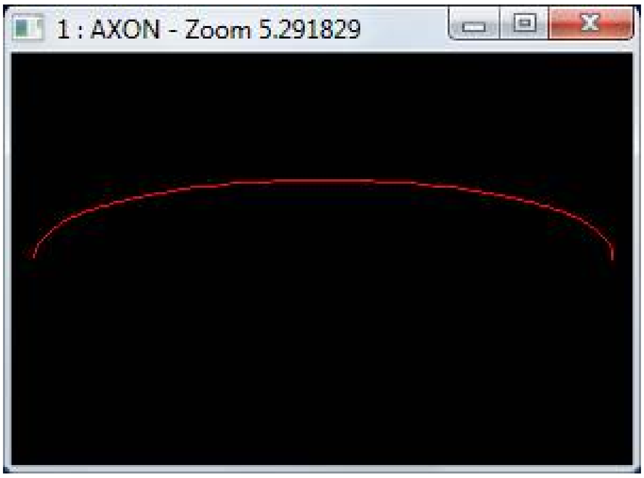


Figure 86: Result of CUT operation obtained with Fuzzy Option

This example stresses not only the validity, but also the performance issue. The usage of Fuzzy option with the appropriate value allows processing the case much faster than with the pure Basic operation. The performance gain for the case is 45 (Processor: Intel(R) Core(TM) i5-3450 CPU @ 3.10 GHz).

15.2 Gluing Operation

The Gluing operation is the option of the Basic Operations such as General Fuse, Splitting, Boolean, Section, Maker Volume and Cells building operations. It has been designed to speed up the computation of the interferences among arguments of the operations on special cases, in which the arguments may be overlapping but do not have real intersections between their sub-shapes.

This option cannot be used on the shapes having real intersections, like intersection vertex between edges, or intersection vertex between edge and a face or intersection line between faces:

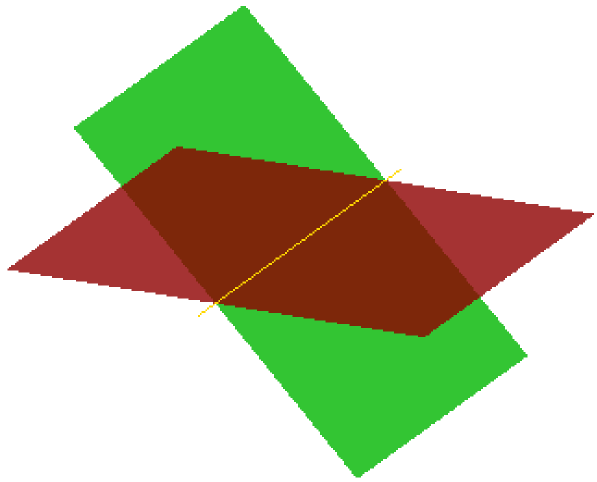


Figure 87: Intersecting faces

There are two possibilities of overlapping shapes:

- The shapes can be partially coinciding - the faces do not have intersection curves, but overlapping. The faces of such arguments will be split during the operation. The following picture illustrates such shapes:

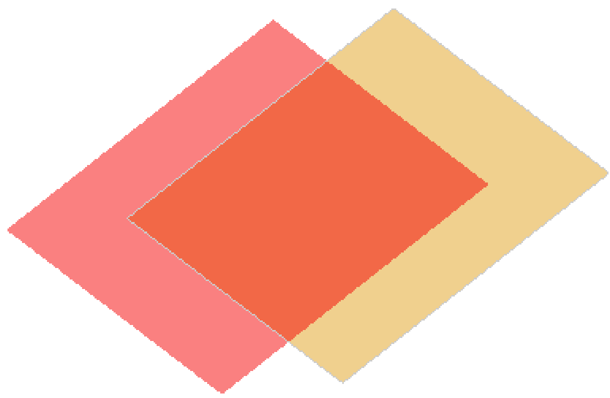


Figure 88: Partially coinciding faces

- The shapes can be fully coinciding - there should be no partial overlapping of the faces, thus no intersection of type EDGE/FACE at all. In such cases the faces will not be split during the operation.

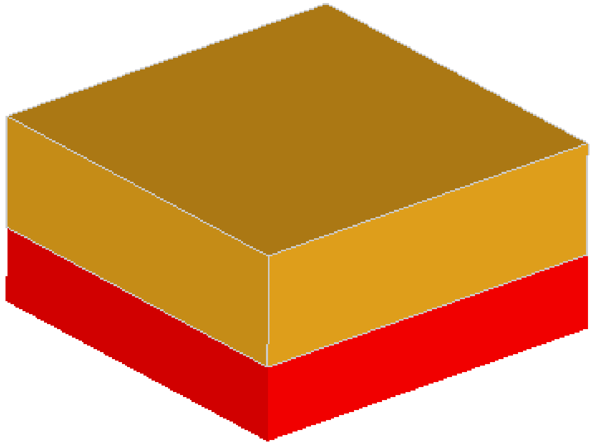


Figure 89: Full coinciding faces of the boxes

Thus, there are two possible options - for full and partial coincidence of the shapes.

Even though there are no real intersections on such cases without Gluing options the algorithm will still intersect the sub-shapes of the arguments with interfering bounding boxes.

The performance improvement in gluing mode is achieved by excluding the most time consuming computations and in some case can go up to 90%:

- Exclude computation of FACE/FACE intersections for partial coincidence;
- Exclude computation of VERTEX/FACE, EDGE/FACE and FACE/FACE intersections for full coincidence.

By setting the Gluing option for the operation user should guarantee that the arguments are really coinciding. The algorithm does not check this itself. Setting inappropriate option for the operation is likely to lead to incorrect result.

15.2.1 Usage

The Gluing option is an enumeration implemented in BOPAlgo_GlueEnum.hxx:

- BOPAlgo_GlueOff - default value for the algorithms, Gluing is switched off;
- BOPAlgo_GlueShift - Glue option for shapes with partial coincidence;
- BOPAlgo_GlueFull - Glue option for shapes with full coincidence.

API level

For setting the Gluing options for the algorithm it is just necessary to call the SetGlue(const BOPAlgo_Glue) method with appropriate value:

```
BOPAlgo_Builder aGF;
//
....
// setting the gluing option to speed up intersection of the arguments
aGF.SetGlue(BOPAlgo_GlueShift)
//
....
```

TCL level

For setting the Gluing options in DRAW it is necessary to call the *bglue* command with appropriate value:

- 0 - default value, Gluing is off;
- 1 - for partial coincidence;
- 2 - for full coincidence

```
bglue 1
```

15.2.2 Examples

Case1 - Fusing the 64 bspline boxes into one solid

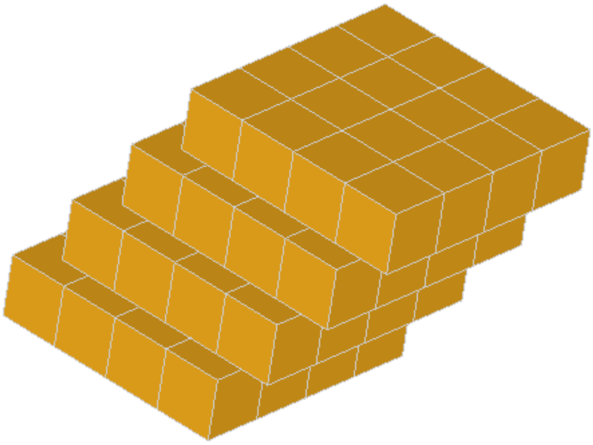


Figure 90: BSpline Boxes with partial coincidence

Performance improvement from using the GlueShift option in this case is about 70 percent.

Case2 - Sewing faces of the shape after reading from IGES

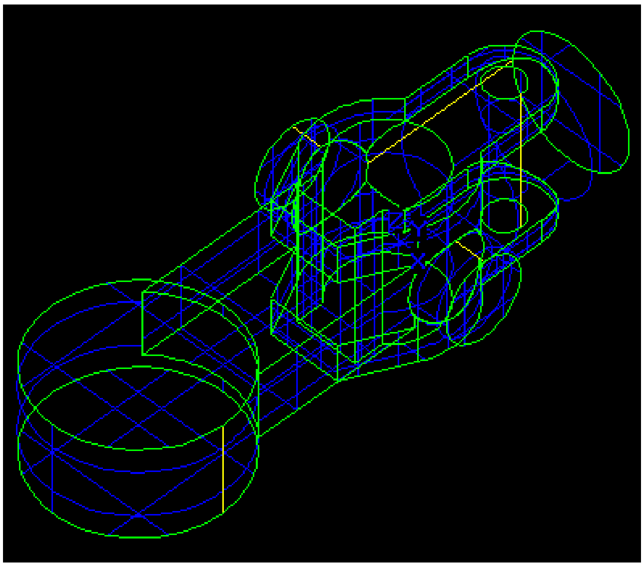


Figure 91: Faces with coinciding but not shared edges

Performance improvement in this case is also about 70 percent.

15.3 Safe processing mode

The safe processing mode is the advanced option in Boolean Operation component. This mode can be applied to all Basic operations such as General Fuse, Splitting, Boolean, Section, Maker Volume, Cells building. This option allows keeping the input arguments untouched. In other words, switching this option on prevents the input arguments from any modification such as tolerance increase, addition of the P-Curves on edges, etc.

The option can be very useful for implementation of the Undo/Redo mechanism in the applications and allows performing the operation many times without changing the inputs.

By default the safe processing option is switched off for the algorithms. Enabling this option might slightly decrease the performance of the operation, because instead of the modification of some entity it will be necessary to create the copy of this entity and modify it. However, this degradation should be very small because the copying is performed only in case of necessity.

The option is also available in the Intersection algorithm - *BOPAlgo_PaveFiller*. To perform several different operations on the same arguments, the safe processing mode can be enabled in PaveFiller, prepared only once and then used in operations. It is enough to set this option to PaveFiller only and all algorithms taking this PaveFiller will also work in the safe mode.

15.3.1 Usage

API level

To enable/disable the safe processing mode for the algorithm, it is necessary to call *SetNonDestructive()* method with the appropriate value:

```
BOPAlgo_Builder aGF;
//
....
// enabling the safe processing mode to prevent modification of the input shapes
aGF.SetNonDestructive(Standard_True);
//
....
```

TCL level

To enable the safe processing mode for the operation in DRAW, it is necessary to call the *bnondestructive* command with the appropriate value:

- 0 - default value, the safe mode is switched off;
- 1 - the safe mode will be switched on.

```
bnondestructive 1
```

15.4 How to disable check of input solids for inverted status

By default, all input solids are checked for inverted status, i.e. the solids are classified to understand if they are holes in the space (negative volumes) or normal solids (positive volumes). The possibility to disable the check of the input solids for inverted status is the advanced option in Boolean Operation component. This option can be applied to all Basic operations, such as General Fuse, Splitting, Boolean, Section, Maker Volume and Cells building. This option allows avoiding time-consuming classification of the input solids and processing them in the same way as positive volumes, saving up to 10 percent of time on the cases with a big number of input solids.

The classification should be disabled only if the user is sure that there are no negative volumes among the input solids, otherwise the result may be invalid.

15.4.1 Usage

API level

To enable/disable the classification of the input solids it is necessary to call *SetCheckInverted()* method with the appropriate value:

```
BOPAlgo_Builder aGF;
//
....
// disabling the classification of the input solid
aGF.SetCheckInverted(Standard_False);
//
....
```

TCL level

To enable/disable the classification of the solids in DRAW, it is necessary to call *bcheckinverted* command with the appropriate value:

- 0 - disabling the classification;
- 1 - default value, enabling the classification.

```
bcheckinverted 0
```

15.5 Usage of Oriented Bounding Boxes

Since Oriented Bounding Boxes are usually much tighter than Axes Aligned Bounding Boxes (for more information on OBB see the Bounding boxes chapter of Modeling data User guide) its usage can significantly speed-up the intersection stage of the operation by reducing the number of interfering objects.

15.5.1 Usage

API level

To enable/disable the usage of OBB in the operation it is necessary to call the *SetUseOBB()* method with the appropriate value:

```
BOPAlgo_Builder aGF;
//
....
// Enabling the usage of OBB in the operation
aGF.SetUseOBB(Standard_True);
//
....
```

TCL level

To enable/disable the usage of OBB in the operation in DRAW it is necessary to call the *buseobb* command with the appropriate value:

- 0 - disabling the usage of OBB;
- 1 - enabling the usage of OBB.

```
buseobb 1
```

16 Errors and warnings reporting system

The chapter describes the Error/Warning reporting system of the algorithms in the Boolean Component.

The errors and warnings are collected in the instance of the class *Message_Report* maintained as a field by common base class of Boolean operation algorithms *BOPAlgo_Options*.

The error is reported in for problems which cannot be treated and cause the algorithm to fail. In this case the result of the operation will be incorrect or incomplete or there will be no result at all.

The warnings are reported for the problems which can be potentially handled or ignored and thus do not cause the algorithms to stop their work (but probably affect the result).

All possible errors and warnings that can be set by the algorithm are listed in its header file. The complete list of errors and warnings that can be generated by Boolean operations is defined in *BOPAlgo_Alerts.hxx*.

Use method *HasErrors()* to check for presence of error; method *HasError()* can be used to check for particular error. Methods *DumpErrors()* outputs textual description of collected errors into the stream. Similar methods *Has↩ Warnings()*, *HasWarning()*, and *DumpWarnings()* are provided for warnings.

Note that messages corresponding to errors and warnings are defined in resource file *BOPAlgo.msg*. These messages can be localized; for that put translated version to separate file and load it in the application by call to *Message_MsgFile::Load()* .

Here is the example of how to use this system:

```
BOPAlgo_PaveFiller aPF;
aPF.SetArguments(...);
aPF.Perform();
if (aPF.HasErrors()) {
  aPF.DumpErrors(std::cerr);
  //
  if (aPF.HasError(STANDARD_TYPE(BOPAlgo_AlertNullInputShapes)) {
    // some actions
  }
  if (aPF.HasWarning(STANDARD_TYPE(BOPAlgo_AlertTooSmallEdge)) {
    // some actions
  }
  ...
}
```

DRAW commands executing Boolean operations output errors and warnings generated by these operations in textual form. Additional option allows saving shapes for which warnings have been generated, as DRAW variables. To activate this option, run command *bdrawwarnshapes* with argument 1 (or with 0 to deactivate):

```
bdrawwarnshapes 1
```

After setting this option and running an algorithm the result will look as follows:

```
Warning: The interfering vertices of the same argument: ws_1_1 ws_1_2
Warning: The positioning of the shapes leads to creation of small edges without valid range: ws_2_1
```

17 History Information

All operations in Boolean Component support History information. This chapter describes how the History is filled for these operations.

Additionally to Vertices, Edges and Faces the history is also available for the Solids.

The rules for filling the History information about Deleted and Modified shapes are the same as for the API algorithms.

Only the rules for Generated shapes require clarification. In terms of the algorithms in Boolean Component the shape from the arguments can have Generated shapes only if these new shapes have been obtained as a result of pure intersection (not overlapping) of this shape with any other shapes from arguments. Thus, the Generated shapes are always:

- VERTICES created from the intersection points and may be Generated from edges and faces only;
- EDGES created from the intersection edges and may be Generated from faces only.

So, only EDGES and FACES could have information about Generated shapes. For all other types of shapes the list of Generated shapes will be empty.

17.1 Examples

Here are some examples illustrating the History information.

17.1.1 Deleted shapes

The result of CUT operation of two overlapping planar faces (see the example below) does not contain any parts from the tool face. Thus, the tool face is considered as Deleted. If the faces are not fully coinciding, the result must contain some parts of the object face. In this case object face will be considered as not deleted. But if the faces are fully coinciding, the result must be empty, and both faces will be considered as Deleted.

Example of the overlapping faces:

```
plane p 0 0 0 0 0 1
mkface f1 p -10 10 -10 10
mkface f2 p 0 20 -10 10

bclearobjects
bcleartools
baddobjects f1
baddtools f2
bfillds
bbop r 2

savehistory cut_hist
isdeleted cut_hist f1
# Not deleted

isdeleted cut_hist f2
# Deleted
```

17.1.2 Modified shapes

In the FUSE operation of two edges intersecting in one point (see the example below), both edges will be split by the intersection point. All these splits will be contained in the result. Thus, each of the input edges will be Modified into its two splits. But in the CUT operation on the same edges, the tool edge will be Deleted from the result and, thus, will not have any Modified shapes.

Example of the intersecting edges:

```
line l1 0 0 0 1 0 0
mkedge e1 l1 -10 10
```

```
line l2 0 0 0 0 1 0
mkedge e2 l2 -10 10

bclearobjects
bcleartools
baddobjects e1
baddtools e2
bfillds

# fuse operation
bbop r 1

savehistory fuse_hist

modified m1 fuse_hist e1
nbshapes m1
# EDGES: 2

modified m2 fuse_hist e2
nbshapes m2
# EDGES: 2

# cut operation
bbop r 2

savehistory cut_hist

modified m1 cut_hist e1
nbshapes m1
# EDGES: 2

modified m2 cut_hist e2
# The shape has not been modified
```

17.1.3 Generated shapes

Two intersecting edges will both have the intersection vertices Generated from them.

As for the operation with intersecting faces, consider the following example:

```
plane p1 0 0 0 0 0 1
mkface f1 p1 -10 10 -10 10

plane p2 0 0 0 1 0 0
mkface f2 p2 -10 10 -10 10

bclearobjects
bcleartools
baddobjects f1
baddtools f2
bfillds

# fuse operation
bbop r 1

savehistory fuse_hist

generated gf1 fuse_hist f1
nbshapes gf1
# EDGES: 1

generated gf2 fuse_hist f2
nbshapes gf2
# EDGES: 1


# common operation - result is empty
bbop r 0

savehistory com_hist

generated gf1 com_hist f1
# No shapes were generated from the shape

generated gf2 com_hist f2
# No shapes were generated from the shape
```

18 BOP result simplification

The API algorithms implementing Boolean Operations provide possibility to simplify the result shape by unification of the connected tangential edges and faces. This simplification is performed by the method *SimplifyResult* which is implemented in the class *BRepAlgoAPI_BuilderAlgo* (General Fuse operation). It makes it available for users of the classes *BRepAlgoAPI_BooleanOperation* (all Boolean Operations) and *BRepAlgoAPI_Splitter* (split operation).

The simplification is performed by the means of *ShapeUpgrade_UnifySameDom* algorithm. The result of operation is overwritten with the simplified result.

The simplification is performed without creation of the Internal shapes, i.e. shapes connections will never be broken. It is performed on the whole result shape. Thus, if the input shapes contained connected tangent edges or faces unmodified during the operation they will also be unified.

History of the simplification is merged into the main history of operation, thus it will be accounted when asking for Modified, Generated and Deleted shapes.

Some options of the main operation are passed into the Unifier:

- Fuzzy tolerance of the operation is given to the Unifier as the linear tolerance.
- Non destructive mode here controls the safe input mode in Unifier.

For controlling this possibility in DRAW the command **bsimplify** has been implemented. See the Boolean Operations options chapter in draw user guide.

18.1 Examples

Here is the simple example of simplification of the result of Fuse operation of two boxes:

```
bsimplify -f 1

box b1 10 10 15
box b2 3 7 0 10 10 15
bclearobjects
bcleartools
baddobjects b1
baddtools b2
bfillds
bapibop r 1
```

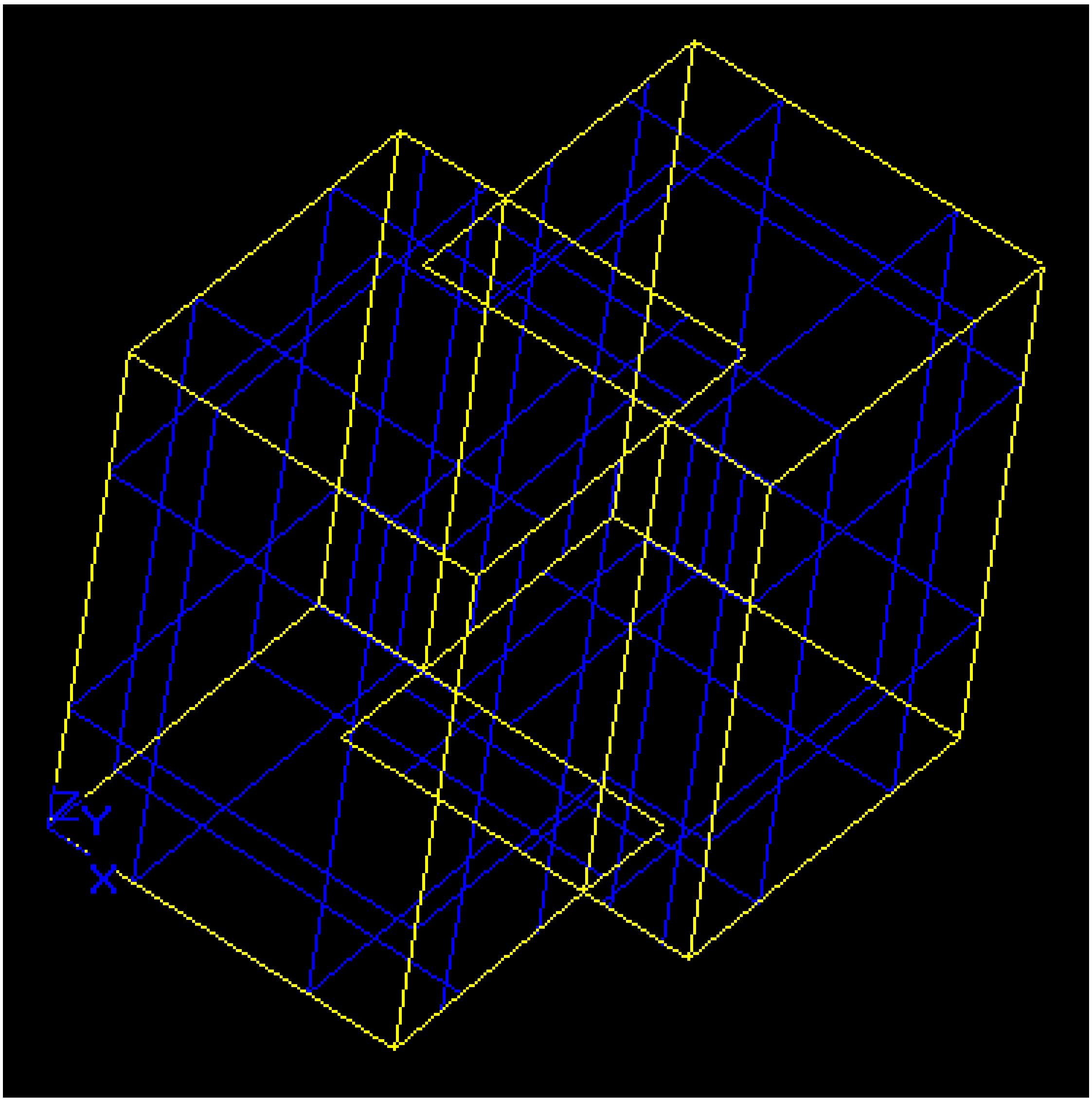


Figure 92: Not simplified result

19 Usage

The chapter contains some examples of the OCCT Boolean Component usage. The usage is possible on two levels: C++ and Tcl.

19.1 Package BRepAlgoAPI

The package *BRepAlgoAPI* provides the Application Programming Interface of the Boolean Component.

The package consists of the following classes:

- *BRepAlgoAPI_Algo* – the root class that provides the interface for algorithms.
- *BRepAlgoAPI_BuilderAlgo* – the class API level of General Fuse algorithm.
- *BRepAlgoAPI_Splitter* – the class API level of the Splitter algorithm.
- *BRepAlgoAPI_BooleanOperation* – the root class for the classes *BRepAlgoAPI_Fuse*. *BRepAlgoAPI_↩ Common*, *BRepAlgoAPI_Cut* and *BRepAlgoAPI_Section*.
- *BRepAlgoAPI_Fuse* – the class provides Boolean fusion operation.
- *BRepAlgoAPI_Common* – the class provides Boolean common operation.
- *BRepAlgoAPI_Cut* – the class provides Boolean cut operation.
- *BRepAlgoAPI_Section* – the class provides Boolean section operation.

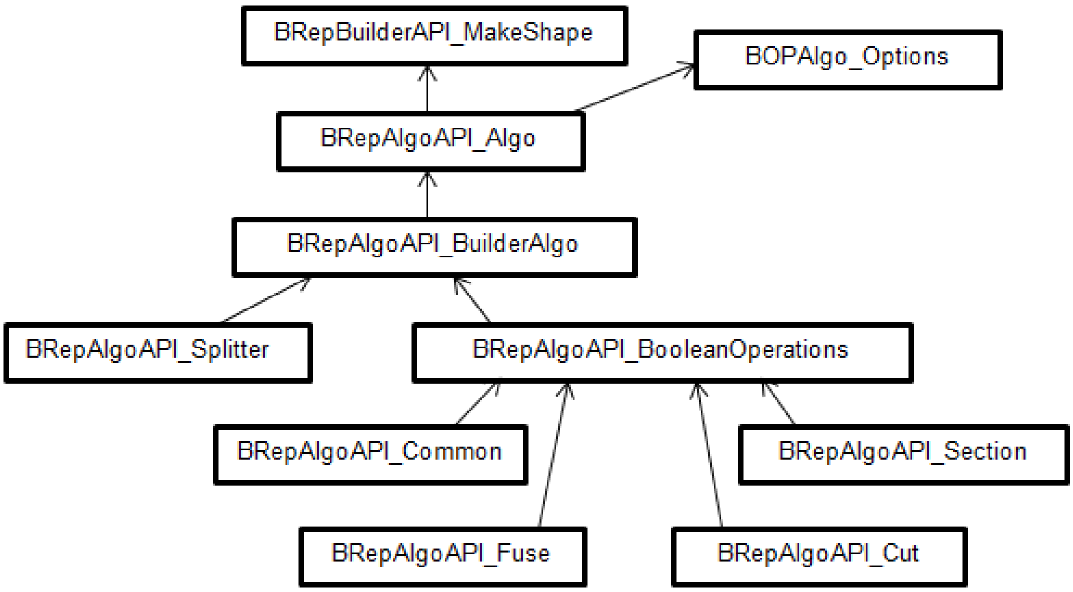


Figure 94: Diagram of BRepAlgoAPI package

The detailed description of the classes can be found in the corresponding .hxx files. The examples are below in this chapter.

19.2 Package BOPTest

The package *BOPTest* provides the usage of the Boolean Component on Tcl level. The method *BOPTest::API↩ Commands* contains corresponding Tcl commands:

- *bapibuild* – for General Fuse Operator;
- *bapisplit* – for Splitter Operator;
- *bapibop* – for Boolean Operator and Section Operator.

The examples of how to use the commands are below in this chapter.

19.2.1 Case 1. General Fuse operation

The following example illustrates how to use General Fuse operator:

C++ Level

```
#include <TopoDS_Shape.hxx>
#include <TopTools_ListOfShape.hxx>
#include <BRepAlgoAPI_BuilderAlgo.hxx>
 {...
  BRepAlgoAPI_BuilderAlgo aBuilder;
  //
  // prepare the arguments
  TopTools_ListOfShape& aLS=...;
  //
  // set the arguments
  aBuilder.SetArguments(aLS);

  // Set options for the algorithm
  // setting options on this level is similar to setting options to GF algorithm on low level (see "GF
       Usage" chapter)
  ...

  // run the algorithm
  aBuilder.Build();
  if (aBuilder.HasErrors()) {
    // an error treatment
    return;
  }
  //
  // result of the operation aR
  const TopoDS_Shape& aR=aBuilder.Shape();
...
}
```

Tcl Level

```
# prepare the arguments
box b1 10 10 10
box b2 3 4 5 10 10 10
box b3 5 6 7 10 10 10
#
# clear inner contents
bclearobjects; bcleartools;
#
# set the arguments
baddobjects b1 b2 b3

# set options for the algorithm (see "GF Usage" chapter)
...

# run the algorithm
# r is the result of the operation
bapibuild r
```

19.2.2 Case 2. Splitting operation

The following example illustrates how to use the Splitter operator:

C++ Level

```
#include <TopoDS_Shape.hxx>
#include <TopTools_ListOfShape.hxx>
#include <BRepAlgoAPI_Splitter.hxx>
//
BRepAlgoAPI_BuilderAlgo aSplitter;
//
// prepare the arguments
// objects
TopTools_ListOfShape& aLSObjects = ... ;
// tools
TopTools_ListOfShape& aLSTools = ... ;
//
// set the arguments
aSplitter.SetArguments(aLSObjects);
aSplitter.SetTools(aLSTools);
//
// Set options for the algorithm
// setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
...
//
// run the algorithm
aSplitter.Build();
// check error status
if (aSplitter.HasErrors()) {
  return;
}
//
// result of the operation aResult
const TopoDS_Shape& aResult = aSplitter.Shape();
```

Tcl Level

```
# prepare the arguments
# objects
box b1 10 10 10
box b2 7 0 0 10 10 10

# tools
plane p 10 5 5 0 1 0
mkface f p -20 20 -20 20
#
# clear inner contents
bclearobjects; bcleartools;
#
# set the objects
baddobjects b1 b2
# set the tools
baddtools f
#
# set options for the algorithm (see "GF Usage" chapter)
...
#
# run the algorithm
# r is the result of the operation
bapisplit r
```

19.2.3 Case 3. Common operation

The following example illustrates how to use Common operation:

C++ Level

```
#include <TopoDS_Shape.hxx>
#include <TopTools_ListOfShape.hxx>
#include < BRepAlgoAPI_Common.hxx>
 {...
  Standard_Boolean bRunParallel;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_Common aBuilder;

  // perpare the arguments
  TopTools_ListOfShape& aLS=...;
  TopTools_ListOfShape& aLT=...;
  //
  bRunParallel=Standard_True;
  aFuzzyValue=2.1e-5;
  //
  // set the arguments
```

```
  aBuilder.SetArguments(aLS);
  aBuilder.SetTools(aLT);
  //
  // Set options for the algorithm
  // setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
  ...
  //
  // run the algorithm
  aBuilder.Build();
  if (aBuilder.HasErrors()) {
    // an error treatment
    return;
  }
  //
  // result of the operation aR
  const TopoDS_Shape& aR=aBuilder.Shape();
...
}
```

Tcl Level

```
# prepare the arguments
box b1 10 10 10
box b2 7 0 4 10 10 10
box b3 14 0 0 10 10 10
#
# clear inner contents
bclearobjects; bcleartools;
#
# set the arguments
baddobjects b1 b3
baddtools b2
#
# set options for the algorithm (see "GF Usage" chapter)
...
#
# run the algorithm
# r is the result of the operation
# 0 means Common operation
bapibop r 0
```

19.2.4 Case 4. Fuse operation

The following example illustrates how to use Fuse operation:

C++ Level

```
#include <TopoDS_Shape.hxx>
#include <TopTools_ListOfShape.hxx>
#include < BRepAlgoAPI_Fuse.hxx>
 {...
  Standard_Boolean bRunParallel;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_Fuse aBuilder;

  // perpare the arguments
  TopTools_ListOfShape& aLS=...;
  TopTools_ListOfShape& aLT=...;
  //
  bRunParallel=Standard_True;
  aFuzzyValue=2.1e-5;
  //
  // set the arguments
  aBuilder.SetArguments(aLS);
  aBuilder.SetTools(aLT);
  //
  // Set options for the algorithm
  // setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
  ...
  //
  // run the algorithm
  aBuilder.Build();
  if (aBuilder.HasErrors()) {
    // an error treatment
    return;
  }
  //
  // result of the operation aR
  const TopoDS_Shape& aR=aBuilder.Shape();
```

```
...
}
```

Tcl Level

```
# prepare the arguments
box b1 10 10 10
box b2 7 0 4 10 10 10
box b3 14 0 0 10 10 10
#
# clear inner contents
bclearobjects; bcleartools;
#
# set the arguments
baddobjects b1 b3
baddtools b2
#
# set options for the algorithm (see "GF Usage" chapter)
...
#
# run the algorithm
# r is the result of the operation
# 1 means Fuse operation
bapibop r 1
```

19.2.5 Case 5. Cut operation

The following example illustrates how to use Cut operation:

C++ Level

```
#include <TopoDS_Shape.hxx>
#include <TopTools_ListOfShape.hxx>
#include < BRepAlgoAPI_Cut.hxx>
 {...
  Standard_Boolean bRunParallel;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_Cut aBuilder;

  // perpare the arguments
  TopTools_ListOfShape& aLS=...;
  TopTools_ListOfShape& aLT=...;
  //
  bRunParallel=Standard_True;
  aFuzzyValue=2.1e-5;
  //
  // set the arguments
  aBuilder.SetArguments(aLS);
  aBuilder.SetTools(aLT);
  //
  // Set options for the algorithm
  // setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
  ...
  //
  // run the algorithm
  aBuilder.Build();
  if (aBuilder.HasErrors()) {
    // an error treatment
    return;
  }
  //
  // result of the operation aR
  const TopoDS_Shape& aR=aBuilder.Shape();
...
}
```

Tcl Level

```
# prepare the arguments
box b1 10 10 10
box b2 7 0 4 10 10 10
box b3 14 0 0 10 10 10
#
# clear inner contents
bclearobjects; bcleartools;
#
# set the arguments
baddobjects b1 b3
baddtools b2
```

```
#
# set options for the algorithm (see "GF Usage" chapter)
...
#
# run the algorithm
# r is the result of the operation
# 2 means Cut operation
bapibop r 2
```

19.2.6 Case 6. Section operation

The following example illustrates how to use Section operation:

C++ Level

```
#include <TopoDS_Shape.hxx>
#include <TopTools_ListOfShape.hxx>
#include < BRepAlgoAPI_Section.hxx>
 {...
  Standard_Boolean bRunParallel;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_Section aBuilder;

  // perpare the arguments
  TopTools_ListOfShape& aLS=...;
  TopTools_ListOfShape& aLT=...;
  //
  bRunParallel=Standard_True;
  aFuzzyValue=2.1e-5;
  //
  // set the arguments
  aBuilder.SetArguments(aLS);
  aBuilder.SetTools(aLT);
  //
  // Set options for the algorithm
  // setting options for this algorithm is similar to setting options for GF algorithm (see "GF Usage"
       chapter)
  ...
  //
  // run the algorithm
  aBuilder.Build();
  if (aBuilder.HasErrors()) {
    // an error treatment
    return;
  }
  //
  // result of the operation aR
  const TopoDS_Shape& aR=aBuilder.Shape();
...
}
```

Tcl Level

```
# prepare the arguments
box b1 10 10 10
box b2 3 4 5 10 10 10
box b3 5 6 7 10 10 10
#
# clear inner contents
bclearobjects; bcleartools;
#
# set the arguments
baddobjects b1 b3
baddtools b2
#
# set options for the algorithm (see "GF Usage" chapter)
...
#
# run the algorithm
# r is the result of the operation
# 4 means Section operation
bapibop r 4
```