Open CASCADE Technology
7.0.0

Boolean Operations

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Contents

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1 Introduction

This document provides a comprehensive description of the Boolean Operation Algorithm (BOA) as it is implemented in Open CASCADE Technology. The Boolean Component contains:

- General Fuse Operator (GFA),
- Boolean Operator (BOA),
- Section Operator (SA),
- Partition Operator (PA).

GFA is the base algorithm for BOA, PA, 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.

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2 Overview

2.1 Operators

2.1.1 Boolean operator

The Boolean operator provides the operations (Common, Fuse, Cut) between two groups: *Objects* and *Tools*. 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);
- $G_1 = \{S_{11} , S_{12} ... S_{1n1} \}$ 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.

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

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:

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

where

- R_{GF} – result of the operation,
- $S_1 , S_2 ... S_n$ – 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

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

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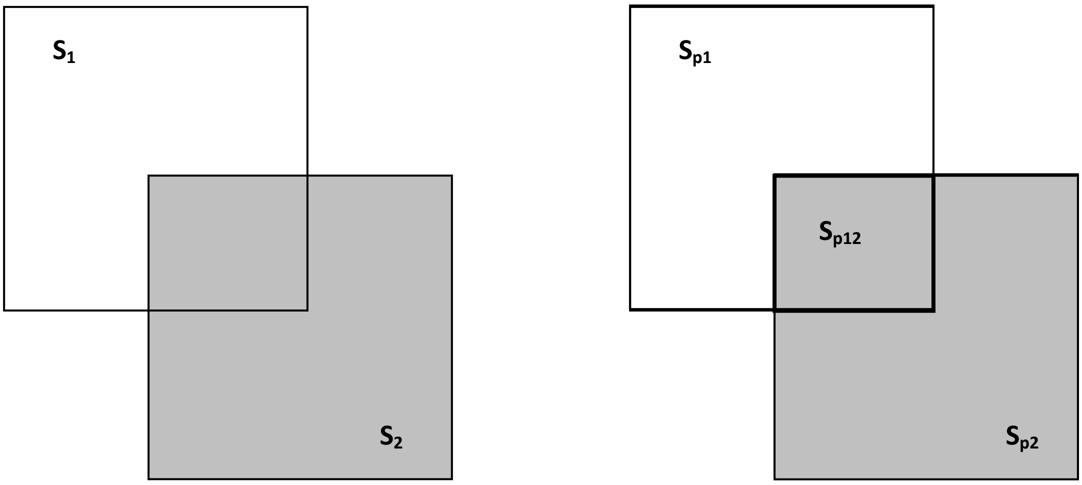

Figure 1: Operators

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.

2.1.3 Partition operator

The Partition operator can be applied to an arbitrary number of arguments in terms of *TopoDS_Shape*. The arguments are divided on two groups: Objects, Tools. The result of PA contains all parts belonging to the Objects but does not contain the parts that belongs to the Tools only.

The PA operator can be represented as follows:

$R_{PA} = PA(G_1, G_2)$, where:

- R_{PA} – 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_{PA} can be obtained from R_{GF}.

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

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

In case when all arguments of the PA are Objects (no Tools), the result of PA is equivalent to the result of GFA.

For example, when G_1 consists of shapes S_1 and S_2 the result of R_{PA} is

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

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

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: $R_{SA} = SA(S1, S2 \ldots Sn)$, where

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

2.2 Parts of algorithms

GFA, BOA, PA 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, PA and SA are in the Building Part. The Intersection Part is the same for the algorithms.

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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)*.

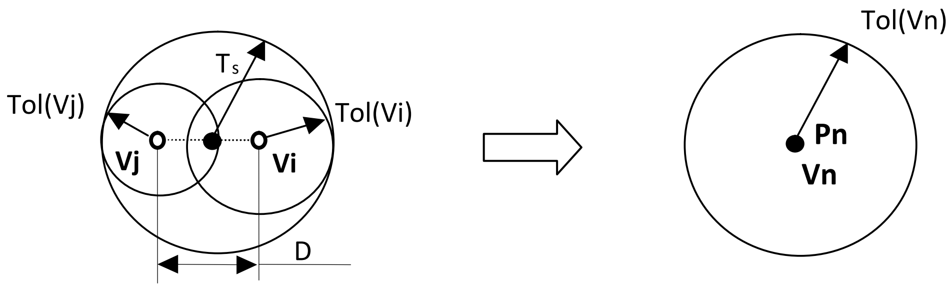

Figure 2: Vertex/vertex interference

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)*.

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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)*.

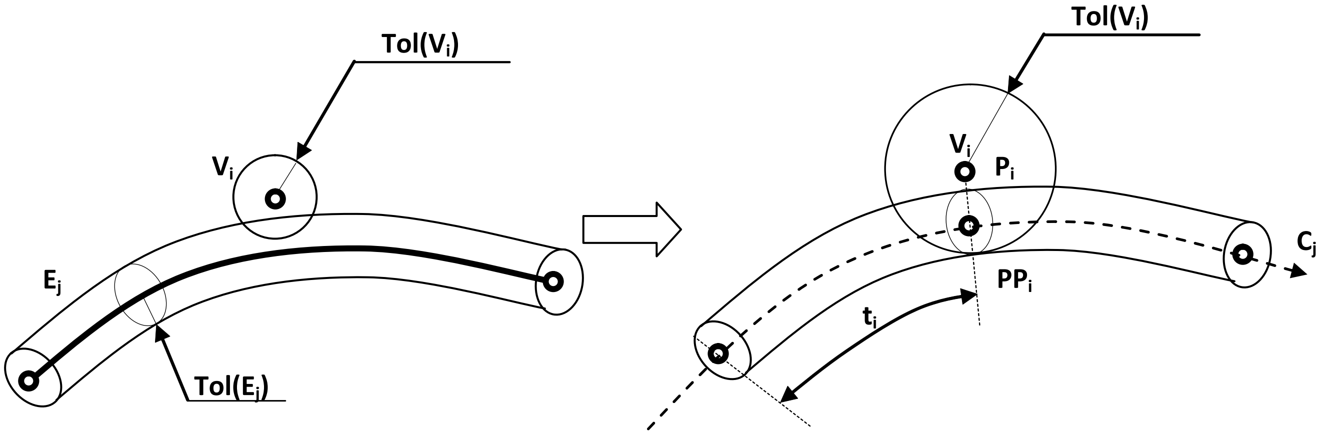

Figure 3: Vertex/edge interference

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)*.

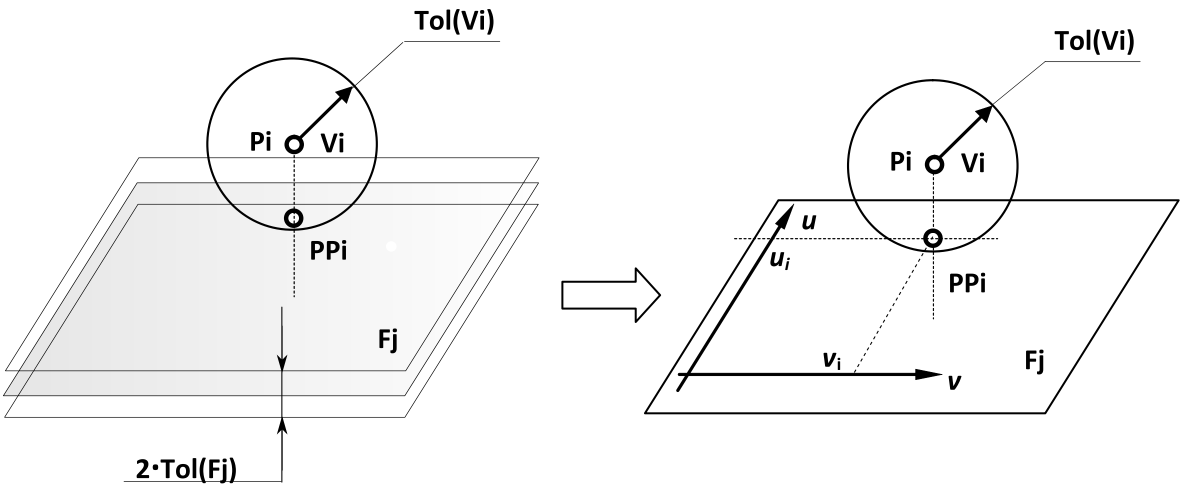

Figure 4: Vertex/face interference

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*.

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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.

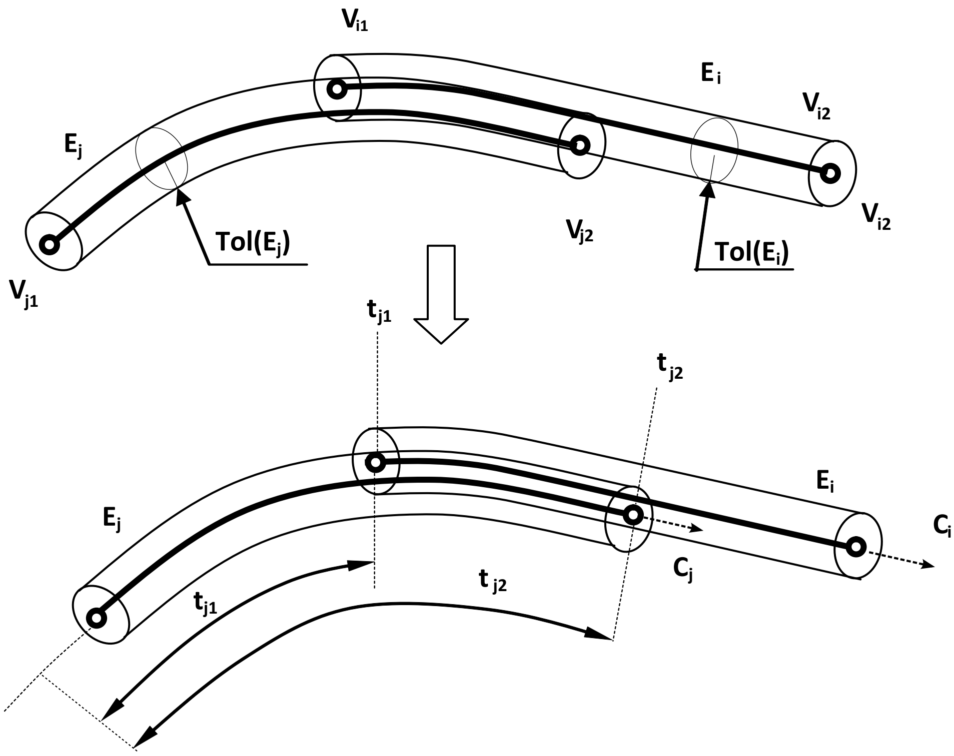

Figure 5: Edge/edge interference: common parts

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.

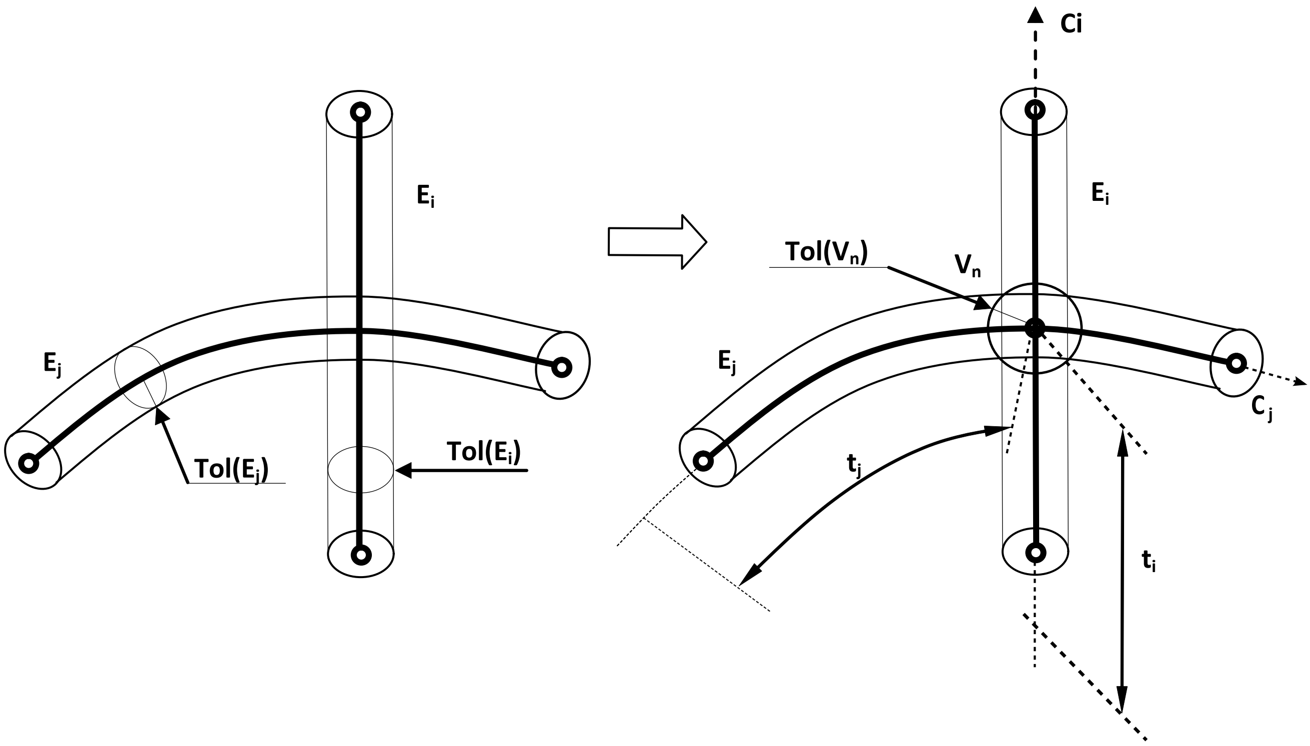

Figure 6: Edge/edge interference: common points

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.

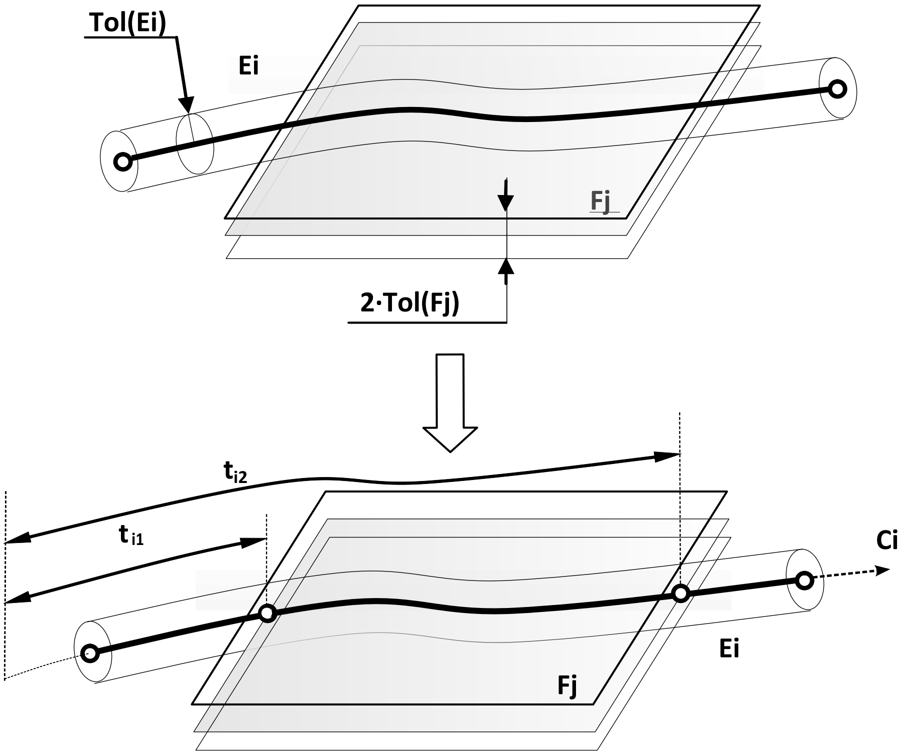

Figure 7: Edge/face interference: common parts

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.

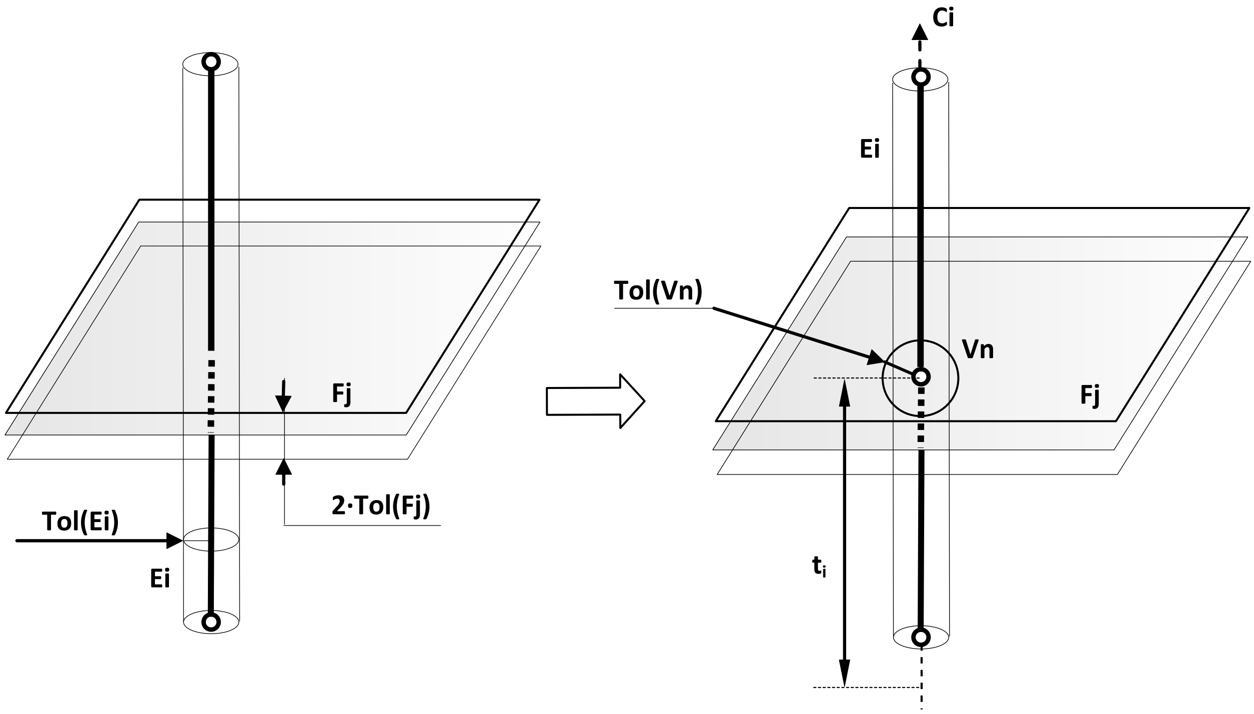

Figure 8: Edge/face interference: common points

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.

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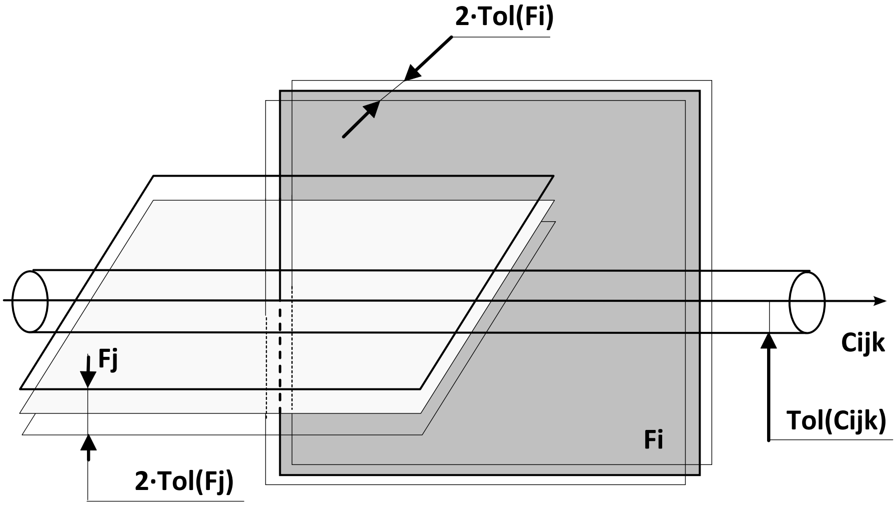

Figure 9: Face/face interference: common curves

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})*.

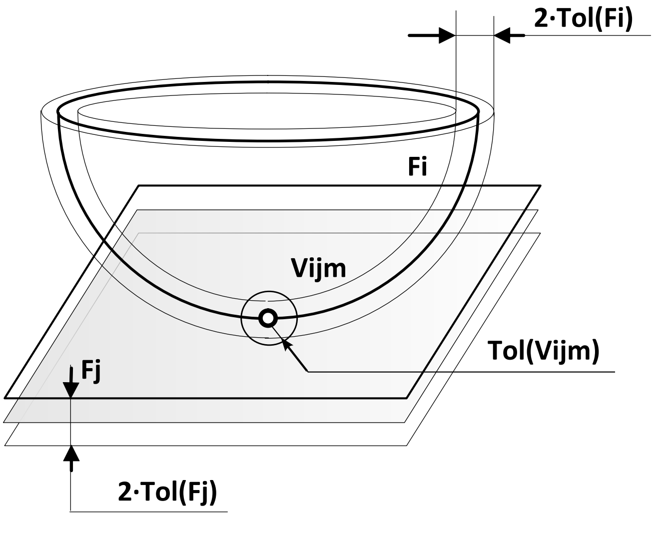

Figure 10: Face/face interference: common points

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*.

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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*.

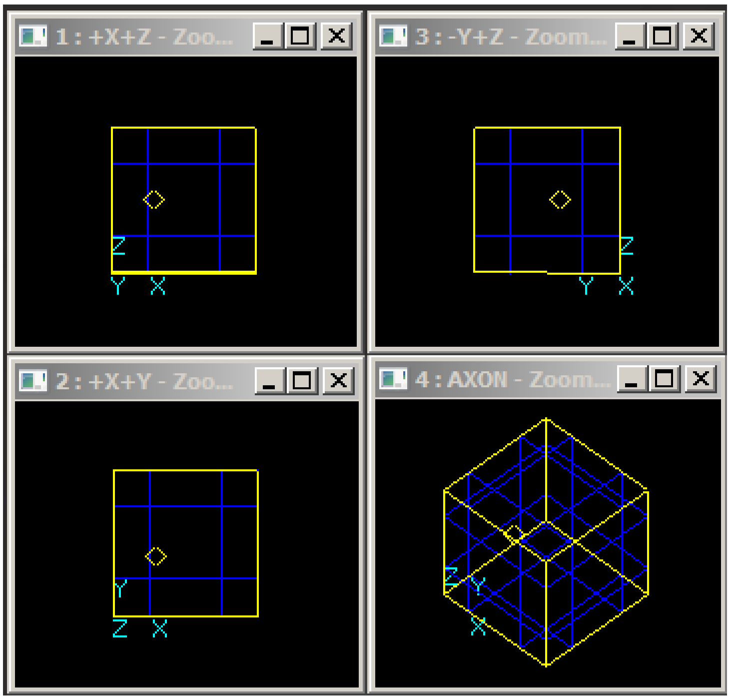

Figure 11: Vertex/Solid Interference

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*.

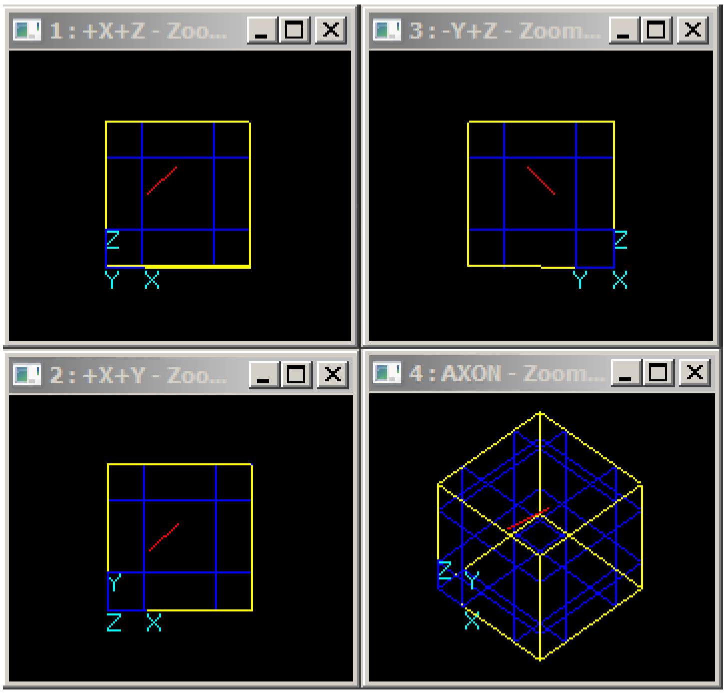

Figure 12: Edge/Solid Interference

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*.

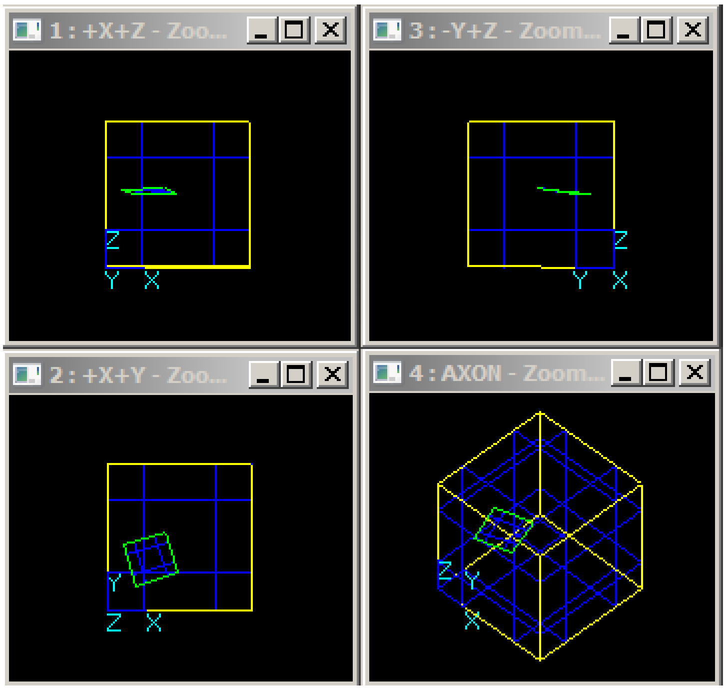

Figure 13: Face/Solid Interference

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*.

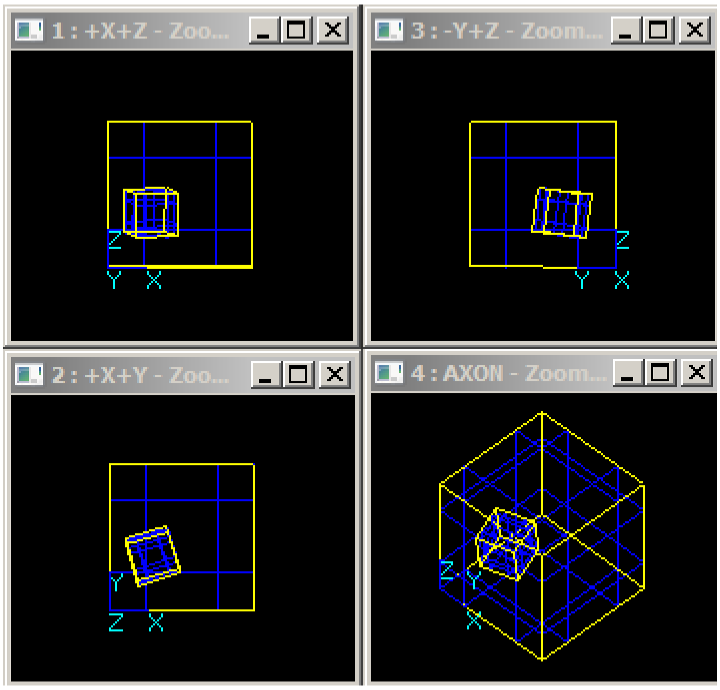

Figure 14: Solid/Solid Interference

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*.

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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.

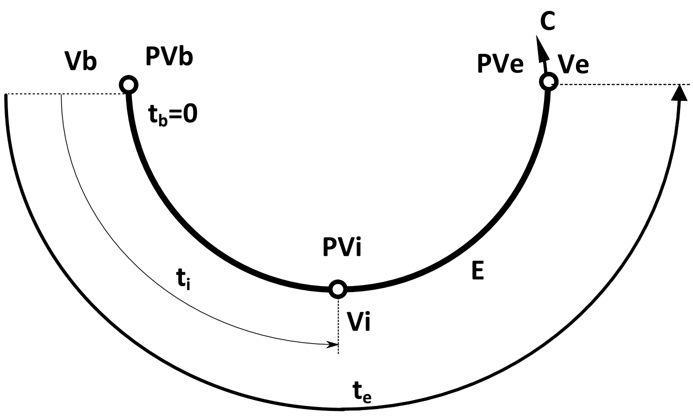

Figure 15: Paves

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.

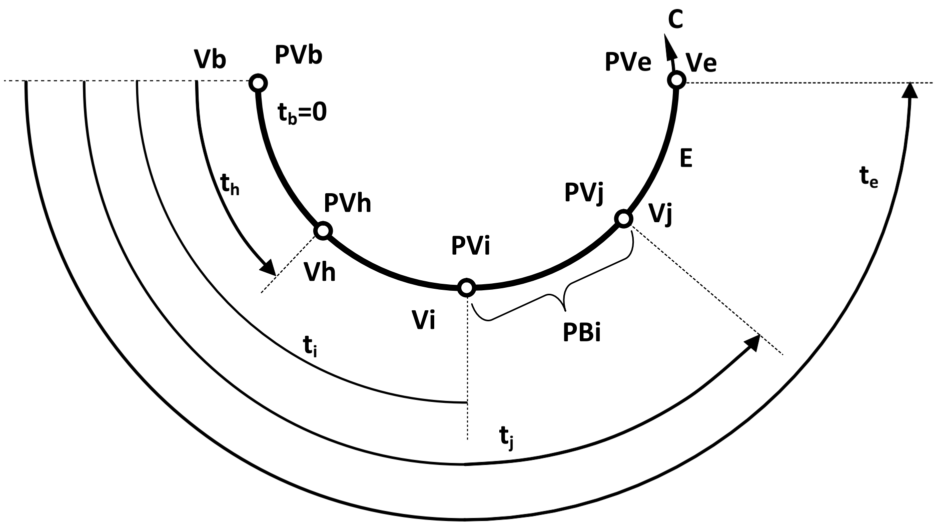

Figure 16: Pave Blocks

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.

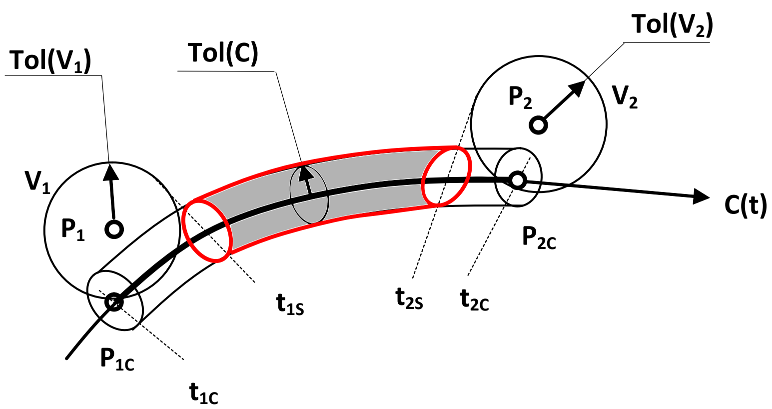

Figure 17: Shrunk Range

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:

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```
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.

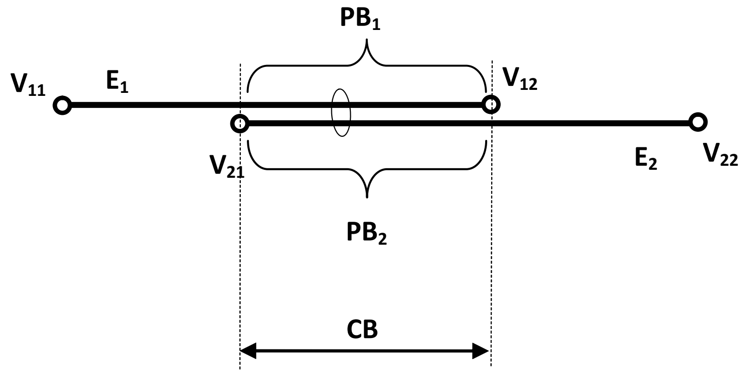

Figure 18: Common Blocks: Edge/Edge interference

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).

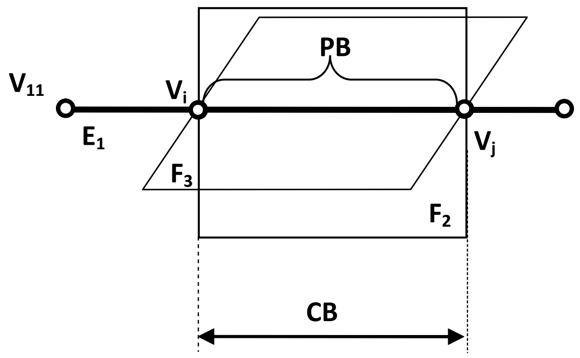

Figure 19: Common Blocks: Edge/Face interference

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.

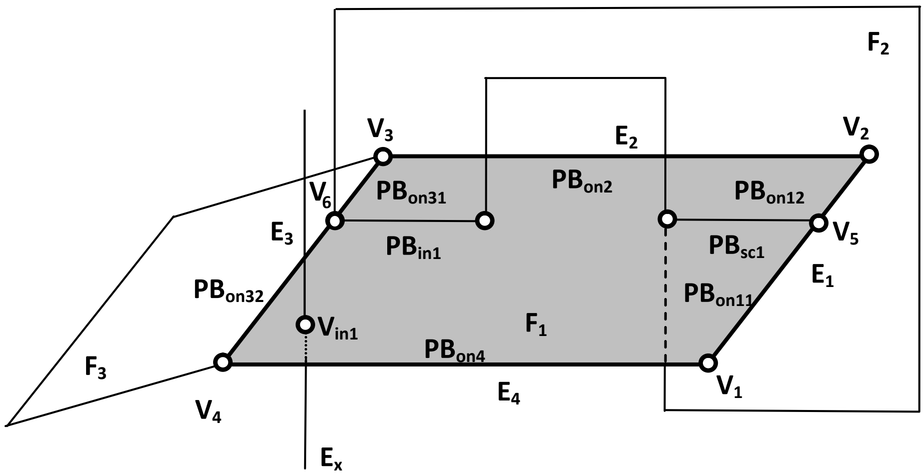

Figure 20: Face Info

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

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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:

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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.

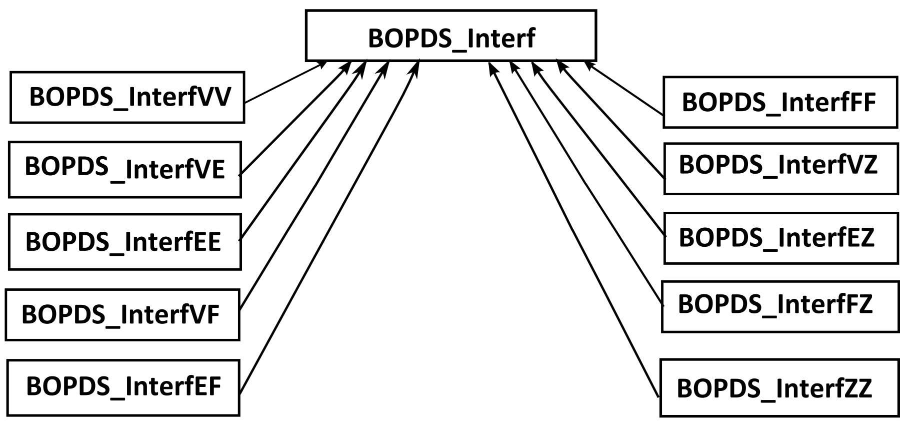

Figure 21: BOPDS_Interf classes

4.4 Pave, PaveBlock and CommonBlock

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

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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** (p. 22)
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.

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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 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*.

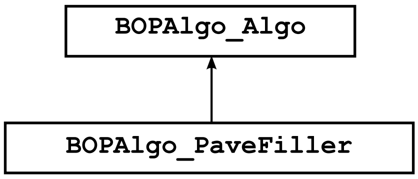

Figure 22: Diagram for Class BOPAlgo_PaveFiller

5.1 Class BOPAlgo_Algo

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

- Get Error status;
- Get Warning status;
- Turn on/off the parallel processing
- Break the operations by user request
- Check data;
- Check the result;
- Set the appropriate memory allocator.

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

5.2 Initialization

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

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No	Contents	Implementation
1	Initialization the array of shapes (in terms of **Shapes** (p. 24)). Filling the array of shapes.	*BOPDS_DS::Init()*
2	Initialization the array pave blocks (in terms of **Pave, PaveBlock, CommonBlock** (p. 26))	*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** (p. 10))	*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*

5.3 Compute Vertex/Vertex Interferences

The input data for this step is the DS after the **Initialization** (p. 29). 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:

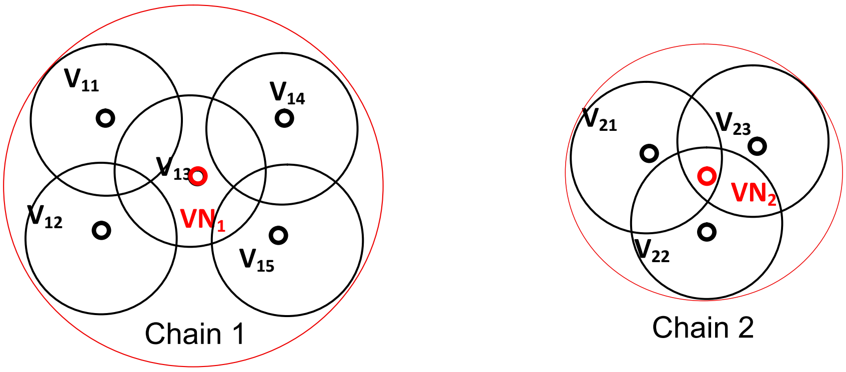

Figure 23: Connexity chains of interfered vertices

5.4 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** (p. 11)	*BOPInt_Context::ComputeVE()*
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** (p. 26)	*BOPDS_PaveBlock:: AppendExtPave()*
6	Append Vertex/Edge interferences in DS	*BOPDS_DS::AddInterf()*

5.5 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()*

5.6 Compute Edge/Edge Interferences

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

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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** (p. 26), if it is necessary.	*BOPAlgo_PaveFiller::FillShrunk-Data()*
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::MakeNew-Vertex()*

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()*
8	Post-processing. Append the paves of *VNXi* into the corresponding pave blocks in terms of **Pave, PaveBlock and CommonBlock** (p. 26)	*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:

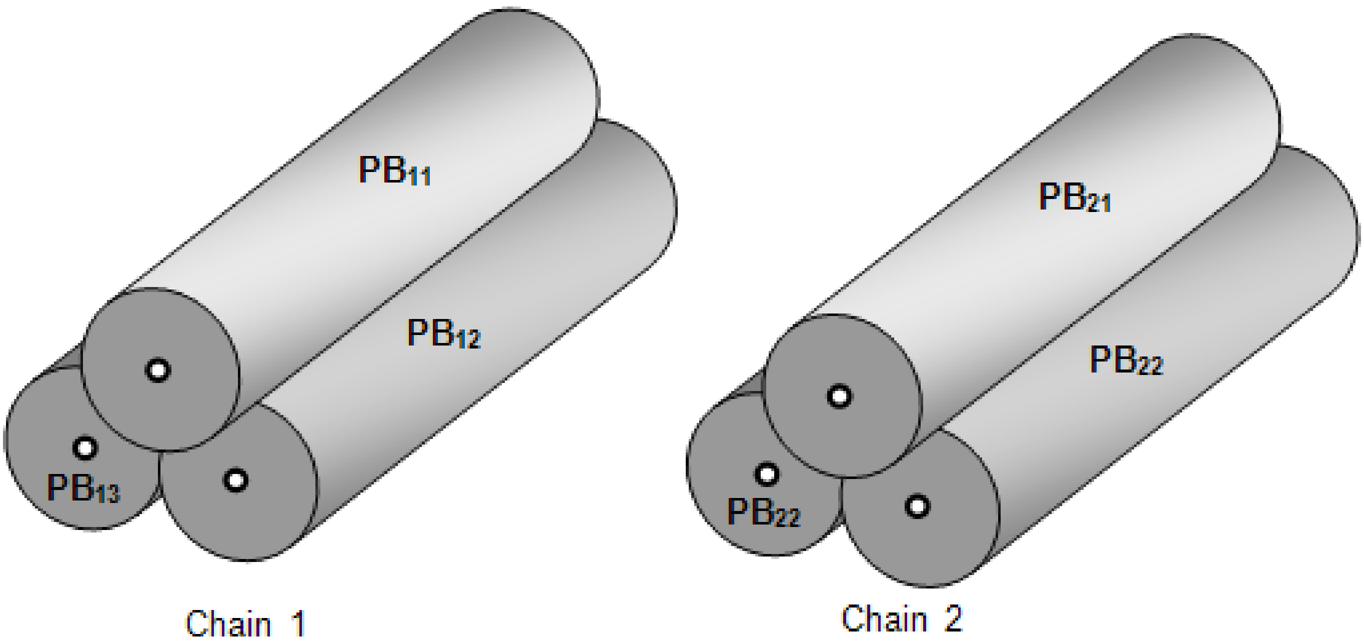

Figure 24: Coinciding chains of pave blocks

- 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).*

5.7 Compute Vertex/Face Interferences

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

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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** (p. 11)	*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::Treat-VerticesEE()*

5.8 Compute Edge/Face Interferences

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

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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** (p. 26)) if it is necessary.	*BOPAlgo_PaveFiller::FillShrunk-Data()*
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 *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::MakeNew-Vertex()* and *BOPAlgo_PaveFiller::Perform-Vertices1()*
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::PerformCommon-Blocks()*
8	Post-processing. Append the paves of *VNXi* into the corresponding pave blocks in terms of **Pave, PaveBlock and CommonBlock** (p. 26).	*BOPDS_PaveBlock:: AppendExtPave()*

9	Split pave blocks and common blocks *CBc* by the paves.	*BOPAlgo_PaveFiller::PerformVertices1()*, *BOPDS_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()*

5.9 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** (p. 26).	*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()*

5.10 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()*

5.11 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** (p. 27). 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** (p. 10).	*BOPAlgo_PaveFiller::Make-Blocks()*
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::PutPaveOn-Curve()* and *BOPDS_PaveBlock::AppendExt-Pave()*
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::PutBound-PaveOnCurve()*
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::Make-Blocks()*
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** (p. 11)).	*BOPTools_Tools::MakeEdge()*

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** (p. 24)) 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()*

5.12 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()*

5.13 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()*

6 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).

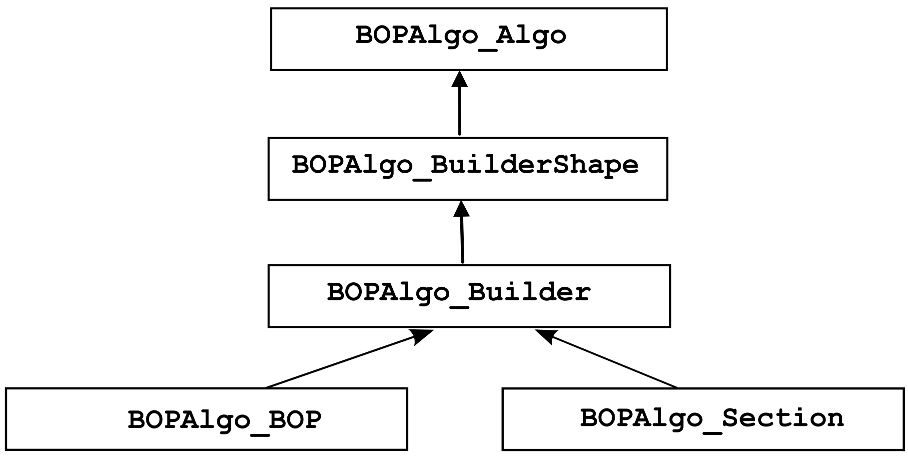

Figure 25: Diagram for BP classes

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()).*

7 General Fuse Algorithm

7.1 Arguments

The arguments of the algorithm are shapes (in terms of *TopoDS_Shape*). The main requirements for the arguments are described in **Data Structure** (p. 24) chapter.

7.2 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, SHELL, 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	

7.3 Examples

Please, have a look at the examples, which can help to better understand the definitions.

7.3.1 Case 1: Three edges intersecting at a point

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

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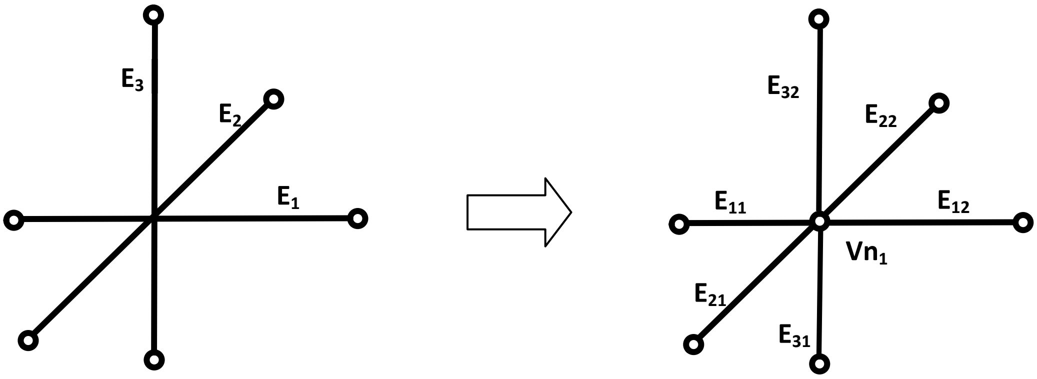

Figure 26: Three Intersecting Edges

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*).

7.3.2 Case 2: Two wires and an edge

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

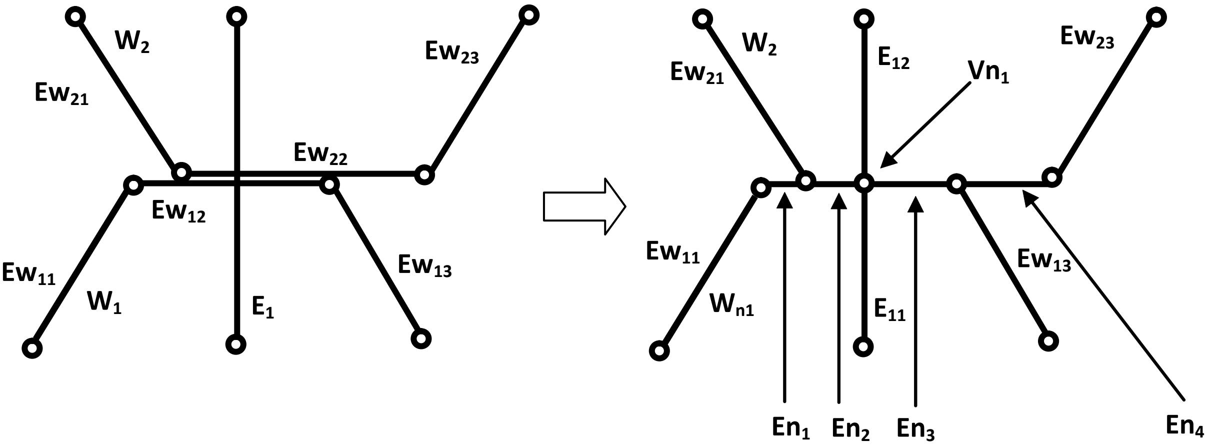

Figure 27: Two wires and an edge

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*.

7.3.3 Case 3: An edge intersecting with a face

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

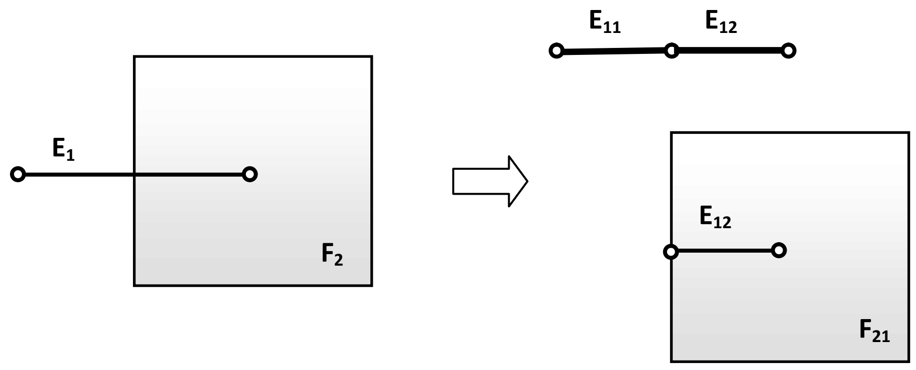

Figure 28: An edge intersecting with a face

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*).

7.3.4 Case 4: An edge lying on a face

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

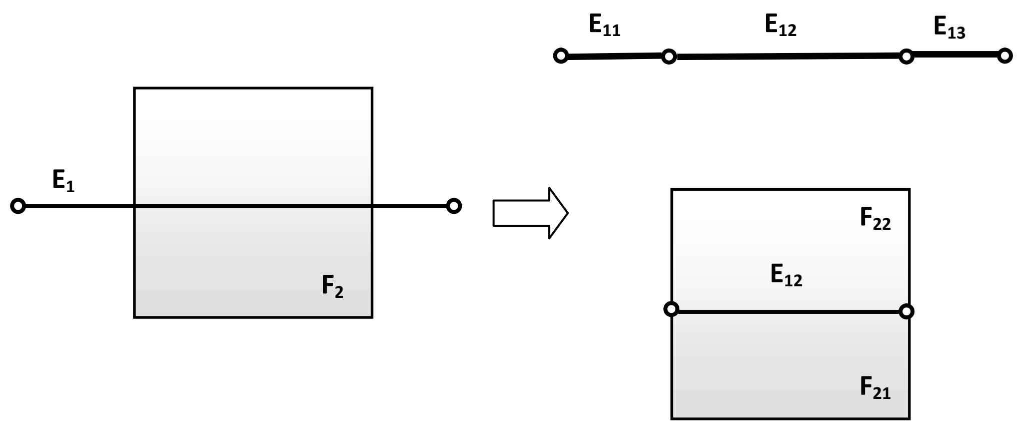

Figure 29: An edge lying on a face

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*).

7.3.5 Case 5: An edge and a shell

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

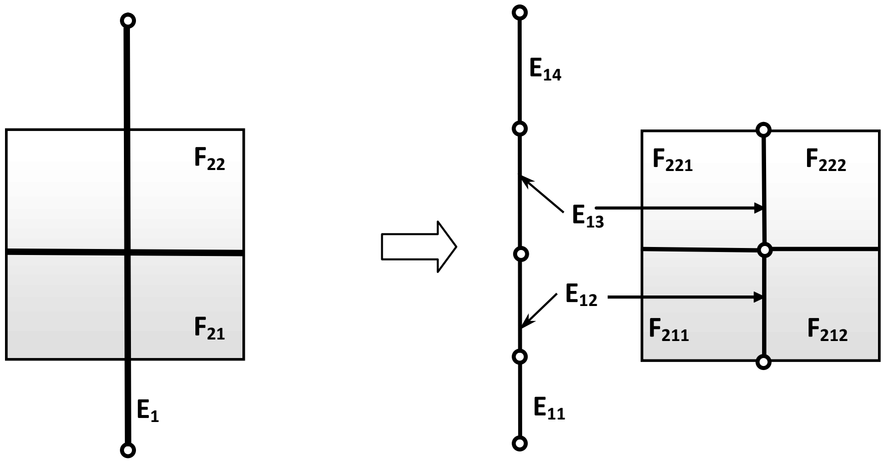

Figure 30: An edge and a shell

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*).

7.3.6 Case 6: A wire and a shell

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

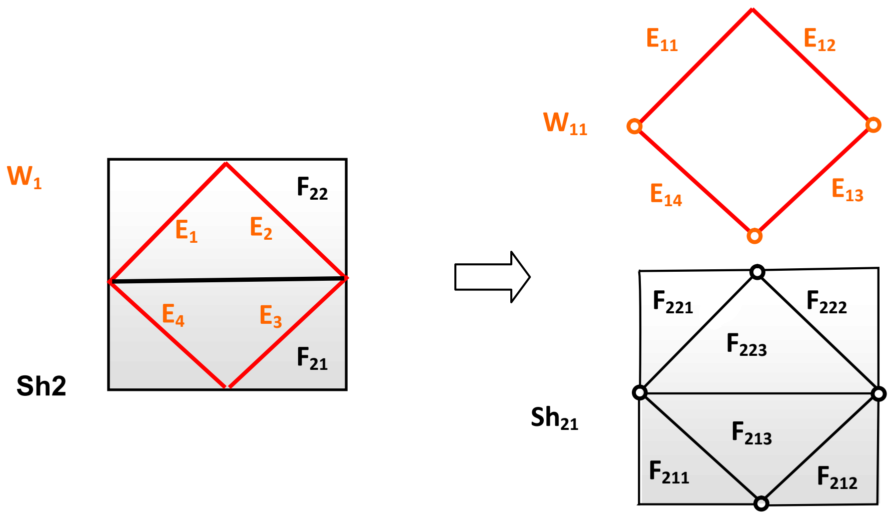

Figure 31: A wire and a shell

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*.

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7.3.7 Case 7: Three faces

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

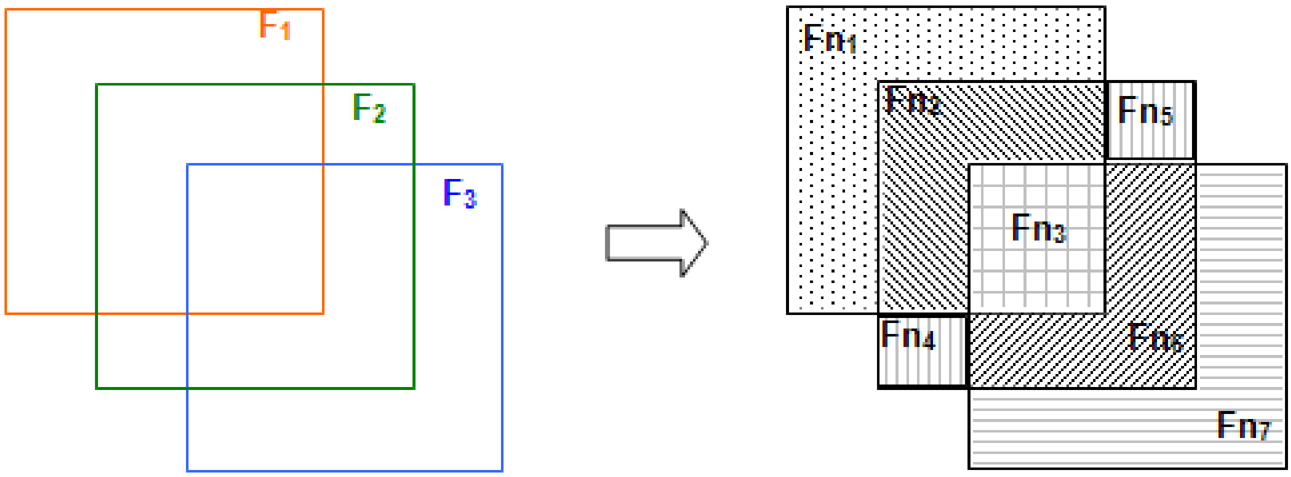

Figure 32: Three faces

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

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

7.3.8 Case 8: A face and a shell

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

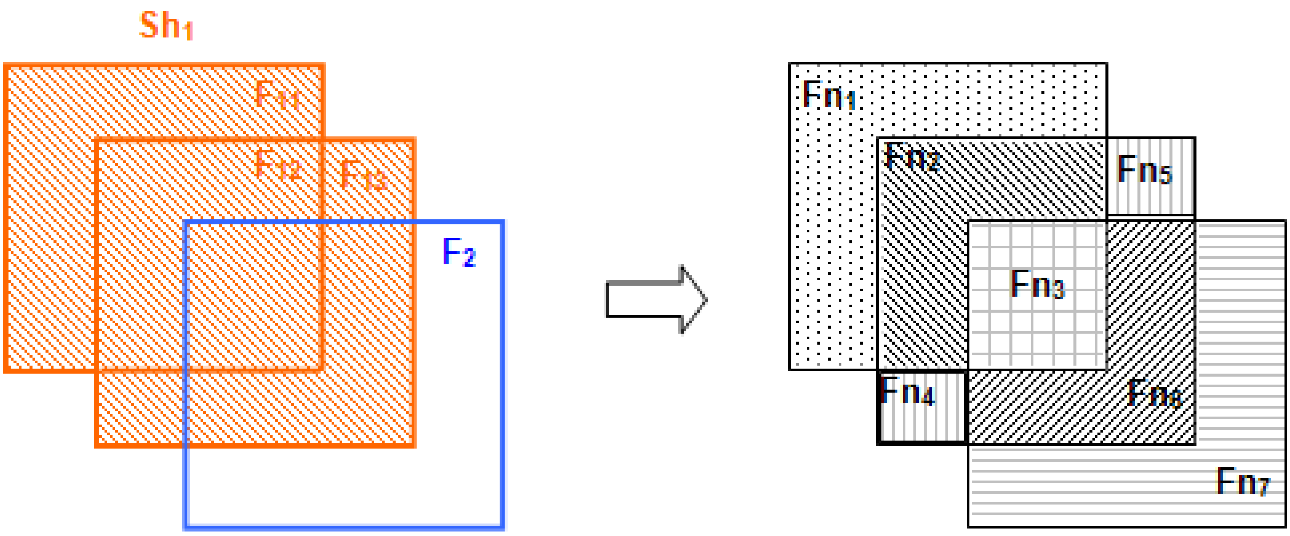

Figure 33: A face and a shell

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

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- 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*.

7.3.9 Case 9: A shell and a solid

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

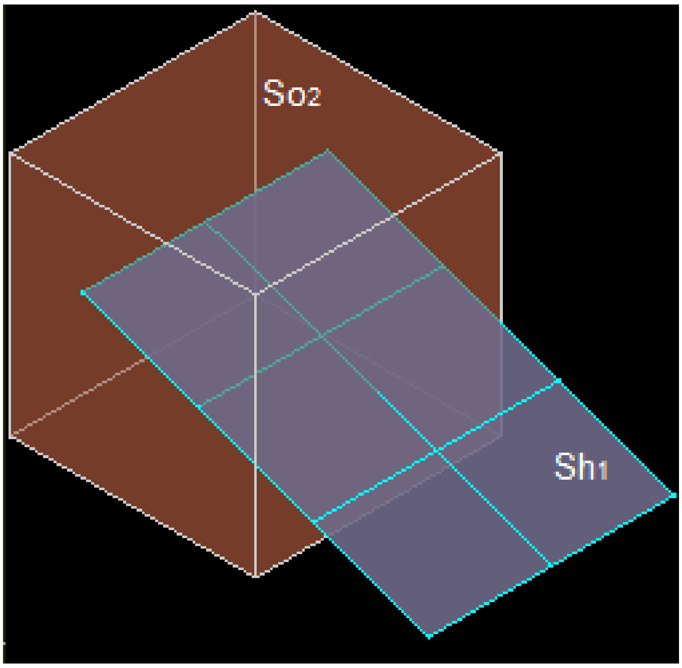

Figure 34: A shell and a solid: arguments

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*).

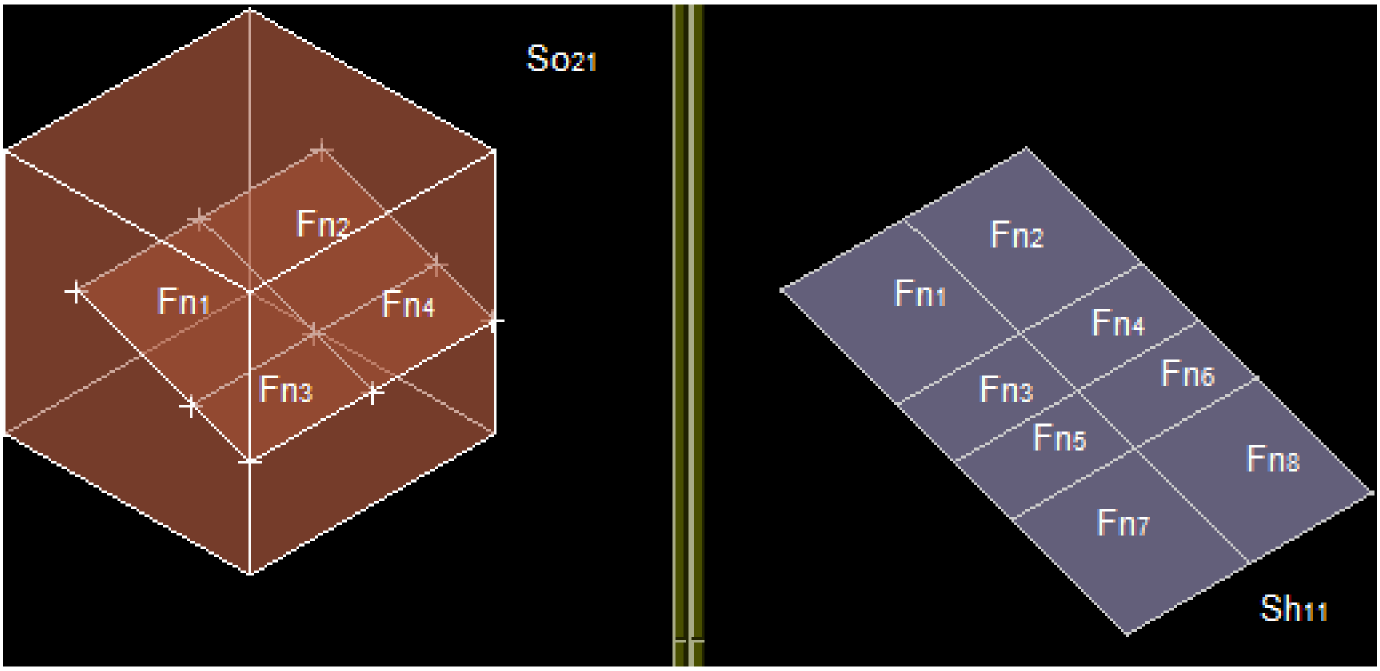

Figure 35: A shell and a solid: results

7.3.10 Case 10: A compound and a solid

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

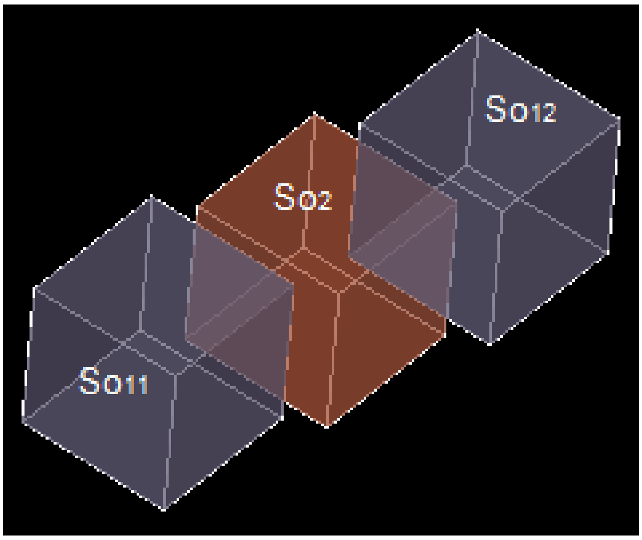

Figure 36: A compound and a solid: arguments

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)*.

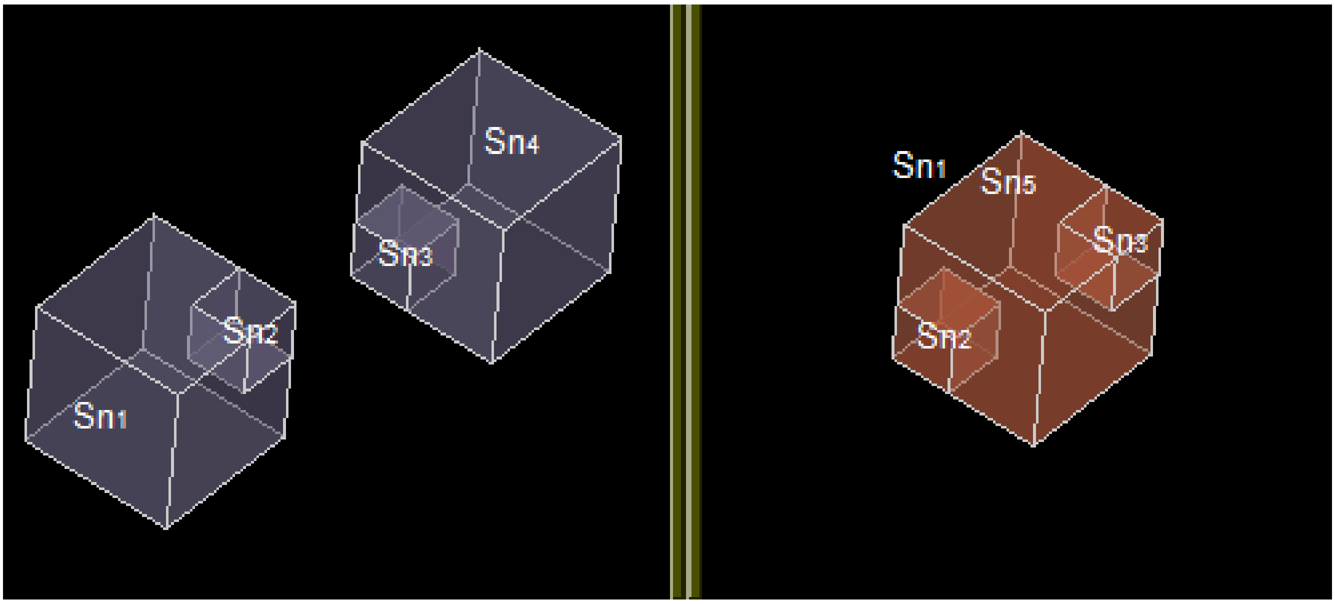

Figure 37: A compound and a solid: results

7.4 Class BOPAlgo_Builder

GFA is implemented in the class *BOPAlgo_Builder*.

7.4.1 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
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.

7.4.2 Initialization

The input data for this step is a *BOPAlgo_PaveFiller* object (in terms of **Intersection** (p. 29)) at the state after **Processing of degenerated edges** (p. 38) 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()*

7.4.3 Build Images for Vertices

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

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

7.4.4 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()*

7.4.5 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::FillImages-Edges()*

7.4.6 Build Result of Type Edge

This step is the same as **Building Result of Type Vertex** (p. 49), but for the type *Edge*.

7.4.7 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::FillImages-Containers()*
2	Add to C the images or non-split parts of the *Original Shape*, taking into account its orientation.	*BOPAlgo_Builder::FillImages-Containers()* *BOPTools_Tools::IsSplitTo-Reverse()*

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3	Fill *myImages* for the *Original Shape* by the information above.	*BOPAlgo_Builder::FillImages-Containers()*

7.4.8 Build Result of Type Wire

This step is the same as **Building Result of Type Vertex** (p. 49) but for the type *Wire*.

7.4.9 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::BuildSplit-Faces()*
1.2	Impart to ESPij the orientation to be coherent with the original one.	*BOPAlgo_Builder::BuildSplit-Faces()*
1.3	Collect all section edges *SEk* for *Fi*.	*BOPAlgo_Builder::BuildSplit-Faces()*
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** (p. 41) for more details).	*BOPAlgo_BuilderFace*
1.5	Impart to *(Fi1, Fi2... FiNbSp)* the orientation coherent with the original face *Fi*.	*BOPAlgo_Builder::BuildSplit-Faces()*
1.6	Fill the map mySplits with *Fi/(Fi1, Fi2... FiNbSp)*	*BOPAlgo_Builder::BuildSplit-Faces()*
2	Fill Same Domain faces	*BOPAlgo_Builder::FillSame-DomainFaces*
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::FillSame-DomainFaces* *BOPTools_Tools::AreFacesSame-Domain()*
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::FillSame-DomainFaces()*
2.3	Fill *myShapesSD* using the chains *(F1C, F2C... FnC)k*	*BOPAlgo_Builder::FillSame-DomainFaces()*
2.4	Add internal vertices to split faces.	*BOPAlgo_Builder::FillSame-DomainFaces()*
2.5	Fill *myImages* using *myShapesSD* and *mySplits*.	*BOPAlgo_Builder::FillSame-DomainFaces()*

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

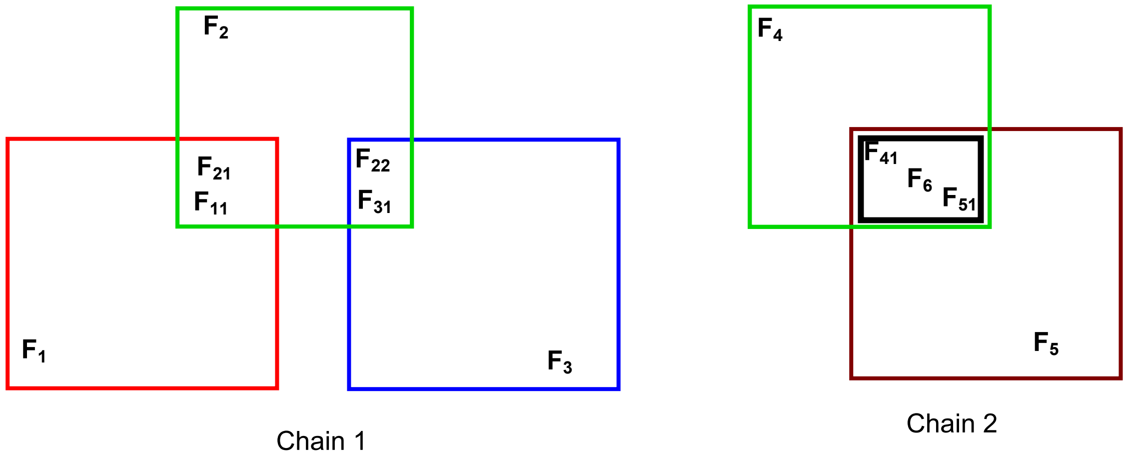

Figure 38: Chains of same domain faces

- 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)*.

7.4.10 Build Result of Type Face

This step is the same as **Building Result of Type Vertex** (p. 49) but for the type *Face*.

7.4.11 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.

7.4.12 Build Result of Type Shell

This step is the same as **Building Result of Type Vertex** (p. 49) but for the type *Shell*.

7.4.13 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::BuildSplit-Solids()*
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** (p. 41) for more details)	*BOPAlgo_BuilderSolid*
4	Fill the map Same Domain solids *myShapesSD*	*BOPAlgo_Builder::BuildSplit-Solids()*
5	Fill the map *myImages*	*BOPAlgo_Builder::BuildSplit-Solids()*
6	Add internal vertices to split solids	*BOPAlgo_Builder::FillInternal-Shapes()*

7.4.14 Build Result of Type Solid

This step is the same as **Building Result of Type Vertex** (p. 49), but for the type Solid.

7.4.15 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.

7.4.16 Build Result of Type Compsolid

This step is the same as **Building Result of Type Vertex** (p. 49), but for the type Compsolid.

7.4.17 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.

7.4.18 Build Result of Type Compound

This step is the same as **Building Result of Type Vertex** (p. 49), but for the type Compound.

7.4.19 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.

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

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8 Boolean Operations Algorithm

8.1 Arguments

- The arguments of BOA are shapes in terms of *TopoDS_Shape*. The main requirements for the arguments are described in the **Data Structure** (p. 24)
- 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.

8.2 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.

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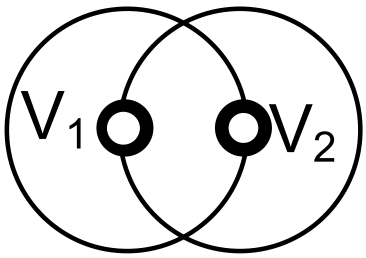
- The result of the operation Cut is defined for arguments *S1* and *S2* that have values of dimensions *Dim(S2)* that should not be less than *Dim(S1)*. The result can contain shapes of different dimensions, but the minimal dimension of the result will be equal to the minimal dimension of the objects *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 result of the operation Fuse for the arguments of collection type (WIRE, SHELL, COMPSOLID) will contain the same number of containers as the arguments. The overlapping parts (EDGES/FACES/SOLIDS) will be shared among them. For example, the result of Fuse operation between two wires will be two wires sharing coinciding edges if any.
- The result of the operation Common for the arguments of collection type (WIRE, SHELL, COMPSOLID) will consist of the containers containing the same overlapping parts. For example, the result of Common operation between two fully/partially overlapping wires will be two wires containing the same edges.

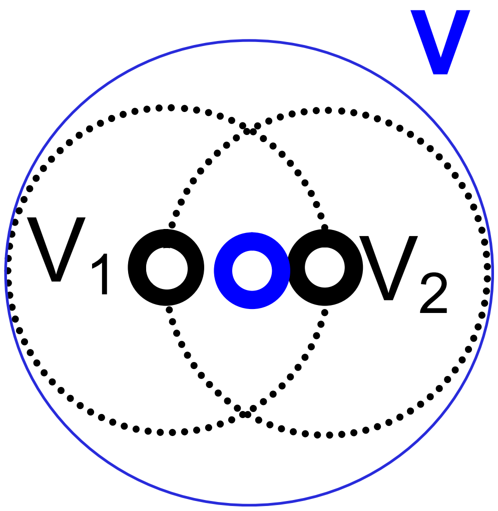
8.3 Examples

8.3.1 Case 1: Two Vertices

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



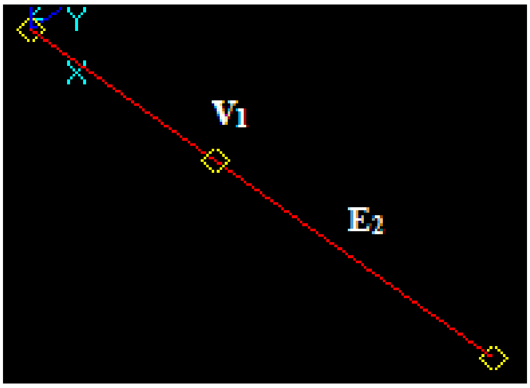
- The result of *Fuse* operation is the compound that contains new vertex *V*.



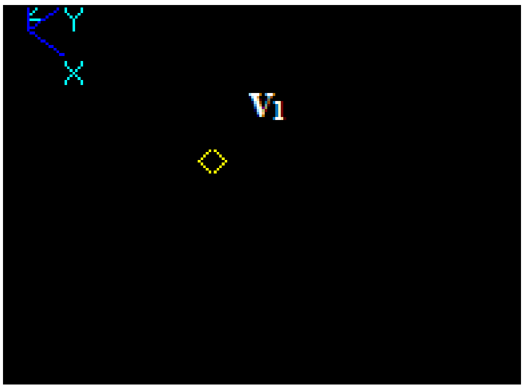
- The result of *Common* operation is a compound containing new vertex *V*.
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is an empty compound.

8.3.2 Case 2: A Vertex and an Edge

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



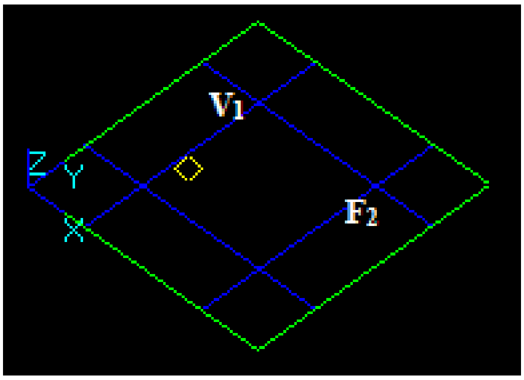
- The result of *Fuse* operation is result is not defined because the dimension of the vertex (0) is not equal to the dimension of the edge (1).
- The result of *Common* operation is a compound containing vertex V_1 as the argument V_1 has a common part with edge *E2*.



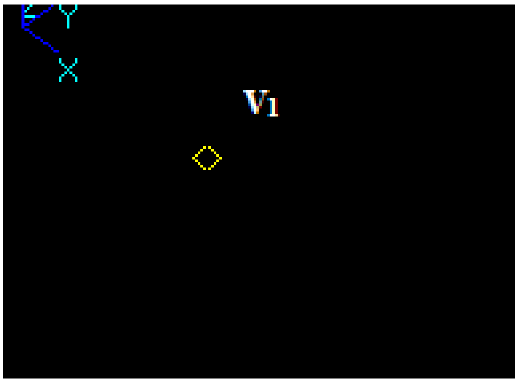
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is not defined because the dimension of the vertex (0) is less than the dimension of the edge (1).

8.3.3 Case 3: A Vertex and a Face

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



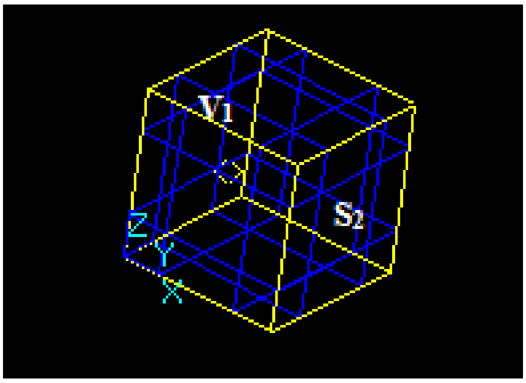
- The result of *Fuse* operation is not defined because the dimension of the vertex (0) is not equal to the dimension of the face (2).
- The result of *Common* operation is a compound containing vertex V_1 as the argument V_1 has a common part with face *F2*.



- 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).

8.3.4 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*.

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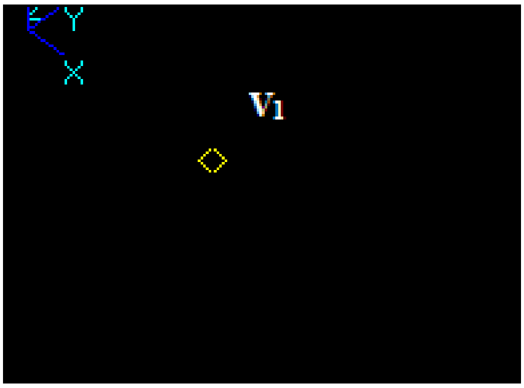
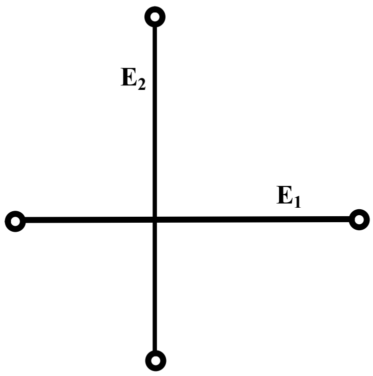


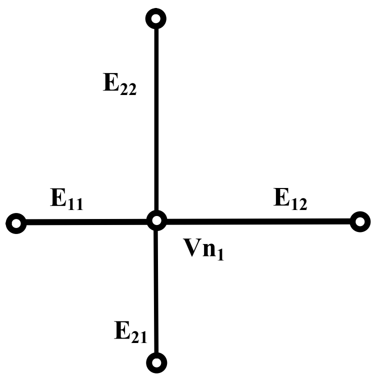
- The result of *Cut12* operation is an empty compound.
- The result of *Cut21* operation is not defined because the dimension of the vertex (0) is less than the dimension of the solid (3).

8.3.5 Case 5: Two edges intersecting at one point

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



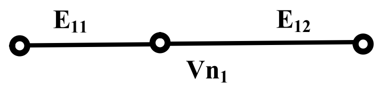
- The result of *Fuse* operation is a compound containing split parts of arguments i.e. 4 new edges *E11, E12, E21*, and *E22*. These edges have one shared vertex *Vn1*. In this case:
  - argument edge *E1* has resulting split edges *E11* and *E12* (image of *E1*);
  - argument edge *E2* has resulting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

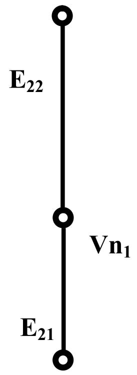
- The result of *Cut12* operation is a compound containing split parts of the argument *E1*, i.e. 2 new edges *E11* and *E12*. These edges have one shared vertex *Vn1*.

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



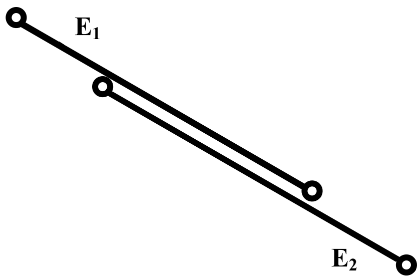
- The result of *Cut21* operation is a compound containing split parts of the argument *E2*, i.e. 2 new edges *E21* and *E12*. These edges have one shared vertex *Vn1*.

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

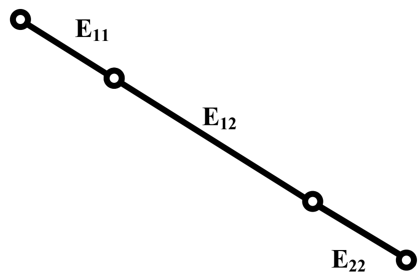


8.3.6 Case 6: Two edges having a common block

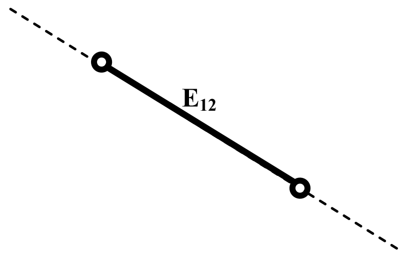
Let us consider edges *E1* and *E2* that have a common block:



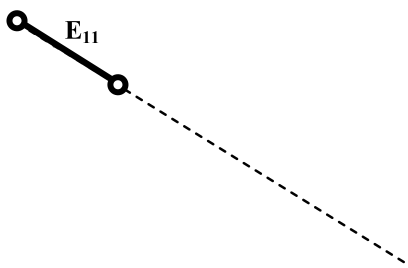
- The result of *Fuse* operation is a compound containing split parts of arguments i.e. 3 new edges *E11*, *E12* and *E22*. These edges have two shared vertices. In this case:
  - argument edge *E1* has resulting split edges *E11* and *E12* (image of *E1*);
  - argument edge *E2* has resulting split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



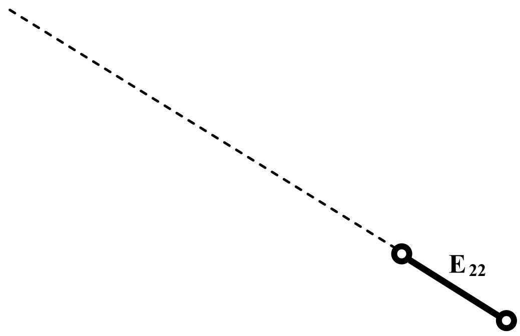
- The result of *Common* operation is a compound containing split parts of arguments i.e. 1 new edge *E12*. In this case edge *E12* is common for the images of *E1* and *E2*. The common part between the edges (edge) has the same dimension (1) as the dimension of the arguments (1).



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

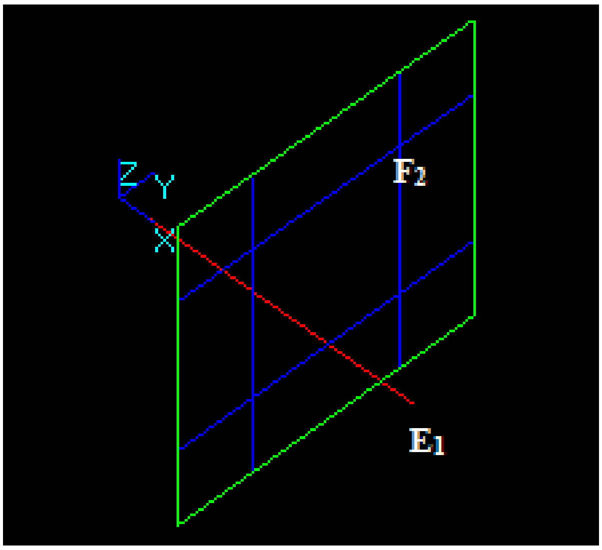


- The result of *Cut21* operation is a compound containing a split part of argument *E2*, i.e. new edge *E22*.



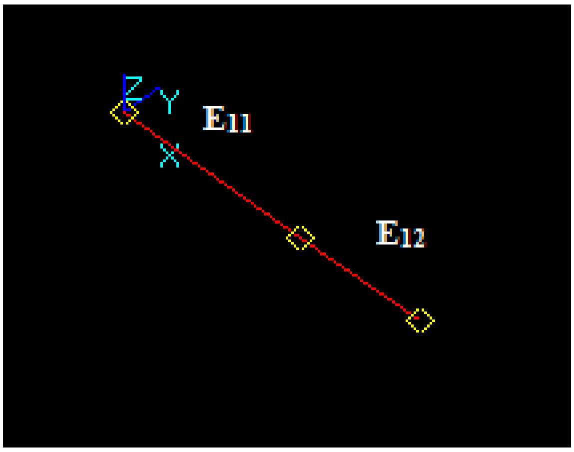
8.3.7 Case 7: An Edge and a Face intersecting at a point

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*.

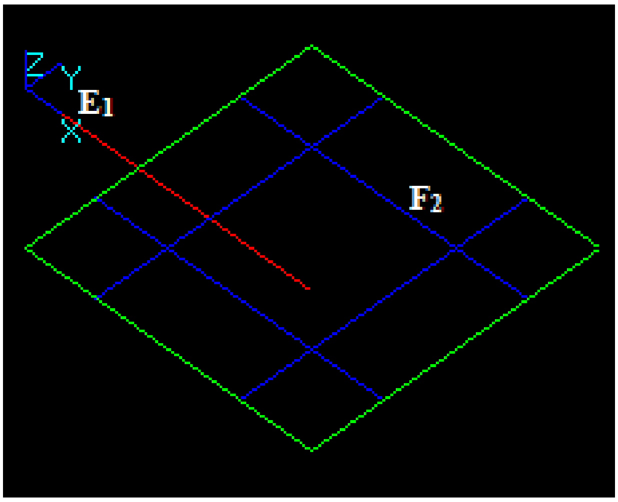
In this case the argument edge *E1* has no common parts with the face *F2* so the whole image of *E1* is in the result.



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

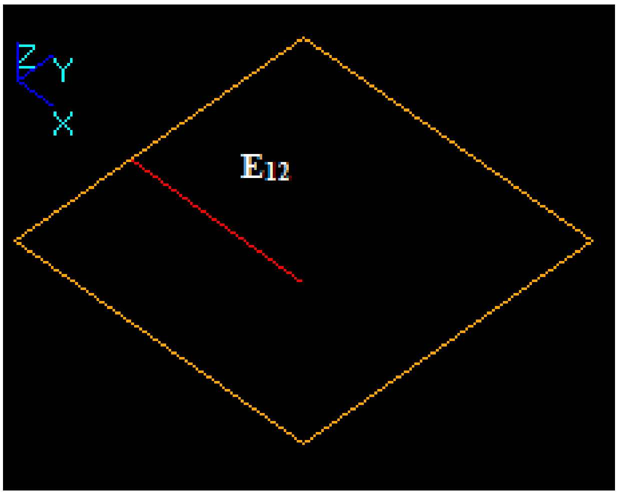
8.3.8 Case 8: A Face and an Edge that have a common block

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



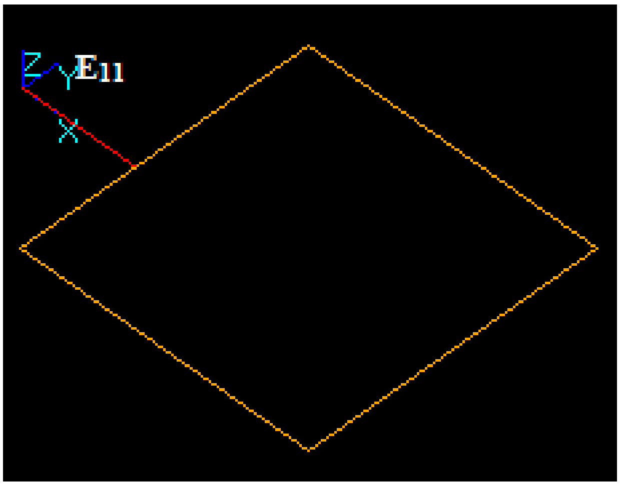
- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the face (2).
- The result of *Common* operation is a compound containing a split part of the argument *E1*, i.e. new edge *E12*.

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*.

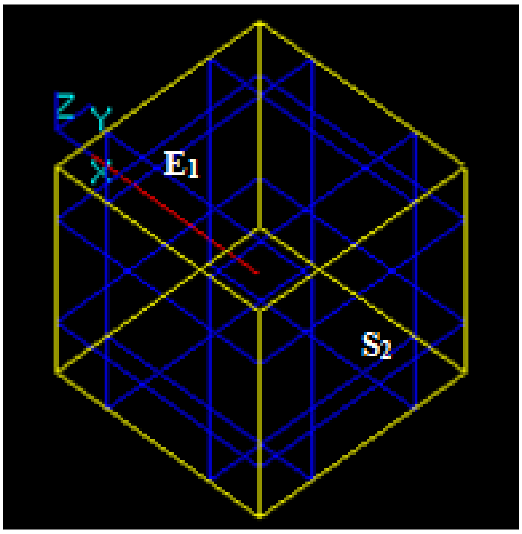
In this case the argument edge *E1* has a common part with face *F2* so the corresponding part is not included into the result. The yellow square is not a part of the result. It only shows the place of F2.



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

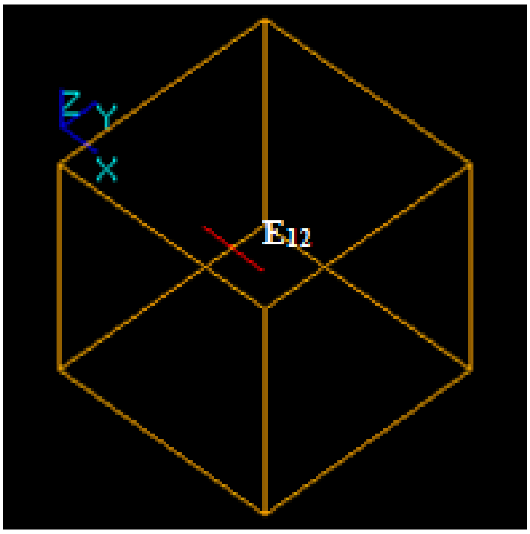
8.3.9 Case 9: An Edge and a Solid intersecting at a point

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



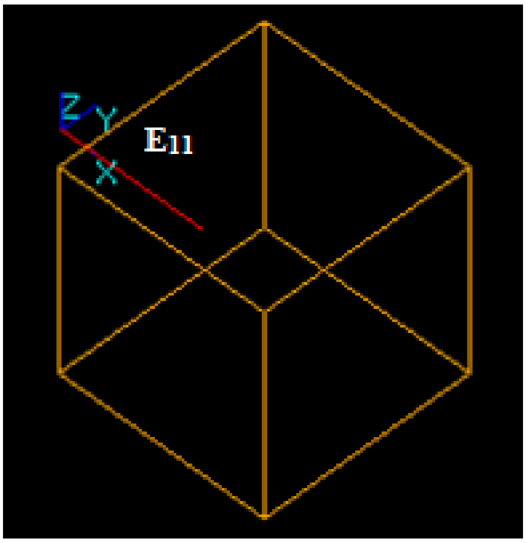
- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing a split part of the argument *E1*, i.e. new edge *E12*.

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*.

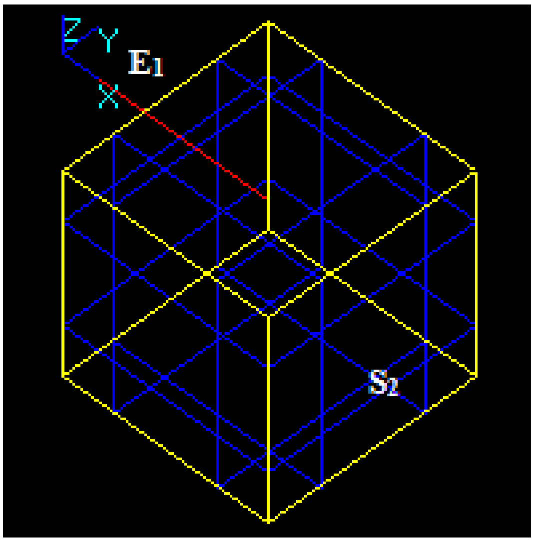
In this case the argument edge *E1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow square is not a part of the result. It only shows the place of *S2*.



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

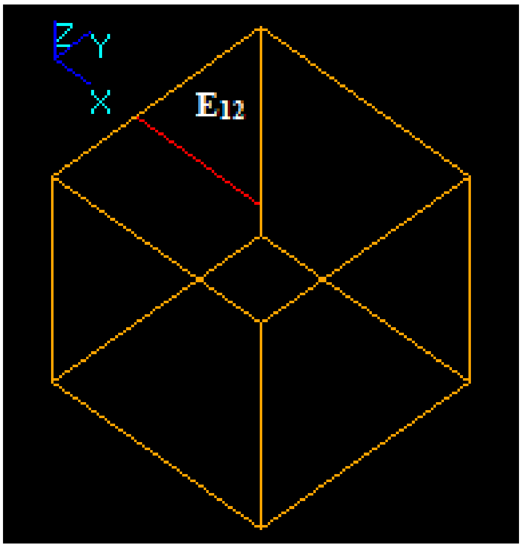
8.3.10 Case 10: An Edge and a Solid that have a common block

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



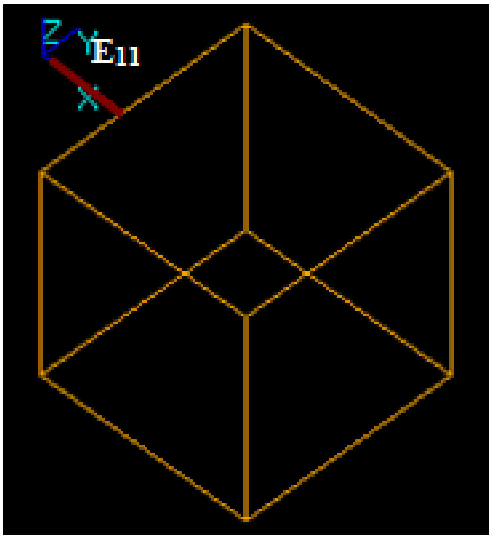
- The result of *Fuse* operation is not defined because the dimension of the edge (1) is not equal to the dimension of the solid (3).
- The result of *Common* operation is a compound containing a split part of the argument *E1*, i.e. new edge *E12*.

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*.

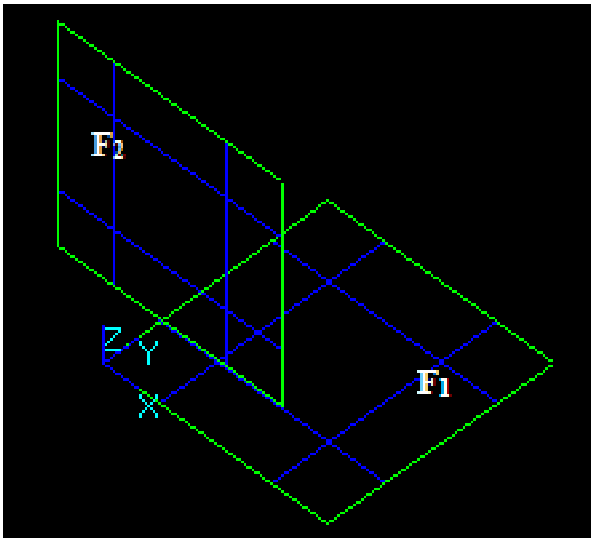
In this case the argument edge *E1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow square is not a part of the result. It only shows the place of *S2*.



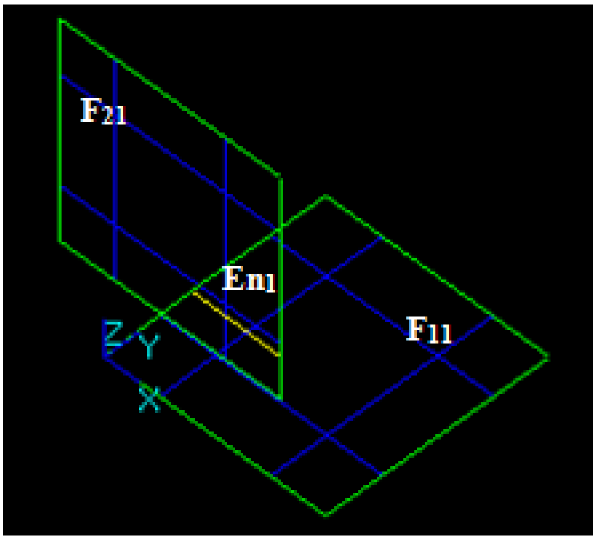
- The result of *Cut21* operation is not defined because the dimension of the edge (1) is less than the dimension of the solid (3).

8.3.11 Case 11: Two intersecting faces

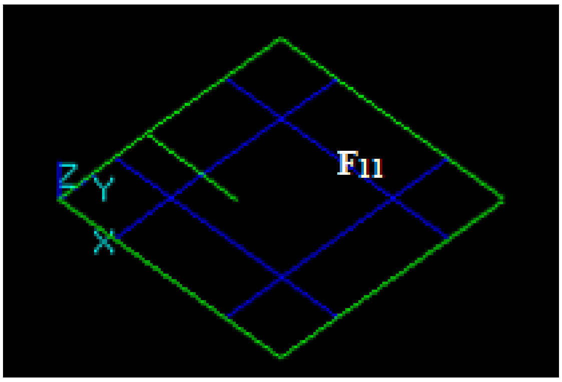
Let us consider two intersecting faces *F1* and *F2*:



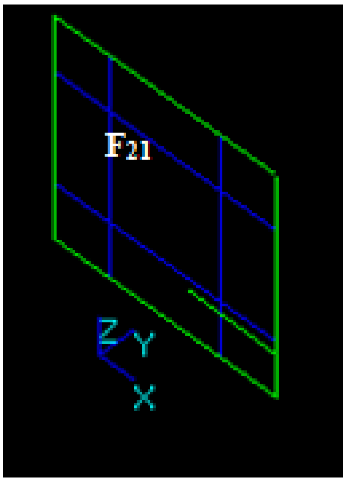
- The result of *Fuse* operation is a compound containing split parts of arguments i.e. 2 new faces *F11* and *F21*. These faces have one shared edge *En1*.



- 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*.

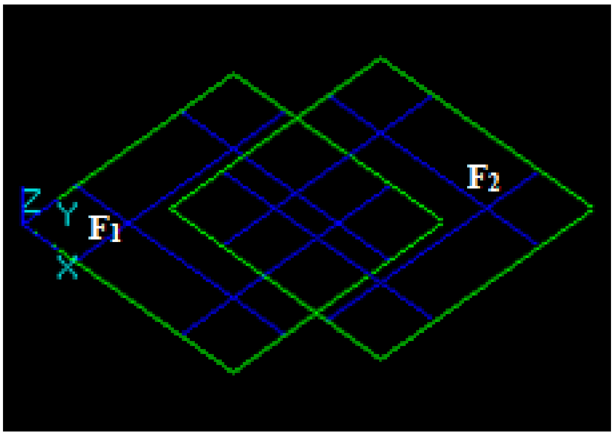


- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*.

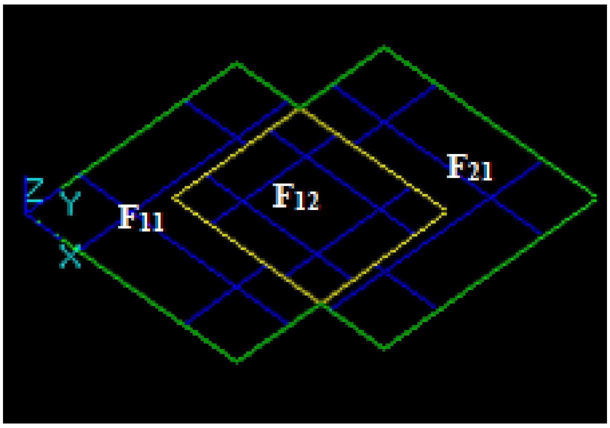


8.3.12 Case 12: Two faces that have a common part

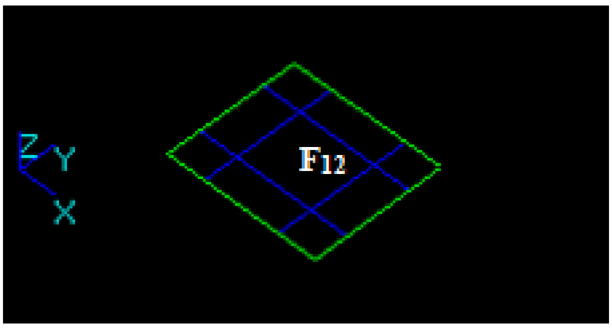
Let us consider two faces *F1* and *F2* that have a common part:



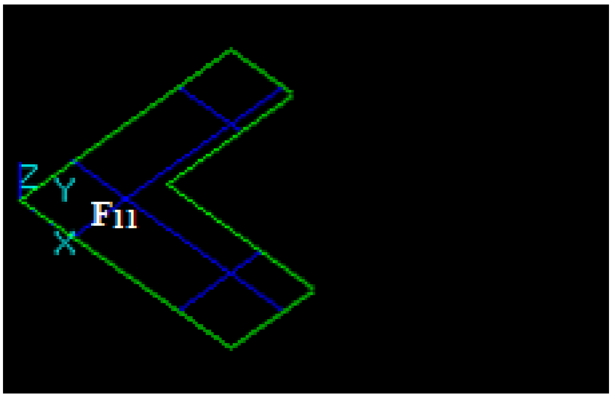
- The result of *Fuse* operation is a compound containing split parts of arguments, i.e. 3 new faces: *F11*, *F12* and *F22*. These faces are shared through edges In this case:
  - the argument edge *F1* has resulting split faces *F11* and *F12* (image of *F1*)
  - the argument face *F2* has resulting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



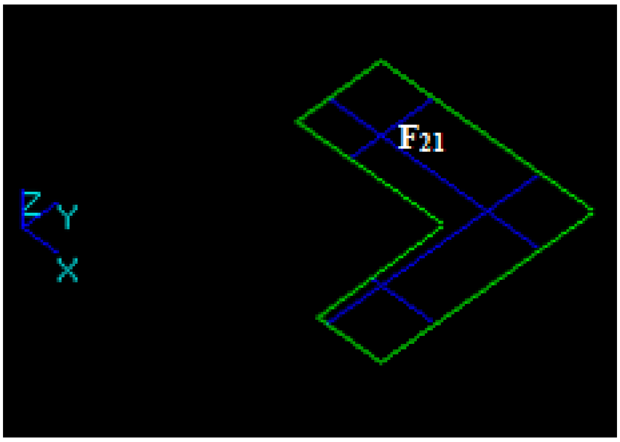
- The result of *Common* operation is a compound containing split parts of arguments i.e. 1 new face *F12*. In this case: face *F12* is common for the images of *F1* and *F2*. The common part between the faces (face) has the same dimension (2) as the dimension of the arguments (2).



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

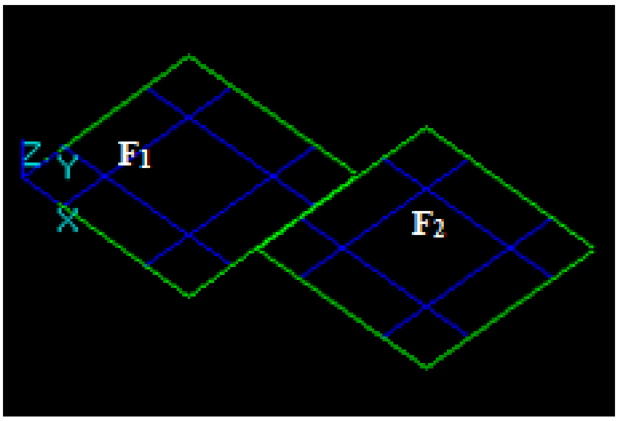


- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*.

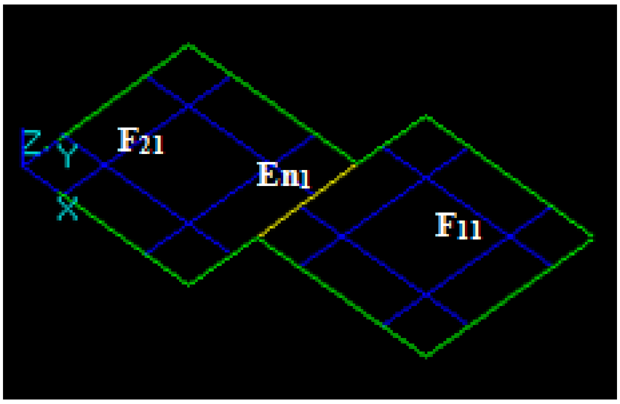


8.3.13 Case 13: Two faces that have a common edge

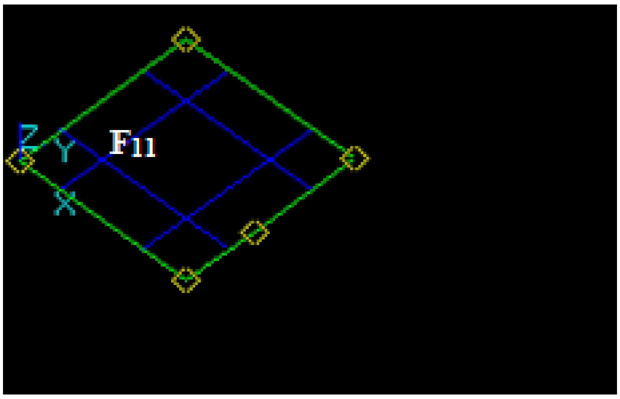
Let us consider two faces *F1* and *F2* that have a common edge:



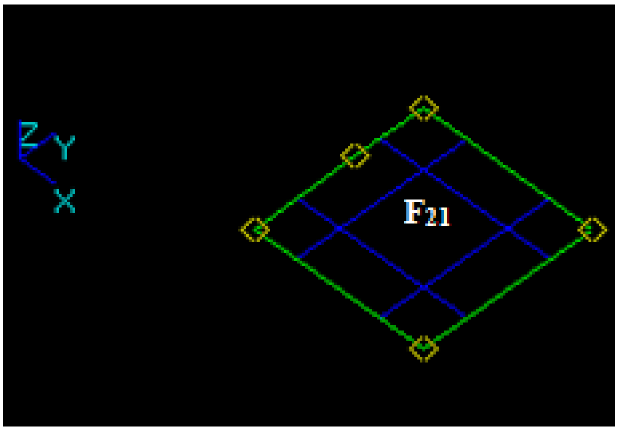
- The result of *Fuse* operation is a compound containing split parts of arguments, i.e. 2 new faces: *F11* and *F21*. These faces have one shared edge *En1*.



- 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.



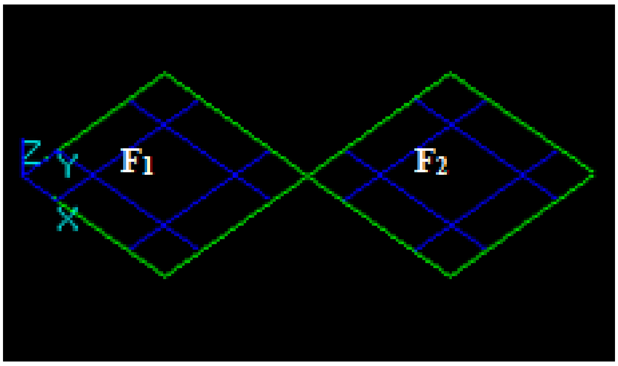
- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*. The vertices are shown just to clarify the fact that the edges are spitted.



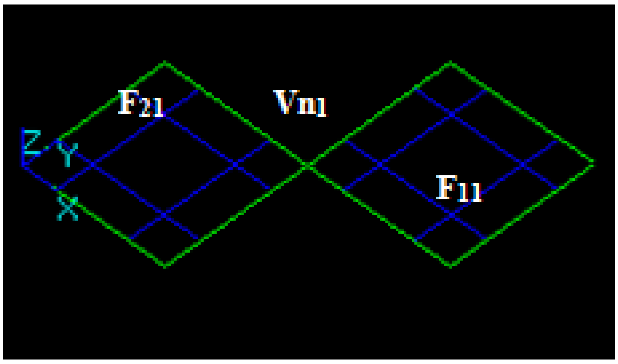
8.3.14 Case 14: Two faces that have a common vertex

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

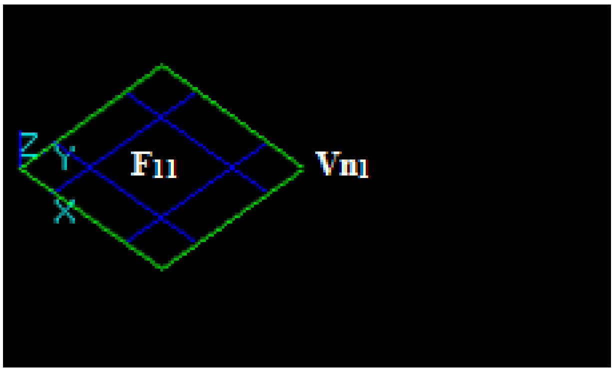
(c) Open CASCADE 2016



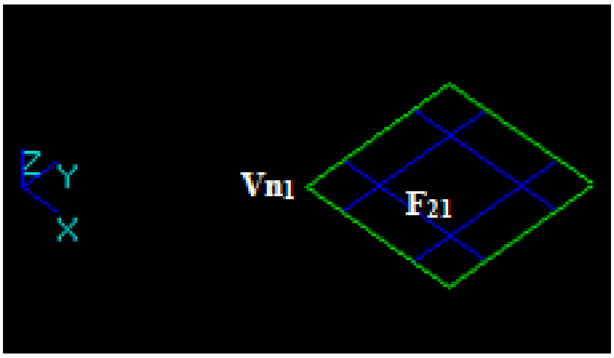
- The result of *Fuse* operation is a compound containing split parts of arguments, i.e. 2 new faces: *F11* and *F21*. These faces have one shared vertex *Vn1*.



- 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*.

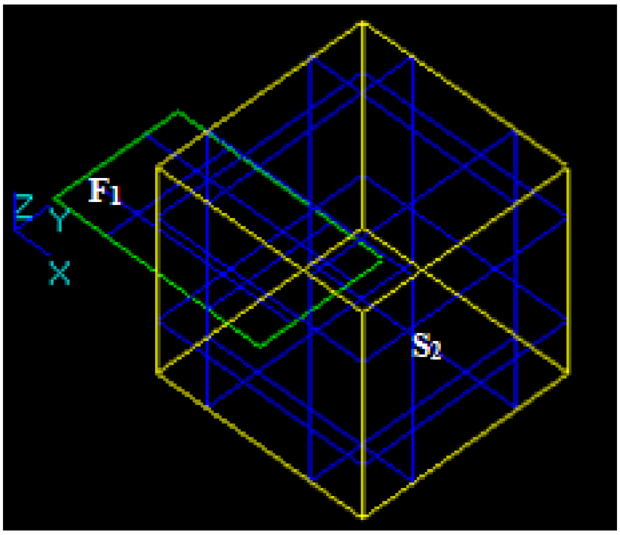


- The result of *Cut21* operation is a compound containing split parts of the argument *F2*, i.e. 1 new face *F21*.

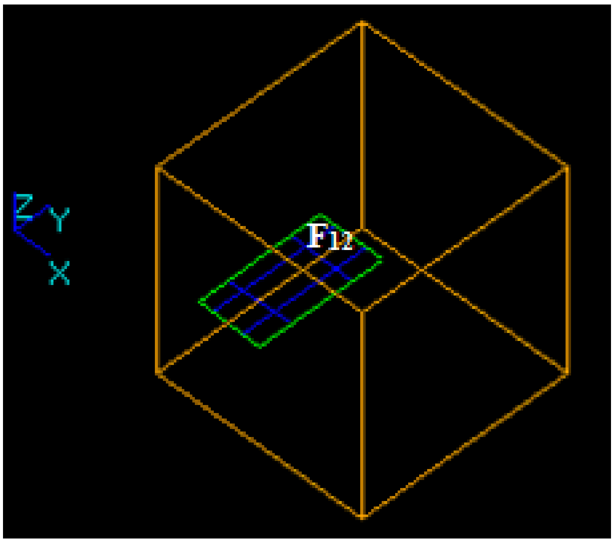


8.3.15 Case 15: A Face and a Solid that have an intersection curve.

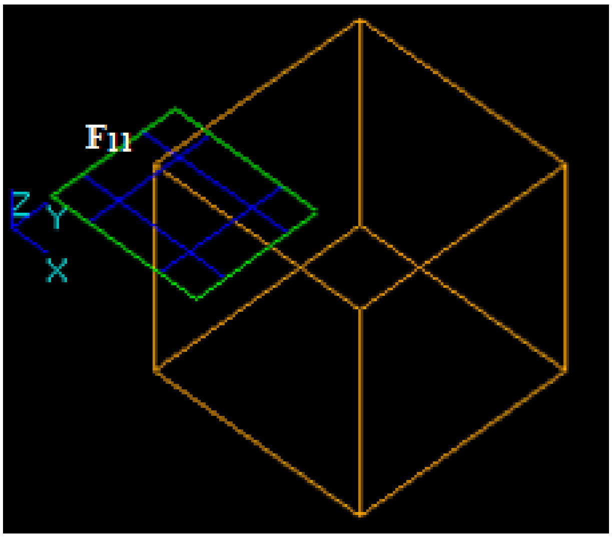
Let us consider face *F1* and solid *S2* that have an intersection curve:



- 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*.



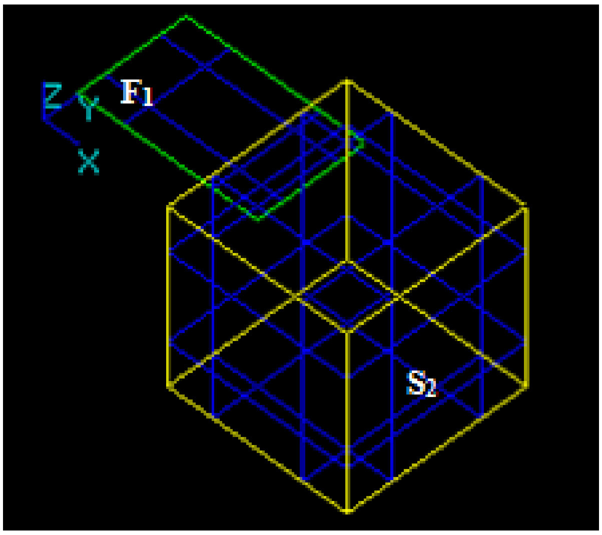
- The result of *Cut12* operation is a compound containing split part of the argument *F1*. In this case argument face *F1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



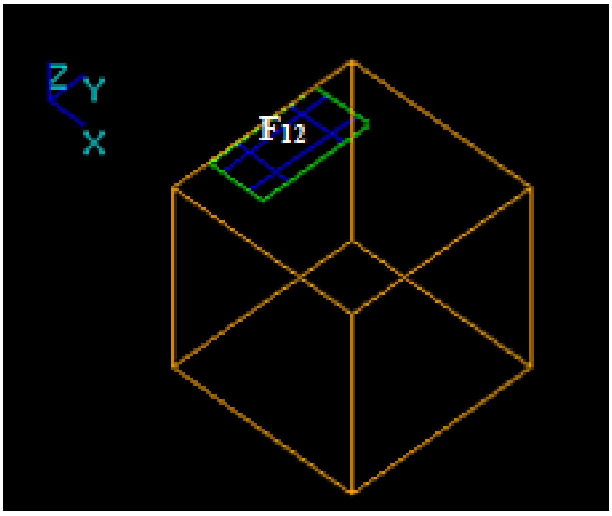
- The result of *Cut21* operation is is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

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

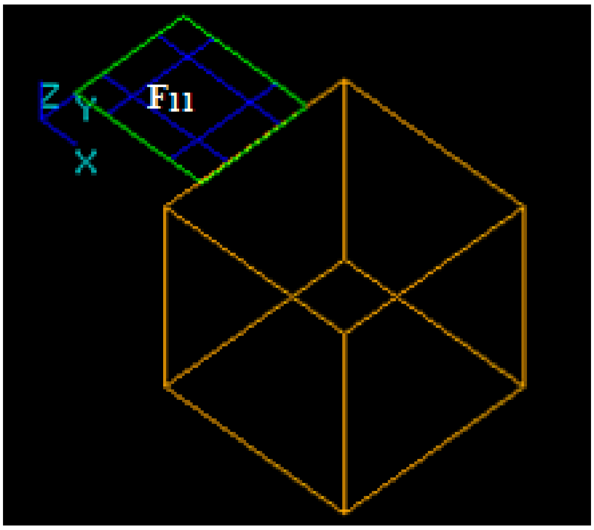
Let us consider face *F1* and solid *S2* that have overlapping faces:



- 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*.



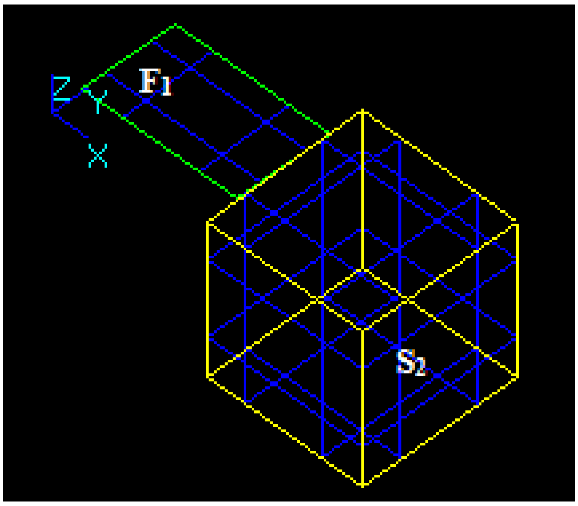
- The result of *Cut12* operation is a compound containing split part of the argument *F1*. In this case argument face *F1* has a common part with solid *S2* so the corresponding part is not included into the result. The yellow contour is not a part of the result. It only shows the place of *S2*.



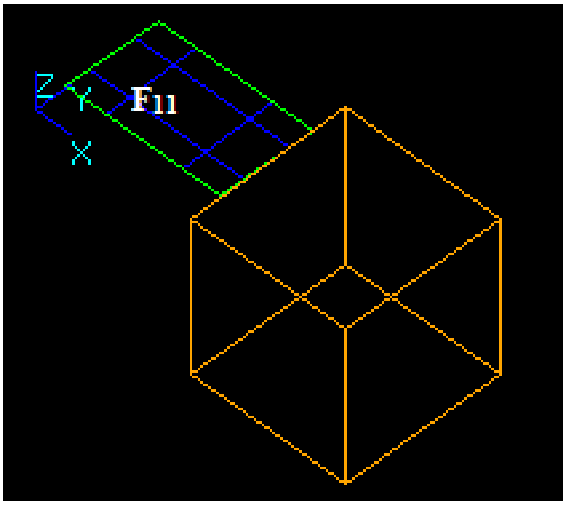
- The result of *Cut21* operation is is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

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

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



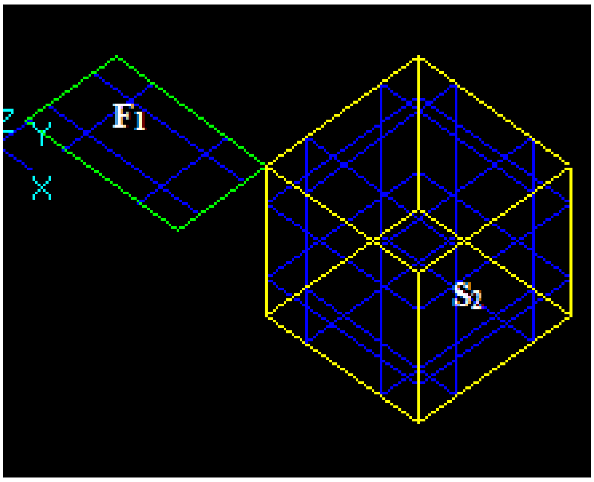
- The result of *Fuse* operation is not defined because the dimension of the face (2) is not equal to the dimension of the solid (3).
- The result of *Common* operation is an empty compound because the dimension (1) of the common part between *F1* and *S2* (edge) is less than the lower dimension of the 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*.



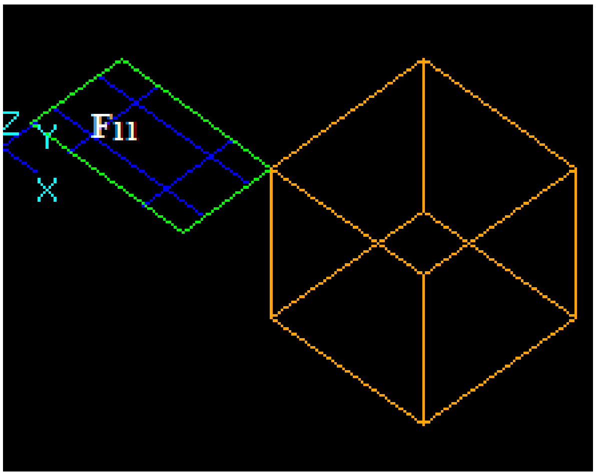
- The result of *Cut21* operation is is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

8.3.18 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 is not defined because the dimension of the face (2) is less than the dimension of the solid (3).

8.3.19 Case 19: Two intersecting Solids.

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

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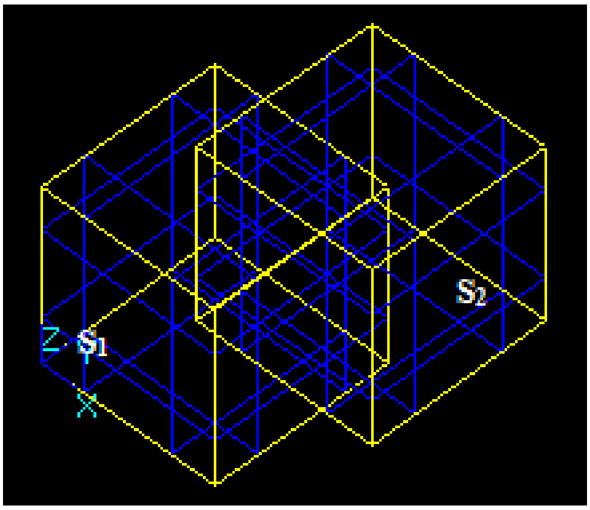
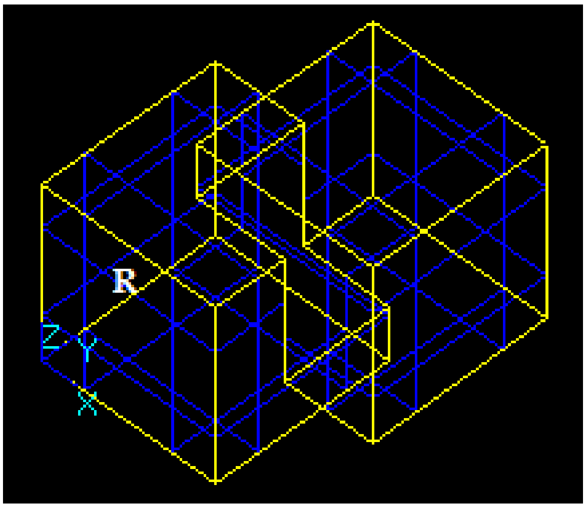
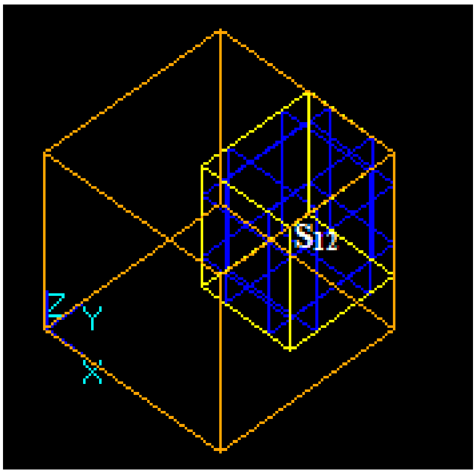


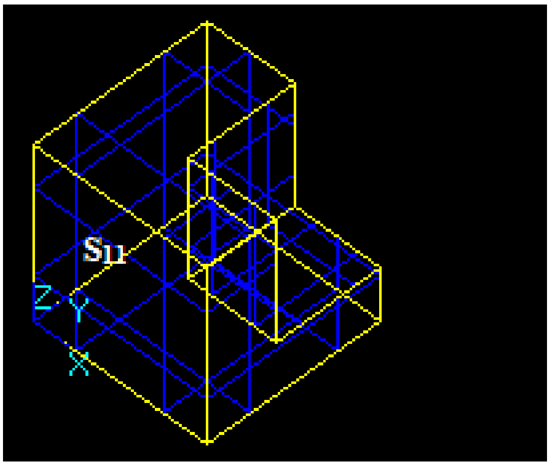
- The result of *Fuse* operation is a compound composed from the split parts of arguments *S11, S12* and *S22 (Cut12, Common, Cut21)*. All inner webs are removed, so the result is one new solid *R*.



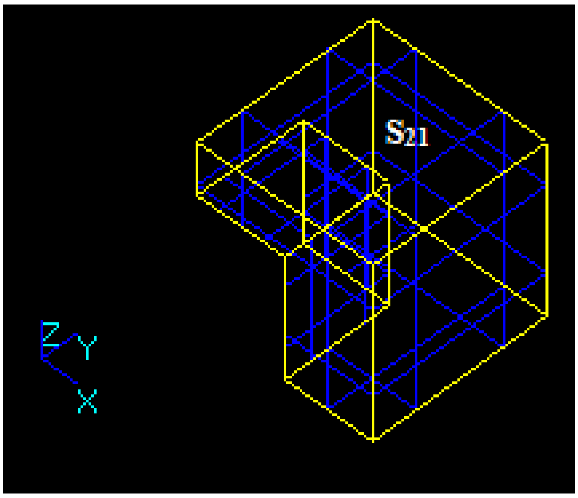
- The result of *Common* operation is a compound containing split parts of arguments i.e. one new solid *S12*. In this case solid *S12* is common for the images of *S1* and *S2*. The common part between the solids (solid) has the same dimension (3) as the dimension of the arguments (3). The yellow contour 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*.

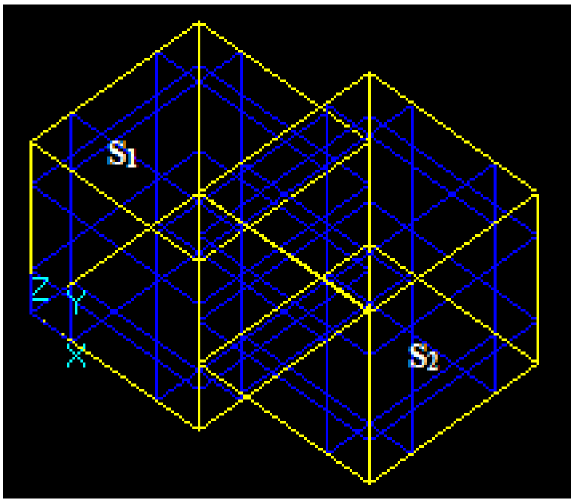


- The result of *Cut21* operation is a compound containing split part of the argument *S2*, i.e. 1 new solid *S21*.

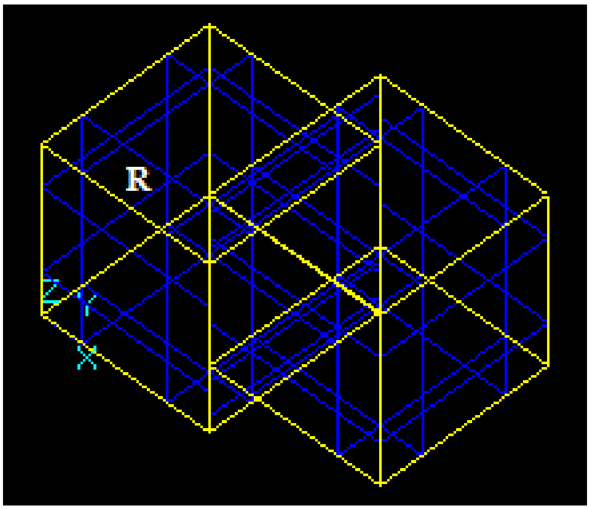


8.3.20 Case 20: Two Solids that have overlapping faces.

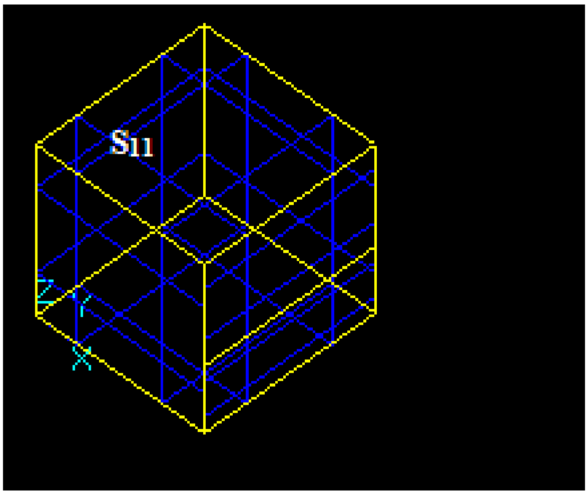
Let us consider two solids *S1* and *S2* that have a common part on face:



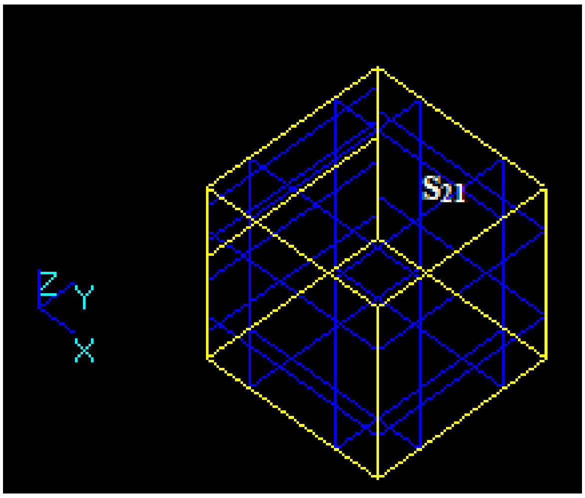
- The result of *Fuse* operation is a compound composed from the split parts of arguments *S11, S12* and *S22 (Cut12, Common, Cut21)*. All inner webs are removed, so the result is one new solid *R*.



- 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*.

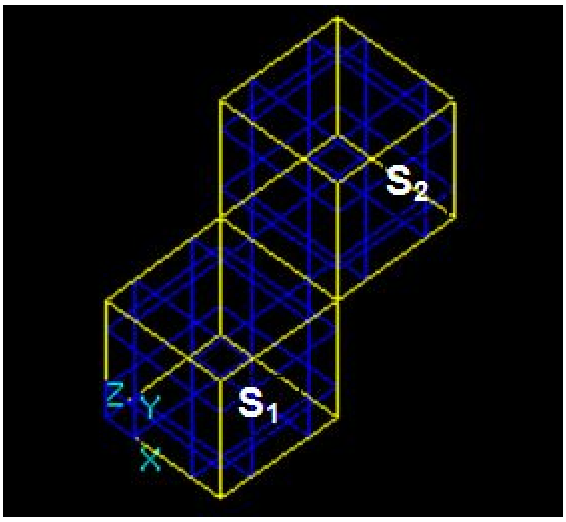


- The result of *Cut21* operation is a compound containing split part of the argument *S2*, i.e. 1 new solid *S21*.

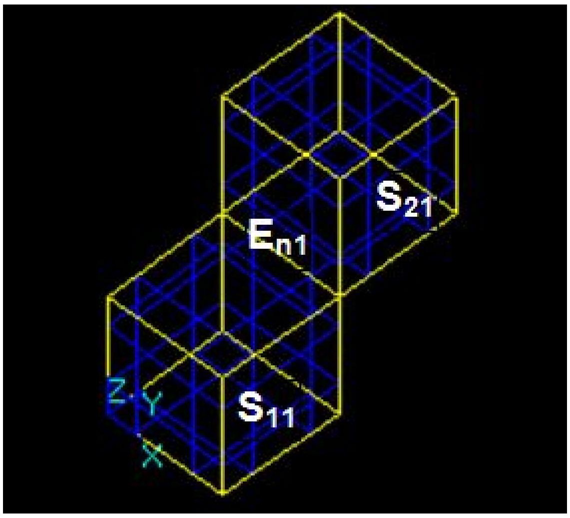


8.3.21 Case 21: Two Solids that have overlapping edges.

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.

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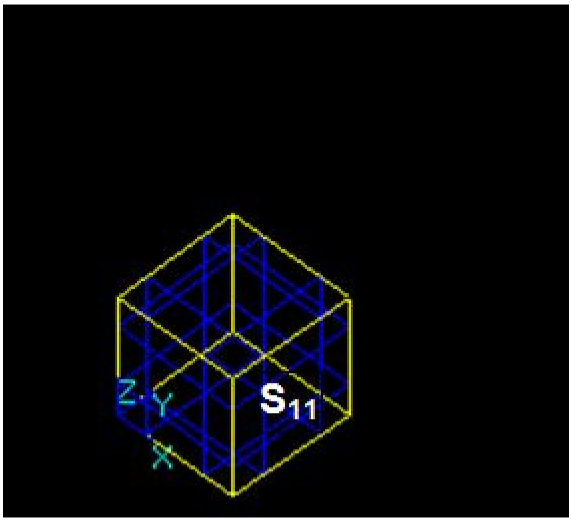
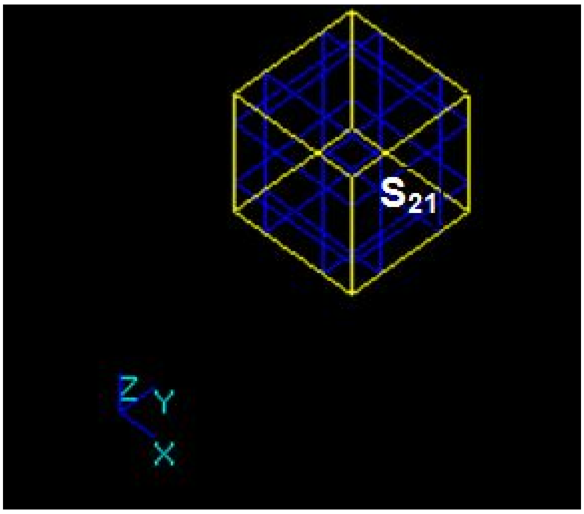
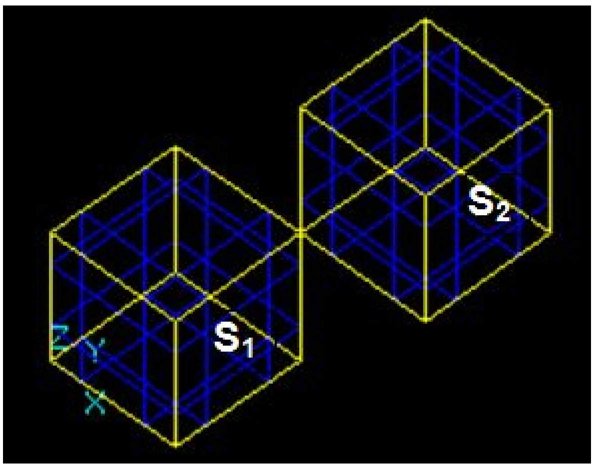


- The result of *Cut21* operation is a compound containing split part of the argument *S2*. In this case argument *S2* has a common part with solid *S1* so the corresponding part is not included into the result.

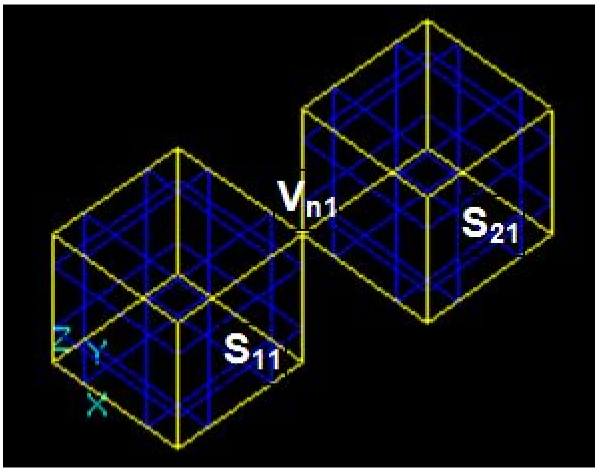


8.3.22 Case 22: Two Solids that have overlapping vertices.

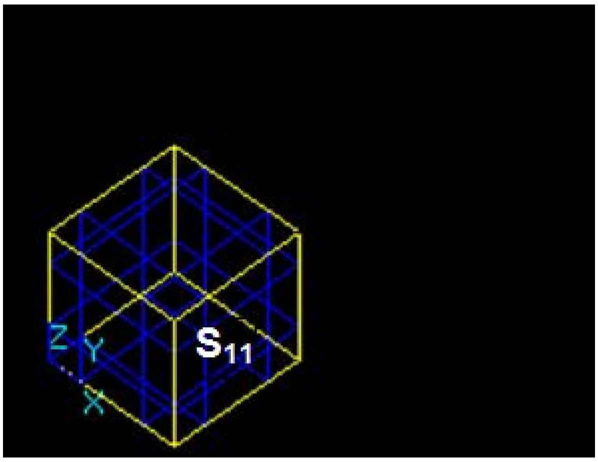
Let us consider two solids *S1* and *S2* that have overlapping vertices:



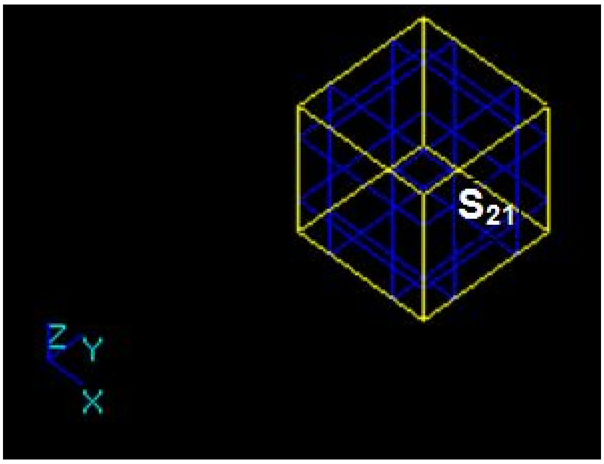
- The result of *Fuse* operation is a compound composed from the split parts of arguments i.e. 2 new solids *S11* and *S21*. These solids share *Vn1*.



- 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*.



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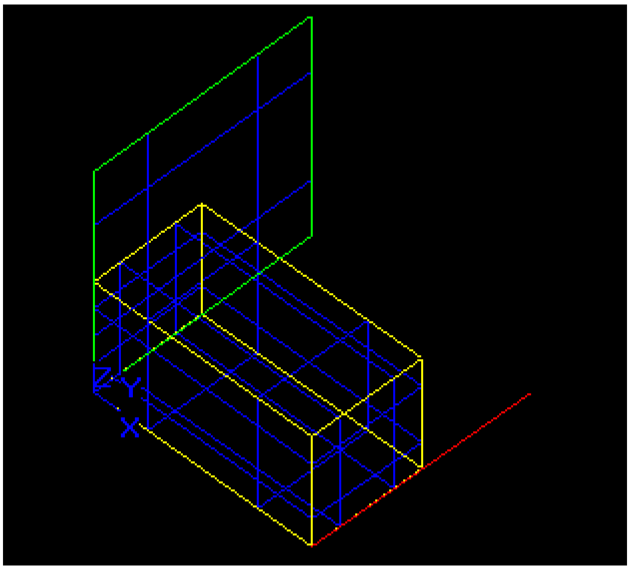
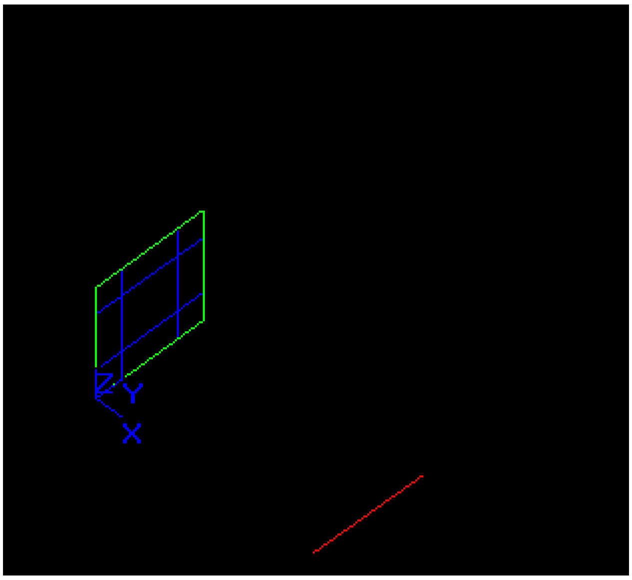
8.3.23 Case 23: A Shell and a Wire cut by a Solid.

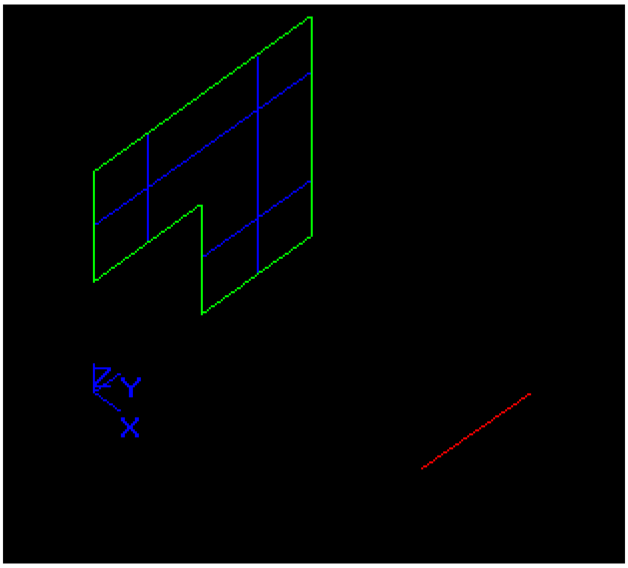
Let us consider Shell *Sh* and Wire *W* as the objects and Solid *S* as the tool:



- 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.



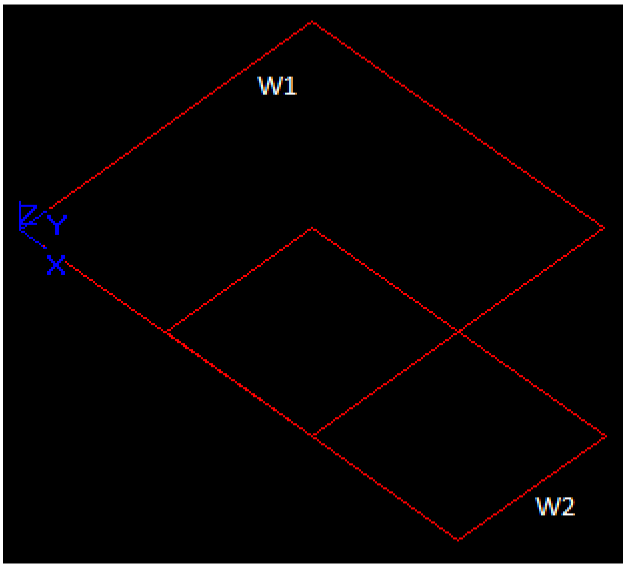
- The result of *Cut12* operation is a compound containing new Shell and Wire split from the arguments *Sh* and *W*. In this case they have a common part with solid *S* so the corresponding part is not included into the result.



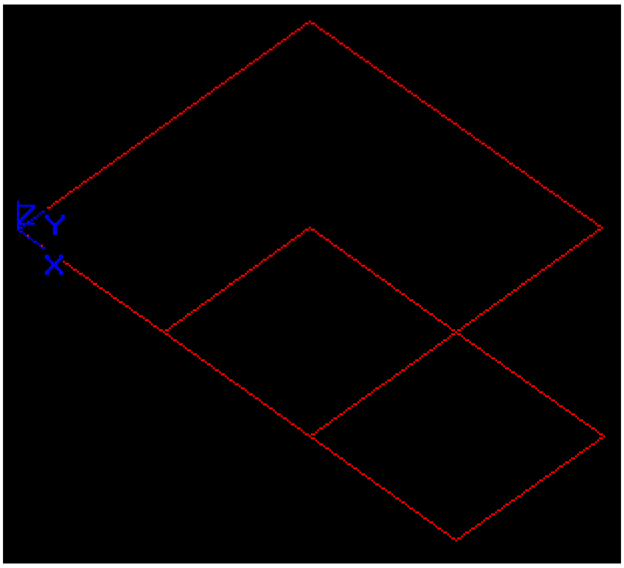
• The result of *Cut21* operation is not defined as the objects have a lower dimension than the tool.

8.3.24 Case 24: Two Wires that have overlapping edges.

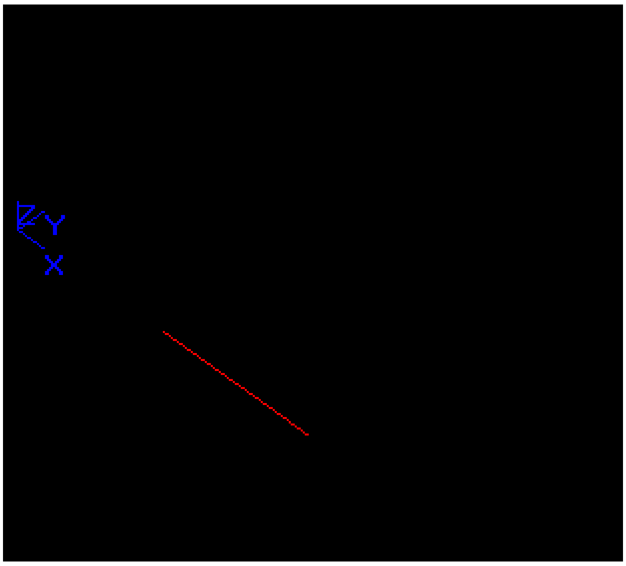
Let us consider two Wires that have overlapping edges, *W1* is the object and *W2* is the tool:



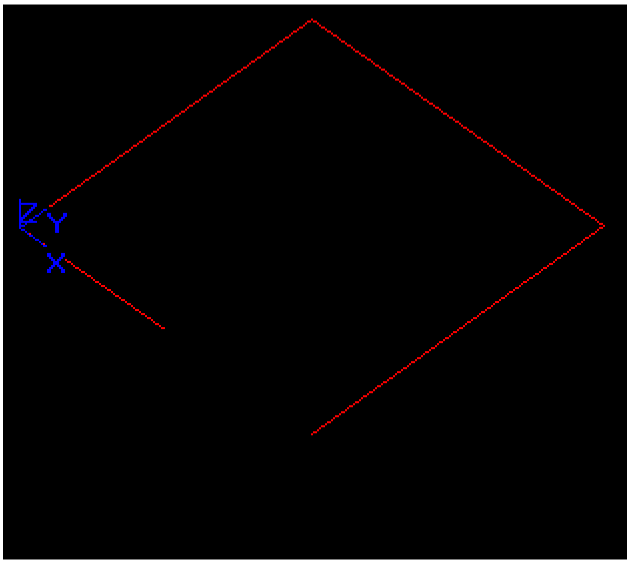
• The result of *Fuse* operation is a compound containing two Wires, which share an overlapping edge. The new Wires are created from the objects:



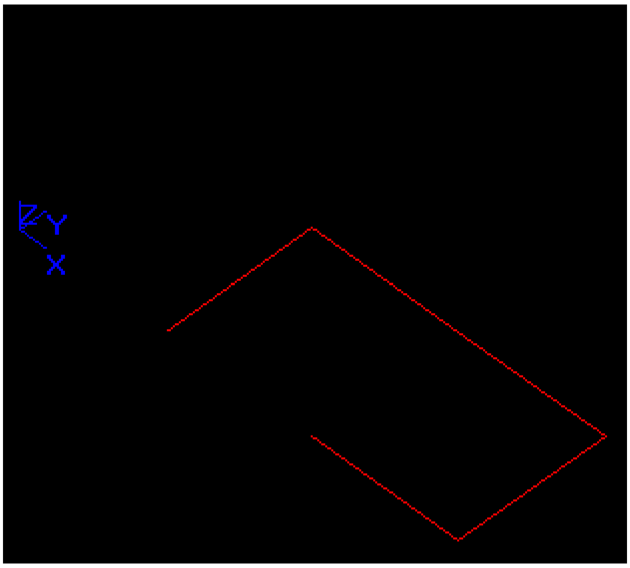
- The result of *Common* operation is a compound containing two Wires both consisting of an overlapping edge. The new Wires are created from the objects:



- 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.



8.4 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** (p. 48) except for some aspects described in the next paragraphs.

8.5 Building Draft Result

The input data for this step is as follows:

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- *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()*

8.6 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::MakeConnexity-Blocks()*
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	

9 Section Algorithm

9.1 Arguments

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

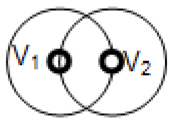
9.2 Results and general rules

- 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),

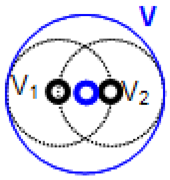
9.3 Examples

9.3.1 Case 1: Two Vertices

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

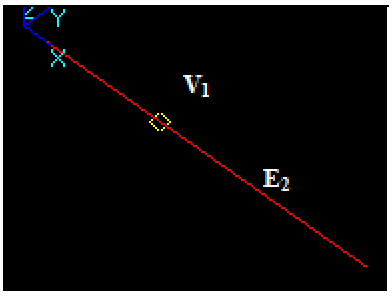


The result of *Section* operation is the compound that contains a new vertex *V*.

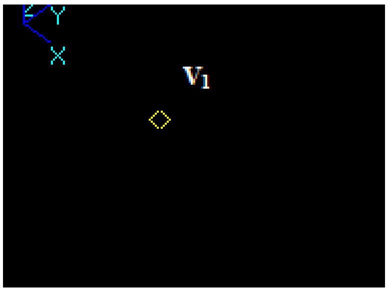


9.3.2 Case 1: Case 2: A Vertex and an Edge

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

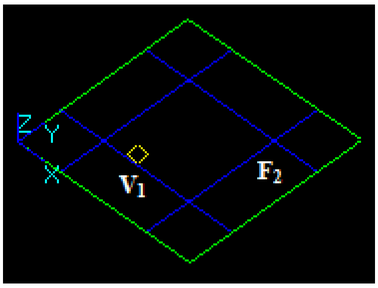


The result of *Section* operation is the compound that contains vertex *V1*.

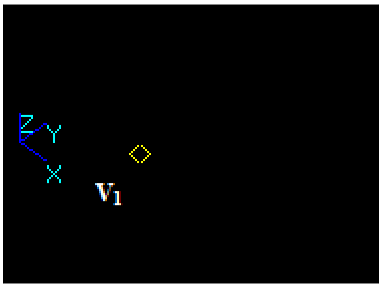


9.3.3 Case 1: Case 2: A Vertex and a Face

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*.



9.3.4 Case 4: A Vertex and a Solid

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

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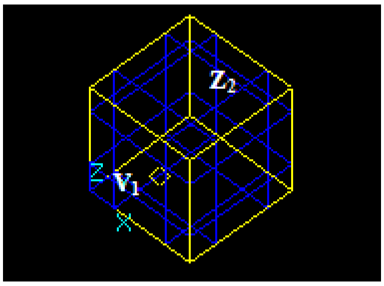
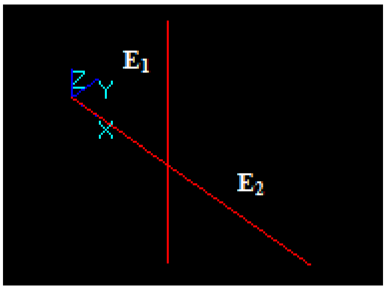


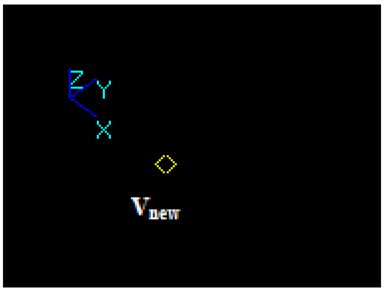
The result of *Section* operation is an empty compound.

9.3.5 Case 5: Two edges intersecting at one point

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

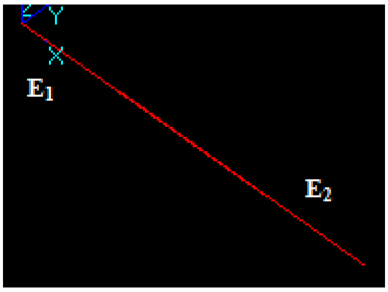


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

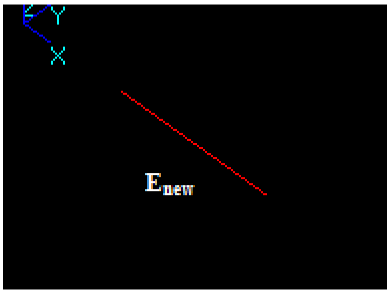


9.3.6 Case 6: Two edges having a common block

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

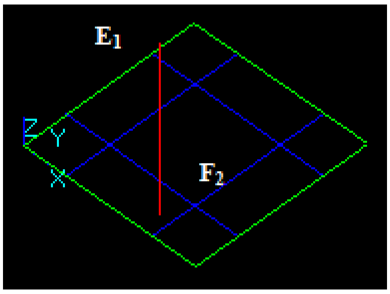


The result of *Section* operation is the compound that contains a new edge *Enew*.

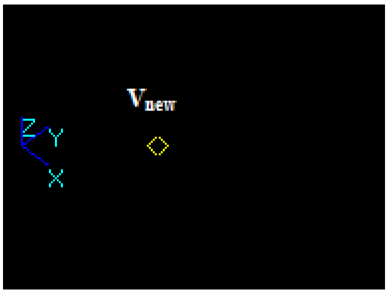


9.3.7 Case 7: An Edge and a Face intersecting at a point

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

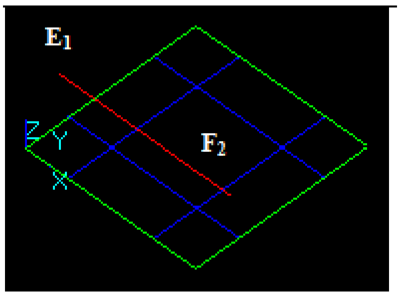


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

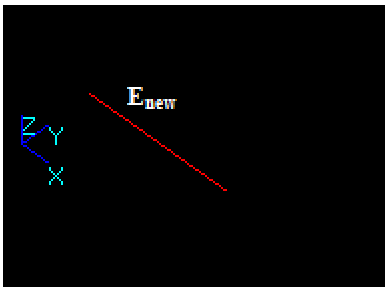


9.3.8 Case 8: A Face and an Edge that have a common block

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

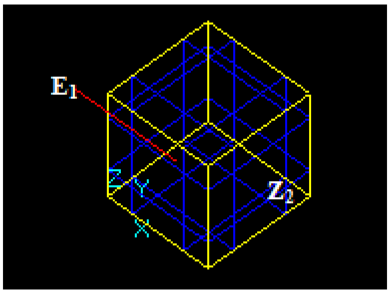


The result of *Section* operation is the compound that contains new edge *Enew*.

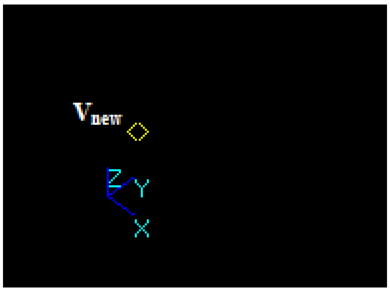


9.3.9 Case 9: An Edge and a Solid intersecting at a point

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

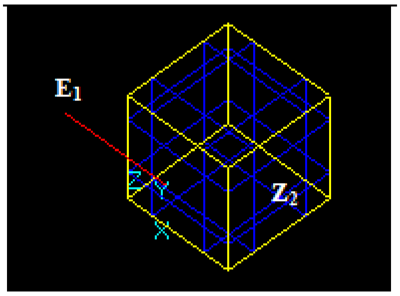


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

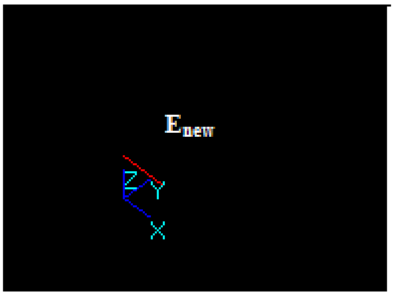


9.3.10 Case 10: An Edge and a Solid that have a common block

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

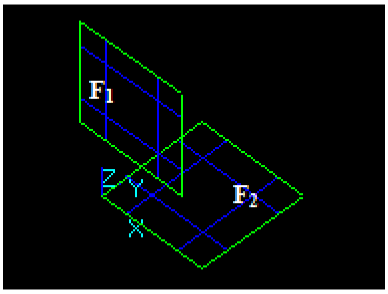


The result of *Section* operation is the compound that contains a new edge *Enew*.

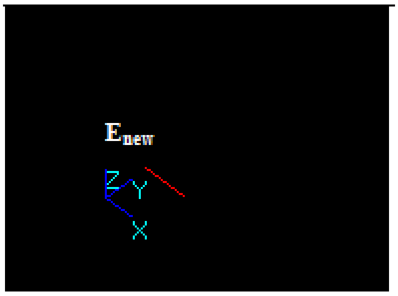


9.3.11 Case 11: Two intersecting faces

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

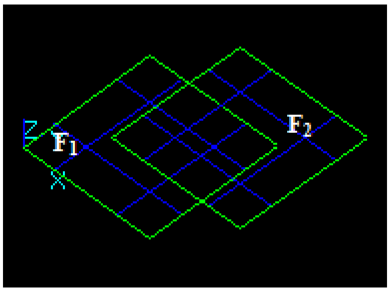


The result of *Section* operation is the compound that contains a new edge *Enew*.

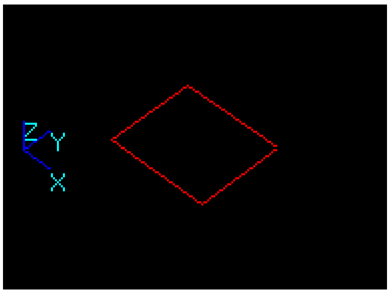


9.3.12 Case 12: Two faces that have a common part

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

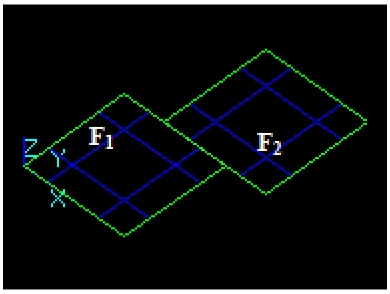


The result of *Section* operation is the compound that contains 4 new edges.



9.3.13 Case 13: Two faces that have overlapping edges

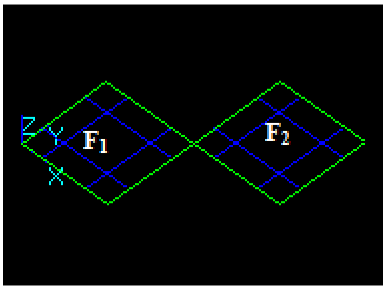
Let us consider two faces *F1* and *F2* that have a overlapping edges:



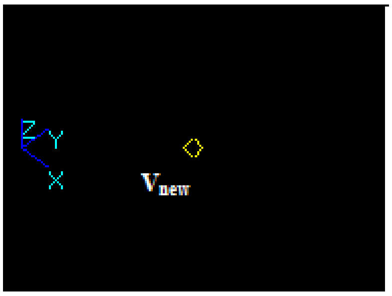
The result of *Section* operation is the compound that contains a new edge *Enew*.

9.3.14 Case 14: Two faces that have overlapping vertices

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

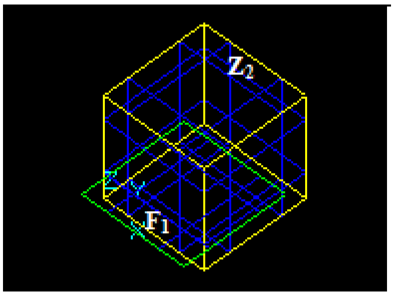


The result of *Section* operation is the compound that contains a new vertex *Vnew*.

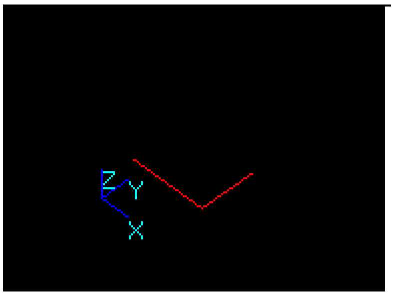


9.3.15 Case 15: A Face and a Solid that have an intersection curve

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

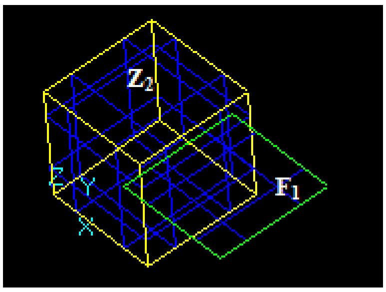


The result of *Section* operation is the compound that contains new edges.

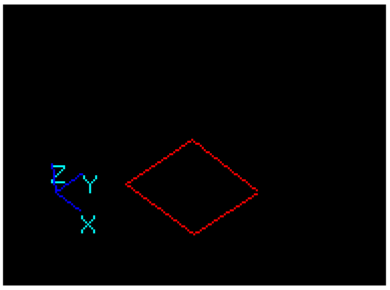


9.3.16 Case 16: A Face and a Solid that have overlapping faces.

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

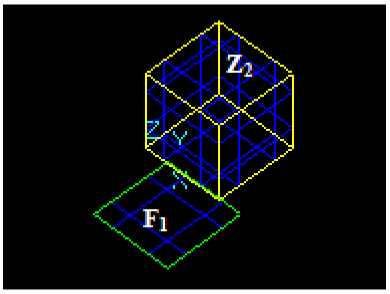


The result of *Section* operation is the compound that contains new edges

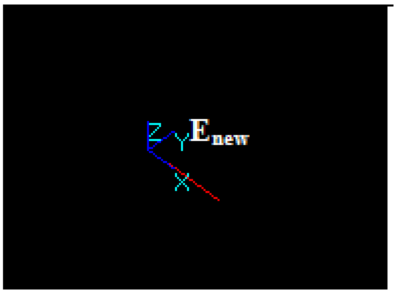


9.3.17 Case 17: A Face and a Solid that have overlapping edges.

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

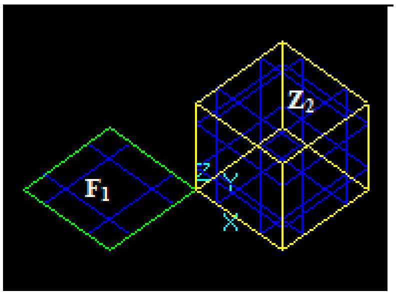


The result of *Section* operation is the compound that contains a new edge *Enew*.



9.3.18 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*.

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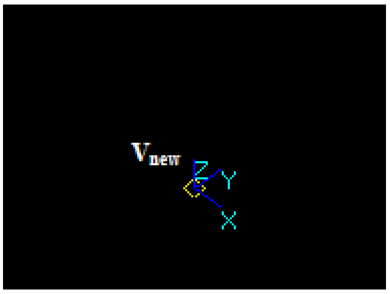
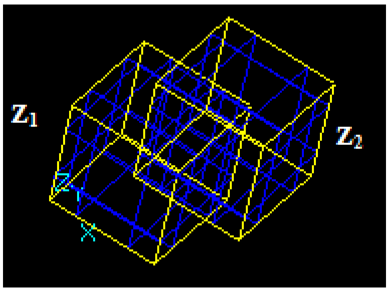
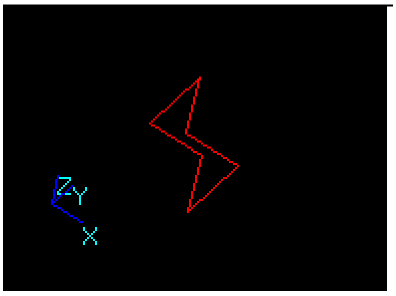


9.3.19 Case 19: Two intersecting Solids

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

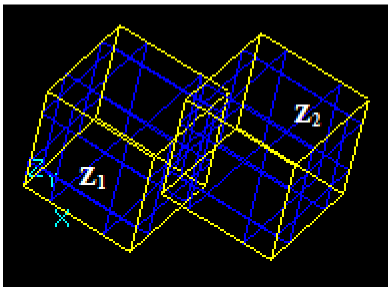


The result of *Section* operation is the compound that contains new edges.

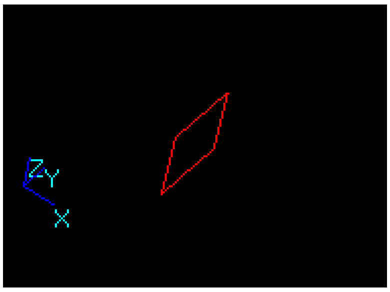


9.3.20 Case 20: Two Solids that have overlapping faces

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

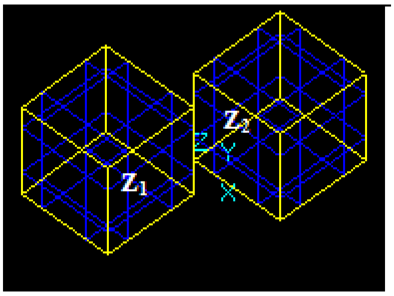


The result of *Section* operation is the compound that contains new edges.

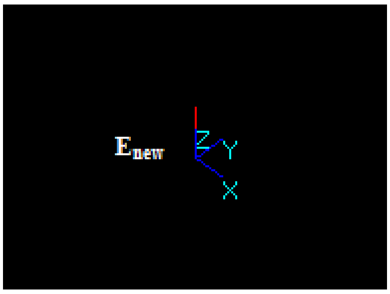


9.3.21 Case 21: Two Solids that have overlapping edges

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

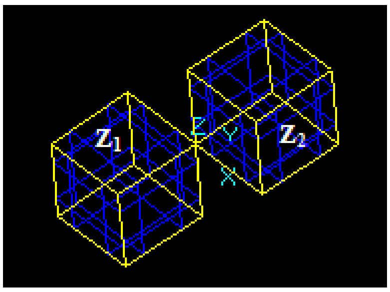


The result of *Section* operation is the compound that contains a new edge *Enew*.

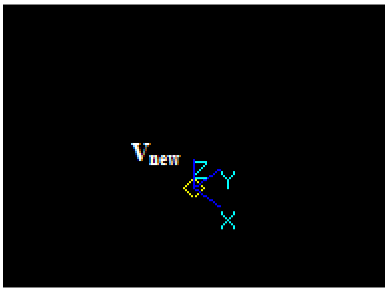


9.3.22 Case 22: Two Solids that have overlapping vertices

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*.



9.4 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

9.5 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()*

10 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.

10.1 Arguments

10.1.1 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.

10.1.2 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.

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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.

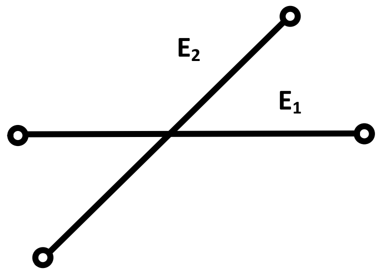

Figure 39: Compound of two edges

Example 2: Self-interfered Edge

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

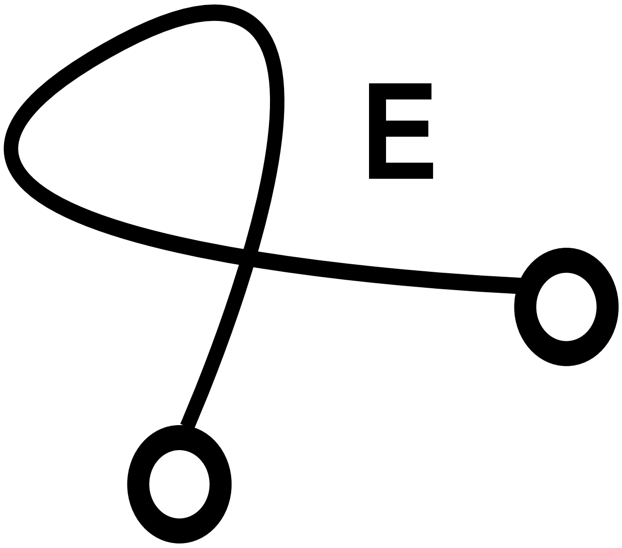

Figure 40: Self-interfered Edge

Example 3: Self-interfered Face

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

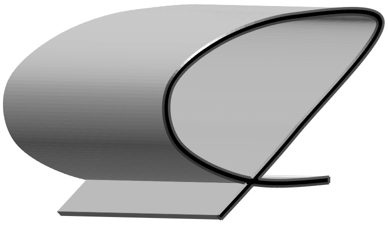

Figure 41: Self-interfered Face

Example 4: Face of Revolution

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

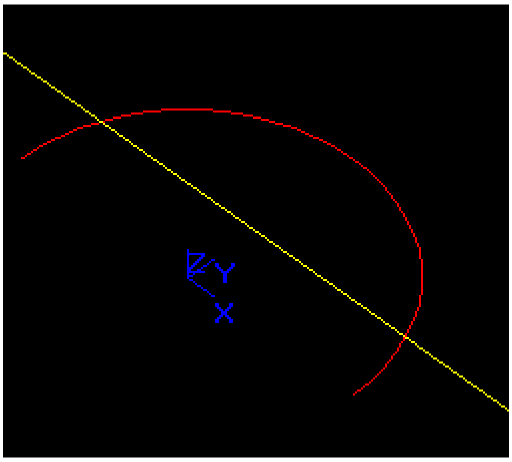

Figure 42: Face of Revolution: Arguments

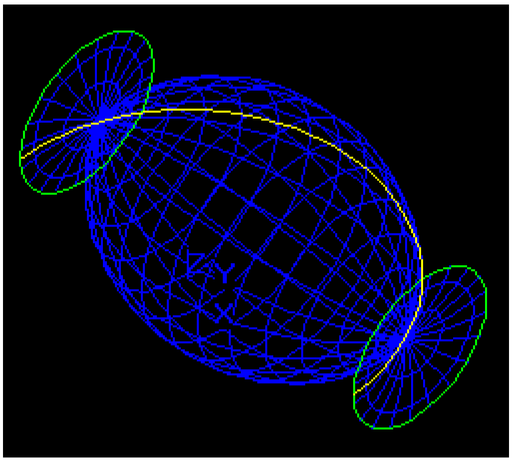

Figure 43: Face of Revolution: Result

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.

10.1.3 Self-interferences due to tolerances

Example 1: Non-closed Edge

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

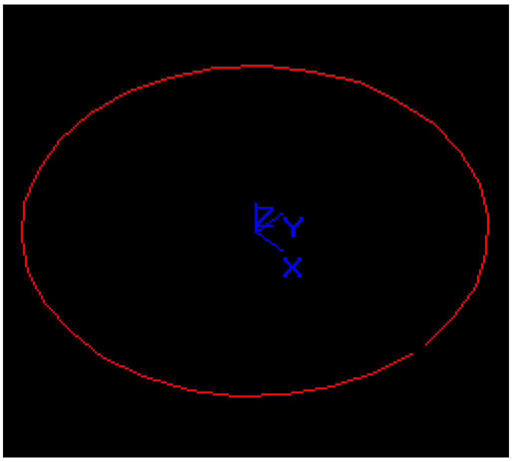

Figure 44: Edge based on a non-closed circle

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

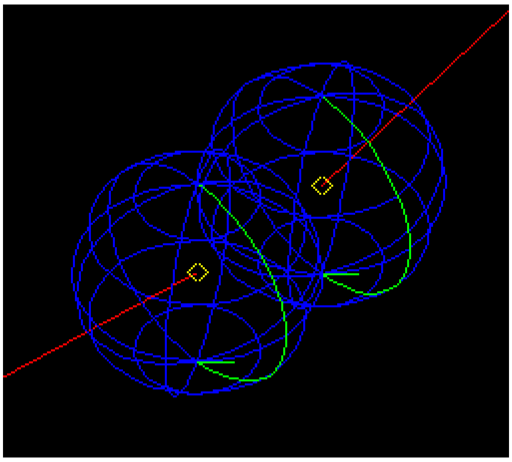

Figure 45: Distance and Tolerances

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.

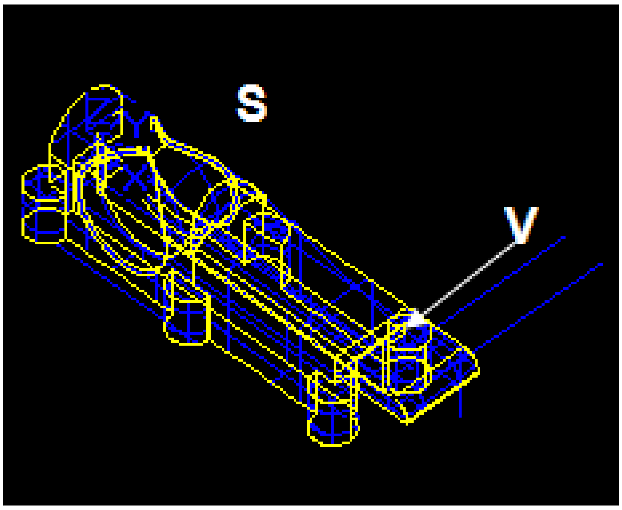

Figure 46: Solid containing an interfered vertex

The value of tolerance Tol(V)= 50.000075982061.

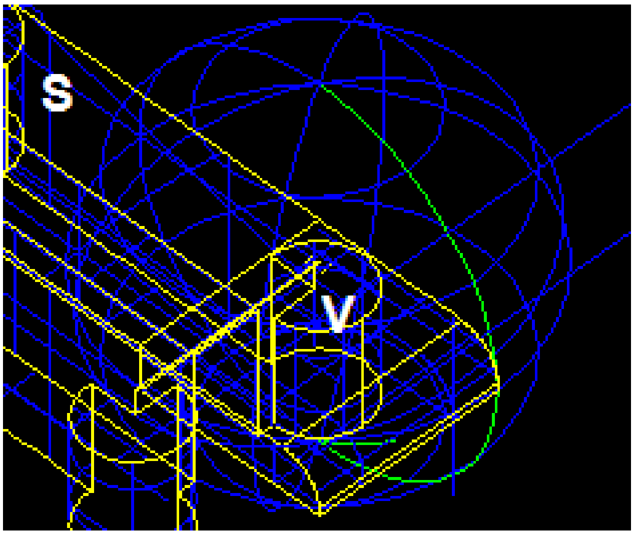

Figure 47: Tolerance

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.

10.1.4 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:

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

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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*.

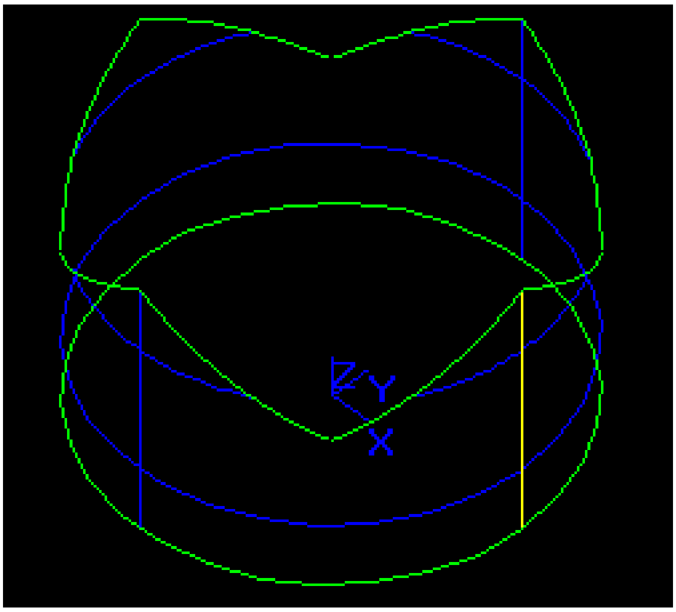

Figure 48: Face 1

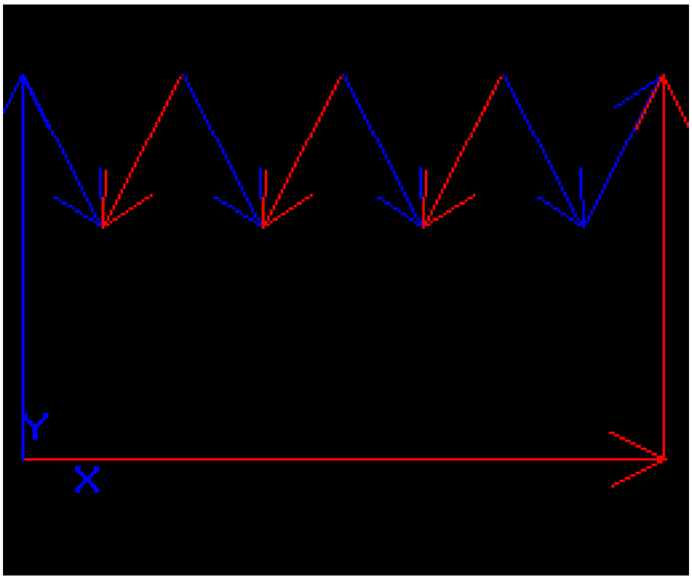

Figure 49: P-Curves for Face 1

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*).

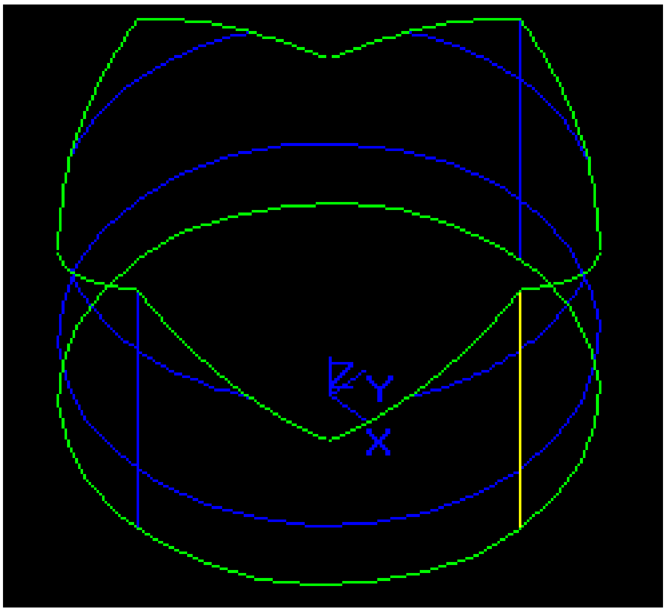

Figure 50: Face 2

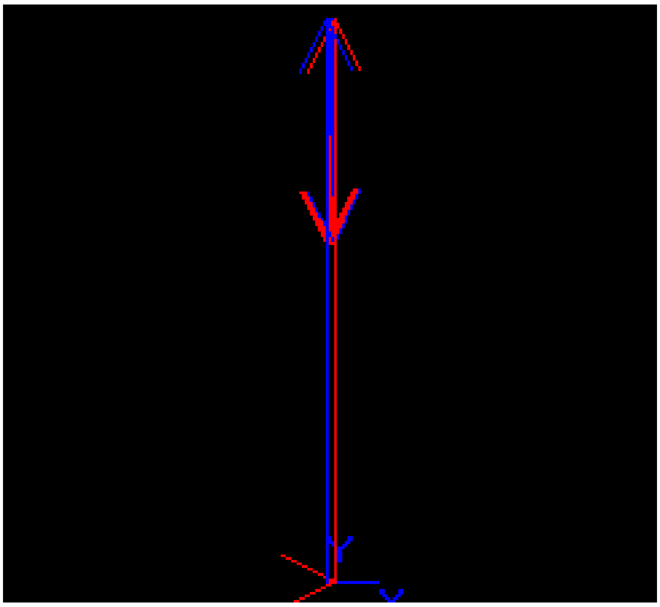

Figure 51: P-Curves for Face 2

Please, 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.

10.1.5 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:

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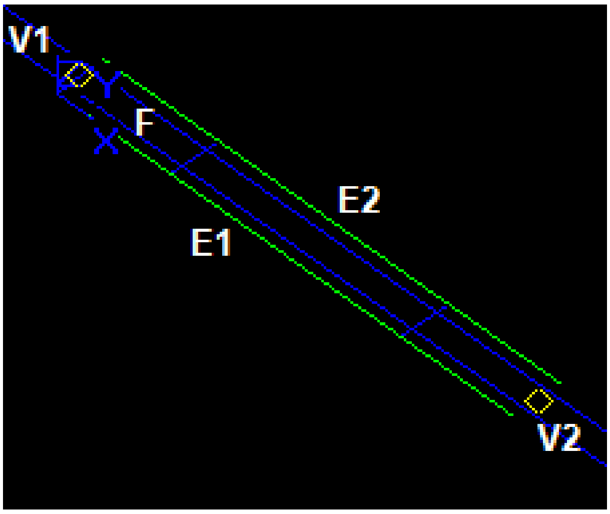

Figure 52: Example

- 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.

10.2 Intersection problems

10.2.1 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.*

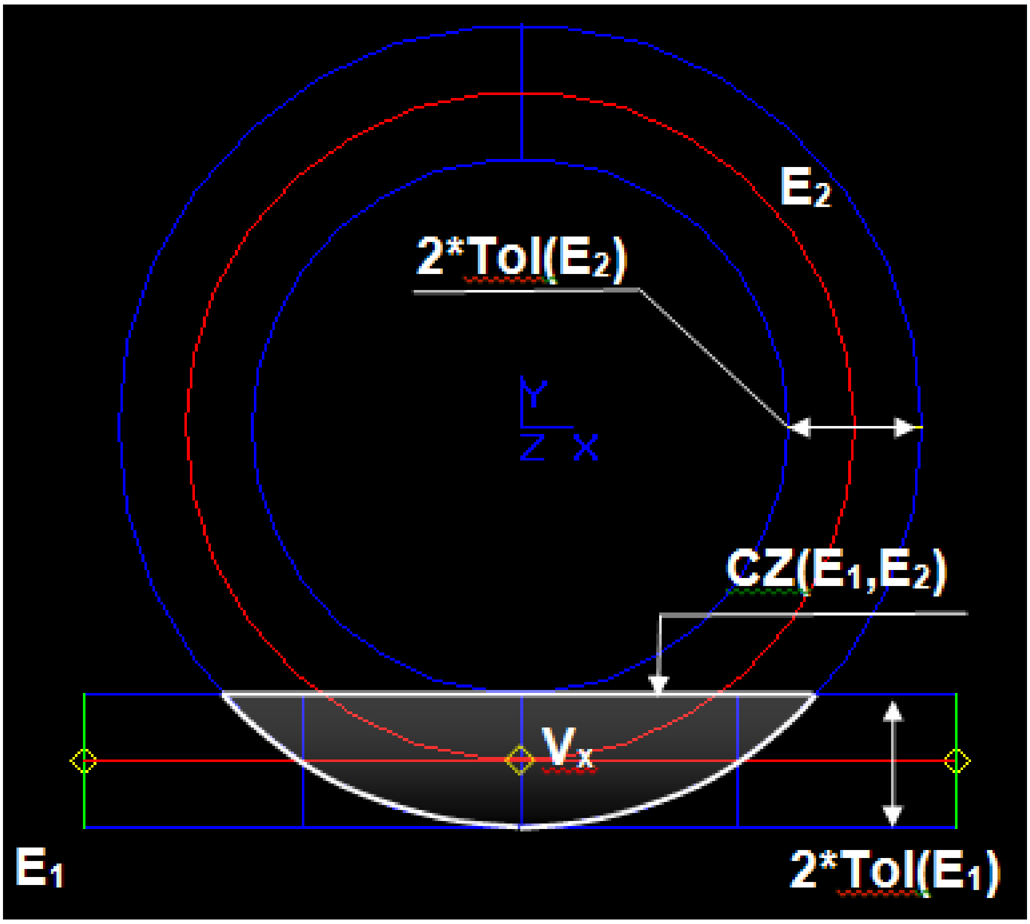

Figure 53: Intersecting Edges

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.

10.2.2 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.

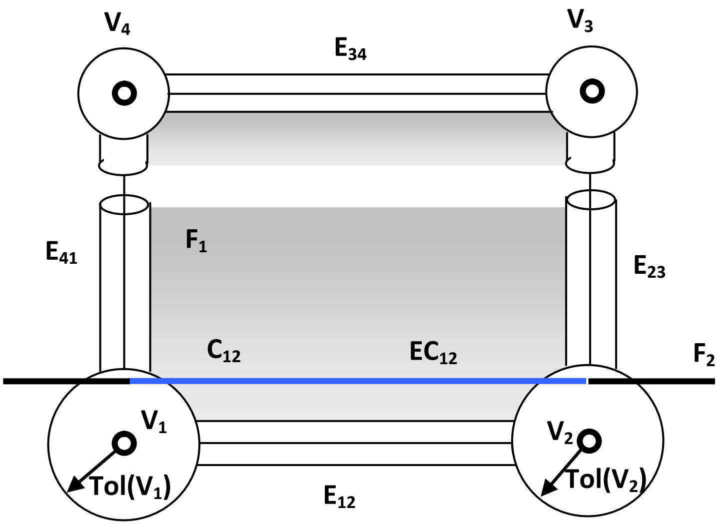

Figure 54: Intersecting Faces

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*$^{-6}$).

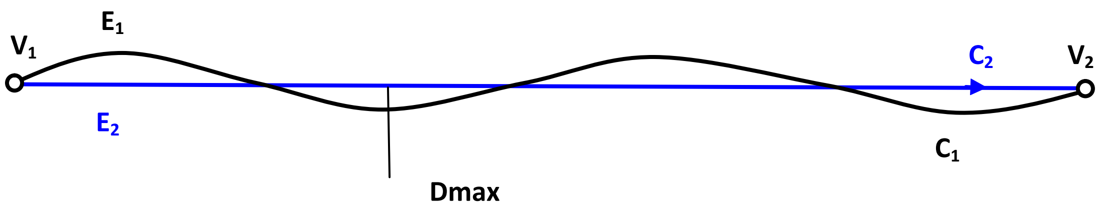

Figure 55: Intersecting Edges

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

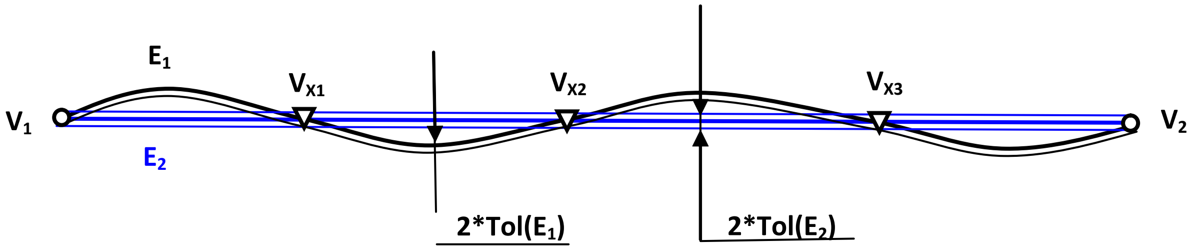

Figure 56: Result of Intersection

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).

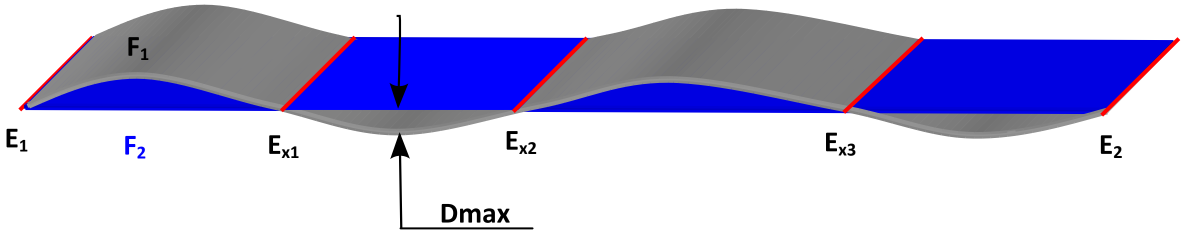

Figure 57: Intersecting Faces

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

10.2.3 Acquired Self-interferences

Example 1: Vertex and edge

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

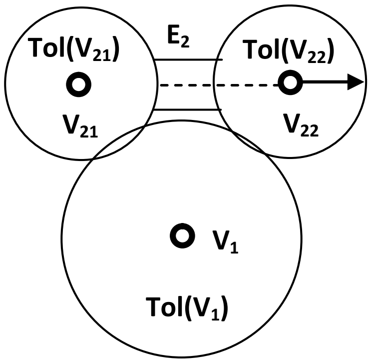

Figure 58: Vertex and Edge

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*.

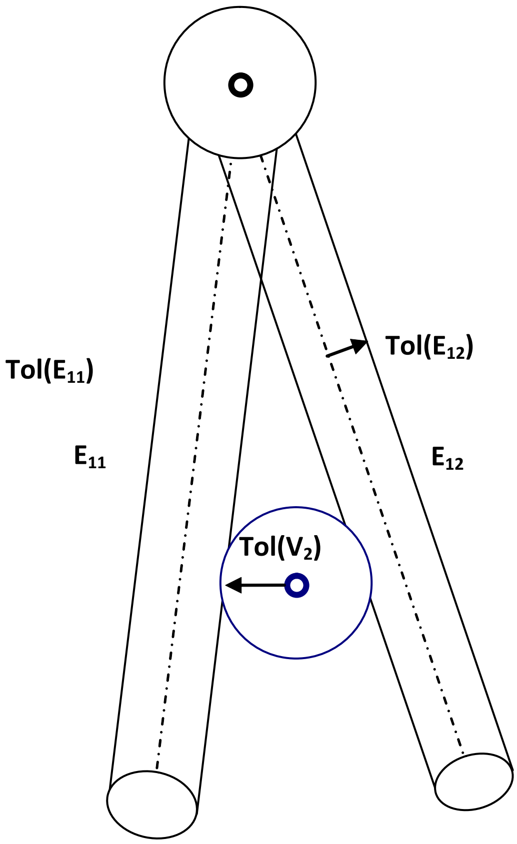

Figure 59: Vertex and Wire

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.

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11 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.

11.1 Fuzzy Boolean Operation

Fuzzy Boolean operation is the option of Basic Operations (GFA, BOA, PA and SA), in which additional user-specified tolerance is used. This option allows operators to handle robustly cases of touching and near-coincident, misalignment 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.

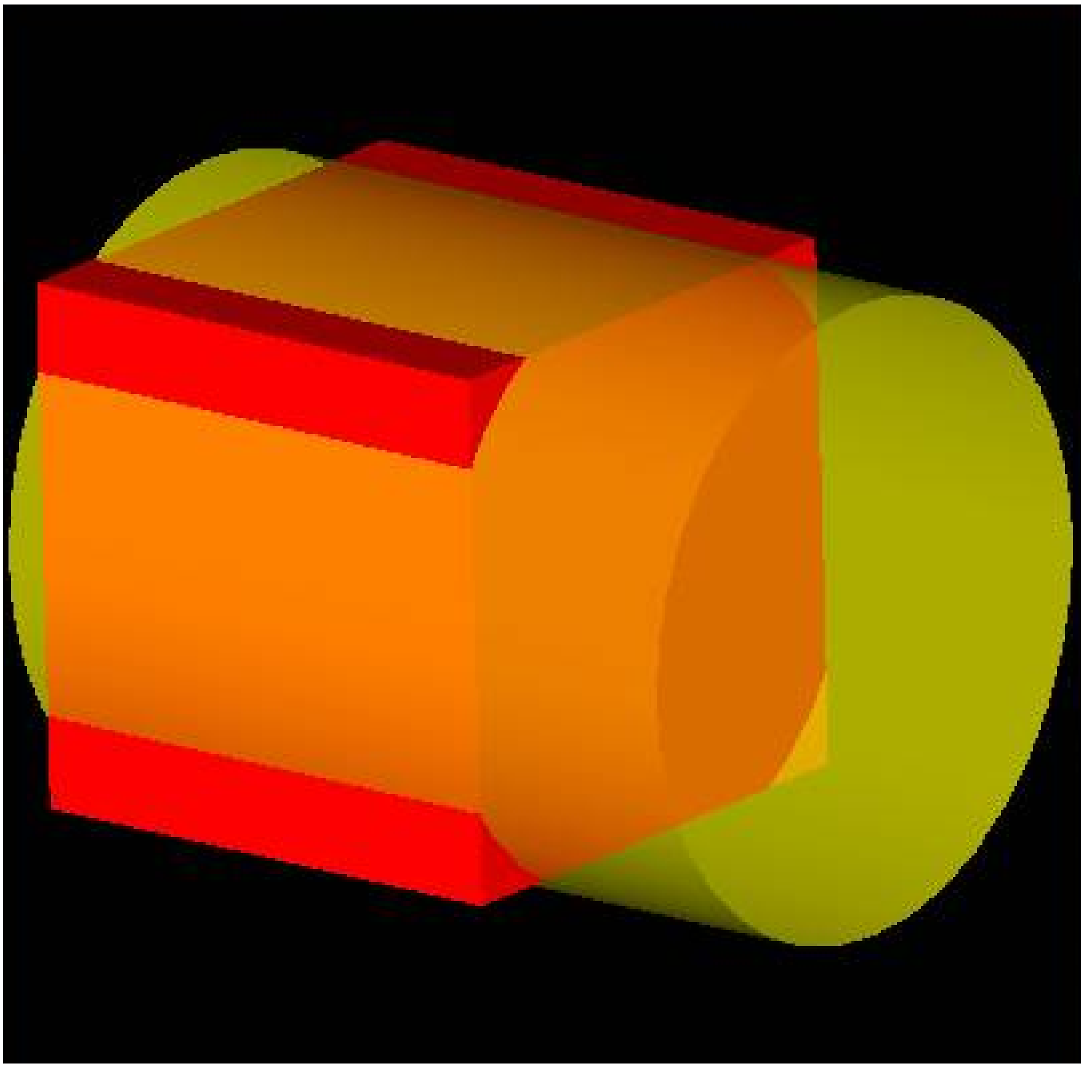
Fuzzy option is included in interface of Intersection Part (class *BOPAlgo_PaveFiller*) and application programming interface (class *BRepAlgoAPI_BooleanOperation*)

11.2 Examples

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

11.2.1 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 $5e^{-5}$:

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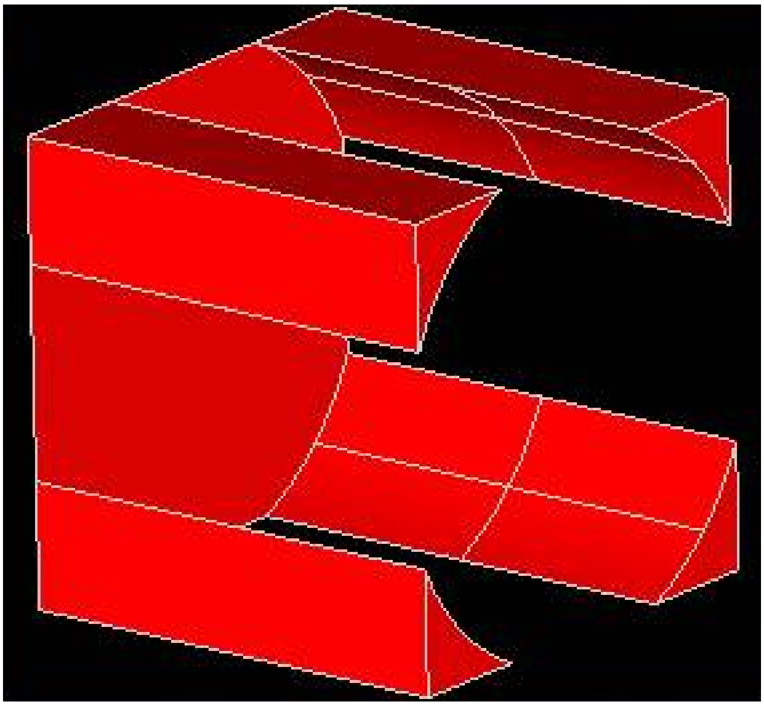


Figure 60: Result of CUT operation obtained with Basic Operations

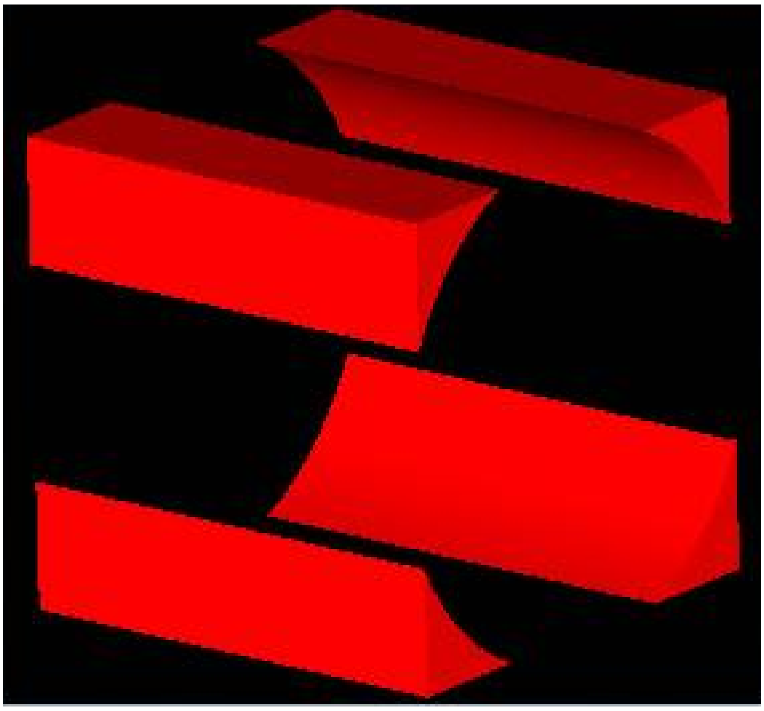
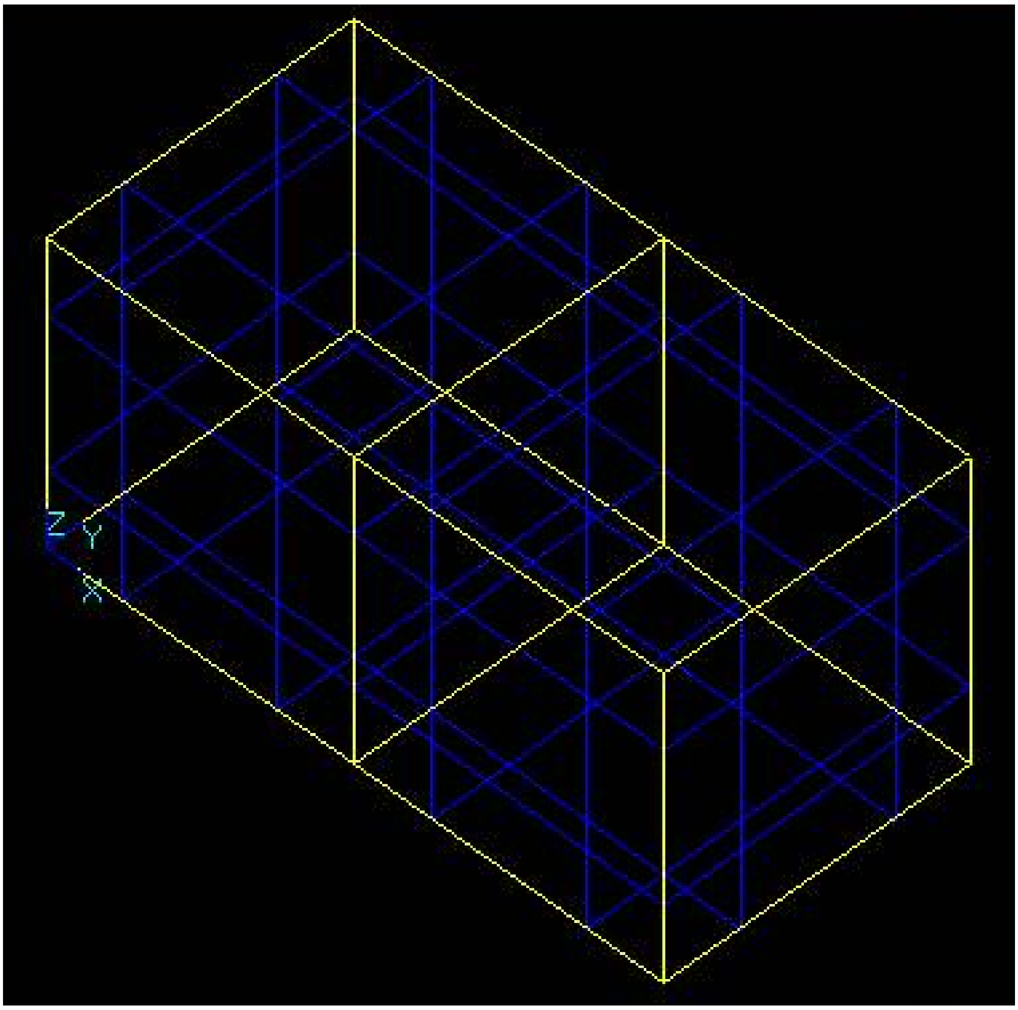


Figure 61: Result of CUT operation obtained with Fuzzy Option

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.

11.2.2 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} :

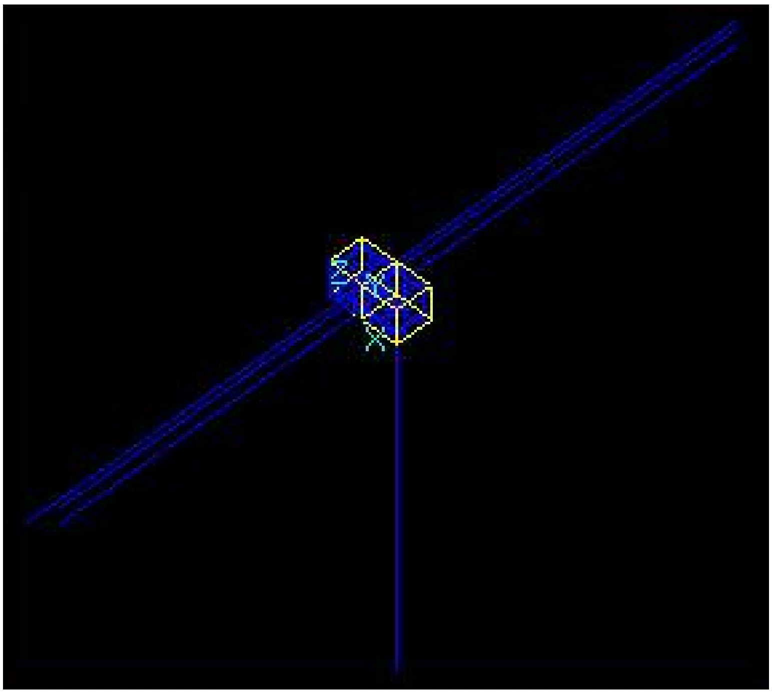


Figure 62: Result of CUT operation obtained with Basic Operations

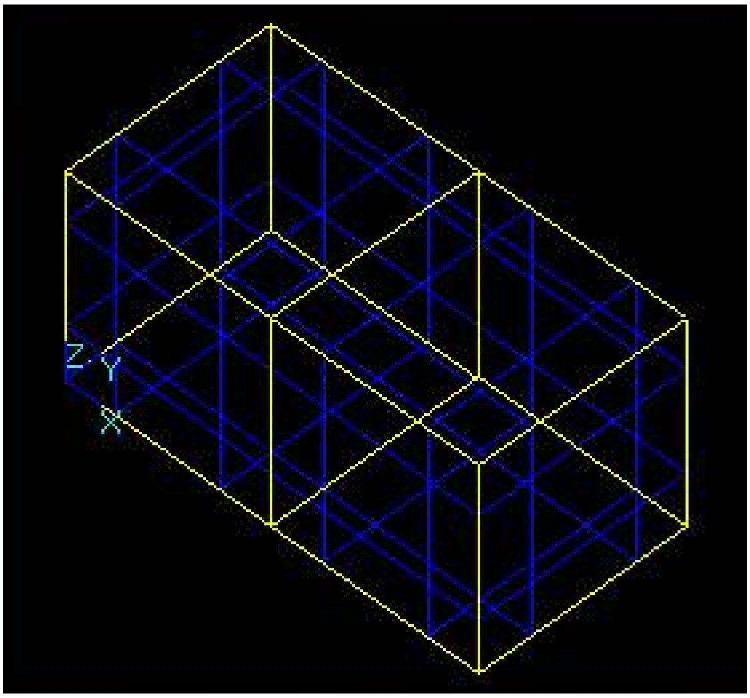
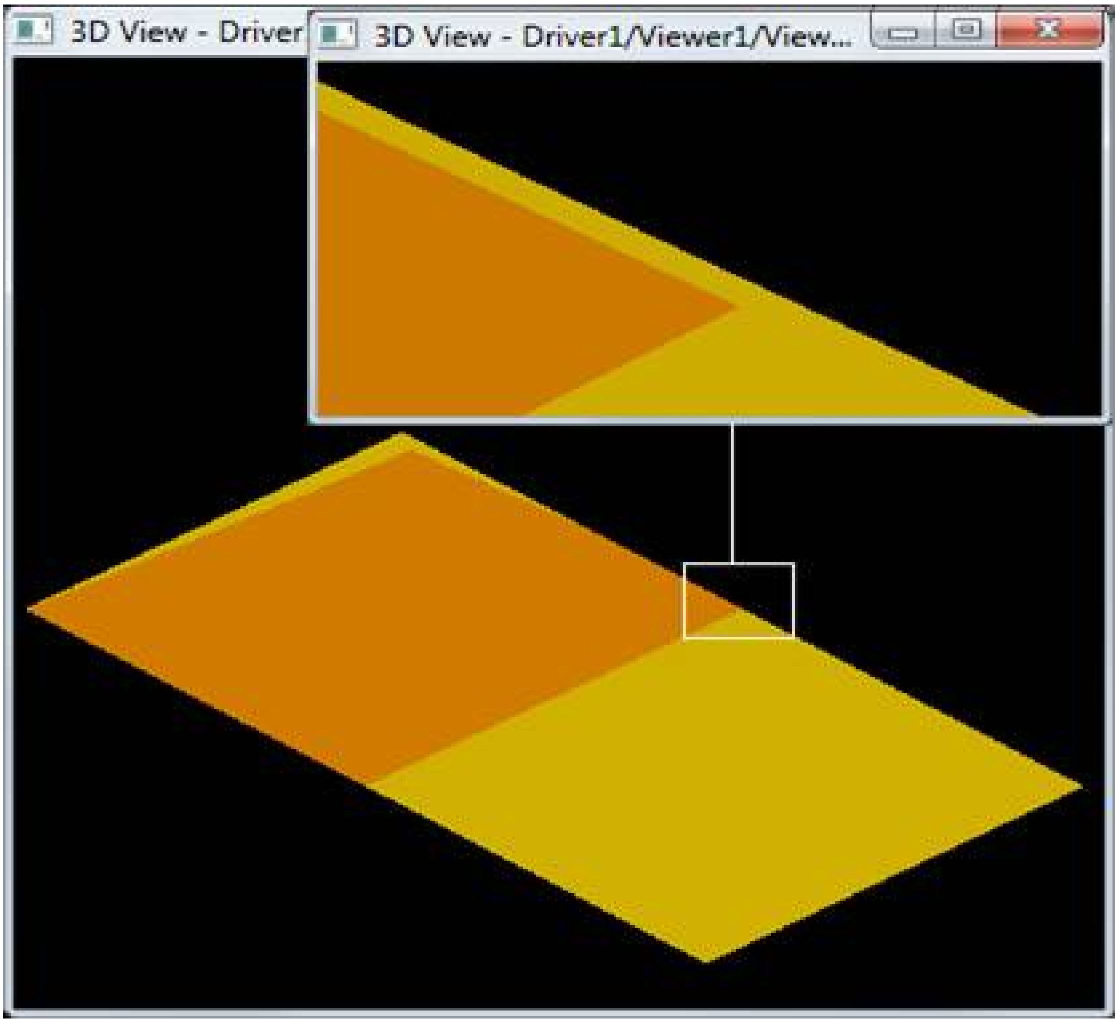


Figure 63: Result of CUT operation obtained with Fuzzy Option

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

11.2.3 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 $1e^{-5}$:

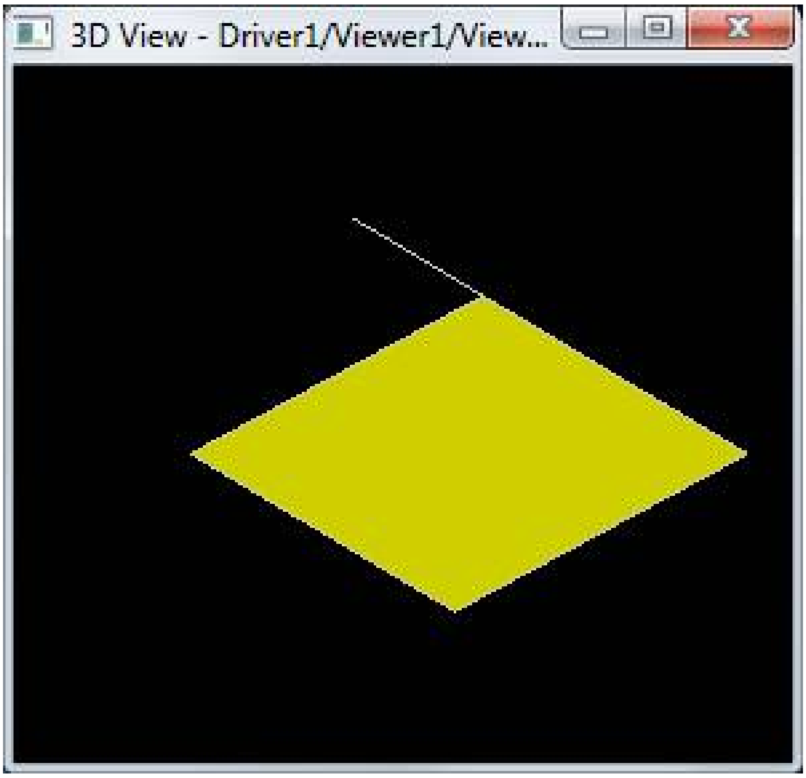


Figure 64: Result of CUT operation obtained with Basic Operations

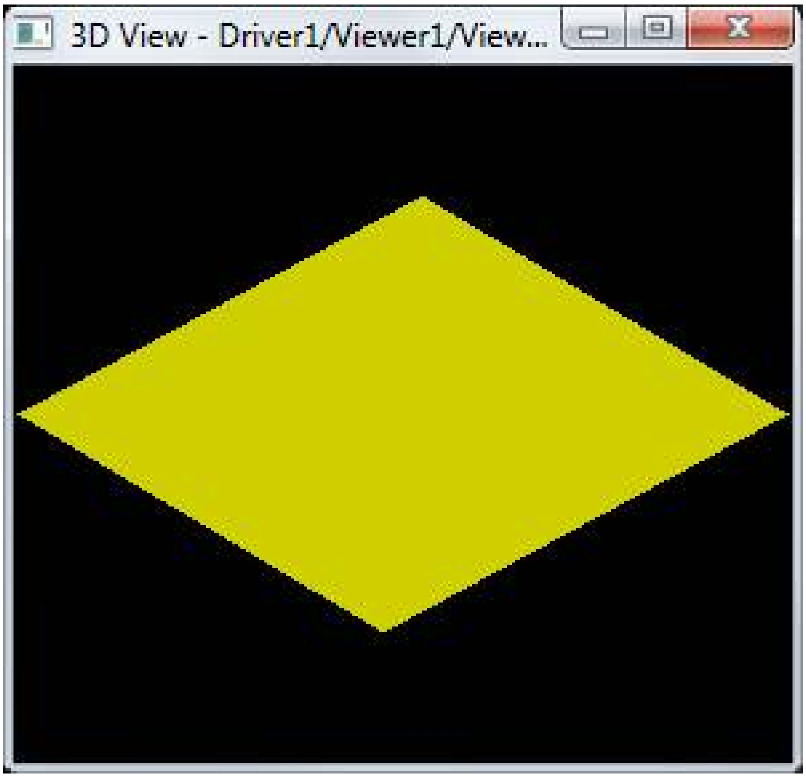
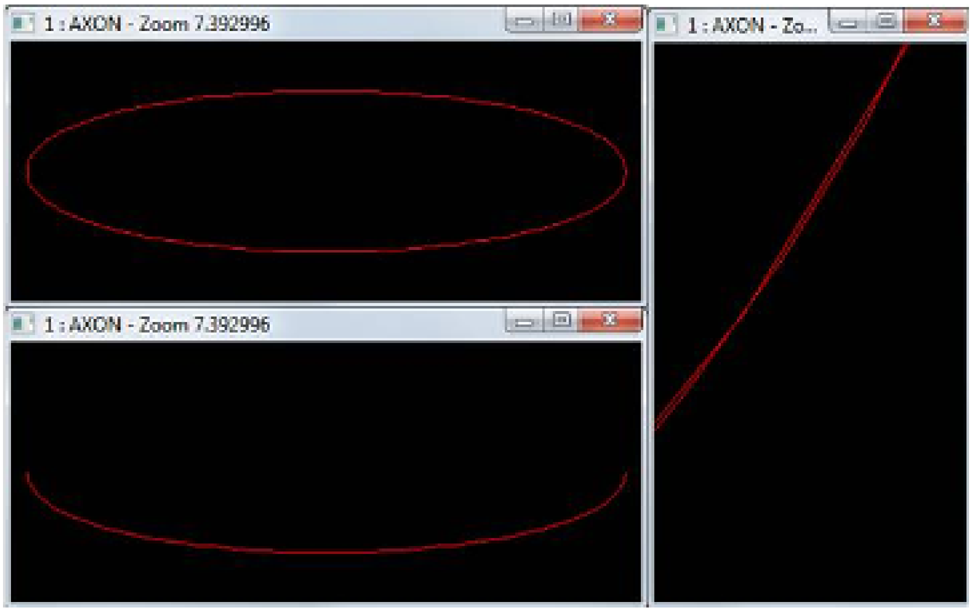


Figure 65: Result of CUT operation obtained with Fuzzy Option

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

11.2.4 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 $6e^{-5}$:

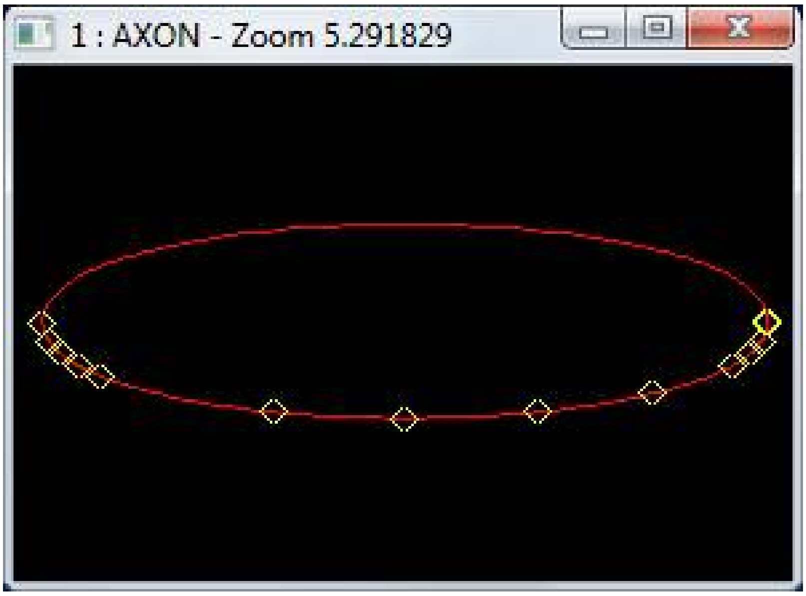


Figure 66: Result of CUT operation obtained with Basic Operations

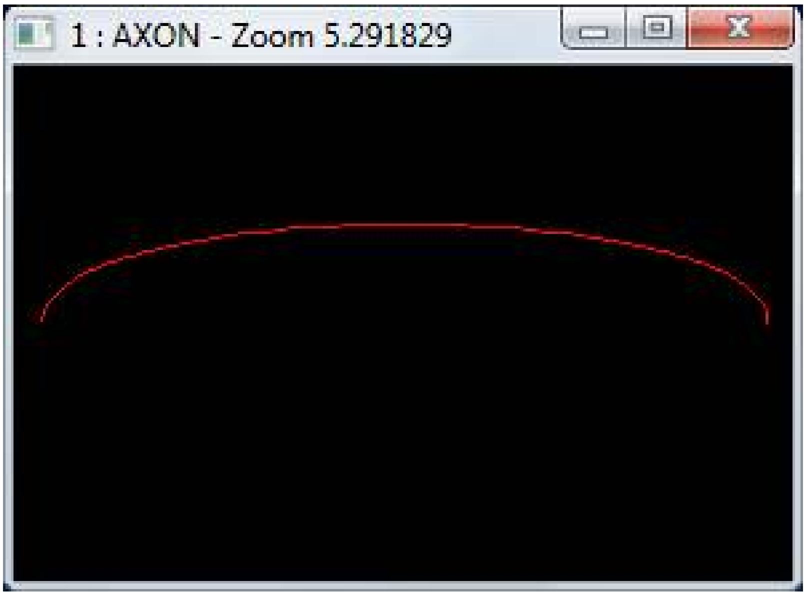


Figure 67: Result of CUT operation obtained with Fuzzy Option

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).

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12 Usage

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

12.1 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_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.

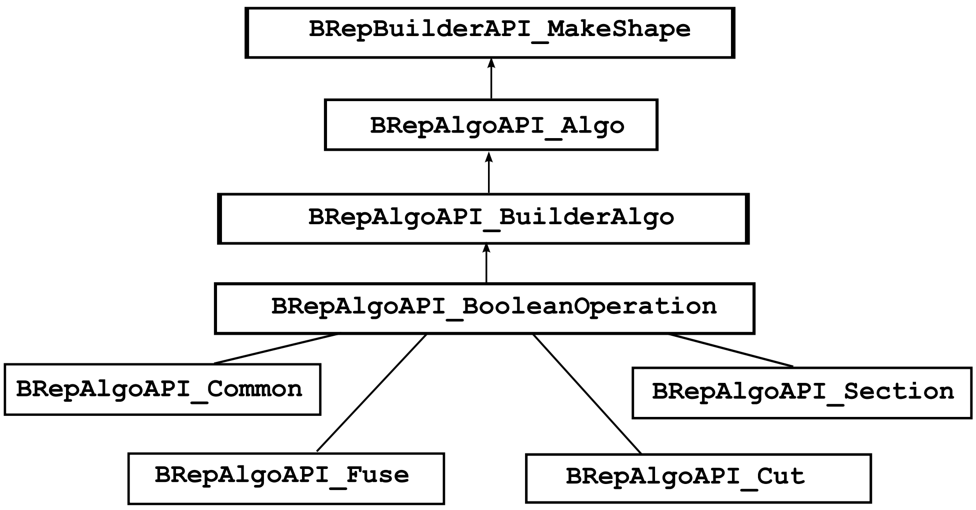

Figure 68: Diagram of BRepAlgoAPI package

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

12.2 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;
- *bapibop* – for Boolean Operator and Section Operator.

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

12.2.1 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>
 {...
  Standard_Boolean bRunParallel;
  Standard_Integer iErr;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_BuilderAlgo aBuilder;
  //
  // prepare the arguments
  TopTools_ListOfShape& aLS=...;
  //
  bRunParallel=Standard_True;
  aFuzzyValue=2.1e-5;
  //
  // set the arguments
  aBuilder.SetArguments(aLS);
  // set parallel processing mode
  // if  bRunParallel= Standard_True :  the parallel processing is switched on
  // if  bRunParallel= Standard_False :  the parallel processing is switched off
  aBuilder.SetRunParallel(bRunParallel);
  //
  // set Fuzzy value
  // if aFuzzyValue=0.: the Fuzzy option is off
  //  if aFuzzyValue>0.: the Fuzzy option is on
  aBuilder.SetFuzzyValue(aFuzzyValue);
  //
  // run the algorithm
  aBuilder.Build();
  iErr=aBuilder.ErrorStatus();
  if (iErr) {
    // 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 parallel processing mode
# 1:  the parallel processing is switched on
# 0:  the parallel processing is switched off
brunparallel 1
# set Fuzzy value
# 0.    : the Fuzzy option is off
# >0. : the Fuzzy option is on
bfuzzyvalue 0.
#
# run the algorithm
# r is the result of the operation
bapibuild r
```

12.2.2 Case 2. 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_Integer iErr;
  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 parallel processing mode
  // if  bRunParallel= Standard_True :  the parallel processing is switched on
  // if  bRunParallel= Standard_False :  the parallel processing is switched off
  aBuilder.SetRunParallel(bRunParallel);
  //
  // set Fuzzy value
  // if aFuzzyValue=0.: the Fuzzy option is off
  //  if aFuzzyValue>0.: the Fuzzy option is on
  aBuilder.SetFuzzyValue(aFuzzyValue);
  //
  // run the algorithm
  aBuilder.Build();
  iErr=aBuilder.ErrorStatus();
  if (iErr) {
    // 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 parallel processing mode
# 1:  the parallel processing is switched on
# 0:  the parallel processing is switched off
brunparallel 1
#
# set Fuzzy value
# 0.    : the Fuzzy option is off
# >0. : the Fuzzy option is on
bfuzzyvalue 0.
#
# run the algorithm
# r is the result of the operation
# 0 means Common operation
bapibop r 0
```

12.2.3 Case 3. 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_Integer iErr;
  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 parallel processing mode
  // if  bRunParallel= Standard_True :  the parallel processing is switched on
  // if  bRunParallel= Standard_False :  the parallel processing is switched off
  aBuilder.SetRunParallel(bRunParallel);
  //
  // set Fuzzy value
  // if aFuzzyValue=0.: the Fuzzy option is off
  //  if aFuzzyValue>0.: the Fuzzy option is on
  aBuilder.SetFuzzyValue(aFuzzyValue);
  //
  // run the algorithm
  aBuilder.Build();
  iErr=aBuilder.ErrorStatus();
  if (iErr) {
    // 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 parallel processing mode
# 1:  the parallel processing is switched on
# 0:  the parallel processing is switched off
brunparallel 1
#
# set Fuzzy value
# 0.     : the Fuzzy option is off
# >0. : the Fuzzy option is on
bfuzzyvalue 0.
#
# run the algorithm
# r is the result of the operation
# 1 means Fuse operation
bapibop r 1
```

12.2.4 Case 4. 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_Integer iErr;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_Cut aBuilder;
```

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```
  // 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 parallel processing mode
  // if  bRunParallel= Standard_True :  the parallel processing is switched on
  // if  bRunParallel= Standard_False :  the parallel processing is switched off
  aBuilder.SetRunParallel(bRunParallel);
  //
  // set Fuzzy value
  // if aFuzzyValue=0.: the Fuzzy option is off
  //  if aFuzzyValue>0.: the Fuzzy option is on
  aBuilder.SetFuzzyValue(aFuzzyValue);
  //
  // run the algorithm
  aBuilder.Build();
  iErr=aBuilder.ErrorStatus();
  if (iErr) {
    // 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 parallel processing mode
# 1:  the parallel processing is switched on
# 0:  the parallel processing is switched off
brunparallel 1
#
# set Fuzzy value
# 0.    : the Fuzzy option is off
# >0. : the Fuzzy option is on
bfuzzyvalue 0.
#
# run the algorithm
# r is the result of the operation
# 2 means Cut operation
bapibop r 2
```

12.2.5 Case 5. 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_Integer iErr;
  Standard_Real aFuzzyValue;
  BRepAlgoAPI_Section aBuilder;

  // perpare the arguments
  TopTools_ListOfShape& aLS=...;
```

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```
  TopTools_ListOfShape& aLT=...;
  //
  bRunParallel=Standard_True;
  aFuzzyValue=2.1e-5;
  //
  // set the arguments
  aBuilder.SetArguments(aLS);
  aBuilder.SetTools(aLT);
  //
  // set parallel processing mode
  // if  bRunParallel= Standard_True :  the parallel processing is switched on
  // if  bRunParallel= Standard_False :  the parallel processing is switched off
  aBuilder.SetRunParallel(bRunParallel);
  //
  // set Fuzzy value
  // if aFuzzyValue=0.: the Fuzzy option is off
  //  if aFuzzyValue>0.: the Fuzzy option is on
  aBuilder.SetFuzzyValue(aFuzzyValue);
  //
  // run the algorithm
  aBuilder.Build();
  iErr=aBuilder.ErrorStatus();
  if (iErr) {
    // 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 parallel processing mode
# 1:  the parallel processing is switched on
# 0:  the parallel processing is switched off
brunparallel 1
#
# set Fuzzy value
# 0.    : the Fuzzy option is off
# >0. : the Fuzzy option is on
bfuzzyvalue 0.
#
# run the algorithm
# r is the result of the operation
# 4 means Section operation
bapibop r 4
```