

Exercise 01: First Steps Using the VLFL-Toolbox for Solid Object Design

2014-11-17: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Creating and visualizing a simple base-contour by four 2D-points
- 2. Append a 3rd coordinate column to get a vertex list
- 3. Predefined functions for the generation of often used planar polygons (PL)
- 4. More predefined functions for planar polygons in 3D (VL)
- 5. Calculation of the surface of a convex polygon
- 6. Calculation of all surfaces of convex polygon-based 2.5D-solid-volumes
- 7. Graphical user interface for STL import, export, and viewing

1. Creating and visualizing a simple base-contour by four 2D-points

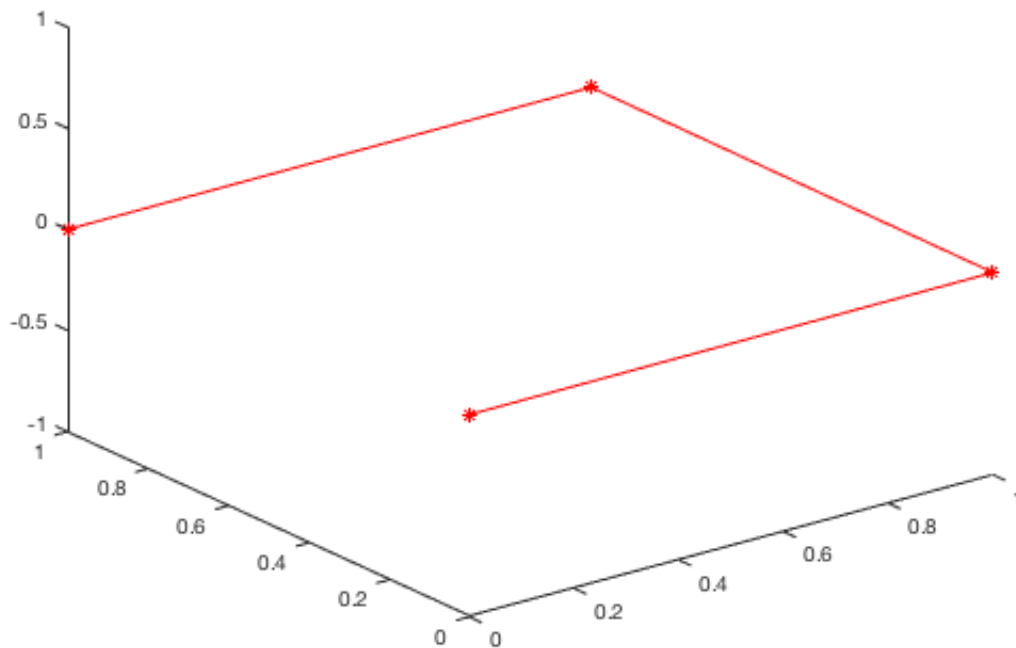
A point list is a nx2 array. The number n is the number of 2D coordinate points [x y]. In general, such a point list can be the basis for designing a boundary surface model. We start with some simple functions to display polygons:

- **PLplot** to plot in 3D a nx2 point list (PL).

```
PL=[ 0 0; 1 0; 1 1; 0 1]
PLplot(PL);
```

PL =

0	0
1	0
1	1
0	1



2. Append a 3rd coordinate column to get a vertex list

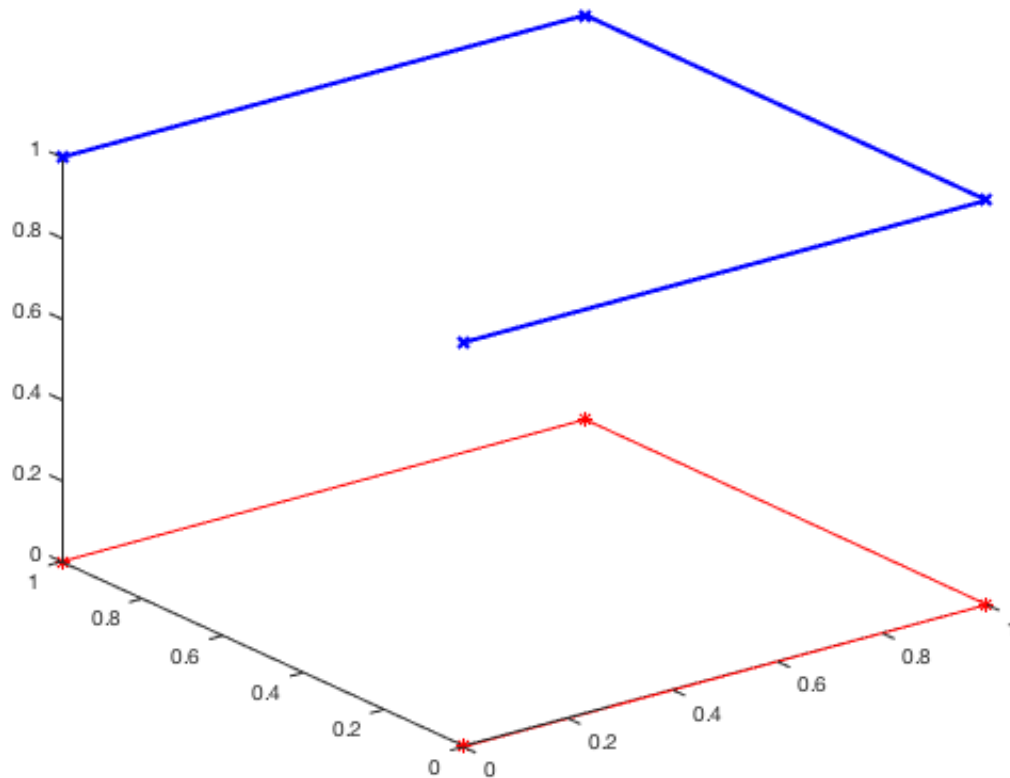
A vertex list is a nx3 array. The number n is the number of 3D coordinate points [x y z]. In fact, the point list can be transferred into a vertex list by appending a third column containing the z-coordinate such as zero or another z-coordinate.

- **VLaddz** for converting a point list (PL) into a vertex list (VL) by adding a 3rd column for the z-coordinate.
- **VLplot** for displaying in 3D a nx3 vertex list (VL).

```
VL=VLaddz(PL,1)
VLplot (VL,'bx-',2);
```

VL =

```
0    0    1
1    0    1
1    1    1
0    1    1
```

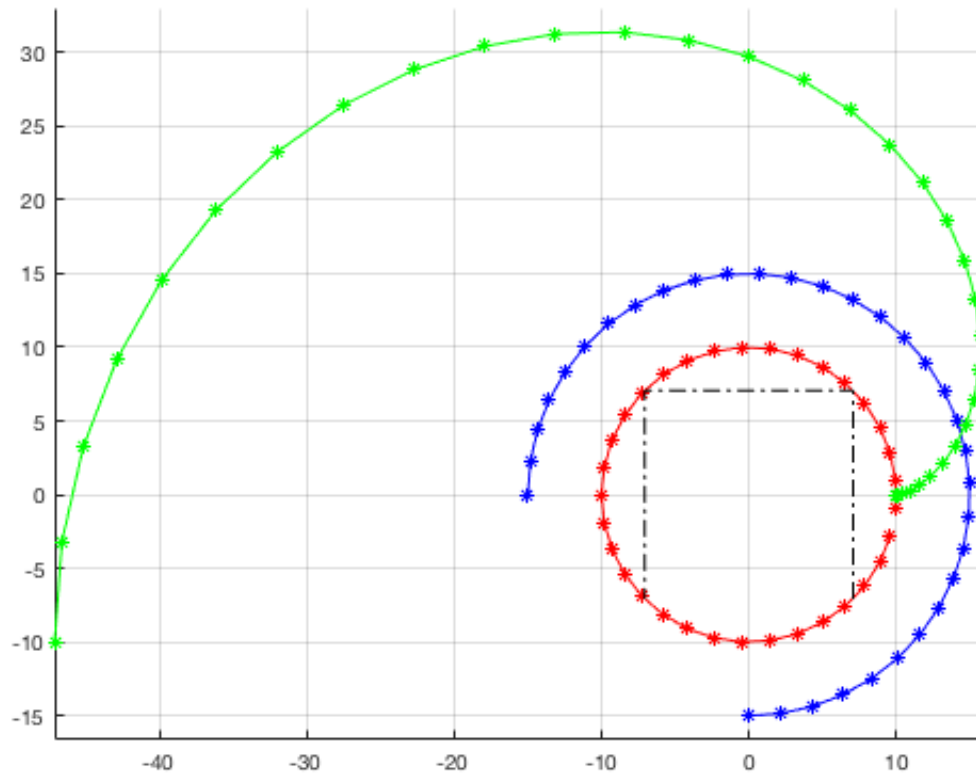


3. Predefined functions for the generation of often used planar polygons (PL)

For some often used contours, there are predefined functions that generate a nx2 coordinate point list (PL).

- **PLcircle** for a polygon with n points.
- **PLcircseg** for a circle segment with n points.
- **PLEvolvente** for an evolvente as contour.

```
close all;
PL=PLcircle (10,33); % Radius 10, 33 points
PLplot(PL); view (0,90); axis equal; grid on;
PL=PLcircle (10,4); % Radius 10, 4 points
PLplot(PL,'k-.'); view (0,90); axis equal; grid on;
PL=PLcircseg (15,33,-pi/2,+pi); % Radius 15, 33 points, 270 degree
PLplot(PL,'b-*'); view (0,90); axis equal; grid on;
PL=PLEvolvente (10,pi/180*270,33)'; % Radius 10, 33 points, 270 degree
PLplot(PL,'g-*'); view (0,90); axis equal; grid on;
```

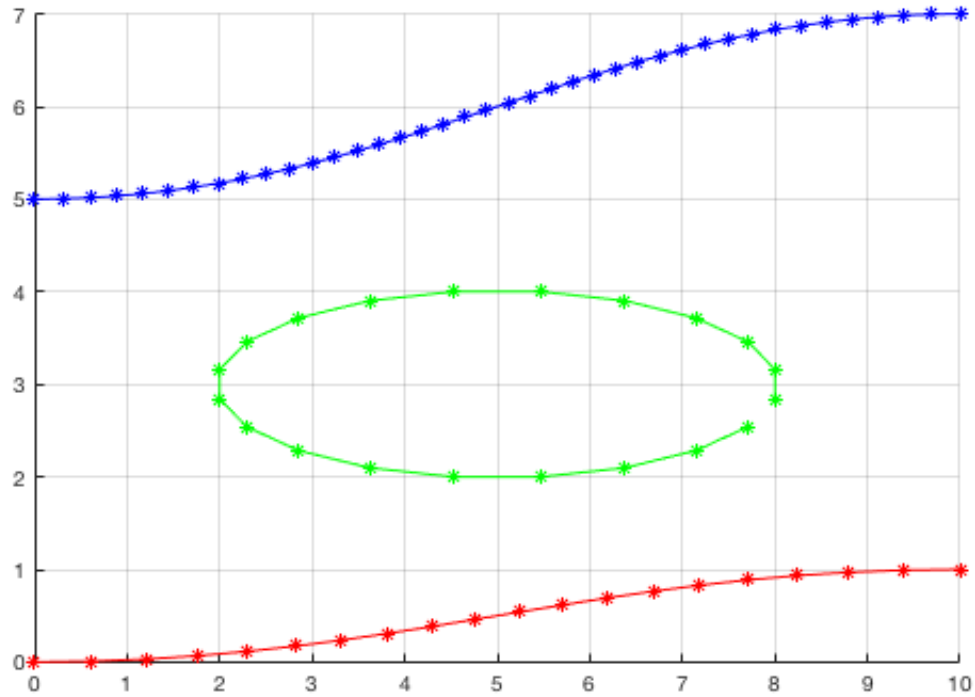


4. More predefined functions for planar polygons in 3D (VL)

Some functions for planar polygons create already 3D points (vertices) and the result of such a function is a vertex list (VL).

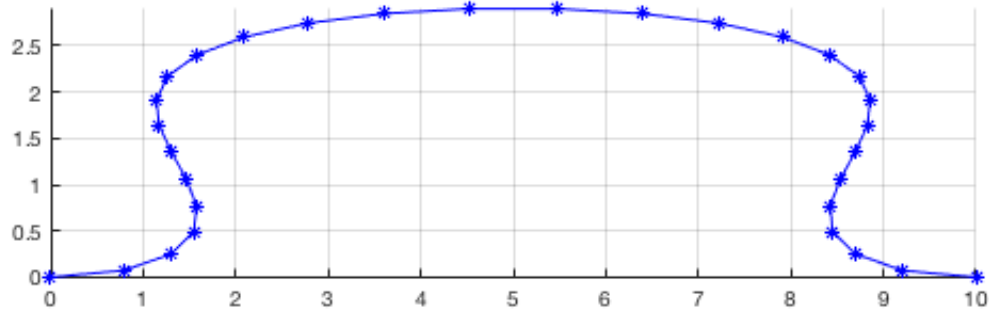
- **VLpolygon** to generate elliptic contours.
- **VLBezier4P** to generate a Bezier-curve using 4 points.
- **VLBezierC** to generate a Bezier-curve using as many points as possible.
- **VLremstraightCVL** to remove obsolete points on straight lines.

```
close all;
VL=VLpolygon(20,3,1,[5 3 0]);
VLplot (VL,'g*-'); show, axis equal, view (0,90); grid on; hold on;
VL=VLBezier4P([0 0 0],[4 0 0],[6 1 0],[10 1 0],20);
VLplot (VL,'r*-'); show, axis equal, view (0,90);
VL=VLBezierC([0 5; 4 5; 6 7; 10 7],40);
VLplot (VL,'b*-'); show, axis equal, view (0,90); grid on
```

- **VLBeziernoose** to generate a Bezier-curve spring-element.

```
close all;
VL=VLBeziernoose(10,2,3,3,30);
VLplot (VL,'b*-'); show, axis equal, view (0,90); grid on
```

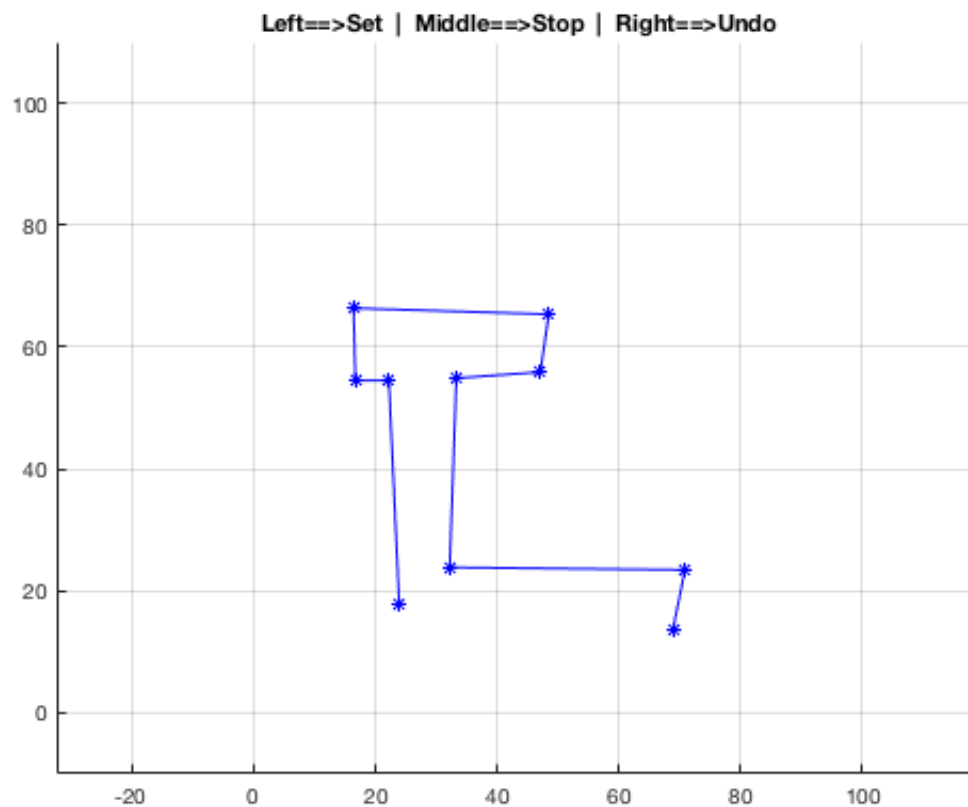


- **VLui** as an user interface to enter points by mouse clicks.

```
close all;
VL=VLui
VLplot (VL,'b*-'); show, axis equal, view (0,90); grid on
```

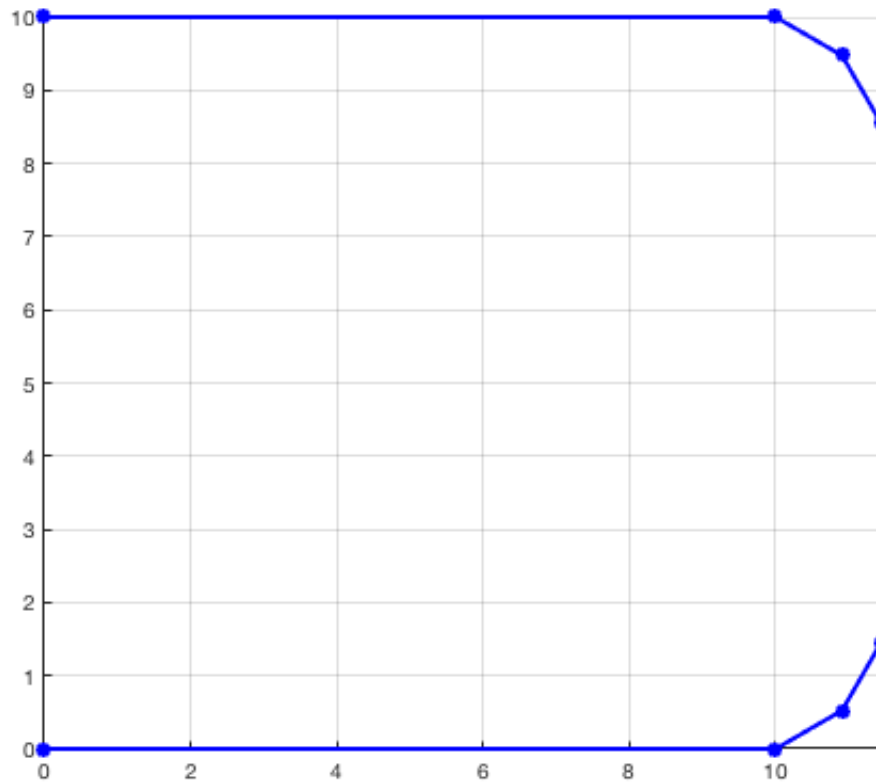
VL =

23.9000	17.8000	0
22.2000	54.5000	0
16.7000	54.5000	0
16.4000	66.4000	0
48.5000	65.4000	0
47.1000	55.9000	0
33.3000	54.9000	0
32.2000	23.8000	0
70.9000	23.4000	0
68.9000	13.6000	0
69.2000	13.6000	0



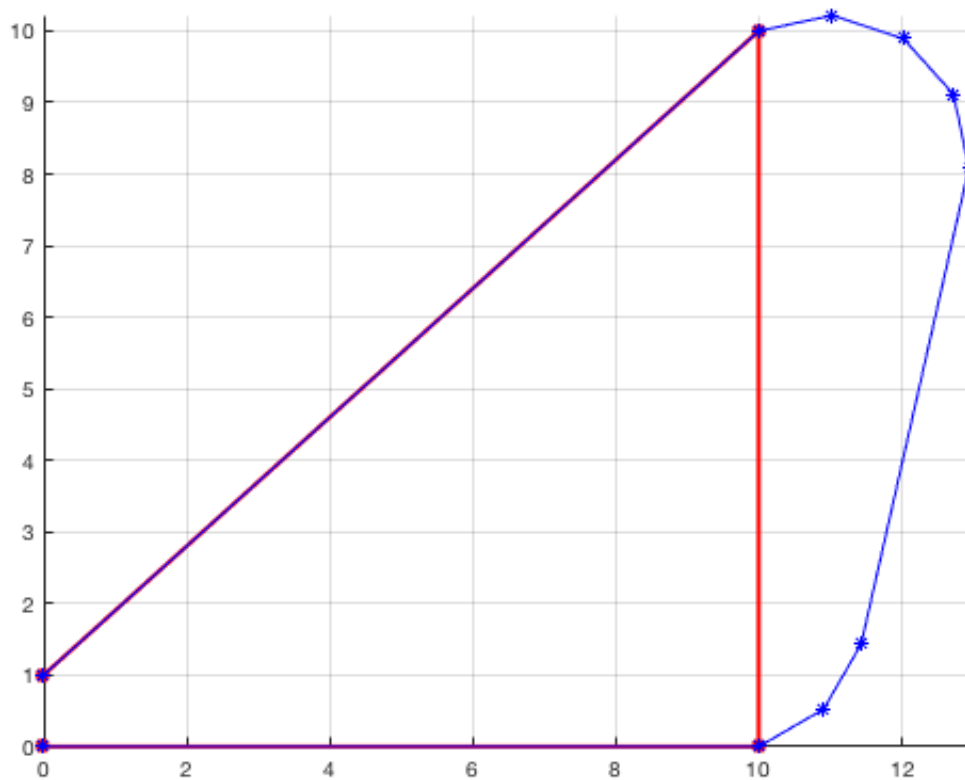
- **VLRadius4P** for inserting points to generate radial curves instead of corners.

```
close all
VL=VLRadius4P([0 0 0],[10 0 0], [10 10 0], [0 10 0], pi/6, 2);
VL=VLremstraightCVL (VL);
VLplot (VL,'b*-',2); show, axis equal, view (0,90); grid on
```



- **VLRadiusC** for inserting points to generate radial curves instead of corners.

```
close all
VLORG=[[0 0 0];[10 0 0];[10 10 0];[0 1 0]];
VLplot (VLORG,'r*-',2); show, axis equal, view (0,90); grid on; hold on
VL=VLRadiusC(VLORG, pi/6, 2);
VL=VLremstraightCVL (VL);
VLplot (VL,'b*-',1); show, axis equal, view (0,90); grid on
```



5. Calculation of the surface of a convex polygon

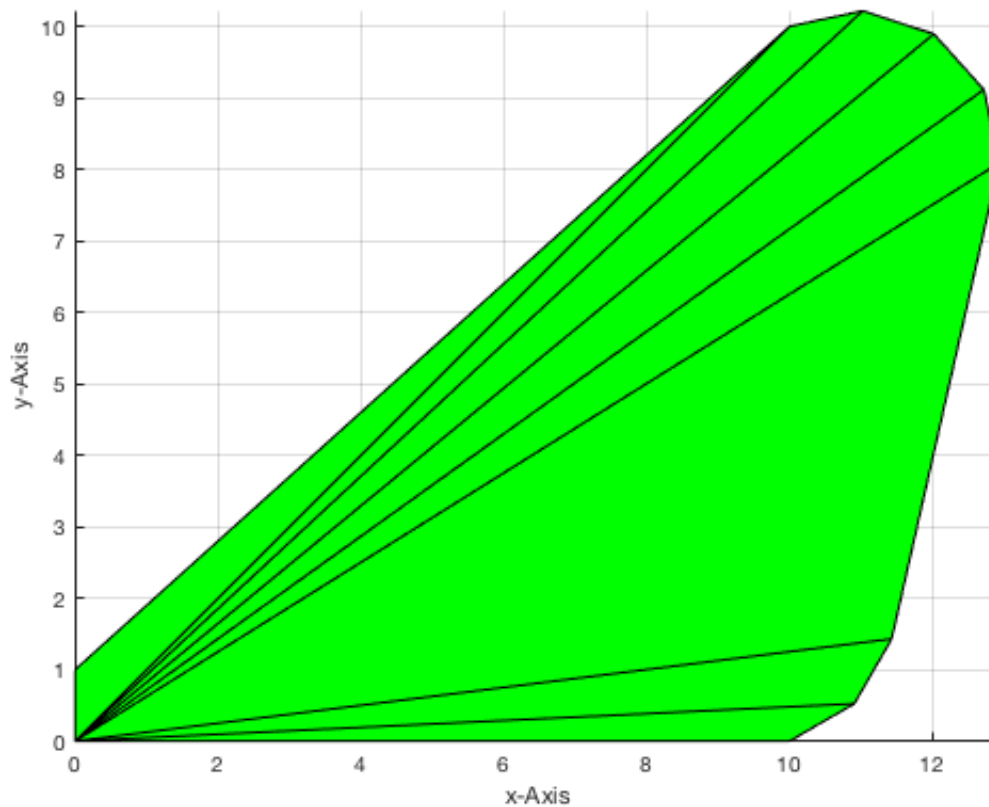
If we have a closed convex polygon, it is possible to generate a surface description by a facet list (FL) describing triangle facets. This is called tessellation of the closed polygon/surface. For closed convex polygons, the simplest form are facets from the 1st to the 2nd and 3rd points [1 2 3], then from the 1st to the 3rd and 4th [1 3 4], and so on. The facet list (FL) is therefore a nx3 index list to the point list or vertex list (VL). To use this concept we have some basic functions. For non convex functions we see later some more solutions.

- **FLoFVL** to generate the facet list (FL) for a **convex** polygon.
- **VLFLplot** to plot a surface given by a vertex list (VL) and a facet list (FL).

```
close all
FL=FLoFVL(VL)
% FL=FLoFCVL(VL)
VLFLplot (VL,FL,'g'); axis equal; view (0,90); grid on
% view (-30,30);
```

FL =

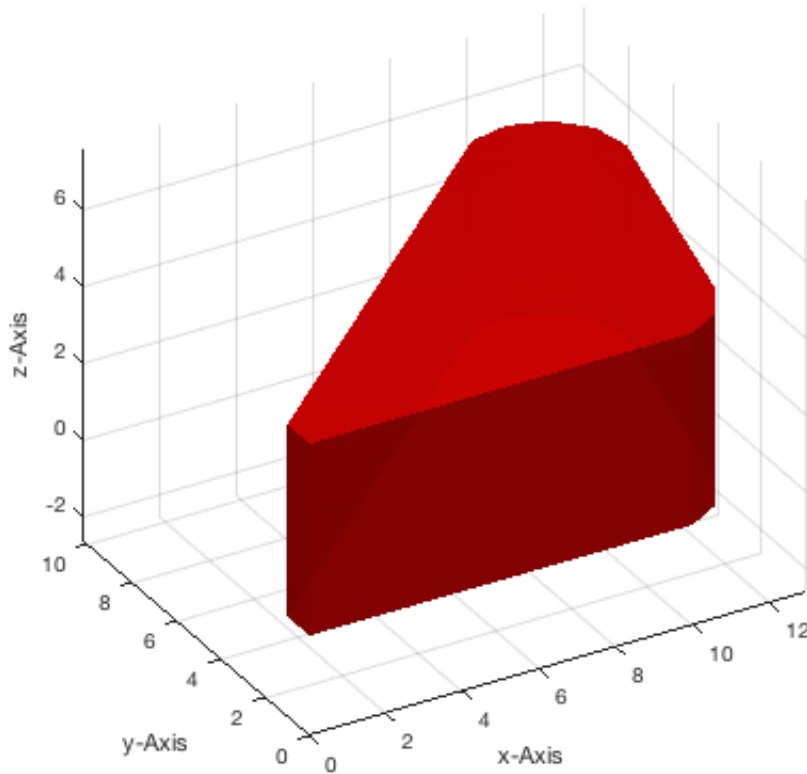
1	2	3
1	3	4
1	4	5
1	5	6
1	6	7
1	7	8
1	8	9
1	9	10



6. Calculation of all surfaces of convex polygon-based 2.5D-solid-volumes

- **VLFLofPLz** to extrude a convex polygon to a solid volume.
- **VLFLplotlight** to adjust the rendering parameter of the current graphic.

```
close all
[VL,FL]=VLFLofPLz (VL(:,1:2),5);
VLFLplot (VL,FL); axis equal; view (-30,30); grid on
VLFLplotlight(1,0.9); show;
```

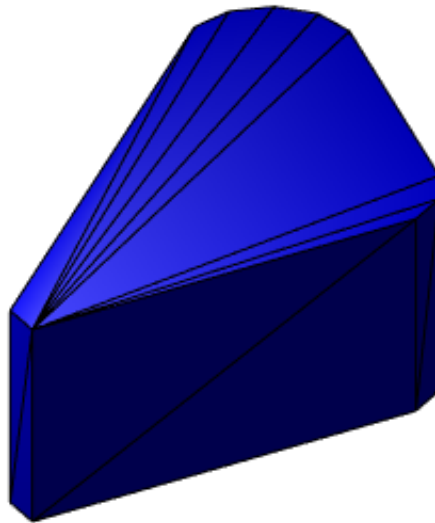


7. Graphical user interface for STL import, export, and viewing

Currently tested only for OSX (Apple Macintosh), there is also a graphical user interface available for displaying the surface objects, to import STL-Files and to export STL-Files. In this example, the tool is just introduced, to explain the capabilities to implement also graphical design tools for solid object modeling.

- **VLFLviewer** to show surface models, to import and to export STL-Files.

```
VLFLviewer (VL,FL,'b'); view (-30,30);
```

'VLFLviewer' : 27-Feb-2017 16:40:24**VLFLlicense**

```
% * Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-18
% * Tim Lueth, executed and published on 64 Bit PC using Windows with Matlab 2014b on 2014-11-18
```

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:40:26 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
map_toolbox
matlab
simulink
=====
=====
```

Published with MATLAB® R2016b

Exercise 02: Using the VLFL-Toolbox for STL-File Export and Import

2014-11-18: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Import and export of STL-files in ASCII format and binary format
- 3. Checking surface volume data and STL-files
- 4. Generation of text, numbers, characters and formulas as solid volume
- 5. Turning and mirroring of solids by manipulating the vertex lists (VL)
- 6. Spatial transformation of solids by manipulating the vertex lists (VL)
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In Experiment 1 we've learned about

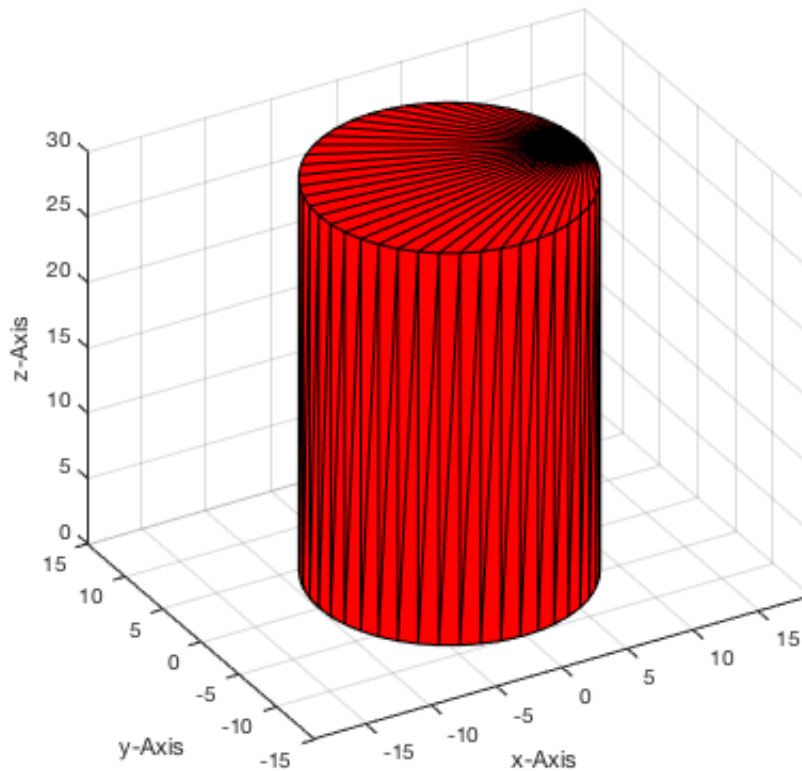
- Point lists (PL) as nx2 coordinate arrays that could be closed to contours.
- Vertex lists (VL) as nx3 coordinate arrays that could be closed to contours.
- Facet lists (FL) as nx3 index arrays that describe triangle facets of a surface.
- Functions for the interactive input of vertex lists.
- Functions for displaying PL and VL in 3D in different color and transparency.
- Functions for generating Bezier-curves or circular-curves.
- Functions for extruding solid volumes based on a closed convex contour.

2. Import and export of STL-files in ASCII format and binary format

Often it is useful to import surface data to solid volumes from STL-Files generated by other programs such as CATIA, ProEngineer, Solidworks etc. On the other hand we want to export our data for documentation, 3D-printing or the exchange with other users. The STL-File format is the most common file format for surface models. It supports ascii-text-format and binary formatted files. For export and import we need a couple of functions:

- **VLFLwriteSTL** for writing STL-files in ascii file format.
- **VLFLwriteSTLb** for writing STL-files in binary file format.

```
close all;  
PL=PLcircle(10);  
[VL,FL]=VLFLofPLz (PL,30);  
VLFLplot(VL,FL); view (-30,30); grid on;
```



```
VLFLwriteSTL(VL,FL,'STL-ASCII','by My Name');
VLFLwriteSTLb(VL,FL,'STL-BINAR','by My Name');
```

```
WRITING STL FILE /Users/timlueth/Desktop/STL-ASCII.STL in ASCII MODE
completed.
```

```
WRITING STL (90 vertices, 176 facets) FILE /Users/timlueth/Desktop/STL-BINAR.STL in BINARY
MODE
completed.
```

Similar it is possible to read the files in again

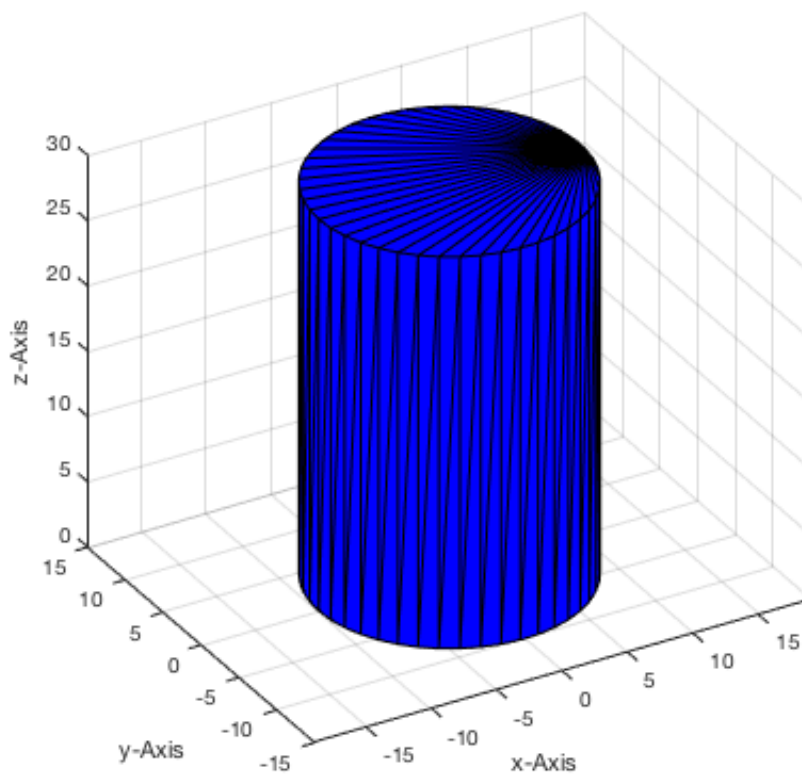
- **VLFLreadSTL** for importing STL-files in ascii file format.
- **VLFLreadSTLb** for importing STL-files in binary file format.

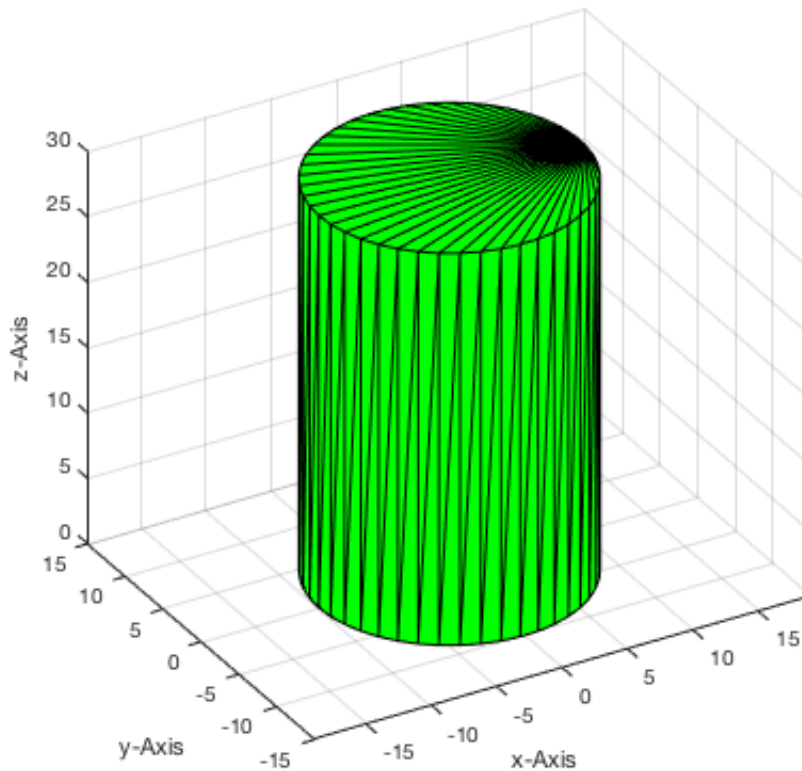
```
close all;
[VL,FL]=VLFLreadSTL ('STL-ASCII');
figure(1); VLFLplot(VL,FL,'b'); view (-30,30); grid on;
[VL,FL]=VLFLreadSTLb ('STL-BINAR');
figure(2); VLFLplot(VL,FL,'g'); view (-30,30); grid on;
```

```
LOADING ASCII STL-File: /Users/timlueth/Desktop/STL-ASCII.STL
Processing 1234 lines:
```

```
Finishing solid AOI-LIB:"STL-ASCII by My Name" 27-Feb-2017 16:53:42 27-Feb-2017 16:53:42
```

```
VLFLchecker: 90 vertices and 176 facets.  
  0 FACET PROBLEMS DETECTED (ERRORS)  
  0 VERTEX PROBLEMS DETECTED (OBSOLETE WARNING)  
  0 EDGE PROBLEMS DETECTED (NON MANIFOLD WARNING)  
  0 SOLID/EDGE PROBLEMS DETECTED (OPEN SOLID WARNING)  
LOADING BINARY STL-File: /Users/timlueth/Desktop/STL-BINAR.STL  
Header: AOI-LIB:"STL-BINAR by My Name" 27-Feb-2017 16:53:42  
Number of facets: 176  
0..  
Finishing and Checking  
VLFLchecker: 90 vertices and 176 facets.  
  0 FACET PROBLEMS DETECTED (ERRORS)  
  0 VERTEX PROBLEMS DETECTED (OBSOLETE WARNING)  
  0 EDGE PROBLEMS DETECTED (NON MANIFOLD WARNING)  
  0 SOLID/EDGE PROBLEMS DETECTED (OPEN SOLID WARNING)
```





3. Checking surface volume data and STL-files

Especially, when reading in STL-Files that are generated by other programs and libraries it makes sense to check the data quality. For that purpose there is a function that will be explained later in more detail. This function is called at the end of each STL import.

- **VLFLchecker** is used to analyze vertex list (VL) and facet list (FL)

```
VLFLchecker(VL,FL);      % Check the data structure

% There are some more procedures to view and analyze solid volumee data
```

```
VLFLchecker: 90 vertices and 176 facets.
0 FACET PROBLEMS DETECTED (ERRORS)
0 VERTEX PROBLEMS DETECTED (OBSOLETE WARNING)
0 EDGE PROBLEMS DETECTED (NON MANIFOLD WARNING)
0 SOLID/EDGE PROBLEMS DETECTED (OPEN SOLID WARNING)
```

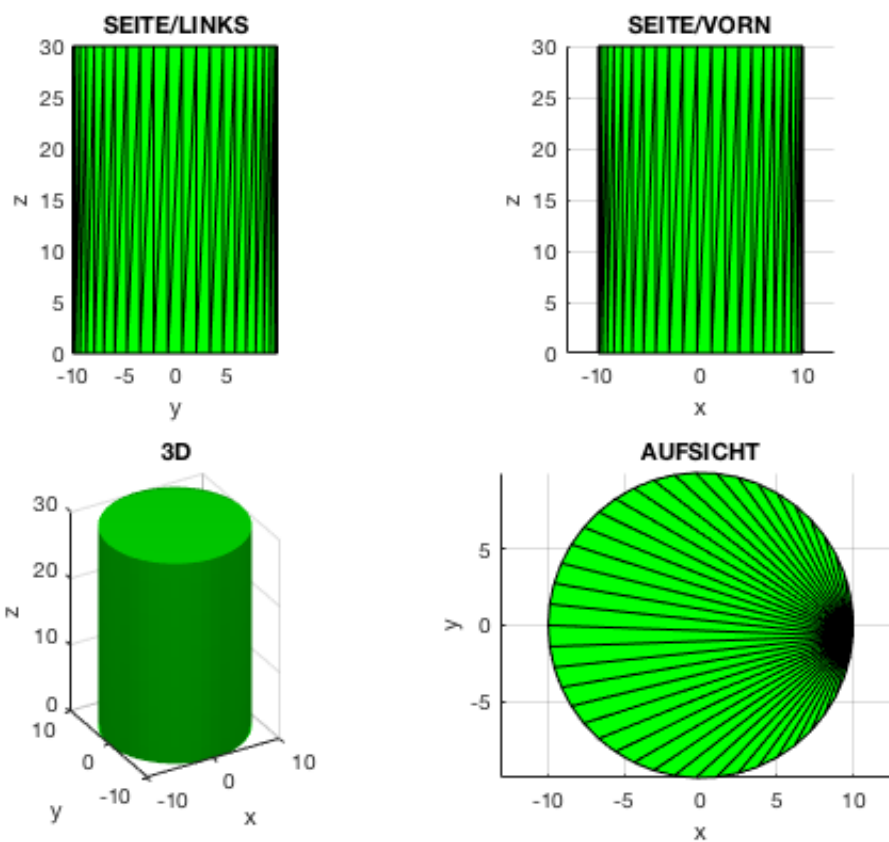
- **BBofVL** generates the bounding box dimensions of the solid
- **VLFLui** is simple user interface to open an STL file
- **VLFLminimize** eliminates doubles in VL and FL
- **VLFLnormf** calculates norm vector direction and size
- **VLFLplot4** figure with 4 subplots
- **VLFLselect** selected vertex list for a given facet list

- **VLFLseparate** find different independent objects in VL and FL
- **VLFLshort** remove unused vertices from VL
- **VLFLsurface** returns only vertex list and facet list for one surface
- **VLFLvertexfusion** shrinks vertex list by merging extremly near vertices

```
BBofVL(VL)
close all; VLFLplots4 (VL,FL,'g');
```

```
ans =
```

```
-10.0000    9.9756   -9.9939    9.9939         0   30.0000
```

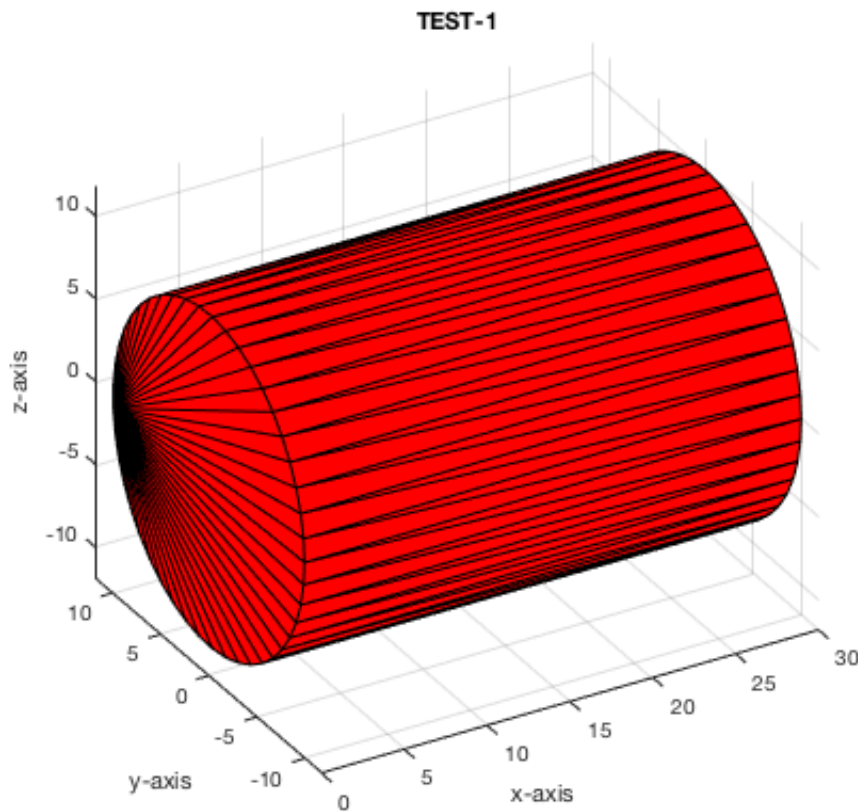


```
close all; VLFLseparate(VL,FL);
```

```
Analyzing 90 facets for separation z=[0.0mm|30.0mm]
Object TEST-1 with 176 facets
```

```
MVL =
```

```
0   -10    0
```



4. Generation of text, numbers, characters and formulas as solid volume

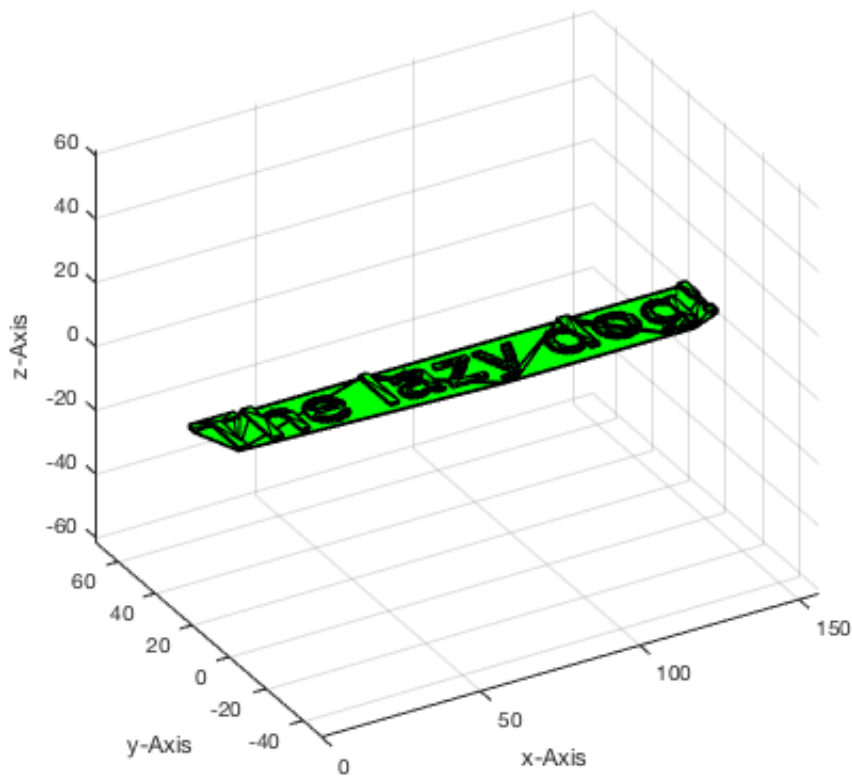
Often you want to write some numbers or code on top of a solid object. For that purpose there is a currently slow function that is able to convert a Matlab-string (even with LaTeX-code) into a solid object.

- **VLFLtextimage** writes a line using the text command and converts it into a solid volume
- **VLFLtext** does the same for a very limited number of characters

```
close all;
[VL,FL]=VLFLtextimage('The lazy dog!');
VLFLplot (VL,FL,'g'); view (-30,30);

[VL,FL,d]=VLFLtext('TL-MMXI-XII-XVII');
VLFLwriteSTL (VL,FL,'exp_2011_12_17', 'by Tim C Lueth');
```

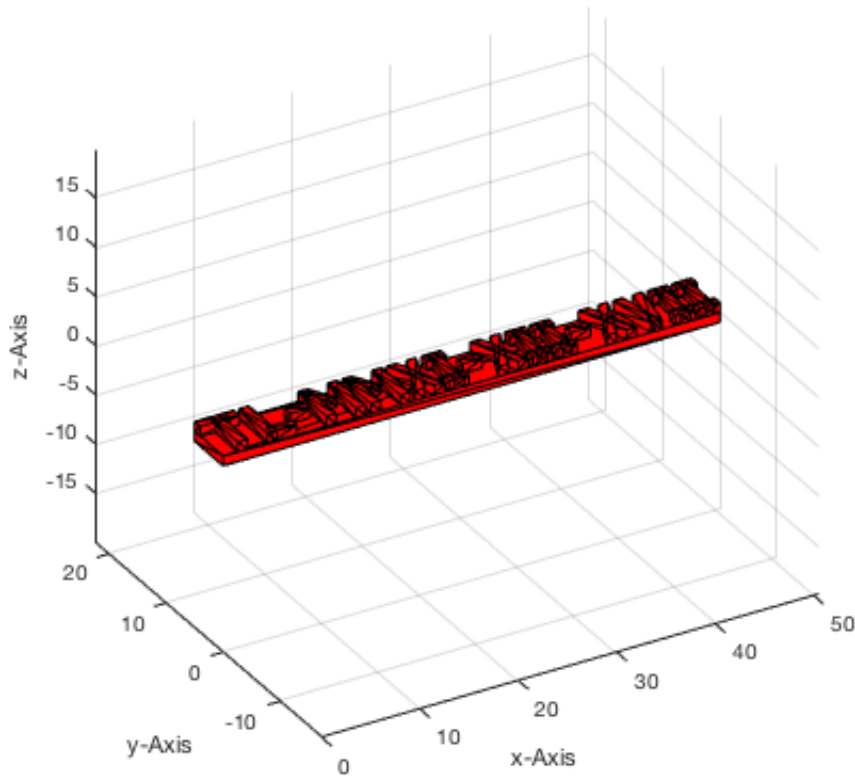
WRITING STL FILE /Users/timlueth/Desktop/exp_2011_12_17.STL in ASCII MODE completed.



5. Turning and mirroring of solids by manipulating the vertex lists (VL)

Turning an object and mirroring is quite simple by exchanging a column of the vertex list to change the sign of a column. To show the use of the functions we generate first a simple roman date string as solid volume.

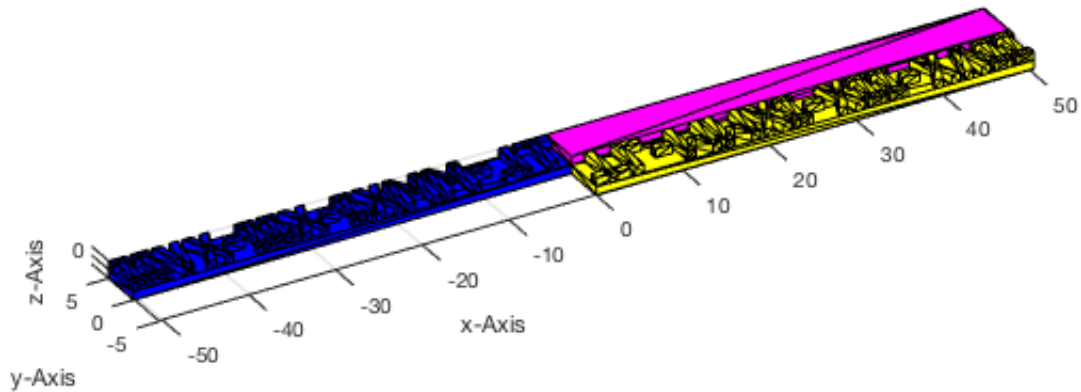
```
close all;
[VL,FL,d]=VLFLtext('TL-MMXI-XII-XVII'); VLFLplot(VL,FL,'r'); view(-30,30);
```



The functions for mirroring solid objects by manipulating the vertex list are the following:

- **VLswapX** mirrors the solid at the x-axis (y/z-plane).
- **VLswapY** mirrors the solid at the y-axis (x/z-plane).
- **VLswapZ** mirrors the solid at the z-axis (x/y-plane).

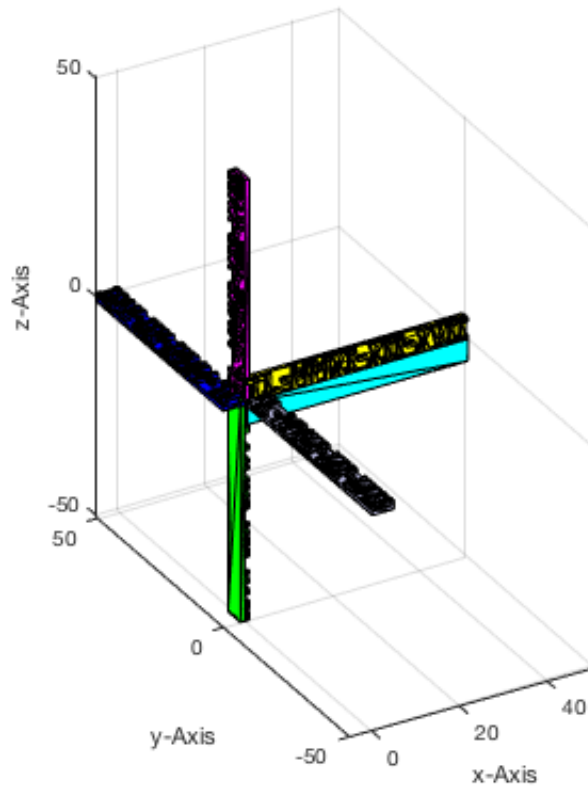
```
close all, view (-30,30); grid on;
VLFLplot(VLswapX(VL),FL,'b');      % mirror at x-axis
VLFLplot(VLswapY(VL),FL,'y');      % mirror at y-axis
VLFLplot(VLswapZ(VL),FL,'m');      % mirror at z-axis
```

The functions for turning solid objects by manipulating the vertex list are the following:

- **VLswapXY** turn the x-axis to the y-axis.
- **VLswapXZ** turn the x-axis to the z-axis.
- **VLswapYX** turn the y-axis to the x-axis.
- **VLswapYZ** turn the y-axis to the z-axis.
- **VLswapZX** turn the z-axis to the x-axis.
- **VLswapZY** turn the z-axis to the y-axis.

```
close all, view (-30,30); grid on
VLFLplot(VL,FL,'r');           % original solid
VLFLplot(VLswapXY(VL),FL,'b'); % turn the x-axis to the y-axis
VLFLplot(VLswapXZ(VL),FL,'m'); % turn the x-axis to the z-axis
VLFLplot(VLswapYZ(VL),FL,'y'); % turn the y-axis to the z-axis
VLFLplot(VLswapZY(VL),FL,'c'); % turn the z-axis to the y-axis
VLFLplot(VLswapZX(VL),FL,'g'); % turn the z-axis to the x-axis
VLFLplot(VLswapYX(VL),FL,'w'); % turn the y-axis to the x-axis
```



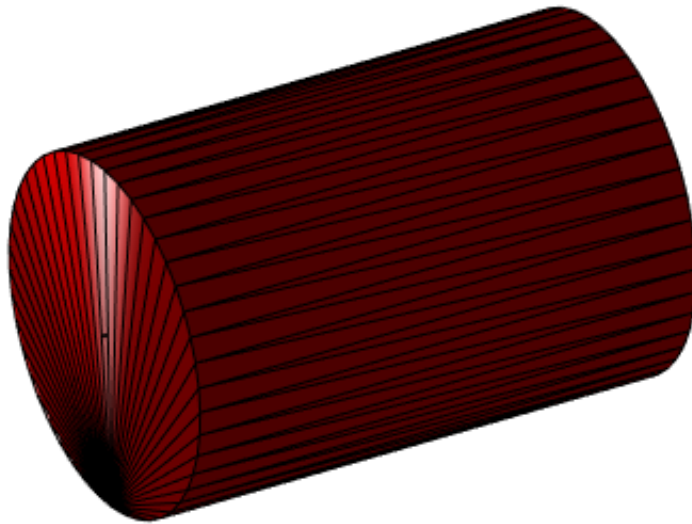
6. Spatial transformation of solids by manipulating the vertex lists (VL)

All solid objects consisting of vertices and facets can be moved and rotated by only manipulating the vertex list (VL). Since the facet list is an index list, the facet list (FL) is not affected by a transformation of the vertex list. The following example generates a cylinder and perform different position and orientation transformations.

```
closeall;
VLFLviewer([]);
PL=PLcircle(10);
[VL,FL]=VLFLofPLz (PL,30);
VL=VLswapZX (VL);
VLFLplot(VL,FL); view (-30,30); grid on;
```

% define a base-contour
% extrude to a solid volume
% swap X and X axis
% plot as red cylinder

'VLFLviewer' : 27-Feb-2017 16:53:50



In detail, there are five basic transformation functions for manipulation a vertex list (VL)

- **VLtrans0** for translating the solid in the coordiante system origin.
- **VLtrans1** for translating the solid into quadrant 1.
- **VLtransP** for translating the solid using a translation vector.
- **VLtransR** for rotation the solid using a rotation matrix.
- **VLtransT** for transforming using an homogenous transformation matrix.

In addition to the already existing matlab functions `rotx`, `roty`, and `rotz`, two new functions are useful.

- **rot** for generating a 3x3 rotation matrix for x y z given in rad.
- **rotdeg** for generating a 3x3 rotation matrix for x y z given in degree.

```
VL=VLtrans0 (VL); % Transformation into the origin (blue)
VLFLplot(VL,FL,'b'); view (-30,30);

VL=VLtrans1 (VL); % Transformation into quadrant 1 (black)
VLFLplot(VL,FL,'k'); view (-30,30);

VL=VLtransP (VL,[0 ;0; 30]); % Transformation upwards 30 mm (yellow)
VLFLplot(VL,FL,'y'); view (-30,30);

VL=VLtransR (VL,rotdeg(0,30,15)); % Rotate 30 degree around y and 15 around z (magenta)
VLFLplot(VL,FL,'m'); view (-30,30);

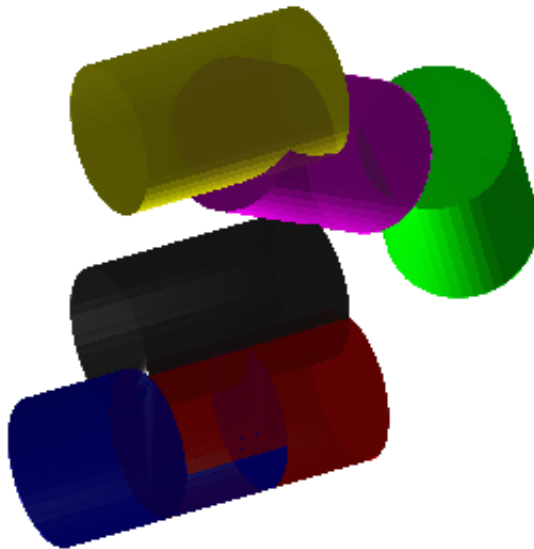
T=[rotdeg(0,30,15), [20;0;0];[0 0 0 1]] % define a homogenous transformation matrix (green)
```

```
VL=VLtransT (VL,T); % Transformation using an HT matrix
VLFLplot(VL,FL,'g'); view (-30,30); grid on;
VLFLplotlight (1,0.9); grid on;
```

T =

```
    0.8365   -0.2241    0.5000   20.0000
    0.2588    0.9659         0         0
   -0.4830    0.1294    0.8660         0
         0         0         0    1.0000
```

'VLFLviewer' : 27-Feb-2017 16:53:50



Final remarks on toolbox version and execution date

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:53:53 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
instr_control_toolbox
matlab
```

```
simmechanics  
simscape  
simulink
```

```
=====
```

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-19
- Tim Lueth, executed and published on 64 Bit PC using Windows with Matlab 2014b on 2014-11-19

Published with MATLAB® R2016b

Exercise 03: Closed 2D Contours and Boolean Operations in 2D

2014-11-19: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. The contour polybool list (mapping toolbox)
- 3. Surface tessellation for contour polybool list (CPL)
- 4. Orientation of outer and inner polygons of a CPL
- 5. Boolean operations of contour polybool lists (CPL)
- 6. Converting a closed polybool list into a point list (PL) and an edge list (EL)
- 7. Extruding point list (PL) and edge list (EL) to a solid volume
- 8. Converting a point list and edge list into a closed polybool list
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In example 1 and 2 we've learned about

- Point lists (PL) and Vextlist (VL) as nx2/nx3 coordinate arrays
- Facet lists (FL) as nx3 index arrays that describe triangle facets of a surface
- Functions for generating/extruding surfaces and surface bounded solid volumes
- Functions for displaying points, surfaces, volumes different colors and transparency
- Functions for import, check, and export of STL-Data
- Functions for turning, mirroring and spatial transformation of objects
- Functions for generation of text string as solid objects

2. The contour polybool list (mapping toolbox)

This 3rd example deals with a different data structure for the description of 2D closed contour polygons: Contour Polybool List (CPL). The CPL is a nx2 x/y-coordinate point list [x y] similar to a point list (PL). Always, the first and last point of the list are considered as closed. In addition, it is possible to concatenate two point list after another. To separate the individual contours, a separator-point [NaN NaN] is inserted between them.

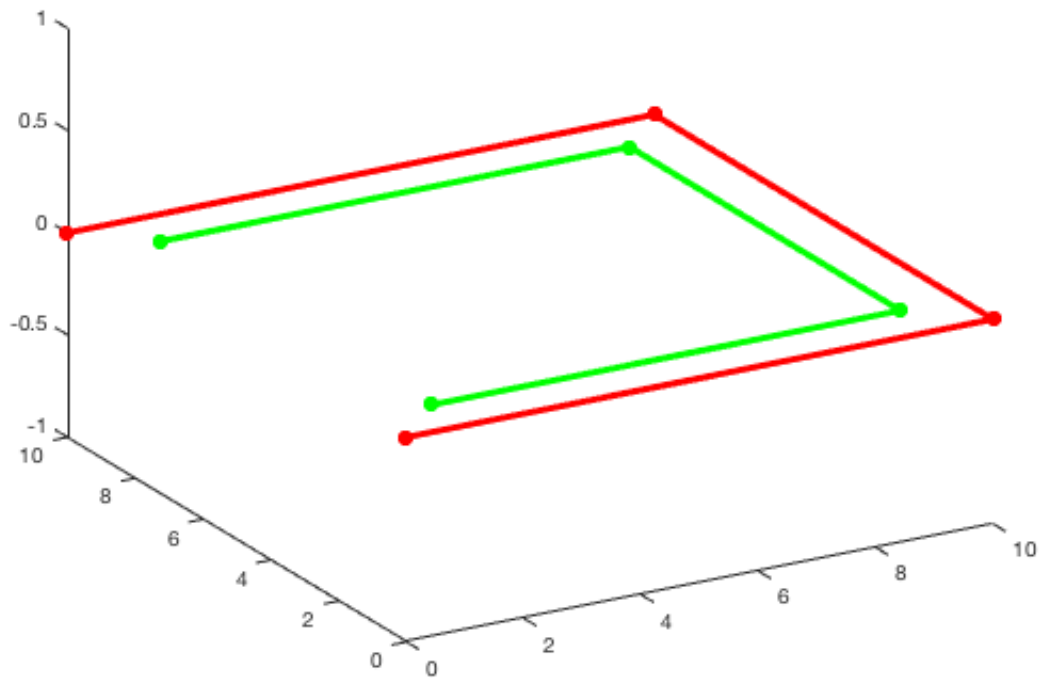
```
close all;
PLA=[0 0; 10 0; 10 10; 0 10], PLB=[1 1; 9 1; 9 9; 1 9]
PLplot (PLA,'r-*',3);PLplot (PLB,'g-*',3); view(-30,30);
```

PLA =

```
0      0
10     0
10    10
0     10
```

PLB =

```
1      1
9      1
9      9
1      9
```



The concatenation generates then the closed polybool list (CPL). Two functions are helpful to draw a CPL and also to show the start point (black cube), the endpoint (black ring) and the direction of each edge of the CPL:

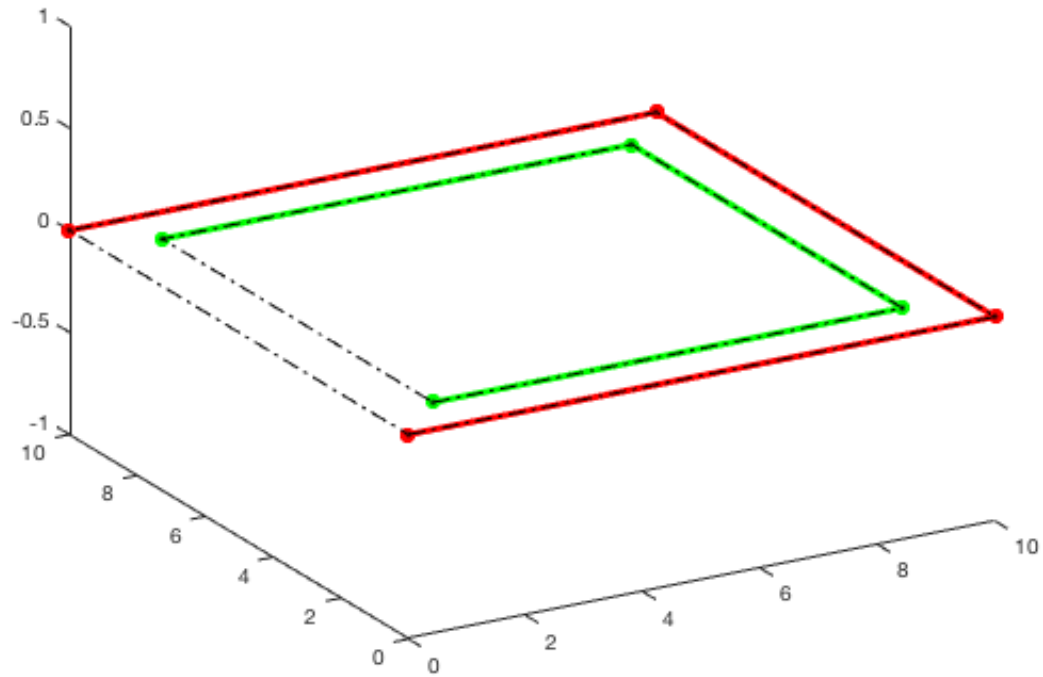
- **CPLplot** draws a closed contour polybool list (CPL).
- **PLELofCPL** draws a start point, end point and direction-arrows, when called without any output variable.

```
CPL=[PLA;NaN NaN;PLB],
CPLplot (CPL,'k.-.',1);
```

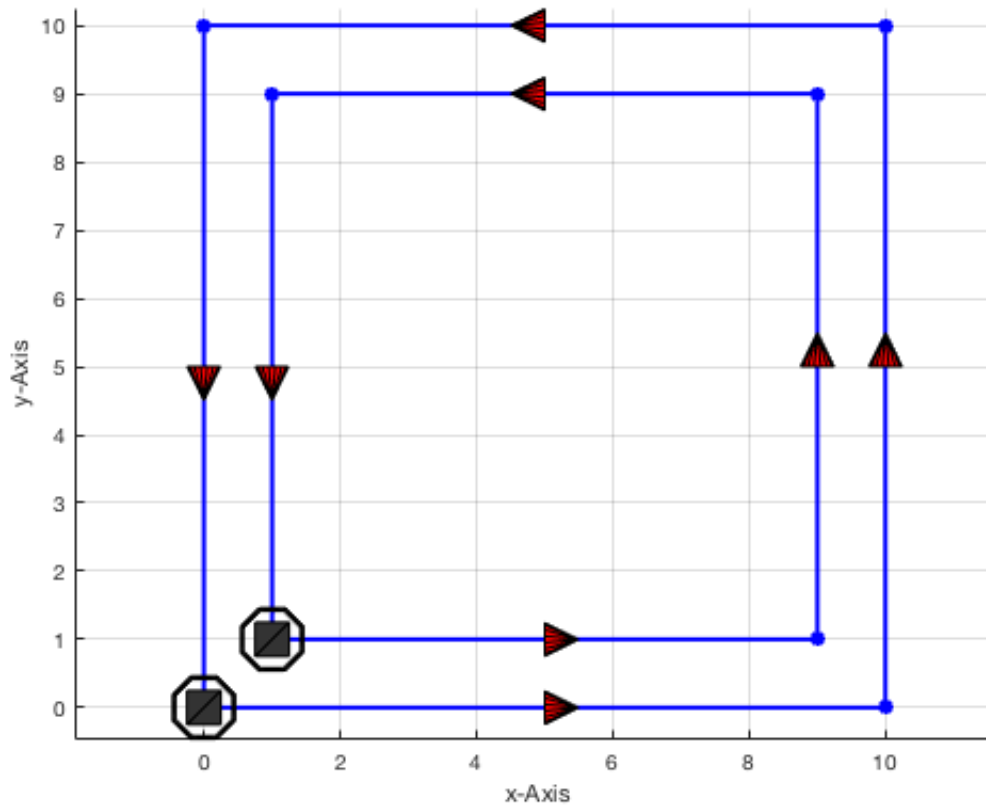
CPL =

```
0      0
10     0
10     10
0      10
NaN    NaN
```

1	1
9	1
9	9
1	9



```
close all;  
PLELofCPL (CPL);
```

3. Surface tessellation for contour polybool list (CPL)

A closed polygon list can be considered as bounding contour for a surface. In general, there exist different strategies, to tessellate a bounding contour, to get a triangle surface description. There is no optimal one. We can distinguish **simple strategies** or more advanced strategies such as **Delaunay-Triangulation** or **Row-Scanning-Triangulation**. In example 1 we used a simple strategy for closing convex polygons.

- **Row-Scanning-Triangulation** is able to handle all kinds of polygons (even enclosed), but the triangle facets are sometimes very small. Furthermore, the point contains redundant information.
- **Delaunay-Triangulation** is able to handle all kinds of polygons (even enclosed), but has problems with polygons that cross each other or share one point or more points, i.e. overlapping edges.

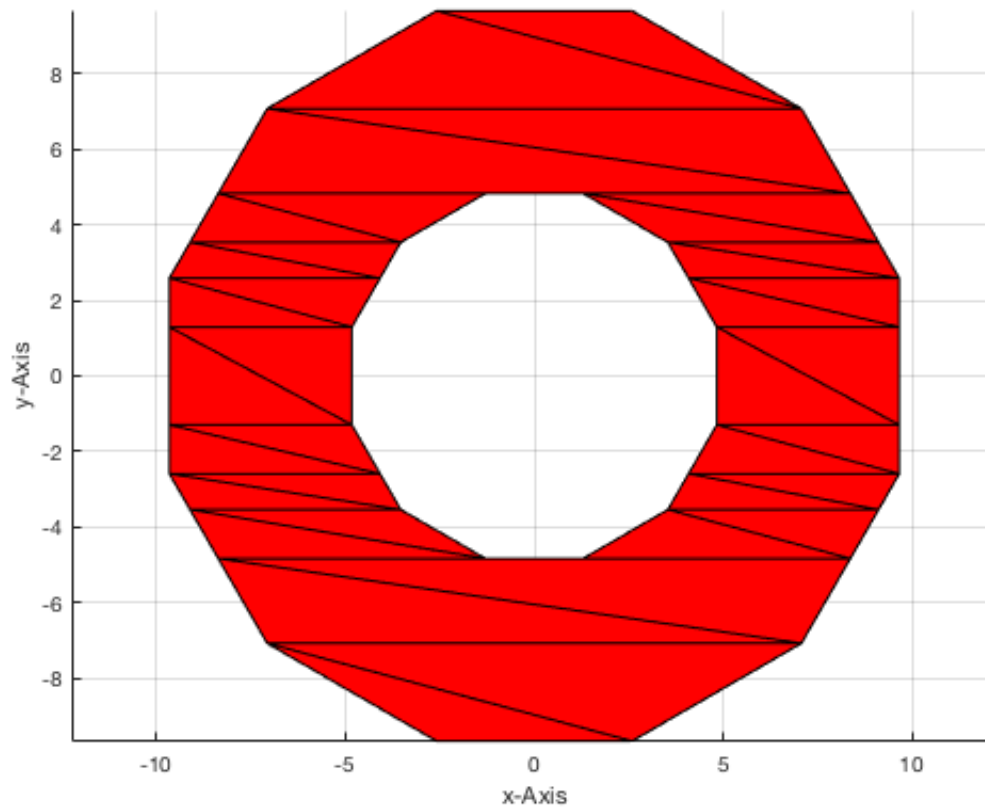
It is not unique to tessellate polygons, if they are enclosed or cross each other. There exist no general purpose solution. Nevertheless, in most cases, the Delaunay-Triangulation is preferable, since this concept does work also in 3D. To generate a facet list (FL) for a CPL, there exist two functions. In case of crossing polygons or overlapping polygons, additional points have to be calculated automatically, and therefore, the points in the point list can change. In this case, you will get a warning, but only in case of the Delaunay-triangulation. Conventionally, additional split/crossing points are added at the end of the point list, in case of the Delaunay-triangulation.

- **PLFLoFCPLpoly** returns a facet tessellation by a simple y-coordinate row scanning (the points are ordered by increasing y, contour by contour, do not mix, but are redundant. Not as efficient as Delaunay, and not useful for 3D).
- **PLFLoFCPLdelaunay** returns a facet tessellation by a Delaunay-triangulation (no crossings or joint points or joint edges are allowed, i.e create additional split points).

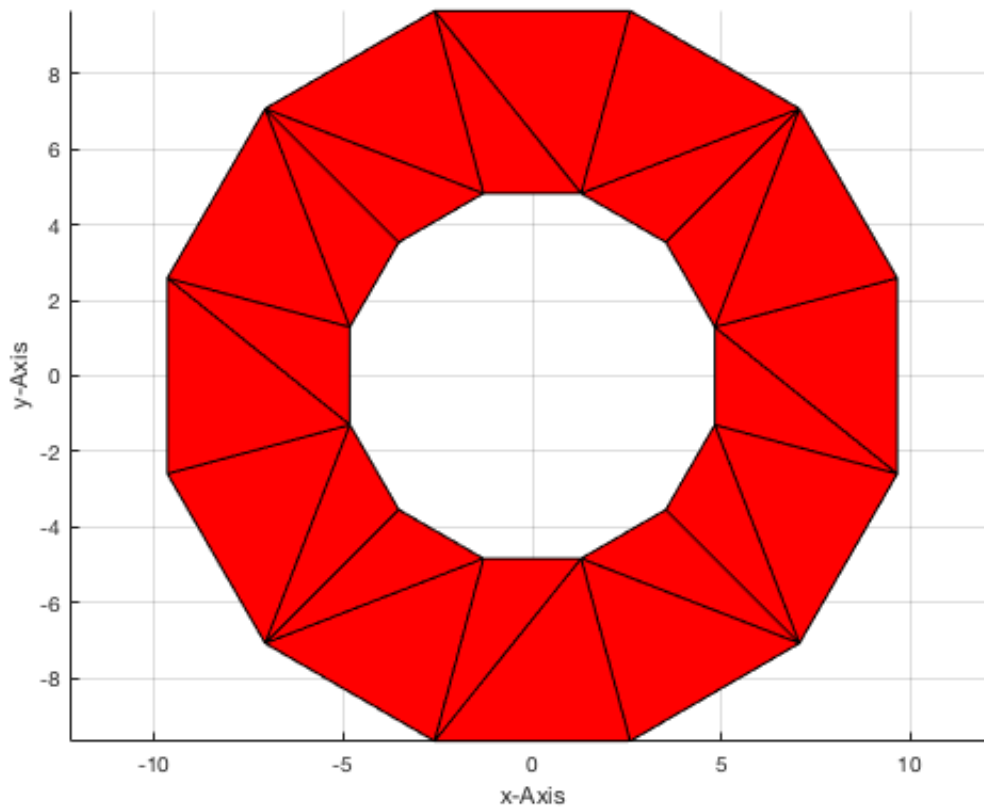
```
close all;
CPL=[PLcircle(10,12);NaN NaN;PLcircle(5,12)]
[PL,FL]=PLFLoFCPLpoly(CPL); VLFLplot(PL,FL);
```

CPL =

9.6593	-2.5882
9.6593	2.5882
7.0711	7.0711
2.5882	9.6593
-2.5882	9.6593
-7.0711	7.0711
-9.6593	2.5882
-9.6593	-2.5882
-7.0711	-7.0711
-2.5882	-9.6593
2.5882	-9.6593
7.0711	-7.0711
NaN	NaN
4.8296	-1.2941
4.8296	1.2941
3.5355	3.5355
1.2941	4.8296
-1.2941	4.8296
-3.5355	3.5355
-4.8296	1.2941
-4.8296	-1.2941
-3.5355	-3.5355
-1.2941	-4.8296
1.2941	-4.8296
3.5355	-3.5355



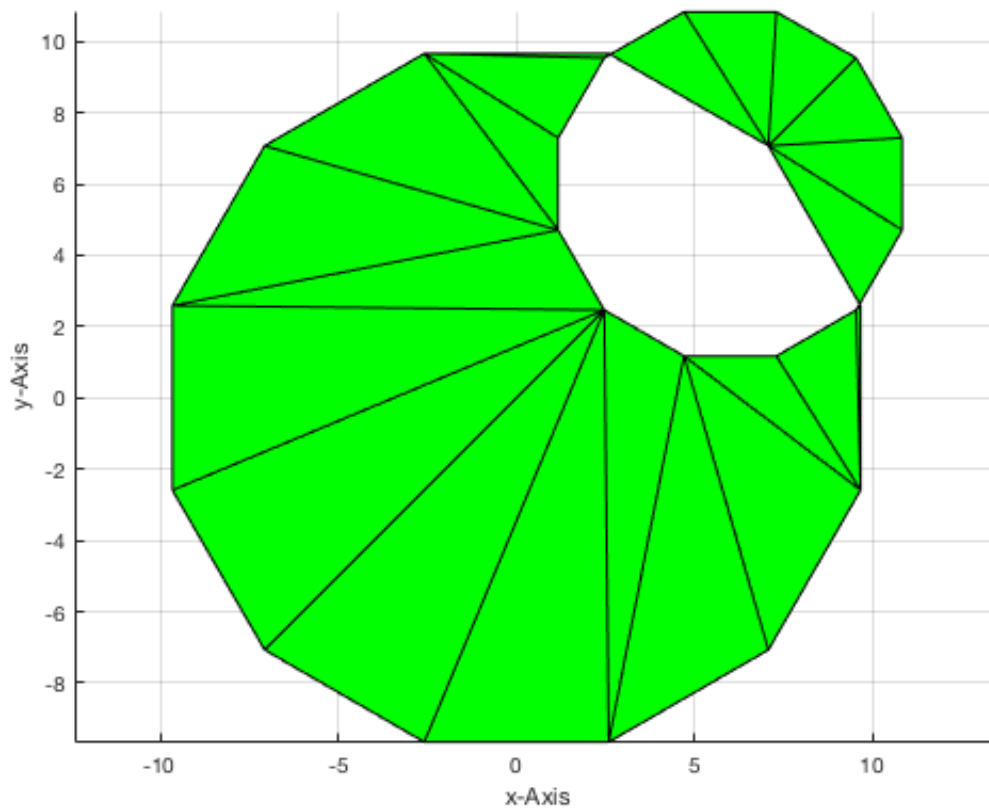
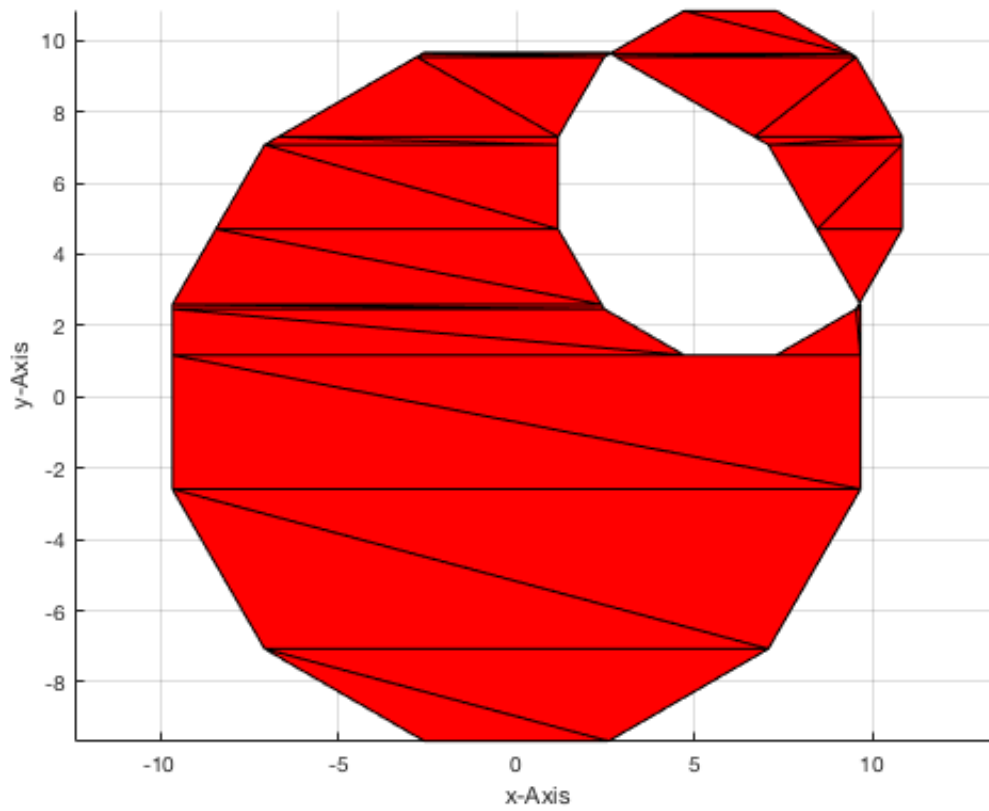
```
close all;  
[PL,FL]=PLFLoofCPLdelaunay(CPL); VLFLplot(PL,FL);
```



The next example shows the need for splitting contours:

```
close all
CPL=[PLcircle(10,12);NaN NaN;PLcircle(5,12)+6];
figure(1); [PL,FL]=PLFLoofCPLpoly(CPL); VLFLplot(PL,FL,'r');
figure(2); [PL,FL]=PLFLoofCPLdelaunay(CPL); VLFLplot(PL,FL,'g');
```

Warning: Intersecting edge constraints have been split, this may have added new points into the triangulation.



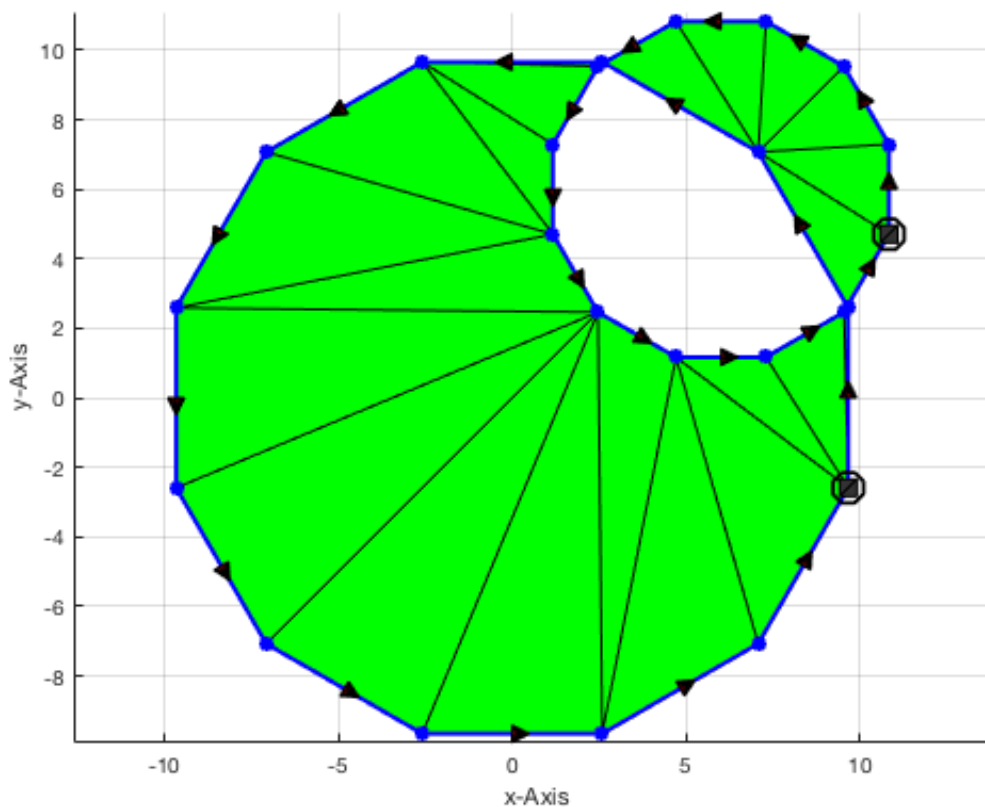
4. Orientation of outer and inner polygons of a CPL

In the mapping tool box, that supports the boolean operation of contours, there is a rule to use outer contours in clockwise (cw) directions and embedded contours always in the opposite direction, which means counter-clockwise (ccw) for the first level of embedding. Unfortunately, this is exactly the other way around to the rules that are used for Delaunay representation and 3D surface description. So we have to be careful later when switching from CPL to surface description for 3D modelling. In 3D modelling, to distinguish outer contours and inner contours of a CPL, we use counter clockwise (ccw) polygons for outside and clockwise (cw) polygons for inside contours. At a later stage we want to generate walls extruded upwards on the contours. If the contour direction is defined correctly for 3D modelling, the facet orientation can be calculated automatically from the contour direction.

- **PLELoFCPL** shows the direction of the used contours.
- **flip(PL)** changes the direction of a point list.

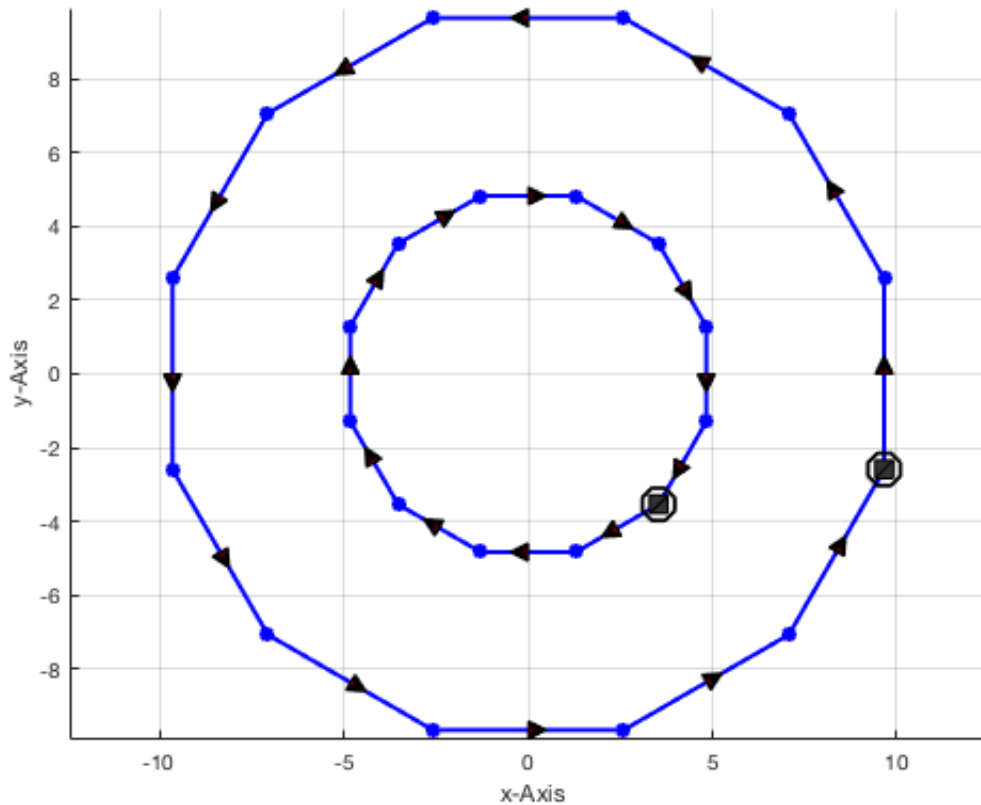
In the next figure, we see both polygons counter-clockwise:

```
PLELoFCPL(CPL);
```



Now, we see the outer polygons counter-clockwise and the inner polygons clockwise

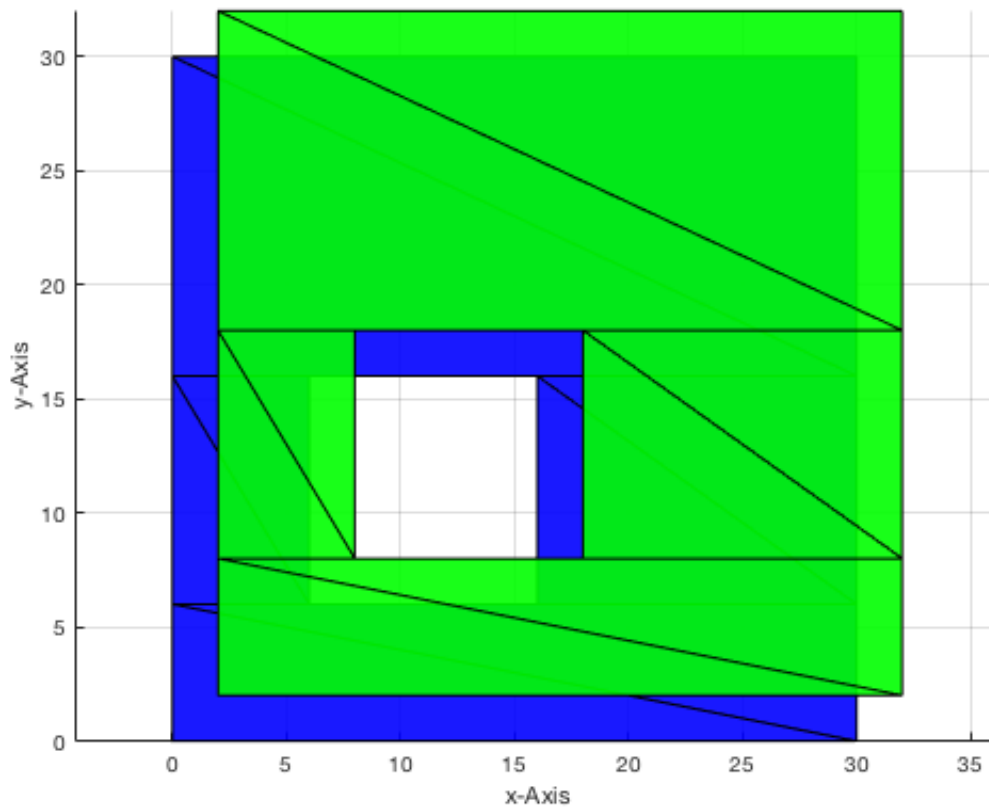
```
close all;
CPL=[PLcircle(10,12);NaN NaN;flip(PLcircle(5,12))];
PLELoFCPL(CPL);
```



5. Boolean operations of contour polybool lists (CPL)

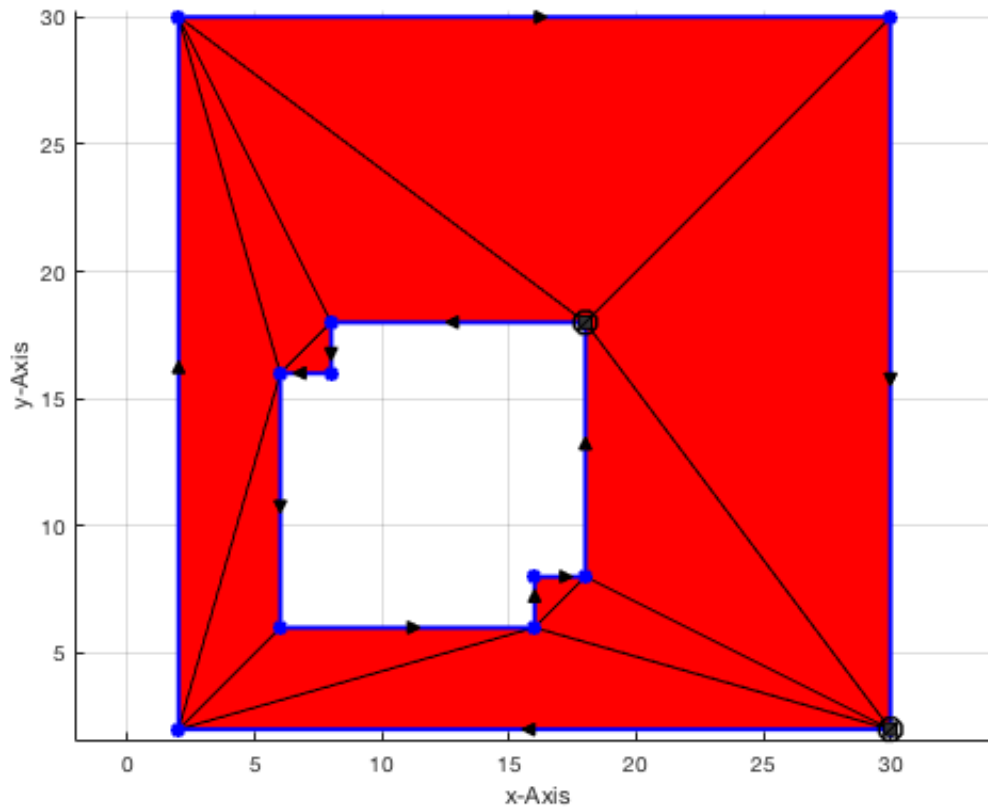
The main advantage of the CPL representation is currently the possibility to use the polybool functions of the mapping toolbox. Here, we show the use in embedded functions that help later to make the step forward to 3D modeling. We start with boolean operations of contour polybool lists (CPL).

```
close all; figure;
CPL=[PLA*3;NaN NaN;(PLA)+6];
CPLA=CPL;    [PL,FL]=PLFLoFCPLpoly(CPLA); VLFLplot(PL,FL,'b');
CPLB=CPL+2;  [PL,FL]=PLFLoFCPLpoly(CPLB); VLFLplot(PL,FL,'g');
VLFLplotlight (0,0.9)
```



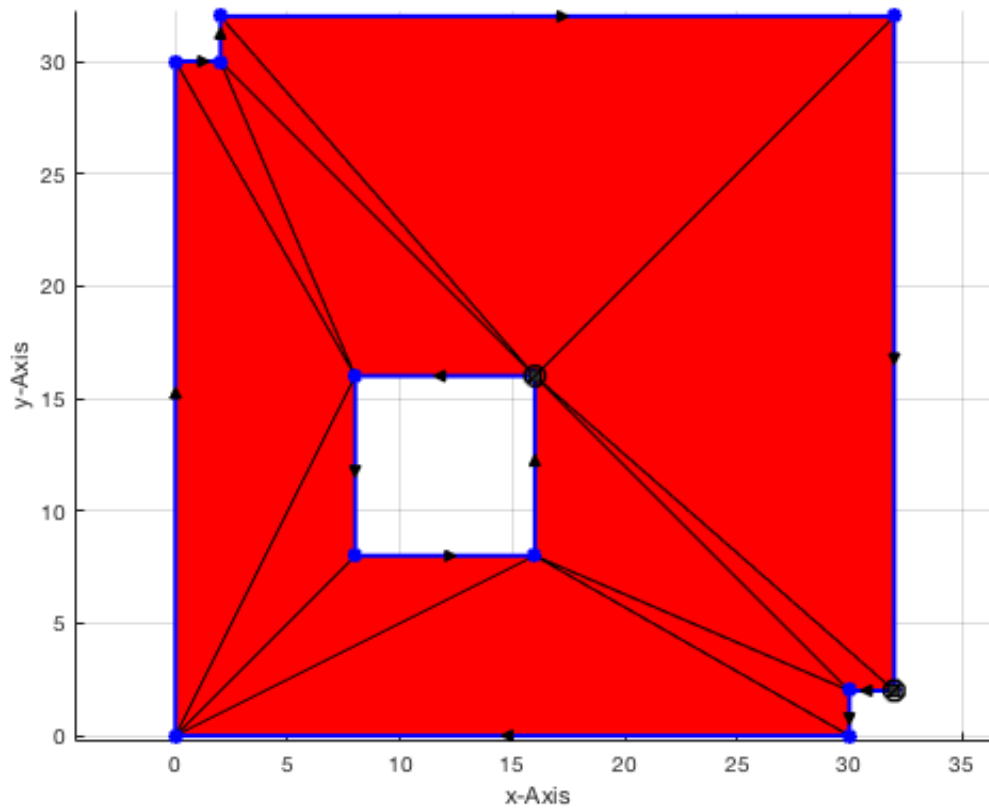
- **CPLpolybool('and',CPLA,CPLB)** delivers CPLA intersecting CPLB.

```
close all;
CPLN=CPLpolybool('and',CPLA,CPLB);
[PL,FL]=PLFLoCPLdelaunay(CPLN); VLFLplot(PL,FL); PLELoCPL(CPLN);
```

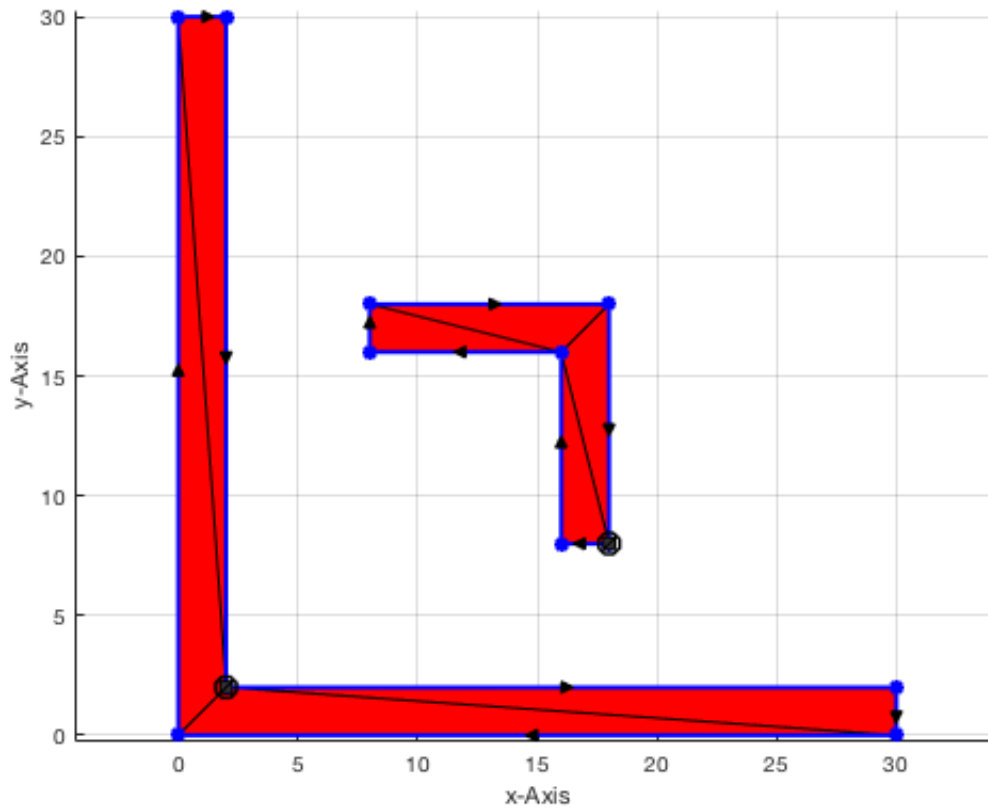
- **CPLpolybool('or',CPLA,CPLB)** delivers CPLA united with CPLB.

```
close all;
CPLN=CPLpolybool('or',CPLA,CPLB);
[PL,FL]=PLFLoCPLdelaunay(CPLN); VLFLplot(PL,FL); PLELoCPL(CPLN);
```



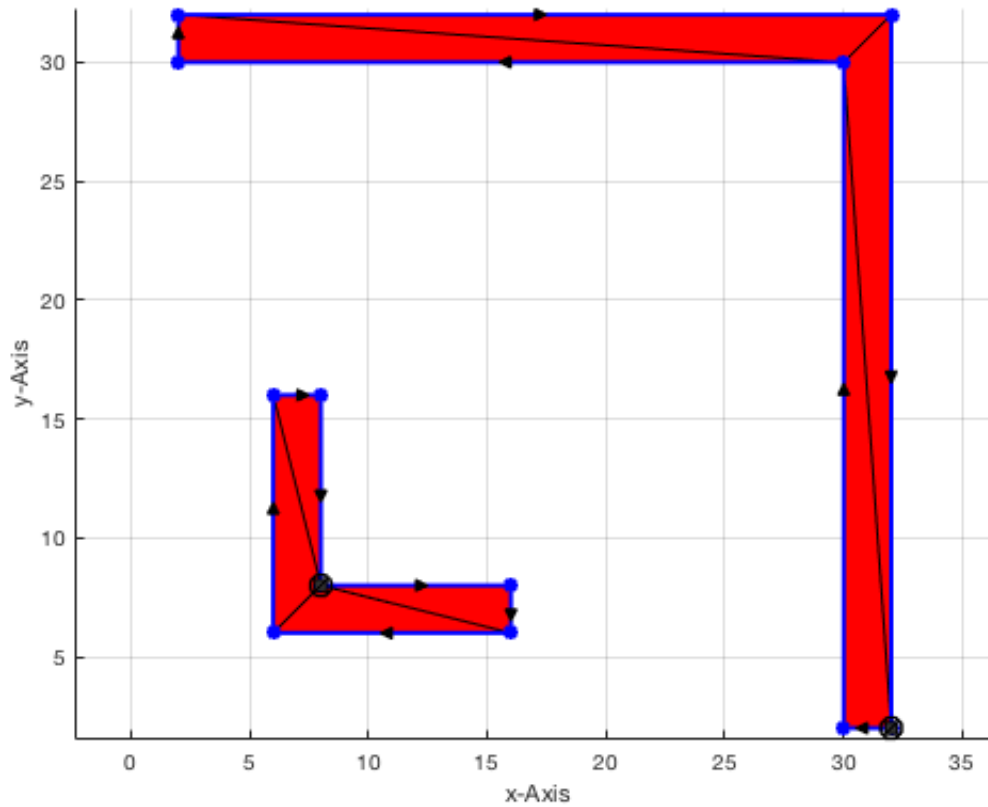
- `CPLpolybool('minus',CPLA,CPLB)` delivers `CPLA` minus `CPLB`.

```
close all;
CPLN=CPLpolybool('minus',CPLA,CPLB);
[PL,FL]=PLFLoCPLdelaunay(CPLN); VLFLplot(PL,FL); PLELoCPL(CPLN);
```



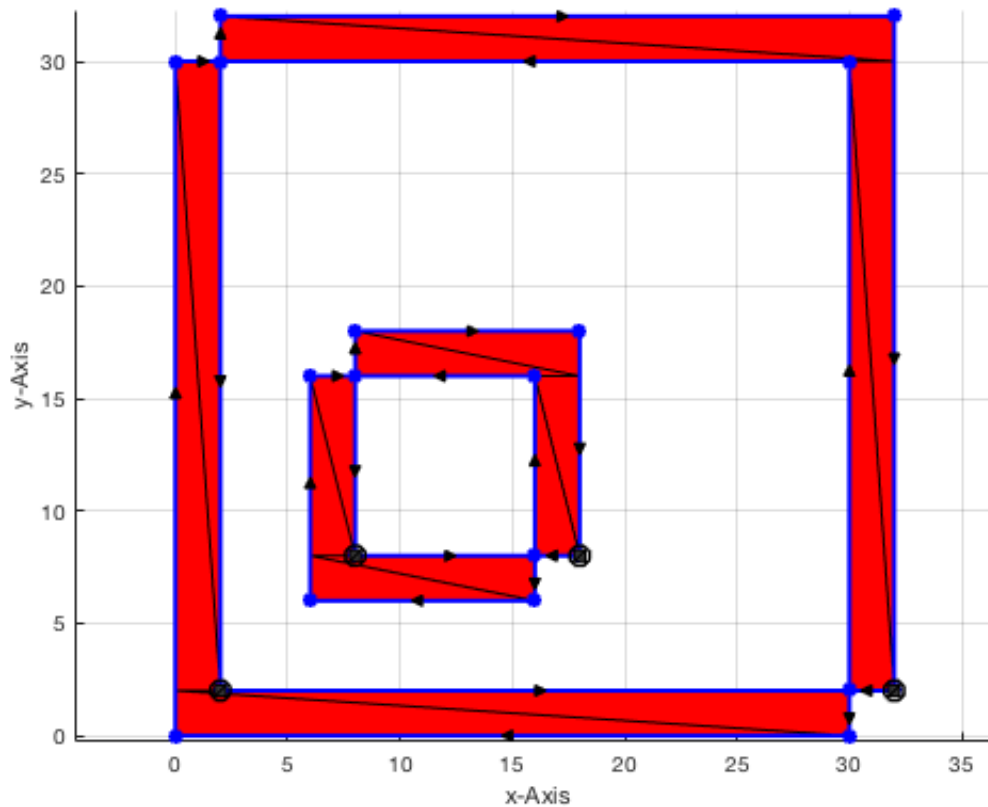
- `CPLpolybool('minus',CPLB,CPLA)` delivers `CPLB` minus `CPLA`.

```
close all;
CPLN=CPLpolybool('minus',CPLB,CPLA);
[PL,FL]=PLFLoofCPLdelaunay(CPLN); VLFLplot(PL,FL); PLELoofCPL(CPLN);
```



- **CPLpolybool('xor',CPLA,CPLB)** delivers CPLA exclusiveor CPLB.

```
close all;
CPLN=CPLpolybool('xor',CPLA,CPLB);
[PL,FL]=PLFLoCPLpoly(CPLN); VLFLplot(PL,FL); PLELoCPL(CPLN);
```



6. Converting a closed polybool list into a point list (PL) and an edge list (EL)

To generate an extruded 2½D solid from a CPL, it makes sense first to convert a CPL to a point list (PL) with an explicit description of the edges of the polygons as edge list (EL). Since the EL, as a result of CPLpolybool, has an inverted direction, ELflip is used to change the direction of the edges.

- **PLElofCPL** transforms the CPL into a point list (PL) and an edge list (EL).
- **ELflip** corrects the edge direction after CPLpolybool.

```
CPLN=CPLpolybool('minus',CPLA,CPLB)
[PL,EL]=PLElofCPL(CPLN), EL=ELflip(EL),
```

CPLN =

```
18      8
16      8
16     16
 8     16
 8     18
18     18
18      8
NaN    NaN
 2      2
30      2
30      0
 0      0
 0     30
```

2	30
2	2

PL =

18	8
16	8
16	16
8	16
8	18
18	18
2	2
30	2
30	0
0	0
0	30
2	30

EL =

1	2
2	3
3	4
4	5
5	6
6	1
7	8
8	9
9	10
10	11
11	12
12	7

EL =

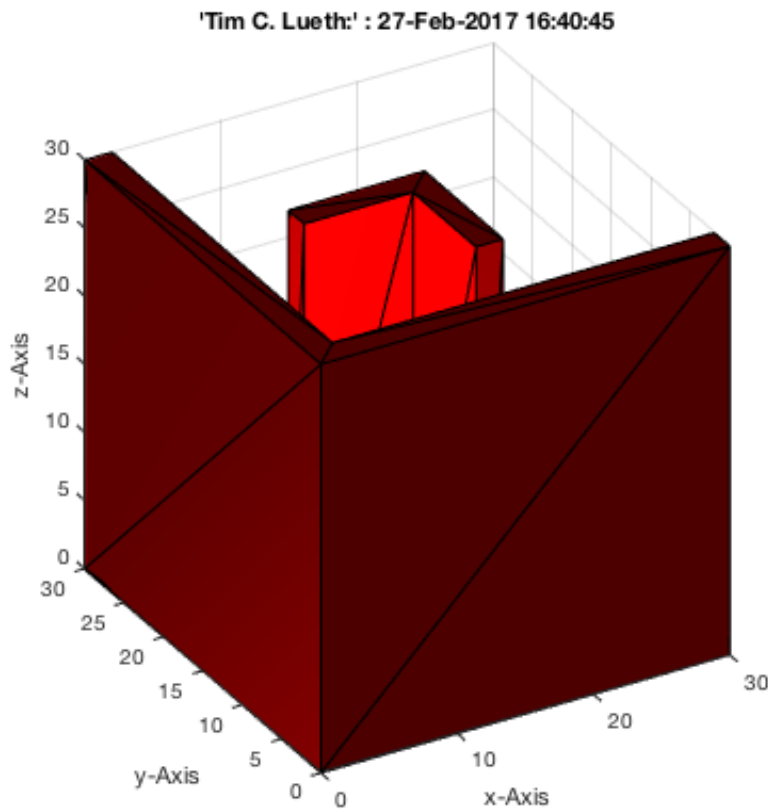
7	12
12	11
11	10
10	9
9	8
8	7
1	6
6	5
5	4
4	3
3	2
2	1

7. Extruding point list (PL) and edge list (EL) to a solid volume

After a boolean operation there is often the wish to extrude the resulting base contour into a 3D solid volume. The function is explained later in more detail. Anyway, it is helpful to see in 3D a model that is the result of a 2D boolean operation.

- **VLFLofPLELz** extruding a point list (PL) and edge list (EL) into 3D.

```
close all; VLFLfigure; view(-30,30);
[VL,FL]=VLFLofPLELz(PL,EL,30); VLFLplots(VL,FL);
```



8. Converting a point list and edge list into a closed polybool list

Finally, as it was possible to convert a CPL into a point list and an edge list, there is a function for the opposite.

- **CPLofPLEL** converting a point list (PL) and an edge list (EL) into a closed polybool list.

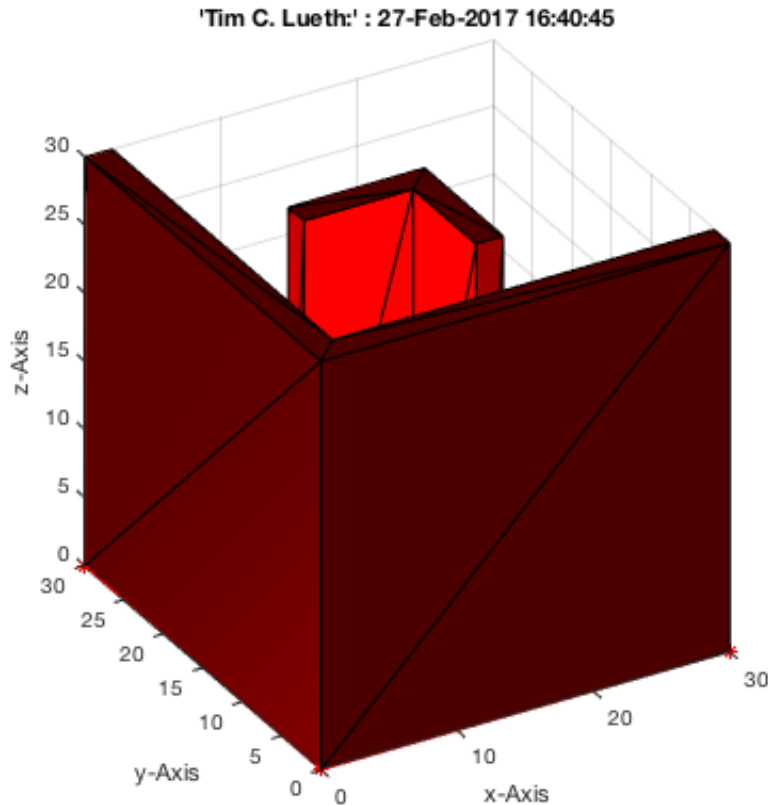
```
CPLofPLEL(PL,EL)
```

ans =

```

2      2
2     30
0     30
0      0
30     0
30     2
2      2
NaN    NaN
18     8
18    18
```

8	18
8	16
16	16
16	8
18	8



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:40:48 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-19

- *Mattias Traeger, executed and published on 64 Bit PC using Windows with Matlab 2014b on 2014-11-20*

Published with MATLAB® R2016b

Exercise 04: 2½D Design Using Boolean Operators on Closed Polygon Lists (CPL)

2014-11-21: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Moving and rotating point lists (PL) and closed polygon lists (CPL)
- 3. Simple extrusion of point lists (PL/CPL) to design 2½D solids
- 4. Simple Design of 2½D solids by boolean operators for point lists (PL/CPL)
- 5. Unite both contours and extrusion: `CPL=CPLpolybool('or',PLA,PLB)`
- 6. Intersect both contours: `CPL=CPLpolybool('and',PLA,PLB)`
- 7. Subtract contour B from A: `CPL=CPLpolybool('-',PLA,PLB)`
- 8. Subtract contour A from B: `CPL=CPLpolybool('-',PLB,PLA)`
- 9. Exclusive or of contour A and B: `CPLpolybool('xor',PLB,PLA)`
- 10. Checking the solid volumes for 3D printing
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In example 1-3 we've learned about:

- Point lists (PL), vertex lists (VL), facet lists (VL) and edge lists (EL)
- Functions for import, check, and export of STL-Data
- Closed polygon lists (CPL) for boolesche operations of embedded contours
- Orientation of inner and outer contours for 3D extrusion
- Different strategies for surface tessellation (Delaunay,row-scanning)
- Functions for generating/extruding surfaces and surface bounded solid volumes
- Functions for displaying points, surfaces, volumes different colors and transparency
- Functions for turning, mirroring and spatial transformation of objects
- Functions for generation of text string as solid objects

2. Moving and rotating point lists (PL) and closed polygon lists (CPL)

By using point lists (PL) and closed polybool lists (CPL) it is very convinient to design 2.5D objects. Here we see a first example to design a simple square by three function:

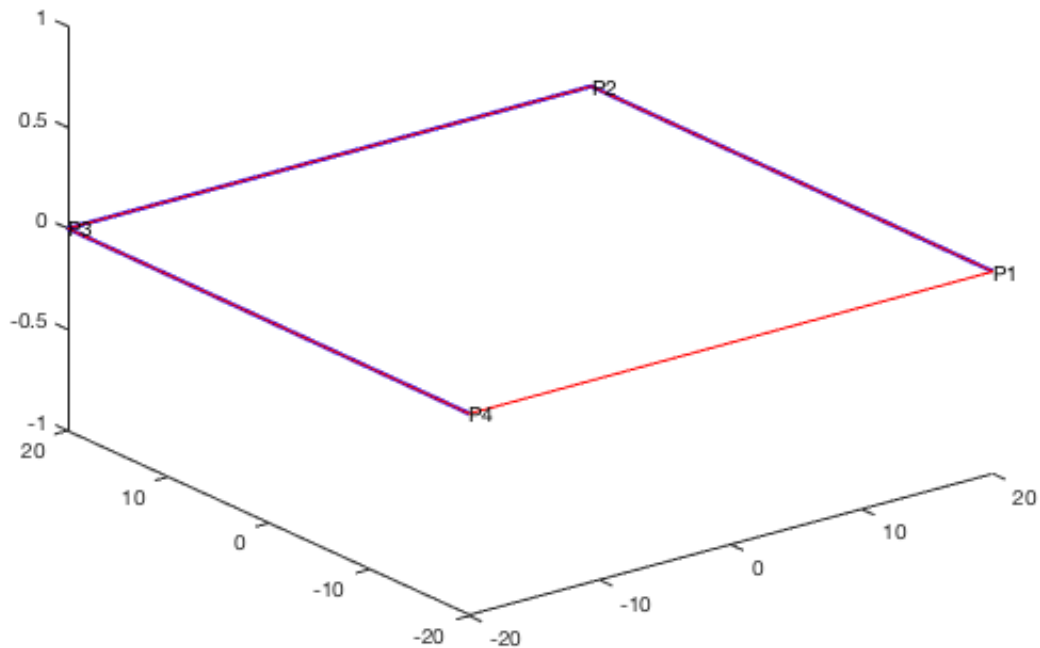
At the beginning we just plot simple point lists or closed polygon lists

- **PLplot** plots the point list as open contour
- **CPLplot** plots the point list as closed contour
- **textVL** plots descriptors at the points

```

close all;
PLA=PLcircle(20*sqrt(2),4);           % Generate a circle with 4 point, i.e. square
PLplot(PLA,'b',2);                    % Plots the points in blue
CPLplot(PLA,'r');                     % Plots the closed polygon in red
textVL (PLA);                         % Plots point descriptors

```



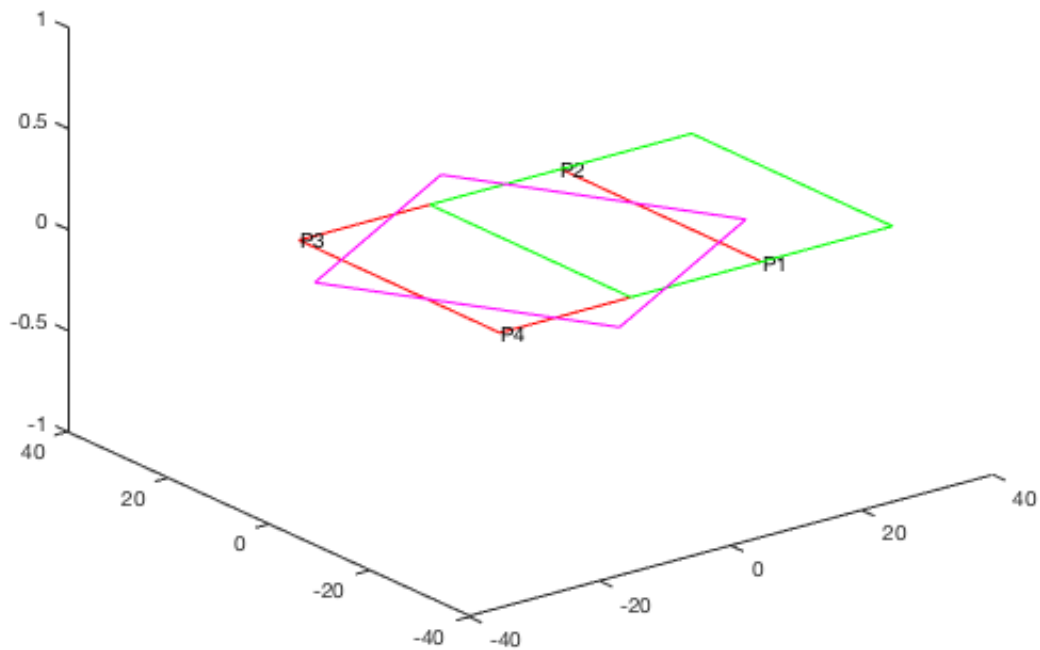
Next we move the square and rotate the square

- **PLtransP** moves a point list (PL) or closed polygon list(CPL)
- **PLtransR** rotates a point list (PL) or closed polygon list(CPL)

```

close all;
CPLplot(PLA,'r');                    % Plots the closed polygon in red
textVL (PLA);                        % Plots point descriptors
CPLplot(PLtransP(PLA,[20 0]),'g');   % Plot the moved polygon in green
CPLplot(PLtransR(PLA,rot(pi/6)), 'm'); % Plot the rotated polygon in magenta

```

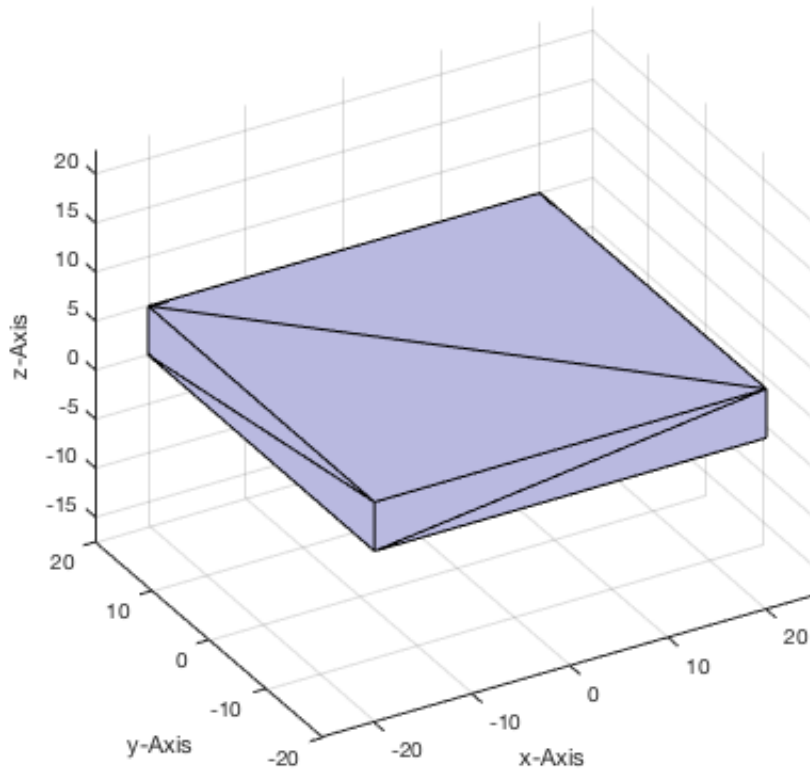


3. Simple extrusion of point lists (PL/CPL) to design 2½D solids

Next we extrude the square in 3D

- **VLFLofCPLz** extrudes point list (PL) or closed polygon list(CPL) in z

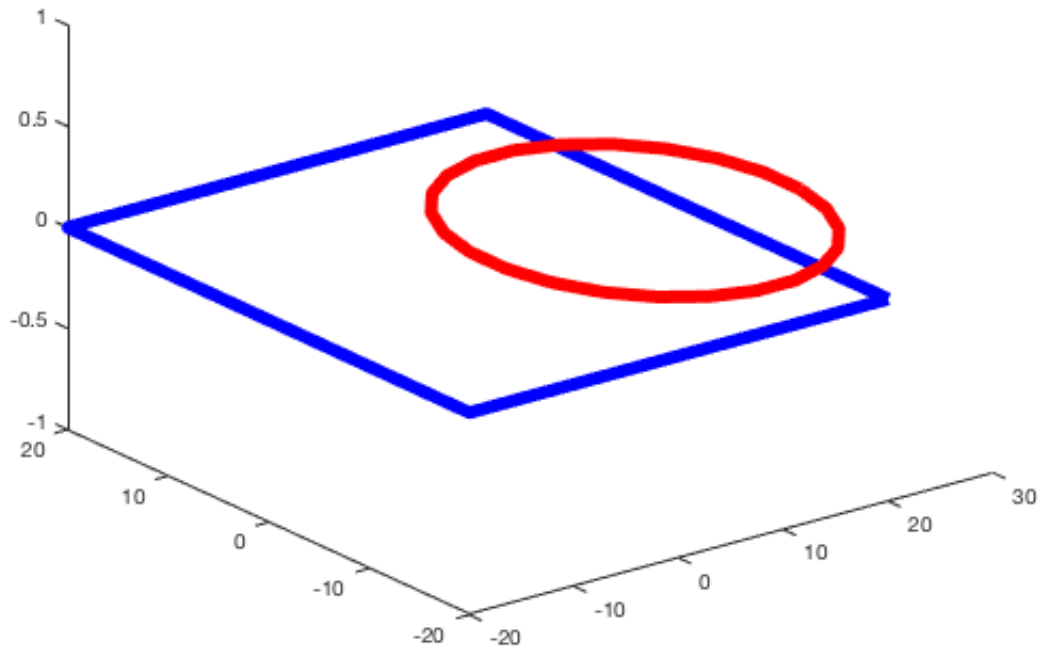
```
close all
[VL,FL]=VLFLofCPLz (PLA,5);
VLFLplot (VL,FL,'w'), axis equal, view(-30,30);
```



4. Simple Design of 2½D solids by boolean operators for point lists (PL/CPL)

In this example we start with two point list, a square and an octaedron

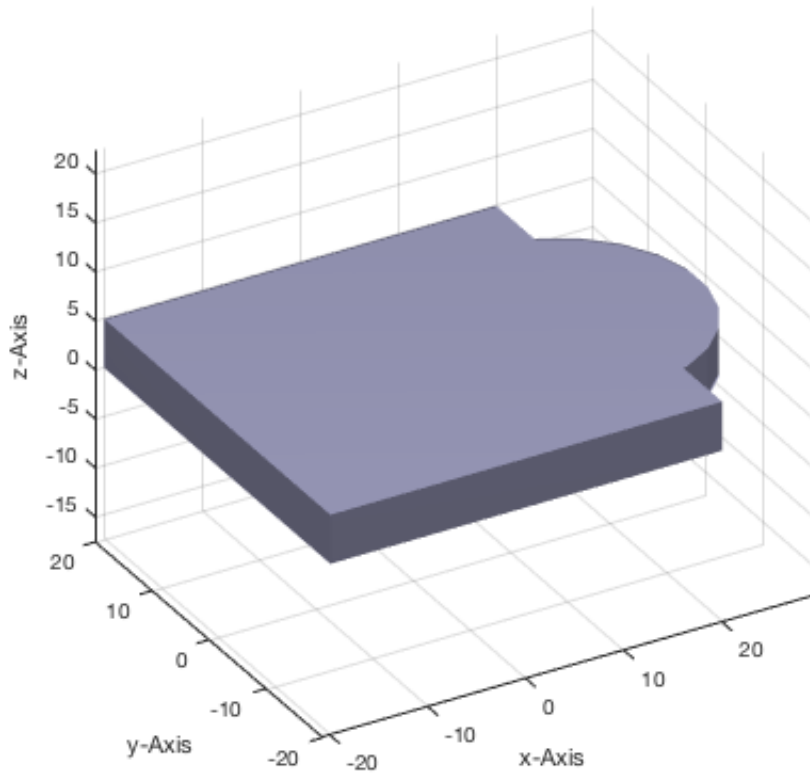
```
close all;  
PLA=PLcircle(20*sqrt(2),4);  
PLB=PLcircle(10*sqrt(2),24);  PLB=PLtransP(PLB,[15 0]);  
CPLplot(PLA,'b',6); CPLplot(PLB,'r',6);
```



5. Unite both contours and extrusion: `CPL=CPLpolybool('or',PLA,PLB)`

```
close all
CPL=CPLpolybool('or',PLA,PLB); [VL,FL]=VLFLofCPLz(CPL,5);
VLFLplot (VL,FL,'w'), axis equal, view(-30,30); VLFLplotlight (1);
VLFLwriteSTL (VL,FL,'A','EXP04-unite')
```

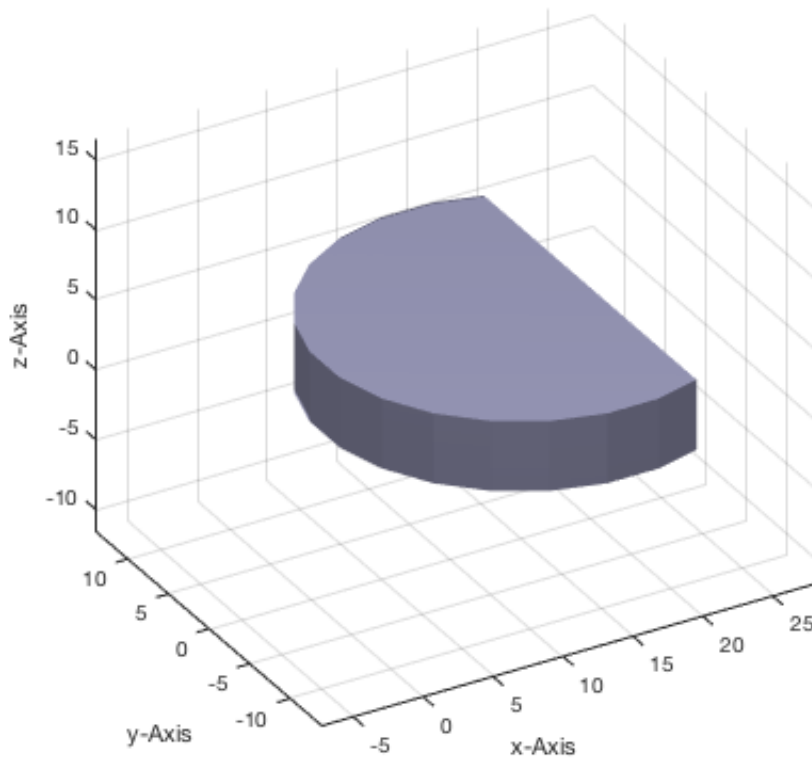
WRITING STL FILE /Users/timlueth/Desktop/A.STL in ASCII MODE
completed.



6. Intersect both contours: $CPL = CPLpolybool('and', PLA, PLB)$

```
close all
CPL=CPLpolybool('and',PLA,PLB); [VL,FL]=VLFLofCPLz(CPL,5);
VLFLplot (VL,FL,'w'), axis equal, view(-30,30); VLFLplotlight (1);
VLFLwriteSTL (VL,FL,'A','EXP04-intersect')
```

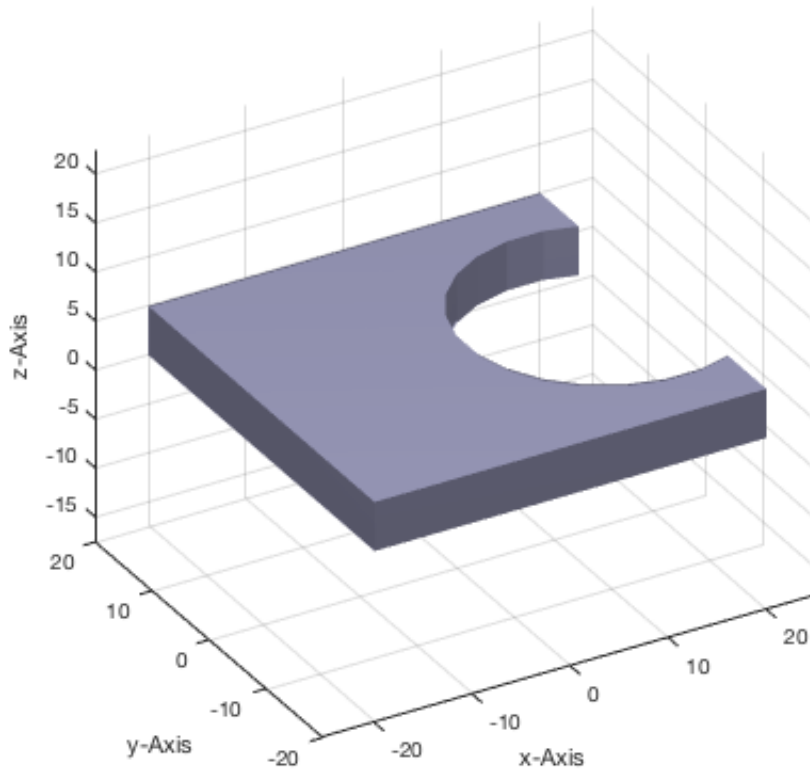
WRITING STL FILE /Users/timlueth/Desktop/A.STL in ASCII MODE
completed.



7. Subtract contour B from A: `CPL=CPLpolybool('-',PLA,PLB)`

```
close all
CPL=CPLpolybool('-',PLA,PLB); [VL,FL]=VLFLofCPLz(CPL,5);
VLFLplot(VL,FL,'w'), axis equal, view(-30,30); VLFLplotlight(1);
VLFLwriteSTL(VL,FL,'A','EXP04-AminusB')
```

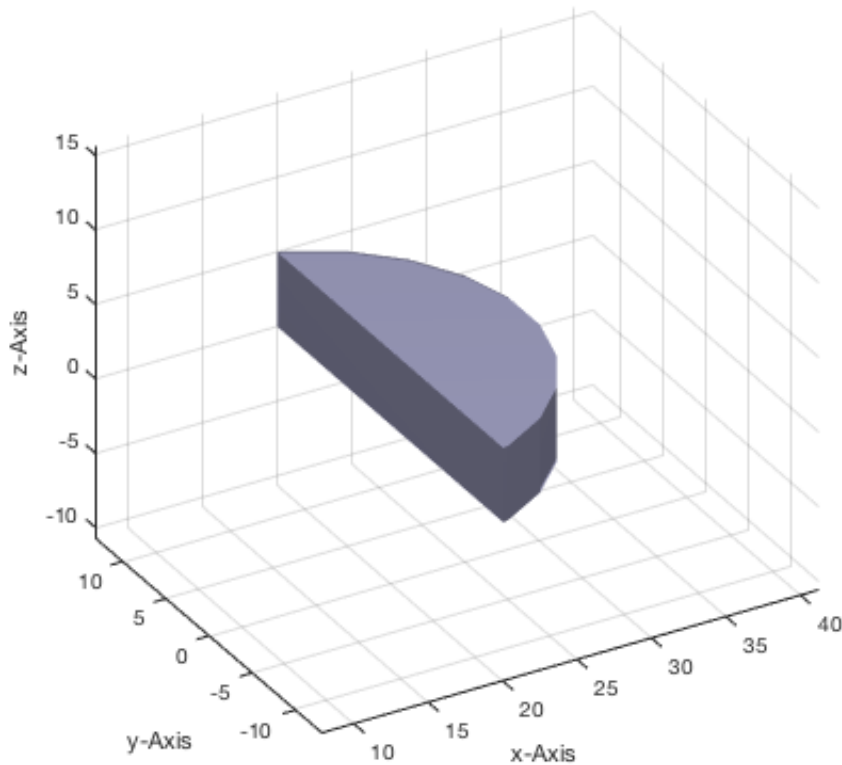
WRITING STL FILE /Users/timlueth/Desktop/A.STL in ASCII MODE
completed.



8. Subtract contour A from B: `CPL=CPLpolybool('-',PLB,PLA)`

```
close all
CPL=CPLpolybool('-',PLB,PLA); [VL,FL]=VLFLofCPLz(CPL,5);
VLFLplot (VL,FL,'w'), axis equal, view(-30,30); VLFLplotlight (1);
VLFLwriteSTL (VL,FL,'EXP04-AminusB')
```

WRITING STL FILE /Users/timlueth/Desktop/EXP04-AminusB.STL in ASCII MODE completed.



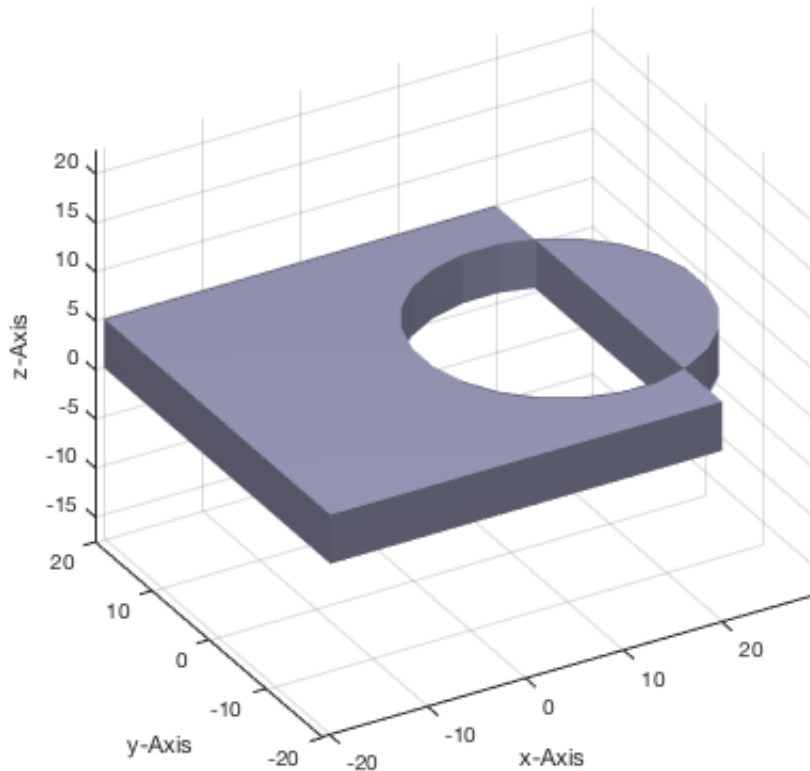
9. Exclusive or of contour A and B: CPLpolybool('xor',PLB,PLA)

```
close all
CPL=CPLpolybool('xor',PLB,PLA); [VL,FL]=VLFLofCPLz(CPL,5);
VLFLplot(VL,FL,'w'), axis equal, view(-30,30); VLFLplotlight(1);
VLFLwriteSTL(VL,FL,'EXP04-AxorB')
% VLFLviewer(VL,FL);
```

Warning: Duplicate data points have been detected and removed.

The Triangulation indices and Constraints are defined with respect to the unique set of points in DelaunayTri property X.

WRITING STL FILE /Users/timlueth/Desktop/EXP04-AxorB.STL in ASCII MODE completed.



10. Checking the solid volumes for 3D printing

During the last extrusion we got a warning from a Delaunay-triangulation during the extrusion function VLFLofCPLz. This is typically a warning that somehow the final part cannot be printed with a 3D printing process such as FDM, SLS, 3DP etc. Here in this case, the result of xor were two parts that touch each other at two edges. Such a part cannot be printed. The reason behind is called non-manifold edge problem. There are also problems with non manifold points and non-manifold facets.

```
VLFLchecker (VL,FL);
```

```
VLFLchecker: 60 vertices and 120 facets.
  0 FACET PROBLEMS DETECTED (ERRORS)
  0 VERTEX PROBLEMS DETECTED (OBSOLETE WARNING)
  4 EDGE PROBLEMS DETECTED (NON MANIFOLD WARNING)
  0 SOLID/EDGE PROBLEMS DETECTED (OPEN SOLID WARNING)
```

Final remarks on toolbox version and execution date

```
VLFLlicense
```

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
```

```
Executed 27-Feb-2017 16:40:54 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
map_toolbox
matlab
simulink
=====
=====
```

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-21*
- *Mattias Traeger, executed and published on 64 Bit PC using Windows with Matlab 2014b on 2014-11-21*

Published with MATLAB® R2016b

Exercise 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)

2014-11-22: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Creating, plotting, writing of the struct *Solid Geometry* (SG)
- 3. Spatial transformations of solid geometries and *sets of solid geometries*
- 4. Merging of solid geometries (SG) and sets of solid geometries
- 5. Non-manifold points, edges, and facets of solid geometries (SG)
- 6. Additive Design: Separate or penetrate solid geometries (SG)
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-4 we've learned about:

- Point lists (PL), vertex lists (VL), facet lists (FL) and edge lists (EL)
- Functions to import, check, and export of STL-Data
- Functions for generating text strings as solid objects
- Closed polygon lists (CPL) for boolesche operations of even embedded contours
- 2½D design by extrusion of closed polygon lists
- Spatial transformation of objects in 2D and 3D

2. Creating, plotting, writing of the struct *Solid Geometry* (SG)

Even if it is useful to know that a vertex list (VL), and a facet list (FL) is required for 3D modeling, it is more convenient to use matlab structs for solid geometries (SG). Instead of writing VL or FL, we use SG.VL, SG.FL as variables. The advantage is, that each solid object is described by one struct that contains vertex list and facet list, but can contain other defined information (such as the underlying CPL, PL or EL) or it is open for your own defined information.

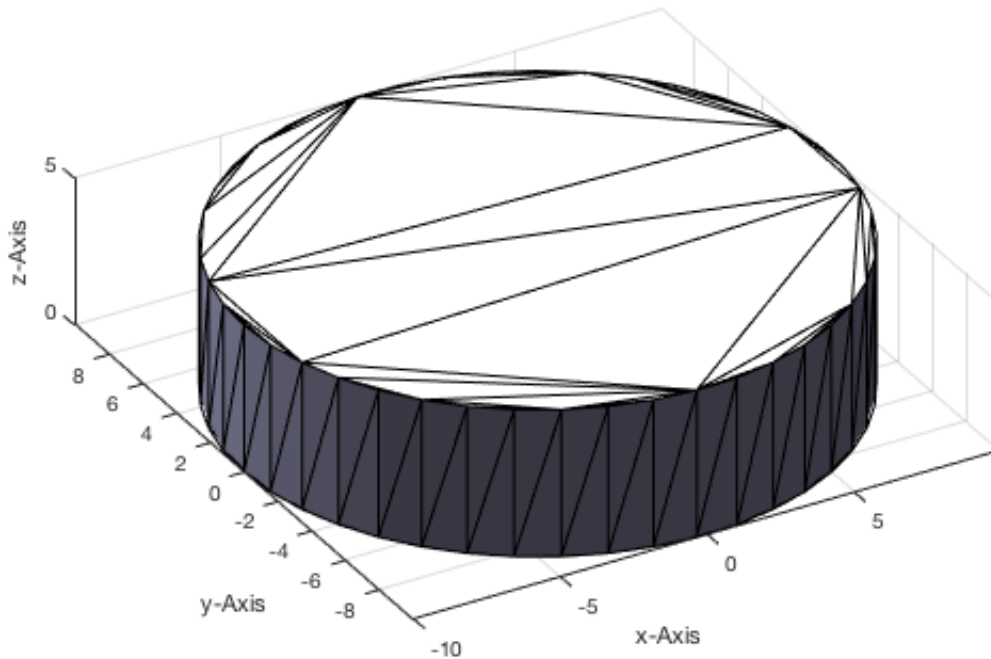
- **SGofCPLz** for extruding a solid object from a CPL similar to VLFLofCPLz.
- **SGplot** for plotting one or more solid objects similar VLFLplots.
- **SGchecker** for checking a solid object similar to VLFLchecker.
- **SGwriteSTL** for writing a solid object similar to VLFLwriteSTLb.
- **SGsize** for generating the bounding box of a solid geometry (SG).

```
close all;
nSG=SGofCPLz(PLcircle(10),5)
SGplot(nSG,'r',1); VLFLplotlight(1); view (-30,30);
SGchecker(nSG);
SGwriteSTL (nSG,'EXP05-1');
```

nSG =

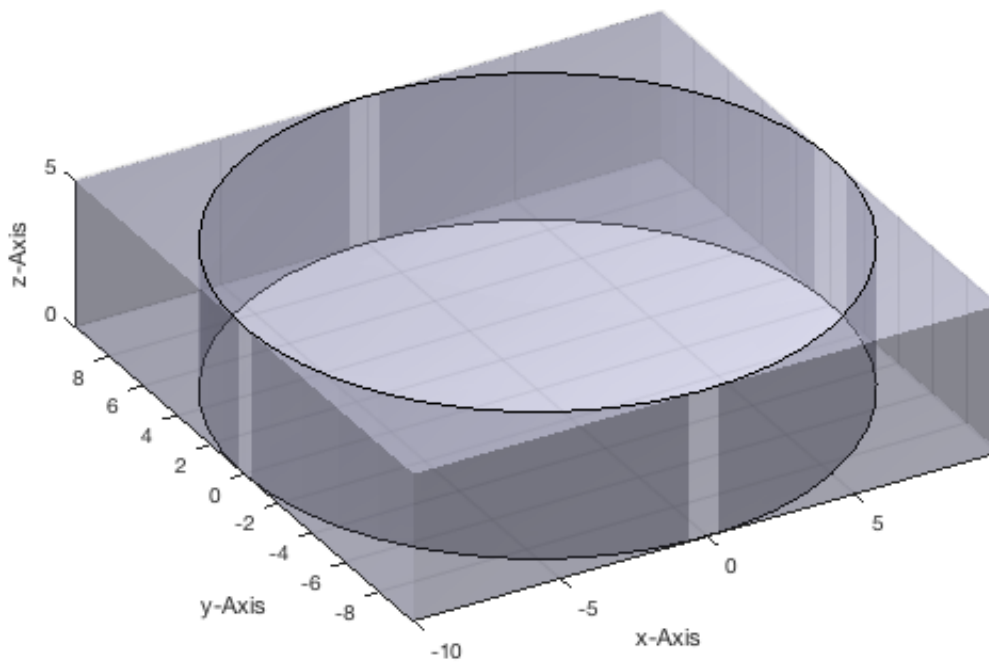
struct with fields:

```
CPL: [45×2 double]
VL: [90×3 double]
FL: [176×3 double]
PL: [45×2 double]
EL: [45×2 double]
```



Often it is useful to know the size of the bounding box of an object and to plot it.

```
bs=SGsize(nSG); [BB.VL,BB.FL]=VLFLofBB(bs); SGplot (BB,'w'); VLFLplotlight(1,0.4);
```

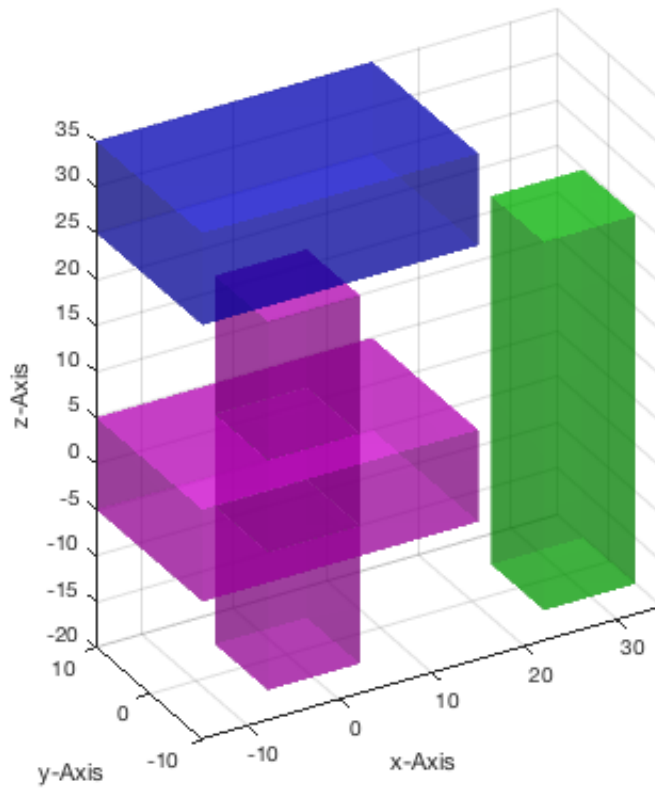


3. Spatial transformations of solid geometries and sets of solid geometries

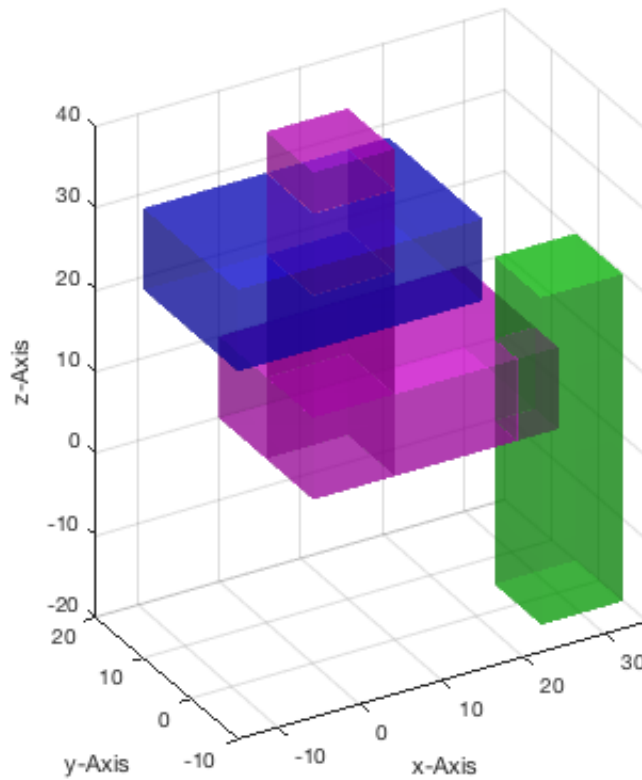
In contrast to manipulate an individual solid geometry as struct, it is often useful to manipulate or handle a set of solid geometries. For this purpose, we use the cell concept of Matlab. `A=SGbox([30,20,10]);` {A, A, A} is a set of three solid geometries that can be given as arguments of a function and can also be the output argument of a function.

- **SGbox** creates a simple box at the origin indimensions [x y z].
- **SGtransP** moves a solid geometry (SG) or a set of SG by a translation vector.
- **SGtransR** rotate a solid geometry (SG) or a set of SG by a rotation matrix .
- **SGtransT** transform a solid geometry (SG) or a set by a homogenous transformation matrix.
- **SGtrans0** moves a solid geometry (SG) or a set of SG into the coordinate systems origin.
- **SGtrans1** moves a solid geometry (SG) or a set of SG into quadrant 1.

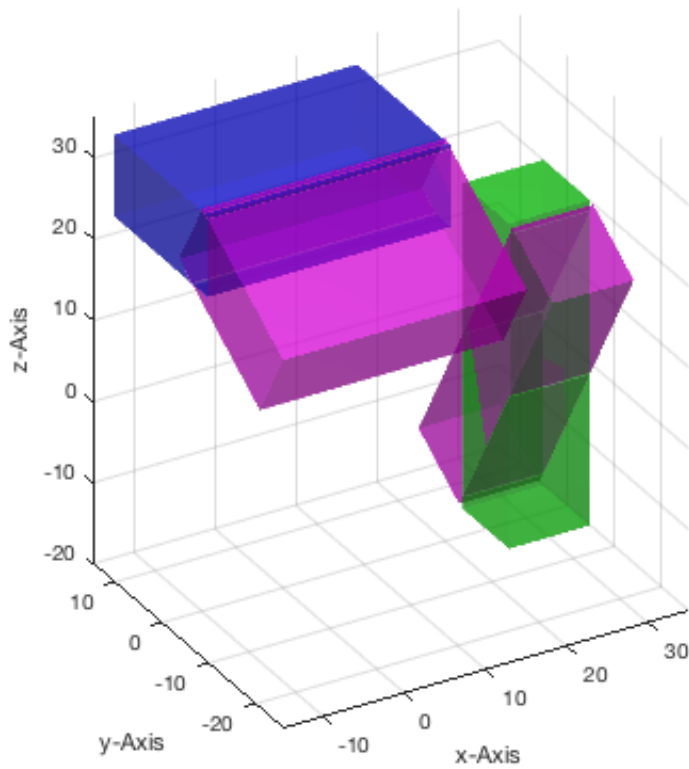
```
close all;
A=SGtransP(SGbox([30,20,10]),[0;0;30]); SGplot (A,'b'); show;
B=SGtransP(SGbox([10,10,40]),[30;0;0]); SGplot (B,'g'); show
view (-30,30);
SGplot(SGtrans0({A,B}),'m'); VLFLplotlight (1,0.5)
```



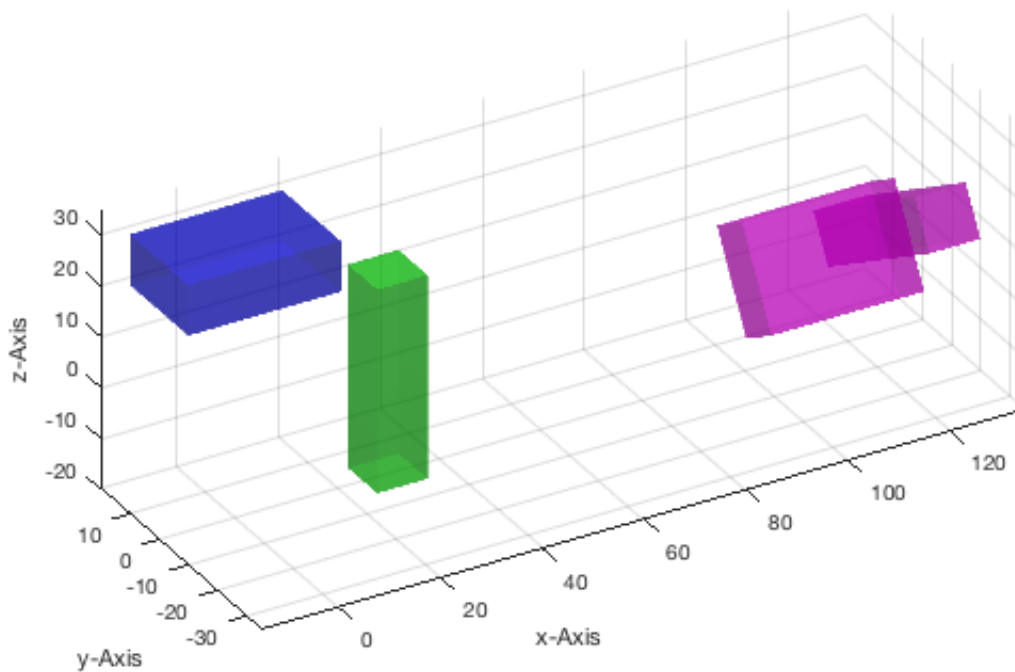
```
close all;
A=SGtransP(SGbox([30,20,10]),[0;0;30]); SGplot (A,'b'); show;
B=SGtransP(SGbox([10,10,40]),[30;0;0]); SGplot (B,'g'); show
view (-30,30);
SGplot(SGtransl({A,B}),'m'); VLFLplotlight (1,0.5)
```

```
close all;
A=SGtransP(SGbox([30,20,10]),[0;0;30]); SGplot (A,'b'); show;
B=SGtransP(SGbox([10,10,40]),[30;0;0]); SGplot (B,'g'); show
view (-30,30);
SGplot(SGtransR({A,B},rot(pi/6,0,0)), 'm'); VLFLplotlight (1,0.5)
```



```
close all;
A=SGtransP(SGbox([30,20,10]),[0;0;30]); SGplot (A,'b'); show;
B=SGtransP(SGbox([10,10,40]),[30;0;0]); SGplot (B,'g'); show
view (-30,30);
SGplot(SGtransT({A,B},[rot(pi/3,0,0),[100;0;0]]),'m'); VLFLplotlight (1,0.5)
```

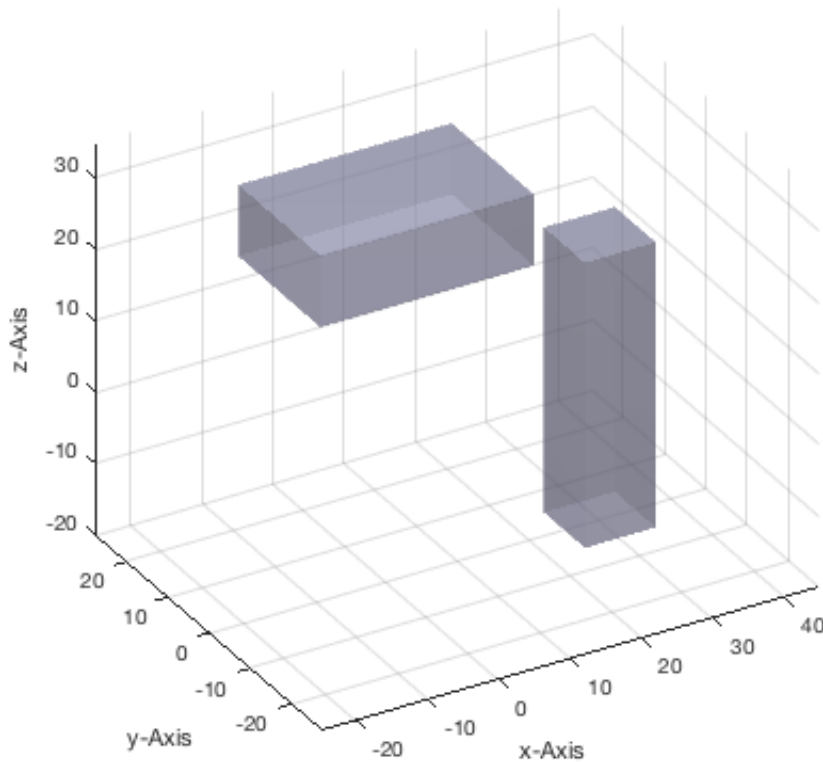


4. Merging of solid geometries (SG) and sets of solid geometries

In the previous example we often created and manipulated two solids. As explained, it is possible to handle several objects at the same time by using sets of elements. Nevertheless, in most cases, after some operations we want to merge several solid geometries into one single object. SGcat concatenates the vertex list and the facet list of a set of given solids into one list. Furthermore like in VLFLcat, doubled vertices are detected and removed. It is not possible anymore to separate the objects in general afterwards.

- **VLFLcat** merges two VL/FL into one VL/FL.
- **VLFLcat2** simply concatenates two VL/FL into one VL/FL.
- **SGcat** merges single solids or a set of solids into one solid object.

```
close all;
nSG=SGcat ({A,B}); SGplot (nSG,'w'); view (-30,30); VLFLplotlight (1,0.5)
SGwriteSTL (nSG,'EXP05-2');
```

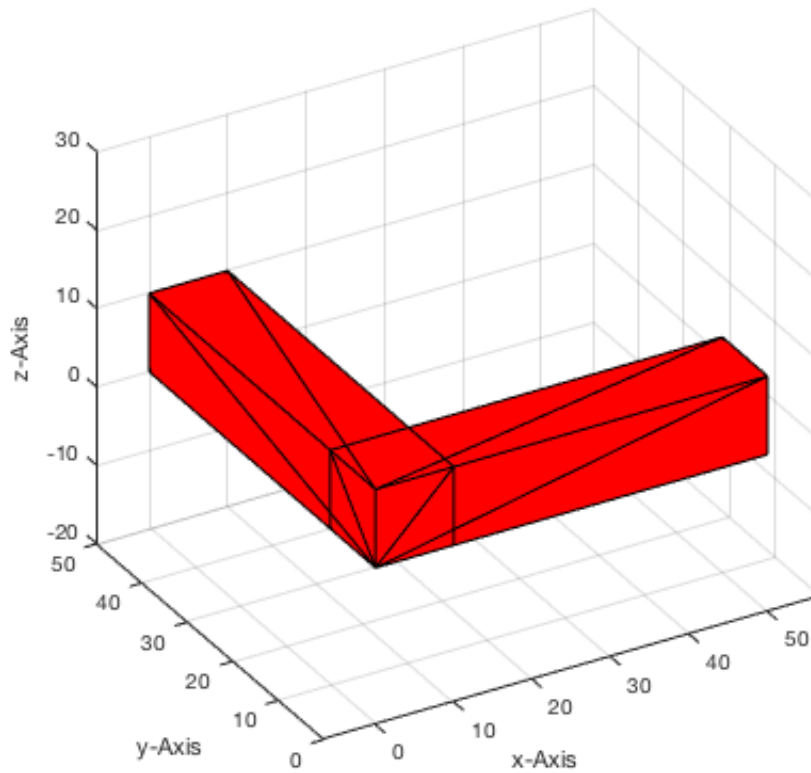


5. Non-manifold points, edges, and facets of solid geometries (SG)

By using functions such as SGcat or VLFLcat/VLcat2, it is very easy and efficient to create solid models and STL-files by simply attaching or penetrating individual solid objects. It is some kind of *additive design of solid objects* in 3D. For a 3D printing process, those additive designed objects are not a real problem, i.e. several independent parts are simply attached or penetrate each other. 3D contour printing of penetrating objects is automatically handled by the slicer, a piece of software that we get to know later.

Nevertheless, as soon as a vertex is used by two independent solids, an edge is used by two independent solids. In this case a slicer software will not be able to solve the manifold problem.

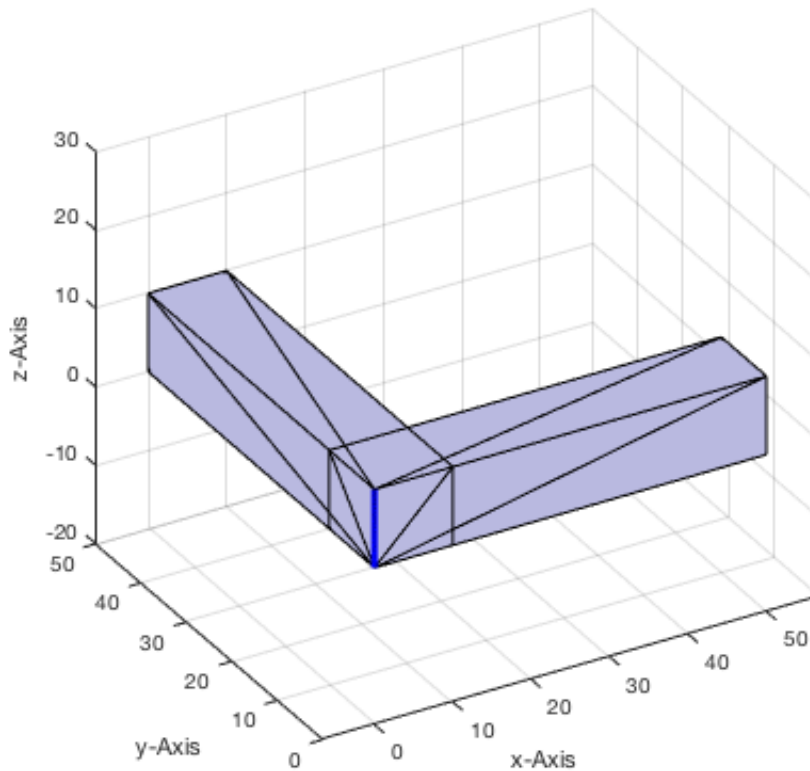
```
close all;
A=SGtransl(SGbox([10,50,10])); B=SGtransl(SGbox([50,10,10]));
nSG=SGcat({A,B}); SGplot (nSG); view (-30,30);
[VL,EL,PEL]=SGchecker (nSG);
if ~isempty(VL); VLFLplots (VL(:,2:4),PEL,'m*- ',4); VLFLplotlight (1,0.7); end
```



If we call SGchecker with a second argument ('plot'), we get a figure showing the non manifold objects that generate the conflict

```
close all; SGchecker (nSG, 'plot');
```

2 edges [blue] are doubled, not removed



6. Additive Design: Separate or penetrate solid geometries (SG)

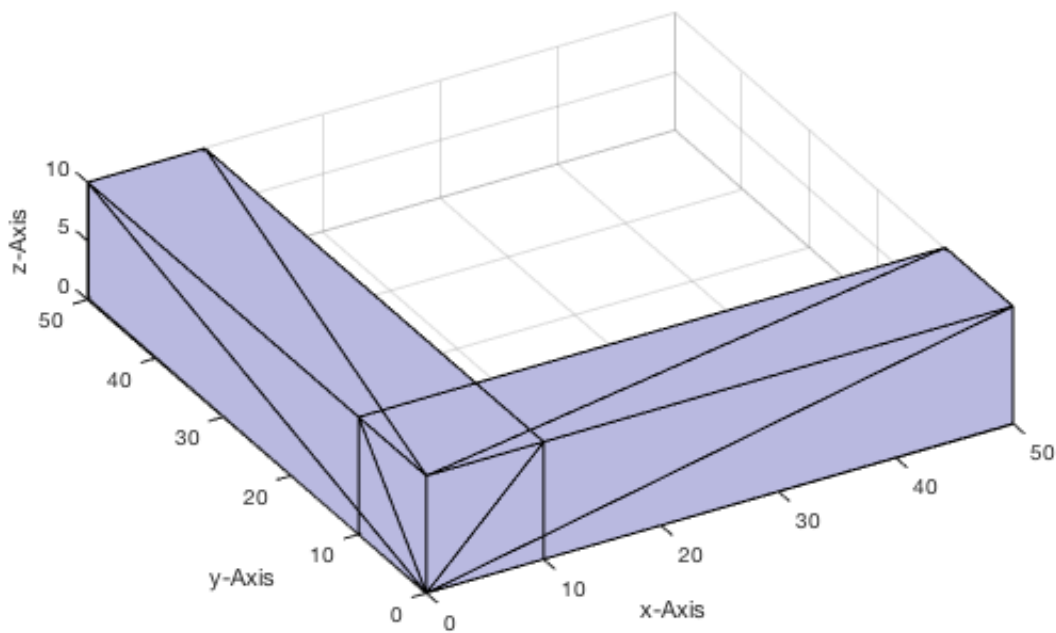
During additive solid geometry design, we will always get problems with non-manifold points or edges, as long as we try always to align objects point-to-point, edge-to-edge or face-to-face. As a basic rule, it is better to shorten or increase the length of a object slightly by a micrometer and do not align it with another face, edge, point. Even if the number of points of a solid geometry is increased by this strategy, the number of facets of this solid is decreased. Additive solid geometry design is therefore, not an inefficient but an efficient design methodology.

```
close all;
slot=1e-3;
A=SGtransl(SGbox([10,50,10]));
B=SGtransl(SGbox([50,10,10])); B=SGtransP(B,[slot;0;0]);
nSG=SGcat({A,B});
SGchecker (nSG,'plot');
```

==> SGchecker: 2 Surfaces to check.

Surface 1:

Surface 2:



The value for shifting the object about 1 micrometer is much lower than the manufacturing accuracy of the 3D printer. Anyway, if this would not be the case, then simply change it to 1 nanometer ($1e-6$) or one picometer ($1e-9$) if we consider a millimeter as default integer unit. It is also clear that we can automate the correction by simply splitting the objects and adding a random submicrometer value to the coordinates.

Another possibility is separating the objects instead of penetrating them. This will lead to the same solution to avoid non manifold edges. Nevertheless, some manufacturing preprocessors analyze STL-Files and detect objects that are separated and do not penetrate each other. These objects are then separated and repositioned in the 3D printing working volume to optimize the use of the print job's working volumen and material use.

The later presented function for relative spatial alignment of solid geometries will support a parameter for a gap between objects. Negative gap sizes correspond to a slightly penetration of the solid geometries.

Final remarks on toolbox version and execution date

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:41:04 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
map_toolbox
matlab
```

simulink

=====

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-23*
- *Tim Lueth, executed and published on 64 Bit PC using Windows with Matlab 2014b on YYYY-MMM-DD*

.....

Published with MATLAB® R2016b

Exercise 06: Relative Positioning and Alignment of Solid Geometries (SG)

2014-11-24: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Relative spatial positioning of solid geometries (SG) using bounding boxes
- 3. Relative spatial alignment of solid geometries (SG) using bounding boxes
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-5 we've learned about:

- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (FL), *Edge lists* (EL)
- Functions to import, check, and export of *STL-File* data
- Functions for generating text strings as solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation and merging of solid geometry sets

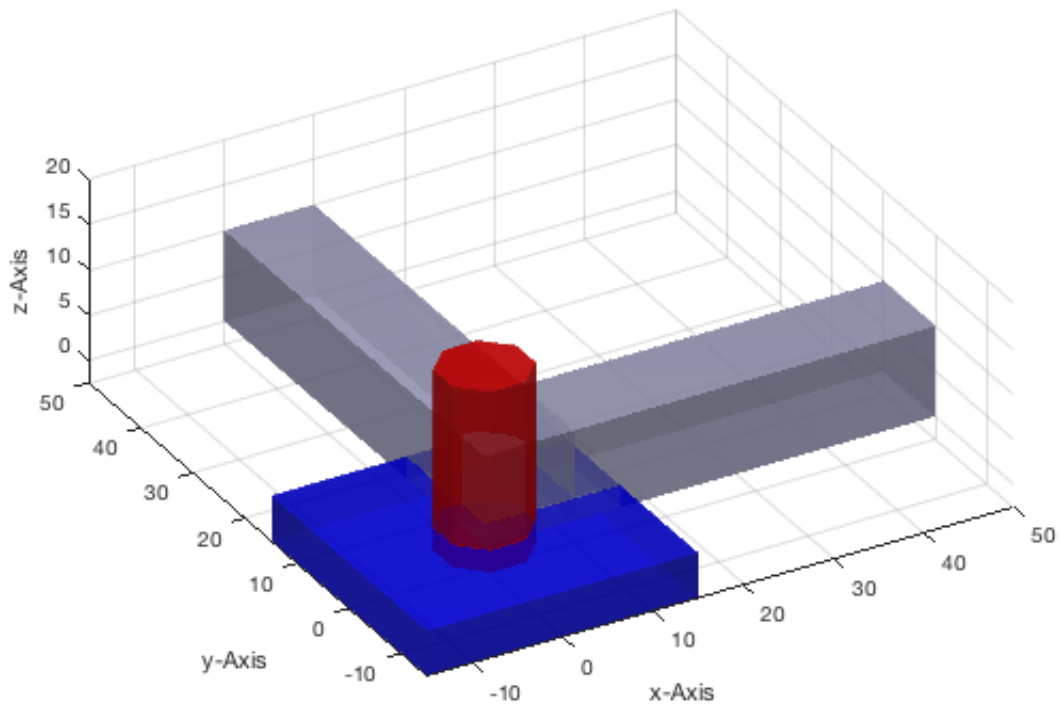
2. Relative spatial positioning of solid geometries (SG) using bounding boxes

Since it is quite convenient to use solid geometries (SG), there is a need for relative spatial positioning of these objects. For 'on top', 'under' (modifies the z-coordinates), 'in front', 'behind' (modifies the y-coordinates), 'left' and 'right' (modifies the x-coordinates), we have six different positioning functions that generate copies of the SG with just a changed vertex list. A third parameter of those functions is a gap, that can be defined. A positive gap value means a separation of those solids, a negative gap value means a penetration of those solids.

- **SGontop** positions a solid geometry 'A' on top of solid geometry 'B'
- **SGunder** positions a solid geometry 'A' under of solid geometry 'B'
- **SGinfront** positions a solid geometry 'A' in front of solid geometry 'B'
- **SGbehind** positions a solid geometry 'A' behind of solid geometry 'B'
- **SGleft** positions a solid geometry 'A' left of solid geometry 'B'
- **SGright** positions a solid geometry 'A' right of solid geometry 'B'

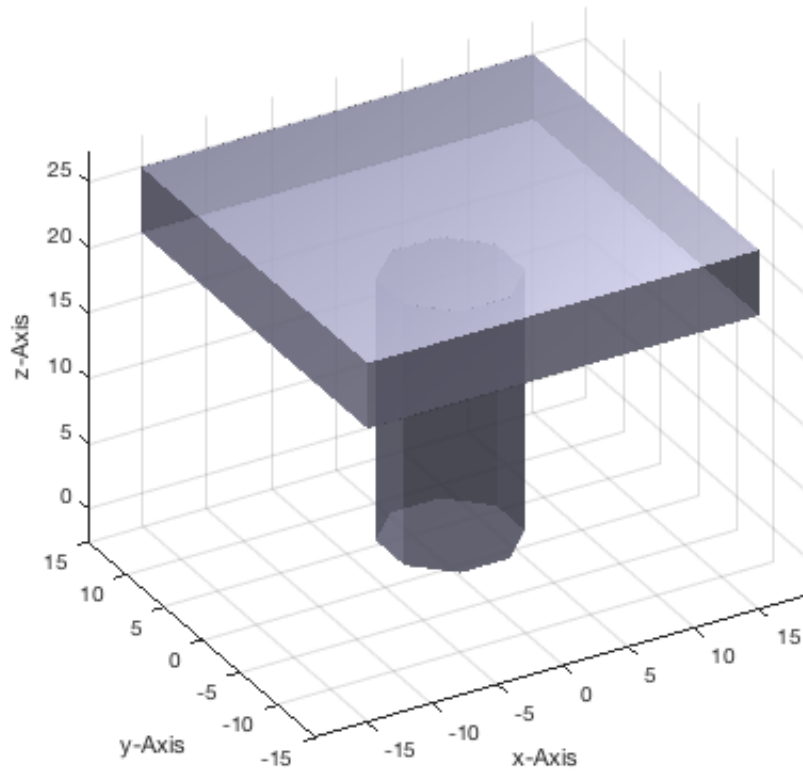
Define two solid geometrys 'A' and 'B'

```
close;
A=SGbox([30,30,5]); B=SGofCPLz(PLcircle(5,8),20);
SGplot (A, 'b'); SGplot (B, 'r'); VLFLplotlight(1,0.7); view (-30,30);
```



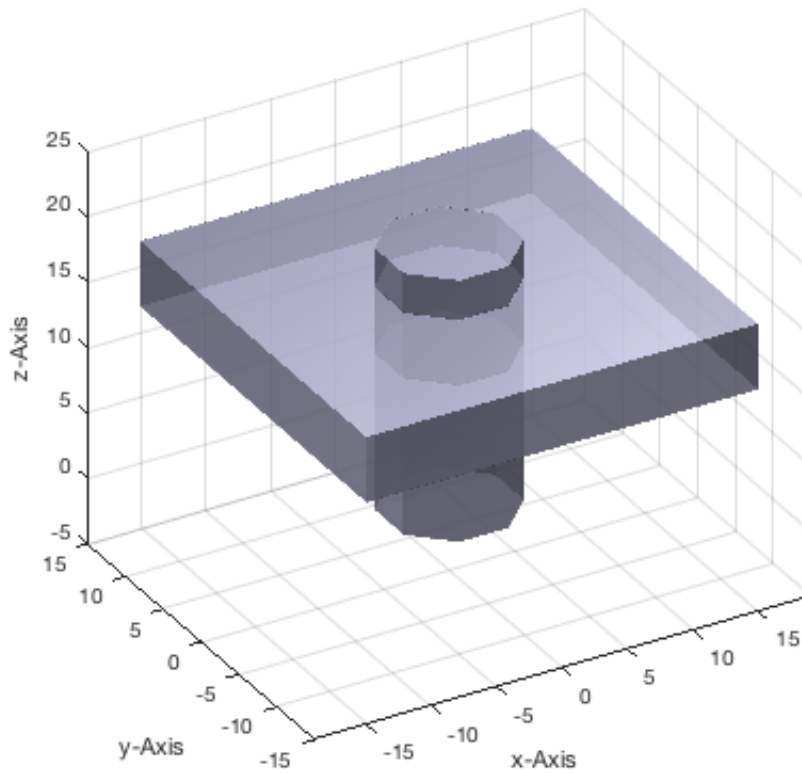
SGontop positions a solid geometry 'A' on top of solid geometry 'B'

```
close;  
SG=SGcat(SGontop(A,B),B);  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



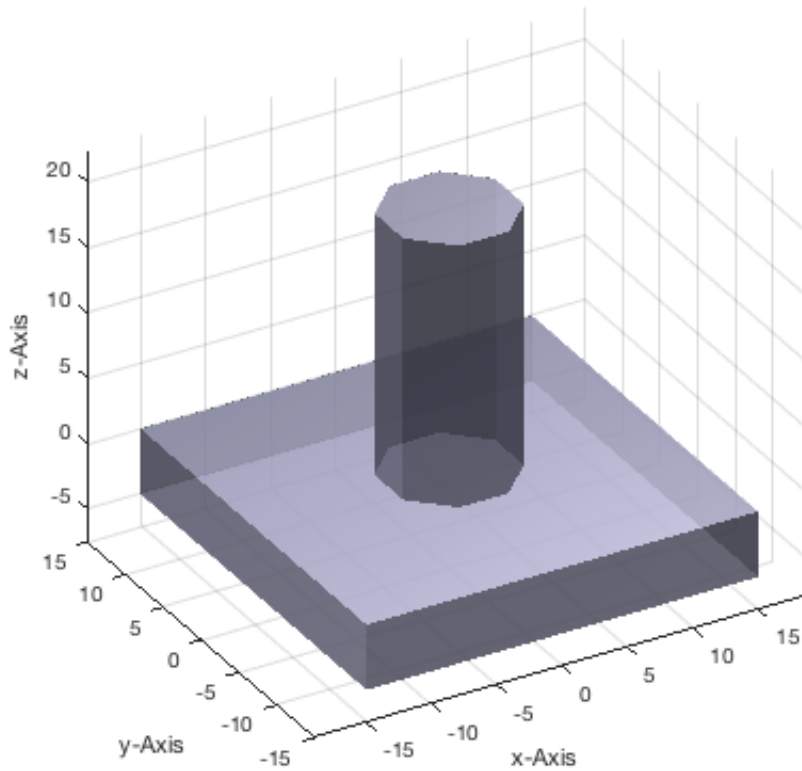
SGontop positions a solid geometry 'A' on top of solid geometry 'B' with a gap of -8

```
close all;
SG=SGcat(SGontop(A,B,-8),B);
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



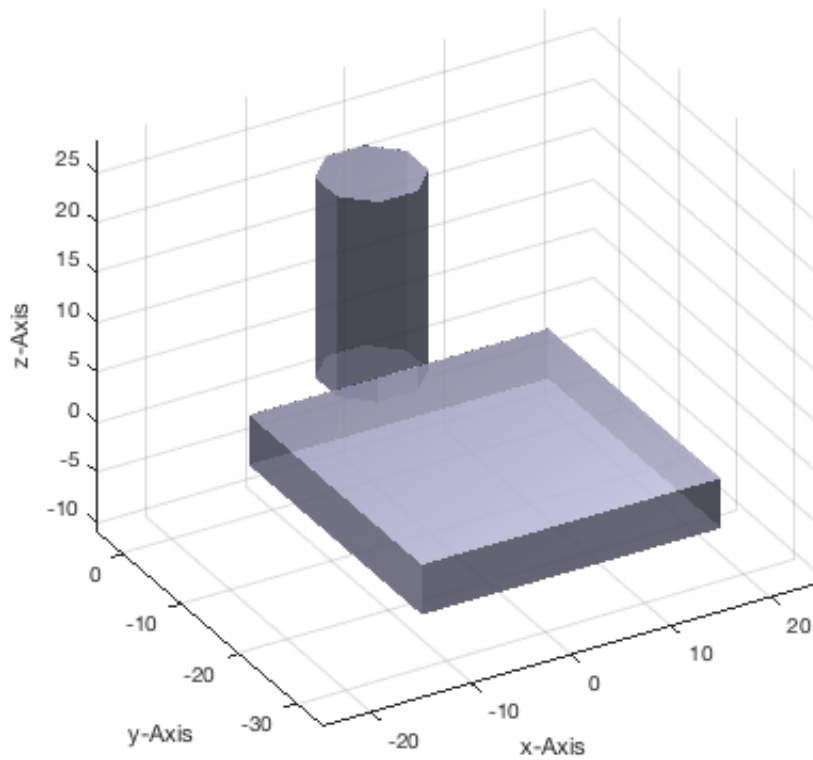
SGunder positions a solid geometry 'A' under of solid geometry 'B'

```
close all;  
SG=SGcat(SGunder(A,B),B);  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



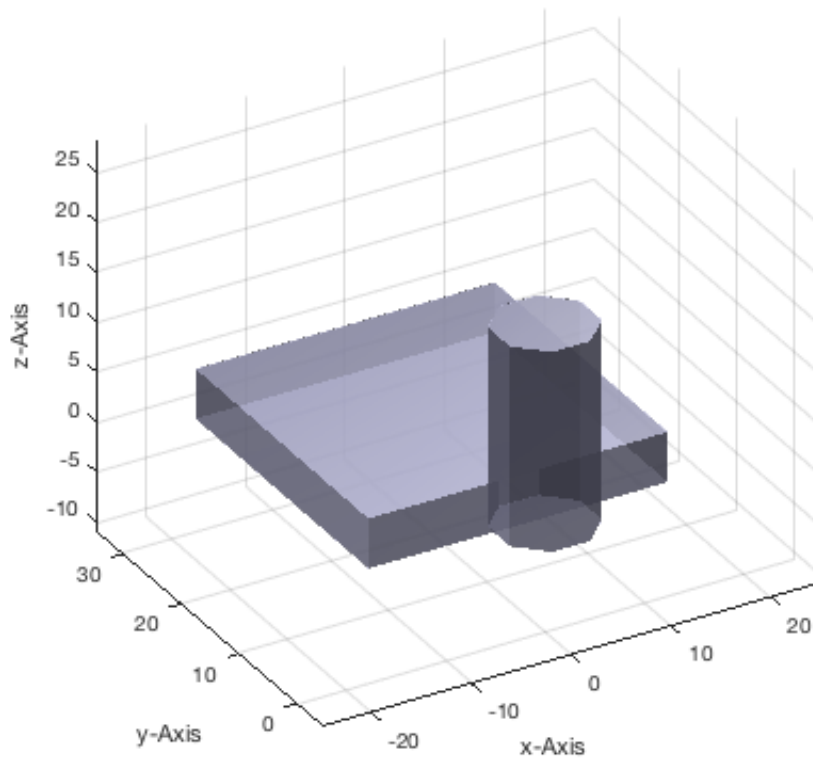
SGinfront positions a solid geometry 'A' in front of solid geometry 'B'

```
close all;  
SG=SGcat(SGinfront (A,B),B);  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



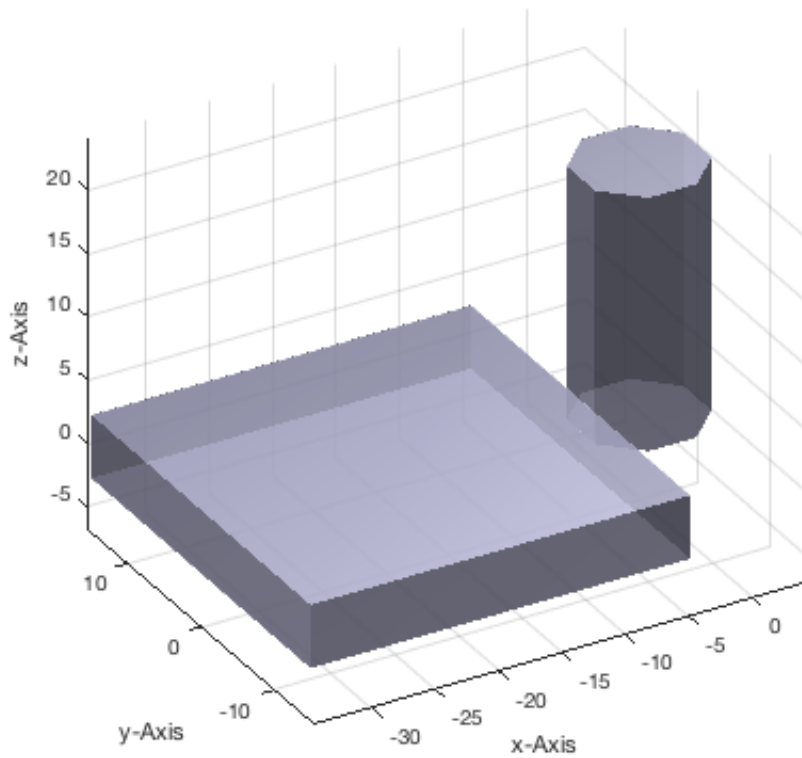
SGbehind positions a solid geometry 'A' behind of solid geometry 'B'

```
close all;  
SG=SGcat(SGbehind (A,B),B);  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



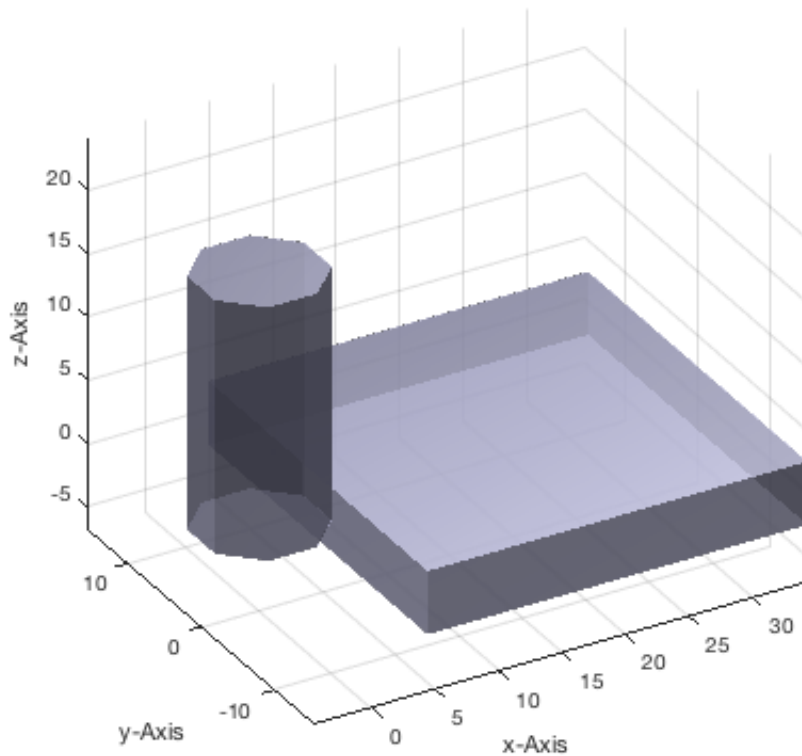
SGleft positions a solid geometry 'A' left of solid geometry 'B'

```
close all;  
SG=SGcat(SGleft (A,B),B);  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



SGrignt positions a solid geometry 'A' right of solid geometry 'B'

```
close all;  
SG=SGcat(SGrignt (A,B),B);  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```

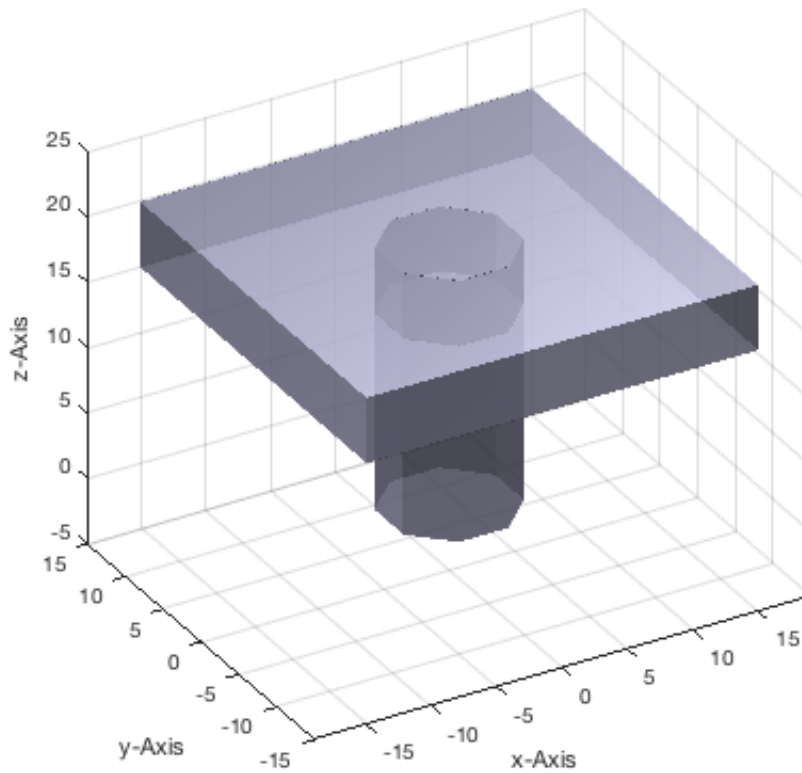
3. Relative spatial alignment of solid geometries (SG) using bounding boxes

Similar to the relative positioning, also the spatial alignment is helpful. For example solid A is aligned with solid B to achieve the same 'top', 'bottom' (modifies the z-coordinates), 'front', 'back' (modifies the y-coordinates), 'left side' or 'right side' (modifies the x-coordinates).

- **SGaligntop** aligns the top of solid A with the top of solid B
- **SGalignbottom** aligns the bottom of solid A with the bottom of solid B
- **SGalignfront** aligns the front of solid A with the front of solid B
- **SGalignback** aligns the back of solid A with the back of solid B
- **SGalignleft** aligns the left side of solid A with the left side of solid B
- **SGalignright** aligns the right side of solid A with the right side of solid B

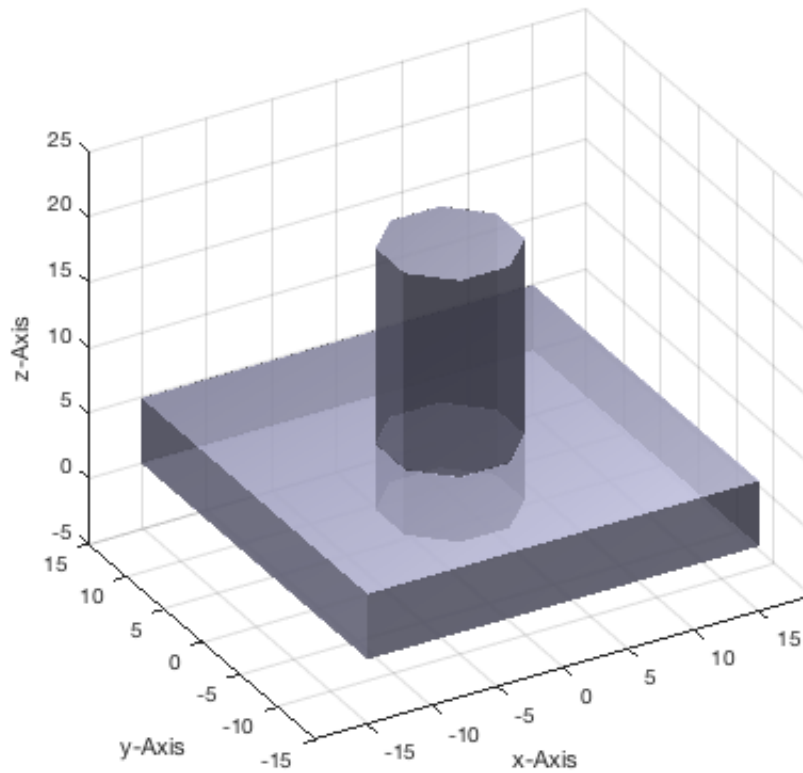
SGaligntop aligns the top of solid A with the top of solid B

```
close all;
SG=SGcat({SGaligntop(A,B),B});
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



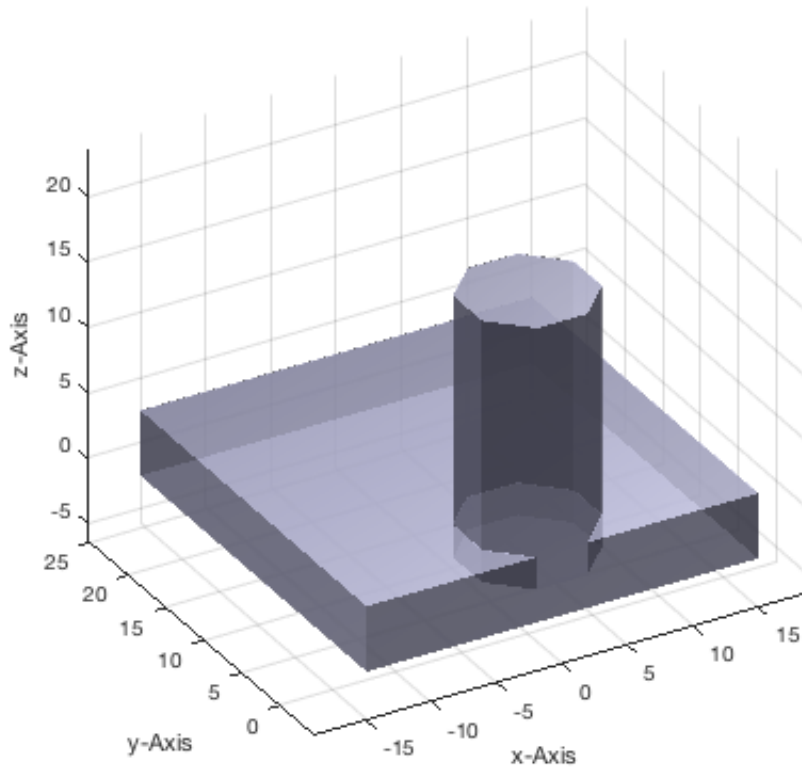
SGalignbottom aligns the bottom of solid A with the bottom of solid B

```
close all;  
SG=SGcat({SGalignbottom(A,B),B});  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



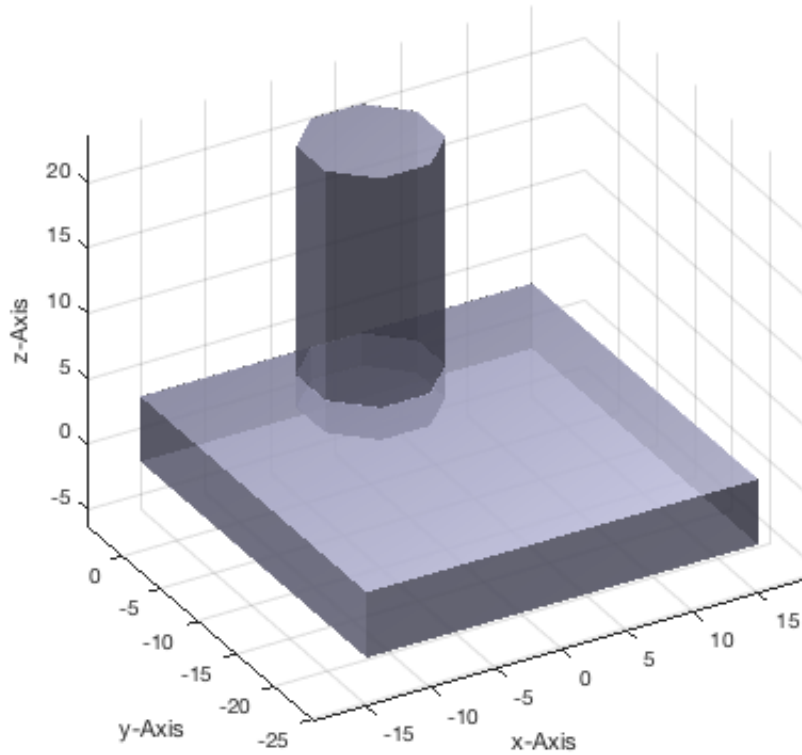
SGalignfront aligns the front of solid A with the front of solid B

```
close all;  
SG=SGcat({SGalignfront(A,B),B});  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



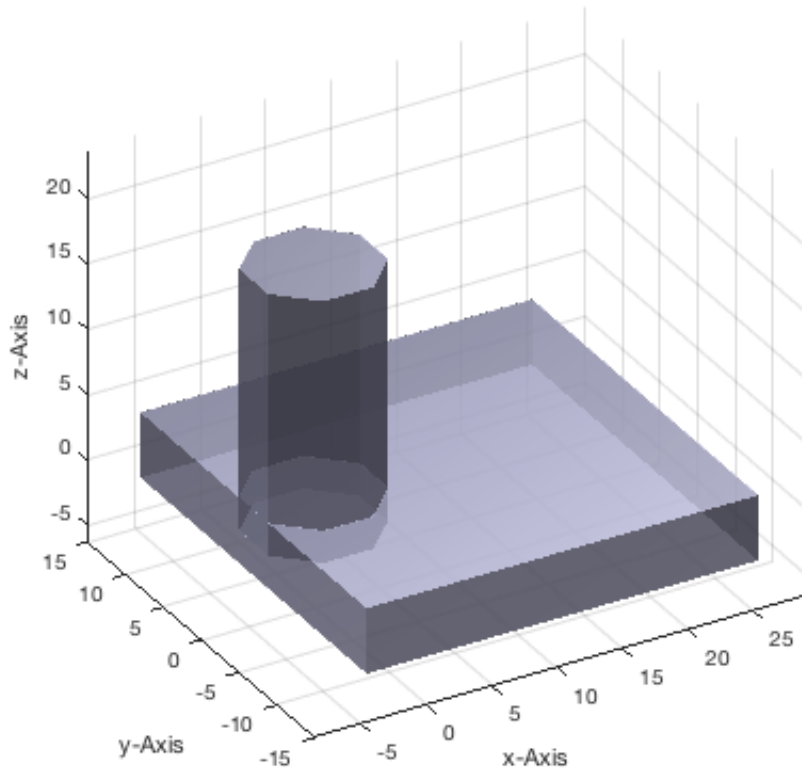
SGalignback aligns the back of solid A with the back of solid B

```
close all;  
SG=SGcat({SGalignback(A,B),B});  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



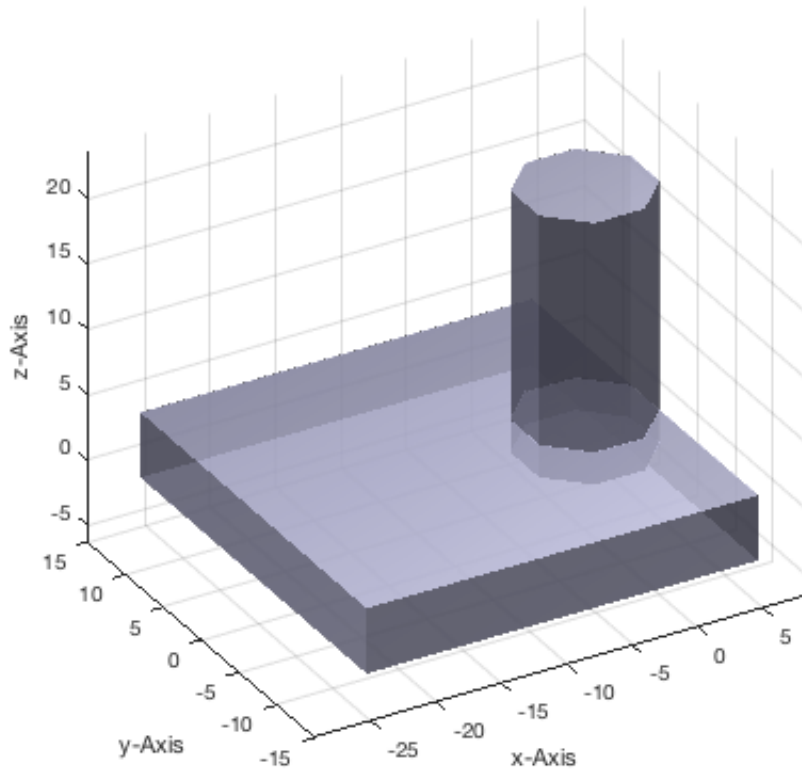
SGalignleft aligns the left side of solid A with the left side of solid B

```
close all;  
SG=SGcat({SGalignleft(A,B),B});  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



SGalignright aligns the right side of solid A with the right side of solid B

```
close all;  
SG=SGcat({SGalignright(A,B),B});  
SGplot (SG,'w'); VLFLplotlight(1,0.7); view (-30,30);
```



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:41:13 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-25
- Mattias Traeger, executed and published on 64 Bit PC using Windows with Matlab 2014b on YYYY-MMM-DD

Published with MATLAB® R2016b

Exercise 07: Rotation of Closed Polygon Lists for Solid Geometry Design

2014-11-26: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. List of functions used in this example
- 3. Rotation of closed polygon lists (CPL)
- 4. Creating spheres by rotating half-circles
- 5. Creating embedded contours
- 6. Rotate Contours around the z-axis
- 7. Samples of 3D Design
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-6 we've learned about:

- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (FL), *Edge lists* (EL)
- Import, and export of *STL-File* data, Conversion of text strings into solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation, positioning, alignment and merging of solid geometry sets

2. List of functions used in this example

As we learned in example 2 and 4, it is possible to extrude a planar point list (PL) or closed polygon (CPL) list into a 2.5D solid geometry. Now, we will rotate a CPL around the z-axis. In this case, we consider the CPL or the PL always as a x/z-list. Using closed polygon lists, we have to remember that before extruding them or rotating them it is necessary to guarantee that the outer contour has a counter-clockwise order (ccw).

In this example, some new functions are introduced:

- **CPLplot** to draw the closed polygon list in the x/y plane.
- **PLELofCPL** to draw the direction, starting point and end point.
- **CPLuniteCPL** to unite several CPL into one and adapt their original directions.
- **SGofCPLrot** to rotate a contour around the z-axis

3. Rotation of closed polygon lists (CPL)

For the rotation of a simple contour we use the following functions

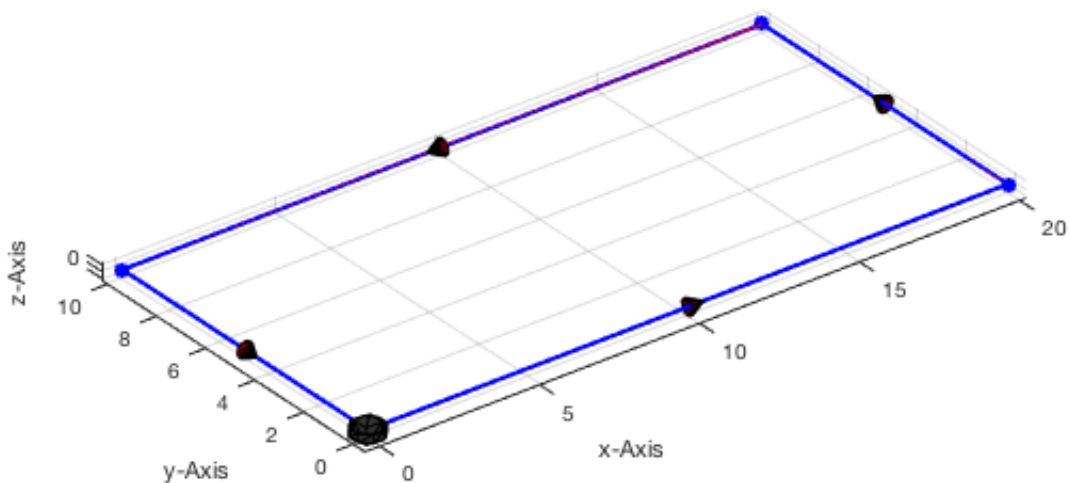
- **CPLplot** to draw the closed polygon list in the x/y plane.
- **PLELofCPL** to draw the direction, starting point and end point.
- **SGofCPLrot** to rotate a contour around the z-axis

Exercise: Create a simple point list that touches the y-axis

```

close all;
CPL=[0 0; 20 0; 20 10; 0 10];           % Create a simple rectangle (ccw)
CPLplot(CPL);                             % plot the rectangle
PLELofCPL(CPL);                           % show edges and directions

```

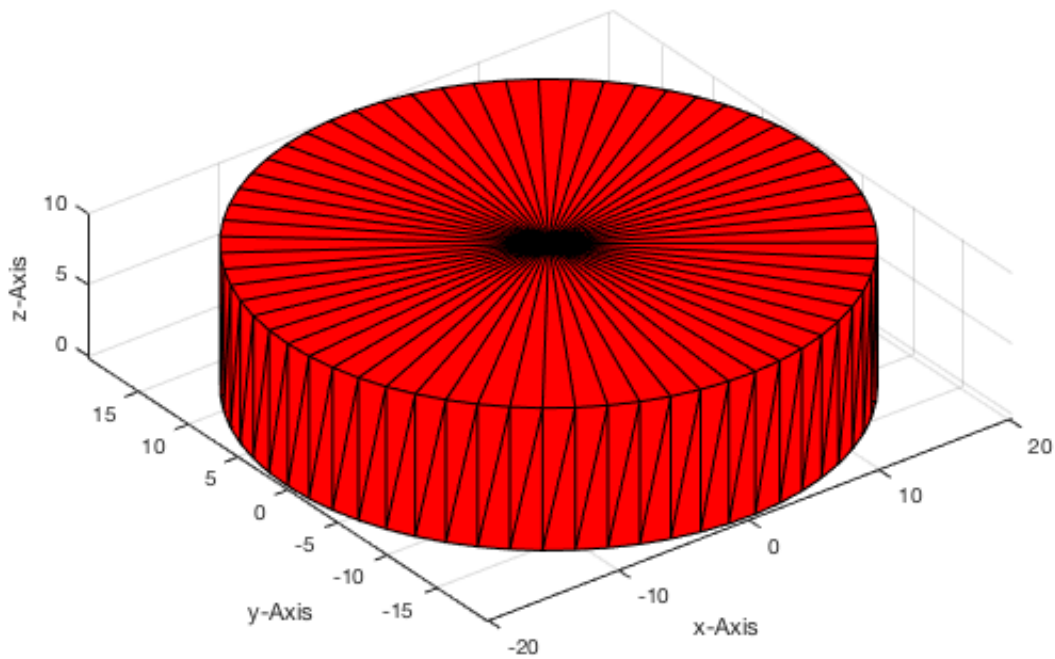
**Exercise: Rotate the point list around the z-axis to create a cylinder**

```

SG=SGofCPLrot(CPL);                       % Solid contour rotation
SGplot(SG);                               % show the solid

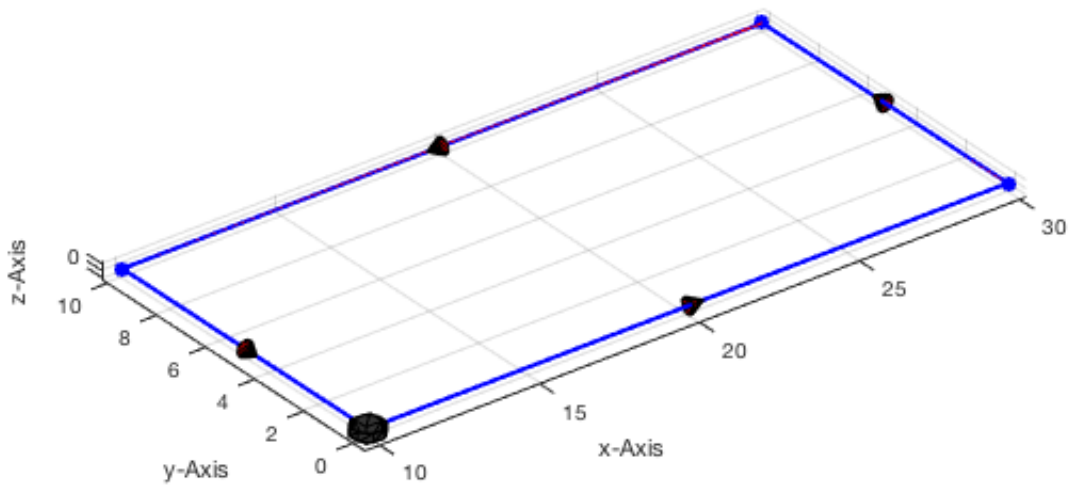
```

Removed 252(504) facets



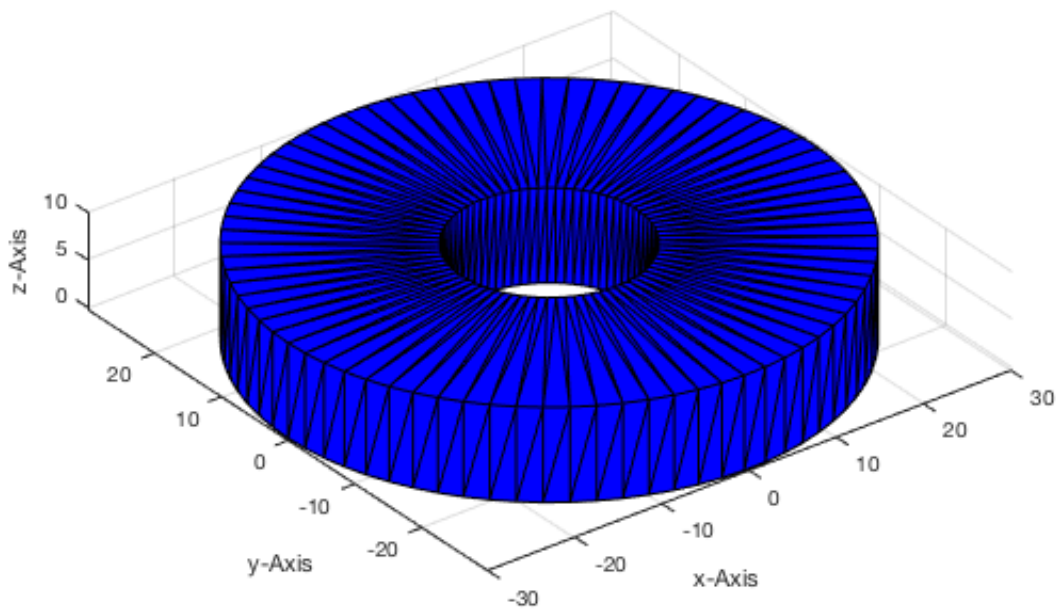
Exercise: Create a simple point list with distance to the y-axis

```
close all;
CPL=[0 0; 20 0; 20 10; 0 10];      % Create a simple rectangle (ccw)
CPL(:,1)=CPL(:,1)+10;               % shift by 1 on the x-axis
CPLplot(CPL);                       % plot the rectangle
PLELofCPL(CPL);                     % show edges and directions
```



Exercise: Rotate the point list around the z-axis to create a hollow cylinder

```
SG=SGofCPLrot(CPL);           % Solid contour rotation
SGplot(SG, 'b');
```



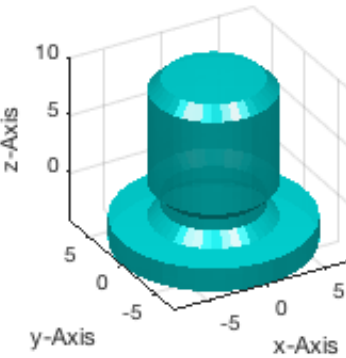
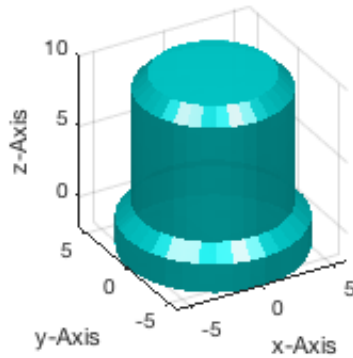
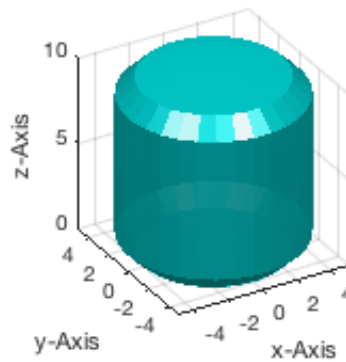
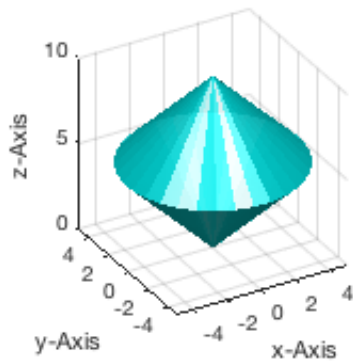
Exercise: Some other examples for massiv rotational symetric solids

```

SG=SGofCPLrot([0 0; 5 5; 0 10]); % Solid contour rotation
subplot(2,2,1); view (-30,30); SGplot(SG,'c'); VLFLplotlight (1,0.9);
SG=SGofCPLrot([0 0; 4 0; 5 1; 5 9; 4 10; 0 10;]); % Solid contour rotation
subplot(2,2,2); view (-30,30); SGplot(SG,'c'); VLFLplotlight (1,0.9);
SG=SGofCPLrot([0 -2; 6 -2; 6 0; 5 1; 5 9; 4 10; 0 10;]); % Solid contour rotation
subplot(2,2,3); view (-30,30); SGplot(SG,'c'); VLFLplotlight (1,0.9);
SG=SGofCPLrot([0 -4; 8 -4; 8 -2; 5 -2; 4 -1; 4 0; 5 1; 5 9; 4 10; 0 10;]); % Solid contour
rotation
subplot(2,2,4); view (-30,30); SGplot(SG,'c'); VLFLplotlight (1,0.9);

```

Removed 192(256) facets
 Removed 256(512) facets
 Removed 350(700) facets
 Removed 560(1200) facets



The warnings 'Removed n(m) facets' can be ignored. These warning appear if a part of the contour touches or crosses the $x=0$ line (y-axis).

Exercise: Creating a bold and a sleeve

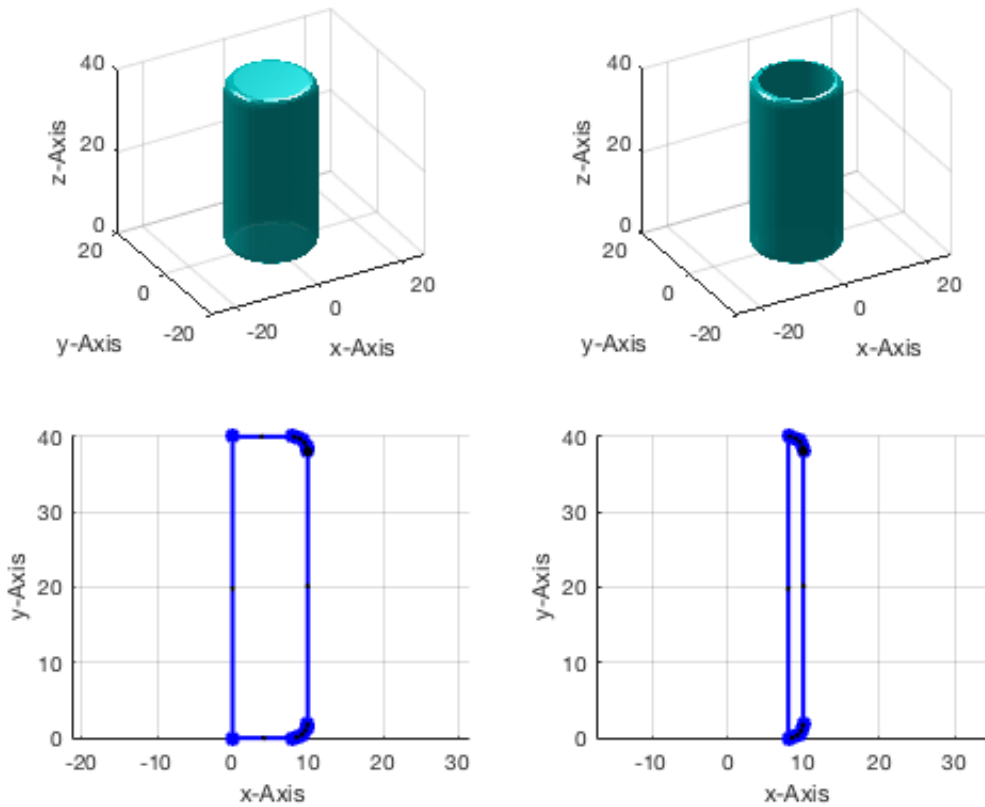
```
closeall;
r=2; H=40; R=10;

PL=PLcircseg (r,[],0,pi/2); CPL=PLtransP(PL,[R-r,H-r]);
PL=PLcircseg (r,[],-pi/2,0); CPL=[CPL;0 H; 0 0;PLtransP(PL,[R-r,r])];
SG=SGofCPLrot(CPL); % Solid contour rotation

subplot(2,2,1); SGplot(SG,'c'); VLFLplotlight (1,0.9); view (-30,30);
subplot(2,2,3); PLELoFCPL (CPL);

PL=PLcircseg (r,[],0,pi/2); CPL=PLtransP(PL,[R-r,H-r]);
PL=PLcircseg (r,[],-pi/2,0); CPL=[CPL;PLtransP(PL,[R-r,r])];
SG=SGofCPLrot(CPL);
subplot(2,2,2); SGplot(SG,'c'); VLFLplotlight (1,0.9); view (-30,30);
subplot(2,2,4); PLELoFCPL (CPL);
```

Removed 900(1800) facets



4. Creating spheres by rotating half-circles

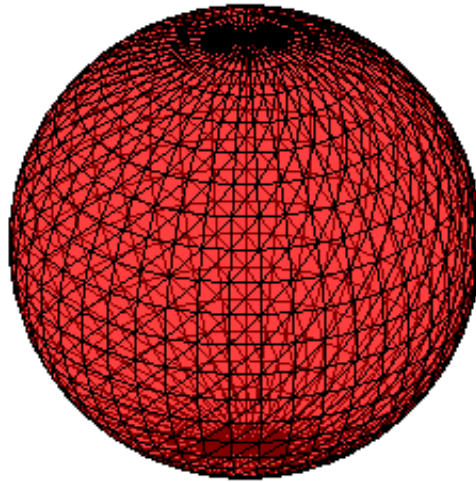
Exercise: Creating a full sphere

```
close all;
PL=PLcircle(10);

VLFLfigure; view(-30,30); grid on;
SG=SGofCPLrot(PL);
SGplot(SG); VLFLplotlight (0,0.5);
```

Removed 2160(4140) facets

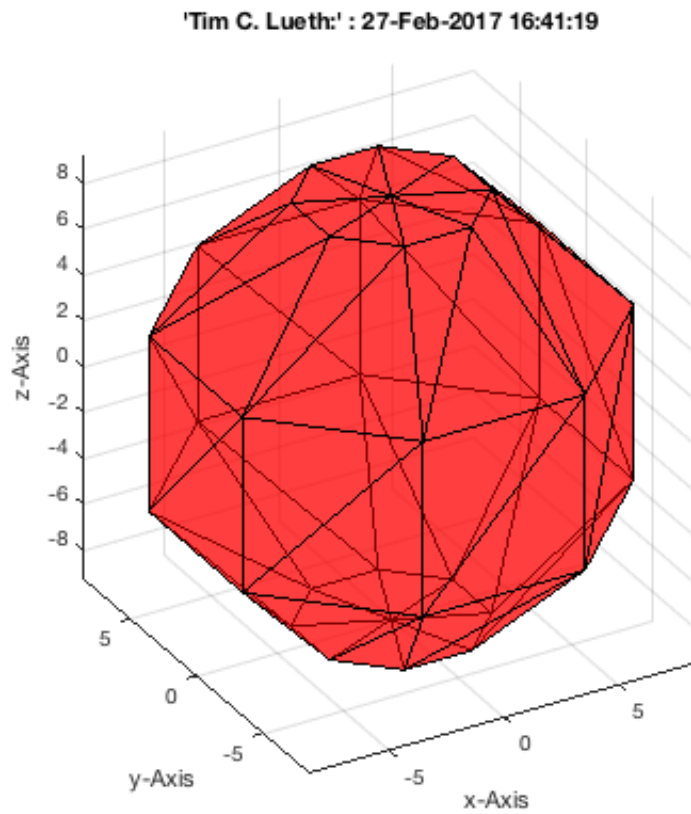
'Tim C. Lueth' : 27-Feb-2017 16:41:19



Exercise: Creating a 8 by 8 sphere

```
close all;  
PL=PLcircle(10,8);  
  
VLFLfigure; view(-30,30); grid on;  
SG=SGofCPLrot(PL,8);  
SGplot(SG); VLFLplotlight (0,0.5);
```

Removed 64(128) facets



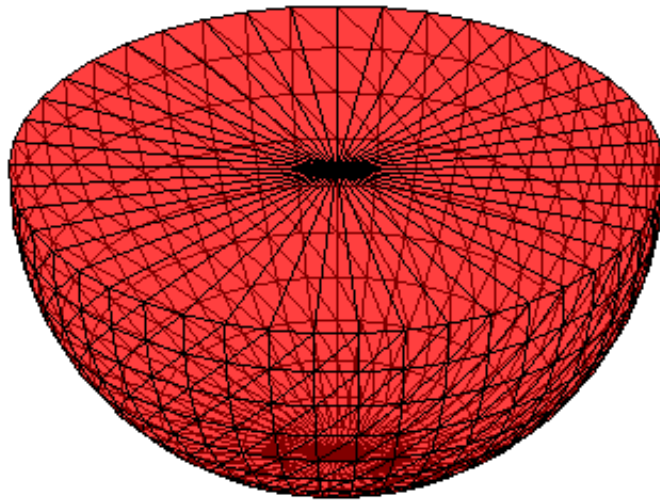
Exercise: Creating a half sphere

```
close all;
PL=[PLcircseg(10,[],-pi/2,0); 0 0];

VLFLfigure; view(-30,30); grid on;
SG=SGofCPLrot(PL);
SGplot(SG); VLFLplotlight (0,0.5);
```

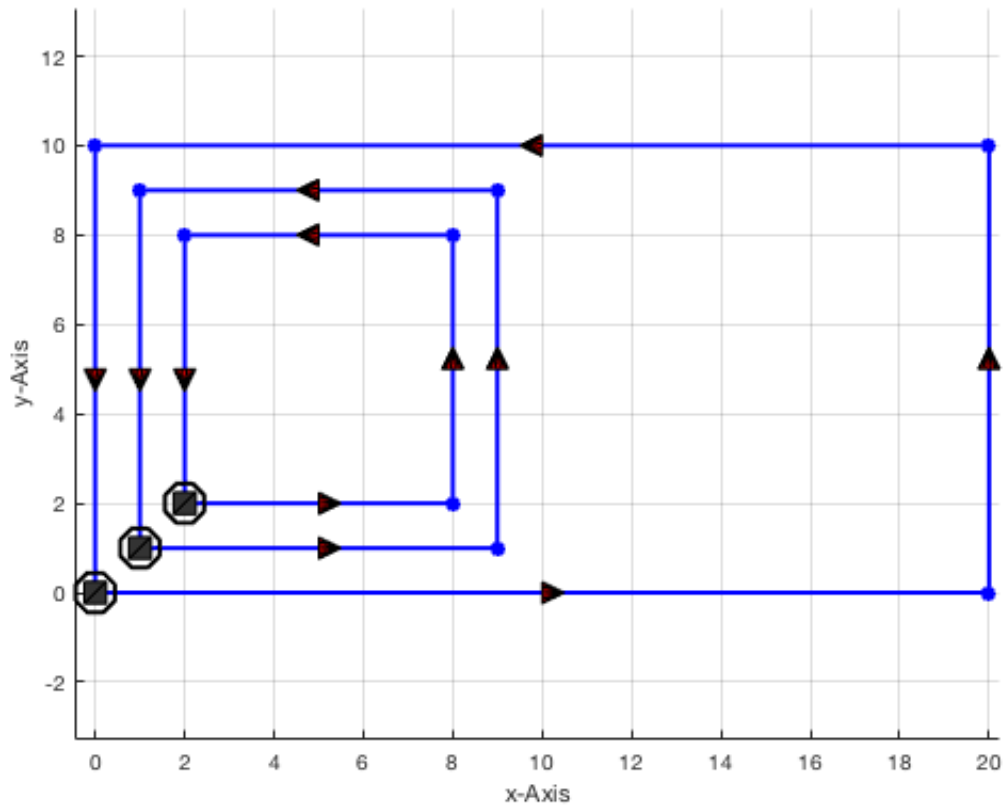
Removed 1080(2070) facets

'Tim C. Lueth' : 27-Feb-2017 16:41:20

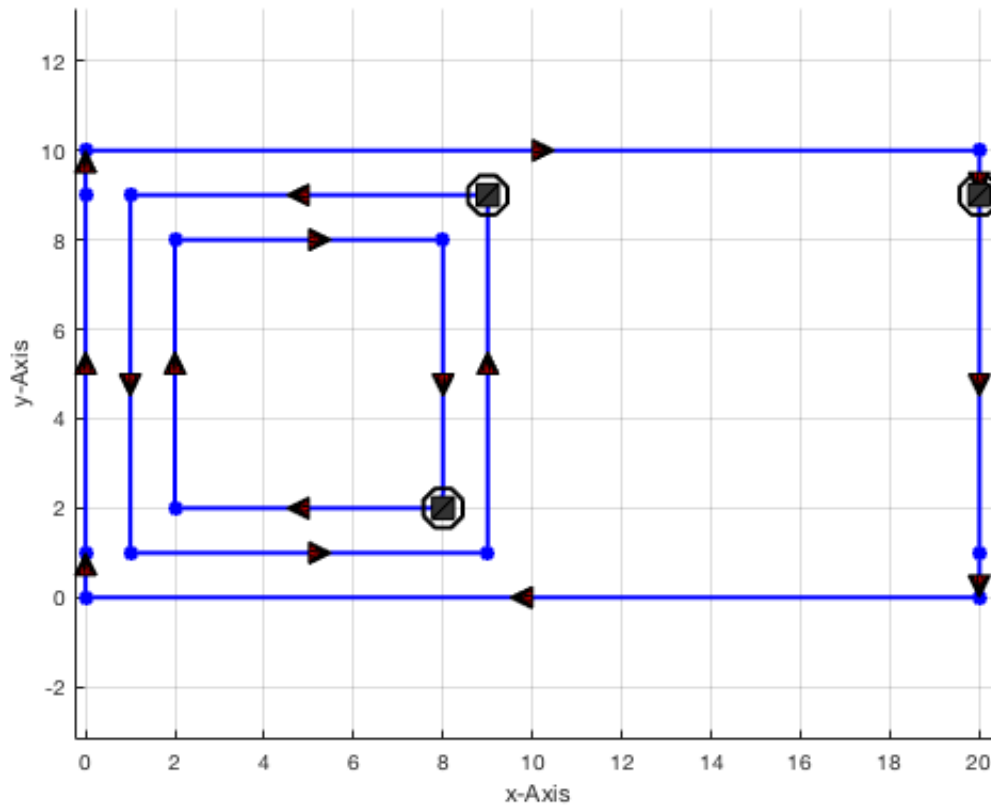


5. Creating embedded contours

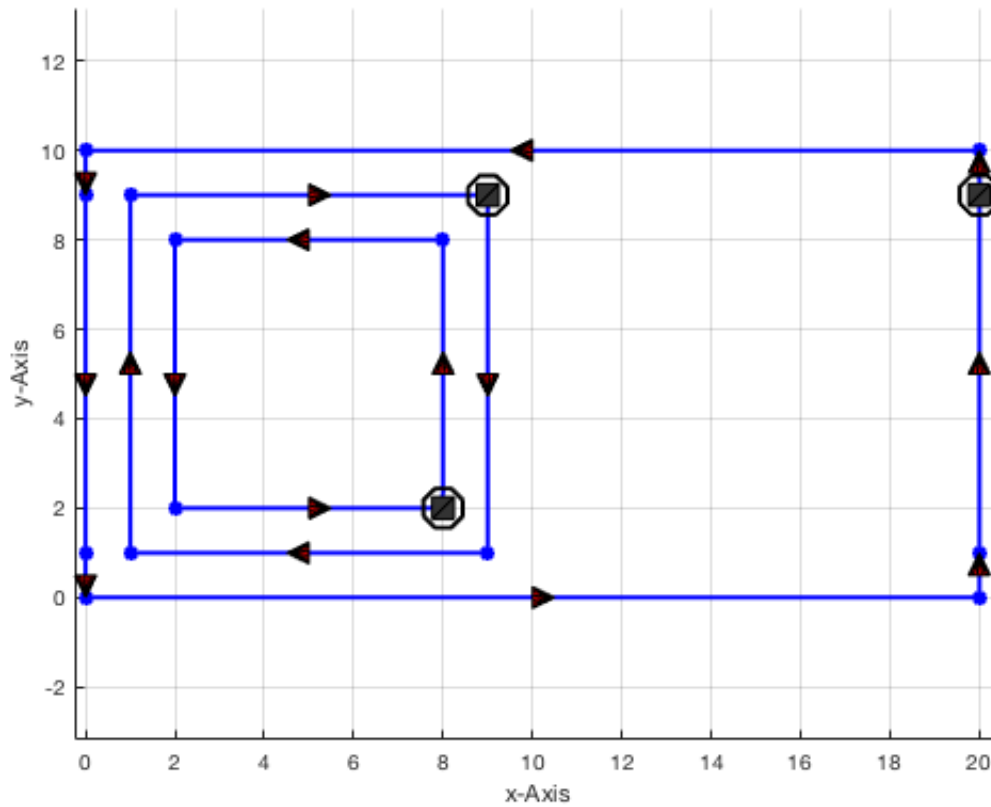
```
CPL=[0 0; 20 0; 20 10; 0 10; NaN NaN; 1 1; 9 1; 9 9; 1 9; NaN NaN; 2 2; 8 2; 8 8; 2 8 ];  
  
close all;PLELofCPL(CPL);
```



```
CPL=CPLuniteCPL(CPL);  
close all; PLELoFCPL(CPL);
```



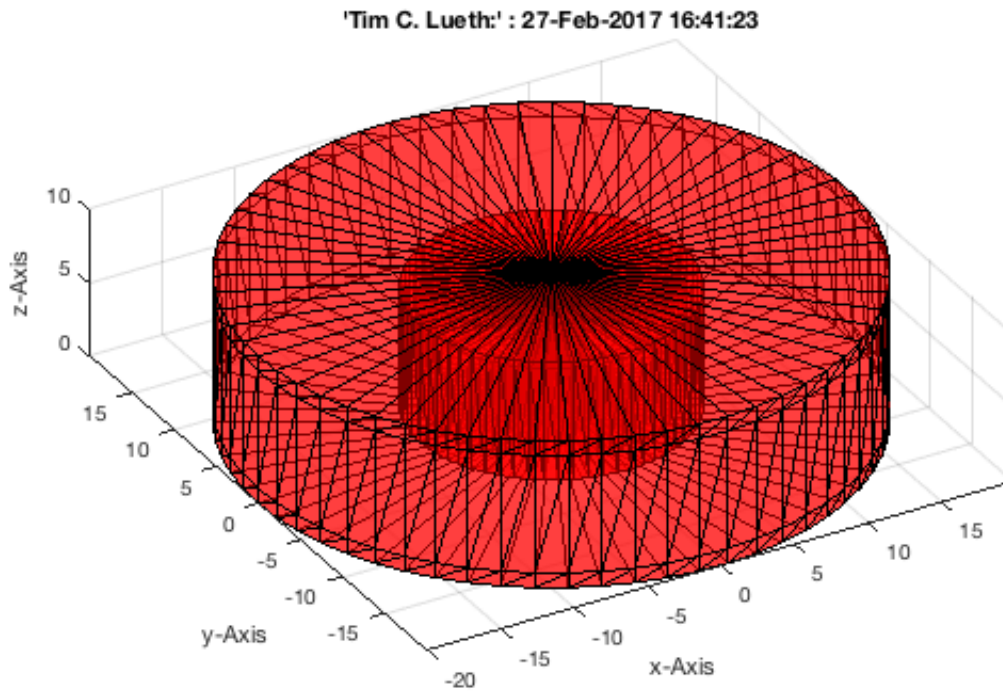
```
CPL=flip(CPL);  
close all; PLELoFCPL(CPL);
```



6. Rotate Contours around the z-axis

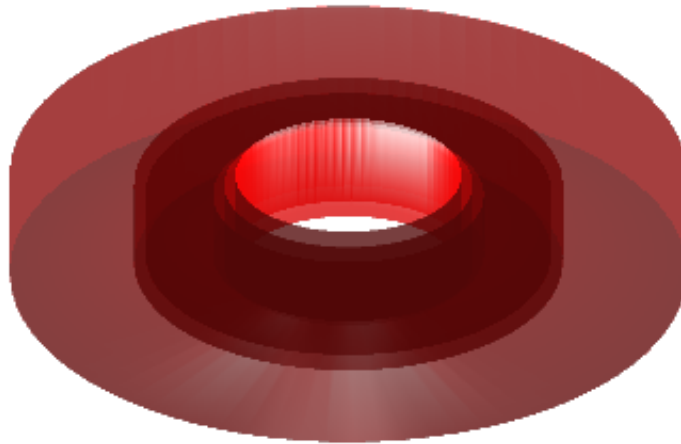
```
VLFLfigure; view(-30,30); grid on;
SG=SGofCPLrot(CPL);
SGplot(SG); VLFLplotlight (0,0.5);
```

Removed 504(1008) facets



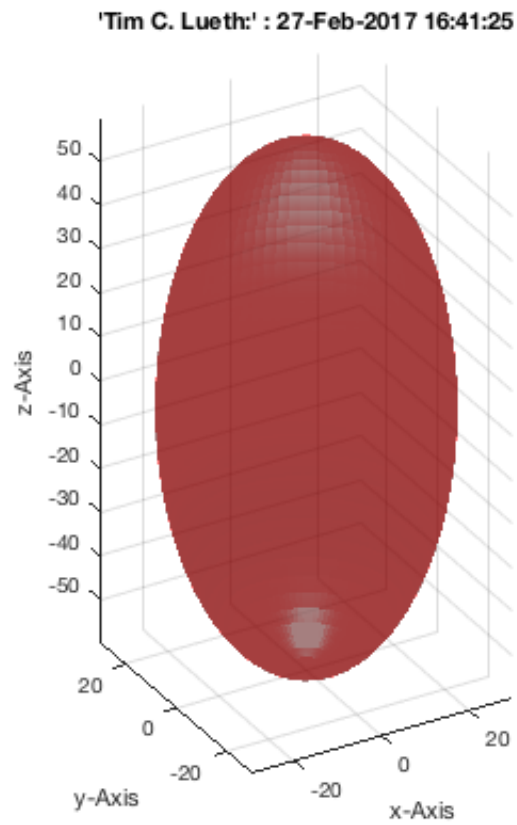
```
VLFLfigure; view(-30,30); grid on;  
CPL(:,1)=CPL(:,1)+10;  
SG=SGofCPLrot(CPL);  
SGplot(SG); VLFLplotlight (1,0.5);
```

'Tim C. Lueth' : 27-Feb-2017 16:41:24



```
VLFLfigure; view(-30,30); grid on;  
CPL=PLcircle(30); CPL(:,2)=CPL(:,2)*2;  
SG=SGofCPLrot(CPL);  
SGplot(SG); VLFLplotlight (1,0.5);
```

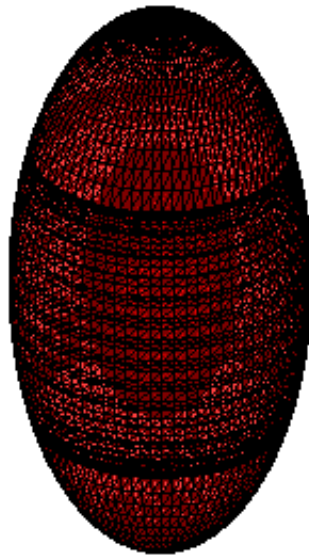
Removed 6160(12012) facets



```
VLFLfigure; view(-30,30); grid on;  
CPL=PLcircle(30); CPL(:,2)=CPL(:,2)*2;  
CPL=[CPL;NaN NaN;CPL*0.5];  
SG=SGofCPLrot(CPL);  
SGplot(SG); VLFLplotlight (0,0.5);
```

Removed 4620(24332) facets

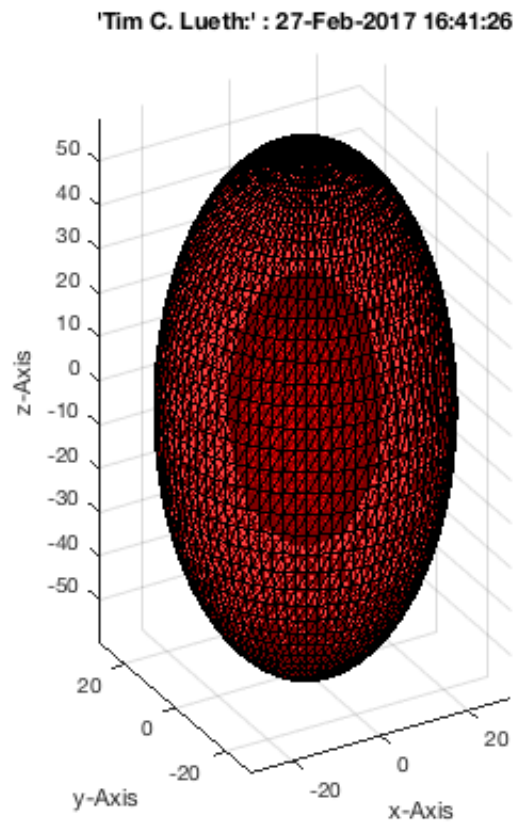
'Tim C. Lueth': 27-Feb-2017 16:41:25



```
VLFLfigure; view(-30,30); grid on;  
CPL=PLcircle(30); CPL(:,2)=CPL(:,2)*2;  
  
SG=SGcat(SGofCPLrot(CPL),SGswap(SGofCPLrot(CPL*0.5)));  
SGplot(SG); VLFLplotlight (0,0.5);
```

Removed 6160(12012) facets

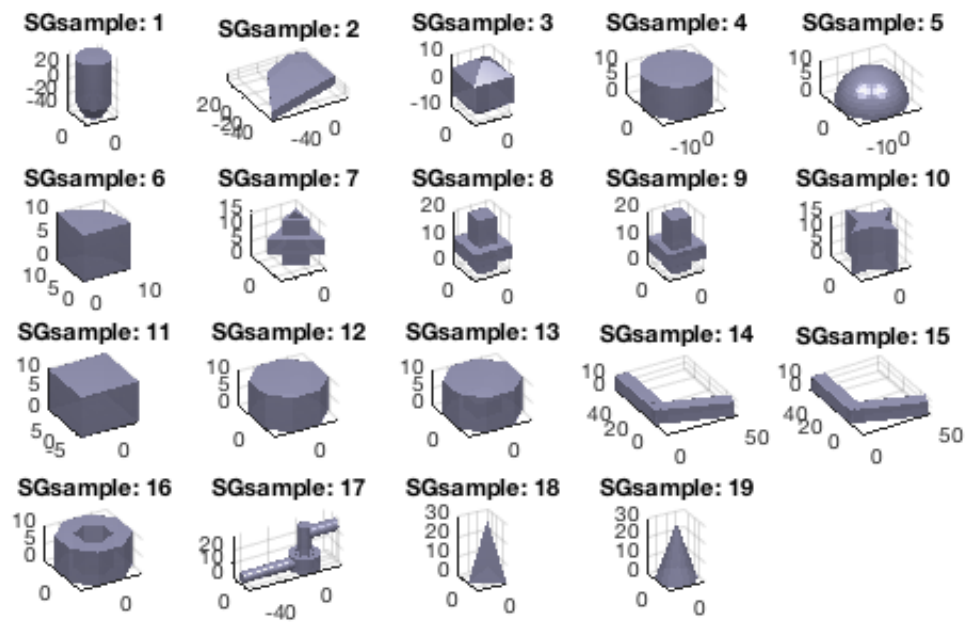
Removed 4400(8580) facets



7. Samples of 3D Design

```
close all  
SGsample;
```

Removed 414(1104) facets
Removed 1080(2070) facets



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:41:32 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2014-11-30
- Mattias Traeger, executed and published on 64 Bit PC using Windows with Matlab 2014b on YYYY-MMM-DD

Published with MATLAB® R2016b

Exercise 08: Slicing, Closing, Cutting and Separation of Solid Geometries

2015-06-08: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- [1. Summary of the already explained aspects of the VLFL-Toolbox](#)
- [2. Create a sample solid for this exercise](#)
- [3. Analyze a slice plane through a solid geometry](#)
- [4. Cutting and separating a solid geometries in two parts](#)
- [5. Cutting as useful tool for the ending of complex shaped geometries](#)
- [Final remarks on toolbox version and execution date](#)

1. Summary of the already explained aspects of the VLFL-Toolbox

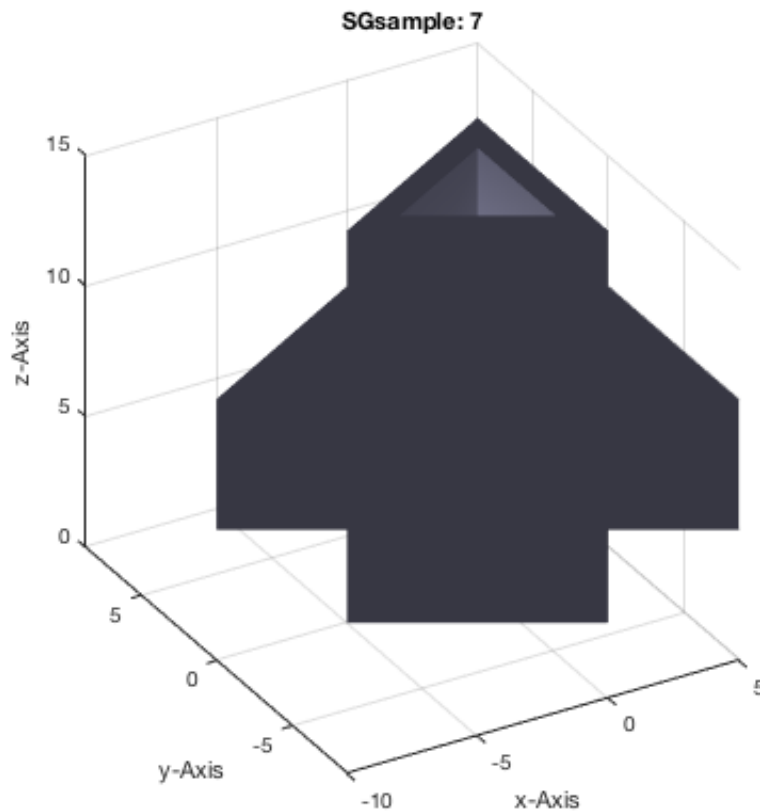
In examples 1-7 we've learned about:

- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (FL), *Edge lists* (EL)
- Import, and export of *STL-File* data, Conversion of text strings into solid volumes
- *Closed polygon lists* (CPL) for boolean operations of contours
- 2.5D extrusion of closed polygon list (CPL) to create *Solid Geometries* (SG)
- 2.5D rotation of closed polygon list (CPL) to create *Solid Geometries* (SG)
- Spatial transformation, positioning, alignment and merging of solid geometry sets

2. Create a sample solid for this exercise

Using the function `SGsample` it is possible to create samples for an experiment, to see all of them or to select one.

```
close all
SGsample(7);
A=SGsample(7);
```

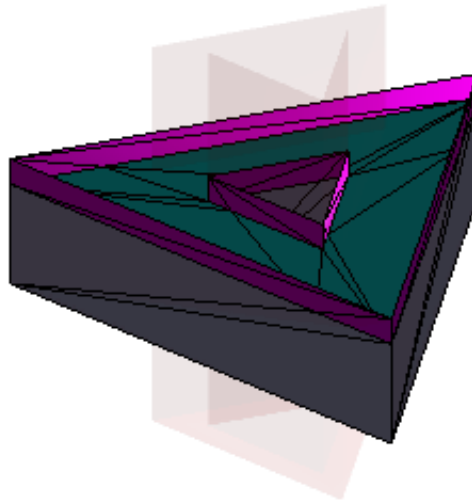


3. Analyze a slice plane through a solid geometry

Slicing at a specified z-coordinates is a more complex procedure than expected if several solids are processed that can penetrate each other. By slicing a single solid, the crossed facets/triangles are separated into 2 upper and lower parts that will lead to 2 lower and 1 upper facets or 1 lower and 2 upper facets depending on how many edges are above or under the cutting plane. For slicing we use the function **SGslicer**. Be aware that it is not possible to slice surfaces without crossing edges (i.e. surfaces in the $z_{\max}$ or $z_{\min}$ plane)

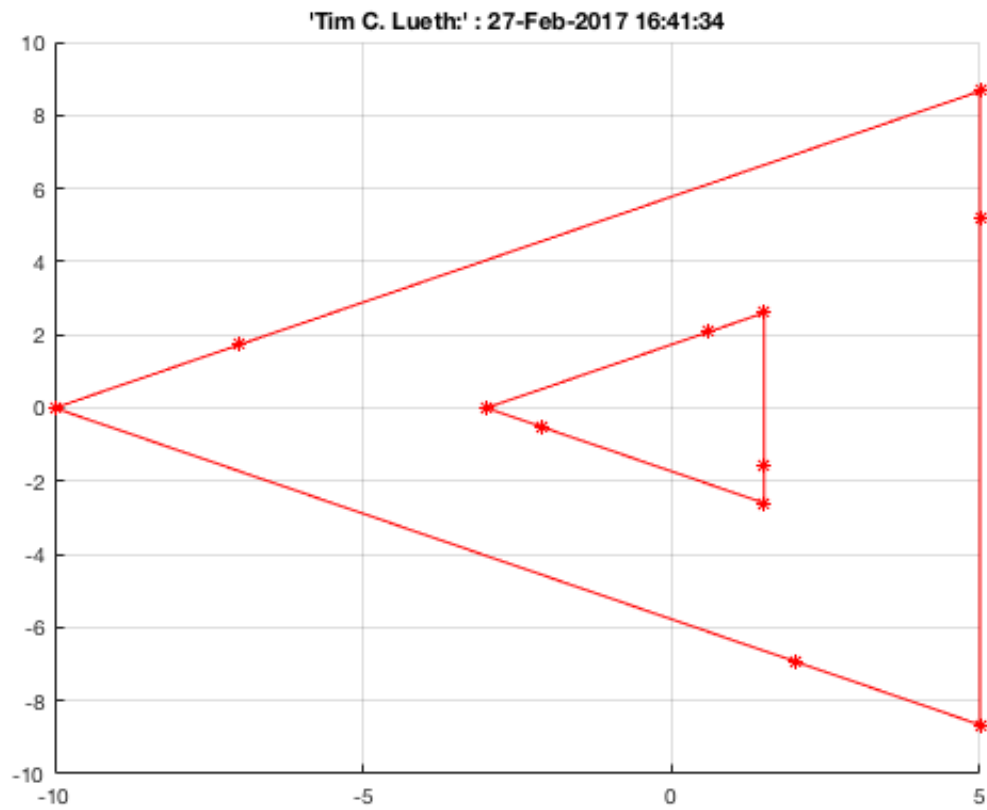
```
SGslicer (A,9);  
view (10,30);
```

'Tim C. Lueth' : 27-Feb-2017 16:41:34



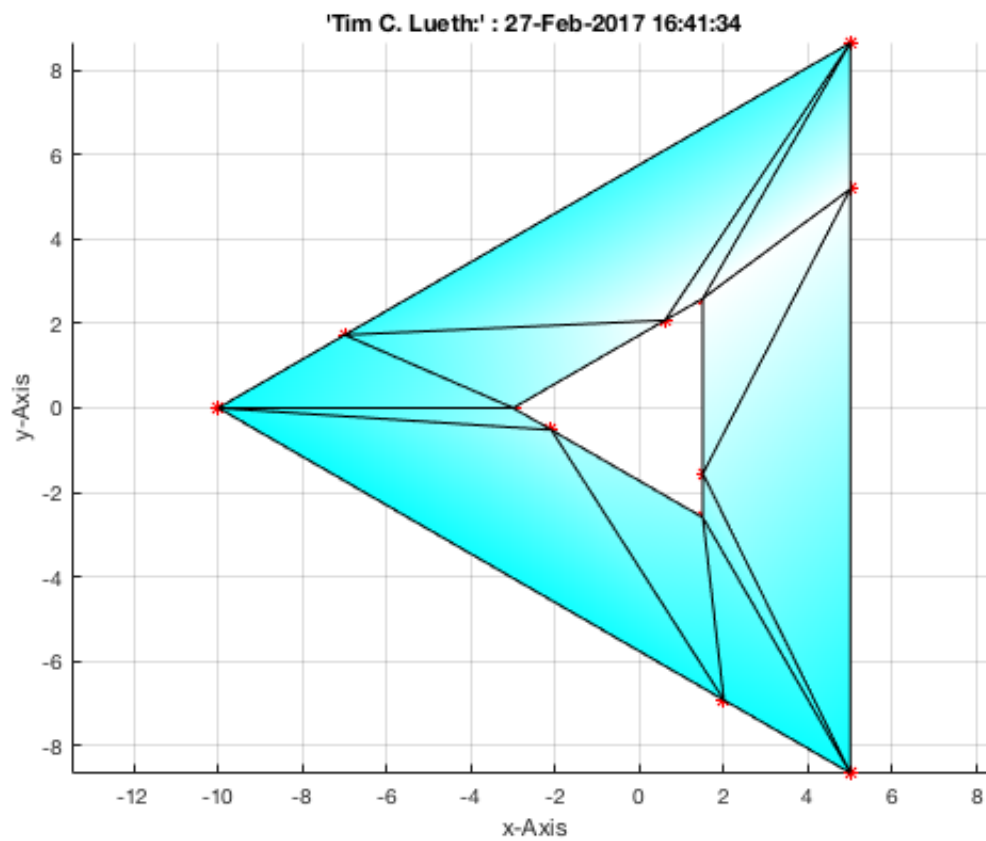
It is also possible just to show the cutting edges of the cutting contour

```
VLFLfigure;  
TR2=SGslicer (A,9);  
VLELplots(TR2.Points, TR2.Constraints);
```



The result of the slicing process is a delaunay triangulation of the cutting plane. It can be used as cover for closing the cutted solids.

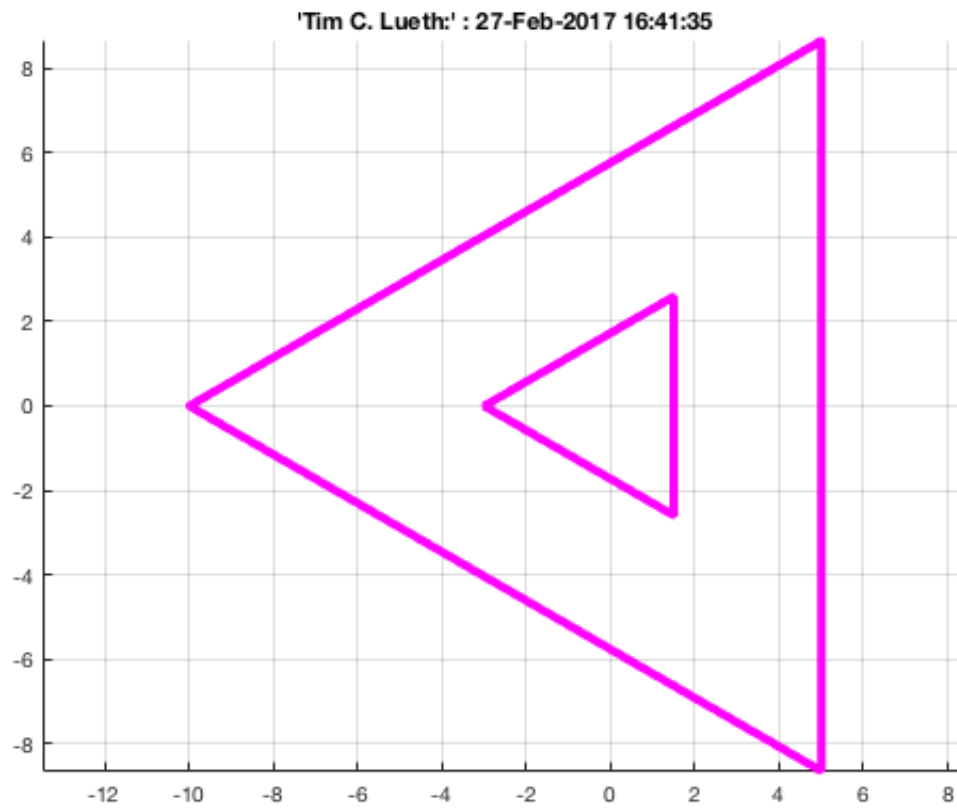
```
in=isInterior(TR2);  
VLFLplots(TR2.Points, TR2.ConnectivityList(in,:), 'c');
```



Often we want directly getting a closed contour of a slice.

```
CPLofSGslice(A,9); [CPL,warn]=CPLofSGslice(A,9); warn
```

```
warn =  
logical  
0
```



The output parameter warns if a ambiguous cutting result exists

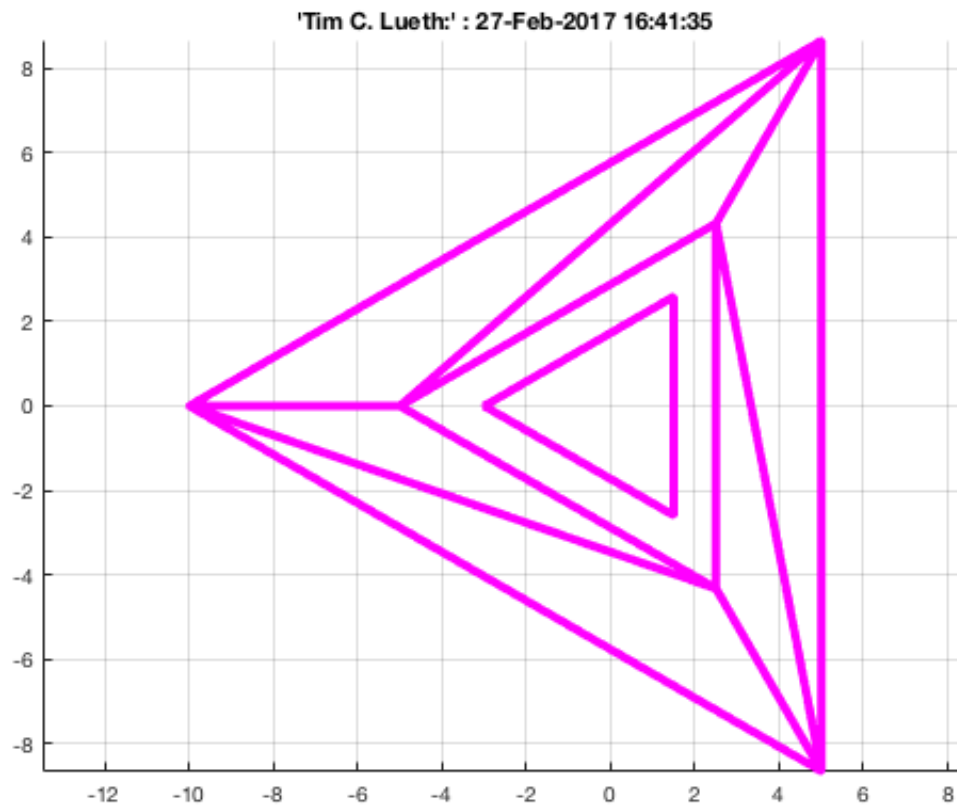
```
CPLofSGslice(A,10); [CPL,warn]=CPLofSGslice(A,10); warn
```

```
Warning: Crossing plane cannot be calculated error-free  
Warning: Crossing plane cannot be calculated error-free
```

```
warn =
```

```
logical
```

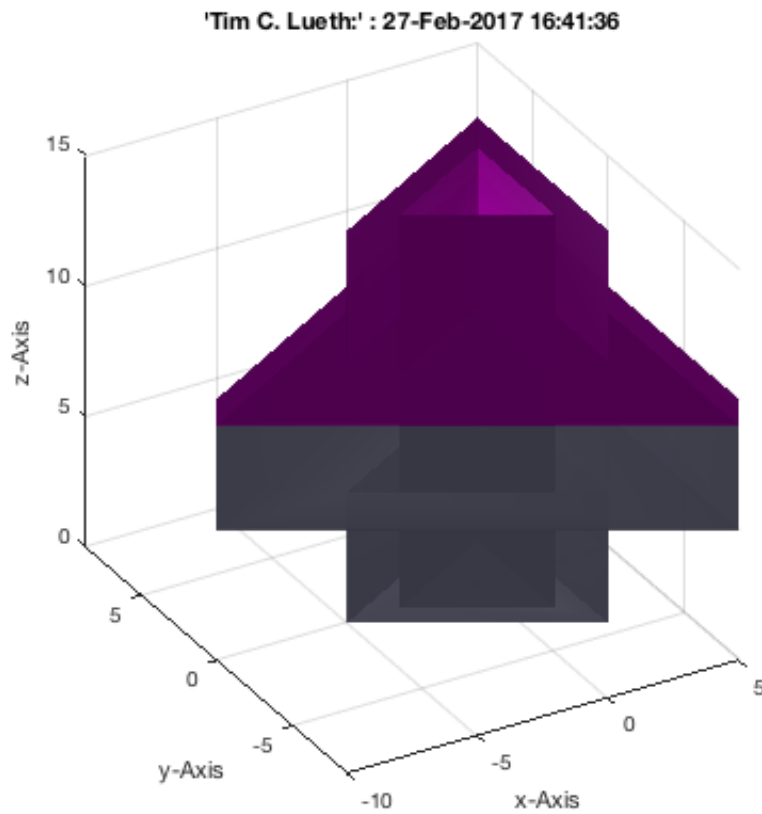
```
1
```

4. Cutting and separating a solid geometries in two parts

By using the output of SGslicer it is possible to create an upper and lower part of an object or even by two cutting plane to cut a part out of a larger object. This is done by the function **SGcut**.

```
VLFLfigure;  
SGcut(A,9);
```



The next figure shows a separation of the two part by moving the upper part upwards.

```
[L,U]=SGcut(A,9)
VLFLfigure;
SGplot(SGtransP(L,[0 0 -3]),'w');
SGplot(SGtransP(U,[0 0 +3]),'m');
view (50,20);
```

L =

struct with fields:

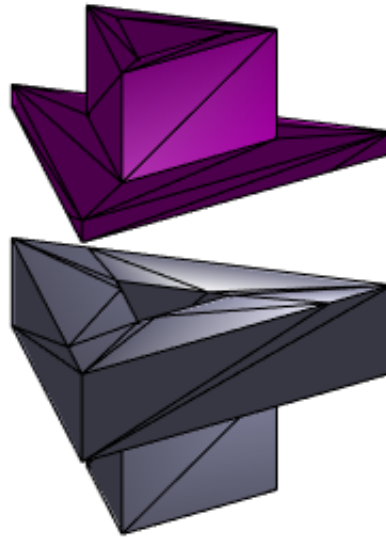
VL: [27×3 double]
FL: [54×3 double]

U =

struct with fields:

VL: [27×3 double]
FL: [54×3 double]

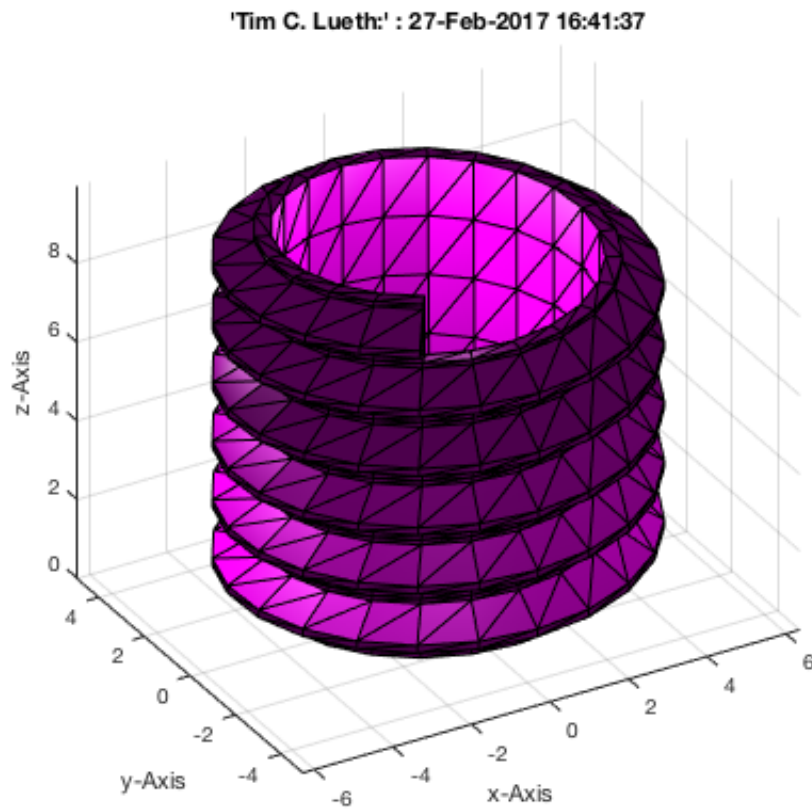
'Tim C. Lueth' : 27-Feb-2017 16:41:36



5. Cutting as useful tool for the ending of complex shaped geometries

Some geometries such as screw nuts have specific geometries that have their origin in the manufacturing process of the threads. To create also similar shapes it is necessary to create a longer thread and to cut out the required length later:

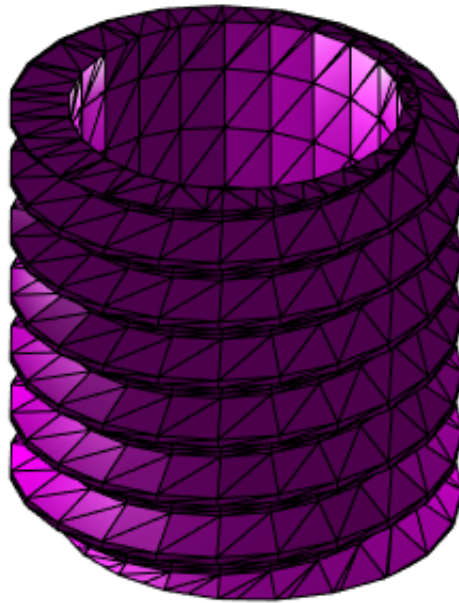
```
VLFLfigure;  
SGthread (10,10,[],[],'C'); view (-30,30);  
% [A,b,c]=SGthread (10,10);
```



Now create a longer thread and cut out the required length later.

```
VLFLfigure;
A=SGthread (10,10+5+5,[],[], 'C');
[~,B]=SGcut(A,[5.05 14.95]); B=SGtransP (B,[0 0 -5]);
SGplot(B, 'm'); view (-30,30);
```

'Tim C. Lueth' : 27-Feb-2017 16:41:37



Final remarks on toolbox version and execution date

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:41:40 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
map_toolbox
matlab
simulink
=====
=====
```

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-06-08*
- *Christina Friedrich, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-06-17*

Published with MATLAB® R2016b

Exercise 09: Boolean Operations with Solid Geometries

2014-11-30: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Remarks on boolean operations for solid geometries based on surfaces
- 3. Creating two solids for showing the boolean operations
- 4. Boolean operator: Substraction $A-B$ or $A \setminus B$
- 5. Boolean operator: Substraction $A+B$
- 6. Boolean operator: Substraction $B \setminus A$
- 7. Boolean operator: $A \text{ xor } B$
- 8. Analyzing the results and comparision with additive design.
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-6 we've learned about:

- *Point lists (PL), Vertex lists (VL), Facet lists (FL), Edge lists (EL)*
- Import, and export of *STL-File* data, Conversion of text strings into solid volumes
- *Closed polygon lists (CPL)* for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to create *Solid Geometries (SG)*
- 2.5D rotation of closed polygon list (CPL) to create *Solid Geometries (SG)*
- Spatial transformation, positioning, alignment and merging of solid geometry sets

2. Remarks on boolean operations for solid geometries based on surfaces

The implementation of the boolean operations based on STL geometries took the author several years. The reason was not only the complexity of the numerous special cases but also the numerical accuracy or resolution of the required geometrical calucations. So even if a normal position is cacluated with 12 digits accuracy, the cross product often has a just an accuracy of 6 digits. Unfortunatly crossing triangles with position errors of 6 digits can easily lead to phantom triangles, phantom edges wich either do not really exist or are just doubles of already existing lines. Since normally all edges must have a second edge with the opposite direction, doubled lines/egdes with the same direction make trouble. So to be successful with the boolean operations you should make sure that

1. No facet should be in the same plane as or overlap another facet or cross with almost parallel edges to the plane of another facet. This is always valid for one solid, but in case of a second solid for boolean operations, it is quite difficult to guarantee this.
2. It is fact that, the more boolean operations took place, to create a new solid, the more vertices and facets were created. The removment of dispensable vertices and facets is possible but is a boring non productive pieve of source code. So the motivation to programm such a procedure is not high.
3. No edge of a triangle should be in the sample plane or crossing but almost parallel to a plane of a facet.
4. It is fact that a normal user just want to use the boolean operator without thinking about those problems. The normal user will just be disappointed if the way to design a physical solid object finally fails because of the limitations of the crossing

5. Make definitely sure that after all boolean operations you use SGchecker to analyze the solid geometry to detect errors immediately.
6. Maybe the only solution is to use a fixed coordinate grid during all calculations to make sure that two vertices are either definitely separated or definitely the same. #

3. Creating two solids for showing the boolean operations

```
VLFLfigure; view(-30,30); grid on;

A=SGofCPLz(PLcircle(10,4),10); A=SGtrans0(A);
B=SGofCPLz(PLcircle(5,10),30); B=SGtrans0(B); B=SGtransR(B,rotdeg(45,5,0));

SGplot(A,'b');
SGplot(B,'r');
VLFLplotlight (0,0.9);
A=SGstripfields(A)
B=SGstripfields(B)
```

A =

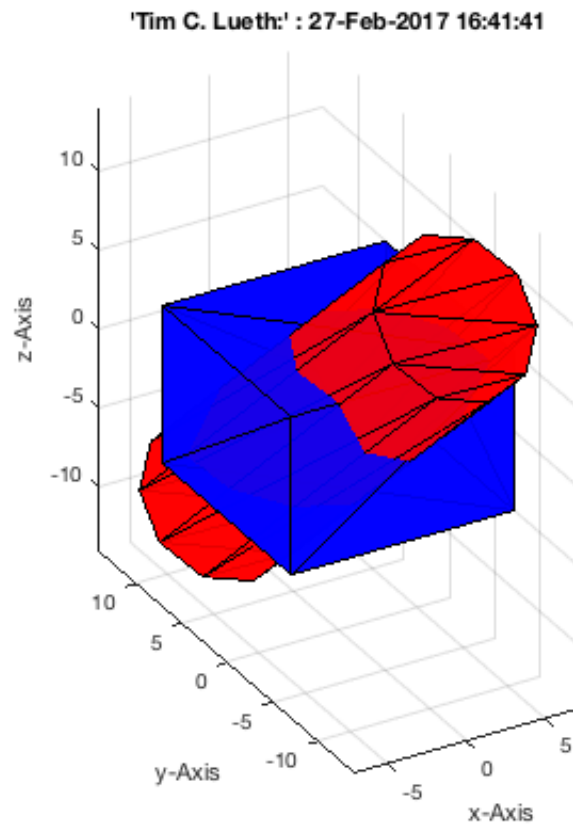
struct with fields:

```
VL: [8×3 double]
FL: [12×3 double]
```

B =

struct with fields:

```
VL: [20×3 double]
FL: [36×3 double]
```



4. Boolean operator: Substraction A-B or A\B

```
close all;

C=SGbool ('-',A,B);

close all;
VLFLfigure; view(-30,30); grid on;

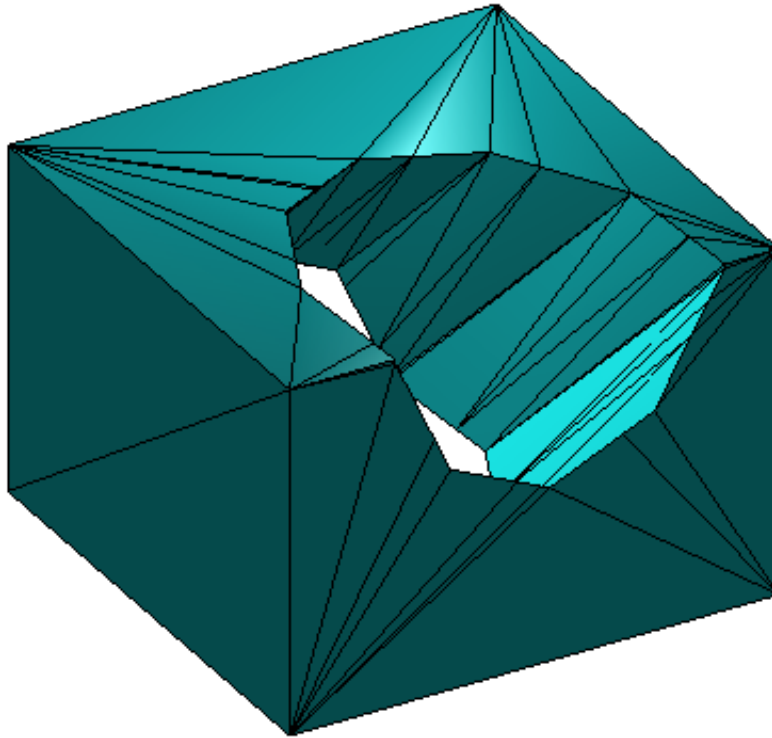
SGplot(C,'c');
VLFLplotlight (1,0.9);
SGchecker(C);
C=SGstripfields(C)
```

C =

struct with fields:

```
VL: [60×3 double]
FL: [120×3 double]
```


'Tim C. Lueth' : 27-Feb-2017 16:41:42



5. Boolean operator: Substraction A+B

```
close all;

C=SGbool ('+',A,B);

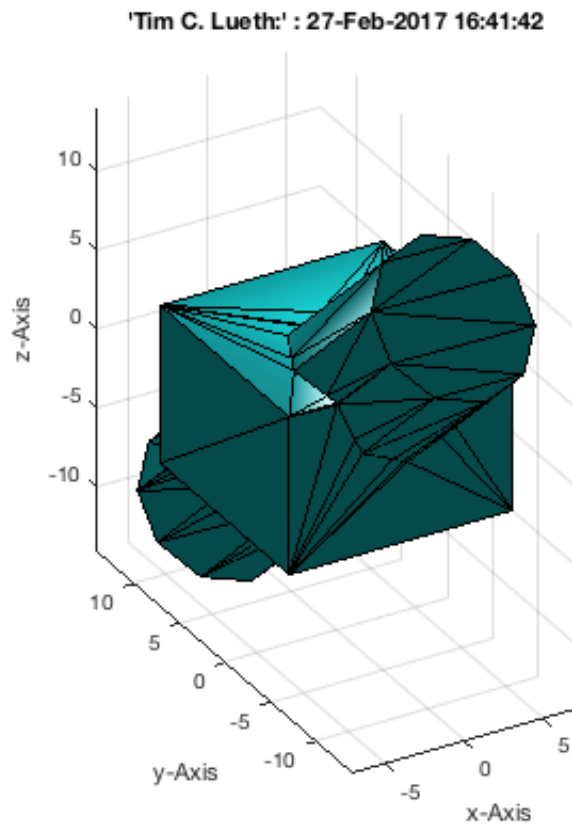
close all;
VLFLfigure; view(-30,30); grid on;

SGplot(C,'c');
VLFLplotlight (1,0.9);
SGchecker(C);
C=SGstripfields(C)
return
```

C =

```
struct with fields:

    VL: [80×3 double]
    FL: [156×3 double]
```



6. Boolean operator: Substraction B/A

```
close all;

C=SGbool ('B',A,B);

close all;
VLFLfigure; view(-30,30); grid on;

SGplot(C,'c');
VLFLplotlight (1,0.9);
SGchecker(C);
C=SGstripfields(C)
```

7. Boolean operator: A xor B

```
close all;

C=SGbool ('x',A,B);

close all;
VLFLfigure; view(-30,30); grid on;

SGplot(C,'c');
VLFLplotlight (1,0.9);
SGchecker(C);
C=SGstripfields(C)
```

8. Analyzing the results and comparison with additive design.

Analyzing the number of vertices and facets of the results of a boolean operation shows clearly that there are much more vertices and facets than the sum of the vertices and facets. In general it makes for STL more sense to add simple solids to a more complex by attaching them together by simply pushing them into another. In this case the final number of vertices and facets is the sum of the individual facets and vertices.

Final remarks on toolbox version and execution date

VLFLlicense

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-06-07*
- *Christina Friedrich, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-06-17*

Published with MATLAB® R2016b

Exercise 10: Packaging of Sets of Solid Geometries (SG)

2015-06-08: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. The four-bar-linkage kit as example for a set of multiple solids
- 3. Packaging a set of solid geometries in a volume
- 4. Using container/collections insted of itemizing the solids
- 5. Create boxes around the packed solids for the final 3D print job
- 6. Create the four-bar-linkage kit as print job
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-9 we've learned about:

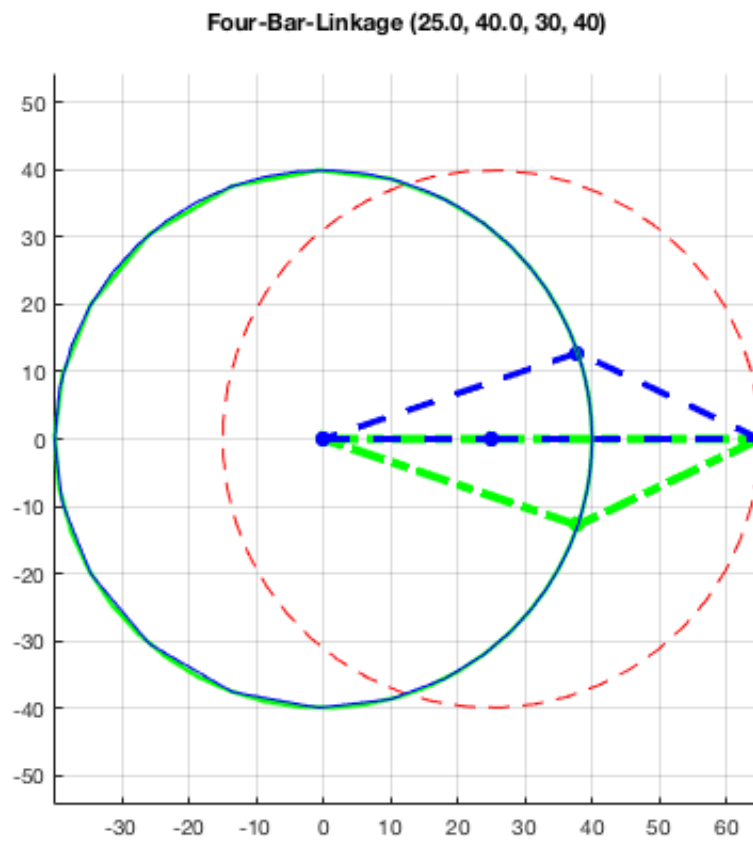
- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (VL), *Edge lists* (EL)
- Functions to import, check, and export of *STL-File* data
- Functions for generating text strings as solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation and merging of solid geometry sets
- Relative positioning of solids geometries and Boolean operations on Solids

2. The four-bar-linkage kit as example for a set of multiple solids

A very interesting mechanism in mechanics is the four-bar-linkage. It consists of four bars that are linked together by 4 rotatorial joints. Such a mechanism can be built by 4 different elememts

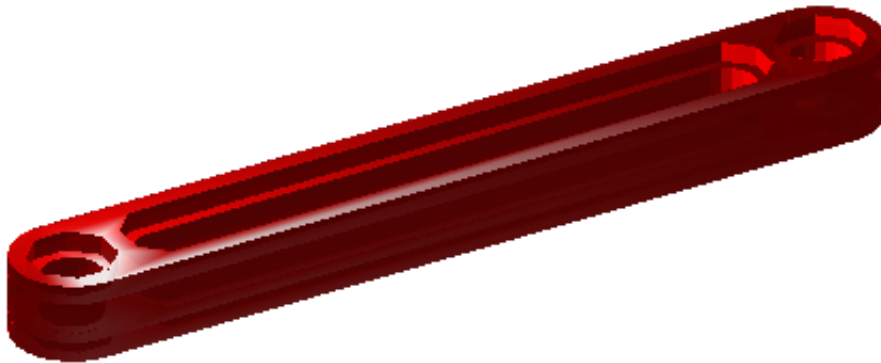
1. Bar: The basic mechanic link
2. Bolt: A simple bolt that allows rotation
3. Shaft: A simple shaft that transfer torque
4. Spacer: A simple element that is required to achieve parallel bars

```
close all;  
fourBarLinkage (25,40,30,40);
```

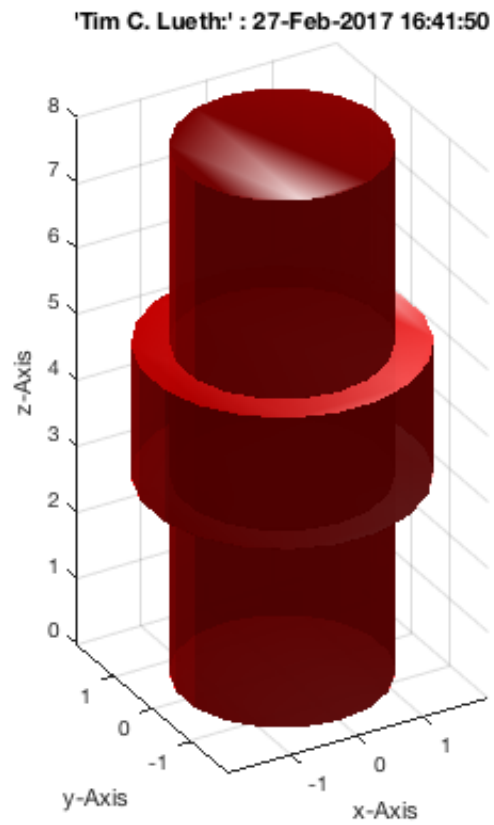


```
fourBarLinkageKit ('Bar',40);
```

'Tim C. Lueth' : 27-Feb-2017 16:41:50

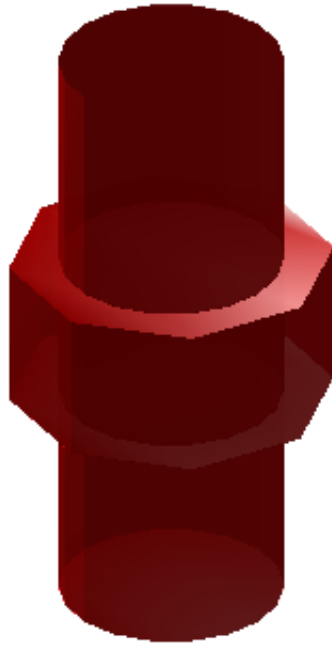


```
fourBarLinkageKit ('Bolt');
```

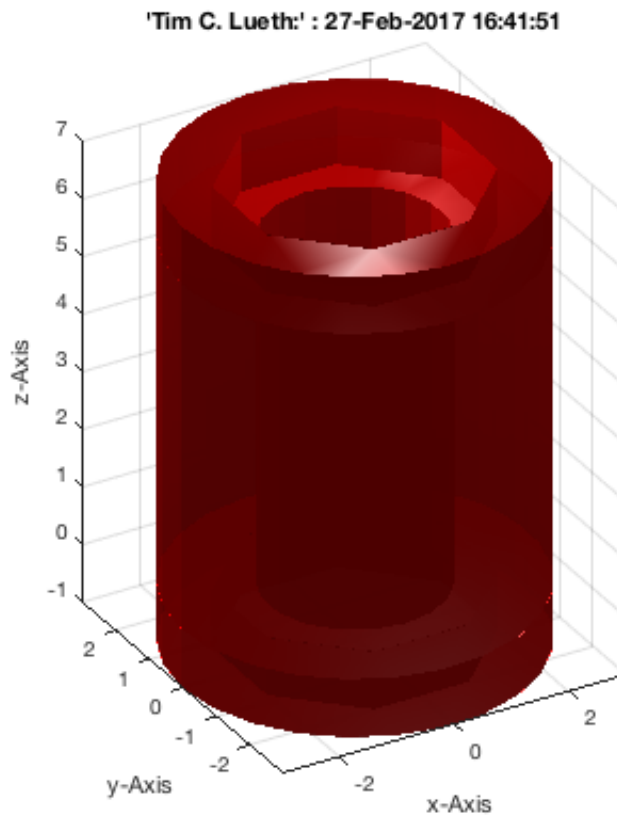


```
fourBarLinkageKit ('Shaft');
```

'Tim C. Lueth': 27-Feb-2017 16:41:51



```
fourBarLinkageKit ('Spacer');
```

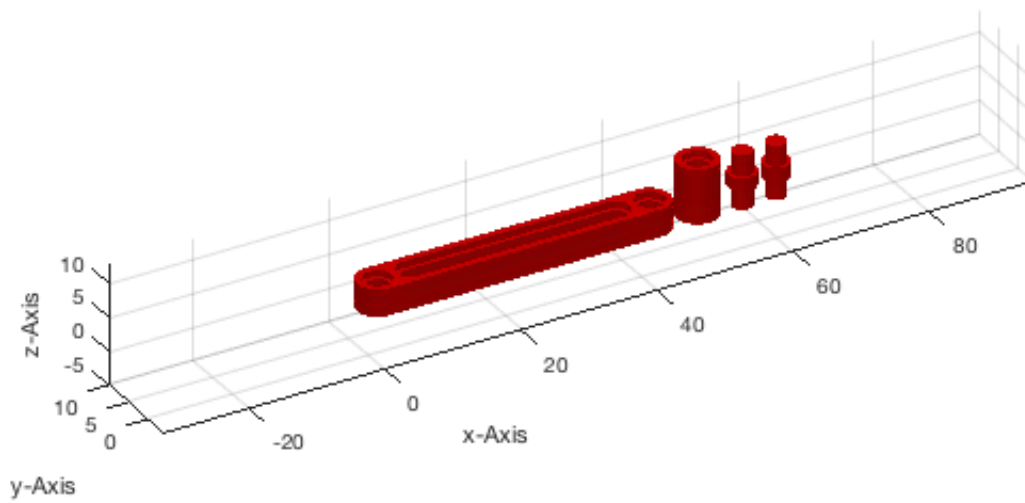
3. Packaging a set of solid geometries in a volume

For a four-bar-linkage we need 4 bars and 4 bolts and may be 2 spacer and 2 shafts. For this purpose there is one function

- **SGpacking** arranges several solid geometries side by side in a volume

```
close all;
A=fourBarLinkageKit ('Bar',40);
B=fourBarLinkageKit ('Bolt');
C=fourBarLinkageKit ('Shaft');
D=fourBarLinkageKit ('Spacer');
SG=SGpacking({A,B,C,D});
SGplot(SG); view (-30,30); VLFLplotlight (1,0.9); zoompatch;
```

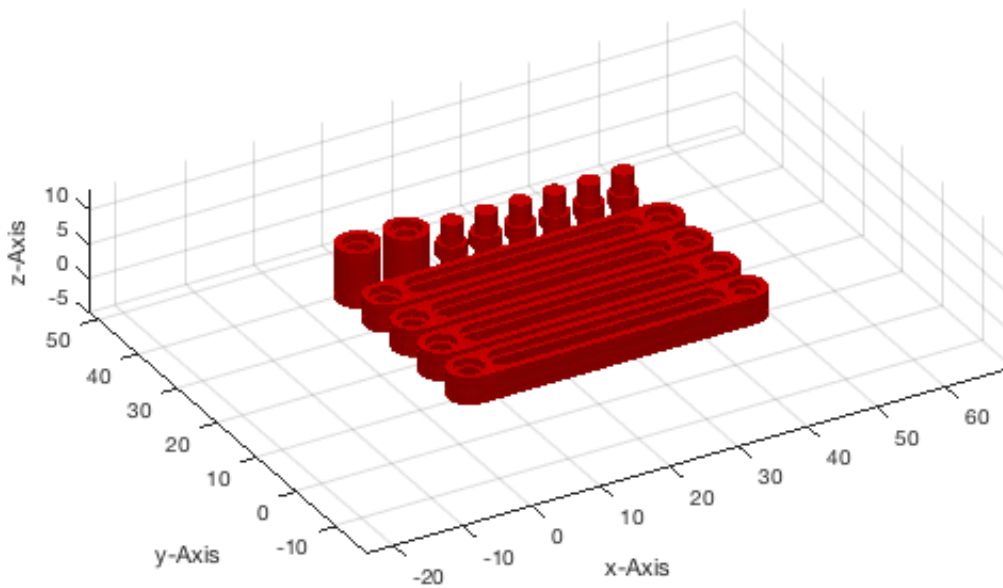
Packing 4 objects (h=23):



Similar it is possible to pack several objects of the same kind into the volume and also to define the dimensions of the packing volume. Typically the z-coordinate of the volume specification is unlimited or much bigger than the xy-coordinates.

```
close all;
SG=SGpacking({A,A,A,A,B,B,B,B,C,C,D,D},[50,50,1000]);
SGplot(SG); view (-30,30); VLFLplotlight (1,0.9); zoompatch;
```

Packing 12 objects (h=43):



4. Using container/collections insted of itemizing the solids

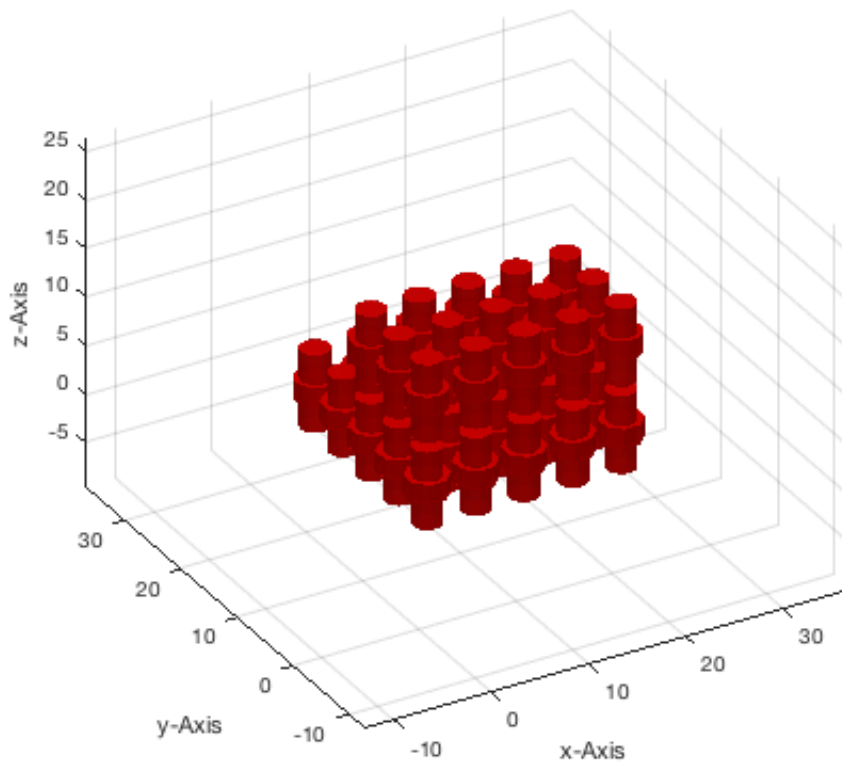
In many cases we are not interested to list the items in the source code but to create a structure containing all objects we want to pack later. Therefor, we need a data structure that allows to collect several solids into something like a container. This can be done by the following functions:

- **SGCaddSG** Add a single solid geometry to a collection
- **SGCaddSGn** Add multiple copies of a single solid geometry to a collection

```
close all
SGC=[]; % Create a Solid Geometry Collection
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Bolt'),20); % Add 20 bolt to the container
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Shaft'),20); % Add 20 shafts to the container

SG=SGpacking(SGC,[30, 30 ,1000]); % SGpacking accepts also SGC structs
SGplot(SG); view (-30,30); VLFLplotlight (1,0.9); zoompatch;
```

Packing 40 objects (h=38):



5. Create boxes around the packed solids for the final 3D print job

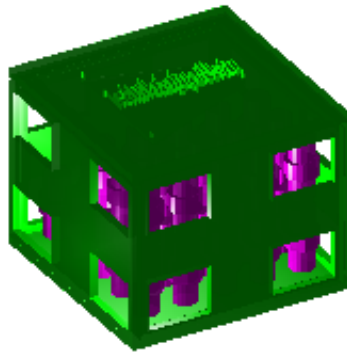
To handle the print job in a convenient way, it makes sense to create a box around the parts and also to write on top of the cover the content or the intended use of the box plus may by a date.

```
close all;
SGboxing(SG,[],[],'.\nTest for Packaging and Boxing\n.');
```

```
view (-30,30); VLFLplotlight (1,0.9); zoompatch;
```

```
==>TEXT GENERATION..Analyze union areas for 60 facets:
Major union vectors: 6 found with maximum size of 1757.
Finally 2 union areas found with size > 100
Text attached to union Nr: 2
..finished!
```

'Tim C. Lueth' : 27-Feb-2017 16:41:58

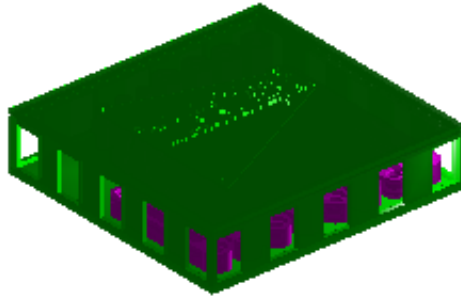


6. Create the four-bar-linkage kit as print job

```
close all;
SGC=[];
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Bar',25),2);
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Bar',35),2);
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Bar',40),4);
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Bolt'),4);
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Shaft'),4);
SGC=SGCaddSGn(SGC,fourBarLinkageKit ('Spacer'),4);
SGA=SGpacking(SGC,[55, 60 ,100]);
SGB=SGboxing(SGA,[],[],'.\nTim Lueth's Linkage Kit\n. ');
VLFLfigure(SGA); SGplot(SGB,'g');
SG=SGcat(SGA,SGB); view (-130,30); VLFLplotlight (1,0.9); zoompatch;
SGwriteSTL(SG,'EXP10: Four-Bar-Linkage-Kit');
```

```
Packing 20 objects (h=57): .....
==>TEXT GENERATION..Analyze union areas for 60 facets:
4 Dimension warnings
Major union vectors: 6 found with maximum size of 7157.
Finally 22 union areas found with size > 100
Text attached to union Nr: 2
..finished!
1000..2000..3000..4000..5000..6000..7000..8000..9000..10000..11000..12000..
```

'Tim C. Lueth': 27-Feb-2017 16:42:02



Final remarks on toolbox version and execution date

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:42:05 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
map_toolbox
matlab
simulink
=====
=====
```

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-06-08*
- *Christina Friedrich, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-06-17*

Published with MATLAB® R2016b

Exercise 11: Attaching Coordinates Frames to Create Kinematik Models

2015-06-08: Tim C. Lueth, MIMED - Technische Universität München, Germany 2015-08-18: Tim C. Lueth, changed for better kinematic model structure (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Loading the 5 components of a 4DoF robot solid model
- 3. The concept of attaching coordinate frames as 4x4 homogenous transformation matrix
- 4. Attaching manually coordinate frames as 4x4 homogenous transformation matrix
- 5. Creating kinematic models consisting of named solids
- 6. Automatic creation of a chain
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

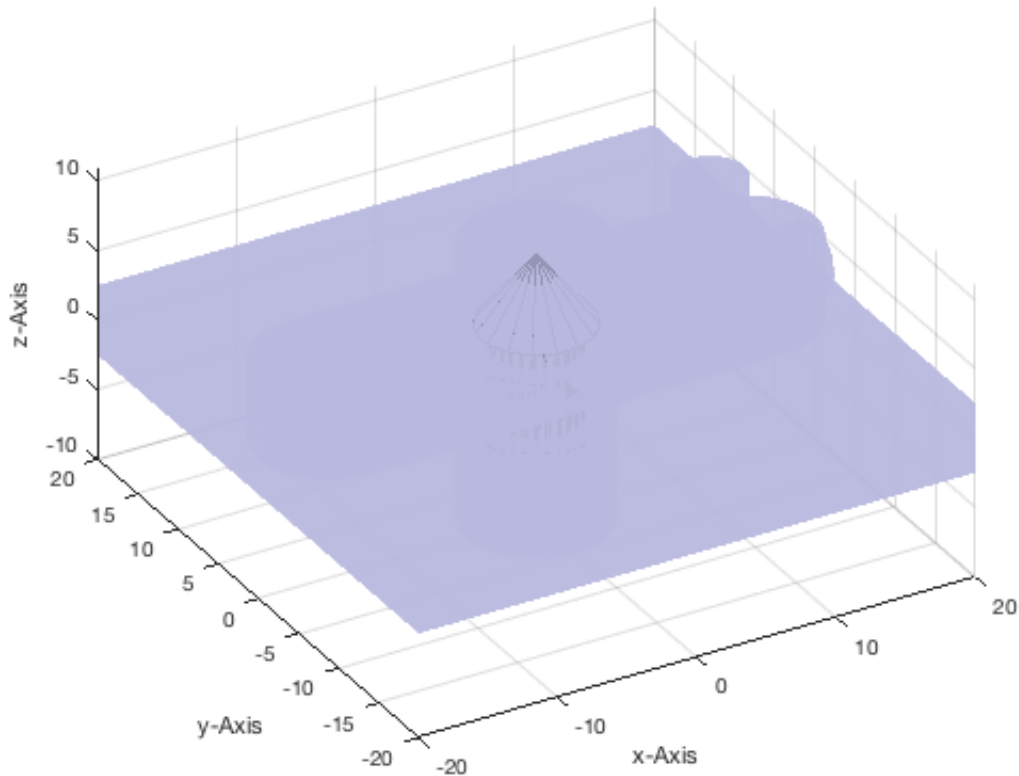
In examples 1-10 we've learned about:

- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (VL), *Edge lists* (EL)
- Functions to import, check, and export of *STL-File* data
- Functions for generating text strings as solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation and merging of solid geometry sets
- Relative positioning of solids geometries and boolean operations on solids
- Packaging and boxing of several parts into a complete assemble kit

2. Loading the 5 components of a 4DoF robot solid model

Before explaining how to create the parts of a robot kinematik we just load such components in. The command line load AIM_robot

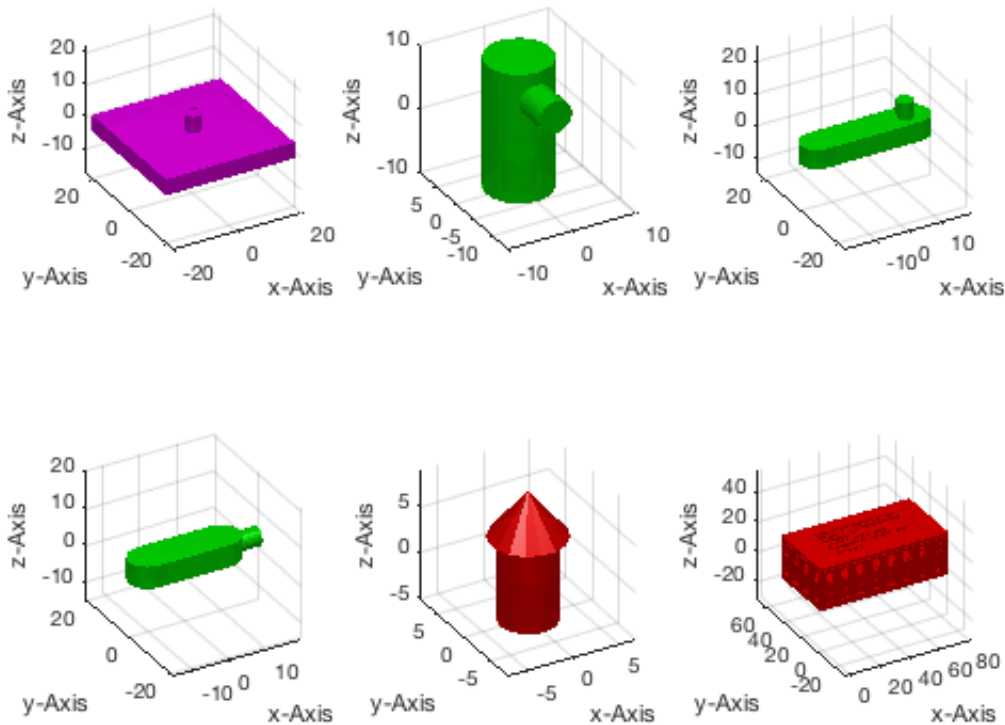
```
load AIM_SGrobot
SG0=SGfixerrors(SG0,1e-3); SGchecker(SG0);
SG1=SGfixerrors(SG1,1e-3); SGchecker(SG1);
SG2=SGfixerrors(SG2,1e-3); SGchecker(SG2);
SG3=SGfixerrors(SG3,1e-3); SGchecker(SG3);
SG4=SGfixerrors(SG4,1e-3); SGchecker(SG4);
save ('AIM_SGrobot', 'SG0', 'SG1', 'SG2', 'SG3', 'SG4', 'SGrobot');
```



- returns a solid geometry SG0 which is a base plate with a rotatorial joint
- returns a solid geometry SG1 which is a link with a rotatorial joint
- returns a solid geometry SG2 which is a link with a rotatorial joint
- returns a solid geometry SG3 which is a link with a rotatorial joint
- returns a solid geometry SG4 which is a hand with a pointing tip
- returns a solid geometry SGrobot which can be written as STL-File and printed using a 3D printer.

```
VLFLfigure;
subplot(2,3,1); SGplot(SG0); view (-30,30); VLFLplotlight(1,0.9);
subplot(2,3,2); SGplot(SG1); view (-30,30); VLFLplotlight(1,0.9);
subplot(2,3,3); SGplot(SG2); view (-30,30); VLFLplotlight(1,0.9);
subplot(2,3,4); SGplot(SG3); view (-30,30); VLFLplotlight(1,0.9);
subplot(2,3,5); SGplot(SG4); view (-30,30); VLFLplotlight(1,0.9);
subplot(2,3,6); SGplot(SGrobot); view (-30,30); VLFLplotlight(1,0.9);
SGwriteSTL (SGrobot, '4-DOF Robot Set');
```

```
1000..2000..3000..4000..5000..6000..7000..8000..9000..10000..11000..12000..13000..14000..15
000..16000..17000..18000..19000..20000..21000..22000..23000..
```

3. The concept of attaching coordinate frames as 4x4 homogenous transformation matrix

If we analyze the structure of one of the components of the robot we see that we have now more than just the surface of the geometry.

SG0

```
% We see that beside vertices and facets (VL, FL) we have a color and a
% alpha value for transparency when plotting.
```

SG0 =

struct with fields:

```
VL: [79x3 double]
FL: [154x3 double]
alpha: 0.8000
color: 'm'
Tname: {'A' 'B'}
T: {[4x4 double] [4x4 double]}
TFil: {[2x1 double] [21x1 double]}
```

- *Tname* is a cell list contain the ascii-string of the names of the coordinate frames
- *T* is the 4x4 homogenous transformation matrix related to the indexed name

- *TFiL* is an optional index of the facets that belong to the surface that defines the coordinate system To the homogenous transformation matrix out of the struct, the most convinient way is to use the function:
- **SGT** returns for a given solid and a given frame name the 4x4 matrix
- **SGT** draws the part and the frames and the defining facets if there is no output parameter

```
A=SGT(SG0, 'A')
B=SGT(SG0, 'B')

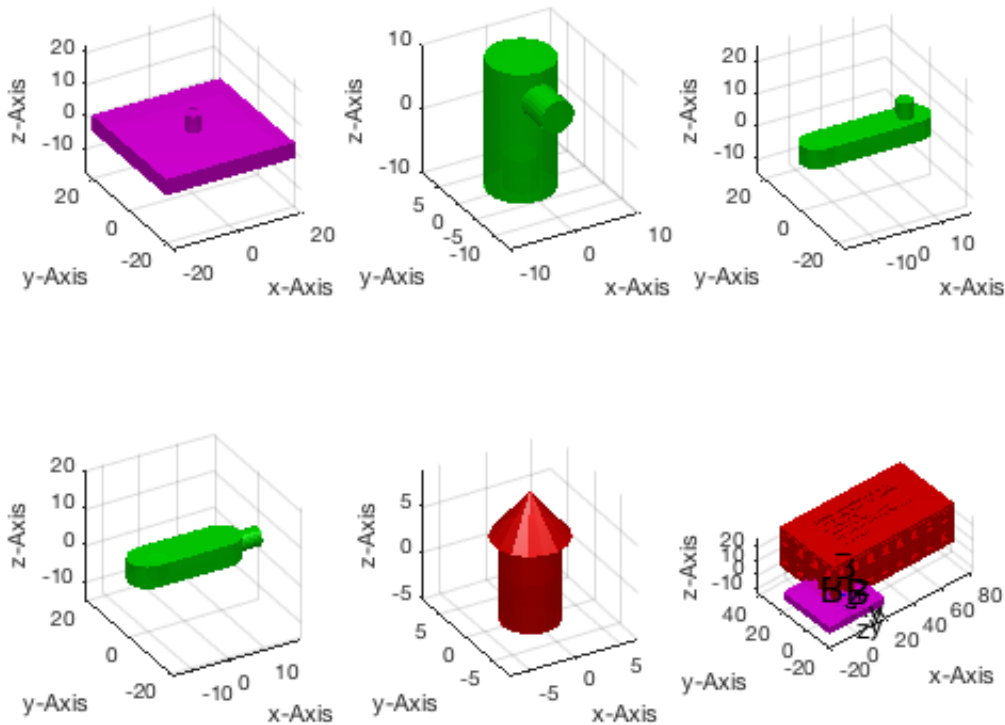
SGT(SG0);
view(-40,40);
```

A =

1.0000	0	0	0
0	-1.0000	0	0
0.0000	0	-1.0000	-2.5000
0	0	0	1.0000

B =

-1.0000	0	0	0.0120
0	-1.0000	0	0
0	0	1.0000	7.5000
0	0	0	1.0000



4. Attaching manually coordinate frames as 4x4 homogenous transformation matrix

Since there is no requirement to use the facets TFiL, T matrices and their name can easily added by a program during the design phase. Nevertheless, there is also a need to add frames interactively. For that purpose there are two other functions to add or to remove frames.

- **SGTremove** removes a named frame from the structure
- **SGTui** opens a figure and allows to generate a frame by touching a surface or point

To use SGTui you should a) first rotate the part on the screen until you see the surface where you like to set a frame, b) press enter and c) click on the plane to set the frame. Now set two Frames 'C' and 'D'

```
A=SGTui(SG0,'C')
A=SGTui(A,'D')
view(-40,40);
```

A =

struct with fields:

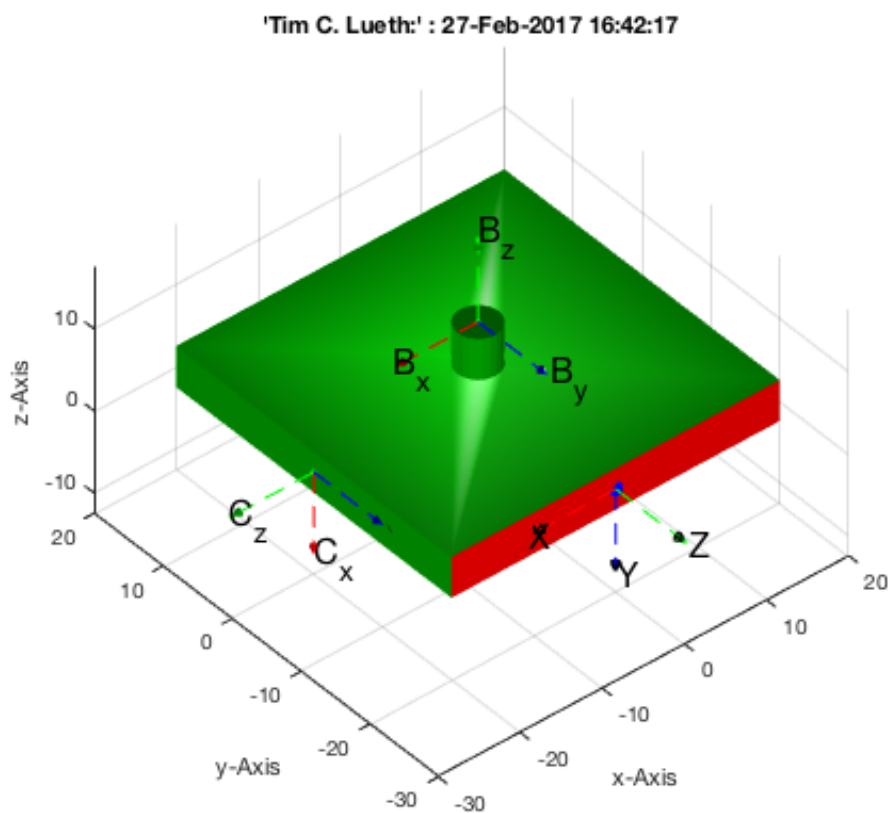
```
VL: [79×3 double]
FL: [154×3 double]
alpha: 0.8000
color: 'm'
Tname: {'A' 'B' 'C'}
T: {[4×4 double] [4×4 double] [4×4 double]}
```

```
TFil: {[2×1 double] [21×1 double] [2×1 double]}
```

```
A =
```

```
struct with fields:
```

```
VL: [79×3 double]
FL: [154×3 double]
alpha: 0.8000
color: 'm'
Tname: {'A' 'B' 'C' 'D'}
T: {[4×4 double] [4×4 double] [4×4 double] [4×4 double]}
TFil: {[2×1 double] [21×1 double] [2×1 double] [2×1 double]}
```



No we remove the first two frames 'A' and 'B'

```
A=SGTremove(A, 'A')
A=SGTremove(A, 'B')
SGT(A); view(-60,30);
```

```
A =
```

```
struct with fields:
```

```

VL: [79×3 double]
FL: [154×3 double]
alpha: 0.8000
color: 'm'
Tname: {'B' 'C' 'D'}
T: {[4×4 double] [4×4 double] [4×4 double]}
TFiL: {[21×1 double] [2×1 double] [2×1 double]}

```

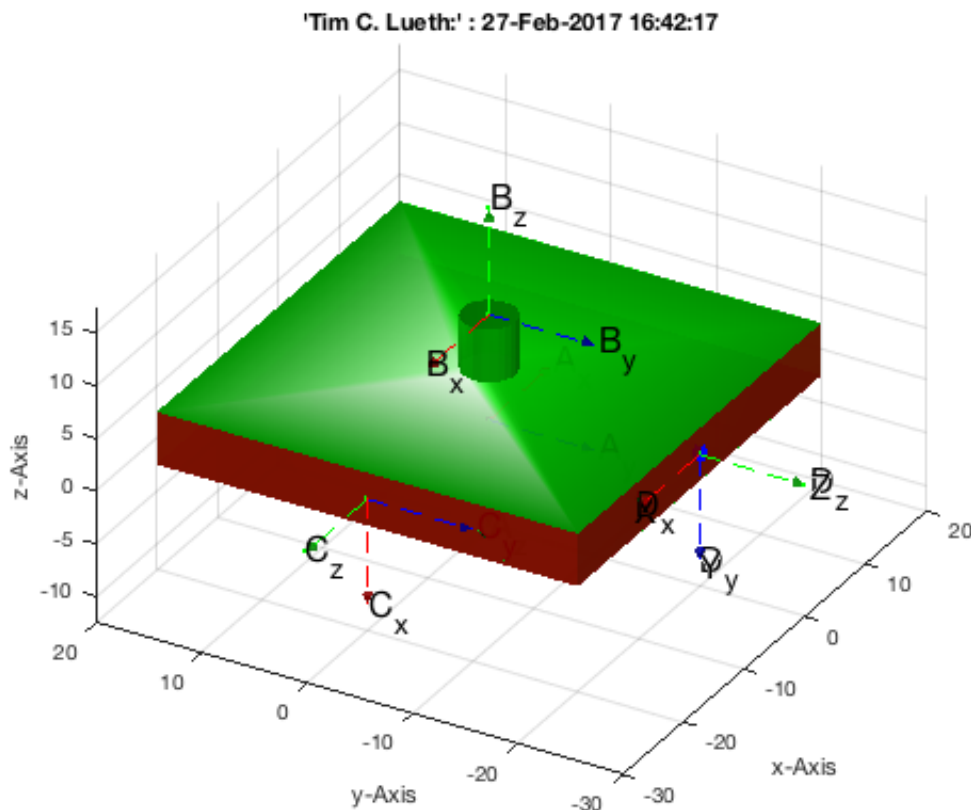
A =

struct with fields:

```

VL: [79×3 double]
FL: [154×3 double]
alpha: 0.8000
color: 'm'
Tname: {'C' 'D'}
T: {[4×4 double] [4×4 double]}
TFiL: {[2×1 double] [2×1 double]}

```



5. Creating kinematic models consisting of named solids

After being able to attach coordinate systems by frames to a solid, we can chain these solids by a string that describes which frames of the individual objects are linked together. For this purpose we define a structure **KM (kinematik model)** that is a list of solids, followed by an ascii identifier and a transformation matrix for the origin of the solid. If the solids are chained, a function **KMchain** calculates those 3rd column transformation matrix to move and rotate the solid so that it fits to the given description of linked frames. **KMplot** shows the position of the individual solids in space.

```
% KM={SG0,'A',eye(4);SG1,'B',eye(4);SG2,'C',eye(4);SG3,'D',eye(4);SG4,'E',eye(4)}

KM.SG={SG0,SG1,SG2,SG3,SG4};
KM.Sname={'A','B','C','D','E'};
KM.BT={eye(4),eye(4),eye(4),eye(4),eye(4)};

KMchain(KM,'A.A-A.B-B.A-B.B-C.A-C.B-D.A-D.B-E.A-E.B-');
KM=KMchain(KM,'A.A-A.B-B.A-B.B-C.A-C.B-D.A-D.B-E.A-E.B-')
KMplot(KM);

% Now let us see how the 3rd column matrices describe the position of the
% solids in 3D space to create the robot model
KM.BT{:}
```

KM =

struct with fields:

```
SG: {1x5 cell}
Sname: {'A' 'B' 'C' 'D' 'E'}
BT: {1x5 cell}
```

ans =

```
-0.0000    1.0000   -0.0000   -0.0000
-1.0000   -0.0000         0         0
-0.0000    0.0000    1.0000    2.5000
         0         0         0    1.0000
```

ans =

```
1.0000    0.0000   -0.0000   -0.0120
-0.0000    1.0000   -0.0000   -0.0120
         0    0.0000    1.0000   15.0000
         0         0         0    1.0000
```

ans =

```
-0.0000   -1.0000    0.0000   -0.0000
 0.0000   -0.0000   -1.0000   -4.9880
 1.0000    0.0000   -0.0000   32.9590
         0         0         0    1.0000
```

ans =

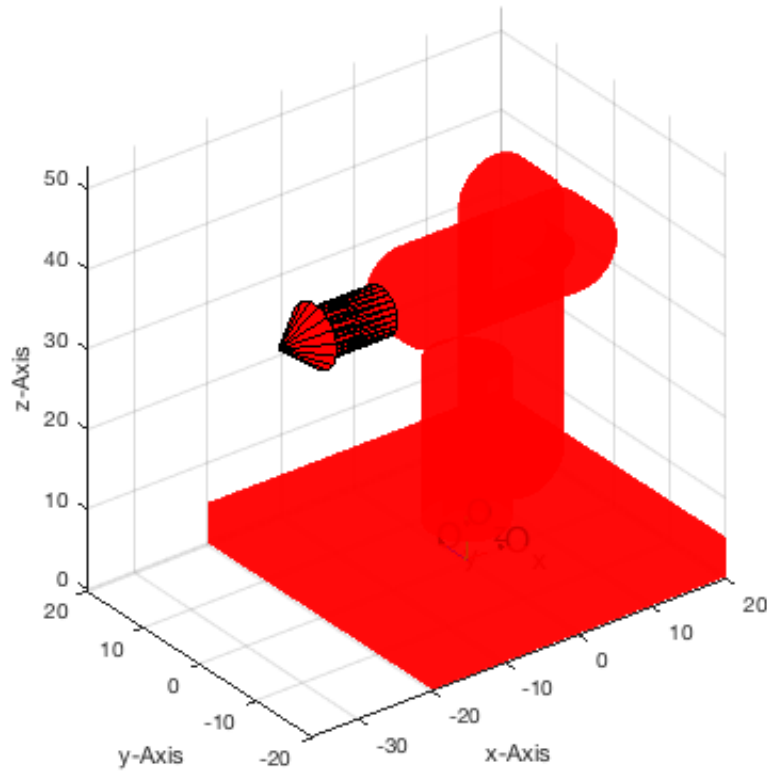
```
-1.0000    0.0000    0.0000   -7.4530
 0.0000   -0.0000   -1.0000  -10.9880
 0.0000   -1.0000   -0.0000   45.4350
         0         0         0    1.0000
```

ans =

```

0.0000    -0.0000    -1.0000   -27.4290
-0.0000    -1.0000     0.0000   -13.9760
-1.0000    -0.0000     0.0000    45.4470
         0         0         0         1.0000

```



6. Automatic creation of a chain

```
KMofSGs({SG0,SG1,SG4})
```

```
KMofSGs: No collisions found for tolerance: 0.10
```

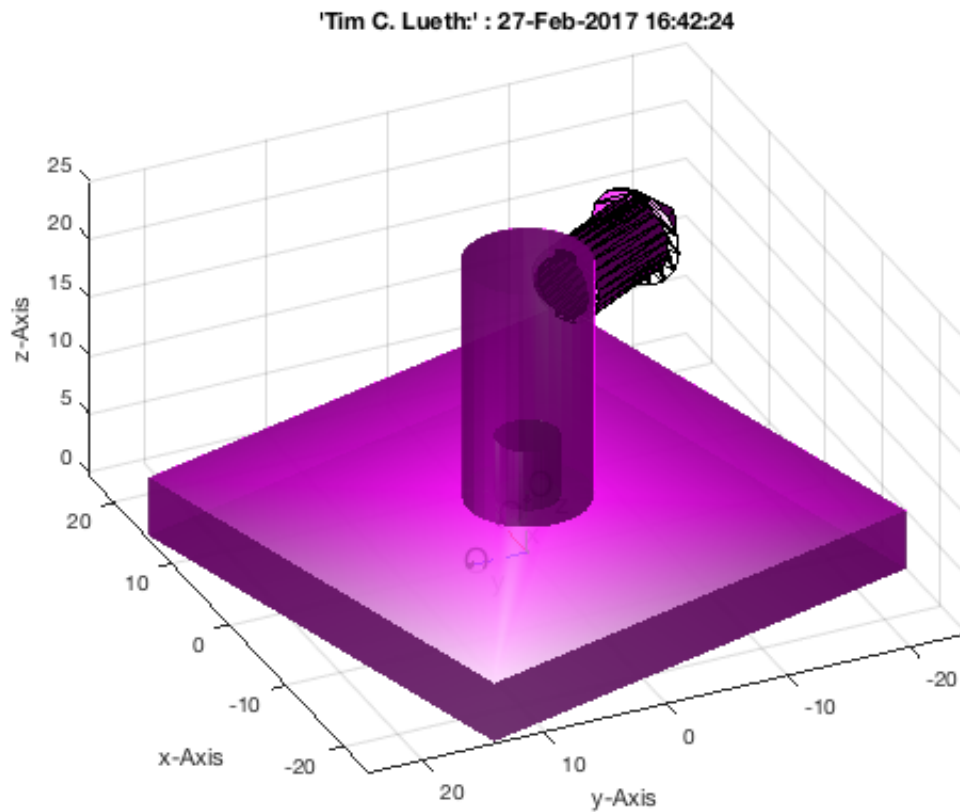
ans =

```
struct with fields:
```

```

SG: {[1x1 struct] [1x1 struct] [1x1 struct]}
Sname: {3x1 cell}
BT: {3x1 cell}
KC: {'A.A-A.B-B.A-B.B-C.A-C.B-' }

```



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:42:27 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-06-08
- Christina Friedrich, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-06-17

Published with MATLAB® R2016b

Exercise 12: Define Robot Kinematics and Detect Collisions

2015-08-09: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Loading the 5 components of a 4DoF robot solid model as last time
- 3. Automatic creation of a the robot
- 3. Collision in the joint by the resolution of the surfaces
- 4. Showing a different robot
- 5. Showing a self collision of a robot
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-11 we've learned about:

- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (VL), *Edge lists* (EL)
- Functions to import, check, and export of *STL-File* data
- Functions for generating text strings as solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation and merging of solid geometry sets
- Relative positioning of solids geometries and boolean operations on solids
- Packaging and boxing of several parts into a complete assemble kit
- Attaching coordinates frames for creation of Kinematik Models

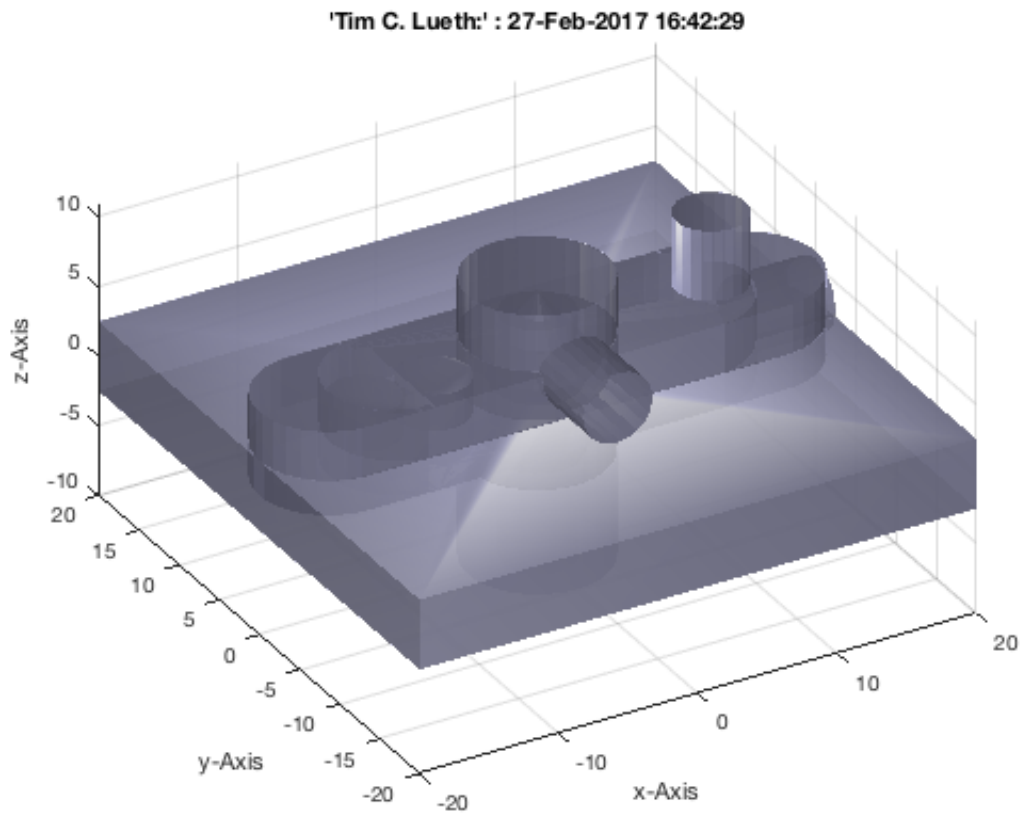
2. Loading the 5 components of a 4DoF robot solid model as last time

Before explaining how to create the parts of a robot kinematik we just load such components in. The command line load AIM_robot

```
clear all; close all; SGfigure;
load ('AIM_SGrobot')
SG0=SGfixerrors(SG0,1e-3); SGchecker(SG0);
SG1=SGfixerrors(SG1,1e-3); SGchecker(SG1);
SG2=SGfixerrors(SG2,1e-3); SGchecker(SG2);
SG3=SGfixerrors(SG3,1e-3); SGchecker(SG3);
SG4=SGfixerrors(SG4,1e-3); SGchecker(SG4);
% save ('AIM_SGrobot','SG0','SG1','SG2','SG3','SG4','SGrobot');
VLFLplotlight(1,0.8);
```

Warning: The file
'/Applications/MATLAB_R2016b.app/toolbox/matlab/codetools/private/evalmxdom.m'
could not be cleared because it contains MATLAB code that is currently

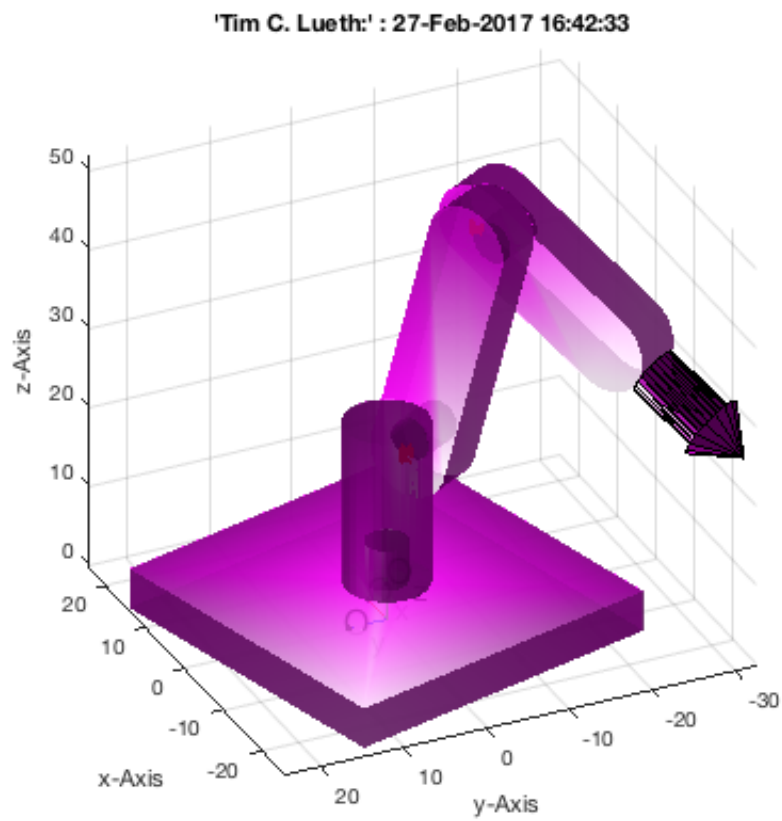
```
executing.  
Warning: The file '/Volumes/LUETH-WIN/WIN AIM Matlab  
Libraries/VLFL-Lib/VLFL_Toolbox_test.m' could not be cleared because it contains  
MATLAB code that is currently executing.  
Warning: The file '/Volumes/LUETH-WIN/WIN AIM Matlab  
Libraries/VLFL-Lib/publishTL.m' could not be cleared because it contains MATLAB  
code that is currently executing.  
Warning: The file  
'/Applications/MATLAB_R2016b.app/toolbox/matlab/codetools/publish.p' could not  
be cleared because it contains MATLAB code that is currently executing.  
Warning: The file '/Users/timlueth/Desktop/2017-02-27_TL_PCODE/VLFL_EXP12.m'  
could not be cleared because it contains MATLAB code that is currently  
executing.  
Warning: The file  
'/Applications/MATLAB_R2016b.app/toolbox/matlab/codetools/private/evalmxdom.m'  
could not be cleared because it contains MATLAB code that is currently  
executing.  
Warning: The file '/Volumes/LUETH-WIN/WIN AIM Matlab  
Libraries/VLFL-Lib/VLFL_Toolbox_test.m' could not be cleared because it contains  
MATLAB code that is currently executing.  
Warning: The file '/Volumes/LUETH-WIN/WIN AIM Matlab  
Libraries/VLFL-Lib/publishTL.m' could not be cleared because it contains MATLAB  
code that is currently executing.  
Warning: The file  
'/Applications/MATLAB_R2016b.app/toolbox/matlab/codetools/publish.p' could not  
be cleared because it contains MATLAB code that is currently executing.  
Warning: The file '/Users/timlueth/Desktop/2017-02-27_TL_PCODE/VLFL_EXP12.m'  
could not be cleared because it contains MATLAB code that is currently  
executing.  
Warning: The file  
'/Applications/MATLAB_R2016b.app/toolbox/matlab/codetools/private/evalmxdom.m'  
could not be cleared because it contains MATLAB code that is currently  
executing.  
Warning: The file '/Volumes/LUETH-WIN/WIN AIM Matlab  
Libraries/VLFL-Lib/VLFL_Toolbox_test.m' could not be cleared because it contains  
MATLAB code that is currently executing.  
Warning: The file '/Volumes/LUETH-WIN/WIN AIM Matlab  
Libraries/VLFL-Lib/publishTL.m' could not be cleared because it contains MATLAB  
code that is currently executing.  
Warning: The file  
'/Applications/MATLAB_R2016b.app/toolbox/matlab/codetools/publish.p' could not  
be cleared because it contains MATLAB code that is currently executing.  
Warning: The file '/Users/timlueth/Desktop/2017-02-27_TL_PCODE/VLFL_EXP12.m'  
could not be cleared because it contains MATLAB code that is currently  
executing.
```



3. Automatic creation of a the robot

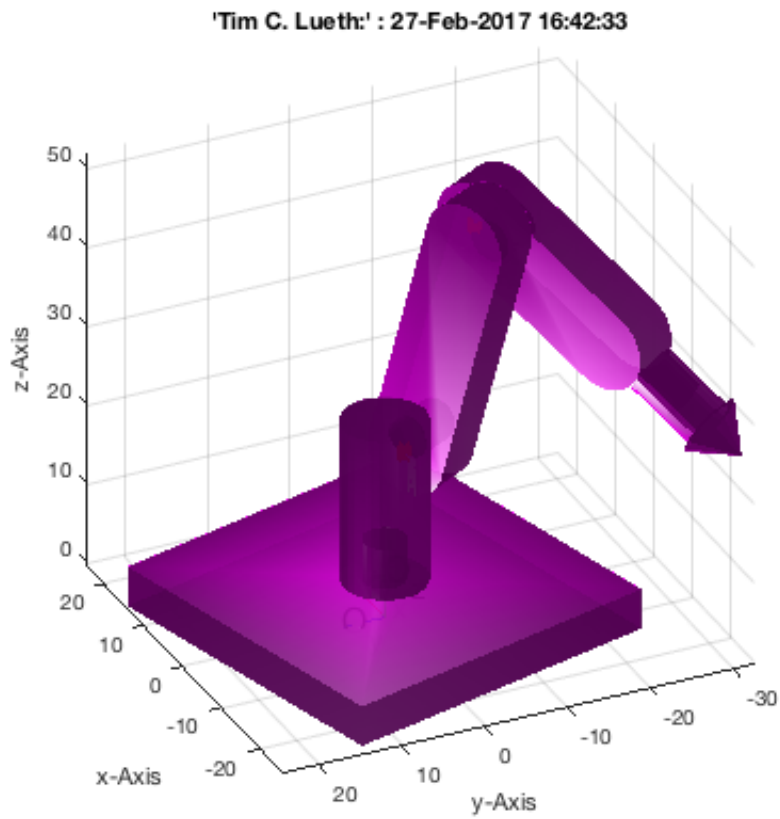
```
KMofSGs({SG0,SG1,SG2,SG3,SG4});
```

Warning in KMofSGs: 20 collisions found for tolerance: 0.10



3. Collision in the joint by the resolution of the surfaces

```
[KM,XVL]=KMofSGs({SG0,SG1,SG2,SG3,SG4},{},0.05);  
KMplot(KM,'m'); VLFLplotlight(1,0.9);
```

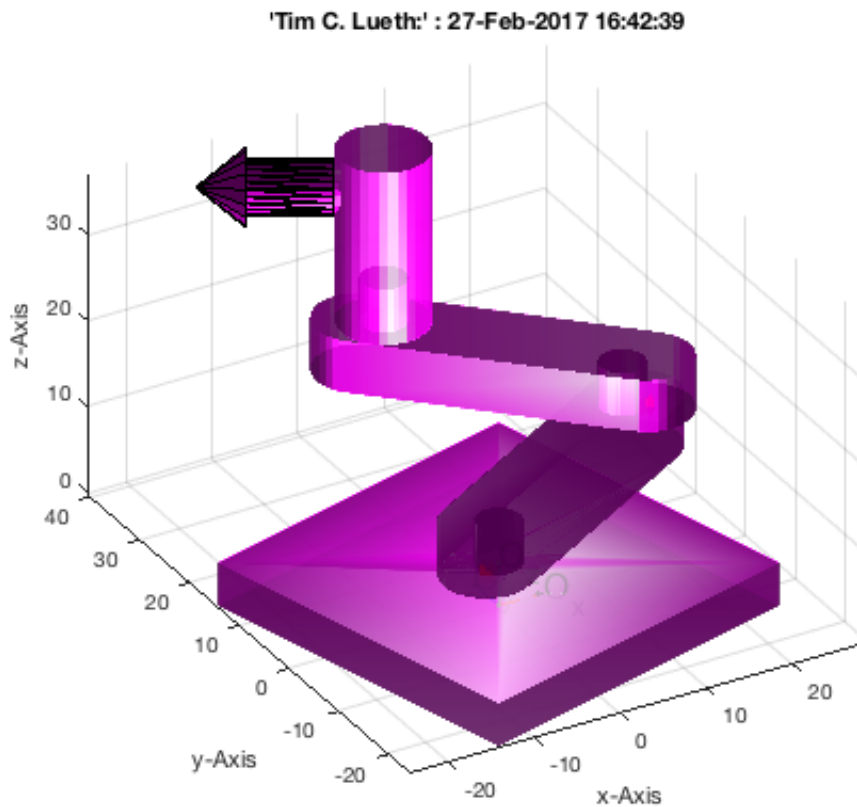


```
if ~isempty(XVL); zoompatch(XVL); VLplot(XVL, 'k*', 10); end;
```

4. Showing a different robot

```
KMofSGs({SG0,SG2,SG2,SG1,SG4});  
view(-30,30);
```

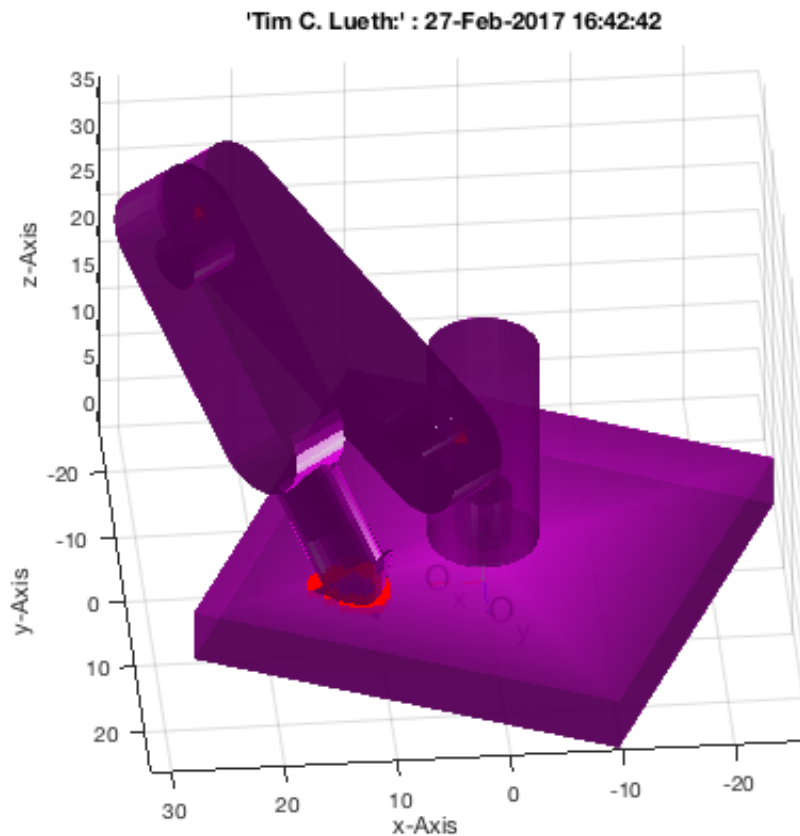
Warning in KMofSGs: 20 collisions found for tolerance: 0.10



5. Showing a self collision of a robot

```
KMofSGs({SG0,SG1,SG2,SG3,SG4},155);  
view(-185,35); VLFLplotlight(1,0.8);
```

Warning in KMofSGs: 128 collisions found for tolerance: 0.10



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:42:45 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-06-08
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 13: Mounting Faces and Conversion of Blocks into Lightweight-structures

2015-09-11: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Analyzing mounting faces of flat surfaces
- 3. Analyzing mounting faces of spherical/freeform surfaces
- 4. Create corresponding surfaces parallel to mounting faces
- 5. Create solids using the parallel surfaces and a plate thickness
- 6. Finding the 2D CPL of a planar 3D Surface
- 7. Replace a solid block by covering plates
- 8. Replace a solid block by covering plates with punched contours
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-12 we've learned about:

- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (VL), *Edge lists* (EL)
- Functions to import, check, and export of *STL-File* data
- Functions for generating text strings as solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation and merging of solid geometry sets
- Relative positioning of solids geometries and boolean operations on solids
- Packaging and boxing of several parts into a complete assemble kit
- Attaching coordinates frames and the creation of kinematik models

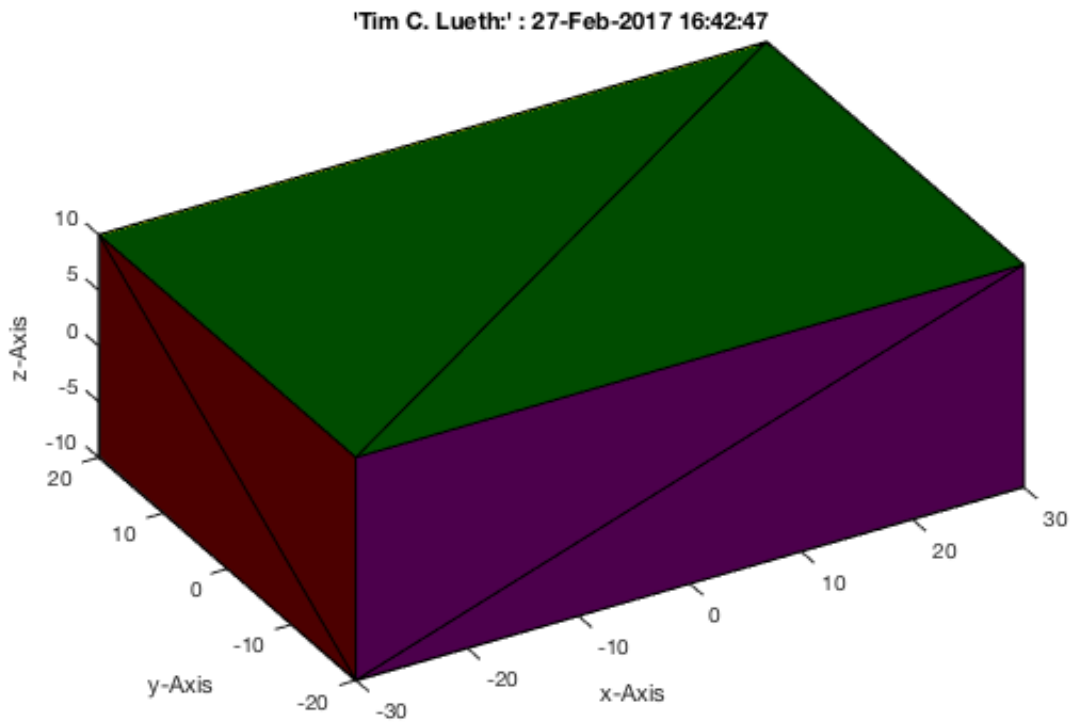
2. Analyzing mounting faces of flat surfaces

All planar faces of a solid can be considered as mounting faces for different design purposes. It is useful to calculate or to handle them using the following functions:

- `MLOfSG` - creates the mounting faces and calculates normal vectors and sizes
- `MLplot` - plots the mounting faces in different colors

The following example shows the separation of a solid into a set of mounting faces wich are represented by a number and a correlation list between triangle faces and mounting faces.

```
close all; SGfigure; view (-30,30);  
[ML,MA,SG]=MLOfSG(SGbox([60,40,20]));  
MLplot(SG);
```

- ML defines for all entries of FL the corresponding mounting face.
- In this example, 12 faces are ordered to 6 mounting faces

ML

ML =

1
1
2
2
3
3
4
4
5
5
6
6

- MA describes for each mounting face, the number, the size, and the normal vector.
- In this example, we see 6 faces with different normal vectors and sizes

MA

MA =

1	4800	0	0	-1
2	4800	0	0	1
3	1600	1	0	0
4	1600	-1	0	0
5	2400	0	-1	0
6	2400	0	1	0

- SG is a struct of VL and FL extended by ML and MA

SG

SG =

struct with fields:

VL: [8×3 double]

FL: [12×3 double]

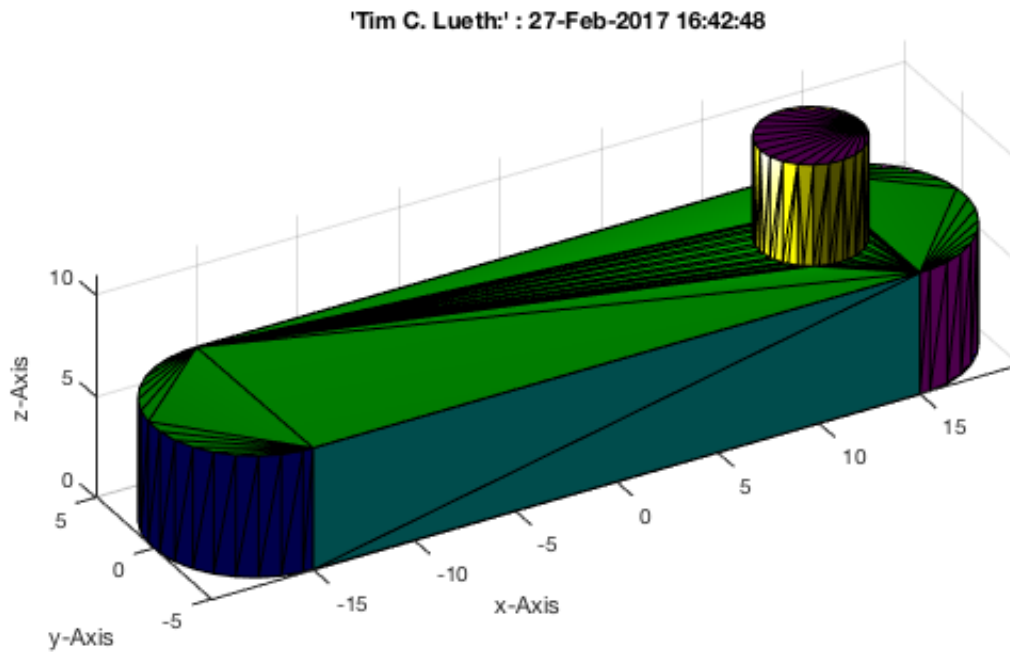
ML: [12×1 double]

MA: [6×5 double]

3. Analyzing mounting faces of spherical/freeform surfaces

The concepts of mounting faces supports also spherical mounting faces. In case of spherical mounting faces the length of the normal vector is shorter than 1!. This information can be used to distinguish between planar and spherical or freeformed mounting faces

```
close all; SGfigure; view (-30,30);
load AIM_SGrobot
[ML,MA,SG]=MLOfSG(SG2);
MLplot(SG);
```



Now we plot only the two half-spherical mounting faces 5 and 1 of the robot link

```
close all; SGfigure; view (-30,30);
MA
MLplot(SG,5); % bended surface, since length of normal vector is less than 1
MLplot(SG,1); % planar surface since length of normal vector is 1
z1=MA(12,3:5) % normal vector of the cylindric surface 1
z2=MA(14,3:5) % normal vector of the cylindric surface 2
```

MA =

1.0000	717.2978	0	0	-1.0000
2.0000	717.2974	0	0	1.0000
3.0000	360.0000	0	-1.0000	0
4.0000	0.2880	1.0000	0	0
5.0000	188.1982	0.5972	-0.0000	0
6.0000	0.2880	1.0000	0	0
7.0000	360.0000	0	1.0000	0
8.0000	0.2880	-1.0000	0	0
9.0000	188.1982	-0.5972	0.0000	0
10.0000	0.2880	-1.0000	0	0
11.0000	38.7854	0	0	-1.0000
12.0000	156.5960	-0.0001	0.0000	0.0000
13.0000	38.7829	0	0	1.0000
14.0000	156.5910	0.0000	0.0000	0.0000

z1 =

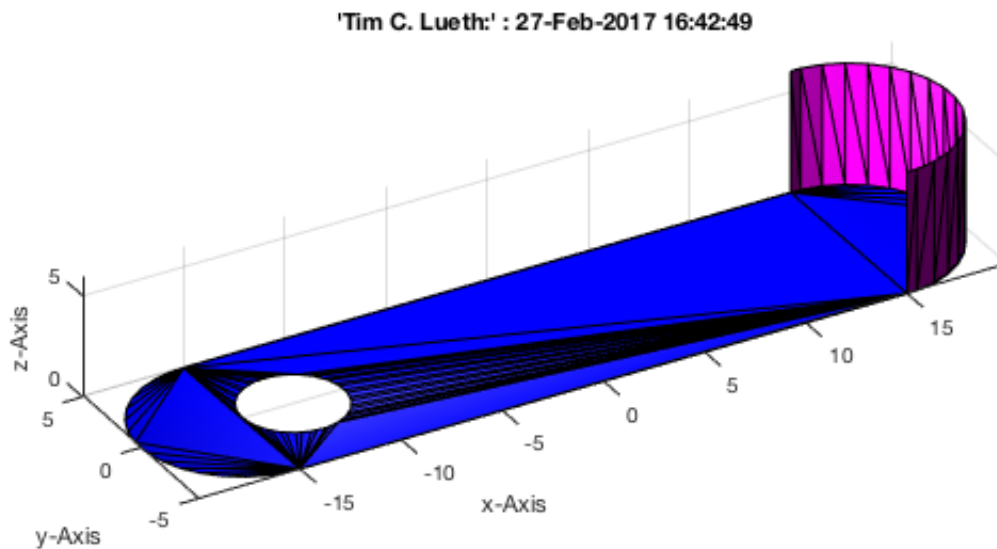
1.0e-04 *

-0.6543 0.2818 0.1521

z2 =

1.0e-04 *

0.1239 0.3370 0.0978



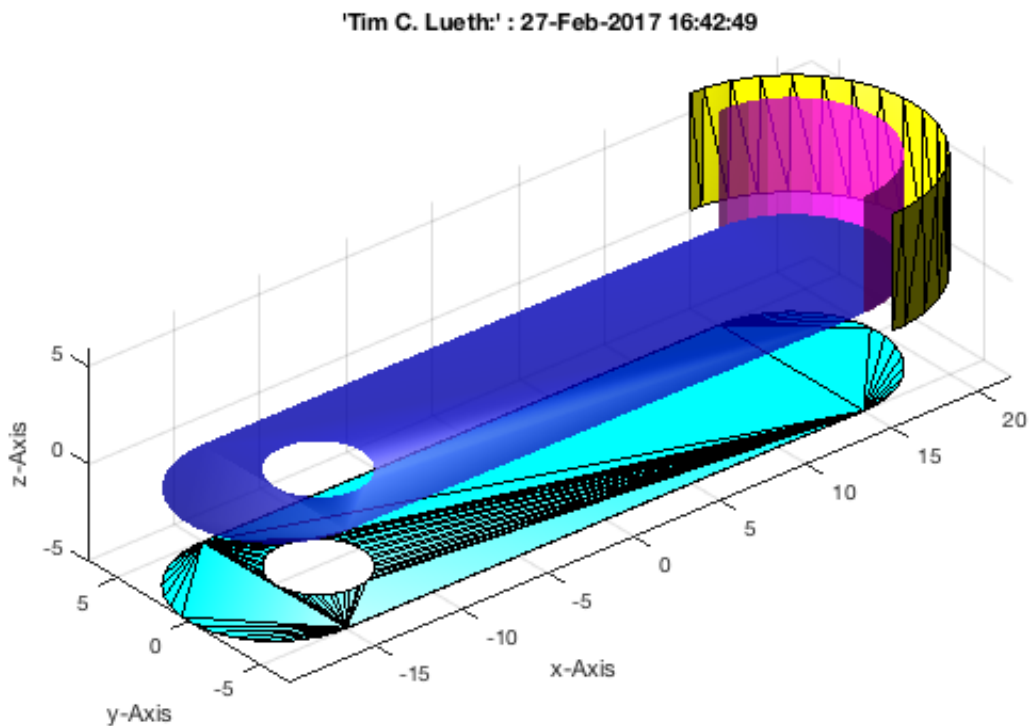
4. Create corresponding surfaces parallel to mounting faces

It is useful to create corresponding surface parallel to mounting faces, which can be smaller or larger than the original one. In the next example it is shown how to create a parallel surface in distance 5mm for a planar surface (#1) and a spherical surface (#5).

- VLtransN(VL,FL,shrink, distance) - helps to create corresponding surfaces

```
VLFLplotlight(1,0.8); view(-40,30);
[VL,~,~,FL]=VLtransN(SG.VL,SG.FL(ML==5,:),0,2);
VLFLplot(VL,FL,'y');

[VL,~,~,FL]=VLtransN(SG.VL,SG.FL(ML==1,:),0,5);
VLFLplot(VL,FL,'c');
```

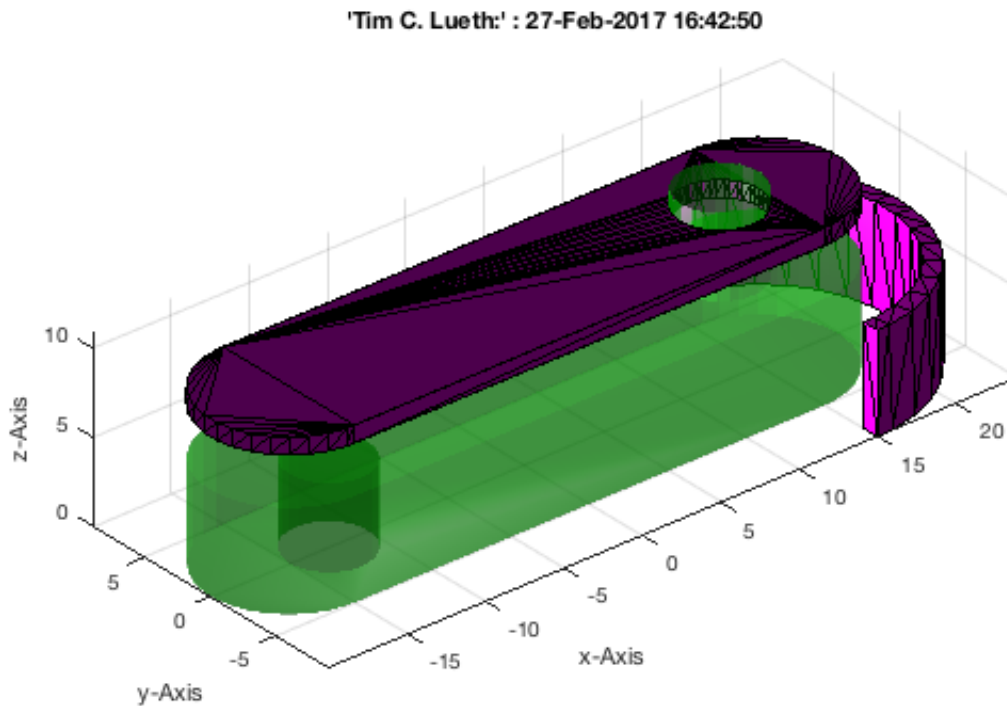


5. Create solids using the parallel surfaces and a plate thickness

Often we want to create a plate solid parallel to the mounting face.

- `SGofSurface(VL,FL,thickness, distance, stretching)` - creates solids parallel to mounting faces.

```
close all; SGfigure; view (-30,30);
SGplot(SG); VLFLplotlight(1,0.5); view(-40,30);
SG2=SGofSurface(SG.VL,SG.FL(ML==2,:),1,3);
SGplot(SG2,'m');
SG2=SGofSurface(SG.VL,SG.FL(ML==5,:),1,3);
SGplot(SG2,'m');
```

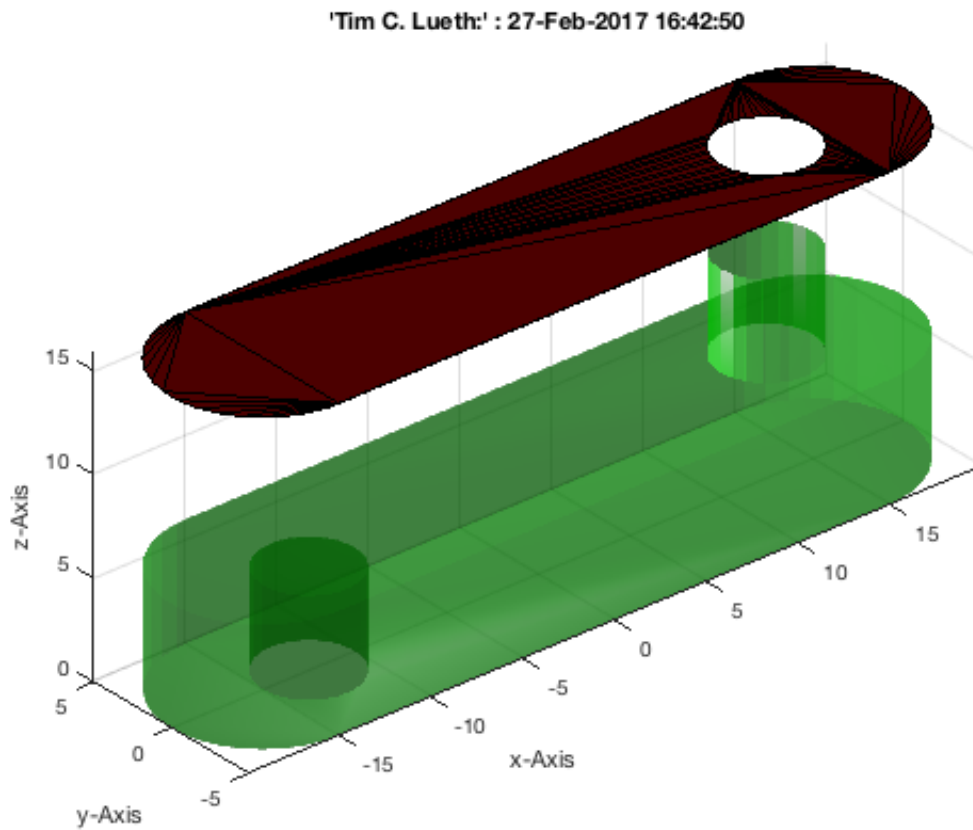


6. Finding the 2D CPL of a planar 3D Surface

Many procedures are based on the manipulation of CPL contours. Nevertheless not all planar surfaces are in the xy-plane. Therefore, there is a function that creates a CPL contour of a surface and returns also the transformation matrix for the back transformation.

- `[PL,T]=PlofVLFL(VL,FL)` - returns a PL and a transformation matrix
- `[CPL,T]=CPLofVLFL(VL,FL)` - returns a CPL and a transformation matrix

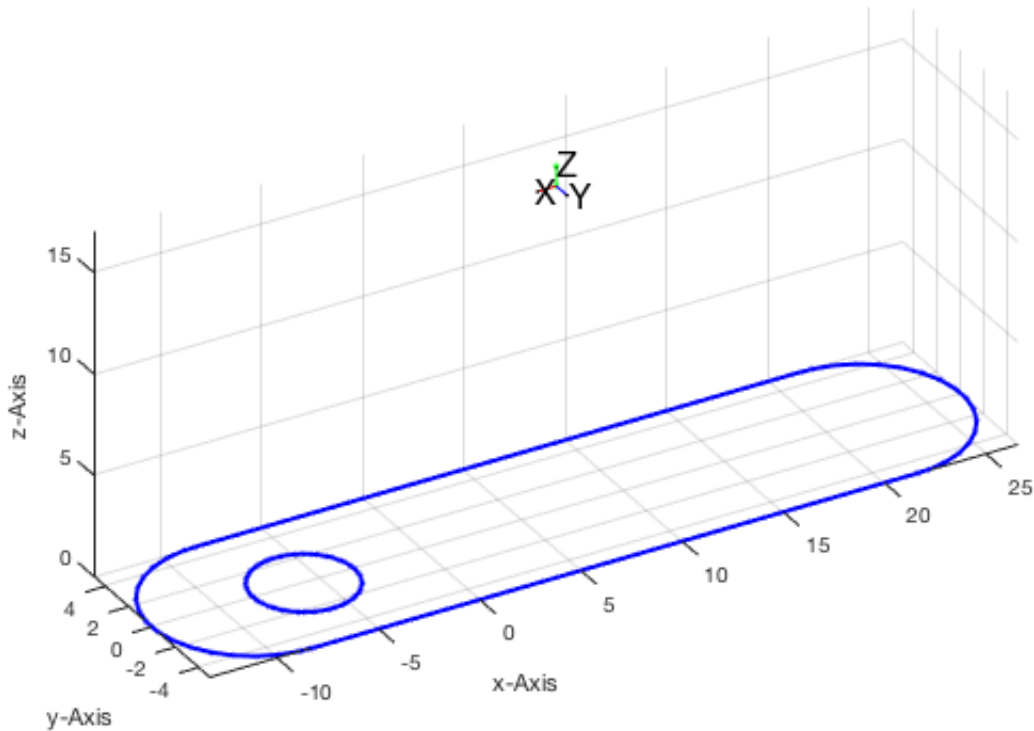
```
close all; SGfigure; view (-30,30);
SGplot(SG); VLFLplotlight(1,0.5); view(-40,30);
[VL,~,~,FL]=VLtransN(SG.VL,SG.FL(ML==2,:),0,10);
VLFLplot(VL,FL);
```



Now show simply the isolated CPL of this mounting face

```
close all; SGfigure; view (-30,30); axis on; grid on;  
[CPL,T]=CPLofVLFL(VL,FL);  
CPLplot(CPL,'b.-',2);  
plotT(T);
```

'Tim C. Lueth:' : 27-Feb-2017 16:42:51



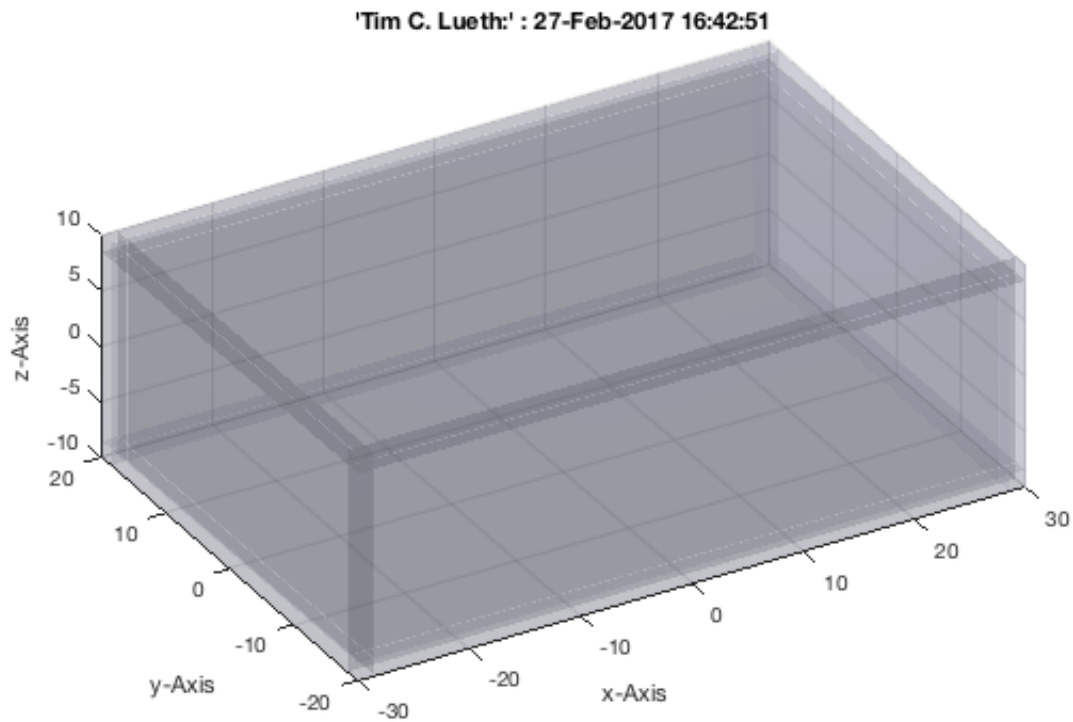
7. Replace a solid block by covering plates

By converting a solid block into a hollow structure using covering plates, the weight and mass inertia of a solid is reduced.

- SGplatesofSGML(SG,thickness) - convert a solid into a plate structure
- SGweight (SG,specific weight,resolution) - slowly calculates the weight

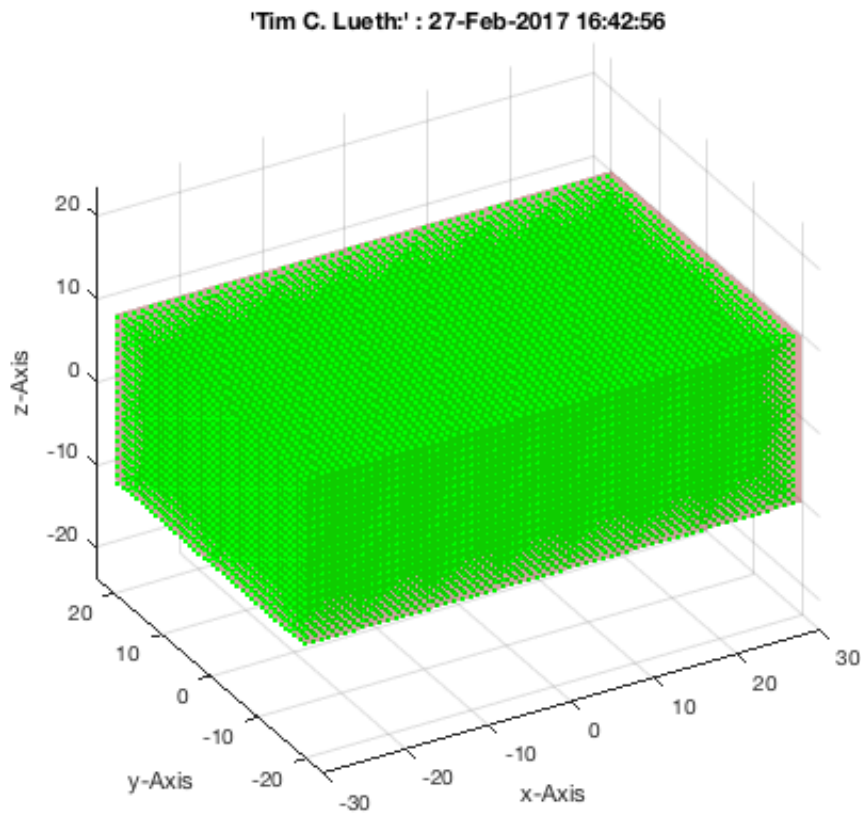
```
close all; SGfigure; view (-30,30);

SGN=SGplatesofSGML(SGbox([60,40,20]),1.5);
SGplot(SGN,'w'); VLFLplotlight(1,0.2);
```

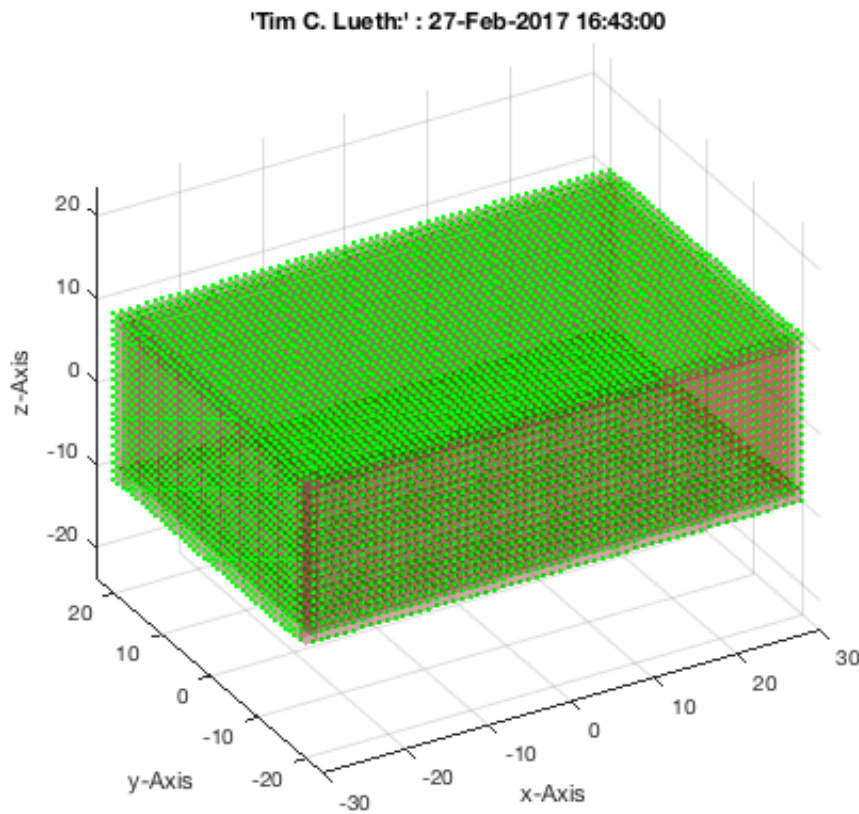
```
SGweight(SGbox([60,40,20]),[],1);
```

Using a resolution of 1.0 mm^3 ($n=62307$) and a specific weight of 1.15 milligramm per mm^3 , the overall weight is ca. 58 gramm.
Elapsed time is 4.195111 seconds.



```
SGweight(SGN,[],1);
```

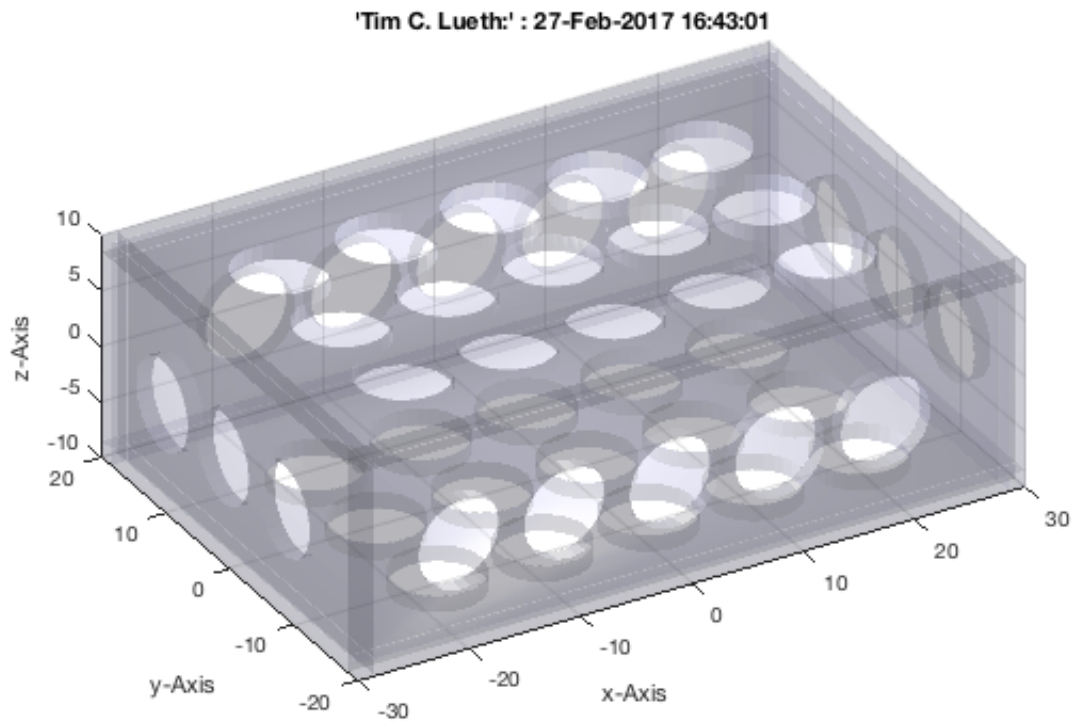
Using a resolution of 1.0 mm^3 ($n=62307$) and a specific weight of 1.15 milligramm per mm^3 , the overall weight is ca. 11 gramm.
Elapsed time is 4.292508 seconds.



8. Replace a solid block by covering plates with punched contours

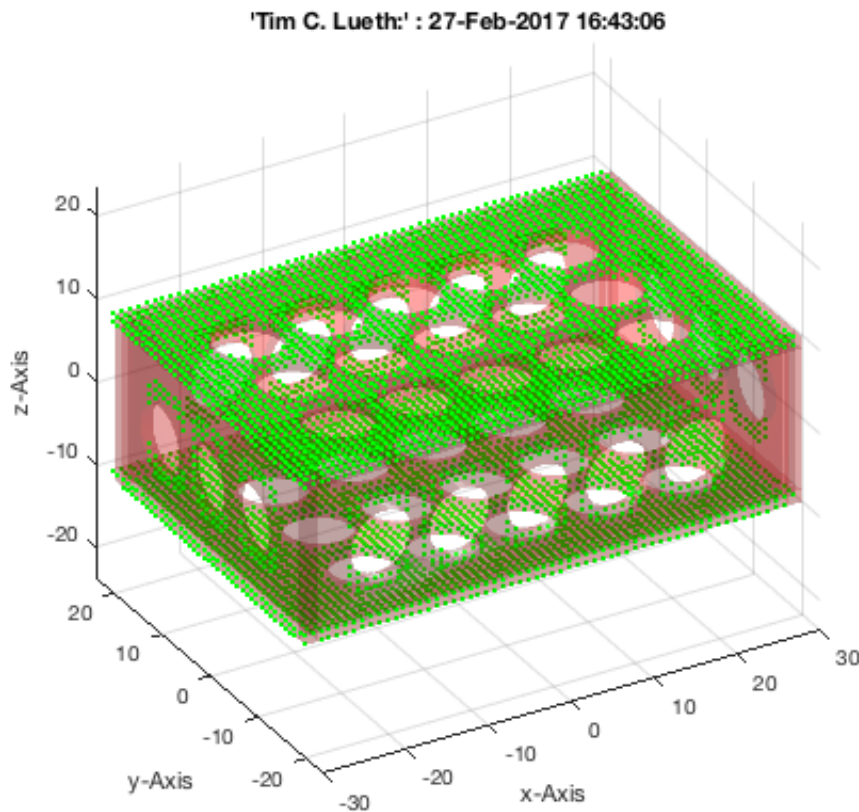
- SGplatesofSGML(SG,thickness,CPL) - convert a solid into a punched plate structure

```
close all; SGfigure; view (-30,30);  
SGN=SGplatesofSGML(SGbox([ 60,40,20]),1.5,PLcircle(4));  
SGplot(SGN,'w'); VLFLplotlight(1,0.2);
```



```
SGweight(SGN,[],1);
```

Using a resolution of 1.0 mm^3 ($n=62307$) and a specific weight of 1.15 milligramm per mm^3 , the overall weight is ca. 9 gramm.
Elapsed time is 4.031337 seconds.



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:43:09 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-09-11
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)

2015-09-20: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Fill a contour with copies of pattern
- 3. Writing a contour as SVG-File for laser-cutting
- 4. Calculating the normal vectors of edges and points
- 5. Growing with same number of points
- 6. Growing with correct distance to edges
- 7. Rounded edges inside a contour
- 8. Sort CPLs around its center
- 9. Informations on contours inside of others
- 10. Order contours for the sequential plot with a laser cutter
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

In examples 1-13 we've learned about:

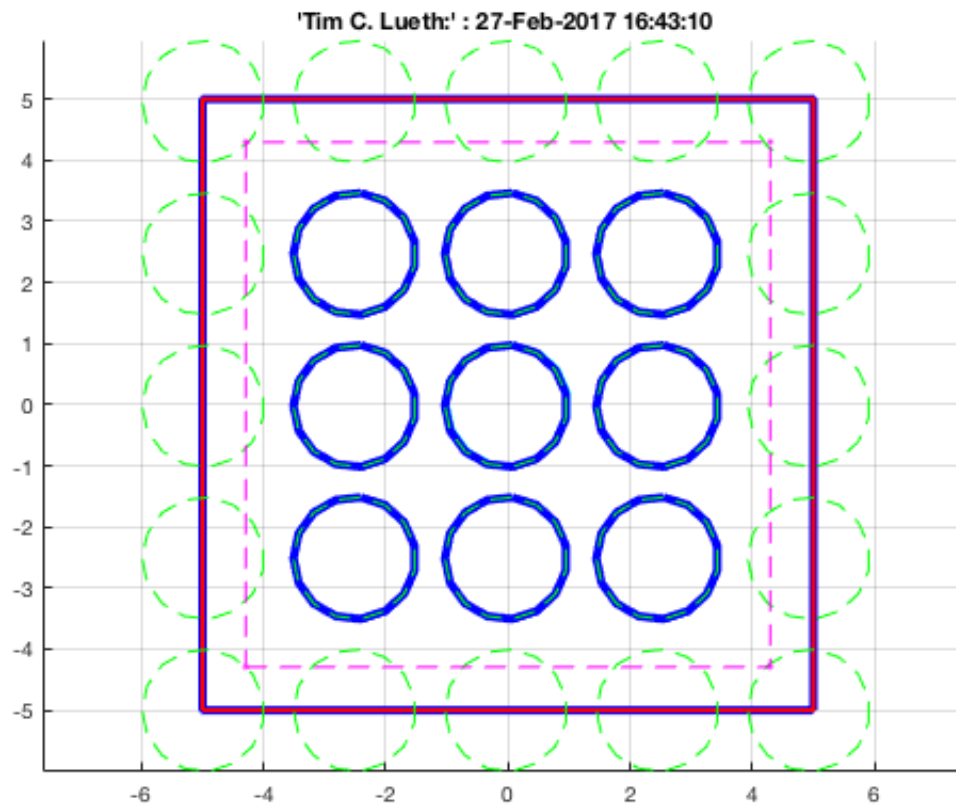
- *Point lists* (PL), *Vertex lists* (VL), *Facet lists* (VL), *Edge lists* (EL)
- Functions to import, check, and export of *STL-File* data
- Functions for generating text strings as solid volumes
- *Closed polygon lists* (CPL) for boolesche operations of contours
- 2.5D extrusion of closed polygon list (CPL) to *Solid Geometries* (SG)
- Spatial transformation and merging of solid geometry sets
- Relative positioning of solids geometries and boolean operations on solids
- Packaging and boxing of several parts into a complete assemble kit
- Attaching coordinates frames and the creation of kinematik models
- Function for mounting faces of solids and creation of lightweight-solids

2. Fill a contour with copies of pattern

As it was shown already in the function SGplatesofSGML, it often makes sense to fill a contour with another pattern. This can be done by using one of the following functions:

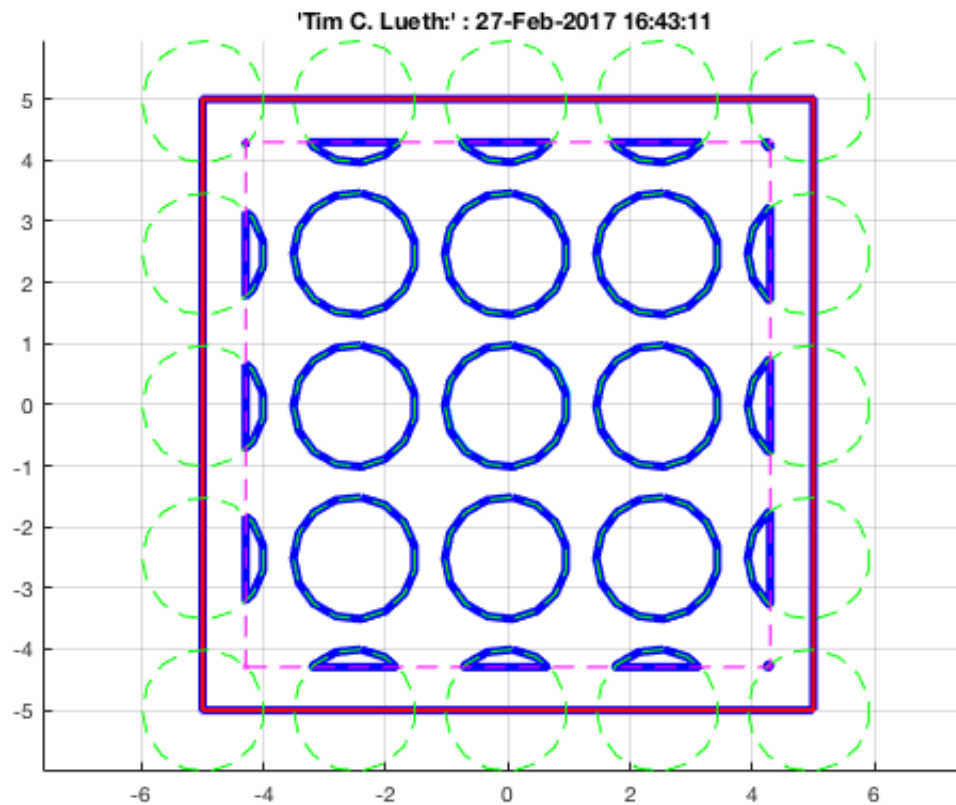
- **CPLfillPattern(CPLA, CPLB,w,d)** - fills a contour CPLA with copies of the pattern CPLB with a distance to the outer contour w and distance between the patterns of d

```
SGfigure; view(0,90); axis on;
CPLfillPattern(PLsquare(10,10),PLcircle(1),1);
```



This can also be done with cutted pattern instead of complete pattern

```
SGfigure; view(0,90); axis on;  
CPLfillPattern(PLsquare(10,10),PLcircle(1),1,[],true);
```



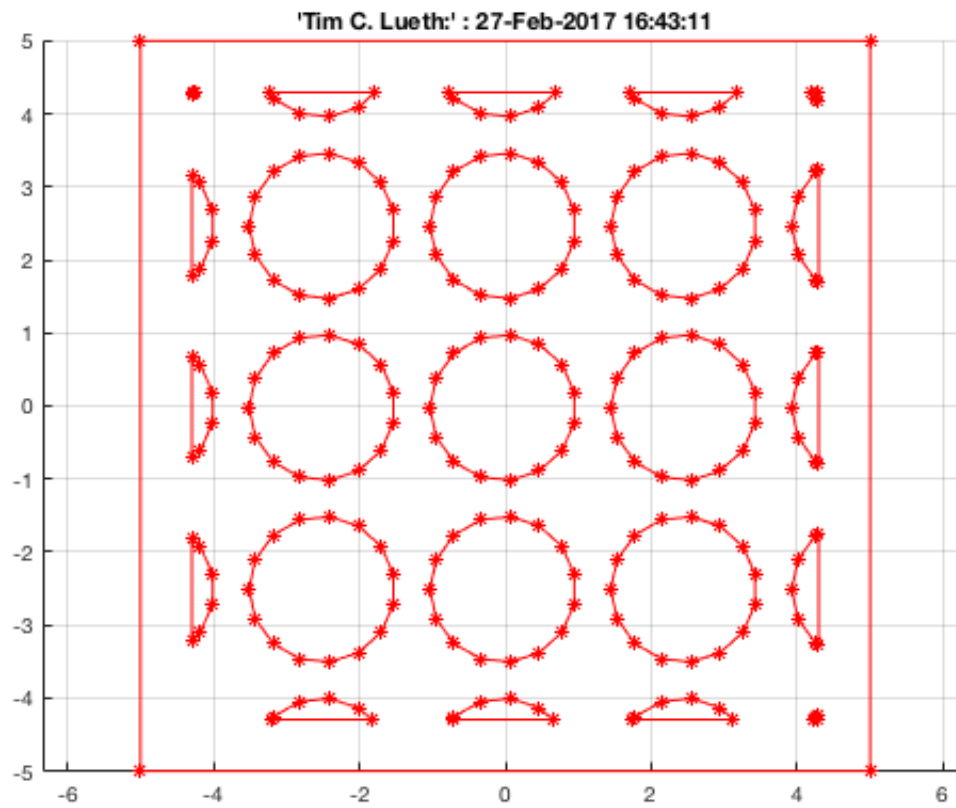
3. Writing a contour as SVG-File for laser-cutting

Especially for laser cutting or plating of contours, the SVG file-format is very popular. Handling of SVG Files is possible using the following functions:

- **CPLwriteSVG (CPL,Filename)** - writes the contours in a SVG-File

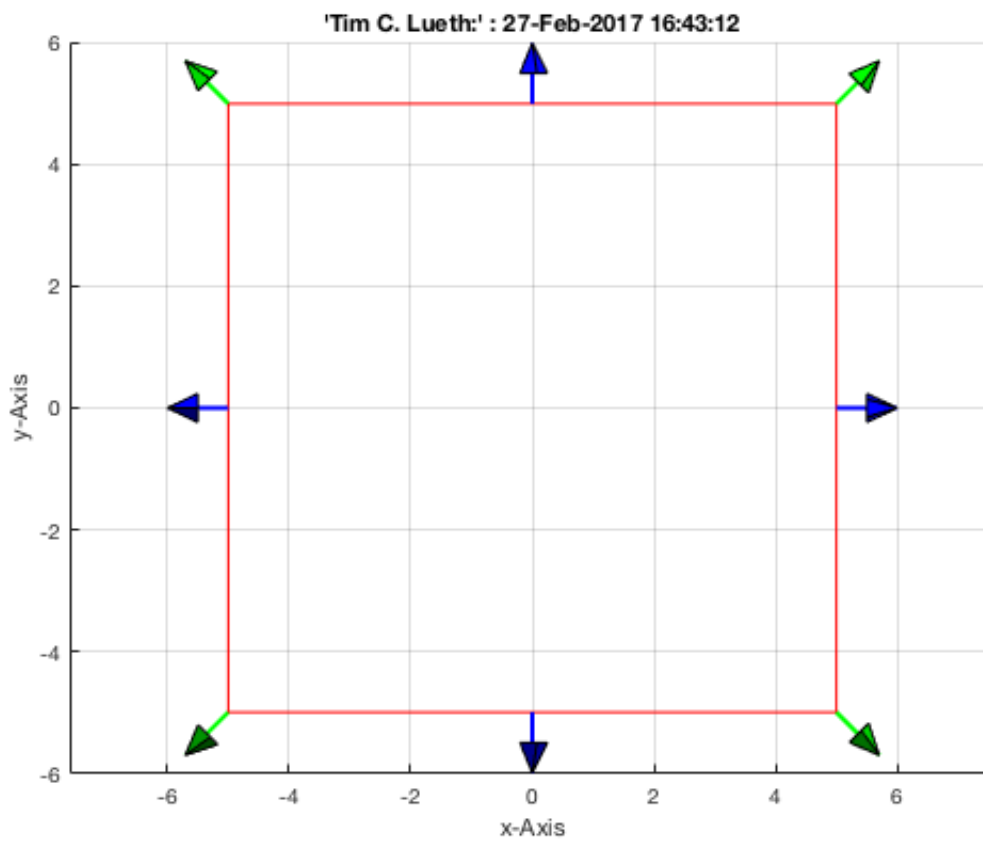
```
SGfigure; view(0,90); axis on;
A=CPLfillPattern(PLsquare(10,10),PLcircle(1),1,[],true);
CPLplot(A);
CPLwriteSVG(A,'VLFL_EXP14');
```

WRITING SVG FILE /Users/timlueth/Desktop/VLFL_EXP14.SVG in ASCII MODE completed.



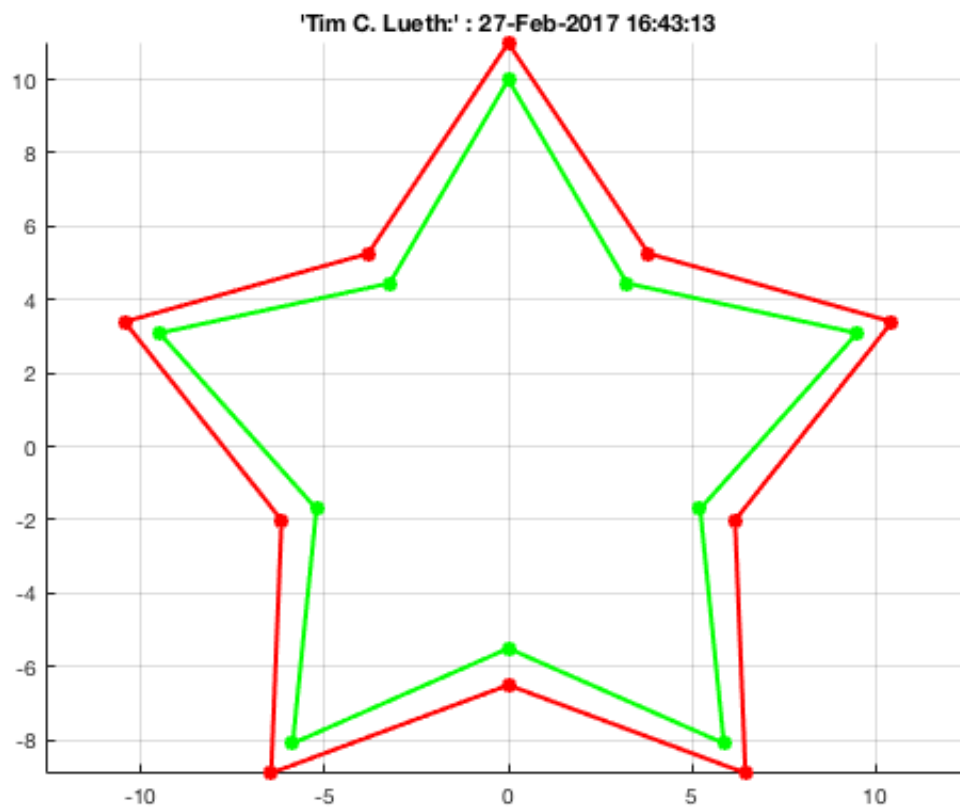
4. Calculating the normal vectors of edges and points

```
SGfigure; view(0,90);
CPLedgeNormal(PLsquare(10,10)); axis on;
```



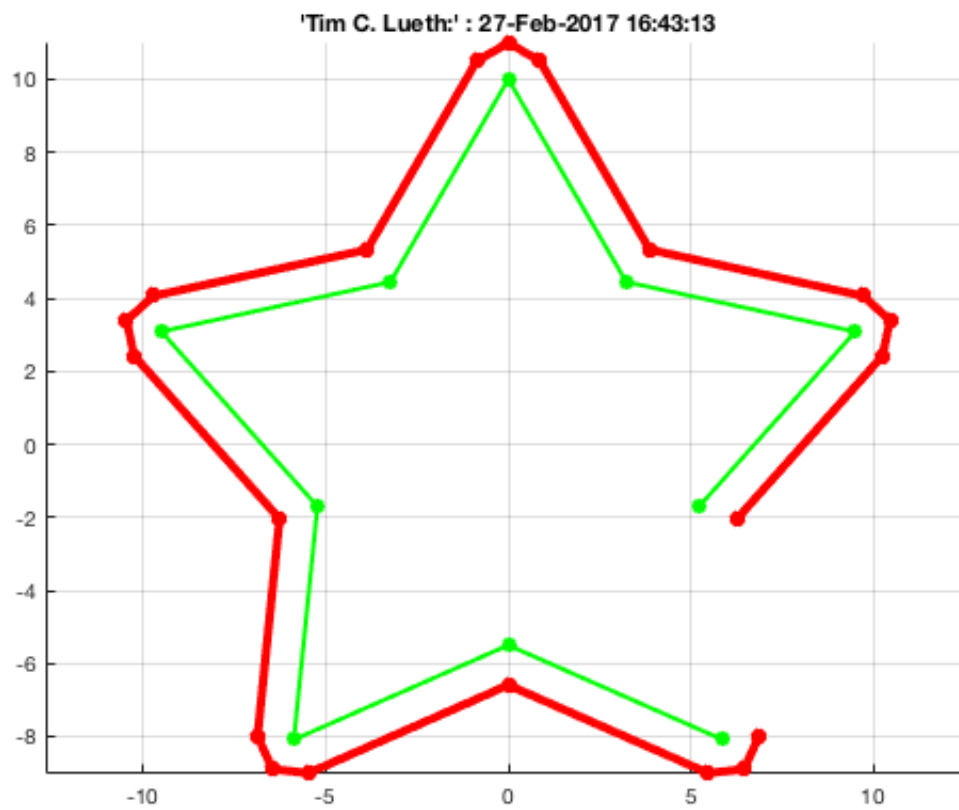
5. Growing with same number of points

```
SGfigure; view(0,90);  
CPLgrow(PLstar(10,10),1); axis on;
```



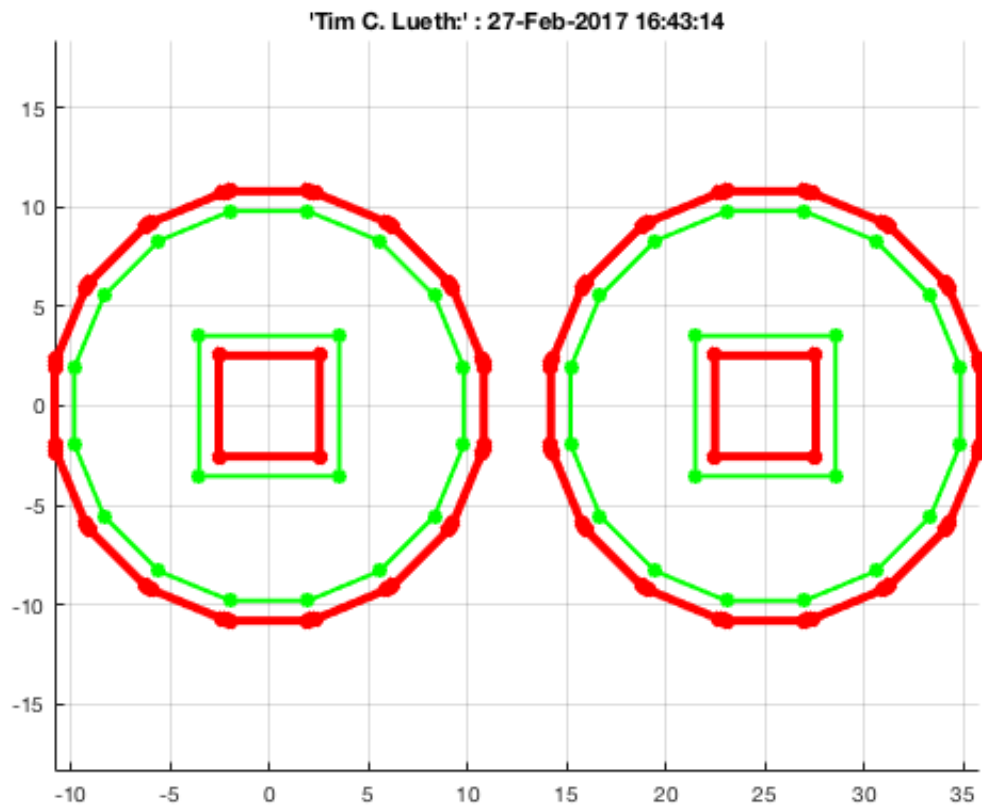
6. Growing with correct distance to edges

```
SGfigure; view(0,90); axis on;  
CPLgrowEdge(PLstar(10,10),1);
```



Another example using CPLsample

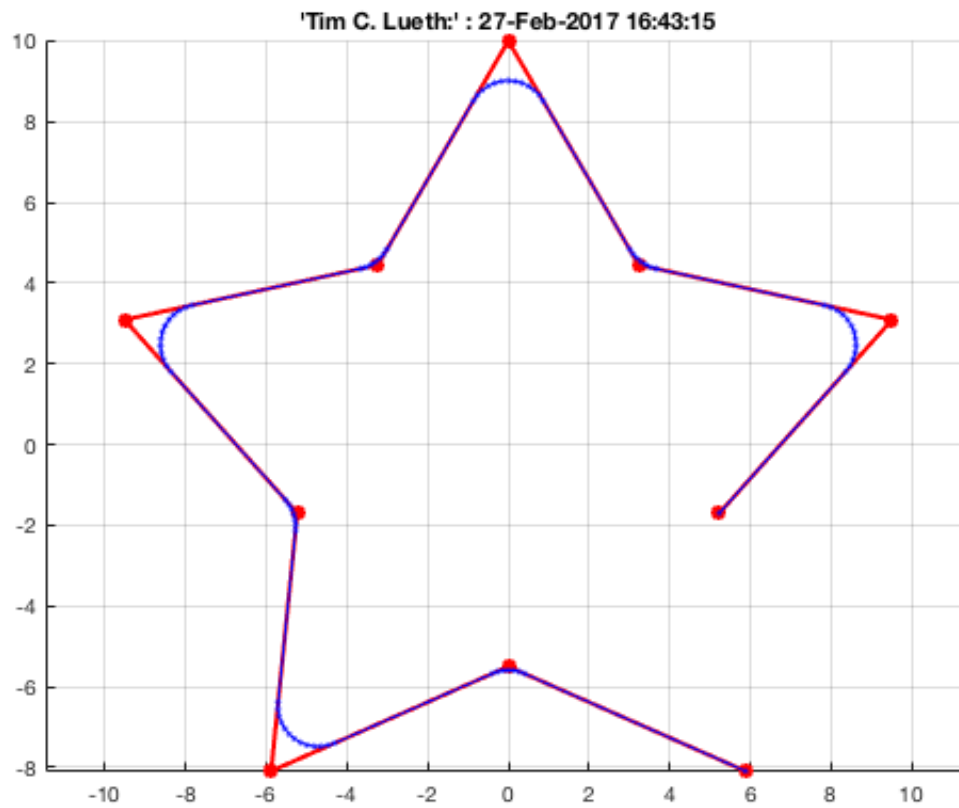
```
SGfigure; view(0,90);  
CPLgrowEdge(CPLsample(12),1); axis on;
```



7. Rounded edges inside a contour

Another method to change the shape of a contour is to round the edges.

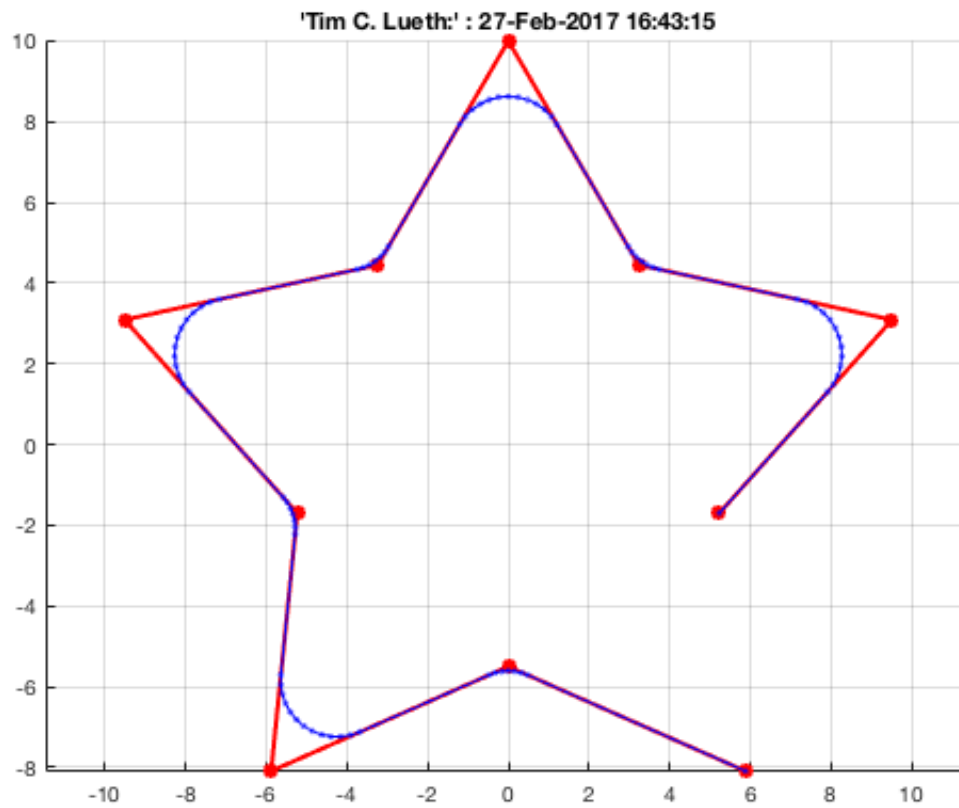
```
SGfigure; view(0,90);  
PLradialEdges(PLstar(10,10));axis on;
```



Another example using radius=2

```
SGfigure; view(0,90); axis on;
PLradialEdges(PLstar(10,10),2); axis on;
```

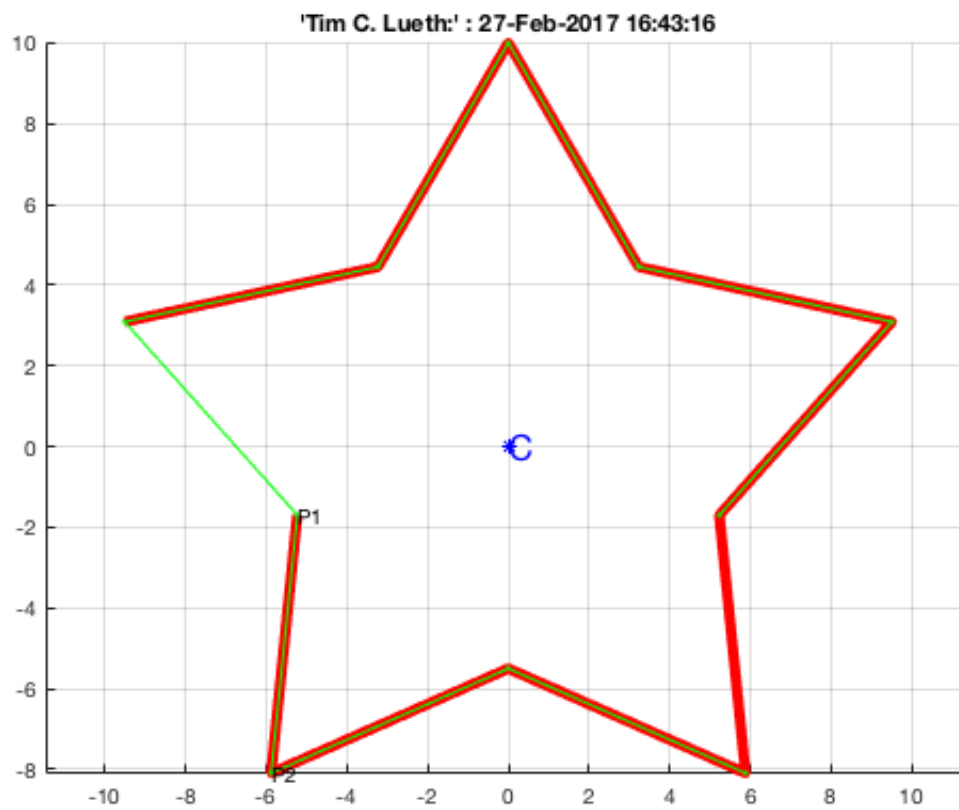
```
Radial egde radius reduced R=2 to 1.4 at [9.5 3.1] w=119.6
Radial egde radius reduced R=2 to 1.2 at [3.2 4.4] w=-47.6
Radial egde radius reduced R=2 to 1.4 at [0.0 10.0] w=119.6
Radial egde radius reduced R=2 to 1.2 at [-3.2 4.4] w=-47.6
Radial egde radius reduced R=2 to 1.4 at [-9.5 3.1] w=119.6
Radial egde radius reduced R=2 to 1.2 at [-5.2 -1.7] w=-47.6
Radial egde radius reduced R=2 to 1.4 at [-5.9 -8.1] w=119.6
Radial egde radius reduced R=2 to 1.2 at [-0.0 -5.5] w=-47.6
```



8. Sort CPLs around its center

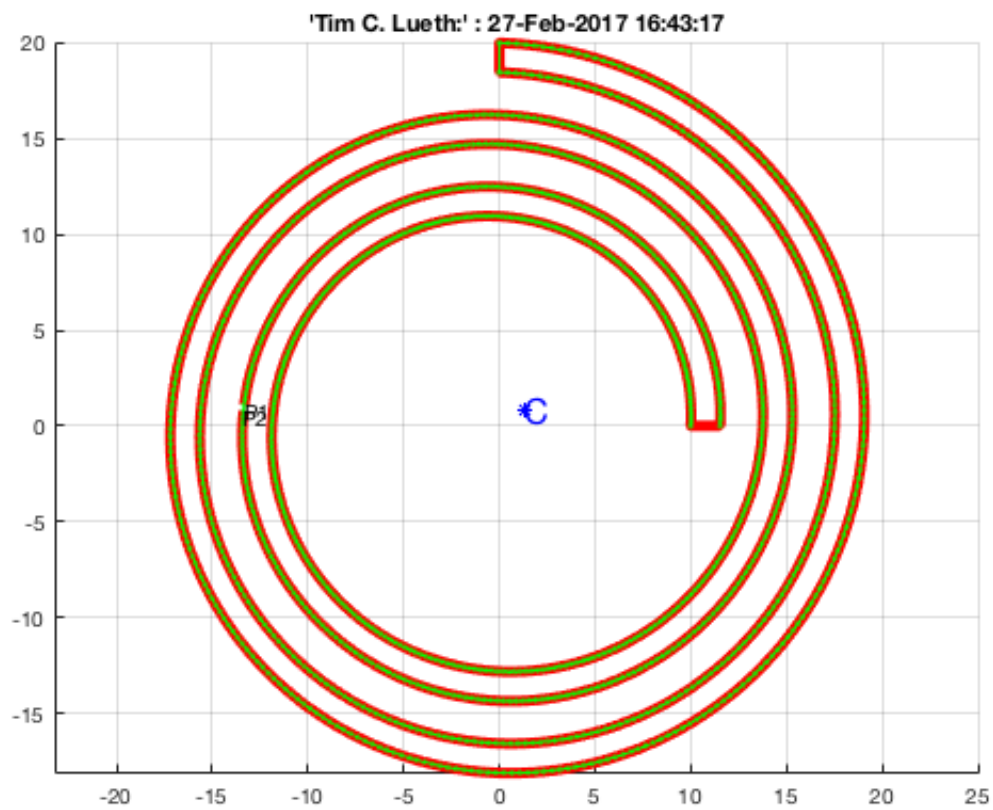
Find the minimal angle value of a star

```
SGfigure; view(0,90);
CPLsortC(PLstar(10,10),'min'); axis on;
```



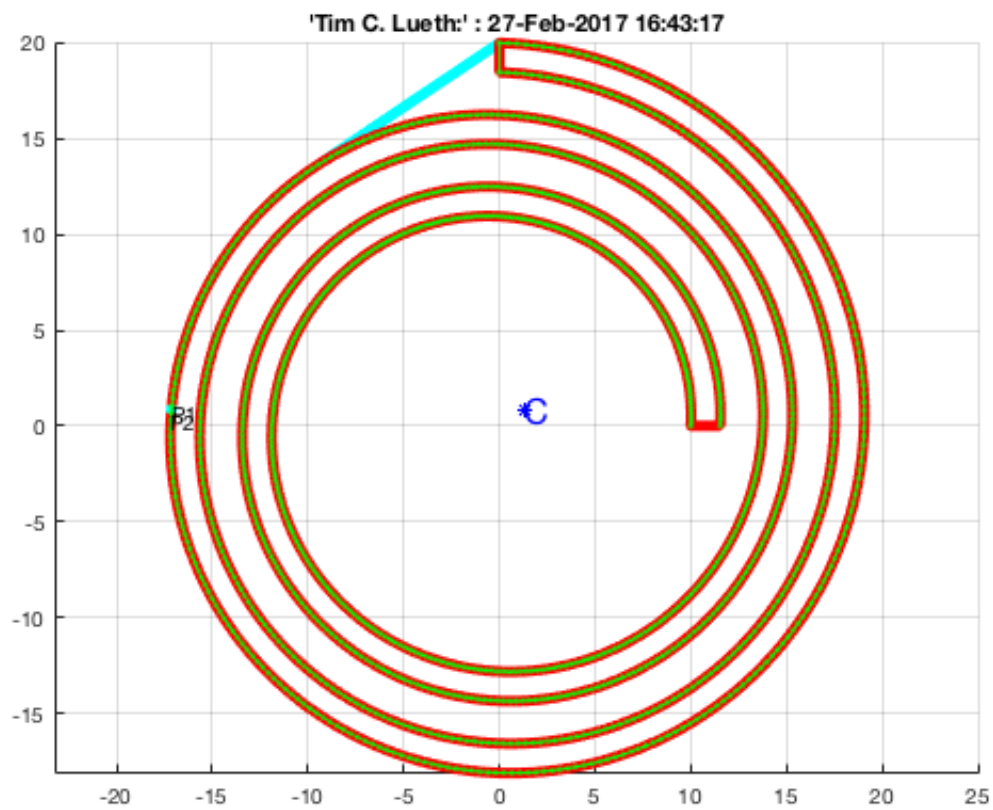
Find the minimal angle value of a spiral

```
SGfigure; view(0,90);  
CPLsortC(CPLspiral(10,20,4*pi+pi/2),'min');
```

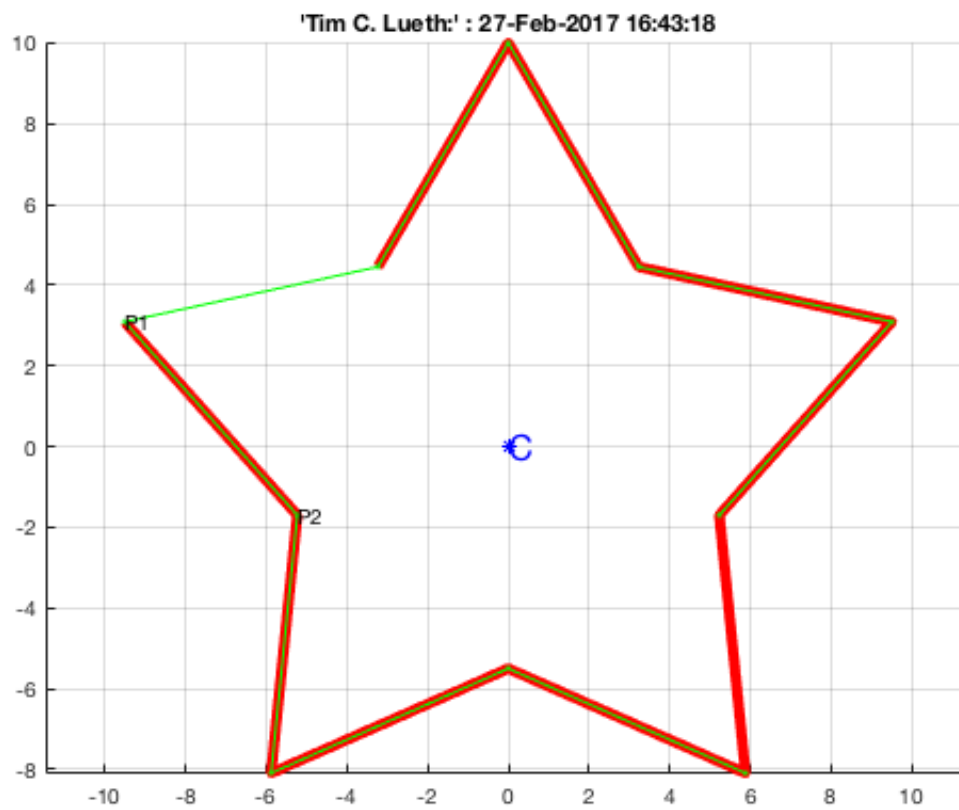
Find the minimal angle value of convex hull of a spiral

```
SGfigure; view(0,90);
CPLsortC(CPLspiral(10,20,4*pi+pi/2),'cmin');
```



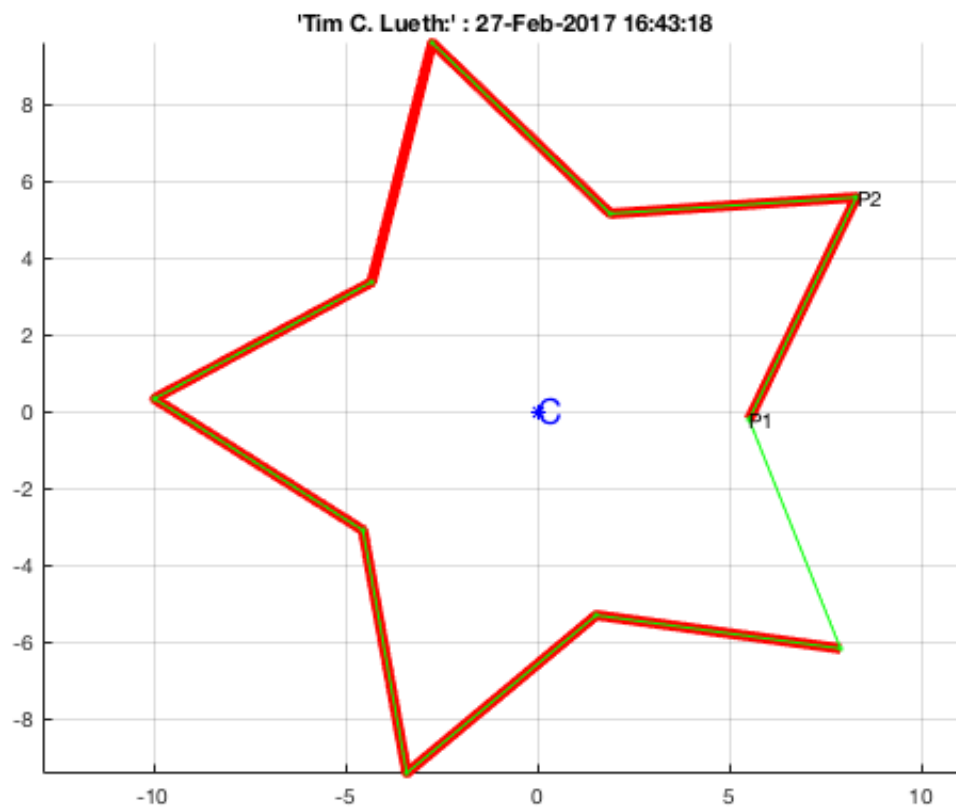
Find the maximum angle value of a star

```
SGfigure; view(0,90);  
CPLsortC(PLstar(10,10),'max'); axis on;
```



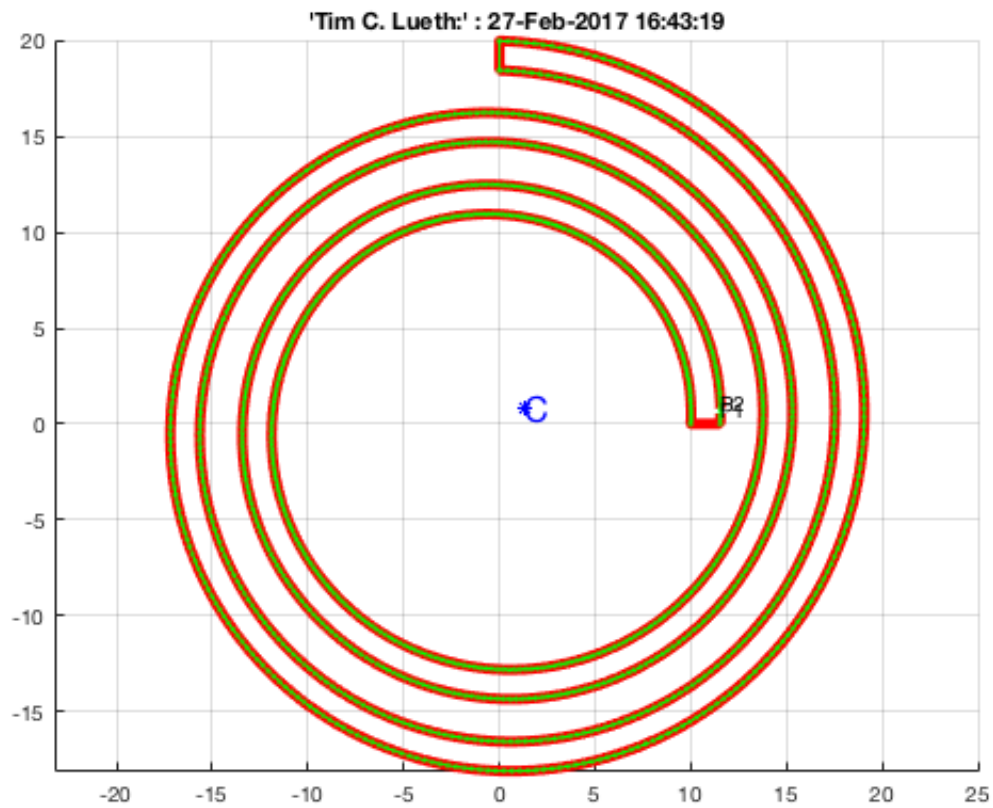
Find the angle value nearest to zero of a star

```
SGfigure; view(0,90);  
CPLsortC(PLtrans(PLstar(10,10),rotdeg(160)), 'zero'); axis on;
```



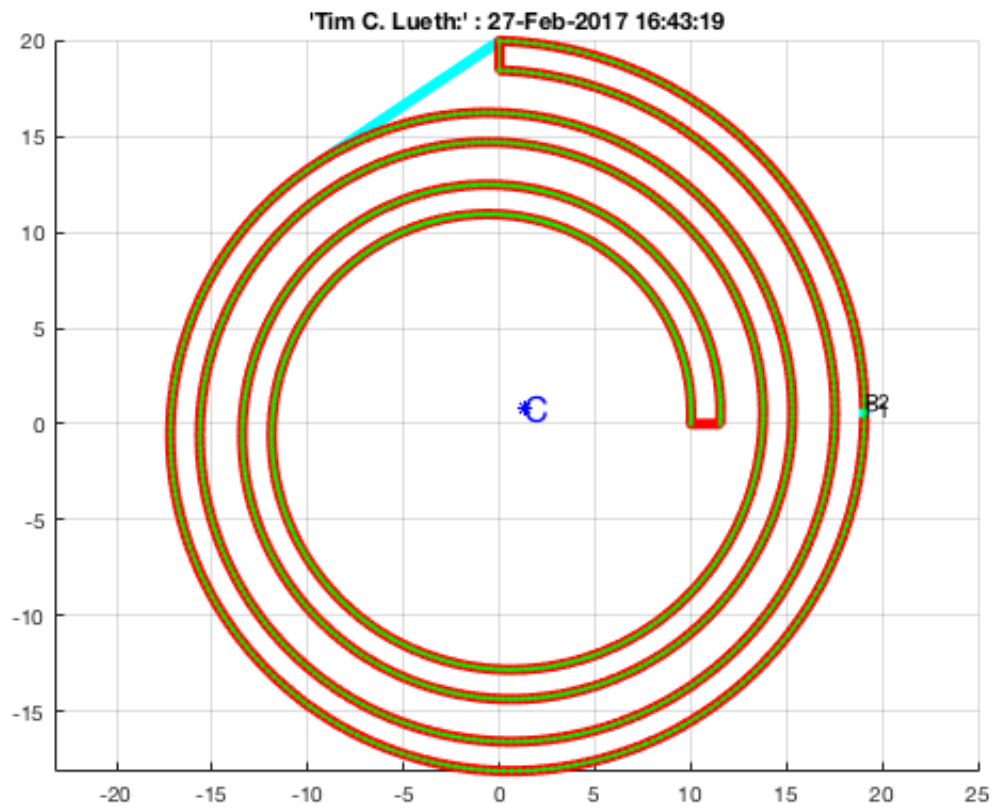
Find the angle value nearest to zero of a spiral

```
SGfigure; view(0,90);  
CPLsortC(CPLspiral(10,20,4*pi+pi/2),'zero');
```



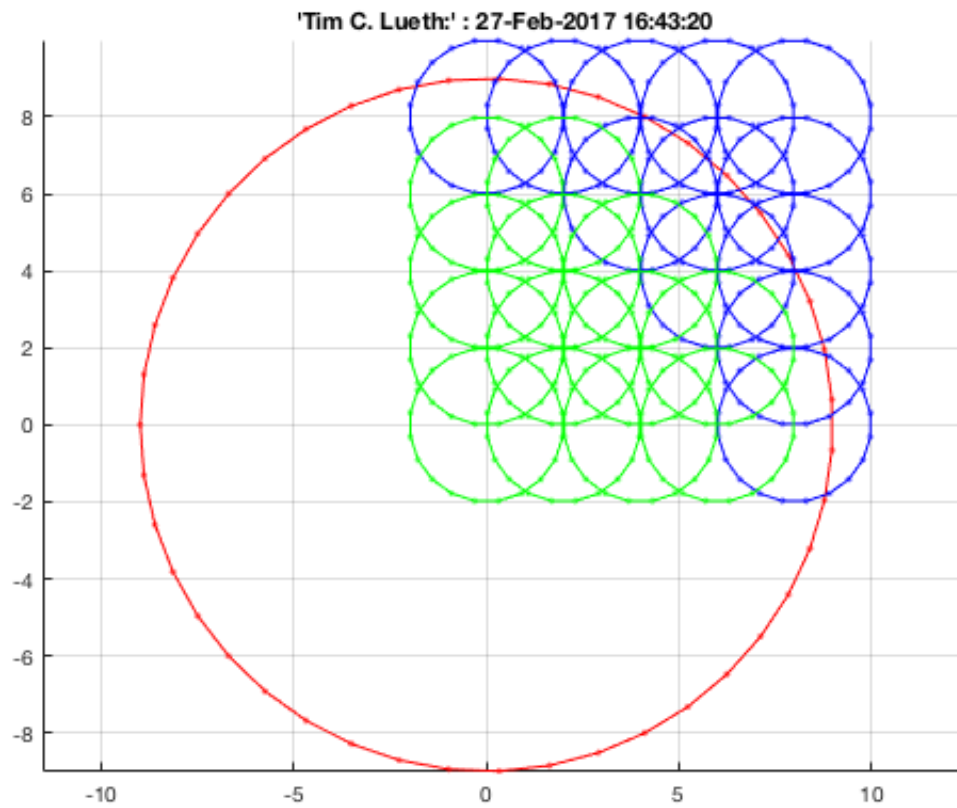
Find the angle value nearest to zero of convex hull of a spiral

```
SGfigure; view(0,90);  
CPLsortC(CPLspiral(10,20,4*pi+pi/2),'czero');
```



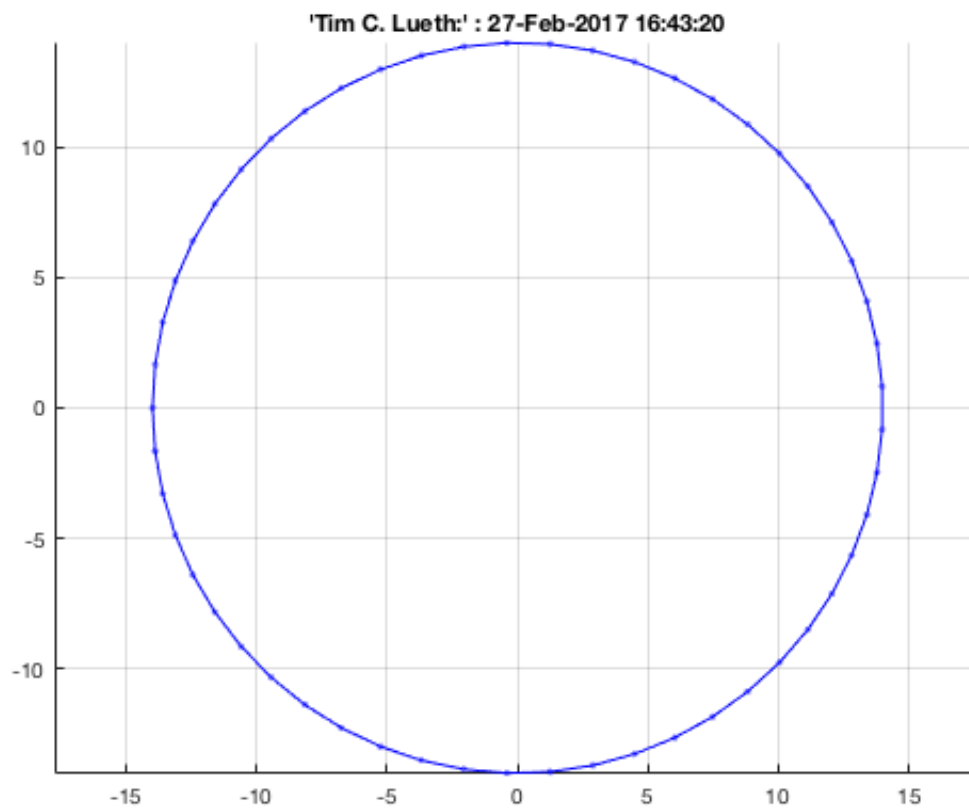
9. Informations on contours inside of others

```
SGfigure; view(0,90);
CPLinsideCPL(PLcircle(9),CPLcopypattern(PLcircle(2),[5 5],[2 2])); axis on;
```



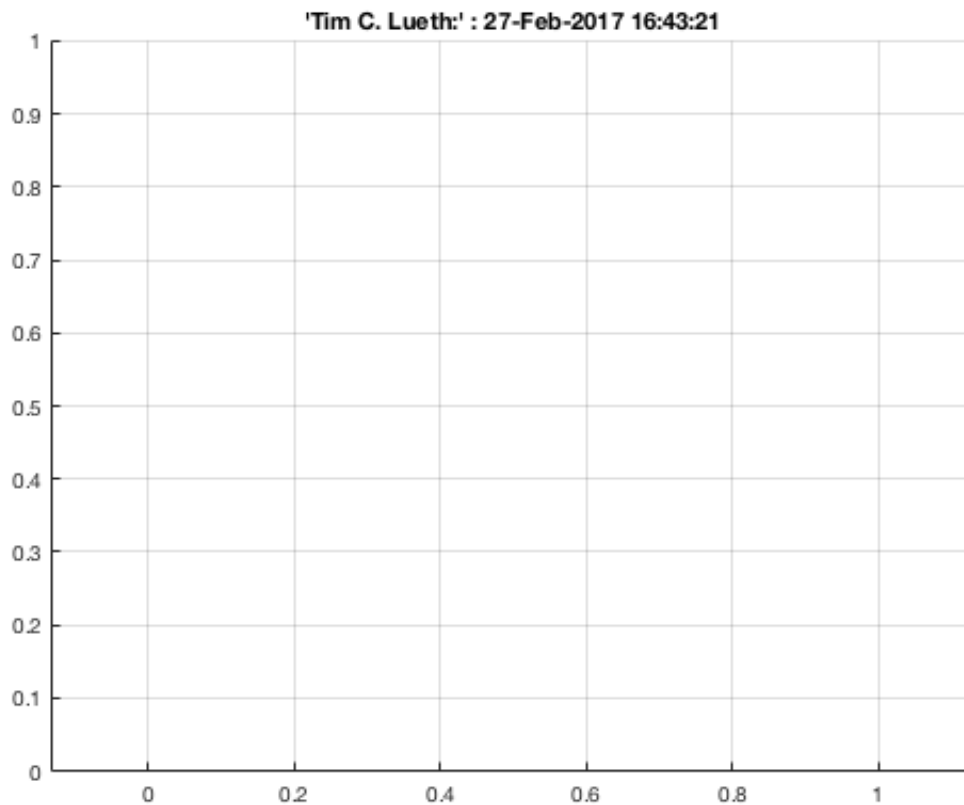
Identical contours are not inside each other

```
CPLinsideCPL(PLcircle(14),CPLsortC(PLcircle(14)));
```



10. Order contours for the sequential plot with a laser cutter

```
SGfigure; view(0,90);
```

Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:43:23 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 simulink
 =====
 =====

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-09-20*
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 15: Create a Solid by 2 Closed Polygons

2015-10-03: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Basics on the creation of a solid between two planar contours in different height
- 3. Solid surface generation and the importance of start point of the contour (turning)
- 4. Solid surface generation and the importance of point assignment strategy
- 5. Solid surface generation for polygons with a small number of points
- 6. Two identical contours with (strictly) monotonic increasing point-center angle
- 7. Two contours of the same shape with different number of points
- 8. Two contours of the similar shape with different number of points
- 9. Two contours of the similar shape with different sum of boundary bending angle sum
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)

2. Basics on the creation of a solid between two planar contours in different height

The creation of a solid based on two CPL (each containing exactly ONE closed polygon) with a z-difference have to be solved by different method depending on the contour.

In general, the inner angle sum of a closed polygon that has no overlaps is exactly 360 degree, i.e. 2π .

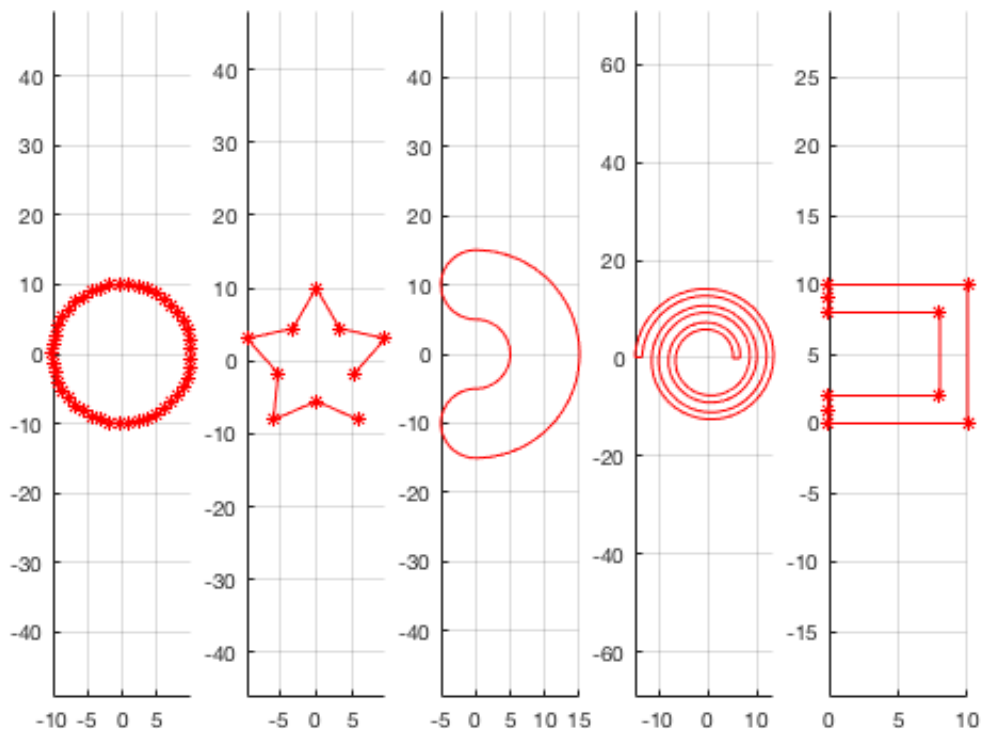
So, for convex polygons there is absolutely no problem by **stepping forward related to the strictly monotonic increasing angle sum**, after **finding a suitable start point** of both polygons (which is a challenge itself).

Even **some concave shaped polygons**, such as stars, **have at least monotonic increasing angle sum** and can be connected by this strategy.

Serious challenges exist if we have non monotonic increasing angle sums such as in u-shaped kidneys, or spirals. Here the challenge is not only the assignment of points of one contour to a corresponding point on the second, but also how to deal with the starting point if the contours are rotated.

A challenge is also that the result changes with the order of the input arguments: SGof2CPLz(PLA,PLB) is not the same as (PLB,PLA);

```
SGfigure; view(0,90);
PLU0=[0 0;10 0; 10 10; 0 10; 0 0];
PLU1=[0 0;10 0; 10 10; 0 10; 0 8; 8 8; 8 2; 0 2; 0 0];
PLU2=[0 0;10 0; 10 10; 0 10; 0 9; 0 8; 8 8; 8 2; 0 2; 0 1; 0 0];
subplot(1,5,1); PL=PLcircle(10);PLplot(PL);
view(0,90); grid on; axis equal;
subplot(1,5,2); PL=PLstar(10,10); PLplot(PL);
view(0,90); grid on; axis equal;
subplot(1,5,3); PL=PLkidney(5,15,pi); CPLplot(PL,'r-');
view(0,90); grid on; axis equal;
subplot(1,5,4); PL=CPLspiral(5,15,5*pi); CPLplot(PL,'r-');
view(0,90); grid on; axis equal;
subplot(1,5,5); PL=CPLspiral(5,15,5*pi); CPLplot(PLU2,'r*-');
view(0,90); grid on; axis equal;
```

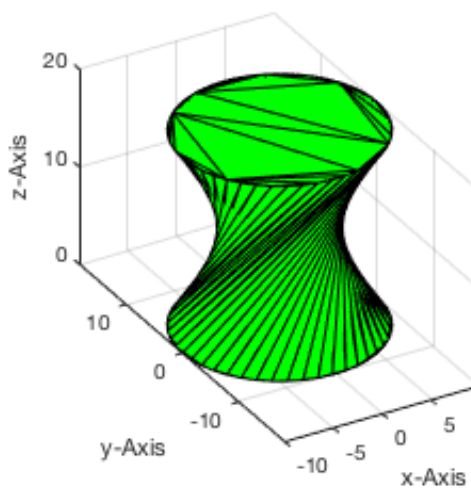
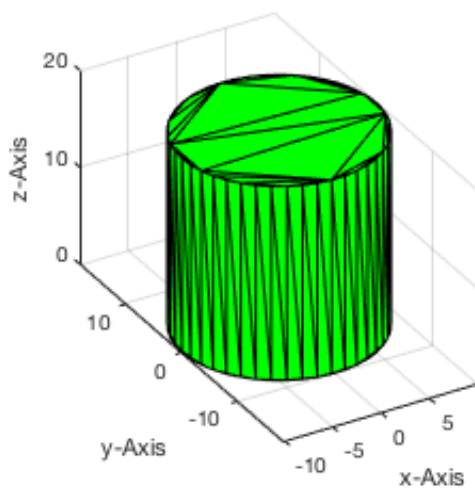


3. Solid surface generation and the importance of start point of the contour (turning)

If two identical contours are assigned, the turning angle around the center is of importance. Already a small turning angle, known or unknown, results in a different shape. For solid generation we use the function:

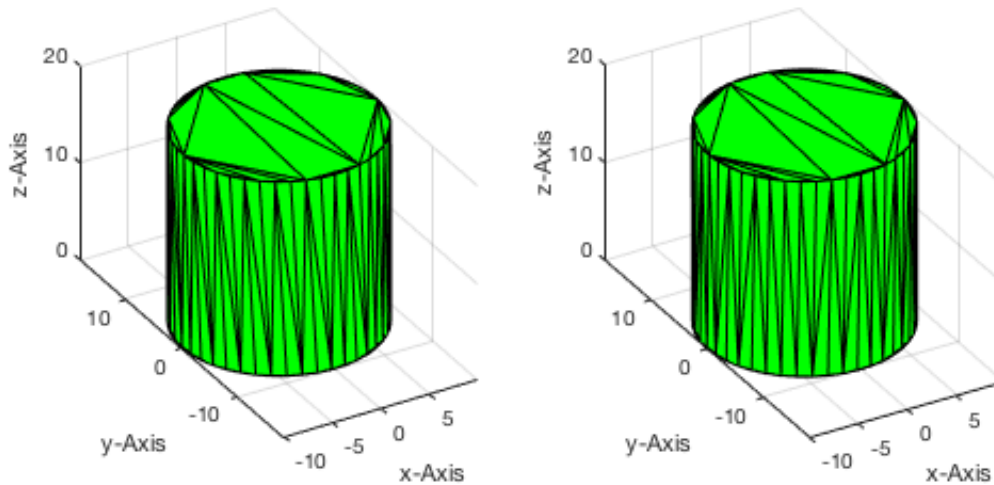
SGof2CPLz(CPLA,CPLB,z) - creates a solid between two plane contours in height 0 and z

```
SGfigure; view(-30,30);
subplot(1,2,1);
SG=SGof2CPLz(PLcircle(10),PLcircle(10),20); SGplot(SG,'g'); view(-30,30);
subplot(1,2,2);
SG=SGof2CPLz(PLcircle(10),PLtransR(PLcircle(10),rotdeg(120)),20,[],'none');
SGplot(SG,'g'); view(-30,30);
```



One input parameter of SGof2CPLz allows to select the turning angle adjustment to 'none', 'rot', or 'miny'. Please read the documentation of 'czero'=rot (minimal angle near zero of the convex hull) of CPLsortC and PLminyx (Point with the minimal y and minimal x value) to understand 'miny'. In addition it is also possible directly to give the assignment of the first points directly by an 1x2 circshift value [1 1] == 'none'

```
SGfigure; view(-30,30);
subplot(1,2,1);
SG=SGof2CPLz(PLcircle(10),PLtransR(PLcircle(10),rotdeg(90)),20,[],'rot');
SGplot(SG,'g'); view(-30,30);
subplot(1,2,2);
SG=SGof2CPLz(PLcircle(10),PLtransR(PLcircle(10),rotdeg(90)),20,[],'miny');
SGplot(SG,'g'); view(-30,30);
```



Turning adjustment 'miny' is the default method for turning both contours! Even if the contour is turned for point assignment, the final order of the points is the same as the original order! This is important for generating tubes based on this function.

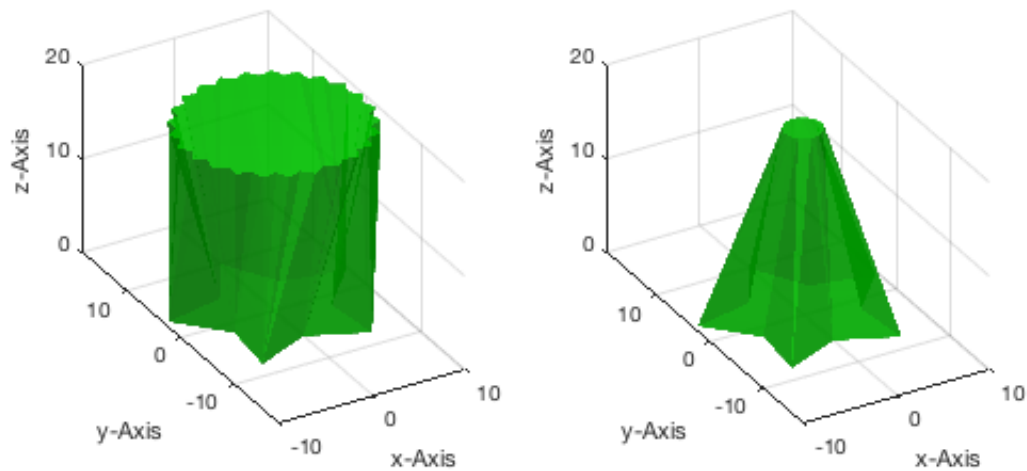
4. Solid surface generation and the importance of point assignment strategy

Currently, there are four strategies for the contour point assignment during contour connections:
 SGof2CPLZ(PLA,PLB,z,assignment,turning);

- **'number' assignment** based on point index / sum(points) - works well for identical contours with different point numbers. Use in combination with both 'miny' or 'rot'.
- **'length' assignment** based on edge length / sum(edge length) - works well for identical contours (shrunked,grown, different sampling). Use in combination with 'miny' or 'rot', the later especially if the number of points is very large.
- **'angle' assignment** based on abs(edge angle) / sum(abs(edge angle)) - required if the sum(abs(edge angle)) differs remarkable. Use in combination with 'rot' and not with 'miny'.
- **'center' assignment** based on angle between center and point - should not be used anymore.
- **In most cases 'length' and 'miny' works well**, wich are the default values
- **For heavy curved contours use 'angle' and 'rot'**

```
SGfigure; view(-30,30);
subplot(1,2,1);
SG=SGof2CPLz(PLstar(10,10),PLstar(10,50),20); SGplot(SG,'g'); view(-30,30);
VLFLplotlight(1,0.7);
subplot(1,2,2);
SG=SGof2CPLz(PLstar(10,10),PLcircle(2),20); SGplot(SG,'g'); view(-30,30);
```

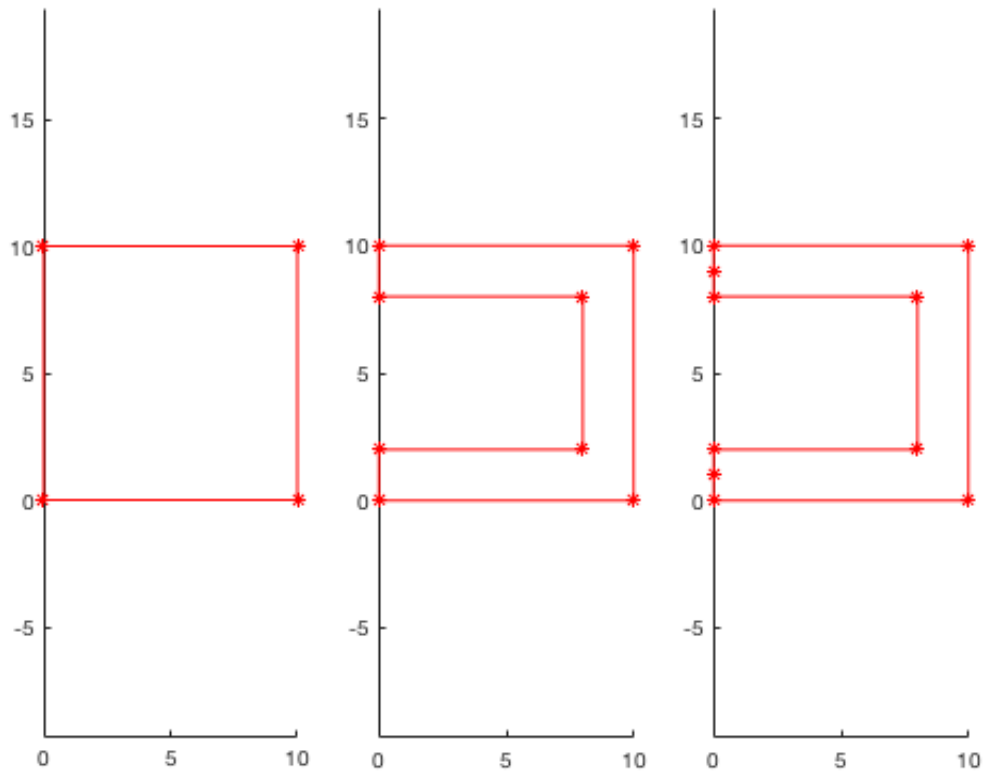
```
VLFLplotlight(1,0.7);
```



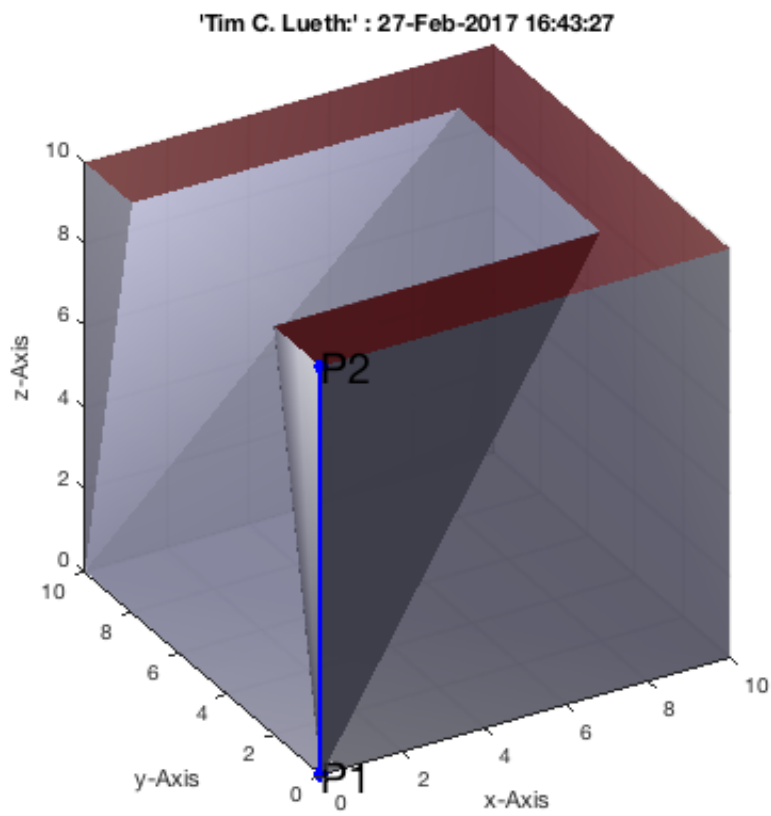
5. Solid surface generation for polygons with a small number of points

For polygon of only a few point, typically, the user has clear expectations about the final result of the solid.

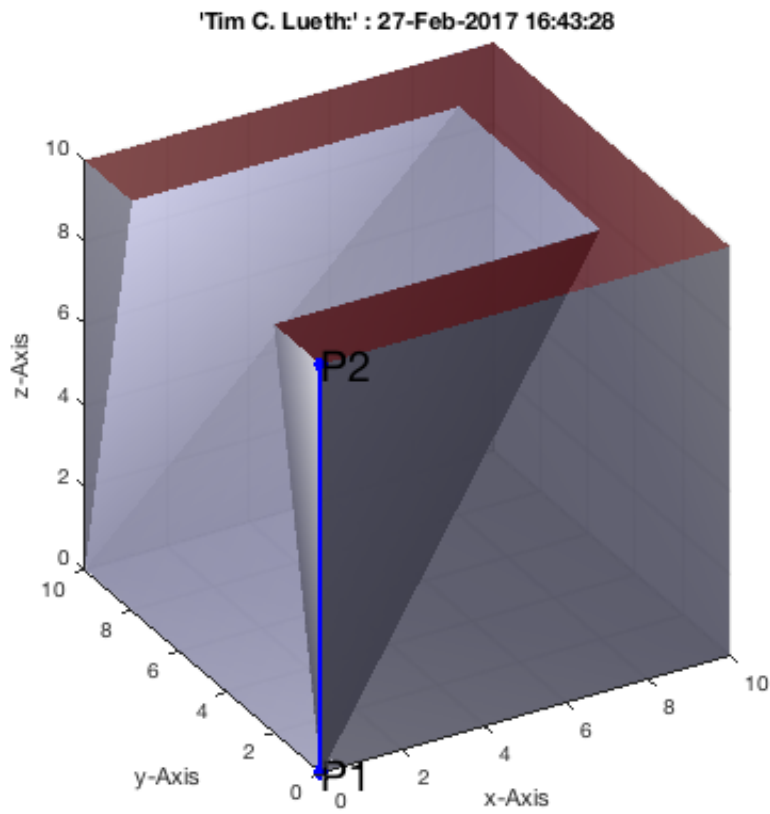
```
SGfigure;
PLU0=[0 0;10 0; 10 10; 0 10; 0 0];
PLU1=[0 0;10 0; 10 10; 0 10; 0 8; 8 8; 8 2; 0 2; 0 0];
PLU2=[0 0;10 0; 10 10; 0 10; 0 9; 0 8; 8 8; 8 2; 0 2; 0 1; 0 0];
subplot(1,3,1); CPLplot(PLU0); view(0,90); axis equal;
subplot(1,3,2); CPLplot(PLU1); view(0,90); axis equal;
subplot(1,3,3); CPLplot(PLU2); view(0,90); axis equal
```



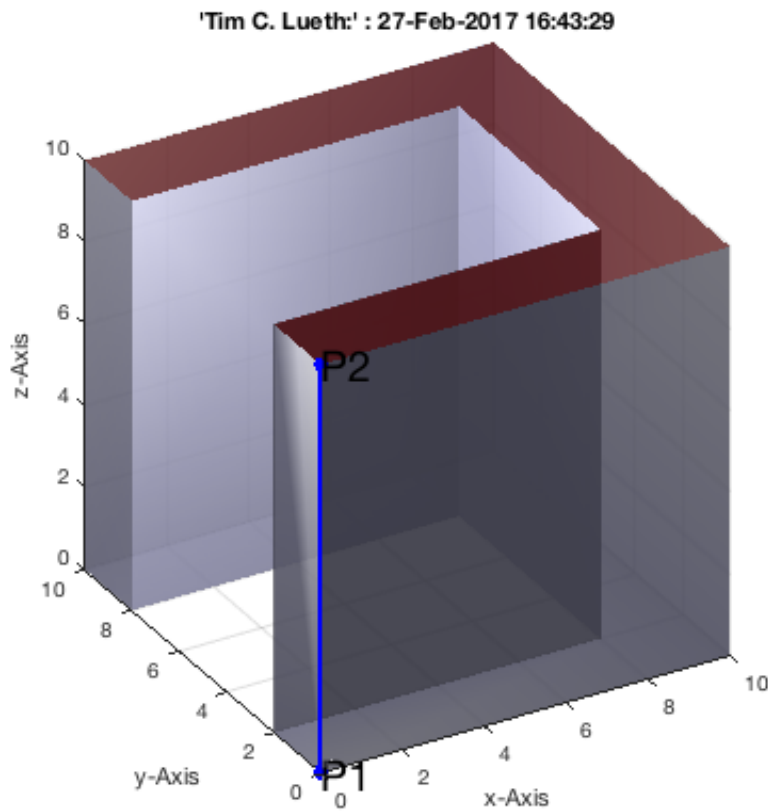
```
SGof2CPLz(PLU0,PLU2,10); VLFLplotlight(1,0.7);
```



```
SGof2CPLz(PLU0,PLU1,10); VLFLplotlight(1,0.7);
```

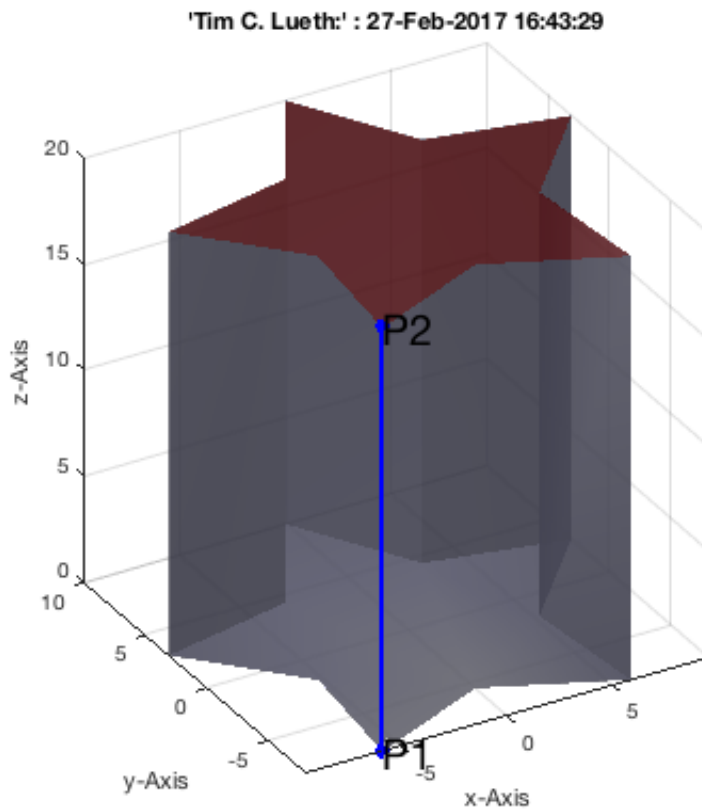
```
SGof2CPLz(PLU1,PLU2,10); VLFLplotlight(1,0.7);
```



6. Two identical contours with (strictly) monotonic increasing point-center angle

In case of two identical polygons that are just shifted or rotated, the default values 'length' and 'miny' work almost always perfectly.

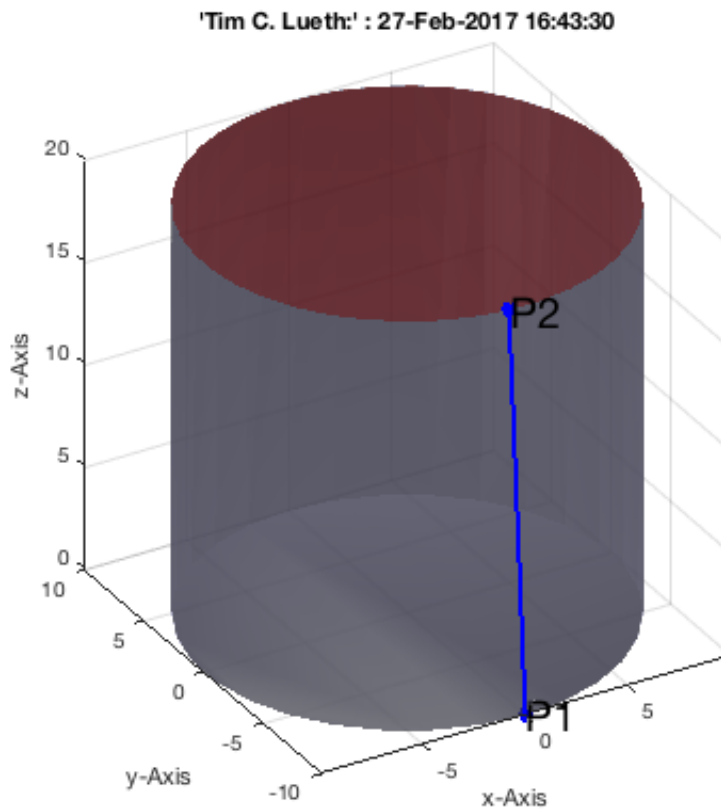
```
SGof2CPLz(PLstar(10,10),PLstar(10,10),20); VLFLplotlight(1,0.7);
```



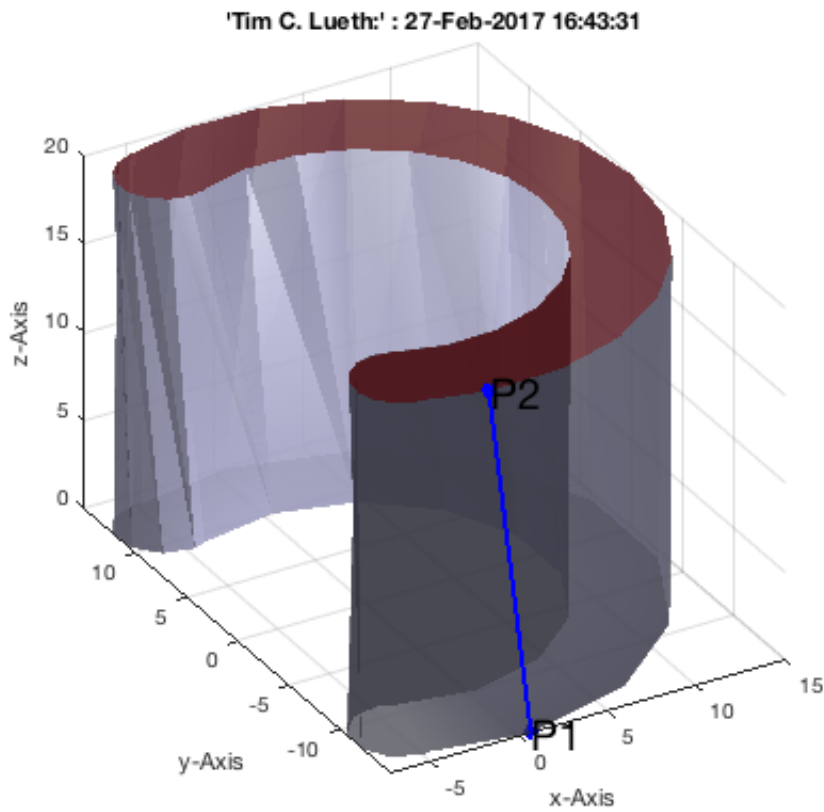
7. Two contours of the same shape with different number of points

In case that there are two identically shaped contours but with a different number of points, 'number' would be a solution but the default values 'length' and 'miny' work almost always perfectly. Even in the case of u-shaped contour.

```
SGof2CPLz(PLcircle(10,30),PLcircle(10,40),20);  
VLFLplotlight(1,0.7);
```



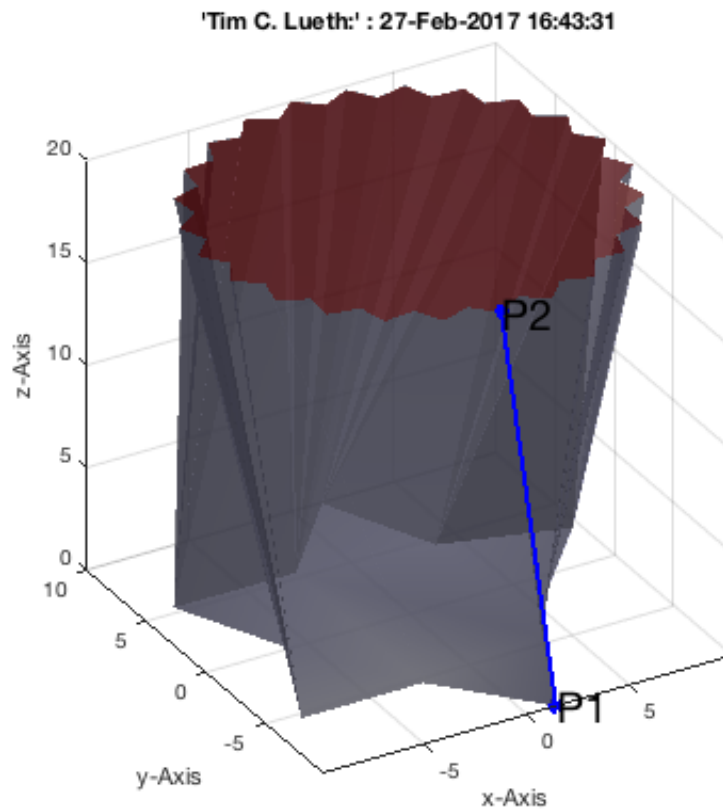
```
SGof2CPLz(PLkidney(10,15,pi/0.8,10),PLkidney(10,15,pi/0.8,15),20);  
VLFLplotlight(1,0.7);
```



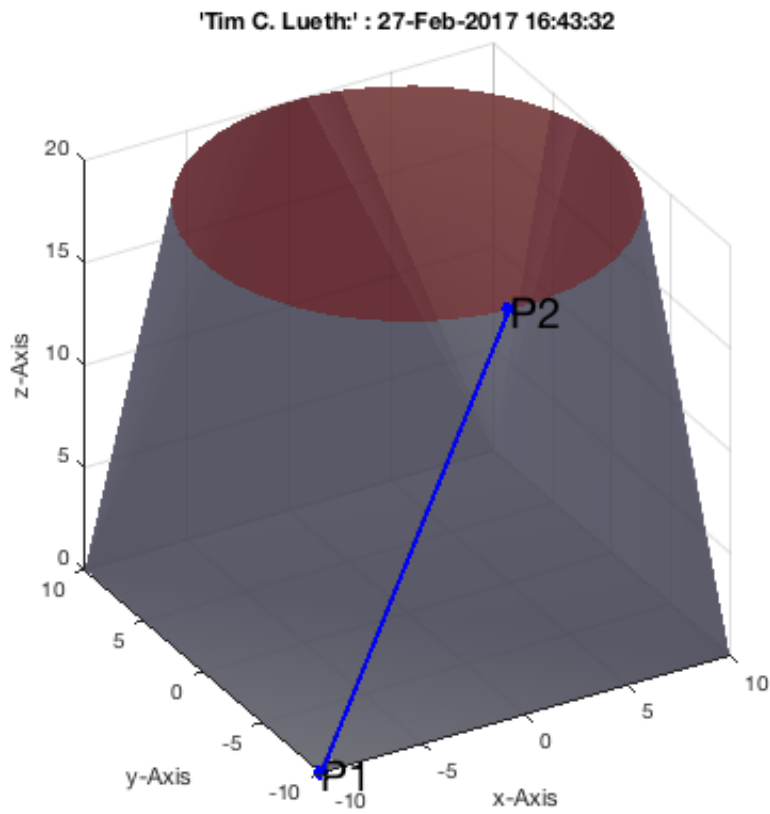
8. Two contours of the similar shape with different number of points

In case that there are two similar not identical contours and with a different number of points, again the default values 'length' and 'miny' work almost always perfectly. Even in the case of u-shaped contour.

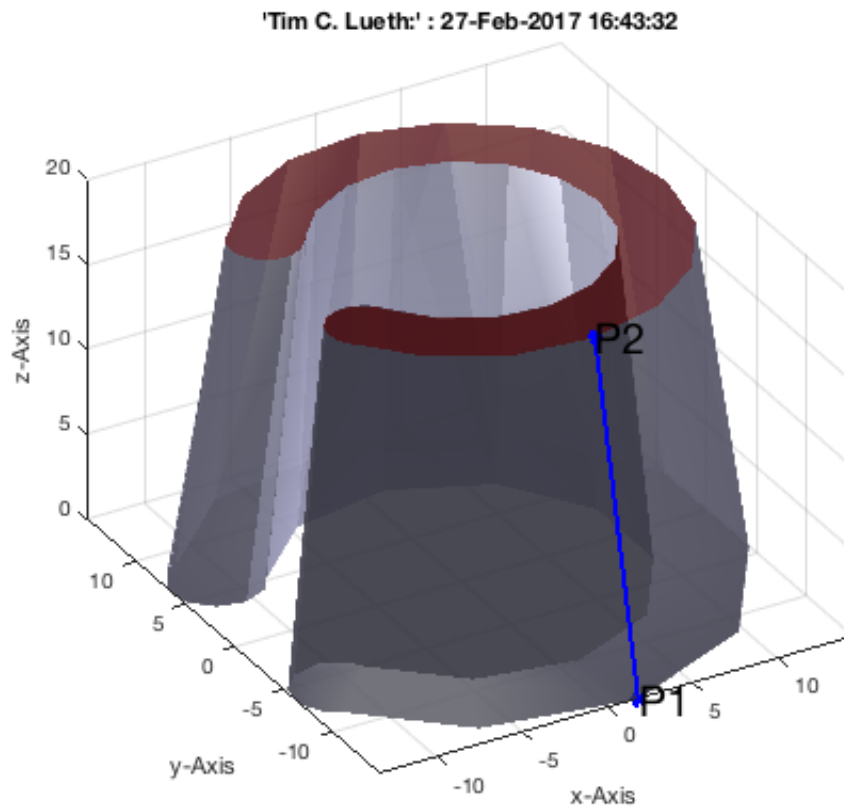
```
SGof2CPLz(PLstar(10,11),PLstar(10,50),20); VLFLplotlight(1,0.7);
```



```
SGof2CPLz(PLcircle(10*sqrt(2),4),PLcircle(10,40),20);  
VLFLplotlight(1,0.7);
```



```
SGof2CPLz(PLkidney(10,15,pi/0.6,10),PLkidney(8,12,pi/0.6,15),20);  
VLFLplotlight(1,0.7);
```

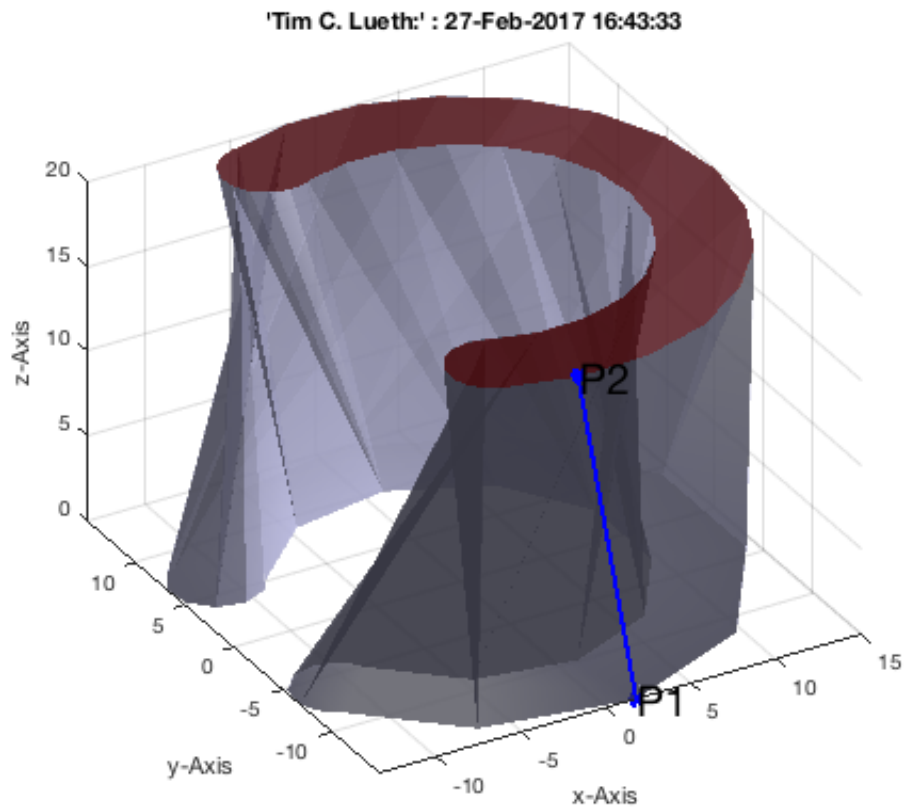


In this case we see that the kidney has different size but the same bending angle of $\pi/6$.

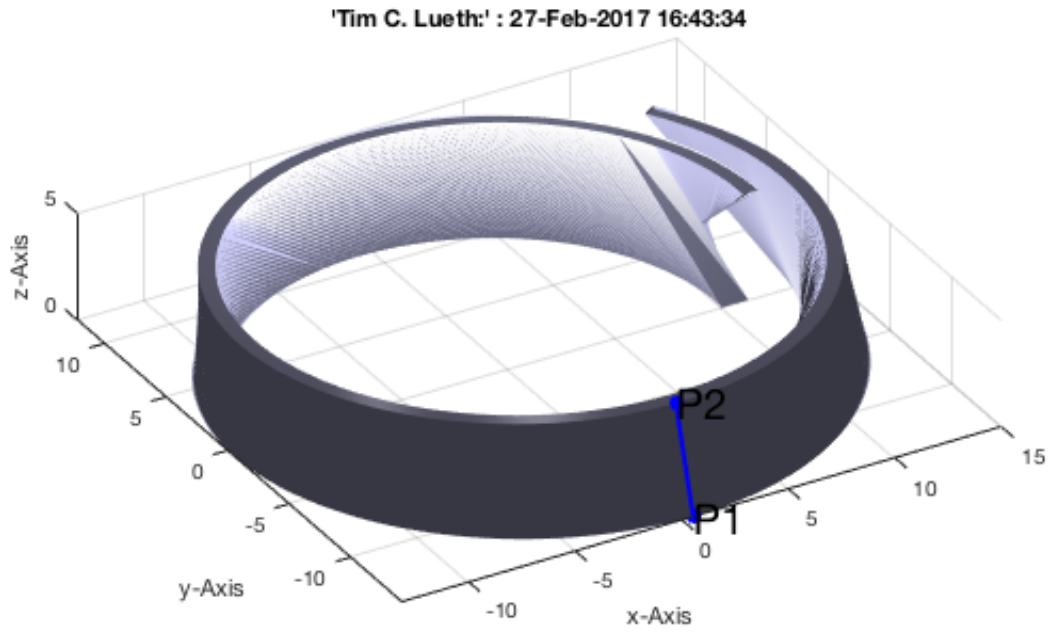
9. Two contours of the similar shape with different sum of boundary bending angle sum

In case that the boundary bending angle is greater than 2π (360 degree), the assignment by length and the turning strategy of miny is not the best anymore.

```
SGof2CPLz(PLkidney(10,15,pi/0.6,10),PLkidney(10,15,pi/0.8,15),20);
VLFLplotlight(1,0.7);
```

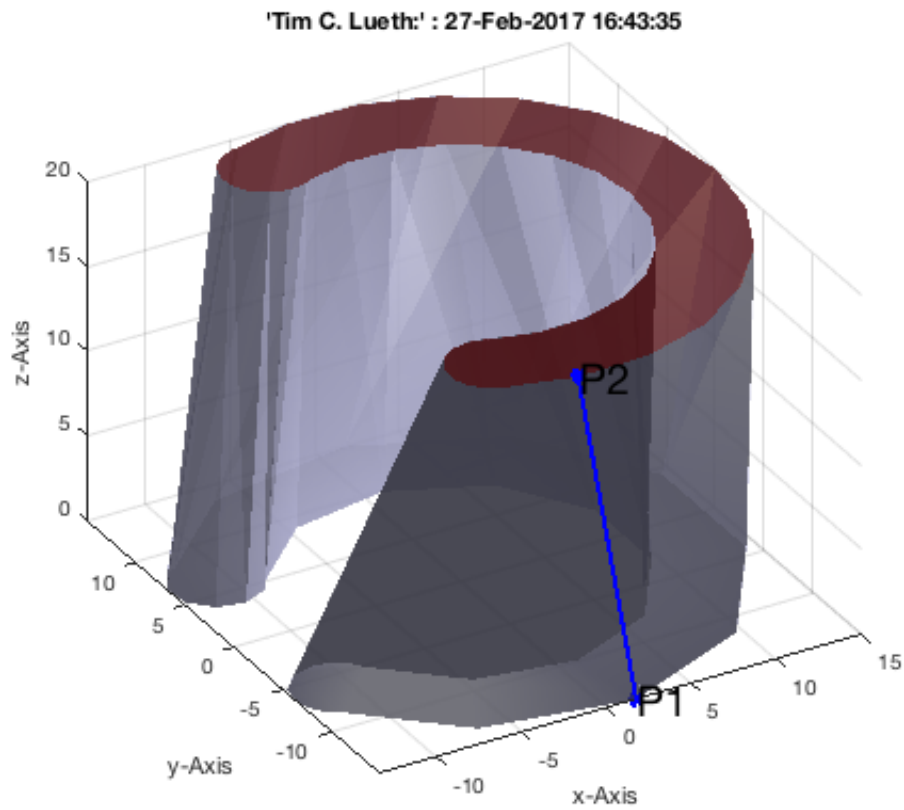



```
SGof2CPLz(CPLspiral(10,15,2*pi),CPLspiral(11,14,2.2*pi),5);  
VLFLplotlight (1,1);
```

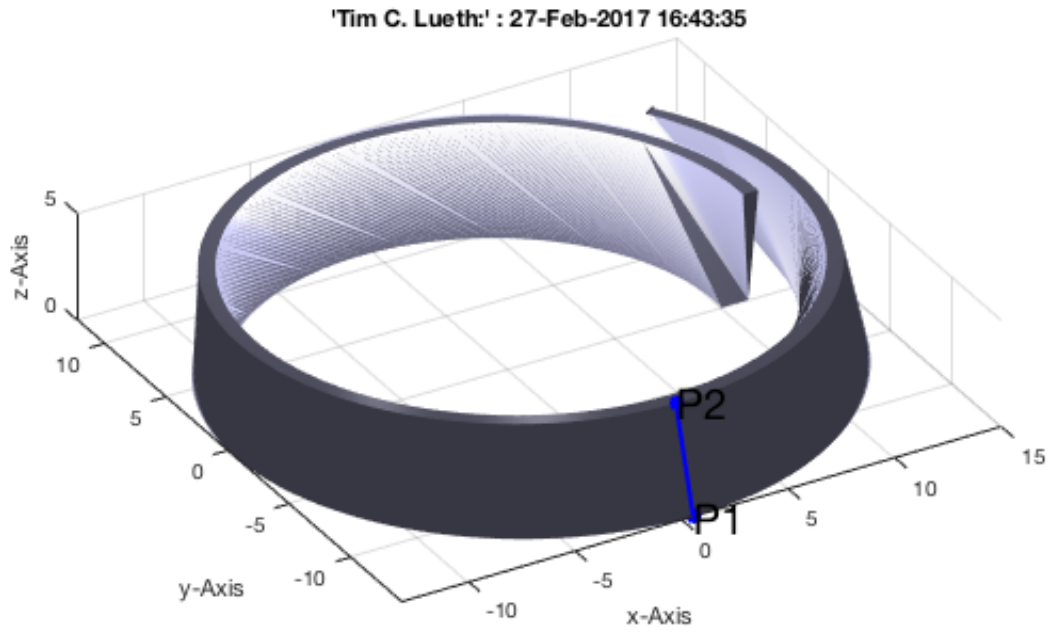


In this case we see malformed solids.

```
SGof2CPLz(PLkidney(10,15,pi/0.6,10),PLkidney(10,15,pi/0.8,15),20,'angle');  
VLFLplotlight(1,0.7);
```

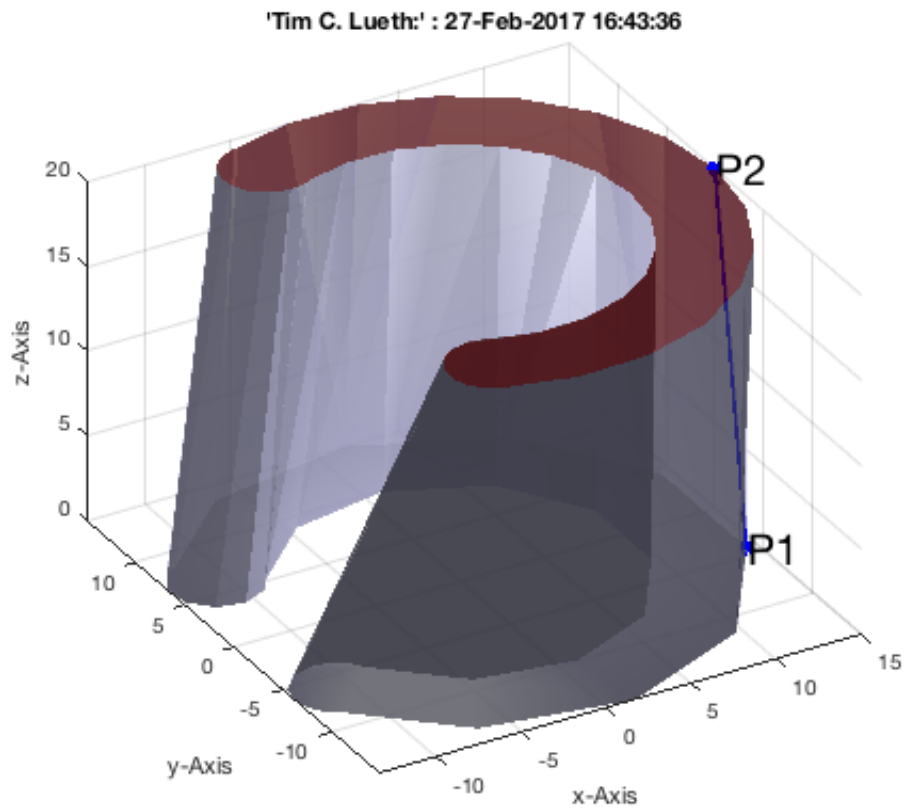


```
SGof2CPLz(CPLspiral(10,15,2*pi),CPLspiral(11,14,2.2*pi),5,'angle');  
VLFLplotlight (1,1);
```

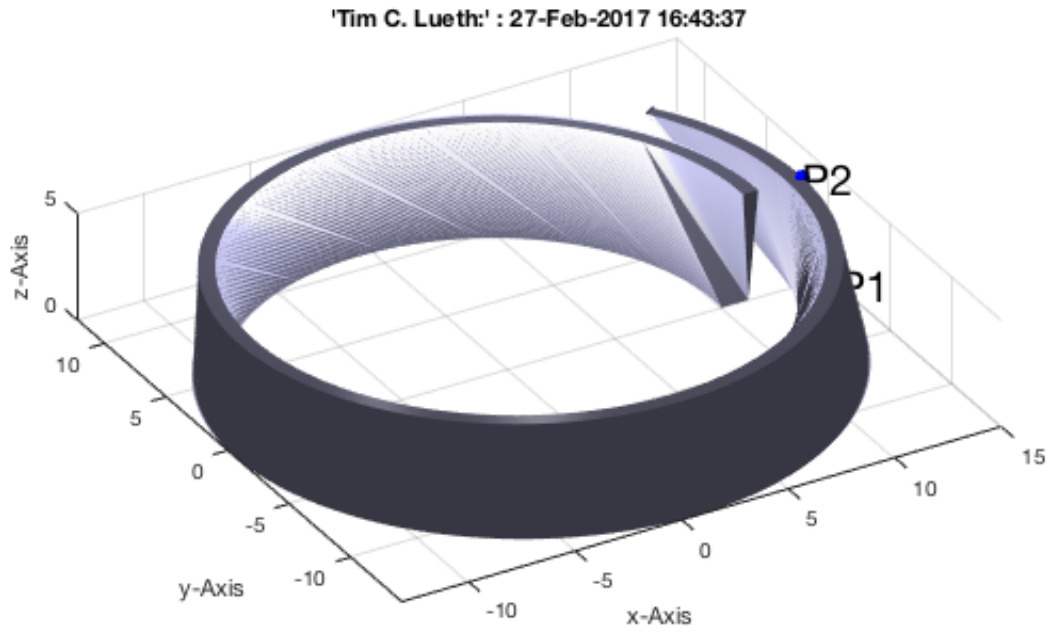


By using 'angle' instead of 'length', the solids are more what we expected.

```
SGof2CPLz(PLkidney(10,15,pi/0.6,10),PLkidney(10,15,pi/0.8,15),20,'angle','rot');  
VLFLplotlight(1,0.7);
```

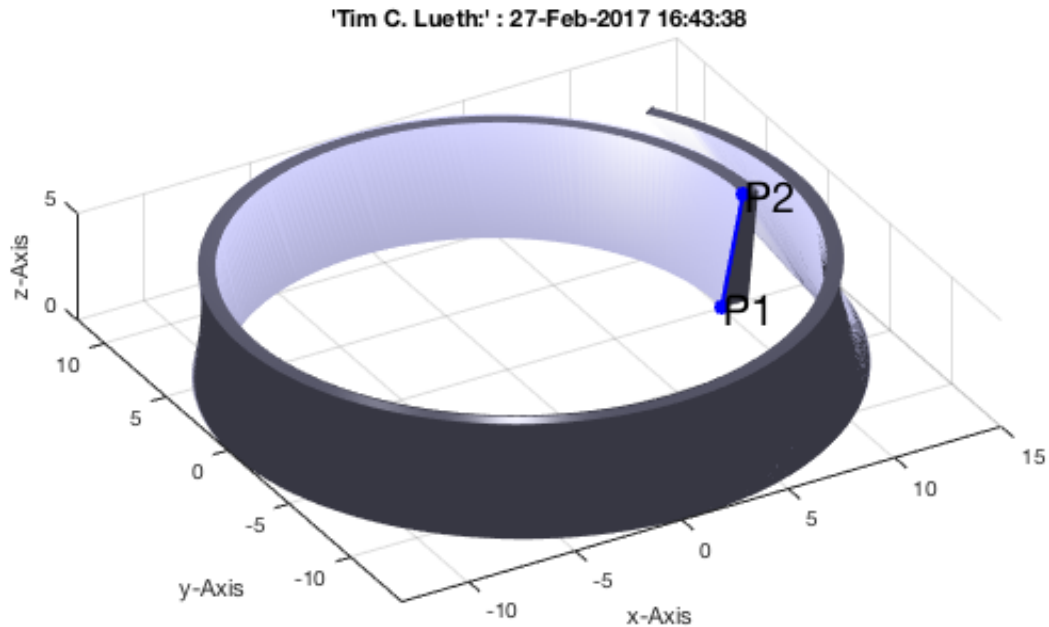


```
SGof2CPLz(CPLspiral(10,15,2*pi),CPLspiral(11,14,2.2*pi),5,'angle','rot');  
VLFLplotlight (1,1);
```



By using 'angle' instead of 'length' AND an explicitly given 1st point assignment, the best result can be achieved.

```
PLA=CPLspiral(10,15,2*pi); PLB=CPLspiral(11,14,2.2*pi);  
SGof2CPLz(PLA,PLB,5,'angle',[size(PLA,1) size(PLB,1)]); VLFLplotlight (1,1);
```



By using 'angle' instead of 'length' AND 'rot' instead of 'miny', the solids are almost what we expected.

Final remarks on toolbox version and execution date

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:43:40 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
map_toolbox
matlab
simulink
=====
=====
```

- Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-10-03
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 16: Create Tube-Style Solids by Succeeding Polygons

- 2015-10-04: Tim C. Lueth, MIMED - Technische Universität München, Germany
- 2016-12-04: Tim C. Lueth, VLradialEdges and SGofCPLCVLR added (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Tube generation by repeating identical CPL along a 3D path
- 3. Tube generation using a 3D path with Bezier-curves or radial edges
- 4. Creating solids by closed polygons in different height: z-coordinate
- 5. Creating a sphere with minimal number of points
- 6. Creating a spherical joint
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons

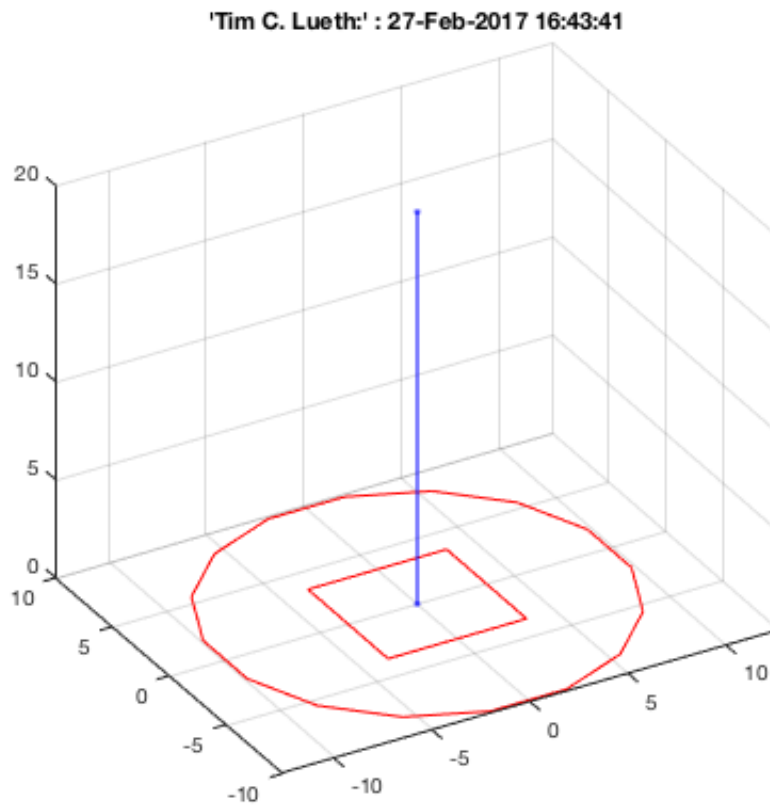
2. Tube generation by repeating identical CPL along a 3D path

For robotics design, very often we have a wish to extrude a CPL not only in an orthogonal z direction to the xy-plane, but in any desired direction even along a path in 3D space. Intuitively we expect a result, but this is not easy to achieve automatically. Anyway, for those tasks we have two functions:

- SGcontourtube - repeats a CPL along a path in 3D
- FLoFCVL

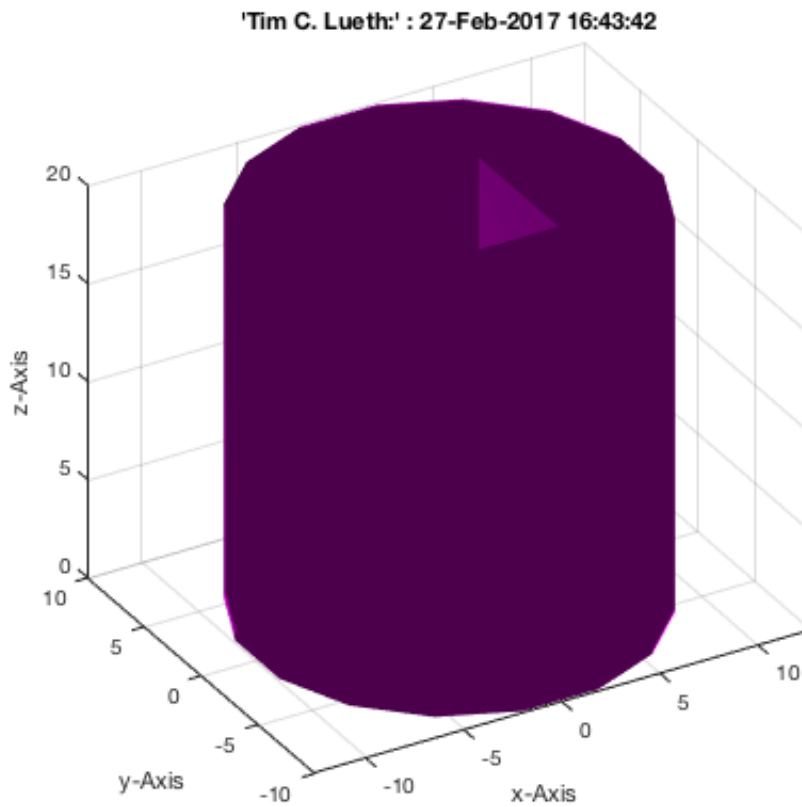
Let us start with a planar contour in the x/y-plane, and an orthogonal path

```
SGfigure; axis on ; grid on;  
CPL=CPLsample(8);  
CPLplot(CPL, 'r-');  
  
VL=[0 0 0; 0 0 20];  
VLplot(VL, 'b.-'); view(-30,30);
```



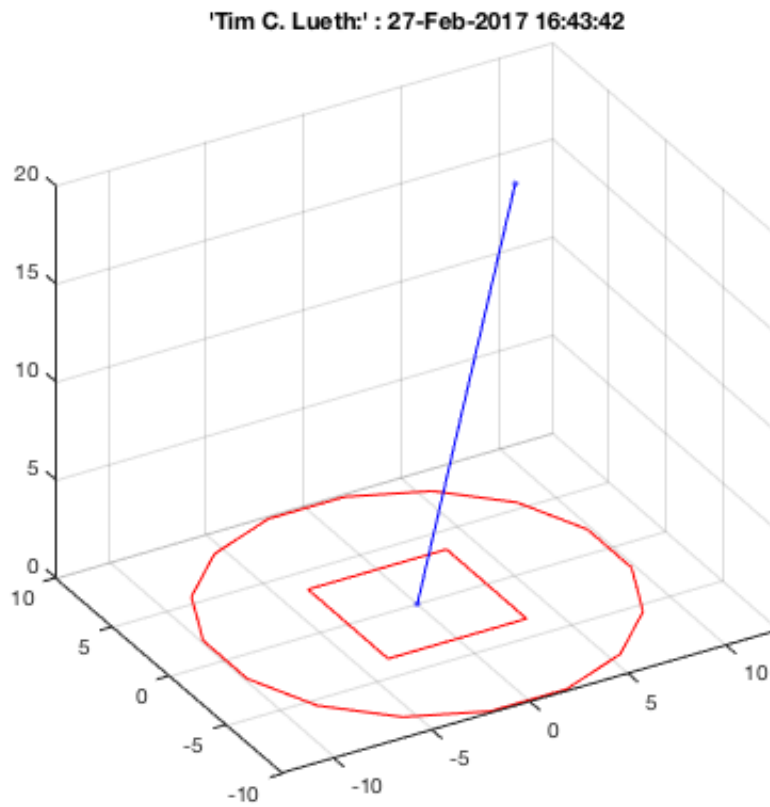
The final result looks as expected

```
SG=SGcontourtube(CPL,VL); SGfigure(SG); VLFLplotlight(1,1);view (-30,30);
```



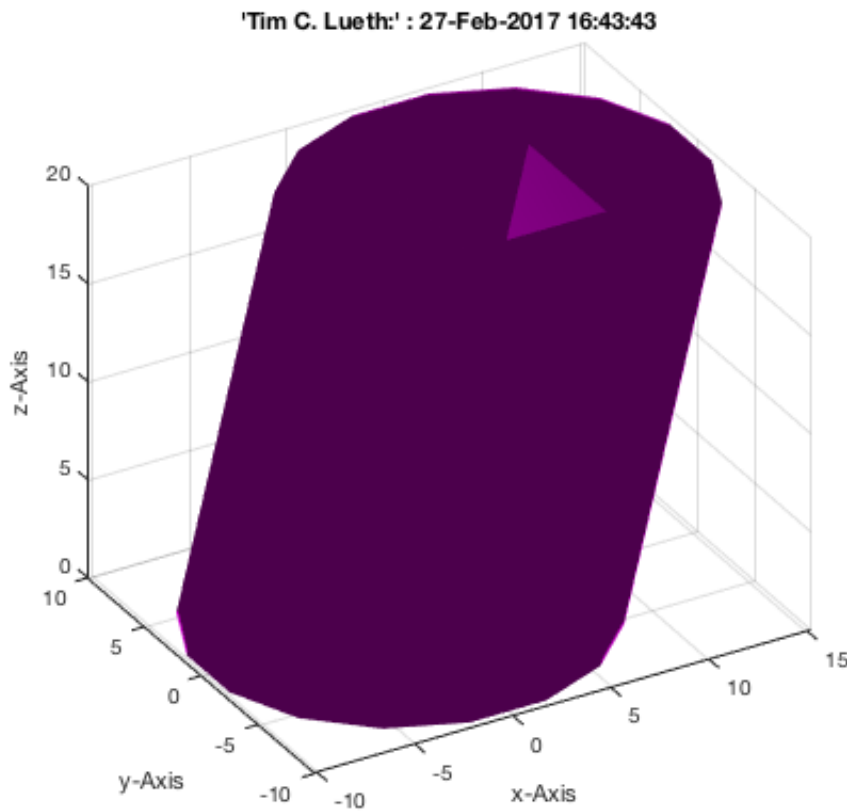
Now we change the path a little

```
SGfigure; axis on ; grid on;  
CPLplot(CPL, 'r-');  
VL=[0 0 0; 5 0 20];  
VLplot(VL, 'b.-'); view(-30,30);
```



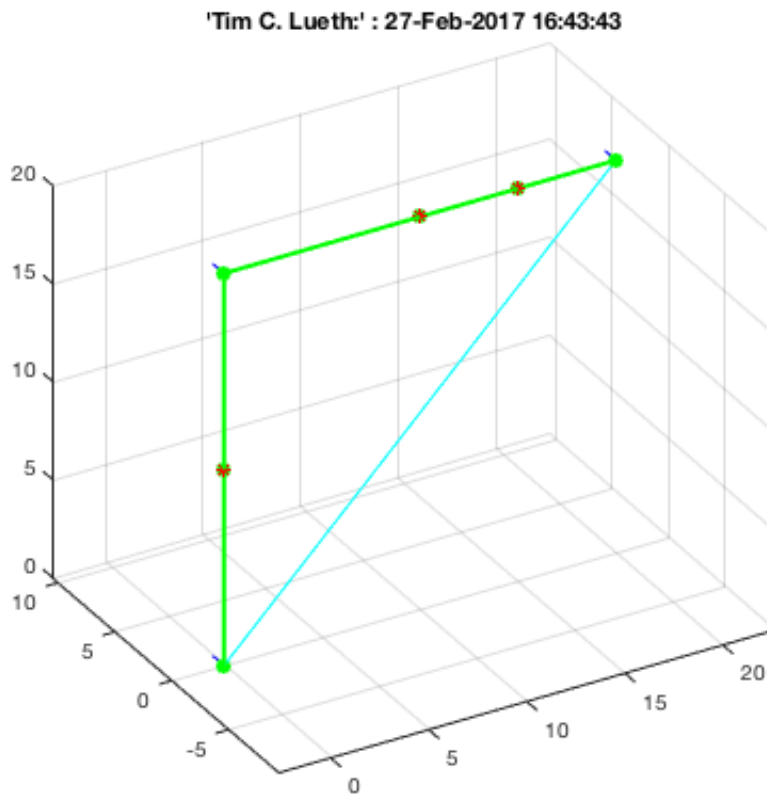
The final result may not look as expected

```
SG=SGcontourtube(CPL,VL);  
SGfigure; axis on ; grid on;  
SGplot(SG, 'm');  
VLFLplotlight(1,1);view (-30,30);
```



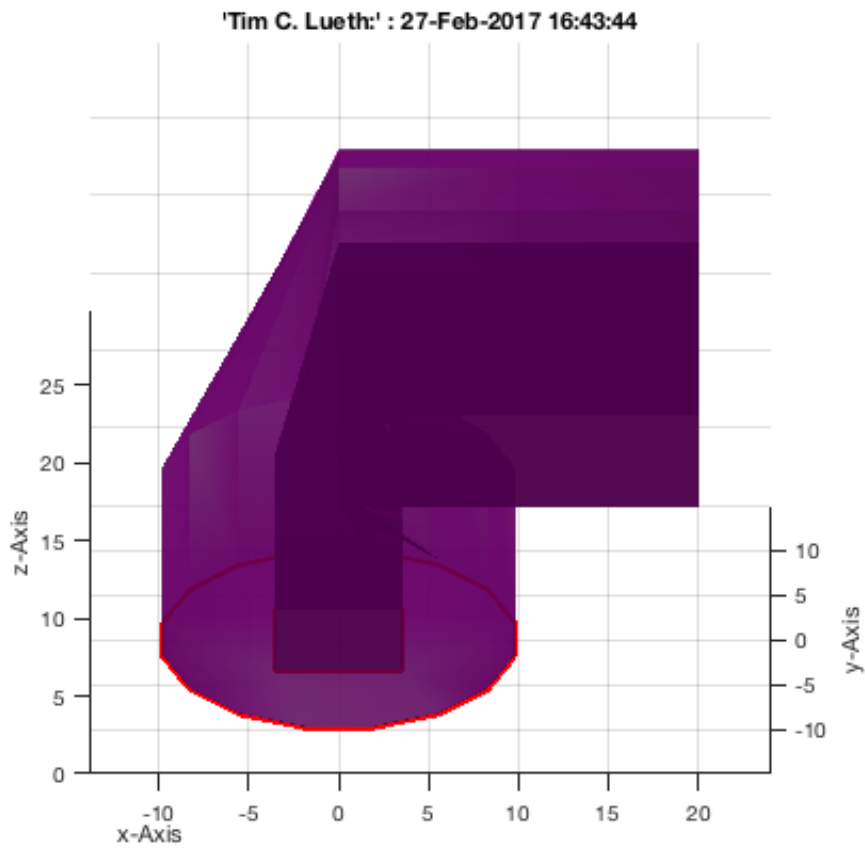
Now we change the path, still a planar one and analyze the angle situation The cyan colored path explain that the vertex list has to be closed to analyze the first and last angle. Furthermore we see that more than one point has no defined orthogonal vector since it sits on a straight line

```
SGfigure; CPLplot(CPL,'r-'); axis on ; grid on;
VL=[0 0 0; 0 0 10; 0 0 20; 10 0 20; 15 0 20; 20 0 20];
VLangle(VL);
```



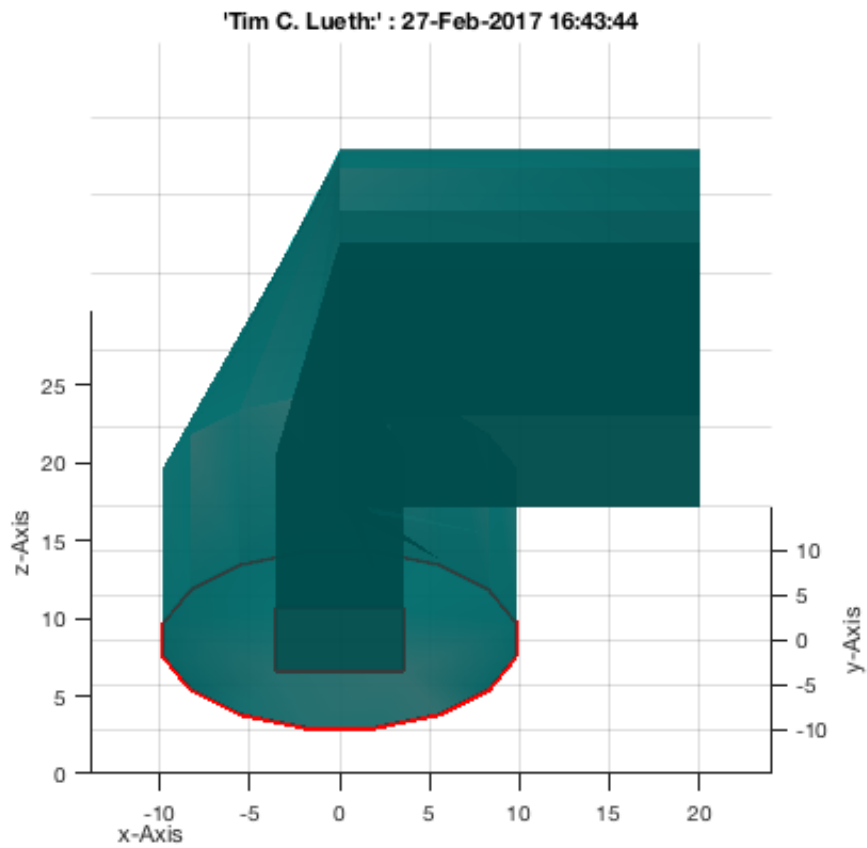
The result is not may be we expected

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGcontourtube(CPL,VL); SGplot(SG,'m'); VLFLplotlight(1,0.8);view (0,30);
```

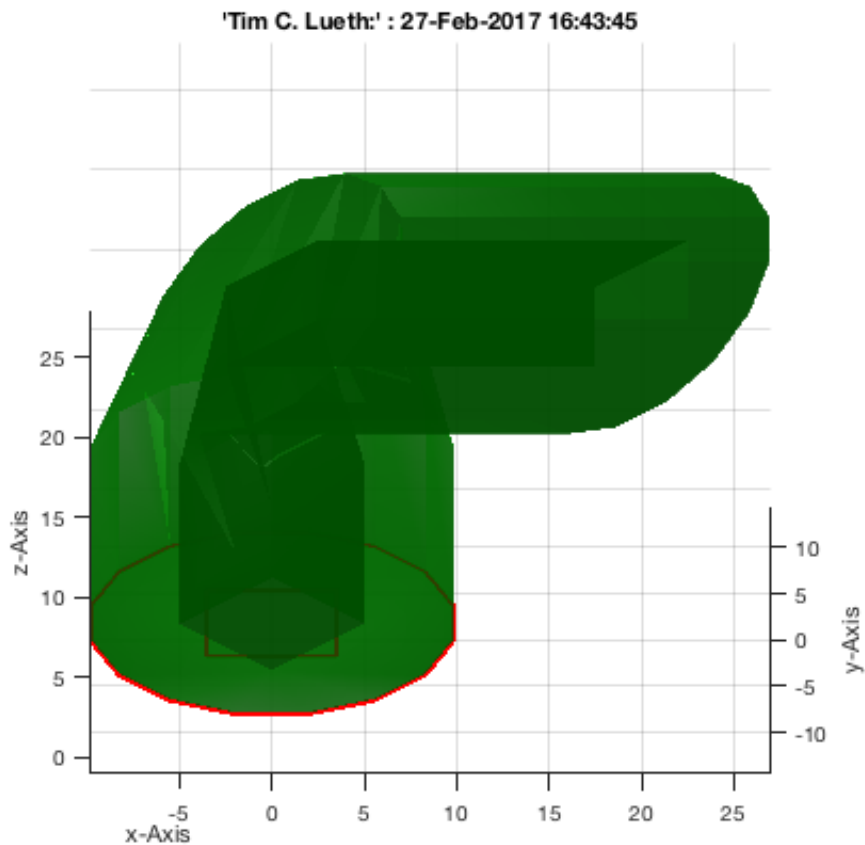


The result can be adjusted by defining the ex-vector at the start point

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGcontourtube(CPL,VL,[0 1 0]); SGplot(SG,'c'); VLFLplotlight(1,0.8);view (0,30);
```



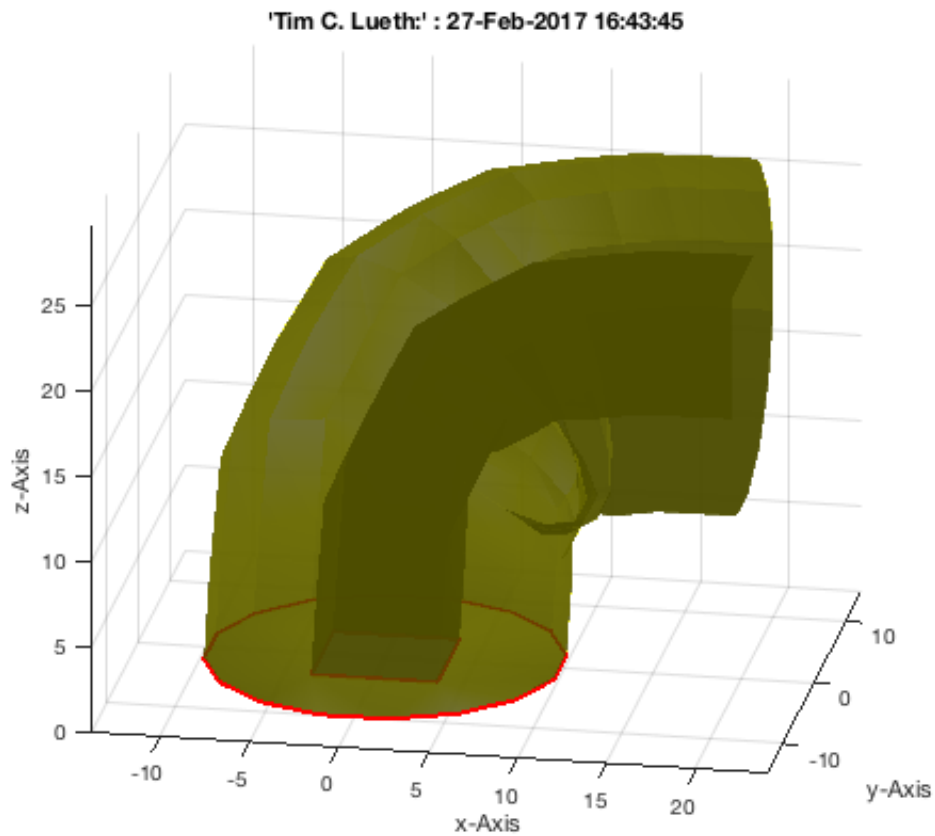
```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGcontourtube(CPL,VL,[1 1 0]); SGplot(SG,'g'); VLFLplotlight(1,0.8);view (0,30);
```

One lazy approach is delivered by SGofCPLCVLR without a given radius

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;
SG=SGofCPLCVLR(CPL,VL); SGplot(SG,'y'); VLFLplotlight(1,0.8);view (10,20);
```

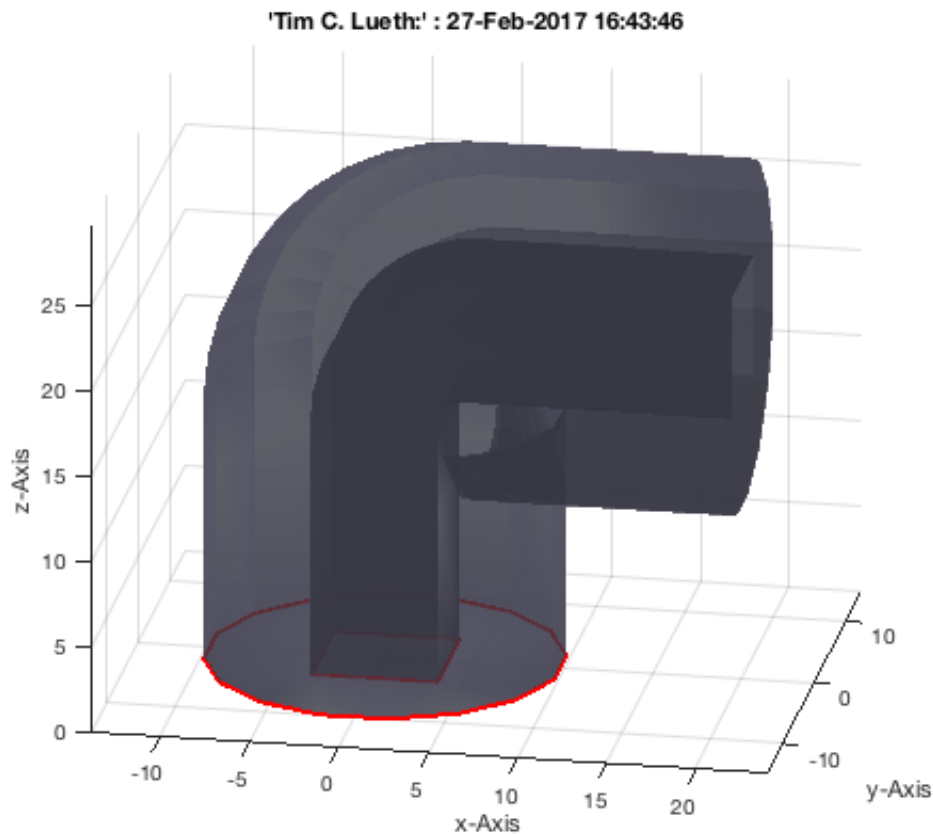
Warning: 1st Euler angle does not fit to vertex list path direction
Warning: Last Euler angle does not fit to vertex list path direction
Warning: 1st Euler angle does not fit to vertex list path direction
Warning: Last Euler angle does not fit to vertex list path direction



One lazy approach is delivered by SGofCPLCVLR including a radius 5

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGofCPLCVLR(CPL,VL,5); SGplot(SG,'w'); VLFLplotlight(1,0.8);view (10,20);
```

tangentcirc: Radius 5.00 reduced to 4.76



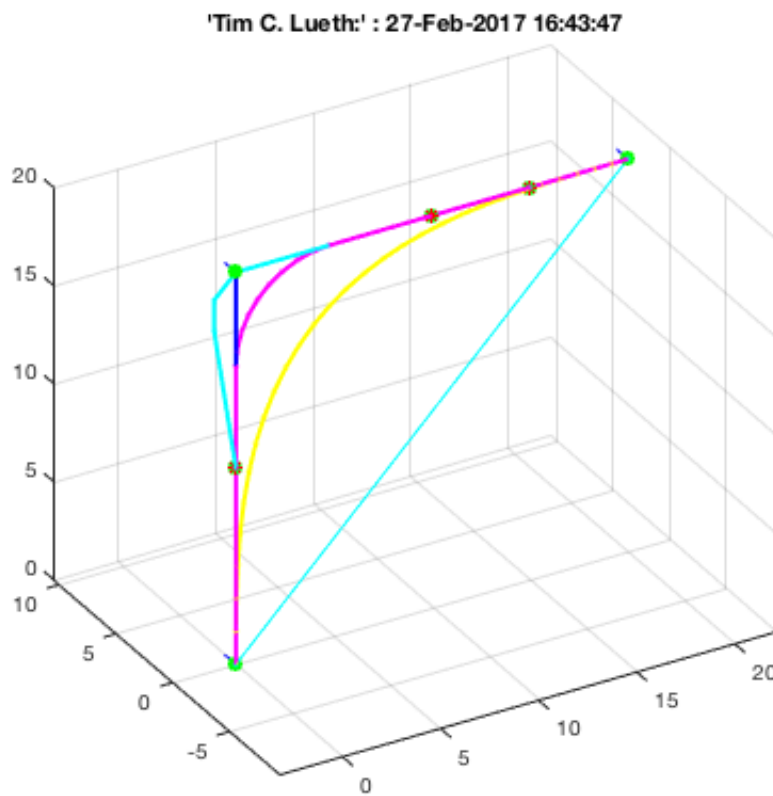
3. Tube generation using a 3D path with Bezier-curves or radial edges

Create a 2D closed polygon line to be copied in 3D space

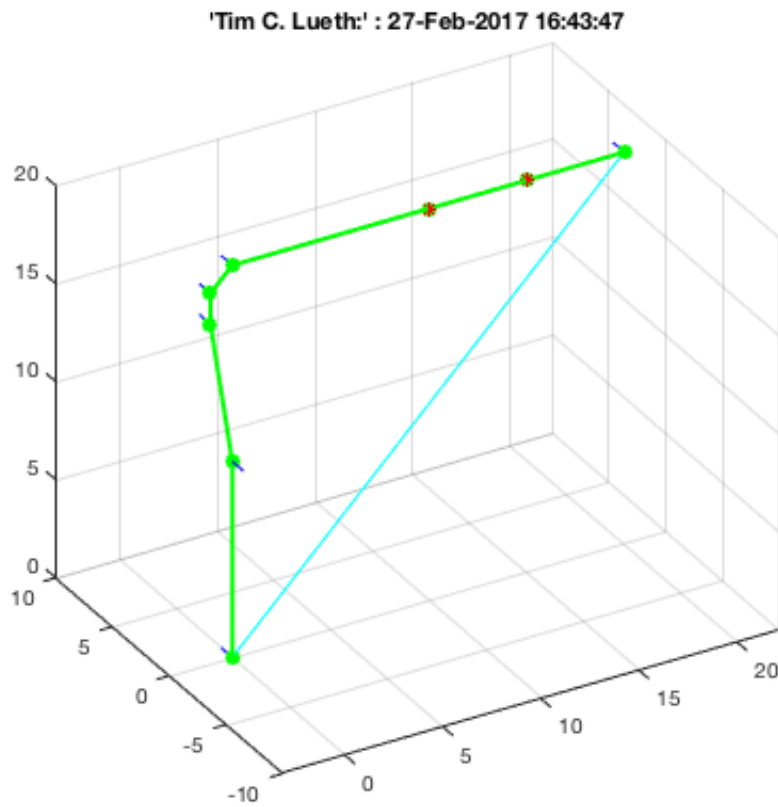
```
SGfigure; CPLplot(CPL,'r-'); axis on ; grid on;
VL=[0 0 0; 0 0 10; 0 0 20; 10 0 20; 15 0 20; 20 0 20];
VLangle(VL);

VLB=VLBezierC(VL,30);
VLR=VLRradiusC(VL,pi/4,2);
VLr=VLradialEdges(VL,5);
VLplot(VL,'b.-',2); view (-30,30);
VLplot(VLB,'y.-',2); view (-30,30);
VLplot(VLR,'c.-',2); view (-30,30);
VLplot(VLr,'m.-',2); view (-30,30);
```

tangentcirc: Radius 5.00 reduced to 4.76

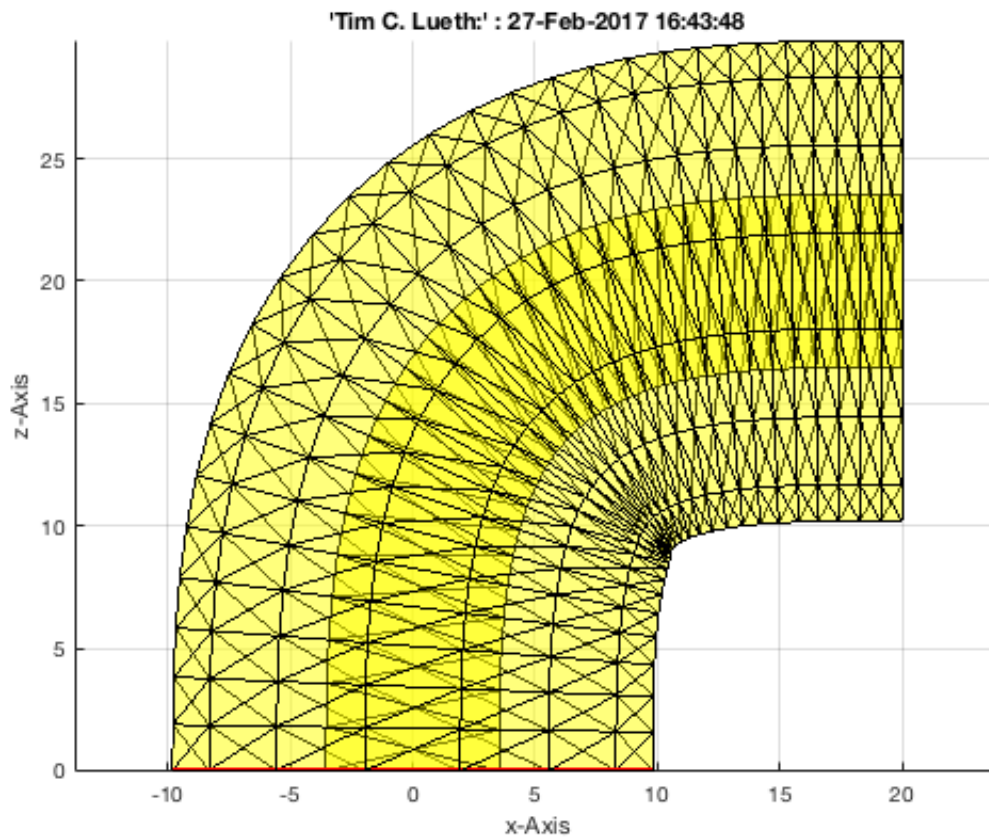


```
VAngle(VLR);
```



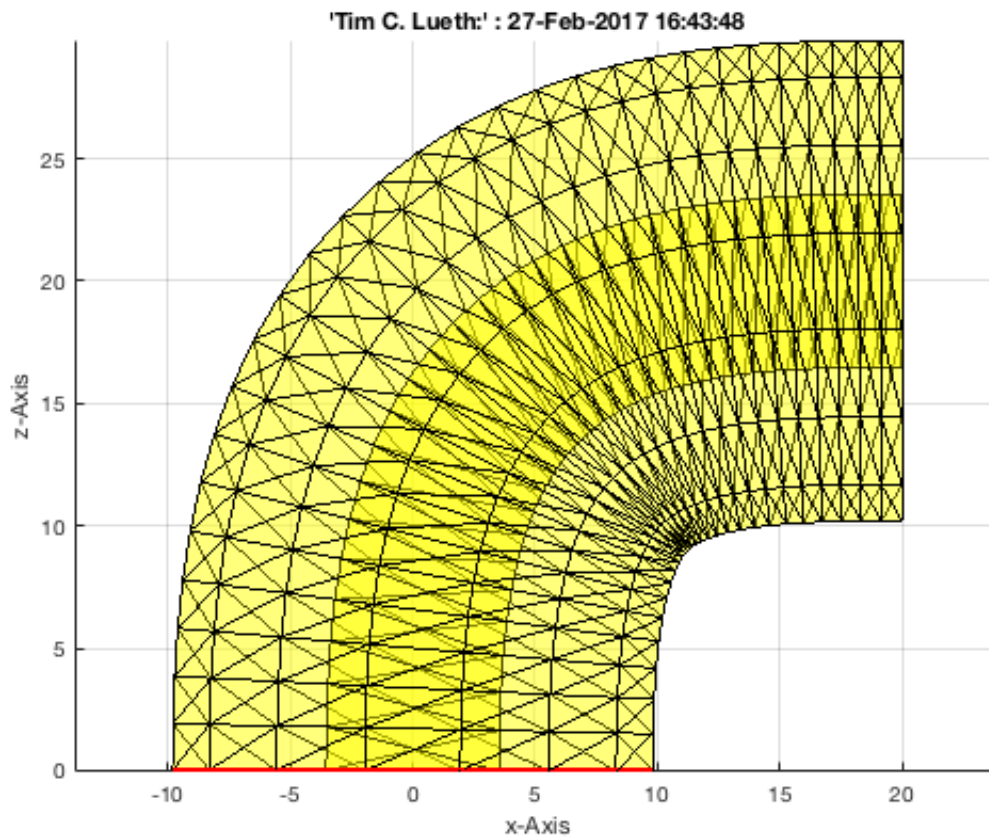
The Bezier-curve tube

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGcontourtube(CPL,VLB); SGplot(SG,'y'); VLFLplotlight(0,0.3);view (0,0);
```



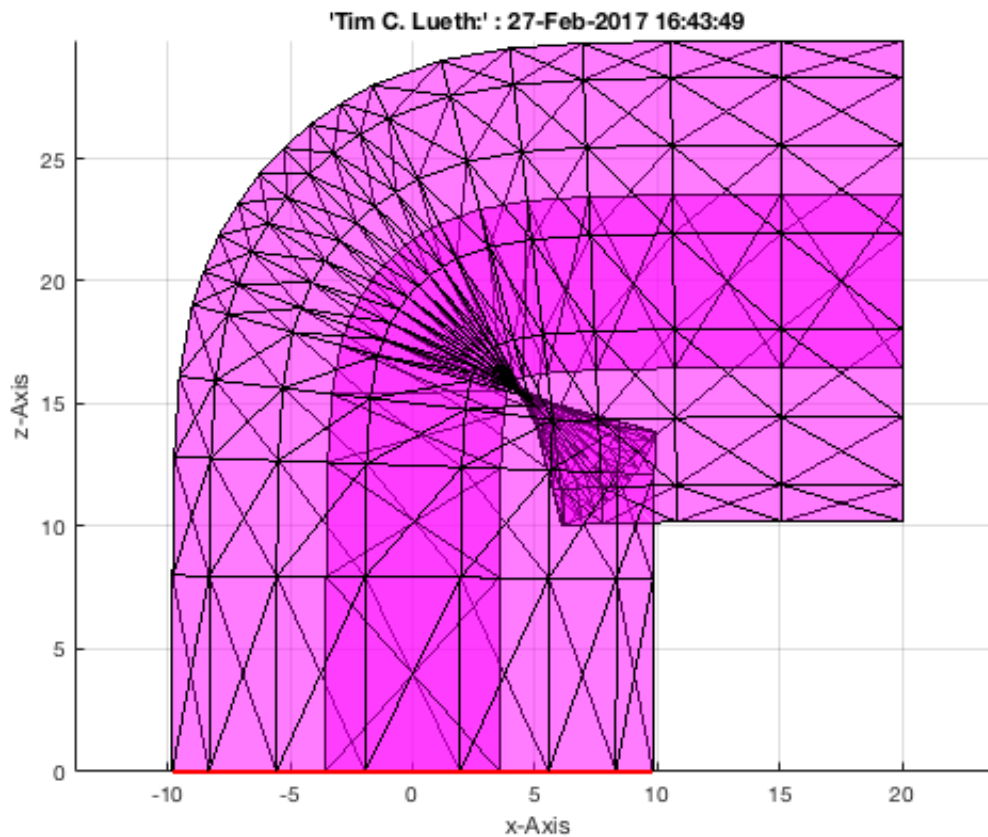
The Bezier-curve tube

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGofCPLCVLR(CPL,VLB); SGplot(SG,'y'); VLFLplotlight(0,0.3);view (0,0);
```



The Radial-curve tube

```
SGfigure; CPLplot(CPL,'r-',2); axis on ; grid on;  
SG=SGofCPLCVLR(CPL,VLr); SGplot(SG,'m'); VLFLplotlight(0,0.3);view (0,0);
```

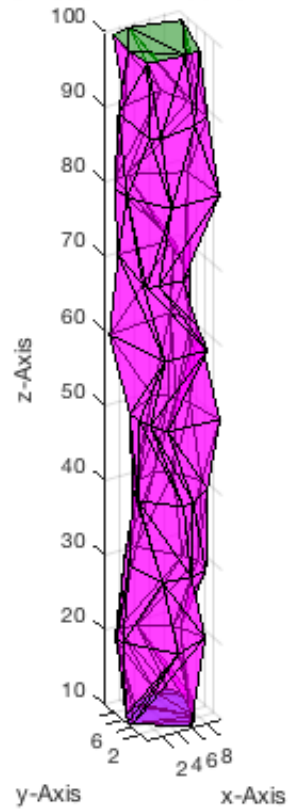


4. Creating solids by closed polygons in different height: z-coordinate

The connection of contours in different z-values works currently only with ONE contour per z-value

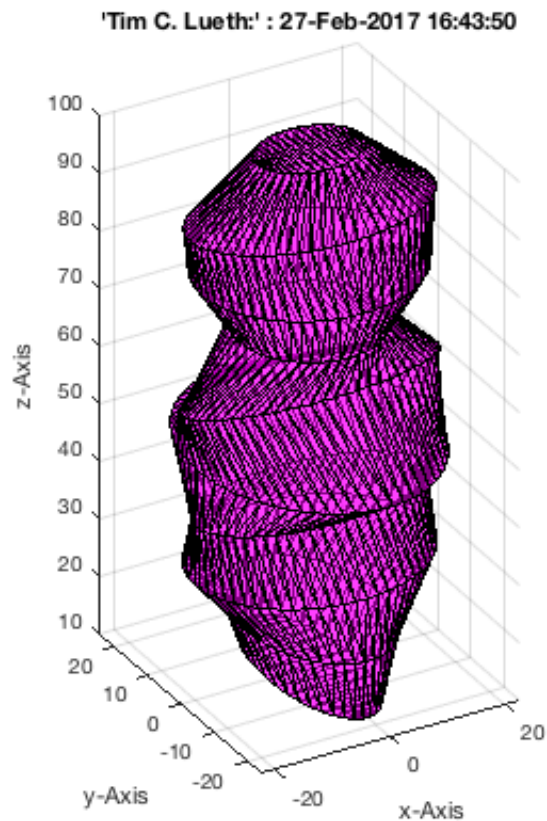
```
SGfigure; view(-30,30); axis on; grid on;
VL=[]; for i=1:10; VL=[VL;VLaddz(PLconvexhull(10*rand(20,2)),i*10)]; end;
[FLB,FLW,FLT]=FLoFCVL(VL);
VLFLplot(VL,FLB,'b'); VLFLplot(VL,FLW,'m'); VLFLplot(VL,FLT,'g'); VLFLplotlight(0,0.5)
```


'Tim C. Lueth' : 27-Feb-2017 16:43:49



Same as but this time with ellipsoids

```
SGfigure; view(-30,30); axis on; grid on;
VL=[]; for i=1:10; VL=[VL;VLaddz(PLcircle(5+20*rand,[],[],5+20*rand),i*10)]; end;
[FLB,FLW,FLT]=FLoFCVL(VL); FL=[FLB;FLW;FLT];
VLFLplot(VL,FL,'m'); VLFLplotlight(0,0.5)
```



5. Creating a sphere with minimal number of points

For the creation of spherical joints, we need sphered shaped geometries. Those spheres consist of circular point lists in different z-height. The number of points of each polygon, the number of polygons and the z-resolution depend on the size of the sphere.

A sphere with just 1mm radius and a resolution of 50 μ m (default) has only hundreds of facets.

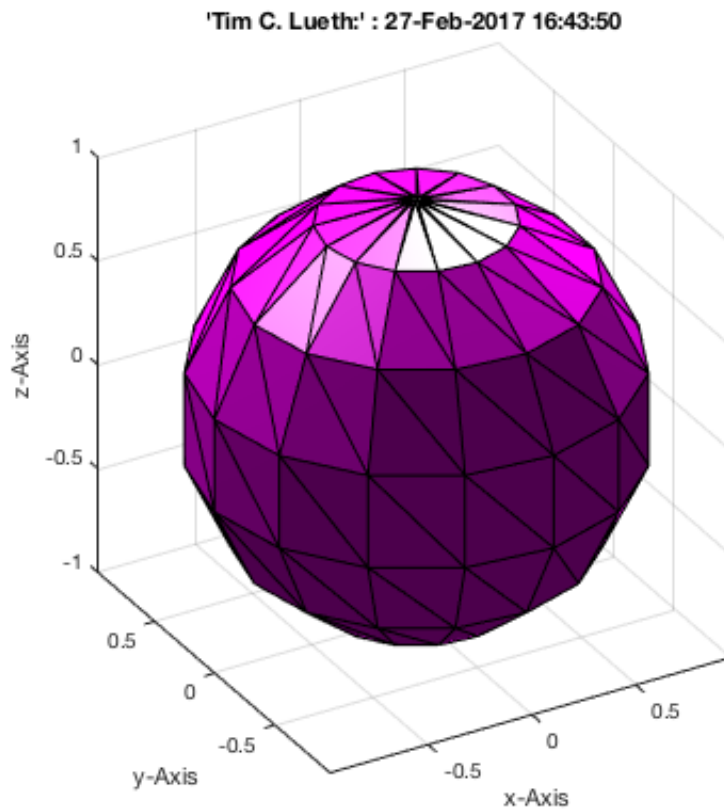
```
SGsphere(1)
```

```
ans =
```

```
struct with fields:
```

```
VL: [120×3 double]
```

```
FL: [236×3 double]
```



Asphere with 100mm radius and a resolution of 50 μ m (default) has then thousands of facets.

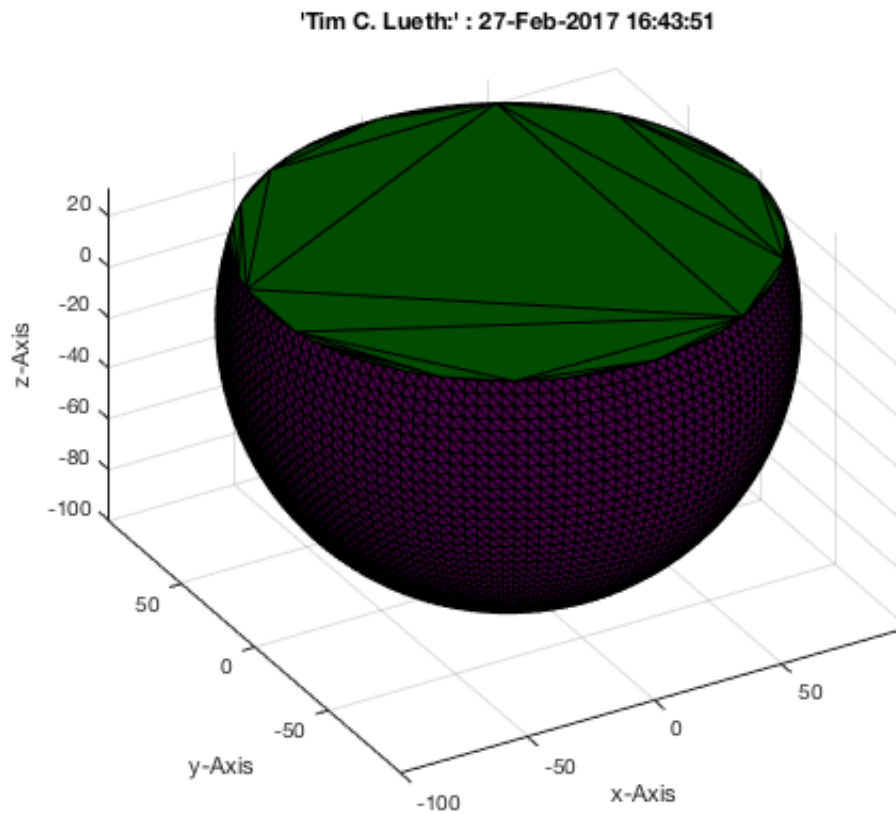
```
SGsphere(100,[],pi/10)
```

```
ans =
```

```
struct with fields:
```

```
VL: [6063×3 double]
```

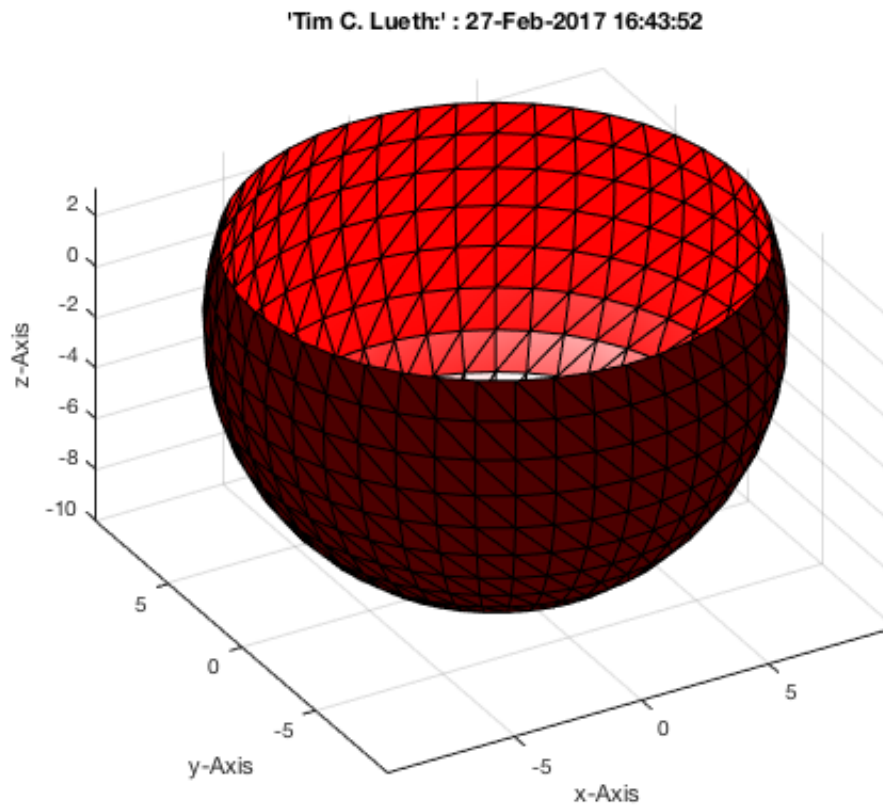
```
FL: [12122×3 double]
```



6. Creating a spherical joint

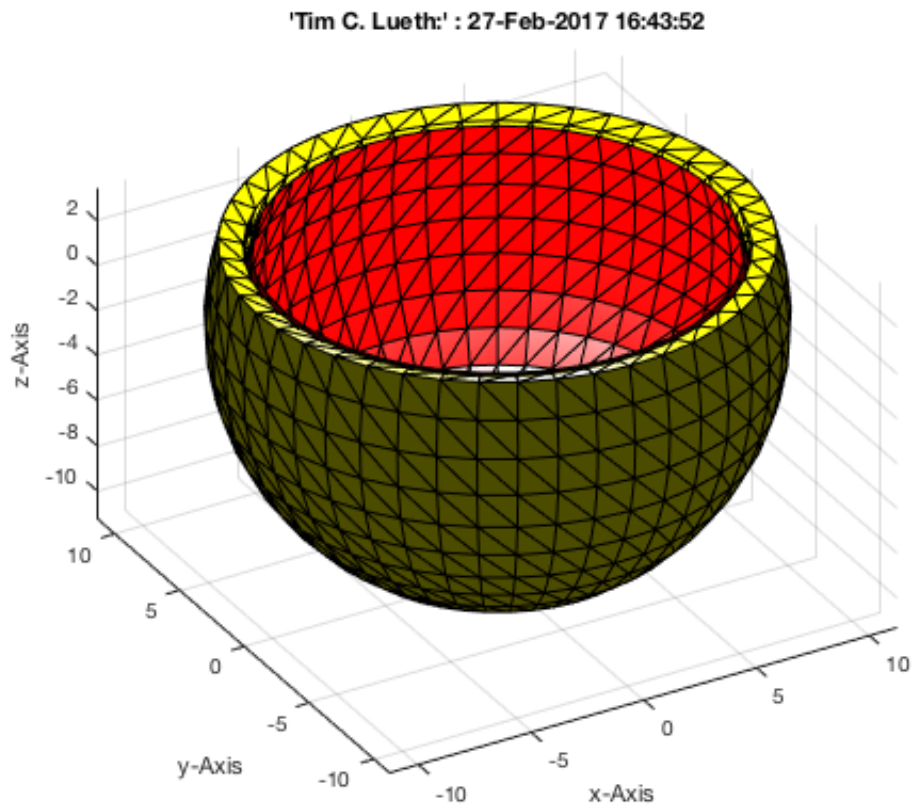
First we have to create a sphere and separate the spherical surface

```
SGfigure; view(-30,30);  
[~,~,SG]=MlofSG(SGsphere(10,[],pi/10));  
VLFLplot(SG.VL,SG.FL(SG.ML(:,1)==1,:));
```



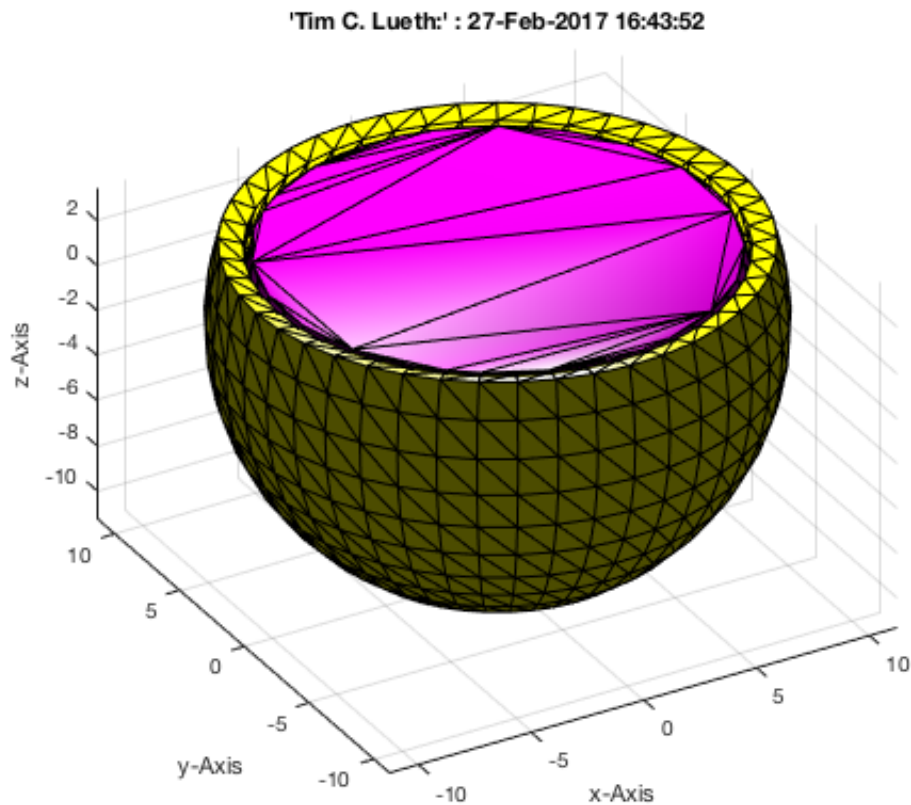
Now create the surface for the joint from the spherical surface with tickness 1 as bearing

```
SGofSurface(SG.VL,SG.FL(SG.ML(:,1)==1,:),1);
```



Now fill in the sphere ball as joint

```
SGplot(SG, 'm');
```



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:43:55 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 map_toolbox
 matlab
 robotics_system_toolbox
 simulink
 =====
 =====

- *Tim Lueth, tested and compiled on OSX 10.7.5 with Matlab 2014b on 2015-10-12*
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 20: Programmatically Interface to SimMechanics Multi-Body Toolbox

2016-11-19: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Creating a new SimMechanics System
- 3. Create two links with length 50 and 80 and one or two mounting holes
- 4. Create SimMechanics models for the four links in different colors
- 5. Create SimMechanics models for the four joint and connect them with the links
- 6. Connect the base frame of link1 to the world coordinate system
- 7. Run the Simulation of the Simulink/SimMechanics diagram for 1 second
- 8. Create a Video of the Simualatin for 5 seconds
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

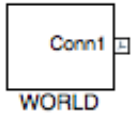
The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Leightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox

2. Creating a new SimMechanics System

```
smbNewSystem ( 'SG_LIB_EXP_20' );           % Creates the mechansim diagramm
smbDrawNow;
```

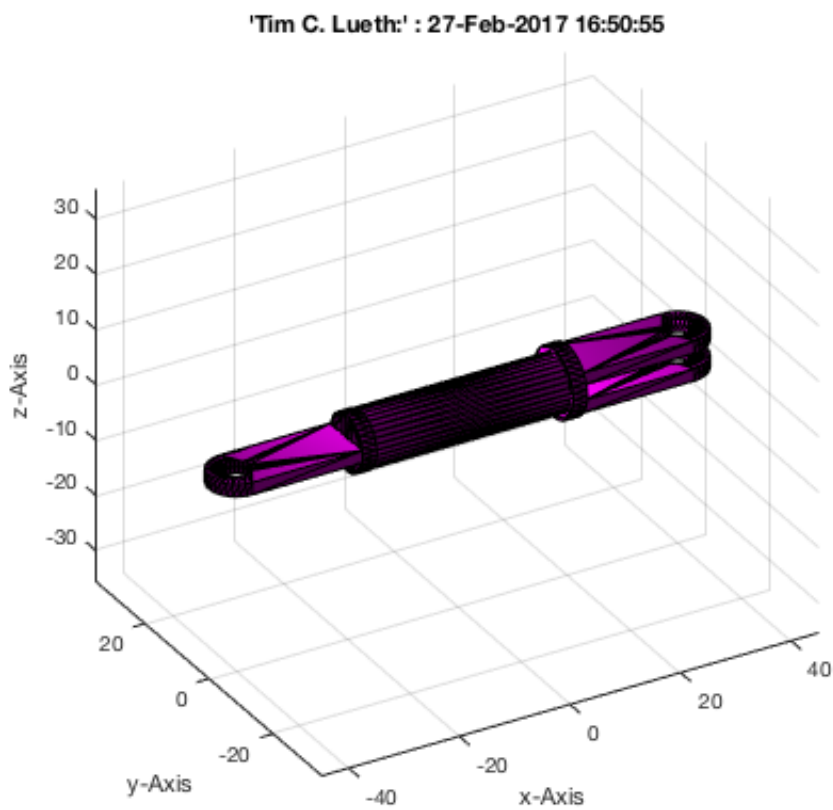
Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_20/'



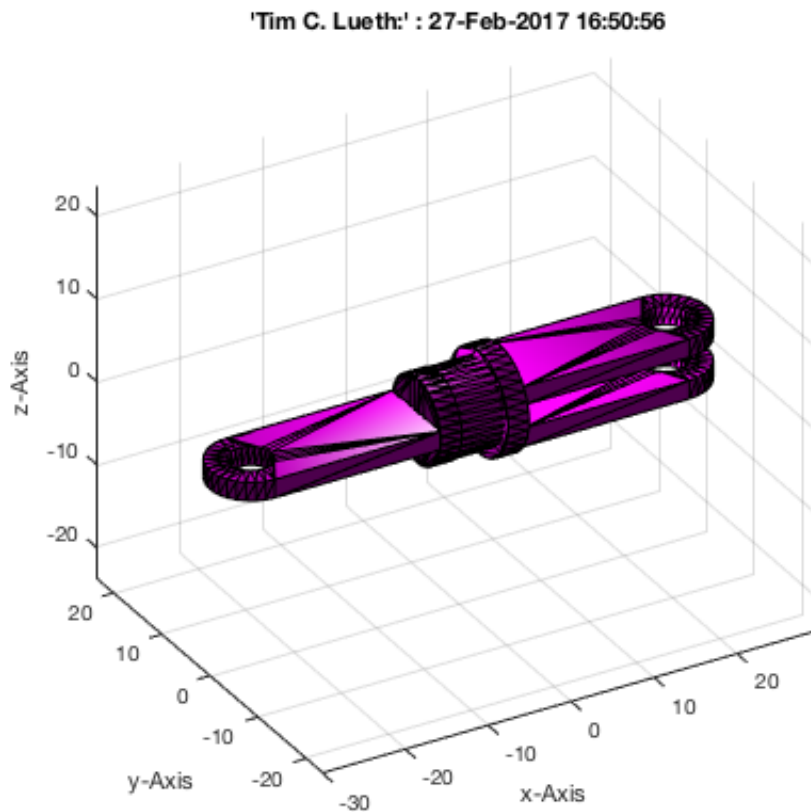
3. Create two links with length 50 and 80 and one or two mounting holes

```
SG1=SGmodelLink(80,'',1,2);           % Creates a long rod with flange
SG2=SGmodelLink(50,'',1,2);           % Creates a short rod with flange
```

```
SGfigure(SG1); view(-30,30);
```

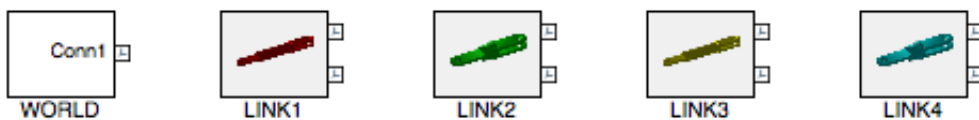


```
SGfigure(SG2); view(-30,30);
```



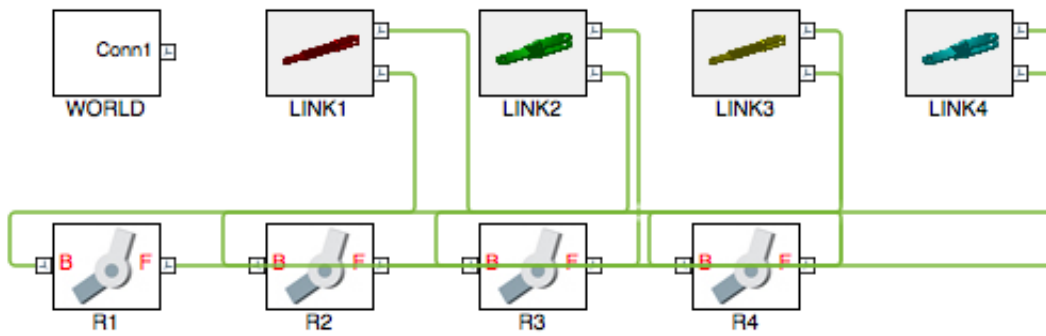
4. Create SimMechanics models for the four links in different colors

```
smbCreateSG (SG1, 'LINK1', 'r'); % Add long rod as LINK1
smbCreateSG (SG2, 'LINK2', 'g'); % Add short rod as LINK2
smbCreateSG (SG1, 'LINK3', 'y'); % Add long rod as LINK3
smbCreateSG (SG2, 'LINK4', 'c'); % Add short rod as LINK4
smbDrawNow;
```



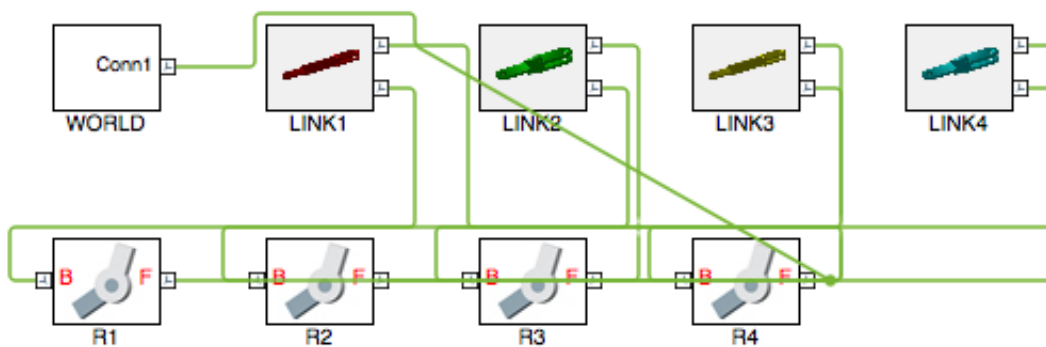
5. Create SimMechanics models for the four joint and connect them with the links

```
smbCreateJoint ('R', 'R1', 'LINK1.F', 'LINK2.B'); % Add a RR Joint
smbCreateJoint ('R', 'R2', 'LINK2.F', 'LINK3.B'); % Add a RR Joint
smbCreateJoint ('R', 'R3', 'LINK3.F', 'LINK4.B'); % Add a RR Joint
smbCreateJoint ('R', 'R4', 'LINK4.F', 'LINK1.B'); % Add a RR Joint
smbDrawNow;
```



6. Connect the base frame of link1 to the world coordinate system

```
smbCreateConnection('WORLD.ORIGIN','LINK1.B'); % Connect Linkage to World Frame
smbDrawNow;
```



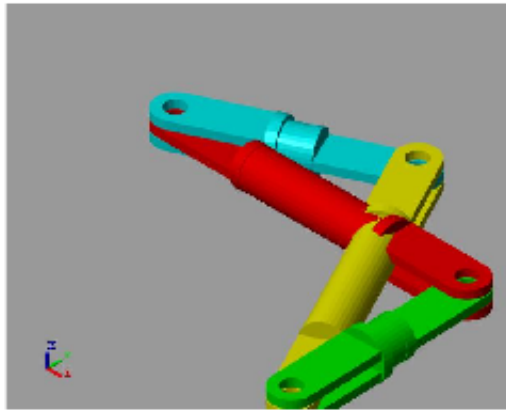
7. Run the Simulation of the Simulink/SimMechanics diagram for 1 second

```
smbSimulate(1); % Simulate for 1 second
```

8. Create a Video of the Simualatin for 5 seconds

```
smbVideoSimulation(5); % Show a 5 seconds video
```

.....



Final remarks on toolbox version and execution date

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:51:27 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
instr_control_toolbox
matlab
simmechanics
simscape
simulink
=====
=====
```

- *Tim Lueth, tested and compiled on OSX 10.11.6 with Matlab 2016 on 2016-12-09*
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 21: Programmatically Convert Joints into Drives (SimMechanics)

2016-11-19: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Creating a new SimMechanics System
- 3. Create two links with length 50 and 80 and one or two mounting holes
- 4. Create SimMechanics models for the four links in different colors
- 5. Create SimMechanics models for the four joint and connect them with the links
- 6. Connect the base frame of link1 to the world coordinate system
- 7. Create a SimMechanics model for a motor/drive and use a Cosinus Rotation
- 8. Create a Simulink models for a cosinus signal
- 9. Create a Video of the Simualati0n for 10 seconds
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Leightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Convert Joints into Drives (SimMechanics)

2. Creating a new SimMechanics System

```
smbNewSystem ( 'SG_LIB_EXP_21' ); % Creates the mechansim diagramm
```

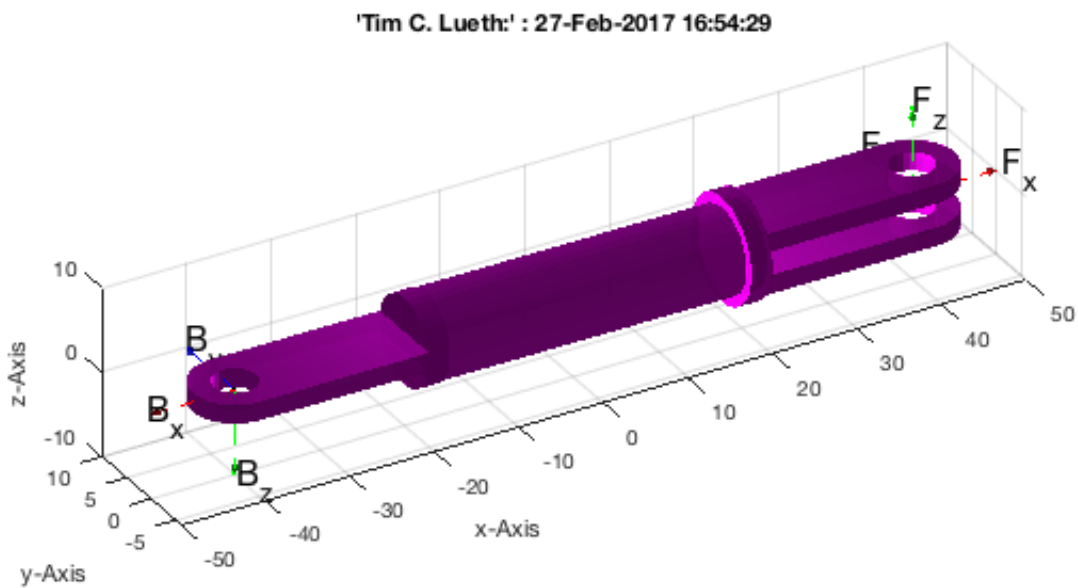
Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_21/'



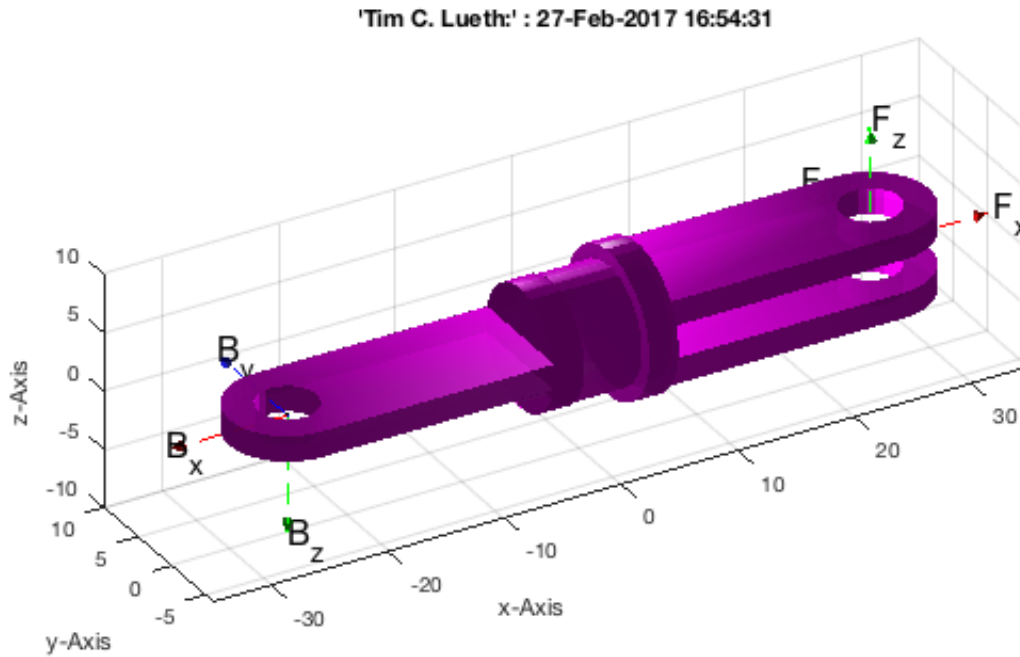
3. Create two links with length 50 and 80 and one or two mounting holes

```
SG1=SGmodelLink(80,'',1,2);           % Creates a long rod with flange
SG2=SGmodelLink(50,'',1,2);           % Creates a short rod with flange
```

```
SGfigure; view(-30,30); axis on;
SGT(SG1);
```

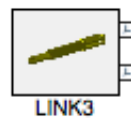
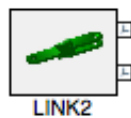
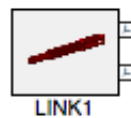


```
SGfigure; view(-30,30); axis on;
SGT (SG2);
```



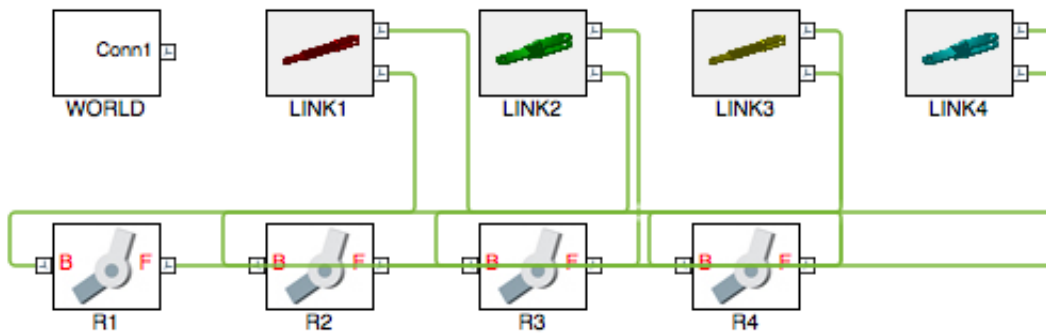
4. Create SimMechanics models for the four links in different colors

```
smbCreateSG (SG1, 'LINK1', 'r'); % Add long rod as LINK1
smbCreateSG (SG2, 'LINK2', 'g'); % Add short rod as LINK2
smbCreateSG (SG1, 'LINK3', 'y'); % Add long rod as LINK3
smbCreateSG (SG2, 'LINK4', 'c'); % Add short rod as LINK4
smbDrawNow;
```



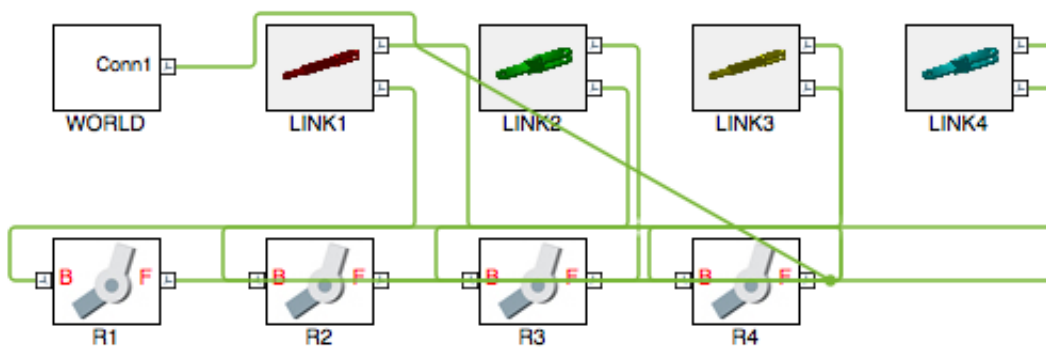
5. Create SimMechanics models for the four joint and connect them with the links

```
smbCreateJoint ('R', 'R1', 'LINK1.F', 'LINK2.B'); % Add a RR Joint
smbCreateJoint ('R', 'R2', 'LINK2.F', 'LINK3.B'); % Add a RR Joint
smbCreateJoint ('R', 'R3', 'LINK3.F', 'LINK4.B'); % Add a RR Joint
smbCreateJoint ('R', 'R4', 'LINK4.F', 'LINK1.B'); % Add a RR Joint
smbDrawNow;
```

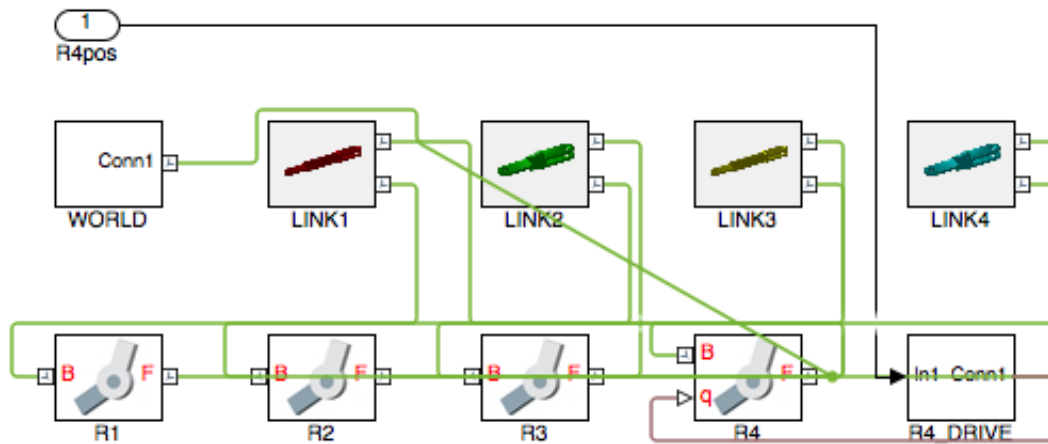
6. Connect the base frame of link1 to the world coordinate system

```
smbCreateConnection('WORLD.ORIGIN', 'LINK1.B'); % Connect Linkage to World Frame
smbDrawNow;
```



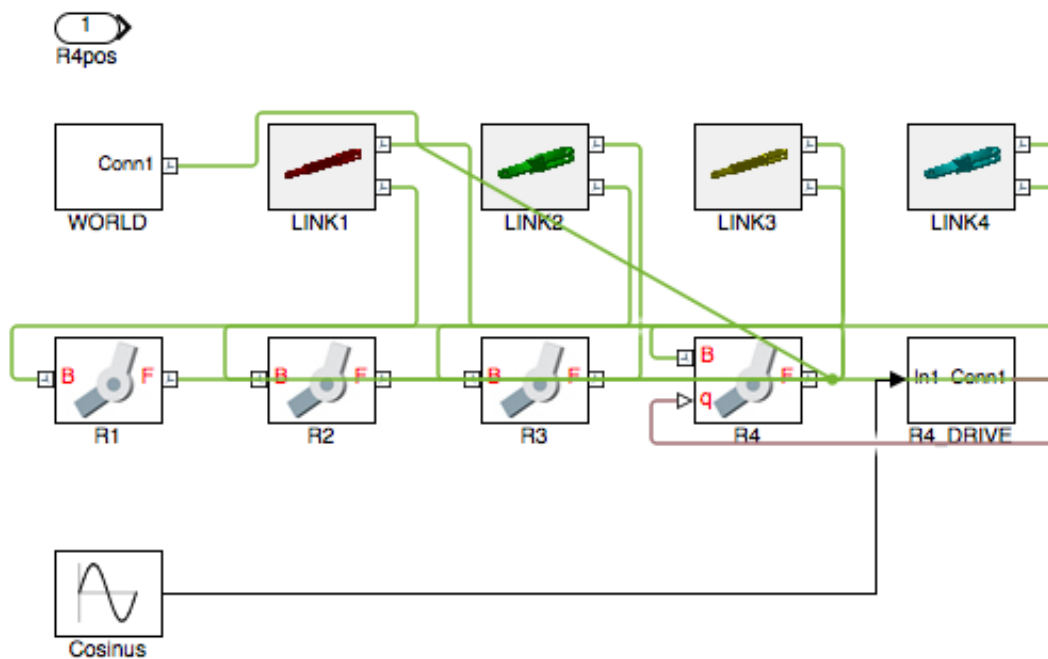
7. Create a SimMechanics model for a motor/drive and use a Cosinus Rotation

```
smbCreateDrive ('R4'); % Convert Joint R4 into a Drive
smbDrawNow;
```



8. Create a Simulink models for a cosinus signal

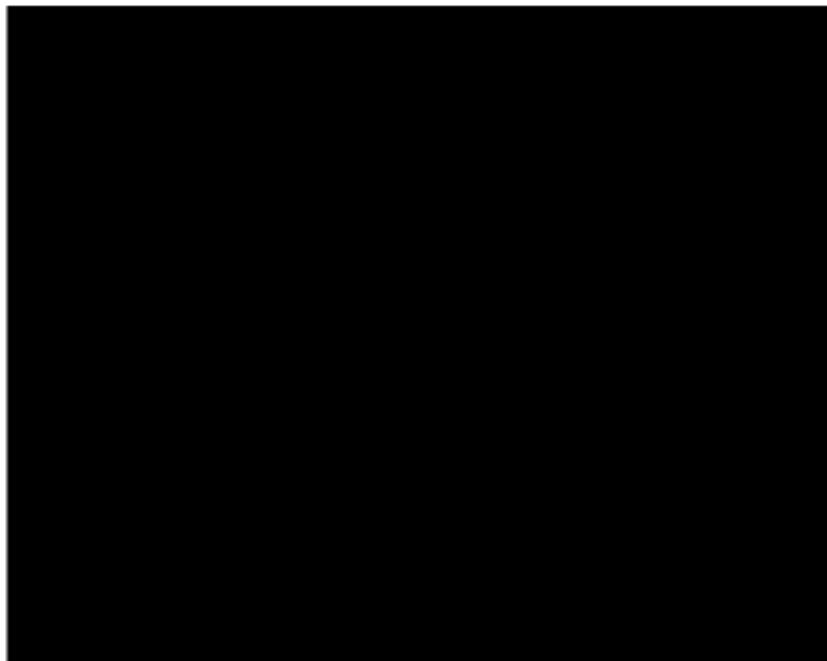
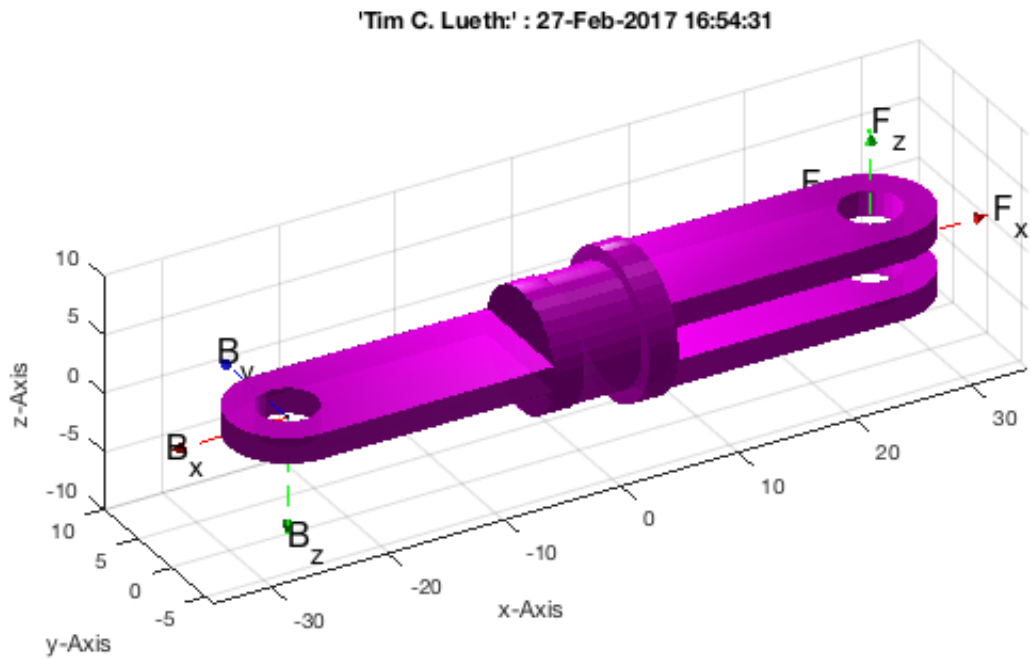
```
smbCreateSineWave ('Cosinus','R4_DRIVE/1');    % Connect a Sinus Generator to Drive
smbDrawNow;
```



9. Create a Video of the Simualati0n for 10 seconds

```
smbVideoSimulation;    % Show a 5 seconds video
```

....



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:54:57 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 instr_control_toolbox
 matlab
 simmechanics
 Simscape
 simulink
 =====
 =====

- *Tim Lueth, tested and compiled on OSX 10.11.6 with Matlab 2016 on 2016-12-09*
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 22: Adding Simulink Signals to Record Frame Movements

2016-12-18: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Creating a new SimMechanics System
- 3. Create two links with length 50 and 80 and one or two mounting holes
- 4. Create SimMechanics models for the four links and four joints in different colors
- 5. Create a video of the movements
- 6. Analyze the simulation for 3 Seconds
- 7. Create Simulink signals for all the frames of the four links
- 8. Simulate and record those signals too
- Final remarks on toolbox version and execution date

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Adding Simulink Signals to Record Frame Movements

2. Creating a new SimMechanics System

```
smbNewSystem ( 'SG_LIB_EXP_22' ); % Creates the mechsims diagramm
```

```
smbDrawNow;
```

Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_22/'

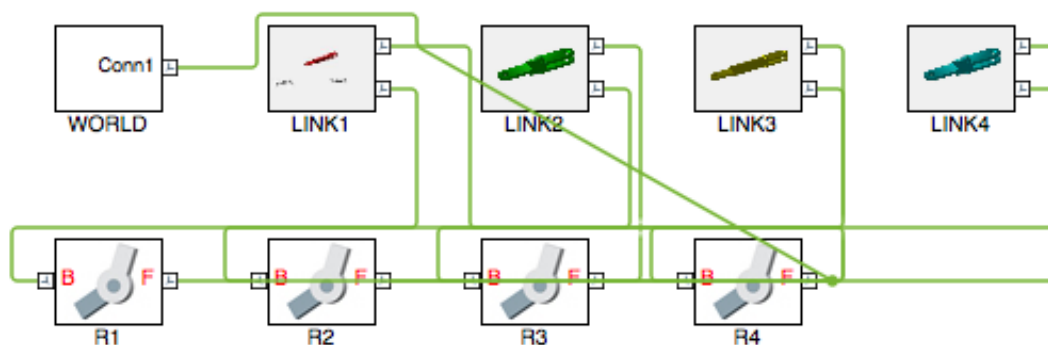


3. Create two links with length 50 and 80 and one or two mounting holes

```
SG1=SGmodelLink(80,'',1,2); % Creates a long rod with flange
SG2=SGmodelLink(50,'',1,2); % Creates a short rod with flange
```

4. Create SimMechanics models for the four links and four joints in different colors

```
smbCreateSG (SG1,'LINK1','r'); % Add long rod as LINK1
smbCreateSG (SG2,'LINK2','g'); % Add short rod as LINK2
smbCreateSG (SG1,'LINK3','y'); % Add long rod as LINK3
smbCreateSG (SG2,'LINK4','c'); % Add short rod as LINK4
smbCreateJoint ('R','R1','LINK1.F','LINK2.B'); % Add a RR Joint
smbCreateJoint ('R','R2','LINK2.F','LINK3.B'); % Add a RR Joint
smbCreateJoint ('R','R3','LINK3.F','LINK4.B'); % Add a RR Joint
smbCreateJoint ('R','R4','LINK4.F','LINK1.B'); % Add a RR Joint
smbCreateConnection('WORLD.ORIGIN','LINK1.B'); % Connect Linkage to World Frame
smbDrawNow;
```



5. Create a video of the movements

```
smbVideoSimulation(3); % Show a 3 seconds video
```

6. Analyze the simulation for 3 Seconds

The result of a simulation is a structure that contains SimMultiBody states (xout) and recorded Simulink signals (sim). If there are no Simulink signals, sout is empty.

```
simOut=smbSimulate(3)
```

```
Simulink.SimulationOutput:
```

```
simlog: [1x1 simscape.logging.Node]
tout: [209x1 double]
xout: [1x1 Simulink.SimulationData.Dataset]
```

Use 'get' to access a variable by name.

Use 'getSimulationMetadata' to access metadata about the simulation.

The states contain the parameter = angles/velocity of the joints

```
xout = simOut.get('xout')
```

```
xout =
```

```
Simulink.SimulationData.Dataset
Package: Simulink.SimulationData
```

```
Characteristics:
```

```
    Name: 'xout'
Total Elements: 8
```

```
Elements:
```

```
1 : 'SG_LIB_EXP_22.R1.Rz.q'
2 : 'SG_LIB_EXP_22.R1.Rz.w'
3 : 'SG_LIB_EXP_22.R2.Rz.q'
4 : 'SG_LIB_EXP_22.R2.Rz.w'
5 : 'SG_LIB_EXP_22.R3.Rz.q'
6 : 'SG_LIB_EXP_22.R3.Rz.w'
7 : 'SG_LIB_EXP_22.R4.Rz.q'
8 : 'SG_LIB_EXP_22.R4.Rz.w'
```

-Use 'get' or 'getElement' to access elements by index or name.

-Use 'addElement' or 'setElement' to modify elements.

There is no Simulink signals yet

```
sout = simOut.get('sout')
```

```
sout =
```

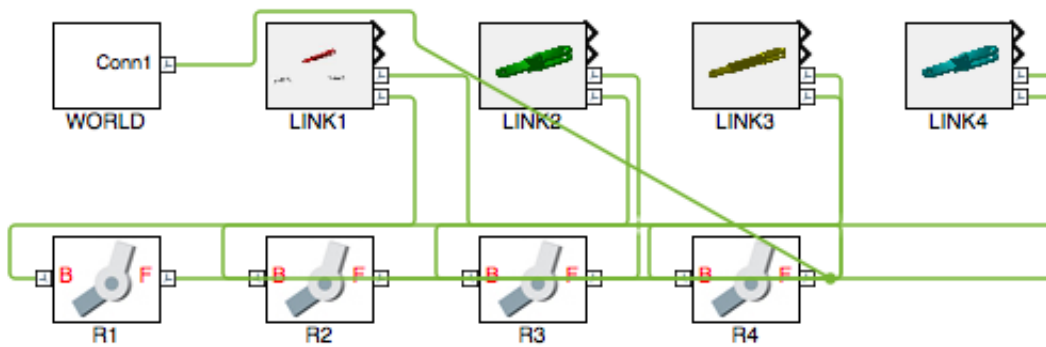
[]

7. Create Simulink signals for all the frames of the four links

```
smbAddFrameSensor ( 'LINK1.RF' );
smbAddFrameSensor ( 'LINK2.RF' );
smbAddFrameSensor ( 'LINK3.RF' );
smbAddFrameSensor ( 'LINK4.RF' );
```

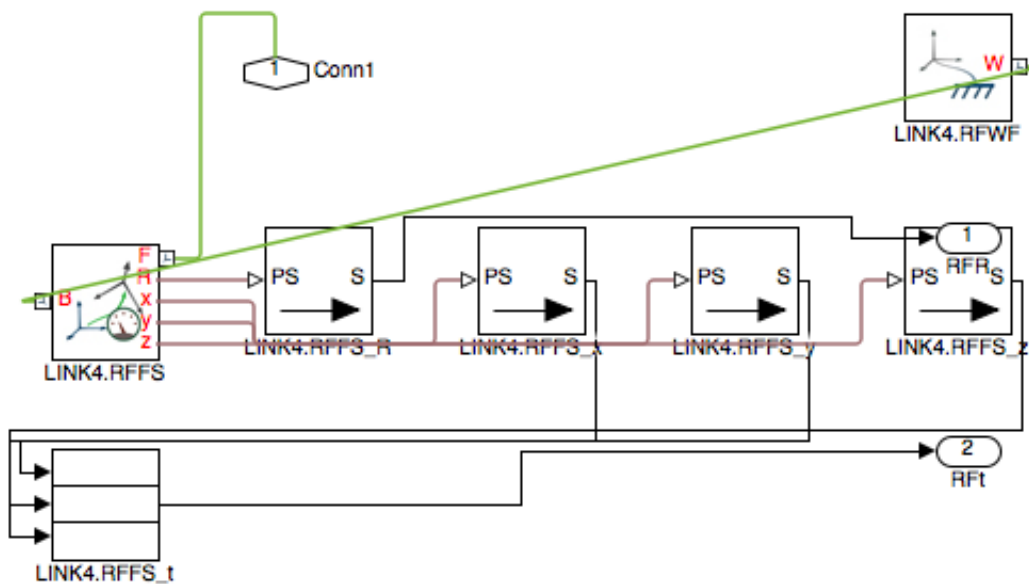
Now, all links have simulink signals and signal output for R and T of the reference frame

```
smbDrawNow;
```



The model of link4 is extended by a transformation sensor

```
smbDrawNow ( 'LINK4.RF_T' );
```

8. Simulate and record those signals too

```
simOut=smbSimulate(3)
smbVideoSimulation(3);
```

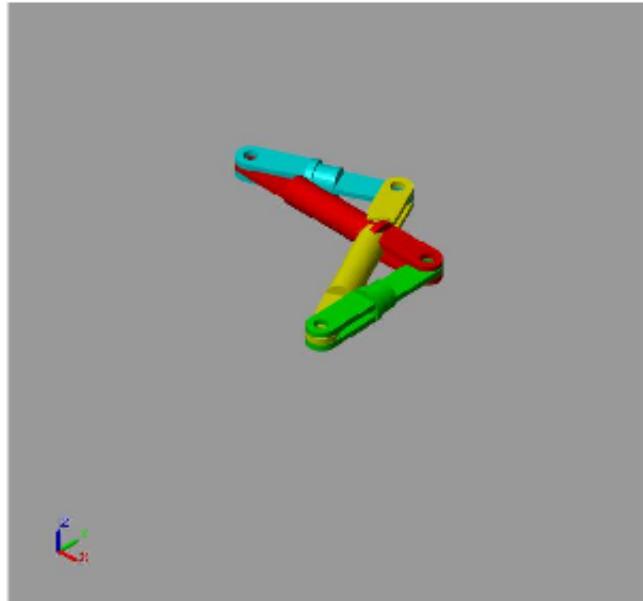
Simulink.SimulationOutput:

```
simlog: [1x1 simscape.logging.Node]
sout: [1x1 Simulink.SimulationData.Dataset]
tout: [209x1 double]
xout: [1x1 Simulink.SimulationData.Dataset]
```

Use 'get' to access a variable by name.

Use 'getSimulationMetadata' to access metadata about the simulation.

.....



The states contain the parameter = angles/velocity of the joints

```
xout = simOut.get('xout')
```

```
xout =
```

```
Simulink.SimulationData.Dataset  
Package: Simulink.SimulationData
```

```
Characteristics:
```

```
    Name: 'xout'  
    Total Elements: 8
```

```
Elements:
```

```
1 : 'SG_LIB_EXP_22.R1.Rz.q'  
2 : 'SG_LIB_EXP_22.R1.Rz.w'  
3 : 'SG_LIB_EXP_22.R2.Rz.q'  
4 : 'SG_LIB_EXP_22.R2.Rz.w'  
5 : 'SG_LIB_EXP_22.R3.Rz.q'  
6 : 'SG_LIB_EXP_22.R3.Rz.w'  
7 : 'SG_LIB_EXP_22.R4.Rz.q'  
8 : 'SG_LIB_EXP_22.R4.Rz.w'
```

```
-Use 'get' or 'getElement' to access elements by index or name.  
-Use 'addElement' or 'setElement' to modify elements.
```

The Simulink signals are related to the reference rotation and translation

```
sout = simOut.get('sout')  
T1=smbTofSimOut(simOut,'LINK1.RF'); VL1=squeeze(T1(1:3,4,:))';
```

```

T2=smbTofSimOut(simOut,'LINK2.RF'); VL2=squeeze(T2(1:3,4,:))';
T3=smbTofSimOut(simOut,'LINK3.RF'); VL3=squeeze(T3(1:3,4,:))';
T4=smbTofSimOut(simOut,'LINK4.RF'); VL4=squeeze(T4(1:3,4,:))';
SGfigure; axis on; view(0,90); grid on;
VLplot(VL1,'r.-');
VLplot(VL2,'g.-');
VLplot(VL3,'y.-');
VLplot(VL4,'c.-');
drawnow;

```

```
sout =
```

```

Simulink.SimulationData.Dataset
Package: Simulink.SimulationData

```

```
Characteristics:
```

```

    Name: 'sout'
  Total Elements: 8

```

```
Elements:
```

```

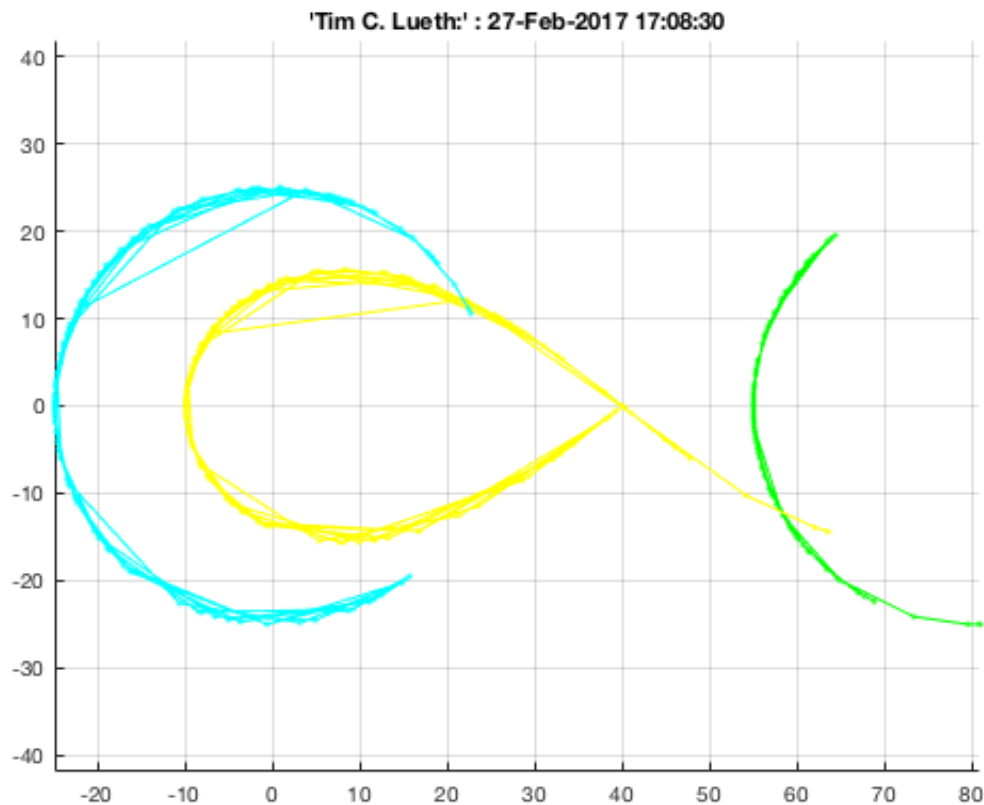
 1 : 'SG_LIB_EXP_22/LINK1/LINK1.RF_T.RFR'
 2 : 'SG_LIB_EXP_22/LINK1/LINK1.RF_T.RFt'
 3 : 'SG_LIB_EXP_22/LINK2/LINK2.RF_T.RFR'
 4 : 'SG_LIB_EXP_22/LINK2/LINK2.RF_T.RFt'
 5 : 'SG_LIB_EXP_22/LINK3/LINK3.RF_T.RFR'
 6 : 'SG_LIB_EXP_22/LINK3/LINK3.RF_T.RFt'
 7 : 'SG_LIB_EXP_22/LINK4/LINK4.RF_T.RFR'
 8 : 'SG_LIB_EXP_22/LINK4/LINK4.RF_T.RFt'

```

```

-Use 'get' or 'getElement' to access elements by index or name.
-Use 'addElement' or 'setElement' to modify elements.

```



Final remarks on toolbox version and execution date

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 17:08:33 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 instr_control_toolbox
 map_toolbox
 matlab
 robotics_system_toolbox
 simmechanics
 simscape
 simulink
 =====
 =====

- *Tim Lueth, tested and compiled on OSX 10.11.6 with Matlab 2016b on 2016-12-18*
- _____, executed and published on 64 Bit PC using Windows with Matlab 2015a on 2015-xx-xx_

Published with MATLAB® R2016b

Exercise 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model

2016-12-19: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Open a system and create several fixed nodes and attach revolute joints
- 3. Create a cylindric joint from two solids an attach it to revolute joint
- 4. Attach two frame sensor to record the movement of the falling cylinder
- 5. Show the Simulation
- 6. Now create a solid between the revolute joint and cylindric joint
- 7. Now connect the new solid in the model
- 8. Show the Simulation: The Mechnism has no Movement anymore
- 9. Now Create a Solid Model of Movement Status at Time = 0.1 Seconds
- Final Remarks

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Leightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model

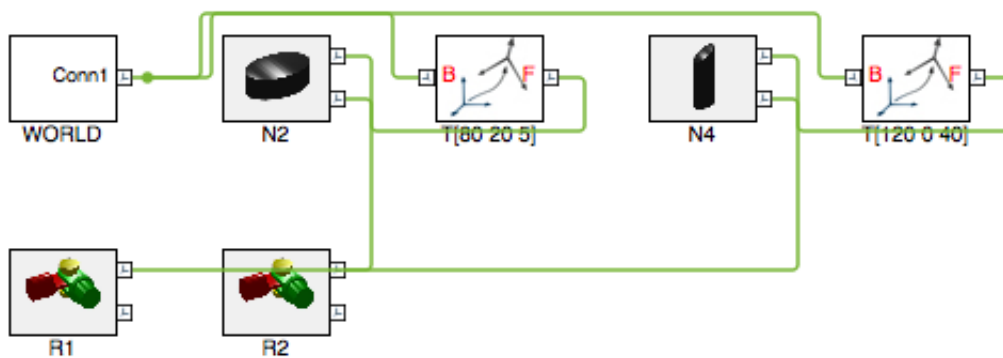
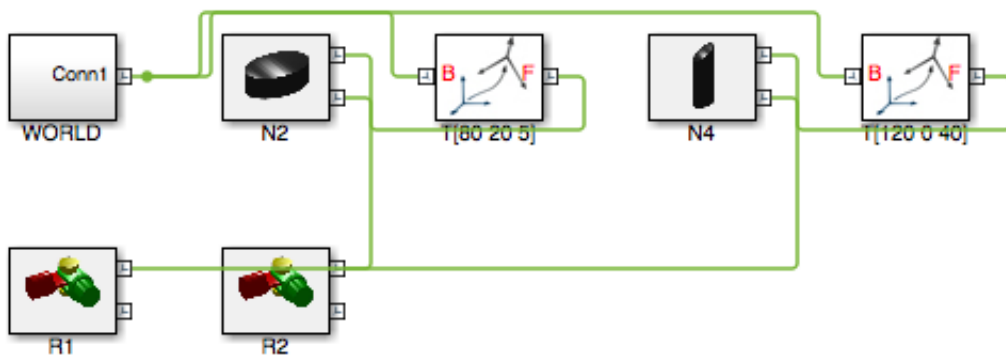
2. Open a system and create several fixed nodes and attach revolute joints

```
function VLFL_EXP23
```

```
smbNewSystem ('SG_LIB_EXP_23');

smbCreateSGNode ([80 20 5], 'N2');
smbCreateSGNode ([120 0 40], 'N4', '', rot(0, -pi/8, 0));
A=SGmodelJoint('R', pi/2);
smbCreateSGJoint('R', 'R1', A, 'N4.F');
smbCreateSGJoint('R', 'R2', A, 'N2.F');
smbDrawNow;
```

Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/'



3. Create a cylindric joint from two solids and attach it to revolute joint

```
Ro=5;
Ri=3;
slot=0.3;

C1=SGofCPLz([PLcircle(Ro);NaN NaN;PLcircle(Ri+slot)],30);
% C1=SGTset(C1,'B',TofSG(C1,'bottom','roty',pi));
```

```

C1=SGTset(C1,'B',TofSG(C1,'incenter','right',-1,'roty',pi/2));
C1=SGTset(C1,'F',TofSG(C1,'bottom'));
smbCreateSG(C1,'C1','r','R1_M');
D1=SGofCPLz(PLcircle(3),30);
D1=SGTset(D1,'B',TofSG(D1,'incenter'));
D1=SGTset(D1,'F',TofSG(D1,'top'));

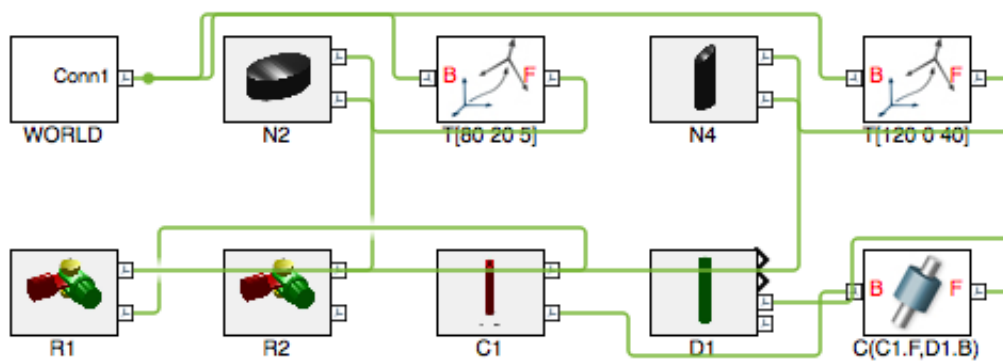
```

4. Attach two frame sensor to record the movement of the falling cylinder

```

smbCreateSG(D1,'D1','g');
smbCreateConnection('C1.F','D1.B','C');
smbAddFrameSensor('R2_M.F');
smbAddFrameSensor('D1.F');
smbDrawNow;

```



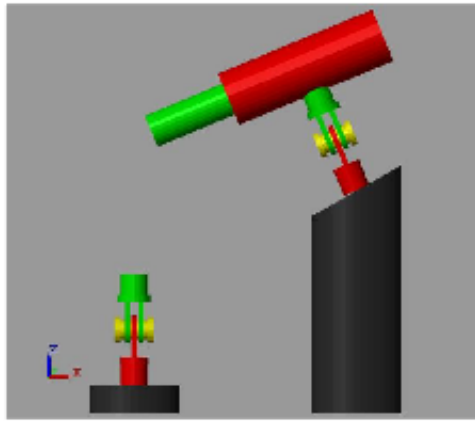
5. Show the Simulation

```

simOut=smbSimulate(0.1);
smbVideoSimulation(1);

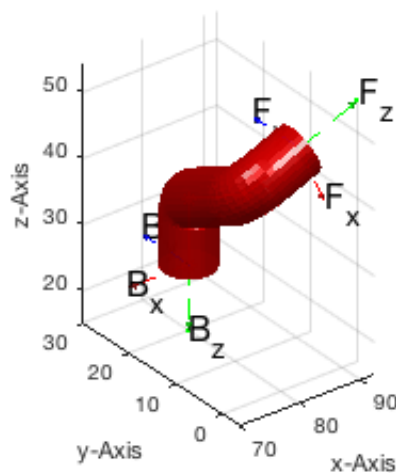
```

...



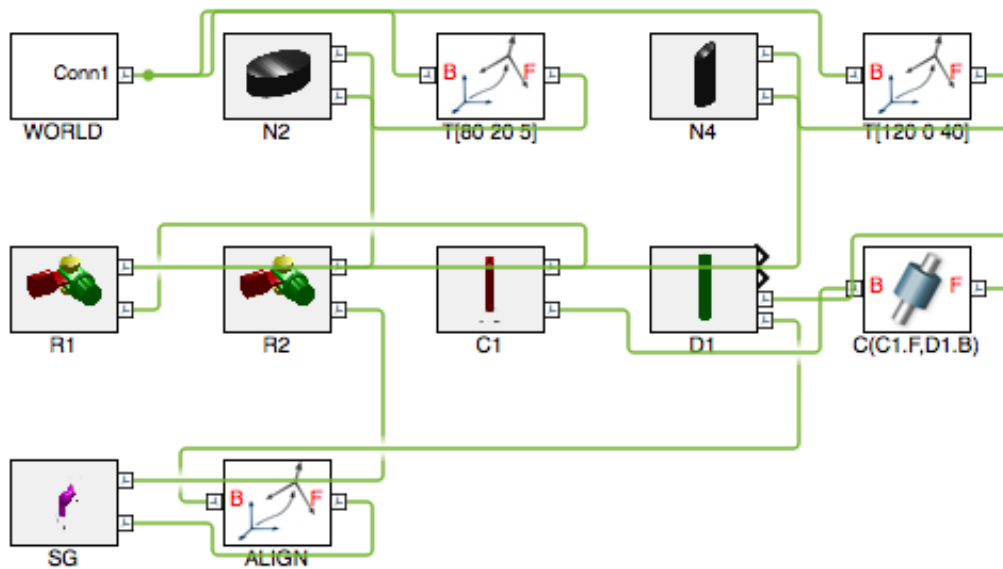
6. Now create a solid between the revolute joint and cylindric joint

```
[T,ta]=smbTofSimOut(simOut,'R2_M.F'); T1=squeeze(T(:,:,1));
[T,tb]=smbTofSimOut(simOut,'D1.F'); T2=squeeze(T(:,:,1));
SG=SGof2T(T1,T2*TofR(rot(0,pi,0)),'',4); % Radius 4
SGTplot(SG);
```



7. Now connect the new solid in the model

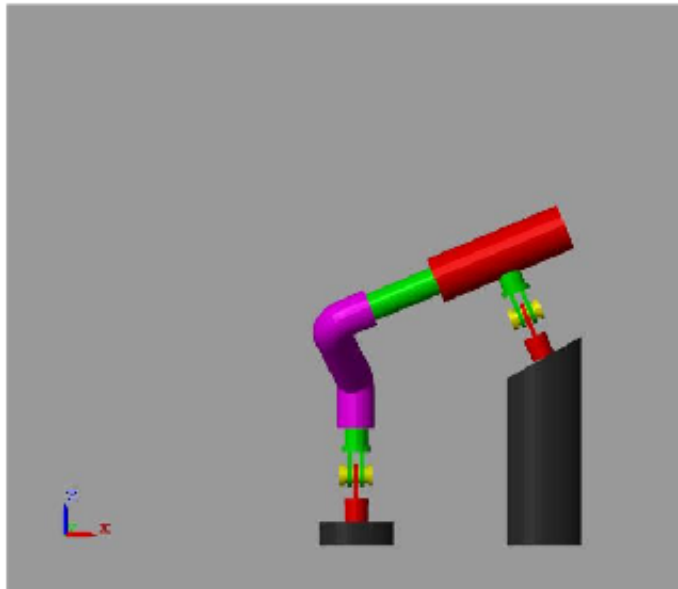
```
smbCreateSG(SG,'SG','m');
smbCreateConnection('R2_M','SG.B');
smbCreateConnection('D1.F','SG.F','align');
smbDrawNow;
```



8. Show the Simulation: The Mechanism has no Movement anymore

```
smbVideoSimulation(1);
```

...



9. Now Create a Solid Model of Movement Status at Time = 0.1 Seconds

```
SG=smbFullModelSimulation(0.1);
```

```
SGfigure; SGplot(SG); view (7,20);
```

```
CREATING A FULL SOLID-MOVEMENT SIMULATION-MODEL 'SG_LIB_EXP_23' THAT RUNS At LEAST 0.10 SEC  
ONDS
```

```
=====
```

```
=====
```

```
Adding frame sensors for all solids of the model
```

```
Add frame sensors for 'C1.SG'
```

```
Add frame sensors for 'D1.SG'
```

```
Add frame sensors for 'N2.SG'
```

```
Add frame sensors for 'N4.SG'
```

```
Add frame sensors for 'R1.FIX1.SG'
```

```
Add frame sensors for 'R1_M.SG'
```

```
Add frame sensors for 'R1_S.SG'
```

```
Add frame sensors for 'R2.FIX1.SG'
```

```
Add frame sensors for 'R2_M.SG'
```

```
Add frame sensors for 'R2_S.SG'
```

```
Add frame sensors for 'SG.SG'
```

```
=====
```

```
Simulink.SimulationOutput:
```

```
    simlog: [1x1 Simscape.Logging.Node]
```

```
    sout: [1x1 Simulink.SimulationData.Dataset]
```

```
    tout: [51x1 double]
```

```
    xout: [1x1 Simulink.SimulationData.Dataset]
```

```
Use 'get' to access a variable by name.
```

```
Use 'getSimulationMetadata' to access metadata about the simulation.
```

```
LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_C1.stl
```

```
Header:
```

```
Number of facets: 232
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_D1.stl
```

```
Header:
```

```
Number of facets: 96
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_N2.stl
```

```
Header:
```

```
Number of facets: 156
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_N4.stl
```

```
Header:
```

```
Number of facets: 156
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_R1.FIX1.stl
```

```
Header:
```

```
Number of facets: 240
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_R1_M.stl
```

```
Header:
```

```
Number of facets: 456
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_R1_S.stl
```

```
Header:
```

```
Number of facets: 448
```

```
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_R2.FIX1.stl
```

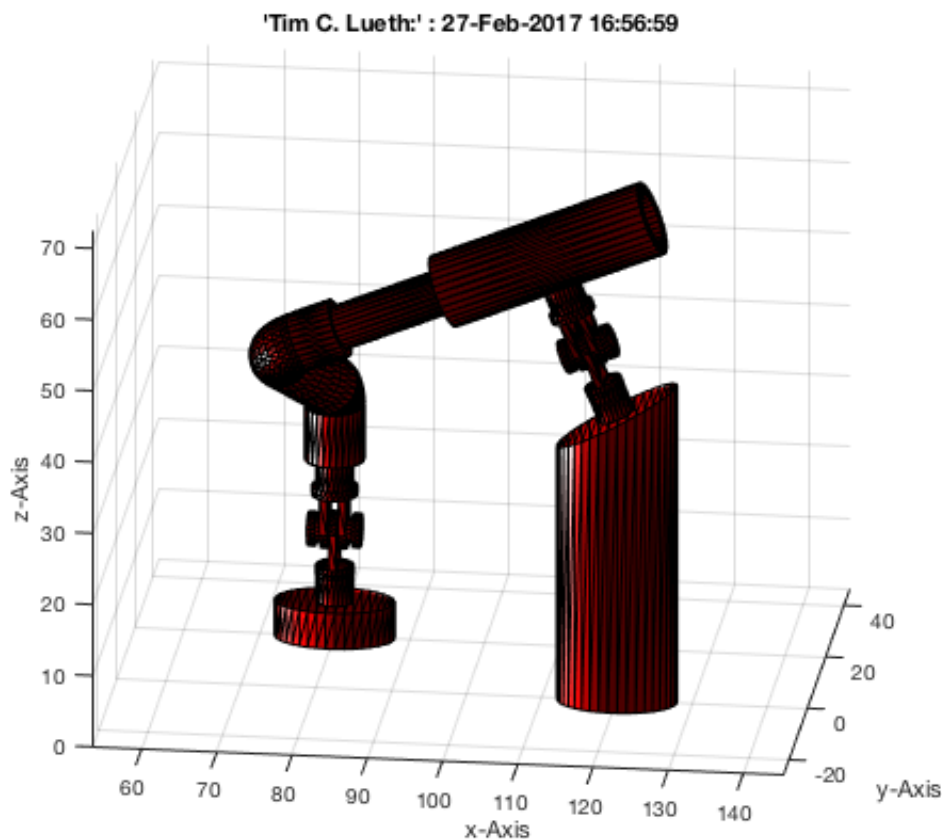
```
Header:
```

```
Number of facets: 240
```

```

0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_R2_M.stl
Header:
Number of facets: 456
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_R2_S.stl
Header:
Number of facets: 448
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_23/sbm_temp_SG.stl
Header:
Number of facets: 1214
0..
CREATED A SOLID GEOMETRY OF THE FULL SIMULATION-MODEL 'SG_LIB_EXP_23' AT TIME: 0.10 SECONDS
=====
=====

```



Write the STL file on disk for 3D printing

```
SGwriteSTL(SG);
```

Final Remarks

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!

```
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 16:57:02 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
instr_control_toolbox
matlab
robotics_system_toolbox
simmechanics
simscape
simulink
=====
=====
```

Published with MATLAB® R2016b

Exercise 24: Automatic Creation of a Joint Limitations

2016-12-25: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Open a system and create several fixed nodes and attach revolute joints
- 3. Create a cylindric joint from two solids an attach it to revolute joint
- 4. Attach two frame sensor to record the movement of the falling cylinder
- 5. Show the Simulation
- 6. Install additional block funktion for joint restrictions
- 7. Create a stopp joint and copy all connections of an existing joint
- 8. Create a stopp joint and replace an existing joint
- 9. Final Remarks

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Leightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations

2. Open a system and create several fixed nodes and attach revolute joints

function VLFL_EXP23

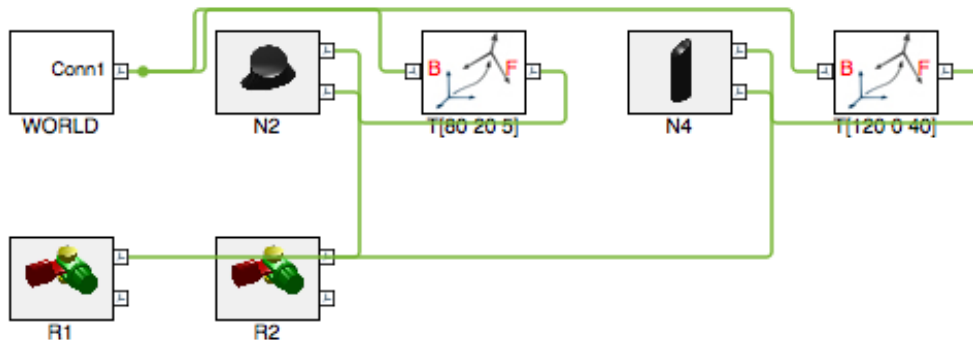
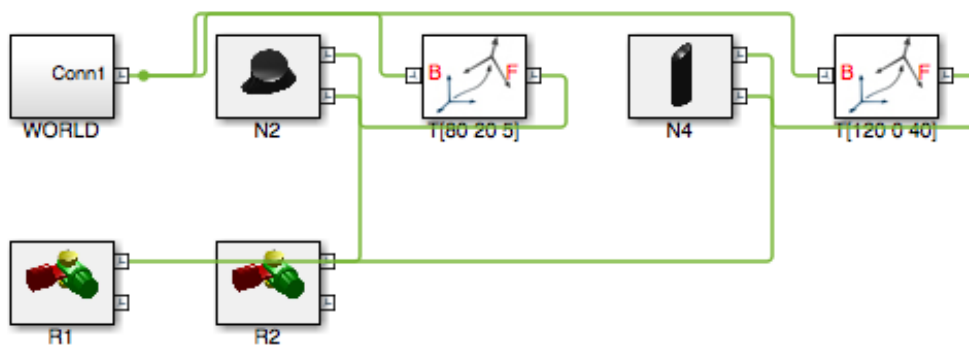
```

smbsys='SG_LIB_EXP_24';
smbNewSystem (smbsys);

smbCreateSGNode ([80 20 5], 'N2', '', rot(0,0,pi/3));
smbCreateSGNode ([120 0 40], 'N4', '', rot(0,-pi/8,0));
A=SGmodelJoint('R',pi/2);
smbCreateSGJoint('R','R1', A, 'N4.F');
smbCreateSGJoint('R','R2',A, 'N2.F');
smbDrawNow;

```

Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/'



3. Create a cylindric joint from two solids and attach it to revolute joint

```

Ro=5;
Ri=3;
slot=0.3;

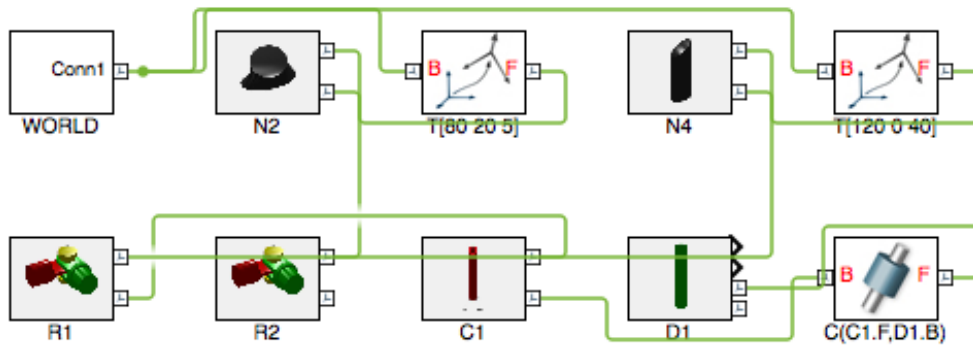
C1=SGofCPLz([PLcircle(Ro);NaN NaN;PLcircle(Ri+slot)],30);
% C1=SGTset(C1,'B',TofSG(C1,'bottom','roty',pi));
C1=SGTset(C1,'B',TofSG(C1,'incenter','right',-1,'roty',pi/2));
C1=SGTset(C1,'F',TofSG(C1,'bottom'));
smbCreateSG(C1,'C1','r','R1_M');
D1=SGofCPLz(PLcircle(3),30);

```

```
D1=SGTset(D1,'B',TofSG(D1,'incenter'));
D1=SGTset(D1,'F',TofSG(D1,'top'));
```

4. Attach two frame sensor to record the movement of the falling cylinder

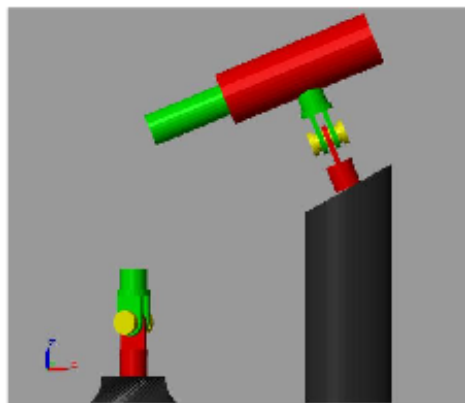
```
smbCreateSG(D1,'D1','g');
smbCreateConnection('C1.F','D1.B','C');
smbAddFrameSensor('R2_M.F');
smbAddFrameSensor('D1.F');
smbDrawNow;
```



5. Show the Simulation

```
simOut=smbSimulate(0.1);
smbVideoSimulation(4);
```

.....



6. Install additional block funktion for joint restrictions

```
smbPSLibInstall
```



```

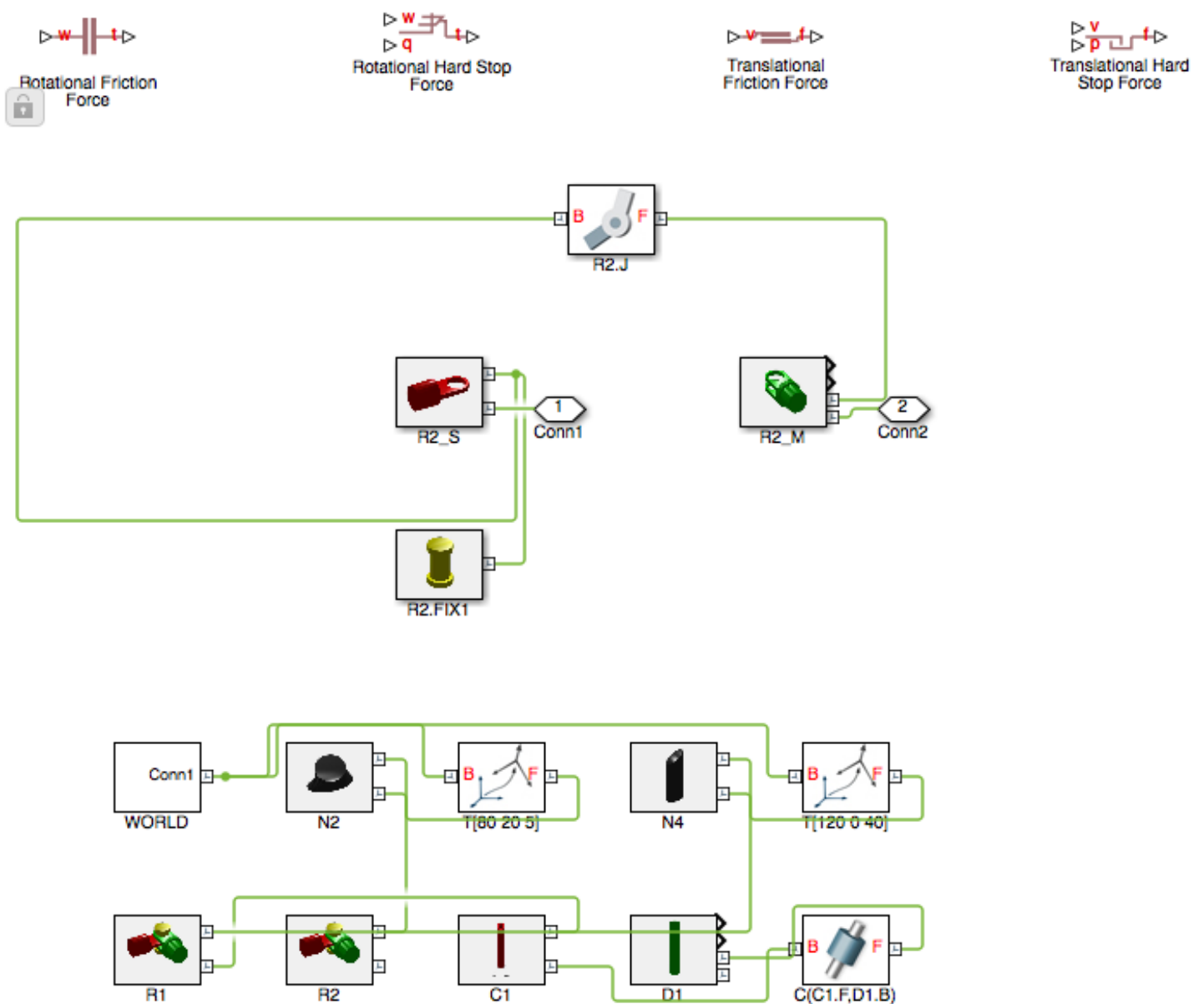
open_system(smbPSBlockname);
open_system(smbsys, 'tab');
open_system(smbWhich('R2'), 'tab');smbDrawNow;

```

```

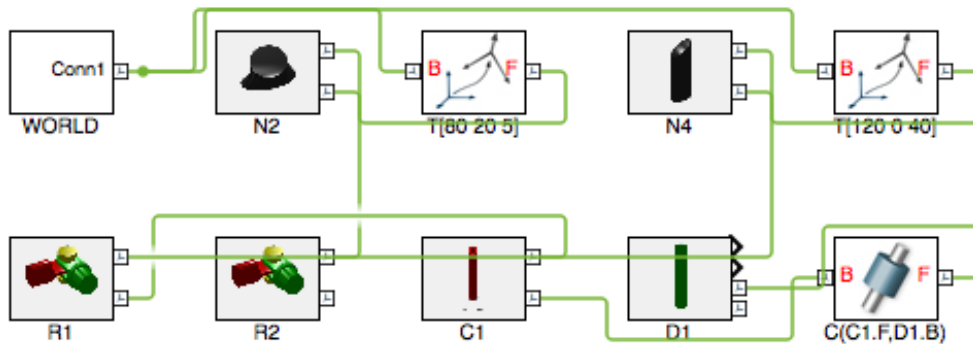
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_friction_rot.ssc
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_friction_rot.svg
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_hardstop_rot.ssc
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_hardstop_rot.svg
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_friction_trans.ssc
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_friction_trans.svg
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_hardstop_trans.ssc
Create /Users/timlueth/Desktop/tmp_SG_LIB_EXP_24/+mechPS_Tim_Lueth/PS_force_hardstop_trans.svg
Generating Simulink library 'mechPS_Tim_Lueth_lib' in the current directory '/Users/timlueth/D
esktop/tmp_SG_LIB_EXP_24' ...

```



7. Create a stopp joint and copy all connections of an existing joint

```
smbCreateStoppJointR ('R2stop.J',[-pi/2 +pi/2]);
smbCopyConnections ('R2.J','R2stop.J');
smbDrawNow;
```



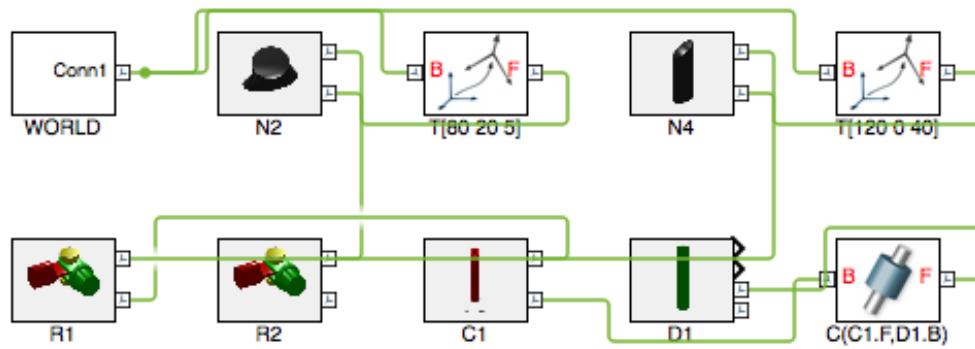
```
smbVideoSimulation(4);
```

.....

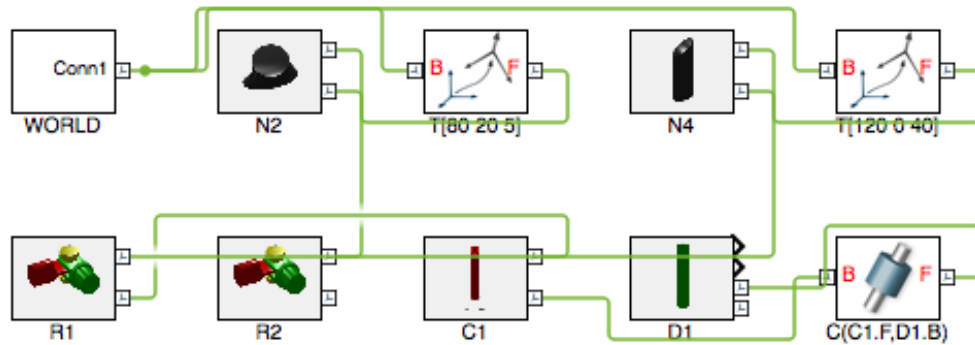


8. Create a stopp joint and replace an existing joint

```
delete_block(smbWhich('R2stop.J'));
smbDeleteUnconnectedLines;
smbDrawNow;
```



```
smbCreateStopJointR ('R2new.J',[-pi/2 +pi/2]);
smbCopyConnections ('R2.J','R2new.J','replace');
smbDrawNow;
```



9. Final Remarks

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 16:58:28 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 instr_control_toolbox
 matlab
 robotics_system_toolbox
 simmechanics
 Simscape
 Simulink
 =====
 =====

.....

Published with MATLAB® R2016b

Exercise 25: Automatic Creation of Video Titels, Endtitels and Textpages

2017-01-01: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- [1. Summary of the already explained aspects of the VLFL-Toolbox](#)
- [2. Motivation for this tutorial](#)
- [3. Create a video clip for a text title](#)
- [4. Create an end title video clip](#)
- [5. Create a text page title for a video](#)
- [6. Now create a SimMultiBody fourbar linkage](#)
- [7. Create a video simulation and creates header and titles](#)
- [Now we create four small video clips in the desktopdir](#)
- [8. Create Video Headers and Explanation](#)
- [Final Remarks](#)

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations
- Example 25: Automatic Creation of Video Titels, Endtitels and Textpages

2. Motivation for this tutorial

The creation of videos of the simulated multi body system, created with the SimMultiBody (2nd Generation) is essential for documentation of the results. Nevertheless, without video titles and end titles and some pages with text description, the videos cannot fulfill their purpose. Therefor it is essential also, to create text for explaining content and make comments on authors and creation date. Therefor we will show

some examples:

- `imageVideoFrames(xy,ptime)`; cuts images out of a video a defined positions
- `imageVideoTitle(xy,STitles,cols,ptime)`, creates a 2 second title page video
- `imageVideoEndtitle(xy,ETitles,cols)`, creates a 1 second end title page video
- `imageVideoTextPage(xy,ETitles,cols)`, creates a 2 second text page video
- `imageVideoWrite (v,l,t)`, creates a video by repeating an image t frames
- `videoCopyFrames(v,vr)`, copies a video content into another video (no sound)
- `videoCopyCutMovies (WName,RName,style)`, complex cutting function

3. Create a video clip for a text title

It is possible to start by defining the size of the video titles. If the function is called without an output parameter, automatically a video clip is created with this image

```
I=imageVideoTitle([640 480],{'Video Titel','$date'});
imshow(I.cdata);
```

VIDEO TITEL

2017-FEB-27

It is also possible to name an existing video or to select it during function execution to define the size from an existing video. In addition, the background color and text color can be defined (in future also font name and font size), and furthermore times for creating a snapshot that becomes part of the title page. `I=imageVideoTitle("",{'Video Titel','SubTitle','Author','$date'},['w' 'r'],[0 1 3]);`

```
close all; figure; imshow(I.cdata);
```

VIDEO TITEL

2017-FEB-27

Calling the function without an output parameter creates a small video clip in the desktopdir. This can later be used to add the original video including text pages, title page and end title page to a video clip that has sound. Matlab in 2016b does not support sound videos on MAC, only on PC platforms. `imageVideoTitle('', 'Video Titel', 'SubTitle', 'Author', '$date'), ['w' 'r'], [0 1 3]);`

4. Create an end title video clip

In similar manner, it is possible to define end titles. The creation date is added automatically. Please use the title page if you want to clarify the result was achieved earlier.

```
I=imageVideoEndtitle([640 480], {'Technical University of Munich', '', 'www.tum.de'});  
imshow(I.cdata);  
imageVideoEndtitle([640 480], {'Technical University of Munich', '', 'www.tum.de'}); % write video clip
```

Creating a new video file: `'/Users/timlueth/Desktop/imageVideoEndtitle.avi'`

TECHNICAL UNIVERSITY OF MUNICH

WWW.TUM.DE

© 2017-FEBRUARY-27

5. Create a text page title for a video

There are several reasons for adding text pages including latex equations too. This is also possible by a toolbox function. Again, the call without an output parameter would create a video clip.

```
I=imageVideoTextPage([640 480],...  
['It is also possible to name an existing video or to select it during function '...  
'execution to define the size from an existing video. In addition, the '...  
'background color and text color can be defined (in future also font name and '...  
'font size), and furthermore times for creating a snapshot that becomes part of '...  
'the title page.', char(13), '©']);  
imshow(I.cdata);
```

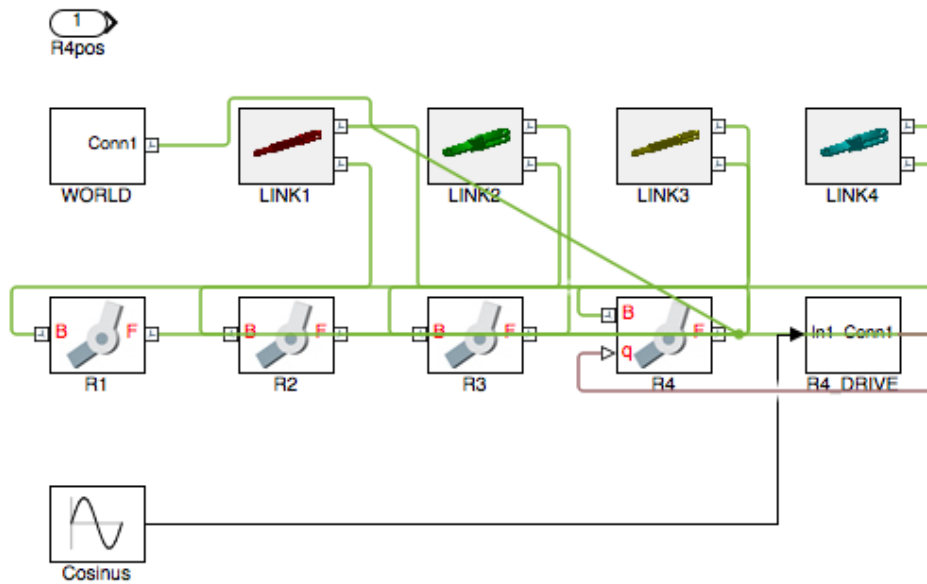
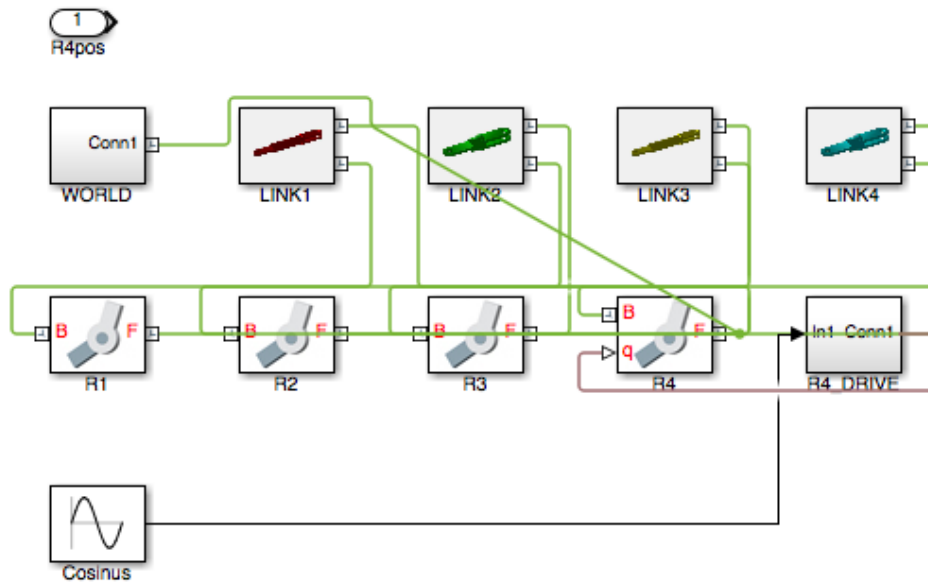

It is also possible to name an existing video or to select it during function execution to define the size from an existing video. In addition, the background color and text color can be defined (in future also font name and font size), and furthermore times for creating a snapshot that becomes part of the title page.

©

6. Now create a SimMultiBody fourbar linkage

```
smbNewSystem ('SG_LIB_EXP_25');           % Creates the mechsims diagramm
SG1=SGmodelLink(80,'',1,2);               % Creates a long rod with flange
SG2=SGmodelLink(50,'',1,2);               % Creates a short rod with flange
smbCreateSG (SG1,'LINK1','r');             % Add long rod as LINK1
smbCreateSG (SG2,'LINK2','g');             % Add short rod as LINK2
smbCreateSG (SG1,'LINK3','y');             % Add long rod as LINK3
smbCreateSG (SG2,'LINK4','c');             % Add short rod as LINK4
smbCreateJoint ('R','R1','LINK1.F','LINK2.B'); % Add a RR Joint
smbCreateJoint ('R','R2','LINK2.F','LINK3.B'); % Add a RR Joint
smbCreateJoint ('R','R3','LINK3.F','LINK4.B'); % Add a RR Joint
smbCreateJoint ('R','R4','LINK4.F','LINK1.B'); % Add a RR Joint
smbCreateConnection('WORLD.ORIGIN','LINK1.B'); % Connect Linkage to World Frame
smbCreateDrive ('R4');                     % Convert Joint R4 into a Drive
smbCreateSineWave ('Cosinus','R4_DRIVE/1'); % Connect a Sinus Generator to Drive
smbDrawNow;
```

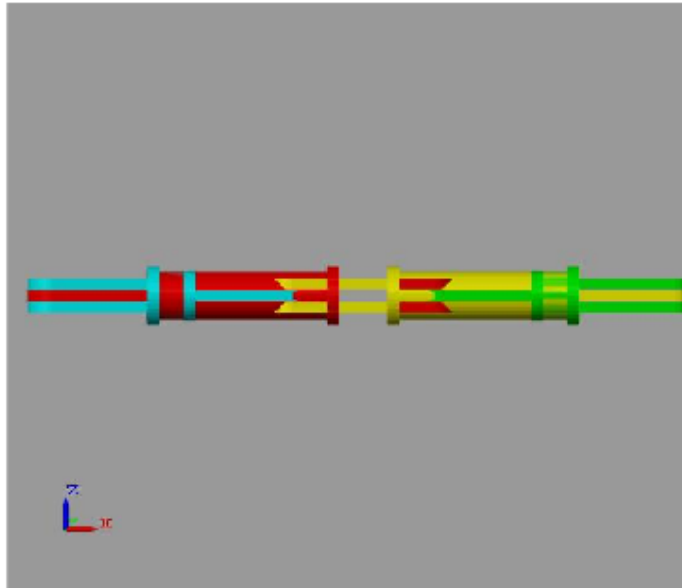
Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_25/'



7. Create a video simulation and creates header and titles

```
[I,FN]=smbVideoSimulation (10);
```

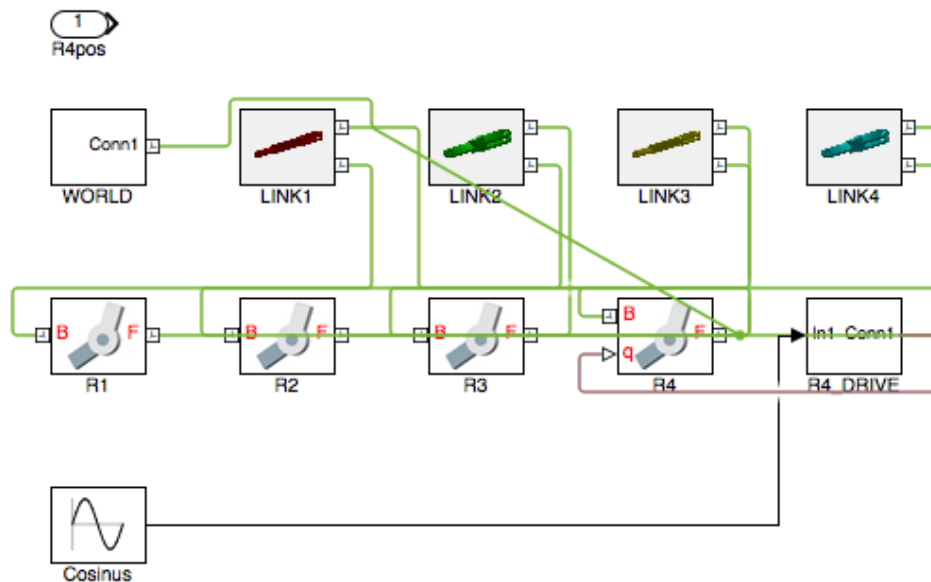
.....



Now we create four small video clips in the desktopdir

```
imageVideoTitle(FN,{ 'SG-Lib Tutorial #25','Creating Videos Titles for SimMultiBody Videos','Tim C. Lueth',
'$date'},'',[2 5]);
imageVideoEndtitle(FN,{ 'Technical University of Munich','', 'www.tum.de' });
imageVideoTextPage(FN,{ ...
['This video was created by using Mathwork''s SimMultiBody environment using the '...
'SG-Library of Tim C. Lueth. The fourbar linkage in the simulation has the '...
'following dimensions:©', char(13), ' '...
'L1= ', sprintf('%0.2f mm',80), char(13), ' '...
'L2= ', sprintf('%0.2f mm',50),char(13), ' '...
'L3= ', sprintf('%0.2f mm',80),char(13), ' '...
'L4= ', sprintf('%0.2f mm',50),char(13), ' ']]);
imageVideoImagePage(FN,smbDrawNow);
```

```
Creating a new video file: '/Users/timlueth/Desktop/imageVideoTitle.avi'
Creating a new video file: '/Users/timlueth/Desktop/imageVideoEndtitle.avi'
Creating a new video file: '/Users/timlueth/Desktop/imageVideoTextPage.avi'
Creating a new video file: '/Users/timlueth/Desktop/imageVideoImagePage.avi'
```



8. Create Video Headers and Explanation

```
[I,FN]=smbVideoSimulation (10,'Video SG_LIB_EXP_25');
IT=imageVideoTitle(FN,{'SG-Lib Tutorial #25','Creating Videos Titles for SimMultiBody Videos','Tim C. Lueth','$date'},'',[2 5]);
IE=imageVideoEndtitle(FN,{'Technical University of Munich','','www.tum.de'});
ID=imageVideoTextPage(FN,{...
['This video was programmatically created by using Mathwork's SimMultiBody environment using the '...
'SG-Library of Tim C. Lueth. The fourbar linkage in the simulation has the '...
'following dimensions:©', char(13), ' '...
'L1= ', sprintf('%0.2f mm',80), char(13), ' '...
'L2= ', sprintf('%0.2f mm',50),char(13), ' '...
'L3= ', sprintf('%0.2f mm',80),char(13), ' '...
'L4= ', sprintf('%0.2f mm',50),char(13), ' '}}];
IM=imageVideoImagePage(FN,smbDrawNow);
videoWriteClipMovie(smbFilename('Video comp SG_LIB_EXP_25.avi'),IT,2,ID,5,IM,5,smbFilename('Video SG_LIB_EXP_25.avi'),IE,1);
```

```
.....Creating a new video file (NO SOUND/2016b): '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_25/
Video comp SG_LIB_EXP_25.avi'
5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%
```

Final Remarks

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 17:00:06 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
image_toolbox
instr_control_toolbox
```

```
matlab
robotics_system_toolbox
simmechanics
simscape
simulink
```

=====

Published with MATLAB® R2016b

Exercise 26: Create Mechanisms using Universal Planar Links

2017-01-20: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- [Summary of the already explained aspects of the VLFL-Toolbox](#)
- [Motivation for this tutorial](#)
- [1. Create a SimMultiBody System for a Fourbar-Linkage](#)
- [2. Now Create a Specific Configuration \(Pose\) and Write a STL-Files](#)
- [3. Now Analyze the Stucture and Group the Solids to Parts](#)
- [4. Now Arrange all Parts for Printing as Separated Solids](#)
- [5. Now Write the Separated Parts into Different STL Files](#)
- [6. Create a Video of the Linkage Simulation](#)
- [Final Remarks](#)

Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations
- Example 25: Automatic Creation of Video Titels, Endtitels and Textpages
- Example 26: Create Mechanisms using Universal Planar Links
- Example 27: Fourbar-Linkage: 2 Pose Syntheses and Linkage Export for 3D Printing
- Example 28: Fourbar-Linkage: 3 Pose Syntheses and Linkage Export for 3D Printing

```
% function VLFL_EXP26
```

Motivation for this tutorial

Ein Mechanismus besteht aus zwei Grundelementen: a) Gelenke und b) Glieder, die diese Gelenke verbinden. Bei der "automatischen Konstruktion" von Mechanismen ist es hilfreich sich auf eine der beiden Elemente zu beschränken. Dies wurde in den vorherigen Tutorials bereits genutzt. In diesem Tutorial wird nun ein neues Verfahren vorgestellt. Es sind "Universelle Planare Glieder". Diese bestehen aus einem einfachen Gelenkglied sowie zwei Hälften eines rotatorischen Gelenks. Werden zwei Glieder an einem der Endpunkte miteinander verbunden, dann verbinden sich die beide Hälften aufgrund einer räumlichen Überlappung zu einer Drehachse und es wird automatisch ein Drehgelenk gebildet. Wird ein Glieder nicht verbunden, dann bleibt dort dennoch eine Drehachse erhalten. Jede Drehachse kann mit "Knöpfen oder Antriebsmechanismen relativ zum Gelenk verbunden werden und in ihrem Winkelbereich eingeschränkt werden. Die Glieder können in festen Ebenen verbunden werden. Dies erlaubt sowohl eine kollisionsfrei Bewegung unter Berücksichtigung der Glieder als auch die Berücksichtigung von Antriebselementen sofern diese in Vielfachen der Gliederhöhe ausgelegt werden. Dieses Tutorial zeigt nun die Verwendung der Universelle Planaren Glieder an einem einfachen Beispiel.

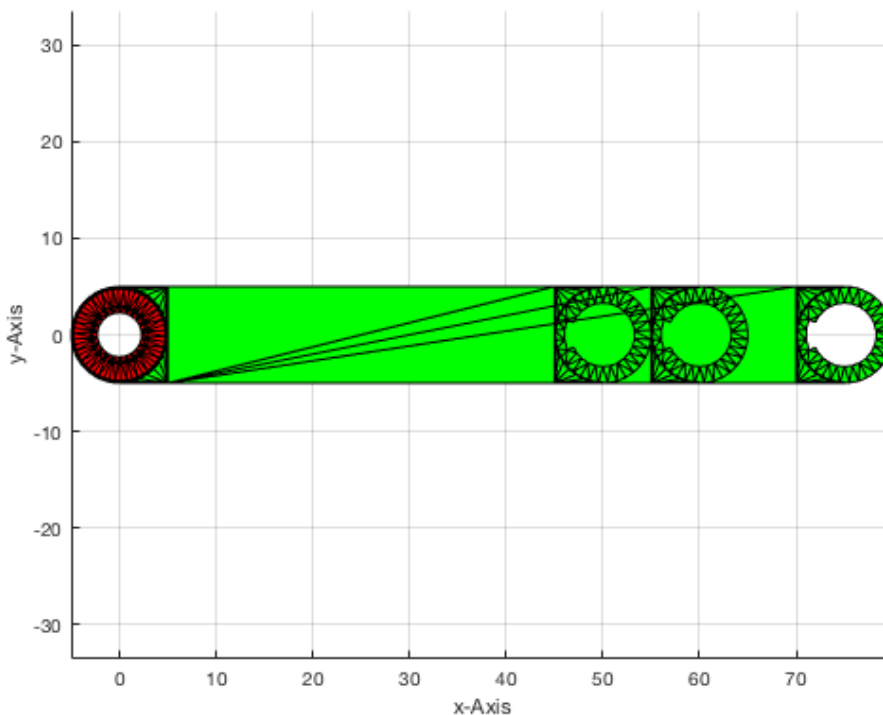
1. Create a SimMultiBody System for a Fourbar-Linkage

```
smbNewSystem ('SG_LIB_EXP_26')    % Creates the mechsanim diagramm

L1=75;
L2=60;
L3=50;
L4=50;

A=SGmodelLink2(L1,0,1,'BL,FL'); A.col='r';
B=SGmodelLink2(L2,0,1);         B.col='g';
C=SGmodelLink2(L3,0,-1);        C.col='y';
D=SGmodelLink2(L4,0,-1);        D.col='m';
```

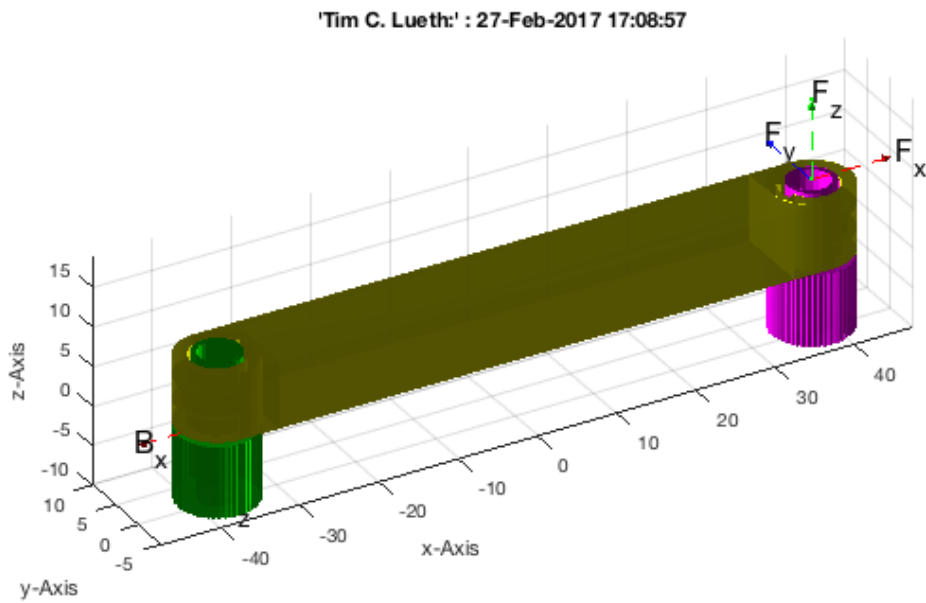
Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_26/'



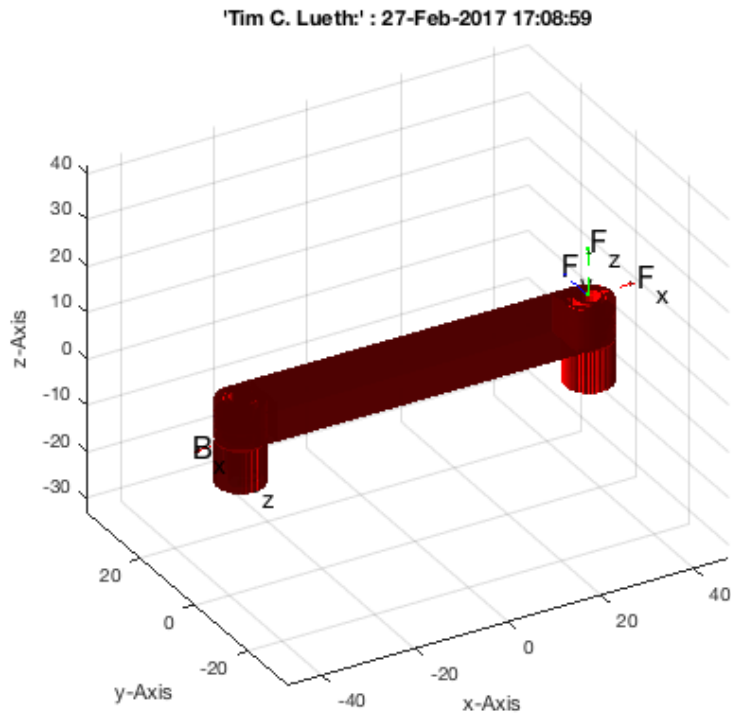
Show the components of the link

```
SGanalyzeGroupParts(A); SGTframeplot(A);
```

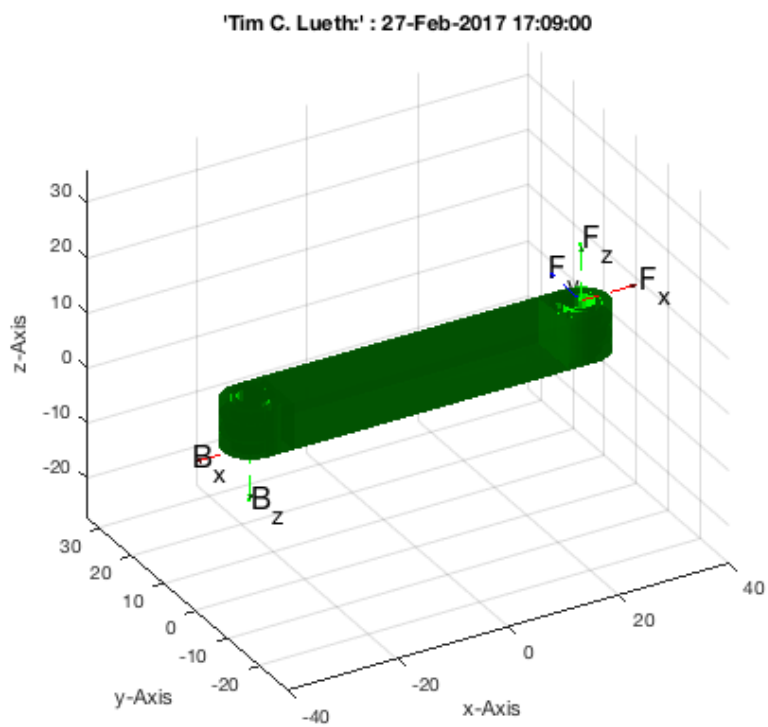
5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 90% 95% 100%
SGanalyzeGroupParts: 3 separated parts found.



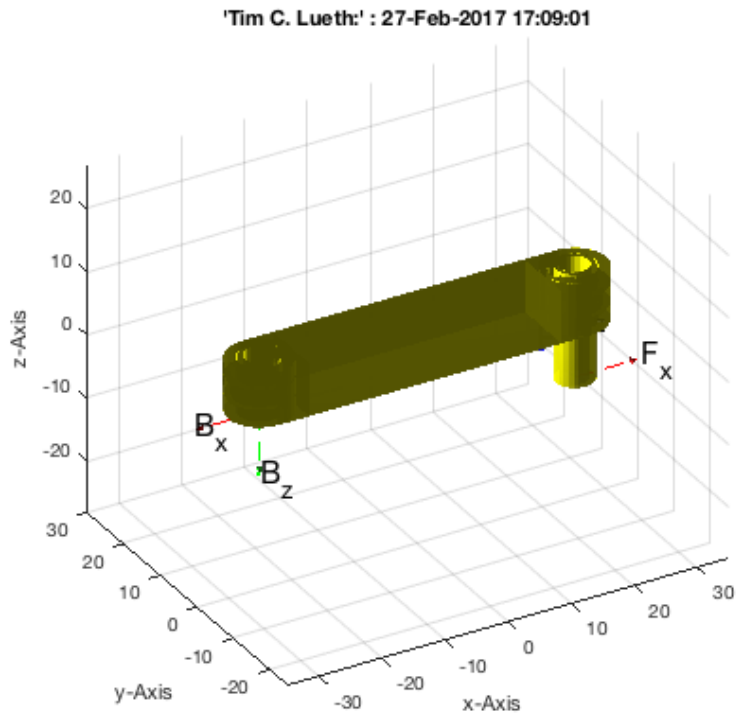
```
SGfigure; SGTplot(A); view(-30,30);
```

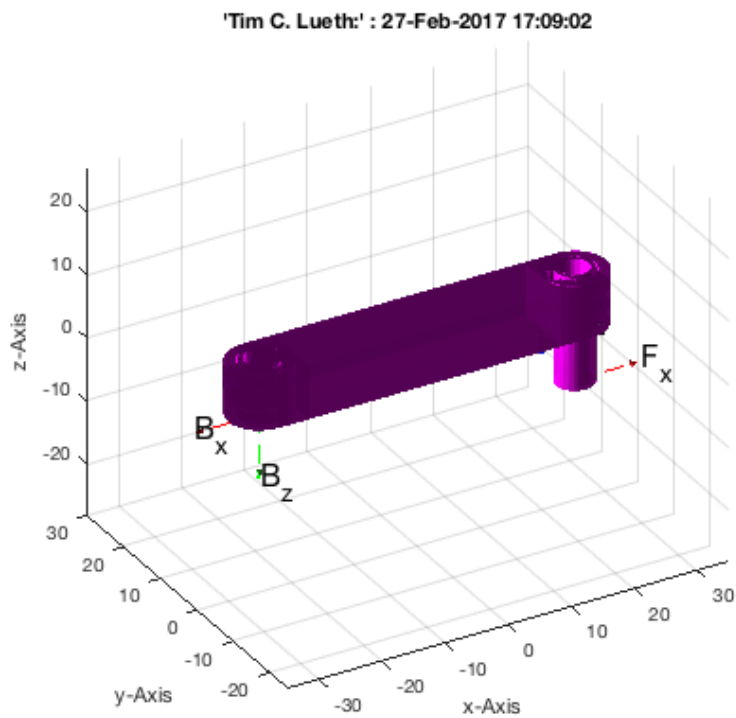
```
SGfigure; SGTplot(B); view(-30,30);
```



```
SGfigure; SGTplot(C); view(-30,30);
```



```
SGfigure; SGTplot(D); view(-30,30);
```



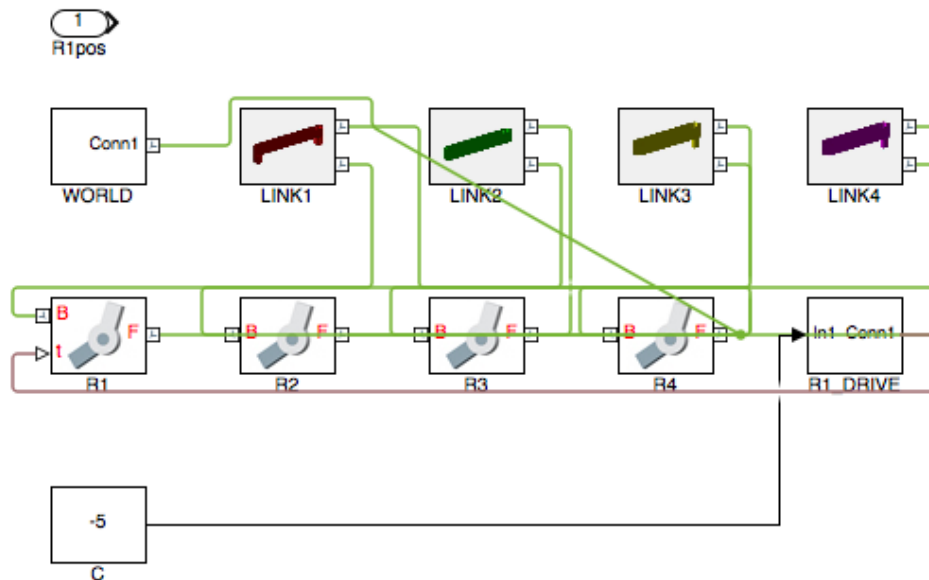
```
smbCreateSG (A,'LINK1','r');           % Add long rod as LINK1
smbCreateSG (B,'LINK2','g');           % Add short rod as LINK2
smbCreateSG (C,'LINK3','y');           % Add long rod as LINK3
smbCreateSG (D,'LINK4','m');           % Add short rod as LINK4
smbCreateJoint ('R','R1','LINK1.F','LINK2.B'); % Add a RR Joint
```

```

smbCreateJoint ('R','R2','LINK2.F','LINK3.B'); % Add a RR Joint
smbCreateJoint ('R','R3','LINK3.F','LINK4.B'); % Add a RR Joint
smbCreateJoint ('R','R4','LINK4.F','LINK1.B'); % Add a RR Joint

smbCreateConnection('WORLD.ORIGIN','LINK1.B'); % Connect Linkage to World Frame
smbCreateDrive ('R1');
smbSetJointInputTorque('R1');
smbCreateBlockConst('C','R1_DRIVE/1',-5)
ID=smbDrawNow;
smbSimulate(4);

```



2. Now Create a Specific Configuration (Pose) and Write a STL-Files

```

SG=smbFullModelSimulation(5);
% SG=SGmagnifyVL(SG,'',[100 100 100]);
SGwriteSTL(SG,smbFilename('Universal Planar Link'));

```

CREATING A FULL SOLID-MOVEMENT SIMULATION-MODEL 'SG_LIB_EXP_26' THAT RUNS At LEAST 5.00 SECONDS

=====

Adding frame sensors for all solids of the model

Add frame sensors for 'LINK1.SG'

Add frame sensors for 'LINK2.SG'

Add frame sensors for 'LINK3.SG'

Add frame sensors for 'LINK4.SG'

=====

Simulink.SimulationOutput:

```

simlog: [1x1 simscape.logging.Node]
sout: [1x1 Simulink.SimulationData.Dataset]
tout: [1097x1 double]
xout: [1x1 Simulink.SimulationData.Dataset]

```

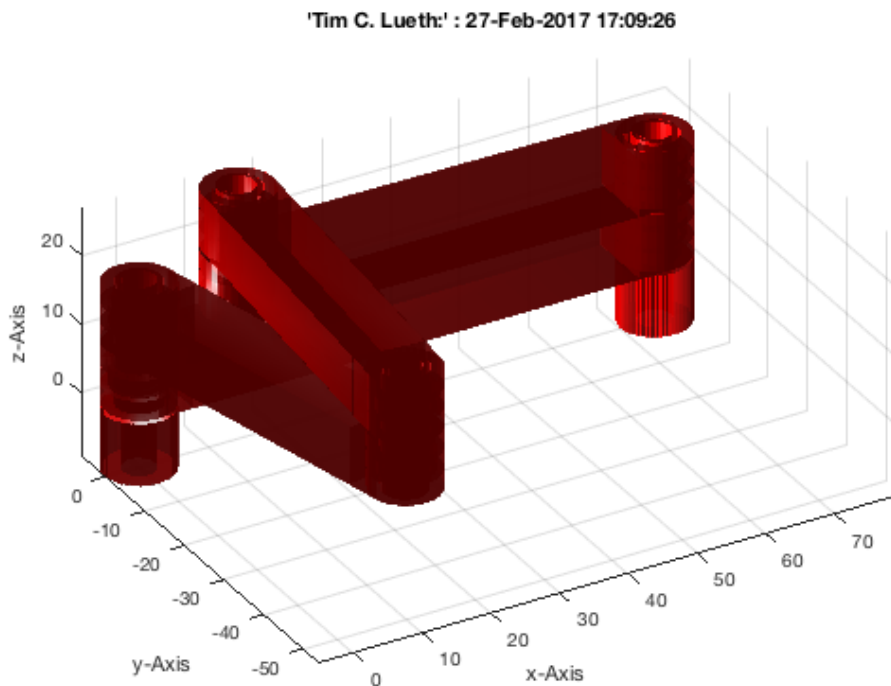
Use 'get' to access a variable by name.

Use 'getSimulationMetadata' to access metadata about the simulation.

```

LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_26/sbm_temp_LINK1.stl
Header:
Number of facets: 3756
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_26/sbm_temp_LINK2.stl
Header:
Number of facets: 2404
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_26/sbm_temp_LINK3.stl
Header:
Number of facets: 2584
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_26/sbm_temp_LINK4.stl
Header:
Number of facets: 2584
0..
CREATED A SOLID GEOMETRY OF THE FULL SIMULATION-MODEL 'SG_LIB_EXP_26' AT TIME: 5.00 SECONDS
=====
1000..2000..3000..4000..5000..6000..7000..8000..9000..10000..11000..

```

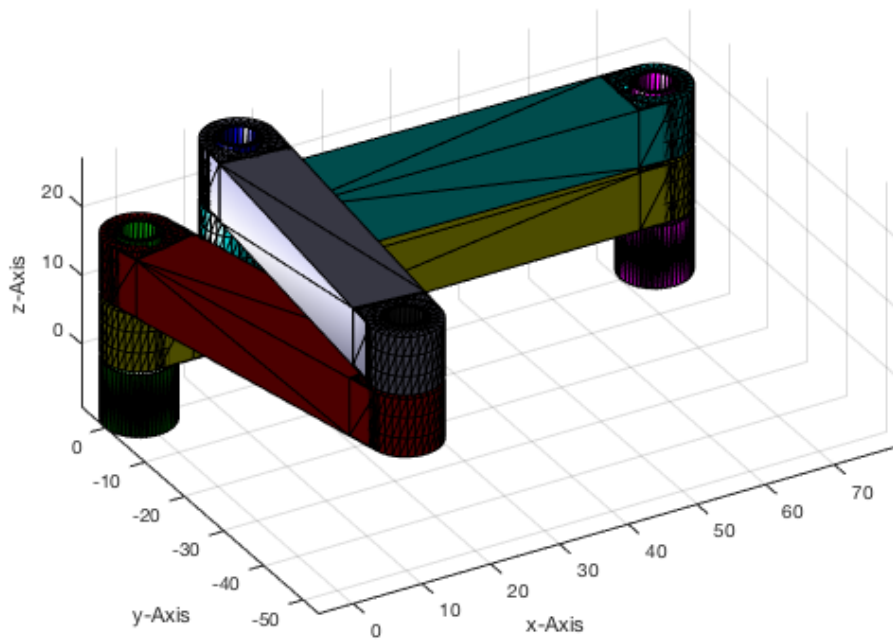


3. Now Analyze the Structure and Group the Solids to Parts

```
SGfigure; view(-30,30); SGplot(SG,'m'); SG=SGanalyzeGroupParts(SG); SGplot(SG);
```

5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%

'Tim C. Lueth': 27-Feb-2017 17:09:28

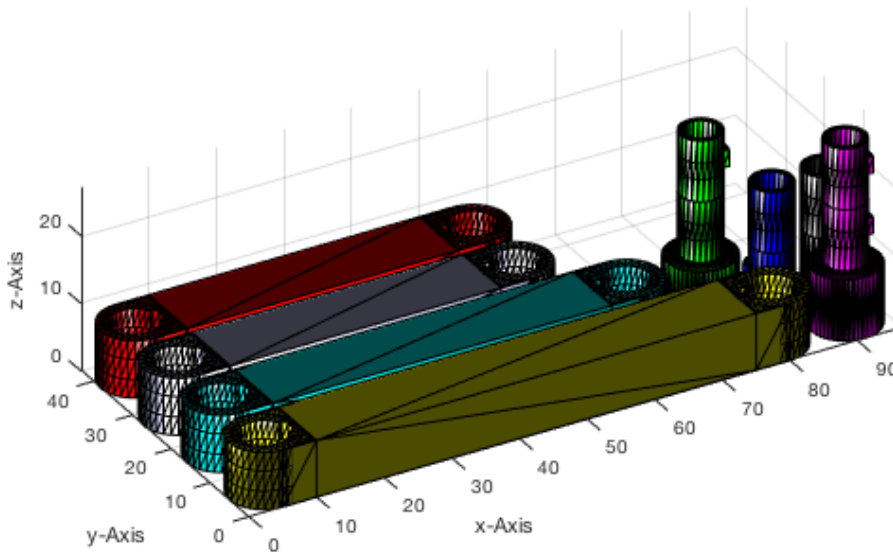


4. Now Arrange all Parts for Printing as Separated Solids

```
[~,SG]=SGpacking(SG); SGfigure; view(-30,30); SGplot(SG);
```

Packing 8 objects (h=61):

'Tim C. Lueth': 27-Feb-2017 17:10:21



5. Now Write the Separated Parts into Different STL Files

```
SGwriteSeparatedSTL(SG);
```

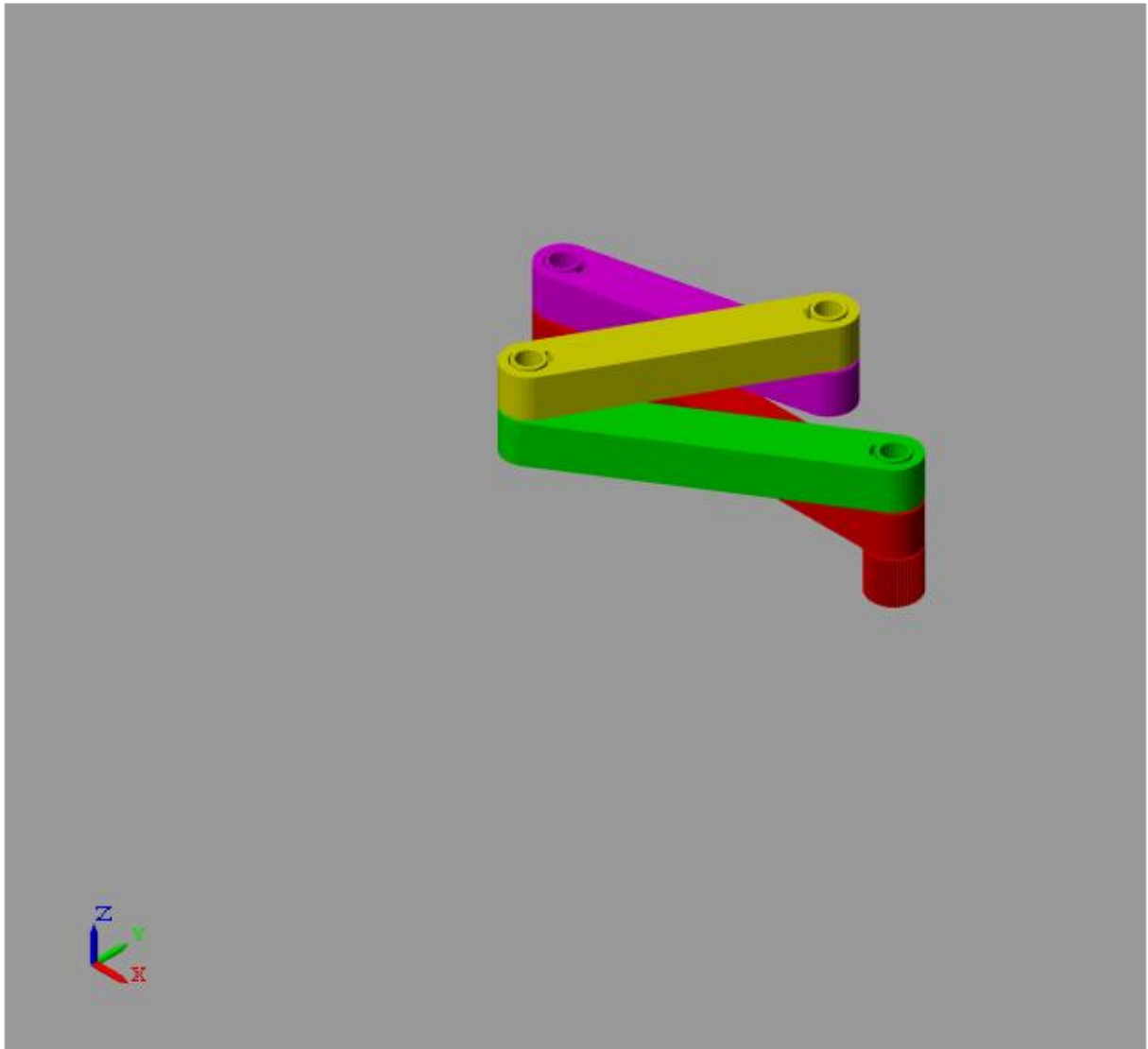
```
SGwriteSeparatedSTL: Writing 8 STL files in /Users/timlueth/Desktop/EXP-2017-02-27/
```

6. Create a Video of the Linkage Simulation

```
[I1,FN]=smbVideoSimulation (4);    % Simulate for 1 second
IT=imageVideoTitle(FN,{'SG-Lib Tutorial #26','Universal Planar Links','Tim C. Lueth','$date'},'',[0.1 0.
2 0.3]);
IE=imageVideoEndtitle(FN);
videoWriteClipMovie(smbFilename('Universal Planar Links SimMultiBody.avi'),IT,2,ID,1,FN,IE,1);
imshow(I1);
```

```
.....Creating a new video file (NO SOUND/2016b): '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_26/Universal
Planar Links SimMultiBody.avi'
```

```
5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%
```



Final Remarks

```
close all
VLFLlicense
```

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!

Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !

Please contact Tim Lueth, Professor at TU Munich, Germany!

WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!

Executed 27-Feb-2017 17:10:44 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64

===== Used Matlab products: =====

```
image_toolbox
instr_control_toolbox
map_toolbox
matlab
robotics_system_toolbox
simmechanics
simscape
simulink
```

Published with MATLAB® R2016b

Exercise 27: Fourbar-Linkage: 2 Pose Syntheses and Linkage Export for 3D Printing

2017-01-05: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- 1. Summary of the already explained aspects of the VLFL-Toolbox
- 2. Motivation for this tutorial
- 3. Show a Two Pose Problem
- 4. Find a General Solutions for the Two Pose Problem
- 5. Find a special Solution for the 4Bar-Linkage wit A0 and B0 on same level
- 6. Create a SimMultiyBody System for the calculated solution
- 7. Show the Video of the Simulation
- 8. Now Create the Solid Geoemtry at time 0.78 seconds
- Final Remarks

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Leightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations
- Example 25: Automatic Creation of Video Titels, Endtitels and Textpages
- Example 26: Create Mechanisms using Universal Planar Links

■ Example 27: Fourbar-Linkage: 2 Pose Syntheses and Linkage Export for 3D Printing

```
function VLFL_EXP27
```

2. Motivation for this tutorial

```
smbNewSystem ('SG_LIB_EXP_27'); % Creates the mechainsim diagramm
```

Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/'



3. Show a Two Pose Problem

Poses are described by the start point and end point of a link. The first point of the coupling defines a point, the second point also the direction. In the simplest case, two poses for the design of a four-bar are given.

```
d=[0 0];
C1=[0 0];
D1=[500 0];
C2=[600 300];
D2=[1000 0];

SGfigure;
PLplot([C1;D1], 'r-', 2);
PLplot([C2;D2], 'r-', 2);
```



4. Find a General Solutions for the Two Pose Problem

As a solution, there are two straight lines on each of which the frame point A0 or the frame point B0 may be located. The intersection point of these two lines is the pole point P12. In a special case, both frame points are located at this point and a triangle is formed from the four-bar. In any case, the rack points can be displaced such that other secondary conditions can also be fulfilled.

```
imageFigureMovie('record');
synth4Bar2Pose(C1,D1,C2,D2,d);
[~,FN2]=imageFigureMovie('write',smbFilename('synth4Bar2Pose.avi'));
```

ans =

250 0 0

ans =

800 150 0

ans =

250 0 0

ans =

800 150 0

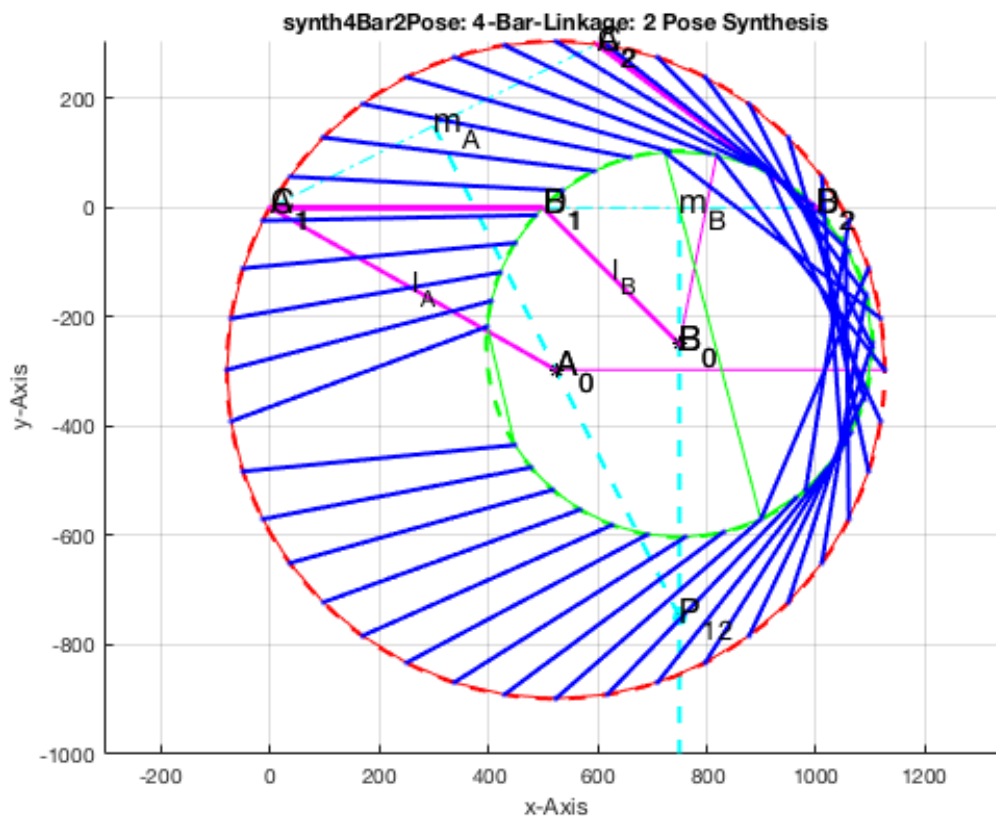
ans =

261.8034 -148.6068 0

ans =

625 -125 0

imageFigureSaveMovie: Writing figure movie with 42 frames in file: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/synth4Bar2Pose.avi.



5. Find a special Solution for the 4Bar-Linkage with A0 and B0 on same level

If A0 and B0 are to lie on the same plane, $B_0 + k \cdot (P_{12} - B_0)$ must correspond to the Y coordinate of the Y coordinate of A0 in the y coordinate

```
[A0,B0,A1,B1,P12]=synth4Bar2Pose(C1,D1,C2,D2,d);
db=P12-B0
k=(A0(2)-B0(2))/db(2)
B0=B0+k*db
A0
L1=norm(B0-A0)
L2=norm(B1-B0)
L3=norm(A1-B1)
L4=norm(A0-A1)
```

```
db =
    0.0000 -500.0000
```

```
k =
    0.0944
```

```
B0 =
    750.0000 -297.2136
```

```
A0 =
    523.6068 -297.2136
```

```
L1 =
    226.3932
```

```
L2 =
    388.3760
```

```
L3 =
    500
```

```
L4 =
    602.0797
```

6. Create a SimMultiyBody System for the calculated solution

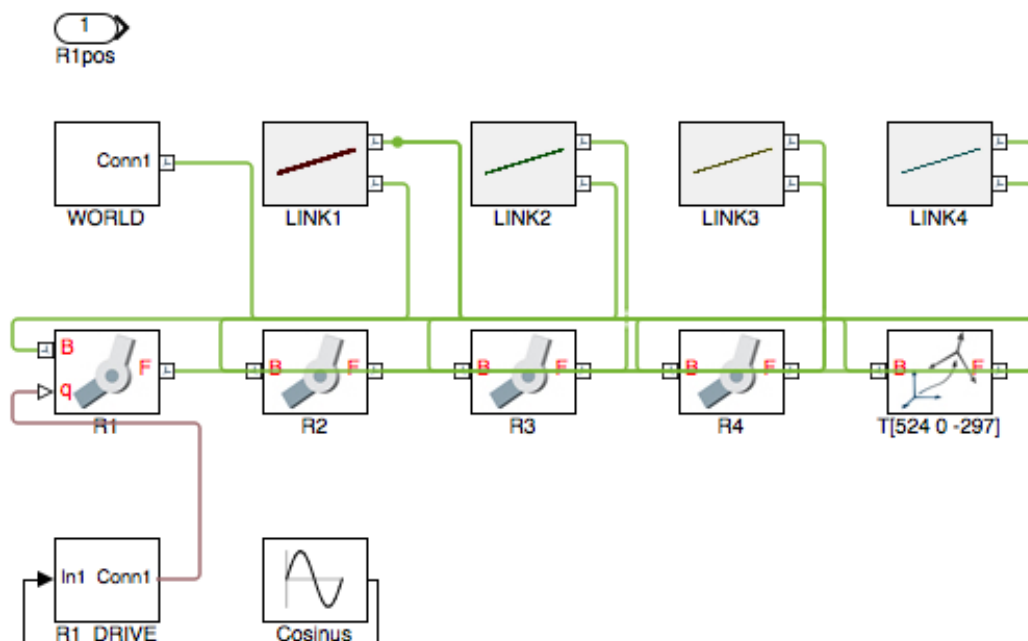
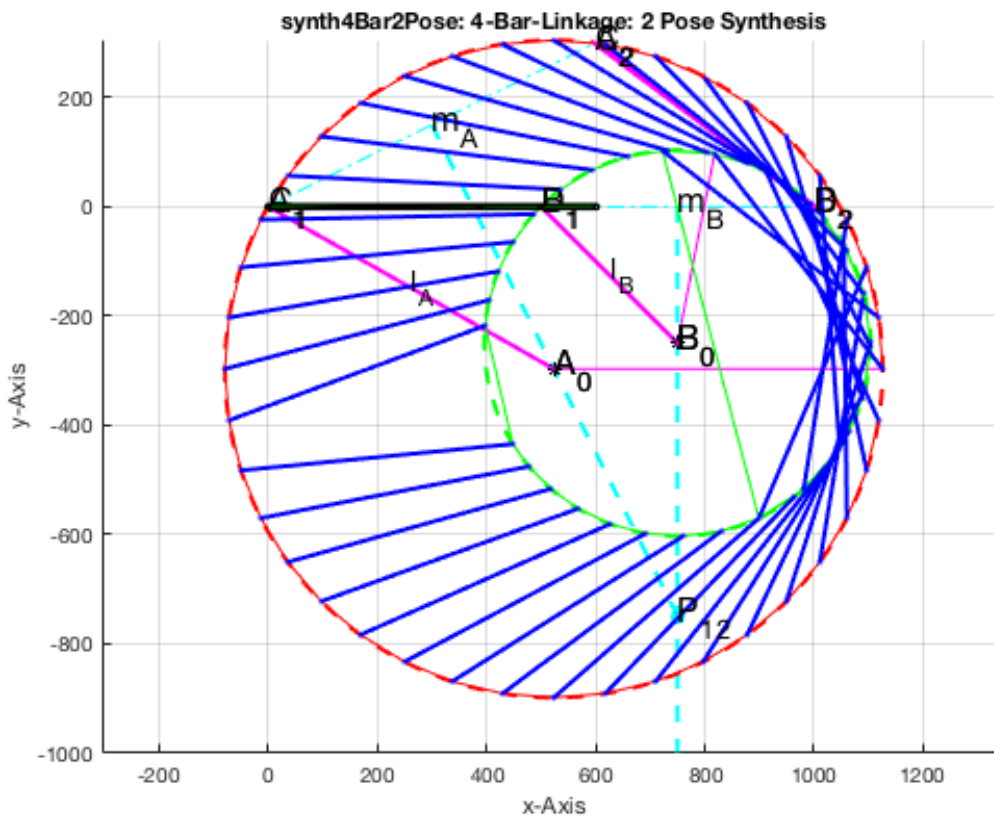
```
A=SGmodelLink(L1,'',1,2); A=SGmodelLink2(L1,0,1);
B=SGmodelLink(L2,'',1,2); B=SGmodelLink2(L2,0,1);
C=SGmodelLink(L3,'',1,2); C=SGmodelLink2(L3,0,-1);
D=SGmodelLink(L4,'',1,2); D=SGmodelLink2(L4,0,-1);

smbCreateSG (A,'LINK1','r'); % Add long rod as LINK1
smbCreateSG (B,'LINK2','g'); % Add short rod as LINK2
smbCreateSG (C,'LINK3','y'); % Add long rod as LINK3
smbCreateSG (D,'LINK4','c'); % Add short rod as LINK4
smbCreateJoint ('R','R1','LINK1.F','LINK2.B'); % Add a RR Joint
smbCreateJoint ('R','R2','LINK2.F','LINK3.B'); % Add a RR Joint
smbCreateJoint ('R','R3','LINK3.F','LINK4.B'); % Add a RR Joint
smbCreateJoint ('R','R4','LINK4.F','LINK1.B'); % Add a RR Joint
smbCreateConnection('WORLD.ORIGIN','LINK1.B',ToFP([A0(1) 0 A0(2)])); % Connect Linkage to Worl
```

```

d Frame
smbCreateDrive ('R1');
smbCreateSineWave ('Cosinus','R1_DRIVE/1');
ID=smbDrawNow;

```



7. Show the Video of the Simulation

```
[I1,FN]=smbVideoSimulation (4);    % Simulate for 1 second
IT=imageVideoTitle(FN,{'SG-Lib Tutorial #27','2 Pose Syntheses','Tim C. Lueth','$date'},'',[0.
78 1.33]);
IE=imageVideoEndtitle(FN);
videoWriteClipMovie(smbFilename('2 Pose Syntheses SimMultiBody.avi'),IT,2,FN2,ID,1,FN,IE,1);
imshow(I1);
```

Warning: Unable to reduce the step size without violating minimum step size of 7.41022264752519E-19 for 1 consecutive times at time 0.00020857922471329357. Continuing simulation with the step size restricted to 7.41022264752519E-19 and using an effective relative error tolerance of 0.0084742961193163945, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model

'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 7.4102226475252156E-19 for 2 consecutive times at time 0.0002085792247132943. Continuing simulation with the step size restricted to 7.4102226475252156E-19 and using an effective relative error tolerance of 0.0012481106134613336, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model

'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 7.4102226654519361E-19 for 1 consecutive times at time 0.00020857922521788663. Continuing simulation with the step size restricted to 7.4102226654519361E-19 and using an effective relative error tolerance of 0.011695417848713387, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model

'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 7.4102226654519621E-19 for 2 consecutive times at time 0.00020857922521788736. Continuing simulation with the step size restricted to 7.4102226654519621E-19 and using an effective relative error tolerance of 0.010469936968904534, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model

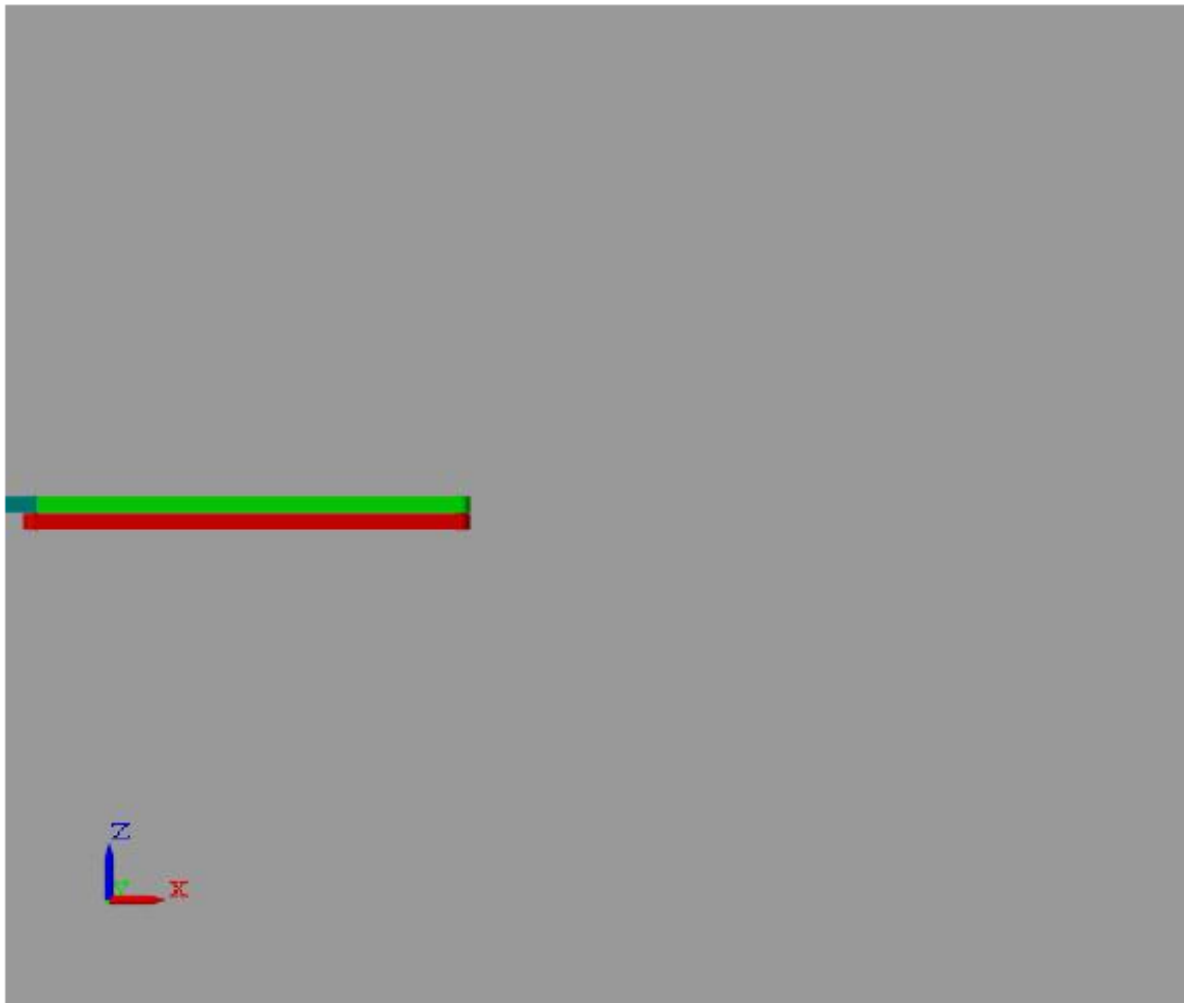
'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 7.4102226654519881E-19 for 3 consecutive times at time 0.00020857922521788809. Continuing simulation with the step size restricted to 7.4102226654519881E-19 and using an effective relative error tolerance of 0.00124811061648053, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model

'SG_LIB_EXP_27' or increase Number of consecutive min steps

.....Creating a new video file (NO SOUND/2016b): '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/2 Pose Syntheses SimMultiBody.avi'

5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100% 5% 10% 15% 20%
25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%



8. Now Create the Solid Geoemtry at time 0.78 seconds

```
SG=smbFullModelSimulation(0.78);
SG=SGmagnifyVL(SG, '[100 100 100]');
SGwriteSTL(SG, smbFilename('2-Pose-Synth'));
```

CREATING A FULL SOLID-MOVEMENT SIMULATION-MODEL 'SG_LIB_EXP_27' THAT RUNS At LEAST 0.78 SECOND S

=====

Adding frame sensors for all solids of the model

Add frame sensors for 'LINK1.SG'

Add frame sensors for 'LINK2.SG'

Add frame sensors for 'LINK3.SG'

Add frame sensors for 'LINK4.SG'

=====

Warning: Unable to reduce the step size without violating minimum step size of 5.3944822254360946E-19 for 1 consecutive times at time 0.00015184117587706779. Continuing simulation with the step size restricted to 5.3944822254360946E-19 and using an effective relative error tolerance of 0.0043035671698391821, which

is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model 'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 5.3944822645165932E-19 for 1 consecutive times at time 0.00015184117697708603. Continuing simulation with the step size restricted to 5.3944822645165932E-19 and using an effective relative error tolerance of 0.0061589696648945867, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model 'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 5.3944822645166125E-19 for 2 consecutive times at time 0.00015184117697708658. Continuing simulation with the step size restricted to 5.3944822645166125E-19 and using an effective relative error tolerance of 0.0087521093125372748, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model 'SG_LIB_EXP_27' or increase Number of consecutive min steps

Warning: Unable to reduce the step size without violating minimum step size of 5.3944822645166317E-19 for 3 consecutive times at time 0.00015184117697708712. Continuing simulation with the step size restricted to 5.3944822645166317E-19 and using an effective relative error tolerance of 0.0012266067701044677, which is greater than the specified relative error tolerance of 0.001. This usually may be caused by the high stiffness of the system. Please check the model 'SG_LIB_EXP_27' or increase Number of consecutive min steps

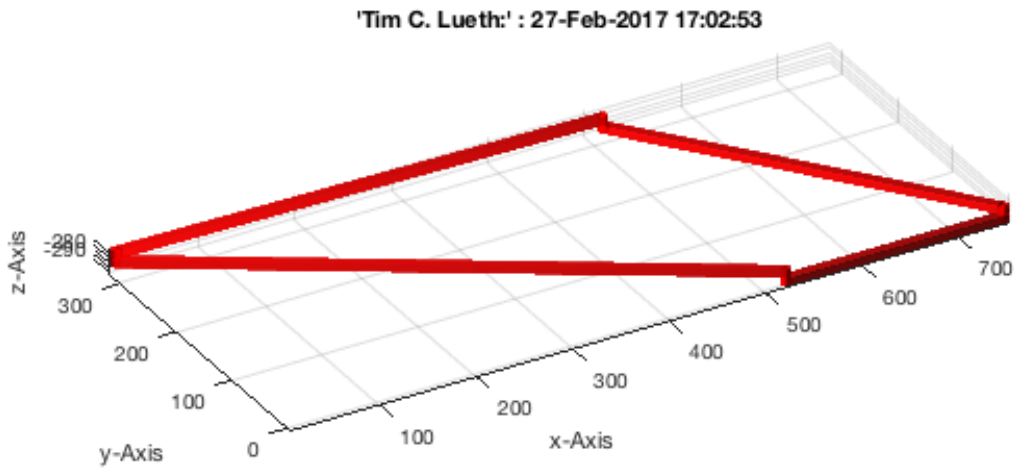
Simulink.SimulationOutput:

```
simlog: [1x1 Simscape.Logging.Node]
sout: [1x1 Simulink.SimulationData.Dataset]
tout: [189x1 double]
xout: [1x1 Simulink.SimulationData.Dataset]
```

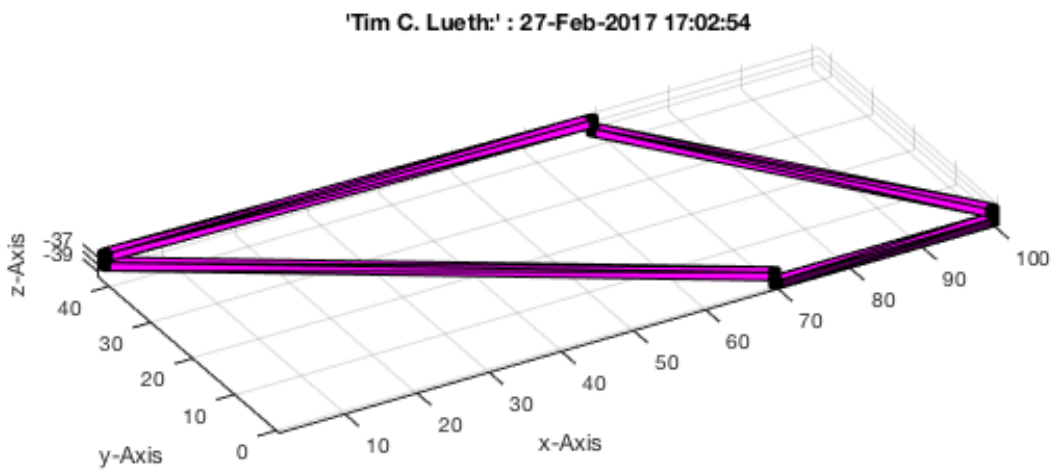
Use 'get' to access a variable by name.

Use 'getSimulationMetadata' to access metadata about the simulation.

```
LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/sbm_temp_LINK1.stl
Header:
Number of facets: 2404
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/sbm_temp_LINK2.stl
Header:
Number of facets: 2404
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/sbm_temp_LINK3.stl
Header:
Number of facets: 2584
0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_27/sbm_temp_LINK4.stl
Header:
Number of facets: 2584
0..
CREATED A SOLID GEOMETRY OF THE FULL SIMULATION-MODEL 'SG_LIB_EXP_27' AT TIME: 0.78 SECONDS
=====
=====
```



```
SGfigure; view(-30,30); SGplot(SG,'m'); % SGanalyzeGroupParts(SG);
```



Final Remarks

VLFLlicense

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 17:02:57 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
=====
image_toolbox
instr_control_toolbox
map_toolbox
matlab
robotics_system_toolbox
simmechanics
simscape
simulink
=====
=====
```

Published with MATLAB® R2016b

Exercise 28: Fourbar-Linkage: 3 Pose Syntheses and Linkage Export for 3D Printing

2017-01-08: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- [1. Summary of the already explained aspects of the VLFL-Toolbox](#)
- [2. Motivation for this tutorial](#)
- [3. Show a Two Pose Problem](#)
- [4. Find a General Solutions for the Three Pose Problem](#)
- [5. Find a special Solution for the 4Bar-Linkage wit A0 and B0 on same level](#)
- [6. Create a SimMultiyBody System for the calculated solution](#)
- [7. Show the Video of the Simulation](#)
- [8. Now Create the Solid Geoemtry at time 0.78 seconds](#)
- [Final Remarks](#)

1. Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Leightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations
- Example 25: Automatic Creation of Video Titels, Endtitels and Textpages
- Example 26: Create Mechanisms using Universal Planar Links
- Example 27: Fourbar-Linkage: 2 Pose Syntheses and Linkage Export for 3D Printing

■ Example 28: Fourbar-Linkage: 3 Pose Syntheses and Linkage Export for 3D Printing

```
% function VLFL_EXP28
```

2. Motivation for this tutorial

```
smbNewSystem ('SG_LIB_EXP_28',[+5 +5 +5]); % Creates the mechsism diagramm
```

Creating temporary directory '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_28/'



3. Show a Two Pose Problem

Poses are described by the start point and end point of a link. The first point of the coupling defines a point, the second point also the direction. In the simplest case, two poses for the design of a four-bar are given.

```
d=[0 0];
C1=[ 0 0];
D1=[40 0];
C2=[60 30];
D2=[100 0];
C3=[90 20];
D3=[50 20];

SGfigure;
PLplot([C1;D1], 'r-',2);
PLplot([C2;D2], 'r-',2);
PLplot([C3;D3], 'r-',2);
```



4. Find a General Solutions for the Three Pose Problem

As a solution, there are two straight lines on each of which the frame point A0 or the frame point B0 may be located. The intersection point of these two lines is the pole point P12. In a special case, both frame points are located at this point and a triangle is formed from the four-bar. In any case, the rack points can be displaced such that other secondary conditions can also be fulfilled.

```
l=500

imageFigureMovie('record');
synth4Bar3Pose(C1,D1,C2,D2,C3,D3,d);
% exp_2017_01_08(C1,D1,C2,D2,C3,D3,l,d);
[~,FN2]=imageFigureMovie('write',smbFilename('synth4Bar3Pose.avi'));
```

l =

500

ans =

20 0 0

ans =

76 18 0

ans =

70 20 0

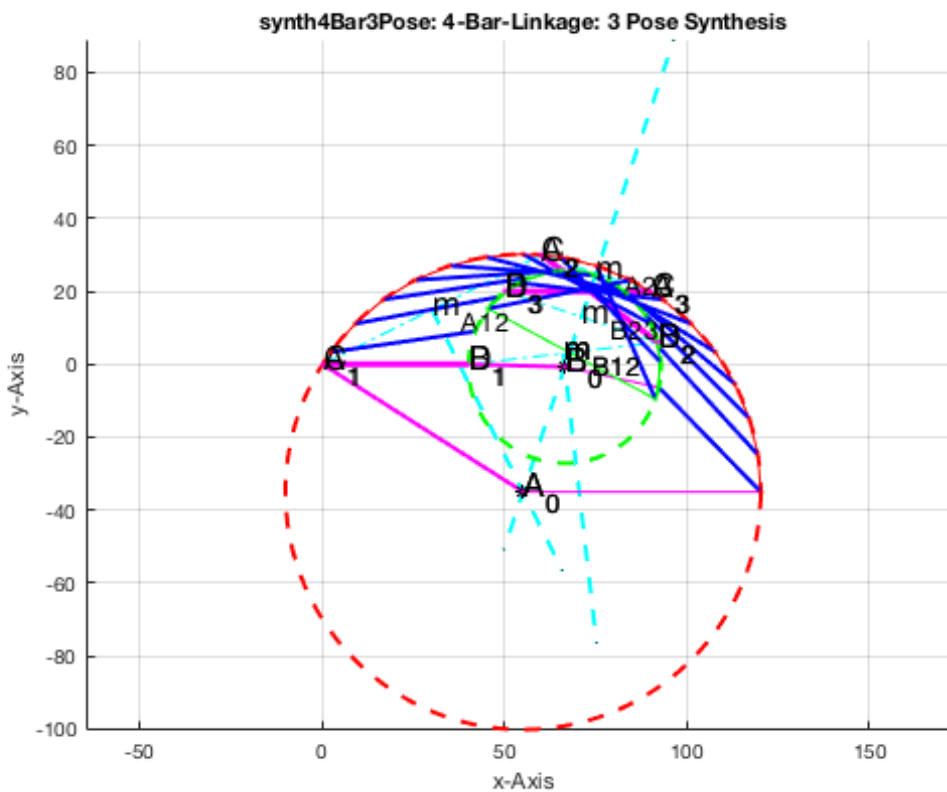
ans =

27.5000 -17.5000 0

ans =

53.2143 -0.3571 0

imageFigureSaveMovie: Writing figure movie with 42 frames in file: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_28/synth4Bar3Pose.avi.



5. Find a special Solution for the 4Bar-Linkage wit A0 and B0 on same level

If A0 and B0 are to lie on the same plane, $B0 + k \cdot (P12 - B0)$ must correspond to the Y coordinate of the Y coordinate of A0 in the y coordinate

```
[A0,B0,A1,B1]=synth4Bar3Pose(C1,D1,C2,D2,C3,D3,d);
% [A0,B0,A1,B1]=exp_2017_01_08(C1,D1,C2,D2,C3,D3,l,d);
A0
B0

L1=norm(B0-A0)
L2=norm(B1-B0)
L3=norm(A1-B1)
L4=norm(A0-A1)

% L1=500; L2=400; L3=500; L4=400
```

```

L=[L1 L2 L3 L4]
LMax=find( (L==max(L)) ); LMax=LMax(1);
LMin=find( (L==min(L)) ); LMin=LMin(1);
l1=L(LMin)+L(LMax);
l2=sum(L)-l1;
l3=l1-l2

```

A0 =

55.0000 -35.0000

B0 =

66.4286 -0.7143

L1 =

36.1403

L2 =

26.4382

L3 =

40

L4 =

65.1920

L =

36.1403 26.4382 40.0000 65.1920

l3 =

15.4899

6. Create a SimMultiyBody System for the calculated solution

```

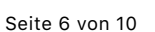
A=SGmodelLink(L1,'',1,2); A=SGmodelLink2(L1,0,1);
B=SGmodelLink(L2,'',1,2); B=SGmodelLink2(L2,0,1);
C=SGmodelLink(L3,'',1,2); C=SGmodelLink2(L3,0,-1);
D=SGmodelLink(L4,'',1,2); D=SGmodelLink2(L4,0,-1);

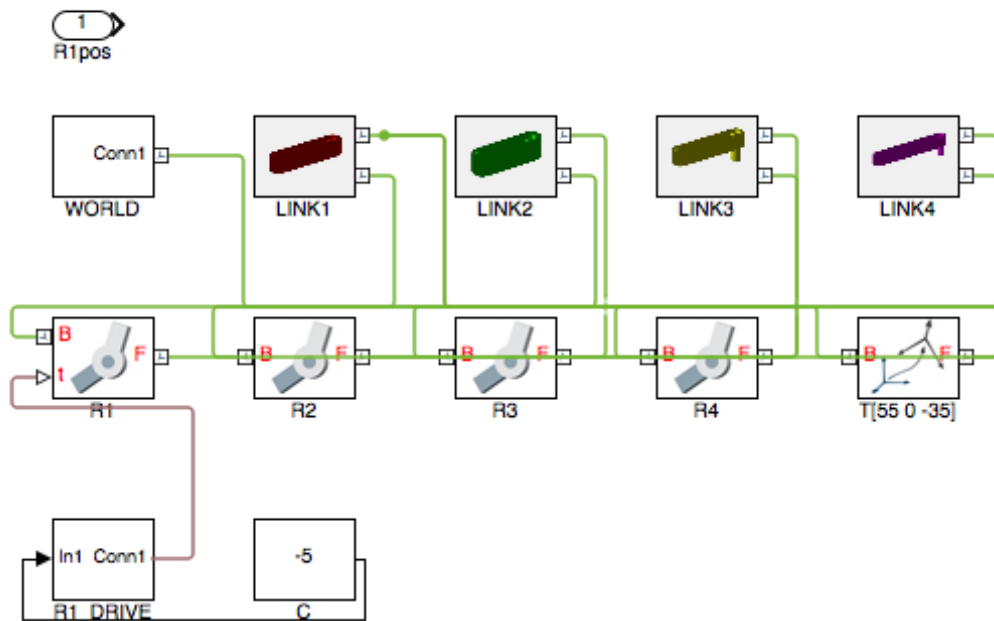
smbCreateSG (A,'LINK1','r');           % Add long rod as LINK1
smbCreateSG (B,'LINK2','g');           % Add short rod as LINK2
smbCreateSG (C,'LINK3','y');           % Add long rod as LINK3

```



```
phi =  
1.2490
```

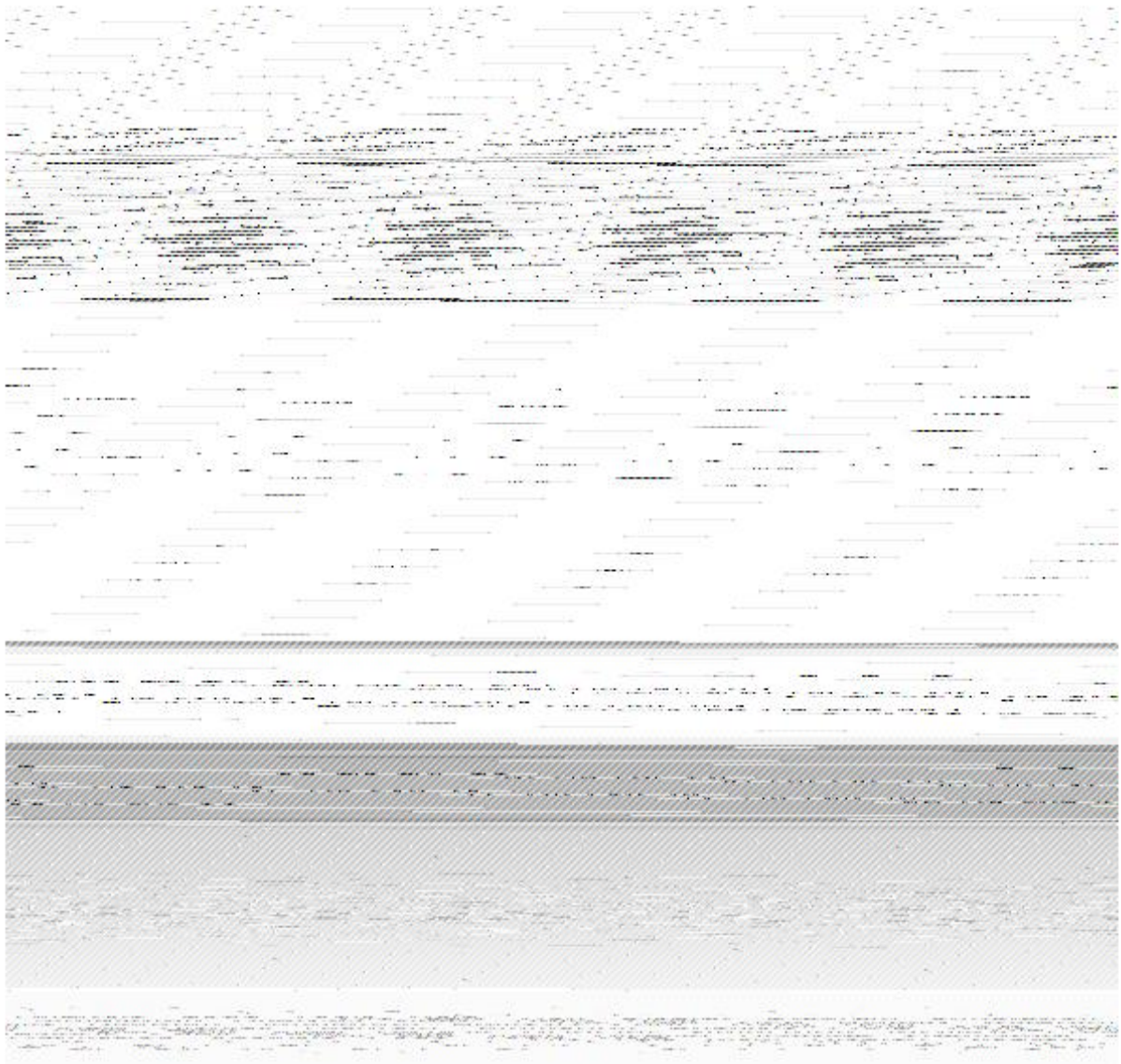




7. Show the Video of the Simulation

```
[I1,FN]=smbVideoSimulation (4);    % Simulate for 1 second
IT=imageVideoTitle(FN,{'SG-Lib Tutorial #27','3 Pose Syntheses','Tim C. Lueth','$date'},'',[0.44
0.74 1.14]);
IE=imageVideoEndtitle(FN);
videoWriteClipMovie(smbFilename('3 Pose Syntheses SimMultiBody.avi'),IT,2,FN2,ID,1,FN,IE,1);
imshow(I1);
```

```
.....Creating a new video file (NO SOUND/2016b): '/Users/timlueth/Desktop/tmp_SG_LIB_EXP_2
8/3 Pose Syntheses SimMultiBody.avi'
5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100% 5% 10% 15% 20% 25
% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%
```



8. Now Create the Solid Geoemtry at time 0.78 seconds

```
SG=smbFullModelSimulation(0.74);
% SG=SGmagnifyVL(SG,',[100 100 100]);
SGwriteSTL(SG,smbFilename('3-Pose-Synth'));
```

```
CREATING A FULL SOLID-MOVEMENT SIMULATION-MODEL 'SG_LIB_EXP_28' THAT RUNS At LEAST 0.74 SECONDS
```

```
=====
```

```
==
```

```
Adding frame sensors for all solids of the model
```

```
Add frame sensors for 'LINK1.SG'
```

```
Add frame sensors for 'LINK2.SG'
```

```
Add frame sensors for 'LINK3.SG'
```

```
Add frame sensors for 'LINK4.SG'
```

```
=====
```

```
==
```

Simulink.SimulationOutput:

```
simlog: [1x1 Simscape.Logging.Node]
sout: [1x1 Simulink.SimulationData.Dataset]
tout: [222x1 double]
xout: [1x1 Simulink.SimulationData.Dataset]
```

Use 'get' to access a variable by name.

Use 'getSimulationMetadata' to access metadata about the simulation.

LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_28/sbm_temp_LINK1.stl

Header:

Number of facets: 2404

0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_28/sbm_temp_LINK2.stl

Header:

Number of facets: 2404

0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_28/sbm_temp_LINK3.stl

Header:

Number of facets: 2584

0..LOADING BINARY STL-File: /Users/timlueth/Desktop/tmp_SG_LIB_EXP_28/sbm_temp_LINK4.stl

Header:

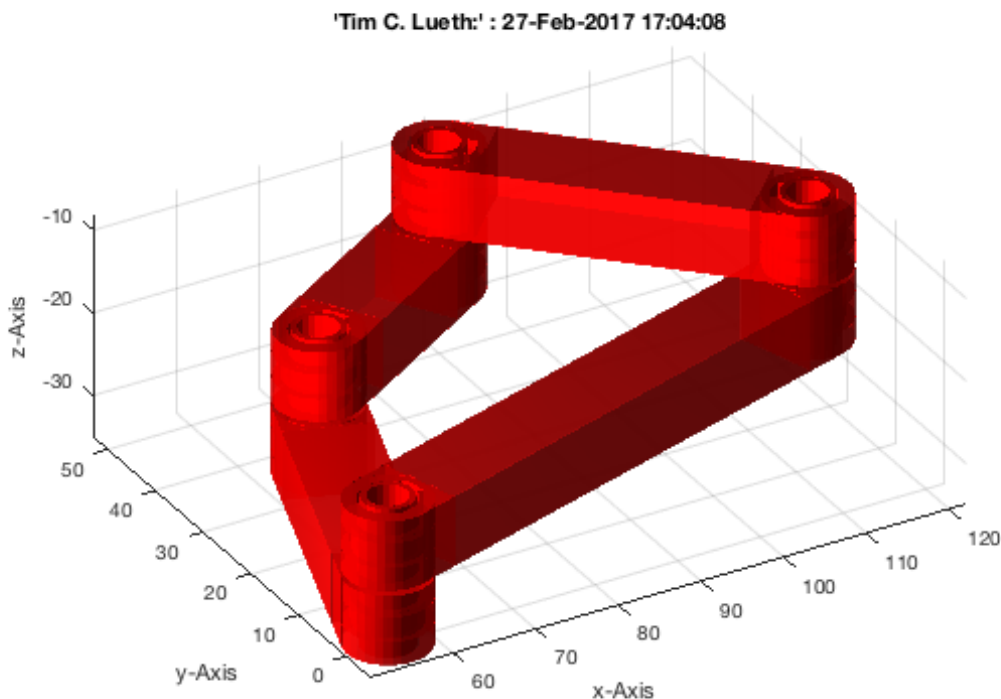
Number of facets: 2584

0..

CREATED A SOLID GEOMETRY OF THE FULL SIMULATION-MODEL 'SG_LIB_EXP_28' AT TIME: 0.74 SECONDS

=====

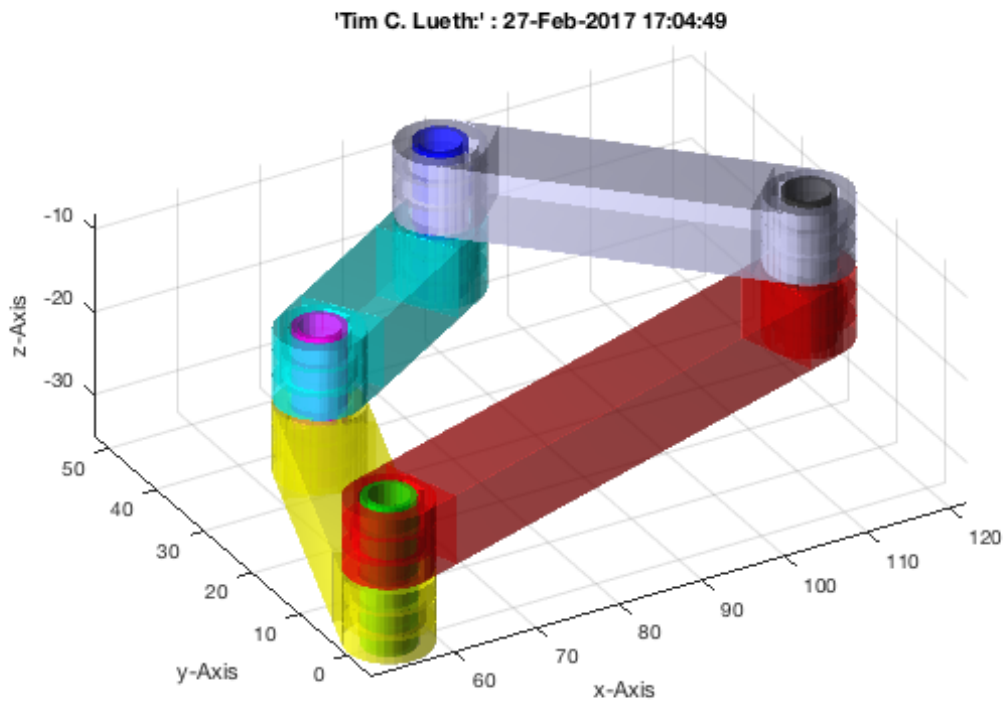
==



```
SGfigure; view(-30,30); SGplot(SG,'m'); SGanalyzeGroupParts(SG);
```

5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%

SGanalyzeGroupParts: 8 separated parts found.



Final Remarks

VLFLlicense

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!

Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !

Please contact Tim Lueth, Professor at TU Munich, Germany!

WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!

Executed 27-Feb-2017 17:04:51 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64

===== Used Matlab products: =====

=====

image_toolbox

instr_control_toolbox

map_toolbox

matlab

robotics_system_toolbox

simmechanics

simscape

simulink

=====

=====

Published with MATLAB® R2016b

Exercise 30: Create Mechanisms using Universal Planar Links

2017-02-10: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- [Summary of the already explained aspects of the VLFL-Toolbox](#)
- [Motivation for this tutorial](#)
- [1. Plotting points \(PL\) and vertices \(3D\)](#)
- [2. Plotting lines](#)
- [3. Plotting angles](#)
- [4. Plotting coordinate](#)
- [8. Adding text to the drawings](#)
- [9. Helpful generic polygons for](#)
- [Final Remarks](#)

Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations
- Example 25: Automatic Creation of Video Titels, Endtitels and Textpages

- Example 26: Create Mechanisms using Universal Planar Links
- Example 27: Fourbar-Linkage: 2 Pose Syntheses and Linkage Export for 3D Printing
- Example 28: Fourbar-Linkage: 3 Pose Syntheses and Linkage Export for 3D Printing

Motivation for this tutorial

In this tutorial, features are introduced that allow you to create drawings for the descriptive geometry using Matlab. The goal is to display lines, planes, spaces and polygons, surfaces and surface-bounded volumes and to label them mathematically (Tex-style). some functions are based in individual points such as:

- pplot - plot a point in defined color, shape and size
- lplot - plot a line between two points with color, width, tip, start point end point
- aplot - plot an angle at a point using a line and a second line or angle
- slplot - plot a straight line using a start point and direction vector
- tplot;
- tfplot; some functions are based on point lists (PL) or vertex lists (VL), such as: PLplot, VLplot,

1. Plotting points (PL) and vertices (3D)

```
p=[0 0]      % row style
p=[0;0]      % column style
v=[0 0 0]    % row style
v=[0; 0; 0]  % column style
```

```
SGfigure; pplot(p);
```

p =

```
0    0
```

p =

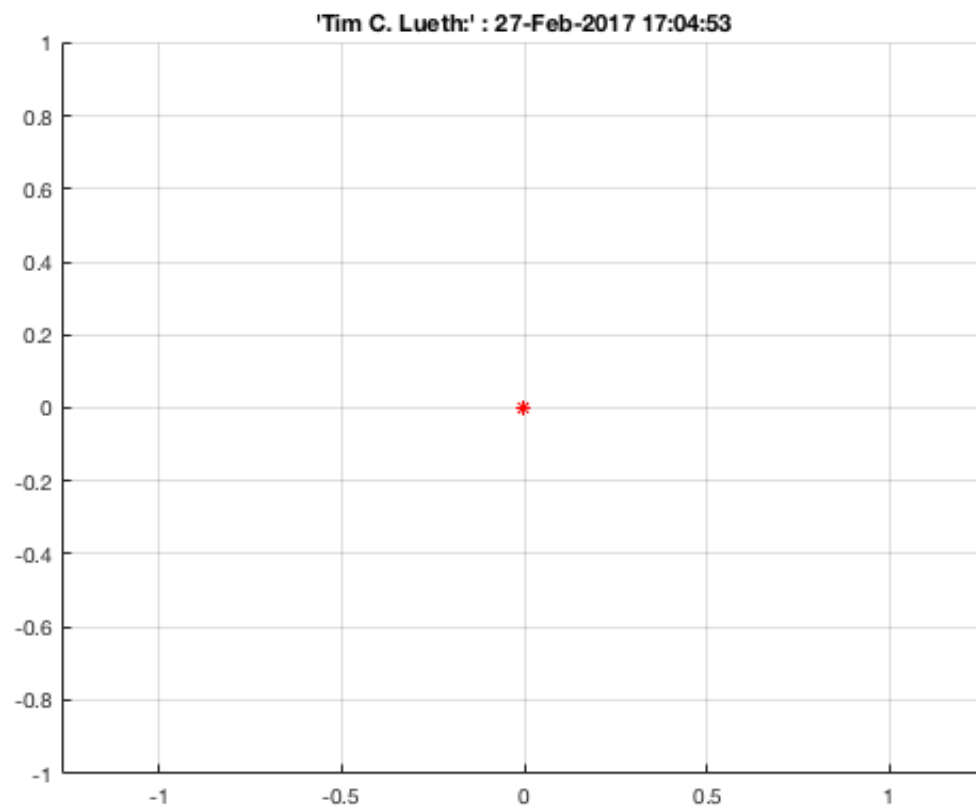
```
0
0
```

v =

```
0    0    0
```

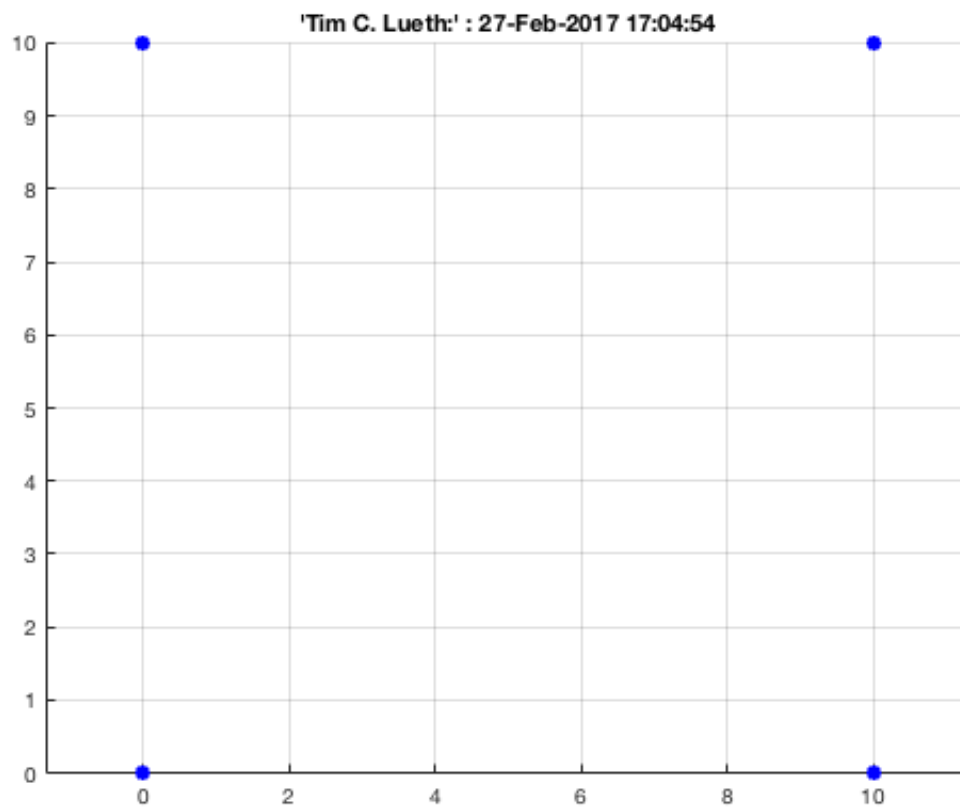
v =

```
0
0
0
```

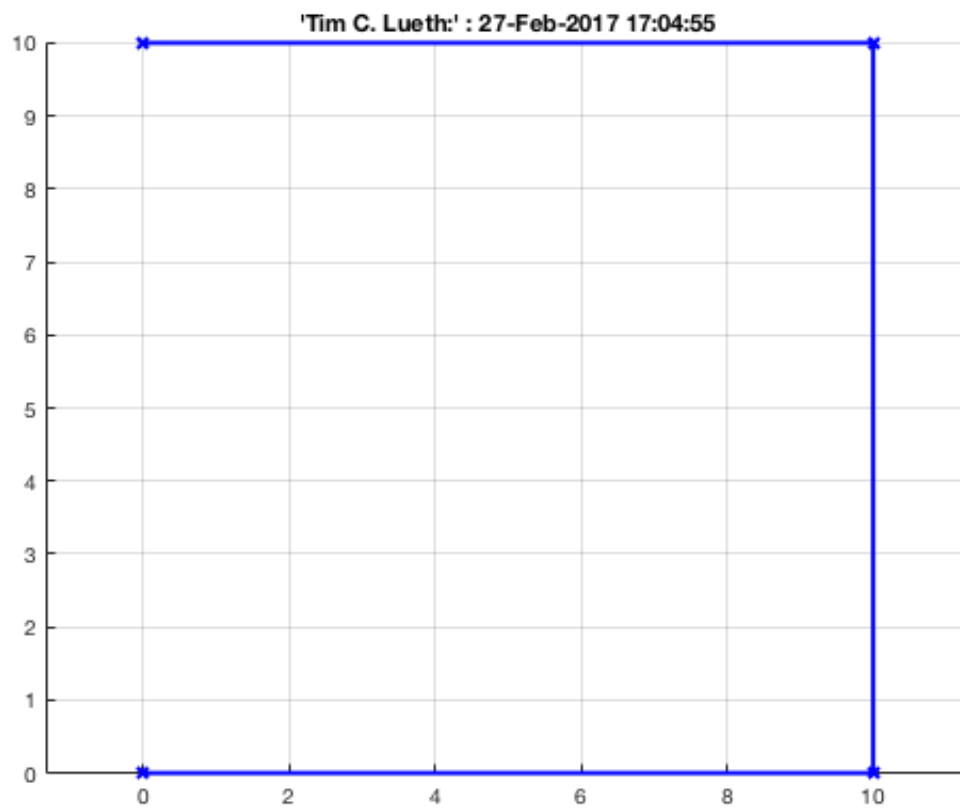


```
SGfigure; PLplot([0 0;10 0;10 10; 0 10], 'b*',2);
```

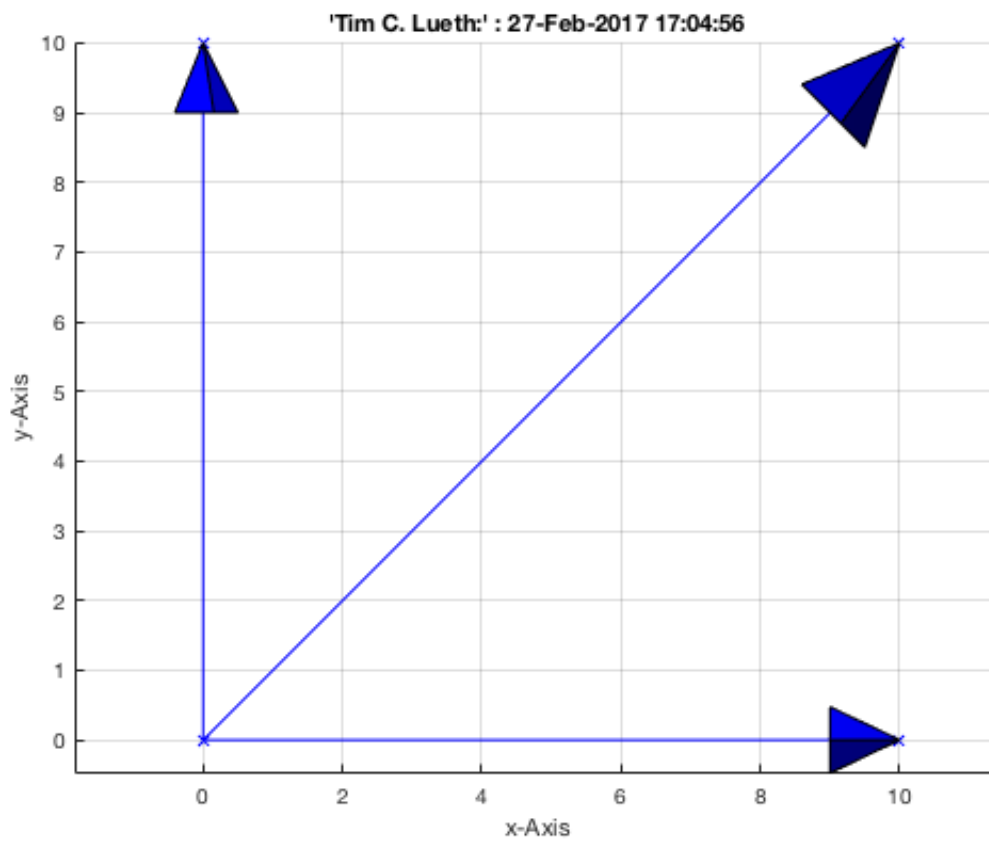
```
% point plot of point list
```

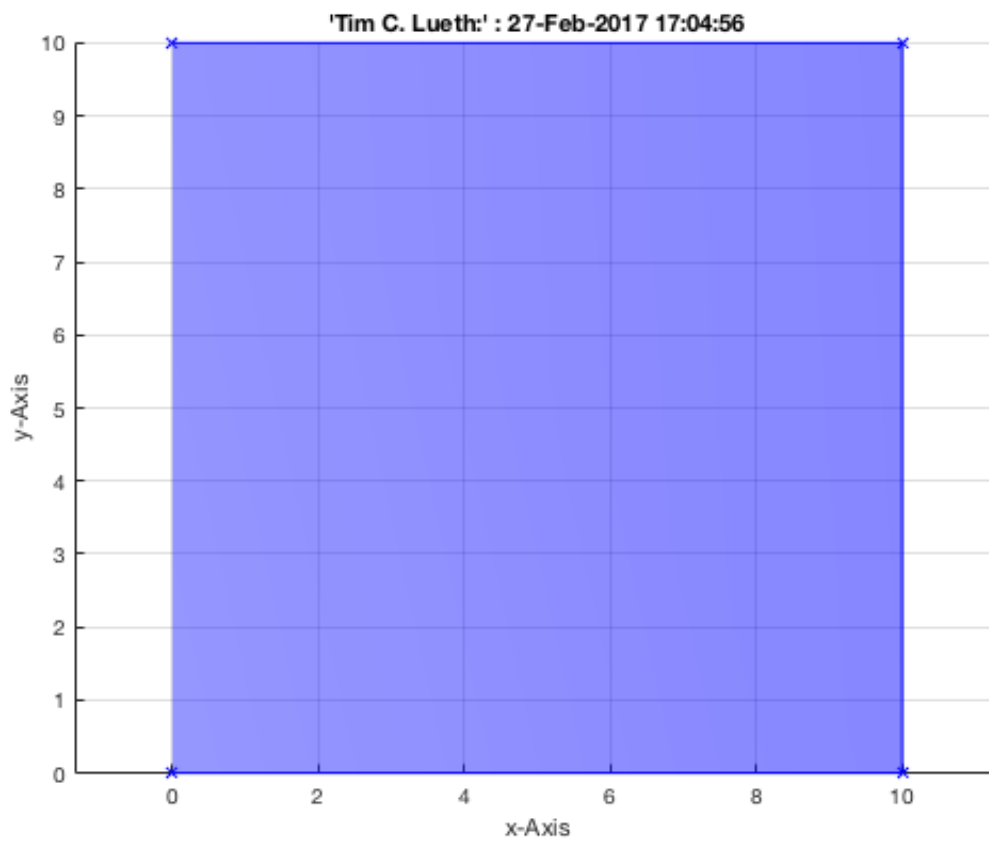
```
SGfigure; PLplot([0 0;10 0;10 10; 0 10], 'bx-',2); % Line plot of point list
```



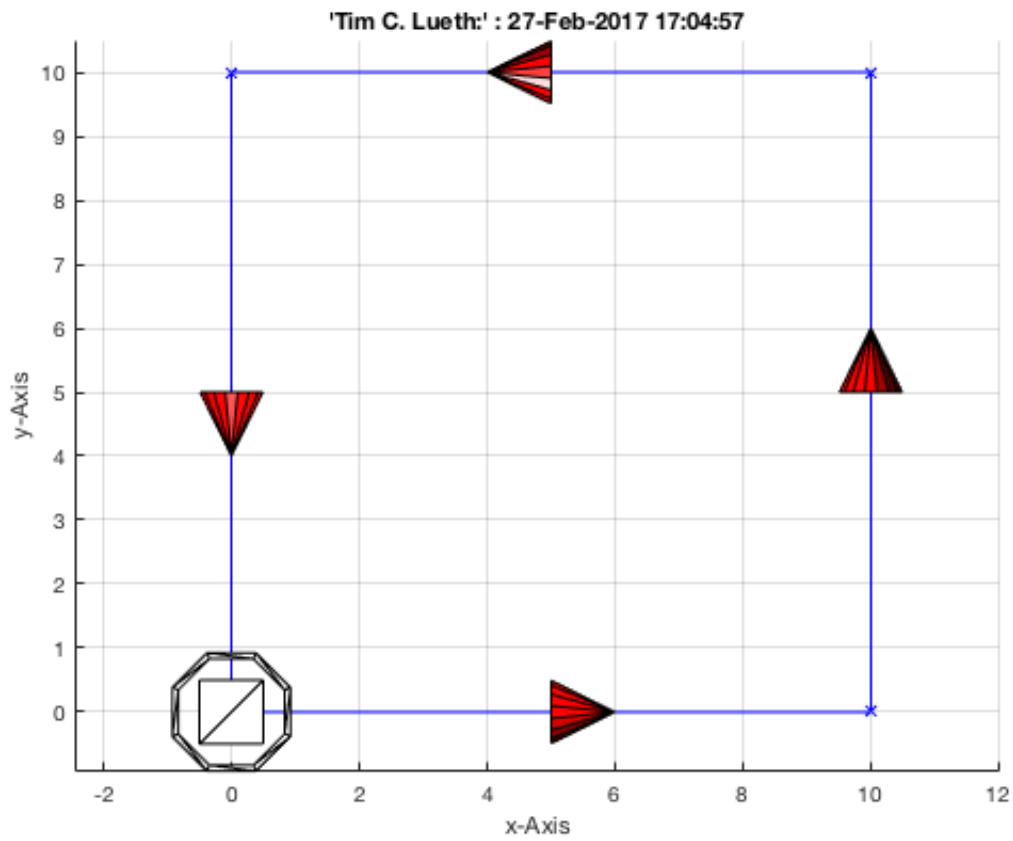
```
SGfigure; PLplot([0 0;10 0;10 10; 0 10], 'bx-',1,1); % Vector plot of point list
```



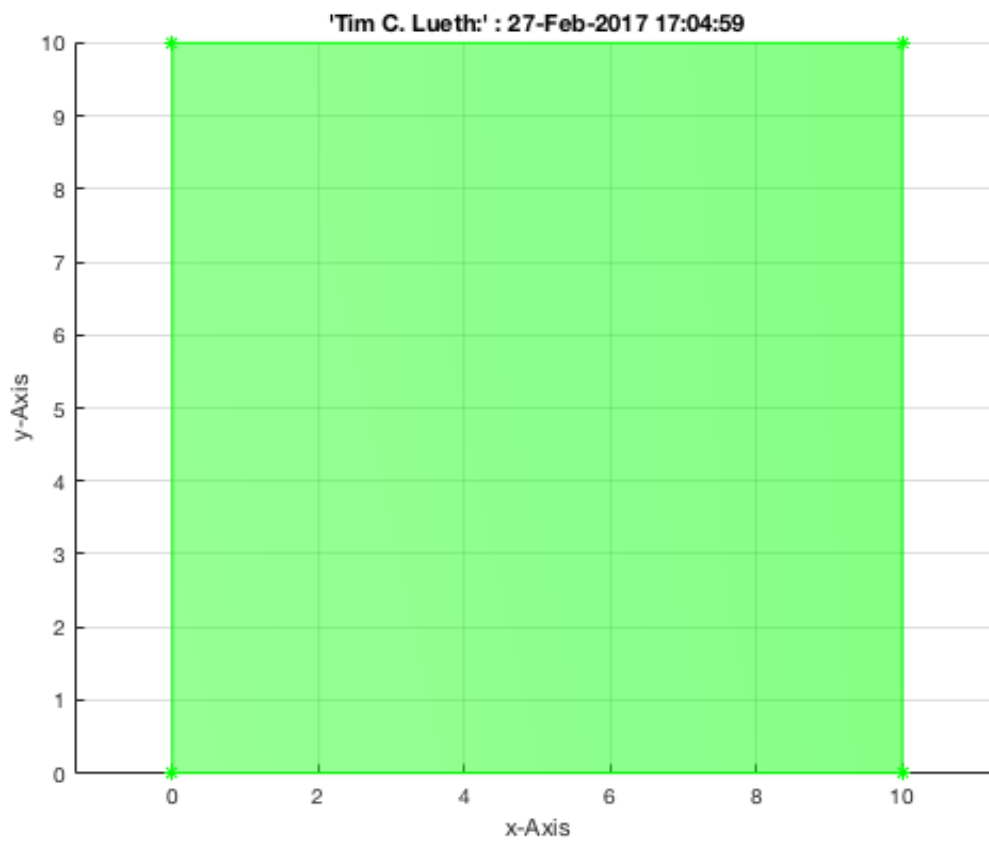
```
SGfigure; PLplot([0 0;10 0;10 10; 0 10], 'bx-',1,'',0.5);    % Surface enclosed by point list
```



```
SGfigure; CPLplot([0 0;10 0;10 10; 0 10], 'bx-',1,1,1,1);    % Plotting closed polygon
```

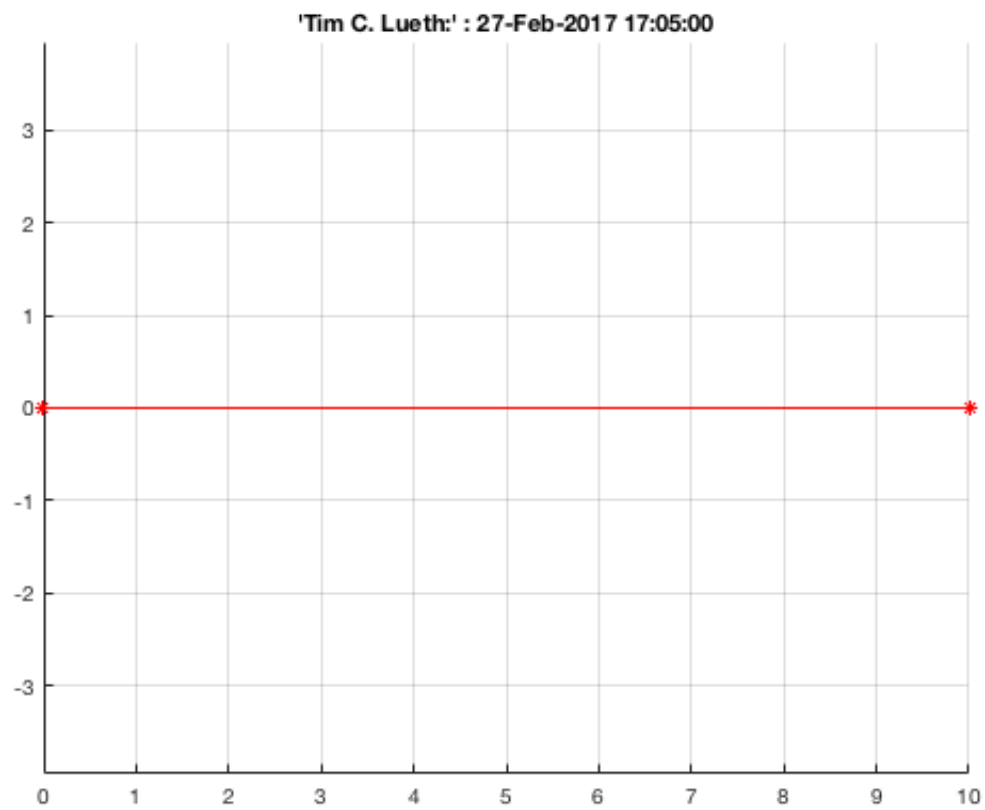


```
SGfigure; CPLfaceplot([0 0;10 0;10 10; 0 10], 'g*-', 1, 0.5); % Plotting closed polygon surfaces
```

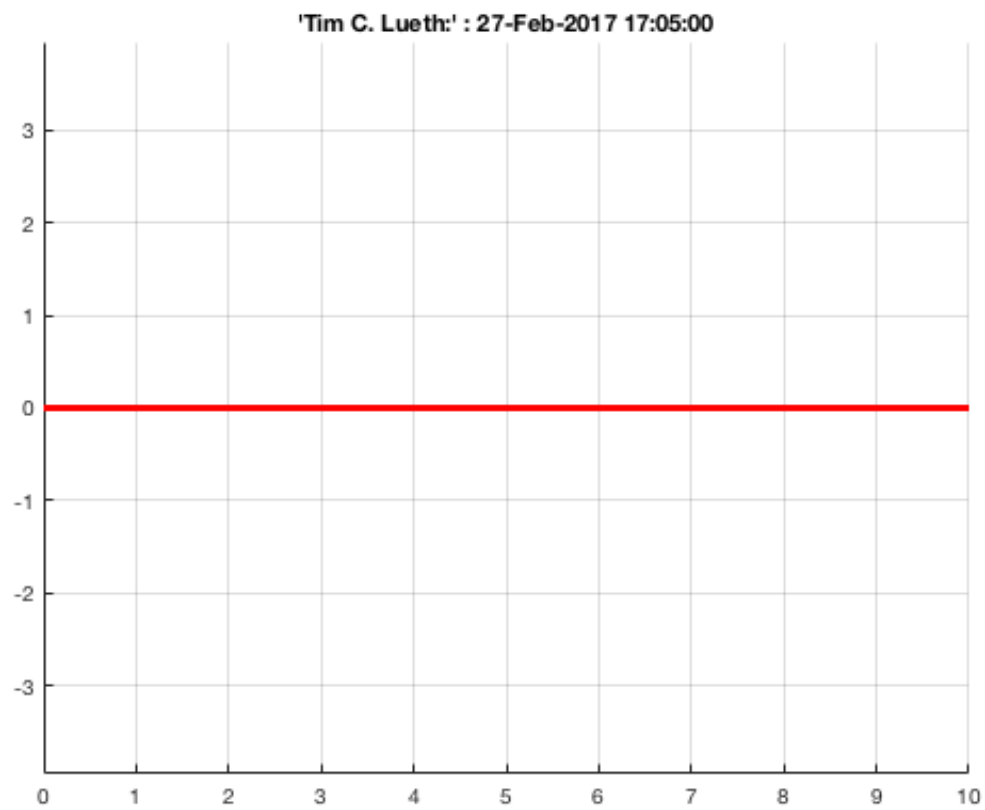


2. Plotting lines

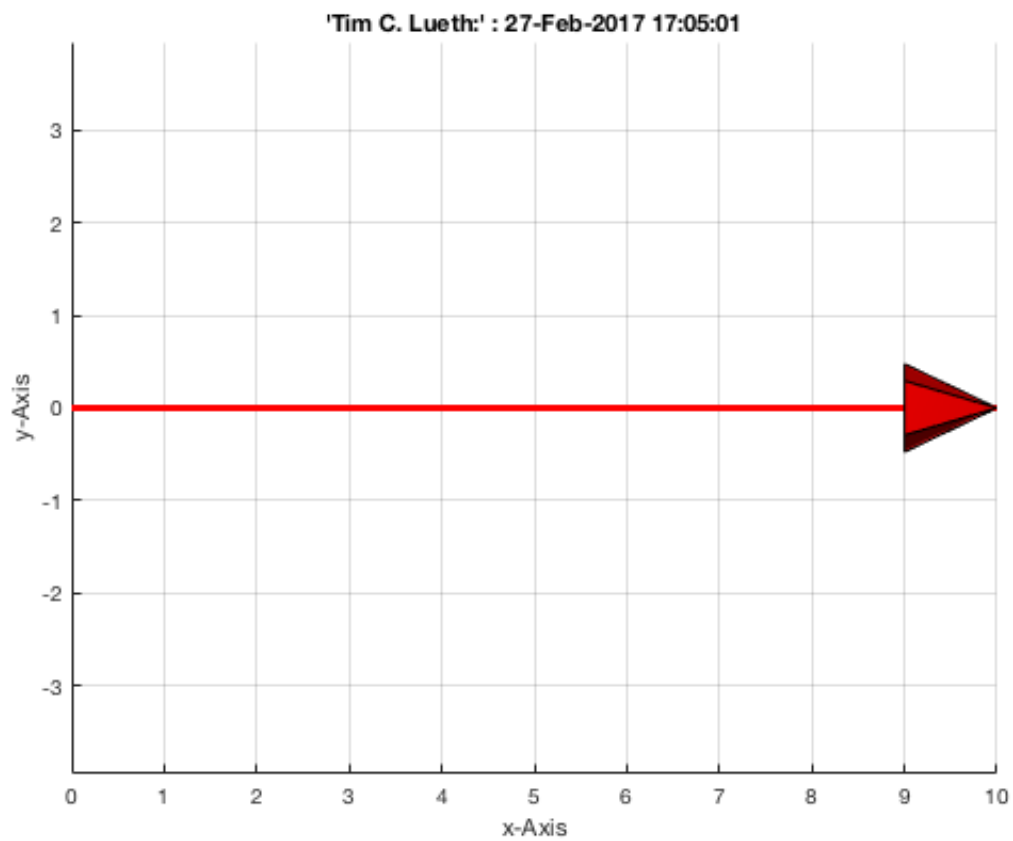
```
SGfigure; lplot([0 0],[10 0], 'r*-');
```



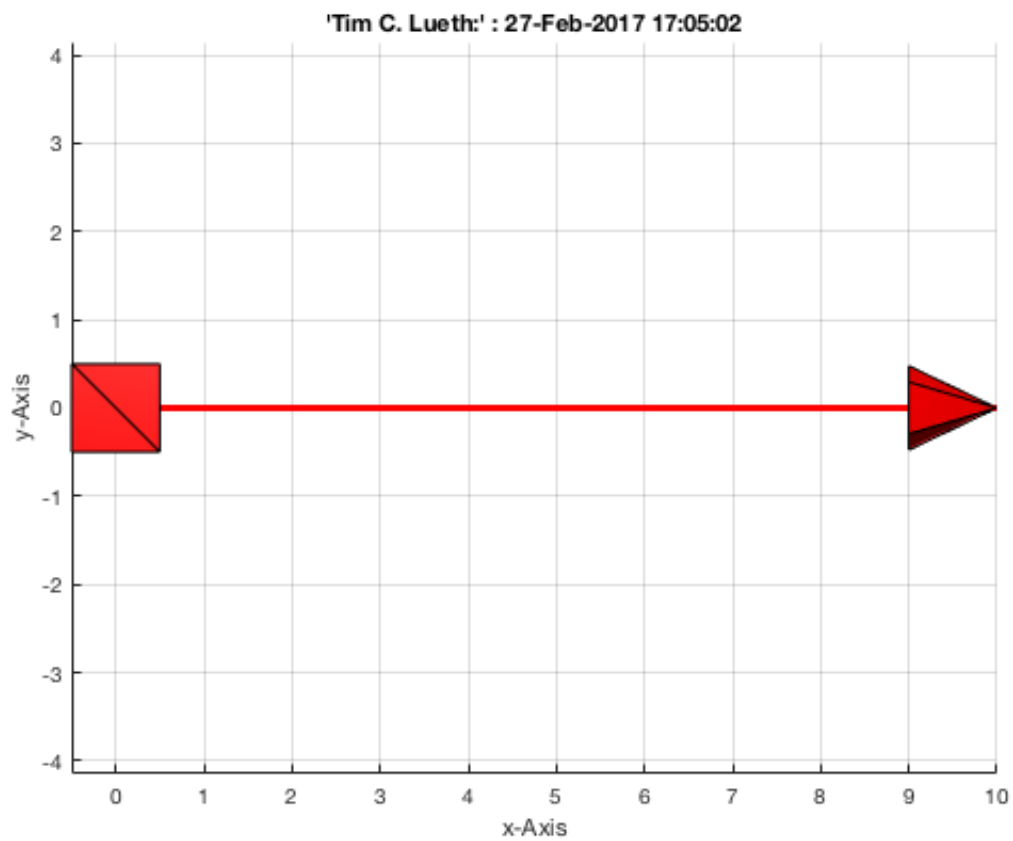
```
SGfigure; lplot([0 0],[10 0], 'r-',3);
```



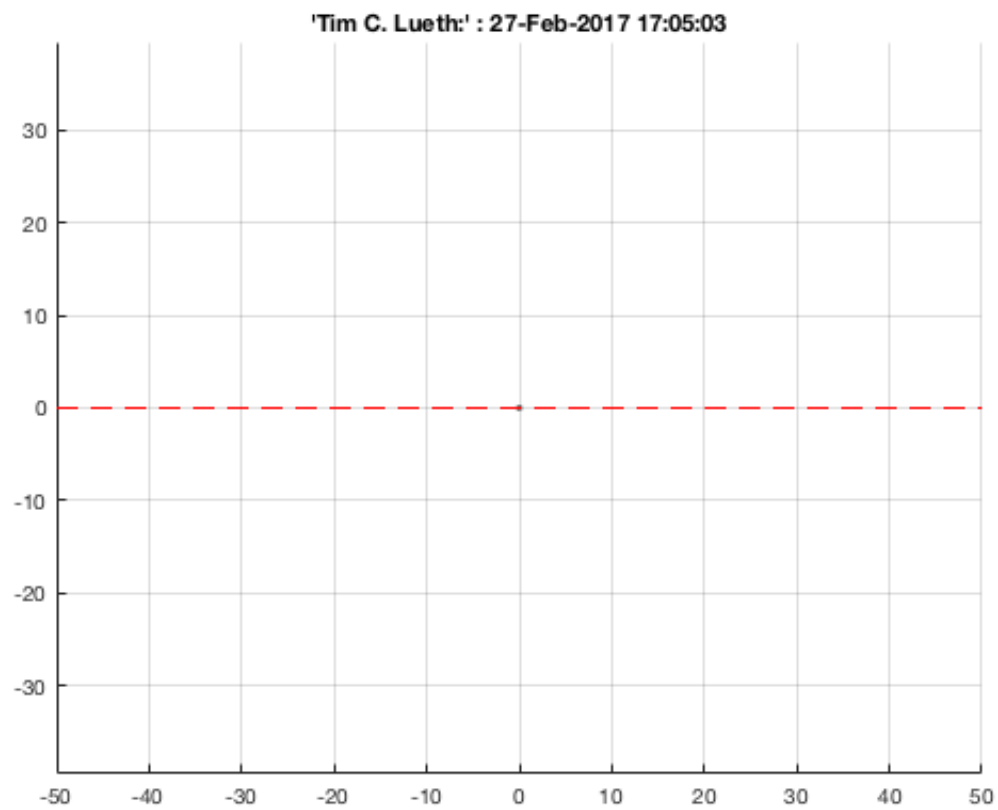
```
SGfigure; lplot([0 0],[10 0], 'r-',3,1);
```

```
SGfigure; lplot([0 0],[10 0], 'r-',3,1,1);
```

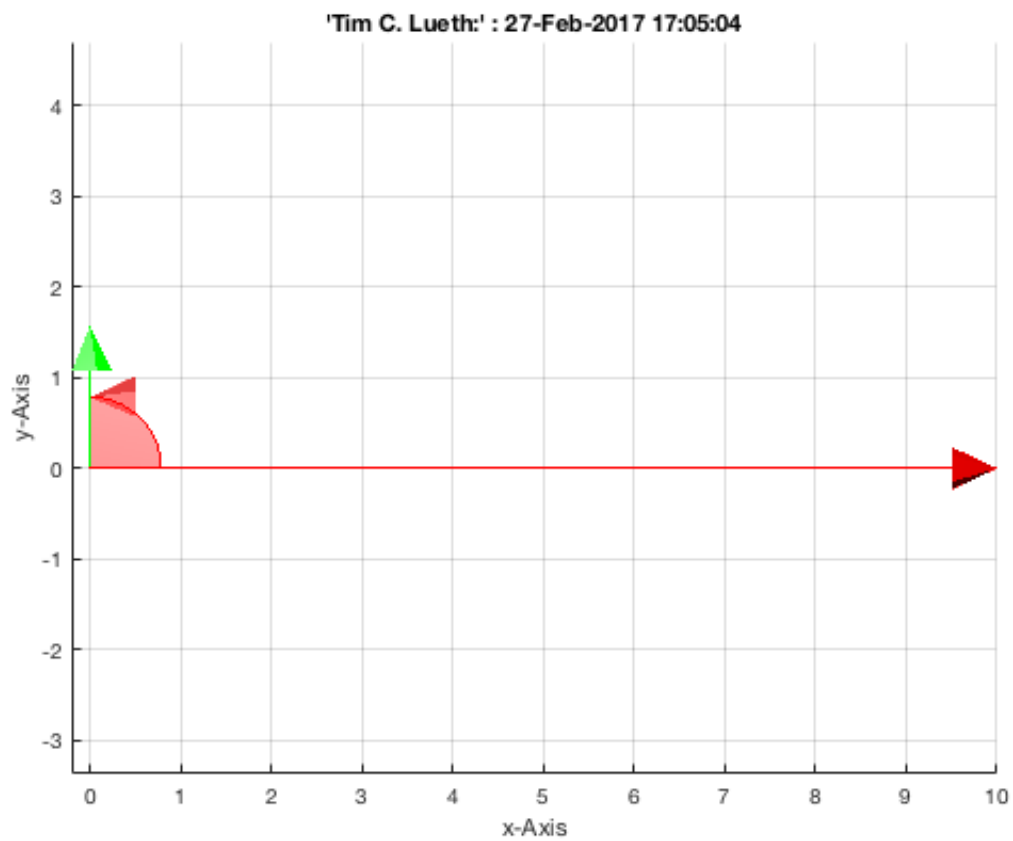


```
SGfigure; splot([0 0],[10 0], 'r-',3,1,1);
```



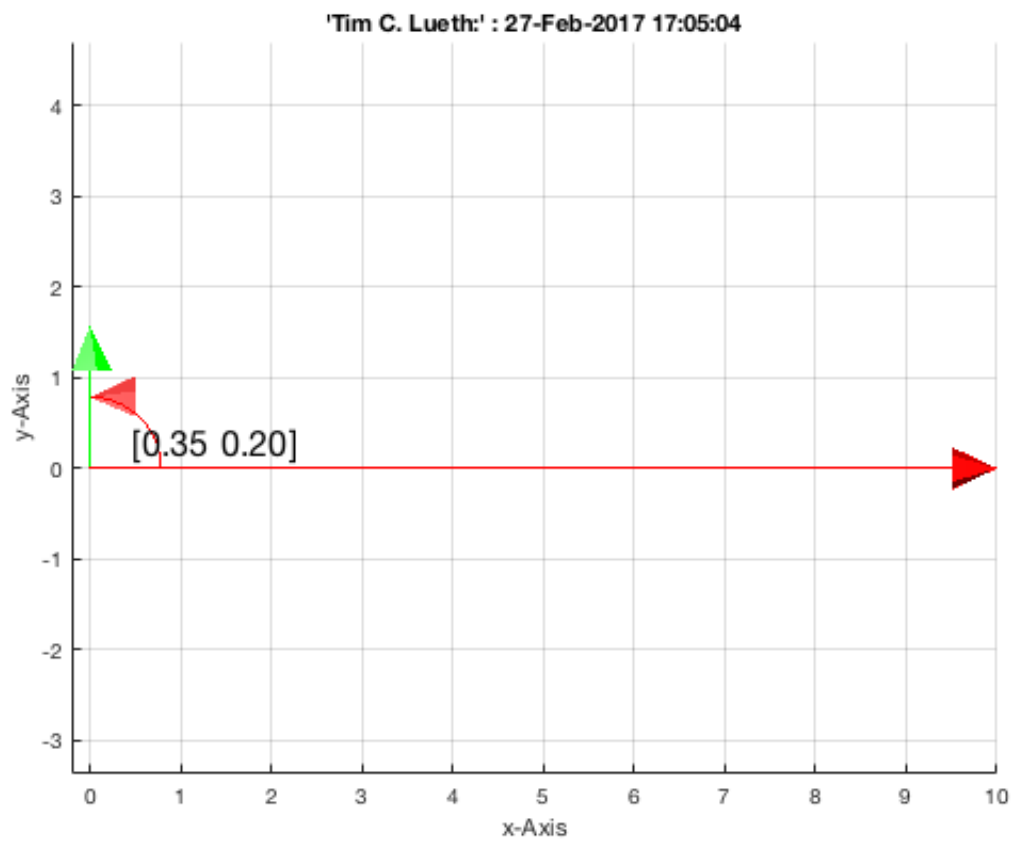
3. Plotting angles

```
SGfigure; applot([0 0],[10 0],pi/2);
```



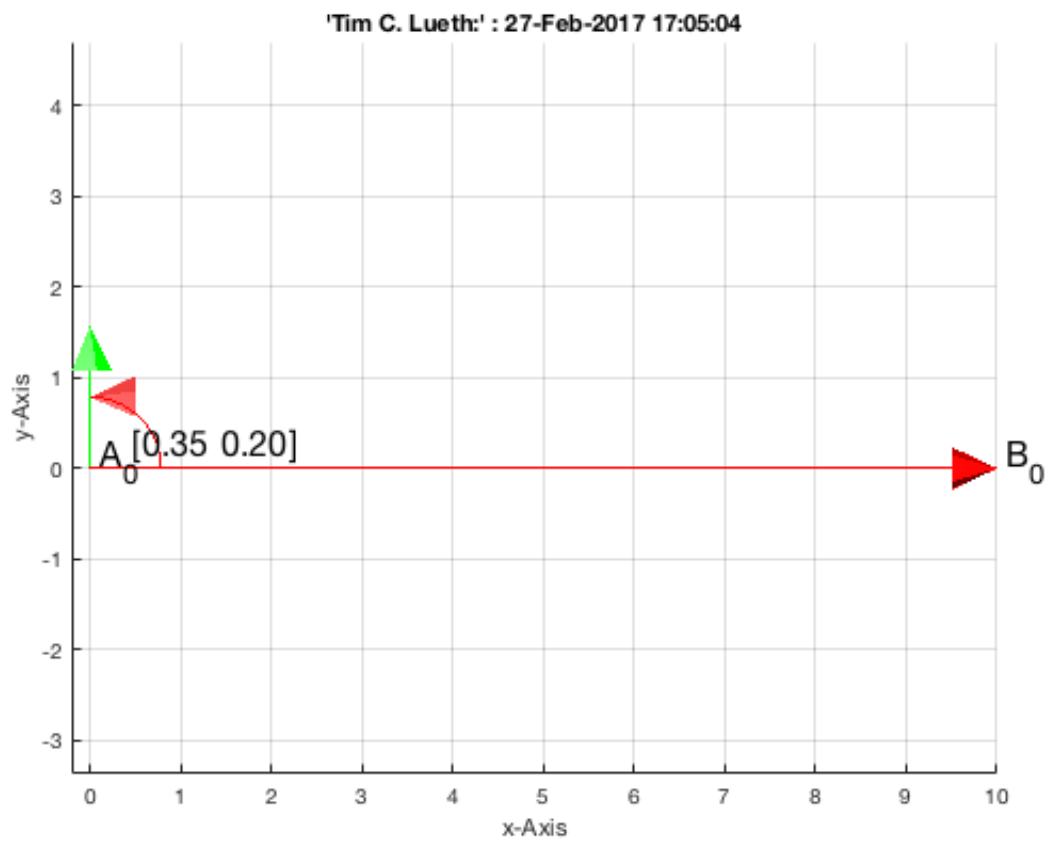
4. Plotting coordinate

```
p=input(1); textP (p,sprintf('%.2f %.2f',p));
```



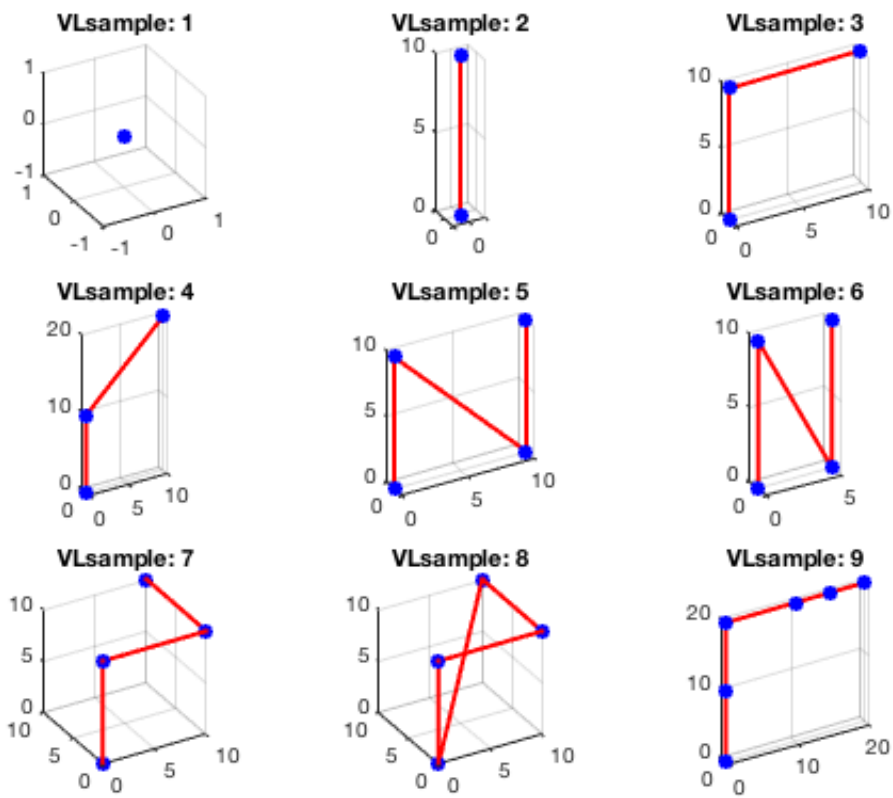
8. Adding text to the drawings

```
textP ([0 0], 'A0'); textP ([10 0], 'B0');
```

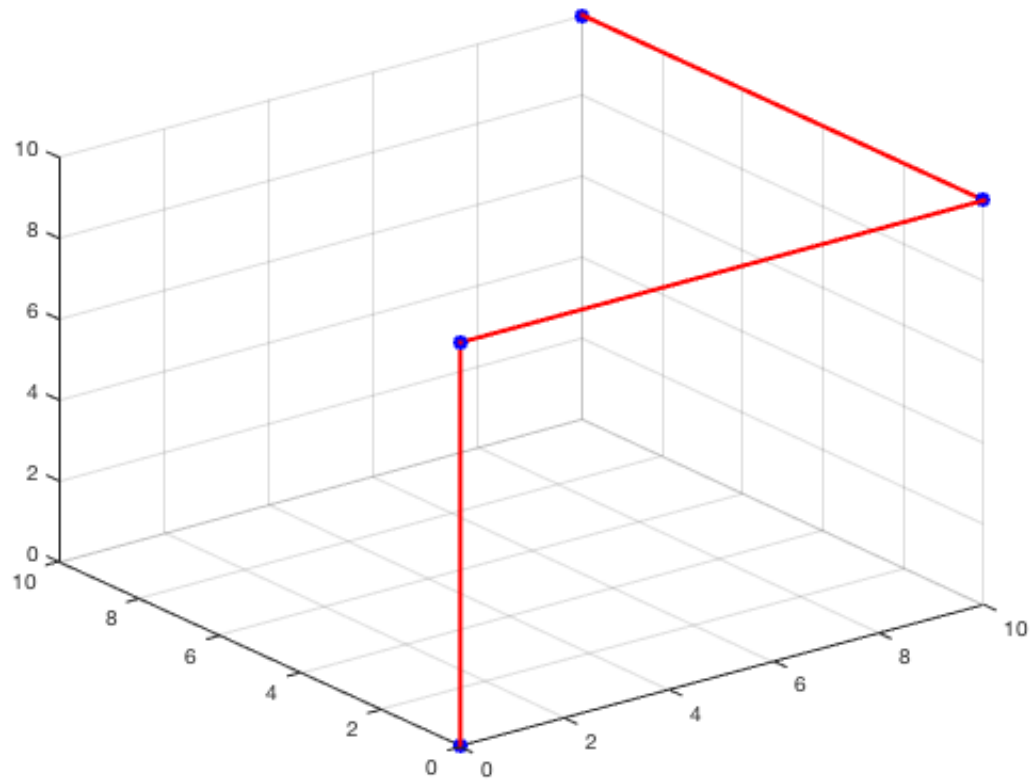


9. Helpful generic polygons for

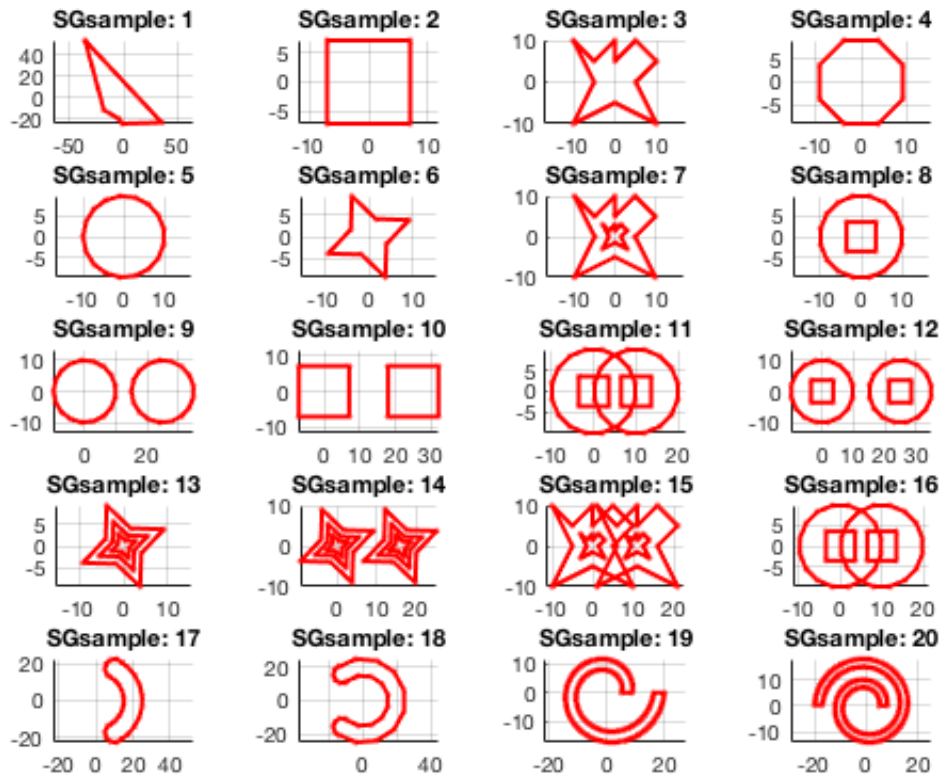
```
SGfigure; VLsample;
```



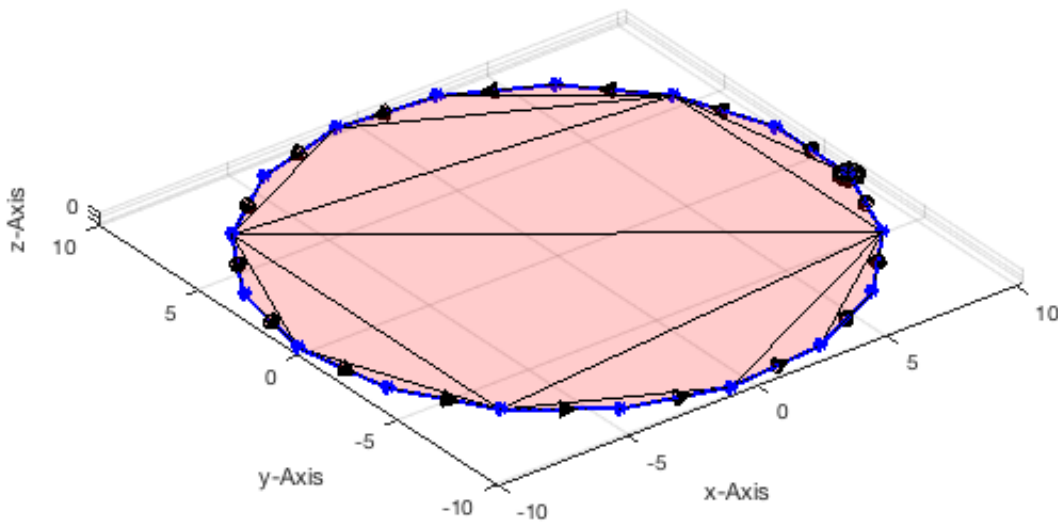
```
SGfigure; VLsample(7);
```



```
SGfigure; CPLsample;
```

```
SGfigure; CPLsample(5);
```



Final Remarks

```
close all
VLFLlicense
```

This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
 Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
 Please contact Tim Lueth, Professor at TU Munich, Germany!
 WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
 Executed 27-Feb-2017 17:05:20 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
 ===== Used Matlab products: =====
 =====
 image_toolbox
 instr_control_toolbox
 map_toolbox
 matlab
 robotics_system_toolbox
 simmechanics
 Simscape
 simulink
 =====
 =====

Published with MATLAB® R2016b

Exercise 31: Importing 3D Medical DICOM Image Data and converting into 3D Solids

2017-02-19: Tim C. Lueth, MIMED - Technische Universität München, Germany (URL: <http://www.mimed.de>)

Contents

- [Summary of the already explained aspects of the VLFL-Toolbox](#)
- [Motivation for this tutorial](#)
- [1. Reading DICOM models as voxel model from disk and resize voxel models \(VM\)](#)
- [2. Solid skull bone reconstruction using SGofVMdelaunay](#)
- [3. Solid skull bone reconstruction using SGofVMmarchcub](#)
- [4 Show the Voxel model in quadrant 1-2-4 and surface model in quadrant 3](#)
- [5. Create a surface model and convert it into a Voxel model](#)
- [6. Plot the surface model in 4 quadrant plot](#)
- [7. Write the surface model as DICOM directory on disk](#)
- [8. Select Point in 3D](#)
- [Final Remarks](#)

Summary of the already explained aspects of the VLFL-Toolbox

The previous examples of this series covered the following topics:

- Example 01: First Steps Using the VLFL-Toolbox for Solid Object Design
- Example 02: Using the VLFL-Toolbox for STL-File Export and Import
- Example 03: Closed 2D Contours and Boolean Operations in 2D
- Example 04: 2.5D Design Using Boolean Operators on Closed Polygon Lists (CPL)
- Example 05: Creation, Relative Positioning and Merging of Solid Geometries (SG)
- Example 06: Relative Positioning and Alignment of Solid Geometries (SG)
- Example 07: Rotation of Closed Polygon Lists for Solid Geometry Design
- Example 08: Slicing, Closing, Cutting and Separation of Solid Geometries
- Example 09: Boolean Operations with Solid Geometries
- Example 10: Packaging of Sets of Solid Geometries (SG)
- Example 11: Attaching Coordinates Frames to Create Kinematik Models
- Example 12: Define Robot Kinematics and Detect Collisions
- Example 13: Mounting Faces and Conversion of Blocks into Lightweight-structures
- Example 14: Manipulation Functions for Closed Polygons and Laser Cutting (SVG)
- Example 15: Create a Solid by 2 Closed Polygons
- Example 16: Create a Solid along a contour
- Example 20: Programmatically Interface to SimMechanics Multi-Body Toolbox
- Example 21: Programmatically Design of SimMechanisms Mechanisms and Simulink Signals
- Example 22: Creation of fixed nodes for the assembly of joints
- Example 23: Automatic Creation of a Missing Link and 3D Print of a Complete Model
- Example 24: Automatic Creation of a Joint Limitations
- Example 25: Automatic Creation of Video Titels, Endtitels and Textpages
- Example 26: Create Mechanisms using Universal Planar Links
- Example 27: Fourbar-Linkage: 2 Pose Syntheses and Linkage Export for 3D Printing
- Example 28: Fourbar-Linkage: 3 Pose Syntheses and Linkage Export for 3D Printing
- Exercise 30: Create Mechanisms using Universal Planar Links
- Exercise 31: Importing 3D Medical DICOM Image Data and converting into 3D Solids

Motivation for this tutorial

- VMreaddicomdir - reads in a voxel model
- VMresize - resizes of a voxel model
- SGofVMdelaunay - creates a surface model using delaunay (slow)
- SGofVMmarchcube - creates a surface model using marching cube (fast)
- SGcut - cuts surface models
- CPLofSGslice - creates a slice contour at a specific height/direction
- PLFLofCPLdelaunay - tessellates the facets of a CPL using delaunay
- PLFLofCPLpoly - tessellates the facets of a CPL using mapping toolbox
- VMplot - plots a voxel mode
- VMplotslide - plots a voxel mode for slider navigation
- VMimage - plots a voxel image

- VMmontage - montage of voxel
- VMpseudo3D - creates a pseudo 3D image
- VMuidicom - select and read a voxel model
- VMreaddicom - read a dicom file

1. Reading DICOM models as voxel model from disk and resize voxel models (VM)

```
[V,vs]=VMreaddicomdir('/Volumes/LUETH-WIN/WIN AIM Matlab Libraries/VLFL-Lib/AIM_DICOMFILES');
vs
[a,as]=VMresize(V,[0.5 0.5 0.5],vs);
as
[a,as]=VMresize(V,vs,vs);
as
```

```
VMreaddicomdir: Analyzing 129 entries in path: /Volumes/LUETH-WIN/WIN AIM Matlab Libraries/VLFL-Lib/AIM_DICOMFILES
.....
Stack of 126 DICOM images read from disk.
```

```
vs =
```

```
    0.4219    0.4219    1.0000
```

```
VMresize: Resize voxel image [512 512 126] to [256 256 63] with voxel size [0.84mm 0.84mm 2.00mm]
```

```
as =
```

```
    0.8438    0.8438    2.0000
```

```
VMresize: Resize voxel image [512 512 126] to [216 216 126] with voxel size [1.00mm 1.00mm 1.00mm]
```

```
as =
```

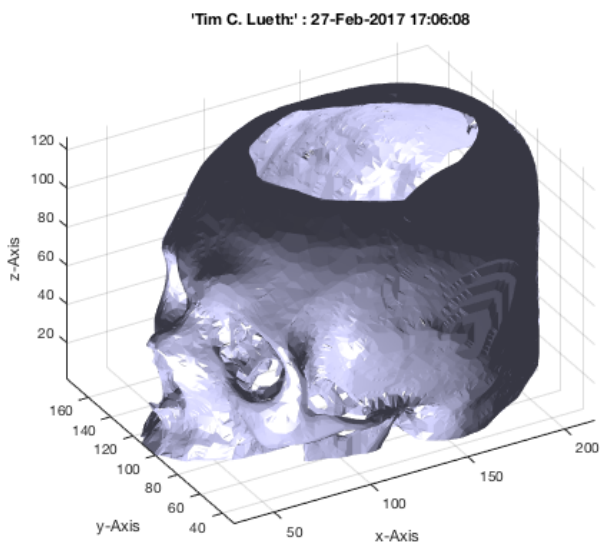
```
     1     1     1
```

2. Solid skull bone reconstruction using SGofVMdelaunay

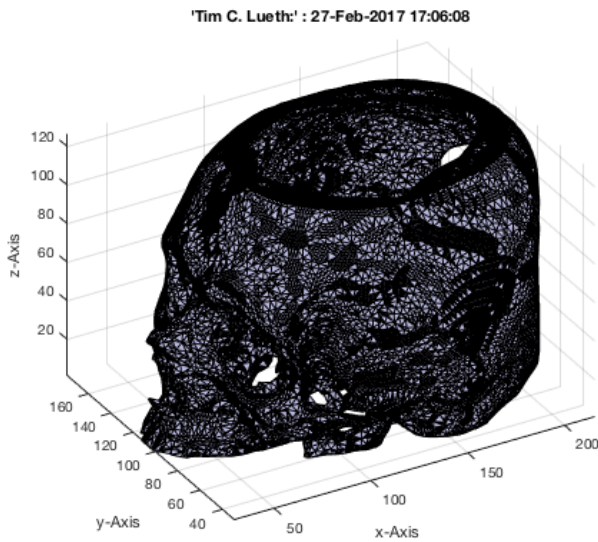
```
SG1=SGofVMdelaunay(a>1400,as); % Takes about 30 seconds
SGfigure; VLFLplotlight (1,1); view(-30,30);
SGplot(SG1,'w');VLFLplotlight(1,1)
```

```
Elapsed time is 5.539232 seconds.
```

```
Elapsed time is 30.324384 seconds.
```



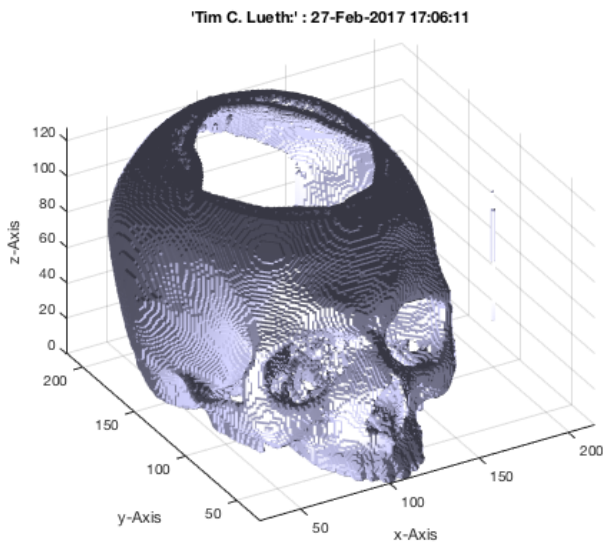
```
VLFLplotlight(0,1);
```



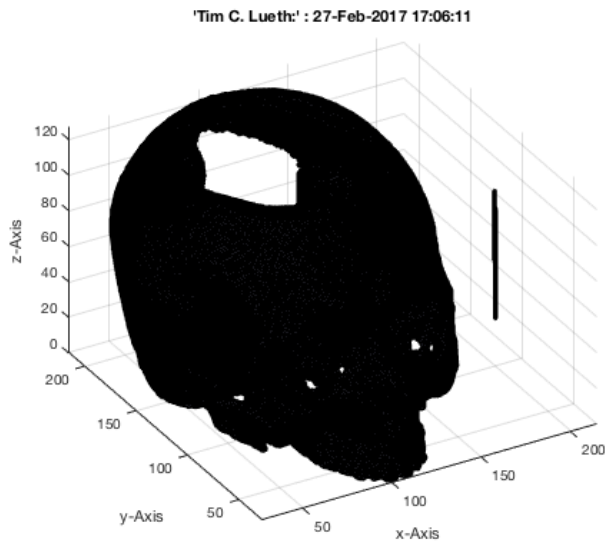
3. Solid skull bone reconstruction using SGofVMmarchcube

```
tic
SG2=SGofVMmarchcube(a>1400,as);      % Takes about 2 seconds
toc
SGfigure; VLFLplotlight (1,1); view(-30,30);
SGplot(SG2,'w');VLFLplotlight(1,1)
```

Elapsed time is 1.957015 seconds.

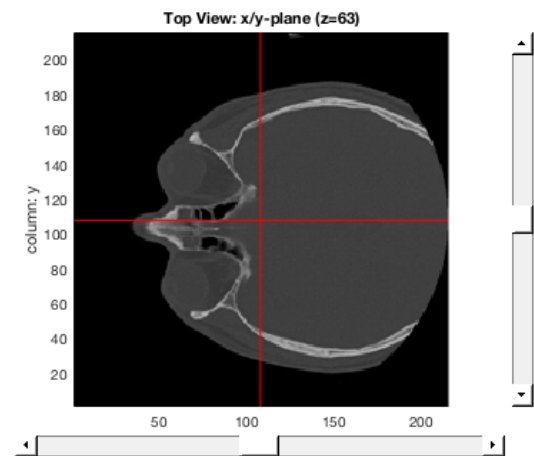
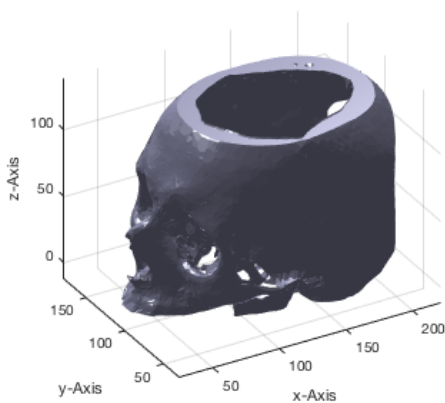
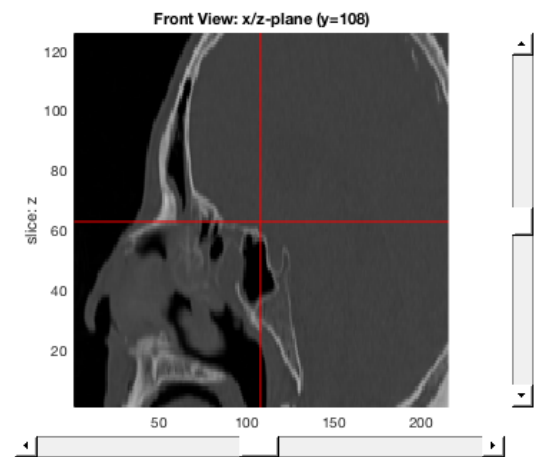
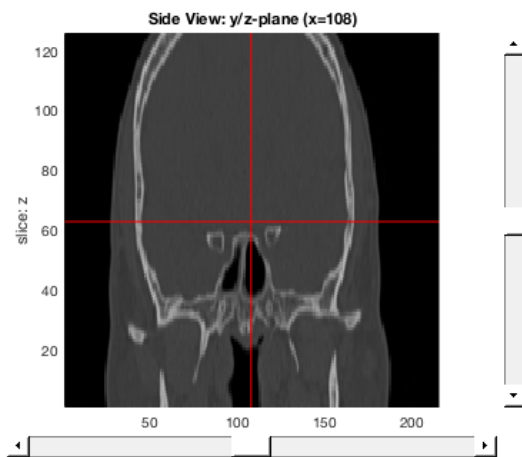


```
VLFLplotlight(0,1);
```



4 Show the Voxel model in quadrant 1-2-4 and surface model in quadrant 3

```
VMplot(a,'',SG1)
```



5. Create a surface model and convert it into a Voxel model

```
SGsample(17); VLFLplotlight(1,1);
```

```
[VM,ms,SG3]=VMofSG(SGsample(17),[128 128 128],true);  
whos VM  
ms  
SG3
```

```
VMofSG: 5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%  
Name      Size      Bytes  Class  Attributes
```

```
VM          128x128x128      16777216  double
```

```
ms =
```

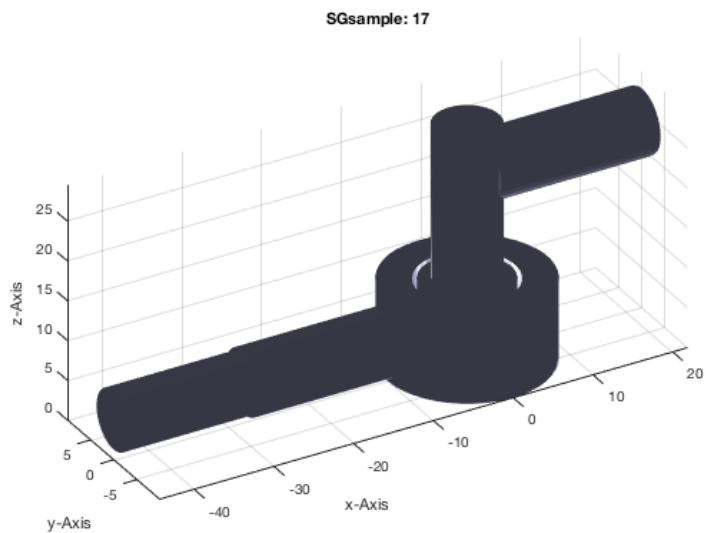
```
    0.5309    0.5309    0.2358
```

```
SG3 =
```

```
struct with fields:
```

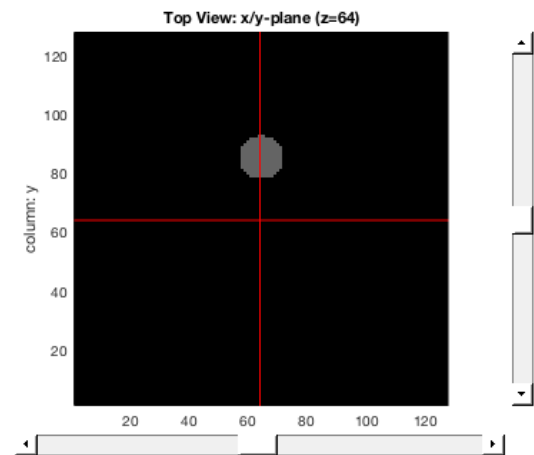
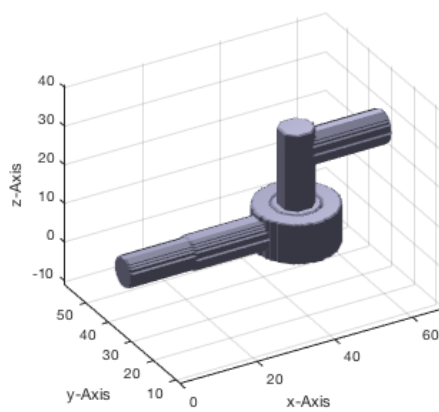
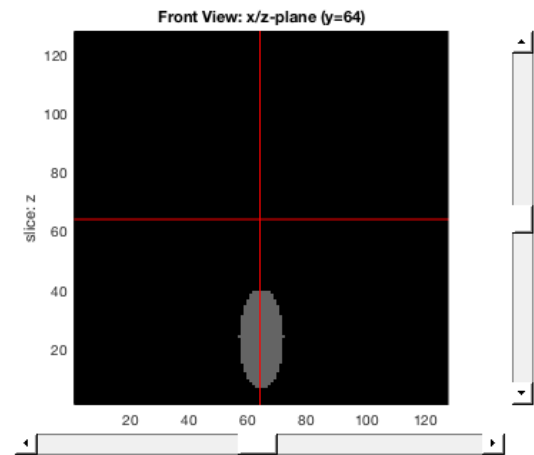
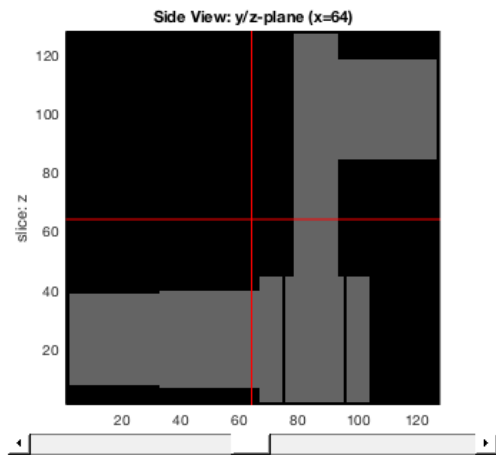
```
VL: [20614x3 double]
```

```
FL: [60580x3 double]
```



6. Plot the surface model in 4 quadrant plot

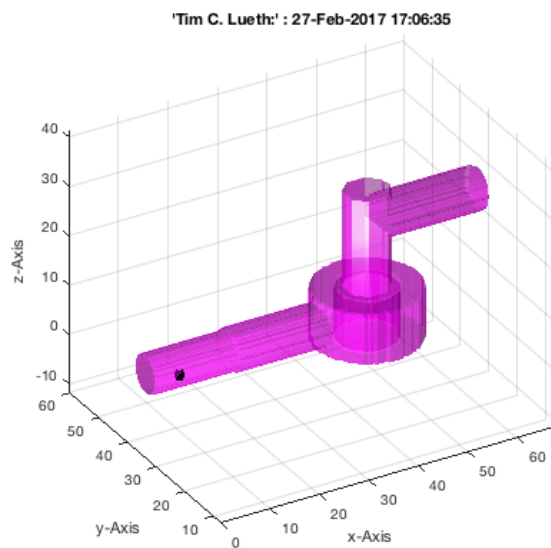
```
VMplot(VM, 'r', SG3)
```

7. Write the surface model as DICOM directory on disk

8. Select Point in 3D

```
SGfigure(SG3); view(-30,30); VLFLplotlight (1,.5);
ginput(1); p=select3d; pplot(p,'k*',4); rotate3d on
```



Final Remarks

```
close all
VLFLlicense
```

```
This VLFL-Lib, Rel. 3.4 (2017-Feb-28), is for limited non commercial educational use only!
Licensee: 3.4 Tim Lueth for academic and education 25-Jan-2017 !
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. 3.4) license will exceed at 23-Feb-2018!
Executed 27-Feb-2017 17:07:24 by 'timlueth' using Matlab 9.1.0.441655 (R2016b) on a MACI64
===== Used Matlab products: =====
image_toolbox
instr_control_toolbox
map_toolbox
matlab
robotics_system_toolbox
simmechanics
simscape
simulink
=====
```

Published with MATLAB® R2016b