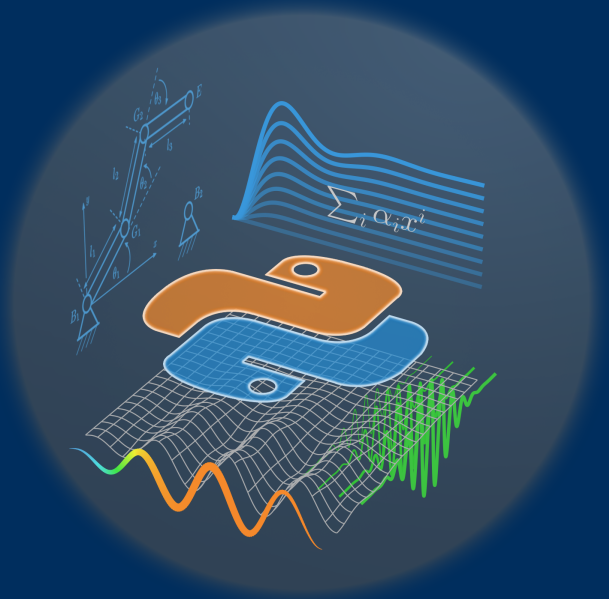
TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Electrical and Computer Engineering Institute of Control Theory

PYTHON FOR ENGINEERS
PYTHONKURS FÜR INGENIEUR:INNEN

3D-Visualization (with vtk)
3D-Visualisierung (mit vtk)



Slides: Sebastian Voigt, Carsten Knoll

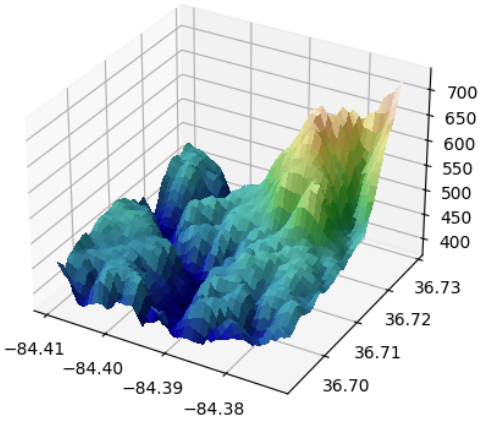
https://tu-dresden.de/pythonkurs
https://python-fuer-ingenieure.de

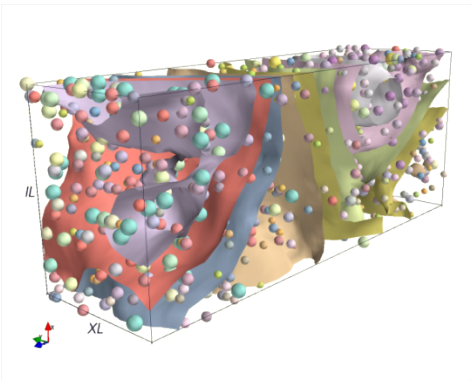
Dresden, 2022-12-16

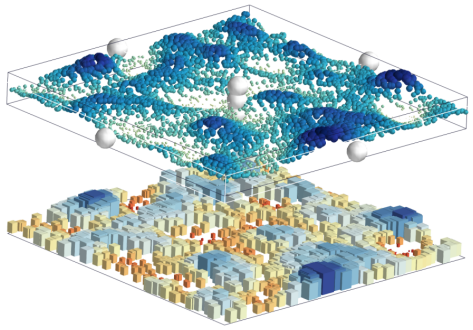
Fields of Applications (1)

- 3D visualization of measurement data, simulation results, etc.

→ higher information density, more illustrative representations







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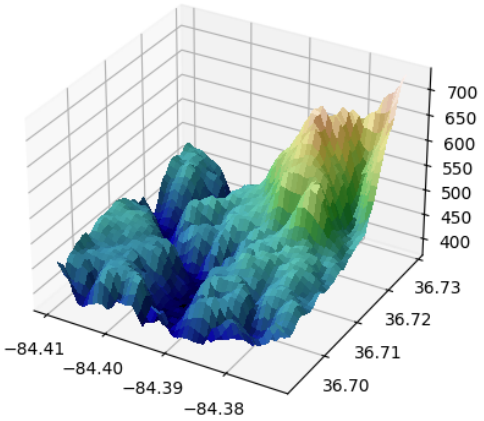
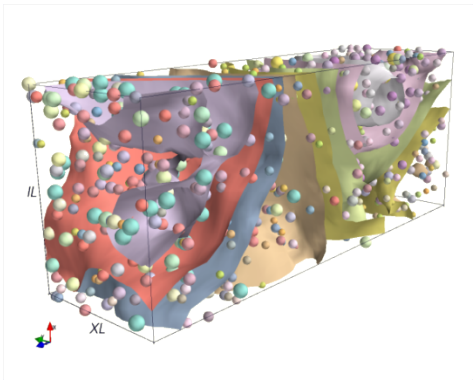
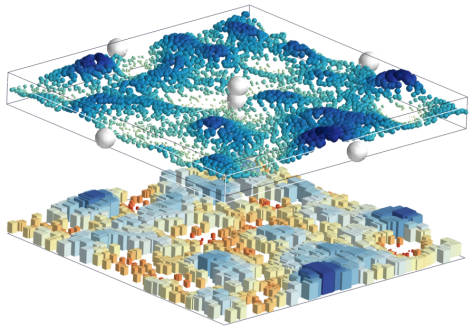




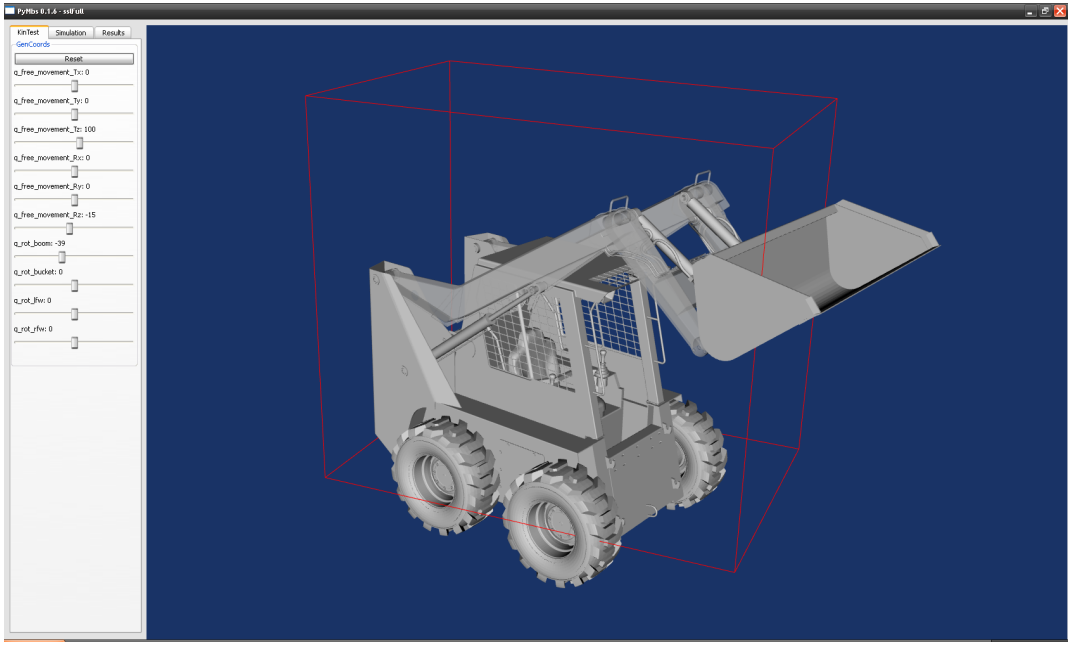


not covered here, but see e.g. matplotlib 3d and Mayavi: 3D data visualization

Fields of Applications (2)

- 3D scenes with bodies, lighting, animations etc.
- use of existing geometry models

→ better understanding of technical relations



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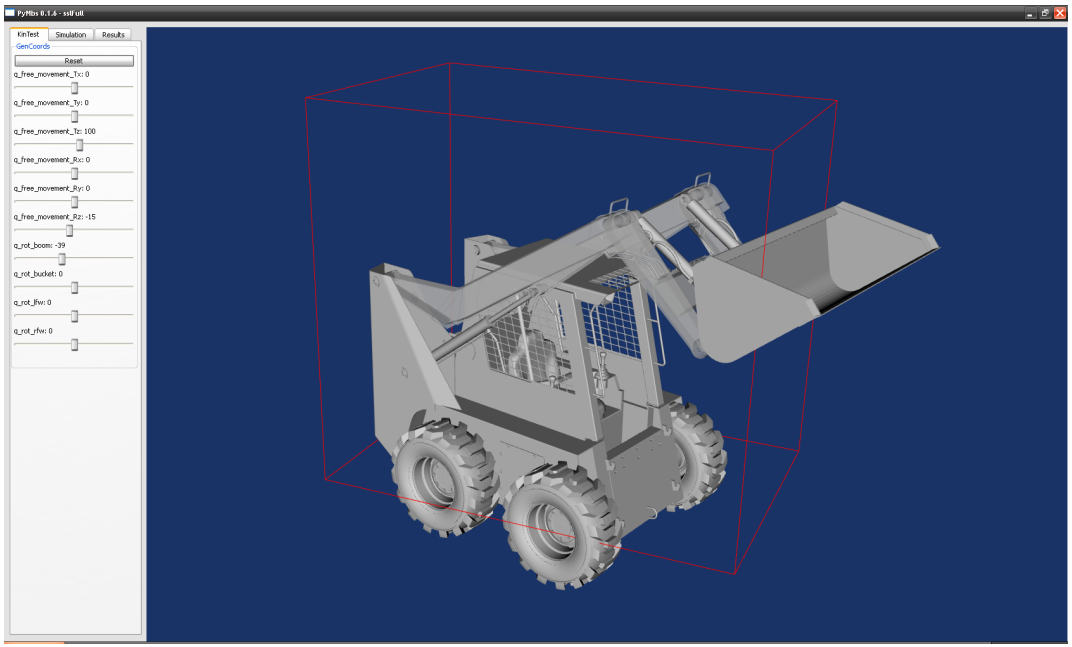


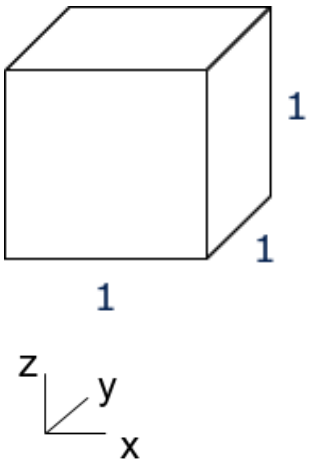
- we use: vtk (**v**isualisation **t**ool**k**it), see `http://www.vtk.org/`
  - installation: `pip install vtk` (from anaconda prompt)
  - Python wrapper arround C++ library

vtk: Introduction by Example (1)

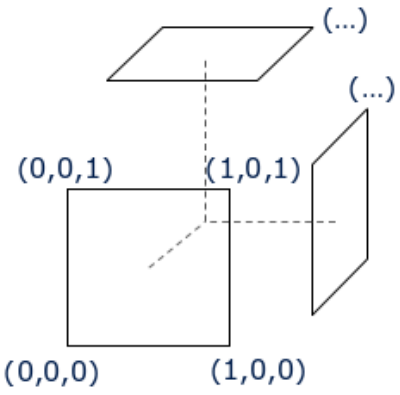
- create geometry primitive (here: cuboid):
- we need three objects (instances):
  - a source (geometric information)
  - a mapper (low level graphical representation; polygon mesh)
  - an actor (high level graphical representation; position, orientation, textures, ...)

Background on the Visualization Pipeline

Source

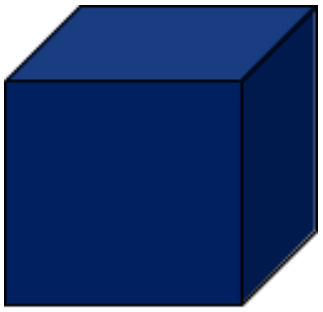


Mapper



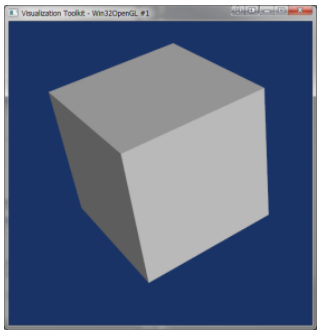
polygon mesh

Actor



optical properties, placement in space (most important object)

Renderer



2D image, light, camera

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listing: example-code/vtk1.py

```
1  import vtk
2
3  # create cuboid source
4  my_cuboidSource = vtk.vtkCubeSource()
5  my_cuboidSource.SetXLength(0.3)
6  my_cuboidSource.SetYLength(0.1)
7  my_cuboidSource.SetZLength(0.1)
8
9  # create and connect cuboid mapper
10 my_cuboidMapper = vtk.vtkPolyDataMapper()
11 my_cuboidMapper.SetInputConnection(my_cuboidSource.GetOutputPort())
12
13 # create and connect cuboid actor
14 my_cuboid = vtk.vtkLODActor()
15 my_cuboid.SetMapper(my_cuboidMapper)
```

vtk: Introduction by Example (2)

- create geometry primitive (here: cuboid):
- again: source, mapper, actor

listing: example-code/vtk1.py

```
17  # same (source, mapper, actor) for sphere
18  my_sphereSource = vtk.vtkSphereSource()
19  my_sphereSource.SetRadius(0.04)
20  my_sphereSource.SetThetaResolution(10)  # discretization
21  my_sphereSource.SetPhiResolution(10)
22
23  # mapper
24  my_sphereMapper = vtk.vtkPolyDataMapper()
25  my_sphereMapper.SetInputConnection(my_sphereSource.GetOutputPort())
26
27  # actor
28  my_sphere = vtk.vtkLODActor()
29  my_sphere.SetMapper(my_sphereMapper)
```

vtk: Introduction by Example (3)

displaying requires more objects:

- renderer (camera perspective, which object is behind which other, ...)
- render window (the 2D window to draw into)
- render window interactor (handle camera rotation, zoom (mouse and keyboard events))

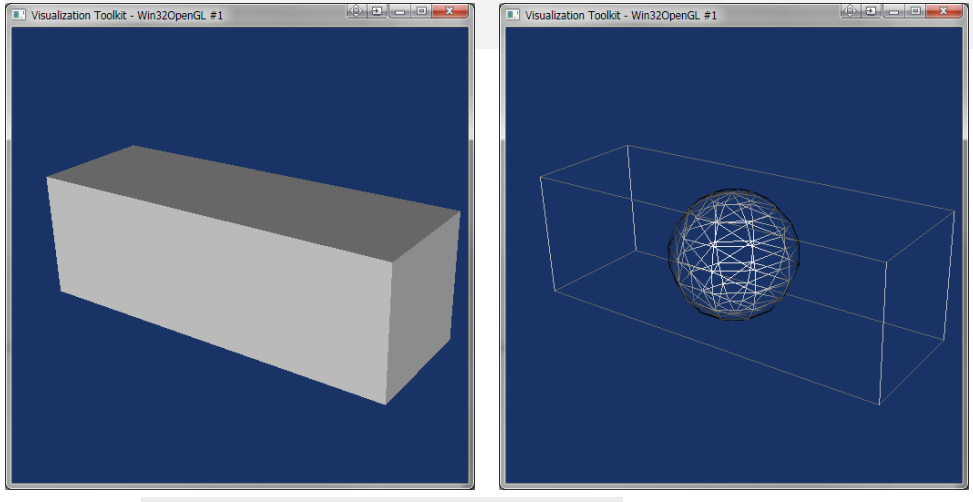
listing: example-code/vtk1.py

```
32  # create renderer
33  ren = vtk.vtkRenderer()
34
35  # add actors to renderer
36  ren.AddActor(my_cuboid)
37  ren.AddActor(my_sphere)
38
39  # create RenderWindow and RenderWindowInteractor
40  renWin = vtk.vtkRenderWindow()
41  renWin.AddRenderer(ren)
42  iren = vtk.vtkRenderWindowInteractor()
43  iren.SetRenderWindow(renWin)
```

vtk: Introduction by Example (4)

listing: example-code/vtk1.py

```
45  # background color and window size
46  ren.SetBackground(0.1, 0.2, 0.4)
47  renWin.SetSize(800, 800)
48
49  # select a more convenient interactor style and initialize
50  iren.SetInteractorStyle(vtk.vtkInteractorStyleTrackballCamera())
51  iren.Initialize()
52
53  # open window
54  iren.Start()
```



→ run `example-code/vtk1`

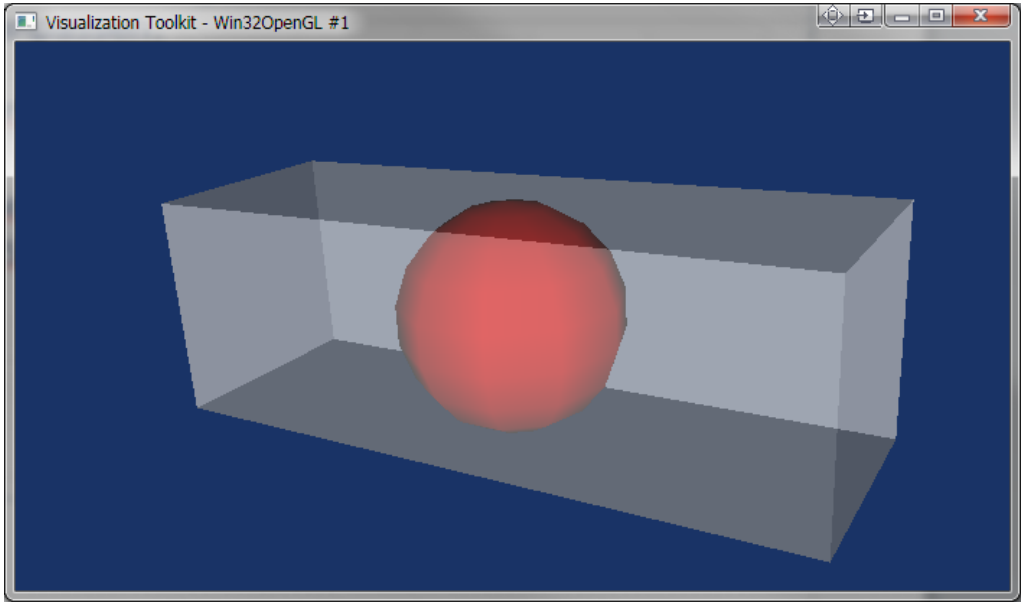
use mouse to zoom, rotate; switch views with W (wireframe) and S (solid).

Introduction by Example (5)

- customize color and transparency (of actor objects):

```
import vtk.util.colors as colors
my_sphere.GetProperty().SetColor(colors.red)
my_cuboid.GetProperty().SetOpacity(0.5)
```

- result:



Positioning of vtk Actors (1)

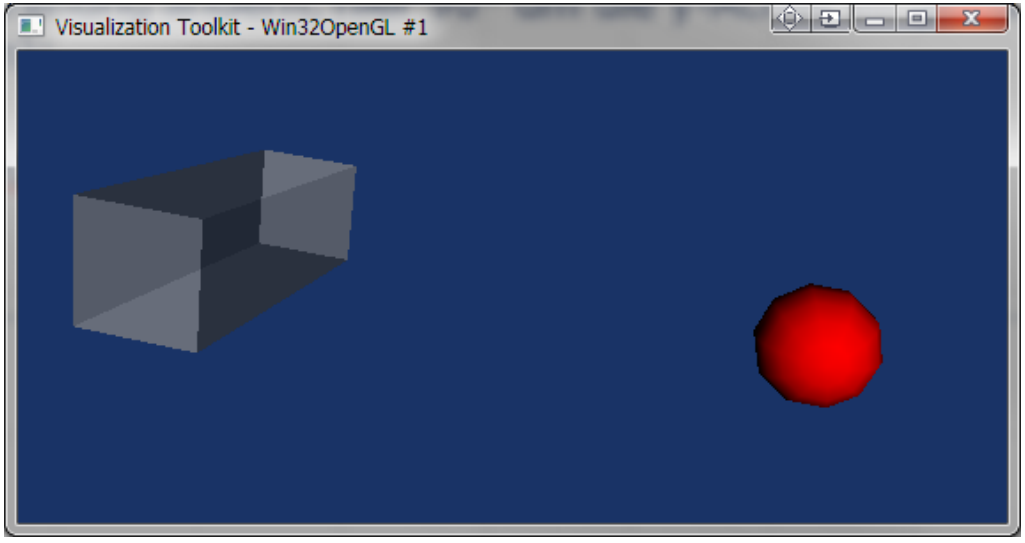
- change position (shift by x, y, z in the global coordinate system):

```
my_sphere.SetPosition(0.5, 0, 0)
```

- change orientation (rotate by 90° about the y axis in the global coordinate system):

```
my_cuboid.RotateWXYZ(90, 0, 1, 0)
```

- result:



Positioning of vtk Actors (2)

- universal transformations via poke matrix
- structure: $P = \left(\begin{array}{ccc|c} . & . & . & \vdots \\ . & R & . & r \\ . & . & . & \vdots \\ \hline 0 & 0 & 0 & 1 \end{array}\right)$, R 3D rotation matrix, r : 3D displacement vector

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example 1: rotation about y axis:

$$R_y(\varphi) = \begin{pmatrix} \cos\varphi & 0 & -\sin(\varphi) \\ 0 & 1 & 0 \\ \sin(\varphi) & 0 & \cos\varphi \end{pmatrix}$$

Bsp 2: no rotation:

$$R = I_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Positioning of vtk Actors (2)

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Listing: example-code/vtk2.py

```
62 P = np.eye(4)  # 4x4 unit matrix as numpy array
63 P[:-1, -1] = np.array([1, 2, 2.8])
64
65 # vtk does not understand numpy datatypes directly
66 # create empty vtk matrix and copy values from P
67 poke_matrix = vtk.vtkMatrix4x4()
68 vtk.vtkMatrix4x4.DeepCopy(poke_matrix, P.flatten())
69 my_cuboid.PokeMatrix(poke_matrix)
```

example 1: rotation about y axis:

$$R_y(\varphi) = \begin{pmatrix} \cos\varphi & 0 & -\sin(\varphi) \\ 0 & 1 & 0 \\ \sin(\varphi) & 0 & \cos\varphi \end{pmatrix}$$

Bsp 2: no rotation:

$$R = I_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Properties of the Actor Object

- optical properties are set via the `Property` object of the actor:
  ```
  propObj = actor.GetProperty()
  ```
- transparency: `propObj.SetOpacity(0.5)`
- color: `propObj.SetColor(0, 0, 1)  # rgb`
- reflexion type:

  ```
  propObj.SetAmbient(0.2)
  propObj.SetDiffuse(0.8)
  propObj.SetSpecular(0.5)
  propObj.SetSpecularPower(0.5)
  ```

- visibility of edges: `propObj.SetEdgeVisibility(1)`
- size: `propObj.SetScale(0.1)`

More Complex Geometries

- vtk $\neq$ 3D CAD software

$\rightarrow$ complex geometries should be loaded from files

- widespread file format: STL (originally for stereo lithography, see Wikipedia)

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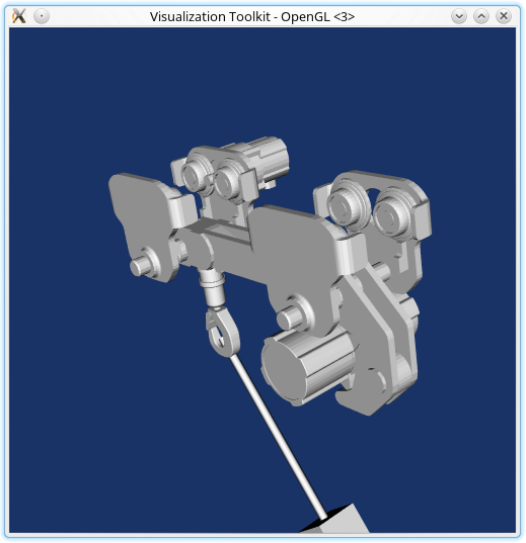
```
part = vtk.vtkSTLReader()
part.SetFileName("exercise/data/trolley.stl")
```

result:



Overview on Geometry Primitives

∃ source classes for: cuboid, sphere, line, cone, cylinder, ...

```
part = vtk.vtkCubeSource()
part.SetXLength(10)
part.SetYLength(1)
part.SetZLength(1)

part = vtk.vtkSphereSource()
part.SetRadius(5)
part.SetThetaResolution(20)
part.SetPhiResolution(20)

part = vtk.vtkCylinderSource()
part.SetRadius(1)
part.SetHeight(10)
Part.SetResolution(20)

part = vtk.vtkLineSource()
part.SetPoint1(0,0,0)
part.SetPoint2(10,0,0)
```

```
part = vtk.vtkConeSource()
part.SetHeight(10)
part.SetRadius(5)
part.SetResolution(20)
part.SetAngle(30)
part.Capping(2)

part = vtk.vtkAxes()
part.SetScaleFactor(1)

part = vtk.vtkSTLReader()
part.SetFileName("part.stl")

part = vtk.vtkTextSource()
part.SetText("Hello World")
```

Summary

- basics of 3D visualization with vtk
- visualization pipeline (source, mapper, actor, renderer, window, ...)
- actor objects are the most important
- placement via poke matrix
- geometry loading from stl files

- more information:
  - vtk Python examples
  - vtk book
  - introduction to vtk and paraview (lecture slides)