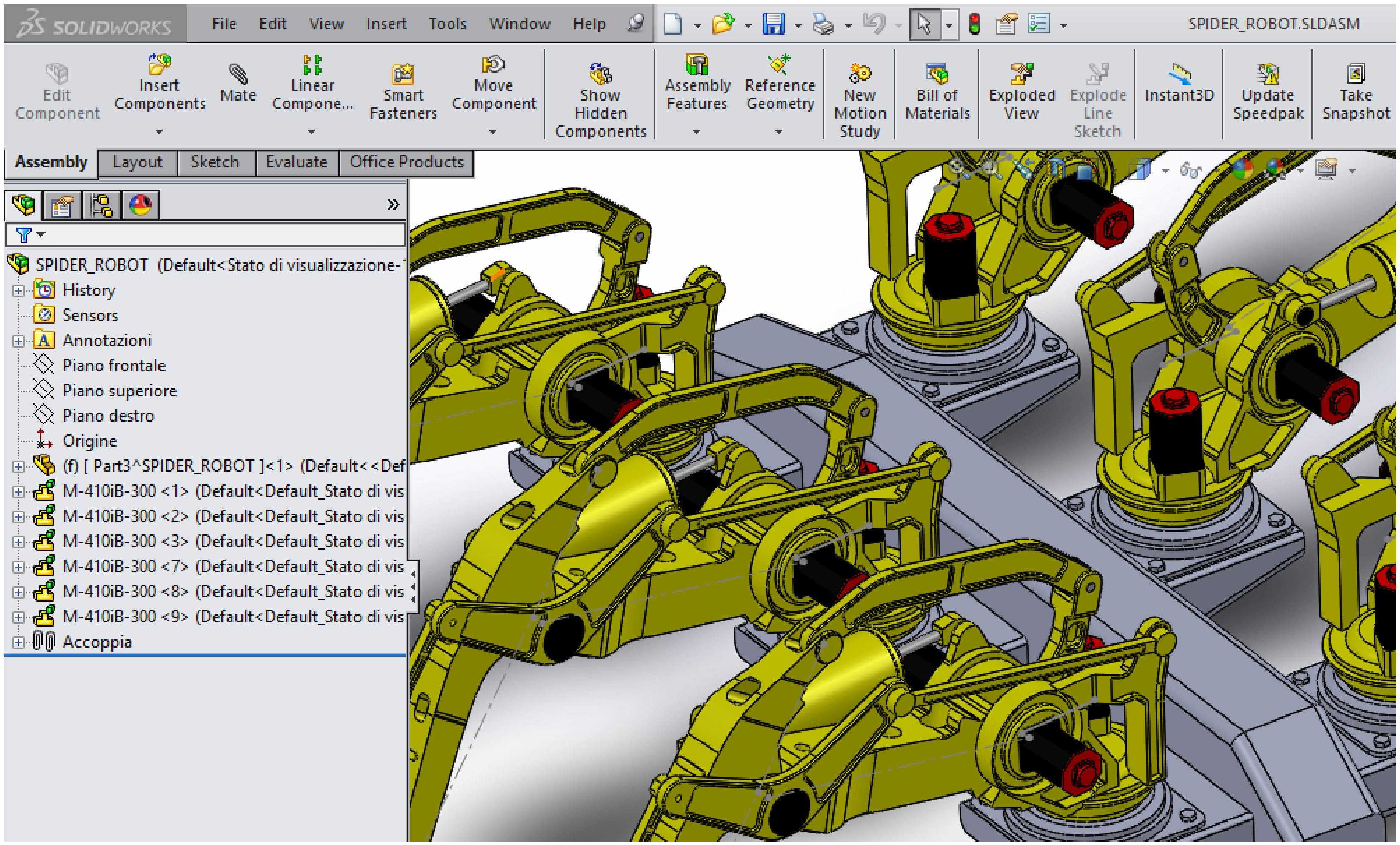
Chrono Support for Modeling Robotic Systems

A bio-inspired robot, using Chrono::Solidworks

Robotics: an example of workflow

- Use SolidWorks 3D CAD to model the robot
- Export the 3D CAD model using the Chrono::Solidworks add-in as a Python model
- Import the Python model
  - … in your C++ program (using the PYPARSER module in Chrono::Engine API)
  - … in your PYTHON program (using the Chrono::PyEngine units)
- Add actuators or additional parts/links using Chrono
- Impose motion to actuators
- Simulate the mechanism

Use SolidWorks CAD to model a bio-inspired robot



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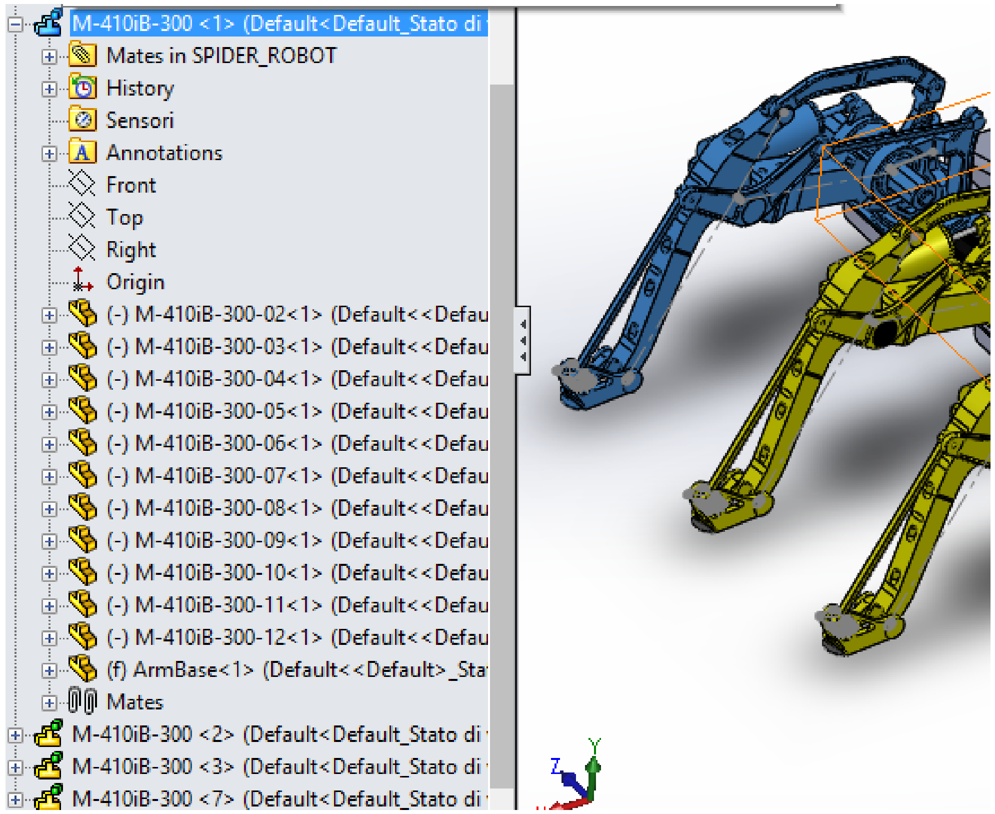
Accoppia

SolidWorks - rigid bodies

The Chrono::SolidWorks Add-in supports:

- Assemblies of parts
  - Ex: the robot arms
- Sub-assemblies of assembles
  - Ex: the full robot



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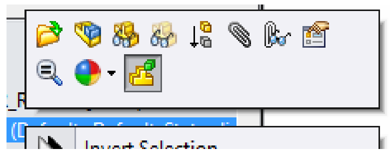
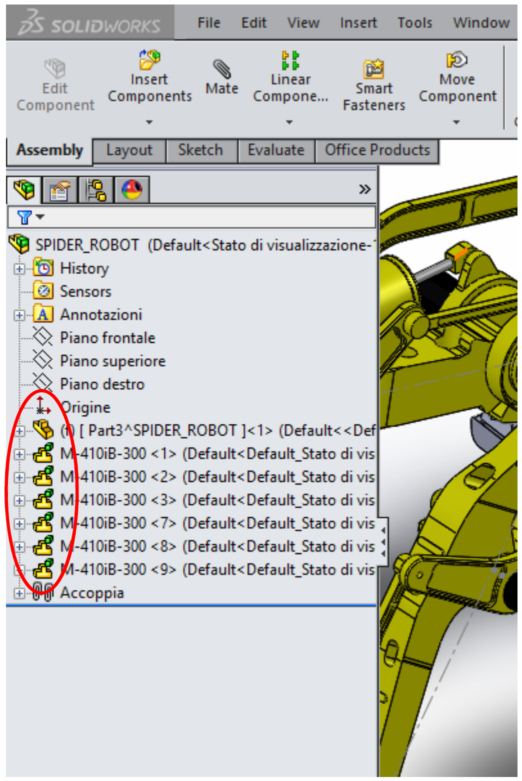
SolidWorks - rigid bodies

Hints:

- A sub-assembly by default in SW is considered a whole rigid body
  - Sub-assemblies like the robot arms would become single ChBody objects on the Chrono side…
  - Inner constraints would not be considered…

- Select the sub-assembly and use this icon of pop-up menu to switch to “flexible” SW assembly:
  - All SW parts in sub-assembly will become separate ChBody objects on the Chrono side
  - Inner constraints will be translated into ChLink constraints on the Chrono side

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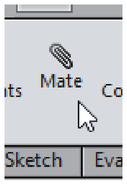
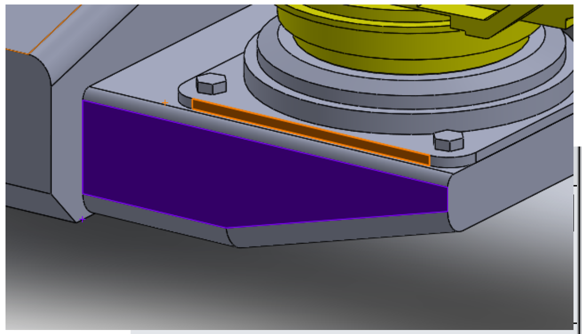
Accoppia

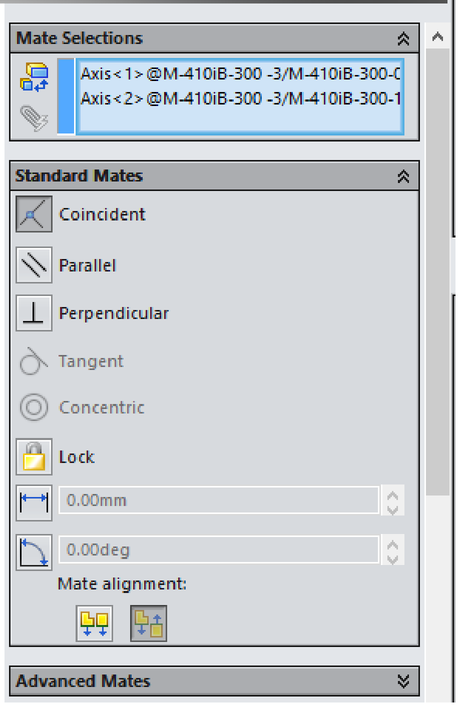
SolidWorks - constraints

- Use the “mates” tool to create constraints in SW
- Most SW “mates” constraints will be translated into ChLink constraints on the Chrono side:
  - Coincident (plane vs plane, plane vs point, edge vs plane, …)
  - Parallel (plane vs plane, plane vs edge, edge vs edge, …)
  - Parpendicular …
  - Distance …
  - Concentric …

- Some SW mates are not yet supported, sorry
  - Advanced mates
  - Tangent etc.







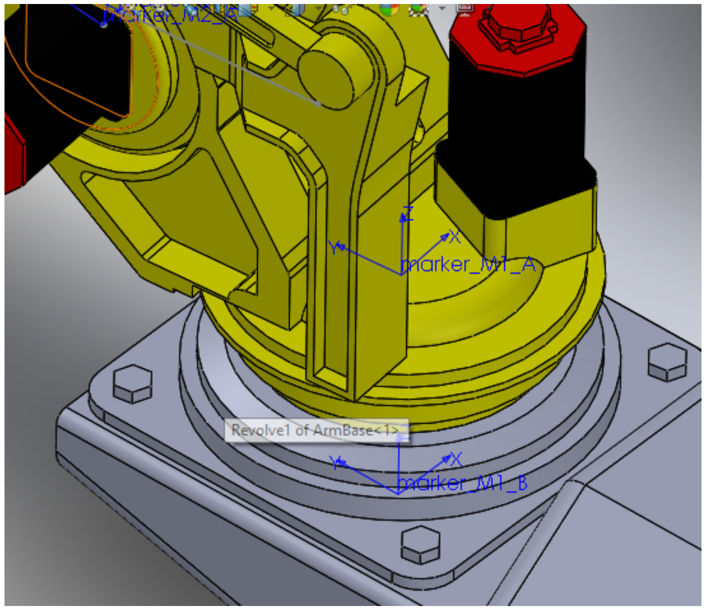
Axis<1>@M-410iB-300 -3/M-410iB-300-C
Axis<2>@M-410iB-300 -3/M-410iB-300-1

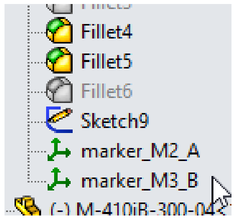
0.00mm

0.00deg

SolidWorks - markers

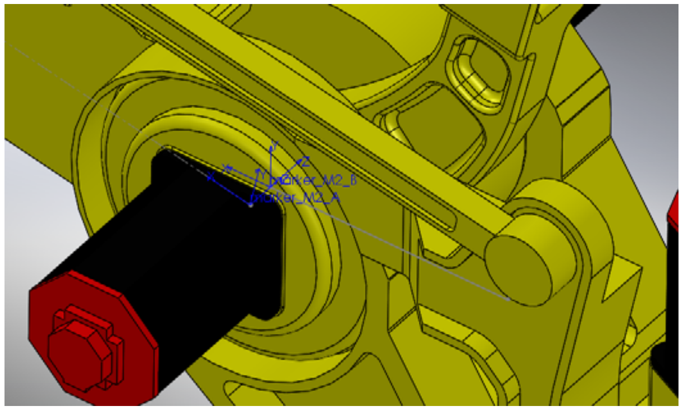
- SolidWorks “coordinate systems” are translated in ChMarker objects on the Chrono side
- This is a useful way to add custom Chrono constraints from the C++ side, later, by referencing pairs of markers
- In our robot example: add pair of markers where you need to create ChLinkEngine objects (with Z axis aligned to the engine shaft):
- Give them a mnemonic name in SW, so it is easier to retrieve them from the C++ side:

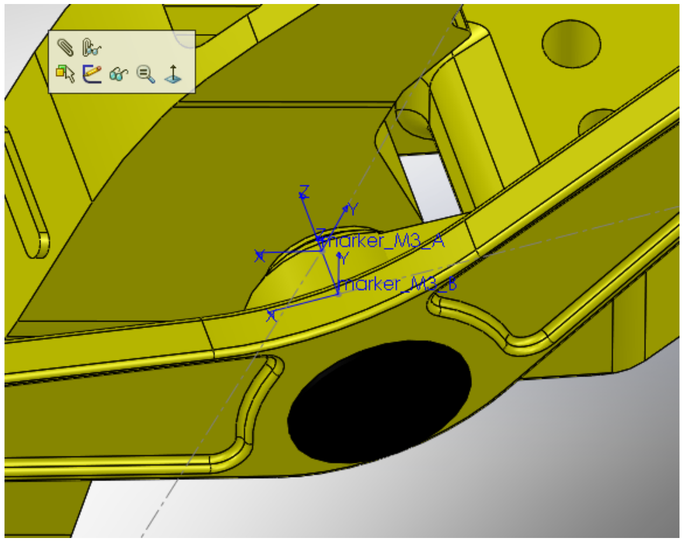




SolidWorks - actuators

- For our spider robot example:
  - Each leg is a 3 DOF arm (like a 'top loader' packaging robot, without gripper)
  - We need 3 actuators (three 'ChLinkEngine') per leg
  - Sorry, the SolidWorks "motor" object is not yet translated into a Chrono ChLinkEngine object (planned for future releases)..
  - ..so we just add couples of markers per each motor, and we'll add the ChLinkEngine objects programmatically, later from the Chrono side
    - Two for the vertical shoulder rotation
    - Two for the up-down rotation
    - Two for the forearm rotation

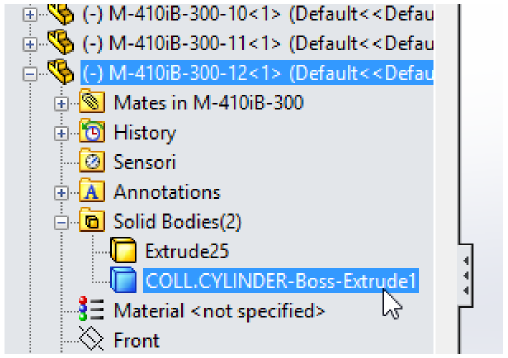




SolidWorks - collision shapes

Collision shapes can be defined in the SolidWorks interface

- Each part of SolidWorks can contain multiple “solid bodies”
- Use one SW “solid body” for the shape (mass, visualization), and create others for collision shapes
- Supported collision shapes:
    - Cylinders
    - Spheres
    - Boxes
    - Convex hulls
    - (compounds of the above)



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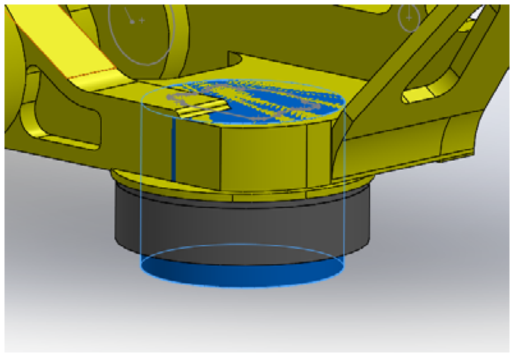
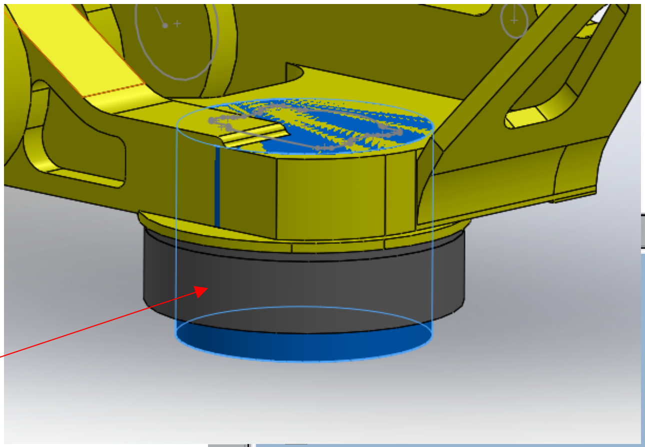
COLL.CYLINDER-Boss-Extrude1
Material <not specified>
Front

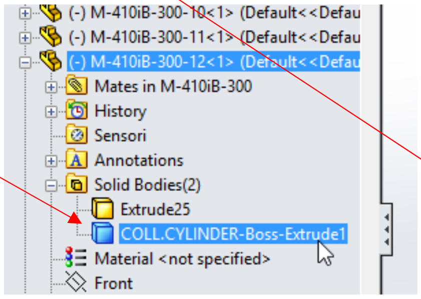


SolidWorks - collision shapes

Collision shapes can be defined in the SolidWorks interface

- For the spider robot example: add a collision shape for the foot contact
  - Extrude a cylinder feature in the foot part
  - Do not merge the cylinder feature with the foot shape
  - Select the cylinder and use the “Set body as collision shape” button
  - Look how the name of the cylinder changed:





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Annotations
Solid Bodies(2)
Extrude25
COLL.CYLINDER-Boss-Extrude1
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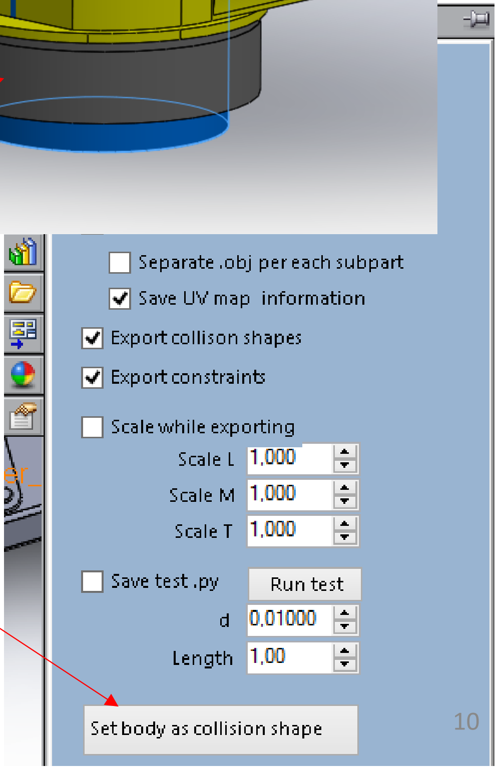


- [ ] Separate .obj per each subpart
- [x] Save UV map information
- [x] Export collison shapes
- [x] Export constraints
- [ ] Scale while exporting

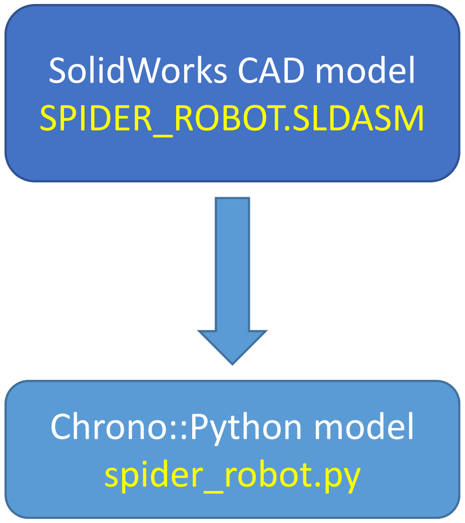
Scale L 1,000
Scale M 1,000
Scale T 1,000

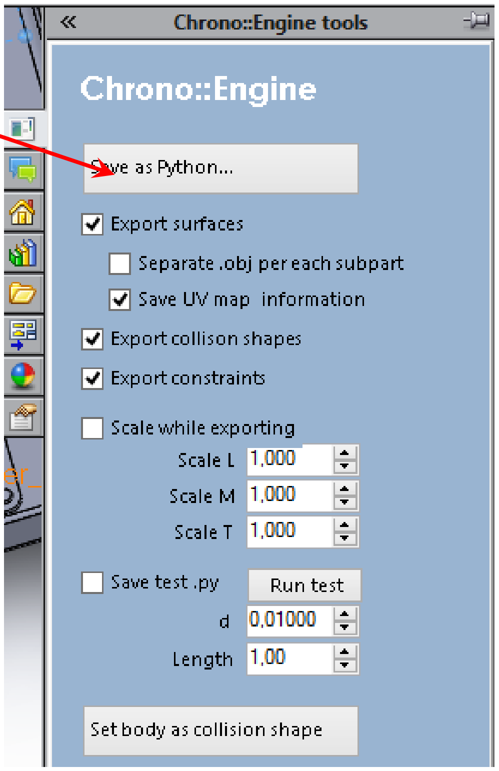
- [ ] Save test .py

d 0,01000
Length 1,00

Export the 3D CAD model to a .py file

- Use the “Save as Python” button to export the model into a .py file for later use in Chrono programs





Chrono::Engine tools

[✓] Export surfaces
[ ] Separate .obj per each subpart
[✓] Save UV map information
[✓] Export collison shapes
[✓] Export constraints
[ ] Scale while exporting

Scale L 1,000
Scale M 1,000
Scale T 1,000

[ ] Save test .py

d 0,01000
Length 1,00

A peek into the spider_robot.py model

```
import ChronoEngine_python_core as chrono
import builtins

shapes_dir = 'spider_robot_shapes/'

if hasattr(builtins, 'exported_system_relpath'):
    shapes_dir = builtins.exported_system_relpath + shapes_dir

exported_items = []

body_0= chrono.ChBodyAuxRef()
body_0.SetName('ground')
body_0.SetBodyFixed(True)
exported_items.append(body_0)

# Rigid body part
body_1= chrono.ChBodyAuxRef()
body_1.SetName('M-410iB-300 -9/M-410iB-300-12-1')
body_1.SetPos(chrono.ChVectorD(-4.07967425969663,1.53452994138092,0.579942165862929))
body_1.SetRot(chrono.ChQuaternionD(-0.0412727252884181,-0.000468569478897146,0.999147807992026,1.93556340954814e-05))
body_1.SetMass(16.1636065115335)
body_1.SetInertiaXX(chrono.ChVectorD(0.270733820597613,0.400877809867468,0.427371867141468))
body_1.SetInertiaXY(chrono.ChVectorD(0.0574221068634287,0.0377110505251339,-0.0625539343672037))
body_1.SetFrame_COG_to_REF(chrono.ChFrameD(chrono.ChVectorD(-0.0294847451383035,0.131793864973377,-0.039955675141979),chrono.ChQuaternionD(1,0,0,0)))

# Visualization shape
body_1_1_shape = chrono.ChObjShapeFile()
body_1_1_shape.SetFilename(shapes_dir +'body_1_1.obj')
body_1_1_level = chrono.ChAssetLevel()
body_1_1_level.GetFrame().SetPos(chrono.ChVectorD(0,0,0))
body_1_1_level.GetFrame().SetRot(chrono.ChQuaternionD(1,0,0,0))
body_1_1_level.GetAssets().push_back(body_1_1_shape)
body_1.GetAssets().push_back(body_1_1_level)

# Collision shapes
body_1.GetCollisionModel().ClearModel()
mr = chrono.ChMatrix33D()
mr[0,0]=0; mr[1,0]=0; mr[2,0]=-1
mr[0,1]=0; mr[1,1]=-1; mr[2,1]=0
mr[0,2]=-1; mr[1,2]=0; mr[2,2]=0
body_1.GetCollisionModel().AddCylinder(0.0891514706007005,0.0891514706007005,0.0737653824400992,chrono.ChVectorD(4.57739150408006E-17,0.0737653824400992,0),mr)
body_1.GetCollisionModel().BuildModel()
body_1.SetCollide(True)

exported_items.append(body_1)

.. .
```

Import the Python model

There are two ways to load and simulate a .py file generated by the SolidWorks add-in:

- In a **C++ program** – use the pyparser library from the PYTHON unit of Chrono, to load **spider_robot.py** with `ImportSolidWorksSystem()`

- In a **PYTHON program** – just use the chrono python modules to load **spider_robot.py** with `ImportSolidWorksSystem()`

Used in this demo, for simplicity

(Not so many differences, by the way)

Import the Python model

- The Chrono::PyEngine modules must be correctly installed
  - Compile Chrono with the PYTHON unit enabled
  - If all is fine, Chrono modules will be available from the Python side, try demo_python_1.py
  - Suggested: use a Python IDE , ex. PyScripter

- Create a **demo_spider.py** program

- First: import the Chrono::PyEngine by writing

```
import os
import math
import ChronoEngine_python_core as chrono
import ChronoEngine_python_postprocess as postprocess
import ChronoEngine_python_irrlicht as chronoirr
```

Import the Python model

- Then, use the following to load the .py model:

```
mysystem  = chrono.ChSystem()

parts = chrono.ImportSolidWorksSystem('./spider_robot');

for ib in parts:
    mysystem.Add(ib);
```

- Note, do not pass ".py" suffix in ImportSolidWorksSystem()

Import the Python model

- Some components are not present in the .py model – the actuators!
- We will add them programmatically, connecting pair of **ChMarker** with ChLinkEngine
- Retrieve the ChMarker objects from their names as in:

```
bbody    = mysystem.SearchBody('Part3^SPIDER_ROBOT-1');
bbody.SetBodyFixed(False);
b1base    = mysystem.SearchBody('M-410iB-300 -1/ArmBase-1');
b1turret  = mysystem.SearchBody('M-410iB-300 -1/M-410iB-300-02-1');
b1bicept  = mysystem.SearchBody('M-410iB-300 -1/M-410iB-300-03-1');
b1forearm = mysystem.SearchBody('M-410iB-300 -1/M-410iB-300-06-1');
m1_1B = b1base.   SearchMarker('marker_M1_B');
m1_1A = b1turret. SearchMarker('marker_M1_A');
m1_2B = b1turret. SearchMarker('marker_M2_B');
. . .
```

- Note, look in SolidWorks GUI or in spider_robot.py if you do not remember the mnemonic names, and remember that `M-410iB-300 <1>` in GUI becomes `M-410iB-300 -1` in code

Add actuators or additional parts/links using Chrono

- Create some f(t) motion functions to be assigned to the actuators
- ChLinkEngines will use them in ‘impose rotation mode’
- Each represents the imposed rotation of the joint [rad], as a function of time [s]
- (In a more sophisticated simulator, one can put the ChLinkEngines in ZOH ‘impose torque’ and adjust torque in real time using some PID, IK, i.e. complex controller systems)
- The f(t) functions are created from the ChFunction class hierarchy
- Interesting: use ChFunction_Sequence to queue multiple curves, and ChFunction_Repeat to make periodic functions

Add actuators or additional parts/links using Chrono

- Example of f(t) functions for this example:

```
period = 2;
mfunc_sineS   = chrono.ChFunction_Sine(0, 1.0/period,  0.2);  # phase, frequency, amplitude
mfunc_swingSa = chrono.ChFunction_Repeat();
mfunc_swingSa.Set_fa(mfunc_sineS);
mfunc_swingSa.Set_window_length(period);
mfunc_swingSa.Set_window_start(0);
mfunc_swingSb = chrono.ChFunction_Repeat();
mfunc_swingSb.Set_fa(mfunc_sineS);
mfunc_swingSb.Set_window_length(period);
mfunc_swingSb.Set_window_start(period/2.0);
mfunc_sineD   = chrono.ChFunction_Sine(0, 1.0/period, -0.2);  # phase, frequency, amplitude
mfunc_swingDb = chrono.ChFunction_Repeat();
mfunc_swingDb.Set_fa(mfunc_sineD);
mfunc_swingDb.Set_window_length(period);
mfunc_swingDb.Set_window_start(period/2.0);
mfunc_swingDa = chrono.ChFunction_Repeat();
mfunc_swingDa.Set_fa(mfunc_sineD);
mfunc_swingDa.Set_window_length(period);
mfunc_swingDa.Set_window_start(0);
Etc. . .
```

Add actuators or additional parts/links using Chrono

- Create the actuators using **ChLinkEngine** objects between couple of ChMarker objects:

```
# Add actuators to Leg n.1

motor1_1 = chrono.ChLinkEngine();
motor1_1.Initialize(m1_1A, m1_1B);
motor1_1.Set_eng_mode(chrono.ChLinkEngine.ENG_MODE_ROTATION);
motor1_1.Set_rot_funct(mfunc_swingSa);
mysystem.Add(motor1_1);

motor1_2 = chrono.ChLinkEngine();
motor1_2.Initialize(m1_2A, m1_2B);
motor1_2.Set_eng_mode(chrono.ChLinkEngine.ENG_MODE_ROTATION);
motor1_2.Set_rot_funct(mfunc_updownA);
mysystem.Add(motor1_2);

motor1_3 = chrono.ChLinkEngine();
motor1_3.Initialize(m1_3A, m1_3B);
motor1_3.Set_eng_mode(chrono.ChLinkEngine.ENG_MODE_ROTATION);
motor1_3.Set_rot_funct(mfunc_const);
mysystem.Add(motor1_3);
```

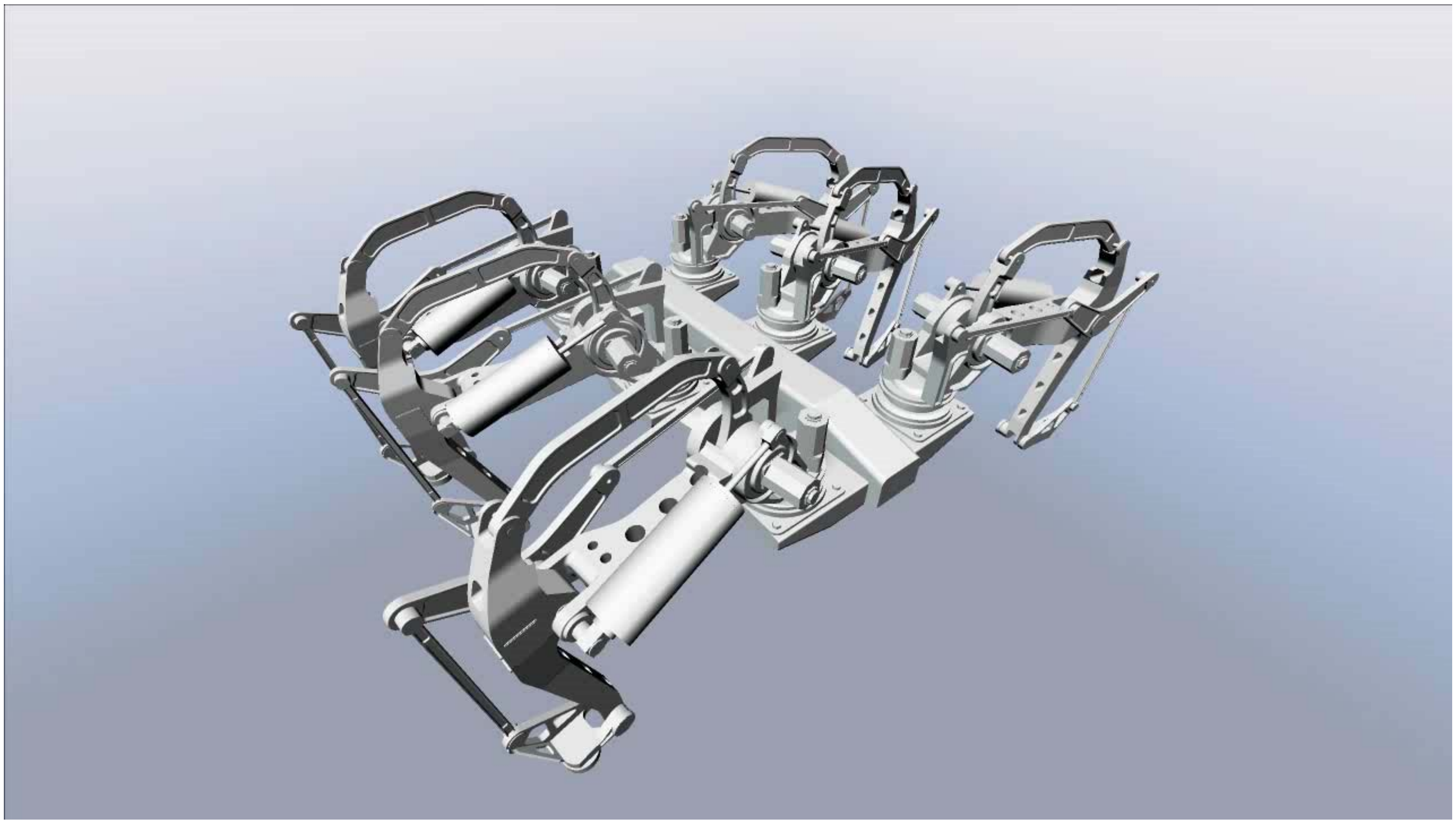
Setup Irrlicht visualization

```
myapplication = chronoirr.ChIrrApp(
                     mysystem,
                     'Test',
                     chronoirr.dimension2du(1280,720))

myapplication.AddTypicalSky('./data/skybox/')
myapplication.AddTypicalCamera(
                     chronoirr.vector3df(2.8,2.6,2.8),
                     chronoirr.vector3df(0.0,2.6,0.0))
myapplication.AddTypicalLights()
myapplication.AddLightWithShadow(
                     chronoirr.vector3df(10,20,10),
                     chronoirr.vector3df(0,2.6,0),
                     10 ,10,40, 60, 512);


myapplication.AssetBindAll();


myapplication.AssetUpdateAll();


myapplication.AddShadowAll();
```

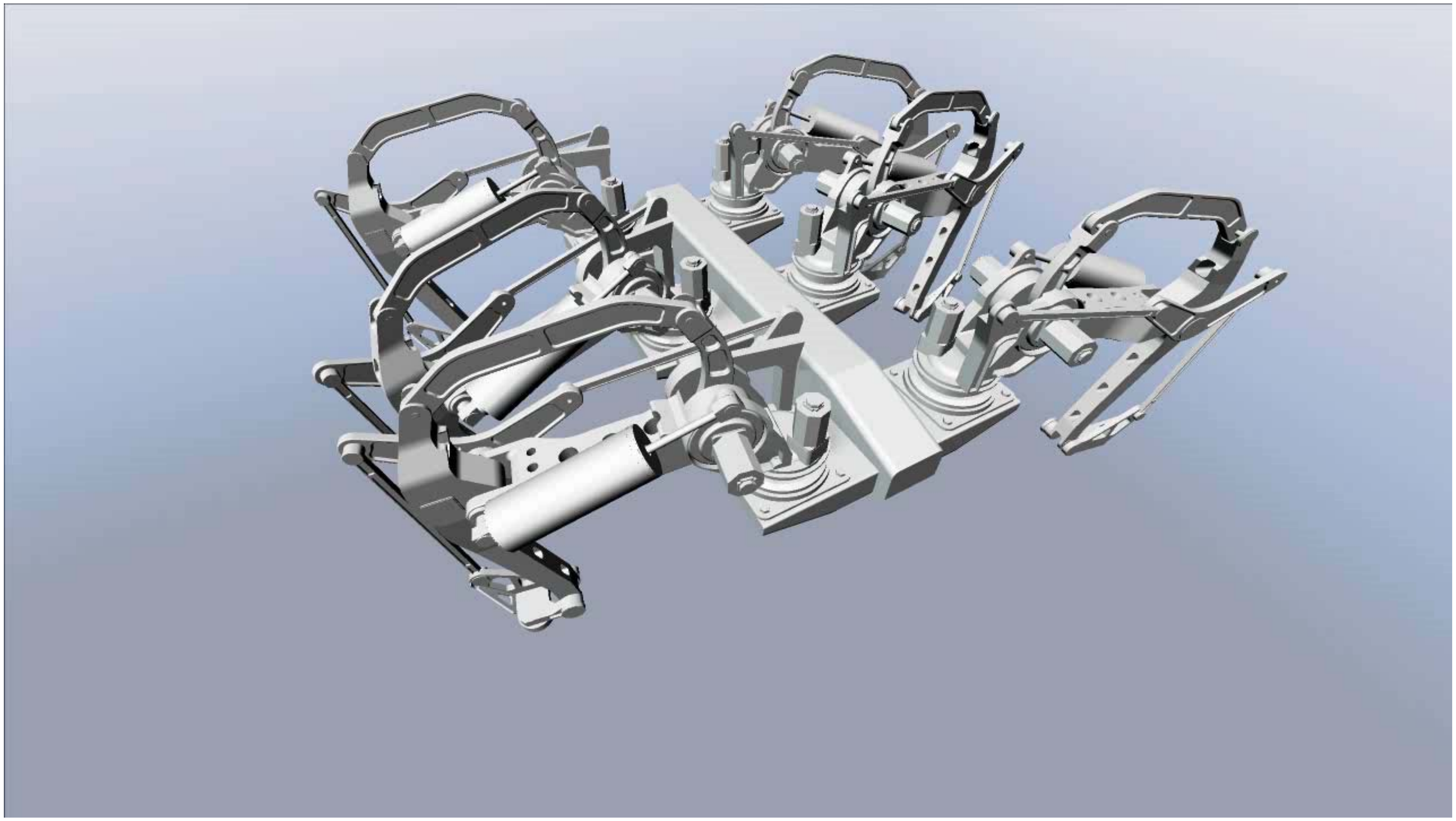
The simulation loop

```
mysystem.SetMaxItersSolverSpeed(600);
mysystem.SetSolverWarmStarting(True);
mysystem.SetSolverType(chrono.ChSystem.SOLVER_BARZILAIBORWEIN);
myapplication.SetTimestep(0.002);


while(myapplication.GetDevice().run()):
    myapplication.BeginScene()
    myapplication.DrawAll()
    myapplication.DoStep()
    myapplication.EndScene()
```

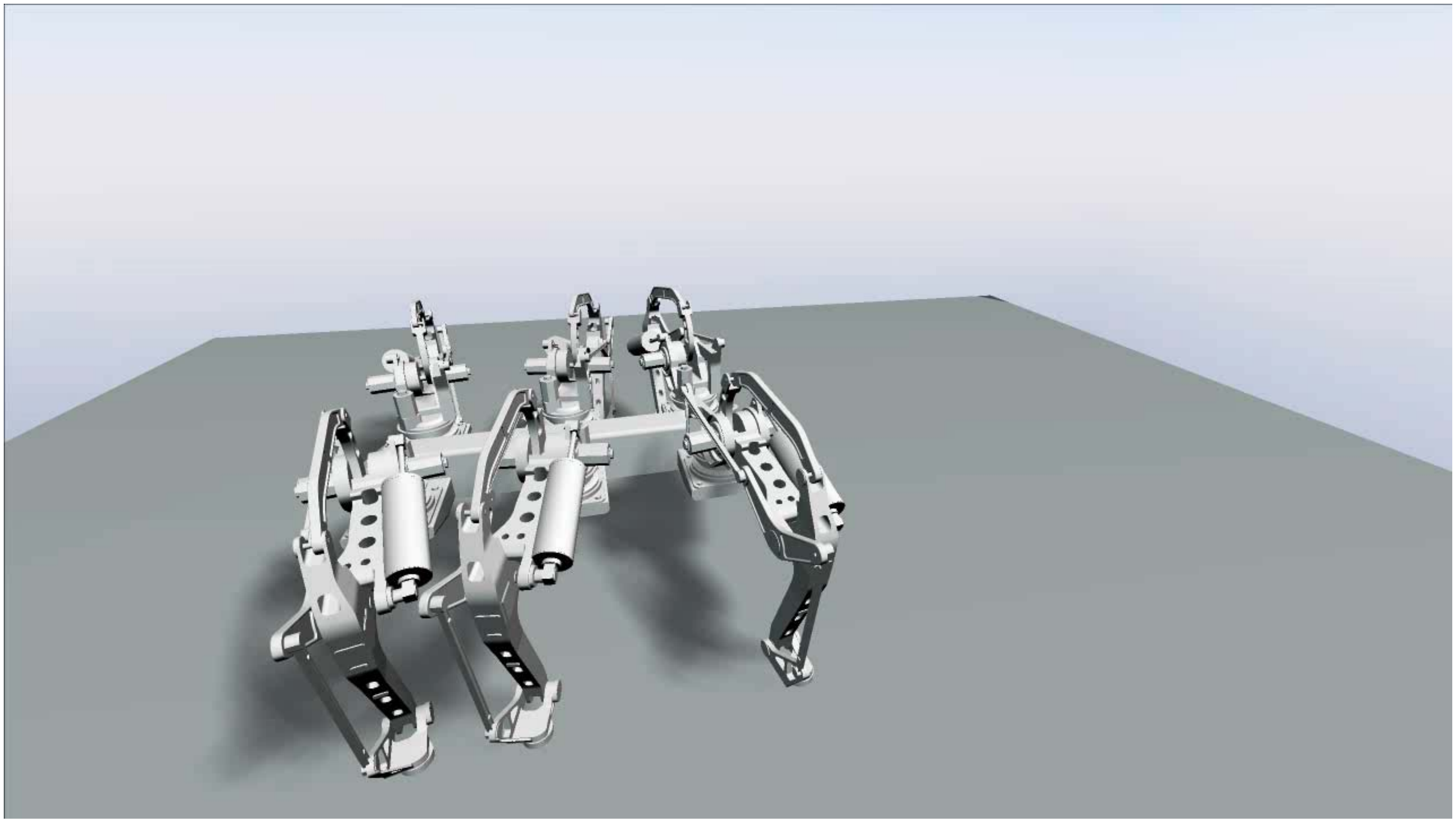
Simulate the mechanism (walk pattern A)



Simulate the mechanism (walk pattern B – better)



Simulate the mechanism



Conclusions

- Used Chrono::SolidWorks add-in as a preprocessor
- This add-in is under development: some SolidWorks mates are not yet translated into equivalent Chrono constraints
- Exported models in .py files can be load in C++ programs or Python programs
- One can add engines, actuators etc. programmatically
- The demo_spider.py program could be written as a C++ program with minimal differences
- This is a quick demo: a more advanced simulator could include sophisticated gait algorithms, path following, PID based actuators, Simulink co-simulation, etc.

Future developments

- We are developing a new ROBOTICS module for Chrono

- Some features are already in development
  - Support for artificial vision
  - Support for sensors
  - Path following, controllers,
  - Visualization tools
  - Etc.