This lecture will be recorded

064-0026-00L: COMPAS II

Introduction to Computational Methods for Digital Fabrication in Architecture

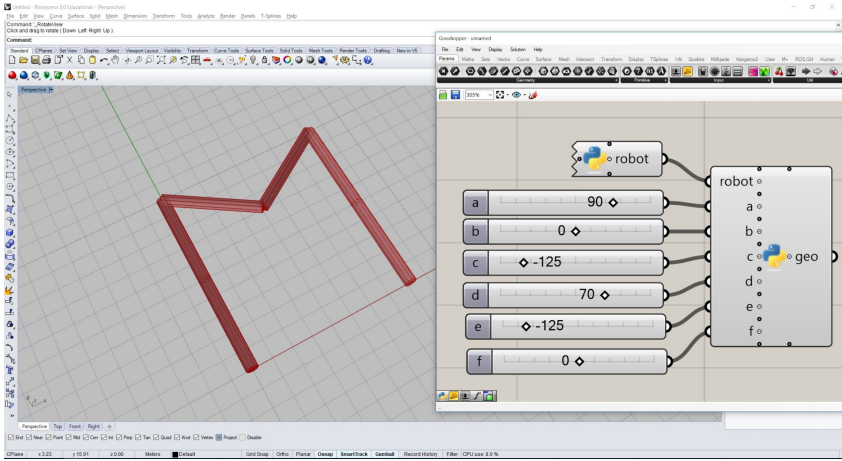
slides + code

*https://***dfab.link/fs2022**

docker/first_steps

Review of last week's assignment

1. Build your own robot with a certain number n of links and n - 1 configurable joints.
2. Create a `Configuration` with certain values and the correct joint types.
3. Create a `Artist`.
4. Use the artist to `update` the robot with the created configuration, such that it configures into the letter of your choice (or any other identifiable figure).



TODAY

robot backends: ros

interconnecting nodes

planning with moveit

Understand **basics of ROS and MoveIt** for planning

robot backends: ros

Robotic backends

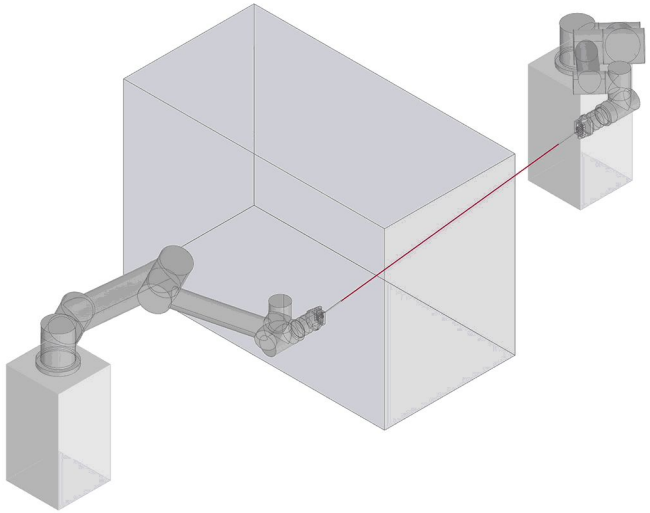
`V-REP`
Robot simulator

`ROS + MoveIt!`
Robot Operating System

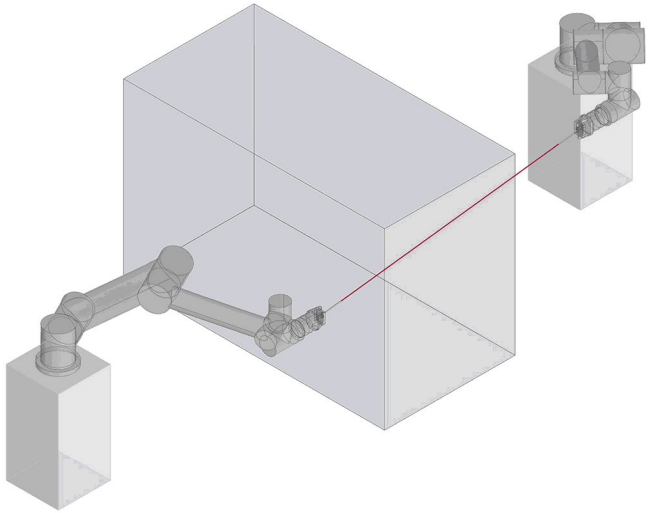
`Pybullet`
Physics library

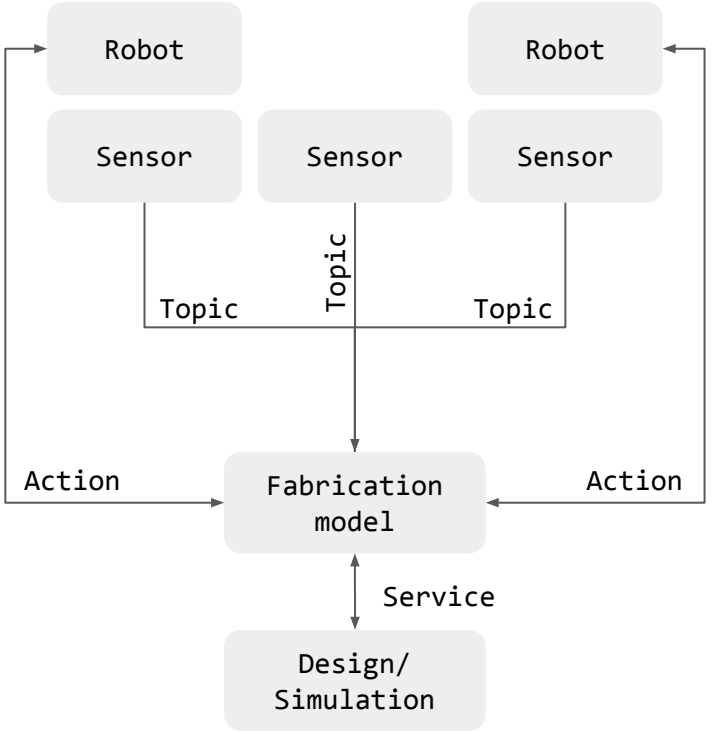

ROS
Open Source Robotics Foundation

Fabrication processes

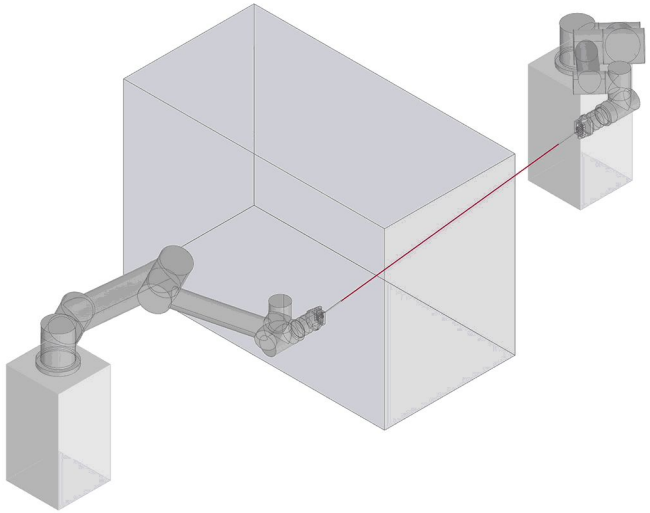


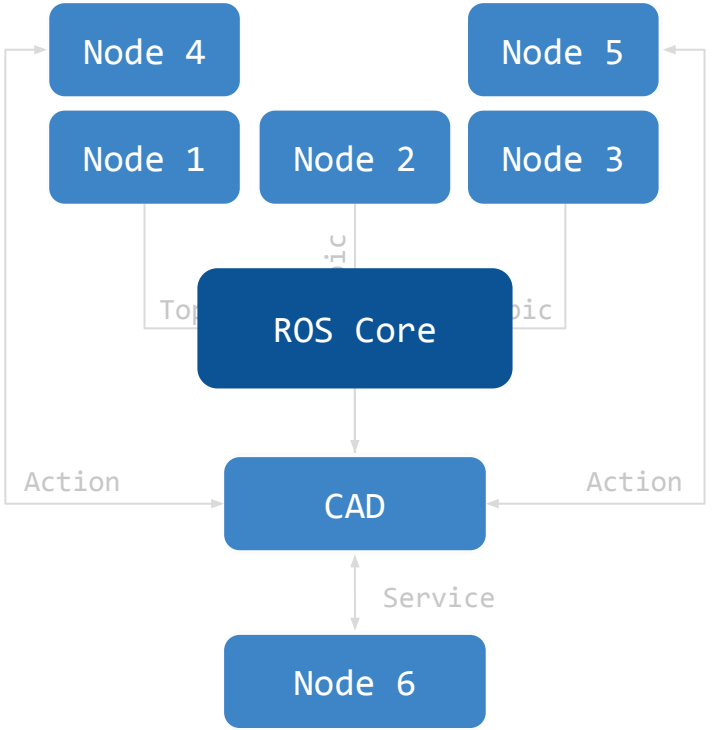
Fabrication processes



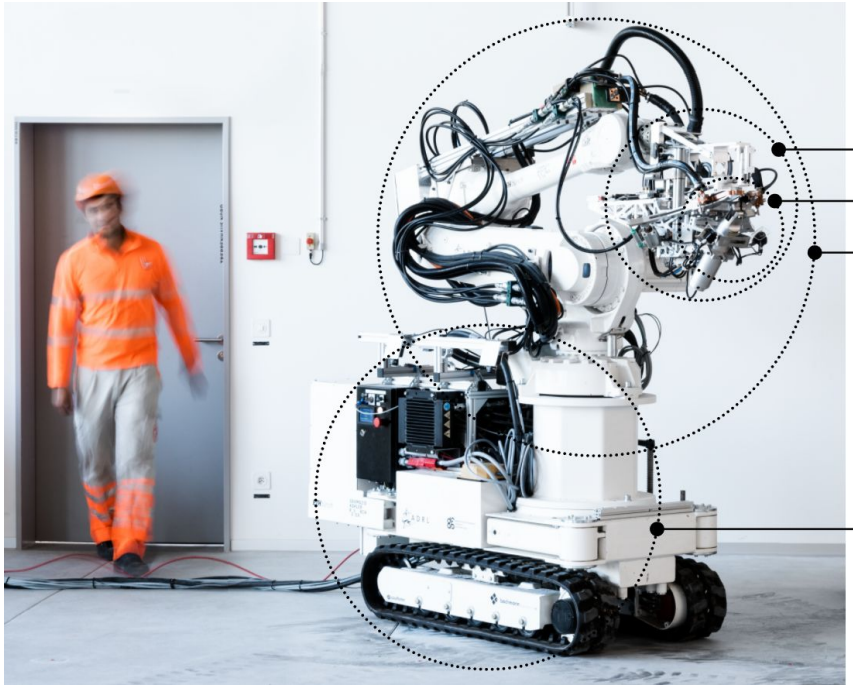


Fabrication processes





What is ROS?


ROS Node 1: End Effector
ROS Node 2: Localization
ROS Node 3: Robot Arm
ROS Node 4: Mobile Base

What is ROS?

`plumbing`

- Process management
- Interprocess communication
- Device drivers

`tools`

- Simulation
- Visualization
- Graphical UI
- Data logging

`capabilities`

- Control
- Planning
- Perception
- Mapping
- Manipulation

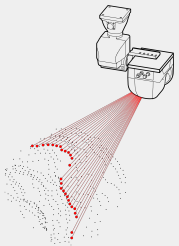
`ecosystem`

- Package organization
- Software distribution
- Community
- Documentation
- Tutorials

ROS Concepts

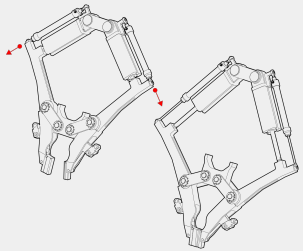
Topics

- Nodes communicate over topics
- **Publish/subscribe** model
- **One-way** data stream
- e.g: *robot states, sensor data*



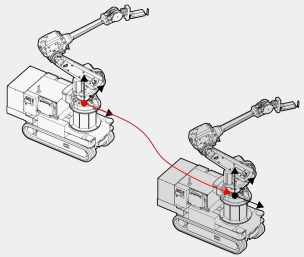
Services

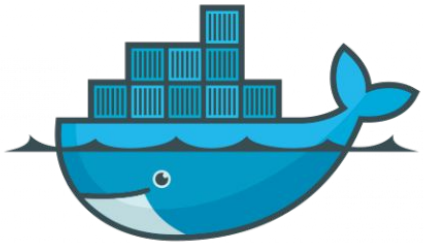
- **Blocking** call per request
- Request/response model
- Short trigger or calculation
- e.g: *calculate path, open gripper*

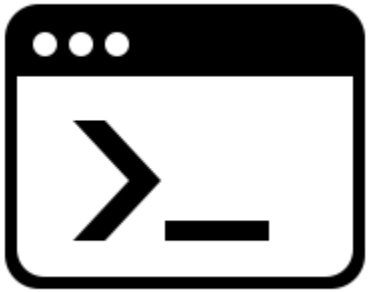


Actions

- **Non-blocking** requests
- Goal-oriented and cancellable
- Implemented with topics
- e.g: *navigation, motion execution*




docker



`docker-compose up -d`

Right-click → Compose Up

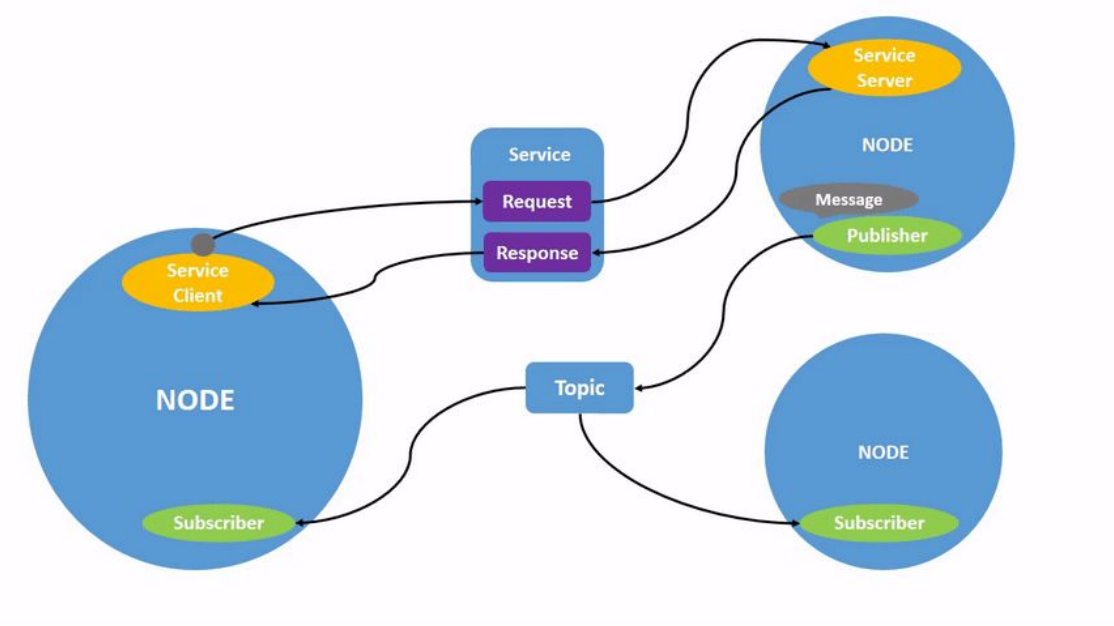
docker/first_steps

Verify connection to ROS

```
from compas_fab.backends import RosClient

with RosClient('localhost') as client:
    print('Connected:', client.is_connected)
```

interconnecting nodes

ROS communication model



Source: https://docs.ros.org/en/foxy/Tutorials/Understanding-ROS2-Nodes.html

Subscribe to topics

Subscribe to topic: **connect**

```
def receive_message(message):
    print(Received: ' + message['data'])

with RosClient('localhost') as client:
    listener = Topic(client, '/messages', 'std_msgs/String')
    listener.subscribe(receive_message)

    while client.is_connected:
        time.sleep(1)
```

Subscribe to topic: **subscribe**

```
def receive_message(message):
    print(Received: ' + message['data'])

with RosClient('localhost') as client:
    listener = Topic(client, '/messages', 'std_msgs/String')
    listener.subscribe(receive_message)

    while client.is_connected:
        time.sleep(1)
```

Publish to topics

Publish to topic: **connect**

```
with RosClient('localhost') as client:
    talker = Topic(client, '/messages', 'std_msgs/String')
    talker.advertise()

    while client.is_connected:
        talker.publish({'data': 'Hello'})
        time.sleep(1)
```

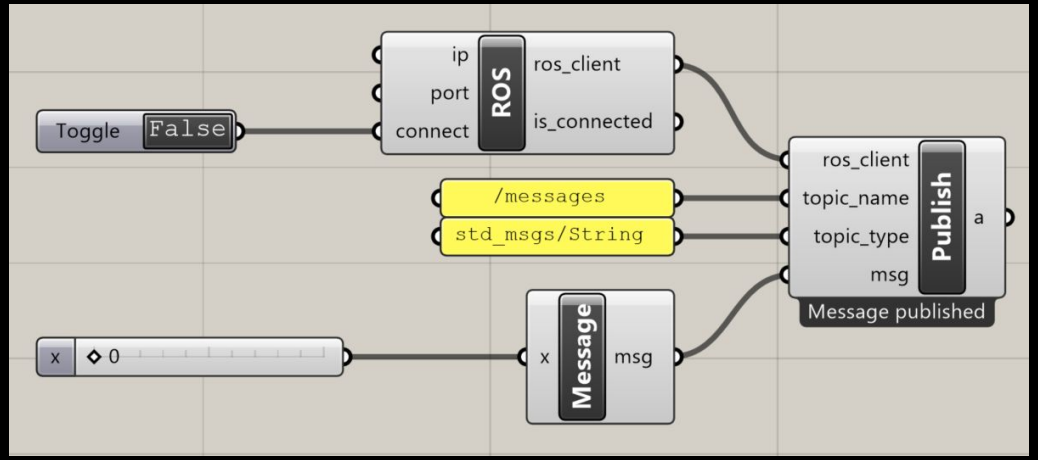
Publish to topic: **advertise**

```
with RosClient('localhost') as client:
    talker = Topic(client, '/messages', 'std_msgs/String')
    talker.advertise()

    while client.is_connected:
        talker.publish({'data': 'Hello'})
        time.sleep(1)
```

Publish to topic: **publish**

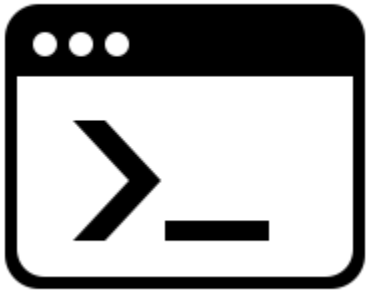
```
with RosClient('localhost') as client:
    talker = Topic(client, '/messages', 'std_msgs/String')
    talker.advertise()

    while client.is_connected:
        talker.publish({'data': 'Hello'})
        time.sleep(1)
```

Publish to topic **from Grasshopper**



planning with moveit

docker/moveit_noetic

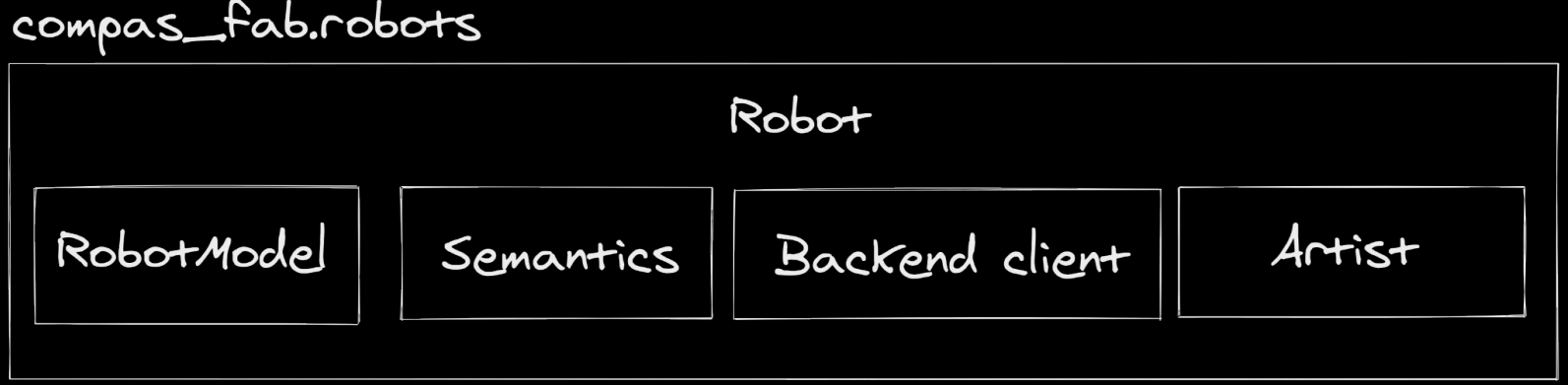


`docker-compose up -d`

Right-click → Compose Up

Loading ROS robot

```python
# Load robot without geometry
with RosClient("localhost") as ros:
    robot = ros.load_robot(load_geometry=False)
    robot.info()
```


compas_fab.robots
Robot
RobotModel
Semantics
Backend client
Artist

`compas.robots.RobotModel`

Describes the kinematics, linkage geometry and dynamics of a robot cell.

`compas_fab.robots.Robot`

Integrates a robot model, additional semantic information for planning, a backend client and artist instance.

Planning

Kinematics

Motion planning

Planning scene

Forward Kinematics

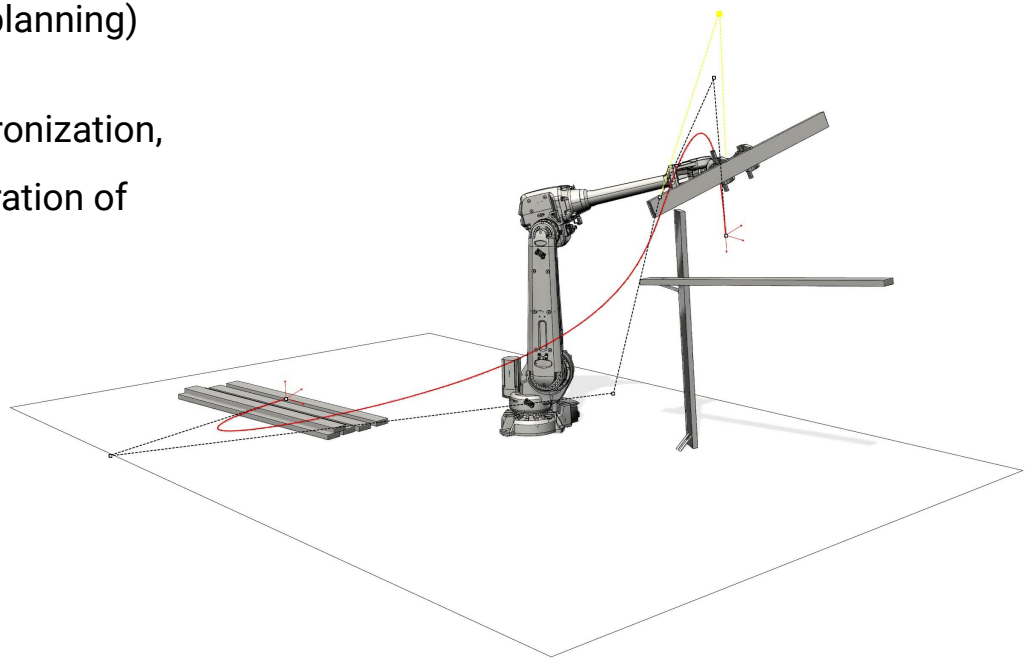
```
from compas_fab.backends import RosClient
from compas.robots import Configuration

with RosClient('localhost') as client:
    robot = client.load_robot()

    configuration = robot.zero_configuration()
    configuration.joint_values = (-0.106, -5.254, -2.231, 5.915, 4.712, -4.818)

    frame_WCF = robot.forward_kinematics(configuration)
```

Inverse Kinematics

```python
from compas.geometry import Frame
from compas_fab.backends import RosClient

with RosClient('localhost') as client:
    robot = client.load_robot()

    frame_WCF = Frame((0.3, 0.1, 0.05), (-1, 0, 0), (0, 1, 0))
    start_configuration = robot.zero_configuration()

    configuration = robot.inverse_kinematics(frame_WCF, start_configuration)
```

Motion planning

- Collision checking (= path planning)
- Trajectory checking (synchronization, consider speed and acceleration of moving objects)



Motion planning

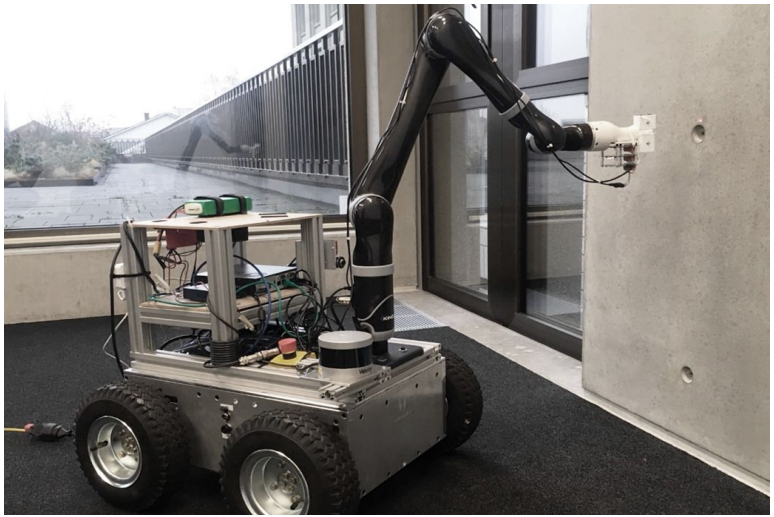
Collision checks

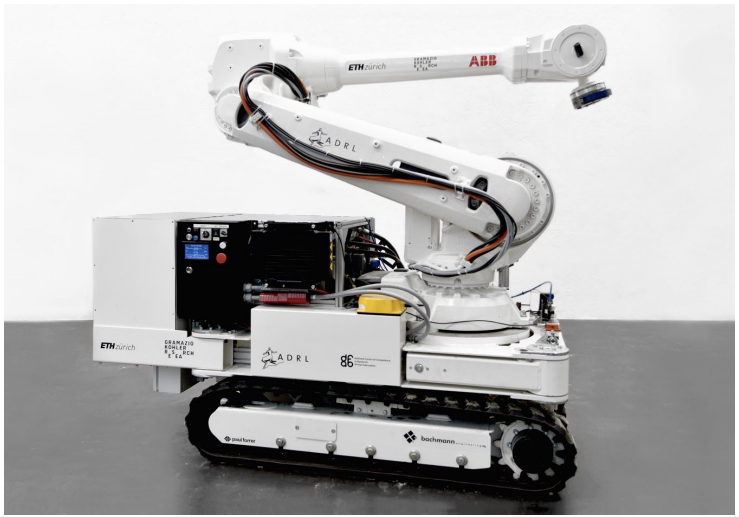
- Intricate positions (spatial assembly)
- Multiple robots working closely

Motion planning

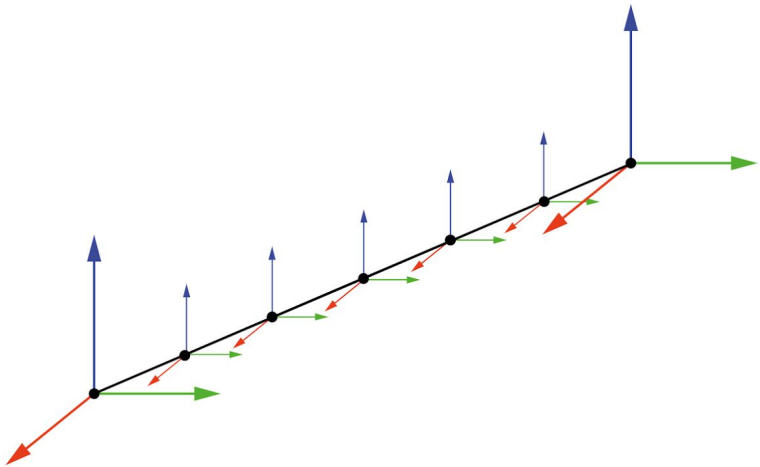
Trajectory checks

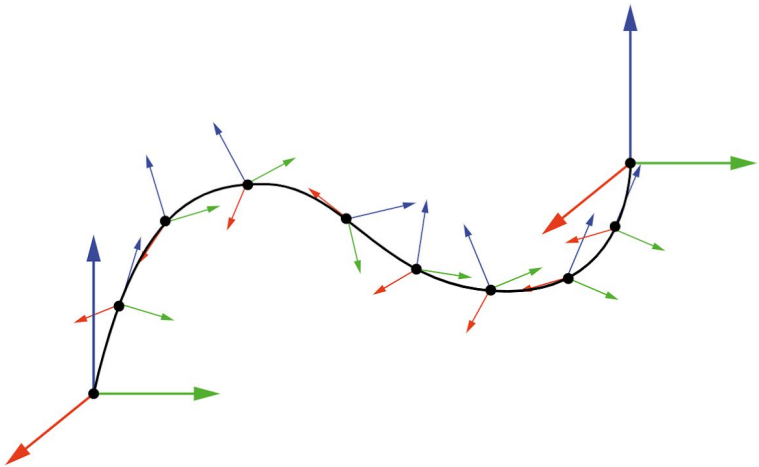
- Synchronization
- Continuous processes





Cartesian motion vs free-space motion





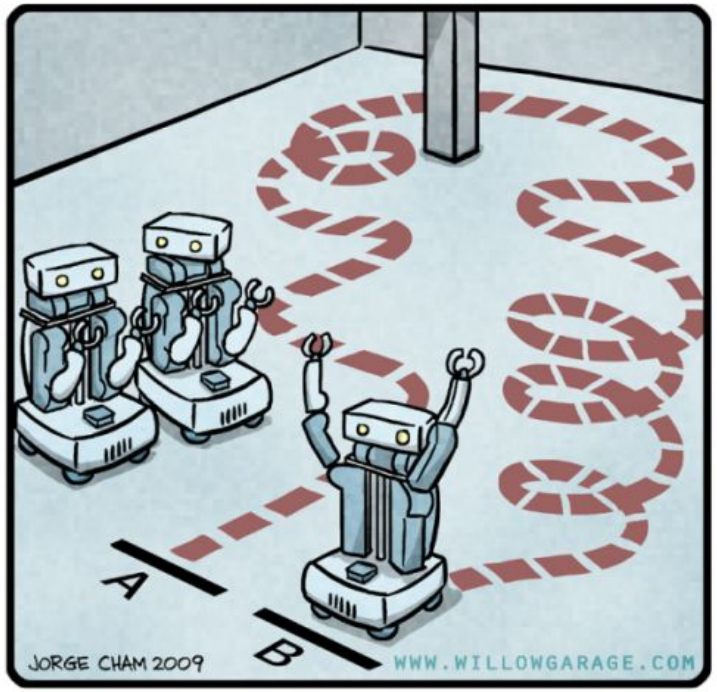
Plan cartesian motion

```
from compas.geometry import Frame
from compas_fab.backends import RosClient
from compas_fab.robots import Configuration

with RosClient('localhost') as client:
    robot = client.load_robot()

    frames = []
    frames.append(Frame([0.3, 0.1, 0.5], [1, 0, 0], [0, 1, 0]))
    frames.append(Frame([0.5, 0.1, 0.6], [1, 0, 0], [0, 1, 0]))

    start_configuration = Configuration.from_revolute_values([-0.04, 0.03, -2.17, 5.28, -1.52, 0.0])
    trajectory = robot.plan_cartesian_motion(frames, start_configuration)
```

Plan motion

```
from compas.geometry import Frame
from compas_fab.backends import RosClient
from compas_fab.robots import Configuration

with RosClient('localhost') as client:
    robot = client.load_robot()

    frame = Frame([0.4, 0.3, 0.4], [0, 1, 0], [0, 0, 1])
    start_configuration = Configuration.from_revolute_values([-0.042, 4.295, 0, -3.327, 4.755, 0.])

    goal_constraints = robot.constraints_from_frame(frame,
                                                     tolerance_position=0.001,
                                                     tolerance_axes=[0.01, 0.01, 0.01])
    trajectory = robot.plan_motion(goal_constraints, start_configuration)
```

R.O.B.O.T. Comics



"HIS PATH-PLANNING MAY BE SUB-OPTIMAL, BUT IT'S GOT FLAIR."

Defining constraints

- **`JointConstraint`**
  Constrains the value of a joint to be within a certain bound.

- **`OrientationConstraint`**
  Constrains a link to be within a certain orientation.

- **`PositionConstraint`**
  Constrains a link to be within a certain bounding volume.

Constraints

```python
frame = Frame([0.4, 0.3, 0.4], [0, 1, 0], [0, 0, 1])
tolerance_position = 0.001
tolerance_axes = [math.radians(1)] * 3

# create goal constraints from frame
goal_constraints = robot.constraints_from_frame(frame, tolerance_position, tolerance_axes)
```

planning scene

Planning scene operations

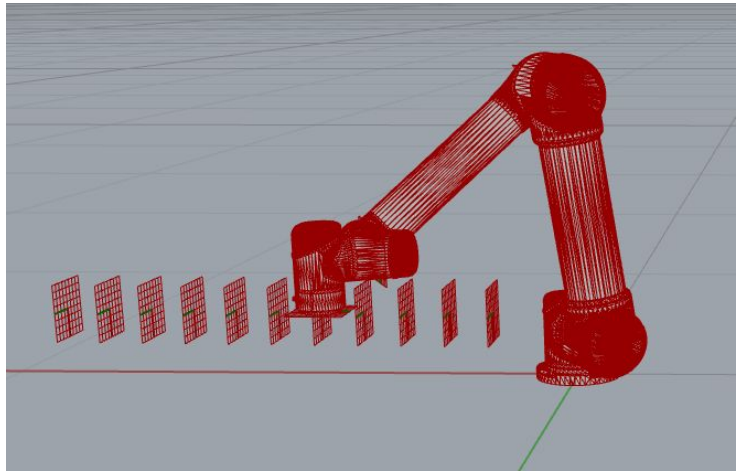
Add/append/remove collision meshes (i.e. obstacles) and add/remove attached collision meshes (i.e. meshes attached to the end effector).

- **Usage:**

```
scene = compas_fab.robots.PlanningScene(robot)
scene.add_collision_mesh(..)
scene.remove_collision_mesh(..)
scene.append_collision_mesh(..)

scene.add_attached_collision_mesh(..)
scene.remove_attached_collision_mesh(..)
scene.attach_collision_mesh_to_robot_end_effector(..)
```

Assignment

1. Start the MoveIt container for a UR3e
2. Use the `RosClient` to load the robot
3. Taking a robot and a list of frames as parameter, calculate a feasible configuration for each of the frames
4. Try to find an optimal `start_configuration` for each so that the motion from one config to the next is minimized
5. Store all found configurations in a JSON file using `compas.json_dump` or `compas.json_dumps`
6. Commit **BOTH** the Python and JSON files



Next week

- Assignment submission due: Wed 23rd March, 9AM.
- Ask for help if needed: Slack, Forum, Office Hours (Fridays, request via Slack)
- Next week:
  - Path planning using MoveIt
  - Customizing end effectors
  - Pick & Place process for discrete assemblies

Thanks!