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  - Chapter 1

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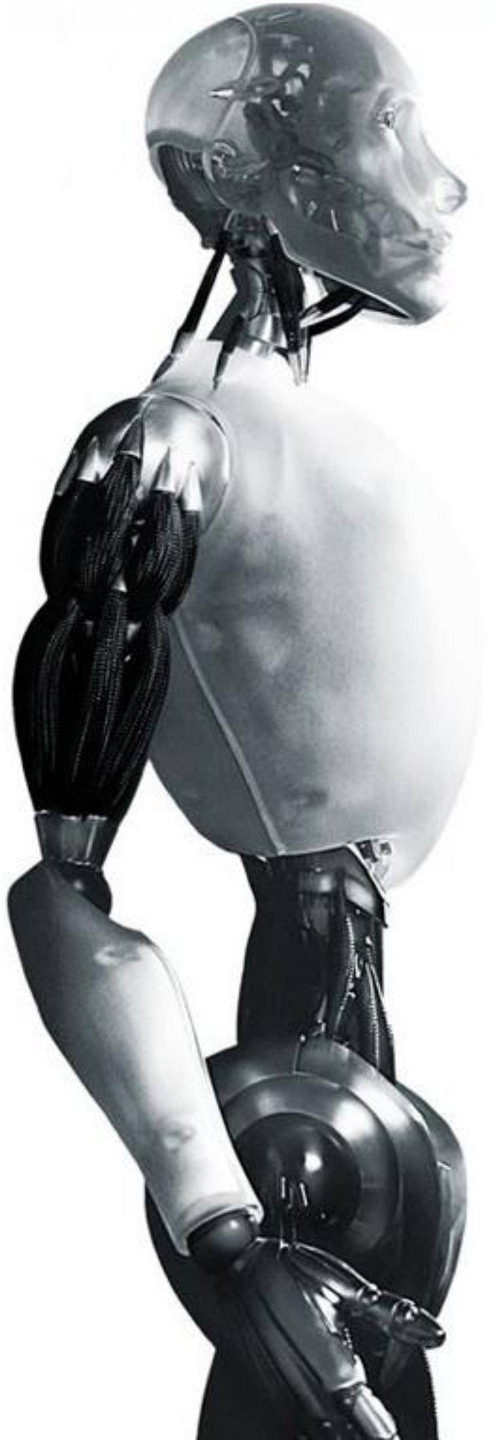
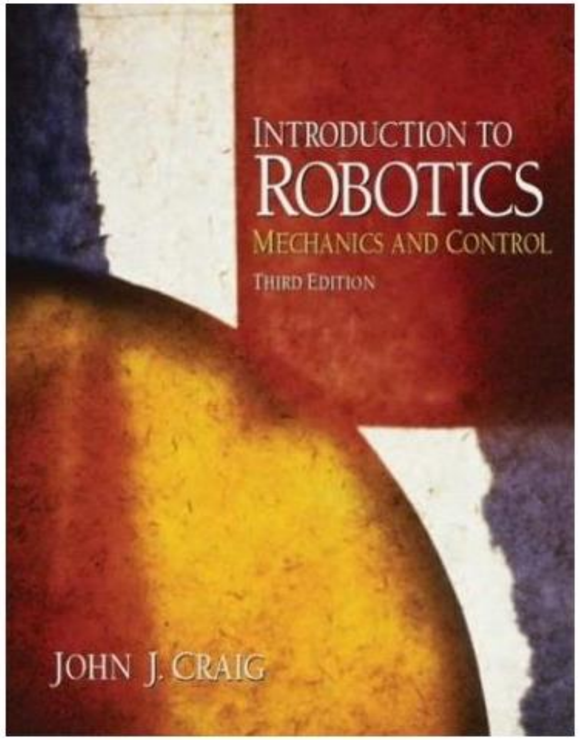


Robotics

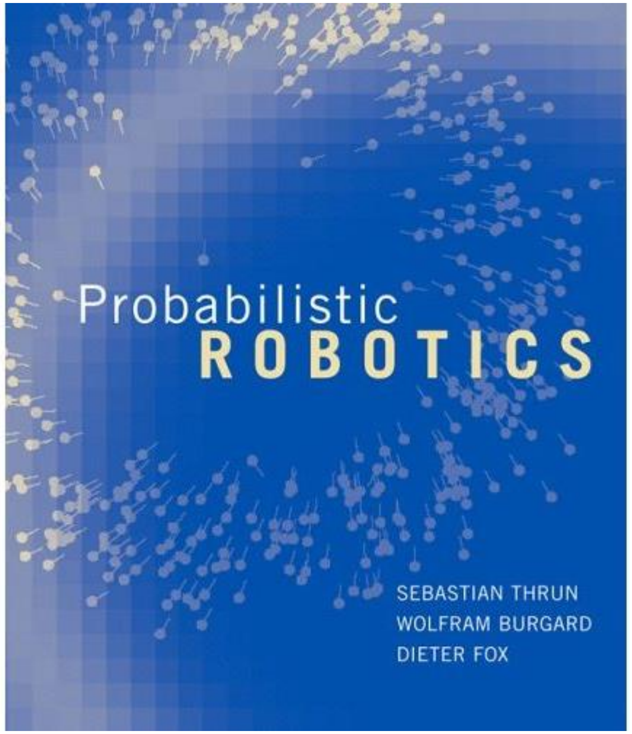
Our First Task: Hold Still!

TU Berlin

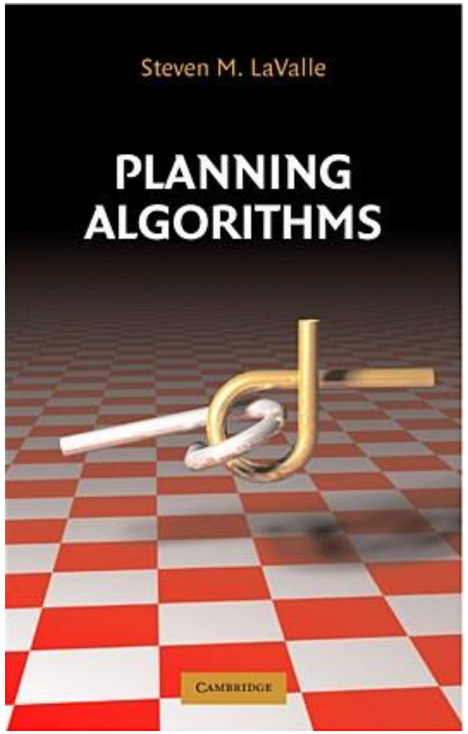
Oliver Brock



In the library



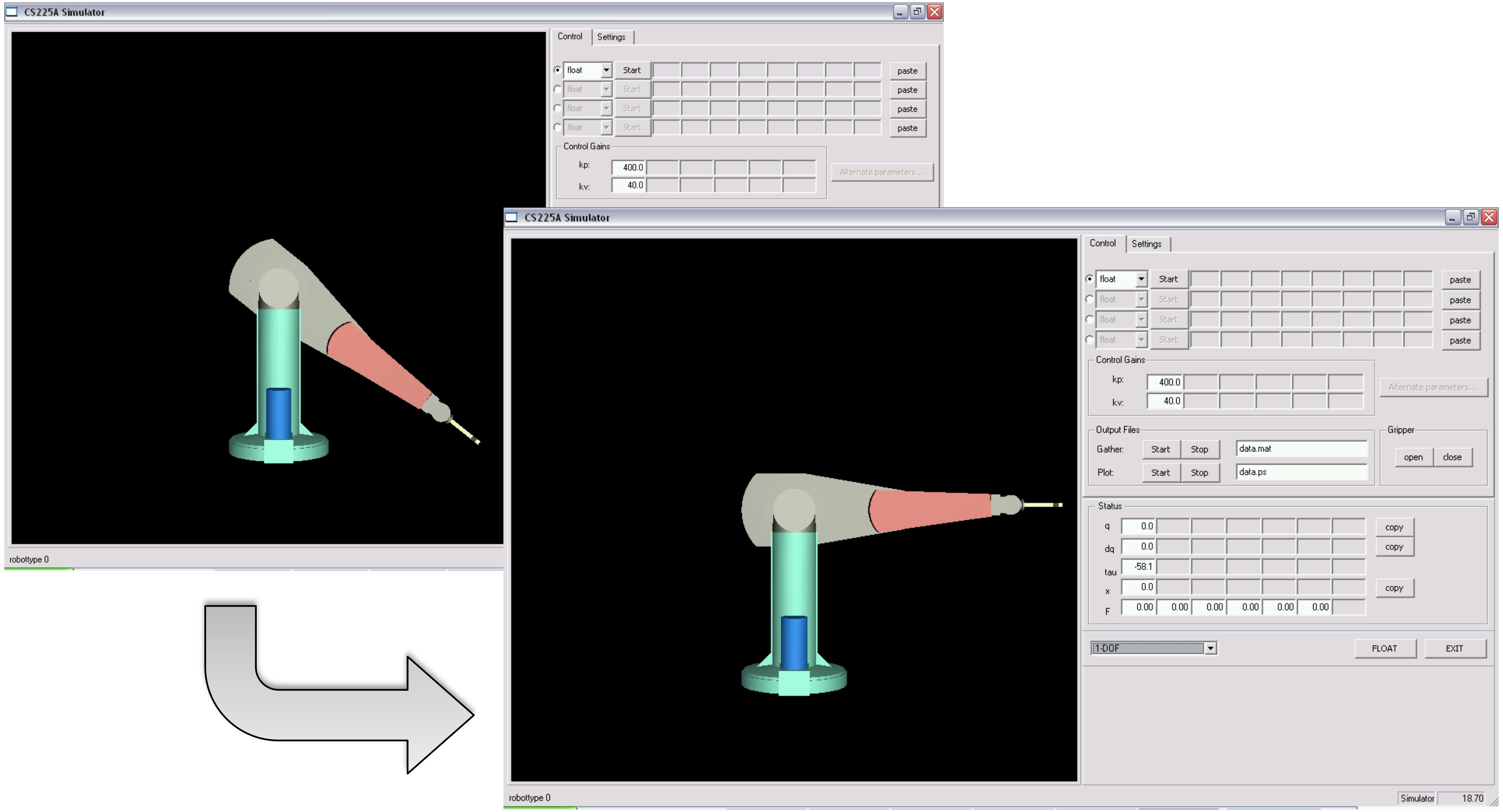
In the library
http://www.probabilistic-robotics.org



Free online
http://planning.cs.uiuc.edu


PUMA 500
UNIMATE

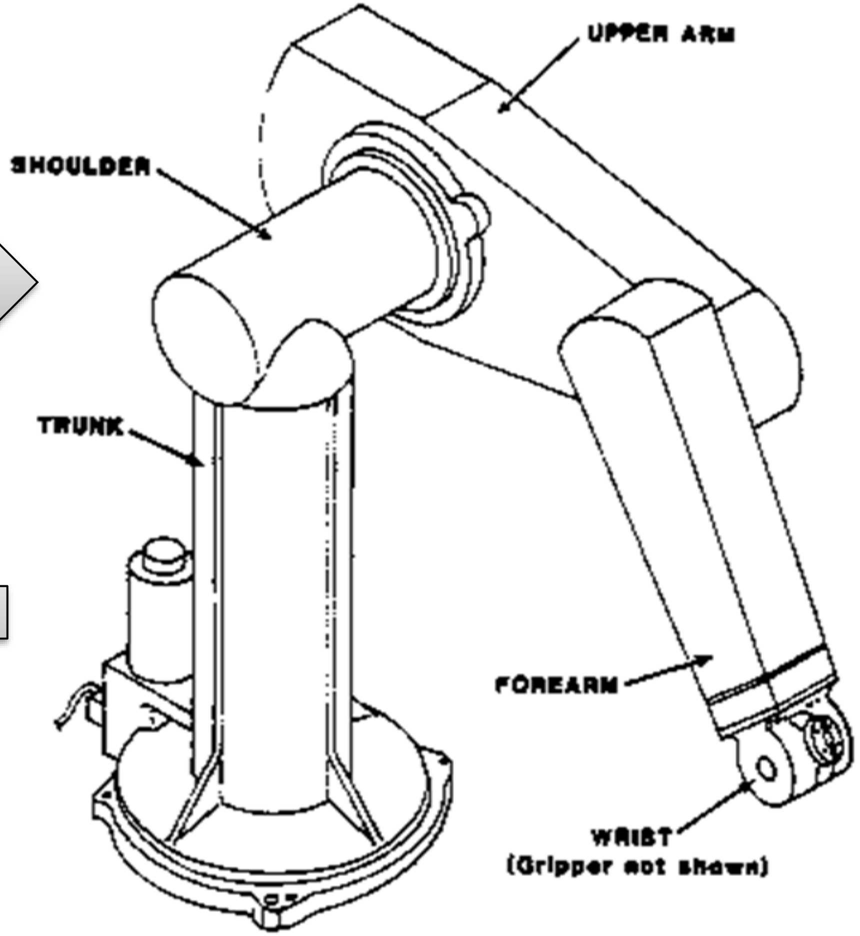
Our Task: Hold Still!



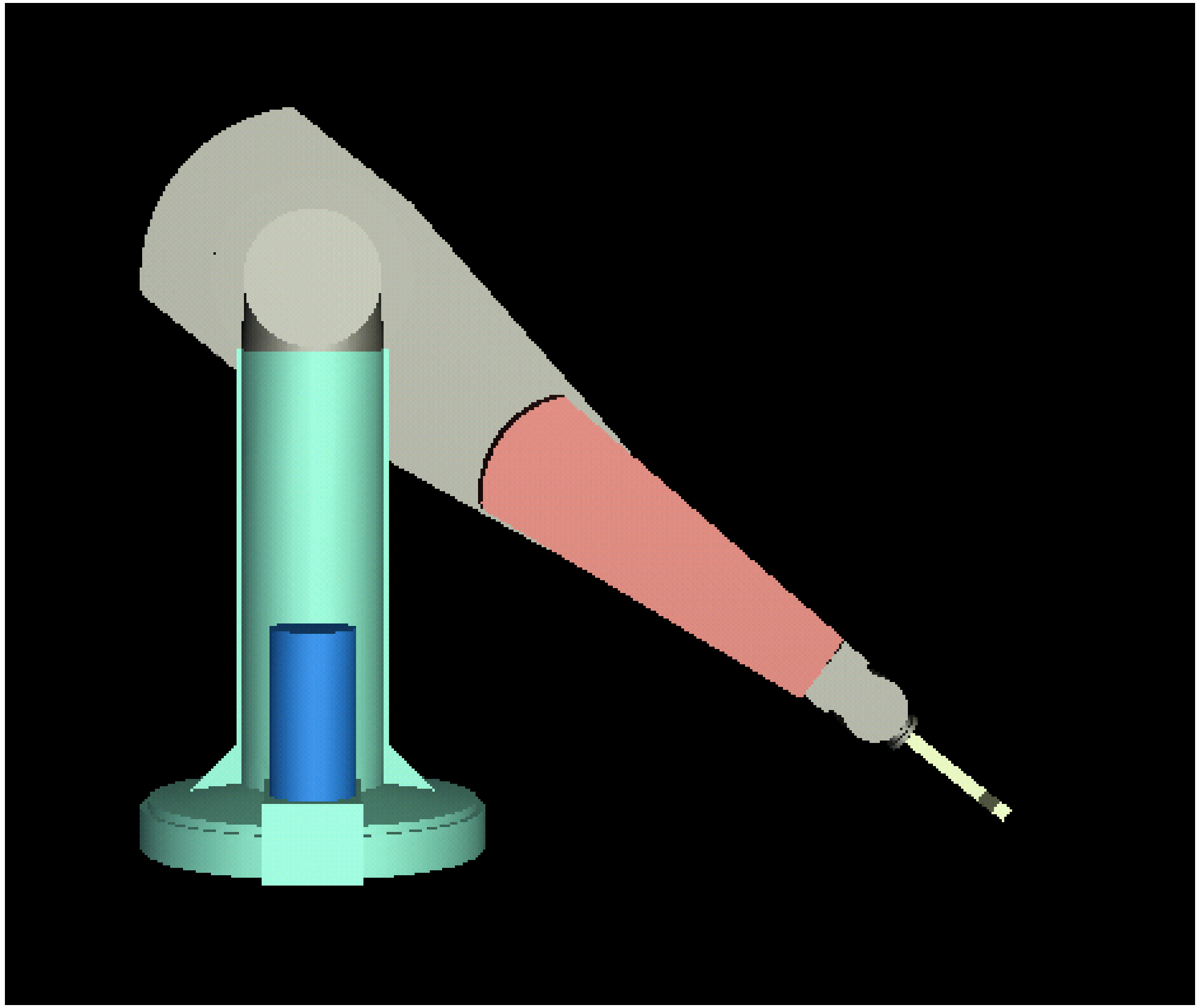
The Interface

torque / force τ (tau)
(really: current)
[Drehmoment, Kraft]

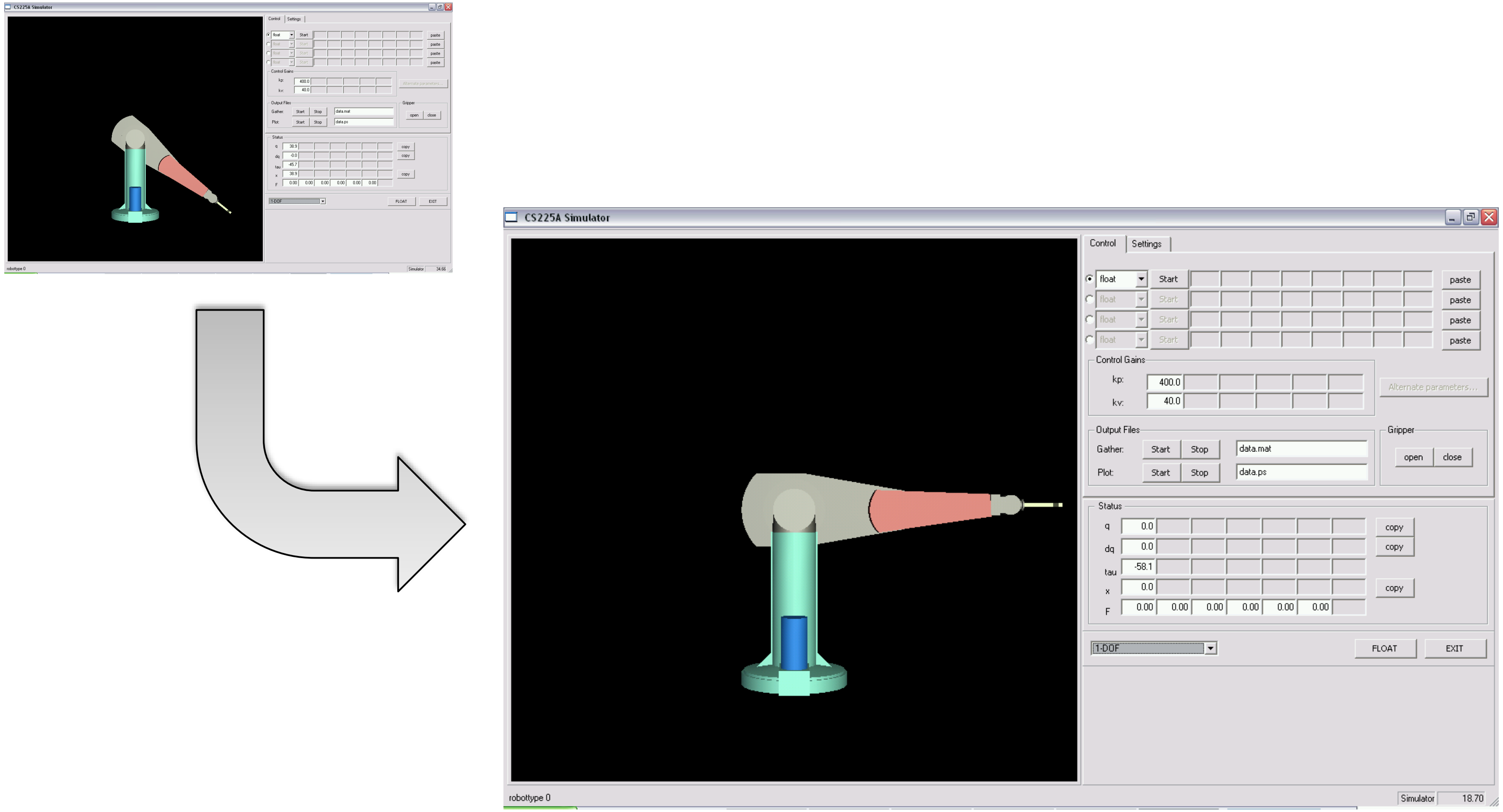
joint positions:
configuration *q*



Don’t fall. Hold still!

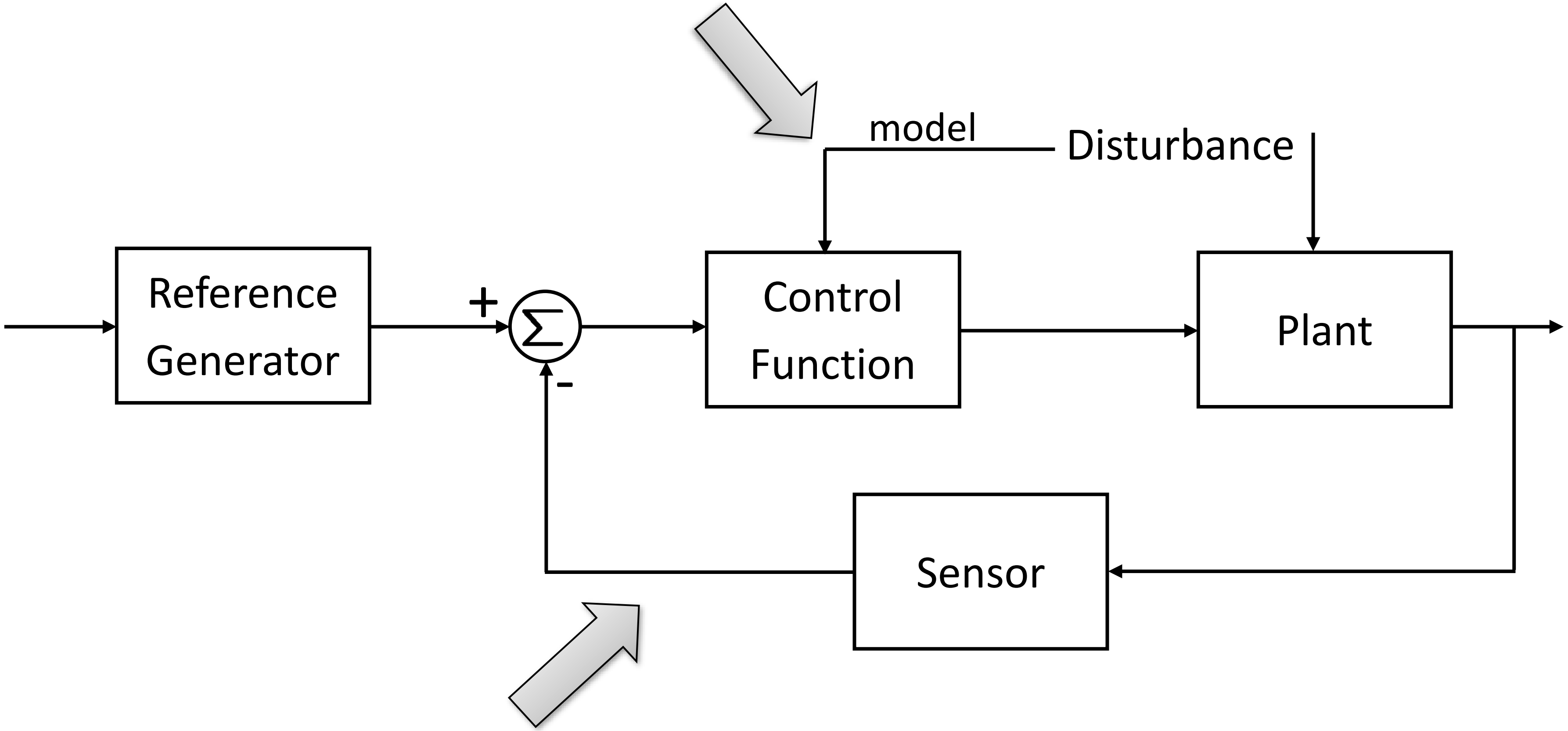


Let’s try...


CS225A Simulator
Control
Settings
float
Start
paste
Control Gains
kp:
400.0
kv:
40.0
Alternate parameters...
Output Files
Gather:
Start
Stop
data.mat
Plot:
Start
Stop
data.ps
Gripper
open
close
Status
q
0.0
copy
dq
0.0
copy
tau
-58.1
x
0.0
copy
F
0.00
0.00
0.00
0.00
0.00
0.00
1-DOF
FLOAT
EXIT
robottype 0
Simulator
18.70

A Simple Controller [Regler]

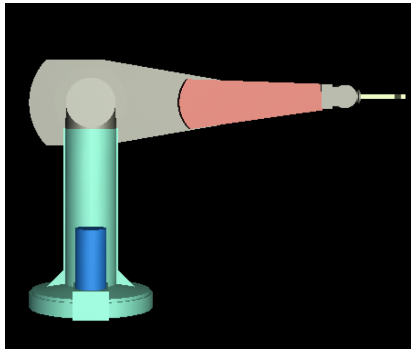
Feed-forward

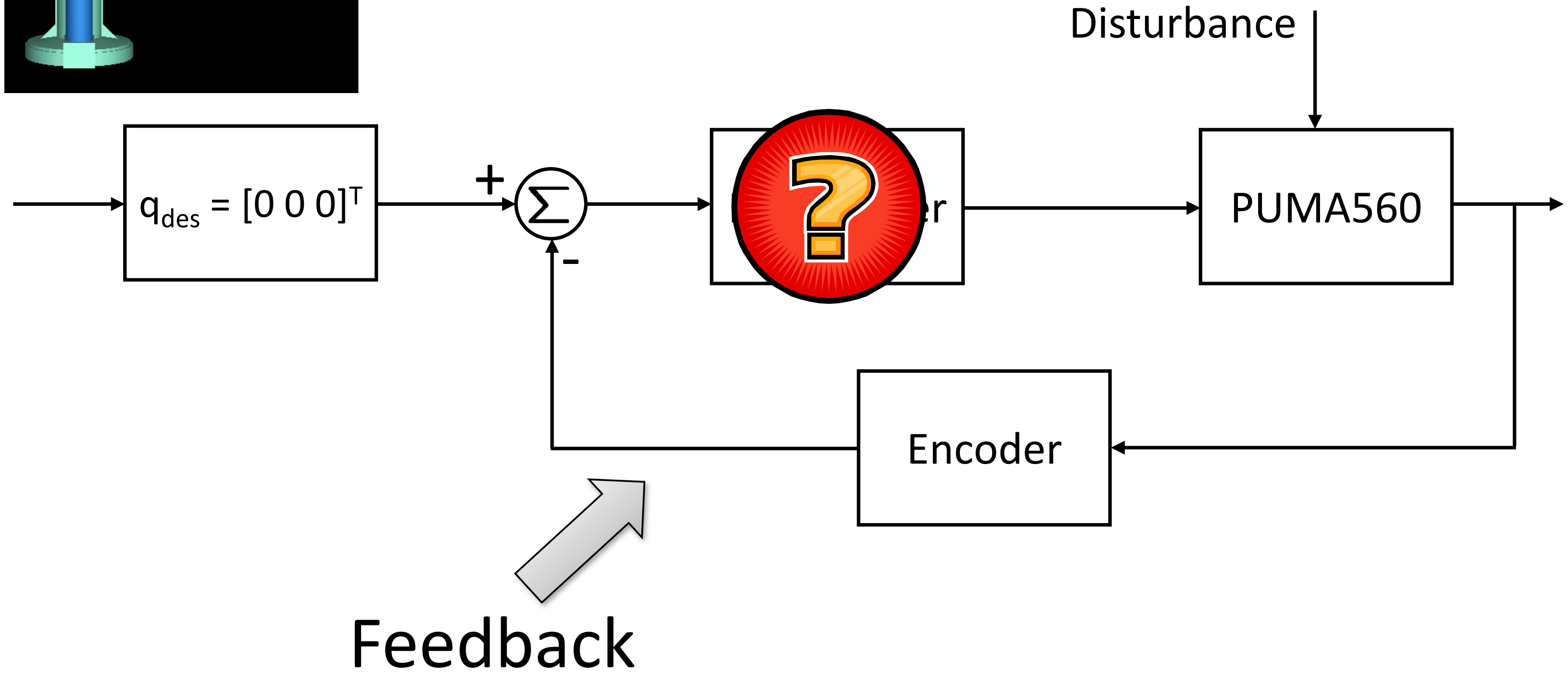


Feedback (we used proportional feedback or P control)

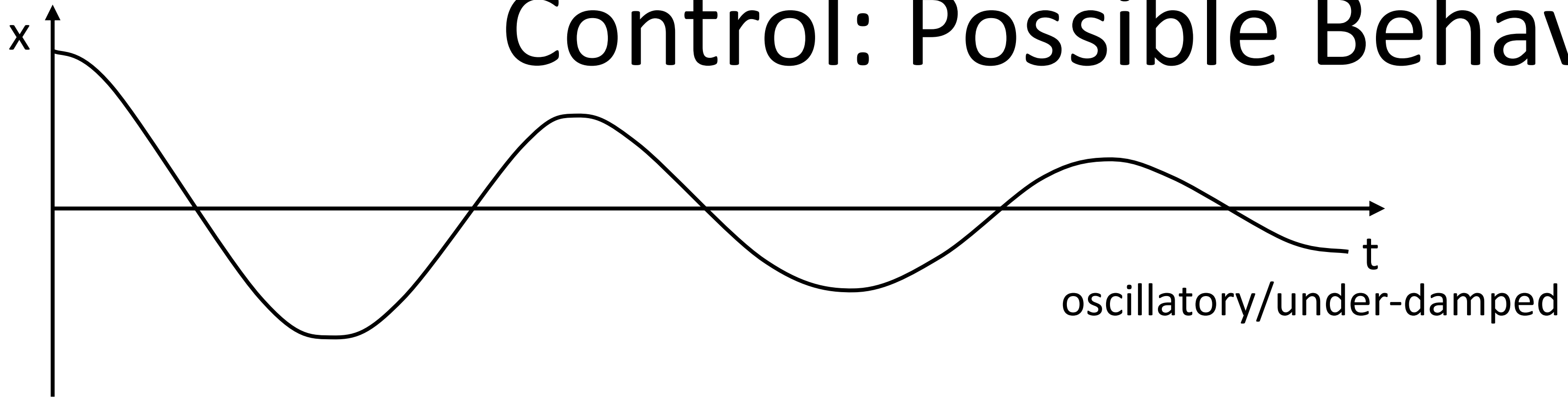
(also: closed loop – as opposed to open loop)

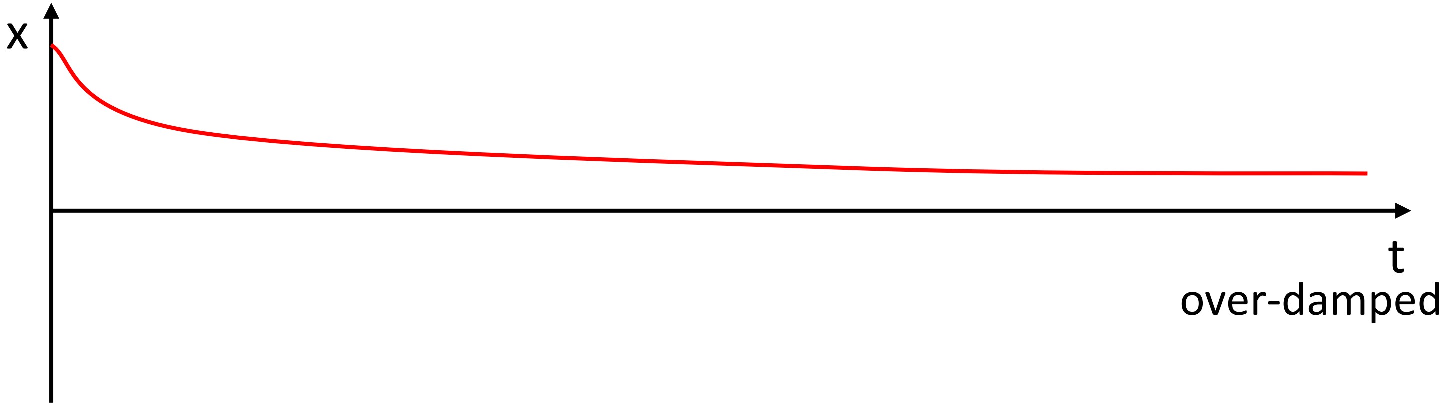
A Proportional Controller

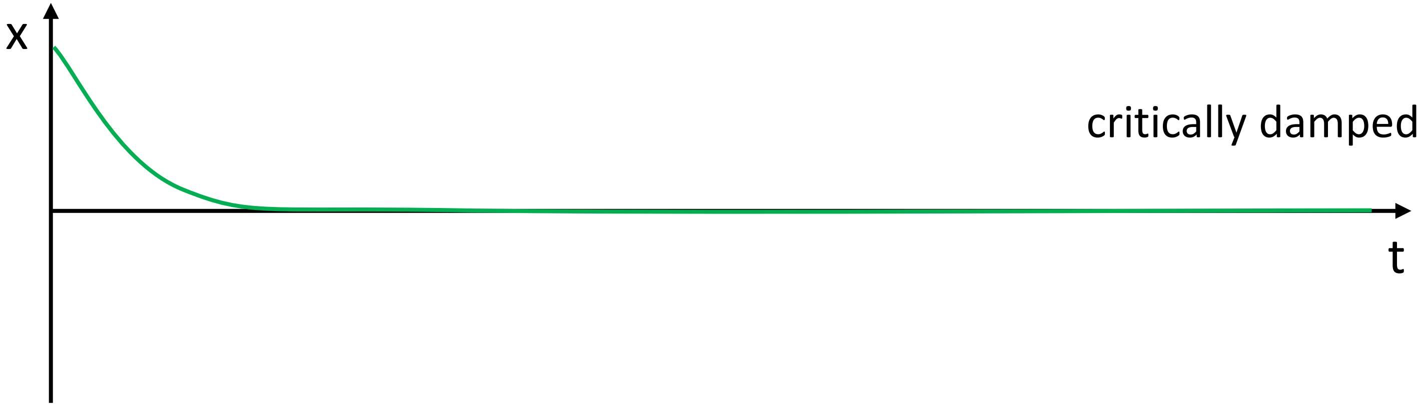




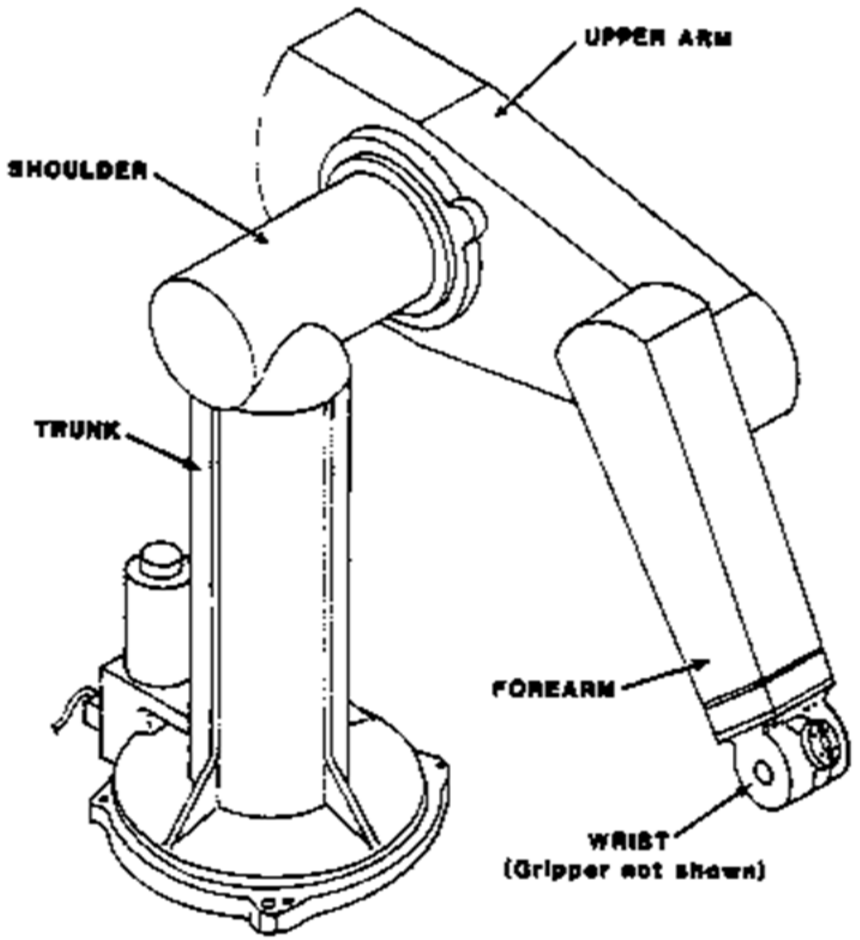
Control: Possible Behaviors







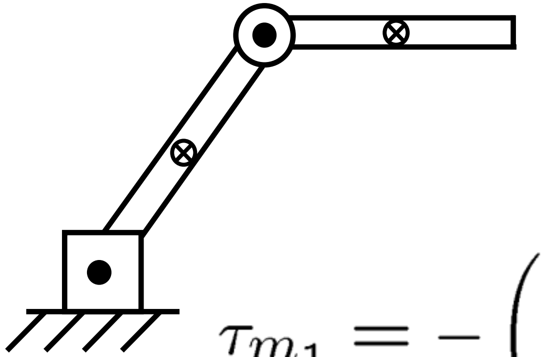
Possible Disturbances



- Gravity
- Inertia
- Centrifugal forces
- Coriolis effect
- Gears
- Actuator
- Friction
- Grasped object
- Contact
- …

What we need to solve the problem

- Fixed parameters of the robot
  - Kinematic
  - Dynamic
- Changing parameters
- Then we can:
  - Compensate gravity (feed-forward)
  - Reject error (feedback, P-controller)
- But: what happens when the robot moves?



$$\tau_{m_1} = -\begin{pmatrix} l\, c_1\, \mathbf{g}\, m_1 \\ 0 \end{pmatrix}$$

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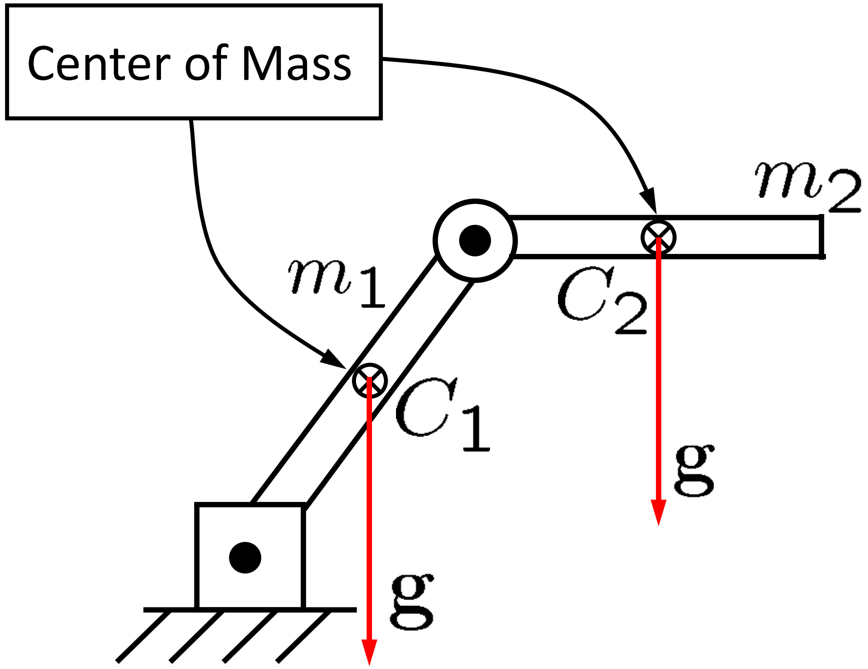
Robotics

A model of gravity based on simple physics

TU Berlin

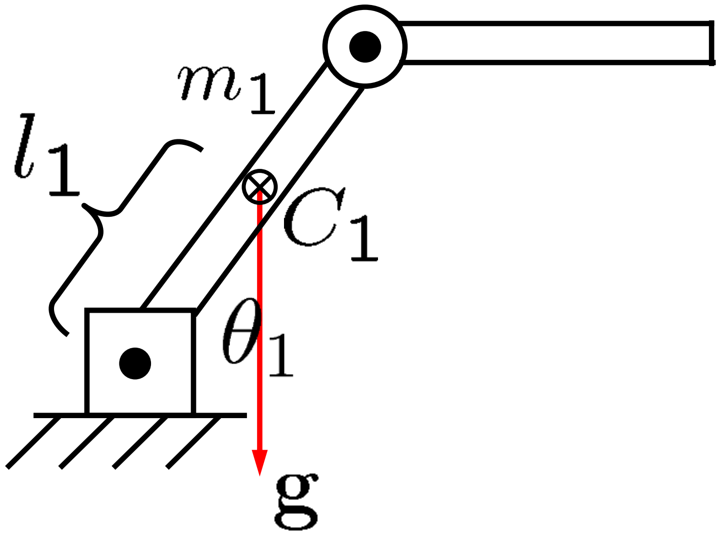
Oliver Brock

Gravity



$c_1 = \cos(\theta_1)$

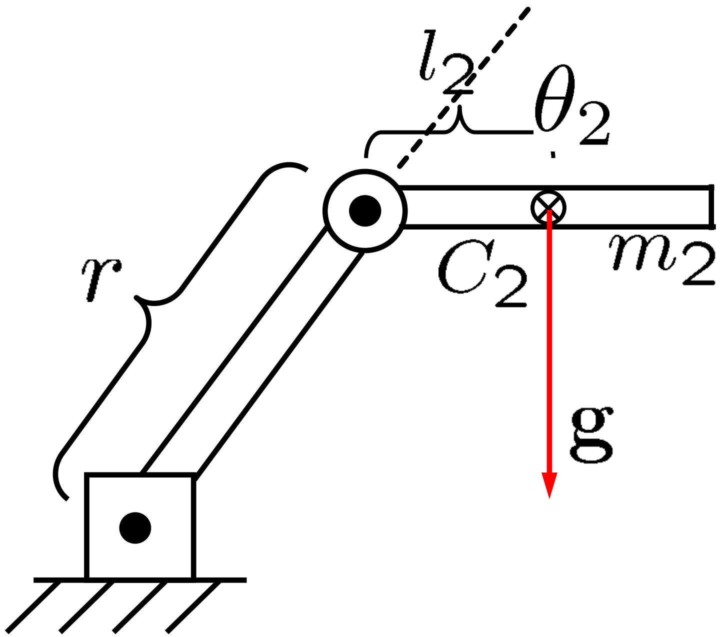
Gravity: Link 1



$$\tau_{m_1} = -\begin{pmatrix} l_1\ c_1\ \mathbf{g}\ m_1 \\ 0 \end{pmatrix}$$

$c_{12} = \cos(\theta_1 + \theta_2)$

Gravity: Link 2



$$\tau_{m_1} = -\begin{pmatrix} l_1\ c_1\ \mathbf{g}\ m_1 \\ 0 \end{pmatrix}$$

$$\tau_{m_2} = -\begin{pmatrix} (r\ c_1 + l_2\ c_{12})\ \mathbf{g}\ m_2 \\ l_2\ c_{12}\ \mathbf{g}\ m_2 \end{pmatrix}$$

$$\tau_g = \tau_{m_1} + \tau_{m_2} = -\begin{pmatrix} (r\ c_1 + l_2\ c_{12})\ m_2 + l_1\ c_1\ m_1 \\ l_2\ c_{12}\ m_2 \end{pmatrix} \mathbf{g}$$

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Reading for this set of slides

- Craig – Intro to Robotics (3rd Edition)
  - Chapter 9.1 – 9.4

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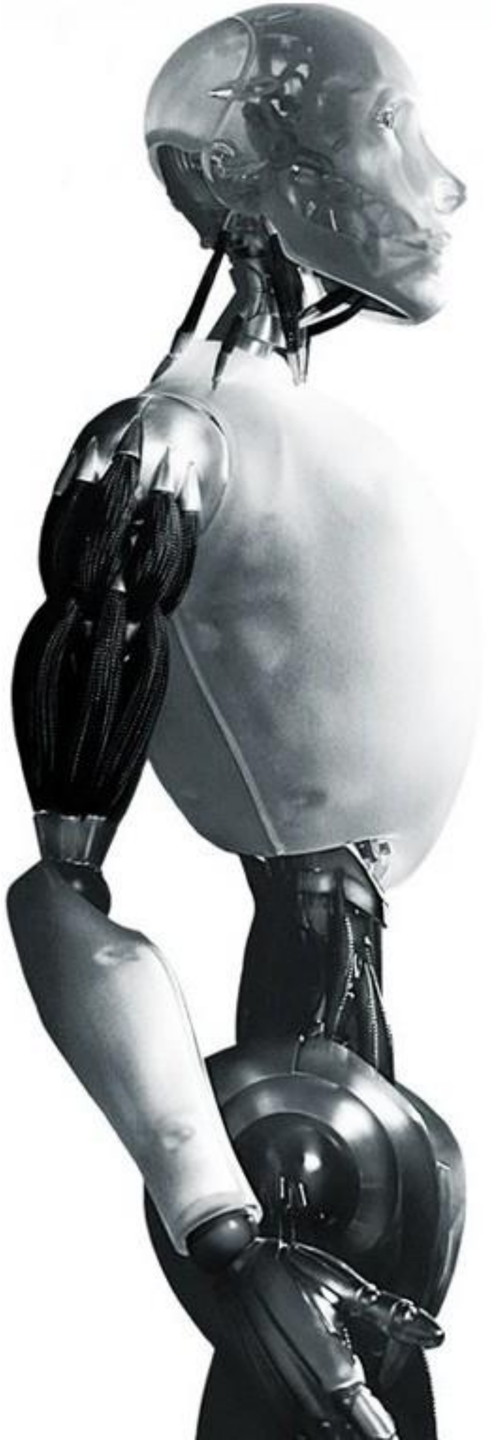


Robotics

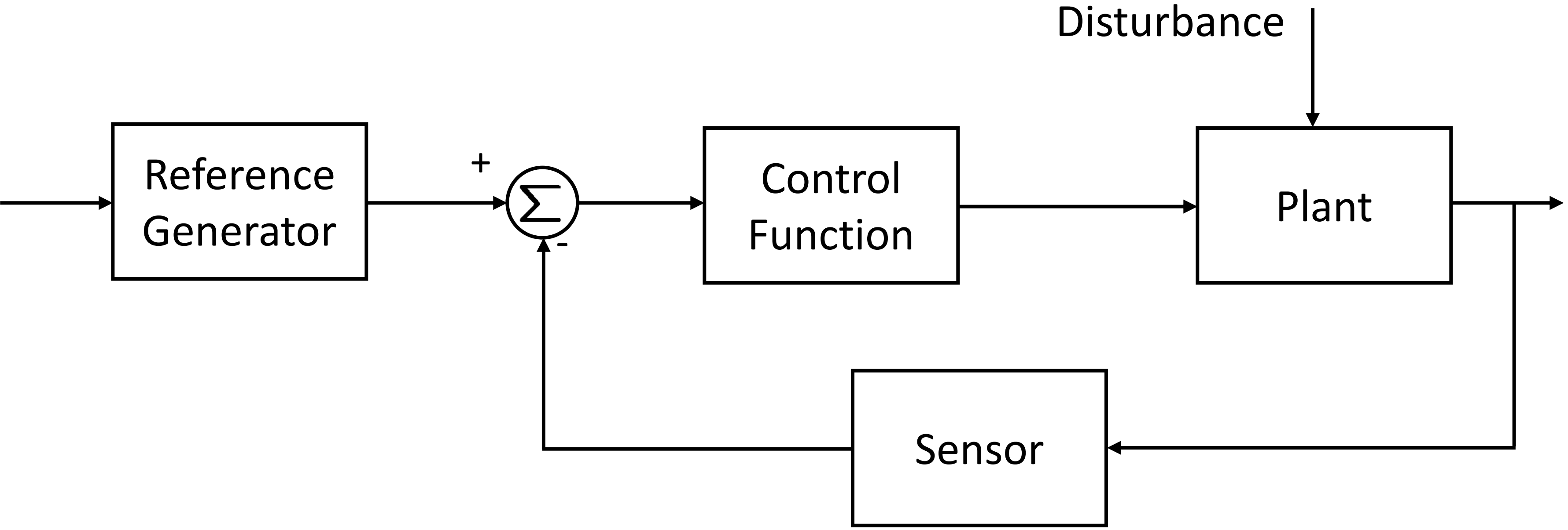
First Steps in Control

TU Berlin

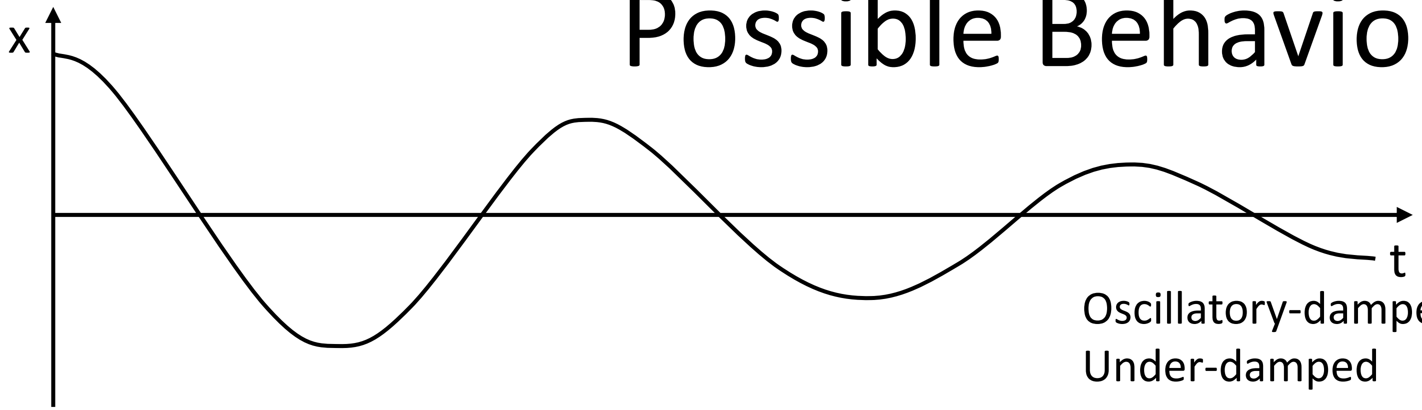
Oliver Brock

Control

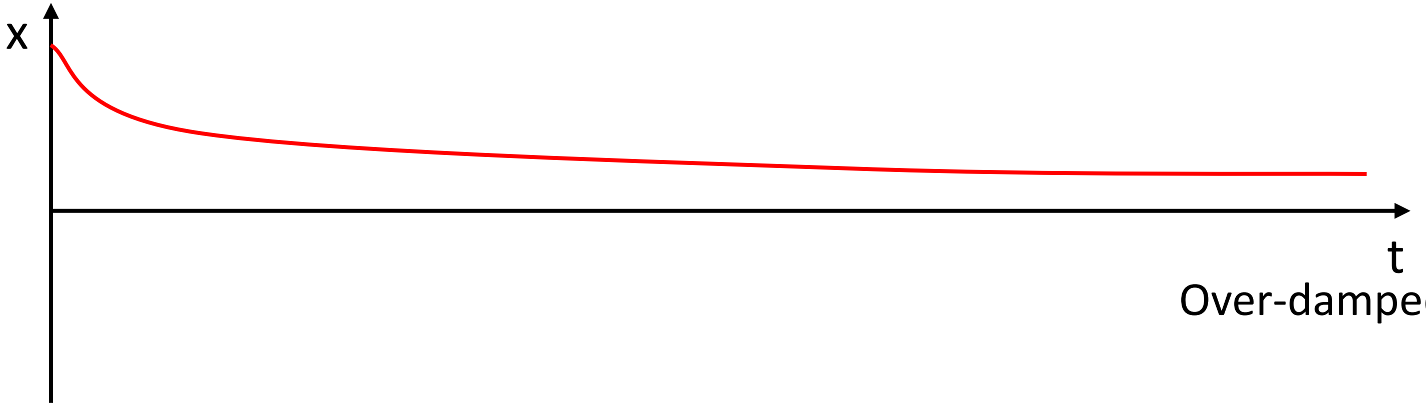
- **Control** is the process of causing a *system variable* to conform to some desired value, called a *reference value*.



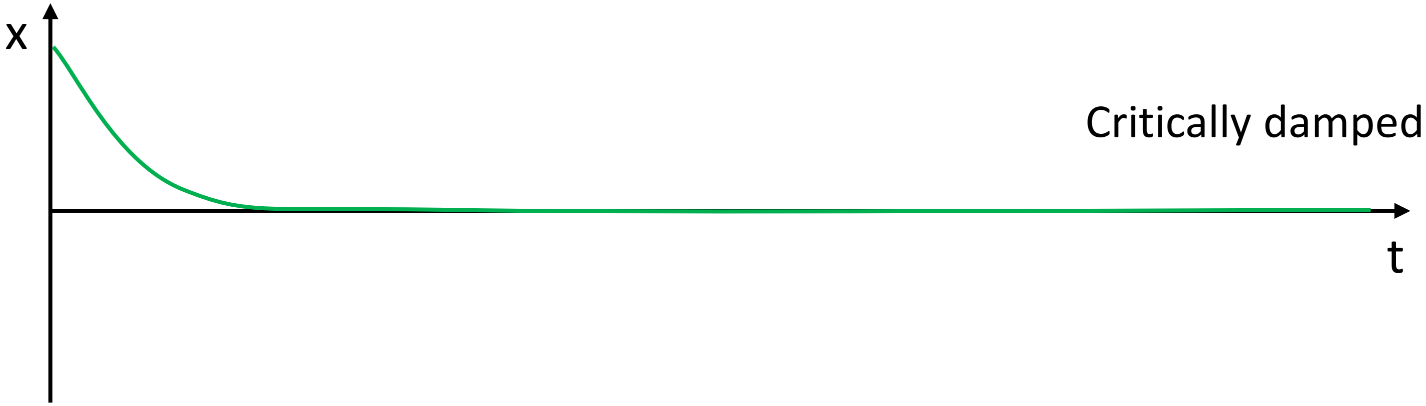
Possible Behaviors



Oscillatory-damped
Under-damped

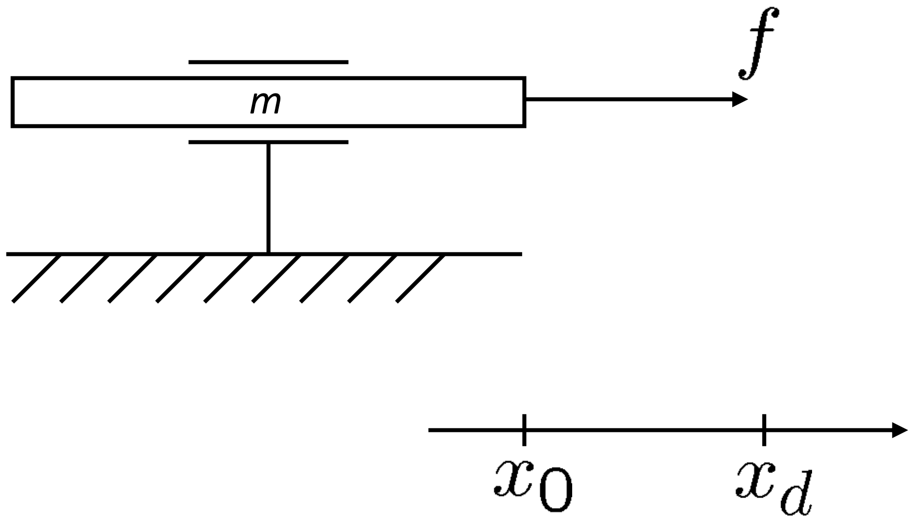


Over-damped



Critically damped

Simplest Case: Prismatic Joint

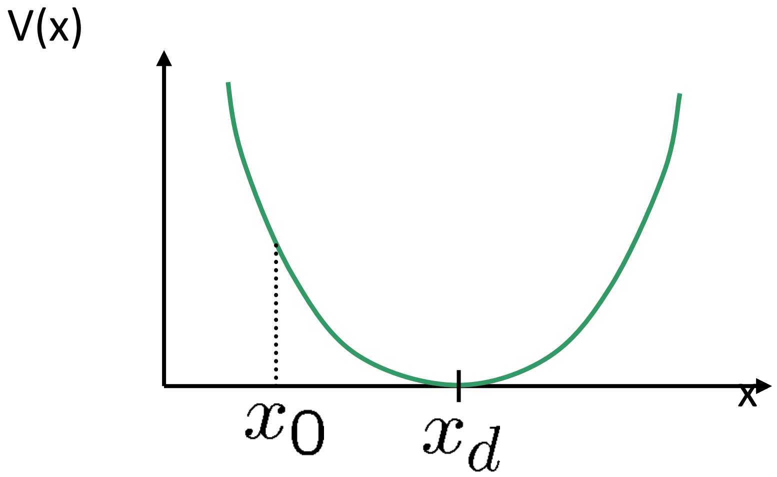


Proportional Control

Idea: apply force proportional to error

$$f = -\boxed{k_p}(x - x_d)$$

position gain

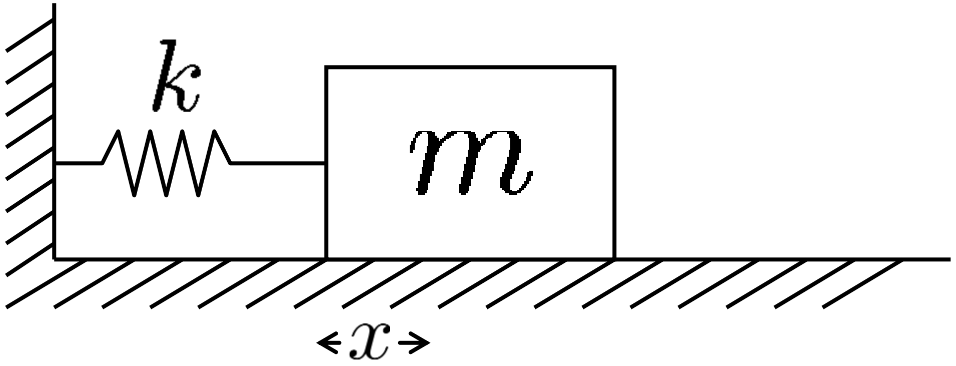


$$V(x) = \frac{1}{2} k_p (x - x_d)^2$$

$$\mathbf{F} = -\nabla V(x) = -\frac{\partial V}{\partial x}$$

Let’s start simple…

Conservative System / Simple Harmonic Oscillator



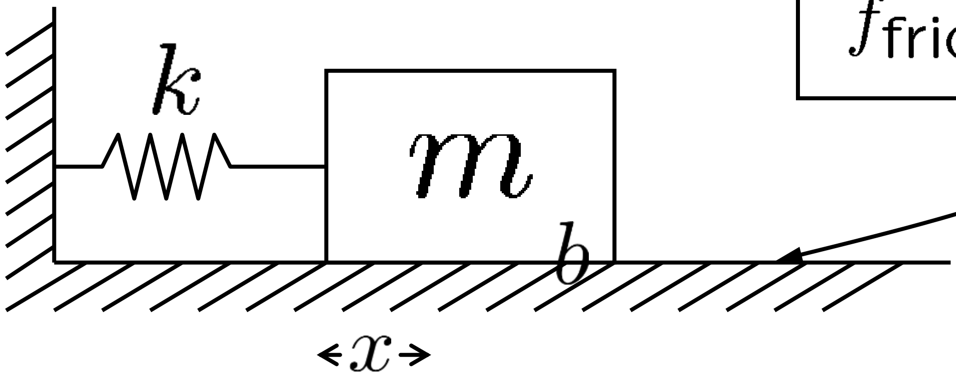
Equation of motion

$$m\ddot{x} + kx = 0$$

Dissipative System: Add Friction

viscous friction

$$f_{\text{friction}} = -b\dot{x}$$



Equation of motion

$$m\ddot{x} + b\dot{x} + kx = 0$$

Introduction of Dissipation

Idea: apply force opposing velocity

this leads to dissipation (or dampening)

$$f = -k_p x - \underbrace{\boxed{k_v}}_{\text{velocity gain}} \dot{x}$$

PD Control: Adding an Actuator

$$m\ddot{x} + b\dot{x} + kx = 0$$

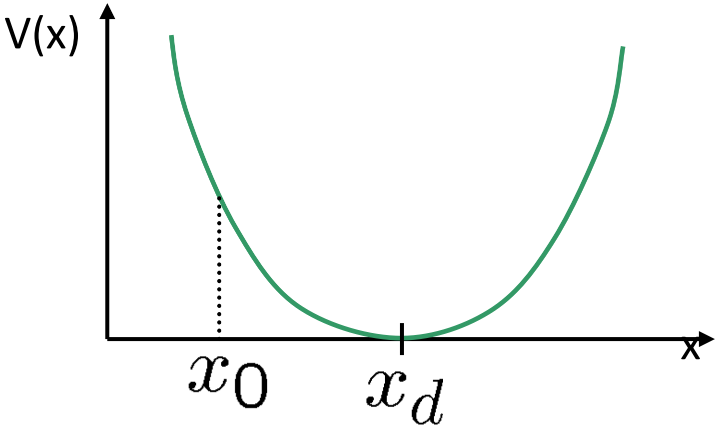
$$f = m\ddot{x} + b\dot{x} + kx$$

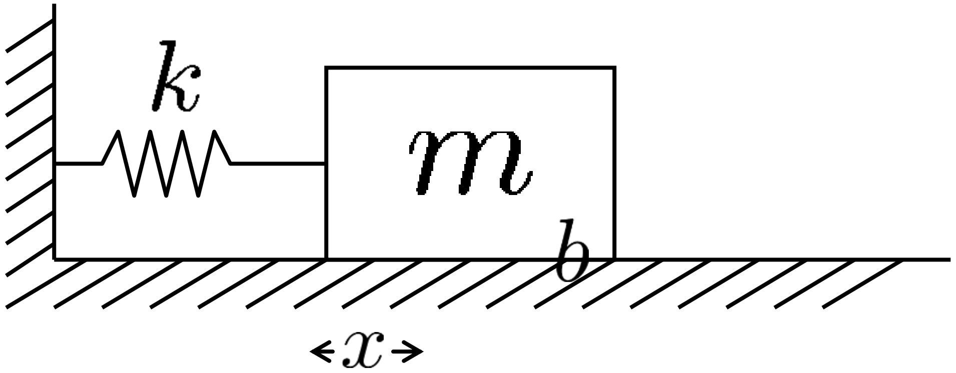
$$f = -k_p\,x - k_v\,\dot{x}$$

$$m\ddot{x} + b\dot{x} + kx = -k_p x - k_v \dot{x}$$

$$m\ddot{x} + (b + k_v)\dot{x} + (k + k_p)x = 0$$

Summary





$$\mathbf{F} = -\nabla V(x) = -\frac{\partial V}{\partial x}$$

$$\tau = -k_p(p - q_d) - k_v \dot{q}$$

Robotics – Tutorial for Assignment #1

By **Előd Páll**

The Puma560 Simulator

- Software that simulates the Kinematics, Dynamics, Friction etc. of the Puma560 robot
- *pumasim* binary or Virtual-Box
- Provides a GUI for controlling, monitoring and configuring the simulation

Running the simulator natively

- Known to work on Ubuntu 20.04 and 18.04
- Download the pumasimulator-xxxx.tgz

  tar –xzvf pumasimulator-xxxx.tgz
  cd pumasimulator
- Read the *Readme.md* for installation instructions

Running the simulator with a VM image

- Install Oracle **Virtualbox 6.1**
  http://virtualbox.org/
- Download the Virtual Machine image (.ova) from ISIS
  - Tip: Do it on the campus net (ca. 2.6GB)
- Start the machine
- Login: student
- Password: student
- Open a terminal and type *pumasim*

Simulator internals

- Controller are called every 2 ms
- Predefined names
- The pumasim executable does not contain controllers, but loads them from the shared library *controlDLL.so*
- Pumasim first looks for the library in the current working directory, then in /opt/pumasim
- You only need to compile controlDLL.so

control.cpp

- Here you implement your robot controller
- **Important:**
  - File must also be compatible on the Real-Time-PC running QNX.
- `init…()` functions are called when you click on „Start" (controller).
- `…control()` functions are called periodically in the servo loop with 500Hz.
- A lot of global variables are declared via the structure *gv*: they contain the simulator/robot's state

data.mat

- Plain ASCII text file
- Each line is a timepoint:

time q(1..n) dq(1..n) qd(1..n) tau(1..n) x(1..m) dx(1..m) xd(1..m)

- n = DOF
- m = 7 in „6-DOF (quaternions)“ mode
  else m = DOF
- You can import it into Excel, Matlab, gnuplot, Octave, matplotlib, a.s.o. and make nice graphs

gains_*.txt

- Text file containing separate gains for all controllers for a specific robot mode
  - gains_1.txt = gains during 3DOF mode
  - gains_6.txt = gains during 6DOF quaternion mode
  - a.s.o.

- Please do not edit the text file manually, but use *Store gains* and *Load gains in the GUI*

Before you start coding

- **Read** *Notes and Restrictions on Coding.pdf* (available on ISIS)
- Information about available math library (vector, matrix, etc.), global variables, etc.

P-controller

- Important variables for the P-controller in the gv struct:

```
tau     : joint torques
q       : joint position
kp      : position gains for the current control mode
qd      : desired joint position
```

- You can tune your controller via the GUI
- You can visualize signals by writing them to a text file (.mat)

Compile System for controlDLL

- Cmake based compile template:

```
cd 1/
mkdir build
cd build
cmake ..
make
```

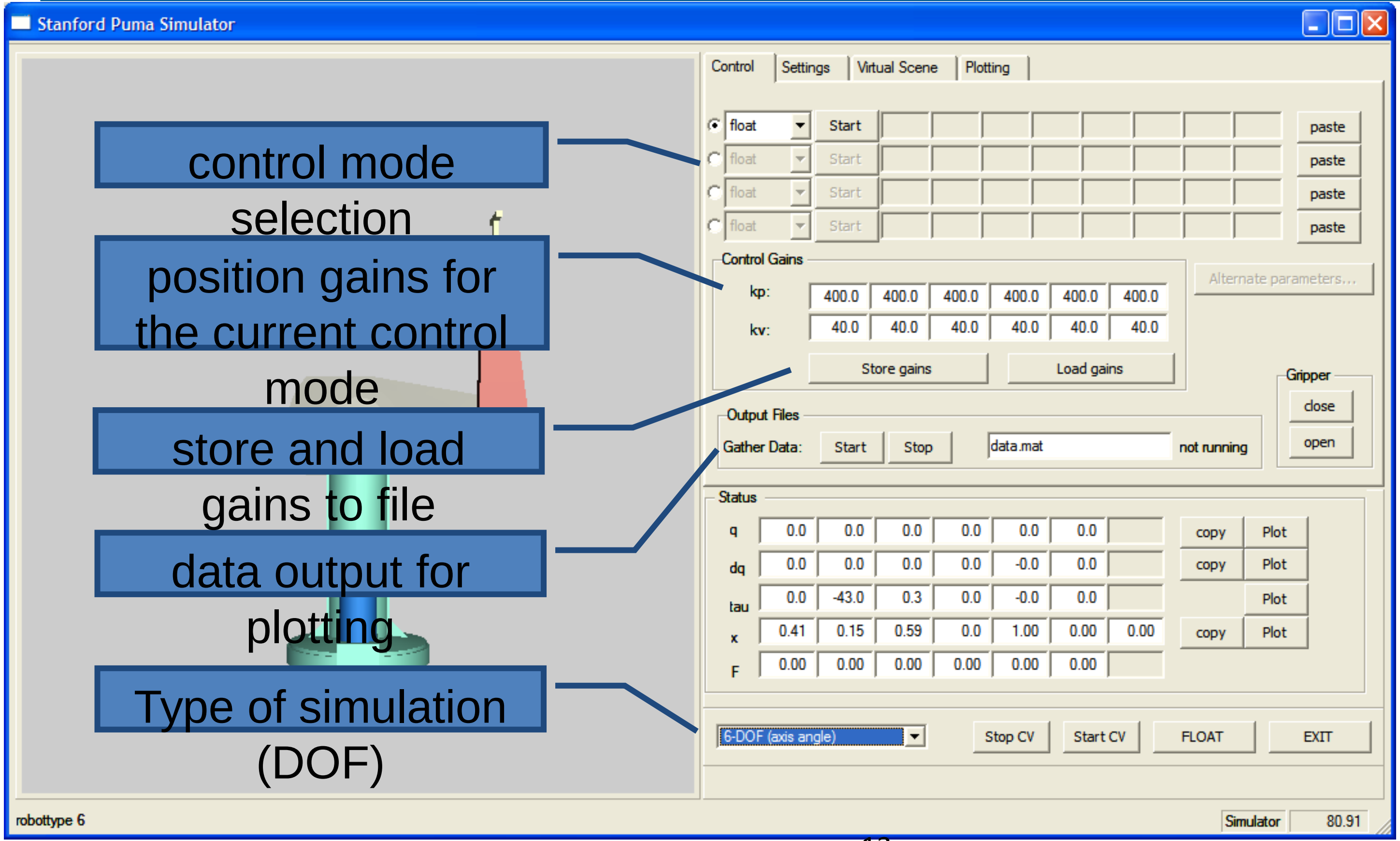
- This creates a controlDLL.so from control.cpp
- To use your controller, call *pumasim* in the *build/* directory:

```
pumasim
```

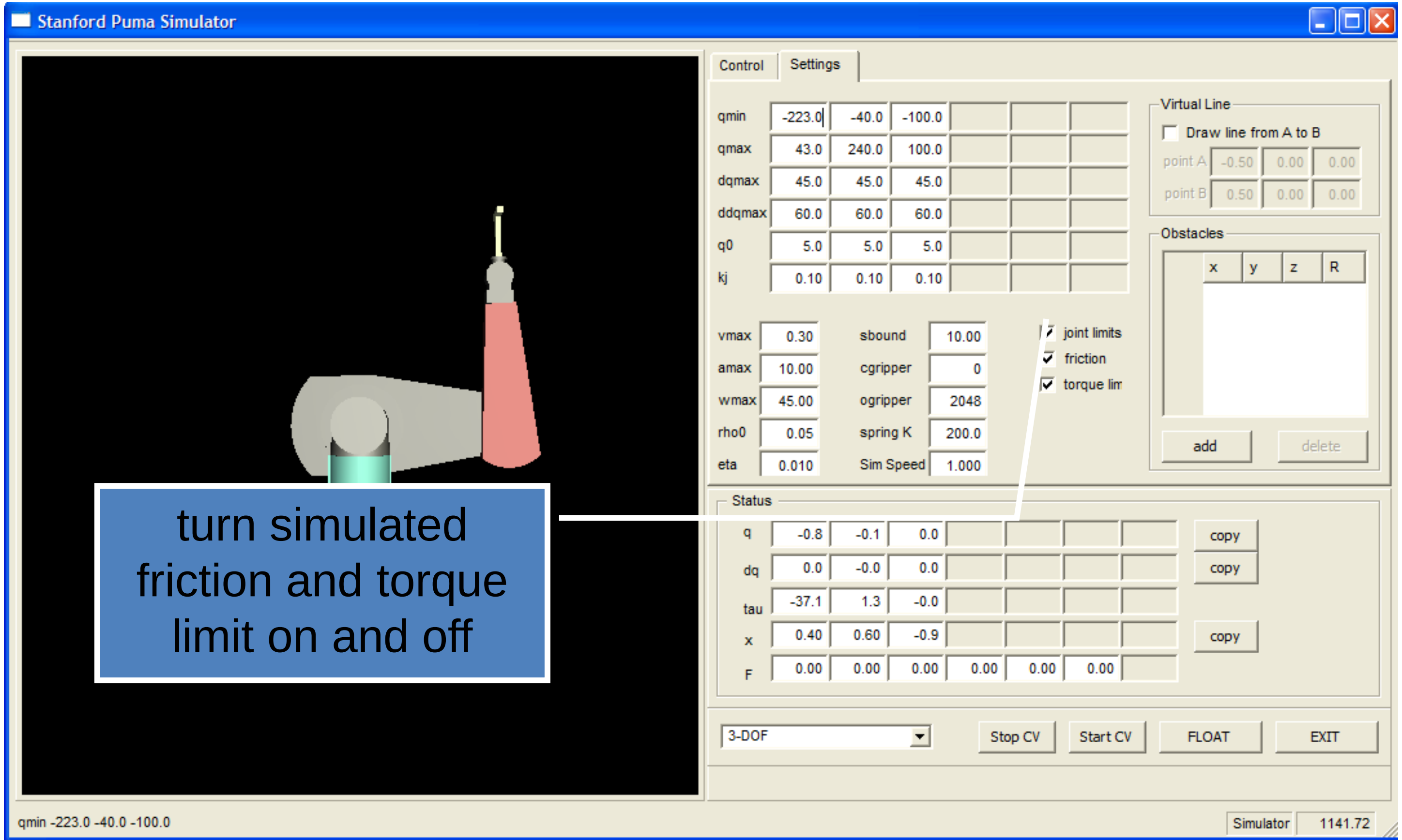
Q&A

- ISIS discussion forum
- teaching@robotics.tu-berlin.de

Puma Simulator



Puma Simulator Settings



turn simulated friction and torque limit on and off