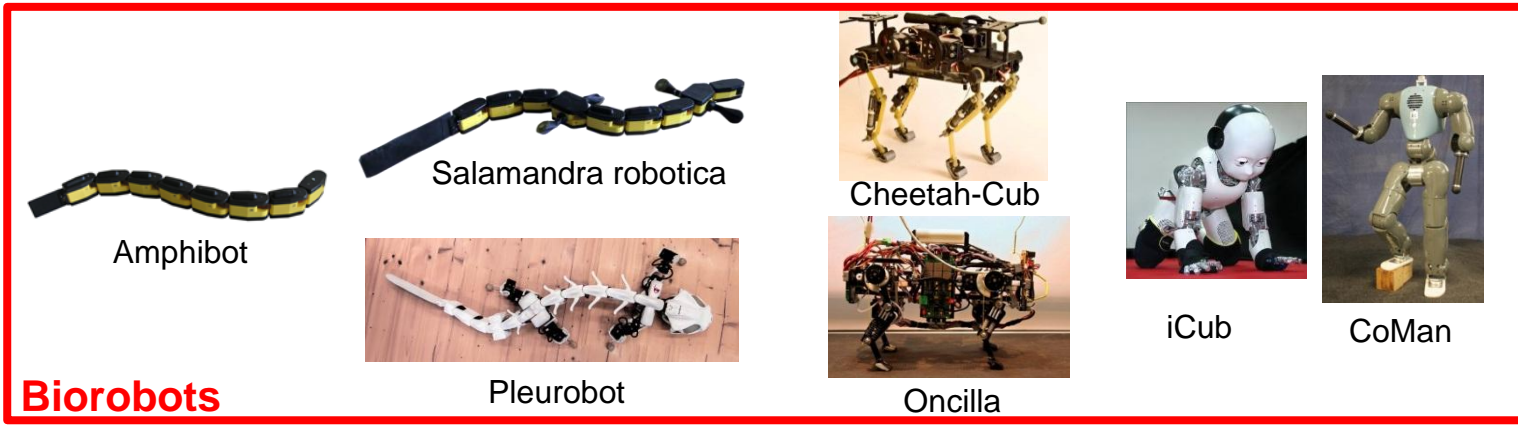
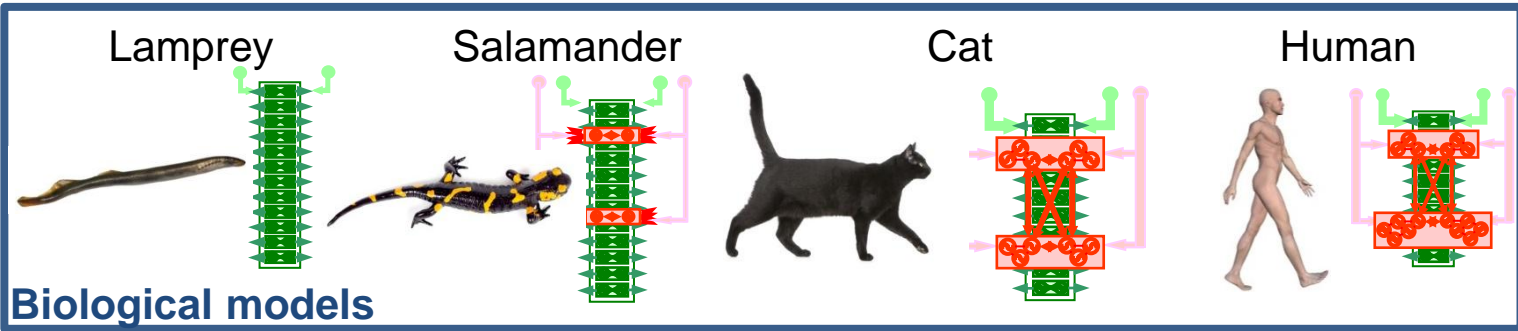


# Legged Robots

## Introduction, Content and organization of the course

Auke Jan Ijspeert



$$\tau \dot{z} = \alpha_z (\beta_z (g - y) - z) + f + C_t$$

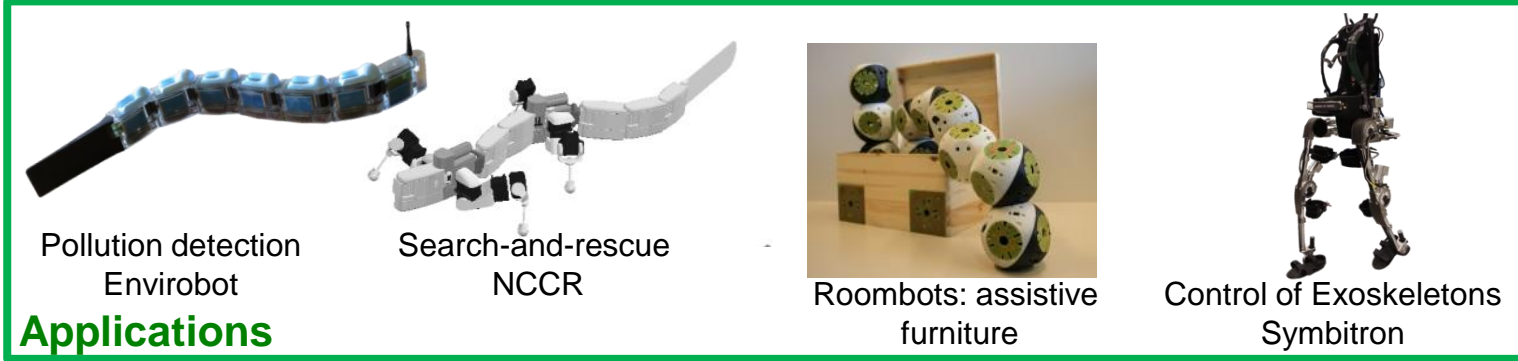
$$\tau \dot{y} = z$$

$$\tau \dot{x} = -\alpha_x x + C_c$$

$$f(x) = \frac{\sum_{i=1}^N \Psi_i(x) w_i}{\sum_{i=1}^N \Psi_i(x)} x (g - y_0)$$

**Dyn. movement primitives**      **Adaptive frequency oscillators**      **Discrete and rhythmic pattern generator**      **Morphed oscillators**

**Dynamical systems**



# Legged robots



ANYmal  
ETHZ, Switzerland



Aibo, SONY, Japan



Go 2, UNITREE, China



ATLAS  
Boston Dynamics, USA



RHex robot, USA



Asimo, Honda, Japan



Digit, USA



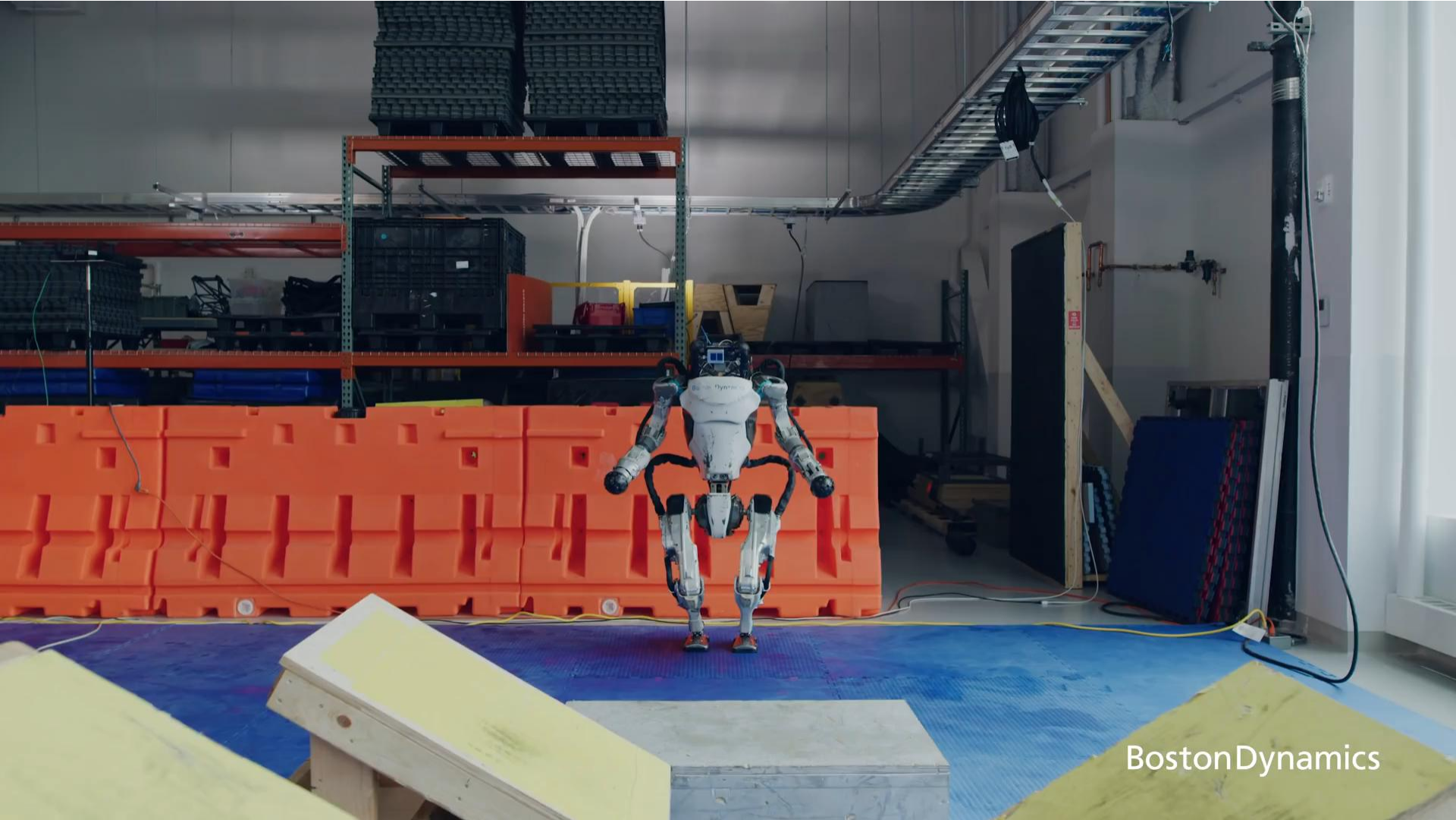
Spot  
Boston Dynamics, USA

# Mini Cheetah MIT



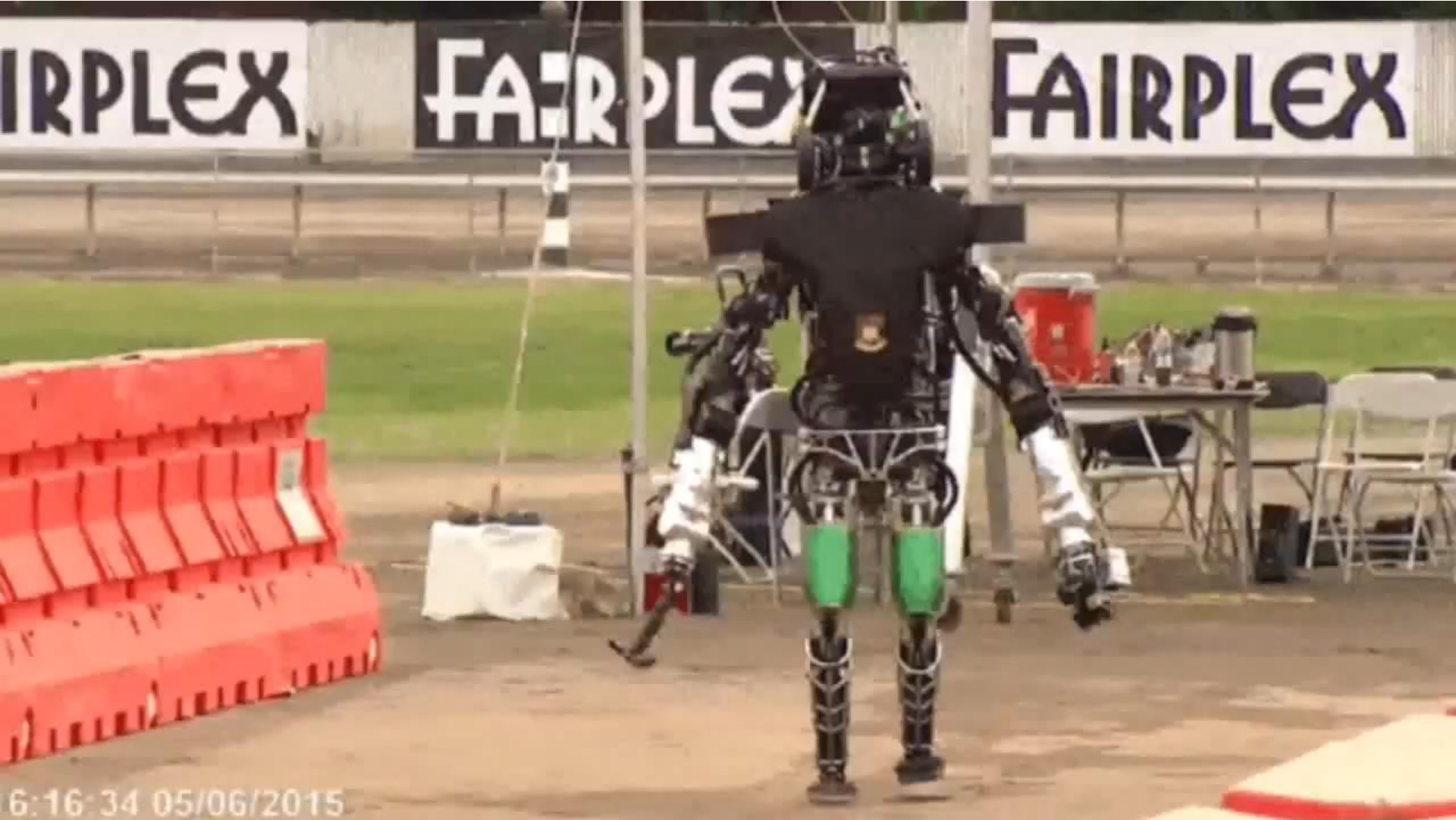
MIT Mini Cheetah  
MIT Biomimetic Robotics Laboratory

# ATLAS Boston Dynamics



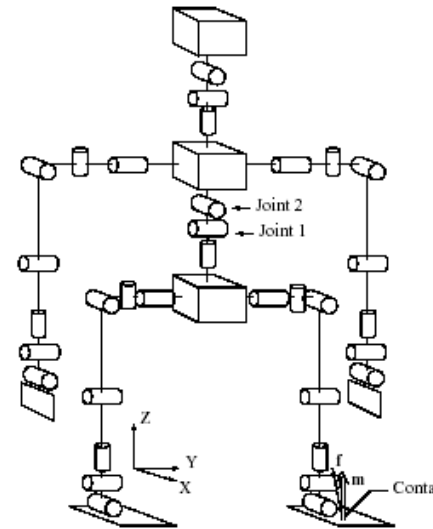
<https://www.youtube.com/watch?v=tF4DML7FIWk>

# 2015 DARPA Robotics Challenge Fails



# The problems of legged locomotion control

- **Underactuated problem:** a robot cannot follow arbitrary motion commands (because it is not attached to the ground)
- **Need to keep balance.** Many robots are only dynamically stable (e.g. quadruped and biped robots) and require careful control for staying upright.
- **Need to coordinate multiple degrees of freedom,** most legged robots are **redundant robots** (i.e. more controllable DOFs than the state DOFs)
- Legged robots are **highly nonlinear systems**, with complex relationships between joint motor commands and robot posture.
- The control of legged robots is has to **take into account the robot dynamics** (not only the kinematics, as in wheeled robots).



# Objectives

- Present the **design, control, and applications of legged robots** (from two, to four to more legs)
- Learn to **read the literature**
- Critically read and **present an article** to the class
- **Mini-project**: model a simulated 2D walker, and control a simulated quadruped robot, comparing two different control approaches (optimal control and reinforcement learning). All in Python.

# Pre-requisites

- Ideally:
  - Mobile Robots
  - Model Predictive Control (or other control courses)
- Programming in Python
- But the course is quite self-standing, so fine to follow without (by spending some time to catch up in Python programming)

# Organization

- **Series of lectures** by guest lecturers and me for the first weeks
- **Practicals and Mini-project**, starting this afternoon
- Around weeks 8-12, **student presentations** + mini-project
- **Written exam** on December 9 2025 (tbc).
- Use of Moodle. Key: “legs rock!” (lower case)
- **Grading**: Student presentations of articles 20% of grade, mini-project 50%, and written exam 30%.  
Work for the presentations and the mini-project will be done by groups of 3 students.

# Content of lectures

- Brief history of legged robots
- Different types of legged robot structures, typical actuators and sensors
- Pros and cons of legged versus wheeled robots
- Defining and measuring locomotion metrics (e.g. stability, energy consumption, ...)
- Overview of different locomotion models
- Overview of different control approaches
- Guest lectures by experts

# Different approaches to legged robot locomotion control in current robots

## **Model-based control:**

1. Trajectory based methods (ZMP)
2. Heuristic control methods
  1. Virtual leg control (Raibert)
  2. Virtual model control (Pratt et al)
  3. Hybrid Zero Dynamics control
3. Planning methods (Little dog project)
4. Inverse dynamics

## **Optimization and learning:**

1. Optimal control
2. Reinforcement learning

## **Biologically-inspired control:**

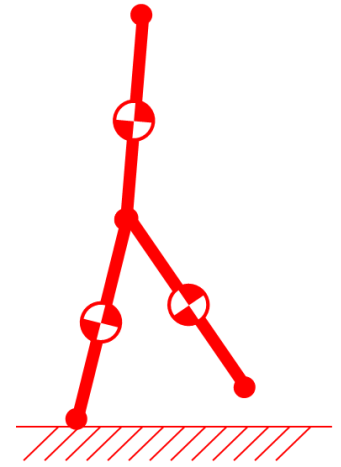
1. Passive and dynamic walkers
2. Sensory-driven methods,
3. CPG-and-reflex based methods

# Student presentations

- Chose one article among a list of key articles in legged robots. The list will be provided soon.
- Carefully read the article, critically analyze its pros and cons, and present it to the class.
- Work done in teams of 3. Each student should participate to the presentation
- Graded by the professor and teaching assistants (TAs).
- Schedule will be organized in the coming weeks.
- Counts for 20% of grade.

# Mini-Project

- **Modeling** a leg (double pendulum kinematics and dynamics)
- **Controlling** a quadruped robot in Python
- Teams of 3 students (same as for presentations)
- Done on your own laptops
- Grade based on one report + code + videos
- Counts for 50% of grade
- Presentation by Louis and Javier today



# Written exam

- Will take place on **December 9 2025** (to be confirmed)
- Questions about the lectures and the practicals
- Examples of questions will be provided at the end of each lecture
- 30% of grade, each student will be **graded individually.**

# To do list

- Find friends and **create teams of 3 students**.
  - Deadline Sept 23. Instructions will follow on how to transmit us the team members.
- **Browse through article lists** when available (very soon)
- **Choose article** (first come, first served)
- **Choose date for student presentation** (first come, first served)

# Contacts

- Main communication tool: **Forums on Moodle**
- Professor: [auke.ljspeert@epfl.ch](mailto:auke.ljspeert@epfl.ch)
- Main teaching assistants:
  - [Louis.Gevers@epfl.ch](mailto:Louis.Gevers@epfl.ch)
  - [Javier.Pey@epfl.ch](mailto:Javier.Pey@epfl.ch)
- Additional teaching assistants:
  - [Astha.Gupta@epfl.ch](mailto:Astha.Gupta@epfl.ch), [Chuanfang.Ning@epfl.ch](mailto:Chuanfang.Ning@epfl.ch),  
[Lixuan.Tang@epfl.ch](mailto:Lixuan.Tang@epfl.ch), [zhuoran.ren@epfl.ch](mailto:zhuoran.ren@epfl.ch),  
[advait.sriram@epfl.ch](mailto:advait.sriram@epfl.ch), [alifuat.sahin@epfl.ch](mailto:alifuat.sahin@epfl.ch),  
[theo.lemonnier@epfl.ch](mailto:theo.lemonnier@epfl.ch), [mehmet.dogan@epfl.ch](mailto:mehmet.dogan@epfl.ch)

End of introduction

Next: Lecture 1

Moodle key: “legs rock!”  
(all lower case, no quotes)