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ARTIFICIAL & NATURAL INTELLIGENCE
TOULOUSE INSTITUTE

(Artificial and Natural) Motion

Nicolas Mansard, Philippe Souères, Olivier Stasse

Université Fédérale
Toulouse Midi-Pyrénées

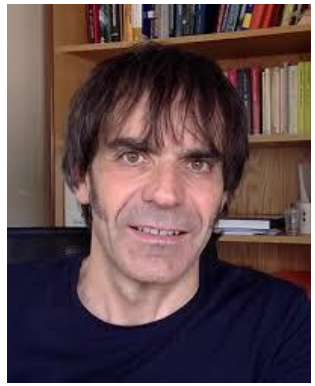
Outline

- **General presentation**
- **Some results**
  - Scientific results
  - Related works
  - Planned PhD / post doc proposals
- **Interaction with other chairs / industrial**

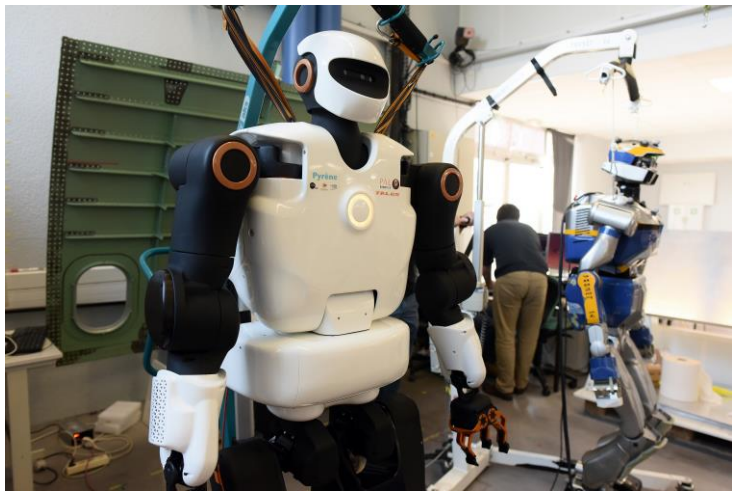
Chair members

Olivier Stasse

Nicolas Mansard

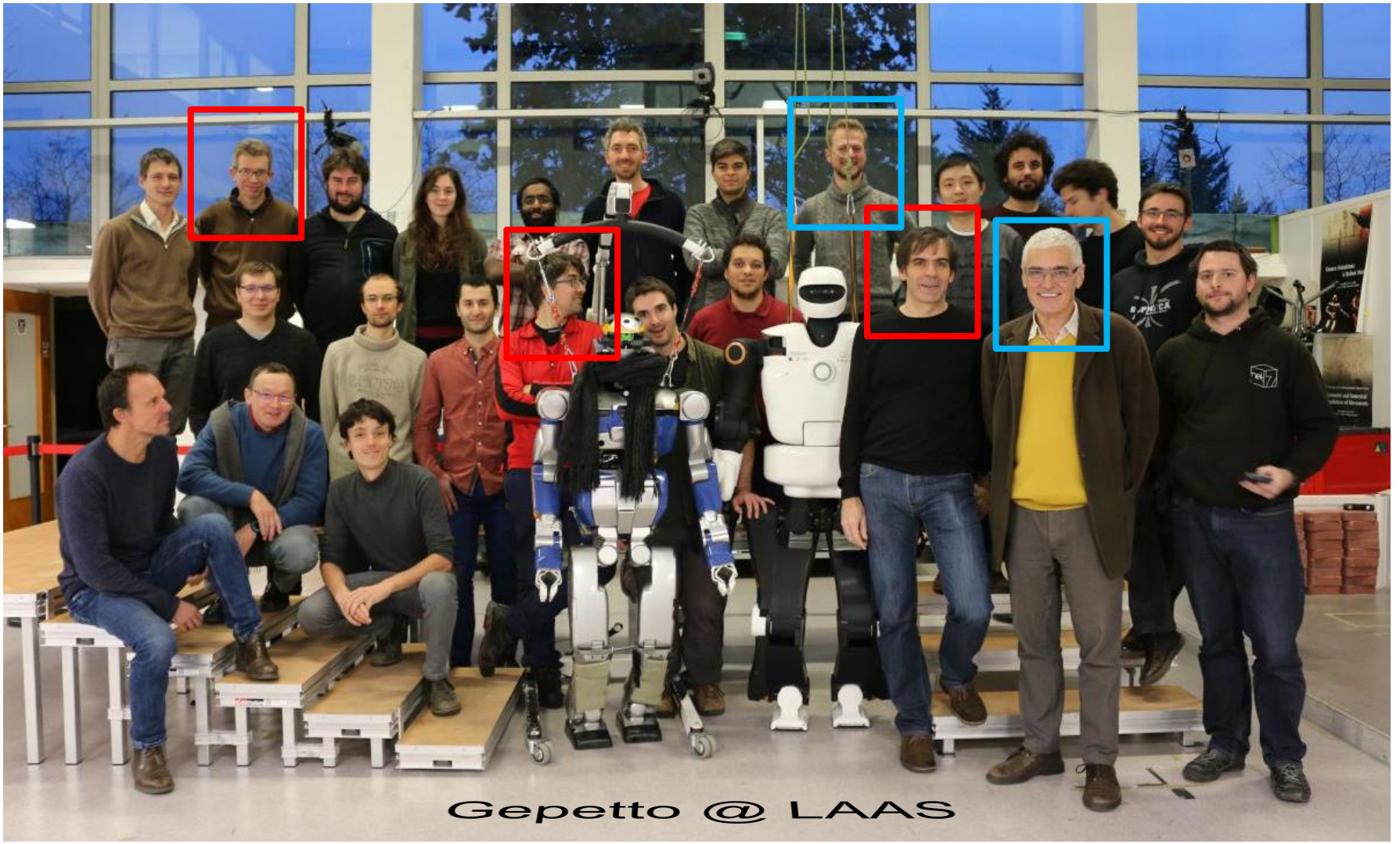


Philippe Souères

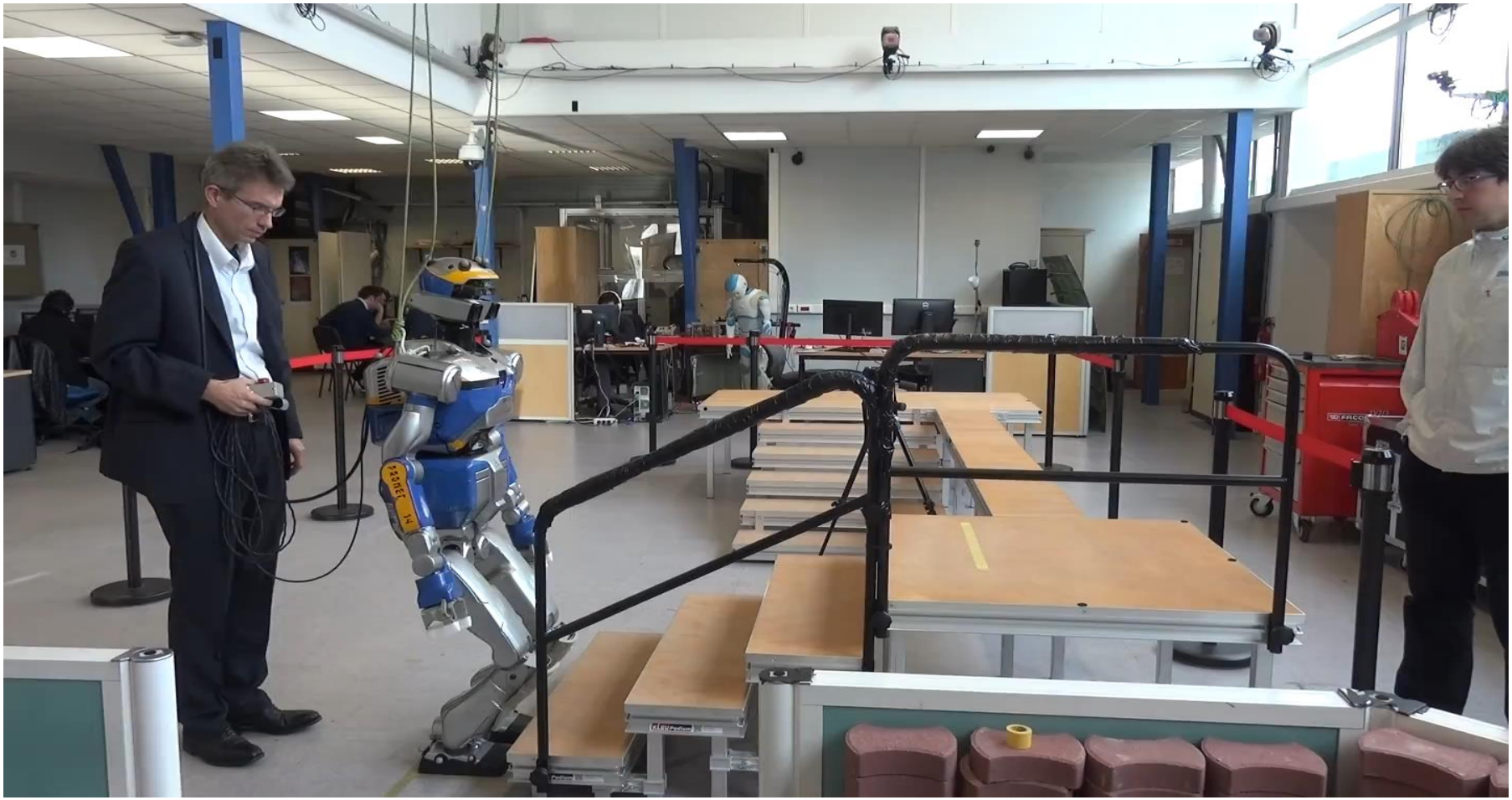


Pyrène & HRP-2

Chair members

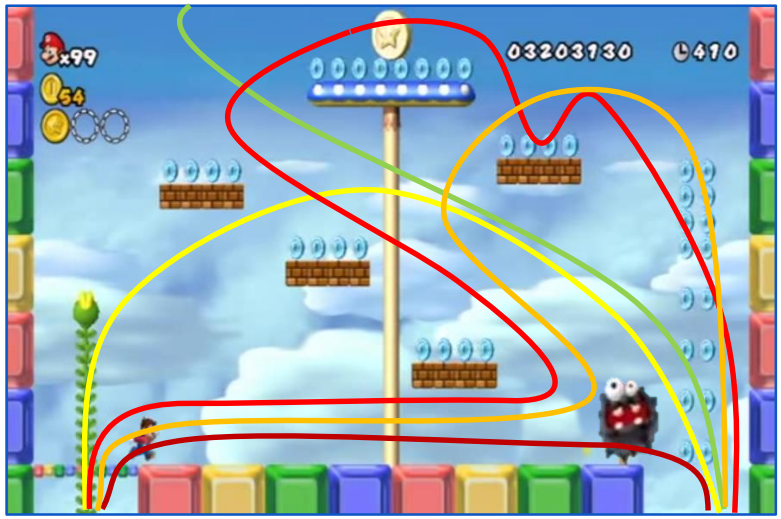


Context



Context

Optimal control – as a universal toolbox



Dynamics

$$\dot{x} = f(x, u)$$

State
(e.g. configuration
+ velocity)

Control
(e.g. motor
torques)

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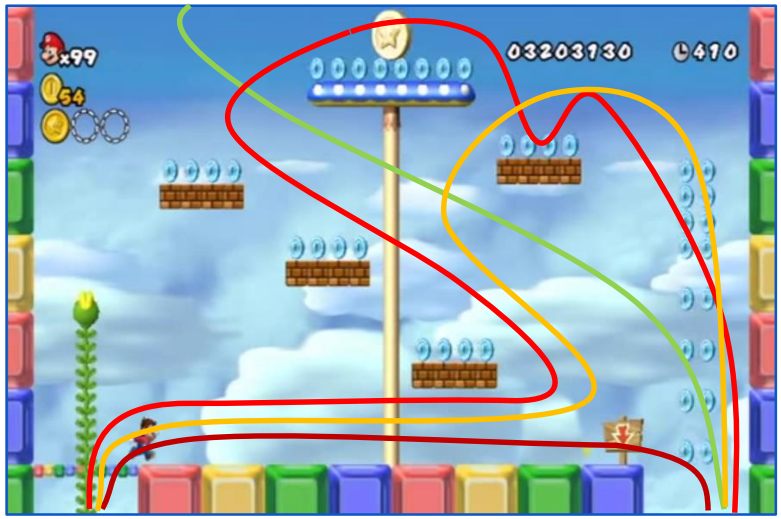
Optimal control – as a universal toolbox



Dynamics

$$\dot{x} = f(x, u)$$

Constraints

$$x(0) = x_0$$

$$h(x, u) \geq 0$$

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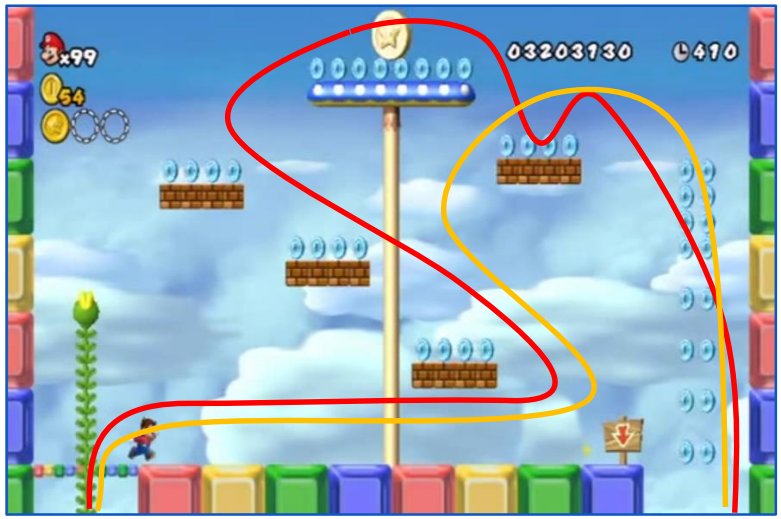
Optimal control – as a universal toolbox



Dynamics

$$\dot{x} = f(x, u)$$

Constraints

$$x(0) = x_0$$

$$h(x, u) \geq 0$$

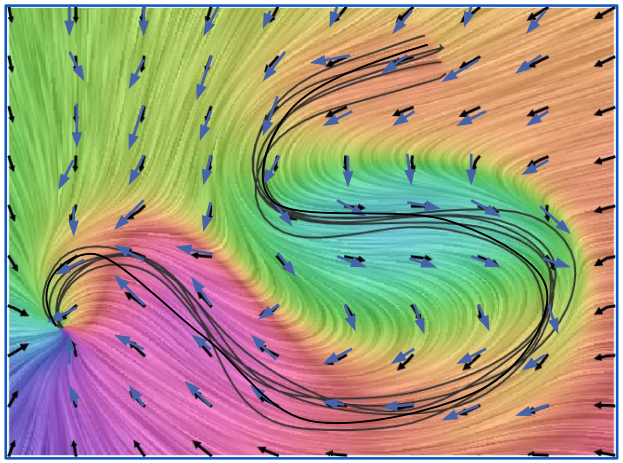
Cost / reward

$$\int_0^T l\big(x(t), u(t)\big)dt$$

Context

$$\min_{\{x_t\},\{u_t\}} \int_0^T l_1(x_t, u_t)dt \quad \text{AND} \quad l_2(x_T) \ldots \text{AND} \quad \int_0^T l_p(x_t, u_t)dt$$

$$\text{so that} \qquad \forall t,\ \dot{x}(t) = f(x(t), u(t))$$



Optimizing a trajectory

- U: t → u(t)
- Motion planning

Optimizing a policy

- Π: x → u = Π(x)
- Reinforcement learning

Context

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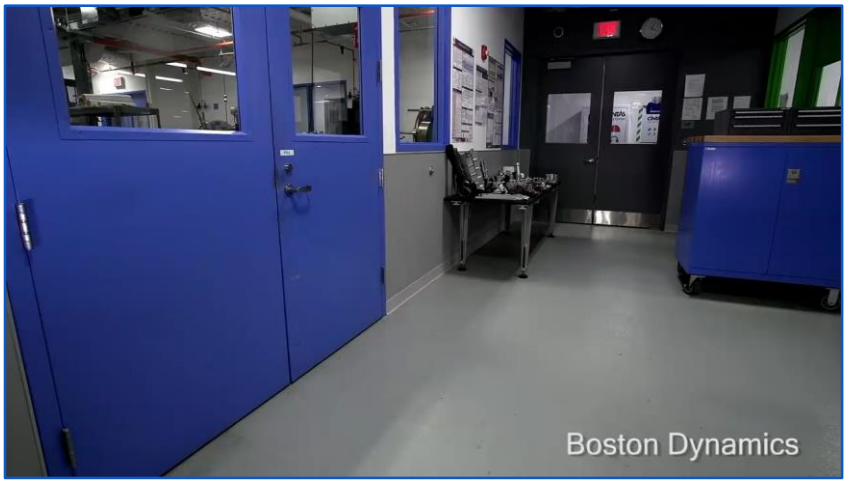
Model versus data in legged robotics



Boston Dynamics

- Feedback linearization
- Expert tuning

- Few trials and errors

DeepMind

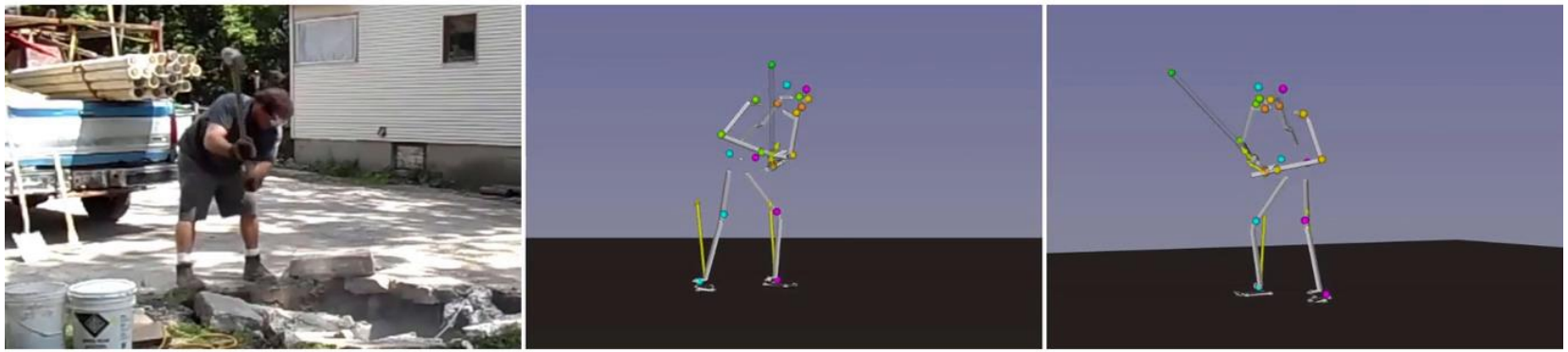
- Policy learning
- Bullet-proof simulator

- Tons of data

Context

Data-driven strategies … some examples

Hammer



Input video | Output motion and forces | Output from another viewpoint

CVPR'19, best-paper finalist

Computer vision (with Willow@Inria/Prairie)

- How to detect an axe?
- Where to find a database of axe images?

Objectives

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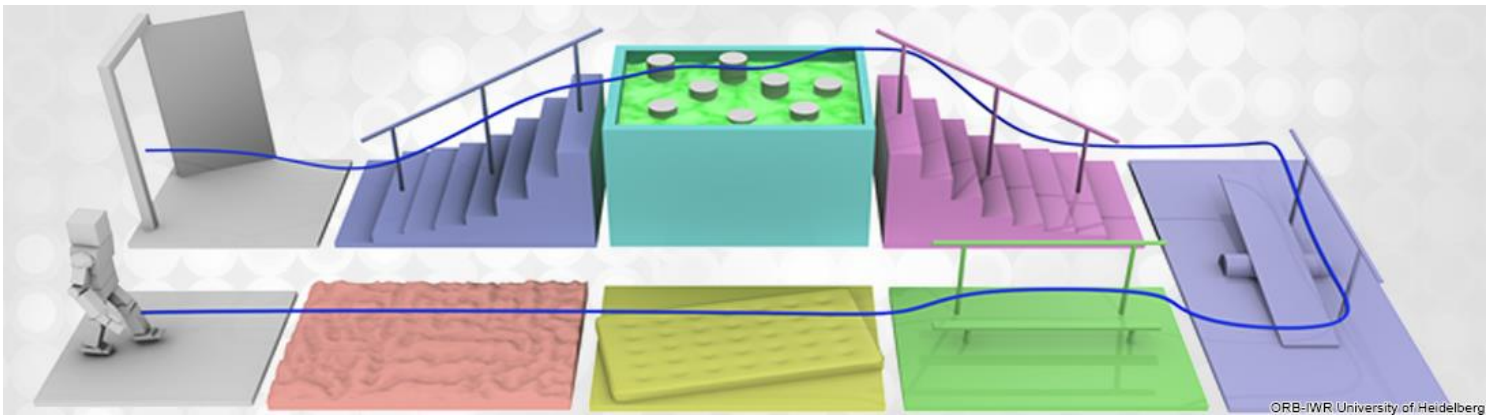
Understand how **data** and **models** can work together

Theoretical side

- Joint policy (RL = data) and trajectory (planning=model) optimization
- Realistic constrained optimization (real-time, robust, fast, etc)

Practical side

- Solve the locomotion problem
- Generalize it to other problems in robotics (manipulation first)



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Locomotion: model-based heuristics

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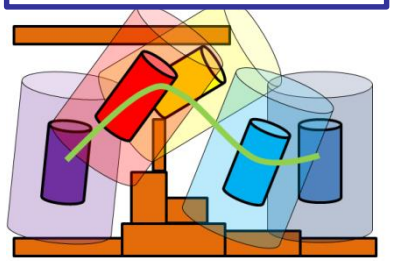
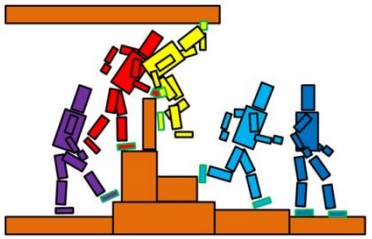
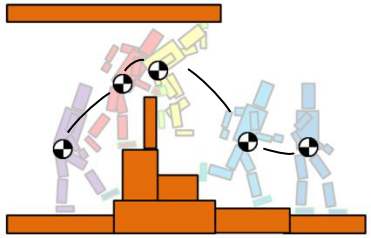
Reachability planner



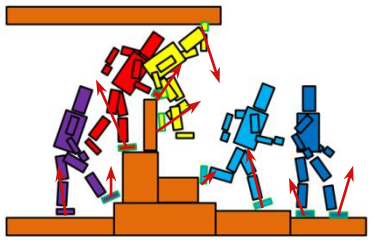
Sequence of contacts

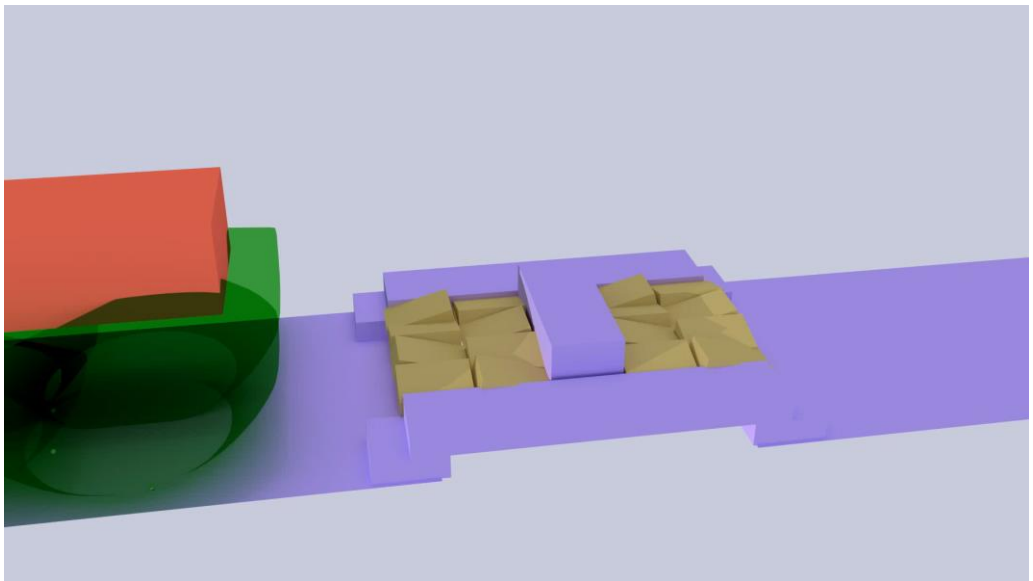


3D Pattern generator



Whole-body force control





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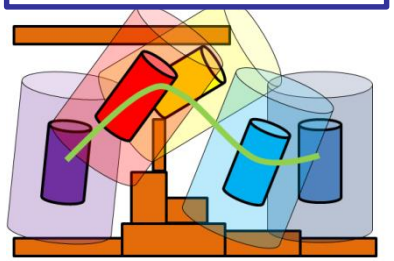

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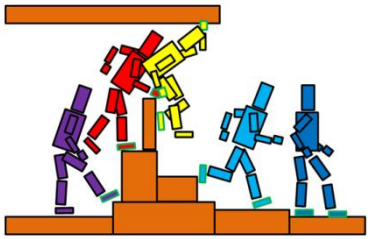

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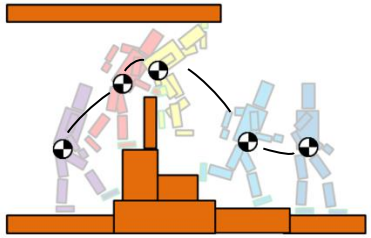

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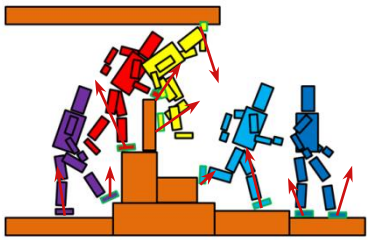

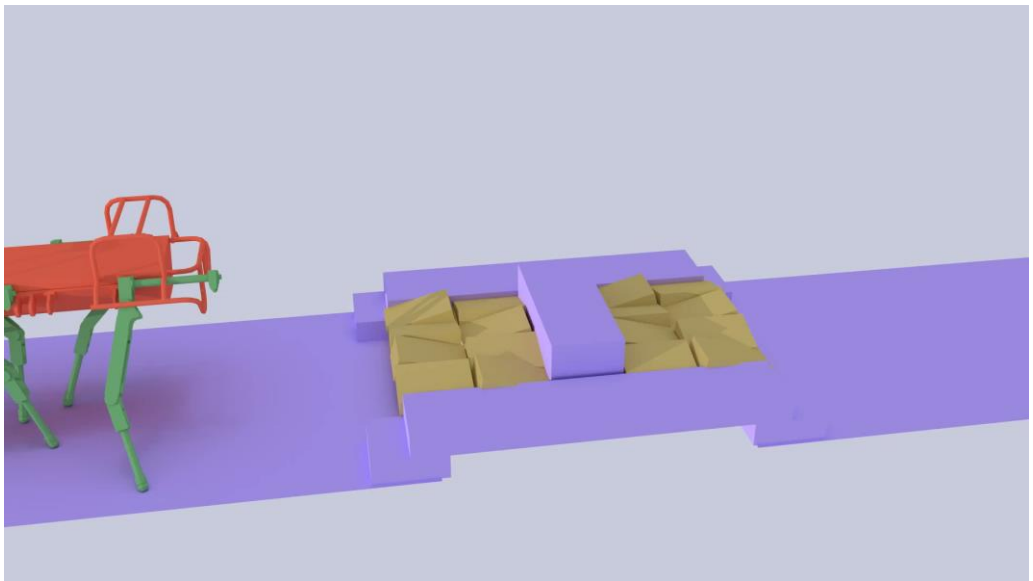

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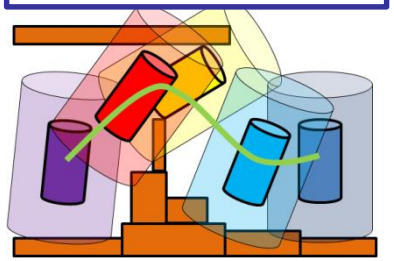

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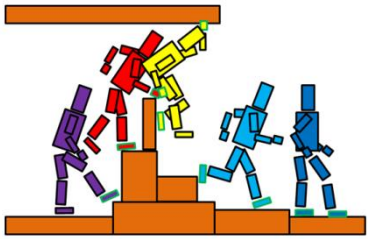

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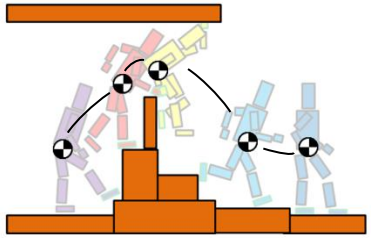

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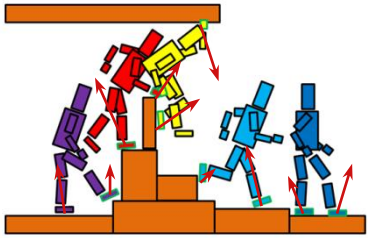

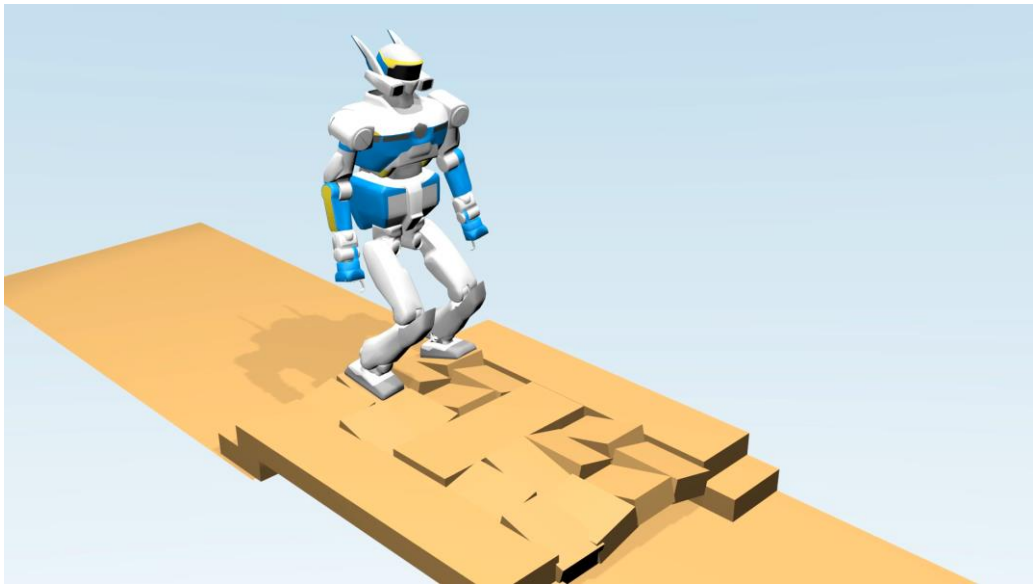

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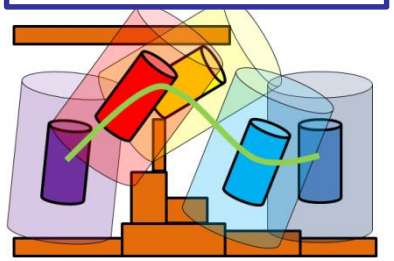

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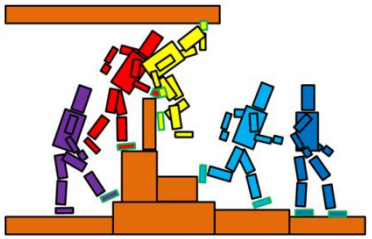

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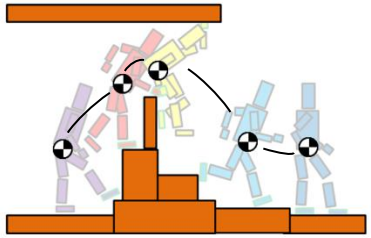

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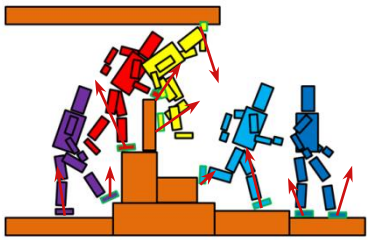
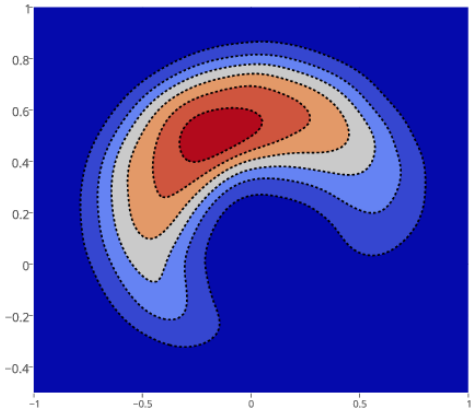




Data-based GM model

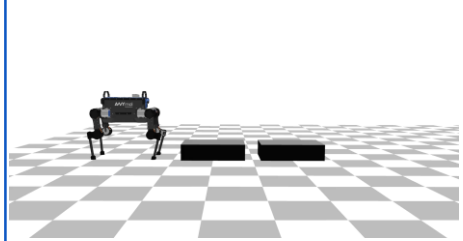
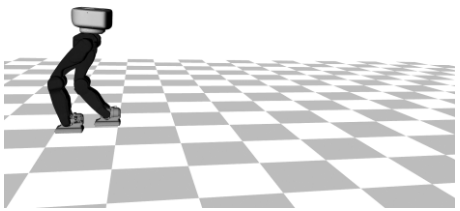
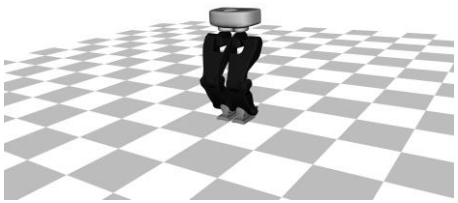
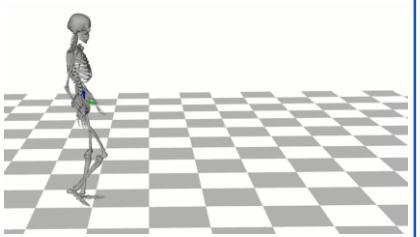
Real-speed optimal control

Project with H2020 Memmo and Prairie

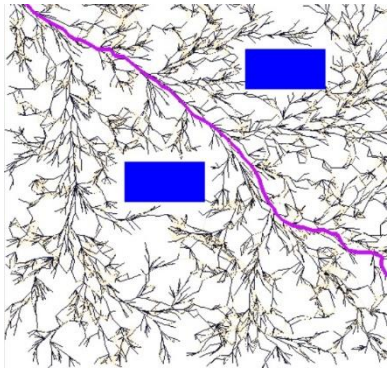
$$\min_{\substack{X=(Q,\dot{Q}),\\ U=\tau}} \int_0^T l(x_t, u_t)dt$$

$$\text{so that} \quad \forall t,\ \underbrace{\dot{x}(t) = f(x(t), u(t))}_{\text{robot dynamics}},\ \underbrace{g\big(x(t), u(t)\big) = 0}_{\text{robot dynamics}}$$

- Differential dynamic programming (sparse SQP with multiple shooting)
  - Dim(x) = 50, dim(u) = 20, T = 200 … total = 14,000 variables
  - One descent step = 7 ms
- Introduce additional hard constraints with augmented Lagrangian

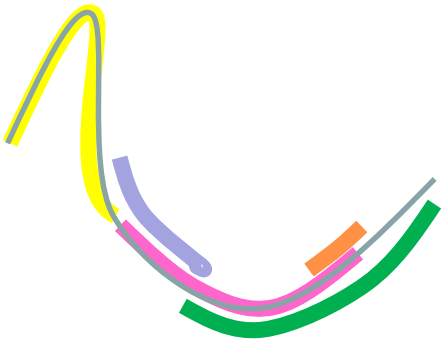





Model-based reinforcement learning



Kino-dynamic
Probabilistic Roadmap
30-50 states, dense connect

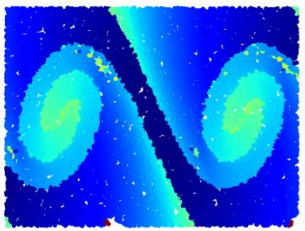
Sampling



Dataset of subtrajectories
10-100k items

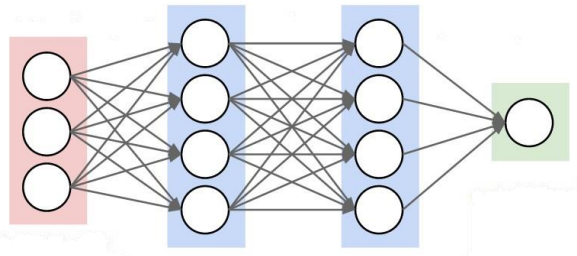
Roadmap
extension

Regression
(stoch.grad.)



HJB approximation
Value function as metric
Policy function as warm-start

Query

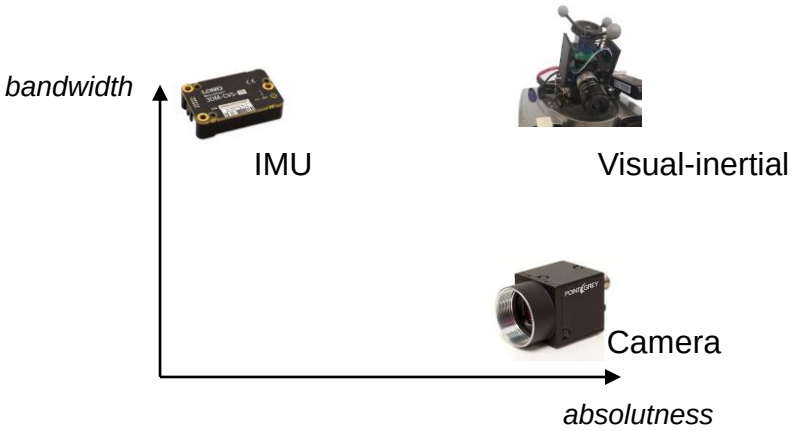


Neural network
2x512 hidden units

Kilohertz localization and mapping

Project with IRI-UPC Barcelona

- Two complementary sensors



- Optimal estimation (max likelihood)
  - Camera: artificial (or natural) landmarks
  - IMU: pre-integration in Lie groups
  - Optimization: off-constraint stochastic optimization

PhD subject and post-doc proposals

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- PhD thesis in constrained optimization … Ewen Dantec
- PhD thesis in model-based reinforcement learning … Amit Parag
- Looking for a post-doc
  - Expertise in robotics or numerical optimization welcome

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On-going collaboration

- Industrial collaboration to be emphasized in ANITI
  - AIRBUS joint lab ROB4FAM (future of aerospace manufacturing)
  - Naver Labs: co-supervision of a PhD
  - Proposition of CIFRE by Continental Corp

- Academic collaboration
  - Coordinator of H2020 Memmo

    Max-Planck Inst., Univ. Edinburgh, IDIAP Swiss
  - Collaboration with 3IA

    with PRAIRIE (Ponce, Laumond, Carpentier, Schmidt)

    with MIAI (Naver Labs, Schmidt)

Hopped collaborations

- In (continuous) constrained optimization
  - Jérôme Bolte, Edouard Pauwel, Marc Teboulle, JB Lasserre
  - GANs? Jérôme Renaut
- In data-driven reinforcement learning
  - Emmanuel Rachelson
- In computer vision ?
- Looking for data?

  We have many experimental setup for you !