Program / simulation tools / ROS / Gazebo / OpenHRP

Olivier Stasse

Program/simulation tools ROS/Gazebo/OpenHRP

Robotics Principia

24th January 2019, Sophia-Antipolis, France

O. Stasse, Gepetto,
LAAS-CNRS

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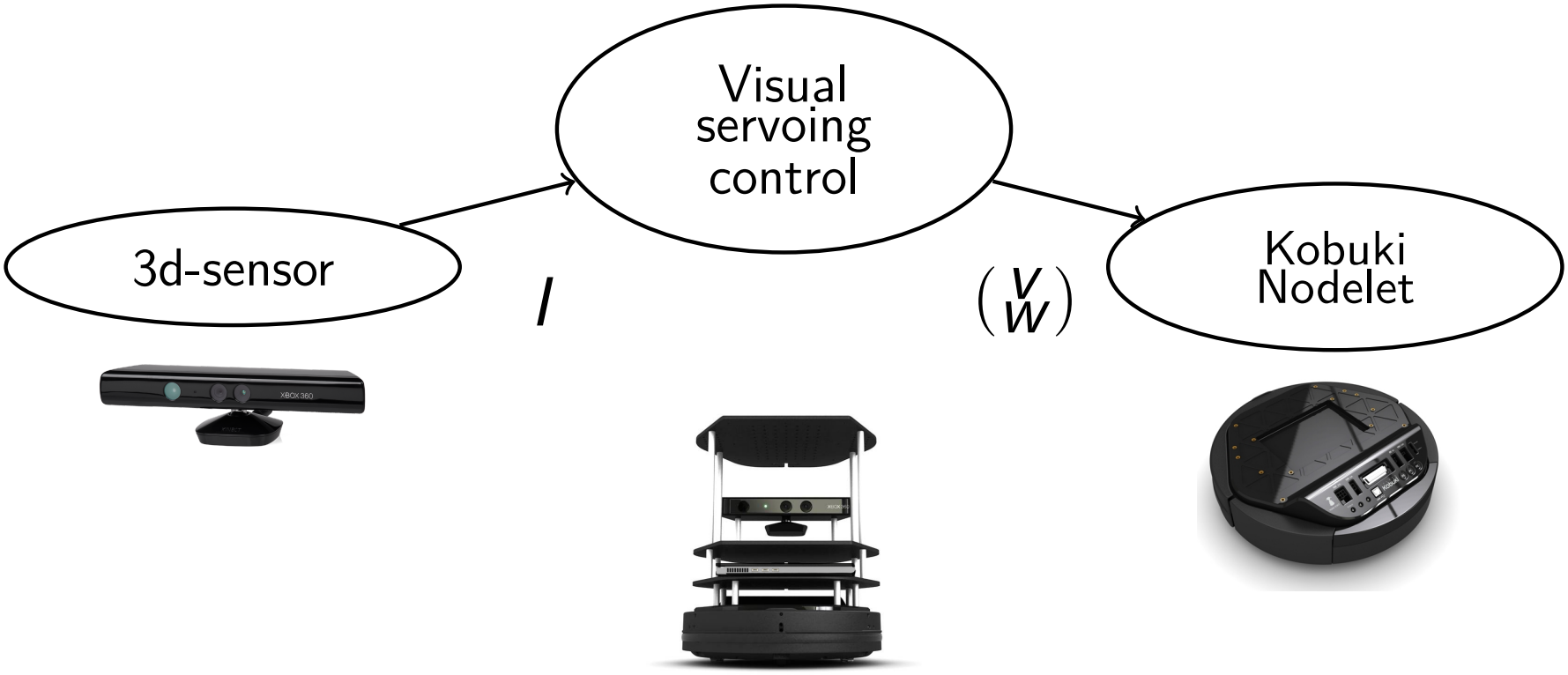
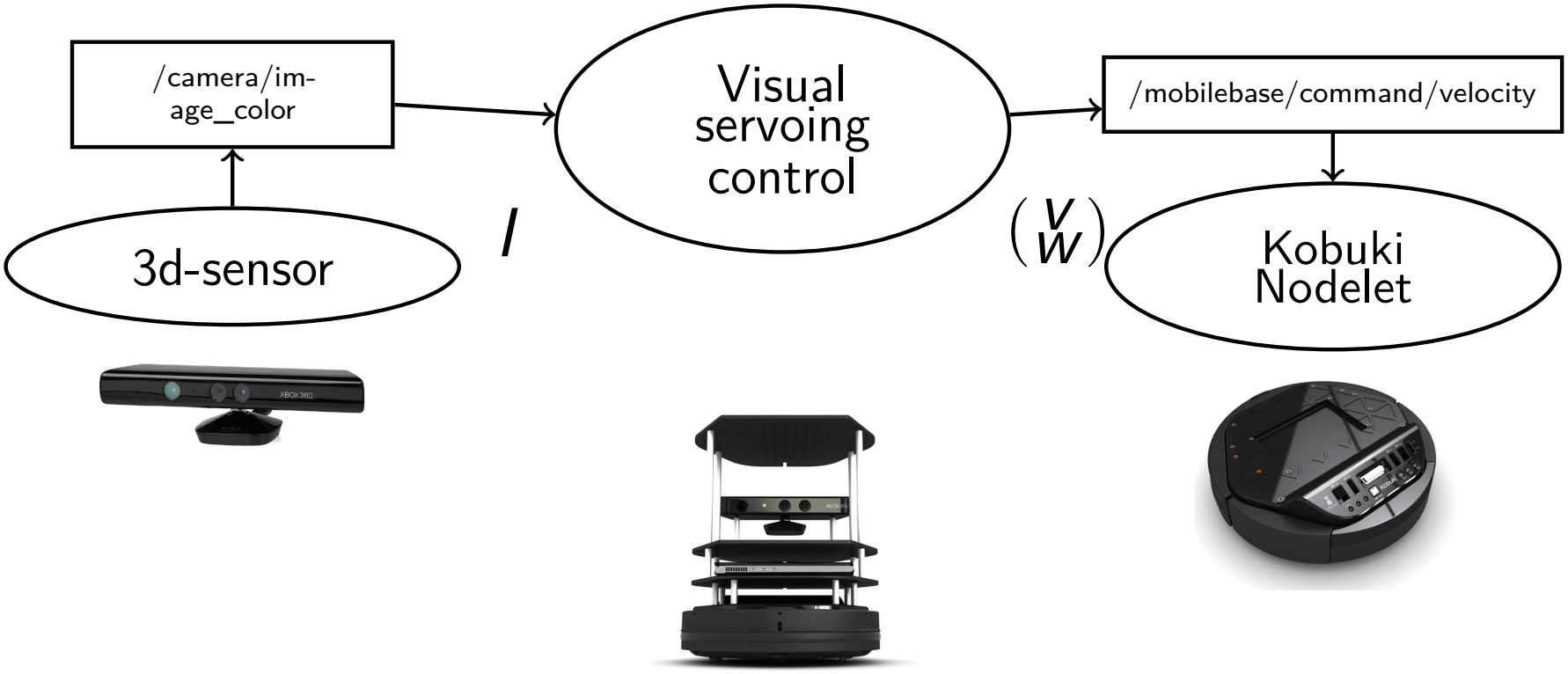
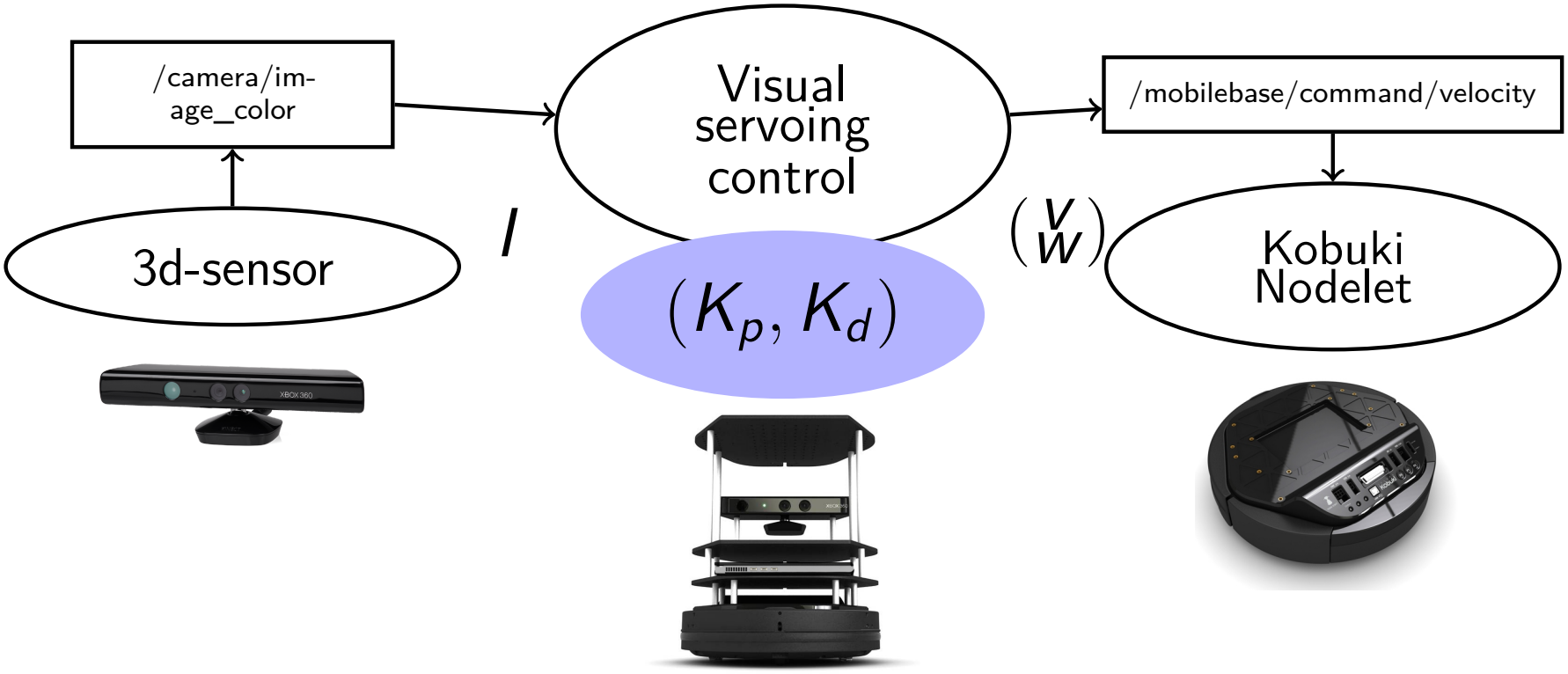
Exemple: Asservissement visuel



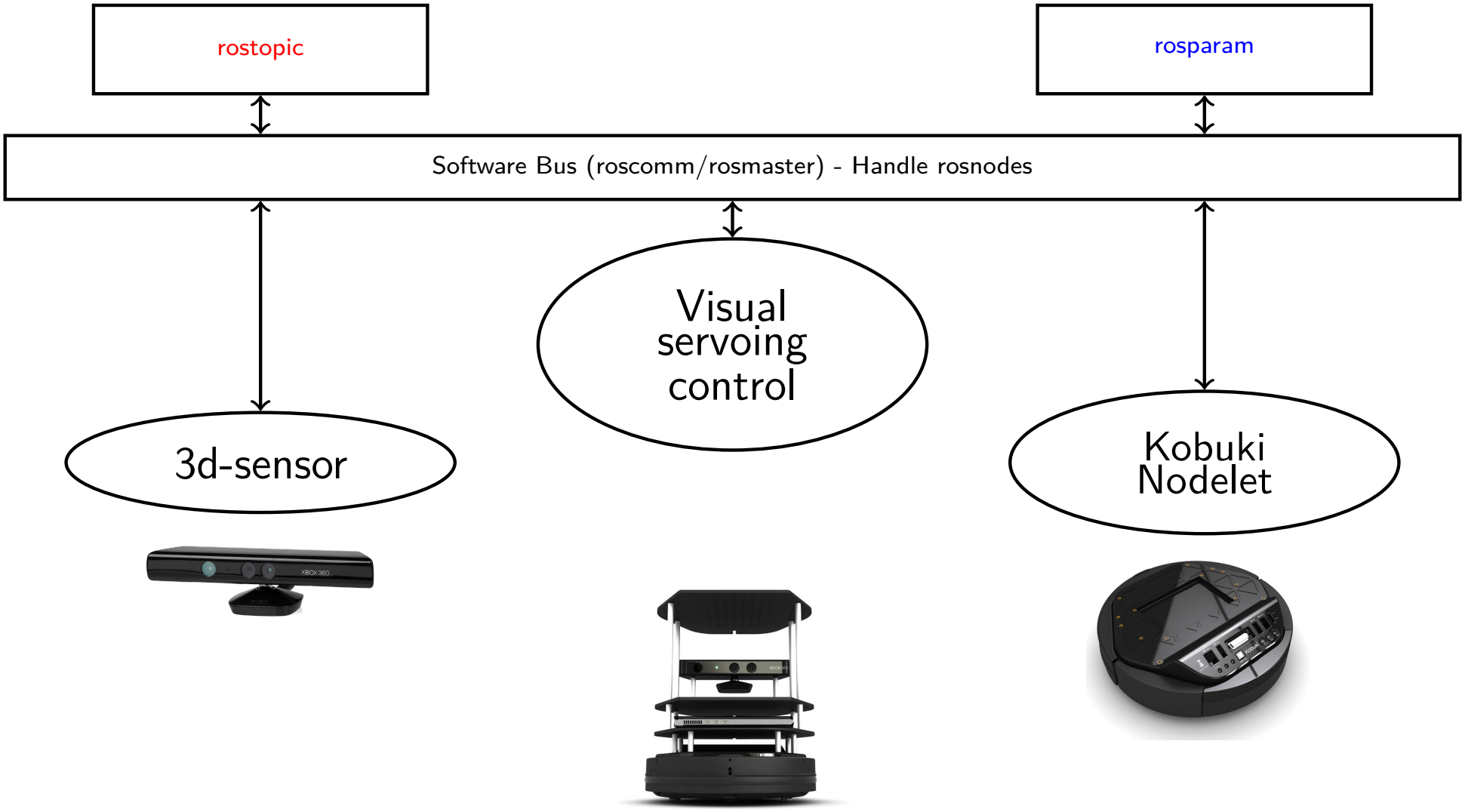
Exemple: Asservissement visuel - Topics



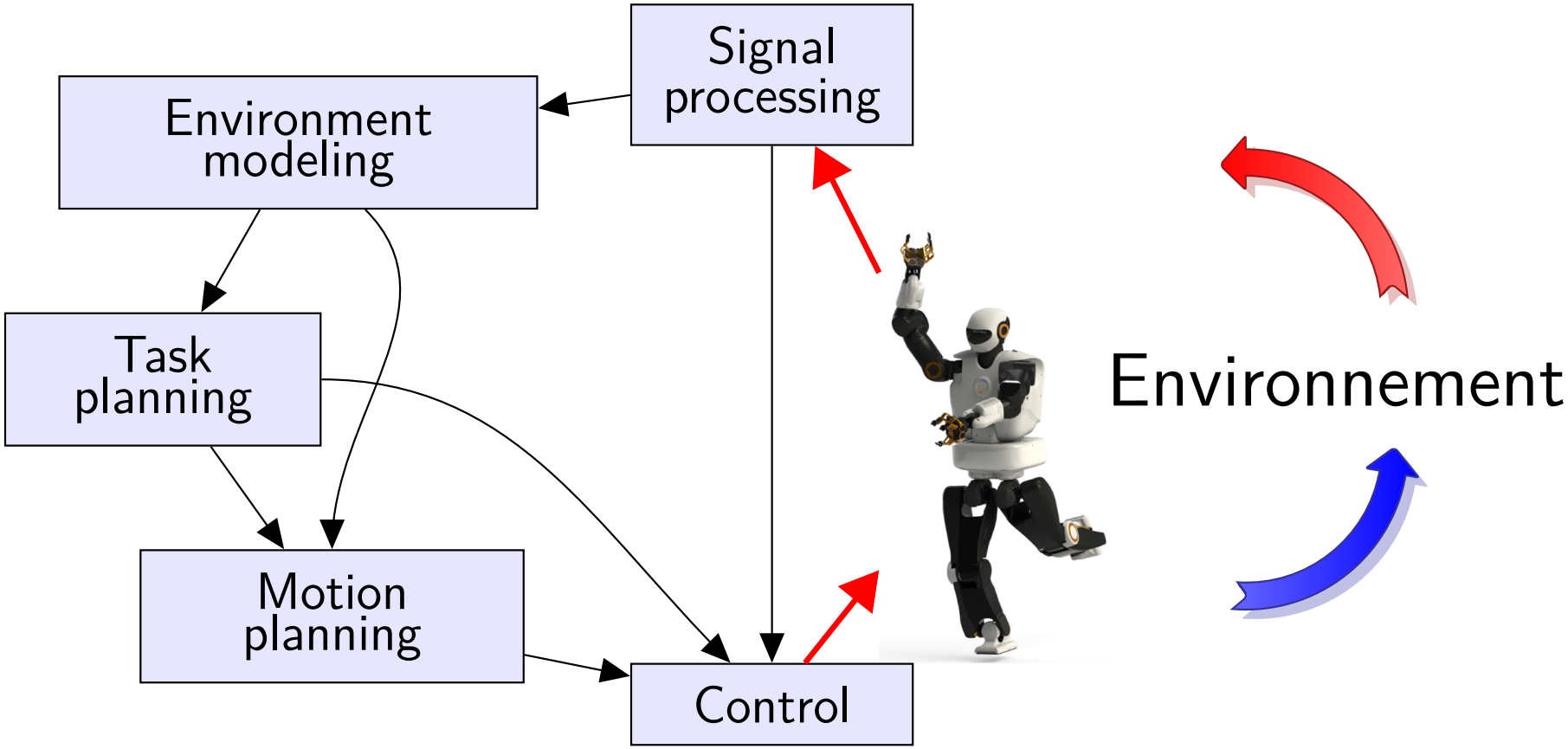
Exemple: Asservissement visuel - Topics - Params



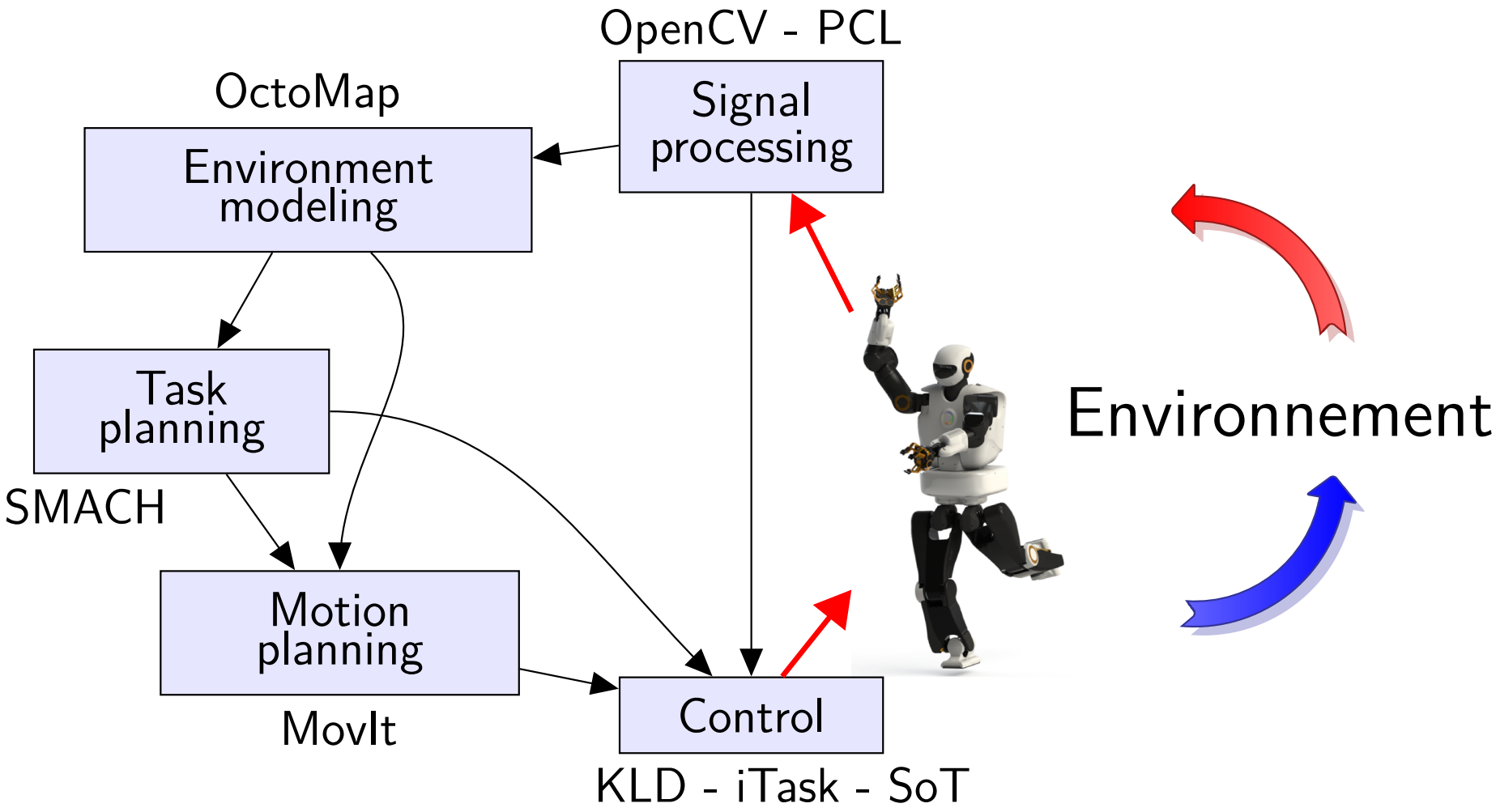
Exemple: Asservissement visuel - Software bus



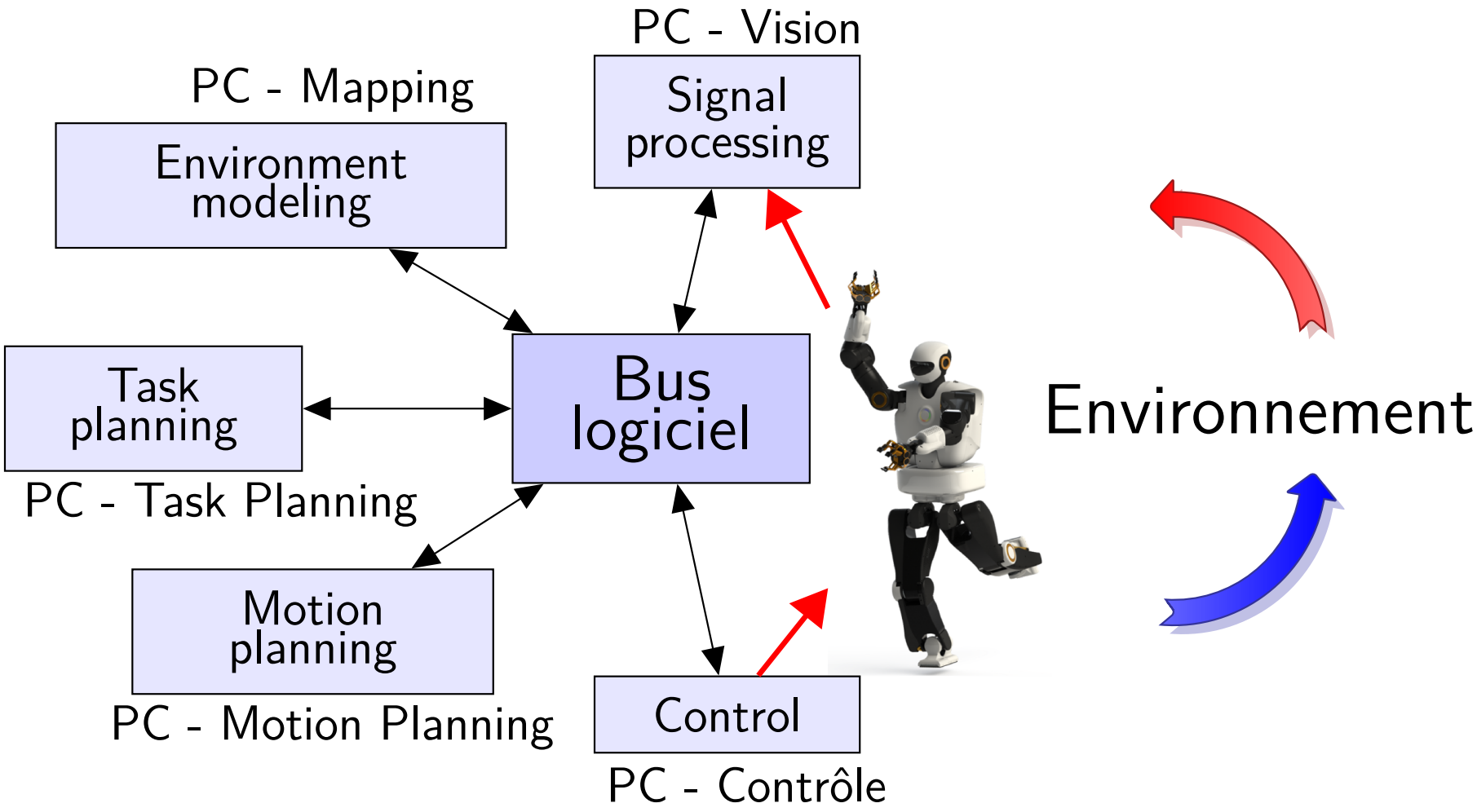
Motivations - Robotics application



Motivations - Robotics application - Tools

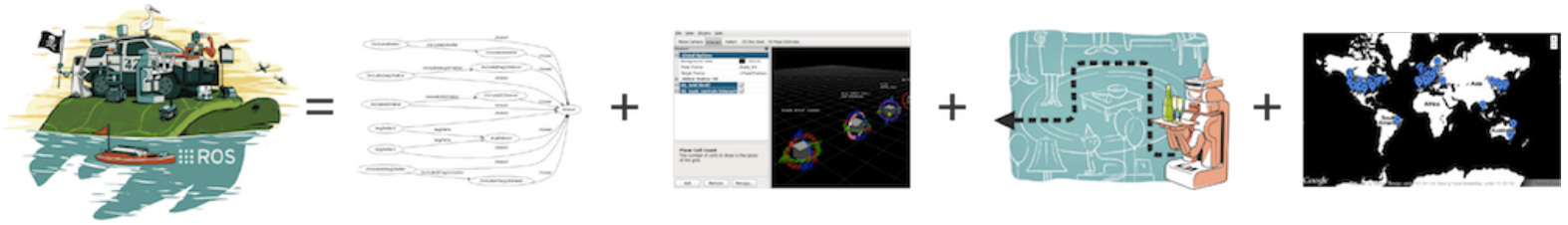


Motivations - Robotics application distributed



Motivations

The robotics community must *collaborate* to create robotics systems of the same quality than in the computer science and physics community.
ROS is the tool that allowed to scale-up.



Plumbery Tools Capacities Ecosystem

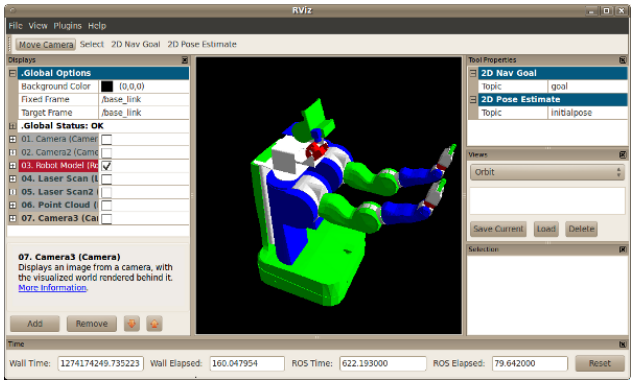
Motivations - Plumbery

Middleware

- Publication/subscription transmission on anonymous messages (Message Passing)
- Record and playback messages
- Requests/answers using remote procedure calls
- Distributed parameter server

Motivations - Tools

rviz	3D graphical interface
rosbag	Record and data visualizing
rxplot	Online viewing quantities
rxgraph	Graph application structure display
rqt	Incremental Graphical User Interface
catkin	Compiling and packages management system



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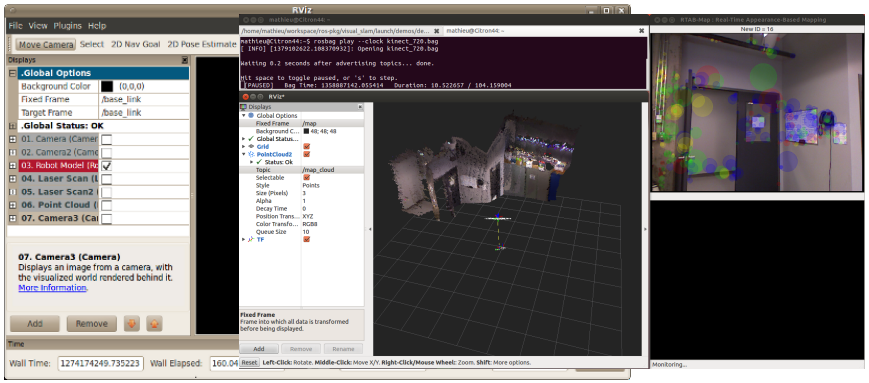

Motivations - Tools

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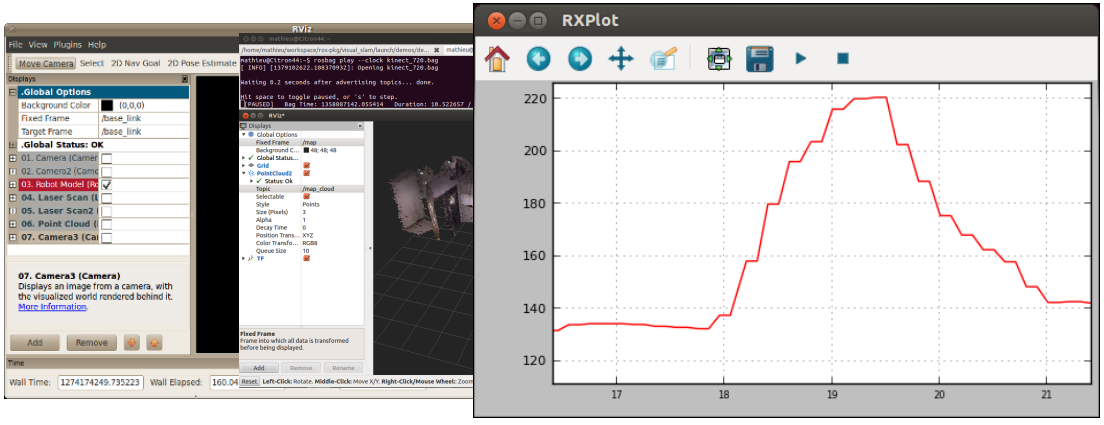

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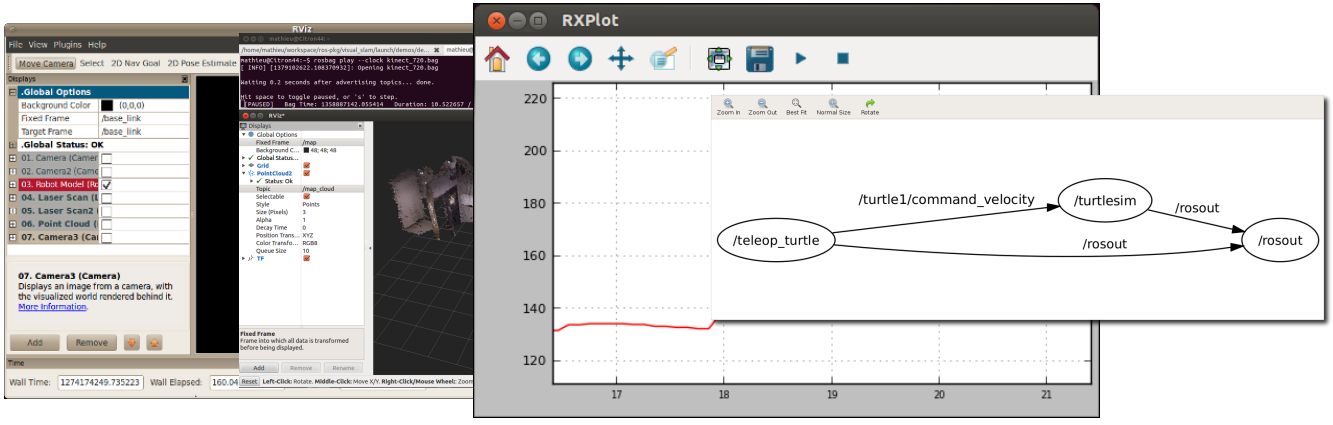

Motivations - Tools

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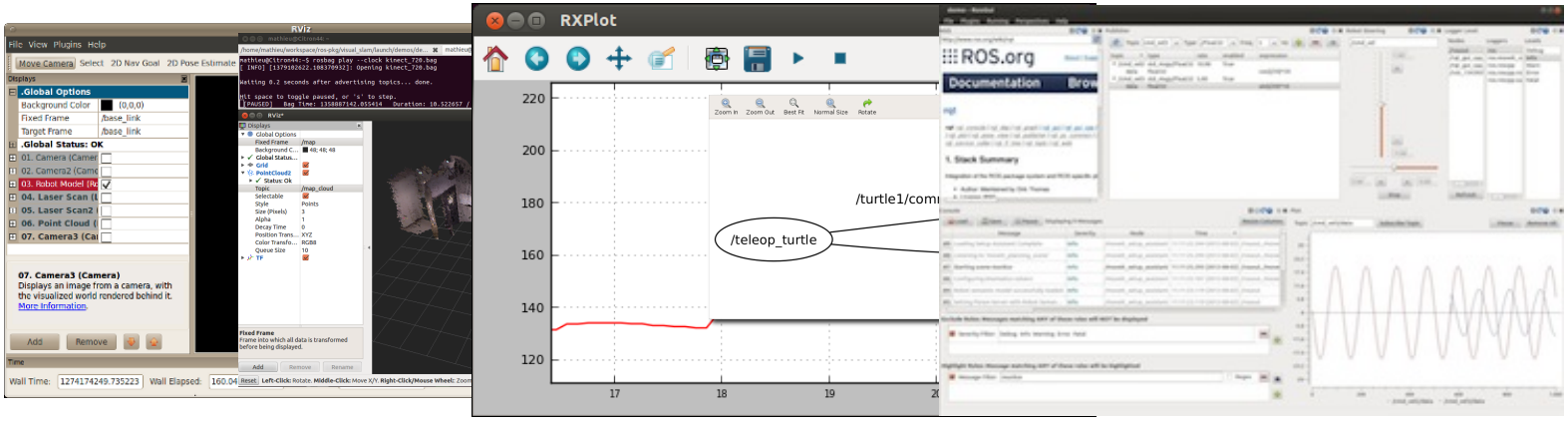


Motivations - Ecosystem

- Messages standardization for the robots
- Model description language (even if imperfect)
- Geometry - Dynamical libraries for robots
- Preemptable remote procedure calls
- Diagnostics
- Pose estimation
- Localization
- Map building
- Navigation

Motivations - Ecosystem

Operating Systems

Robots

Packages

Support : Ubuntu

Experimental :

Ubuntu ARM

OS X (Homebrew)

OS X (MacPorts)

OpenEmbedded/Yocto

Debian

Arch Linux

Windows

Ångström

UDOO

Motivations - Ecosystem

Operating Systems

Robots

Packages

01/05/2014 : 111 Supported robots on `http://wiki.ros.org/Robots`
25/04/2017 : 27 Supported robots on `http://wiki.ros.org/Robots`
01/05/2014 : 2048 Supported packages on `http://wiki.ros.org/Packages`
25/04/2017 : 1400 Supported packages on `http://wiki.ros.org/Packages`

ROS: short history

2008	ROS started with Willow Garage
2010 - Jan	ROS 1.0
2010 - Mar	Box Turtle
2010 - Aug	C Turtle
2011 - Mar	Diamondback
2011 - Aug	Electric Emys
2012 - Mar	Fuerte Turtle
2012 - Dec	Groovy Galapagos
2013 - Feb	Open Source Robotics Fundation continues ROS
2013 - Aug	Willow Garage became Suitable Technologies
2013 - Aug	PR-2 Support is handled by Clearpath Robotics
2013 - Aug	Hydro Medusa
2014 - Jul	Indigo Igloo (EOL - Apr 2019)
2015 - May	Jade Turtle (EOL - May 2017)
2016 - May	Kinetic Kame (EOL - May 2021)
2017 - May	Lunar Loggerhead (EOL - May 2019)
2018 - May	Melodic Morenia (EOL - May 2023)

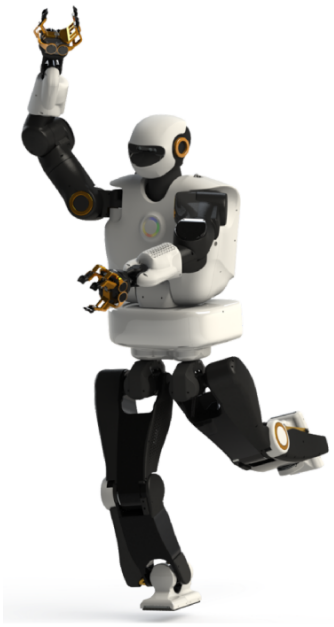
ROS: Release normalization

- Lunar Loggerheard (May 2017- May 2019)
  - Ubuntu Xenial (16.04), Yakkety (16.10)
  - Ubuntu Zesty (17.04 LTS)
  - C++11, Boost 1.62, Lisp SBCL 1.2.4, Python 2.7 (tests against Python 3.5 recommended) CMake 3.7.2
  - Ogre3D 1.9.x, Gazebo 7.5, PCL 1.8.0, OpenCV 3.x, Qt 5.7.1, PyQt5 5.7
- Melodic Morenia (May 2016 - May 2023)
  - Ubuntu Artful (17.10)
  - Ubuntu Bionic (18.04 LTS)
  - C++14, Boost 1.55, Lisp SBCL 1.3.14, Python 2.7 (tests against Python 3.5 recommended), CMake 3.10.2
  - Ogre3D 1.9.x, Gazebo 9, PCL 1.8.1, OpenCV 3.2, Qt 5.9.5, PyQt5 5.10.1
- Lien vers la ROS Enhancement Proposal (REPs) : `http://www.ros.org/reps/rep-0003.html`

Tutorials ROS

Online exercices

What is a simulator ?



[Ivaldi,ICHR,2014]

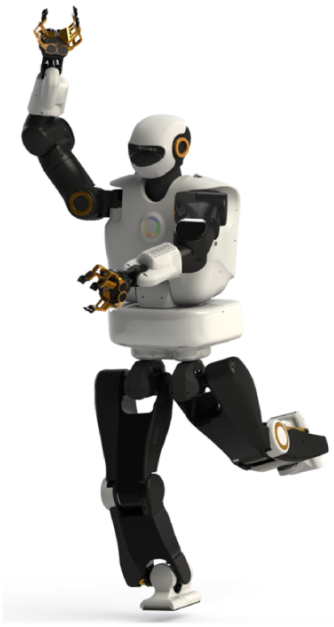
System simulators

- Simulate sensors, actuators, environment
- Smoothly going from simulation to real robot
- Accurate representation of reality
- Stability

Control simulator

- Real-time
- Catch the robot main dynamics
- To be integrate inside the control loop

What is a simulator ?



[Ivaldi,ICHR,2014]

System simulators

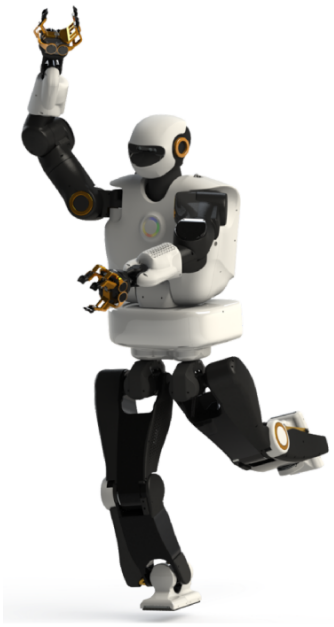
- Gazebo
- Stage
- Morse
- OpenHRP

Control simulator

- MuJoCo
- RBDL
- Pinocchio
- Robotran

What is a simulator ?

[Ivaldi,ICHR,2014]



System simulators

- Gazebo
- Stage
- Morse
- OpenHRP

Dynamics Engine: ODE

Control simulator

- MuJoCo
- RBDL
- Pinocchio
- Robotran

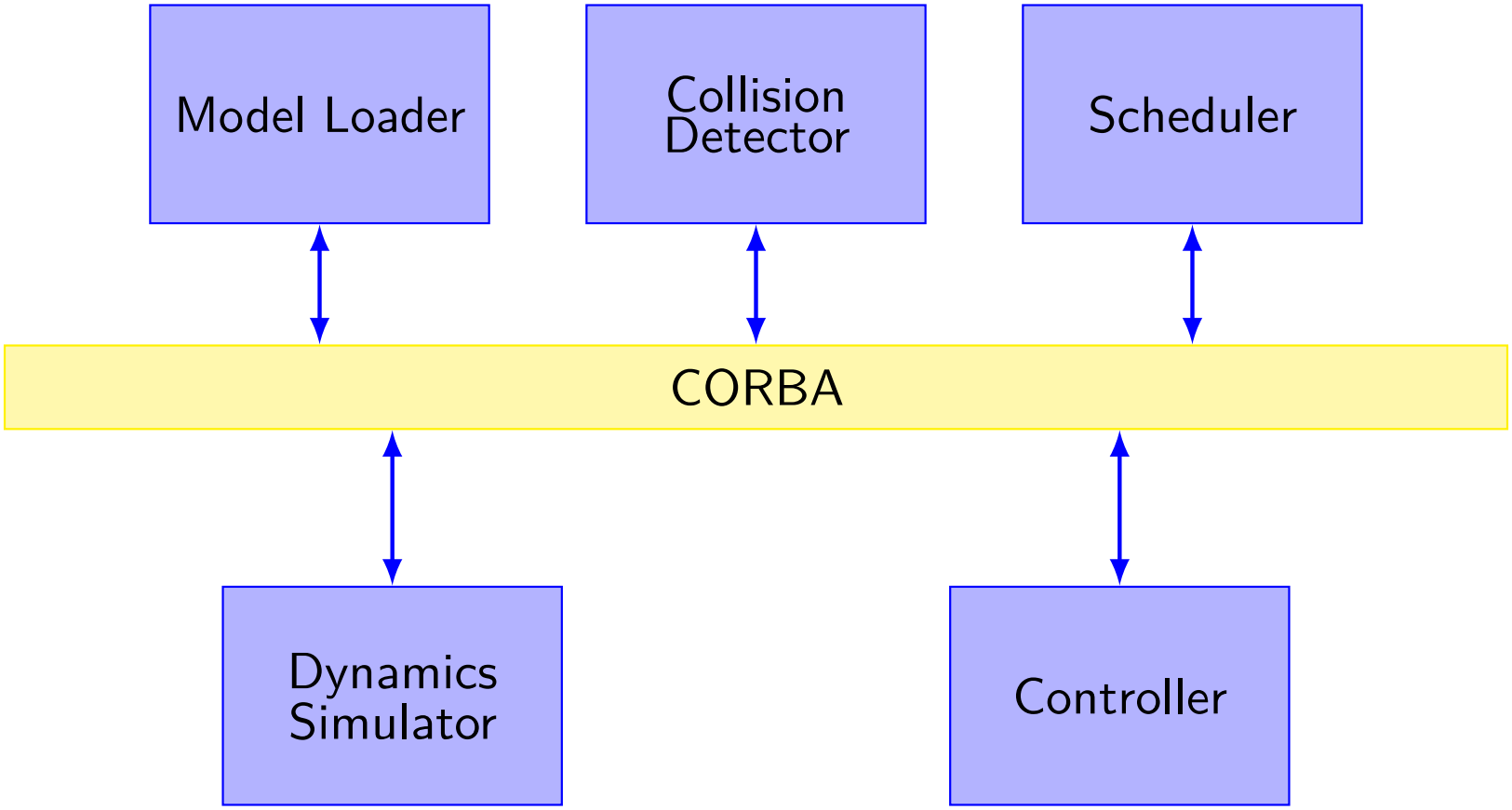
Problem 1: Reality

- Impact
- OpenHRP 2.x: 800 N
- Real robot: 1300 N
- Giving up speed
- Compliant material
- Dynamics
- Vision

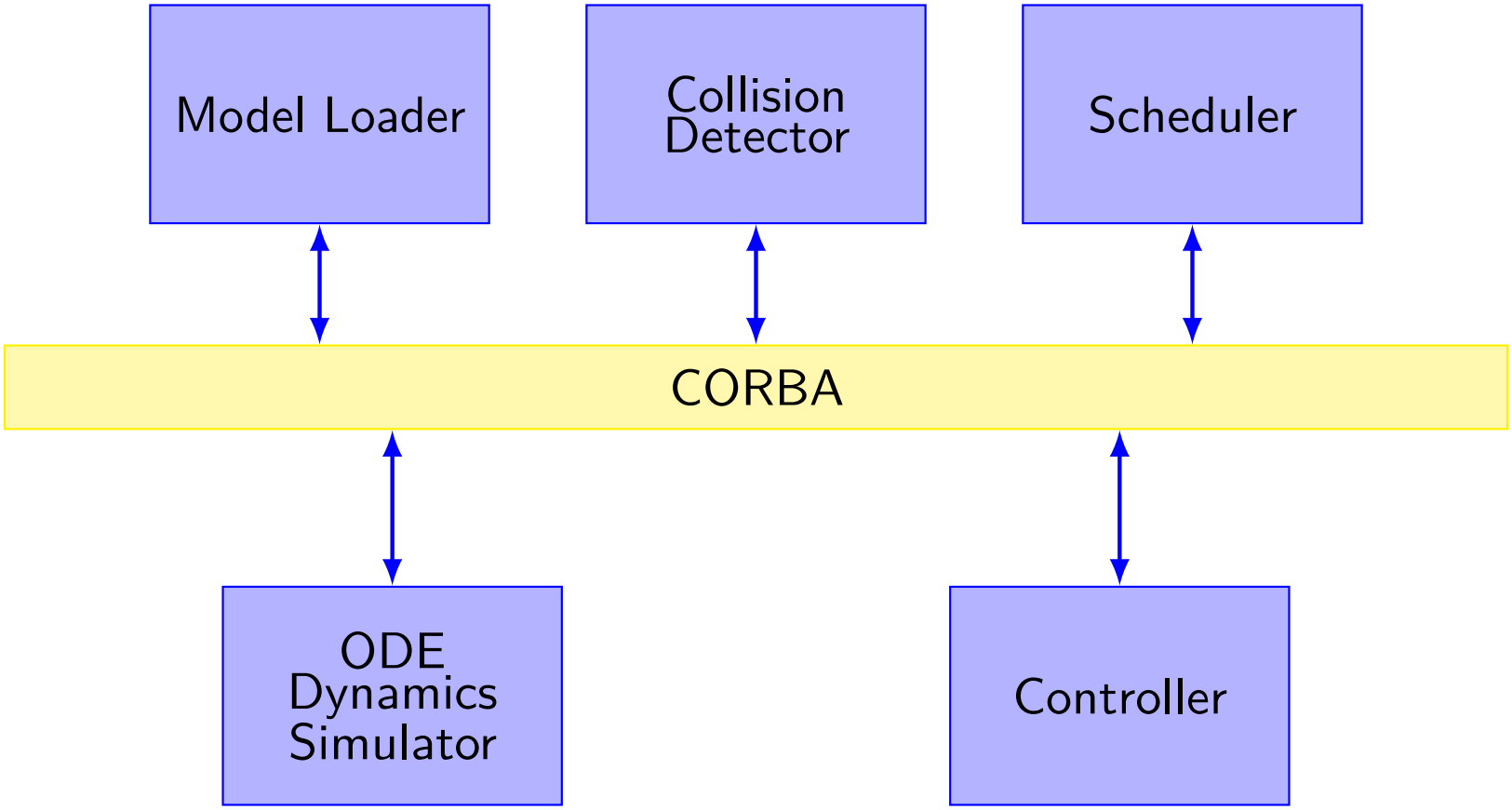
Problem 2: Software flexibility

- From simulation to real robot
- Being able to change parts of the simulator
- Strong middleware
- Sensor simulation

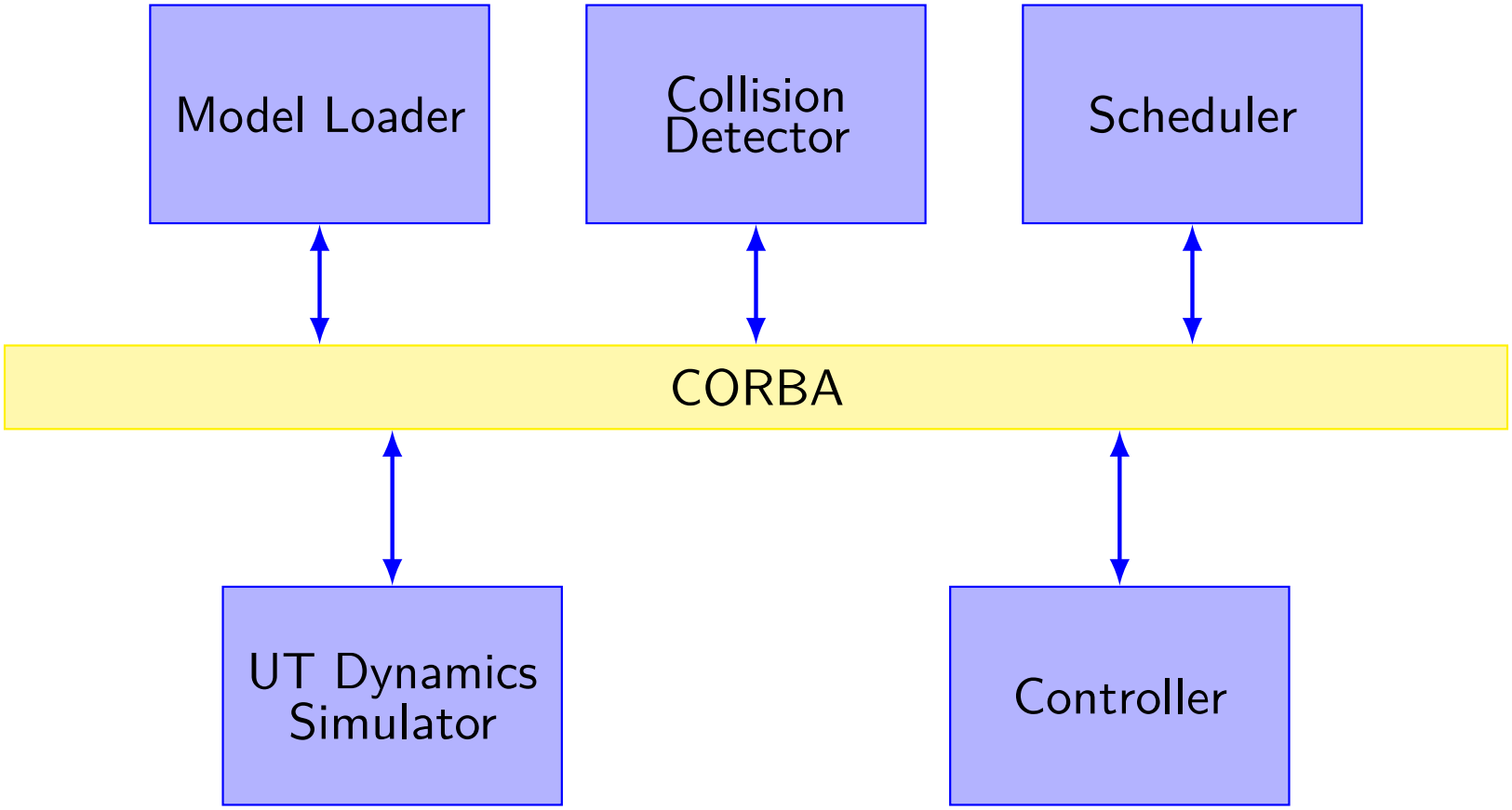
OpenHRP architecture



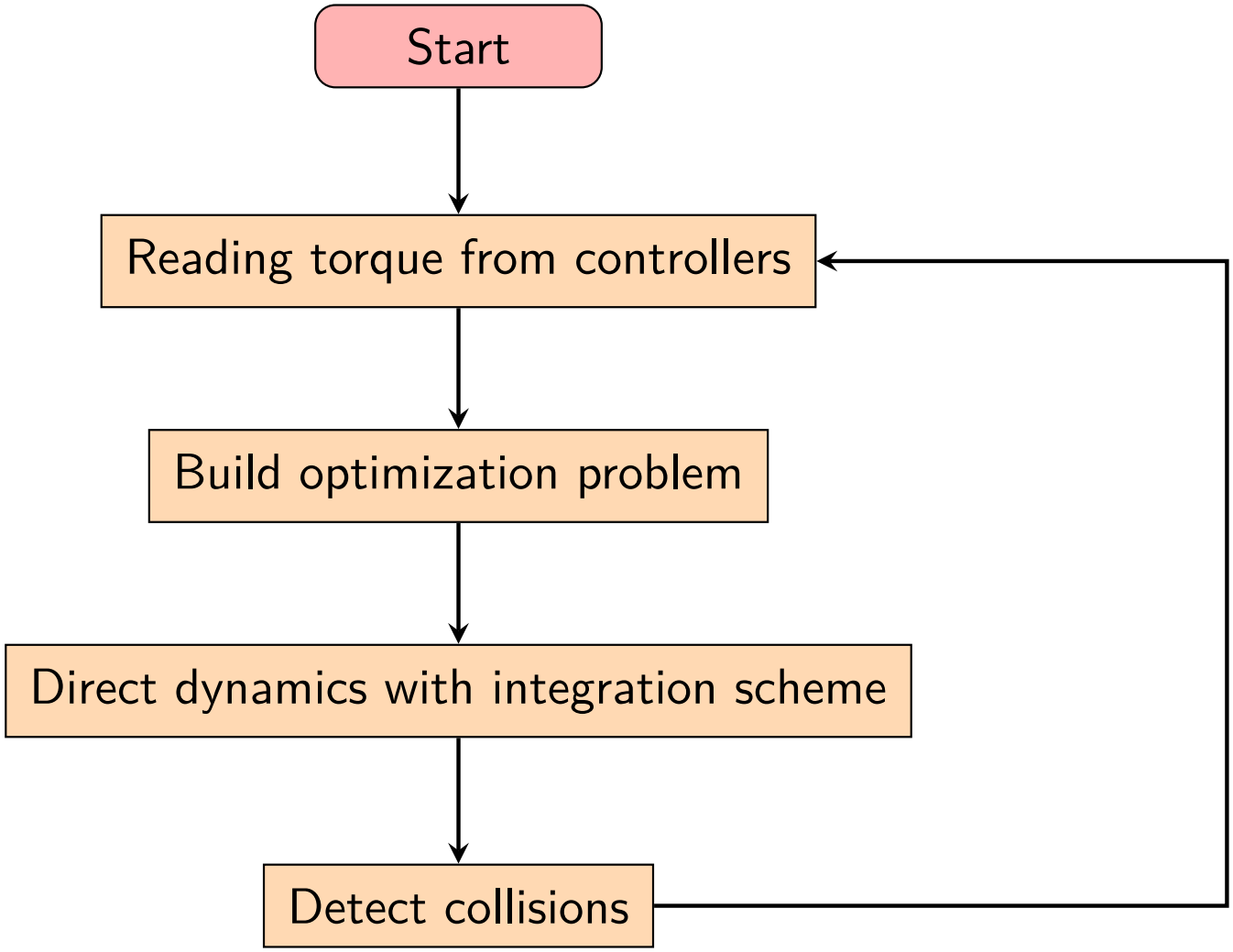
OpenHRP architecture



OpenHRP architecture



Global sequence - scheduler

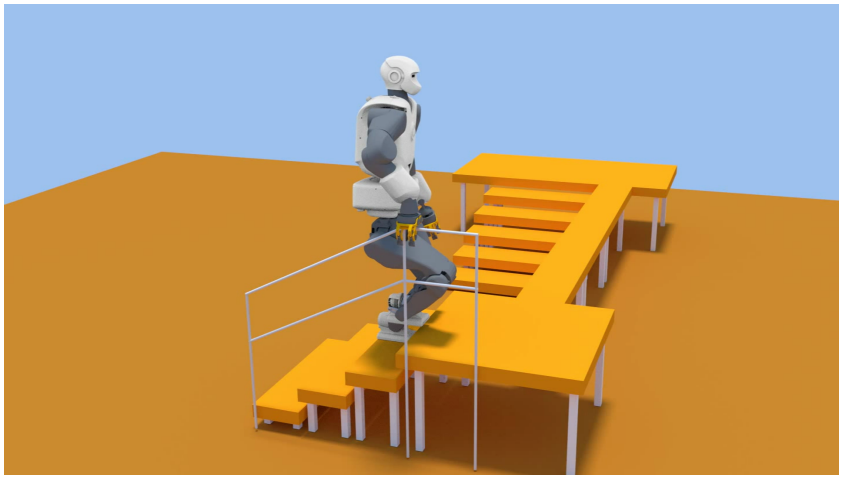


OpenHRP AIST Dynamics Simulator

- Uses a mixture of *generalized* and *maximal* coordinates formulation
- The *generalized* coordinates are used to compute the robot state.
- This assumes a perfect rigid body dynamics (true for a high PID control)
- The *maximal* coordinates are used to compute the rest of the world state.
- Specific compliant joint are introduced in the direct dynamics of the robot.

ODE: The problem

Definitions [Hsu,Simpar,2014]



i-th body - position, quaternion x, q

velocity $\dot{\nu}_i = [\dot{x}^T, \omega^T]^T \in \mathbb{R}^{dim(i)}$

force $F_i \in \mathbb{R}^{dim(i)}$

acceleration $\dot{\nu}_i$

then $M_i \dot{\nu}_i = F_i$

$$M\dot{\nu} = F$$

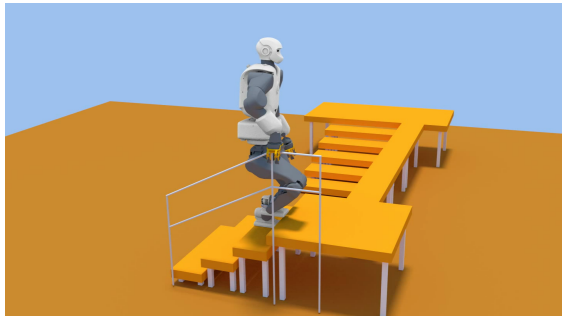
$$M_i \dot{\nu}_i = \begin{bmatrix} m_i \delta & 0 \\ 0 & I_i \end{bmatrix} \begin{bmatrix} \ddot{x}_i \\ \dot{\omega}_i \end{bmatrix} = \begin{bmatrix} f \\ \tau - \omega \times I\omega \end{bmatrix} = F_i$$

ODE: The problem

[Hsu,Simpar,2014]

i-th constraint $h_e(x, q) = 0,\ h_i(x, q) \geq 0,$

Let us linearize constraints



ODE: The problem

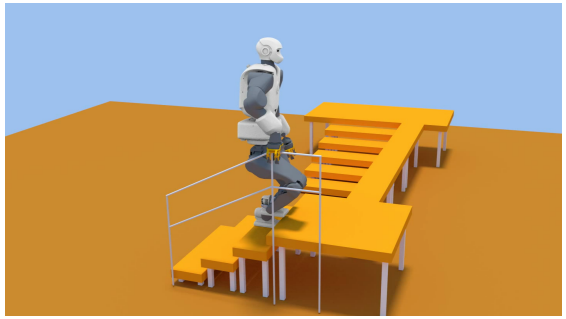
[Hsu,Simpar,2014]

i-th constraint $h_e(x, q) = 0,\ h_i(x, q) \geq 0,$

speed $J_{i1}\nu_1 + \cdots + J_{ik}\nu_k + \cdots + J_{in}\nu_n + c_i = 0$

all together $J\dot{\nu} + c = 0\ (1)$

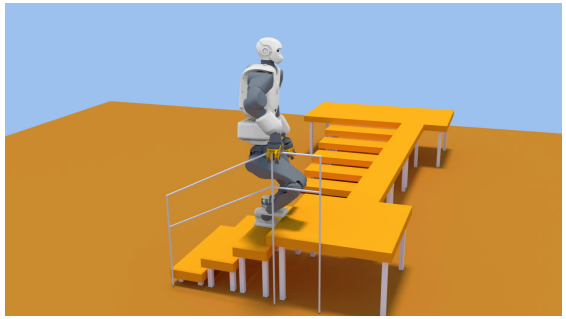
$M\dot{\nu} = F^c + F$



ODE: The problem

[Hsu,Simpar,2014]

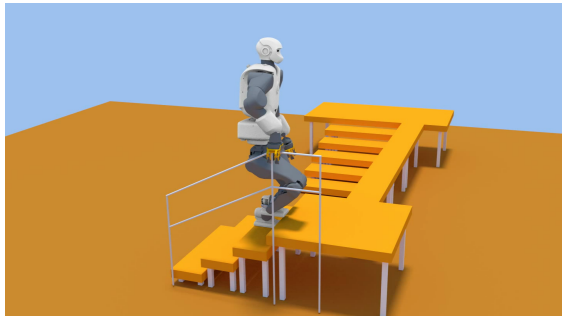
i-th constraint	$h_e(x,q)=0,\ h_i(x,q)\geq 0,$
speed	$J_{i1}\nu_1+\cdots+J_{ik}\nu_k+\cdots+J_{in}\nu_n+c_i=0$
all together	$J\dot{\nu}+c=0\ (1)$
	$M\dot{\nu}=F^c+F$
with	$F^c=J^T\lambda$
then	$M\dot{\nu}=J^T\lambda+F$



ODE: The problem

[Hsu,Simpar,2014]

i-th constraint	$h_e(x,q)=0,\ h_i(x,q)\geq 0,$
speed	$J_{i1}\nu_1+\cdots+J_{ik}\nu_k+\cdots+J_{in}\nu_n+c_i=0$
all together	$J\dot{\nu}+c=0\ (1)$
	$M\dot{\nu}=F^c+F$
with	$F^c=J^T\lambda$
then	$M\dot{\nu}=J^T\lambda+F$
then with (1)	$J(M^{-1}J^T\lambda+M^{-1}F)+c=0$
then	$A\lambda=b$
with	$A=JM^{-1}J^T$ et $b=-(JM^{-1}F^{ext}+c)$



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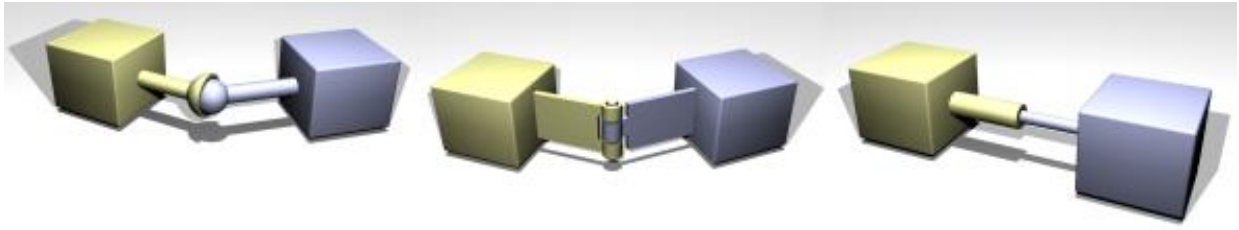
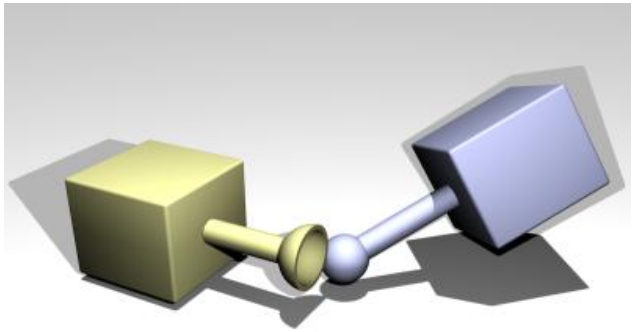


Joints when everythings goes well

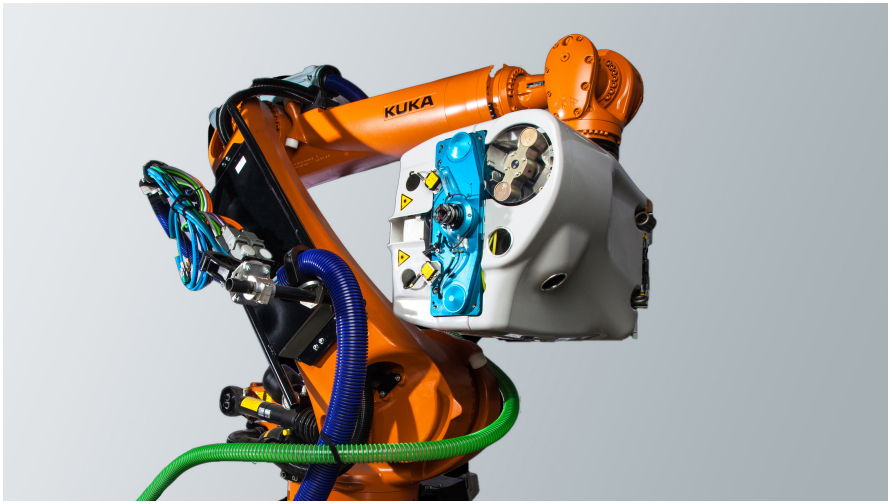


Error Reduction Parameter

Tutorials

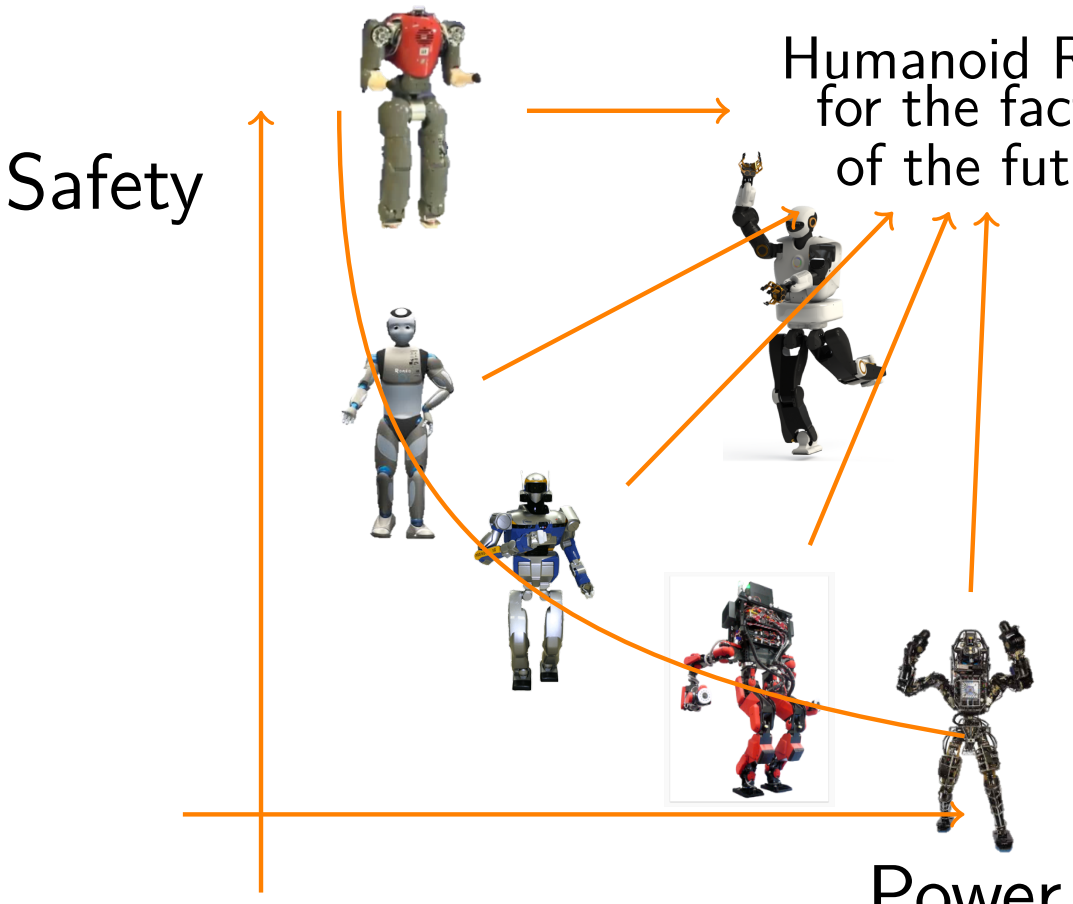
Online Exercices

The problem



Costly, heavy,
not user friendly

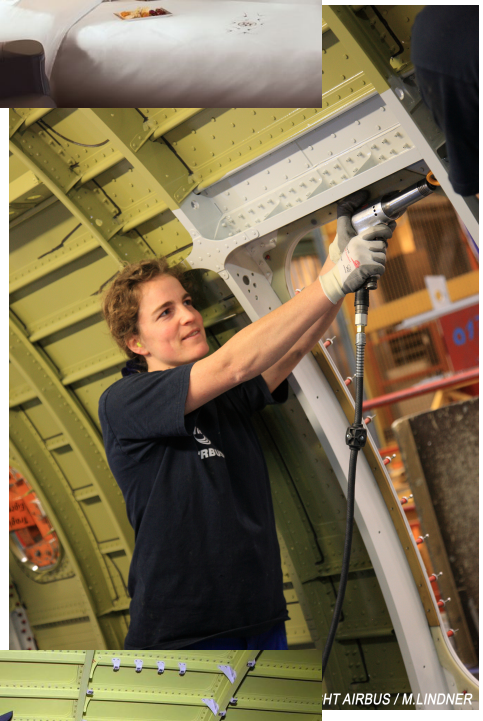
The problem - The vision



125 millions of holes drilled by year

75 % are done *manually*

The problem - The vision



Problem 1: Variability according to the customers

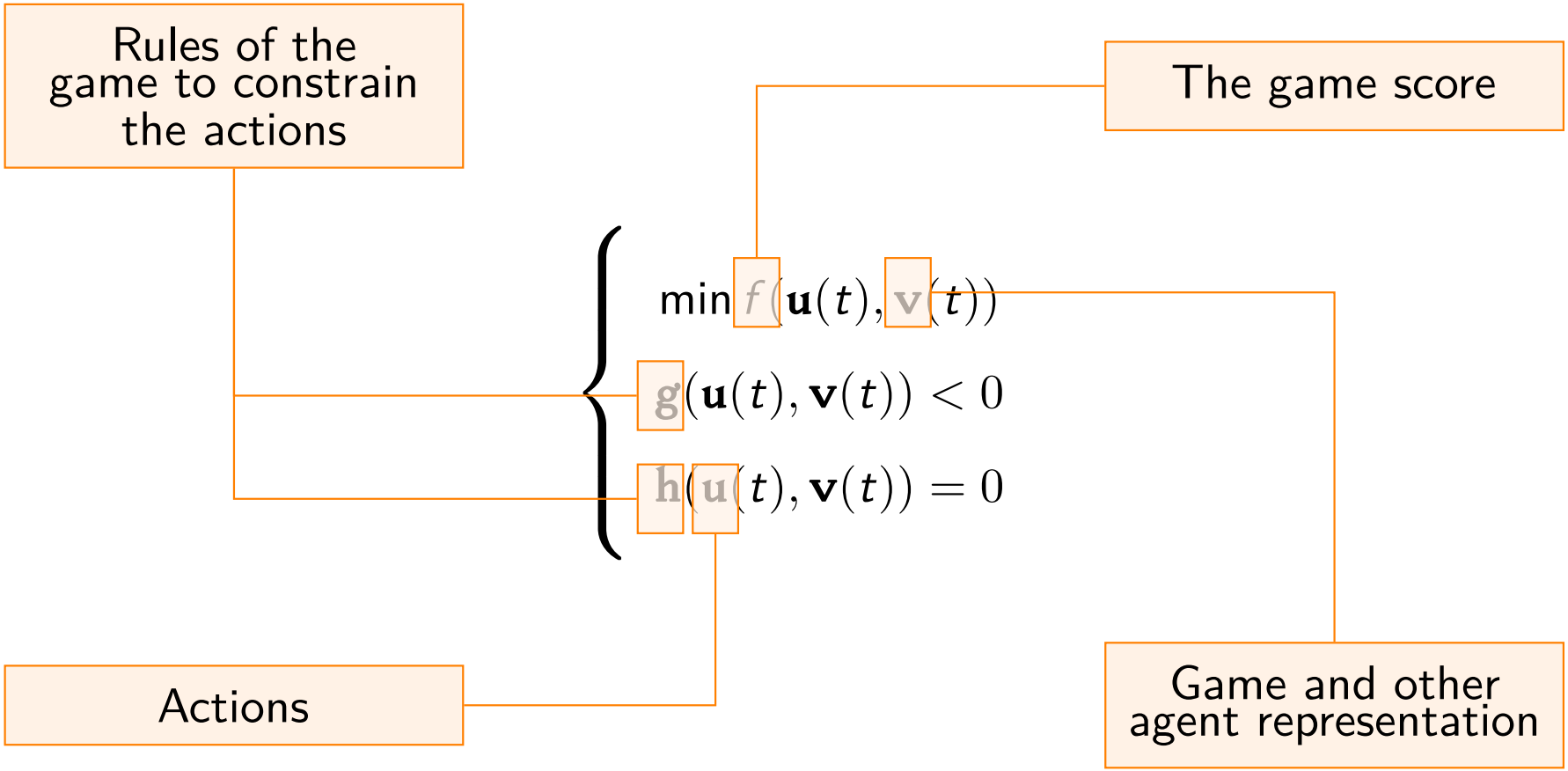
Problem 2: Variability in the realization (humans)

Problem 3: Variability in the delivery

Problem 4: Collaboration with humans

Problem 5: Certification

Behavior - Game theory



Behavior - Game theory

What are the necessary and meaningful constraints ?

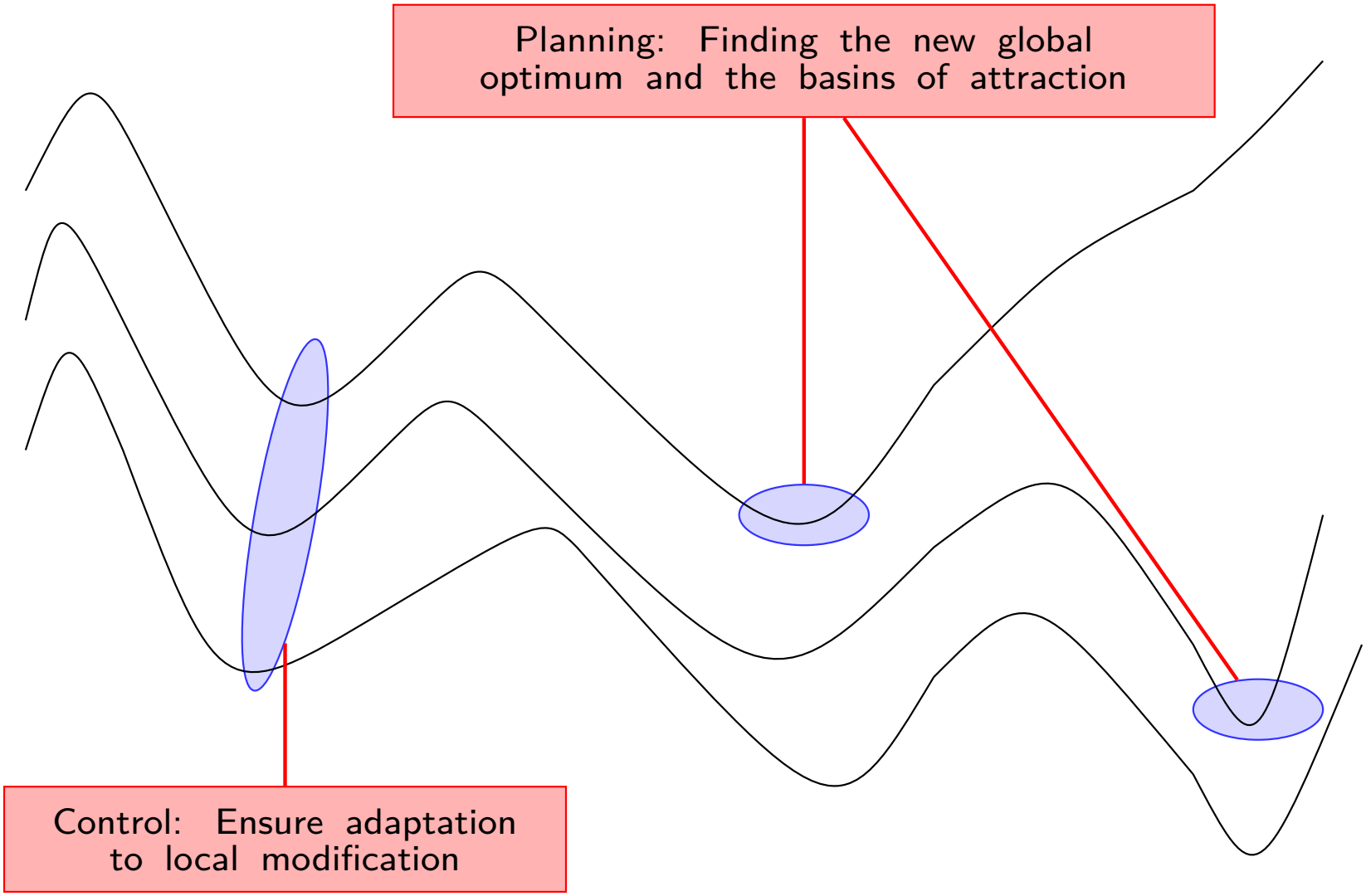
How to build the cost function for the behavior of interest ?

$$\begin{cases} \min f(\mathbf{u}(t), \mathbf{v}(t)) \\ \mathbf{g}(\mathbf{u}(t), \mathbf{v}(t)) < 0 \\ \mathbf{h}(\mathbf{u}(t), \mathbf{v}(t)) = 0 \end{cases}$$

How to deal with such a huge search space ?

How to build an efficient world representation ?

Approach


Planning: Finding the new global optimum and the basins of attraction
Control: Ensure adaptation to local modification

Autonomous Motion generation: the problem

$$\begin{cases} \min f(\mathbf{u}(t), \mathbf{v}(t)) \\ \mathbf{g}(\mathbf{u}(t), \mathbf{v}(t)) < 0 \\ \mathbf{h}(\mathbf{u}(t), \mathbf{v}(t)) = 0 \end{cases}$$

[Saidi,IROS 2007]

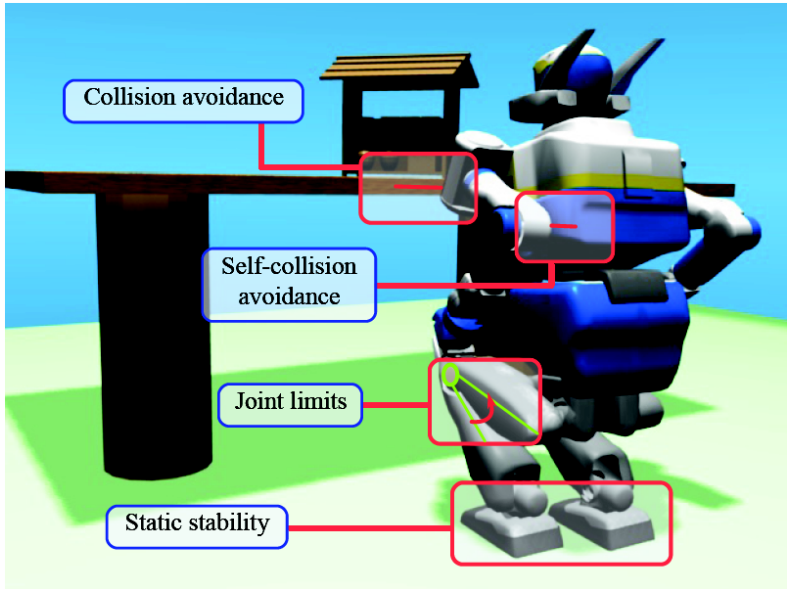
$\mathbf{f}(t)$: The cost function

$\mathbf{u}(t)$: The control vector

$\mathbf{g}(t)$: The inequality constraints

$\mathbf{h}(t)$: The equality constraints

$\mathbf{v}(t)$: The environment representation



Autonomous Motion generation: the problem

$$\begin{cases} \min_{\mathbf{q}(\cdot),\mathbf{u}(\cdot)} \quad \int_0^T L(t,\mathbf{q}(t),\mathbf{u}(t))dt \\ \dot{\mathbf{q}}(t) = f(\mathbf{q}(t),\mathbf{u}(t)), \quad t \in [0,T] \\ \mathbf{q}(0) = \mathbf{q}_0,\ T > 0 \\ 0 \leq \mathbf{gh}(\mathbf{q}(t),\mathbf{u}(t)), \quad t \in [0,T] \end{cases}$$

[Saidi,IROS 2007]

f: The system dynamics

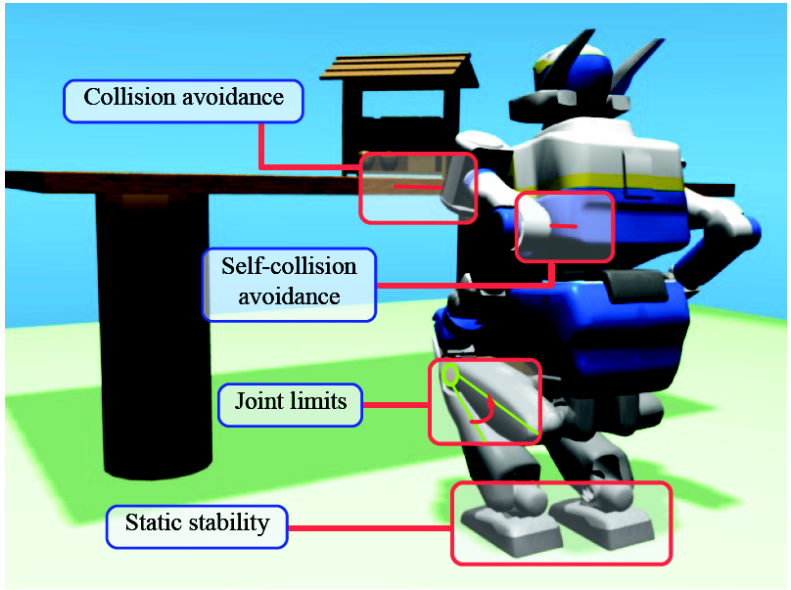
u: The control vector

q: The system state

gh: The (in)equality constraints

v: The environment representation

L: The cost

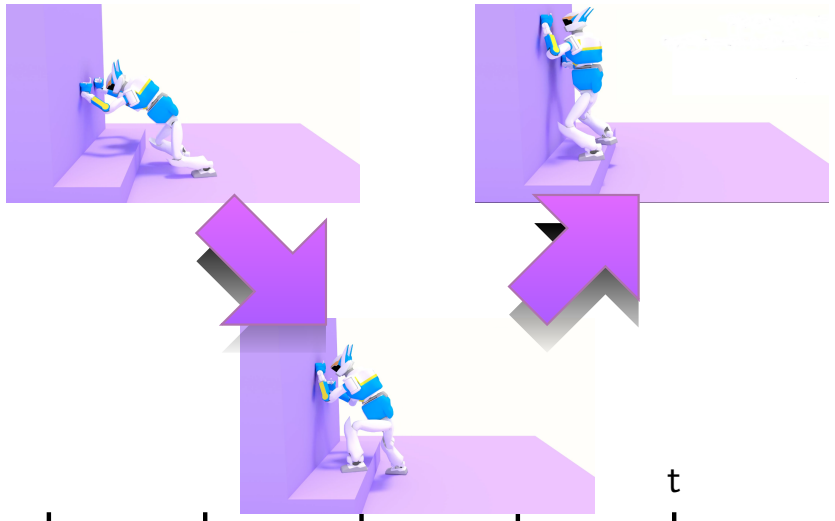


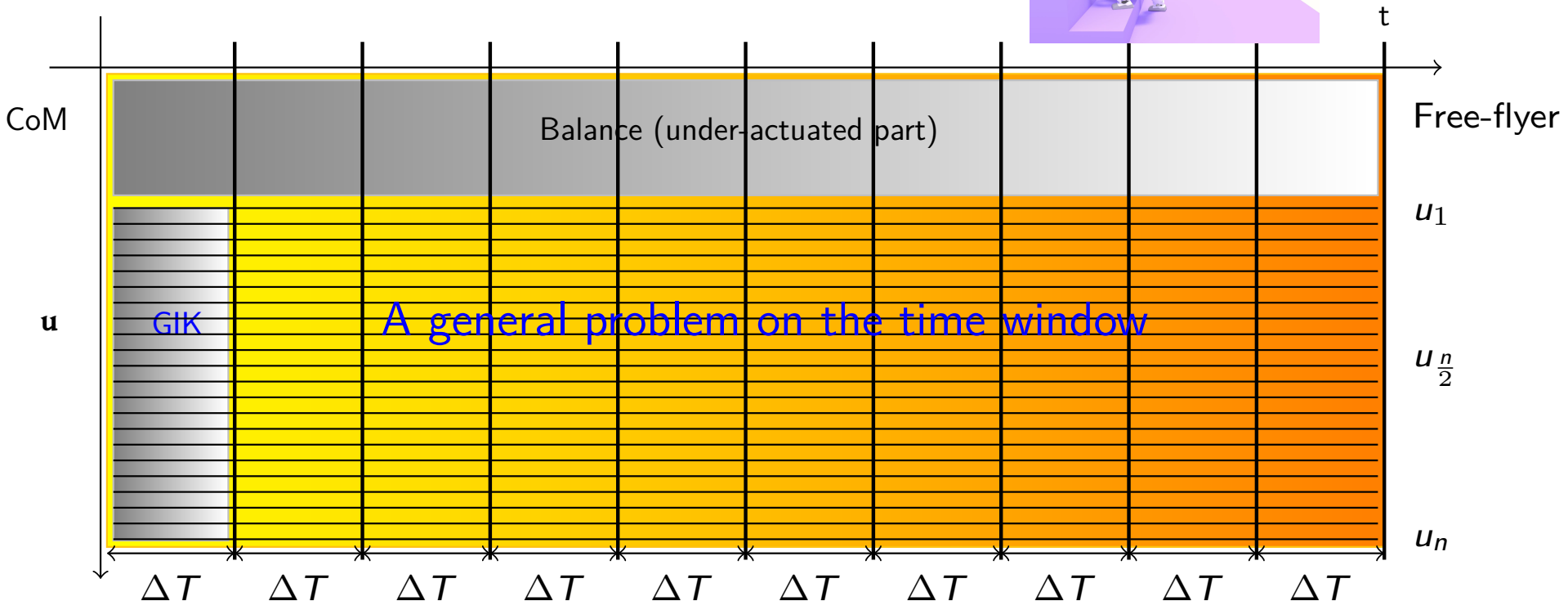
Motion generation: Model Predictive Control

- Size of the problem

$$1.6 \times 200 \times 30 = 9600 \text{ variables}$$

- Non linear constraints
- Discrete nature due to contacts

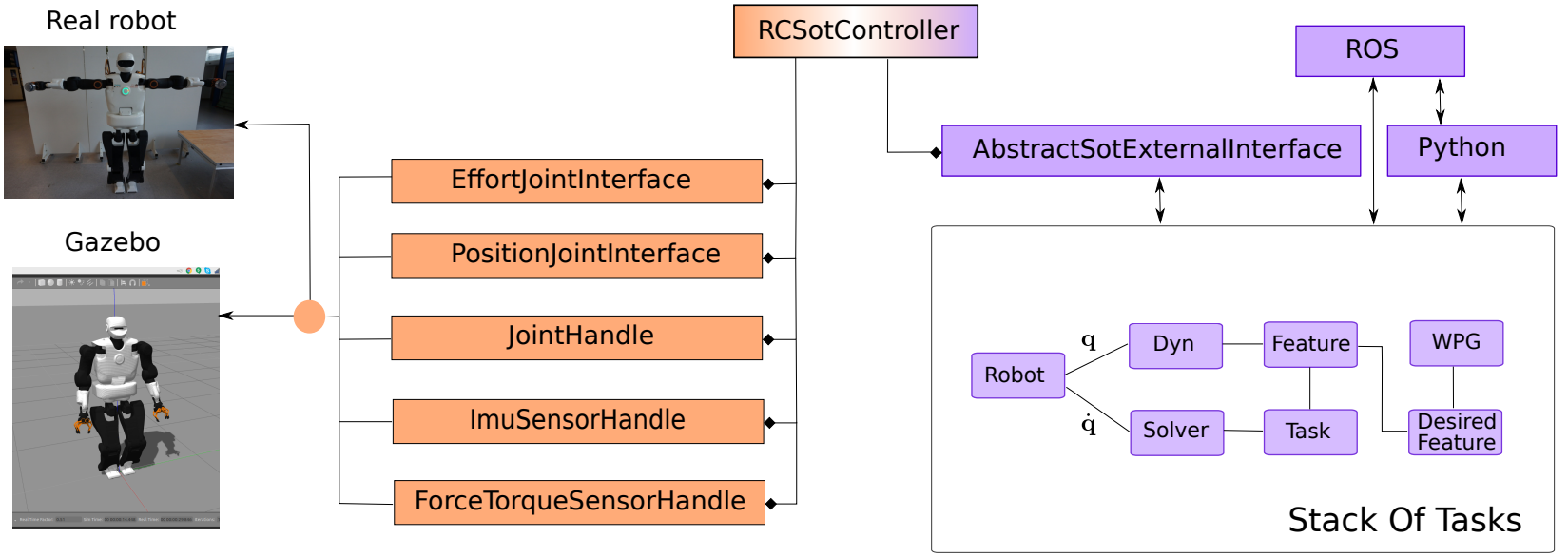




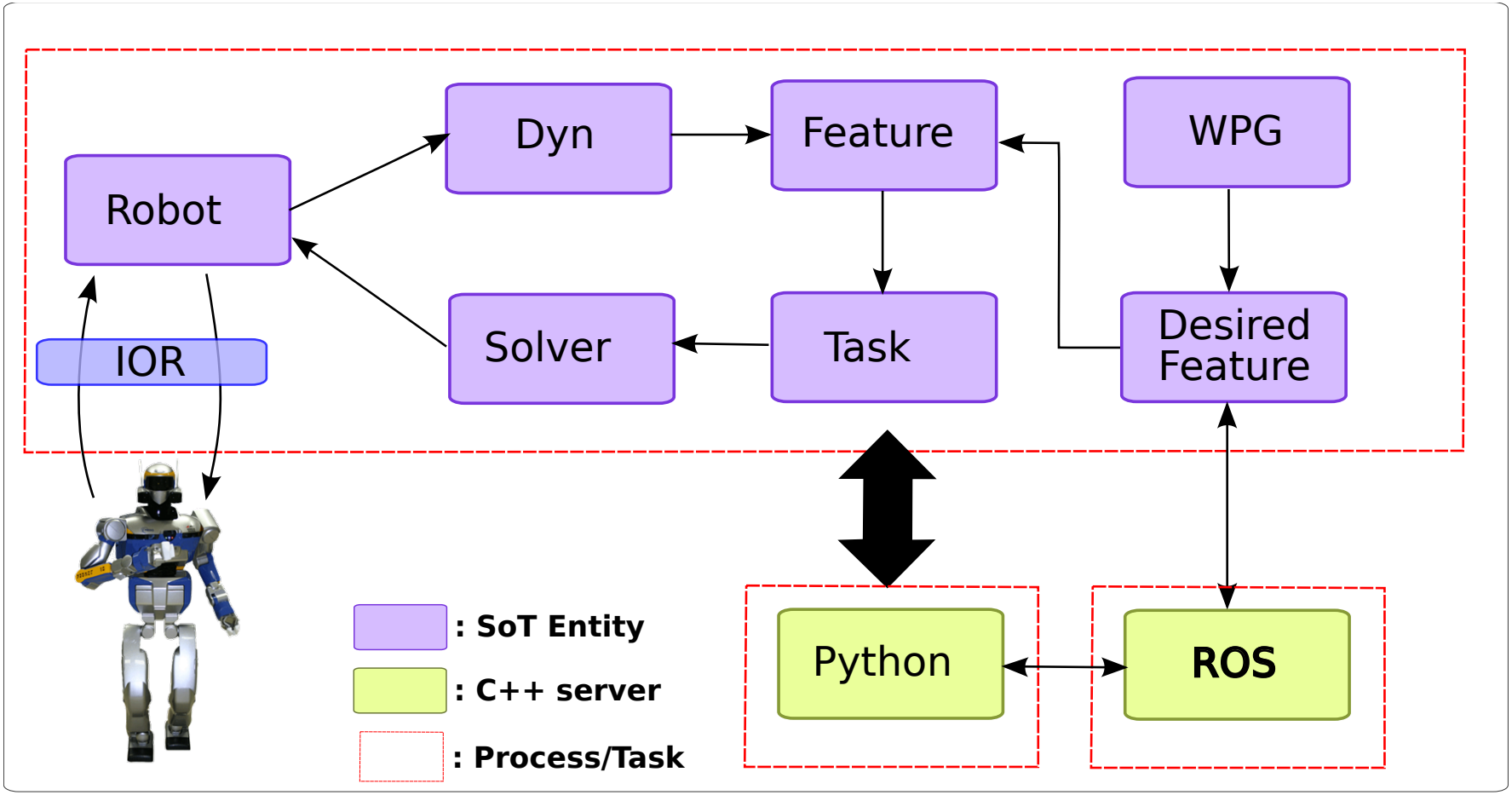
MuJoCo [Koenemann, IROS 2015]

https://www.youtube.com/watch?v=WbsQBPzQakc

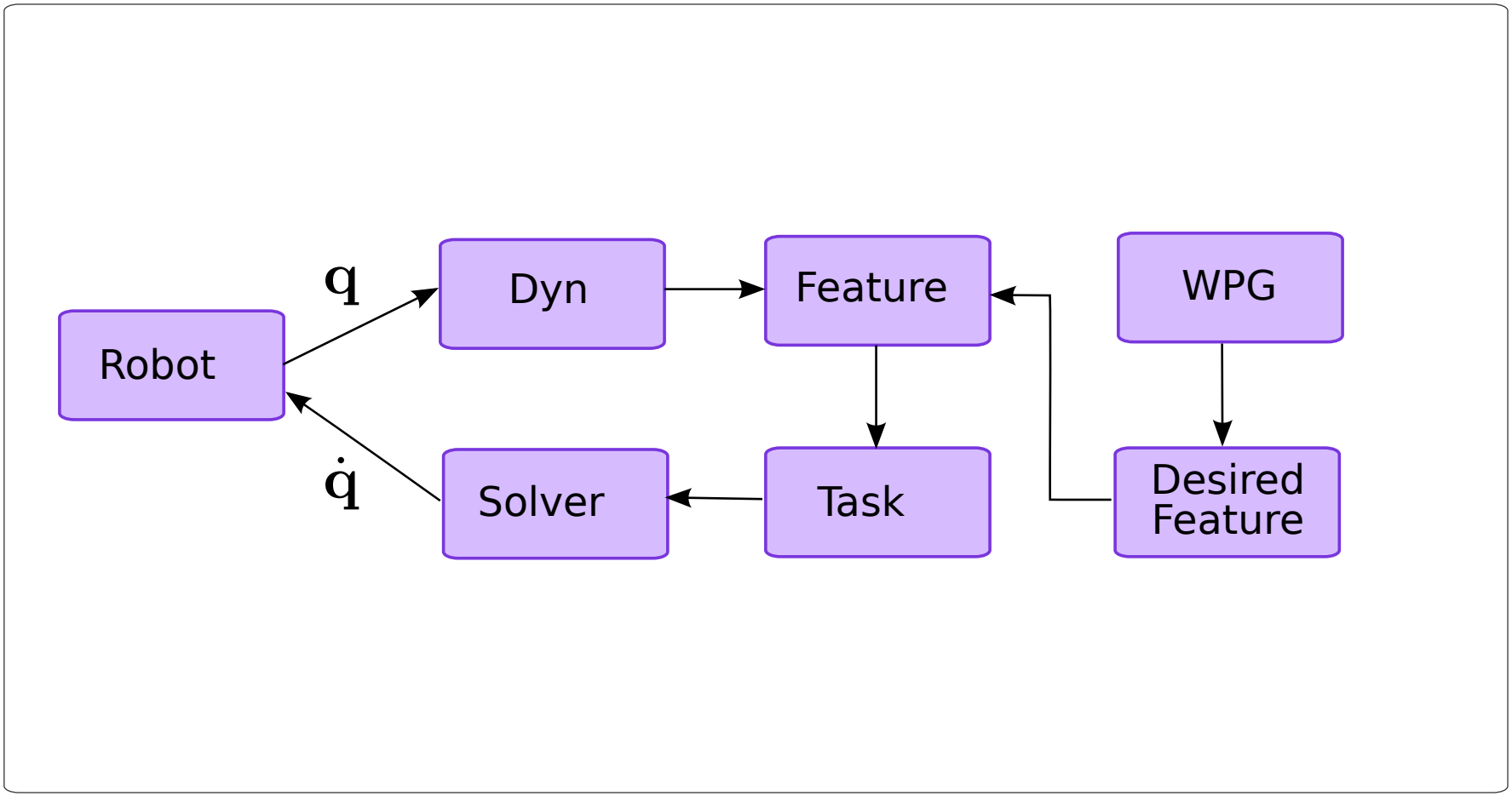
Structure de l'encapsulation



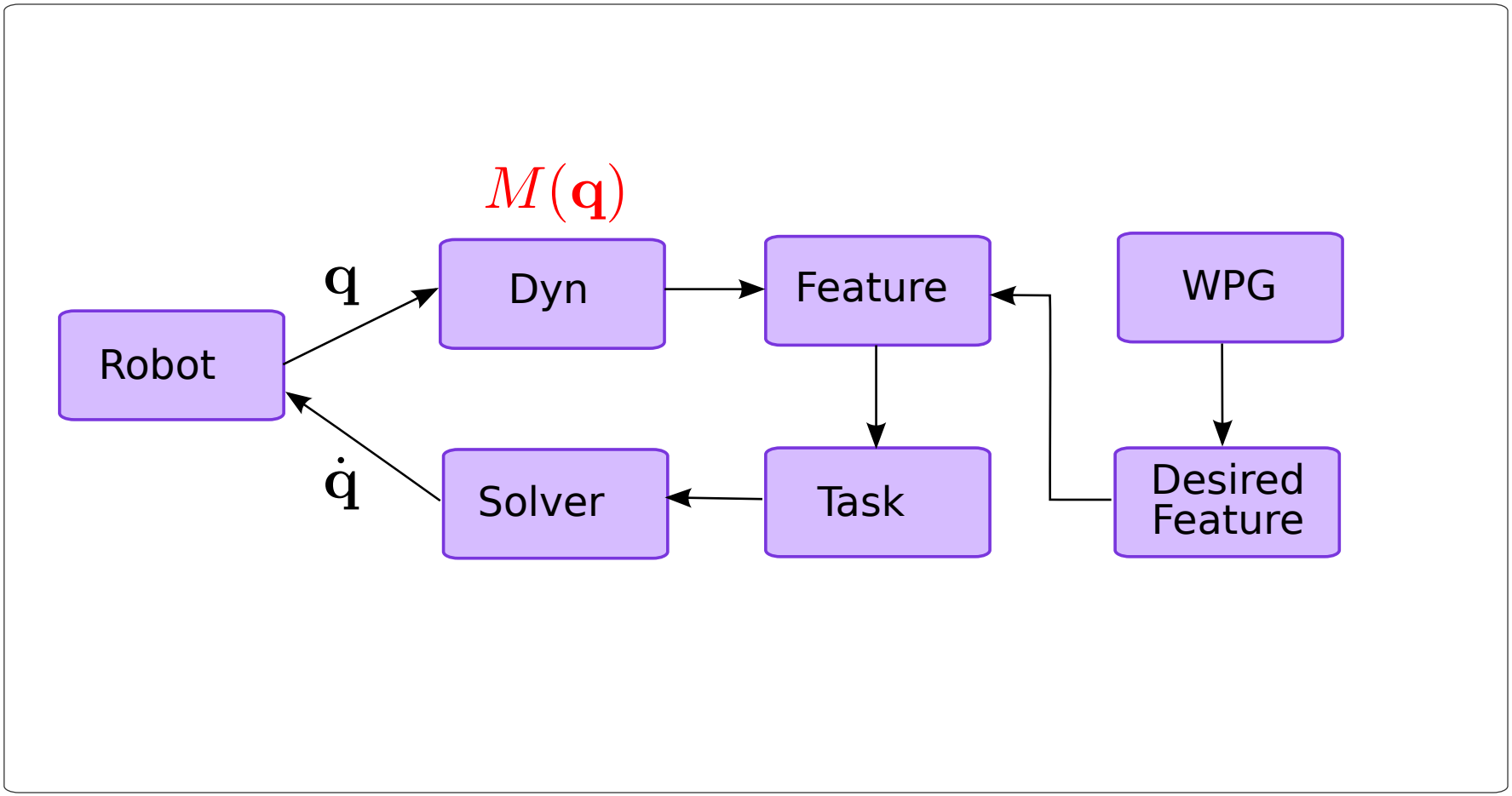
Software structure - Conceptual view



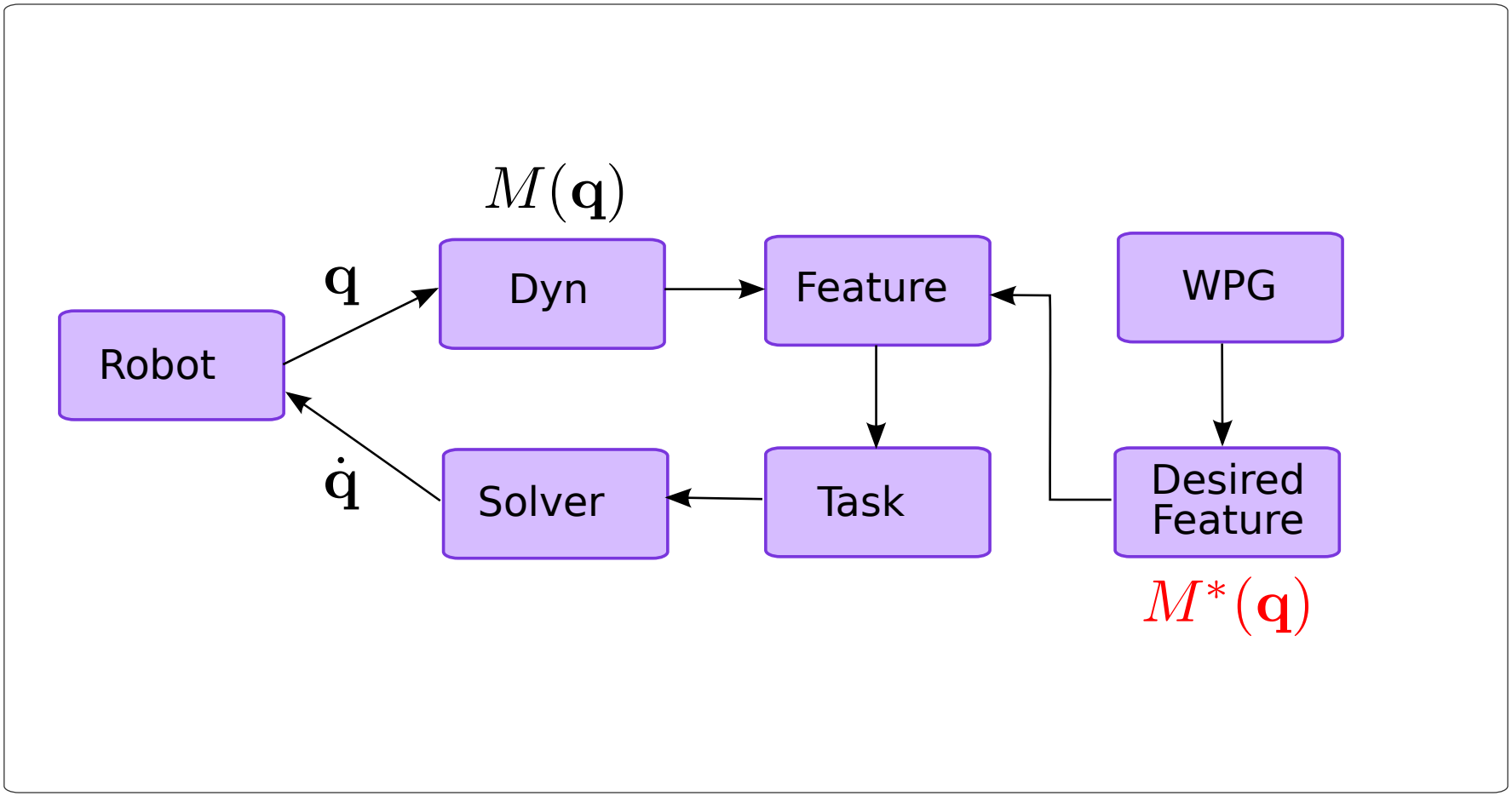
Software structure - Link with Model



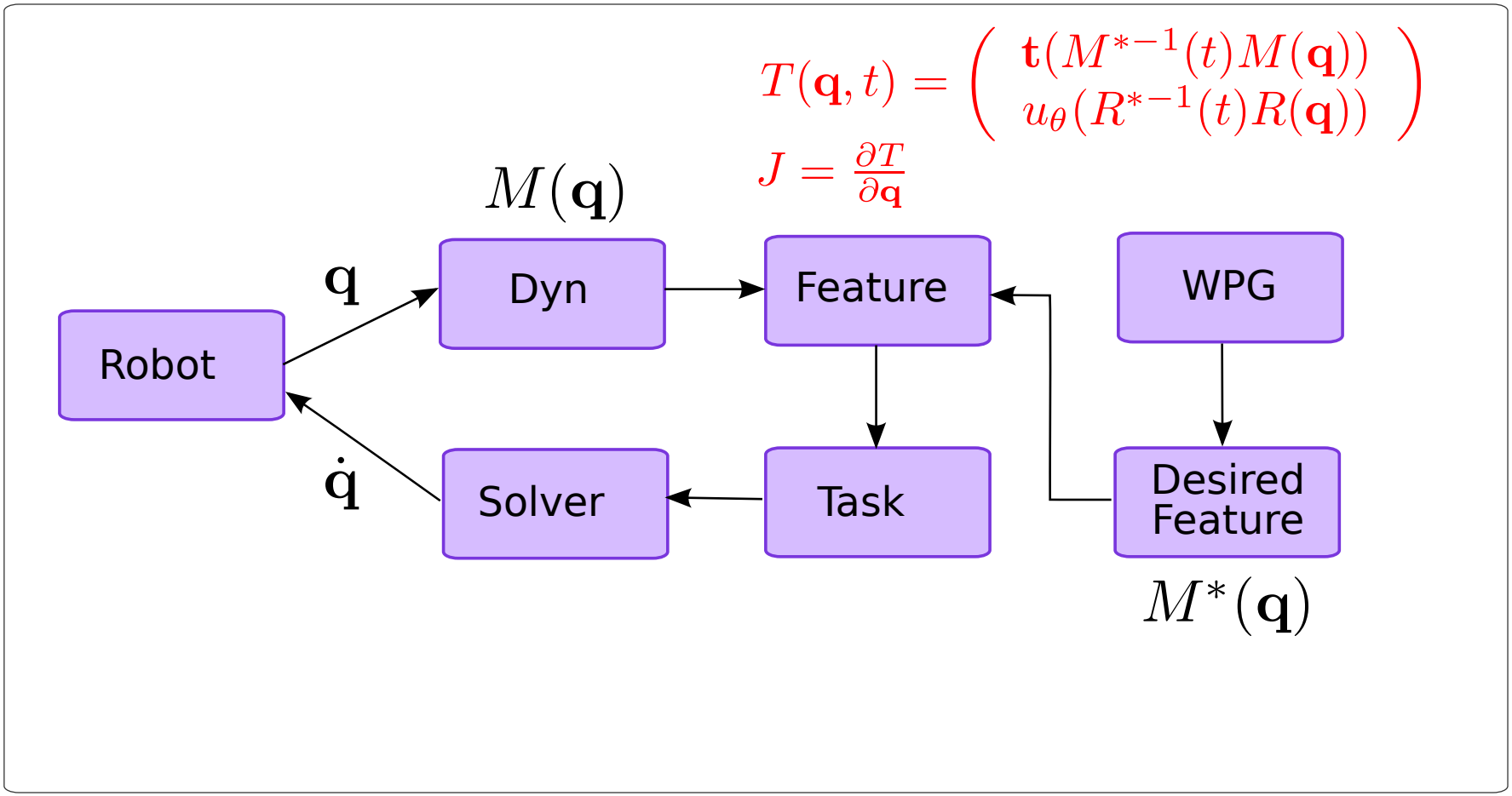
Software structure - Link with Model



Software structure - Link with Model



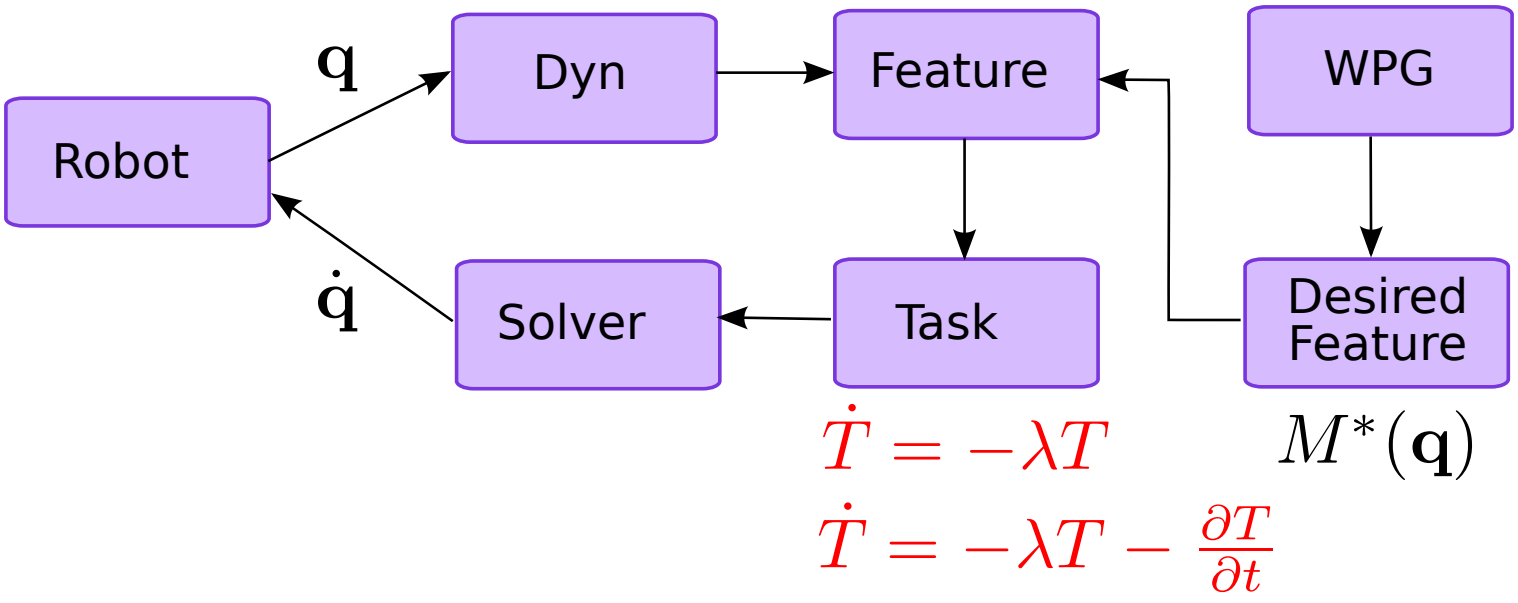
Software structure - Link with Model



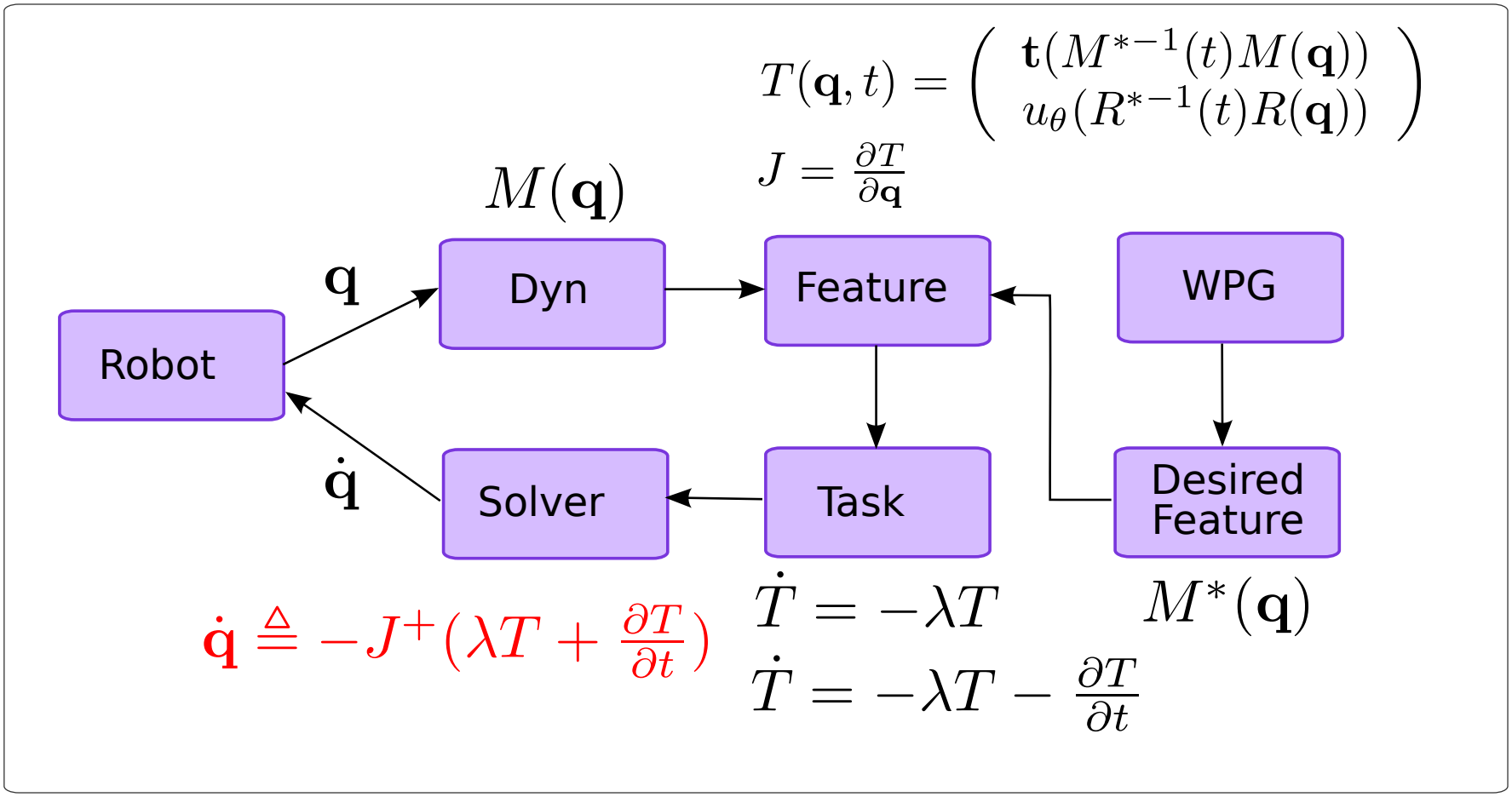
Software structure - Link with Model

$$T(\mathbf{q},t) = \begin{pmatrix} \mathbf{t}(M^{*-1}(t)M(\mathbf{q})) \\ u_\theta(R^{*-1}(t)R(\mathbf{q})) \end{pmatrix}$$

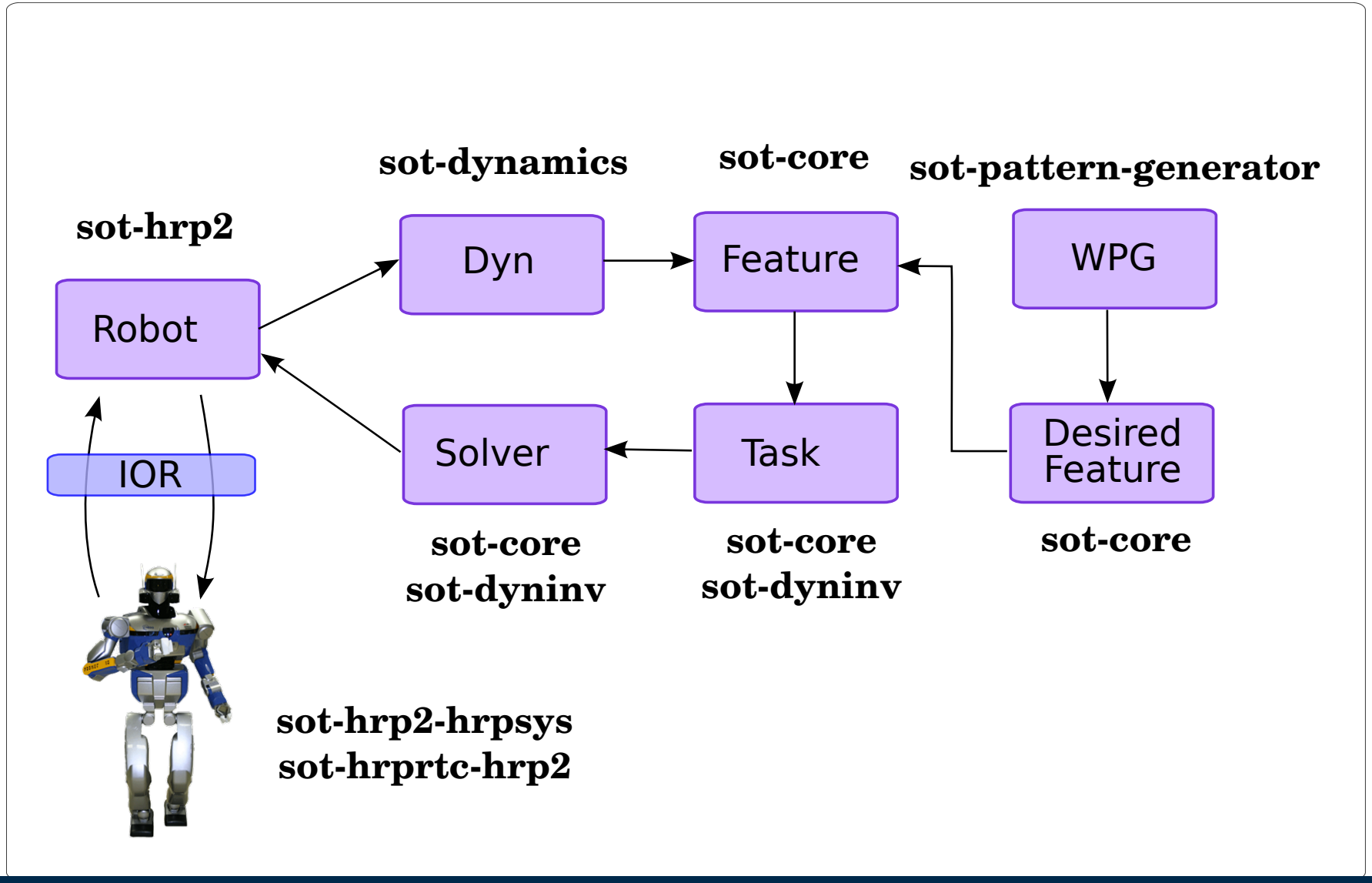
$$J = \frac{\partial T}{\partial \mathbf{q}}$$



Software structure - Link with Model



Software structure - Repositories



Example

Solvers

Inverse Dynamics

Weighted Pseudo Inverse

- Faster (!?) computation
- Easier to formulate
- Do not guarantee convergence
- Difficulty to tune the weights
- Do not handle properly inequalities

Hierarchical Quadratic Program

- Slower (!?) computation time
- Warranty on priority
- Handle easily inequalities
- Difficult to formulate (here hidden in the solver)
- Known problems with cycles and singularities management

Conclusions

Pros

- Generic to put instantaneous controller together
- Allow code reusability
- Real-time performance
- Adapted to complex applications
- Binary packages support
- Eigen support

Cons

- Research code
- The learning curve seems to be yet steep