

The role of cognition in present and future robotics

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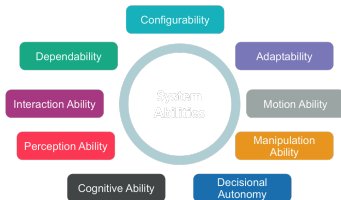
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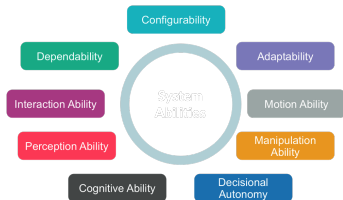
Context of this presentation

- ▶ **euRobotics** association
(for ever. . .)
- ▶ **SPARC** Robotics
Public-Private Partnership
(till 2020)
- ▶ **Multi-Annual Roadmap:**
 - ▶ **integrated capabilities**
("Skills")
 - ▶ driven by **step changes**
(updated yearly)



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Public money → knowledge creation → **socio-economic value**

Objectives of this presentation

1. Advocate the **core** role of cognition in *all* (Research & Innovation Actions of the upcoming H2020 Robotics Call 2015. **Especially** in the industry-focused ones!
2. Focus on *identification* of MAR *step changes* with *mid-term* commercial market impact.
*“The **next** robot controller **must** be cognitive!”*
3. Explain an approach **how** this could be done.
“Human-centricity/conformity is key!”
*“Act as humans **expect**, but no need to be human.”*
4. Find out *how motivated* the community is to realise the step changes *towards (a new) industry. . .*

“Cognition” according to SPARC Robotics’ Multi-Annual Roadmap

- ▶ The *ability* to interpret the task and environment such that tasks can be effectively and efficiently executed even where there exist environmental and/or task uncertainty.
- ▶ The *ability* to interpret human commands delivered in natural language or gestures.
- ▶ The *ability* to interpret the function and interrelationships between different objects in the environment and understand how to use or manipulate them.
- ▶ The *ability* to plan and execute tasks in unknown environments in response to high level commands.
- ▶ The *ability* to work interactively with people as if like a person.

My pragmatic definition of “Cognition”

A cognitive robot can, at all times, explain:

- ▶ what it is doing;
- ▶ why it is doing it;
- ▶ how well it is doing it;
- ▶ what it most likely will do next;
- ▶ what it could do more;
- ▶ what it takes into account in its action;
- ▶ what its role is in a system.

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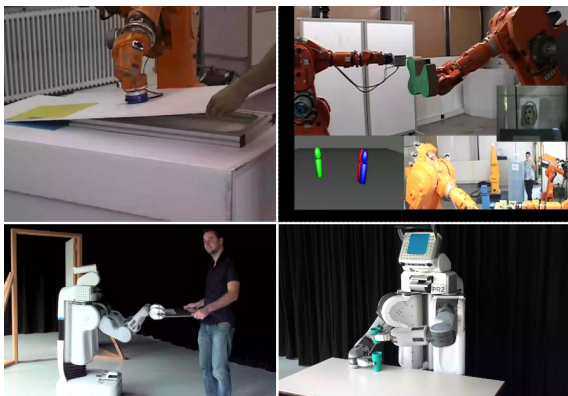
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Hypothesis: “skills” (not *jobs!*) is the right concept to discuss the *socio-economic impacts* of (cognitive) robotics!

My research “skill” demos faking “cognition”



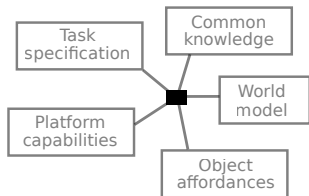
- ▶ “cognitive” = **all motions** generated at runtime, from **(semi) symbolic** specifications (“skill languages”).
- ▶ “faking” = **human** can explain, not the robot. . .

My research approach towards “cognition”

- ▶ **basis: formally represented knowledge** (badly missing!)

Hypothesis: this is the right set of concepts:

- Task
- Platform capabilities
- Environment
- Object affordances
- Common knowledge



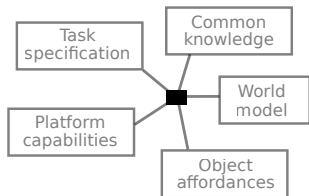
¹Mechanism to realise “multimodality of representations”! (L. Fadiga)

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- ▶ **skill** = “affordances”¹ of object, environment *and* robot, **integrated together**, for **one particular** Task.
- ▶ every **Task** is a **constrained optimization problem**
- ▶ and is **configured** by one or more **knowledge contexts**

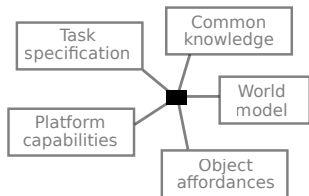
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- ▶ every **Task** is a **constrained optimization problem**
- ▶ and is **configured** by one or more **knowledge contexts**
- ▶ R&D focus on **building & exploiting** the **skill corpus**, not on *learning* it.

¹Mechanism to realise “multimodality of representations”! (L. Fadiga)

Task = constrained optimization problem

task state & domain	$X \in \mathcal{D}$
desired state	X_d
robot state & domain	$q \in \mathcal{Q}$
objective function	$\min_q f(X)$
equality constraints	$g(X) = 0$
inequality constraints	$h(X) \leq 0$
tolerances	$d(X, X_d) \leq A$
solver	algorithm computes q

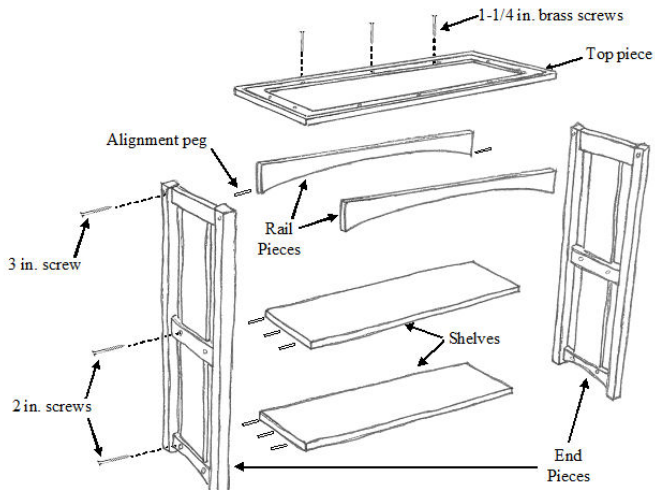
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Skill:

- ▶ makes **context** of COP **explicit**
- ▶ fills in **parameter values** for f , X , d , ... and their **tolerances**
- ▶ provides (explicit!) **"Finite State Machine"** to sequence Tasks (and makes it **explicit** to avoid "UI mode confusion"!)
- ▶ provides **mechanism** for **prediction**, **expectation**, ...
- ▶ fills in concrete solver implementation \rightarrow **"grounding"**!

Intermezzo: symbolic/cognitive COP example



Task = constrained optimization problem (2)

Formal representation of COPs allows robot **to explain**:

- ▶ *what it is doing*: solving this particular COP;
- ▶ *why it is doing it*: maximize objective functions in COP;
- ▶ *how well it is doing it*: **monitoring**² of objective functions & constraints for their tolerances;
- ▶ *what it most likely will do next*: “FSM”.

²(Underused!) mechanism for “motor ideas”, “attention”, ...

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- ▶ *what it could do more*: COPs are **composable + bi-directional + explicit!**

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But it can not yet **explain the context**:

- ▶ *what it takes into account in its action*;
- ▶ *what its role is in a system*.

⇒ “Composition Pattern” paradigm! (see later)

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Intermezzo: perception & control

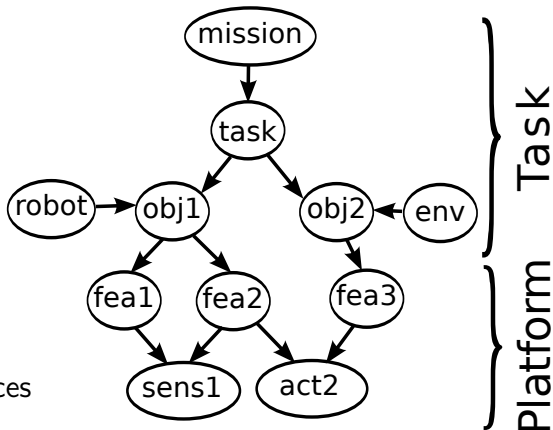
"We don't need pipelines, but COP networks!"

Higher → lower:

- ▶ objective functions
- = artificial constraints
- ▶ tolerances

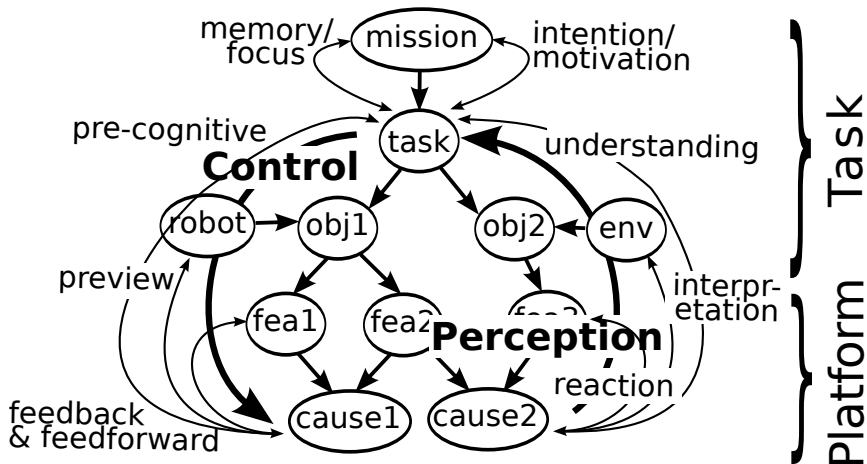
Lower → higher:

- ▶ objective functions
- = physical constraints
- ▶ monitoring of tolerances



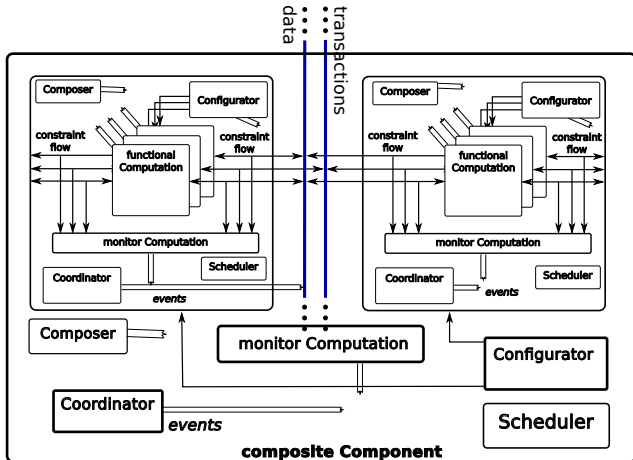
"All arrows are bi-directional!"

Intermezzo: perception & control (2)

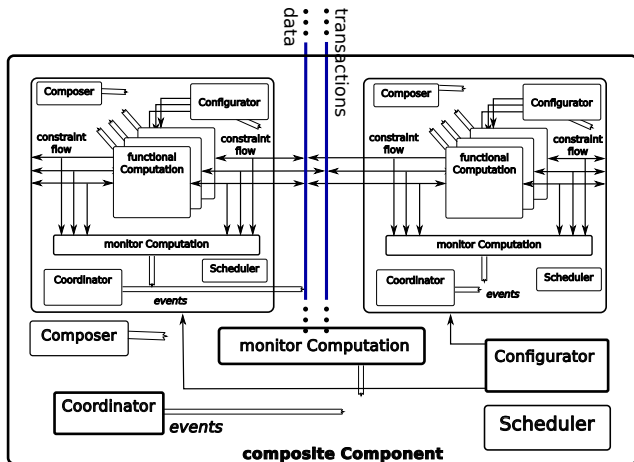


"Nothing is missing to standardize the formal representations...!"

Composition Pattern for context



Composition Pattern for context



- ▶ “Hierarchy” = **knowledge context/locality**, not *data hiding*.
- ⇒ “ROS” does everything to make this *impossible*..

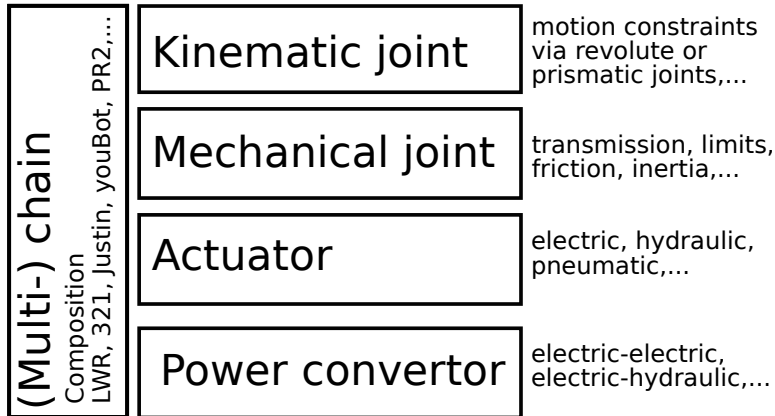
Step changes: “simple” to “impossible”

Ordering is according to the **scale** of the **cognitive context**:

1. **platform** cognition: robot explains *how well* it is *executing its sensori-motor tasks*, **monitoring** only its own “platform”.
2. **task** cognition: explains how/why it **(re)configures** the platform capabilities, **monitoring** the task requirements.
3. **object** cognition: explains nominal/non-nominal task execution, **monitoring** what happens to the objects involved.
4. **environment** cognition: explains task execution, **monitoring** the **interaction** of robot, task, objects and environment.
5. **skill creation**: *makes* skills given symbolic Task COP.

First step for “platform cognition”

Formal ontology (and not just a “URDF” file format...!) for the ‘natural knowledge ‘hierarchy’ of robot mechatronics:



Each “level” has its own objective functions, constraints, tolerances!

Conclusion: cognitive robot closer than we think a.k.a. necessary conditions for market impact

As a **community**, we have to:

- ▶ move from “WordNet” to “**SkillNet**”
“**Act** as humans (expect), without trying *to be* human.”

Hypotheses:

- ▶ **standardization** is necessary!
 - ▶ only (big) industry can do standardization. . .
 - ▶ academic system stimulates **fragmentation**, not *consolidation!*
- ▶ move from **pipelines** to **networks**, all the time, spanning symbolic, discrete *and* continuous worlds.
- ▶ **scale, Scale, SCALE!**

Hypotheses:

- ▶ only industry can do this. . . (but doesn't want to, presently. . .)
- ▶ **bi-directional interactions + monitored prediction** are key
- ▶ start: “**full**” representation of **motor control knowledge**