Skills for mobile manipulation

—

(To ROS or not to ROS)

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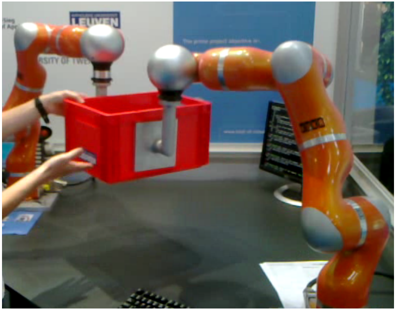
München, November 6, 2010

Overview

- My profile
- The Task – Skill – Motion trinity
  (a.k.a.: *How to do this manipulation in ROS?*)



- Motion & Skill specification, sensing and control

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- ...and smart enough to look *outside* of robotics!

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  3. *Proceedings of the International Symposium on Industrial Robotics* (1980s) → current robotics conferences and journals

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- Why...? *"Putting more developers on a* **late** *software project will only make it later."*

  Replace "*late*" by any other quality measure for software...
- personal *role models* in open source projects:
  - Linux kernel (+ *Linux Weekly News*, *KernelNewbies*)
  - Apache
  - Eclipse + OSGi

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- favourite *software benchmark*: bi-directional, inter-project reusability and composability
- carreer ambitions:
  - to make open source the best *professional* choice in robotics
  - *paradigm shift* in motion *specification*
  - *citation index* for robotics software
  - stimulate fair citation *attitude*

My profile (6)

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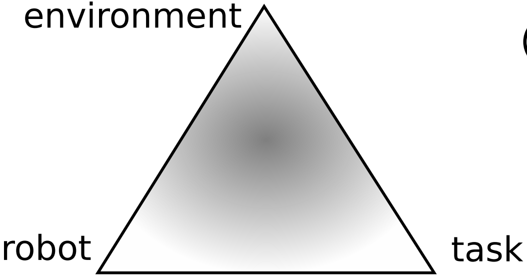
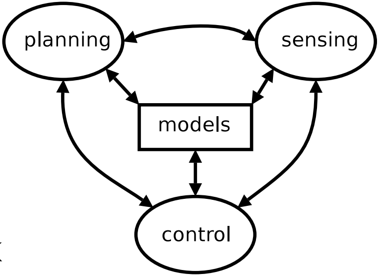
- my (short-sighted) ROS quote:

  ROS: I love it, but I hate it. . . !
  Herman Bruyninckx (Munich), 2010

My profile (4)

- most useful figures in my robotics classes:





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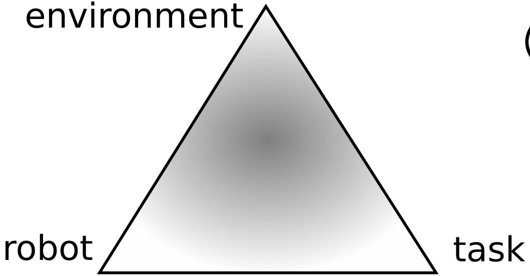
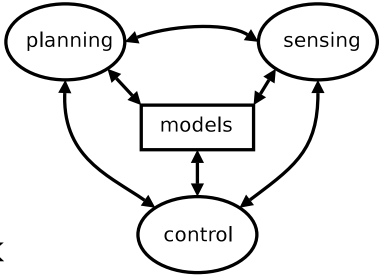




- my benchmark of intelligence & cognition:

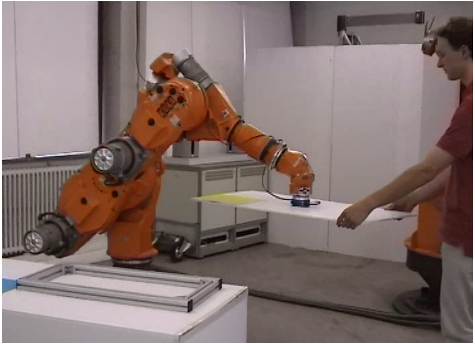
  to explain more with less concepts

- my current research hypothesis:

  cognitive models are the best software models

Mobile manipulation

Another example of *"How to do this in ROS?"*



How to extend this to **real mobile manipulation** on the PR2? And other similar robots!

ROS = Sense–Plan–Act

- **very few** good "control" functionalities
  (⇒ not grounded in traditional robotics. . .)
- emphasis on (only) **geometric, static planning**
- **uni-directional, input–output, hard set-point** "stack" hierarchies
- poor **"4C" separation of concerns**:

  Computation, Communication, Configuration, Coordination

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⇒ PR2 moves like a robot...

4C: separation of concerns

C1 **Computation**

C2 **Communication**

C3 **Configuration**

C4 **Coordination**

4C: separation of concerns

C1 **Computation**: the useful functionality within the components that (hopefully) *pays the bill*

C2 **Communication**: overhead of supporting components/nodes to exchange data

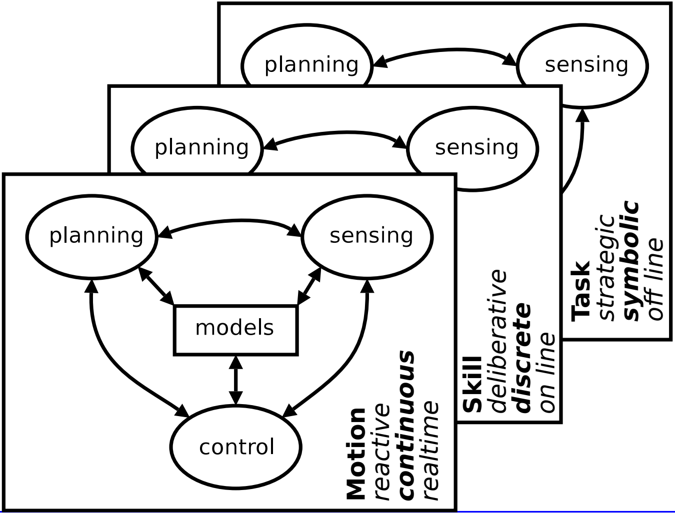
C3 **Configuration**: to give each component appropriate (task-dependent!) parameters

C4 **Coordination**: to help components in switching their functional behaviour in a coordinated way

Holds for hardware, algorithms, middleware,. . . !

Task—Skill—Motion

Traditional **three levels** of robot "architectures"



Three-level (meta) architecture

- first(?) **explicit** description: Saridis 1977
  - *Organization, Coordination, Direct control*
  - *Increasing order of intelligence, decreasing order of precision*
- is known under **various other names** (e.g., *strategic, deliberative, reactive*,...)
- research challenge for coming decade: to weave **more reasoning/intelligence** through all levels

My definitions

- **Motion**:
- **Skill**:
- **Task**:

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- **Motion**: a **continuous** **time/space activity** of a robot, moving its **joints and/or tool(s)** in a specified way, **until some constraint is violated** that can be **checked by sensors**.
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My definitions

- **Motion**: a **continuous time/space activity** of a robot, moving its **joints and/or tool(s)** in a specified way, **until some constraint is violated** that can be **checked by sensors**.
  (Extremely simple) examples:
  - a **force-controlled peg-in-hole** motion, terminated by reaching a force threshold in the insertion direction
  - a **force-guarded approach motion** in free space, terminated by sensing a non-zero approach force.
- **Skill**:
- **Task**:

My definitions

- **Motion**:
- **Skill**: a **discrete** state automaton (FSM), in which each State **runs** one single **Motion**, and each violation of a motion constraint (can) give rise to a **transition** **event**.
- **Task**:

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- **Motion**:
- **Skill**: a **discrete** state automaton (FSM), in which each State **runs** one single **Motion**, and each violation of a motion constraint (can) give rise to a **transition event**.
  (Extremely simple) examples:
  - **assemble a peg into a hole**: approach, find hole, align, insert
  - **opening a door**: locating the handle, reaching out to grasp it, grasping it, opening the door
- **Task**:

My definitions

- **Motion**:
- **Skill**:
- **Task**: **symbolic constraints** between sub-Tasks (= partial fulfilment of the whole Task), in which each transition between two such sub-Tasks (compatible with the constraints) is realised by one out of a set of appropriate Skills.

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- **Motion**:
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- **Task**: **symbolic constraints** between sub-Tasks (= partial fulfilment of the whole Task), in which each transition between two such sub-Tasks (compatible with the constraints) is realised by one out of a set of appropriate Skills. (Not so extremely simple) example: **bring a bottle of beer from the fridge**

Intermediate reflections

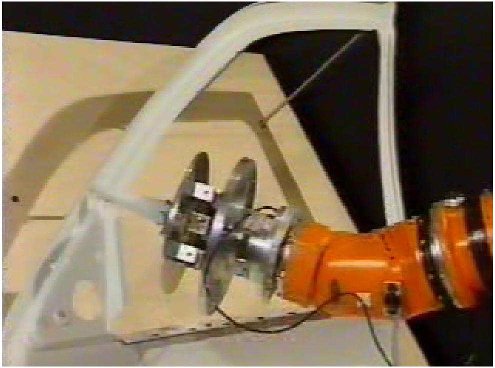
- Skills are the **“glue”** between the symbolic and the real worlds
- **reasoning** can take place at all levels
- **hierarchy** can exist at all levels.
- main & major & inevitable **research errors**: try to apply solutions fit for one level to problems at other levels.

Intermediate overview

Our research in Motion/Skill specification & execution:

- **Past**: (single) Task Frame Formalism
- **(Recent) Past**: (multiple) Feature Frame Formalism ("iTaSC")
- **Present**: Skills

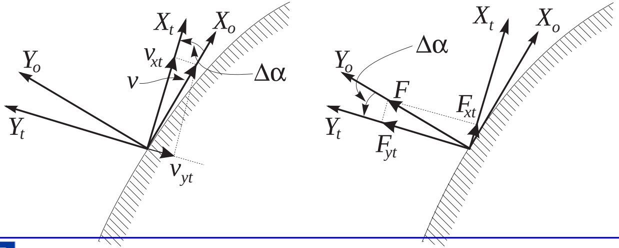
Past (1985–2000)
—Task Frame Formalism—



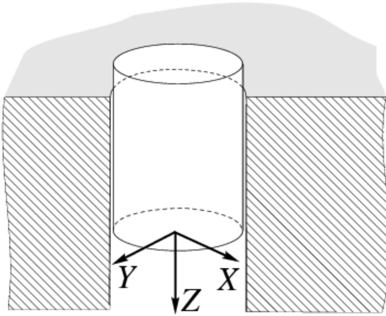
(Expected outcome of our PR2/WG contract!)

Task Frame Formalism (2)

- Single frame with six DOFs.
- Explicit setpoints (= hard, uni-directional constraints)
- Velocity + Force.
- Only serial "skill" logic.
- Sensor-based tracking. (E.g., force, vision.)



```
move compliantly {
 with task frame directions
      xt:  force 0 N
      yt:  force 0 N
      zt:  velocity v mm/sec
      axt: force 0 Nmm
      ayt: force 0 Nmm
      axt velocity 0 rad/sec
 } until zt force < -f N
```



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       xt: velocity v mm/sec
       yt: force f N
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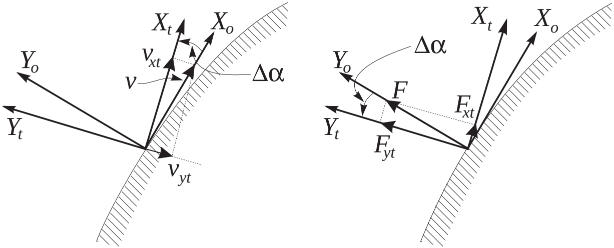
       axt: velocity 0 rad/sec
       ayt: velocity 0 rad/sec
       azt: track (on velocities)
  } until until distance > d mm
```

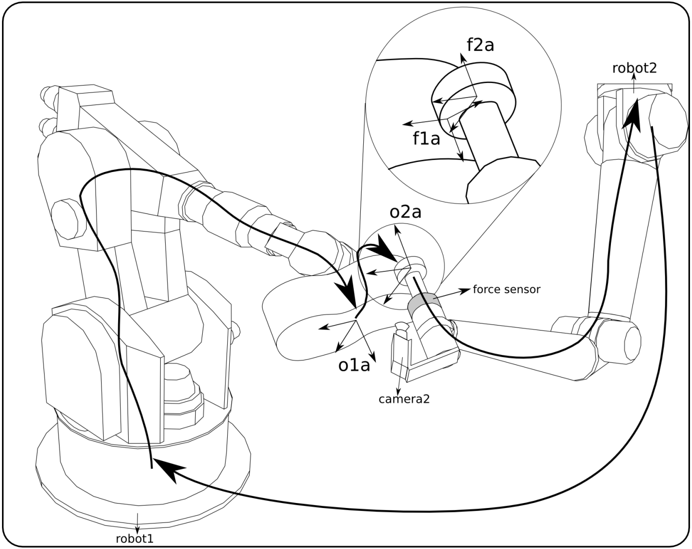


Past (2004–2009) —iTaSC—

“Instantaneous Task Specification with Constraints”

- **Multiple** frames. . .
- . . . with **partial** specification per frame. . .
- . . . and **constraint-based** i.s.o. setpoints.
- **Planning & Estimation** can be included.

Modelling primitives: kinematic loops



Step 1.: "Scene graph" model

- Relative geometric relationships between "feature frames" (⇒ ROS `tf2`?)
- Assign plan, estimation, uncertainty,... to each feature.

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Step 4.: Update the "scene graph" and iterate Step 3.

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- **Modelling**
- **Configuration**
- **Computation**
- **Coordination**

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    including weights between motion primitives and objective functions
  - learning: model parameter priors
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  - instantaneous motion solver
  - estimation/learning/reasoning calculations

  includes monitoring of constraint **violations**!
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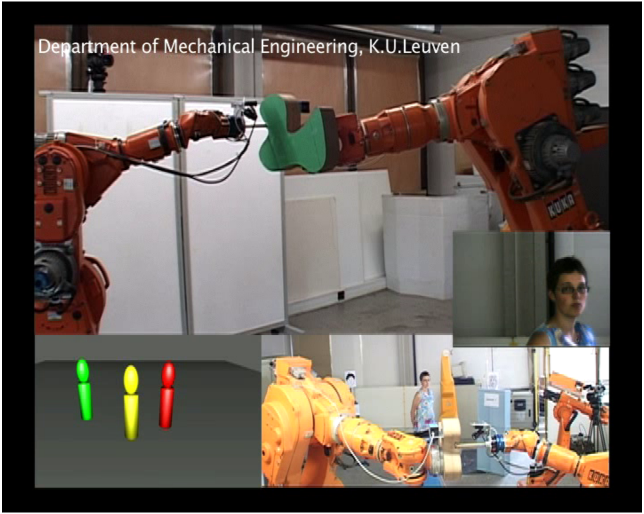
- **Coordination** (constraint violation event-driven FSM)
  includes "discrete scheduling" of **Bayesian network**!

Example experiment
—Human-aware dual-arm Skill—



Summary of presented paradigm

- our paradigm: a **methodological** way of **specifying** Skills and Motions
- Methodology = **4C** + constrained optimiz.
- **constraint-based**:
  - (**soft**) constraints are composable & bi-directional
  - constraints = **knowledge relationships**
  - allow **single-concept** **integration** of cognition and reasoning at all three **levels of abstraction** (Task, Skill, Motion)
- **multi-frame**, **partial** specification
- **scene graph** is central **shared** **resource**
- **traditional** *Sense-Plan-Act* is **smooth** limit case

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- . . . including professional/**commercially supported** implementation inside Orocos/ROS ecosystem
- *"To ROS or not to ROS?"*
  Wrong question!

⇒ *"Let's professionalize open source robotics!"*

Summary of presented paradigm (3)

- currently *best practice* and most impressive[a] implementations of our paradigm: **DLR Justin**…
- …using Simulink/RTW, and no open source…

[a] *Coffee making* video does *not* need "$\times$10" annotation…