Dealing with Run-Time Variability in Service Robotics: Towards a DSL for Non-Functional Properties

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Motivation

How to improve the execution quality of a service robot acting in open-ended environments given limited onboard resources?

Example:
Optimize coffee delivery service

1. guarantee minimum coffee temperature (preference is to serve as hot as possible)
2. maximum velocity bound due to safety issues (hot coffee) and battery level
3. minimum required velocity depending on distance since coffee cools down
4. fast delivery can increase volume of coffee sales

Motivation

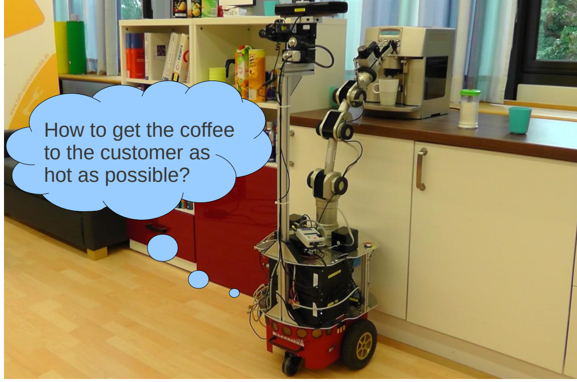
Focus so far in service robotics still mostly on:

- pure task achievement
- robot functionality
- ***how*** to do something

What cannot be ignored any longer:

- non-functional properties
  - quality of service
  - safety
  - energy consumption
  - …
- ***do it efficiently***
  - *which possibilities are better than others in terms of non-functional properties?*

Motivation



Robotics engineer / design-time

- identify and enumerate all eventualities in advance???
- code proper configurations, resource assignments and reactions for all situations???

➢ *not efficient due to the combinatorial explosion of situations & parameterizations*
➢ *even the most skilled robotics engineer cannot foresee all eventualities*

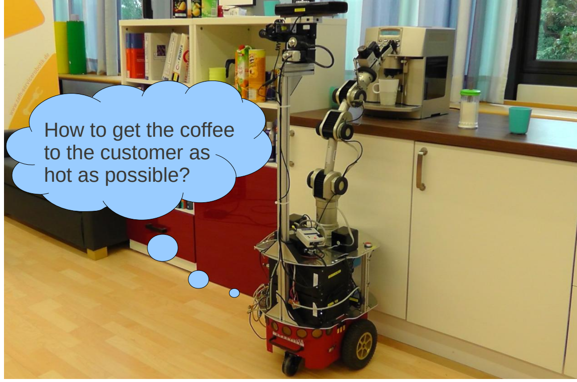
Robot / run-time:

- just (re)plan in order to take into account latest information as soon as it becomes available???

➢ *complexity far too high when it comes to real-world problems*

(not possible to generate action plots given partial information only while also taking into account additional properties like, e.g. safety and resource awareness)

Our Approach:



- Express variability at design-time
  - make it as simple as possible for the *designer* to *express variability*

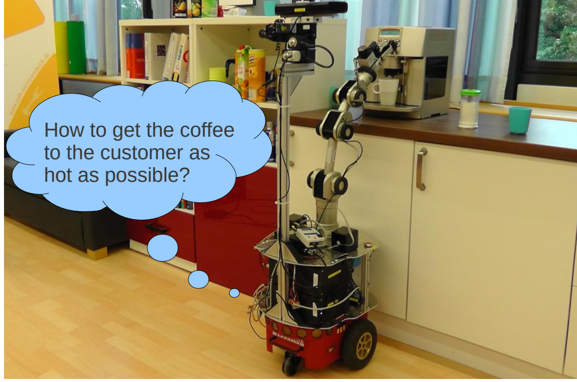
- Bind variability at run-time based on the then available information
  - enable the *robot* to *bind variability* at *run-time* based on the then available information

- *remove complexity from the designer by a DSL*
- *remove complexity from the robot's run-time decision by modeling variability*

We present:

- first version of a DSL to express variability in terms of non-functional properties
- integration into our robotic architecture
- real-world example

Our Approach

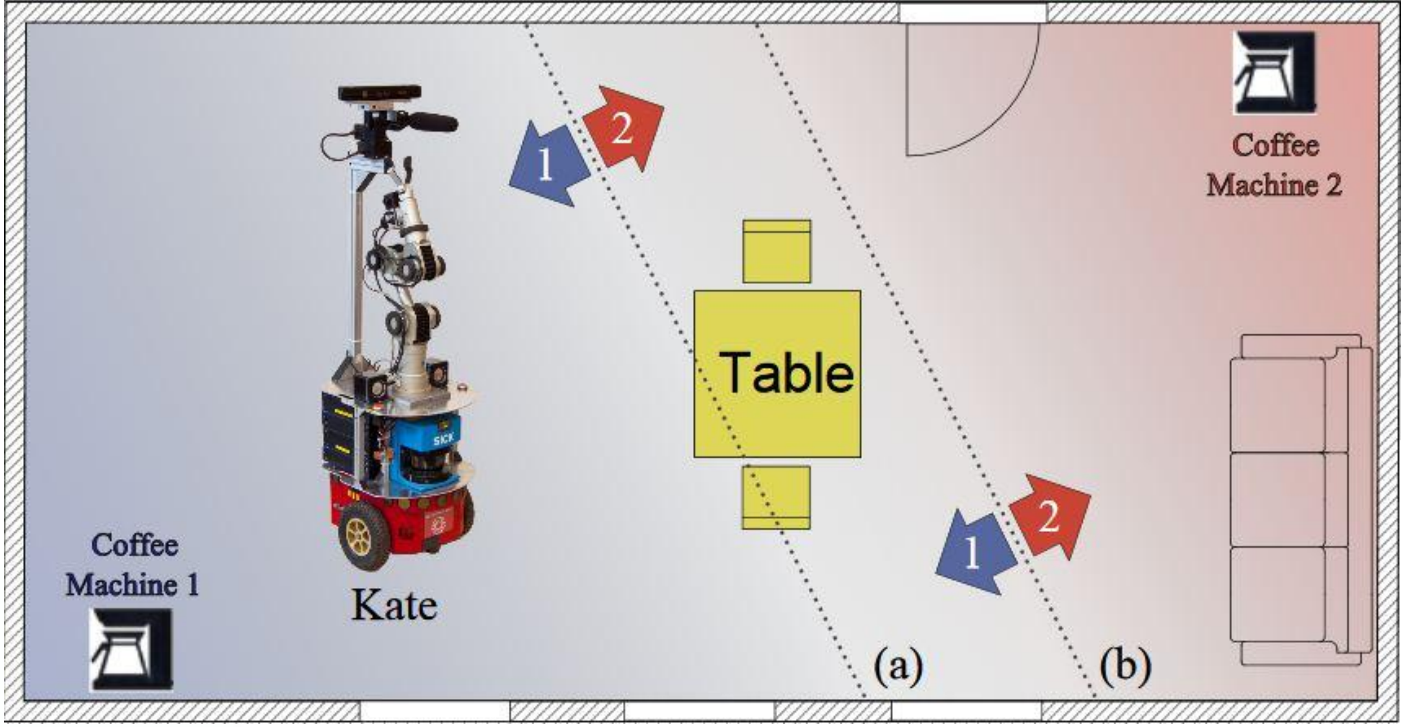


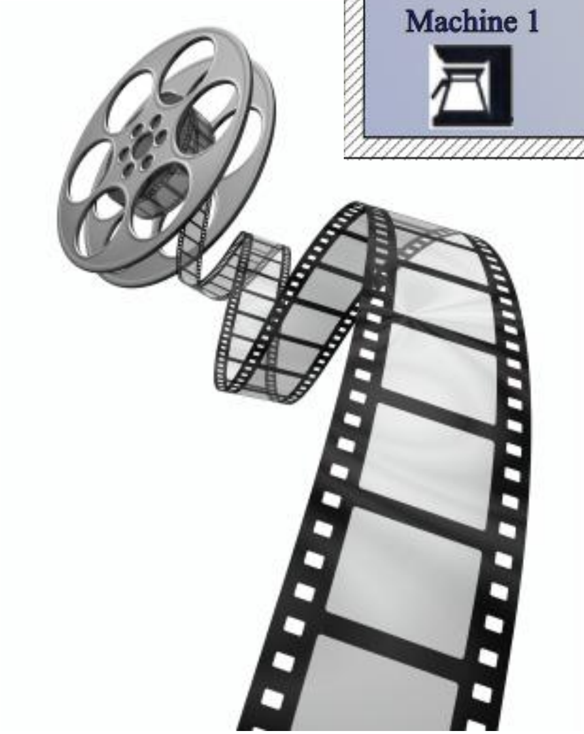
Separation of concerns:

- models (e.g. task net) describe ***how*** to deliver a coffee
- models specify ***what is a good way (policy)*** of delivering a coffee
  (e.g. in terms of non-functional properties like safety, energy consumption, etc.)

Separation of roles:

- designer at design-time: provides models
  - action plots with variation points to be bound later by the robot
  - policies for task fulfillment
  - problem solvers to use for binding variability
- robot at run-time: decides on proper bindings for variation points
  - apply policies
  - take into account current situation and context





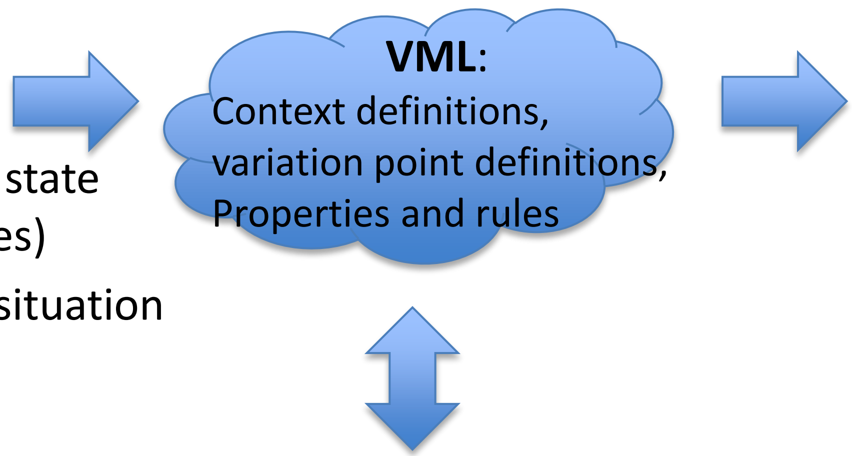
http://youtu.be/-nmliXl9kik

Modeling Variability

Objective: ***Optimize service quality of a system (non-functional properties):***
power consumption, performance, etc.
balance conflicting properties by minimizing overall cost function
(constrained optimization problem)

- property importance varies according to the current context → ***property priority***
- properties are expressed as functions of variation points → ***property definition***

Inputs
(context variables)
- the current robot state (task and resources)
- the environment situation



Outputs
(***variation point*** bindings)
- binding system variability (non conflicting with functionality)

adaptation rules:
- define direct relationships between context variables and variation points
- event-condition-action rules
- directly constrain the possible values of variation points according to current context

Modeling Variability

```
/* Data type definitions */
number percentType { range: [0, 100];    precision: 1; }
number velocityType { range: [100 600]; precision: 0.1; unit: "mm/s"; }

/* Contexts */
context ctx_battery : percentType;
context ctx_noise : percentType;

/* Adaptation rules */
rule low_noise : ctx_noise < 20 => speakerVolume = 35;
rule medium_noise : ctx_noise >= 20 & ctx_noise < 70 => speakerVolume = 55;
rule high_noise : ctx_noise >= 70 => speakerVolume = 85;

/* Properties */
property efficiency : percentType maximized {
        priorities: f(batteryCtx) = max(exp(-batteryCtx/15)) - exp(-batteryCtx/15);
        definitions: f(maxVelocity) = maxVelocity; }

property powerConsumption : percentType minimized {
        priorities: f(batteryCtx) = exp(-1 * batteryCtx/15);
        definitions: f(maxVelocity) = exp(maxVelocity/150); }

/* Variation points */
varpoint maximumVelocity : velocityType;
varpoint speakerVolume   : percentType;
```

← Context variables

← Adaptation rules

← Properties

← Variation points

Execution Semantics

- M2M transformation from *VML model* into *MiniZinc model*
  - *MiniZinc is currently supported by many constraint solvers*
    - *context variables => parameters*
    - *variation points => decision variables*
    - *adaptation rules / variation point dependencies => constraints*
    - *properties => cost function*
  - *we use*
    - **The G12 Constraint Programming Platform — University of Melbourne**

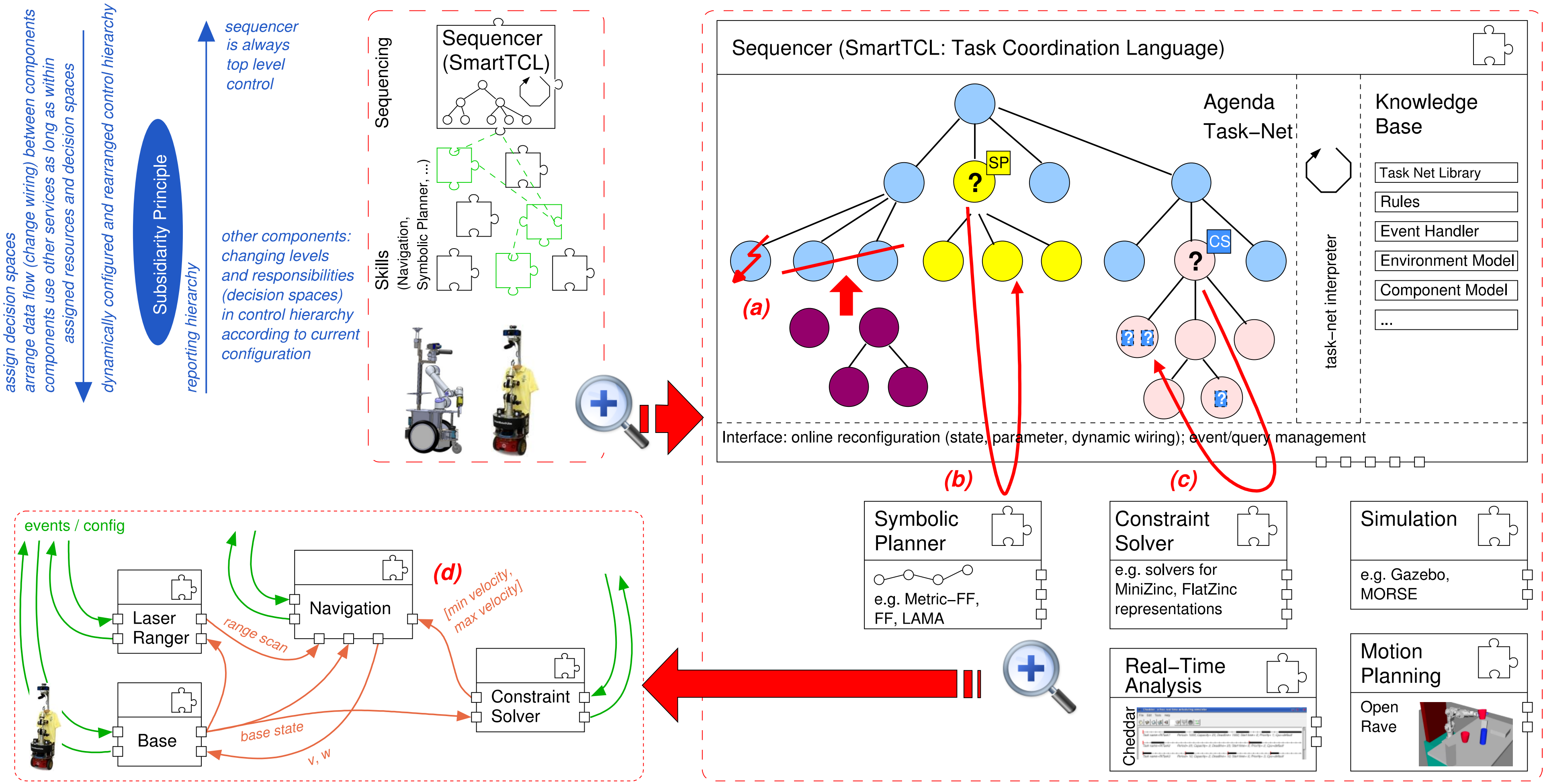
$$f(ctx, vp) = \sum_{\forall i} (-1)^{d_i} \cdot w_i(ctx) \cdot p_i(vp)$$

minimize
maximize

normalized priority function

normalized definition function

Integration into robotic architecture



Conclusions & Future Work

- VML enables designers to focus on modeling the adaptation strategies without having to foresee and explicitly deal with all the potential situations that may arise in real-world and open-ended environments.
- The variability, purposefully left open by the designers in the VML models, is then bound by the robot at run-time according to its current tasks and context (separation of roles and separation of concerns).
- We underpinned the applicability of our approach by integrating it into our overall robotic architecture and by implementing it in a sophisticated real-world scenario on our service robot Kate.
- For the future, we fully integrate VML into our *SmartSoft MDSD* toolchain.

Overall Vision: MDSD in Robotics…

- *Use models for the entire life-cyle of the robot*
- *Models are refined step-by-step until finally they become executable*
- *Separate inside view (component builder) from outside view (system integrator)*
- *Separate stable execution container from implementational technologies (middleware, OS)*
- *Variation points: design-time (component builder, system integrator), runtime (robot)*
  - *Explicitly model variability for late binding (by system integrator and even by the robot at runtime)*