Integrating Discrete Controller Synthesis in a Programming Language

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Motivation

- mixed imperative/declarative programming language
  separation of concerns between:
  - functionality of sub-systems
  - properties of their assembly in a system

  declarative contracts are enforced upon
  imperatively described behaviors (automata)

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  events, states, control modes $\leftrightarrow$ automata (e.g., StateFlow)

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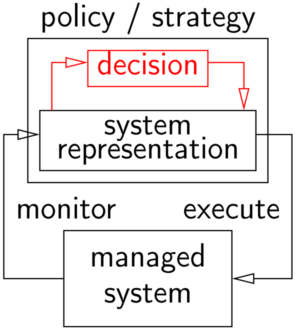
- Contributions
  1. BZR programming language: semantics and compilation
  2. case study : robot arm controller

Control Techniques for Adaptive Computing

- Control of computation adaptation as a closed control loop



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Use of Discrete Event Systems and supervisory control:

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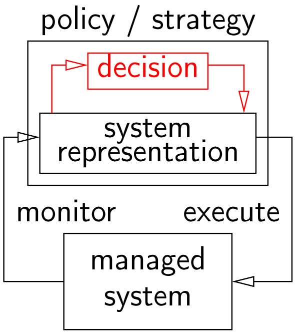

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Use of Discrete Event Systems and supervisory control:
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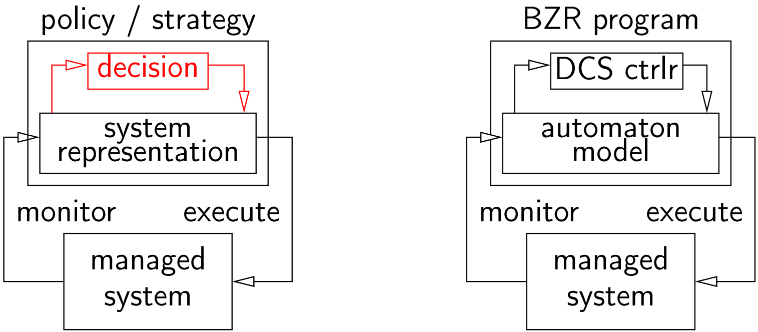
- Control of computation adaptation as a closed control loop
- BZR programming language, and Discrete Controller Synthesis to compute the decision component (controller)



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resource access, level of consumption/quality, ...

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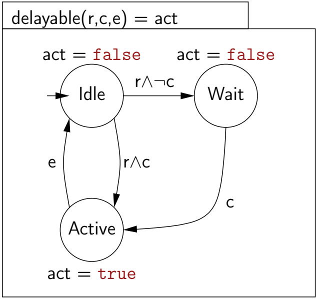

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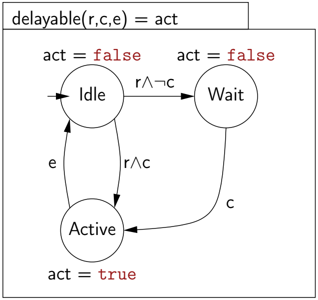

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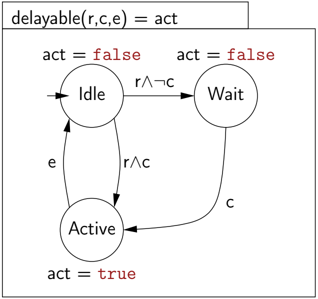

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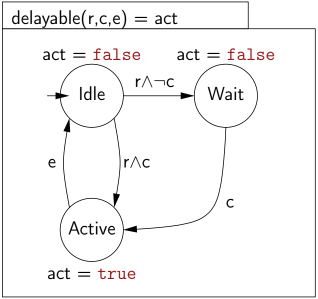

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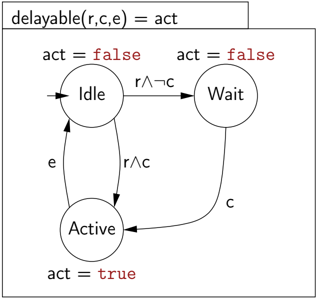

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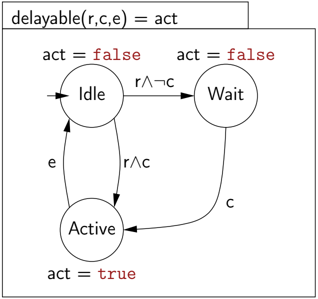

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- architecture control: frequency, DVS, stand-by in MPSoC

Discrete controller synthesis: principle

Goal

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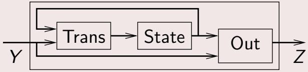
Out	output function



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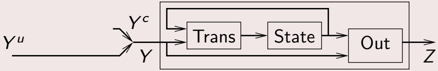

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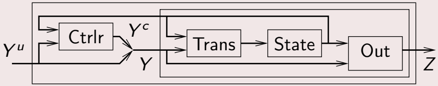

- Partition of inputs into controllable (Y^c) and uncontrollable (Y^u) inputs
- Computation of a controller, *maximally permissive*, such as the controlled system satisfies Φ
- tool: `sigali` (H. Marchand, INRIA Rennes)

BZR: contracts and DCS

$$f(x_1, \dots, x_n) = (y_1, \dots, y_p)$$

$$e_A \Longrightarrow e_G$$

$$\texttt{with } c_1, \dots, c_q$$

$$y_1 = f_1(x_1, \dots, x_n, c_1, \dots, c_q)$$

$$\dots$$

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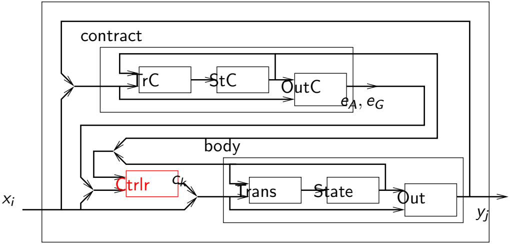

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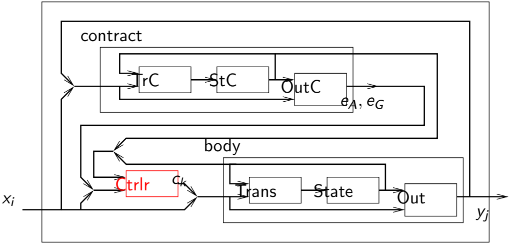

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[ACM LCTES'10]

BZR modularity

BZR composite contract node:

re-use contracts of sub-nodes for the controller of the composite

assuming e_A, as well as $(e_{A1} \Rightarrow e_{G1})$ and $(e_{A2} \Rightarrow e_{G2})$

enforce e_G, as well as e_{A1} et e_{A2}

$f(x_1, \ldots, x_n) = y_1, \ldots, y_p$

assume e_A

enforce e_G

with $c_1, \ldots, c_q$

$f_1(x_{11}, \ldots, x_{1n}, c_1, \ldots, c_q) = y_{11}, \ldots, y_{1p}$

assume e_{A1}

enforce e_{G1}

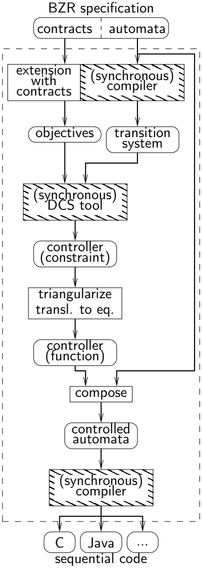
...

$f_p(x_{p1}, \ldots, x_{pn}, c_1, \ldots, c_q) = y_{p1}, \ldots, y_{pp}$

assume e_{Ap}

enforce e_{Gp}

Compilation & implementation



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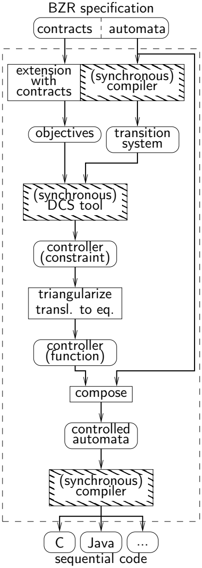
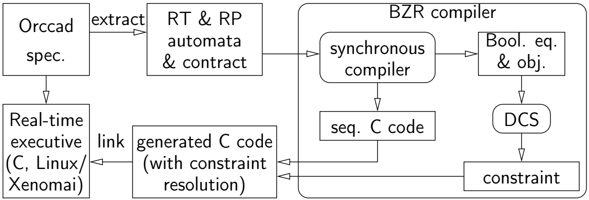


Development process:

integration in computing system

(here: Orccad):



Programming methodology

classical programming: write the solution, then verify
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  different objectives can be possible
  controllability for a specific objective is not always given
- compile the program to obtain the controller using DCS
  can be seen as completion of partially specified program

Case study: robot arm

- robot arm (inspired from [IFAC11])
  articulations define mechanically reachable workspace
  always under control of a control law (at least one)
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  - *CJ*: grouping 2 tasks *C*: moving *inside workspace* (*Cartesian* coord.) and *J*: moving around singularities (*Joint* coord.)
  - *F*: trajectory following, to point to a target *outside workspace*
  - *B*: same, for a target at the *border of workspace*
  - *CT*: *tool change*, with move towards tool rack, and change two arm-held tools: gripper, camera
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  - *CT*: *tool change*, with move towards tool rack, and change two arm-held tools: gripper, camera
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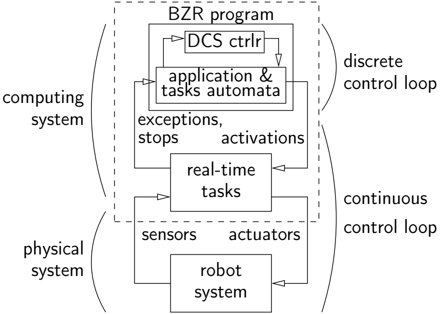
- application:
  when target is *inside* workspace: grip it
  when *at border*: go to center, and point with camera
  when *outside*: point towards it, with camera

Discrete control handlers of continuous control tasks

Discrete control of tasks sequencings and mode changes

- Discrete and continuous layers



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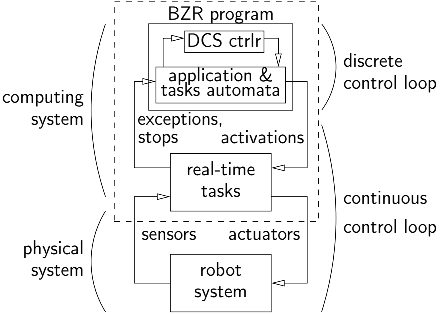
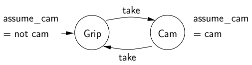


- Local task automata, coordinated by application automata with discrete supervisor, enforcing logical objective

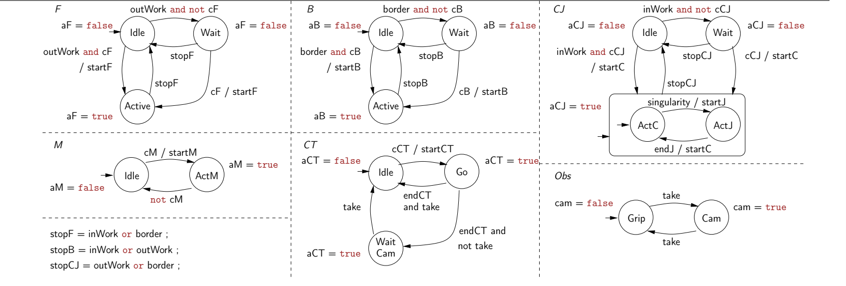
Modeling behaviors and specifying contract

behaviors of control tasks, contract featuring an observer

```
rob ( endCT, endJ, singularity, inWork, outWork, border , take ) returns startC, startF, startB, startM, startJ, startCT, cam
```




```
righttool = ( aCJ implies (not cam) )
        and ( (aF or aB) implies cam );
ex = aF xor aCJ xor aB xor aCT xor aM;
morethanone = (inWork and outWork)
           or (outWork and border)
           or (inWork and border)
assume ( assume_cam and take implies aCT and not morethanone )
enforce ( righttool and ex )
with cF, cB, cCJ, cCT, cM
```



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  - the user clicks outside of the workspace → input `outWork` true
    transition: CJ to its initial state; F quits initial, choice cF
    contract `righttool`: $\Rightarrow cF =$ `false`: F to Wait;
    contract `ex`: $\Rightarrow cCT =$ `true`: CT to Active

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  - CT ends → input `EndCT`
    transition: `take` true, CT to Init; tool observer to `Cam`
    contracts `ex` and `goodtool`: $\Rightarrow cF =$ `true`: F to Active

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- modular contracts
  two robots sharing an exclusive camera, with each its gripper

```
tworobs ( endCT1, ... border1, endCT2, ... border2 )
returns  startC1, ... startCT1, startC2, ... startCT2
enforce ( not ( cam1 and cam2 ))
with take1, take2
  startC1, ... startCT1, cam1 = rob (endCT1, ... border1, take1);
  startC2, ... startCT2, cam2 = rob (endCT2, ... border2, take2);
```

Conclusion & Perspectives

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    Integration of DCS tool in compiler
  - **Application of DCS to computing system**
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  - **Case study** robot arm, specification & simulation

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- Perspectives
  - **more DCS** : efficiency, expressivity
    reachability, dynamical controllers, costs on paths [WODES10]
  - **more elaborate models** of adaptive systems
    finer grain, e.g. fault tolerance [FMSD09]
  - **more integration** in existing frameworks
    e.g. component-based Fractal [EMSOFT11]
  - **more adaptive computing systems**
    reconfigurable FPGA architectures (ANR Famous)
    administration loops in data-centers (ANR CtrlGreen)