Automatic generation of discrete handlers of real-time continuous control tasks

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Real-Time Operating Systems and reactive control

- Programming control systems

  continuous control loops $\leftrightarrow$ tasks on RTOS

  performance & quality $\leftrightarrow$ periods, latencies

  $\longrightarrow$ Orccad design environment

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- Discrete, reactive controllers

  events, states, control modes ↔ automata (e.g., StateFlow)

  model-based design ↔ synchronous languages

  discrete control loops ↔ discrete controller synthesis (DCS)

  → BZR programming language

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- Contributions

  Discrete control handlers of continuous control tasks

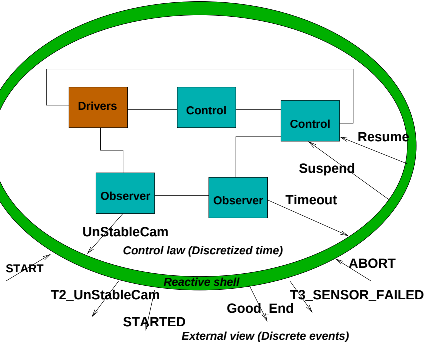
  1. integration of DCS via BZR in Orccad
  2. case study: robot arm controller

Programming control systems in Orccad (continuous)

Orccad: design, validation, implementation of robotic applications

Real-time tasks for continuous control:

- fixed-rate sampling, or multi-rate
- control/scheduling co-design : periods, latencies, gains
- Robot-Task (RT): encapsulation in a reactive shell



Programming control systems in Orccad (discrete)

Automata for task management

- Generic control of RTs, with events for: synchronizations, exceptions (3 types), pre & postconditions
- Missions design: assembling RTs (abstracted to automata) into hierarchical Robot Procedures (RPs)
- Specification and validation: Esterel synchronous language
- Real-time execution machine for the synchronous automata

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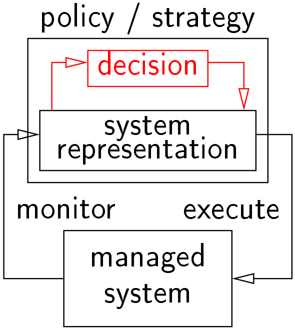
Position of the contribution in this work:
instead of programming then verifying,
use DCS to generate correct task controllers

Control Techniques for Adaptive Computing

- Control of computation adaptation as a closed control loop



Discrete Control Techniques for Adaptive Computing

Use of Discrete Event Systems and supervisory control:
Petri nets, language theory (R&W), automata (synchronous)

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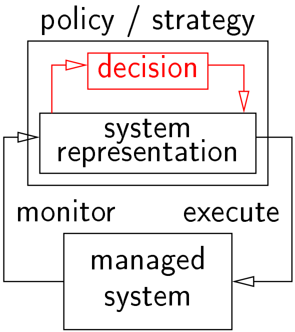

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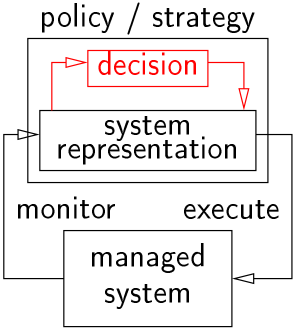
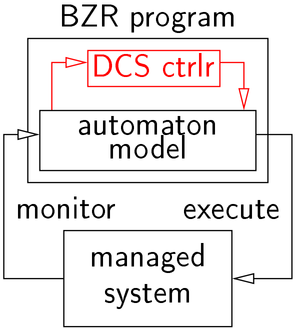
- Control of computation adaptation as a closed control loop
- BZR programming language, and Discrete Controller Synthesis to compute the decision component (controller)



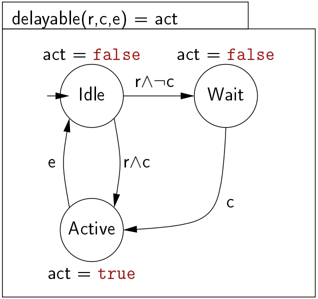


Examples of discrete computing modes

state ↔ configuration

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

- computation task control (example of Heptagon node)
- modes: algorithm variants for a functionality (resource, QoS)
- placement and migration: task T_i on processor/core P_j
- resource budgeting: proc./core taken for other application



- fault tolerance: migration/rollback upon processor failure
- architecture control: frequency, DVS, stand-by in MPSoC

Discrete controller synthesis: principle

Goal

Enforcing a temporal property Φ on a system (on which Φ does not a priori hold)

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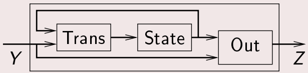
Principle (on implicit equational representation)

State	memory
Trans	transition function
Out	output function



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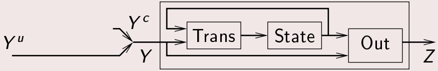

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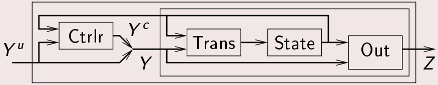

- Partition of inputs into controllable (Y^c) and uncontrollable (Y^u) inputs
- Computation of a controller, *maximally permissive*, such as the controlled system satisfies Φ
- tool: `sigali` (H. Marchand, INRIA Rennes)

BZR: contracts and DCS

$f(x_1, \ldots, x_n) = (y_1, \ldots, y_p)$
$e_A \Longrightarrow e_G$
with $c_1, \ldots, c_q$

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

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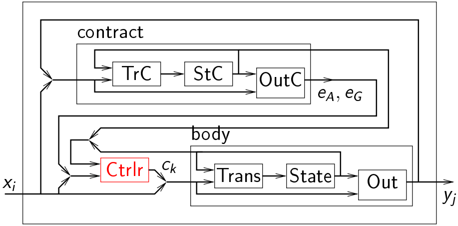

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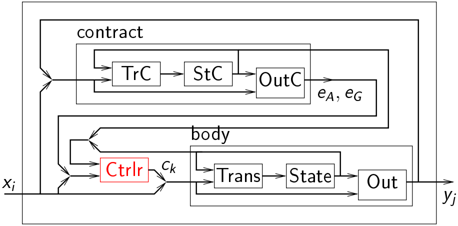

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[ACM LCTES'10]

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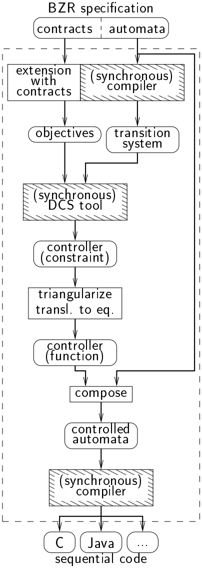

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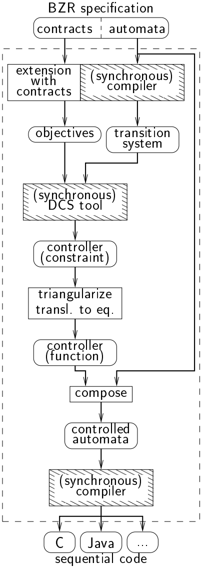
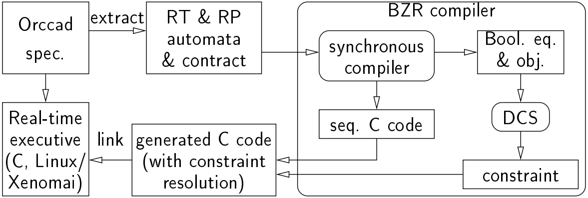
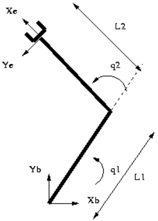


Development process:
integration in computing system
(here: Orccad):



Case study: ArmX robot arm

- two links
  rotational joints (q1,q2)



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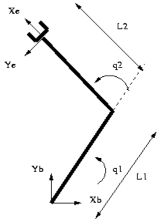

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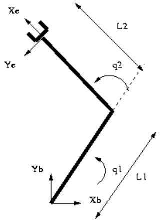

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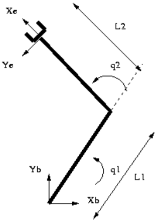

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- joint space move
- cartesian space move
- target aiming
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- tool change (at initial position $(q1 = 0, q2 = 0)$)

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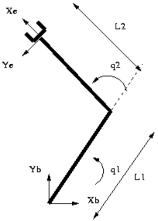

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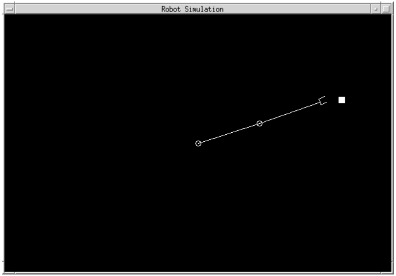
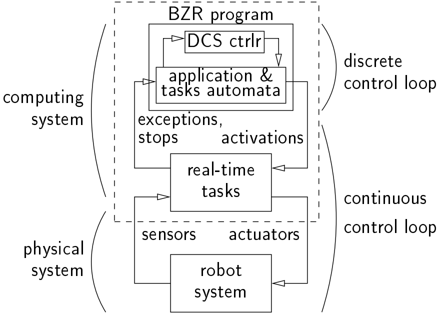
ArmX 2D simulation



Discrete control handlers of continuous control tasks

Discrete control of tasks sequencings and mode changes

- Discrete and continuous layers



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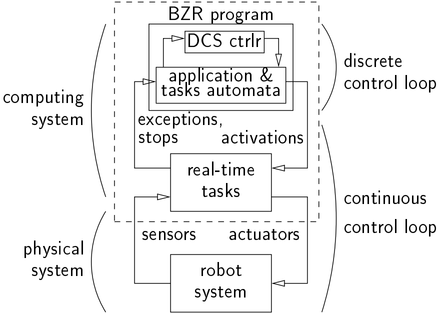
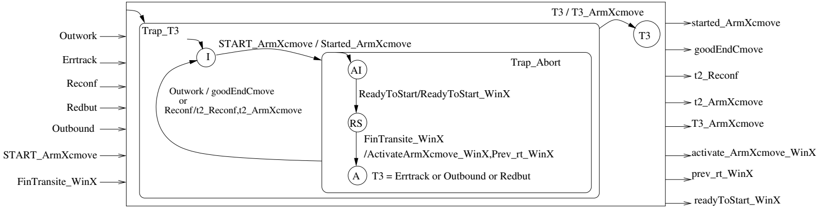


- Local task automata, coordinated by application automata with discrete supervisor, enforcing logical objective

Language-level integration: Robot Tasks

BZR/Heptagon programming of the generic RT control automaton
Example of `ArmXcmove`:



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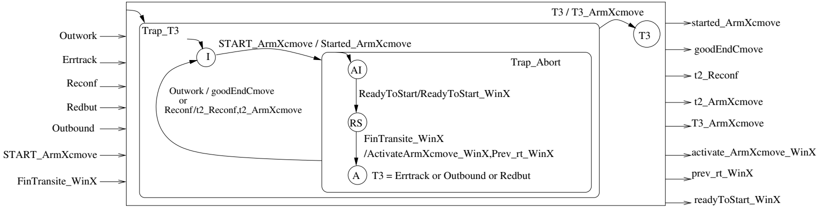

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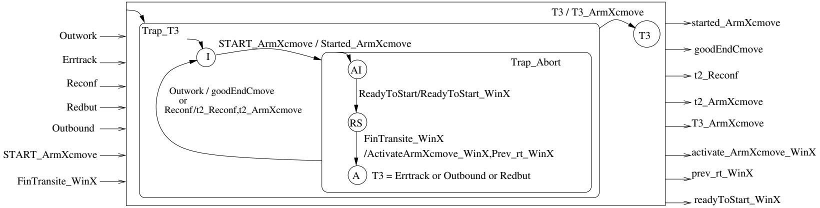

- inputs & outputs: interaction with application level, and from sensors and RTOS, to RTOS
- behaviour: phases (initialization, control) exceptions (T2, T3)

Language-level integration: Robot Procedure

Global automaton: synchronous composition
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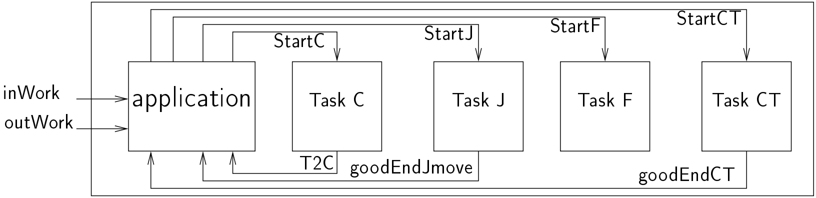
Example: complete BZR program (simplified).



Global BZR node, with contract

```
node procRobot (goodEndCT,goodEndJmove,t2,outWork,inWork:bool)
               returns ( startC, startF, startJ, startCT:bool)

with (ok1,ok2,ok3:bool)
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BZR programming methodology:

- possible behaviors
- declarative contract

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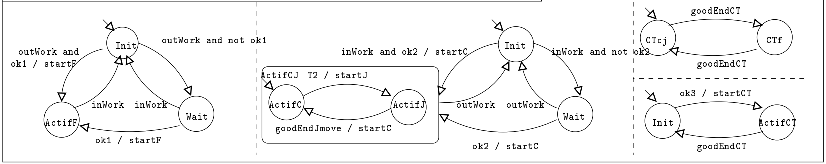

BZR programming methodology:

- possible behaviors: 4 automata in $||$: 1 observer, 3 task mgrs
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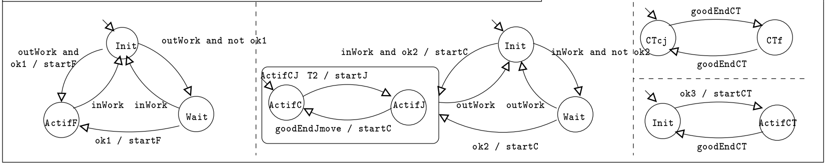

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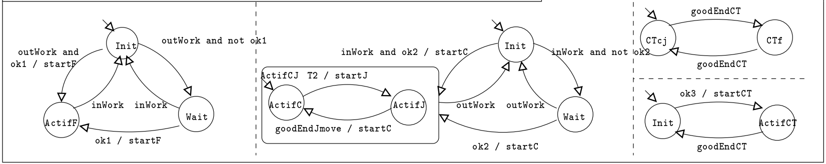

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  - mutual exclusion and default control: `ex`

Typical scenario

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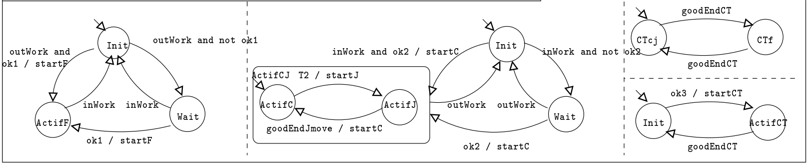

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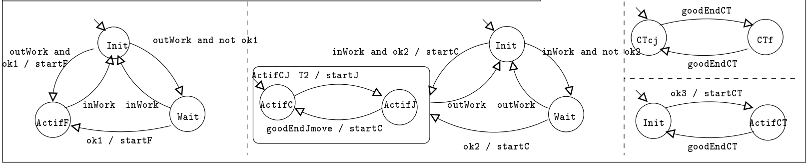

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- the user clicks outside of the workspace → input outWork

transition: CJ to its initial state; F quits initial, condition ok_1
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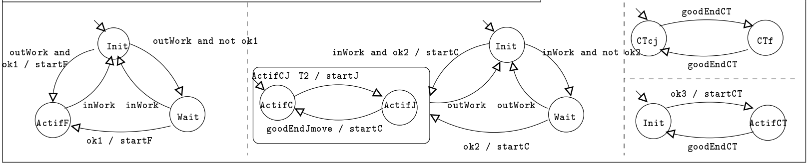

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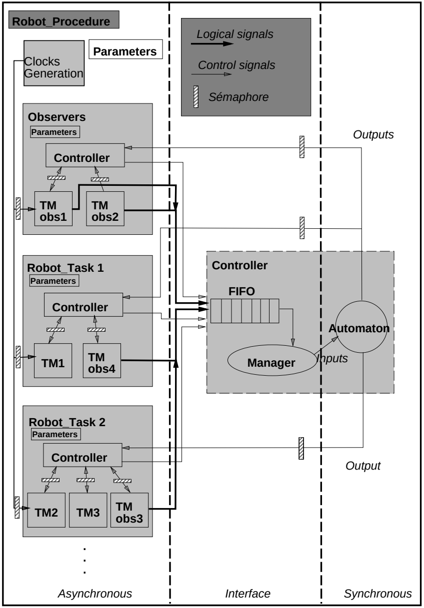
- CT ends (no inWork) → input GoodEndCT
  transition: CT to Init; tool observer to CTf
  contracts ex and goodtool: $\Rightarrow ok_1 = \texttt{true}$: F to Active

Executive-level integration

Implementation of the execution machine:



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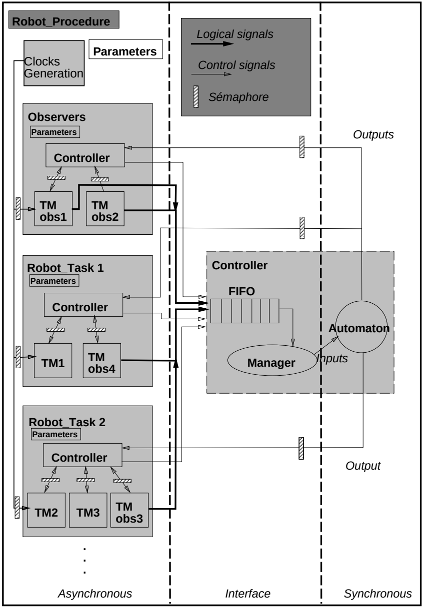

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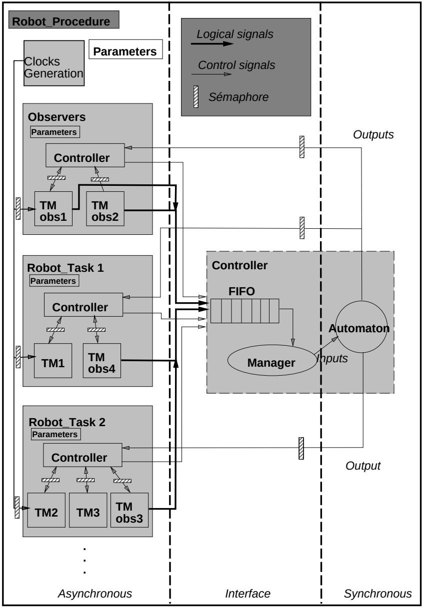

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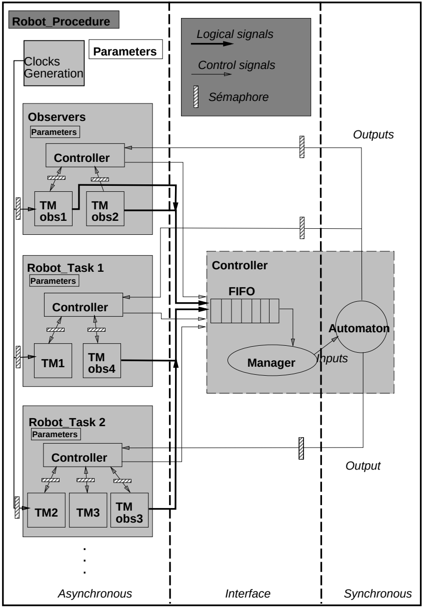
  - fast transition (μsecs)
- Linux/Posix threads, Xenomai



Conclusion & Perspectives

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  - **Discrete control of real-time continuous control tasks**
    application of DCS to computing system
  - **Integration of tools**
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  - **Case study** Robot arm, specification & simulation

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- Perspectives
  - **more integration** designing controllable runtime executives
  - **more elaborate models**
    finer grain, e.g. fault tolerance [FMSD09]
  - **more DCS** costs on paths, reachability, dynamical controllers
  - **more applications** e.g. GreenIT (sustainable IT)
    Green4IT: energy/power consumption models
    for sensor networks, servers and parallel computing
    IT4Green: applying control programming techniques
    to program e.g., "intelligent" buildings