Model-Driven Design of Simulation Support for the TERRA Robot Software Tool Suite

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Introduction – Context

- **Cyber-Physical System**
  - CPS: cyber domain and physical domain are closely integrated
  - Most of them are safety-critical systems
  - Design challenges of CPS: complex design spaces, too costly
    - Joint dynamics of software, networks, and physical processes, etc.
    - Operate dependably, safely, efficiently and in real-time w.r.t. requirements
    - Gap, between C&P parts when integrating in the end of the design phase

(M.M. Bezemer, PhD Thesis)
Introduction – Motivation

- Concurrency in CPS
  - Concurrency is intrinsically present in CPS
    - Physical: compositions of many things occurring at the same time
    - Cyber: measuring and controlling the dynamics of physical processes

- Model-Driven Development
  - Model transformation – formal verification
  - Meta-model – reusability and extensibility
  - Off-target simulation and testing, first-time-right implementation

- Communicating Sequential Processes
  - Solution for formalization and concurrency issues in CPS

- Simulation needs
  - Precise modeling for C&P parts are required in CPS design
  - FDR: check the software architecture problems
  - The executing order of processes is required as well

26-08-2015
Introduction – Goals

- Project Goals
  - Develop methods and tools for model-driven C&P co-design
    - Integrate C&P parts, co-modeling and co-simulation
    - Eliminate the gap between C&P parts during the early design phase
    - Achieve first-time-right designs

- Our work reported in this paper
  - Design and develop simulation support for the TERRA tool suite
    - Make the TERRA model ‘executable’
    - Determine the order of software processes
Background – Modeling Approach

- **TERRA**
  - Graphically CSP-based modeling for discrete-event domain [CPA2012]

- **20-sim**
  - Graphically modeling for continuous-time domain
    - Control algorithms
    - Plant dynamics

- **LUNA**
  - C++ execution framework for QNX/Xenomai [CPA2011]

- **Simulation/Co-simulation**

(M. M. Bezemer, PhD thesis)
Background – Existing Tool Suite

- **TERRA**
  - Twente Embedded Real-time Robot Application

- **Eclipse-based tool suite**
  - EMF
    - Meta-model design
      - Explicit CSP meta-model
  - Epsilon Framework
    - Model transformation
    - Code generation
    - Model validation

(M. M. Bezemer, PhD thesis)
Simulation Support for TERRA

- **Design methodology**
  - Based on
    - MDE
    - Meta-models
    - EMF, Epsilon ETL, EGL
  
  A: Transform TERRA model to simulation model
  B: Generate simulation trace text
  C: Present status to user
  D: Simulate by user choice
  E: Broadcast event for animation
Simulation Support for TERRA

- Simulation meta-model

CSP Meta-model

Simulation Meta-model

CSPDiagram

CSPCompositionalGroup
CSPModel
CSPWriter
CSPReader

CSPModel
CSPWriter
CSPReader
CSPCompositionalGroup
Simulation Support for TERRA

**Implementation**

- Task-specific Languages
  - Epsilon Transformation Language (ETL)
  - Epsilon Generation Language (EGL)
  - Epsilon Validation Language (EVL)
  - Epsilon Comparison Language (ECL)

- Epsilon Object Language (EOL) \(\approx\) JavaScript + OCL
- Epsilon Model Connectivity (EMC)

- Technology-specific Drivers
  - EMF
  - MetaEdit+
  - Schema-less XML
  - Meta Data Repository

- TERRA M2M transformation
  - M2T generation
  - Model validation

- CPC meta-model
- CSP meta-model
- Simulation meta-model

**Why adding a new simulation meta-model?**

- No conflict/influence with/to the existing CSP meta-model
- Simplified abstraction of a TERRA CSP model, w.r.t simulation needs
- More flexibility, extensibility
Example

- TERRA model example

Source TERRA model

Generated CSPm

```cspm
-- Channels
channel channel_C1_Wr_C1_to_C2_Rd_C2

-- Processes
MainModel_SEQUENTIAL = if (true) then
  (MainModel_P ; MainModel_PARALLEL ) ; MainModel_SEQUENTIAL else SKIP

MainModel_P = P_subPARALLEL
P_subPARALLEL = P_subP1 ||| P_subP2
P_subP1 = SKIP
P_subP2 = SKIP

MainModel_PARALLEL =
  MainModel_C1 [ | { channel_C1_Wr_C1_to_C2_Rd_C2 } ] |] MainModel_C2
MainModel_C1 = C1_sub_C1_SEQ
C1_sub_C1_SEQ = C1_C1Code ; C1_Wr_C1
C1_C1Code = SKIP
C1_Wr_C1 = channel_C1_Wr_C1_to_C2_Rd_C2 -> SKIP
MainModel_C2 = C2_sub_C2_SEQ
C2_sub_C2_SEQ = C2_Rd_C2 ; C2_C2Code
C2_Rd_C2 = channel_C1_Wr_C1_to_C2_Rd_C2 -> SKIP
C2_C2Code = SKIP
```
Example

- Transformed to a simulation model
Example

- Transformed to a simulation model
Example

- Transformed to a simulation model
Transformed to a simulation model
- Transformed to a simulation model
Example

- Generated simulation trace text
  - Indicate the execution order of processes
  - Random selection

```plaintext
-- Generated by TERRA SIM to simTrace version 0.0.4
-- Input file: test.sim

-- Execution Queue
SimDiagram = MainModel
Top Level Object = SEQUENTIAL
SEQUENTIAL is Recursive
SEQUENTIAL -> Start SP = SEQUENTIAL
SEQUENTIAL -> Next SP = P

SimDiagram = P
Top Level Object = subPARALLEL
subPARALLEL -> Start SP = subPARALLEL
subPARALLEL -> Next SP = subP1
subP1 -> Next SP = subP2
subP2 = isEnd

SimDiagram = C1
Top Level Object = sub_C1_SEQ
sub_C1_SEQ -> Start SP = sub_C1_SEQ
sub_C1_SEQ -> Next SP = C1Code
C1Code -> Next SP = Wr_C1
Wr_C1 = isEnd

SimDiagram = C2
Top Level Object = sub_C2_SEQ
sub_C2_SEQ -> Start SP = sub_C2_SEQ
sub_C2_SEQ -> Next SP = Rd_C2
Rd_C2 -> Next SP = C2Code
C2Code = isEnd
```
Example

- Generated simulation trace text
  - Indicate the execution order of processes
  - Random selection

```plaintext
SimDiagram = P
Top Level Object = subPARALLEL
subPARALLEL -> Start SP = subPARALLEL
subPARALLEL -> Next SP = subP2
subP2 -> Next SP = subP1
subP1 = isEnd

operation CSPCompositionalGroup getGroupedObjects() : Sequence {
  var objects: Sequence;
  for(relation in self.relations) {
    for(object in relation.compositeObjects) {
      objects.add(object);
    }
  }
  if(self.getGroupSymbol() == "||" and Sequence{1..2}.random()==1) {
    return objects.invert();
  } else {
    return objects;
  }
}"
```
Conclusion and future work

- ✔ Sim meta model
- ✔ TERRA2Sim transformation
- ✔ Produce simulation trace text
- ✔ Show process orders
- ✔ Show random selections
- ? Graphical animation
- ? Show computations
- ? Co-simulation interface (between TERRA & 20-sim)
Conclusion and future work

- ✓ Sim meta model
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Thanks!