Model-Driven Engineering of Fault Tolerance Solutions in Enterprise Distributed Real-time and Embedded Systems

Sumant Tambe*
Aniruddha Gokhale
Jaiganesh Balasubramanian
Krishnakumar Balasubramanian
Douglas C. Schmidt

Vanderbilt University, Nashville, TN, USA
Contact: *sutambe@dre.vanderbilt.edu

Presented at OMG RTWS 2006
Arlington, VA, July 2006

This work is supported by subcontracts from LMCO & BBN
Component-based Enterprise DRE Systems

- Characteristics of component-based enterprise DRE systems
  - Applications composed of one or more “operational string” of services or systems of systems
  - Simultaneous QoS (Availability, Time Critical) requirements
  - Dynamic (re)-deployment of components into operational strings

- Examples of Enterprise DRE systems
  - Advanced air-traffic control systems
  - Continuous patient monitoring systems

Goal: Provide Fault Tolerance and predictability simultaneously in the DRE systems
QoS Issues in Enterprise DRE Systems

- Regulating & adapting to changes in runtime environments
- Negotiating tradeoffs between multiple (often tangled) QoS requirements
  - e.g., fault-tolerance, high performance, real-time etc.
- Satisfying QoS demands in the face of fluctuating and/or insufficient resources
  - e.g., hardware/software failures, mobile ad hoc networks

This talk focuses on Fault Tolerance
Tangled QoS-Concerns in Fault-Tolerance

- Use-case: FT & RT for operational string
- Balance tradeoffs between multiple (often tangled) QoS requirements
  - e.g., fault-tolerance, high performance, real-time etc.
- Significant sources of variability that affect end-to-end QoS (performance + availability)

Separation of Concerns using higher level abstractions is the key
Fault-Tolerance Issues in DRE Systems

- **Per-component concern** – choice of implementation
  - Depends of resources, compatibility with other components in assembly
- **Availability concern** – what is the degree of redundancy? What replication styles to use? Does it apply to whole assembly?
- **Failure recovery concern** – what is the unit of failover?
- **State synchronization concerns** – What is data-sync frequency?
- **Deployment concern** – how to place components? Minimize failure risk to the system
Model-Driven Engineering – A Promising Approach

- Higher level of abstraction than third generation programming languages
- Modeling each concern separately alleviates system complexity
  - Deployment model
  - Component assembly model
  - System structural model
  - Different QoS models (Fault-tolerance)
- Generative and model transformation techniques to weave in appropriate glue code
Fault-tolerance Modeling Abstractions

**PICML** (Platform Independent Component Modeling Language) Metamodel Enhancements made to CoSMIC Modeling Tool suite

- **Fail-over Unit (FOU):** Abstracts away details of granularity of protection (e.g. Component, Assembly, App-string)
- **Replica Group (RPG):** Abstracts away fault-tolerance policy details (e.g. Active/passive replication, state-synchronization, topology of replica)
- **Shared Risk Group (SRG):** Captures associations related to risk. (e.g. shared power supply among processors, shared LAN)

**Interpreter (component placement constraint solver):** Encapsulates an algorithm for component-node assignment based on replica distance metric
Fail-over Unit Example

Primary Component

“Client”

Replica Component

Primary FOU

container/component server

container/component server

container/component server

A

B

C

A’

B’

C’

container/component server

container/component server

container/component server

container/component server

container/component server

container/component server

Institute for Software Integrated Systems

Vanderbilt University
Shared Risk Group Example
Formulation of Replica Placement Problem

Define \( N \) orthogonal vectors, one for each of the distance values computed for the \( N \) components (with respect to a primary) and vector-sum these to obtain a resultant. Compute the magnitude of the resultant as a representation of the composite distance captured by the placement.

1. Compute the distance from each of the replicas to the primary for a placement.
2. Record each distance as a vector, where all vectors are orthogonal.
3. Add the vectors to obtain a resultant.
4. Compute the magnitude of the resultant.
5. Use the resultant in all comparisons (either among placements or against a threshold)
6. Apply a penalty function to the composite distance (e.g. pairwise replica distance or uniformity)

\[
s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2}
\]
Component Placement Example using SRGs
1. Model components and application strings in PICML
2. Model Fail Over Units (FOUs) and Shared Risk Groups (SRGs)
3. Determine deployment of primary components

4. Interpreter automatically injects replicas and associated CCM IOGRs
5. Distance-based constraint algorithm determines replica placement in deployment descriptors.
FT Requirements Screenshot in CoSMIC (PICML)

Component FOU Replication Style = Active

Replica = 3
Min Distance = 4

Deployment plan to be augmented

Shared Risk Group (SRG) hierarchy

LEGEND
FOU: Fail Over Unit
SRG: Shared Risk Group
Generative Capabilities for Provisioning FT

- Automatic Injection of replicas
  - Augmentation of deployment plan based on number of replicas
- Automatic Injection of FT infrastructure components
  - E.g. Collocated “heartbeat” (HB) component with every protected component.
- Automatic Injection of connection meta-data
  - Specialized connection setup for protected components (e.g. Interoperable Group References IOGR)
Example of Automated Heartbeat Component Injection

Primary Component

“client” (港)

Primary IOR

FPC

HB

A

container/component server

intra-FOU heartbeat

Replica Component

Connection Injection

A’

FPC

HB

container/component server

periodic FPC heartbeat

Connection Injection

B’

FPC

HB

container/component server

Connection Injection

C’

FPC

HB

container/component server

Collocated heartbeat component

Vanderbilt University

Institute for Software Integrated Systems
Future Work

- Developing advanced constraint solver algorithms to incorporate multiple dimensions of constraints in component placement decision (e.g. resources, communication latency)
- Optimizing the number of generated heartbeat components for collocated, protected application components.
- Enhancing the DSL and the tools to capture the configurability required by the new Lightweight RT/FT CORBA specification.
  - e.g. Enhancing the model interpreter to support a wide spectrum of established fault-tolerance mechanisms
- Enhancing working prototypes and evaluating them in representative DRE systems
Concluding Remarks

- Model-Driven Engineering separates dependability concerns from other system development concerns
- Separation of concerns helps alleviate system complexity
- Model-based generative capabilities “compile” FT infrastructure (e.g. heartbeat components and connections) during model interpretation time and synthesize meta-data

Tools available for download from
www.dre.vanderbilt.edu/cosmic
www.dre.vanderbilt.edu/CIAO