Realizing the Model-Driven Engineering (MDE) Vision

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Outline of talk

- On the difficulty of developing complex software
- Why model software?
- Meeting the MDE Challenges
- Beyond MDE

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"We know why (software) projects fail, we know how to prevent their failure … so why do they still fail?"

Martin Cobb
Treasury Board of Canada
Secretariat

The Problem-Implementation Gap

- A problem-implementation gap exists when software is implemented using abstractions that are different than those used to understand and describe the problem
  - when the gap is wide significant effort is required to implement solutions
  - bridging the gap using manual techniques introduces significant accidental complexities

Factors behind the gap widening

- Technology advances open the door to new software opportunities that are acted upon
  - Result is a new generation of software that gives rise to a new breed of software development problems
- The growing complexity of the problem spaces tackled by software overwhelms the available implementation abstractions
  - Leads to a dependence on "expert" developers who have developed mentally-held "patterns" to cope with growing complexity
  - Eventually, growing problem complexity can overwhelm the patterns held by the experts

The abstraction-raising dilemma

- Each successful attempt at raising the level of abstraction triggers concerted effort to develop even more complex software
- Existing forms of software development problems and concerns change and new problems/concerns emerge

The nature of the "software crisis" evolves

Evolving development concerns

- 60’,70’s: Standalone applications
  - Functional correctness
- 70’s,80’s: Closed network systems
  - Network reliability, availability
  - data integrity
  - Functional correctness of concurrent distributed systems
- 90’s: Open network systems
  - Transparent access to distributed resources
  - Usability
  - Service availability, reliability, security
- 2000’s: Open, mobile, pervasive, embedded systems of systems
  - Reasoning about correctness in the presence of mobility
  - Balancing multiple dependability concerns

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Developers of mission-critical open distributed software systems need to balance multiple, interdependent design concerns such as availability, performance, survivability, fault tolerance, and security.

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Balancing dependability concerns

- Balancing requires making trade-offs and assessing risks associated with design features that address the concerns
  - Organizations seldom have all the resources needed to build software systems that have the desired levels of dependability
  - Need to consider and evaluate alternative features to determine the extent they
    - address concerns
    - cost-effectively mitigate product-related risks.
  - Pervasiveness of dependability features complicates their evaluation and evolution

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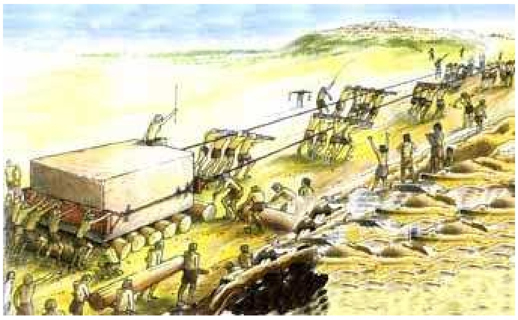
Building software pyramids

Building dependable software with current tools is akin to building pyramids in ancient Egypt



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Why consider modeling techniques?

Software development is a modeling activity!

Programmers build and evolve mental models of problems and solutions as they develop code

Programmers express solutions in terms of abstractions provided by a programming language

How can we better leverage modeling techniques?

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Model Driven Engineering Research Question

How can modeling techniques be used to tame the complexity of bridging the gap between the problem domain and the software implementation domain?

A peek ahead …

What MDE researchers should target:

- Development of technologies supporting the generation of domain-specific software development environments

The reality …

- Requires codifying knowledge that reflects a deep understanding of the gap bridging process
- Understanding can only be gained through costly experimentation and systematic accumulation and examination of experience

Accomplishing the MDE vision of development is a wicked problem!

Realizing the vision

The MDE vision may not be realized in its entirety

but close approximations can have a significant impact on quality and productivity

- … MDE/software engineering research will be needed well into the future
  - Building close approximations will require developing successive generations of technologies;
  - Each new generation should address the accidental complexities of the previous generation

MDE Challenges

- Abstraction
- Separation of Concerns
- Model Analysis
- Model Manipulation and Management

The Abstraction Challenge

The Abstraction Challenge

- MDD claims to raise the level of abstraction at which software is conceived, designed, analyzed and implemented
- Abstraction: Can we build an analyzable general-purpose, language for describing software systems at a level of abstraction above the current high-level programming languages?

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Looking for the "right" abstractions

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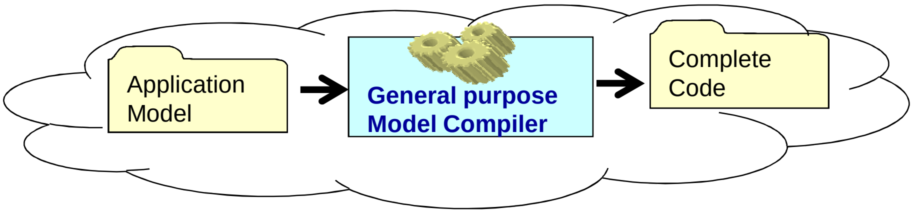
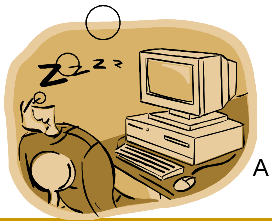
The Automation Challenge

- Automation: Can we build it such that it is "compilable"?





A modeler's daydream

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Bridging the Abstraction Gap

The gap between models that we typically build using languages such as the UML and code seems wider than the gap between models we build in a programming language like Java and machine code.

The needed abstractions tend to be domain-specific and thus general-purpose "compilers" that attempt to bridge the gap have to incorporate domain-knowledge in some form

Leads to consideration of domain-specific languages and frameworks for building domain-specific development environments

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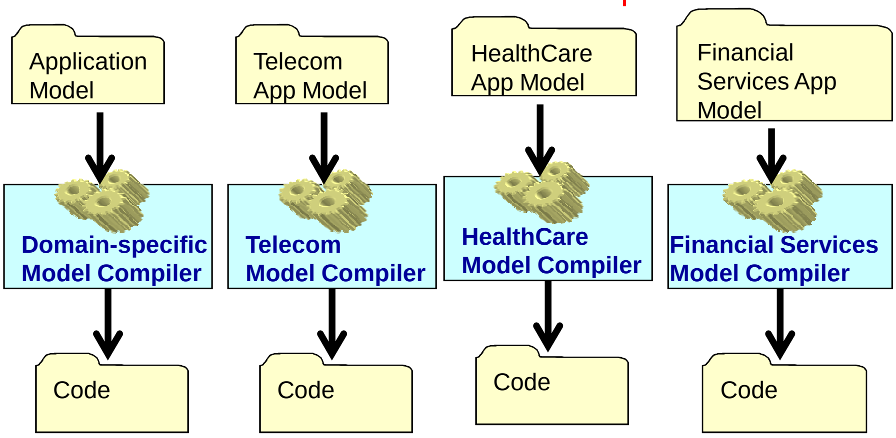
The Domain Specific Modeling Language Challenge

How can we avoid the "Tower of Babel" problem?



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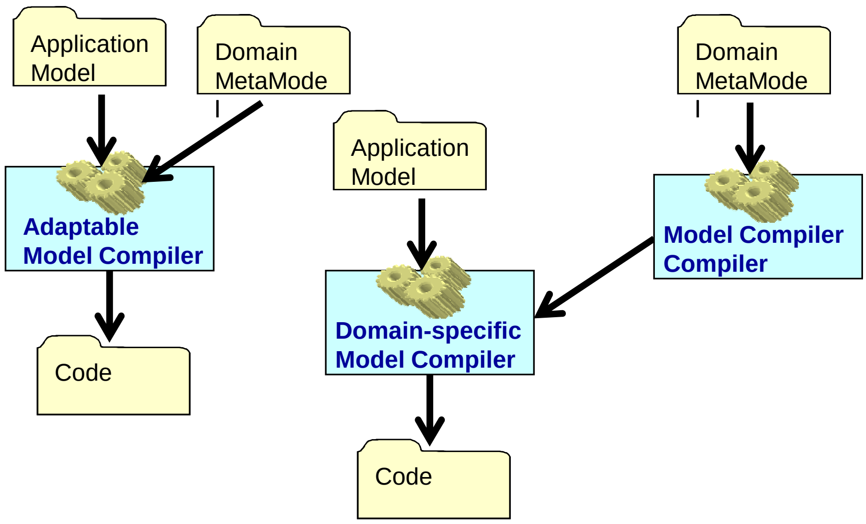
Towards Model Compiler Compilers



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MDD Frameworks

- A MDD framework provides concepts and tools that domain architects can use to build domain-specific MDD development environments
  - Can be based on a family of languages (e.g., the UML) … a formal notion of profiles is needed to support MDD frameworks
  - Focus of Software Factory research at Microsoft [Jack Greenfield, Keith Short, Steve Cool, Stuart Kent, "*Software Factories, Assembling Applications with Patterns, Models, Frameworks and Tools. Wiley, 2004*]
  - Requires deep understanding of modeling phenomena
  - … and thus full frameworks are not likely to appear in the near future

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Separating Concerns Challenges

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Going beyond traditional support for separation of concerns

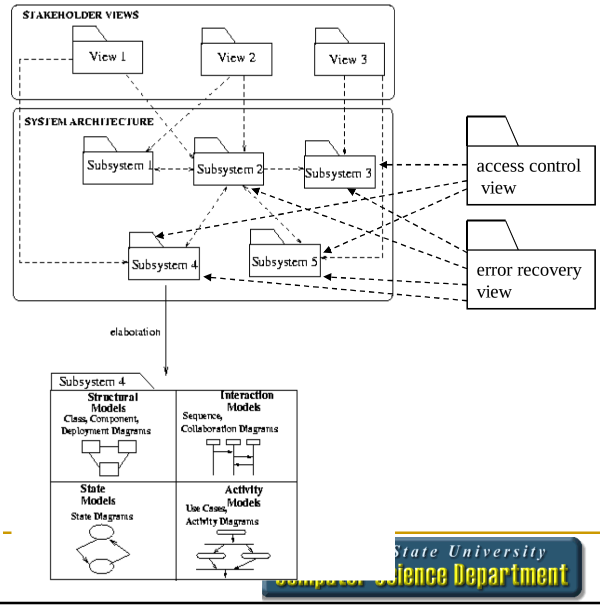
- The Separation of Concerns principle is considered fundamental in software engineering
- Much attention paid to providing support for modularizing descriptions of problems and solutions (separation of parts)
- Less attention has been paid to providing support for understanding interactions across separated parts

On the importance of understanding interactions across features: An example

The first launch of the space shuttle Columbia was delayed because "(b)ackup flight software failed to synchronize with primary avionics software system"

(http://science.ksc.nasa.gov/shuttle/missions/sts-1/mission-sts-1.html)

Crosscutting Design Views



- Trade-offs necessary when crosscutting solutions interact to produce undesirable behavior
- Current modeling techniques do not support separation of crosscutting solutions.

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Aspect-Oriented Design

- Separation of Concerns
  - *Primary Model* : A model of core functionality; determines dominant structure
  - *Aspect Model* : Describes a feature that cross-cuts modules in the dominant design structure
- Design Patterns
  - Aspects are patterns: Promotes reuse

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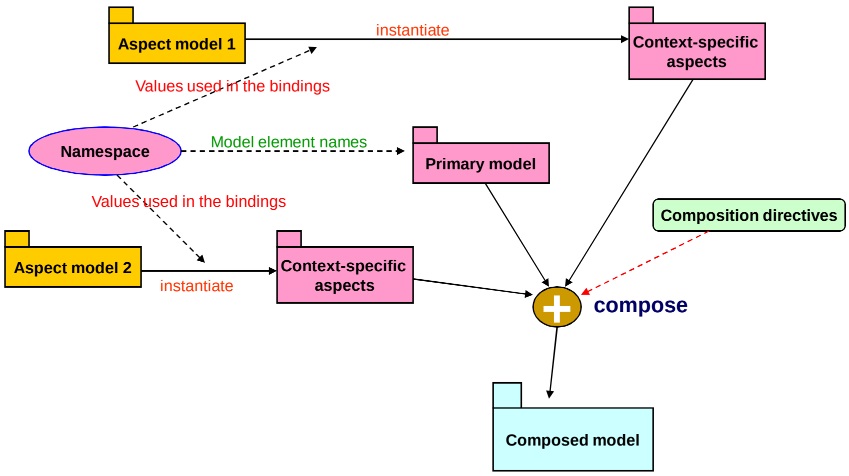
Aspect Oriented Modeling



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Composition Directives

- Used to ensure that basic composition procedure produces desired result
- Two types
  - **Model directives**: determine the order in which aspect models are merged
  - **Element directives**: affect how model elements are composed
- Types of element directives
  - **Matching directives**: used to force or prevent model element matching
  - **Merge directives**: used to override merging rules used in basic procedure
  - **Build directives**: used to introduce or remove elements in models

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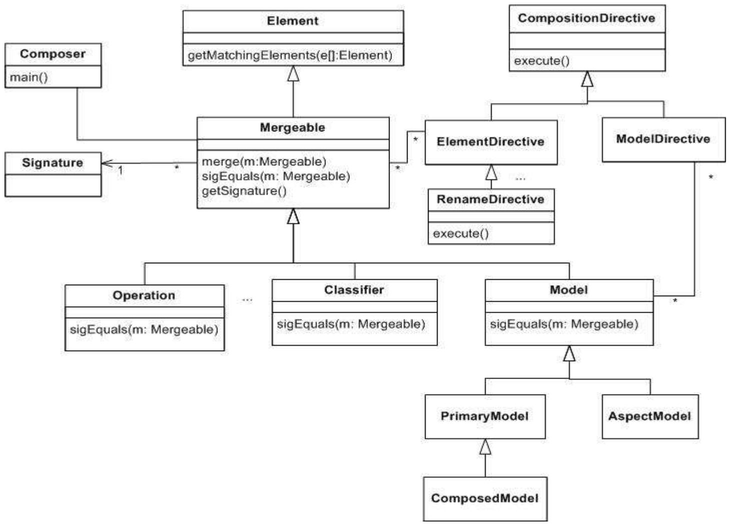
Composition Metamodel



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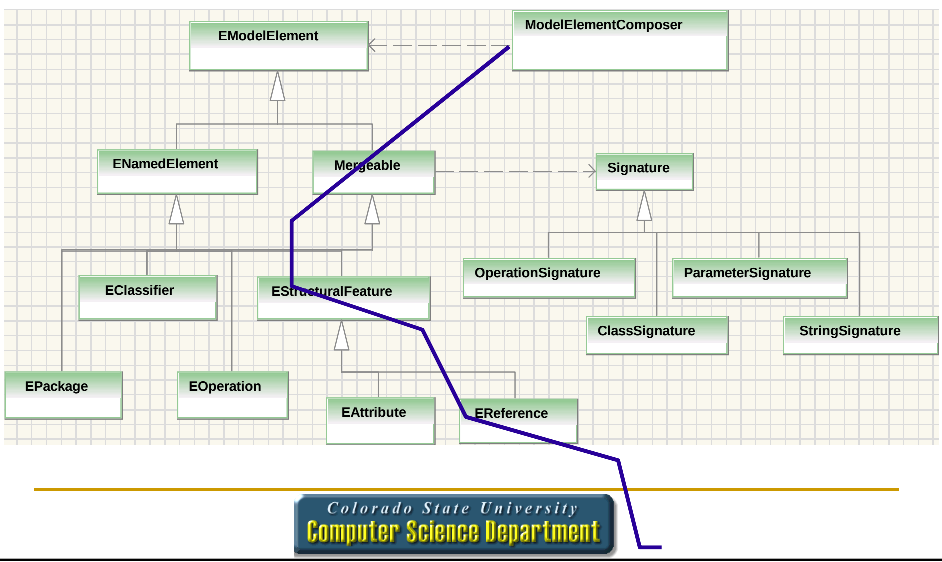
Composition Meta-model (merge)

Class diagram

Composition



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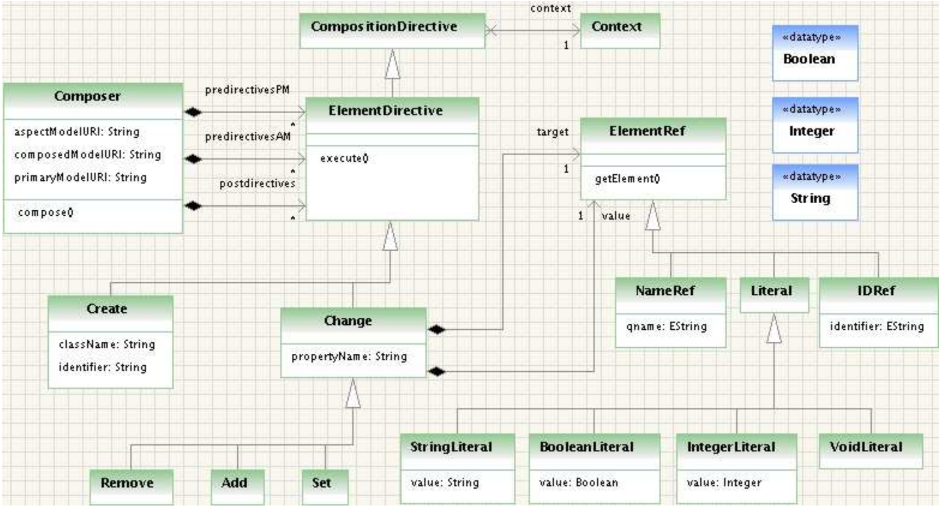
Composition Meta-model (directives)



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AORDD Framework

- AORDD: **Aspect-Oriented Risk-Driven Development**
- The framework
  - Models security solutions as security aspects
  - Includes security analysis and verification of security aspects
  - Includes verification of composed models using properties
  - Support cost-effective development through the AORDD security solution design trade-off analysis

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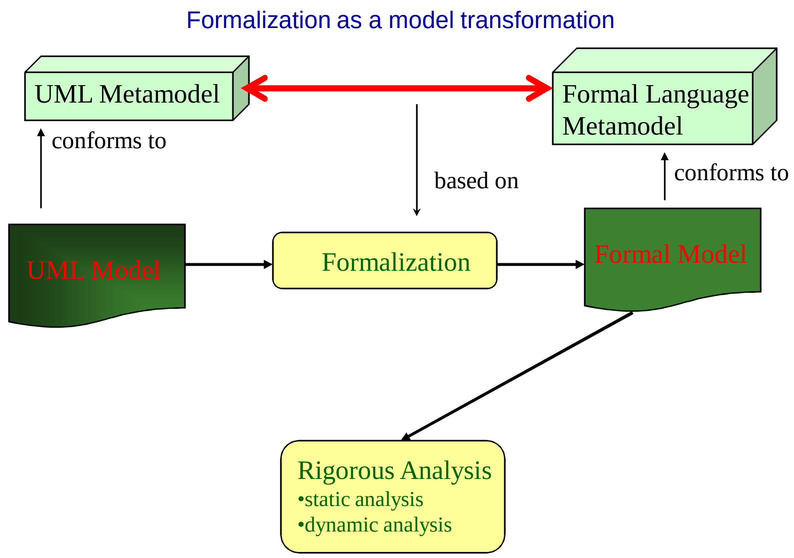
Analyzing Models

Role of Formal Methods

- Some formal method researchers have commented that FST research subsumes MDE research
- My opinion: MDE research provides a context for FST research
  - Current formal techniques are applicable to only specific views of a system
  - MDE concerns go beyond describing and analyzing systems from a limited set of viewpoints

Integrated Methods



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Pitfalls

- Many UML to formal X notation approaches
  - Most force users to be familiar with both UML and formal notation
  - Not aware of any that express formal analysis results in terms of UML
- Assumption that a single semantics for the UML will suffice
  - UML is a family of languages
  - BUT a semantic core for some models may be useful
    - Formalizing class model concepts (Evans, France, Bruel, …)
    - Formalizing interaction diagrams (Engels, Knapp, …)

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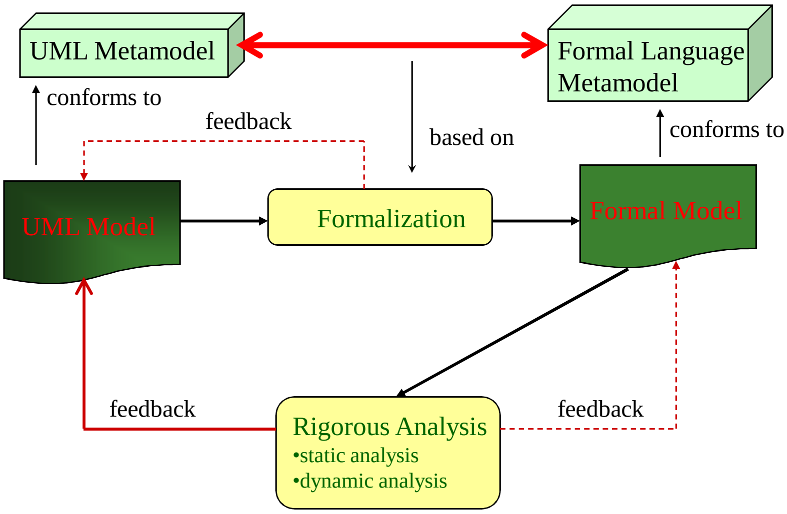
Integrated Methods

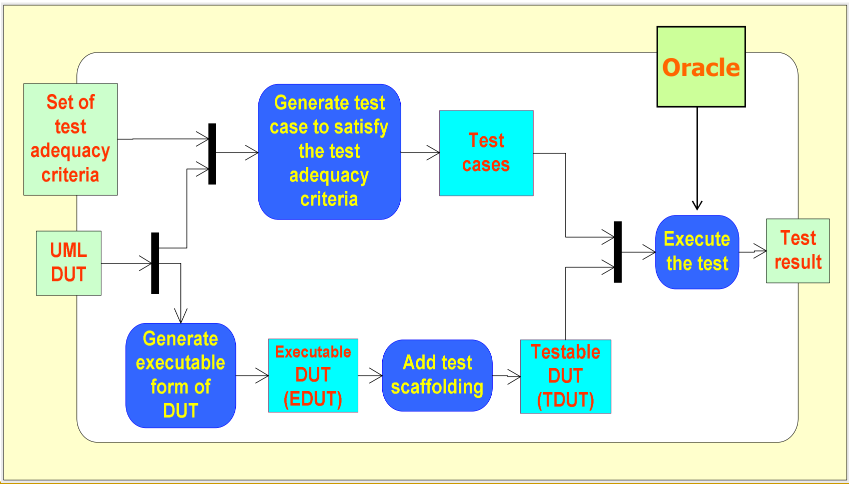


A Systematic Approach to Testing UML Designs

Robert France, Sudipto Ghosh, Trung T. Dinh-Trong
Department of Computer Science, Colorado State University

Sponsors: NSF, IBM Eclipse Innovation Grants

Test approach

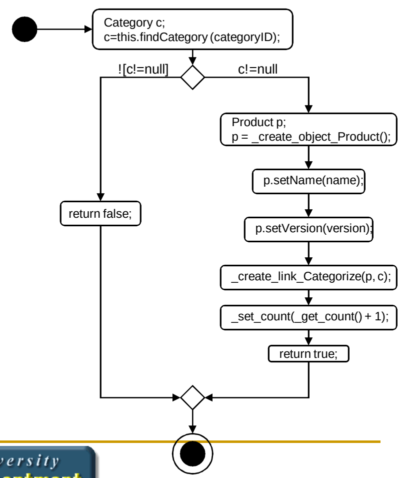


Execution semantics

- UML action semantics
  - E.g., Create/destroy instances, links; read/set attributes
- Java-like Action Language (JAL)
  - Java syntax
  - Surface syntax for UML action semantics
  - Used to describe sequence of actions performed by a class instance during execution of operation call
  - Currently, no support for parallel structures or asynchronous actions

A JAL Example

```
boolean addProduct(int categoryID, int version,
    String name)
{
    Category c;
    c = this.findCategory (categoryID);
    if(c != null) {
        Product p;
        p = _create_object_Product();
        p.setName(name);
        p.setVersion(version);
        _create_link_Categorize(p, c);
        return true;
    }
    else
        return false;
}
```



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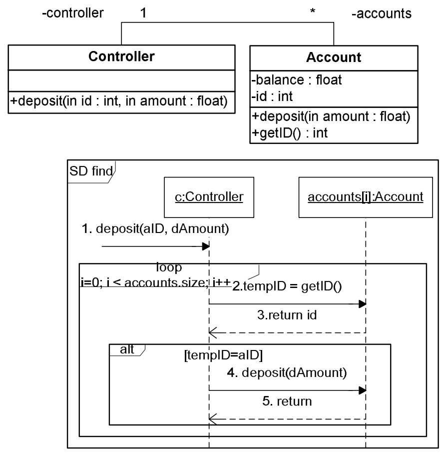
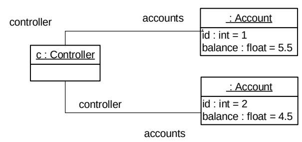
Test input

- Each test input tests one scenario described in a sequence diagram
- Test input (S, Pr)
  - S: Start configuration
  - Pr: System operation with parameter values



S:



Pr: c.deposit(1, 2)

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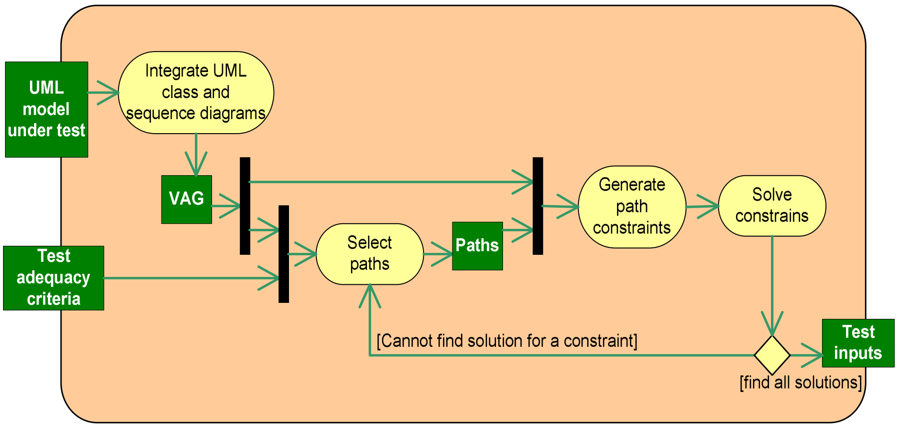
Test Input generation process



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Model Manipulation and Management

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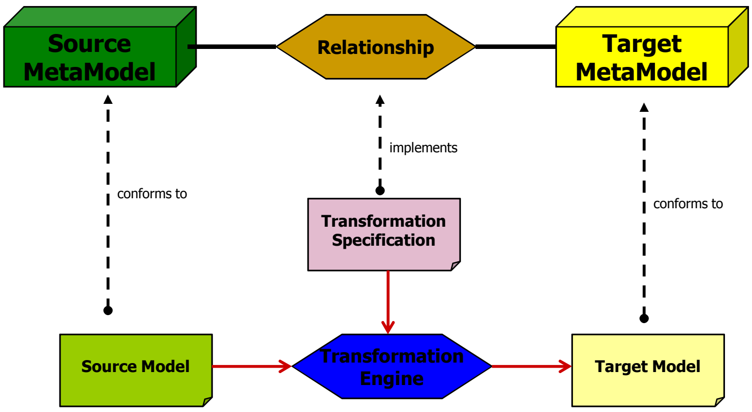
Model Management Initiatives

- Megamodeling (Jean Bezivin, Univ. of Nantes)
- Model Repository (Dan Matheson, Colorado State University)
- Community-based model repository (PlanetMDE, REMODD, models.org, …)

Model Transformations



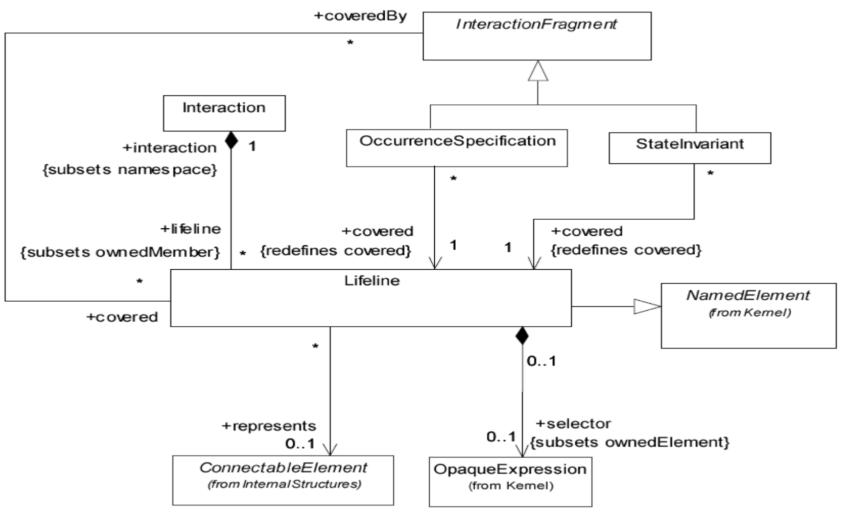
Work on model transformations

- QVT
  - Creating a standard when there is very little practical experience is challenging!
- Transformations that preserve QoS properties
- Middleware transparent software development

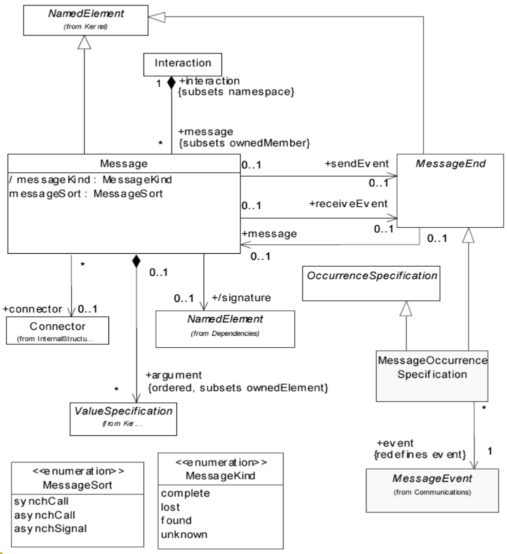
The UML metamodel challenge: Navigating the metamuddle

Using the UML 2.0 metamodel find the relationships between message ends and lifelines

Lifelines (from the UML 2.0 specification)



Messages (from the UML 2.0 specification)



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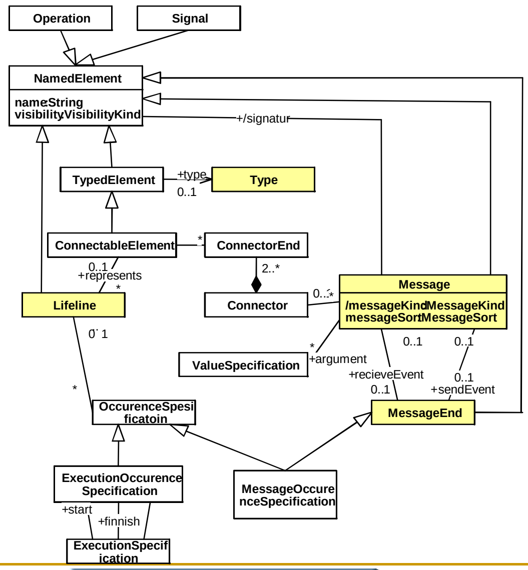
A *simple* UML interactions metamodel



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Beyond MDE

Models@run.time

Models can be used at runtime to:

- Present aspects of runtime phenomenon
- Support software adaptation
  - Adaptation agents can use runtime models to determine the need for adaptation and to determine the adaptation needed
- Support controlled evolution of software
  - Change agents can use runtime models to correct design errors and to introduce new features during runtime

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Summary

- Realizing the MDE vision is a wicked problem
- Software engineering (technical aspects) is essentially a modeling activity
  - MDE highlights the importance of models as explicit representations of intent.
  - Reduces the cognitive burden and accidental complexities associated with maintaining mental models.
- It may seem that MDE contributes to development complexity but the web of models produced in a MDE project reflect inherent complexity (when done well!)
- There will always be accidental complexities associated with using modeling languages and MDE technologies

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Conclusion

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