Colorado State University
Computer Science Department

# Model-driven Development of Complex Software: A Research Roadmap

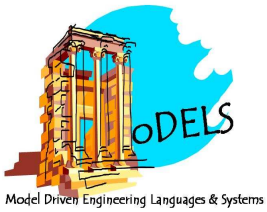
Robert B. France
Dept. of Computer Science
Colorado State University
USA
france@cs.colostate.edu

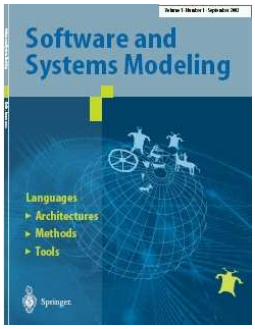
Bernhard Rumpe
Software Systems Engineering Institute
Braunschweig University of Technology
Germany



## About the authors

- Organizers and steering committee members of the UML/MODELS conference series
- Founding editors-in-chief, Software and System Modeling journal (SoSyM)
  - http://www.sosym.org
- Member of UML 1.X revision task forces
- … but not involved in work on UML 2.0 standard
- Actively engaged in MDE research

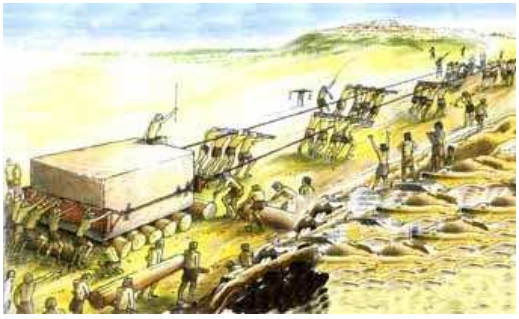





Colorado State University
Computer Science Department

# State of the practice



Building software pyramids



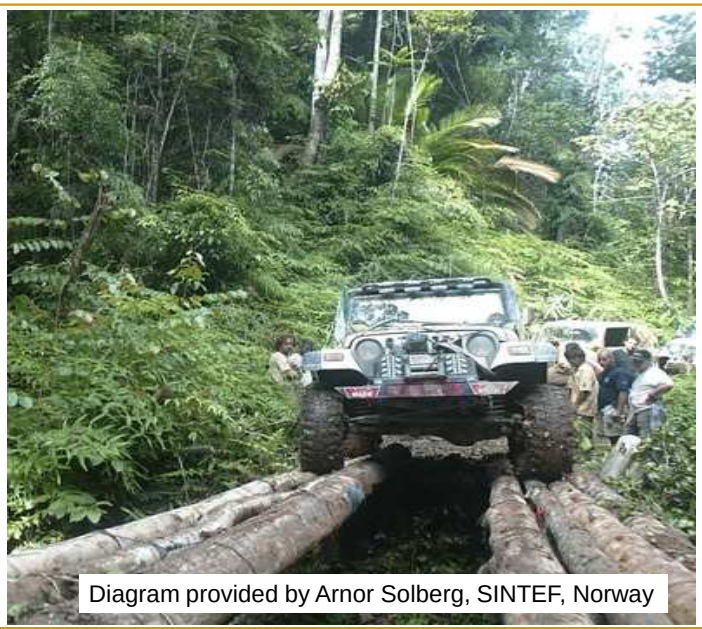


Diagram provided by Arnor Solberg, SINTEF, Norway

## 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



## MDE is concerned with …

- reducing accidental complexities associated with bridging wide problem-implementation gaps
- through use of technologies that support systematic transformation of abstractions to software implementations

MDE is concerned with developing software to support the work of software developers

## Key MDE principles

- Separation of concerns
  - Horizontal separation of concerns: e.g., UML views
  - Vertical separation of concerns: e.g., PIM/PSM, detailed design model/code
- Automation (Formality and Rigor)
  - Generation of code and deployment artifacts from models
  - Automated analysis of models



## Why modeling techniques?

Software development is a modeling activity

*Programmers build and evolve (mentally-held) 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?

## What is a model?

A description of an aspect of a software-based system that may or may not exist. A model is created to serve particular purposes.



## Where are we now?

- Generation 1: Models as documentation/communication artifacts
  - a.k.a the Computer Aided Software Engineering (CASE) generation
- Generation 2: Models as artifacts for generating implementation and deployment artifacts
  - Raising the level of abstraction
  - Exemplified by OMG's work on MDA/MDD
  - Emphasis on separation of platform independent concerns from platform specific concerns

## The abstraction-raising cycle – Part 1

- Each successful attempt at raising the level of abstraction triggers concerted effort to develop even more complex software
  - New technologies also give rise 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 gap widens



## The abstraction-raising cycle – Part 2

- The growing complexity of the problem and solution spaces overwhelms the abstractions provided by implementation languages
  - Leads to development of technology layers that extend current languages in an attempt to provide needed abstractions (gap contraction)
- Complexity of technology-based abstraction layers leads to reliance on expert software developers (gap widening)
- Eventually, complexity overwhelms even the experts (accelerated gap widening)
- Need for raising the "level of abstraction" is painfully apparent – a "crisis" is declared …

The nature of the "software crisis" evolves

## MDE research questions

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

How can MDE be used to manage the rate at which the gap is widening?



## Where are we going?

- Providing support for engineering domain-specific languages and associated tool sets
- A MDE framework provides concepts and tools that developers can use to build domain-specific development environments
  - Can be based on a family of languages (e.g., the UML)
  - or on meta-metamodel facilities
    - Jack Greenfield, Keith Short, Steve Cook, Stuart Kent, "*Software Factories, Assembling Applications with Patterns, Models, Frameworks and Tools. Wiley, 2004*
    - Jean Bézivin, Reiko Heckel (Eds.) "*Language Engineering for Model-Driven Software Development*", Dagstuhl Seminar Proceedings, 2005

## Getting there

- Requires deep understanding of modeling phenomena
  - Understanding can only be gained through development of solutions, costly experimentation, and systematic accumulation and examination of modeling and software development experience
  - … full MDE frameworks are not likely to appear in the near future



## Next steps

- Generation 3: MDE frameworks that support creation of DSML editors and some code generation facilities
- Generation 4: MDE frameworks with support for mega-modeling

# Accelerating MDE research

- Need facilities for collecting, analyzing and sharing modeling experience
  - A number of initiatives are taking form: PlanetMDE, ZoooM, Open Models Initiative, REMODD



# MDE challenges

- Modeling languages
  - Providing support for creating and using appropriate abstractions
- Separation of concerns
  - Providing support for modeling and analyzing views possibly expressed in different languages
- Model Manipulation and Management
  - Providing support for model transformation, model evolution, analysis, roundtrip engineering, …

Colorado State University Computer Science Department

# Modeling Languages



## Tackling the abstraction challenge

Finding the "right" abstractions

Two schools of thought

- The extensible general-purpose modeling language (GPML) school
  - UML with semantic variation points and profiles
- The domain-specific language (DSML) school
  - Software factories, GME



Colorado State University Computer Science Department

# What about the UML?

B. Henderson-Sellers, S. Cook, S. Mellor, J. Miller, B. Selic, **UML – the Good, the Bad or the Ugly? Perspectives from a panel of experts**, Software and Systems Modeling 4(1), 2005.

R. France, S. Ghosh, T. Dinh-Trong, A. Solberg, **Model-Driven Development Using UML 2.0: Promises and Pitfalls**, IEEE Computer, Vol. 39, No. 2, February 2006, 59-66


"It is easier to perceive error than to find truth, for the former lies on the surface and is easily seen, while the latter lies in the depth, where few are willing to search for it."

Johann Wolfgang von Goethe



# Learning from the UML experience: Avoiding bloat

- Difficulty of identifying a small base set of modeling concepts that can be used to express a broad range of abstractions

## Learning from the UML experience: Avoiding "meta-muddles"

- UML abstract syntax described by a complex meta-model
  - Complexity problematic for application developers, modeling tool developers, and for language standards committees
- Need tools for navigating and for extracting views from meta-models
- Reflects need for research on engineering modeling languages



## DSML challenges - 1

- Creating and evolving languages and their toolsets
  - Need facilities for engineering languages quickly
    - Composing language units
  - Domains evolve and thus languages and supporting tools must evolve
  - Tool challenge: Need to provide a foundation for building meta-toolsets
  - Language challenge: Need to provide support for language versioning and migration

## DSML challenges - 2

- Avoiding the "DSL-Babel"
  - A project may use many DSMLs and thus language interoperability is a concern
  - Need to relate concepts across different DSLs and provide support for maintaining consistency of concept representations across the languages



## Tackling the formality challenge: Why not just use formal specification languages?

- Does formal methods research subsume MDE research?
- Not likely
  - MDE research provides a context for FST research
    - Current formal techniques are applicable in specific views of a system
    - MDE concerns go beyond describing and analyzing systems using a limited set of viewpoints

Colorado State University
Computer Science Department

# Separating Concerns




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



Colorado State University
Computer Science Department

## Supporting separation of concerns

- UML 2.0: Supports modeling of artifacts using 13 diagram types
- OMG's MDA: advocates modeling systems using a fixed set of viewpoints (CIM, PIM, PSM)
- Challenge: Providing support for more flexible separation of concerns
  - Aspect Oriented Modeling



## Separation of concerns challenges

- Supporting verifiable integration of views
  - Property preservation
  - Establishing presence or absence of emergent properties
  - Use of aspect contracts
- Supporting evolution of models consisting of multiple overlapping views

Research in the viewpoint analysis and feature interactions domains should be leveraged

Colorado State University Computer Science Department

# Model Manipulation and Management

"A model is something you can play with. You can change it, see how it responds, and in many other ways experiment with it."
(from a slide show produced by Pille Bunnell, Douglas Tait, Inst. of Animal Resource Ecology, University of British Columbia)



## Challenges

- Supporting model analysis
  - What is a "good" model?
  - Analyzing functional properties and system attributes using models
- Supporting model transformations, evolution, roundtrip engineering
  - Traceability
  - Model versioning
  - Integrating generated code and legacy systems
  - Analyzing model transformations
- Supporting distributed multi-developer modeling environments
  - ModelBus (ModelWare/ModelPlex EU project)
- Supporting mega-modeling
  - Models as manipulable entities
  - Model type systems



Colorado State University Computer Science Department

## Beyond development models …

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



## The future of MDE research?

There is no future!

The systematic creation and use of models will become an integral part of the engineering of software, thus making the MDE label superfluous

# Conclusion