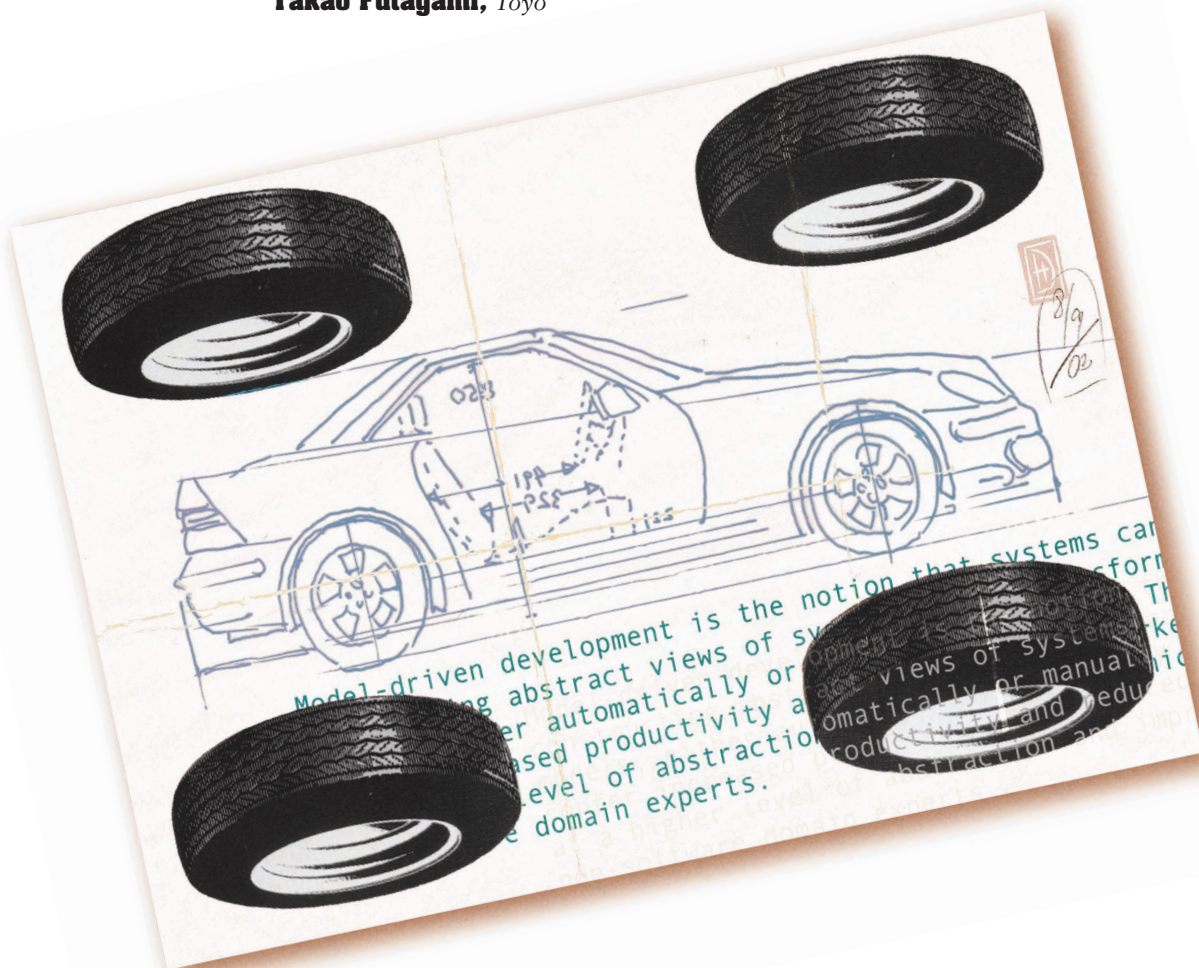


Model-Driven Development

Stephen J. Mellor, *Project Technology*

Anthony N. Clark, *King's College London*

Takao Futagami, *Toyo*



Model-driven development is simply the notion that we can construct a model of a system that we can then transform into the real thing.

By this definition, we are all—right now—model-driven developers. When we write a program in Smalltalk, Java, or C#, we don't expect it to execute directly. We expect it to be transformed into the language of some virtual machine that can cause our model to do its job.

But this is not how many developers think about “models” today. Too often, they equate models with simply drawing pictures—removed from real systems development and needlessly heavy on process. Before deconstructing this narrow perception, let's take a deeper look at what a model is and isn't.

What is a model?

A model is a coherent set of formal elements describing something (for example, a system, bank, phone, or train) built for some purpose that is amenable to a particular form of analysis, such as

- Communication of ideas between people and machines
- Completeness checking
- Race condition analysis
- Test case generation
- Viability in terms of indicators such as cost and estimation
- Standards
- Transformation into an implementation

Each model addresses some number of subject matters. For example, we could build a bank model, ignoring security and user interface aspects, or we could model a combination of these domains. We choose which subject matters to include and which to ignore, although we might then need to weave several models together. When a model's subject matter has a high degree of abstraction, the model is closer to the eventual user's language—that is, a smaller gap exists between a noncomputer expert and the model.

Additionally, we express a model in a language that exists at some (language) abstraction level. A model written in the C modeling language will ignore (or “abstract away”) the realization of function calls and expressions, leaving CPU-oriented issues such as register allocation to the compiler or to a virtual machine interpreter that adds such realizations at runtime. Similarly, a model expressed in the Unified Modeling Language will ignore the realization of associations, leaving those deci-

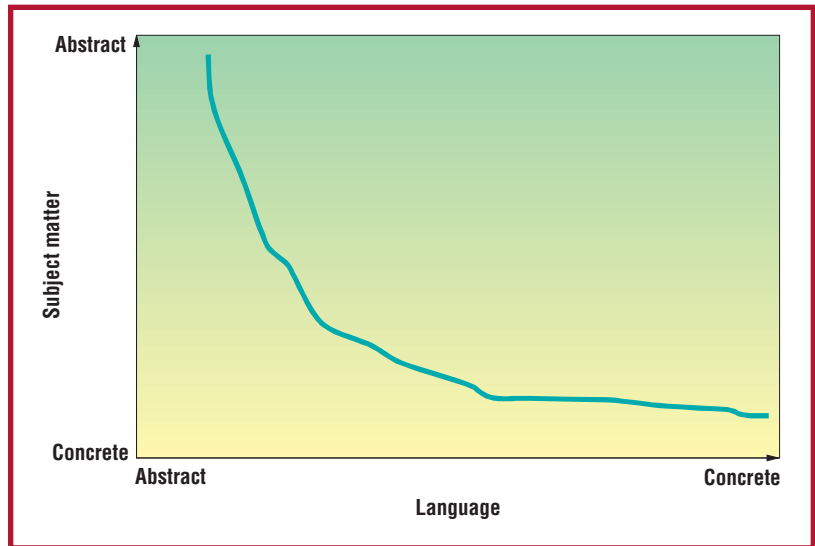


Figure 1. A language's abstraction level and the degree of abstraction of the subject matter under study. Start with an abstract problem (for example, a bank) with an abstract modeling language (for example, the Unified Modeling Language) and end with a concrete statement of the solution in a low-level concrete language (for example, Java).

sions to a model compiler or human designer.

Figure 1 illustrates these two dimensions: the language's abstraction level and the degree of abstraction of the subject matter under study. The subject matter axis has an inverted scale, which leads to a neat curve with analysis models at the top and design models lower down. However, we don't have to migrate in both dimensions at once, and there are plenty of reasons why we shouldn't.

Help or hindrance?

A model need not be complete. Often, a graphical model excludes code, although it's by no means necessary now that UML is a computationally complete language. Moreover, a model has multiple views, some of which are revealed. For example, we can expose individual collaborating state machines on a statechart diagram, or we can emphasize their collaborations directly using a sequence diagram. Clearly, any set of diagrammatic views must be consistent with the underlying model of which they are projections. Incompleteness and a high degree of abstraction do not equate to imprecision. Not all models are or need to be executable or even formal, but those that are can benefit from automation.

We use models to increase productivity.

TLAs You Need

OMG: The Object Management Group is an international, not-for-profit industrial consortium that creates and maintains software interoperability specifications. The OMG's specifications include the UML modeling notation, XMI (XML metadata interchange), CORBA (common object request broker architecture) middleware, and dozens of domain-specific interoperability specifications in such areas as transportation, life sciences, telecommunications, and manufacturing.

UML: The Unified Modeling Language is an industry standard visual language for modeling software systems. These models capture knowledge about a system at various abstraction levels, ranging from requirements and analysis models to design models. This means that modelers can specify software systems using higher-level domain-oriented concepts that abstract away much of the underlying implementation technology used to realize such systems. UML enables automated tools that interchange and transform models as part of the process and generate a system's implementation artifacts (typically source code and metadata).

MOF: The Meta-Object Facility is OMG's standard for metadata and model management and lies at the heart of MDA. It specifies how to define metamodels (using a UML subset), generate XML schemas for interchange, and generate application programming interfaces for manipulating actual models (for example, UML designs). It is also being extended to specify services for managing models and their elements such as identity, life cycle, versioning, views, and—very importantly for MDA—transformations.

MDA: The Model-Driven Architecture is a set of OMG standards that enables the specification of models and their transformation into other models and complete systems. MDA separates subject matters so that application-oriented models are independently reusable across multiple implementations and vice versa.

PIM: A platform-independent model is a model that contains no reference to the platforms on which it depends. (MDA classifies the relative relationship between two models in terms of the *platform*, the set of technologies a model assumes to exist.)

PSM: A platform-specific model is the result of weaving a PIM with the platforms on which it depends.

TLA: Three-letter acronym.

It's cheaper to write one line of Java than to write 10 lines of assembly language. Similarly, or so the argument goes, it's cheaper to build a graphical model in UML, say, than to write in Java. We pause now to allow the squirming to abate.

The squirming comes about because others argue that models offer more hindrance than help. Some proponents of Extreme processes argue that a model is often used to mean a blueprint that acts as an interface between developers. Moreover, they argue that this interface has flaws:

- The analyst's concerns are not the programmer's—so much so that analysis blueprints are merely advisory, and likely bad advice at that.
- The language in which modelers construct the blueprints is often ill defined and difficult to translate reliably into code.
- The blueprints are out-of-date before they're even finished.
- Modelers often intend these blueprints to predict the unpredictable—the creative act of inventing abstractions in code.

These arguments are valid to the extent that models are transformed by passing through the developer's mind. When models are fully automated—as with executable models (such as models constructed with a programming language)—or successively extended by adding content, these arguments become less persuasive.

Furthermore, model-driven development offers the potential for automatic transformation of high-level abstract application-subject matter models into running systems. In this issue, Bran Selic (“The Pragmatics of Model-Driven Software Development”) argues that modeling technology has matured to the point where it can offer significant leverage in all aspects of software development. He also argues that, in an increasing number of application areas, you can generate much of the application code directly from models.

Automation doesn't remove the requirement for creativity. Rather, it formalizes existing solutions and raises the level at which we can apply creativity, thus giving the developer more leverage. In turn, we must now ask how we can produce developers that think at a level of abstraction above the currently fashionable programming language or technology.

Models and metamodels

To make automation a reality, models must have a defined meaning, and that's a loaded topic itself. A language consists of syntax and

semantics. The syntax can be human- or machine-centric. Semantics define what the syntax means by linking the syntax to a semantic domain, rather than arithmetic expressions “mean” numbers. Ed Seidewitz’s article—“What Models Mean”—tackles this tricky topic by relating the meaning of computer system models to how people use models in mathematics and physics. Conrad Bock, in a short article, “UML without Pictures,” neatly highlights the separation of a modeling language’s meaning from its syntax, which is important because developers must base automation on a definition of the language’s meaning.

Model-driven development automates the transformation of models from one form to another. We express each model, both source and target, in some language. The target model’s language, for example, might define a meaning for remote access of objects, even though the source model’s language does not. We must define the two languages somehow, and because modeling is an appropriate formalism to formalize knowledge, we can define a modeling language’s syntax and semantics by building a model of the modeling language—a so-called metamodel. (The Greek word *meta* means “after.”) For example, the UML standard is written in UML (the UML metamodel), which raises interesting issues with respect to the precise definition of a language defined in terms of itself. In “Model-Driven Development: A Metamodeling Foundation,” Colin Atkinson and Thomas Kühne investigate model-driven development’s technical foundations and discuss the role of metamodeling in a supporting infrastructure.

Mapping functions

The productivity gains accrued by using models in a defined modeling language pale against those accrued by defining mappings between models. Consider the case in which an expert designer transforms an application model by applying knowledge of transaction safety and rollback or squeezes an application into an embedded system-on-a-chip. When the inevitable happens and the application is extended or the underlying technology is enhanced, it’s difficult to reuse the expert knowledge, particularly in a consistent way across an integrated system. Practically, that expert knowledge is lost; more accurately, that know-

ledge is embedded in code ready for architectural archeology by someone who probably “wouldn’t have done it *that* way!”

Model-driven development captures expert knowledge as mapping functions that transform between one model and another. Executing those mapping functions transforms one model into another form. Mapping functions capture expert knowledge, so designers can reuse it when an application changes or when any of the technologies the application depends on change. This effectively decouples the several models so that each can evolve independently, which in turn increases the models’ longevity.

Shane Sendall and Wojtek Kozaczynski (“Model Transformation: The Heart and Soul of Model-Driven Software Development”) give an overview of the issues involved in model transformation, and Robert France, Sudipto Ghosh, Eunjee Song, and Dae-Kyoo Kim (“A Metamodeling Approach to Pattern-Based Model Refactoring”) neatly illustrate the concept of capturing expert knowledge by describing an approach for model refactoring based on patterns. In “Model Metamorphosis,” Torben Weis, Andreas Ulbrich, and Kurt Giehs describe a scheme for transforming models using a graphical modeling language that veils explicit reference to the metamodels involved.

Conceptual models express requirements that we can then address in engineering models. These models address the requirements with commitments about how things get done. Because conceptual and engineering models address different problem domains, modelers seldom try to relate one to the other. When the modeler does make this effort—linking the conceptual requirement to the engineering means—interesting things become possible. Peter Denno, Michelle Potts Steves, Don Libes, and Edward J. Barkmeyer explore this issue in “Model-Driven Integration Using Existing Models.”

Agile MDA

Mapping functions access models expressed in a modeling language as defined by its metamodel. We can express all metamodels using the OMG Meta-Object Facility, which enables standard definitions for mapping functions between metamodels. This proposed standard is called QVT. It provides a standard

**How we
can produce
developers that
think at a level
of abstraction
above the
currently
fashionable
programming
language or
technology?**

scheme for querying, viewing, and transforming metamodels represented in OMG MOF.

Successive model transformations provide a basis for mapping between analysis and design models that use different metamodels. However, this raises an issue: Mapping functions are inextricably linked to the metamodels that they transform. This could lead—and some would argue that it already has—to metamodel “silos” that link vertical domains (such as telecommunications) to implementation technologies (such as sophisticated distribution profiles) or Web services to JavaBeans. This approach results in models that are not universal, but instead mix the modeling language (the metamodel) and the subject matter at hand. This is a form of *architectural mismatch*, a term coined by David Garlan to refer to components that require tubes and tubes of glue code to fit together—the very problem MDA is intended to avoid!

Figure 1 suggests that we can model subject matters using languages at varying abstraction levels and can use the same language to model domains at different abstraction levels. In other words, it makes sense to model a bank, a security subject matter, a user interface, or even an operating system using *the same* abstract mod-

eling language. Consequently, mapping functions will always apply to models expressed in that modeling language, broadening their applicability and increasing their longevity.

Capturing models at a single (high) level of language abstraction requires computationally complete models, which in turn means that we can execute and then translate them to the target software platform. We would express these models using a single executable, translatable formalism using several subsets of the UML notation. Each model would state one fact about its subject matter in just one place, even though it does not (yet) incorporate other required domains or the mechanisms actually required to make the model run in its target environment.

This is an agile form of model-driven development in which each model stands alone, complete, capable of execution and being woven together with other models.

A more general expression of the challenges addressed here is the notion of weaving models together. Each subject matter model captures a single cross-cutting concern in the system, called an *aspect* in the programming world. Vinay Kulkarni and Sreedhar Reddy, in “Separation of Concerns in Model-Driven Development,” describe a system that applies these concepts in a modeling environment.

About the Authors



Stephen J. Mellor is vice president and cofounder of Project Technology, a company focused on tools to execute and translate UML models in the context of Agile MDA. His work focuses on creating effective engineering approaches to software development. He received a BA in computer science from the University of Essex, UK. He's the coauthor of *Model-Driven Architecture Distilled* (Addison-Wesley, 2004). He is a member of the *IEEE Software Industrial Advisory Board*. Contact him at steve@projtech.com; www.projtech.com.

Anthony N. Clark is a lecturer in computer science at King's College London. His research interests include designing and implementing languages for system modeling. He received a PhD in computer science from London University. He is a member of the British Computer Society. Contact him at the Dept. of Computer Science, King's College London, Strand, London, UK WC2R 2LS; anclark@dcs.kcl.ac.uk; www.dcs.kcl.ac.uk/staff/anclark.



Takao Futagami is a chief consultant at Toyo. His research interests focus on embedded engineering. He received a bachelor's degree in physics from Tsukuba University. He is a member of the Information Processing Society of Japan. Contact him at Toyo Corp., 1-1-6 Yaesu, Tokyo, Japan; futagami@sonata.plala.or.jp; www.toyo.co.jp/ss.

Model-driven development is still not widespread, but the potential is large. A software development environment with off-the-shelf models and mapping functions changes the way in which we build systems. Instead of building and rebuilding systems as the application or the technological infrastructure changes—an expensive proposal to be sure—we'll select models, subset or extend them, then weave them together with other models to build the system.

Model-driven development enables reuse at the domain level, increases quality as models are successively improved, reduces costs by using an automated process, and increases software solutions' longevity. In this way, models become assets instead of expenses—quite the business proposition! ☞