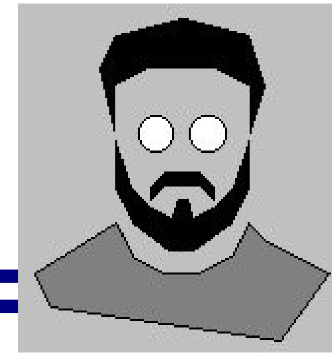
Model-Driven Development

Model-Driven Methods in Software Engineering

Alar Raabe

Content

Alar Raabe



- Over 30 years in IT
  - held various roles from programmer to a software architect
- 15 years in insurance and last 4 years in banking domain
  - developed model-driven technology for insurance applications product-line
    - models
    - method/process
    - tools and platform framework
  - developing/implmenting business architecture methods for a banking group
- Interests
  - software engineering (tools and technologies)
  - software architectures
  - model-driven software development
  - industry reference models (e.g. IBM IAA, IFW)
  - domain specific languages

Content

- Introduction
    - Common Language – some Definitions
    - The Problem
    - Beginning (Excursion into the History)
- Models in Software Development
  - Direct Modeling
    - Convergent Engineering
    - Domain-Driven Design
  - Models as Primary Artifacts
    - Model-Driven Development Methods
    - Generative Programming
    - Domain Specific Languages
- Practical Aspects
    - Model Management
    - Best Practices
    - Examples
- Conclusions
- References

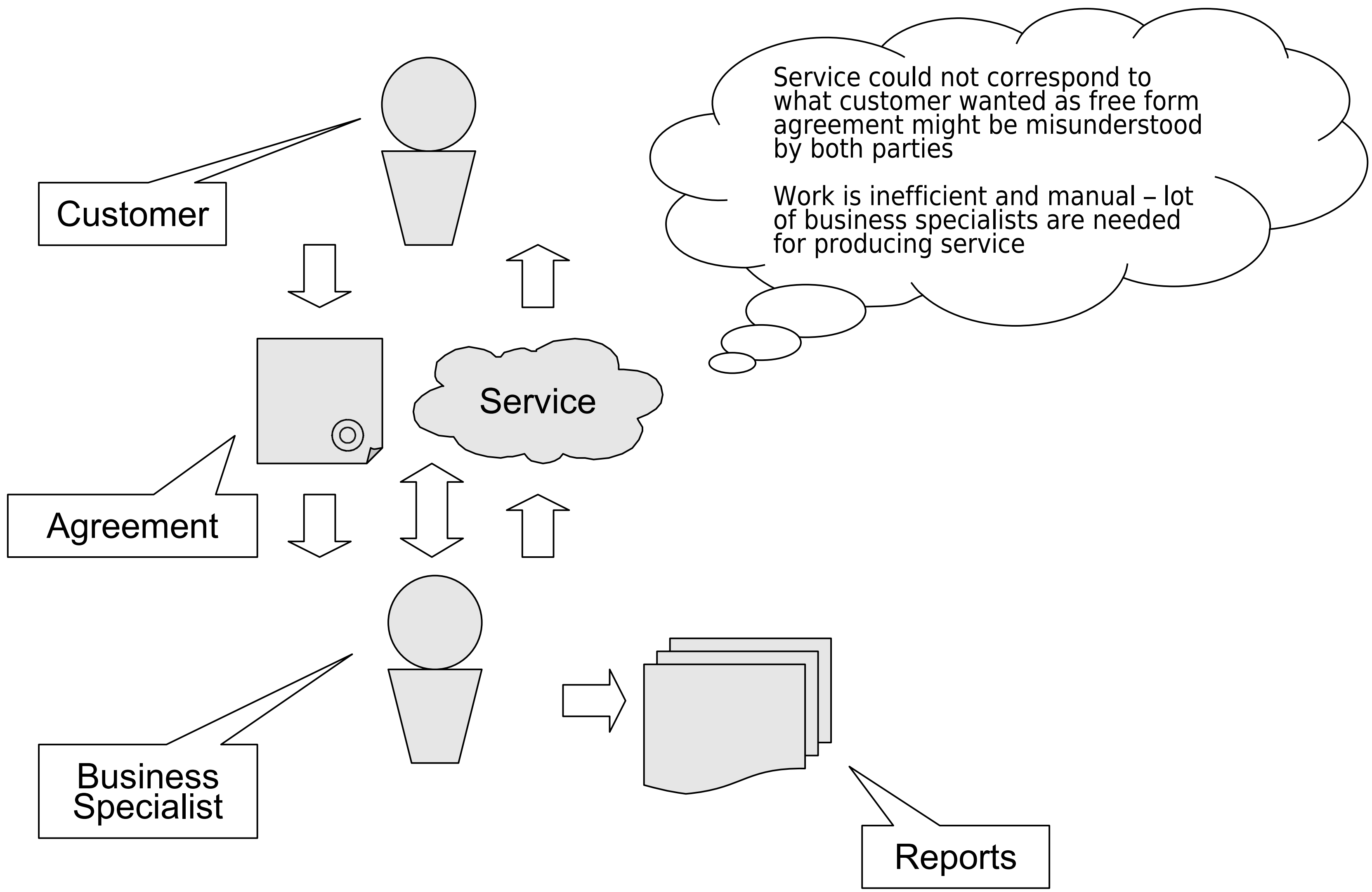
Common Language – some Definitions 1

- Abstraction
  - a view of an object that focuses on the information relevant to a particular purpose and ignores the remainder of the information
  - the process of formulating a view
- **Model**
  - an interpretation of a theory for which all the axioms of the theory are true
  - a semantically closed abstraction of a system or a complete description of a system from a particular perspective
  - anything that can be used to answer questions about system
    - Marvin Minsky & Doug Ross
  - **a set of structured information NOT JUST A PICTURE!**
- **Metamodel**
  - a logical information model that specifies the modeling elements used within another (or the same) modeling notation
  - specification of the concepts, relationships and rules that are used to define a methodology
  - **a model of models** (or a language for models)

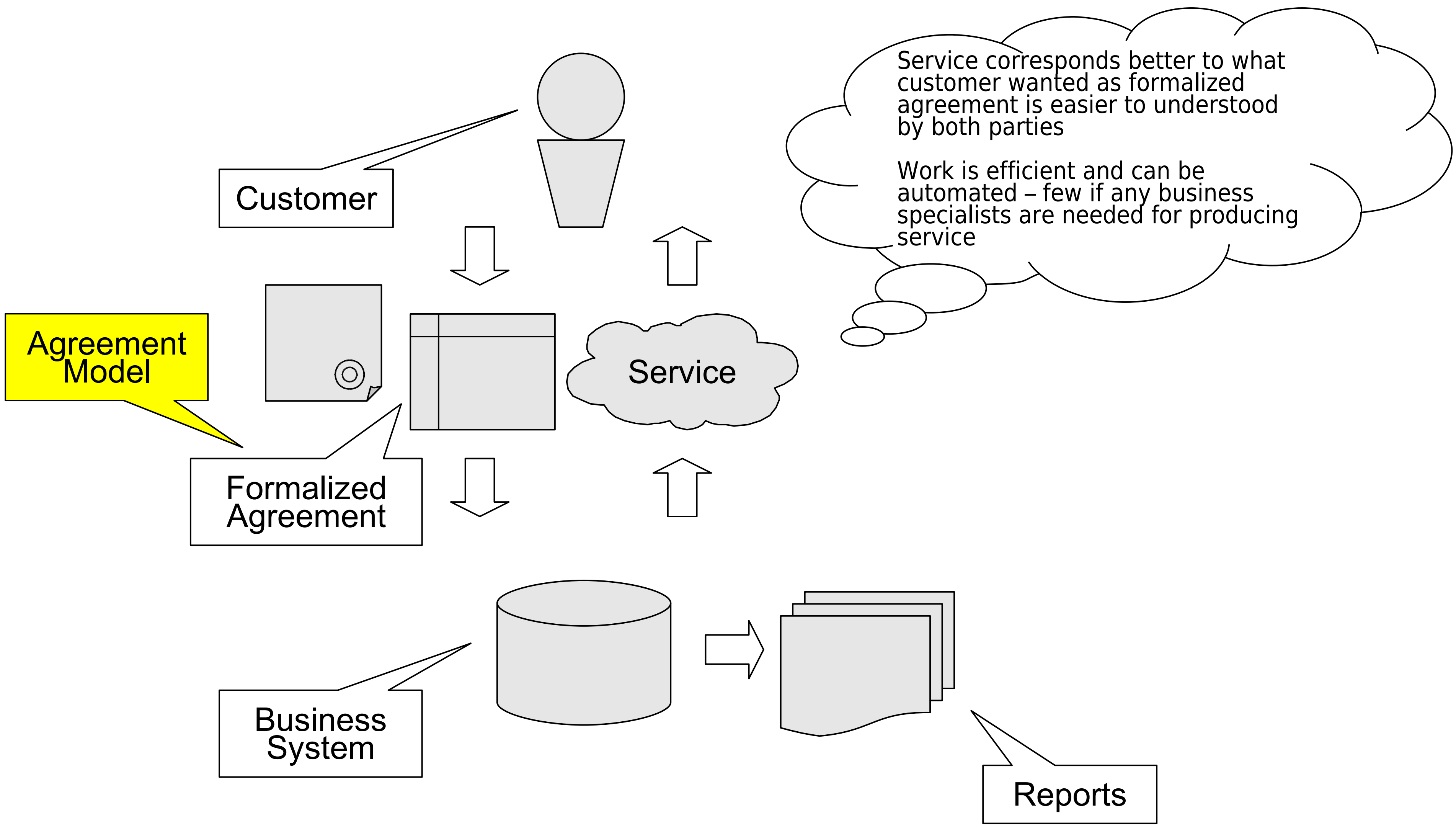
Common Language – Some Definitions 2

- Model **Transformations**
  - changing the form of the model while preserving semantics and some desirable properties (like correctness)
- Model **Refinements**
  - changing (enlarging) the content of the model – adding details
- **Domain**
  - a problem space
  - a distinct scope, within which common characteristics are exhibited, common rules observed, and over which a distribution transparency is preserved
  - an area of knowledge or activity characterized by a set of concepts and terminology understood by practitioners in that area (UML)
- Domain Specific Language (DSL)
  - language dedicated to a specific problem domain, problem representation technique, and/or problem solution technique

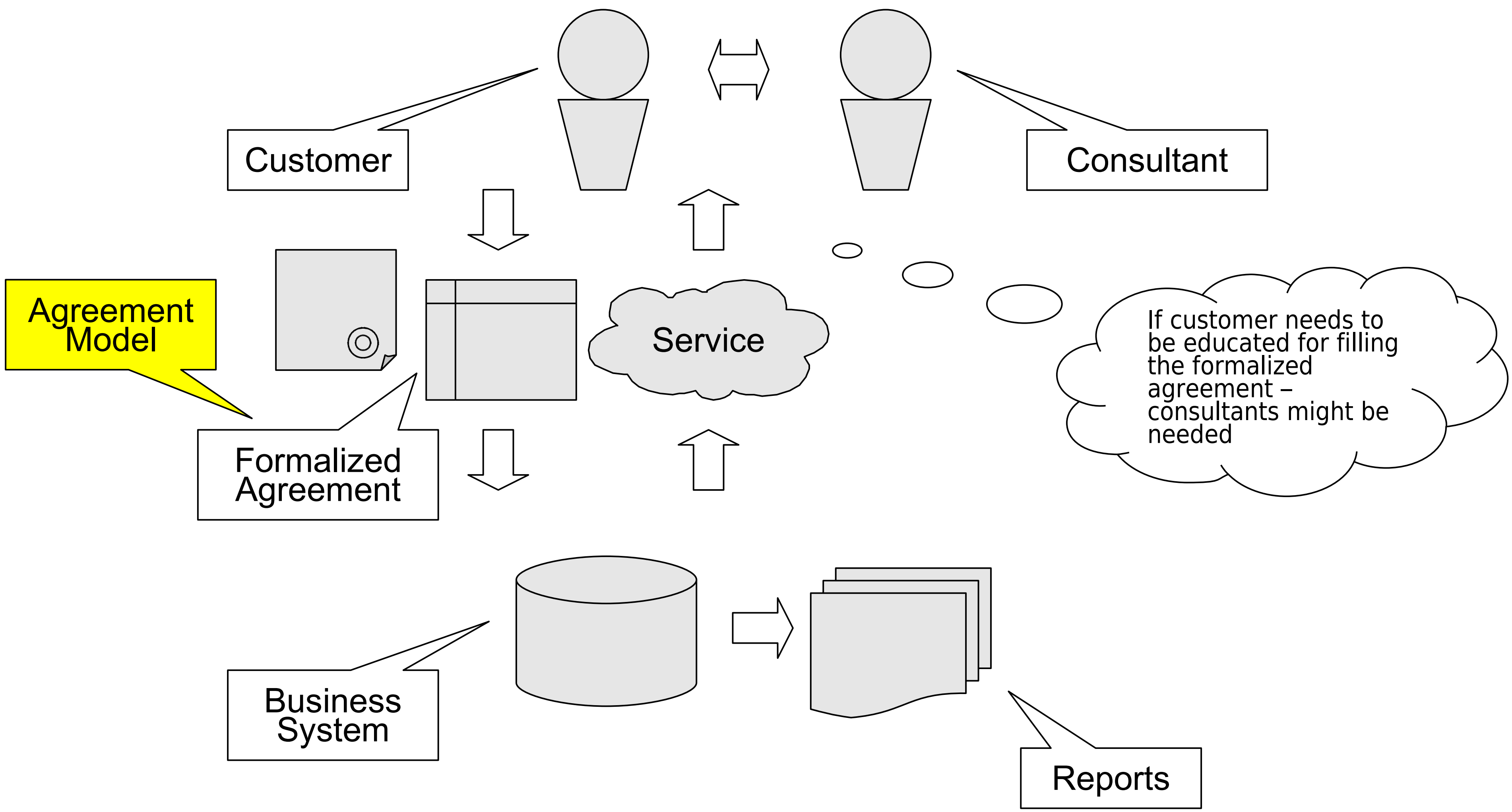
How we did Business Yesterday



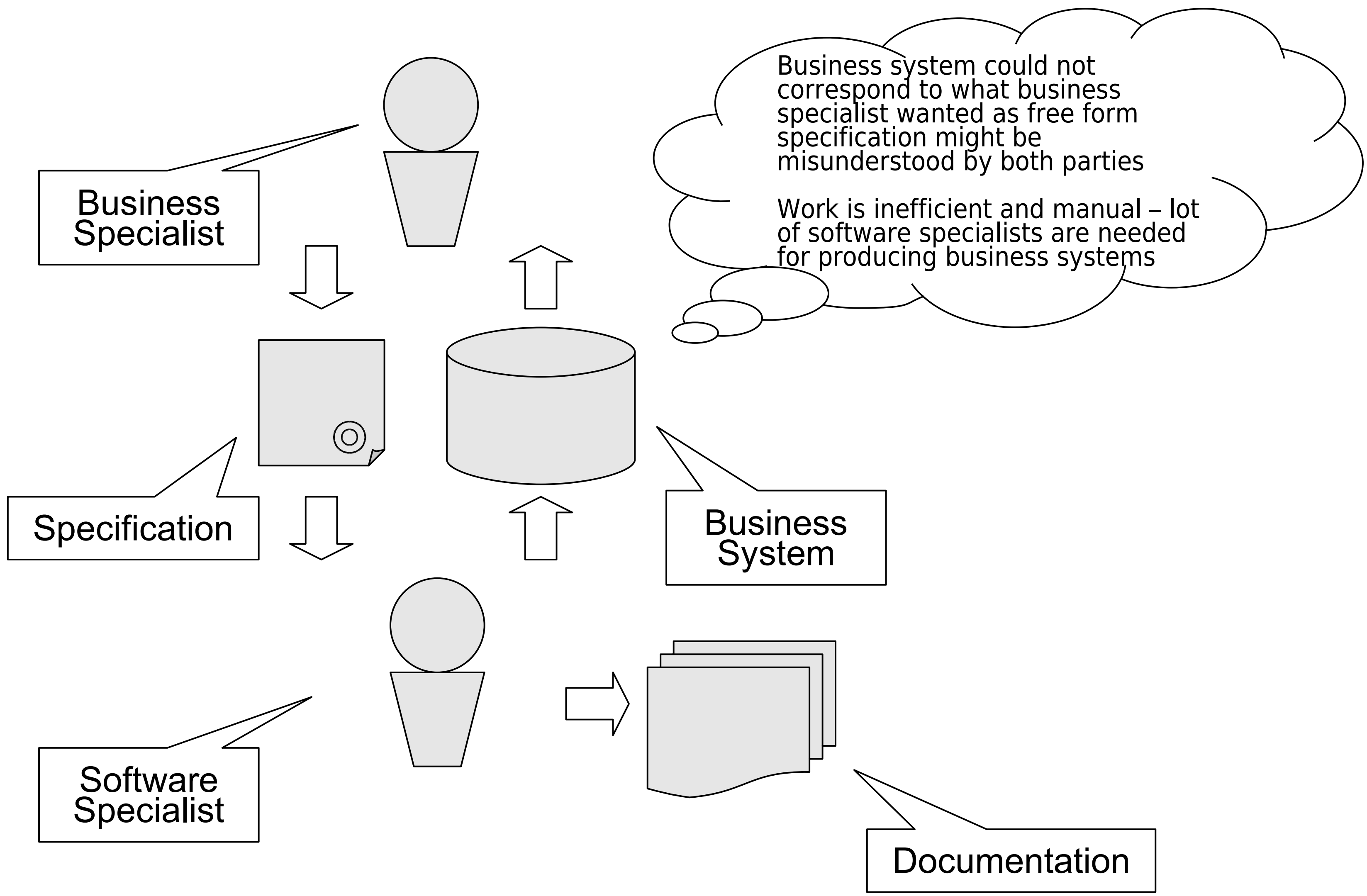
How we do Business Today



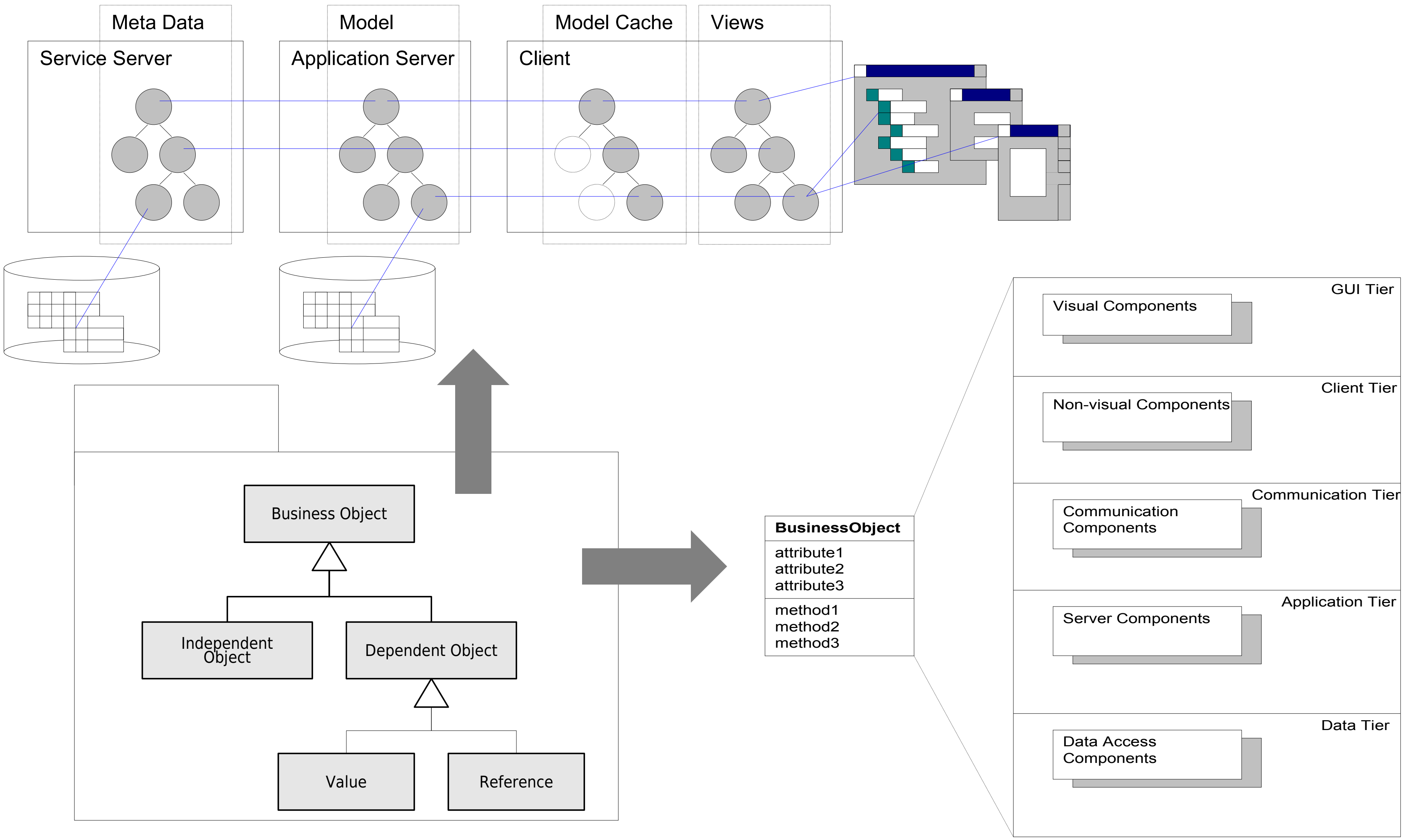
How we do Business Tomorrow



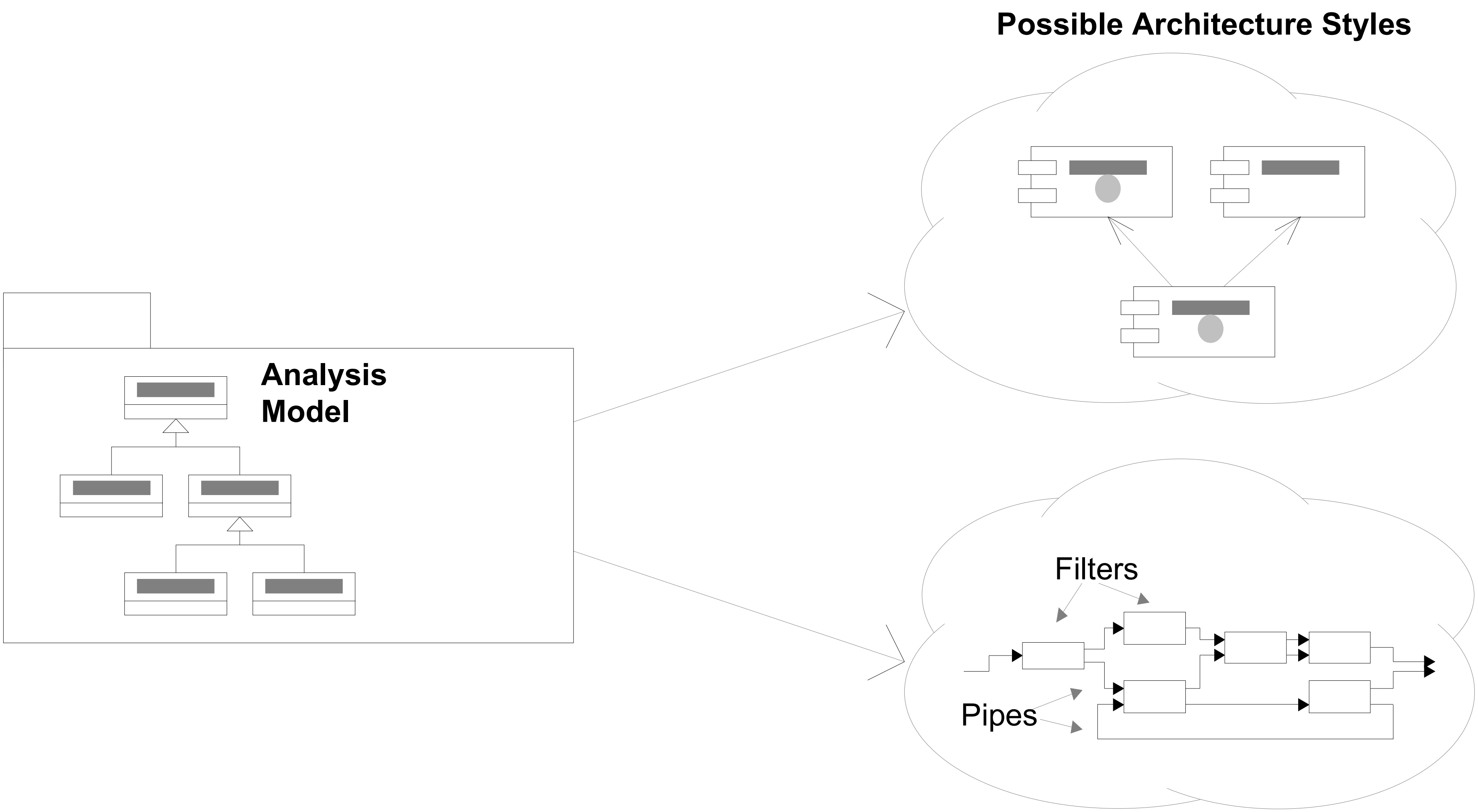
How we Develop Software Today



PROBLEM
Consistency of Implementation



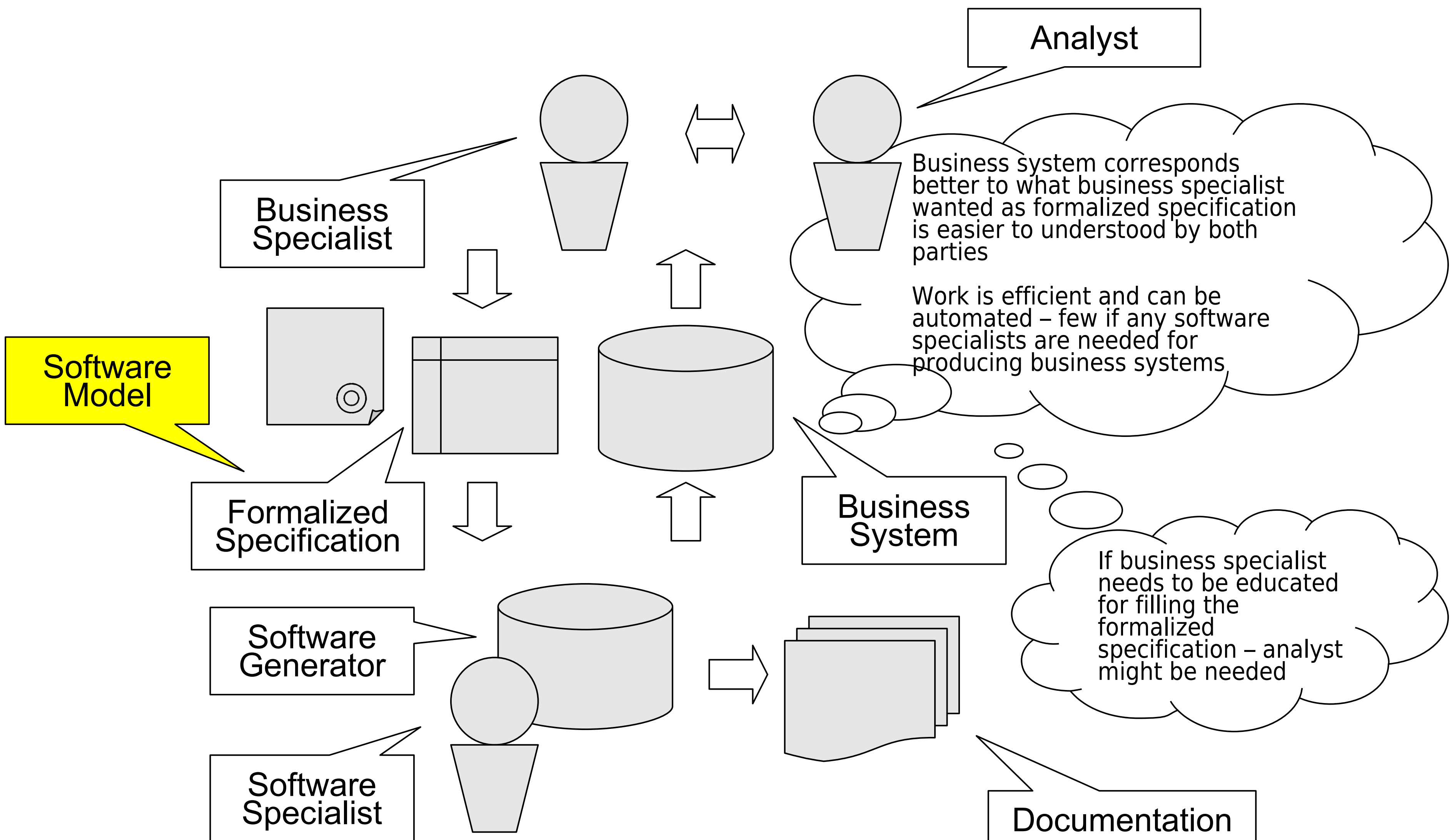
PROBLEM
Mapping to Different Implementations



Problems → Solution

- Requirements for today's business information systems
  - fast time-to-market – rapid delivery of initial results
  - flexibility – effortless and cheap change during the life-cycle
  - independence of business know-how from technology know-how
  - minimal (acquisition and ownership) cost
  - independence of technological platform
- Problem ⟶ Manual work
  - communication errors (systematic defects)
  - construction errors (random defects)
  - insufficient scalability of development process (sourcing)
  - difficult transfer of knowledge (continuity)
  - low reuse of both analysis and construction results (high cost)
  - long development time (low productivity)
  - insufficient flexibilitty of systems (high cost of changes)
- Solution ⟶ **Automation**

How we should Develop Software



Beginning (Excursion into the History)

> What has been will be again,
> what has been done will be done again;
> there is nothing new under the sun.
>
> -- Ecclesiastes 1:9

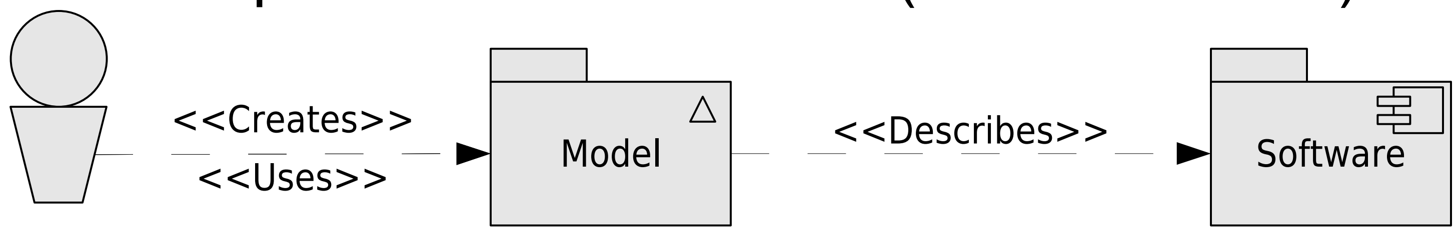
- Programming Languages – to automate coding
  - FORTRAN (1954)
  - Lisp (1956)
  - APT (MIT 1957)
  - Algol (1958)
- Problem-Oriented Languages/Systems – to automate programming
  - ICES (MIT 1961)
    - COGO, STRUDL, BRIDGE, ...
  - PRIZ
- Compiler Generators – generation of solution from model of problem
  - Yacc/Lex (1979)
- Application Generators
  - MetaTool & ... (Bell Labs 1988)
  - GENOA

Content

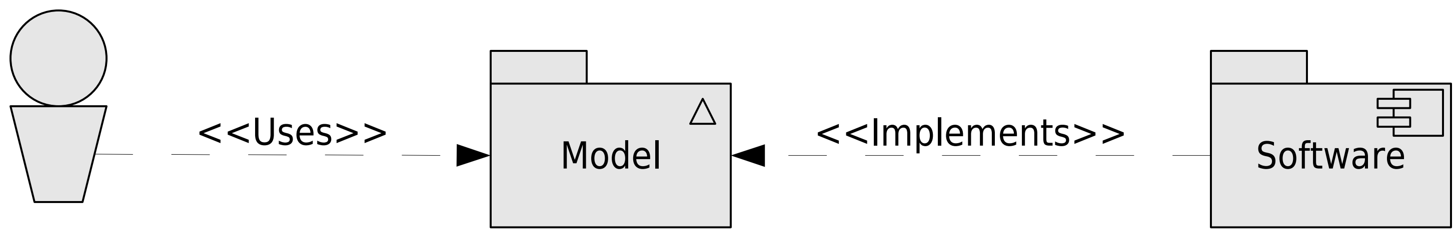
Using Models in Software Development

Most usual – we will not deal with this (models as documentation)

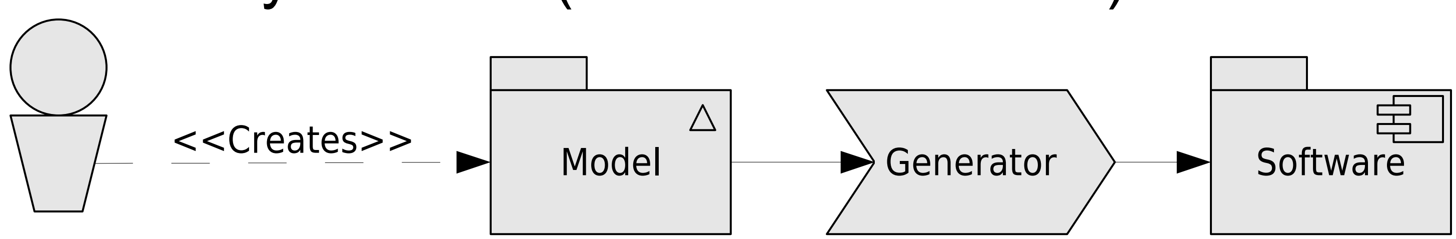
- Models as Descriptions and Illustrations (Documentation)



- Software as Model – Direct Modeling (of Domain)



- Models as Primary Artifacts (Executable Models)



Direct Modeling

- History
  - Structured Programming / Structured Design [Jackson 1975]

  "program structure should correspond to the structure of the problem"

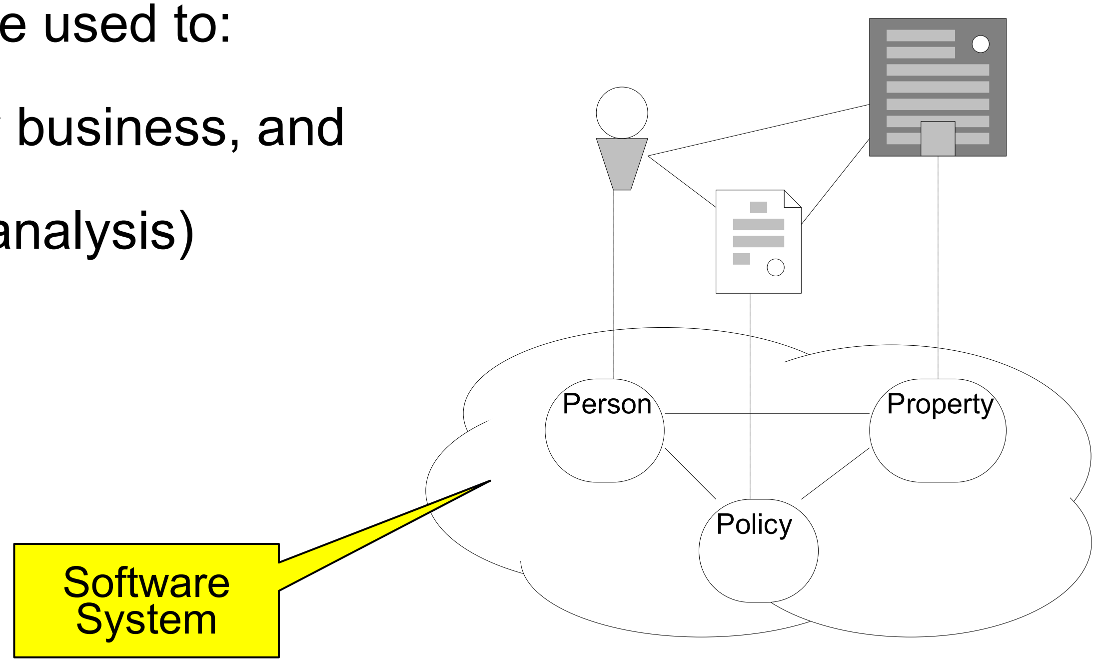
- Convergent Engineering
  - structure of business and business software should converge
  - flexibility and multiple usages of same software
- Domain-Driven Design
- Examples
  - Modeling Programs – programs that directly model something
    - Recursive Descent Parser
  - Generative Programs – programs, which are models and generate other programs

Convergent Engineering

- Convergent engineering – construct business software as a model of business (organization and processes) [Taylor]
  - business and the supporting software can be designed together
  - changes in business are easier – greater flexibility of software
  - same software can be used to:

    1) run the day-to-day business, and

    2) plan (do “what-if” analysis)



Domain-Driven Design

- Domain-Driven Design – a way of thinking and a set of priorities, for accelerating software projects, which deal with complicated domains [Evans]
  - the primary focus should be on the domain and domain logic
  - complex domain designs should be based on a model

- Some techniques an practices of Domain-Driven Design
    - *declarative design*
    - *intention revealing interfaces (fluent interfaces)*
    - side-effect-free functions
    - assertions (explicit constraints)
    - *conceptual contours (modules)*
    - standalone classes (low coupling)
    - closure of operations (for value objects)
    - *bounded context (explicit context)*
    - *context map (connecting models)*
    - *shared kernel (common subset of models)*
    - *anticorruption layer (interface between models)*

Content

History of Model-Driven Software Development (MDSD)

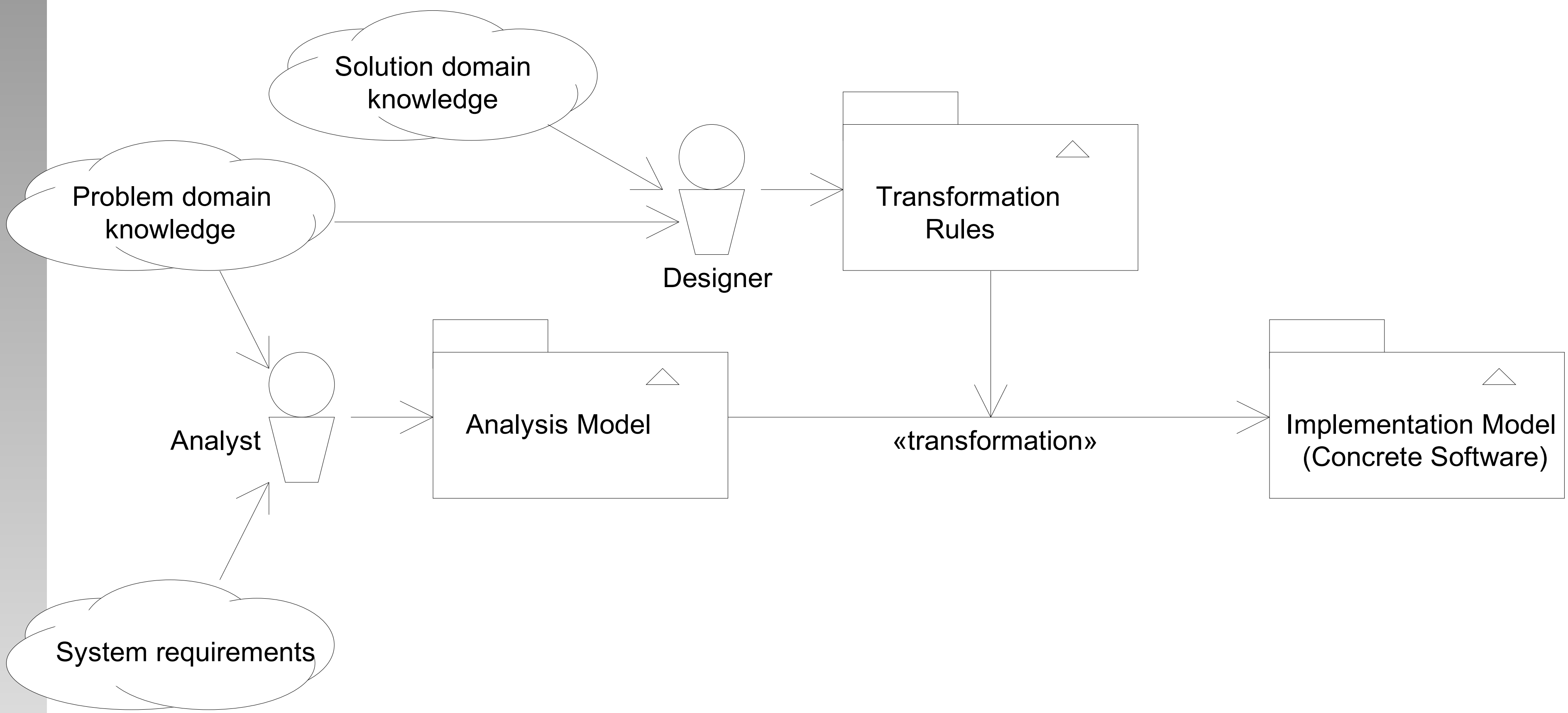
- Real-time and embedded systems
  - Model-Integrated Computing (MIC) and model-based software synthesis – (Vanderbilt Univ. (ISIS), 1993; Abbott et al., 1994)
  - Model-based development – (Mellor, 1995)
- Generative programming
  - GenVoca – (Batory, 1992)
  - Family-Oriented Abstraction, Specification, and Translation (FAST) – (Weiss, 1996; AT&T, Lucent, 1999)
- Software system families (a.k.a. product-lines)
  - Model-Based Software Engineering (MBSE) – (SEI, 1993)
- Integration and interoperability
  - Model-Driven Architecture (MDA) – (OMG, 2001)

Four Components of MDSD

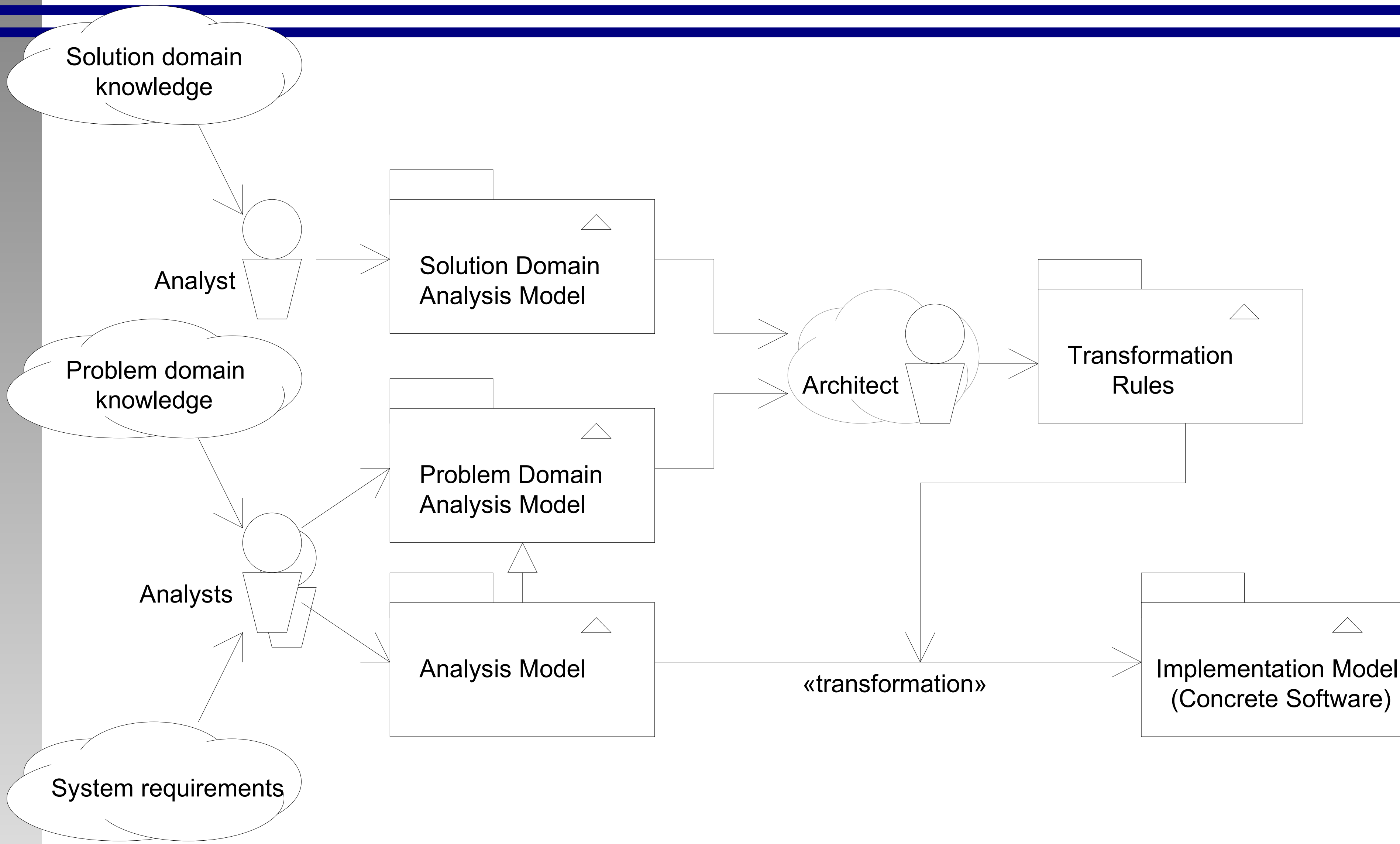
- Models
  - Analysis and design meta-models
  - Domain (reference) models
- Architecture
  - Architecture style
  - Domain (reference) architecture (in selected architecture style(s))
- Process
  - Generation/transformation rules
  - Process of application of generation rules
- Tools
  - Model manipulation tools
  - Generators

Traditional MDSD Approach

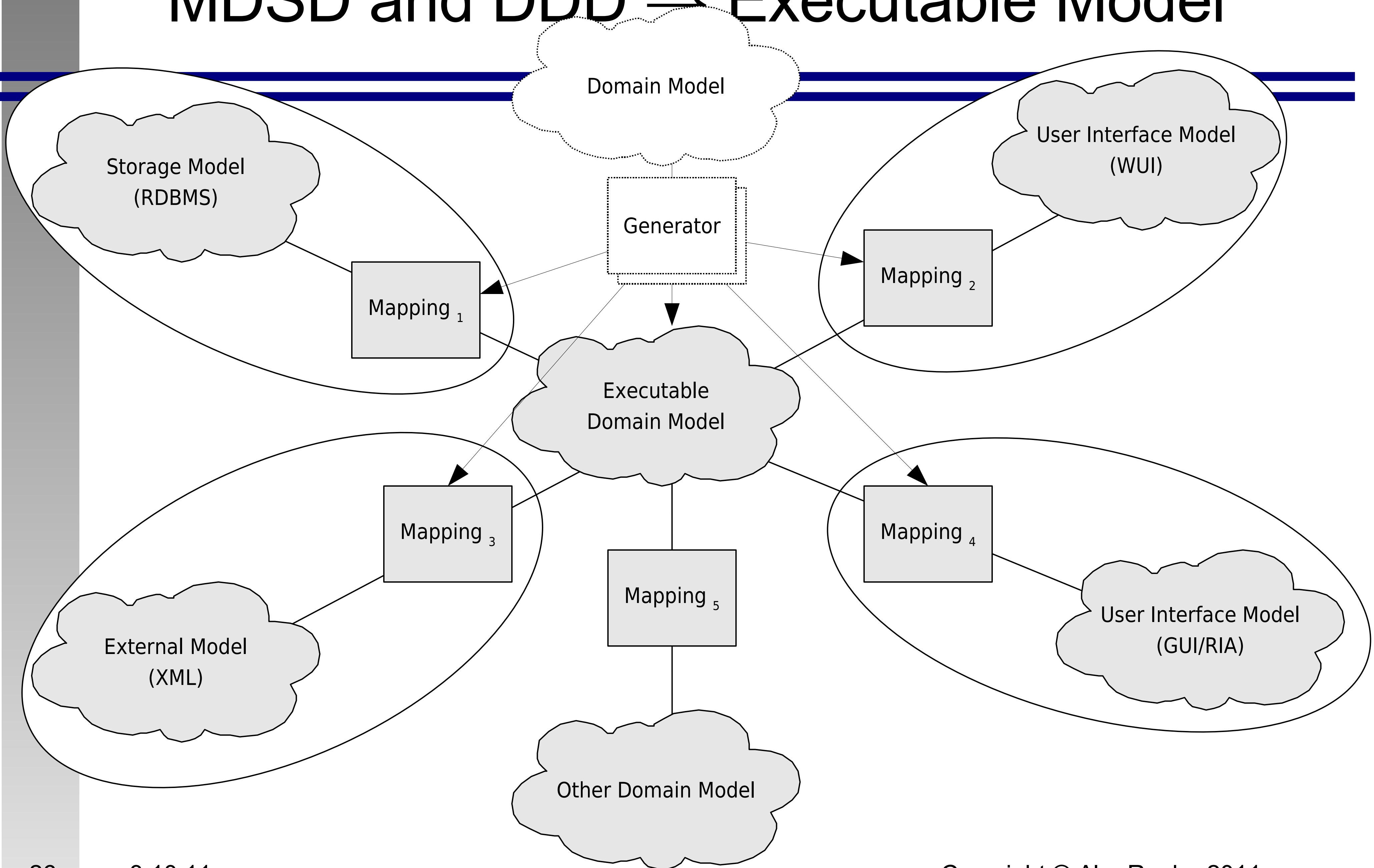
Solution knowledge is not separated from technical knowledge !



Extended MDSD Approach

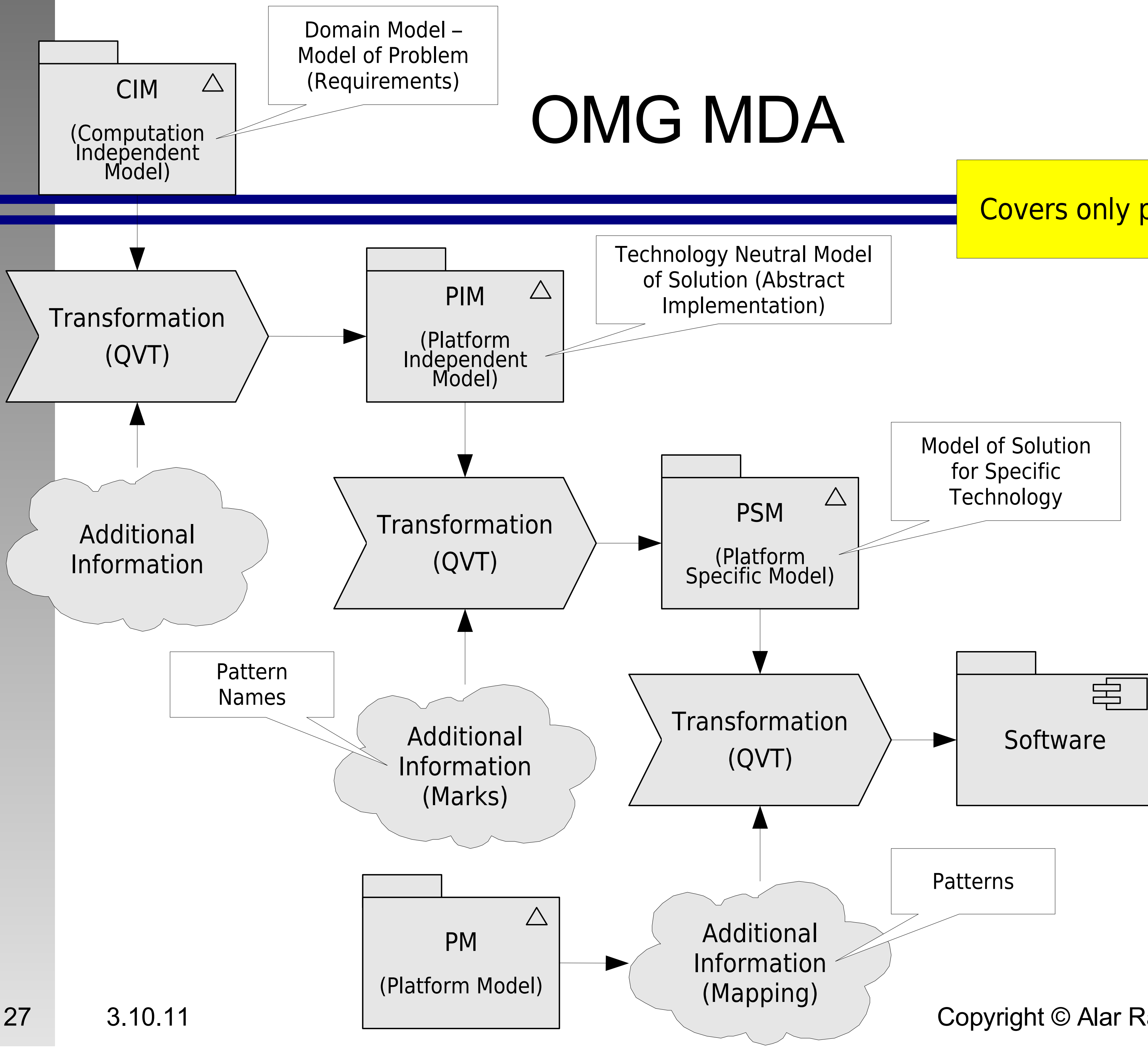


MDSD and DDD → Executable Model



OMG MDA

Covers only part of MDSD !



Generative Programming

[Czarnecki, Eisenecker]

Problem Space
•domain specific concepts
•features

Configuration knowledge
•illegal feature combinations
•default settings
•default dependencies
•construction rules
•optimizations

Solution Space
•elementary components
•maximum combinability
•minimum redundancy

Domain Specific Language (DSL)

Generator
Reflection

Components + System Family Architecture

Generative Programming Technologies

Problem Space
- domain specific concepts
- features

Configuration knowledge
- illegal feature combinations
- default settings
- default dependencies
- construction rules
- optimizations

Solution Space
- elementary components
- maximum combinability
- minimum redundancy

DSL Technologies
- programming language
- extensible languages
- textual languages
- graphical languages
- interactive wizards
- any mixture of above

Generator Technologies
- simple traversal
- templates and frames
- transformation systems
- languages with meta-programming support
- extensible programming systems

Component Technologies
- generic components
- component models
- AOP approaches

Generator Technologies

- Model traversal

- Templates and frames
  - text with meta-instructions (referencing model)
    - retrieval of information from domain/problem model
    - conditional configuration of output
  - JSP, XSL, Velocity

- Transformation systems
  - operate on abstract syntax trees
    - rewrite rules
    - transformation procedures
  - DMS, XT, QVT

- Languages with meta-programming support
  - template meta-programming in C++

Domain Specific Languages

- Domain-Specific Languages (DSLs) – customized languages that provide a high-level of abstraction for specifying a problem concept in a particular domain

- Defining DSL
  - concrete syntax
    - specific representation of a DSL in a human-usable form
      - style: declarative | imperative
      - representation: textual, graphical, table, form(wizard), ...
  - abstract syntax
    - elements + relationships of a domain without representation consideration
  - semantics
    - the meaning of the phrases and sentences that the domain expert may express
      - static semantics: typing rules, truth value
      - dynamic semantics: evaluation rules, change in context
      - defined: formally | informally (interpreters, generators, transformers, ...)

DSL Technologies

WARNING:
Don't be too Clever !

- Internal DSLs
  - Built-in features of programming languages
    - C++ templates
    - Lisp Macros
  - Extendible languages
    - XML, Seed7
    - Ruby, Groovy, JavaScript, ...
  - Well-Designed APIs
- External DSLs
  - Textual languages
  - Graphical languages
    - UML, MetaCASE
  - Interactive wizards

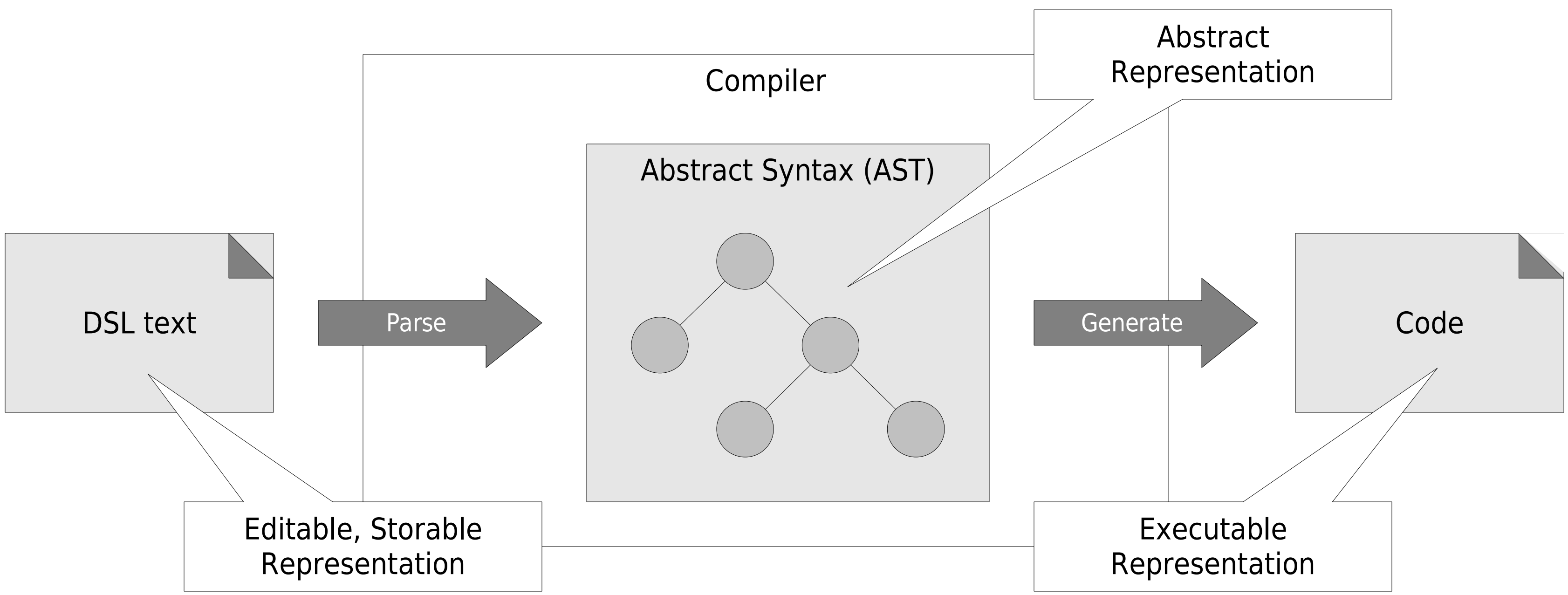
DSL Example 1

- Ojay (JavaScript internal DSL)

```
...
// Define some validation rules

    form('signup')
        .requires('username')   .toHaveLength({minimum: 6})
        .requires('email')      .toMatch(EMAIL_FORMAT, 'must be a valid email address')
        .expects('email_conf')  .toConfirm('email')
        .expects('title')       .toBeOneOf(['Mr', 'Mrs', 'Miss'])
        .requires('dob', 'Birth date').toMatch(/^\d{4}\D*\d{2}\D*\d{2}$/)
        .requires('tickets')    .toHaveValue({maximum: 12})
        .requires('phone')
        .requires('accept', 'Terms and conditions').toBeChecked('must be accepted');
...
```

DSL Implementation $_1$

- Compiler-Based



DSL Example 2

- Simple External DSL (yacc)

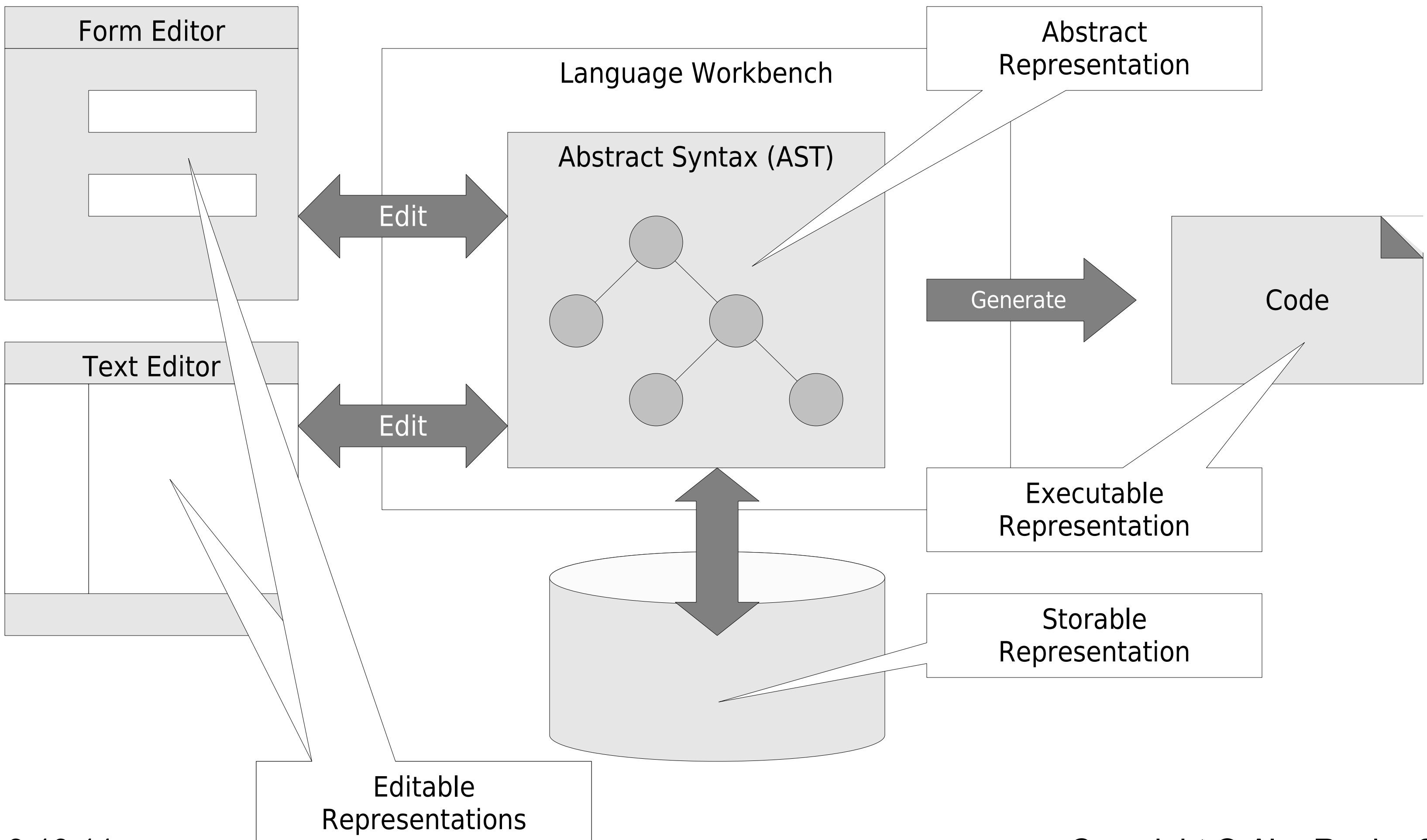
```
...
list:   /*empty */ | list stat '\n' | list error '\n' { yyerrok; } ;
stat:   expr { printf("%d\n",$1); } | LETTER '=' expr { regs[$1] = $3; } ;
expr:   '(' expr ')' { $$ = $2; } |
        expr '*' expr { $$ = $1 * $3; } | expr '/' expr { $$ = $1 / $3; } |
        expr '%' expr { $$ = $1 % $3; } |
        expr '+' expr { $$ = $1 + $3; } | expr '-' expr { $$ = $1 - $3; } |
        expr '&' expr { $$ = $1 & $3; } | expr '|' expr { $$ = $1 | $3; } |
        '-' expr %prec UMINUS { $$ = -$2; } |
        LETTER { $$ = regs[$1]; } | number ;
number: DIGIT { $$ = $1; base = ($1==0) ? 8 : 10; } |
        number DIGIT { $$ = base * $1 + $2; } ;
...
```

- Example

```
...
a = 10
b = 5
a + 4 * (b - 3)
...
```

DSL Implementation $_2$

- Language Workbench



DSL Example $_3$

- xText (oAW)

```
Entity :
  "entity" name=ID ("extends" superType=[Entity])?
  "{"
     (features+=Feature)*
  "}";
Feature :
  Attribute | Reference;
Attribute :
  type=ID name=ID ";";
Reference :
  "ref" (containment?"+")? type=ID name=ID ("<->" oppositeName=ID)? ";";
```

- Example

```
entity Customer {
  String  name;
  String  street;
  Integer age;
  Boolean isPremiumCustomer;
}
```

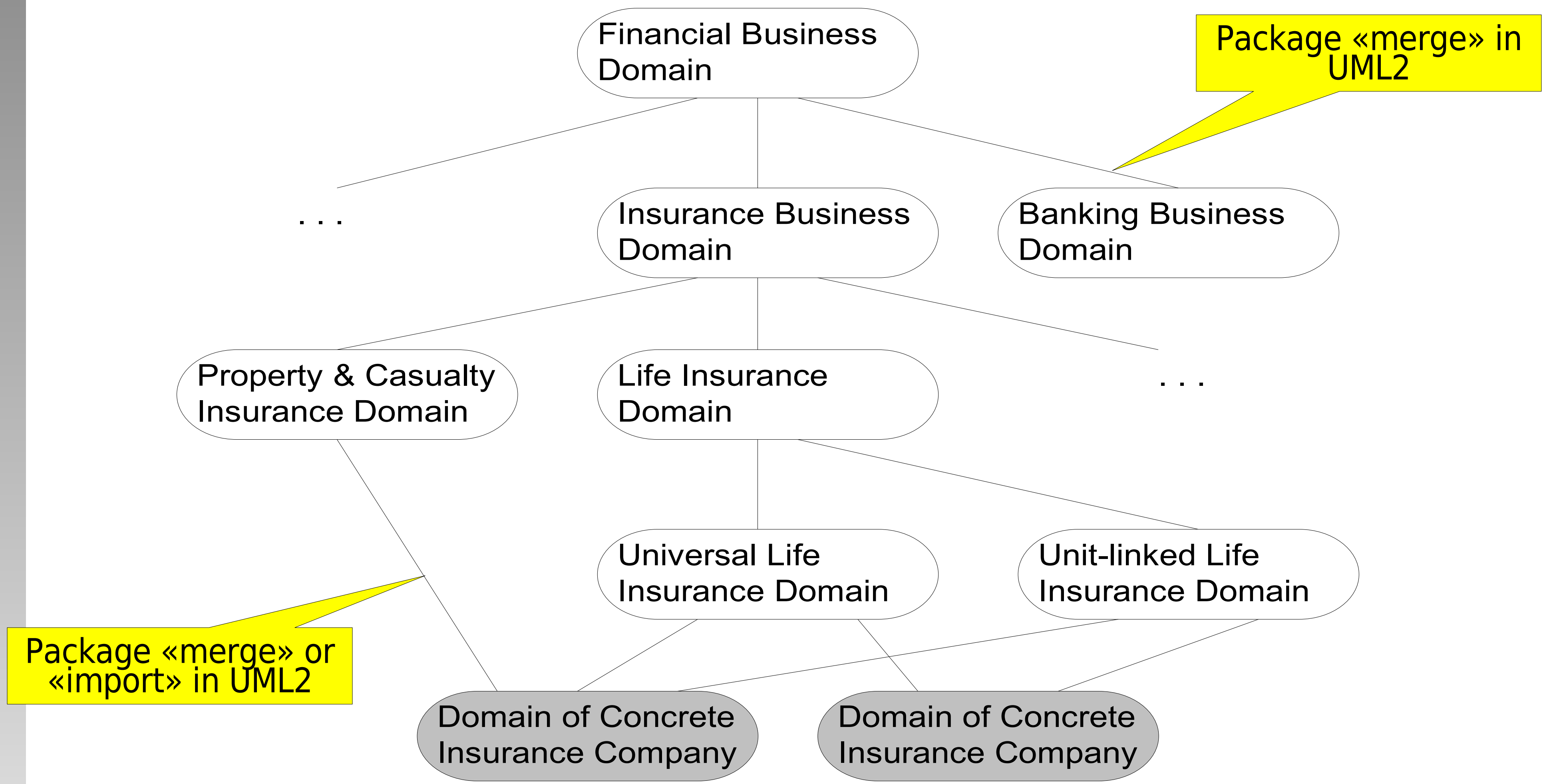
Content

- Introduction
    - Common Language – some Definitions
    - The Problem
    - Beginning (Excursion into the History)
- Models in Software Development
  - Direct Modeling
    - Convergent Engineering
    - Domain-Driven Design
  - Models as Primary Artifacts
    - Model-Driven Development Methods
    - Generative Programming
    - Domain Specific Languages
- Practical Aspects
    - Model Management
    - Best Practices
    - Examples
- Conclusions
- References

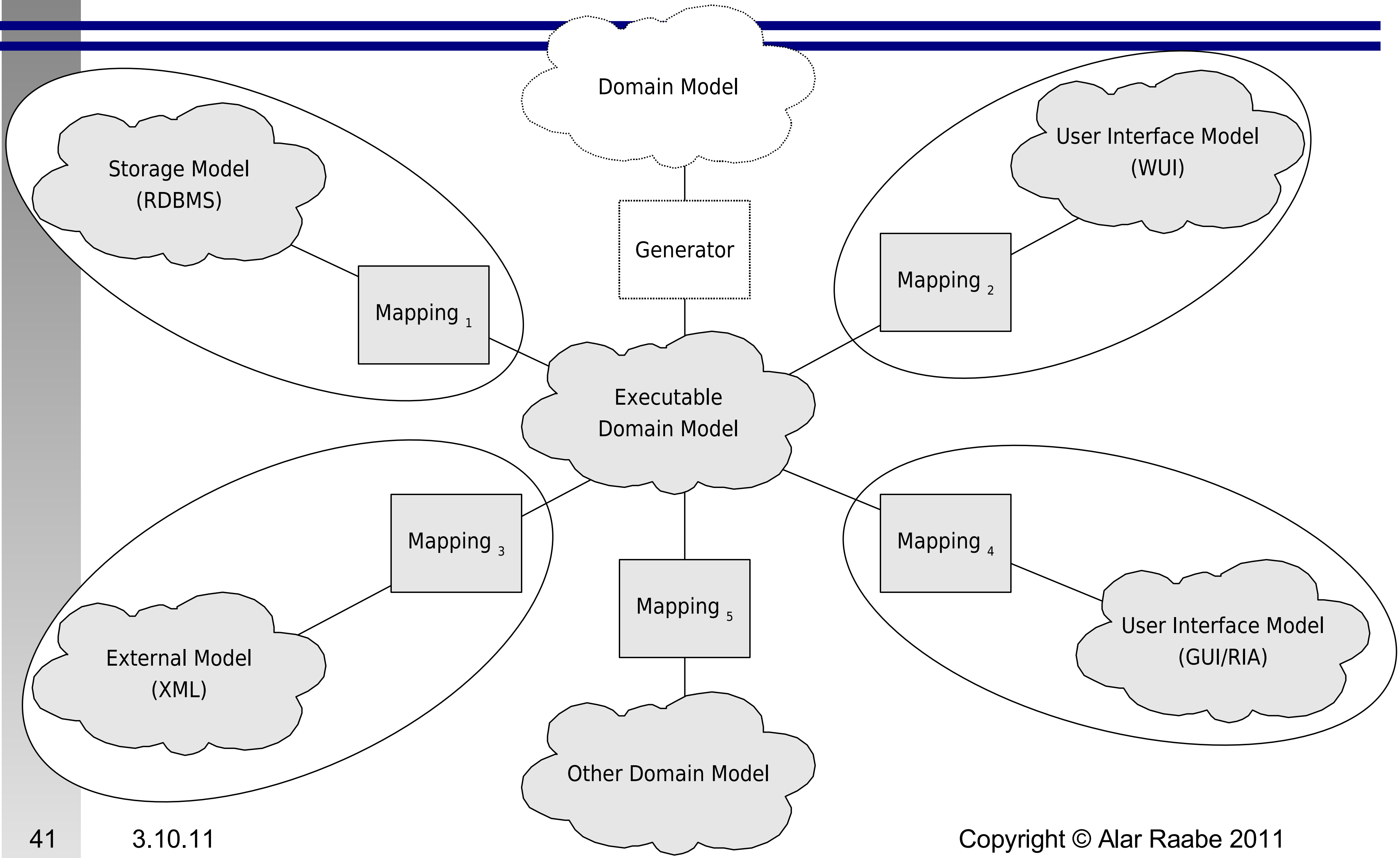
Model Management

- Relationships between Models
  - “inheritance” – extension of models (package/model merge in UML2)
  - correspondence mappings between models
  - references to external models (package/model import in UML 2)
- Operations on Models
  - editing models
    - graphical model editors
    - form-based model editors
    - text-based model editors
  - storing models
    - repository
    - source code control
    - embedding into code

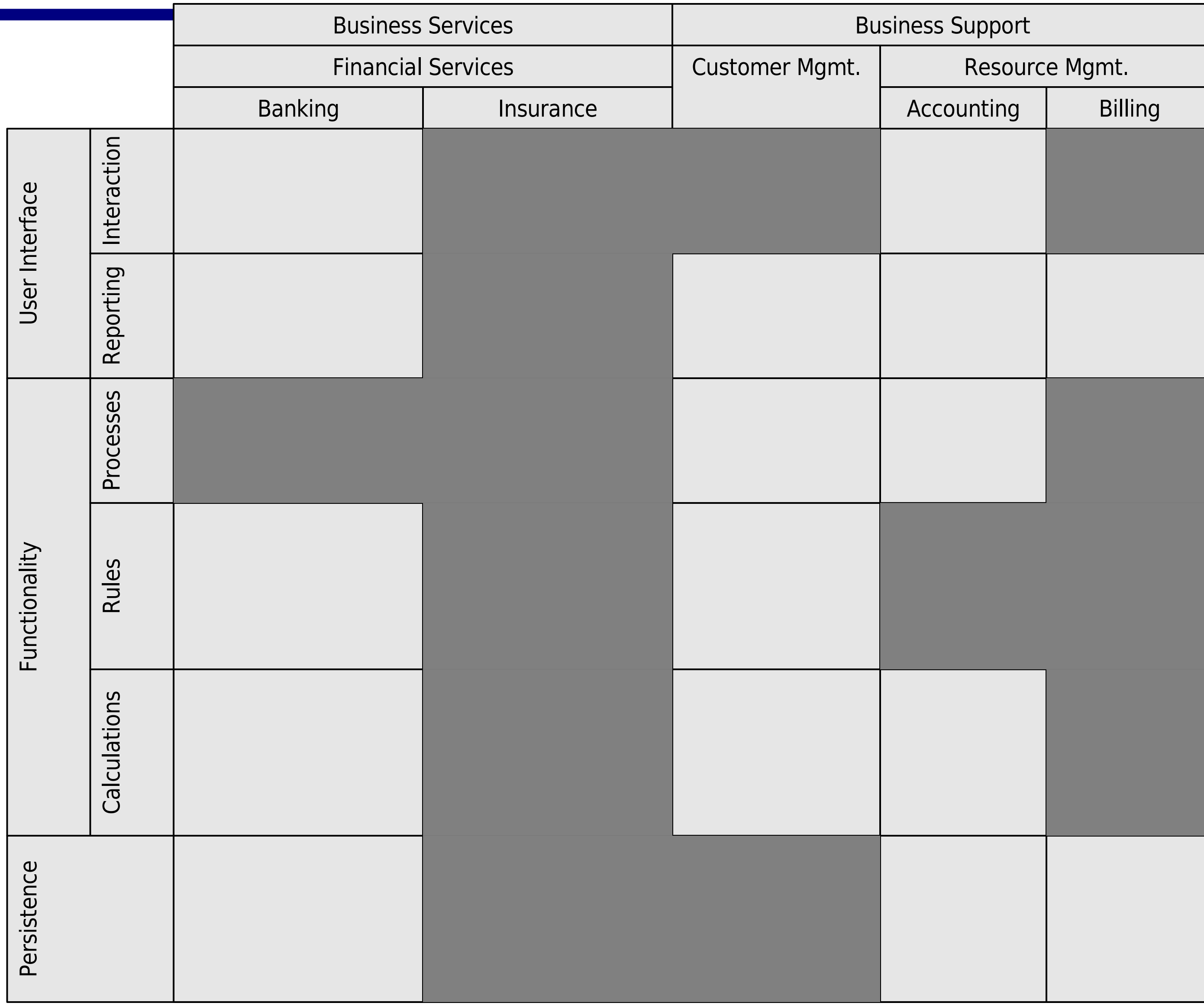
Network of Problem Domains



Main Domain and Periferal Domains



Different Problem and Solution Domains in a Specific System



Domain-Driven Design Best Practices

[Evans]

- Use the Domain Model as **Ubiquitous Language**
- Design Part of the System to Reflect Domain Model – **Avoid Divide between Analysis and Design**
  - Domain Model is Constrained to Support Efficient Implementation
- Express Domain Model in Code – Hands-On Modeling
  - with Services, Entities, Aggregates and Value Objects
    - Encapsulate Entities, Value Objects and Aggregates with Factories and Value Objects with Aggregates
    - Maintain Integrity with Aggregates (Entities act as roots of Aggregates)
    - Access Entities and Aggregates with Repositories
- Isolate Domain with Layered Architecture
  - Presentation Layer
  - Application Layer
  - Domain Layer
  - Infrastructure Layer

MDSD Best Practices 1

[Voelter, ...]

- Separate the Generated and Manually Created Code
  - protected regions (generated code must be revision controlled)
  - separate directory (e.g. src-gen)
  - language mechanisms (e.g. subclassing/inheritance, wrapping/containment, aspects, ...)
- Don't Manage Generated Code in Revision Control System
  - exception when using protected regions or when generator can't be integrated with build
- Integrate the Generator/Generation into the Build Process
  - generation phase must be added before the compilation phase
- Generate Clean and Readable Code
  - code is primarily meant for humans
  - follow coding styles used for manually written code
  - generate comments that identify generated code and describe the used (parts of) source model
  - use code formatter

MDSD Best Practices $_2$

[Voelter, ...]

- Use the Native Techniques of Target Platform for Separating Generated and Manually Created Code
  - object languages – subclassing/inheritance, wrapping/containment
  - aspect languages – aspects/pointcuts (weaving)
  - procedural languages – preprocessing (e.g. includes), libraries
- Use the Compiler (to Guide the Developer)
  - let compiler check the constraints for manually written code (e.g. overriding of mandatory methods)
  - generate dummy code as example for manually written code
- Use Meta-Model as Ubiquitous Language
  - use consistent terminology that connects generated code with other parts of project
  - verify the adequacy of DSLs through constant usage of metamodel concepts

MDSD Best Practices $_3$

[Voelter, ...]

- Develop DSLs Incrementally
  - DSLs should be developed as understanding grows
  - DSLs are public interfces – should be developed and evolved like APIs
  - provide facilities for migrating old models to new metamodel (e.g. model transformation)
- Develop Model Validation (Iteratively)
  - semantics cannot be represented by metamodel alone (it describes only static aspects of model – structure)
  - constraints representing semantics should be added incrementally
  - integrate model validation into build process
- Test the Generator(s) (using Reference Model)
  - use reference (test) models as unit tests to test the generator
  - generate unit tests for combination of generated and manually created code

MDSD Best Practices $_4$

[Voelter, ...]

- Select Suitable Technology – Avoid too Complex Meta-Models
  - define core abstractions clearly and expandable
  - models should be quickly editable and turnaround (model ⟶ generate ⟶ execute) should be quick
  - avoid overly complex metamodels (like UML) or encpsulate these
  - transform complex metamodels into simpler metamodels targetted for specific domains
  - formulate domain specific constraints on simpler metamodels
- Use Graphical and Textual Syntax Correctly (to Support Modeller)
  - don't overburden model with details – **use implicit knowledge**
  - compromise between compactness and comprehensiveness
- Use Configuration by Exception
  - use defaults for normal configurations (e.g. only specify the exceptions)
  - remember, that defaults become the part of interface (API)

MDSD Best Practices 5

[Voelter, ...]

- Teamwork Prefers Textual DSLs
  - use exclusive locking for graphical models
  - if possible, use both textual and graphical DSL (both representations of same model)
- Use Model Transformations to Reduce Complexity
  - divide the step between source model and code into several transformation steps to fight complexity
- Generate towards a Comprehensive Platform – Keep Translation Steps as Small as Possible
  - develop domain specific platforms to reduce the complexity of generators
- Many Small DSLs – Concentrate on the Task
  - swiss army knife is nice as present, but specialised tools are used for serious work
  - *divide et impera* – models should be modular

MDSD Best Practices $_6$

[Voelter, ...]

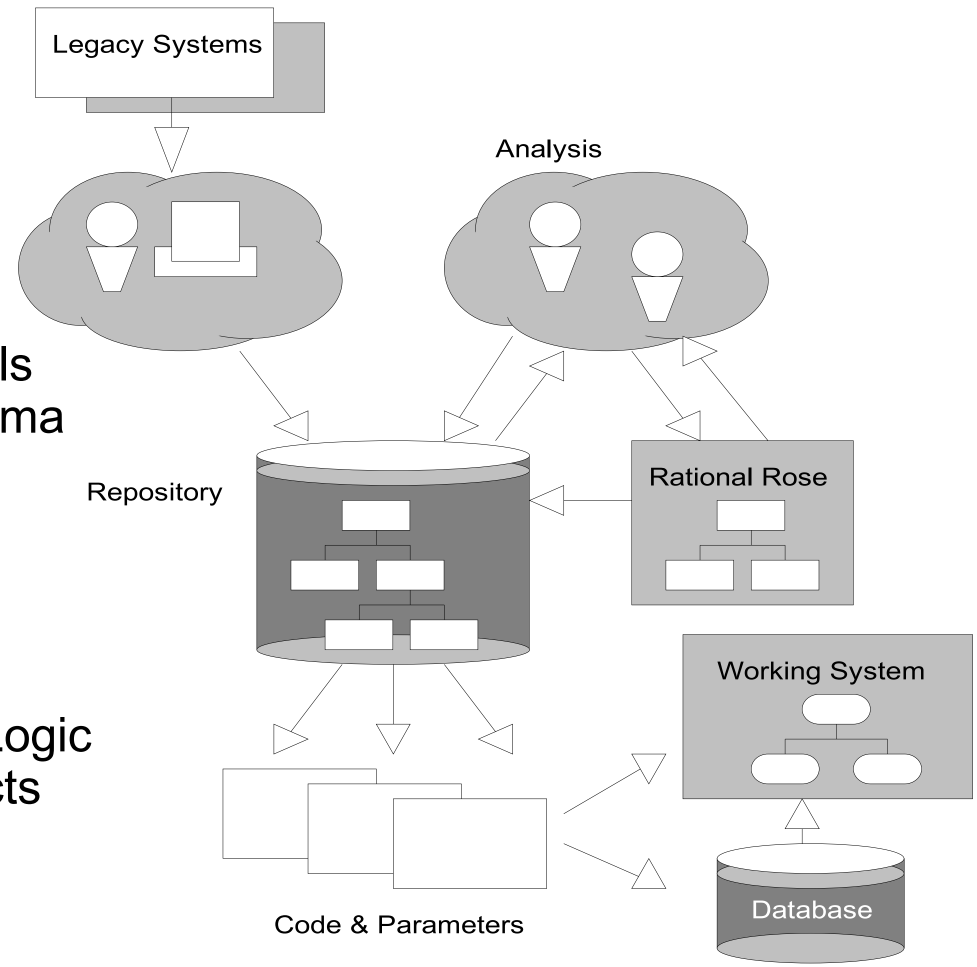
- Don't Reverse Engineer – Model is Primary Artifact
  - all changes should be done in model, and then all derived artifacts should be regenerated
- Regenerate Frequently
  - include generation into continuous build process
  - frequent regeneration ensures compliance with model and architectural constraints (embedded into generator)

Examples of MDSD

- Example of Model-Driven Development in Insurance
  - Once & Done – a model-driven technology for insurance systems product-line
- Example of Model-Driven Development in Banking
  - RISLA – a DSL for credit products
  - MLFi – a DSL for financial instruments and contracts

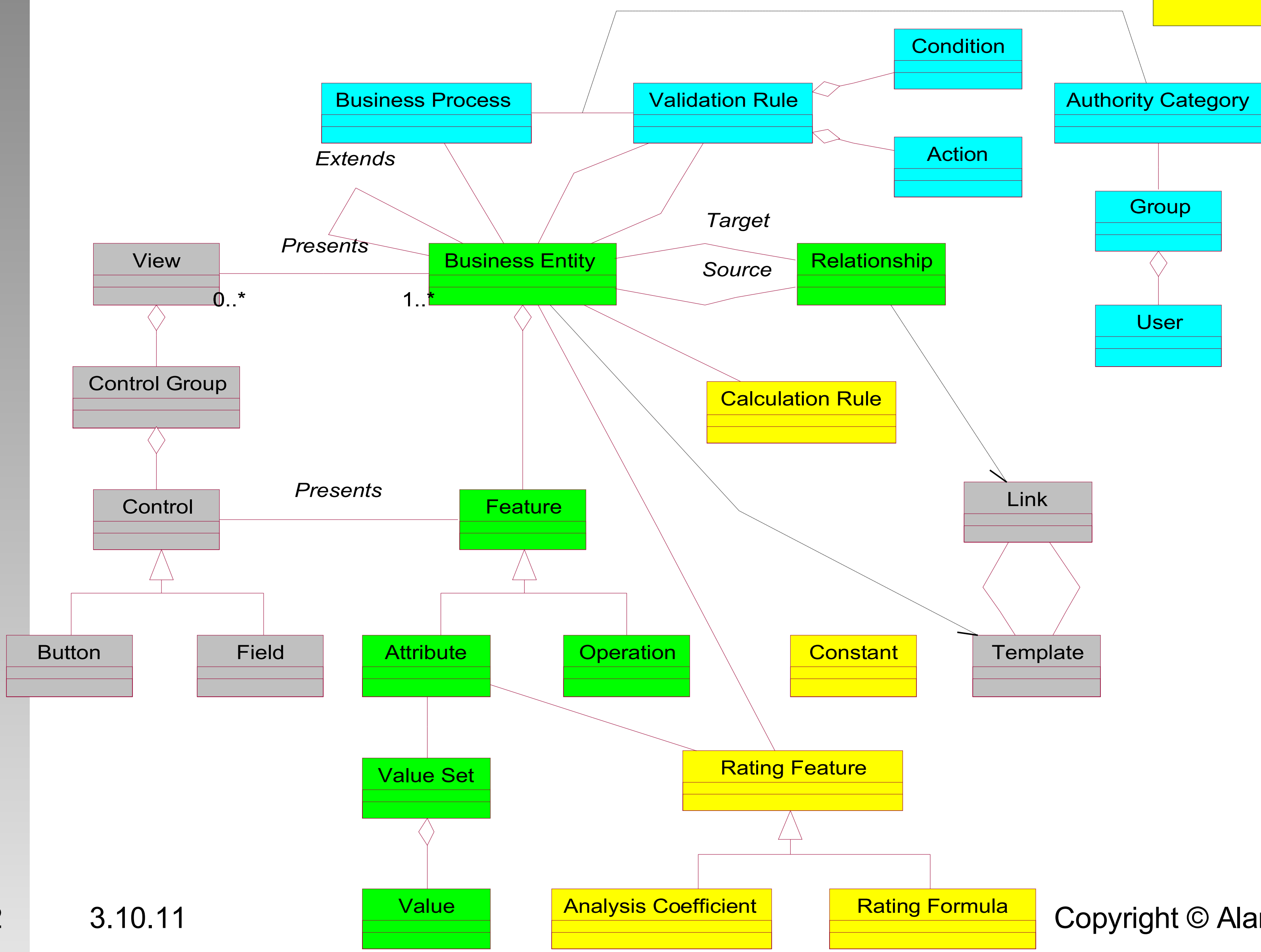
Overview of OD Software Process

- Beginning
- Anaysis
  - Business Domain Analysis
  - Modeling Domain Objects
  - Modeling Insurance Products
- Design
  - Refinement of Analysis Models
  - Design of the Database Schema
  - Design of the User Interface
  - Design of the Printouts
- Implementation
  - Generation of Code
  - Implementation of Business Logic
  - Installation of Business Objects into the Base System
- Finalisation



Extended OOA/OOD Meta-Model

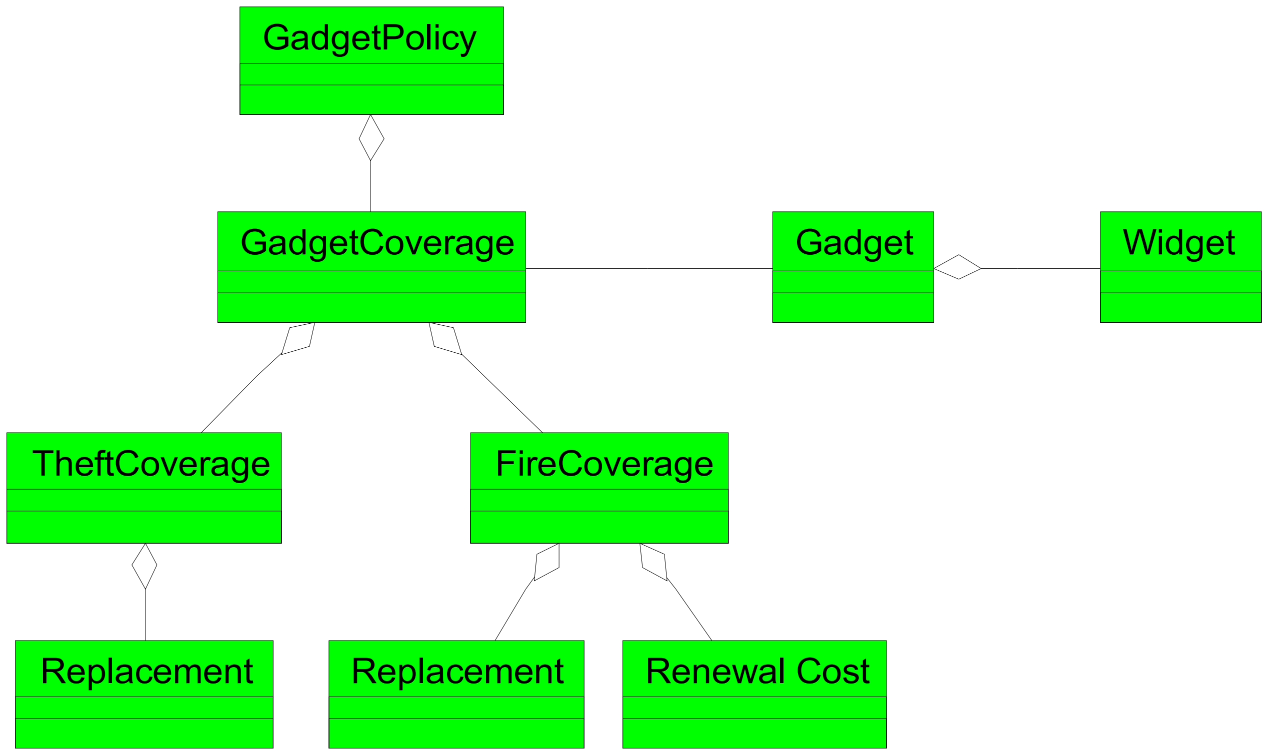
a DSL for Insurance Systems



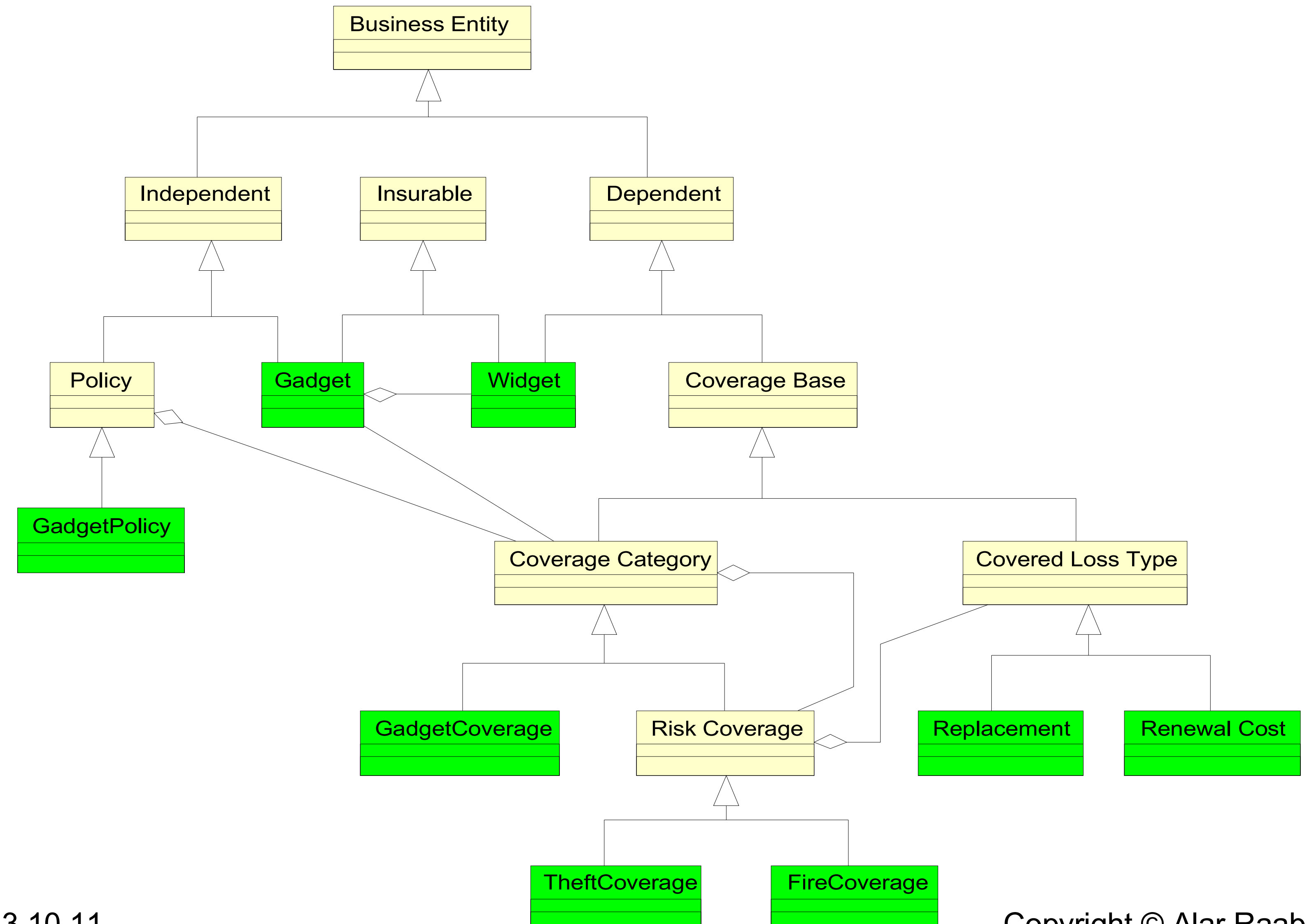
Example of Using Once&Done

- “Gadget Insurance”
  - Gadgets consist of Widgets
  - Gadgets can be insured against Fire and Theft
- Analysis model of “Gadget Insurance”
- Extending insurance domain model with “Gadget Insurance”
- “Gadget Insurance” product model
- Design model for “Gadget Insurance” policy management system

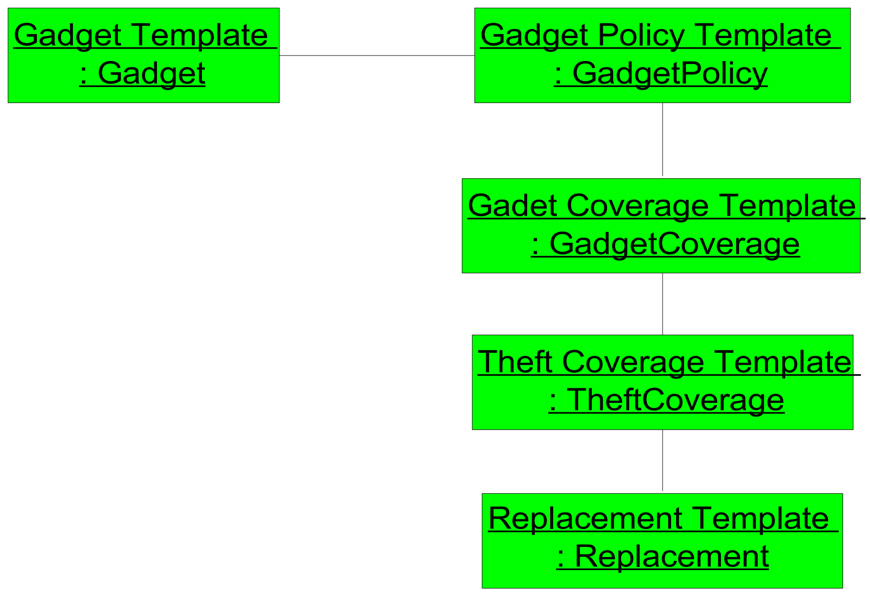
"Gadget Insurance" Analysis Model



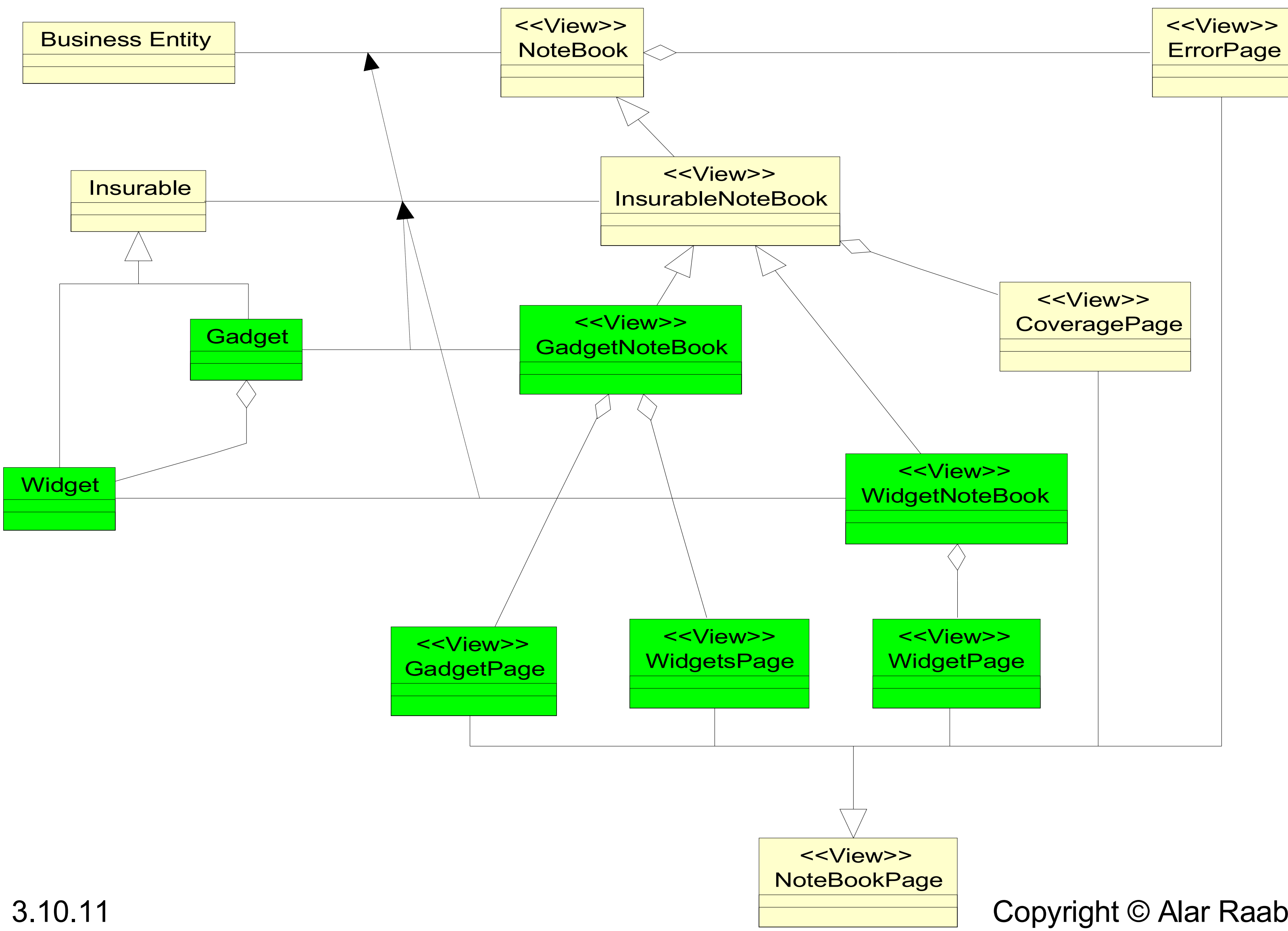
“Gadget Insurance” Model as Extension to Insurance Domain Model



“Gadget Insurance” Product Model



"Gadget Insurance" Design Model



Once&Done – Results

- Reduction of development time
  - standard functionality generated from model
  - some parts of the model interpreted at run-time
- Quality of developed code
  - generated code had hints for developers
  - regeneration forced to conform to architecture
- Flexibility of resulting systems
  - business people were able to maintain parameters
- Technology independence of domain knowledge
  - easy transition from C/C++ client-server to
    - Java-based Rich Client, furter
    - HTML-based web-application

Comparing Model-Driven Method with Traditional

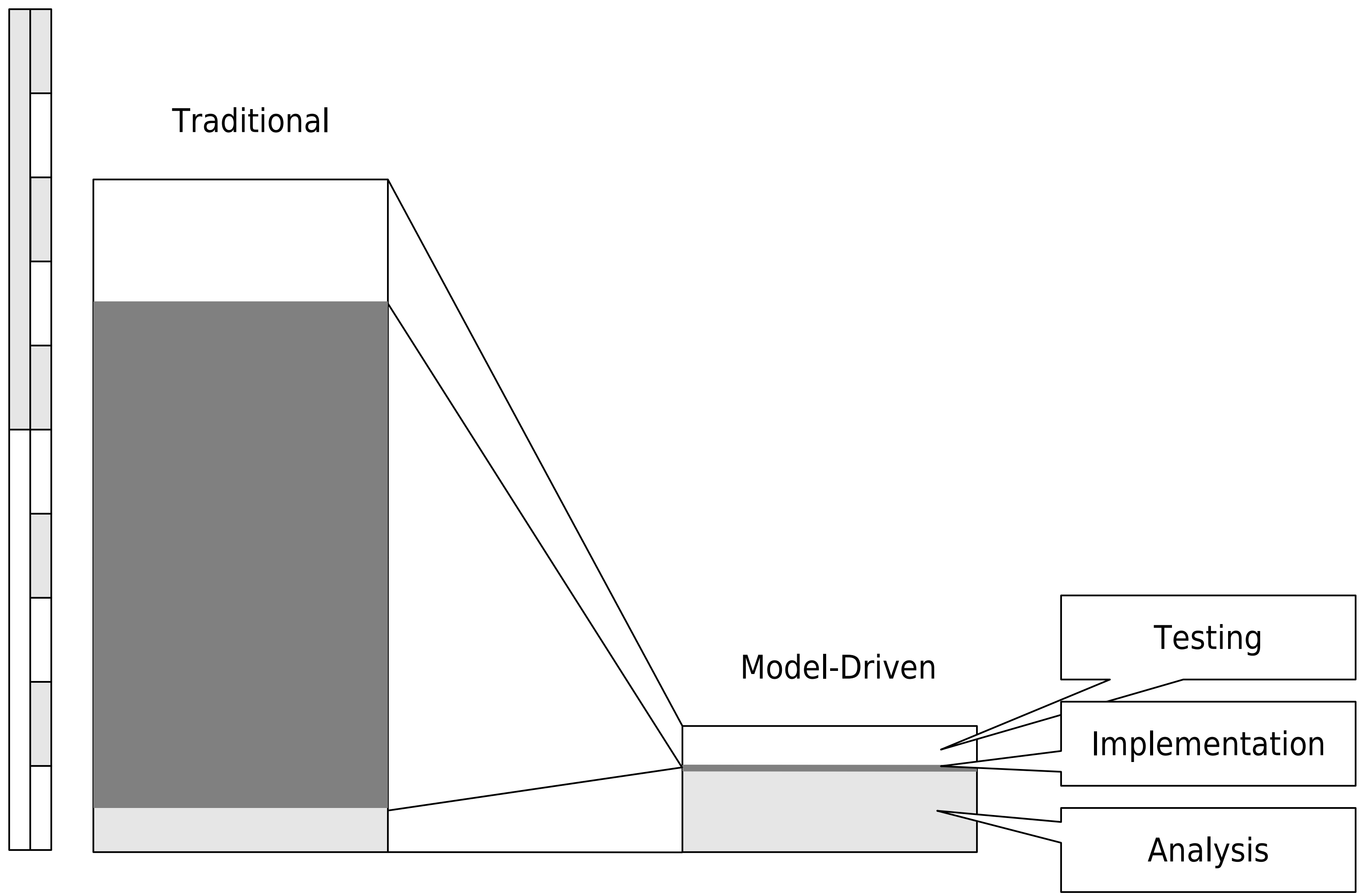
- Effort for First Iteration – Basically CRUD Application

- Manually coded Claims application
  - Volume
    - Domain Model: 30 entities, 30 relationships
    - Functionality: 10 use-cases (CRUD excl.)
    - User Interface: 34 screens
  - Effort: ~800 man-days (~50 analysis, ~550 implementation)

- Generated Claims application
  - Volume
    - Domain Model: 20 entities, 45 relationships
    - Functionality: 15 use-cases (CRUD excl.), 20 business rules
    - User Interface: 25 screens
  - Effort: ~130 man-days (~80 analysis, ~2 implementation)

- Generated Claims was regenerated on different platform

Comparing Model-Driven Method with Traditional



Lessons Learned

- Modeling is hard work and requires domain knowledge
- Project budget structure changes when using generation
- Generated system can be used as analysis tool
- Repository is good for concurrent work, analysis and synthesis, model checking and transformations, but has problems with versioning and version management
- Textual models can be versioned as code, but this is not best for concurrent work with graphical models
- Interpreters of meta-info (heavily parametric software components) are very difficult to debug – here generation/compilation is better

RISLA – Language for Product Models

- Started 1990 – CAP, MeesPierson, ING, CWI
- Describes interest rate products
  - Characterised by cash-flows

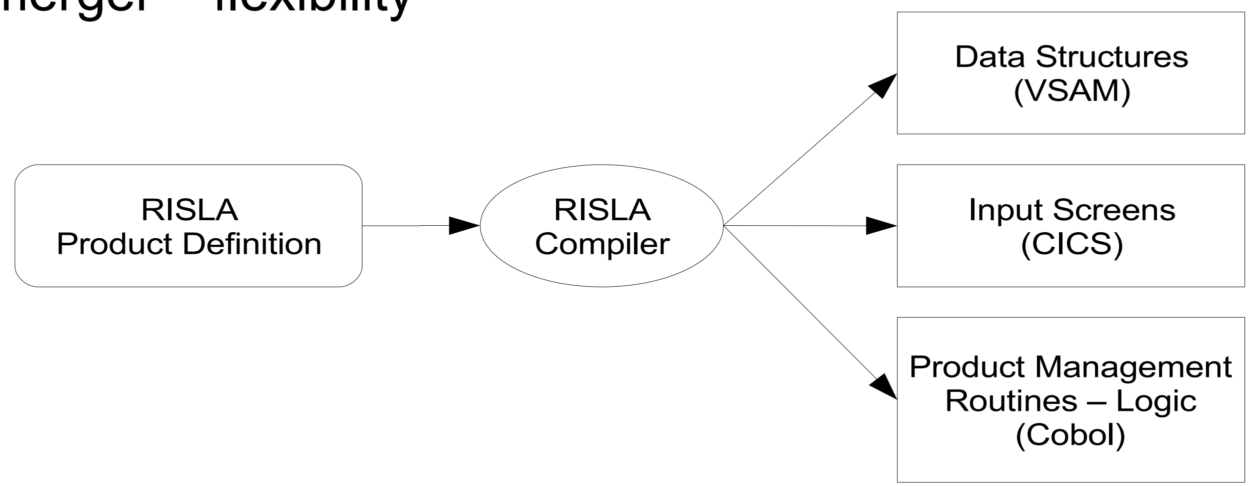
- Generates
  - Database
  - User Interface
  - Product Logic

- Example:
  - Loan

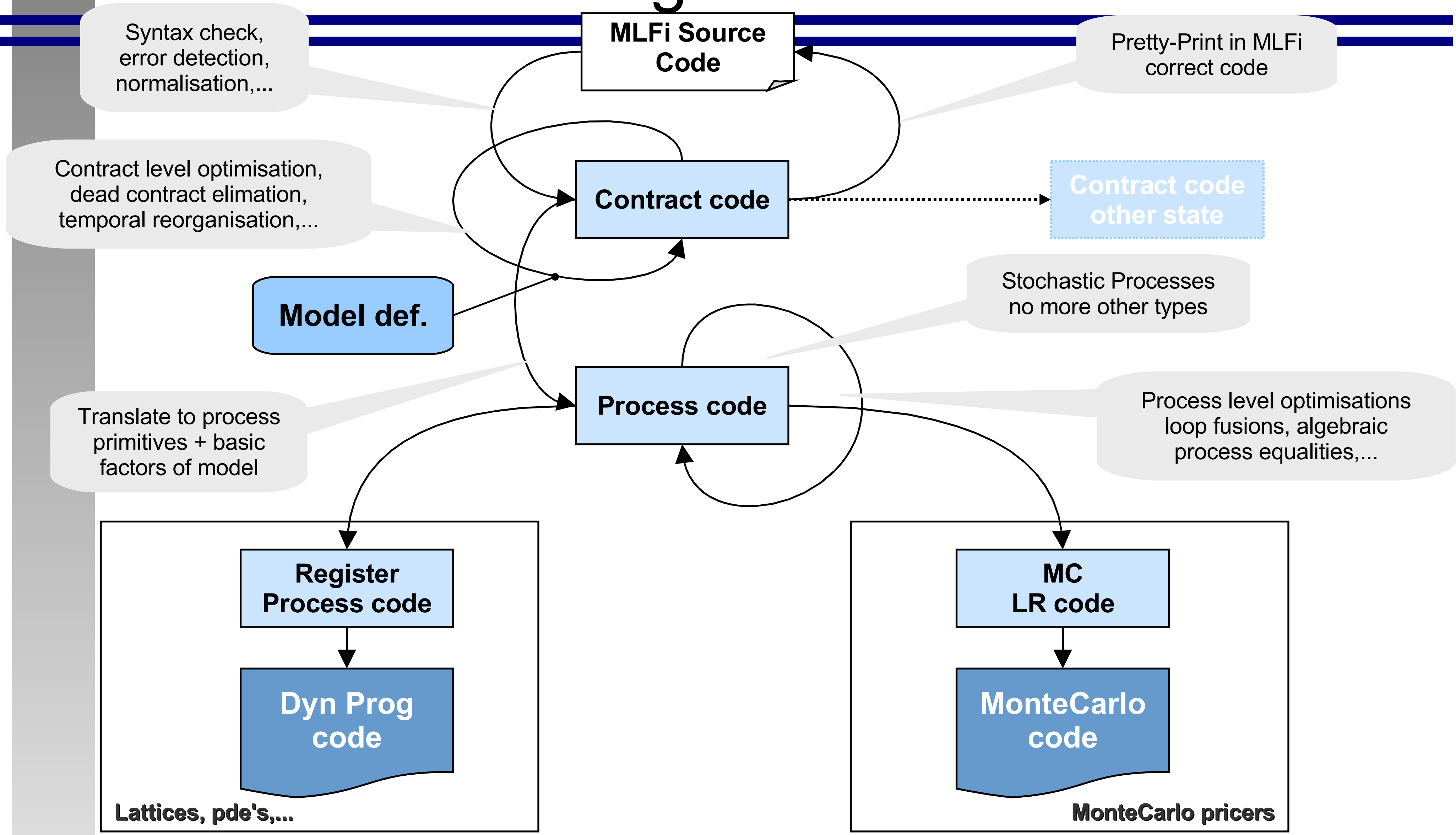
```
product LOAN

declaration
  contract data
    PAMOUNT : amount                   %% Principal Amount
    STARTDATE : date                   %% Starting date
    MATURDATE : date                   %% Maturity data
    INTRATE : int-rate                 %% Interest rate
    RDMLIST := [] : cashflow-list      %% List of redemptions.

  information
    PAF : cashflow-list                %% Principal Amount Flow
    IAF : cashflow-list                %% Interest Amount Flow

  registration
    %% Register one redemption.
    RDM(AMOUNT : amount, DATE : date)

...
```

RISLA – Result

- Success
  - Business people use – appropriate level of abstraction
  - Time to market decreased from 3 months to 3 weeks
  - Library of 100 components and 50 products
  - Survived merger – flexibility



Generating Code for Financial Instrument Agreement Valuation



Financial Instrument Models in MLFi

- American Option

```
american : (date * date * contract) -> contract
american(t1, t2, u) =
         anytime({[t1, t2]}, zero, u)
```

- Zero Coupon

```
one : currency -> contract
(* if you acquire the contract (one k), then
 you acquire one unit of k. *)

scale : (observable * contract) -> contract
(* if you acquire scale(o, c), then you acquire
 c, but where all incoming and outgoing payments
 are multiplied by the value of o at acquisition
 date. *)

obs_from_float : float -> observable
(* obs_from_float k is an observable always equal to k *)
```

Contract Model in MLFi

- Custom-built Contracts

```
let option1 =

  let strike = cashflow(USD:2.00, 2001-12-27) in

  let option2 =

    let option3 =
      let t = 2001-12-18T15:00 in
      either
        ("--> GBP payment", cashflow(GBP:1.20, 2001-12-30))
        ("reinvest in EUR + receive cash later",
         (give(cashflow(EUR:1.00, t))) 'and' cashflow(EUR:3.20, 2001-12-29))
        t in

    either
      ("--> EUR payment", cashflow(EUR:2.20, 2001-12-28))
      ("wait for last option", option3)
      2001-12-11T15:00 in

  (either
     ("--> USD payment", cashflow(USD:1.95, 2001-12-29))
     ("wait for second option", option2)
    2001-12-04T15:00) 'and' (give (strike))
```

Content

- Introduction
    - Common Language – some Definitions
    - The Problem
    - Beginning (Excursion into the History)
- Models in Software Development
  - Direct Modeling
    - Convergent Engineering
    - Domain-Driven Design
  - Models as Primary Artifacts
    - Generative Programming
    - Domain Specific Languages
    - Model-Driven Development Methods
- Practical Aspects
    - Model Management
    - Best Practices
    - Examples
- Conclusions
- References

Conclusions

- **No Round-Trips**
  – when you are Model-Driven, **models are primary artifacts (models are your code)**
- **Model is Not the Picture**
  – model is a collection of structured information in the form, which is best fore given Domain (**pictures should be Model-Driven**)
- **Keep Focus, Don't Mix Domains (fight Complexity)**
  – to represent information about problems/solutions in different Domains **use several Models with different Meta-Models**
- **Let the Models drive the Analysis & Design**
  – models are **the ubiquitous language** for stakeholders
- **This is not a Religion !**
  – use Model-Driven Approaches **only where it makes sense** and brings value

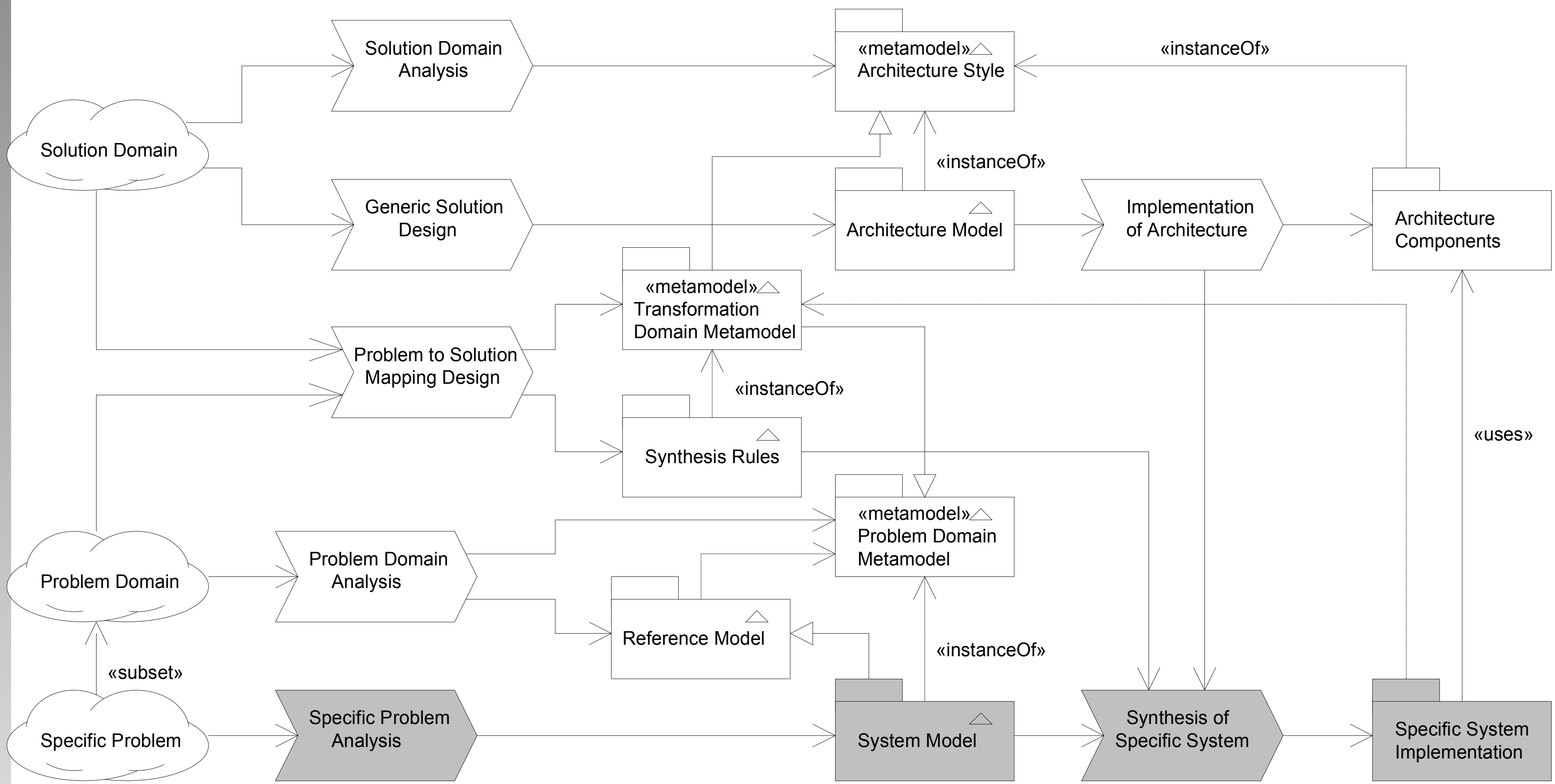
References

- Some books to read
  - Krzysztof Czarnecki and Ulrich W. Eisenecker, Generative Programming - Methods, Tools, and Applications, 2000
    - http://www.generaative-programming.org/
  - Tom Stahl, Markus Völter, Model-Driven Software Development: Technology, Engineering, Management, 2006
    - http://www.voelter.de/publications/books-mdsd-en.html
  - Eric Evans, Domain-Driven Design: Tackling Complexity in the Heart of Software, 2004
    - http://domaindrivendesign.org/
- Some WWW sites to look
    - http://www.omg.org/mda
    - http://www.eclipse.org/modeling/emf/
    - http://www.infoq.com/minibooks/domain-driven-design-quickly
    - http://www.andromda.org/
    - http://www.openarchitectureware.org/
    - http://www.voelter.de/services/mdsd-tutorial.html
    - http://www.martinfowler.com/bliki/dsl.html
    - http://www.prakinf.tu-ilmenau.de/~czarn/gpsummerschool02/

Thank You!

Questions?

Steps of Model-Oriented Software Development



MDSD Benefits (1)

- Reasons for MDSD
  - domain experts can formally specify their knowledge
  - need to provide diffierent implementations of the same model
  - need to capture knowledge about the domains and their mapping
  - separate functionality from implementation details
  - same model is source for several targets (consistency)
  - domain specific product-lines and software system families
- Benefits MDSD
  - models directly represent domain knowledge – are free from implementation artifacts (sepration of concerns)
  - generation for various platforms is possible
  - experts of different domains don't interfere
  - domain experts are directly involved in development
  - due to automation development is more efficient
  - enforcement of architectural constraints/rules/patterns
  - cross-cutting concerns are easily addressed by generators

MDSD Benefits (2)

- Benefits for Quality
  - explicit, well-defined architecture is needed
  - transformations capture expert knowledge
  - architecture defines strict programming model for manually developed parts
  - generator doesn't produce accidental/random errors
  - documentation is always up-to-date
- You are forced to
  - do domain/application scoping
  - do variability management
  - create well-defined architecture
  - understand domain and target architecture

MDSD Costs

- You need aditional skills
  - domain analysis
  - metamodeling
  - generator development
  - architecture
- Development process is more complex
  - domain architecture development
  - application development

Examples of 4 Layers of Models

- M_3 – meta-metamodel
  - a language for compilers – Yacc language syntax definition (maybe in Yacc or in EBNF)
  - XML definiton in EBNF
- M_2 – metamodel
  - C language syntax definition in Yacc (".y" file)
  - XSD schema definition in XSD (or in DTD)
- M_1 – model
  - program in C (".c" file)
  - schema definition in XSD (or in DTD)
- M_0 – an instance of a model
  - executable code
  - XML file

Definitions 1

- System
  - a collection of interacting components organized to accomplish a specific function or set of functions within a specific environment
- Interface (Connection)
  - a shared boundary between two functional units, defined by various characteristics of the functions
  - component that connects two or more other components for the purpose of passing information from one to the other
- Module (Component)
  - a logically separable part of a system
- Encapsulation
  - isolating some parts of the system from the rest of the system
  - a module has an outside that is distinct from its inside (an external interface and an internal implementation)

Definitions $_2$

- Modularity
  - the degree to which a system is composed of discrete components such that a change to one component has minimal impact on other components
  - the extent to which a module is like a black box
- Coupling
  - the manner and degree of interdependence between modules
  - the strength of the relationships between modules
  - a measure of how closely connected two modules are
- Cohesion
  - the manner and degree to which the tasks performed by a single module are related to one another
  - a measure of the strength of association of the elements within a module

Definitions $_3$

- Model
  - an interpretation of a theory for which all the axioms of the theory are true
  - a semantically closed abstraction of a system or a complete description of a system from a particular perspective
  - anything that can be used to answer questions about system
      - to an observer B, an object M_A is a model of an object A to the extent that B can use M_A to answer questions that interest him about A
        Marvin Minsky
      - M is a model of A with respect to question set Q if and only if M may be used to answer questions about A in Q within tolerance T
        Doug Ross