TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Informatik, Institut für Software- und Multimediatechnik, Lehrstuhl für Softwaretechnologie

# 20 Design Methods - An Overview


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- http://st.inf.tu-dresden.de/teaching/swt2

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1. From Requirements to Design
2. What is a Design Method?
3. Overview of Design Methods
    1. Functional Development
    2. Action-Based Development
    3. Component-Based Development
    4. Data-Oriented Development
    5. Object-oriented Development
    6. Transformative Development
    7. Generative Development
    8. Model-Driven Software Development
    9. Formal Methods
    10. Aspect-oriented Development
4. Other Architectural Styles
5. Design Heuristics and Best Practices

# Obligatory Readings

- Pfleeger Chapter 5
- Ghezzi Chapter 3

# Secondary Literature


- [Thayer] Richard Thayer. Software Engineering. A curriculum book. IEEE Press
- [Budgen] David Budgen. Software Design: An Introduction. In [Thayer]
- [Thayer&McGettrick] Richard Thayer, Andrew McGettrick. Software Engineering - A European Perspective. IEEE Press
- [Parnas] David Parnas. On the Criteria To Be Used in Decomposing Systems into Modules. Communications of the ACM Dec. 1972. The classic article on modularity
- [Brooks] Frederick P. Brooks jr. No Silver Bullet. Essence and Accidents of Software Engineering. In [Thayer]. Wonderful article on what software engineering is all about
- Heise Developer Podcast http://www.heise.de/developer/podcast/

# Literature

- [Budgen] David Budgen. Software Design. Addison-Wesley. Expands on the Budgen paper. Pretty systematic.
- [Shaw/Garlan] Software Architecture. 1996. Prentice-Hall. Great book for architects.
- [Shaw/Clements] M. Shaw, P. Clements. A Field Guide to Boxology.
- [Endres/Rombach] A. Endres, D. Rombach. A Handbook of software and systems engineering. Empirical observations, laws and theories. Addison-Wesley. Very good collection of software laws. Nice!

- Get an overview on the available methods to come from a requirements specification to the design
- Understand that software engineers shouldn't get stuck by a specific design method

- You are a project manager in Miller Car Radios, Inc
- Your boss comes into your office and says:

"Our competitor Smith Car Radios has a new satellite radio. Their sales are growing, and our customers demand it, too. How quickly can you deliver me a satellite radio?"

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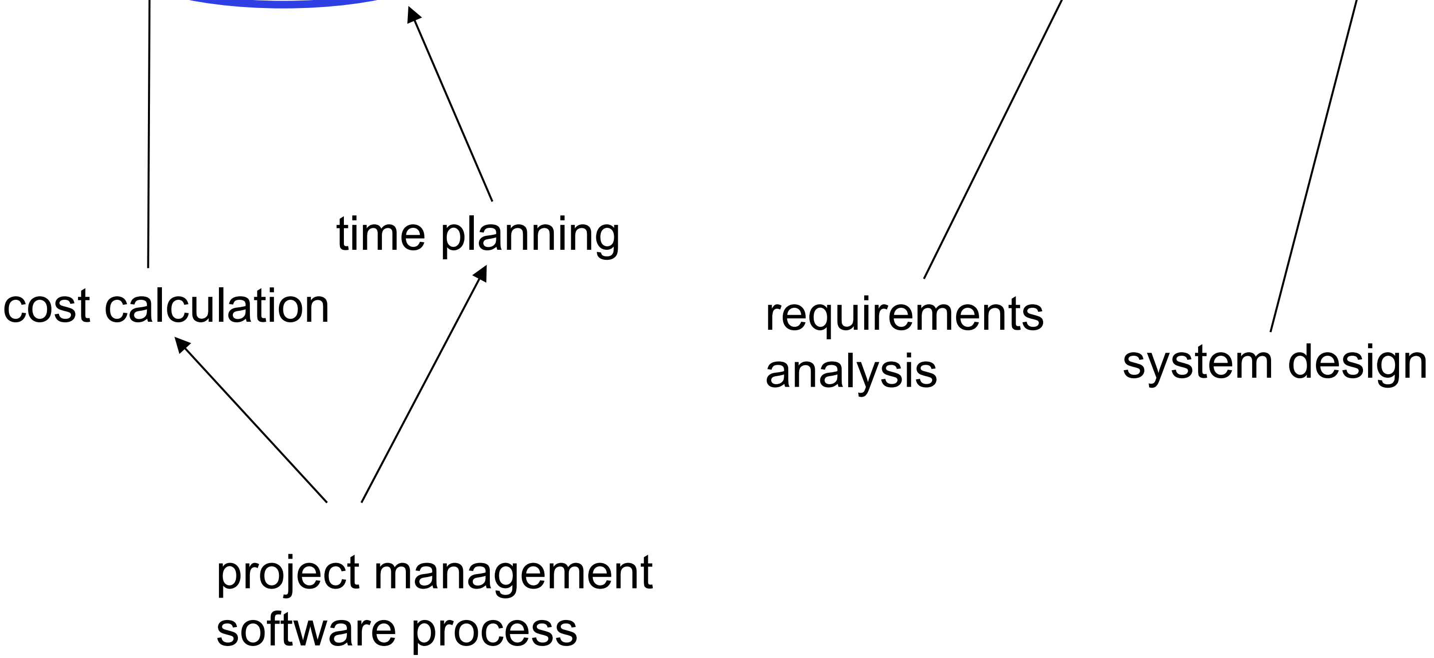
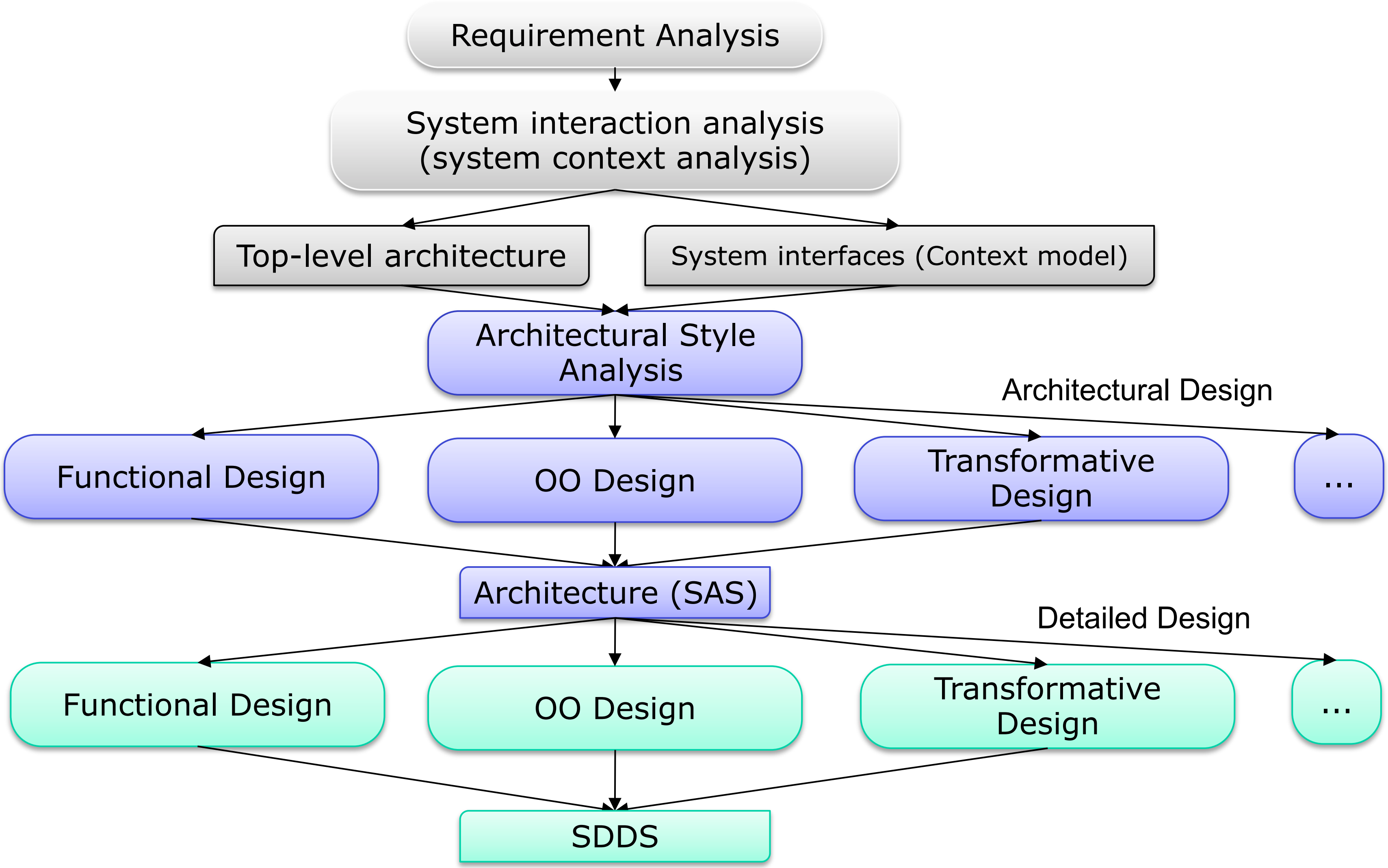


# The Ideal Design Process

- "Design produces a workable solution to a given problem" [Budgen]
- "Design is the description of a solution" [Pfleeger]
- "The Design Process is the creative process of transforming the problem into a solution" [Pfleeger]
- Goal: This lecture presents some systematic ways how to come to a workable solution for a given problem


Requirement Analysis
System interaction analysis
(system context analysis)
Top-level architecture
System interfaces (Context model)
Architectural Style
Analysis
Architectural Design
Functional Design
OO Design
Transformative
Design
...
Architecture (SAS)
Detailed Design
Functional Design
OO Design
Transformative
Design
...
SDDS

- The Software Requirement Specification (SRS) contains a list of things the system has to fulfill
- Example [Richard Fairley, Software Engineering]

- Usually, specification languages are the same or similar for requirements  and design

- Overview of Product
- *Background, Environment*
- *Interfaces of the System (context model)*
  - I/O interfaces, data formats (screens, protocols, etc.), Commands
  - Overview of data flow through system, Data dictionary
- *Functional requirements*
- Non-functional requirements
- *Error handling*
- Prioritization
- *Possible extensions*
- Acceptance test criteria
- Documentation guideline
- Literature
- Glossary

- Conceptual abstraction level
  - Conceptual instead of technical
  - Coarse grain instead of detailed
- Design dimensions
  - Structure (part-of relations, is-a relations)
  - Function (types, interfaces)
  - Behavior
- System components and their interfaces
  - Contract specifications of modules: how to use a module?
  - What should it take, what deliver (pre- and postconditions)
- Component relations
  - Uses, is-a, part-of, behaves-like
  - Connections
- Architectural styles (architectural patterns)
  - Coarse grain patterns of the architecture in terms of control flow and data flow
  - Constraints of modules, relations, and connections
- Design patterns
  - Micro-structures in the design model, mostly on the collaboration of 2-5 classes

# Contents of Detailed Design Document (SDDS)

- SDDS = Software Detailed Design Specification

- Fine-grained design
  - Technical instead of conceptual
  - Sketch of the implementation with pseudo code, statecharts, petri nets, or other design notations
  - Behavioral model
  - Tells more about the HOW, without giving the implementation

# 20.2 DESIGN METHODS

# A Software Design Method (aka Development Method)

… has 3 components [Budgen]:

1. Representation part (notation, language)
   - Set of notations in (informal) textual, (semi-formal) diagrammatic, or mathematic (formal) form
2. Process model ("Vorgehensmodell", "Prozessmodell")
   - Design strategy: A basic design question (focus of refinement)
   - Restructuring methods
   - Consistency checking
3. Set of heuristics
   - General rules of thumb
   - Process-specific rules
   - Process patterns
   - Design patterns
   - Adaptation rules

# 20.2.1 Design Representations

# Design Languages

| | Text | Diagrams | Math |
|---|---|---|---|
| Specification Languages: Paper Specification Languages | Informal<br>Natural language<br>Pseudo-code | Flow chart<br>Data-flow Diagram<br>Entity-Relationship<br>Diagram ER | Vienna Development<br>Language VDL/VDM<br>Z<br>B |
| Specification Languages: Executable Specification Languages | Parseable natural language | Colored Petri nets<br>State machines<br>UML<br>Structure Diagram | Larch (with prover)<br>CSP<br>CCS |
| Programming Languages | ELAN<br>SETL<br>Java<br>Scala<br>C# | Statecharts<br>Workflow languages (BPEL, BPMN)... | Modelica<br>Metamodelica<br>Matlab<br>Simulink |

Generic steps

# 20.2.2 DESIGN PROCESSES

- A **design process** is a structured algorithm (or workflow) to achieve a design model from a requirement specification
  - A sequence of steps
  - A set of milestones
- The design process starts from *the system's interfaces (context codel)* and refines its internals
- Every design process
  - Contains several central generic steps
  - Uses general design strategies
  - Ends up in a specific *architectural style*
- Design processes belong to software development methods/ processes
  - Together with requirements, testing etc.

# Repetition: Generic Steps in Design Processes

Every design process contains some generic steps

- Elaboration
  - Work out a certain aspect of the design model, using an appropriate design notation
- Refinement
  - Refine an existing specification/model, replacing abstract parts by details, e.g., add platform-specific details
  - Retain *refinement conditions* such as embedding
  - Abstraction is the opposite of refinement
- Checking Consistency
  - Checking business rules and context constraints
- Restructure (more structure, but keep semantics)
  - Split (decompose, introduce hierarchies, layers, reducibility)
  - Coalesce (rearrange)
- Symmetry operations (semantics-preserving, restructuring):
  - Semantic refinement
  - Refactoring
  - Change Representation (Notation):
    - Simplification (factoring, transitive reduction, facading)
    - Change representation, but keep semantics
    - Transform a certain representation of the model into another one

# Development Operations of Design Methods

- Every notation has elaboration, refinement, checking, and structuring operations
- Hand operations
  - Split (decompose, introduce hierarchies, layers, reducibility
  - Coalesce (rearrange)
- Automatic operations
  - Graph analysis methods, such as constraints
  - Graph structuring methods, e.g., graph analysis or transformations
  - Text-based specifications can be transformed into ASGs and then structured by graph structuring methods
  - Some notations have specific automatic methods

# 20.2.2.1 Architectural Styles as Results of Design Processes

# Denert's Law on Architectural Styles

- Ernst Denert. Software Engineering. Springer, 1991.
- Consequence of Denert's law:
  - if we can split off a concern in an application domain, we arrive at a new standard architecture (architectural style)

**Separation of concerns leads to standard architectures.**

**E. Denert, 1991**

- An **architecture style** employs certain types of concepts
  - Certain types of components with
  - Certain types of connections/connectors
  - And a certain relation between control and data flow
- Architectural styles enable us to talk about the coarse-grain structure of a system
  - Good for documentation and comprehension
  - Good for maintenance
- Architectural Styles vs Design Patterns
  - Design patterns have been called *microarchitectures*
    - They grasp a relationship between several classes of an application, but not of the entire architecture or subsystem
  - Architectural styles are *coarse-grain design patterns*

## What Is In a Style ?

- A style has 5 major concerns, in which it can vary [Shaw/Garlan]
  - **Structural Parts**: components, interfaces (ports), connectors, classes, objects, modules
  - **Control flow**
    - Topology (in which form coordination taken place?)
    - Synchronisation (synchronous, asynchronous)
    - Binding time (When are the components organized?)
  - **Data flow**
    - Topology (How does the data flow?)
    - Continuity (singular, sporadic, continuous, strong, weak)
    - Modus (shared memory, messages, ..)
  - **Interaction** between control- and data flow
    - Isomorphic similar to a data structure
    - Direction (parallel, antiparallel)
  - **Invariants**
    - Features that never change
  - **Analysis features**
    - How can be architecture be analyzed?

# The Design Problem

- How do I derive at a design for the system?
  - How do I derive at an architectural style for the system?
  - How do I derive a detailed design?
- Most often, after reading the requirements, the system looks like in mist
  - Developers have a bad feeling in their stomach
  - They *feel* their way forward
  - Important is: which questions are asked?
- In design meetings, the basic design questions are posed over and over again, until a design is found
  - Select a design method
  - Pose the design method's basic question
  - Perform the design method's process
    - Perform the design method's steps
  - If process gets stuck, change design method and try another one
    - However, be aware, which design method and process you use

# Design Processes have a Focus of Elaboration and Refinement

- A central *viewpoint* with a *set of concerns*, according to which the system is elaborated
  - Decomposed
  - Refined
  - composed
- An elaboration strategy
- The central question

# 20.3 Overview of Elaboration Strategies

- A design method relies on a **elaboration strategy,** including a basic question the developer has to pose himself, or the team asks itself
- A different question gives a different design method
- Methods can be grouped according to their focus of decomposition and the design notation they use.
  - **Function-oriented**: function in focus
  - **Action-oriented, event-action-oriented:** Action in focus
  - **Data-oriented**: A data structure is in focus
  - **Component-oriented (structure-oriented**): parts in focus
  - **Object-oriented**: objects (data and corresp. actions) in focus
  - **Transformational**: basic action is the transformation
  - **Generative:** basic action is a special form of transformation, the generation. Also using planning
  - **Formal methods**: correct refinement and formal proofs in focus
  - **Aspect-oriented methods:** refinement according to viewpoints and concerns

- Design with functional units which transform inputs to outputs
  - Minimal system state
  - Information is typically communicated via parameters or shared memory
  - No temporal aspect to functions
- Functions/operations are grouped to *modules* or *components*
- Divide: finding subfunctions
- Conquer: grouping to modules
- Examples
  - Parnas' change-oriented design (information-hiding based design, see ST-1)
  - Layered abstract machines (see ST-1)
- Use: when the system has a lot of different functions

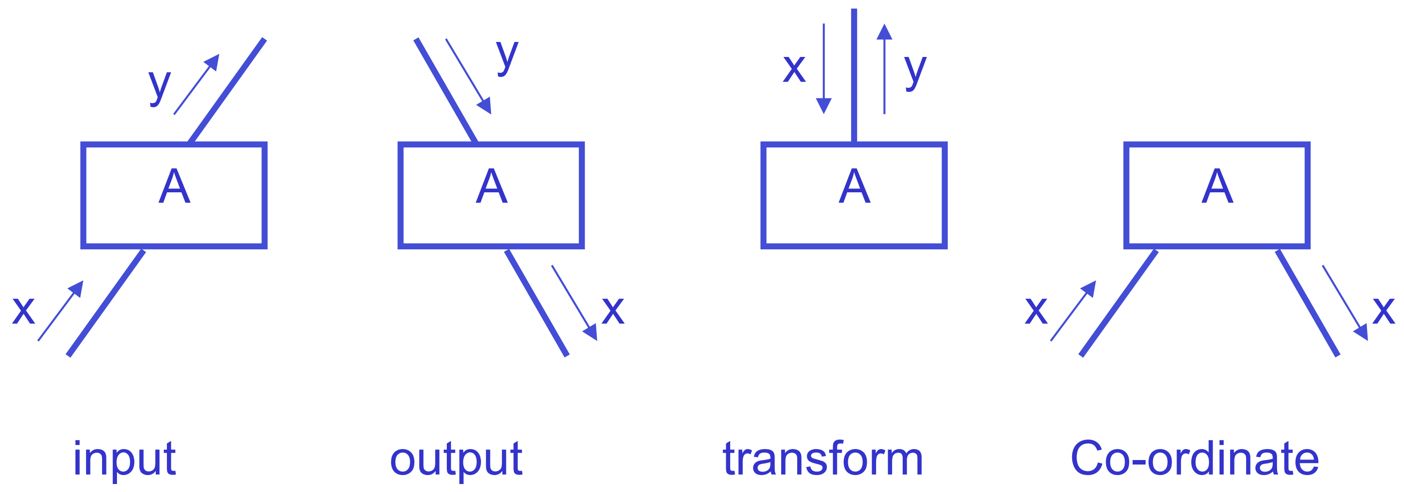
**What are the functions of the software and their subfunctions?**

- "Divide and Conquer" of function
- Decompose system into smaller and smaller pieces
  - Ideally, each piece can be solved separately
  - Ideally, each piece can be modified independent of other pieces
- Reality: each piece must communicate with other pieces
  - This communication implies a certain cost
  - At some point the cost is more than the benefit provided by the individual pieces
  - At this point, the decomposition process can stop

# 20.3.2) Action-Oriented Design

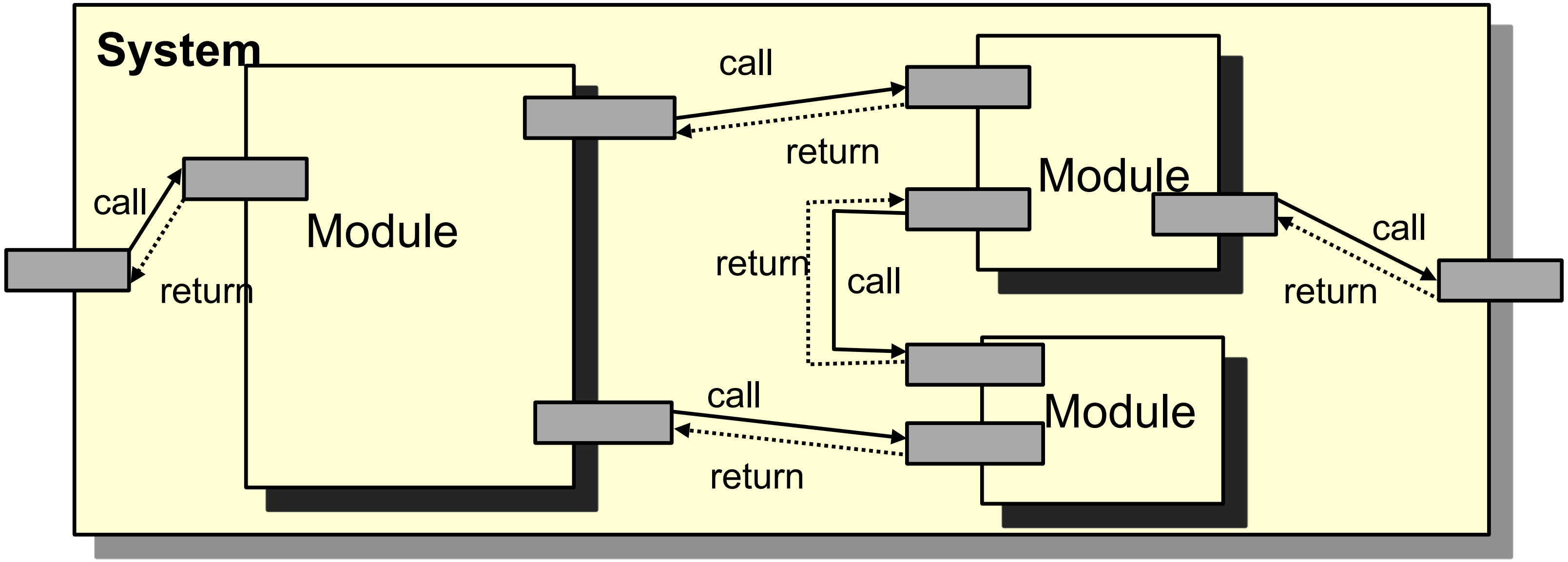
- Action-oriented design is similar to function-oriented design, but actions require *state* on which they are performed (imperative, state-oriented style)
- Divide: finding subactions
- Conquer: grouping to modules
- Examples:
  - Petri Nets
  - Use-case-based development
  - Data-flow based development SA, SADT
- Use: when the system maps to a state space, in which actions form the transitions

**What are the actions the system should perform?**


y
A
x
y
A
x
x
y
A
A
x
x
input
output
transform
Co-ordinate

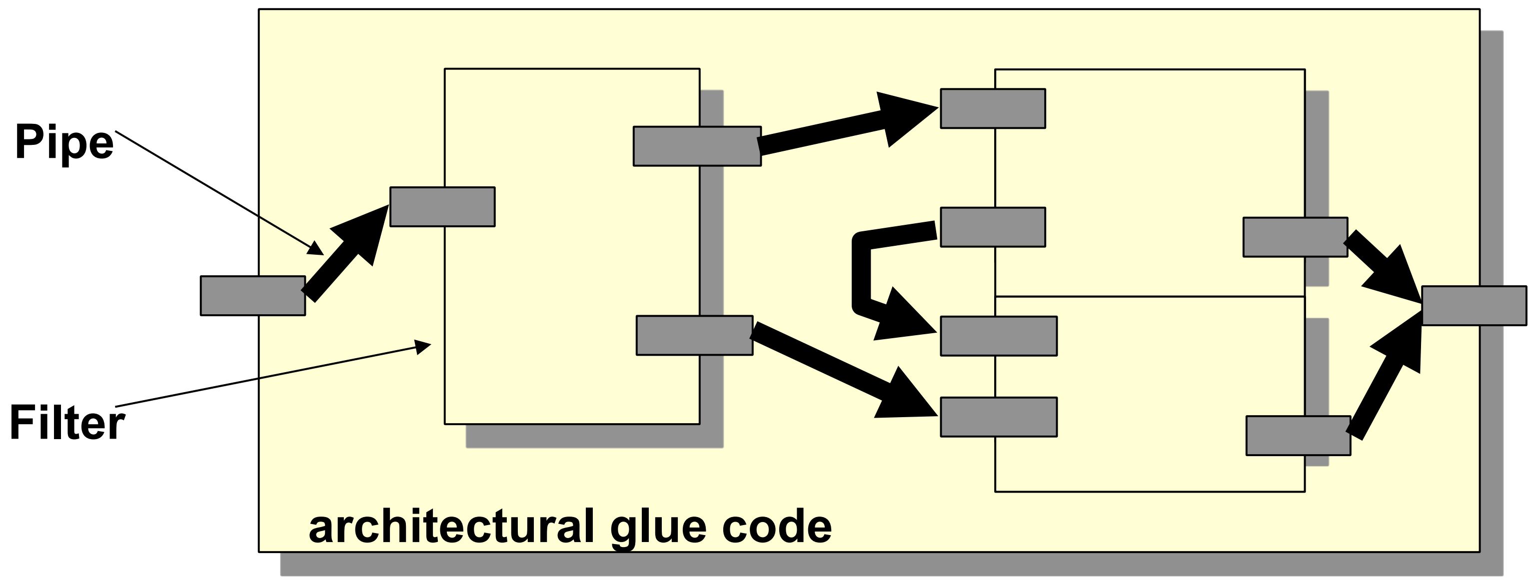
# Result 1: Call-Based Architectural Style

- Components denote procedures that call each other
- Control flow is symmetric (calls and symmetric returns)
- Data-flow can be
  - parallel the call (*push-based system*): caller pushes data into callee
  - antiparallel, i.e., parallel to the return (*pull-based system*): caller drags out data from callee
- Aka “Client-Server” in loosely coupled or distributed systems



# Result 2: Data-Flow Based Systems (Pipe-and-Filter, Channels, Streams)

- If data flows in streams, call-based systems are extended to *stream-based systems*
- Components: processes, connectors: streams
- Control flow is asynchronous, continuous
- Data-flow graph of connections, static or dynamic binding
- Data-flow can be parallel to the control-flow (*push-based system*) or antiparallel (*pull-based system*)




cat server.log | grep "Adding student"

Data-flow based systems:

- Image processing systems
  - Microscopy, object recognition
- Digital signal processing systems
  - Video and audio processing, e.g., the satellite radio
- Content management systems (CMS)
  - Data is stored in XML or relational format
  - Pipelines produce display format
- Batch-processing systems
- UNIX shell scripts provides untyped data flow (texts)
- Microsoft Power Shell provides typed data-flow, typed in XML

Call-based systems:

- Object-oriented frameworks
- Layered architectures

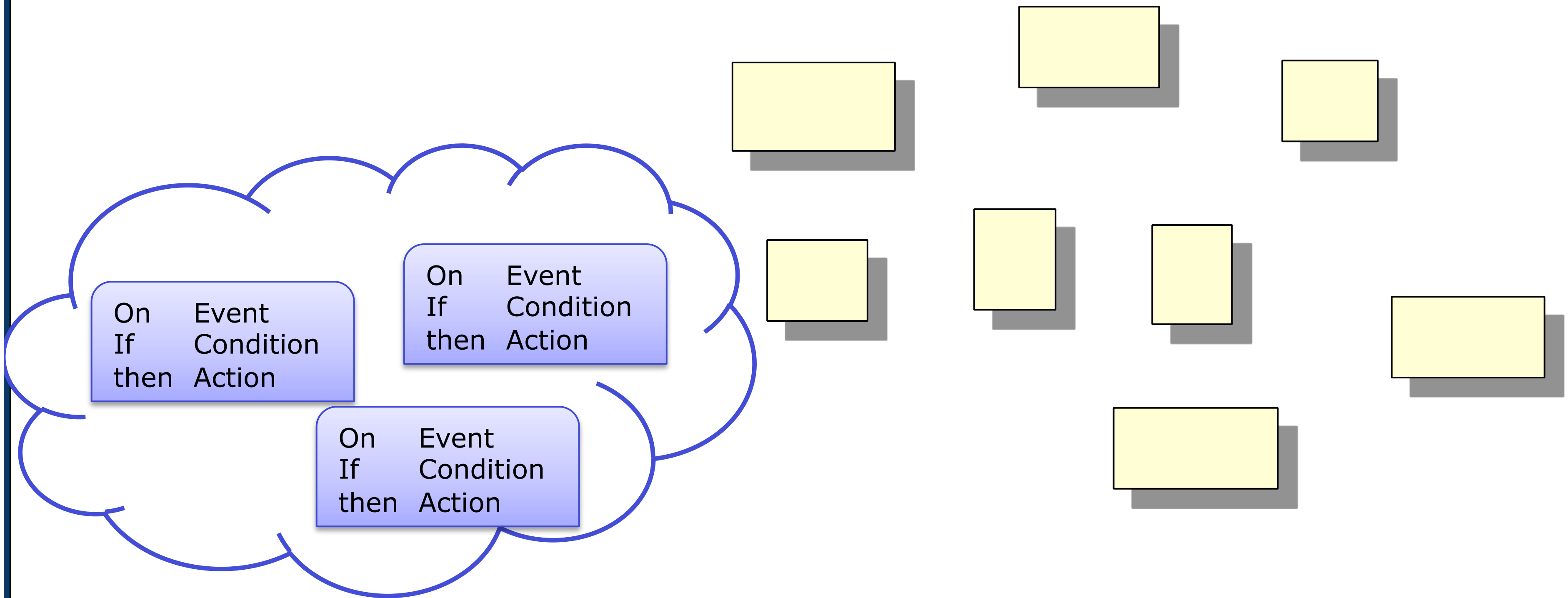
# 20.3.2.2) Event-Condition-Action-Oriented Design

- Event-condition-action rules (ECA rules)
  - On which event, under which condition, follows which action?
- Divide: finding rules for contexts
- Conquer: grouping of rules to rule modules
- Example:
  - Business-rule-based design (SBVR)
- Use: when the system maps to a state space, in which actions form the transitions and the actions are guarded by events

**What are the events that may occur and how does my software react on them?**

# Arch. Style: Event-based Architectural Style (Implicit Invocation Style)

- Components: processes or procedures
- Connectors: Anonymous communication by events
  - Asynchronous communication
  - Dynamic topology: Listeners can dynamically register and unregister
  - Listeners are *implicitly invoked* by events



# SBVR Example (OMG Business Rule Language)

current contact details

| | |
|---|---|
| Concept Type: | role |
| Definition: | contact details *of* rental that *have been confirmed by* renter *of* rental |

rental

| | |
|---|---|
| Definition: | contract that *is with* renter and *specifies use of a car of* car group and *is for* rental period and *is for* rental movement |

optional extra

| | |
|---|---|
| Definition: | Item that may be added to a rental at extra charge if the renter so chooses |
| Example: | One-way rental, fuel pre-payment, additional insurances, fittings (child seats, satellite navigation system, ski rack) |
| Source: | CRISG ["optional extra"] |

rental actual return date/ time

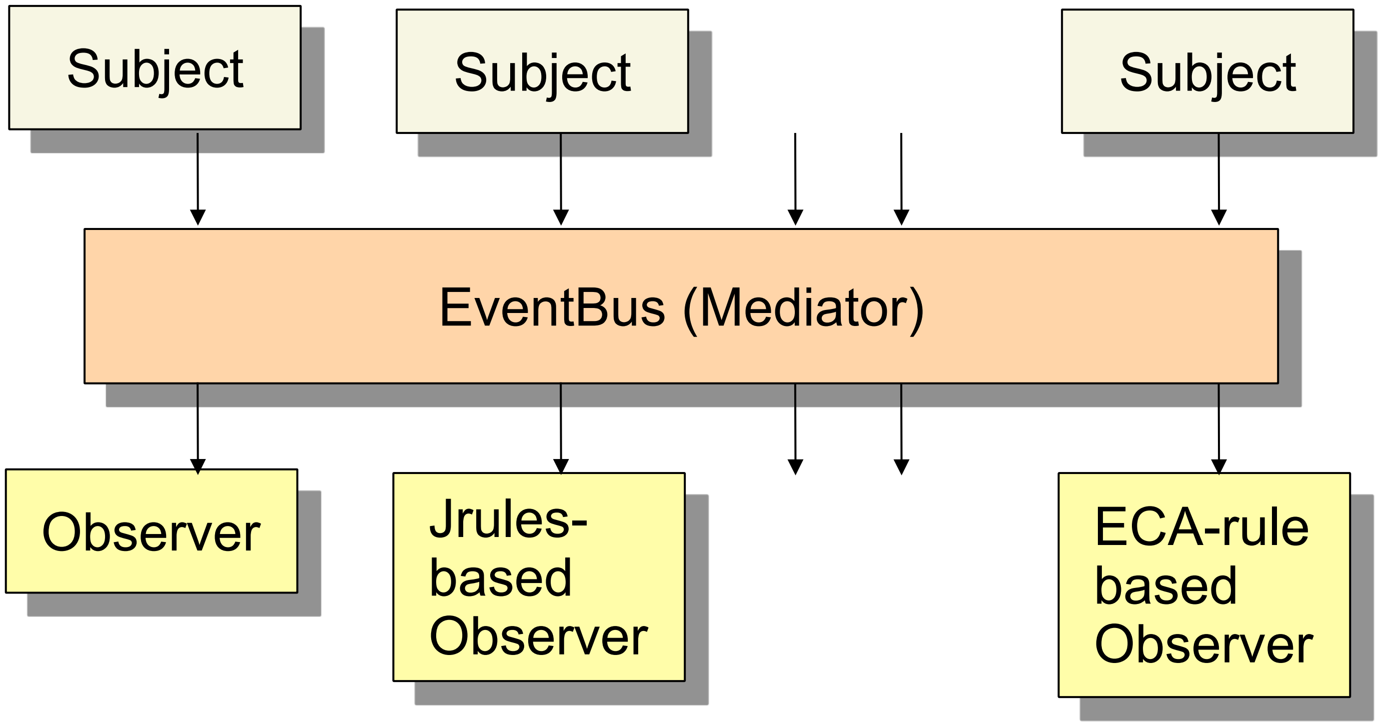
| | |
|---|---|
| Concept Type: | role |
| Definition: | date/time when rented car *of* rental *is returned to* EU-Rent |

rental *requests* car model

| | |
|---|---|
| Synonymous Form: | car model *is requested for* rental |
| Necessity: | Each rental *requests* at most one car model. |
| Possibility: | The car model *requested for* a rental *changes before* the actual pick-up date/time *of* the rental. |
| Necessity: | No car model *requested for* a rental *changes after* the actual pick-up date/time *of* the rental |

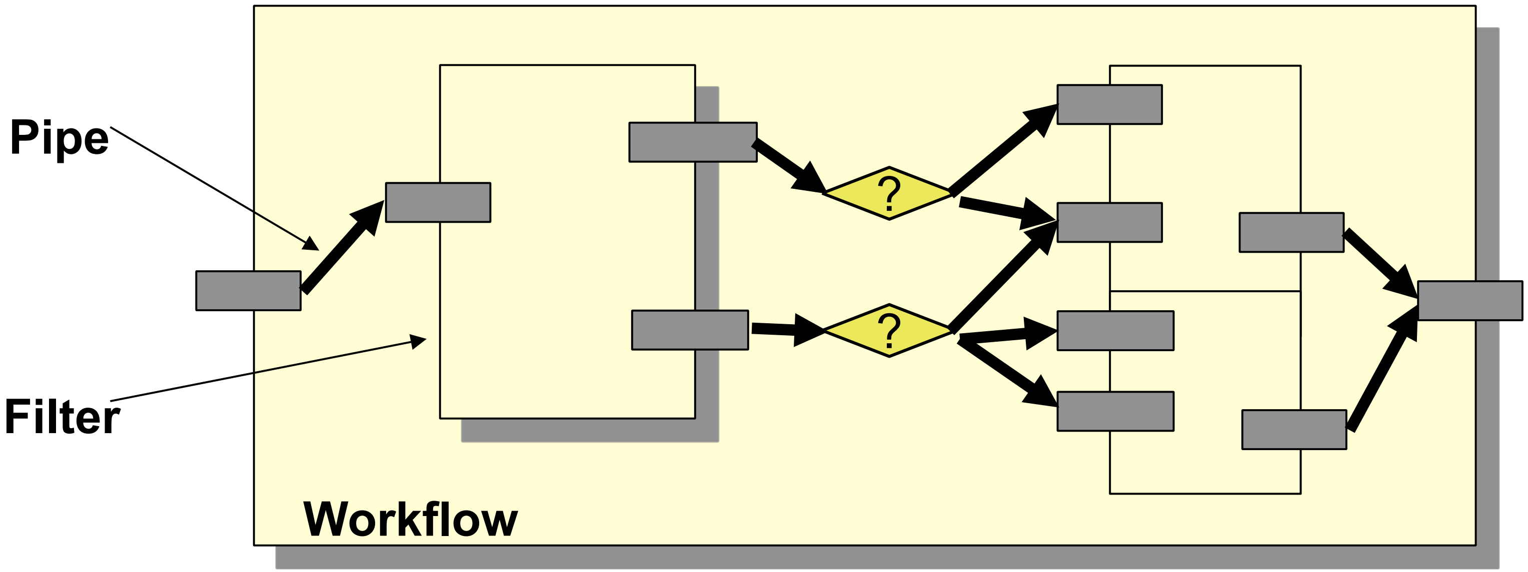
```
<rule name="Free Fish Food Sample">
   <parameter identifier="cart">
      <java:class>org.drools.examples.java.petstore.ShoppingCart</java:class>
   </parameter>
   <parameter identifier="item">
      <java:class>org.drools.examples.java.petstore.CartItem</java:class>
   </parameter>

   <java:condition>cart.getItems( "Fish Food Sample" ).size() == 0</java:condition>
   <java:condition>cart.getItems( "Fish Food" ).size() == 0</java:condition>
   <java:condition>item.getName().equals( "Gold Fish" )</java:condition>

   <java:consequence>
      System.out.println( "Adding free Fish Food Sample to cart" );
      cart.addItem( new org.drools.examples.java.petstore.CartItem( "Fish Food Sample",
    0.00 ) );
      drools.modifyObject( cart );
   </java:consequence>
</rule>
```

- Basis of many interactive application frameworks (XWindows, Java AWT, Java InfoBus, ....)
- See design pattern Observer with Change Manager



# Arch. Style: Workflow-Based Systems

- A *workflow* describes the actions on certain events and conditions
  - Formed by a decision analysis, described by ECA rules
- Instead of a data-flow graph as in pipe-and-filter systems, or a control-flow graph as in call-based systems
  - A control-and-data flow graph steers the system
  - The data-flow graph contains control-flow instructions (if, while, ..)
  - This *workflow graph* is similar to a UML activity diagram, with pipes and switch nodes
  - Often transaction-oriented



# Application Domains of Workflow Architectures

- Business software
  - The big frameworks of SAP, Peoplesoft, etc. all organize workflows in companies
- Production planning software
- Web services are described by workflow languages (BPEL)
  - More in course “Component-based Software Engineering”

# Arch. Style: Architectural Style of Communicating State Machines

- Processes can be modeled with state machines that react on events, perform actions, and communicate
- Model checking can be used for validation of specifications
- Languages:
  - Esterelle, Lotos, SDL
  - UML and its statecharts
  - Heteregenous Rich Components (HRC)
  - EAST-ADL

- *Protocol engineering*
  - Automatic derivation of tests for systems
- Telecommunication software
- Embedded software
  - In cars
  - In planes
  - In robots

# 20.3.3) Data-Oriented Design

- Data-oriented design is grouped around a input/output/inner data structure
  - or a language for a data structure (regular expressions, finite automata, context-free grammars, ...)
- The algorithm of the system is isomorphic to the data and can be derived from the data
  - Input data (input-data driven design)
  - Output data (output-data driven design)
  - Inner data
- Divide: finding sub-data structures
- Conquer: grouping of data and algorithms to modules
- Example:
  - Jackson Structured Programming (JSP)
  - ETL processing in information systems

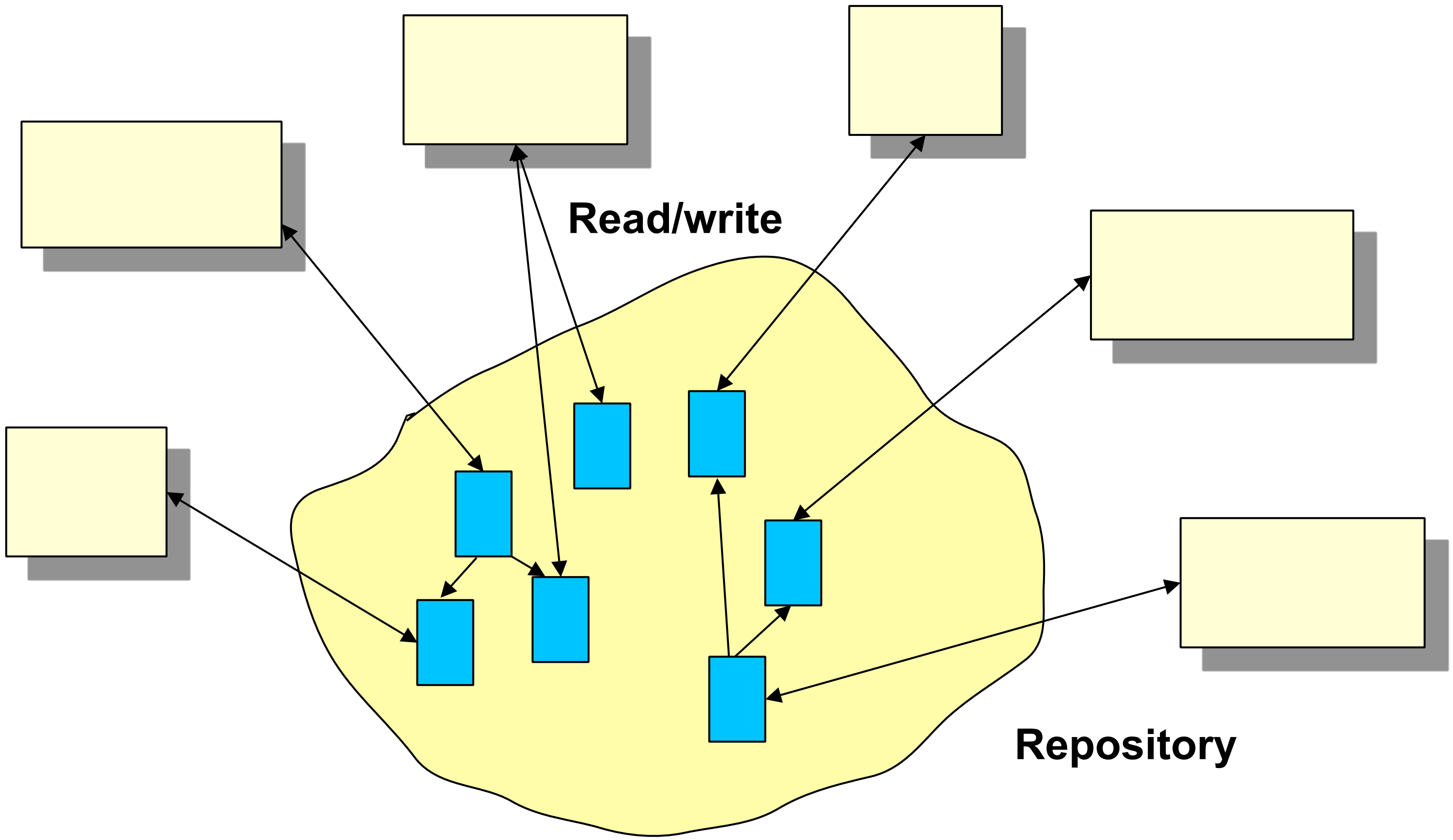
**What does the data look like?**

# Data-Flow Style: Regular Batch Processing (ETL Processing)

- *Regular Batch Processing* is a specific batch-processing style. In such an application, regular domains are processed:
  - Regular string languages, regular action languages, or regular state spaces
- The form of the data can be described by a
  - Regular expression, regular grammar, statechart, or JSP diagram tree
- Often transaction-oriented
- Example:
  - Record processing in bank and business applications:
    - Bank transaction software
    - Database transaction software for business
  - Business report generation for managers (controlling)

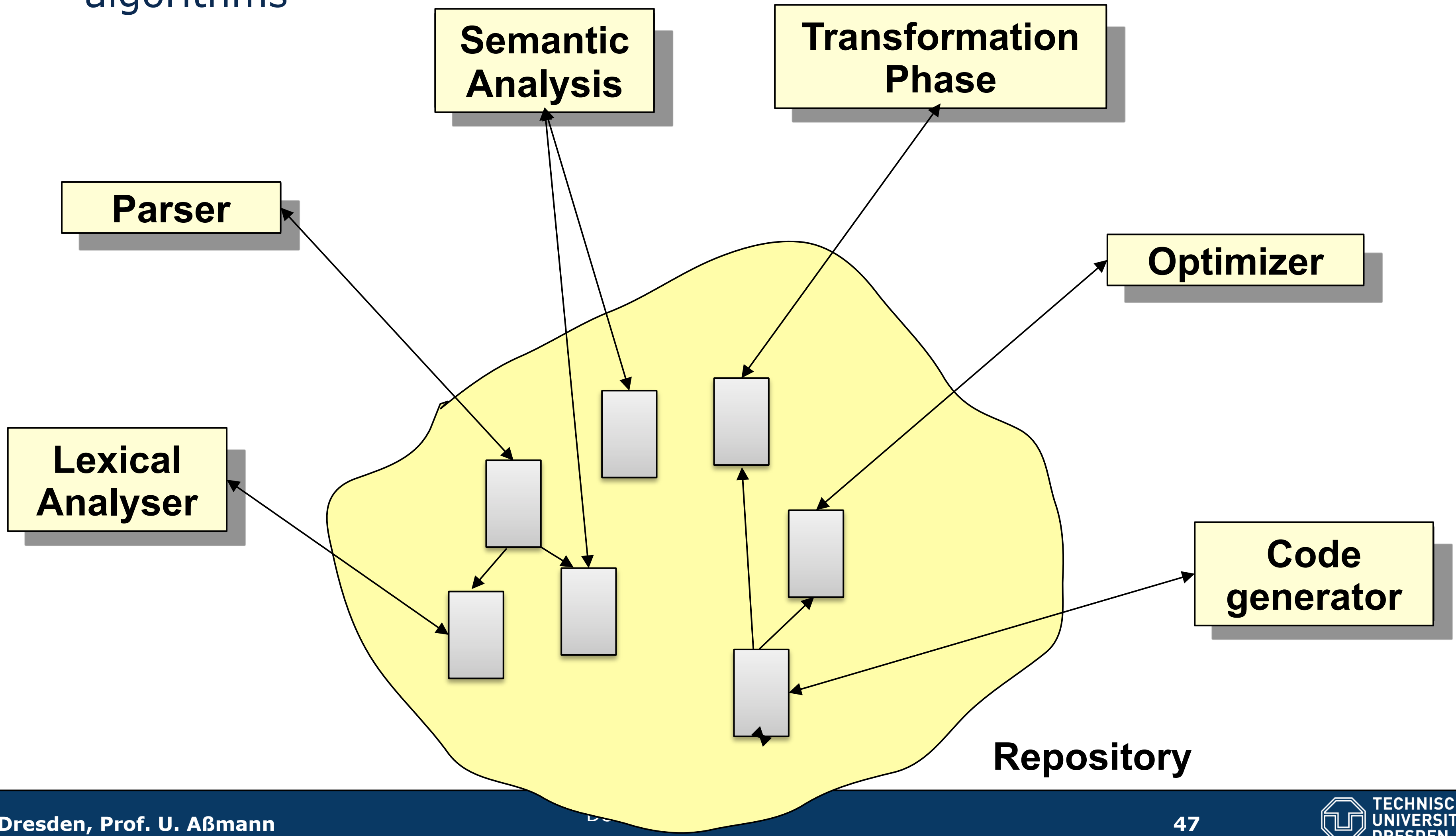
# Arch. Style: Repository Systems (Data Base Systems)

- Processing is data-oriented
- Free coordination the components, can be combined with call-based style or process-style
- Often also state-oriented

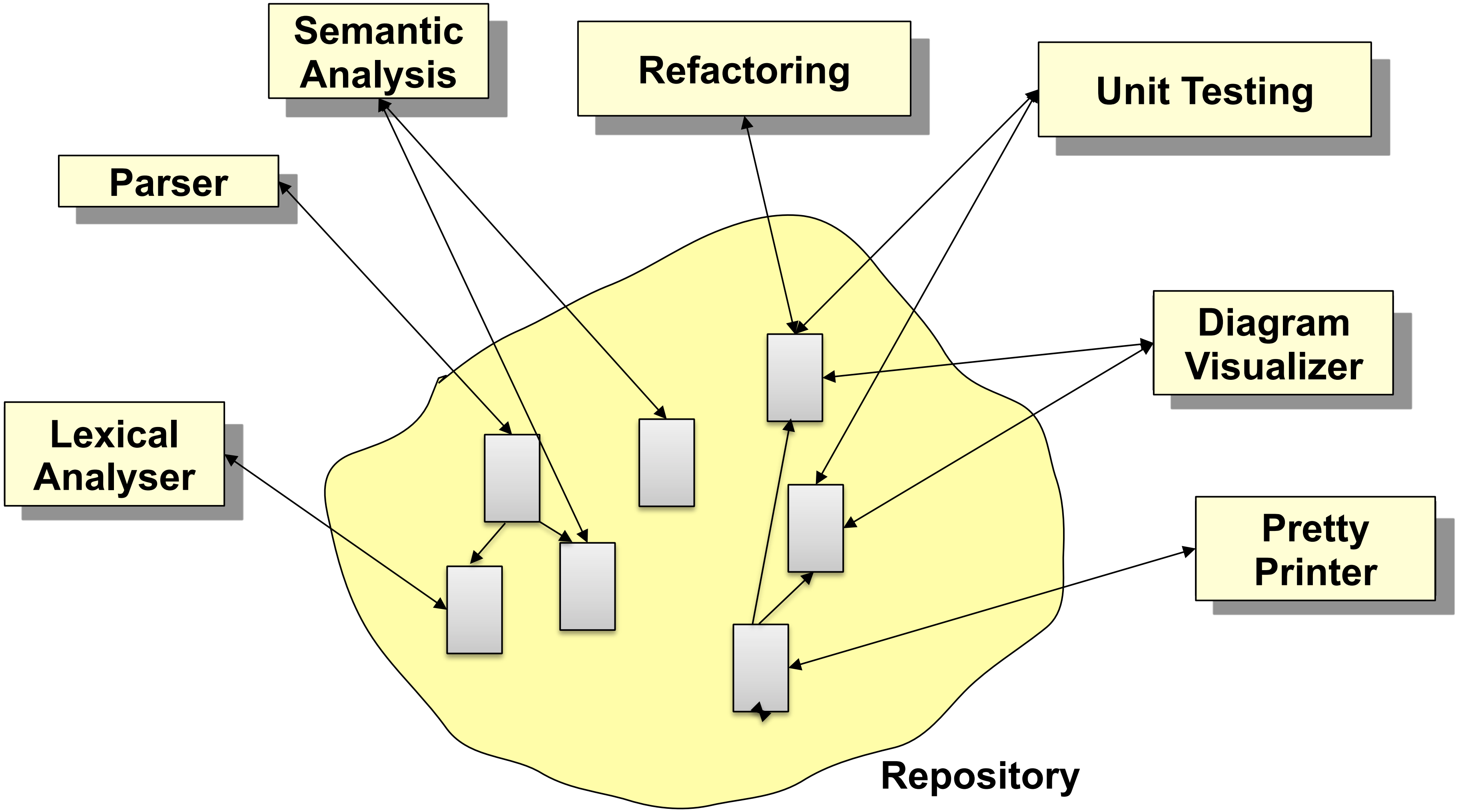


# Example: Repository Style in a Compiler

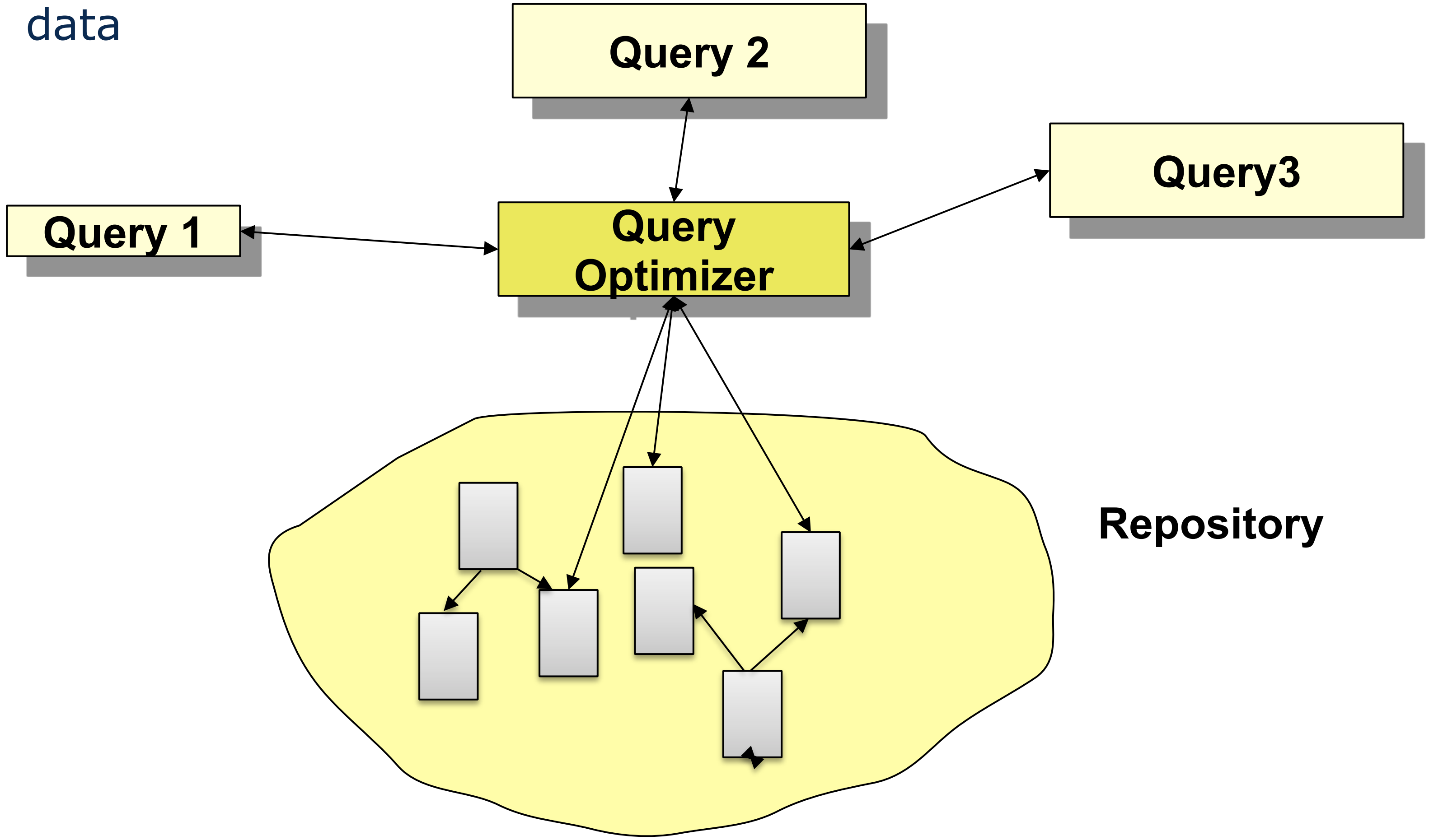
- The algorithms are structured along the syntax of the programs
- The Design Pattern "Visitor" separates data structures from algorithms



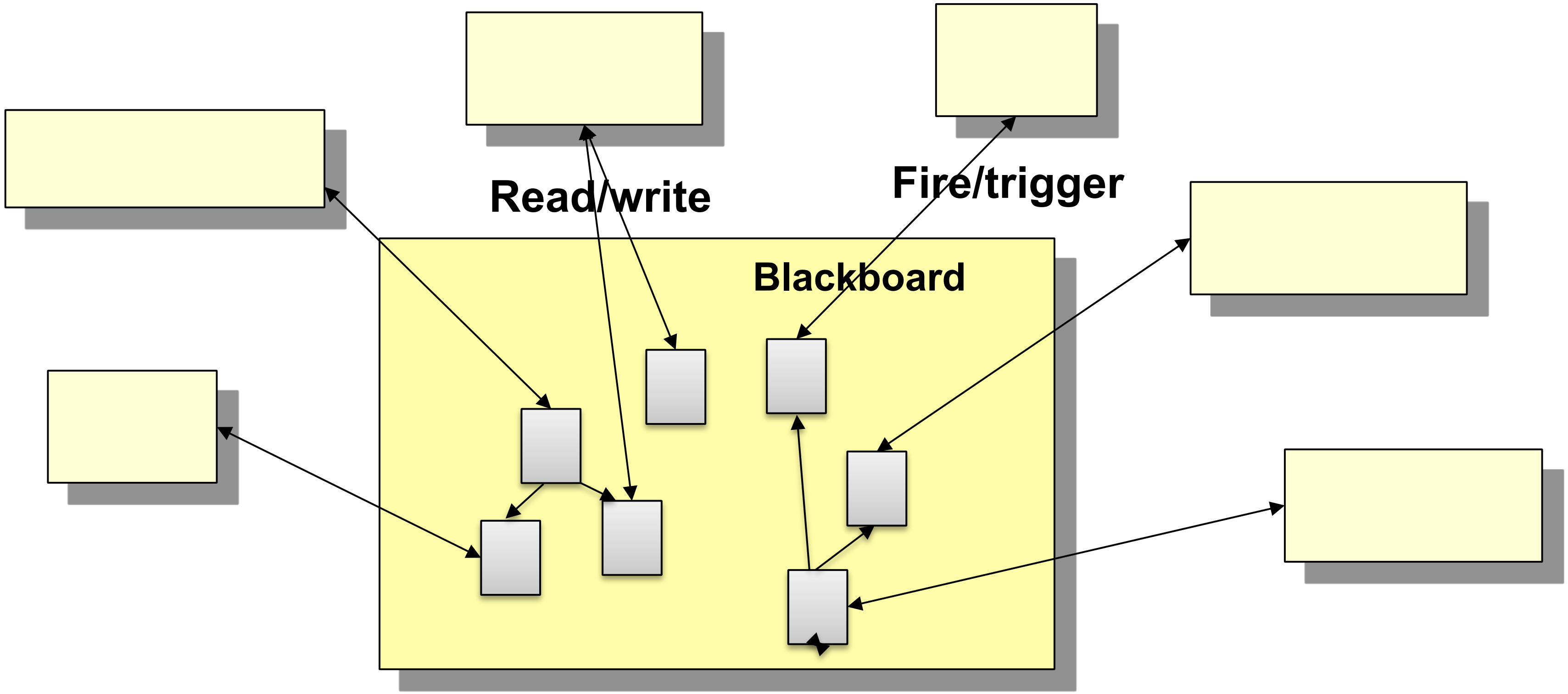
- IDE store programs, models, tests in their repository



- Algorithms are structured along the relational data
- Data warehouse applications provide querying on multidimensional data



- The blackboard is an active repository (i.e., an active component) and coordinates the other components
  - by event notification or call
- Dominant style in expert systems



# 20.3.4) Component-Based Design (Structure-Oriented Design)

- Focus is on the HAS-A (PART-OF) relation
  - Focus is on *parts*, i.e., on an hierarchical structure of the system

- Divide: finding subcomponents (parts)
- Conquer: grouping of components to larger components

- Example:
  - Design with architectural languages (such as EAST-ADL)
  - Design with classical component systems (components-off-the-shelf, COTS), such as CORBA or AutoSAR
- However, many *component models* exist
- Separate course “Component-based software engineering (CBSE)”

**What are the components (parts) of the system, their structure, and their relations?**

- Data and actions are grouped into *objects*, and developed together
  - Focus is on the is-a and the behaves-like relation
  - A part of the system is like or behaves like another part (similarity)

- Divide: finding actions with their enclosing objects
- Conquer: group actions to objects

**What are the "objects" of the system?**

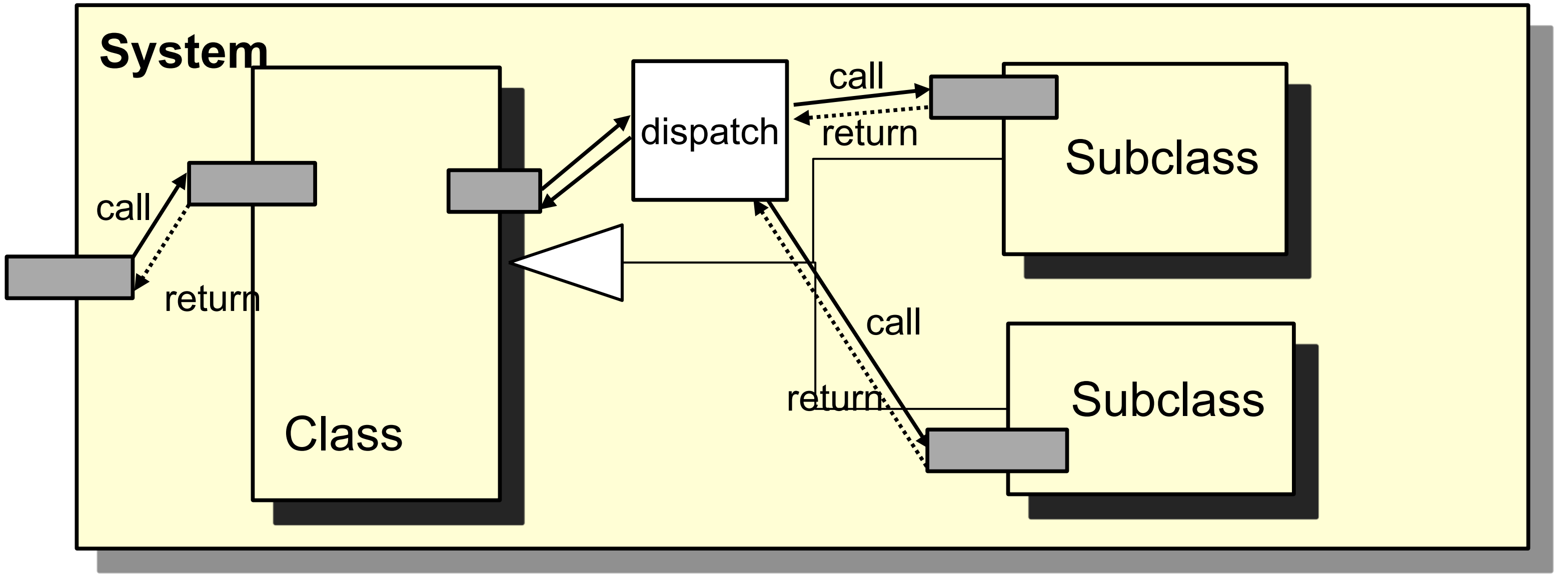
**What are the actions and attributes of the objects?**

- CRC cards (ST-1)
- Verb substantive analysis (ST-1)
- Collaboration-based design and CRRC (ST-1)
- Use-Case Realization Analysis

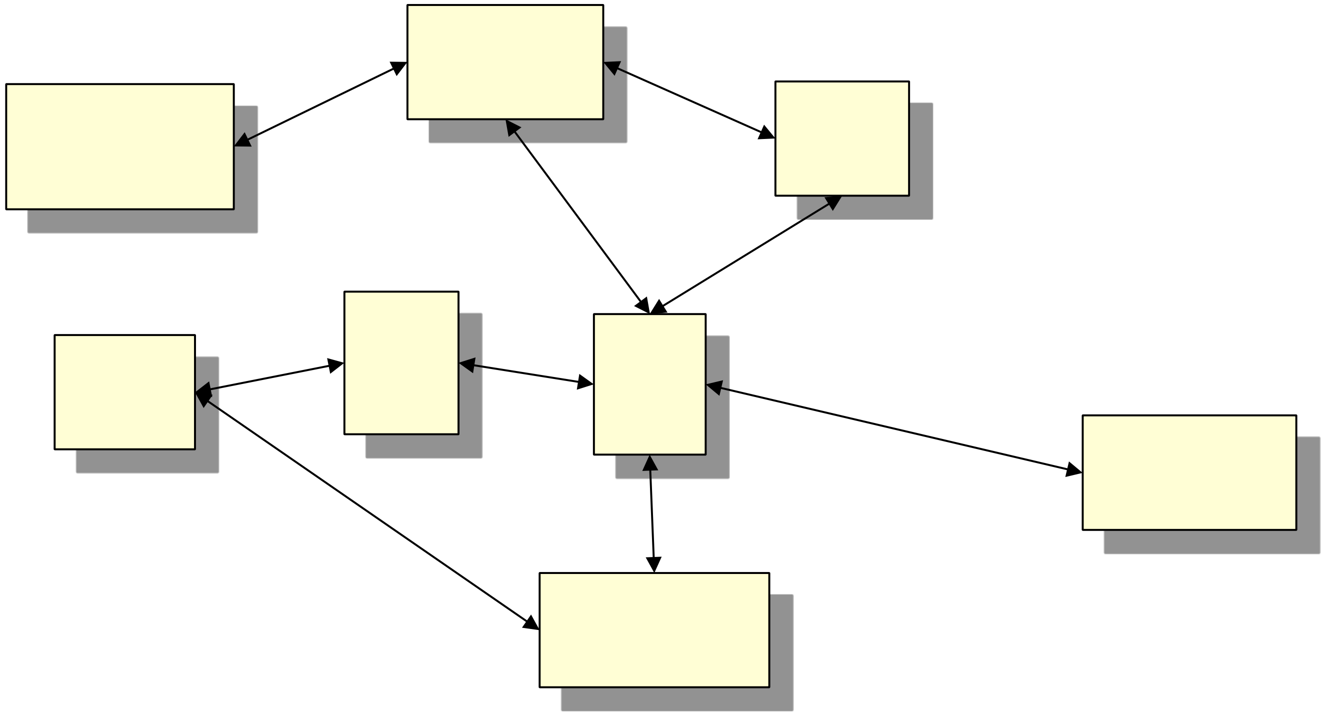
- Booch method
- Rumbaugh method (OMT)
- (Rational) Unified Process (RUP, or Unified Method)
  - uses UML as notation
- Hierarchical OO Method (HOOD)

- Often, OO is used, when the real world should be simulated (simulation programs)

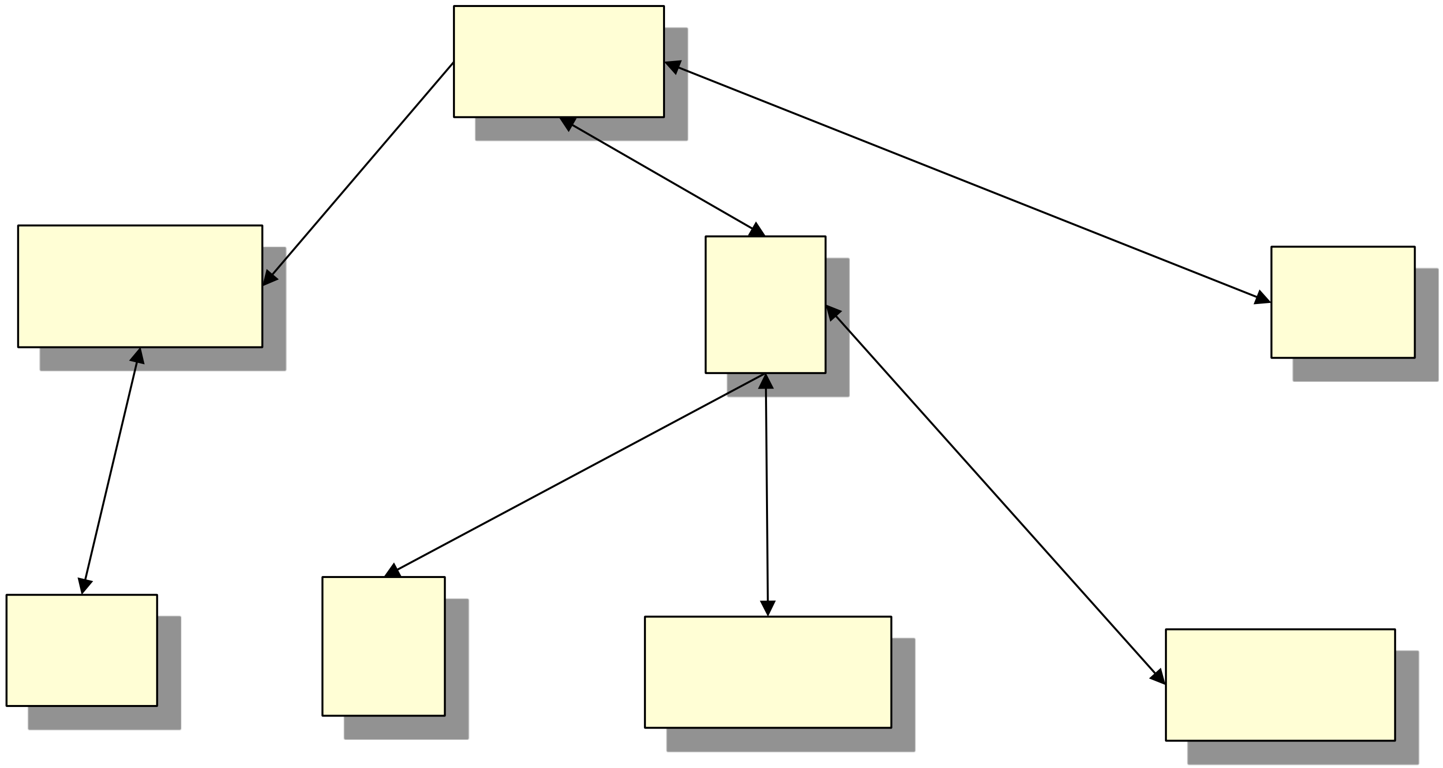
- Control flow is symmetric (calls and returns)
- Control flow is **not fixed** (dynamic architecture via polymorphism)
  - Control-flow can be sequential or parallel
- Data-flow can be parallel the call (*push-based system*) or antiparallel, i.e., parallel to the return (*pull-based system*)



- Object-oriented systems can be parallel
- *Actors* are parallel communicating processes
  - Processes talk directly to each other
  - Unstructured communications



- Processes (parallel objects) are organized in a tree
  - and talk only to their descendants



- We start with an initial, abstract design that meets the requirements
  - The context model and the top-level architecture
- The implementation is achieved by an iterative transformation process, starting from an initial design
  - Refinement-based development
  - Refactoring-based development uses symmetry operations (refactorings)
  - Semi-automatically deriving a final design
- Divide: find steps from the initial to the final design
- Conquer: chain the steps
- Note: this design method is orthogonal to the others, because it can be combined with all of them

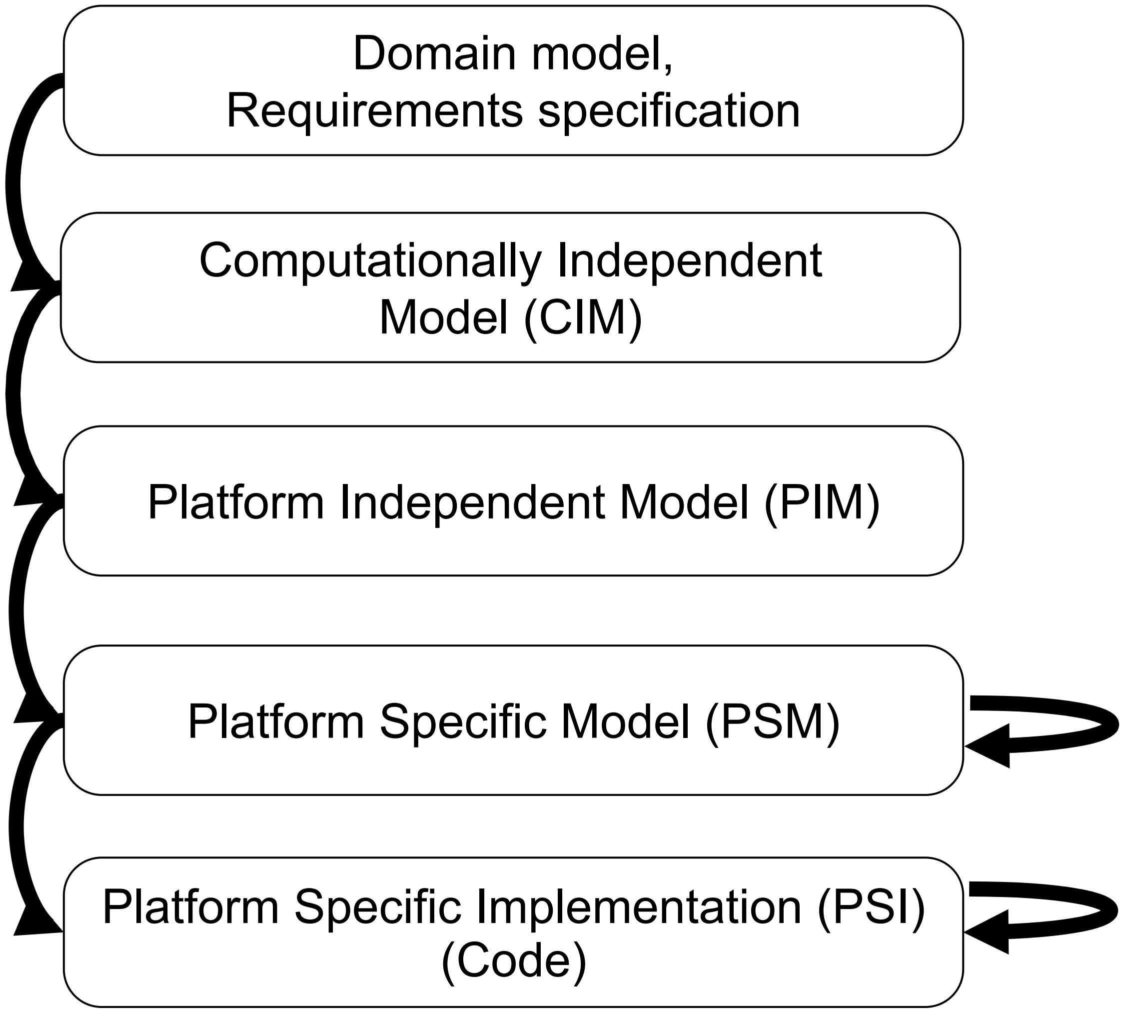
**How should I transform the current design to an better version and finally, the implementation?**

- **Wide spectrum languages** uses rule-based transformation systems and transformation planners
  - This starts at the requirement specification and refines (under proofs of correctness) expressive expressions to executable programs (**semantic-preserving refinement**)
  - The **semantic refinements** are refactorings which **lower** expressive expressions to low-level
  - Semantics can be proven in different forms, e.g., with Hoare logic, Dynamic logic, or denotational semantics
- Semantic-preserving refinement does not need testing, because all derived programs are correct by construction. The method is also a formal method.
- Examples
  - CIP-L (Munich University)
  - F. L. Bauer, M. Broy, R. Gnatz, W. Hesse, B. Krieg-Brückner, H. Partsch, P. Pepper, and H. Wössner. Towards a wide spectrum language to support program specification and program development. SIGPLAN Notices, 13(12) 15-24, 1978.
  - SETL (J. Schwartz, New York University)
  - KIDS (Kestrel institute), VDM, Z, B, Event-B

# Refactoring-Based Extreme Programming (XP)

- More informal and incremental process: Extreme Programming (XP)
  - Based on refactorings for structural improvements, but not particularly for lowerings
  - Refactoring can be supported by refactoring tools
  - Every requirement is implemented and tested in separation
  - Continuous testing and continuous integration (test-driven development)
  - Customer is involved (customer-driven development)
  - Permanent review with pair programming

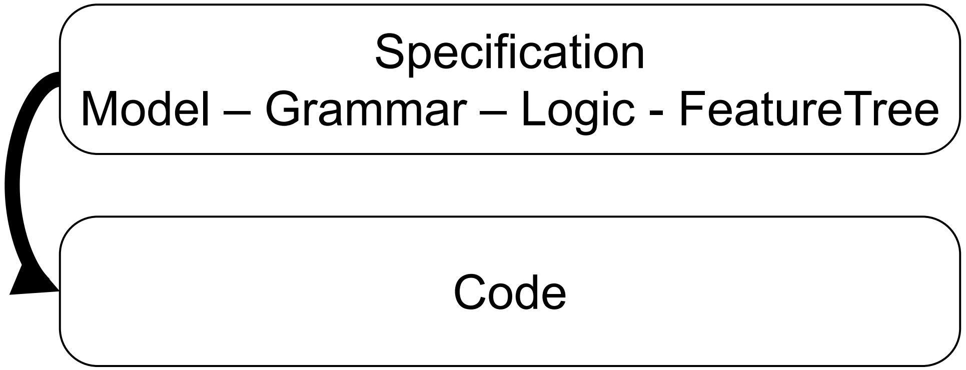
Model mappings



- (aka Generative Programming)
- Specify the solution in
  - a "formal method", a specification language
  - a template which is expanded (generic programming)
  - In UML, which is generated into code by a CASE tool
- Generate a solution with a generator tool that plans the solution
  - Planning the composition of the solution from components
  - Synthesizing the solution
- Divide: depends on the specification language
- Conquer: also
- Fully generative programming is called Automatic Programming

**How can I derive the implementation from the design automatically?**

- Developing a specfication in one of these languages is simpler than writing the code
  - Grammar-oriented development (*grammarware*)
    - Finite automata from regular grammars
    - Large finite automata from modal logic (model checkers)
    - Parsers from Context-free grammars
    - Type checkers, type inferencers from Attribute grammars
    - Type checkers and interpreters from Natural semantics
    - Optimizers from graph rewrite systems (see chapter on GRS)
  - Feature-oriented development (FODA): specify *feature trees* and derive the components from them



- In automatic programming, a planner plans a way to generated the code from the requirement specifications
  - Using a path of transformations
- A.P. is generative, and transformative, and formal method.

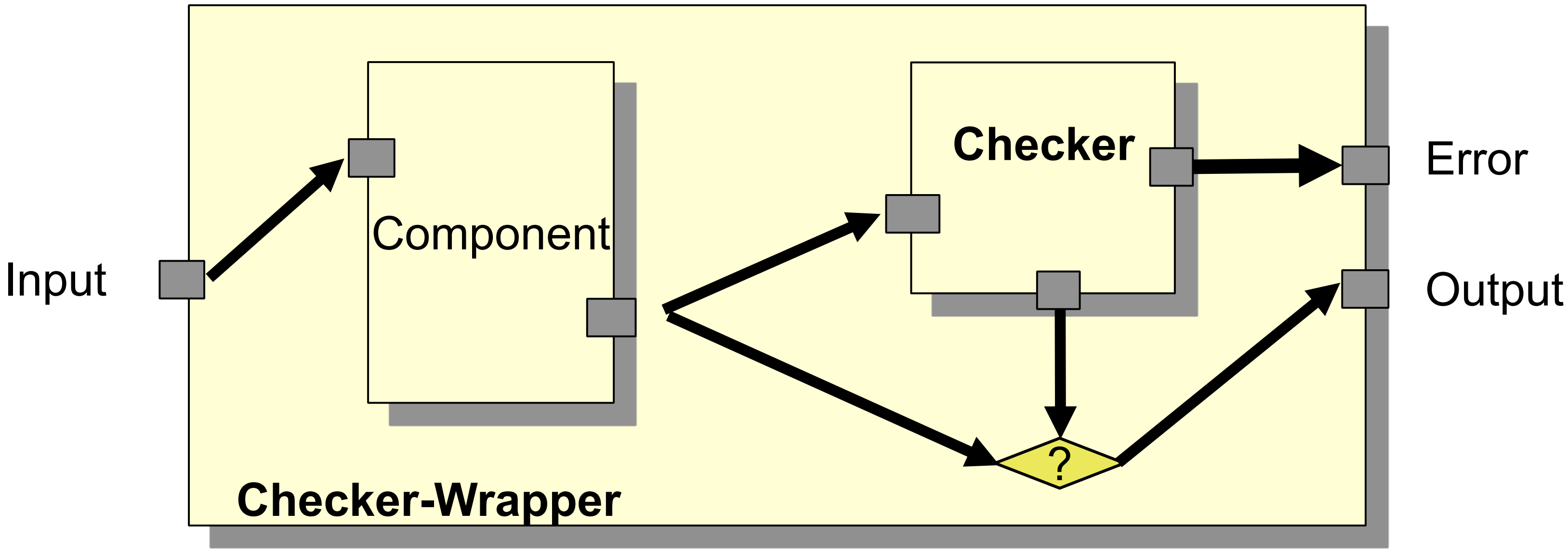
# 1.3.8 Model-Driven Software Development (MDSD)

- MDSD blends Transformational and Generative design
- Models
  - represent partial information about the system
  - Are not directly executable
  - But can be used to generate parts of the code of a system
- Model-driven architecture (MDA®) of OMG) blends Transformational Design and Generative Design
  - See also Chapter “Model-Driven Architecture”
- MDA needs Aspect-Oriented Modeling (model weaving)

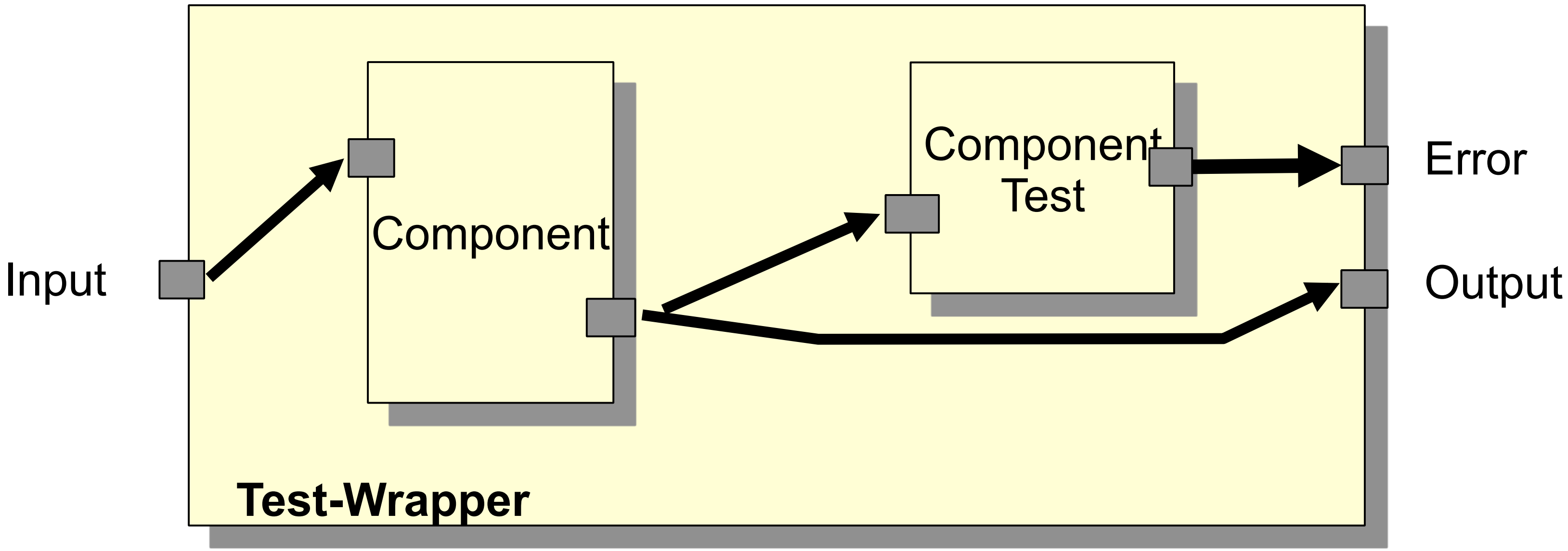
- A *formal method* is a design method that
  - Has a formal (mathematical) specification of the requirements
  - Develops a formal specification of the design
  - The design *can be verified* against the requirements specification
- A formal method allows for *proving a design correct*
  - Very important for safety-critical systems
- Formal methods are orthogonal to the other methods: every method has the potential to be formal
- Important in safety-critical application areas (power plants, cars, embedded and real-time systems)
  - Ex. Petri nets (separate chapter), B, Z, VDM, ...

**How can I prove that my design is correct with regard to the requirements?**

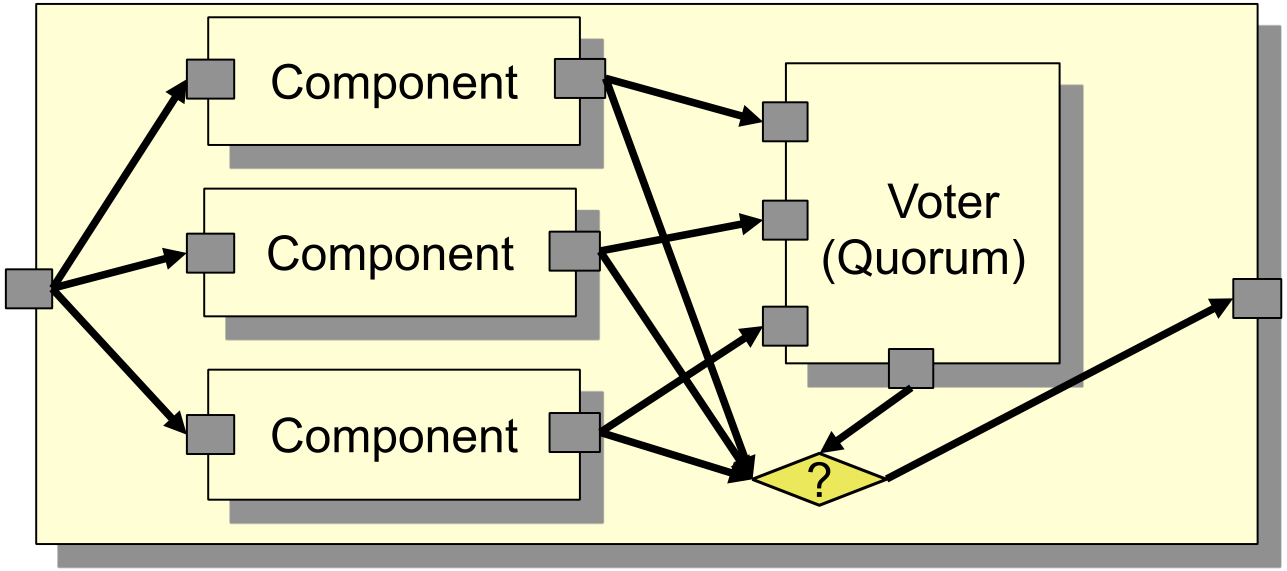
- A **checker-based system** is fault-tolerant in the sense that for every component, a *checker* exists that checks the correctness of an application
  - Also called a *monitor*
- Example: Verified compilers, fault-tolerant 24/7 systems



- A **test-driven system** maintains with every component a test component
- The test runs prior to the system
- Example: TDD (Test-Driven Development)

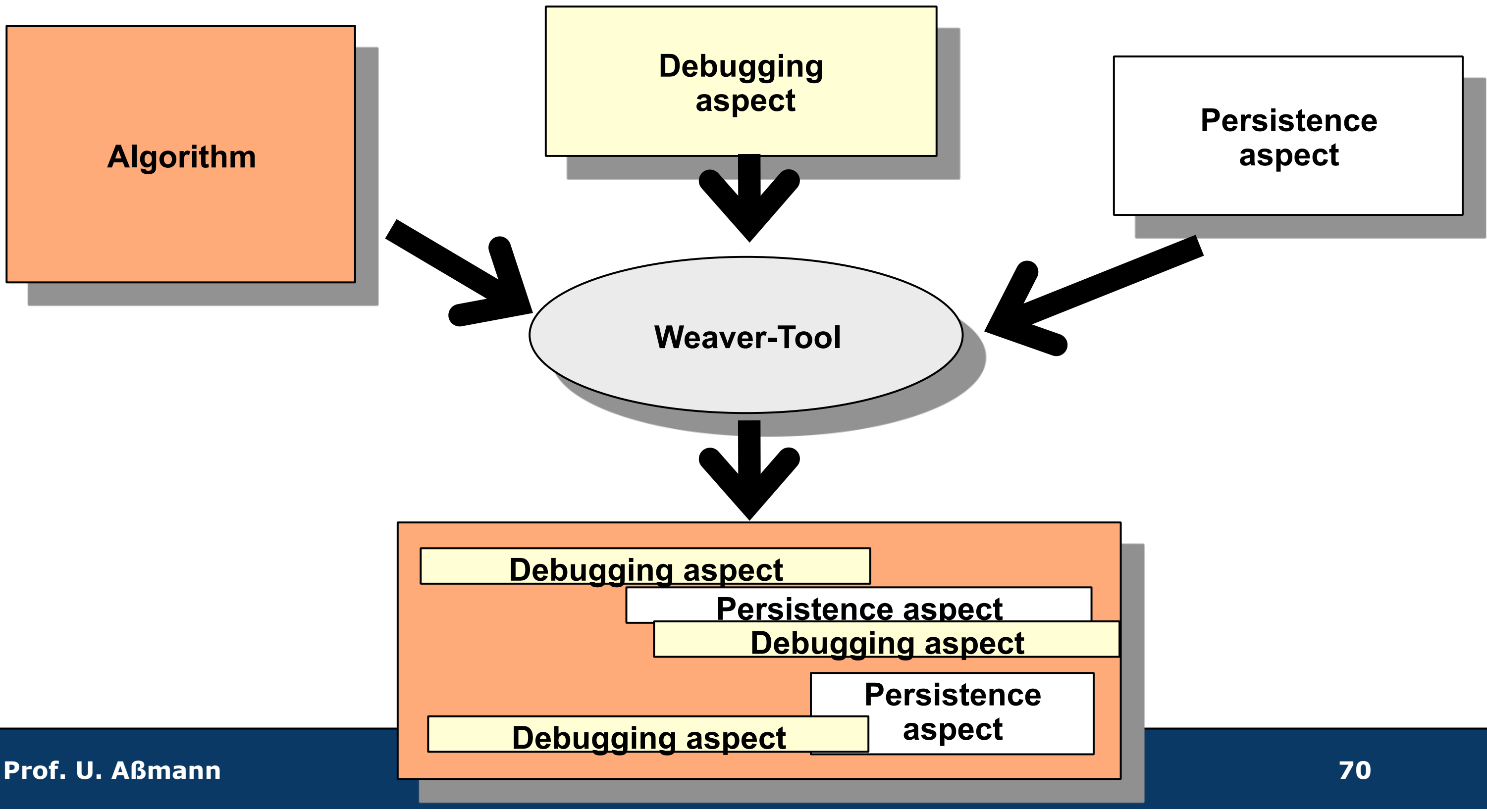


- In a *voting fault-tolerant architecture,* the run-time checker is a majority voter (quorum) that compares the results of several instances of the component
- Example: Space Shuttle



# 20.3.10 ASPECT-ORIENTED SOFTWARE DESIGN

- Usual design methods have *one* aspect of development in focus ("tyranny of decomposition")
- Aspect-oriented systems specify different aspects of a system in separation (separation of concerns)
  - The slices are reintegrated by *generative* Aspect Weavers (Aspect/J)
  - More in chapters "Aspect-orientation", "Feature-based product lines" and course CBSE

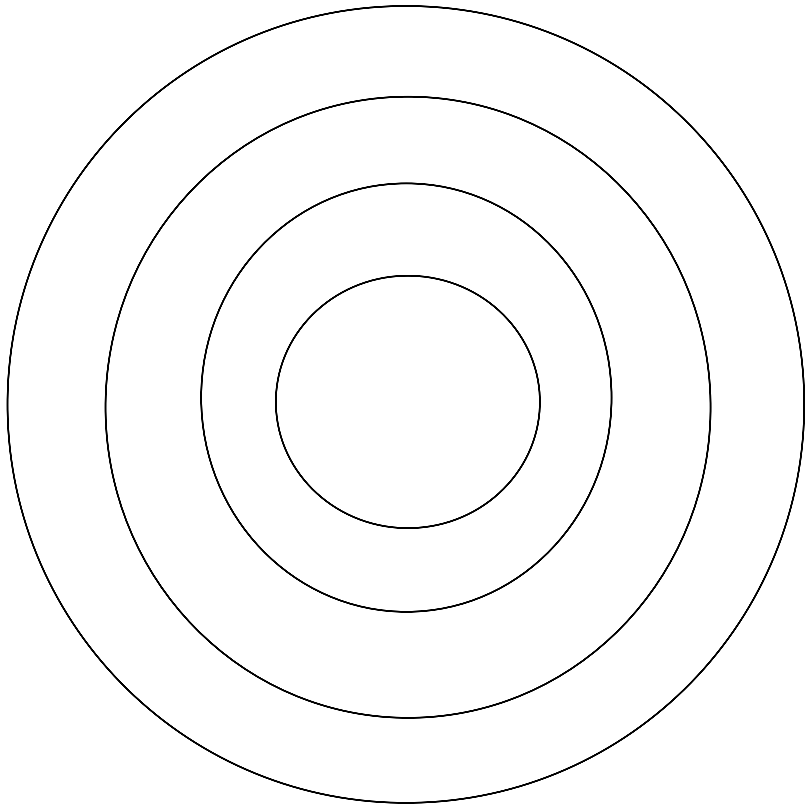


# 20.3.11 ADAPTIVE ARCHITECTURES

# To be filled...

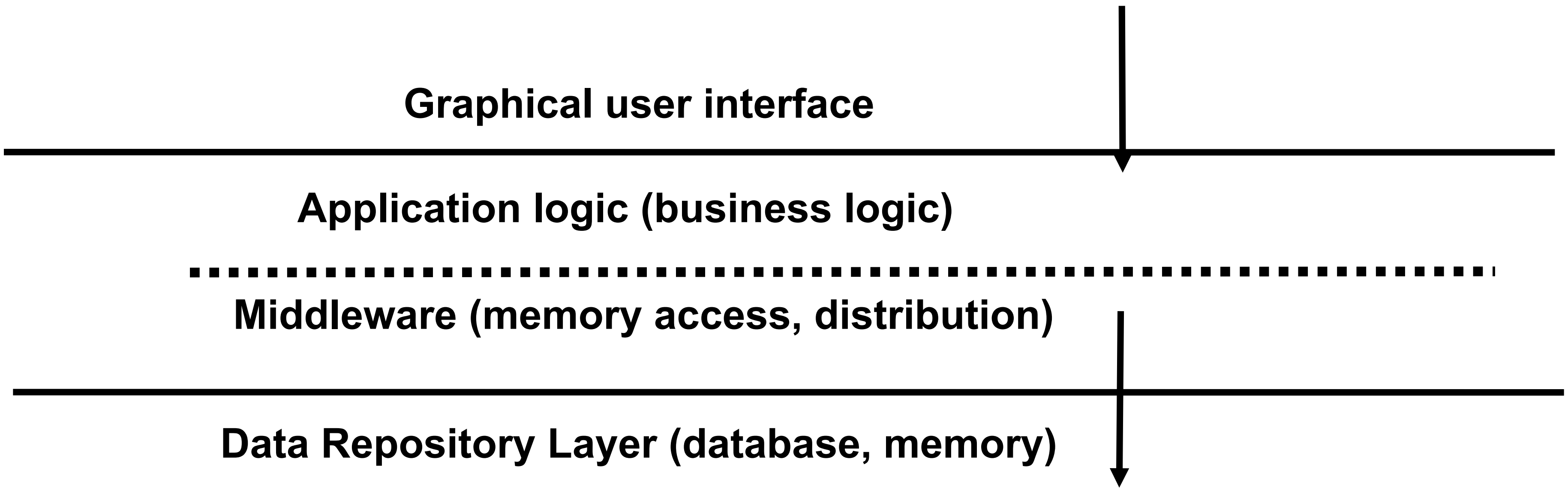
# 20.4 ARCHITECTURAL STYLES SPECIFIC TO LAYERS

- The most general architectural style, which can be combined with all others are **layers**
- Layers can be combined with many other styles
- Ingredients:
  - Connectors: procedure calls or streams
  - Ports: component interfaces
  - Control flow mostly synchronous
  - Data flow along the layers and the call graphs, mostly singulary
  - Data- and control flow are isomorphic
- Dominating style for large systems



# Example: 4-Tier Architectures in GUI-based Applications (BCED)

- Already presented in ST-1
- **Acyclic USES Relation, divided into** 3 (resp. 4) layers:
  - GUI (graphic user interface)
  - Middle layer (Application logic and middleware, transport layer)
  - Data repository (database)



UNIX:

User Space

Kernel

Apple-UNIX:

User Space

Kernel

Microkernel (Mach)

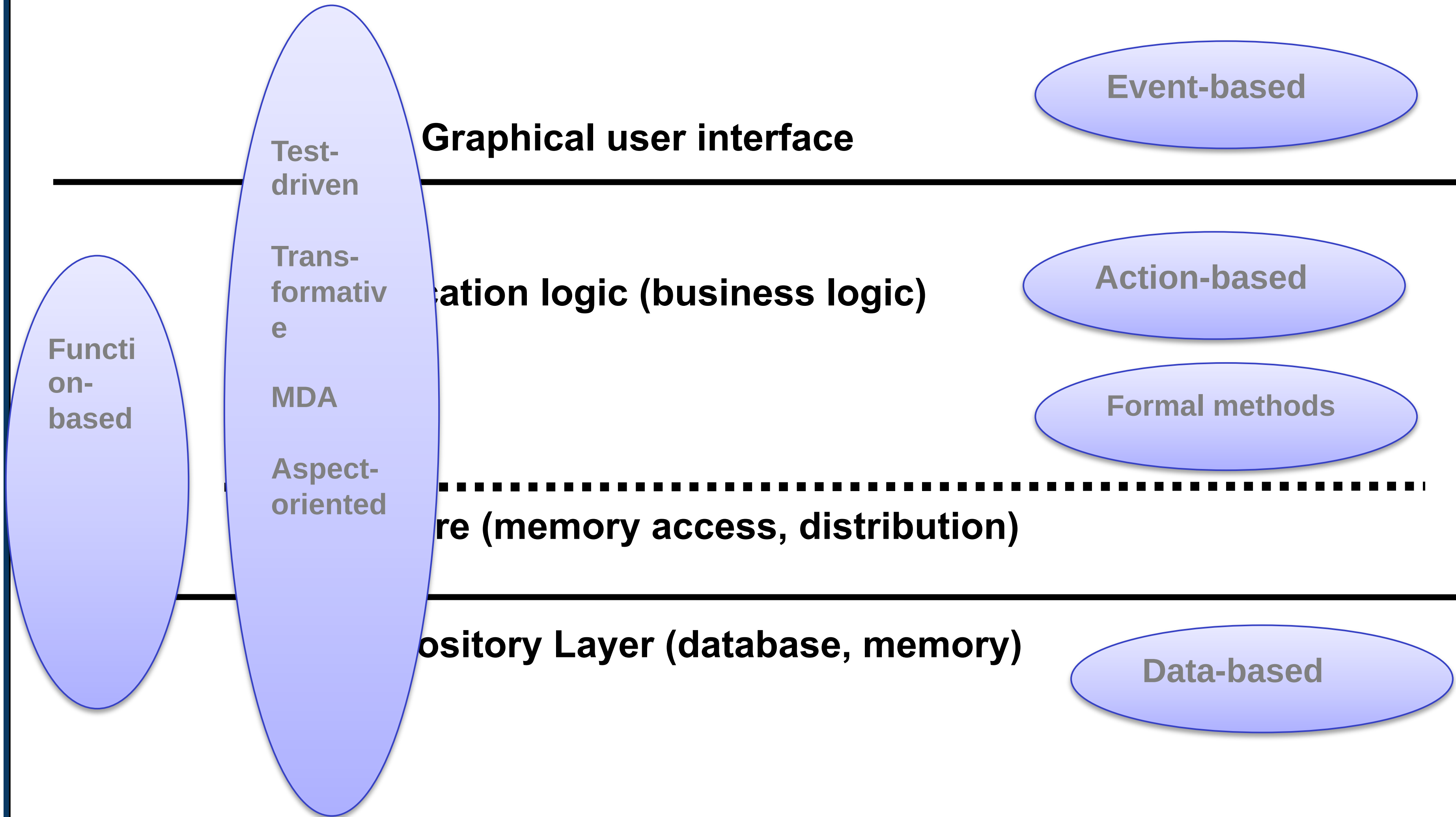
Windows NT/XP:

User Space

Kernel

Hardware Abstraction Layer (HAL)

# Architectural Styles Can Be Layer Specific



# Domain-Specific Architectural Styles

- Often an application domain needs its own style, its *reference architecture*
- It's hard to say something in general about those

- An architectural style results from a specific development method
  - Functional, modular design: call-based style
  - Action design: data-flow style, workflow style, regular processing, process trees
  - Object-oriented design: object-oriented call-based systems, client-server, actors (process systems)
  - Uses-oriented design: layered systems
- Specific layers need specific styles
- Reliable systems need specific styles
- The dedicated engineer knows when to apply what

# Summary: Most Important Architecture Styles

- Data flow styles
  - Sequential pipe-and-filter
  - Data flow graph/network
  - Workflow systems (mixed with control flow)
- Call-style
  - Modular systems
  - Abstract data types
  - Object-oriented systems
  - Client/service provider
- Hierarchical styles
  - Layered architecture
  - Interpreter
  - Checker-based Architectures
- Interacting processes (actors)
  - Threads in a shared memory
  - Distributed objects
  - Event-based systems
  - Agenda parallelism
- Data-oriented (Repository architectures)
  - Transaction systems (data bases)
    - Query-based systems
  - Blackboard (expert systems)
  - Transformation systems (compilers)
  - Generative systems (generators)
  - Data based styles
    - Compound documents
    - Hypertext-based

- Functional and action design ➔ call-based architectural style or component-based style
- Object-oriented design ➔ object-oriented call style or actor style
- Action-based design (with data-flow) ➔ data-flow architectures (pipe-and-filter architectures) or ECA systems

**A specific design method leads to a specific architectural style**

- A specific application domain needs a specific architectural style, and due to that, a specific design method, e.g.,
  - Embedded software needs formal methods
  - Enterprise software needs workflow-based style
  - Information systems need repository style

# Which Design Method for the Satellite Radio?

- Real world objects must be simulated
  - Object-oriented design?
- Events in the real world
  - Event-condition-action based design?
- Flow of data from the satellite to the radio to the user
  - Data-oriented design? data-flow architecture!

# What Have We Learned?

- There is no single “the way to the system”
  - Every project has to find its path employing an appropriate design method
- The basic design questions are posed over and over again, until a design is found
  - Select a design method
  - Pose the design method's basic question
  - Perform the design method's process
  - Perform the design method's steps: elaborate, refine, structure, change representation, ...
- If process gets stuck, change design method and try another one!
- Architectural styles are the result of a design process
  - They give us a way to talk about a system on a rather abstract level
  - Architectural styles can be distinguished by the relation of data-flow and control-flow (parallel vs antiparallel)
  - .. and the type of system structuring relation they use

# What is running in Part III – Design?

- Presentation of Design Methods with Notations, Processes, Heuristics
- Presentation of the Development Focus
- Presentation of resulting Architectural Styles
- Presentation of Variability and Extensibility mechanims, to prepare product line engineering

## Why Is This Important? (The Engineer's Parkinson Disease)

- Don't be discouraged about the diversity of this lecture. There is something to win...
- A good object-oriented designer is not automatically a good software engineer
- A software engineer knows a large toolbox of *different methods* to be able to choose the right method!

- Usually, people stick to the methods in which they have been educated
  - COBOL programmers
  - Imperative vs functional programmers
  - Object-oriented programmers vs procedural programmers
- Do you want to get stuck?
- You will have a large advantage if you are open-minded

General Strategies in Design Processes

# 20.5 DESIGN HEURISTICS AND BEST PRACTICES

- Obligatory Reading
  - [Brooks] Frederick P. Brooks jr. No Silver Bullet. Essence and Accidents of Software Engineering. In [Thayer]. Wonderful article on what software engineering is all about.

- Other Literature
  - [Budgen] David Budgen. Software Design. Addison-Wesley. Expands on the Budgen paper. Pretty systematic.
  - [Endres/Rombach] A. Endres, D. Rombach. A Handbook of software and systems engineering. Empirical observations, laws and theories. Addison-Wesley. Very good collection of software laws. Nice!

# Brook's Paradox on Software Beauty

Exciting

- Unix
- OS/2
- APL
- Pascal
- Modula
- Algol 68
- Smalltalk

Useful, but unexciting

- MVS/370
- MS-DOS
- Cobol
- PL/1
- Fortran
- Algol 60
- php

Nice systems are often too late in the market

... be the first or the second bird!

# Heuristic: Lazy or Eager Design

- In case of a difficult design decision
  - (when elaborating, refining, refactoring or changing representation)
  - ...**defer** it (lazy design)
    - Iterative Software development methods such as Extreme Programming
  - ...**decide** it (eager design)
  - ...**anticipate** further developments in the design (anticipatory design)
- Time-boxed design: (SCRUM XP process)
  - Do iterations in fixed time-slots (1 month)
  - Fix requirements only for one time-slot
  - Have it running under all circumstances
  - Update requirements with customer after the time-slot

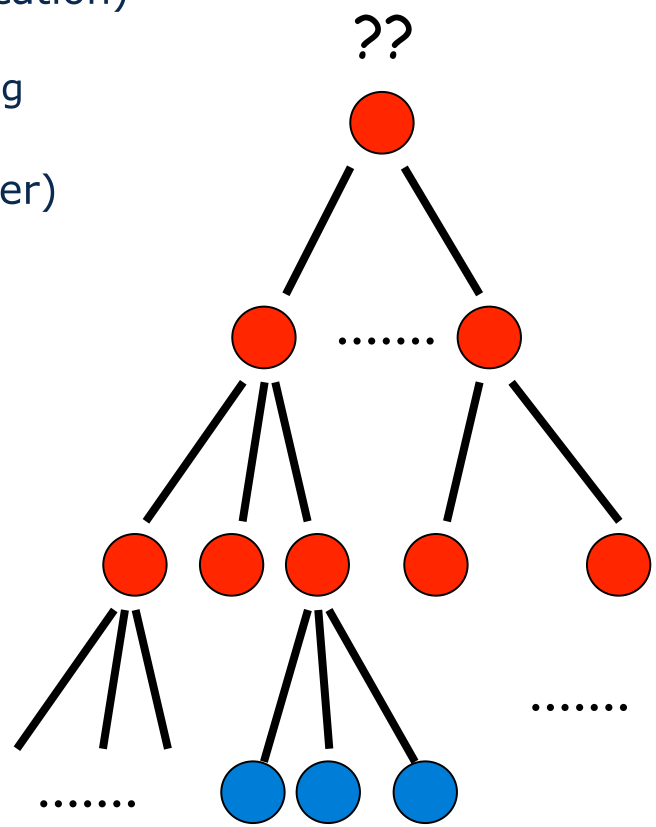
# Prepare for Evolution: Grow Living Software

- Build development: “build, not write” [Brooks]
- Software is a living thing
  - Lehman's first law of software evolution: *“A system that is used will be changed”*

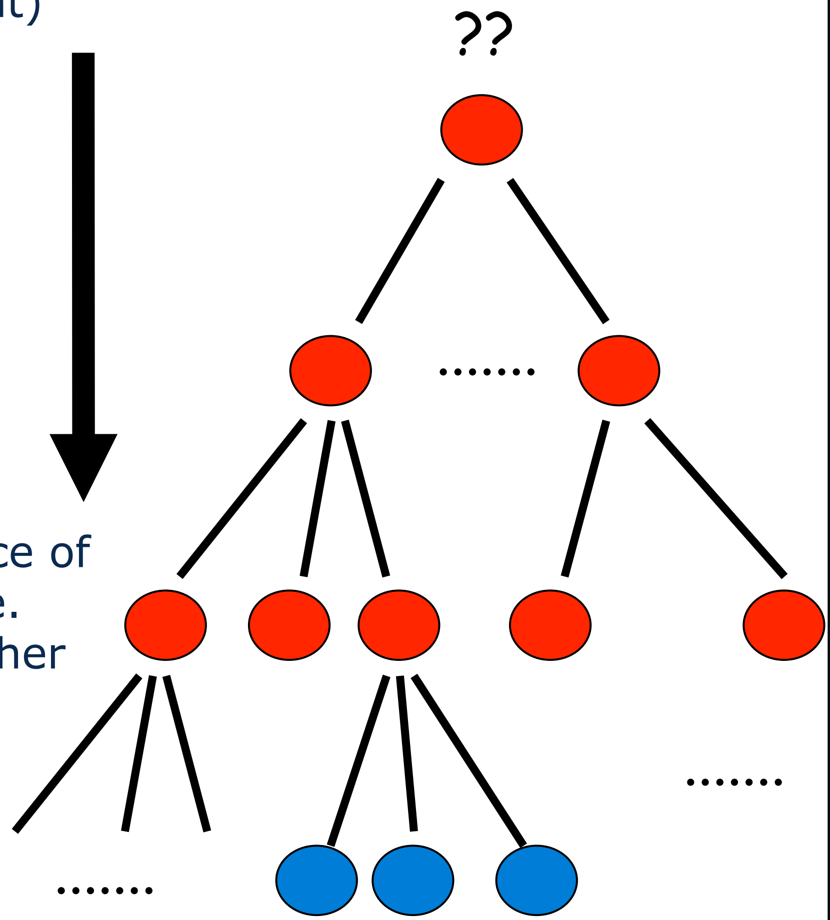
- Incremental development
  - “grow, not build software” [Brooks]
  - Refactorings and refinement should always be possible

# Heuristic: Divide and Conquer Strategy

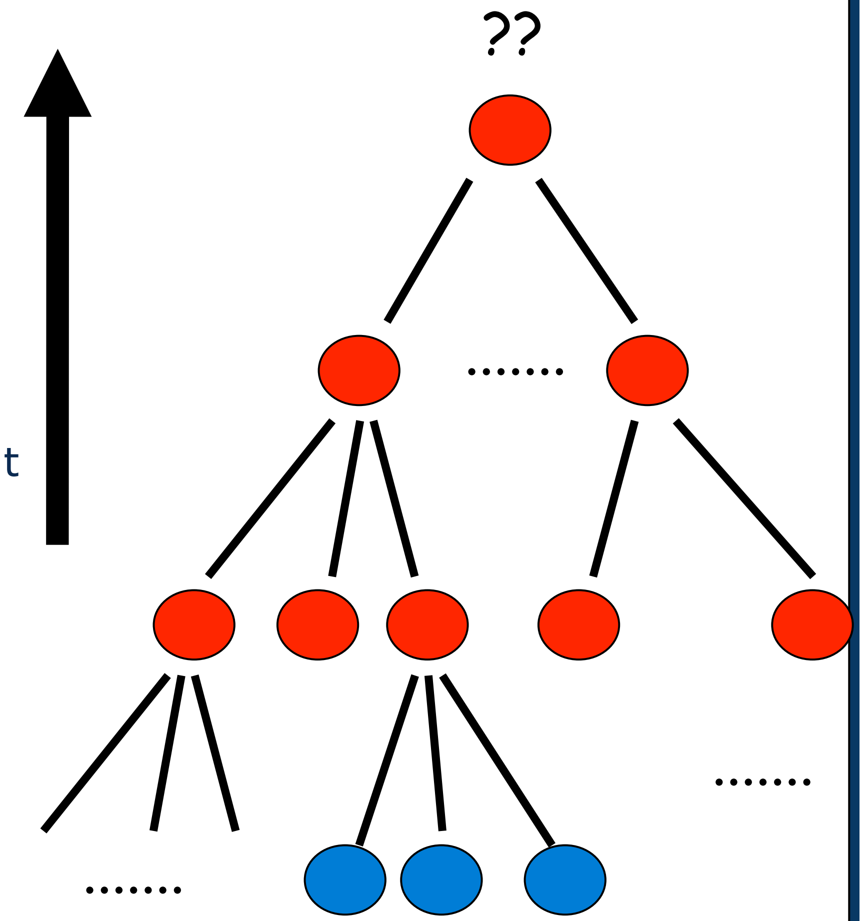
- Divide et impera (from Alexander the Great)
  - **divide**: problems into subproblems (simplification)
    - To find solutions in terms of the abstract machine we can employ. When this mapping is complete, we can conquer
  - **conquer**: solve subproblems (hopefully easier)
  - **compose** (**merge**): compose the complete solution from the subsolutions
    - Reuse of partial solutions is possible (then the tree is a dag)
- Where do we begin?
  - Stepwise refinement (top-down)
  - Assemblage (bottom-up)
  - Design from the middle (middle-out, yo-yo)



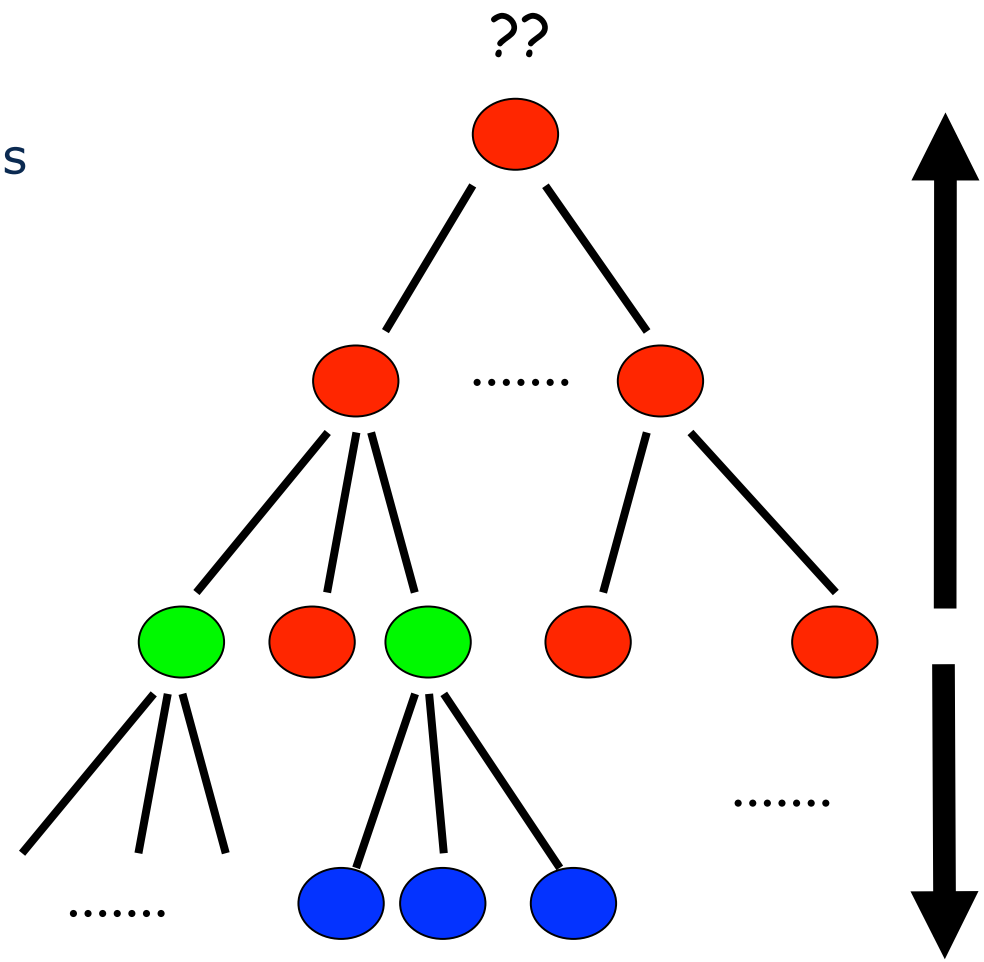
- **Pointwise refinement**
- **Fragment refinement**
- **Control refinement** (operation refinement)
  - We guess the solution of the problem in terms of a higher-level abstract machine
  - We refine their operations until the given abstract machine is reached
- **Data refinement**
  - We may also refine the data structures of the abstract machine
- **Syntactic refinement** does not respect semantics of the original model
- **Semantic refinement** proves conformance of the refined model to the original model, i.e. whether it is semantically equivalent or richer than the original model
- Disadvantage:
  - We might never reach a realization
  - Often "warehouse solutions" are developed, that are inappropriate



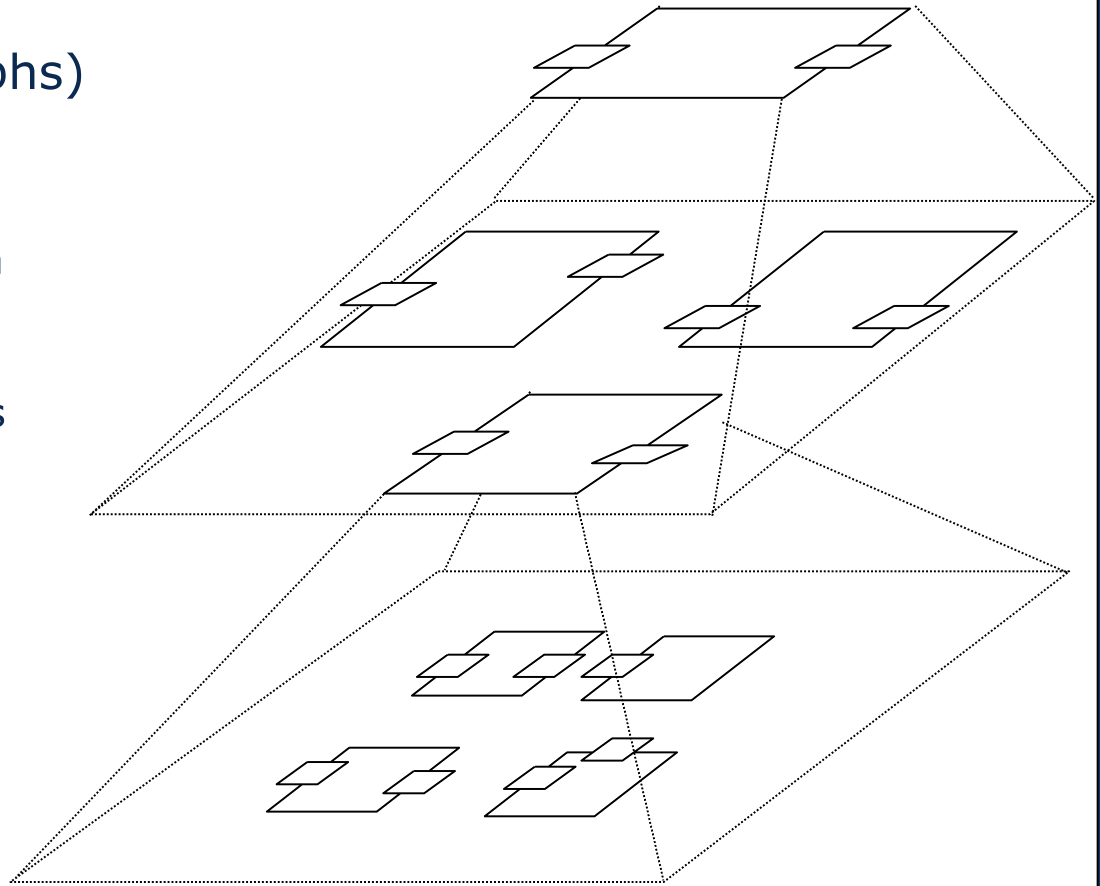
- In this case we start with a given abstract machine and
  - assemble more complex operations of a higher-level abstract machine
  - or assemble the more complex data structures
- Good:
  - Always realistic
  - A running partial solution
- Bad:
  - Design might become clumsy since global picture was not taken into account



- Fix some subproblems in the middle and solve them by refinement
- Then work your way up
- Often avoids the disadvantages of top-down and bottom-up
- Finding lemmas in a mathematical proof is similar



- Trees, trees, trees
- Dags (directed acyclic graphs)
  - Can be layered
- Reducible graphs
  - Can be layered too, on each layer there are cycles
  - Every node can be refined independently and abstracts the lower levels



- Limit yourself to a small number of items
  - Never use more than 5 items
    - on a page
    - on a slide
    - on an abstraction level of a specification or model
- KISS (keep it simple stupid)
  - Remove all superfluous things, make it fit on 1 page
  - Simplification takes a long time “I didn't have the time to make it shorter”
  - Einstein: "Make it as simple as possible, but not simpler!”
  - Stephen King: “When I think, I am ready, I usually have to reduce about 30% fat from my book."
- *Abstraction* is *neglection of unnecessary detail*
  - Focus at one problem at a time and to forget about others
  - Display only essential information
  - Change representation if development strategy changes
  - This leads to design methods or decomposition methods

# Heuristics on Abstraction

- Separation of Concerns (SoC)
  - Different concepts should be separated so that they can be specified independenly
  - Dimensional specifications: specify from different viewpoints
  - If separated, then concerns can be varied independently
- Example of SoC: Separate Policy and Mechanism
  - Mechanism: The way how to technically realize a solution
  - Policy: The way how to parameterize the realization of a solution
  - If separated, then policy and mechanism can be varied independently

The central question in design is how to improve on the software art centers - as it always has be - on

people.

[Brooks]

- Education of people is very important!
  - However, the differences are not minor - they are rather like the differences between Salieri and Mozart.
  - Study after study shows that the very best designers produce structures that are faster, smaller, simpler, cleaner, and produced with less effort.
  - Great designers and great managers are both very rare
- However, Farkas' Law: Fighting helps!
  - Farkas, a prominent trombone teacher, noticed that the most talented pupils didn't make it
  - Instead, the middle-class survived that learned how to work hard

# Other Literature

- Simon Singh. Fermats letzer Satz. Die abenteuerliche Geschichte eines mathematischen Rätsels. dtv.
  - Gute-Nacht-Geschichte über Fermat‵s jahrhundertealtes Rätsel. Erklärt den komplizierten Beweis Andrew Wiles‵ für Nicht-Experten. Zum Verschenken! (Galois inklusive..)
  - Uhrenarithmetik. Elliptische Gleichungen. Modulformen.
- Merke: Genie entsteht aus viel, viel Fleiss (man beachte das Erlebnis Wiles‵ bei der Korrektur des Beweises!)
  - Wenn selbst solch grosse Mathematiker Fehler in ihren Beweisen produzieren..... keine Angst vor grossen Aufgaben...
- Excellence is the result of enormous correction..

# The End

- In the following, we will see several examples  for selected design methods
- With the concepts of simple graph-based models, we can see common concepts in all of them