ESE — Einführung in Software Engineering

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1. ESE — Einführung in Software Engineering

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Principle Texts:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Third Edn., 1994.
- *Designing Object-Oriented Software*, R. Wirfs-Brock, B. Wilkerson, L. Wiener, Prentice Hall, 1990.

Other Books

- *The Mythical Man-Month*, F. Brooks, Addison-Wesley, 1975.
- *Object Lessons — Lessons Learned in Object-Oriented Development Projects*, T. Love, SIGS Books, 1993
- *Object-Oriented Development — The Fusion Method*, D. Coleman, et al., Prentice Hall, 1994.
- *Succeeding with Objects: Decision Frameworks for Project Management*, A. Goldberg and K. Rubin, Addison-Wesley, 1995
- *A Discipline for Software Engineering*, W. Humphrey, Addison Wesley, 1995
- *Object-Oriented Software Construction*, B. Meyer, Prentice Hall, Second Edn., 1997.
- *Objects, Components and Frameworks with UML*, D. D'Souza, A. Wills, Addison-Wesley, 1999
- *UML@Work*, M. Hitz, G. Kappel, DPunkt, 1999

Course Overview

1.	10-27	Introduction — The Software Lifecycle
2.	11-03	Project Management
3.	11-10	Requirements Collection
4.	11-17	Modelling Objects and Classes
5.	11-24	Modelling Behaviour
6.	12-01	Software Architecture
7.	12-08	Responsibility-Driven Design
8.	12-15	Detailed Design
9.	12-22	User Interface Design
10.	01-12	Software Validation
11.	01-19	Software Quality
12.	01-26	Computer-Aided Software Engineering
13.	02-02	4GLs: Delphi — *guest lecture*
	02-09	*Final exam*

What is Software Engineering?

A naive view:

But ...

- Where did the specification come from?
- How do you know the specification correspond to the user's needs?
- How did you decide how to structure your program?
- How do you know the program actually meets the specification?
- How do you know your program will always work correctly?
- What do you do if the users' needs change?
- How do you divide tasks up if you have more than a one-person team?

Software Development Activities

Requirements Collection

- Establish customer's needs

Analysis

- Model and specify the requirements ("what")

Design

- Model and specify a solution ("how")

Implementation

- Construct a solution in software

Testing

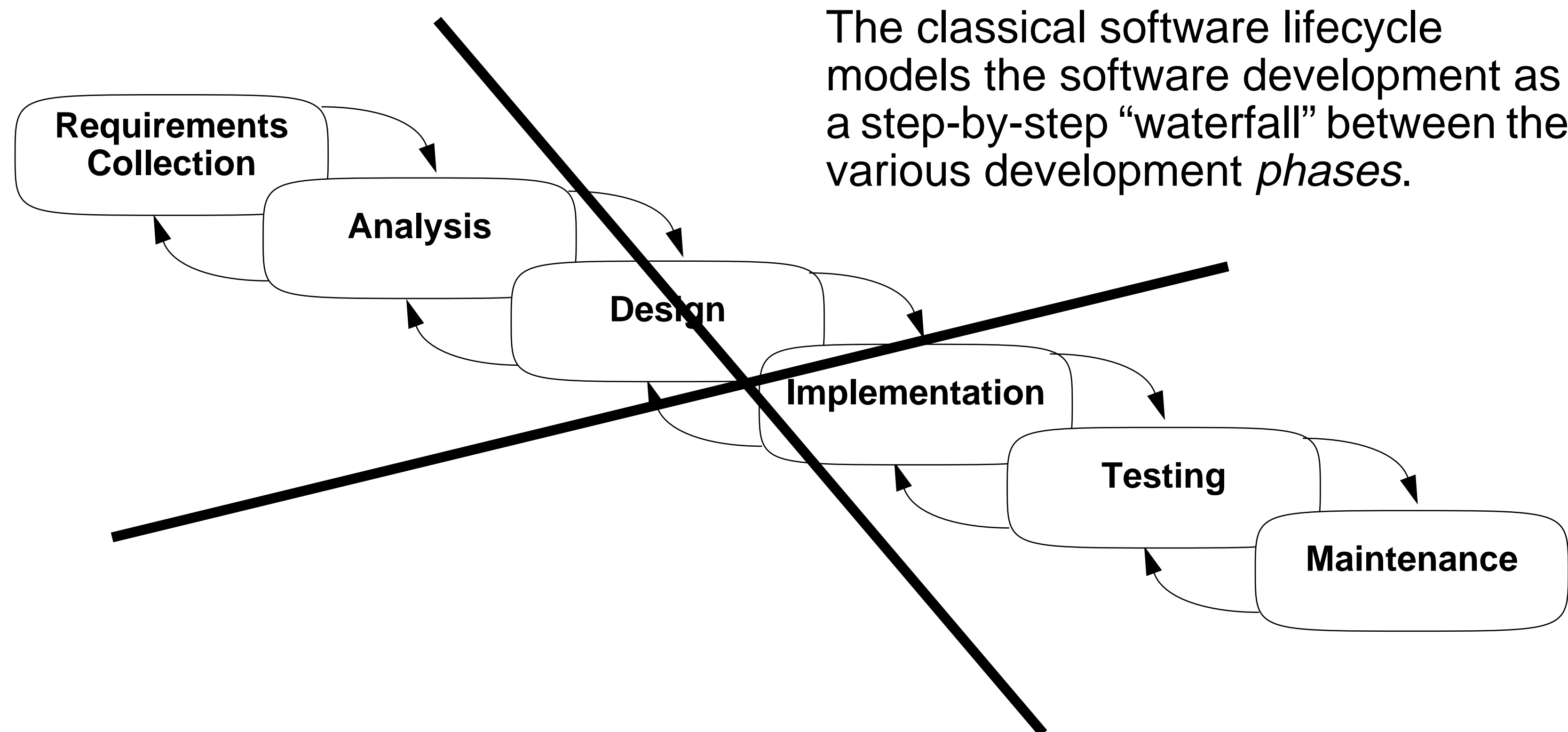
- Validate the solution against the requirements

Maintenance

- Repair defects and adapt the solution to new requirements

NB: these are ongoing activities, not sequential phases!

The Classical Software Lifecycle



The classical software lifecycle models the software development as a step-by-step “waterfall” between the various development *phases*.

The waterfall model is unrealistic for many reasons, especially:

- requirements must be “frozen” too early in the life-cycle
- requirements are validated too late

Problems with the Software Lifecycle

1. “Real projects rarely follow the sequential flow that the model proposes. *Iteration* always occurs and creates problems in the application of the paradigm”

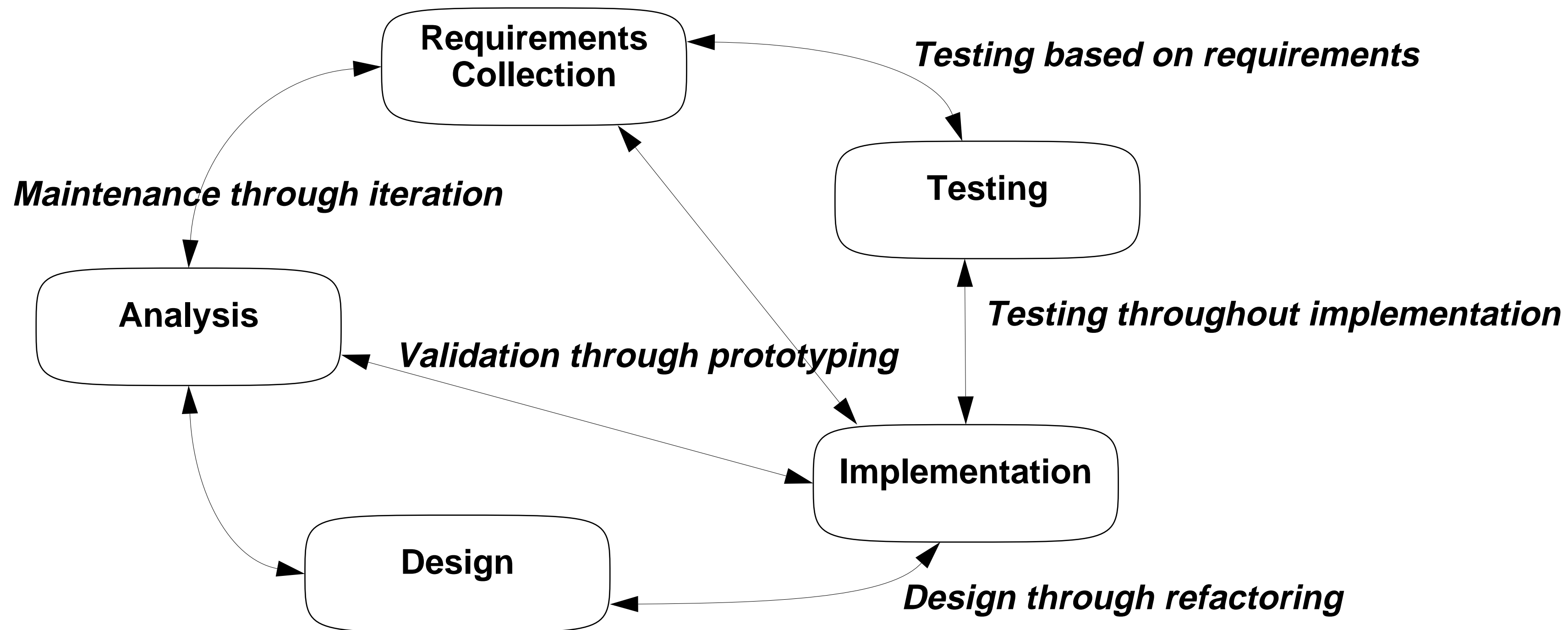
2. “It is often *difficult* for the customer *to state all requirements* explicitly. The classic life cycle requires this and has difficulty accommodating the natural uncertainty that exists at the beginning of many projects.”

3. “The customer must have patience. A *working version* of the program(s) will not be available until *late in the project* timespan. A major blunder, if undetected until the working program is reviewed, can be disastrous.”

— Pressman, SE, p. 26

Iterative Development

In practice, development is always iterative, and *all* activities progress in parallel.



✎ *If the waterfall model is pure fiction, why is it still the standard software process?*

Iterative and Incremental Development

Plan to *iterate* your analysis, design and implementation.

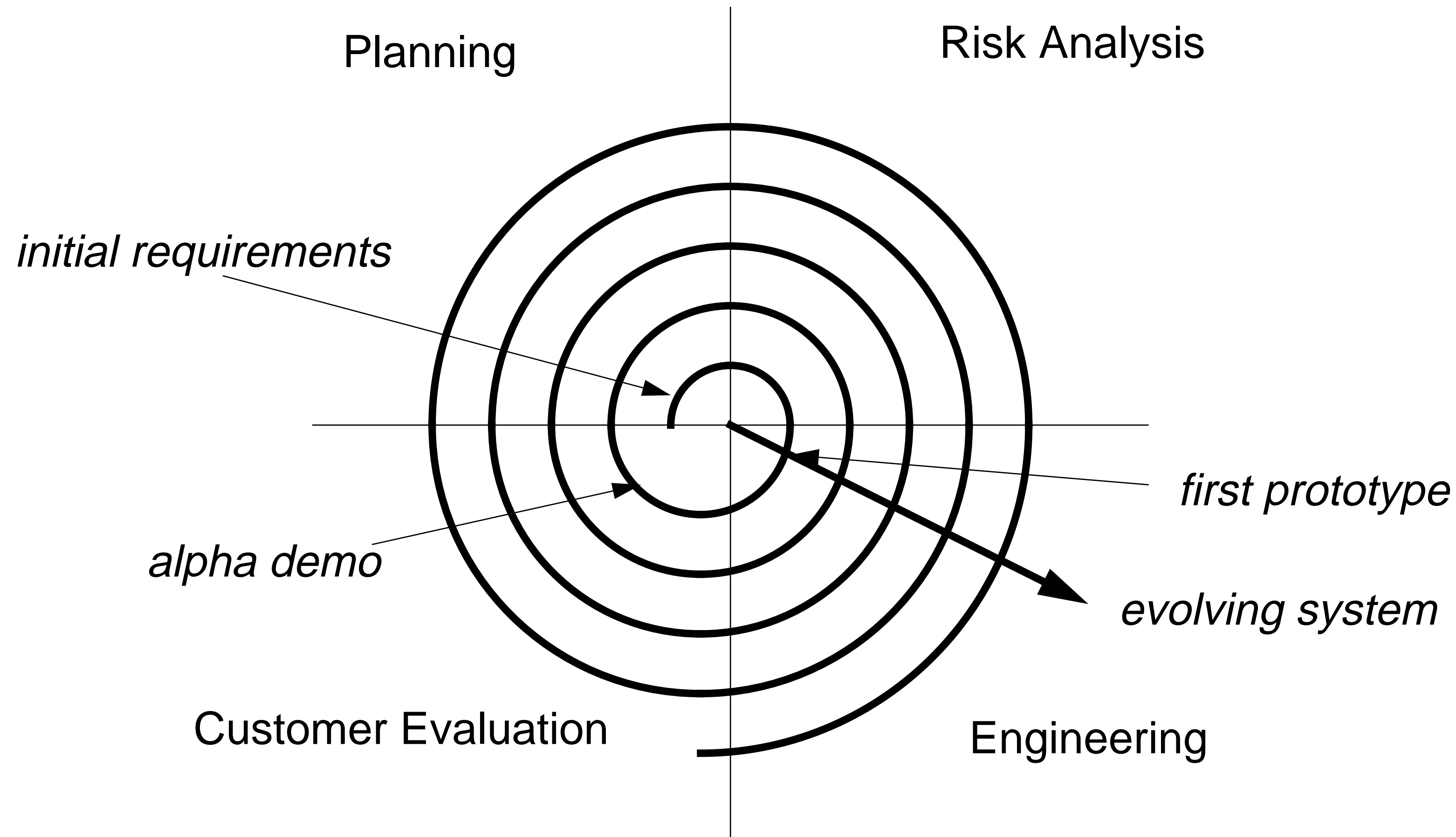
- ☞ You won't get it right the first time, so integrate, validate and test as frequently as possible.

The later in the lifecycle errors are discovered, the more expensive they are to fix!

Plan to *incrementally* develop (i.e., prototype) the system.

- ☞ If possible, always have a running version of the system, even if most functionality is yet to be implemented.
- ☞ Integrate new functionality as soon as possible.
- ☞ Validate incremental versions against user requirements.

Boehm's Spiral Lifecycle



Requirements Collection

User requirements are often expressed informally:

- ☞ features
- ☞ usage scenarios

Although requirements may be documented in written form, they may be incomplete, ambiguous, or even incorrect.

Requirements *will* change!

- ☞ inadequately captured or expressed in the first place
- ☞ user and business needs may change during the project

Validation is needed *throughout* the software lifecycle, not only when the "final system" is delivered!

- ☞ build constant *feedback* into your project plan
- ☞ plan for *change*
- ☞ early *prototyping* [e.g., UI] can help clarify requirements

Requirements Analysis and Specification

Analysis is the process of specifying *what* a system will do. The intention is to provide a clear understanding of what the system is about and what its underlying concepts are. The result of analysis is a *specification document*.

An object-oriented analysis results in models of the system which describe:

- *classes* of objects that exist in the system
- *relationships* between those classes
- *use cases* and *scenarios* describing
  - *operations* that can be performed on the system
  - allowable *sequences* of those operations

Does the requirements specification correspond to the users' actual needs?

Prototyping

A prototype is a software program developed to test, explore or validate a hypothesis, i.e. *to reduce risks.*

An *exploratory prototype*, also known as a *throwaway prototype*, is intended to validate requirements or explore design choices.

- ❑ UI prototype — validate user requirements
- ❑ rapid prototype — validate functional requirements
- ❑ experimental prototype — validate technical feasibility

An *evolutionary prototype* is intended to evolve in steps into a finished product

- ❑ iteratively “grow” the application, redesigning and refactoring along the way

✔ *First do it, then do it right, then do it fast.*

Design

Design is the process of specifying *how* the specified system behaviour will be realized from software components. The results are *architecture* and *detailed design documents.*

Object-oriented design delivers models that describe:

- how system operations are implemented by interacting objects
- how classes refer to one another and how they are related by inheritance
- attributes of, and operations, on classes

Design is an iterative process, proceeding in parallel with implementation!

Implementation and Testing

Implementation is the activity of constructing a software solution to the customer's requirements.

Testing is the process of validating that the solution meets the requirements.

The result of implementation and testing is a *fully documented* and *validated* solution.

- Design, implementation and testing are iterative activities
  - ☞ The implementation does not "implement the design", but rather the design document *documents the implementation*!

- System tests reflect the requirements specification
- Ideally, test case specification *precedes* design and implementation
  - ☞ Repeatable, automated tests *enable evolution* and *refactoring*

Maintenance

Maintenance is the process of changing a system after it has been deployed.

- *Corrective maintenance:* identifying and repairing defects
- *Adaptive maintenance:* adapting the existing solution to new platforms
- *Perfective maintenance:* implementing new requirements

In a spiral lifecycle, everything after the delivery and deployment of the first prototype can be considered "maintenance"!

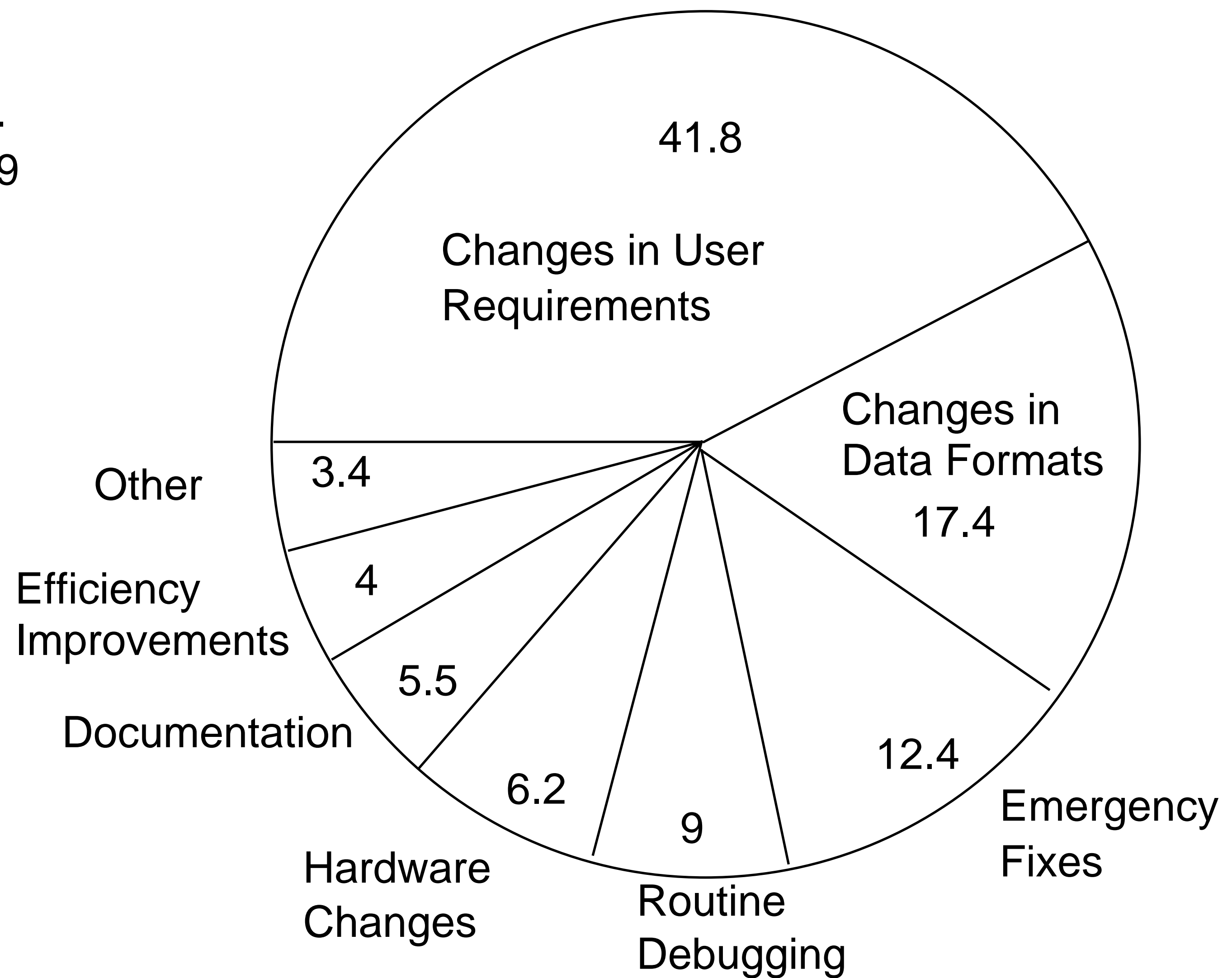
"Maintenance" entails:

- configuration and version management
- reengineering (redesigning and refactoring)
- updating all analysis, design and user documentation

Maintenance

Breakdown of maintenance costs.

Source: Lientz 1979



Why use a Method?

Requirements checking:

- System modelling helps uncover omissions and ambiguities in requirements

Clearer concepts:

- Domain analysis models can be reused/adapted when requirements change

Less design rework:

- Analysis and design models allow alternatives to be studied before implementation starts

Better refactoring of design work:

- Analysis and design helps to decompose large systems into manageable parts

Improved communications between developers:

- Standard notations provide a common vocabulary for analysis and design

Less effort needed on maintenance:

- Analysis and design documents help maintainers understand complex systems

Object-Oriented Methods

First generation:

- Adaptation of existing notations (ER diagrams, state diagrams ...):
  - Booch, OMT, Shlaer and Mellor, ...
- Specialized design techniques:
  - CRC cards; responsibility-driven design; design by contract

Second generation:

- Fusion:
  - Booch + OMT + CRC + formal methods

Third generation:

- Unified Modeling Language:
  - uniform notation: Booch + OMT + Use Cases + ...
  - complete lifecycle support (to be defined!)

Object-oriented methods are still maturing. Notations are converging, but:

- *transition* is still risky
- few methods deal seriously with software *reuse*.

Summary

You should know the answers to these questions:

- ❑ How does Software Engineering differ from programming?
- ❑ Why is the “waterfall” model unrealistic?
- ❑ What is the difference between analysis and design?
- ❑ Why plan to iterate? Why develop incrementally?
- ❑ Why is programming only a small part of the cost of a “real” software project?
- ❑ What are the key advantages and disadvantages of object-oriented methods?

Can you answer the following questions?

- ✎ *Why do requirements change?*
- ✎ *How can you validate that an analysis model captures users’ real needs?*
- ✎ *When does analysis stop and design start?*
- ✎ *When can implementation start?*

2. Project Management

Overview:

- Management activities
- Risk management
- Planning and scheduling
- Teamwork

Sources:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Third Edn., 1994.

Recommended Reading:

- *The Mythical Man-Month*, F. Brooks, Addison-Wesley, 1975
- *Object Lessons*, T. Love, SIGS Books, 1993
- *Succeeding with Objects: Decision Frameworks for Project Management*, A. Goldberg and K. Rubin, Addison-Wesley, 1995
- *Extreme Programming Explained: Embrace Change*, Kent Beck (to appear)

Management activities

- Defining scope and objectives
- Estimating costs
- Analysing and managing risk
- Planning & scheduling
- Selecting and evaluating staff
- Project tracking and control

Risk Management

If you don't actively attack risks, they will actively attack you.

— Tom Gilb

Project risks

☞ budget, schedule, resources, size, personnel, morale ...

Technical risks

☞ implementation technology, verification, maintenance ...

Business risks

☞ market, sales, management, commitment ...

Management must:

- ❑ *identify* risks as early as possible
- ❑ *assess* whether risks are acceptable
- ❑ *monitor* risks throughout the project
- ❑ take appropriate action to *manage* risks
  - ☞ e.g., training, prototyping, iteration, ...

Focus on Scope

For decades, programmers have been whining, “The customers can’t tell us what they want. When we give them what they say they want, they don’t like it.” Get over it. This is an absolute truth of software development. The requirements are never clear at first. Customers can never tell you exactly what they want.

— Kent Beck

Scope and Objectives

Myth: *"A general statement of objectives is enough to start coding."*
Reality: Poor up-front definition is the major cause of project failure.

In order to plan, you must set clear scope & objectives

Objectives identify the *general goals* of the project, *not how they will be achieved*.

Scope identifies the *primary functions* that the software is to accomplish, and *bounds* these functions in a quantitative manner.

- ❑ Goals must be *realistic* and *measurable*
- ❑ *Constraints,* performance, reliability must be explicitly stated
- ❑ *Customer* must set *priorities*

Cost Estimation Objectives

- To establish a budget for a software project
- To provide a means of controlling project costs
- To monitor progress against the budget
  - ☞ comparing planned with estimated costs
- To establish a cost database for future estimation
- Cost estimation and planning/scheduling are closely related activities

Measurement

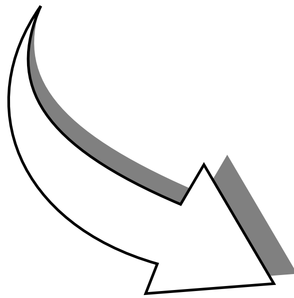
When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science.

— Lord Kelvin

Measurement-based Estimation

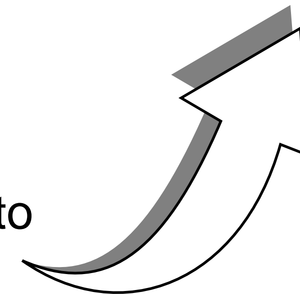
A. Measure

Develop a *system model* and measure its size



B. Estimate

Determine the effort with respect to an *empirical database* of measurements from *similar projects*



C. Interpret

Adapt the effort with respect to a specific *development project plan*

Estimation and Commitment

Example: The XP process

1. a. Customers *write stories* and

   b. Programmers *estimate stories*

   ☞ if they can’t, they ask the customers to split/merge/rewrite stories
2. Programmers *measure the team load factor*, the ratio of ideal programming time to the calendar
3. Customers *sort stories by priority*
4. Programmers *sort stories by risk*
5. a. Customers pick date, programmers calculate budget, customers pick stories adding up to that number, *or*

   b. Customers pick stories, programmers calculate date

   (customers complain, programmers suggest customers reduce scope, customers complain some more but reduce scope anyway)

Product Process Model

***Incremental* decision-making, development, testing and integration produce effective project results.**

- Iterative development:
  - Controlled reworking of parts of a system to remove mistakes or make improvements based on user feedback
  - “We get things wrong before we get them right”
- Incremental development:
  - Partition systems and develop at different times or rates
  - Test and integrate as each partition completes
  - Make progress in small steps to get earlier customer feedback
  - Obtain better quality testing by integrating partitions as early as possible
- Prototyping:
  - Creating a scaled-down model of some or all of the system
  - Benefit by “buying” information before making key decisions

Planning and Scheduling (I)

Myth: *"If we get behind schedule, we can add more programmers and catch up."*
Reality: Adding more people typically slows a project down.

Scheduling problems

- *Estimating* the difficulty of problems and the cost of developing a solution *is hard*
- *Productivity is not proportional* to the number of people working on a task
- *Adding people to a late project makes it later* due to communication overhead
- *The unexpected always happens.* Always allow contingency in planning

Planning under uncertainty

- State clearly what you know and don't know
- State clearly what you will do to eliminate unknowns
- Make sure that all early milestones can be met
- Plan to replan

Planning and Scheduling (II)

Project Scheduling

- ❑ *Split project* into *tasks*.
- ❑ Identify required *milestones* and *cost of each task*.
- ❑ *Organize tasks concurrently* to make optimal use of workforce
- ❑ Document *dependencies* between project tasks
  - ☞ total time depends on longest path in activity graph
- ❑ *Minimize task dependencies* to avoid delays
- ❑ Depend on project manager's *intuition and experience!*

Planning and estimation are *iterative* and schedules must be monitored and revised during the project!

Task Durations and Dependencies

Task	*Duration (days)*	*Dependencies*
T1	8	
T2	15	
T3	15	T1
T4	10	
T5	10	T2, T4
T6	5	T1, T2
T7	20	T1
T8	25	T4
T9	15	T3, T6
T10	15	T5, T7
T11	7	T9
T12	10	T11

✎ *What is the minimum total duration of this project?*

Milestones and Deliverables

Myth: *"The only deliverable for a successful project is the working program."*

Reality: Documentation of all aspects of software development are needed to ensure maintainability.

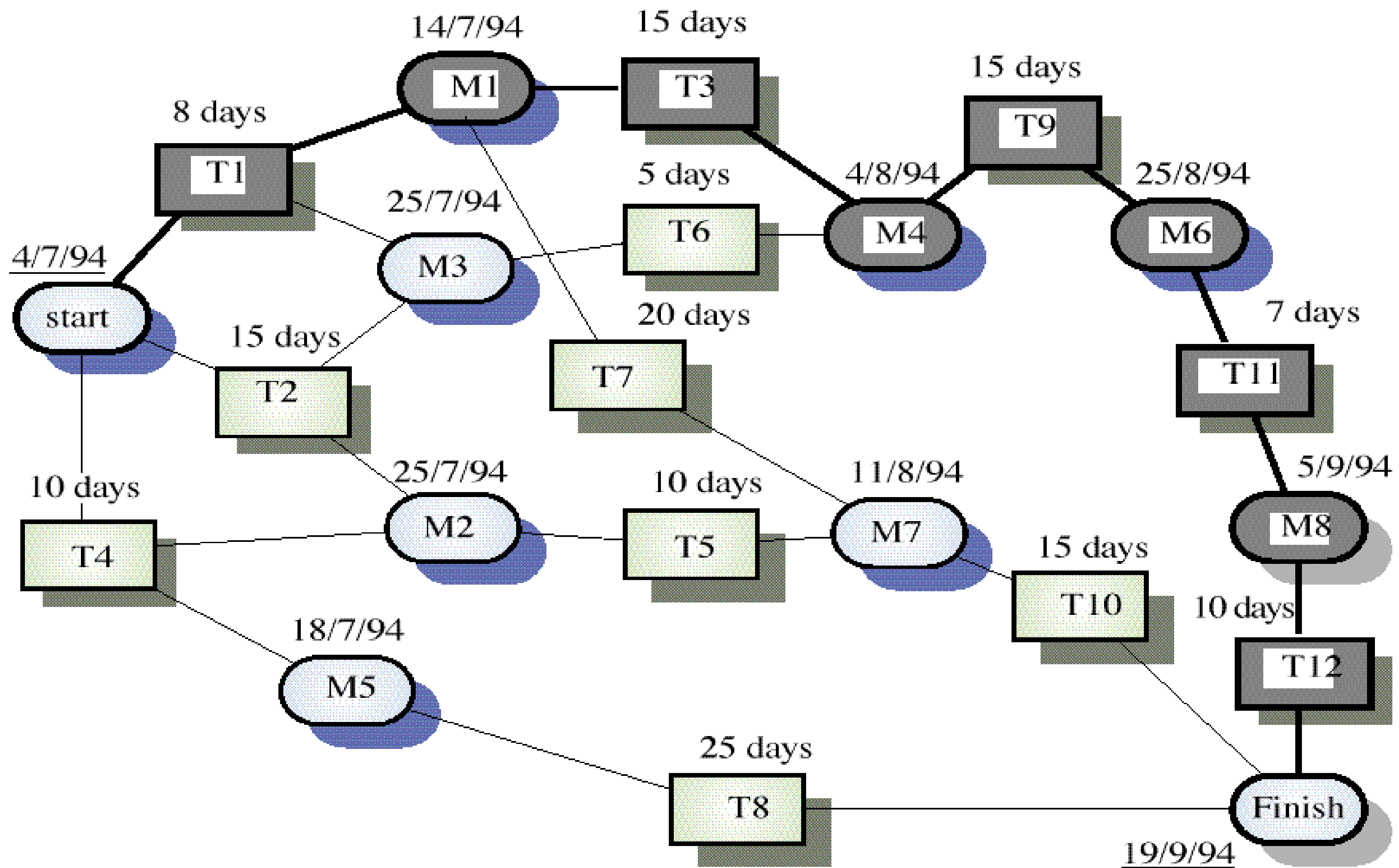
Project milestones mark the end of significant software process activities.

Project deliverables are results that are delivered to the customer.

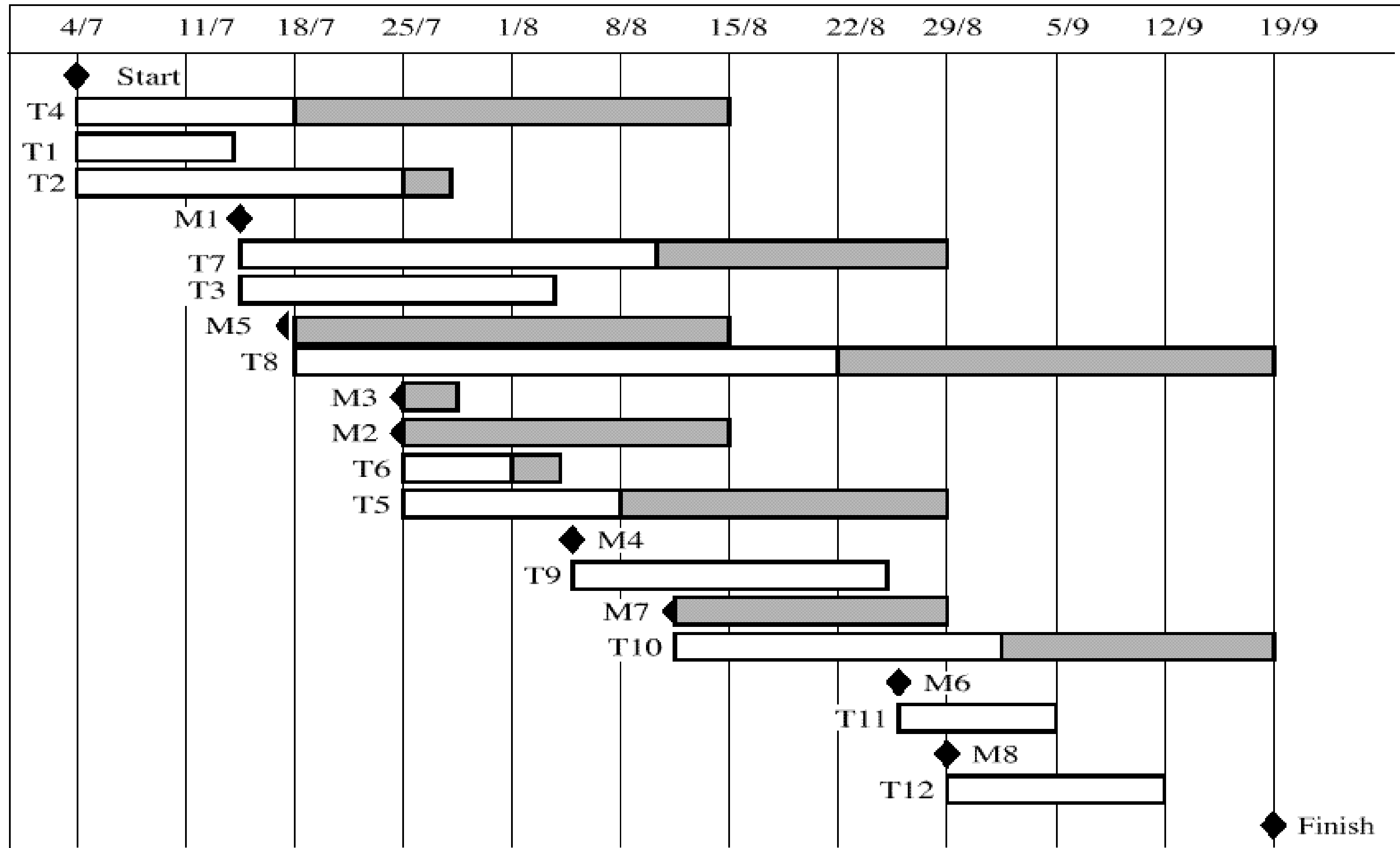
- E.g.:
  - initial requirements document
  - UI prototype
  - architecture specification
- Milestones and deliverables help to *monitor progress*
  - Should be scheduled roughly every 2-3 weeks

NB: Deliverables must evolve as the project progresses!

Activity Network



Activity Timeline



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Software Teams

Team organisation

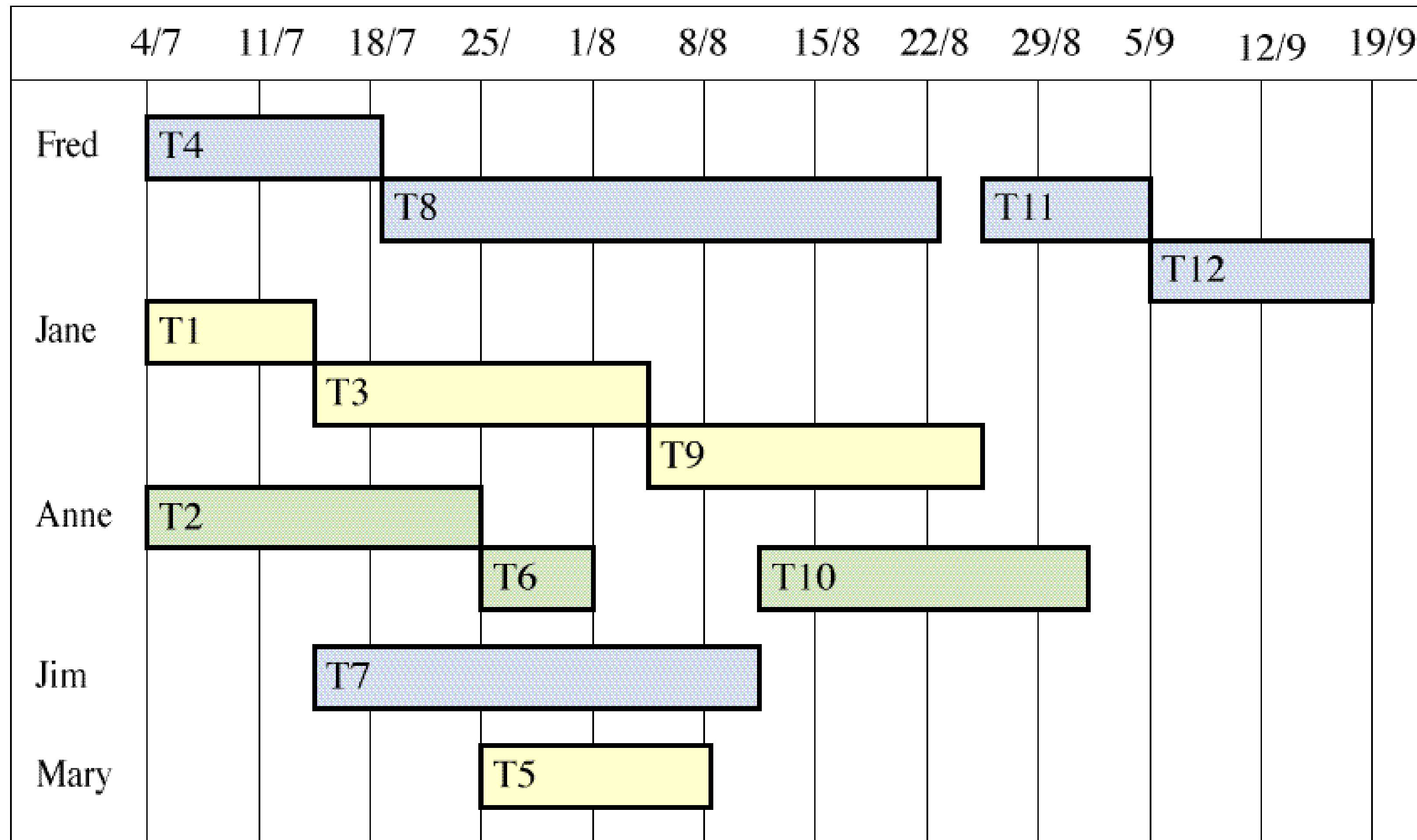
- ❑ Teams should be *relatively small* (< 8 members)
  - ☞ minimize communication *overhead*
  - ☞ team *quality standard* can be developed
  - ☞ members can *work closely* together
  - ☞ programs are regarded as *team property* ("egoless programming")
  - ☞ *continuity* can be maintained if members leave
- ❑ Break big projects down into multiple smaller projects
- ❑ Small teams may be organised in an informal, *democratic* way
- ❑ *Chief programmer teams* try to make the most effective use of skills and experience

Chief Programmer Teams

- Consist of a kernel of specialists helped by others as required
  - *chief programmer* takes full responsibility for design, programming, testing and installation of system
  - *backup programmer* keeps track of CP's work and develops test cases
  - *librarian* manages all information
  - others may include: *project administrator, toolsmith, documentation editor, language/system expert, tester,* and *support programmers*

- Reportedly successful but problems are:
  - *Difficult* to find talented chief programmers
  - *Disrupting* to normal organisational structures
  - *De-motivating* for those who are not chief programmers

Staff Allocation



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Object Lessons

Prototyping

- plan to throw one (two?) away; *prototypes are not products*

Requirements and Design

- must be formally specified and reviewed *with the customer* to correct misunderstandings at the earliest possible stage

Training

- *6-12 months* to train software engineers to *OO productivity* (if ever)

Reusability

- high programmer *resistance*; requires incentives and support

Productivity

- *can vary by 50:1;* match organization to available skills & talents

Tools

- devote 20% of project staff to *toolsmiths* (building, acquiring ...)

Leading vs. Managing

- team leaders should *read & review all code* produced by the team
- managers should be able to read and *understand all code*

Conway's Law

"Organizations that design systems are constrained to produce designs that are copies of the communication structures of these organizations"

Summary

You should know the answers to these questions:

- How can *prototyping* help to reduce risk in a project?
- What is the difference between *iterative* and *incremental* development?
- What are *milestones*, and why are they important?
- What can you learn from an *activity network*? An activity timeline?
- Why should programming teams have no more than about 8 members?
- What is meant by “plan to throw one away”?

Can you answer the following questions?

- *What will happen if the developers, not the customers, set the project priorities?*
- *What is a good way to measure the size of a project (based on requirements alone)?*
- *When should you sign a contract with the customer?*
- *How do you know if you fall behind schedule? What should you do then?*
- *How would you select and organize the perfect software development team?*
- *What are good examples of Conway’s Law in action?*

3. Requirements Collection

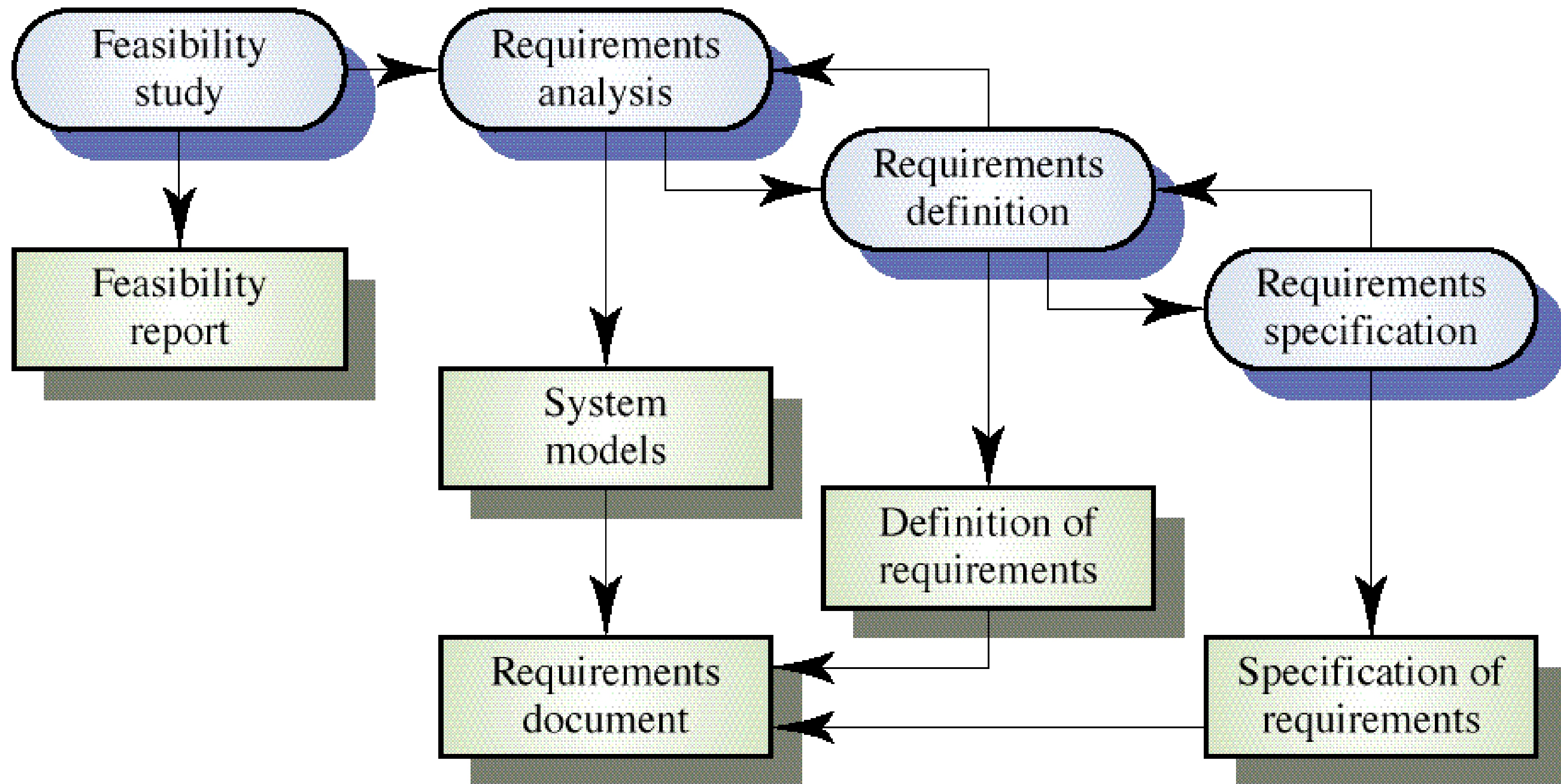
Overview:

- The Requirements Engineering Process
  - ☞ Requirements Analysis, Definition and Specification
- Use cases and scenarios
- Functional and non-functional requirements
- Evolutionary and throw-away prototyping
- Requirements checking and reviews

Sources:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Third Edn., 1994.
- *Objects, Components and Frameworks with UML*, D. D'Souza, A. Wills, Addison-Wesley, 1999

The Requirements Engineering Process



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Requirements Engineering Activities

Feasibility study

- Determine if the user needs can be satisfied with the available technology and budget.

Requirements analysis

- Find out what system stakeholders require from the system.

Requirements definition

- Define the requirements in a form understandable to the customer.

Requirements specification

- Define the requirements in detail.

  Written as a contract between client and contractor.

“Requirements are for users; specifications are for analysts and developers.”

Requirements Analysis

Sometimes called *requirements elicitation* or *requirements discovery*

Technical staff work with customers to determine

- the application domain,
- the services that the system should provide and
- the system's operational constraints.

Involves various *stakeholders:*

- e.g., end-users, managers, engineers involved in maintenance, domain experts, trade unions, etc.

Problems of Requirements Analysis

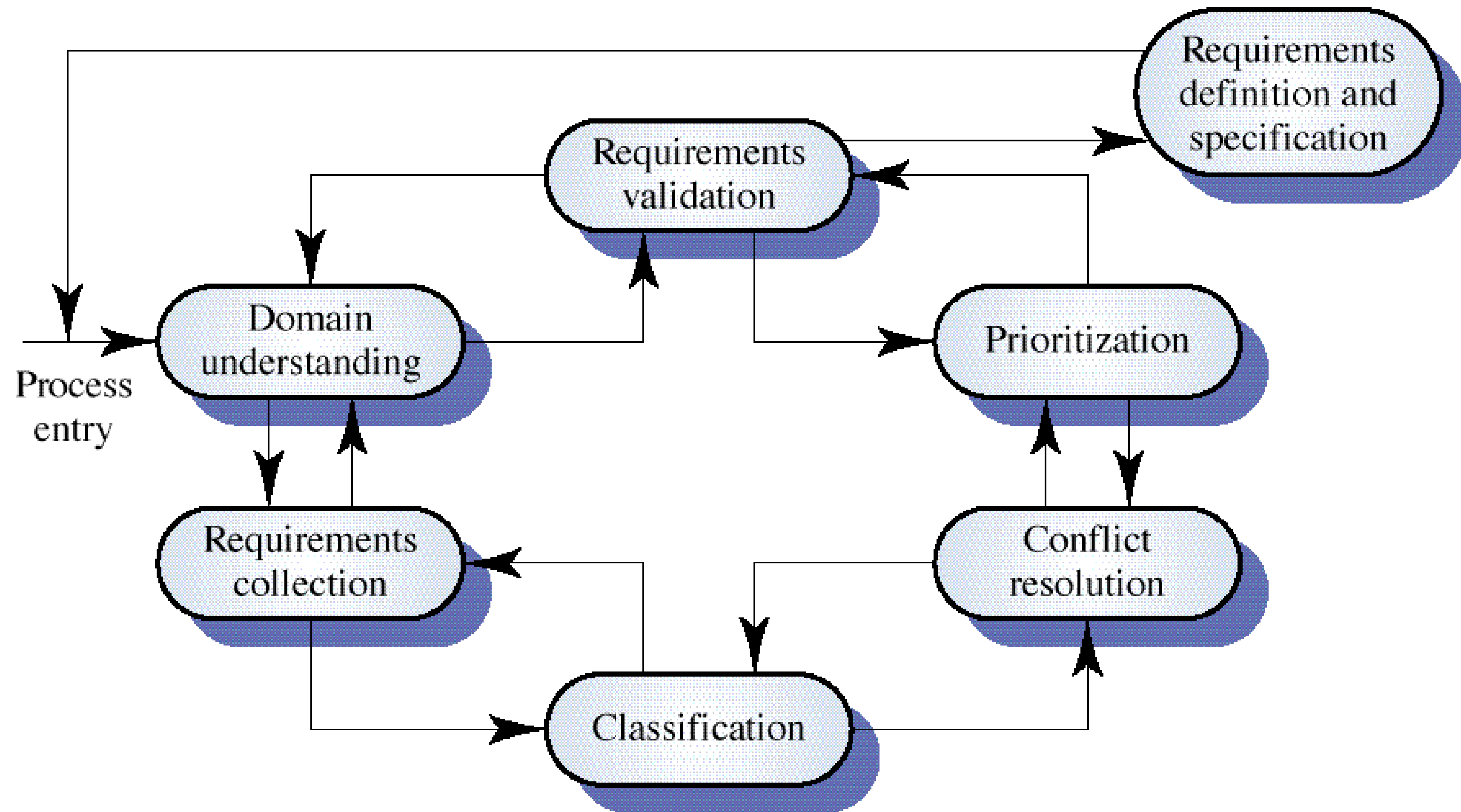
Various problems typically arise:

- Stakeholders don't know what they really want
- Stakeholders express requirements in their own terms
- Different stakeholders may have conflicting requirements
- Organisational and political factors may influence the system requirements
- The requirements change during the analysis process.
  New stakeholders may emerge.

Requirements evolution

- Requirements *always evolve* as a better understanding of user needs is developed and as the organisation's objectives change
- It is essential to *plan for change* in the requirements as the system is being developed and used

The Requirements Analysis Process



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Use Cases and Viewpoints

A use case is the *specification* of a *sequence of actions*, including *variants*, that a system (or other entity) can perform, *interacting with actors* of the system”.

A scenario is a particular trace of action occurrences, starting from a known initial state.

Stakeholders represent different problem *viewpoints*.

- Interview as many *different* kinds of stakeholders as possible/necessary
- Translate requirements into *use cases* or “stories” about the desired system involving a fixed set of *actors* (users and system objects)
- For each use case, capture *both typical* and *exceptional* usage *scenarios*

Users tend to think about systems in terms of “features”.

- You must get them to tell you *stories* involving those features.
- Use cases and scenarios can tell you if the requirements are *complete* and *consistent!*

Unified Modeling Language

The "Unified Modeling Language" (UML) is an emerging industrial standard for documenting object-oriented analysis and design models.

- **Class Diagrams:** specify classes, objects and their relationships
  - visualize logical structure of system
- **Use Case Diagrams:** show external actors and use cases they participate in
- **Sequence Diagrams:** list the message exchanges in a use case scenario
  - visualizes temporal message ordering
- **Collaboration Diagrams:** show messages exchanged by objects
  - visualize object relationships
- **State Diagrams:** specify the possible internal states of an object

and others ...

Writing Requirements Definitions

Requirements definitions usually consist of *natural language,* supplemented by (e.g., UML) *diagrams* and *tables*.

Three types of problem can arise:

- ❑ Lack of clarity:
  - ☞ It is hard to write documents that are both *precise* and *easy-to-read*.
- ❑ Requirements confusion:
  - ☞ *Functional* and *non-functional* requirements tend to be intertwined.
- ❑ Requirements amalgamation:
  - ☞ Several *different requirements* may be expressed together.

Functional and Non-functional Requirements

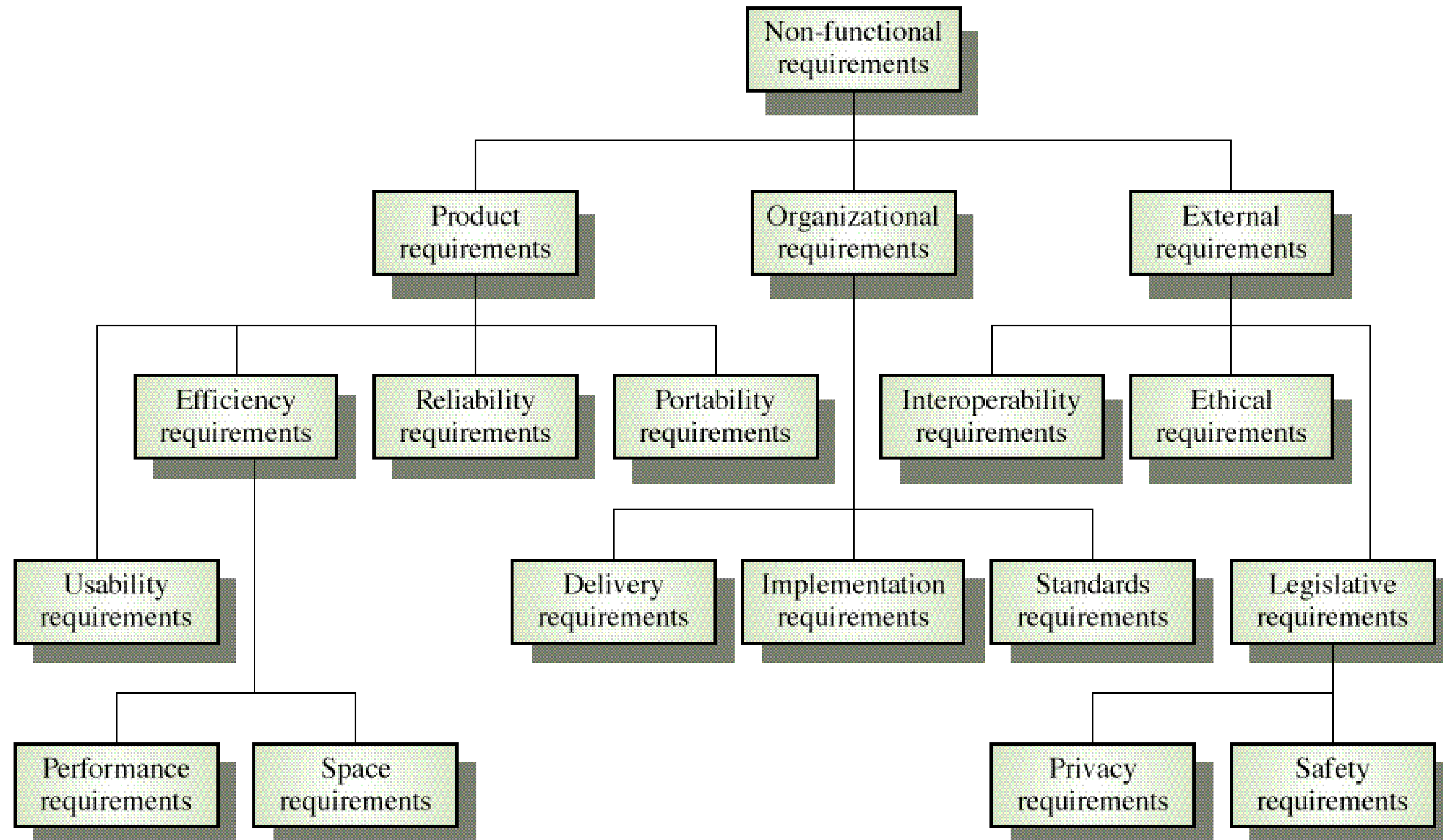
Functional requirements describe system *services* or *functions*

Non-functional requirements are *constraints* on the system or the development process:

- ❑ Product requirements:
  - ☞ specify that the delivered product must behave in a particular way e.g. execution speed, reliability, etc.
- ❑ Organisational requirements:
  - ☞ are a consequence of organisational policies and procedures e.g. process standards used, implementation requirements, etc.
- ❑ External requirements:
  - ☞ arise from factors which are external to the system and its development process e.g. interoperability requirements, legislative requirements, etc.

Non-functional requirements may be more critical than functional requirements.
If these are not met, the system is useless!

Types of Non-functional Requirements



Examples of Non-functional Requirements

Product requirement

- It shall be possible for all necessary communication between the APSE and the user to be expressed in the standard Ada character set.

Organisational requirement

- The system development process and deliverable documents shall conform to the process and deliverables defined in XYZCo-SP-STAN-95.

External requirement

- The system shall provide facilities that allow any user to check if personal data is maintained on the system. A procedure must be defined and supported in the software that will allow users to inspect personal data and to correct any errors in that data.

Requirements Verifiability

Requirements must be written so that they can be *objectively verified.*

Imprecise:

The system should be easy to use by experienced controllers and should be organised in such a way that user errors are minimised.

Terms like “easy to use” and “errors shall be minimised” are useless as specifications.

Verifiable:

Experienced controllers should be able to use all the system functions after a total of two hours training. After this training, the average number of errors made by experienced users should not exceed two per day.

Precise Requirements Measures

Property	*Measure*
Speed	Processed transactions/second User/Event response time Screen refresh time
Size	K Bytes; Number of RAM chips
Ease of use	Training time Number of help frames
Reliability	Mean time to failure Probability of unavailability Rate of failure occurrence Availability
Robustness	Time to restart after failure Percentage of events causing failure Probability of data corruption on failure
Portability	Percentage of target dependent statements Number of target systems

Prototyping Objectives

The objective of evolutionary prototyping is to deliver a *working system* to end-users.

- Development starts with the requirements that are *best understood.*

The objective of throw-away prototyping is to *validate or derive the system requirements.*

- Prototyping starts with that requirements that are *poorly understood.*

Evolutionary Prototyping

- Must be used for systems where the specification cannot be developed in advance.
  - e.g. AI systems and user interface systems
- Based on techniques which allow *rapid system iterations.*
  - e.g., executable specification languages, VHL languages, 4GLs, component toolkits
- *Verification* is impossible as there is no specification.
  - *Validation* means demonstrating the adequacy of the system.

Throw-away Prototyping

- Used to reduce requirements risk
- The prototype is developed from an initial specification, delivered for experiment then discarded
- The throw-away prototype should *not* be considered as a final system
  - Some system characteristics may have been left out (e.g., platform requirements may be ignored)
  - There is no specification for long-term maintenance
  - The system will be poorly structured and difficult to maintain

Requirements Checking

Validity:

- Does the system provide the functions *which best support* the customer's needs?

Consistency:

- Are there any requirements *conflicts?*

Completeness:

- Are *all functions* required by the customer included?

Realism:

- Can the requirements be implemented given *available budget* and *technology?*

Requirements Reviews

Requirements reviews

- *Regular reviews* should be held while the requirements definition is being formulated
- Both *client* and *contractor staff* should be involved in reviews
- Reviews may be *formal* (with completed documents) or *informal*.

  Good communications between developers, customers and users can resolve problems at an *early stage*

Review checks

- *Verifiability.* Is the requirement realistically *testable*?
- *Comprehensibility.* Is the requirement properly *understood*?
- *Traceability.* Is the *origin* of the requirement clearly stated?
- *Adaptability*. Can the requirement be *changed* without a large *impact* on other requirements?

Summary

You should know the answers to these questions:

- ❑ What is the difference between requirements *analysis* and *specification*?
- ❑ Why is it *hard* to define and specify requirements?
- ❑ What are *use cases* and *scenarios*?
- ❑ What is the difference between *functional* and *non-functional* requirements?
- ❑ What's wrong with a requirement that says a product should be "user-friendly"?
- ❑ What's the difference between *evolutionary* and *throw-away* prototyping?

Can you answer the following questions?

- ✎ *Why isn't it enough to specify requirements as a set of desired features?*
- ✎ *Which is better for specifying requirements: natural language or diagrams?*
- ✎ *How would you prototype a user interface for a web-based ordering system?*
- ✎ *Would it be an evolutionary or throw-away prototype?*
- ✎ *What would you expect to gain from the prototype?*
- ✎ *How would you check a requirement for "adaptability"?*

4. Modelling Objects and Classes

- Classes, attributes and operations
- Visibility of Features
- Parameterized Classes
- Objects
- Associations
- Inheritance
- Constraints
- Packages

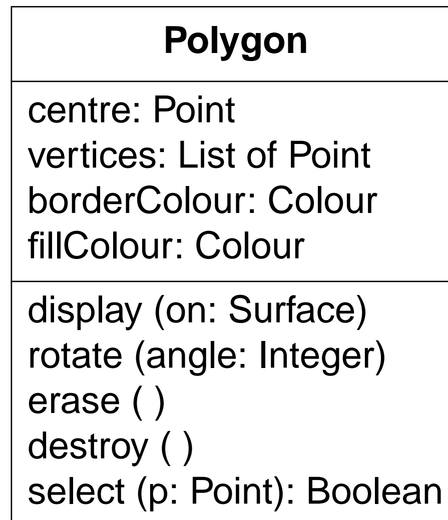
Sources:

- *Unified Modeling Language — Notation Guide*, version 1.1, Rational Software Corporation, 1997.
- *Object-Oriented Development — The Fusion Method*, D. Coleman, et al., Prentice Hall, 1994.

Class Diagrams

"Class diagrams show generic descriptions of possible systems, and object diagrams show particular instantiations of systems and their behaviour."

Class name, attributes and operations:

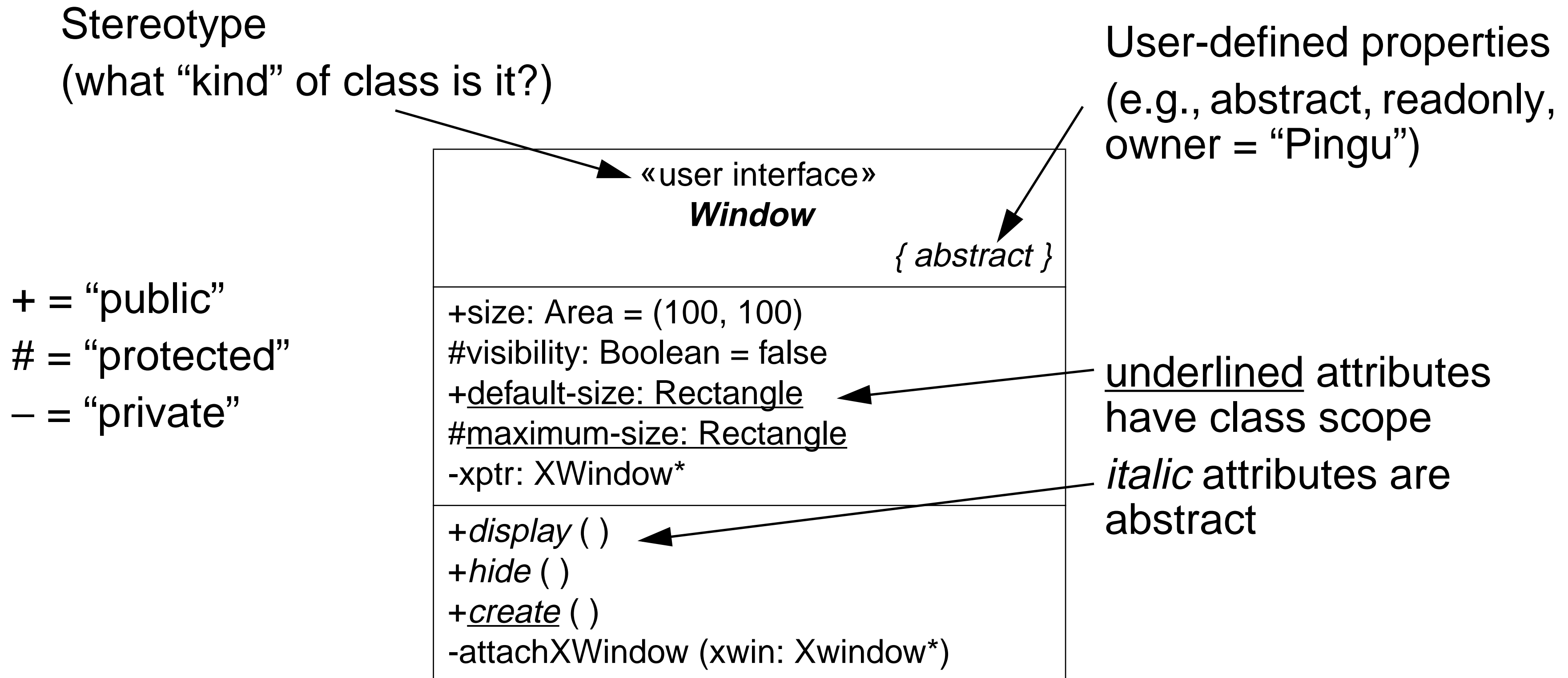


A collapsed class view:

Class with Package name:

Attributes and operations are also collectively called *features*.

Visibility and Scope of Features



Attributes are specified as: *name: type = initialValue { property string }*

Operations are specified as: *name (param: type = defaultValue, ...) : resultType*

UML Lines and Arrows

Constraint
(usually annotated)

Association
e.g., «uses»

Dependency
e.g., «requires», «imports» ...

Navigable association
e.g., part-of

Refinement
e.g., class/template, class/interface

“Generalization”
i.e., specialization (!)
e.g., class/superclass, concrete/abstract class

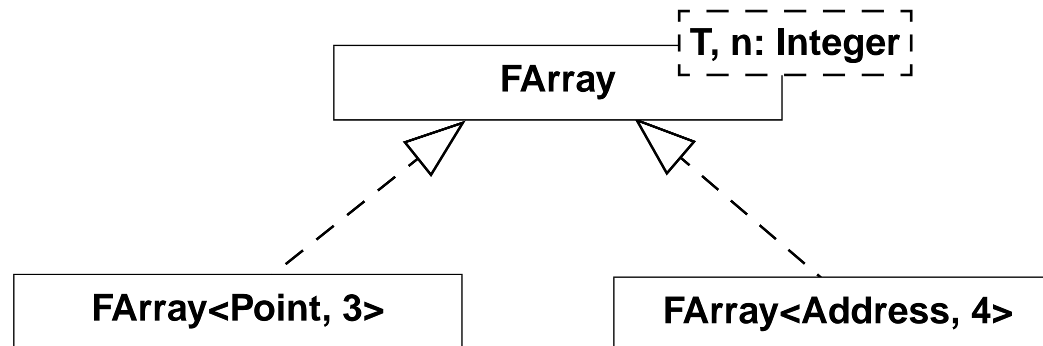
Aggregation
i.e., “consists of”

“Composition”
i.e., containment

Parameterized Classes

Parameterized (aka “template” or “generic”) classes are depicted with their parameters shown in a dashed box.

Parameters may be either types (just a name) or values (**name: Type**).

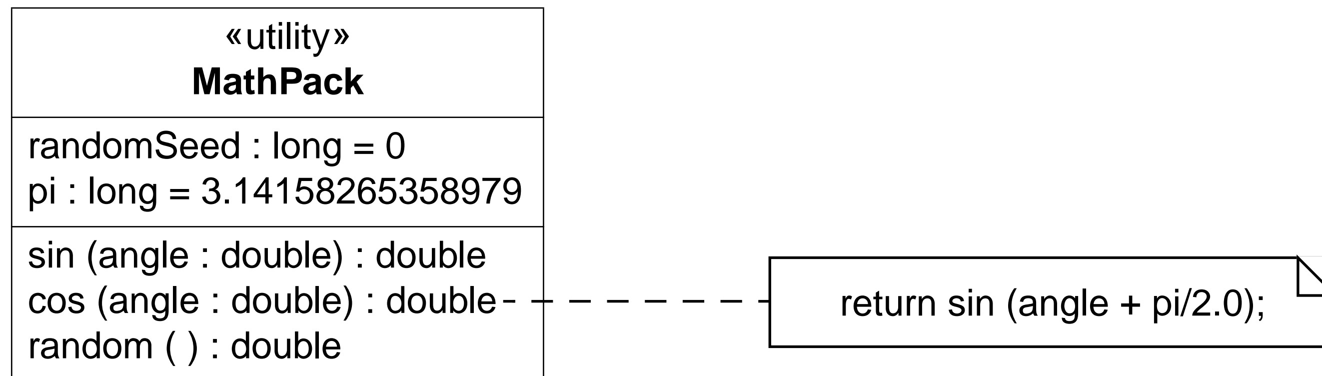


Instantiation of a class from a template can be shown by a dashed arrow.

NB: All forms of arrows (directed arcs) go from the client to the supplier!

Utilities

A "utility" is a grouping of global attributes and operations. It is represented as a class with the stereotype «utility». Utilities may be parameterized.

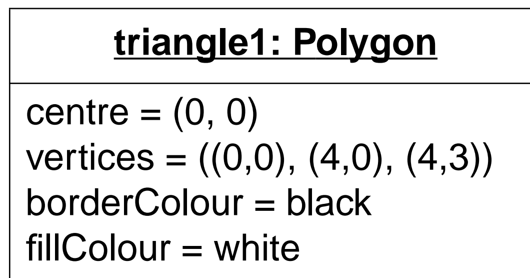


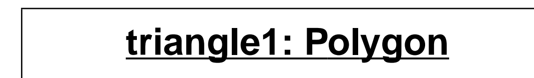
NB: A utility's attributes are already interpreted as being in class scope, so it is redundant to underline them.

A "note" is a text comment associated with a view, and represented as box with the top right corner folded over.

Objects

Objects are shown as rectangles with their name and type underlined in one compartment, and attribute values, optionally, in a second compartment.

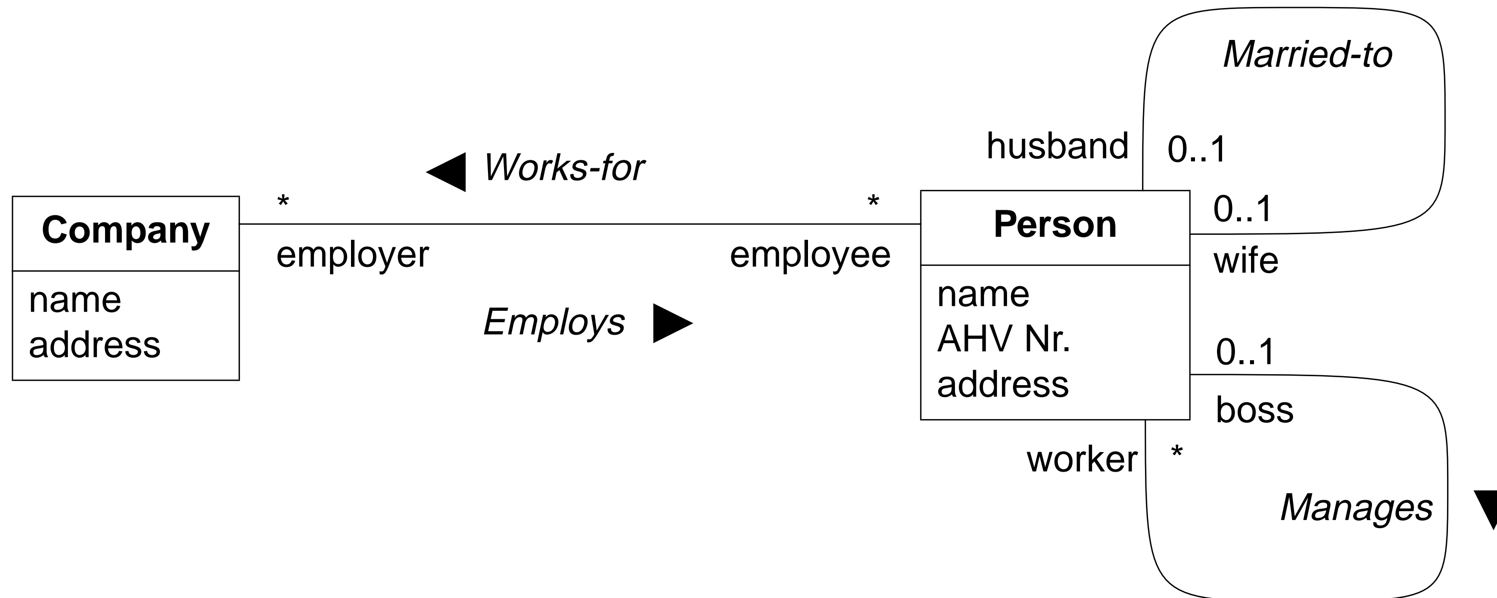




At least one of the name or the type must be present.

Associations

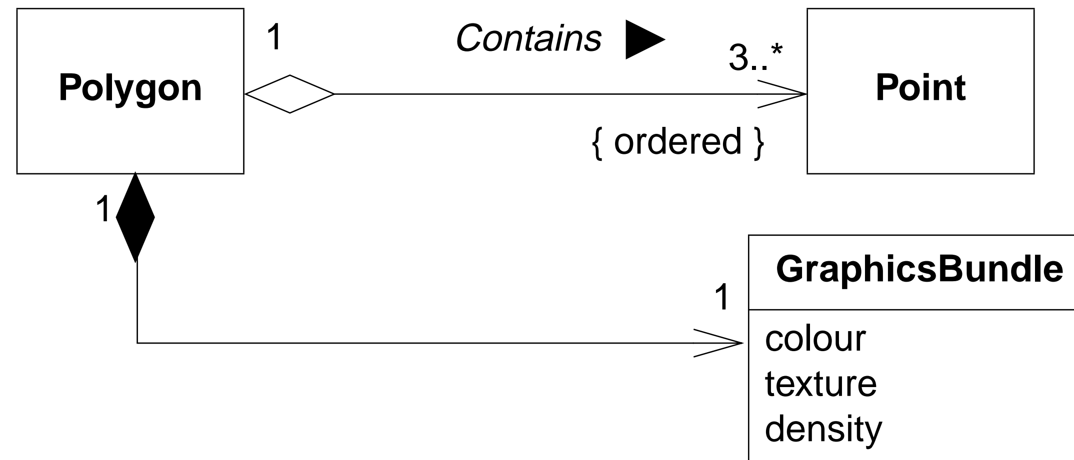
Associations represent structural relationships between objects of different classes.



- usually *binary* (but may be ternary etc.)
- optional *name* and *direction*
- (unique) *role* names and *multiplicities* at end-points
- can traverse using *navigation expressions*
  e.g., Sandoz.employee[name = "Pingu"].boss

Aggregation and Navigability

Aggregation is denoted by a diamond and indicates a part-whole dependency:



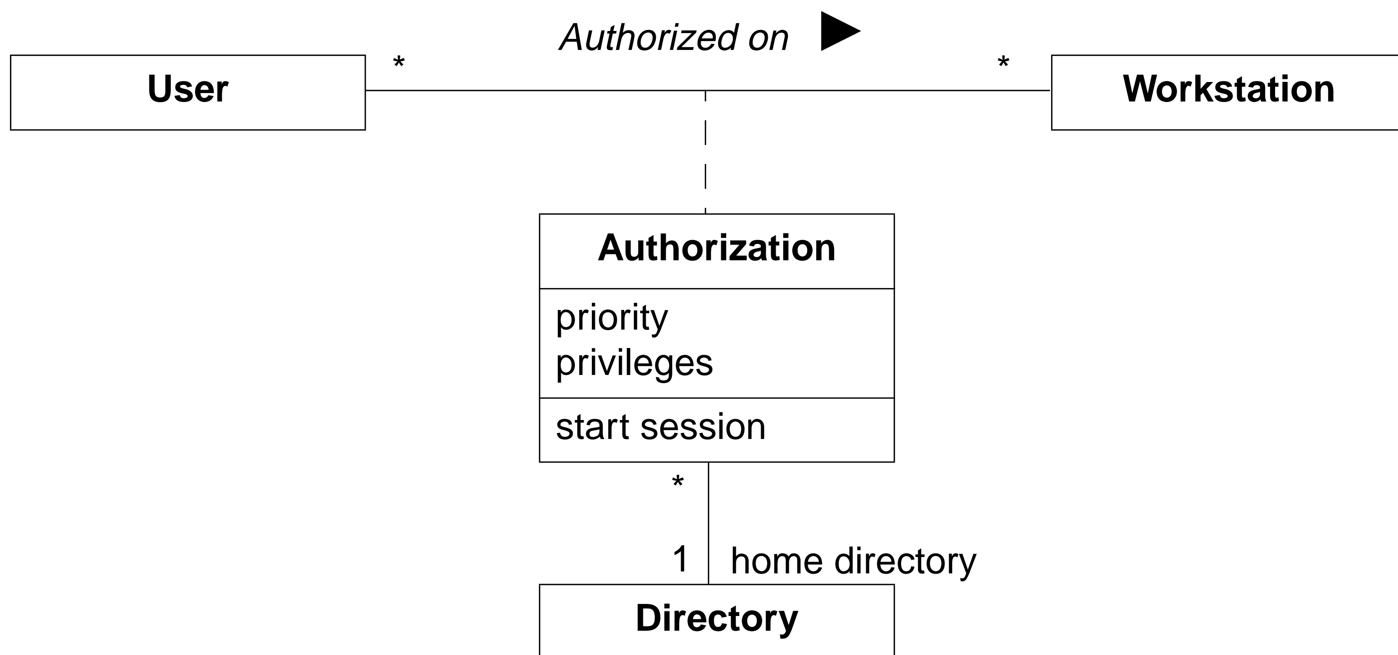
A hollow diamond indicates a reference; a solid diamond an implementation.

If the link terminates with an arrowhead, then one can *navigate* from the whole to the part.

If the multiplicity of a role is > 1, it may be marked as { ordered }, or as { sorted }.

Association Classes

An association may be an instance of an association class:



In many cases the association class only stores attributes, and its name can be left out.

Qualified Associations

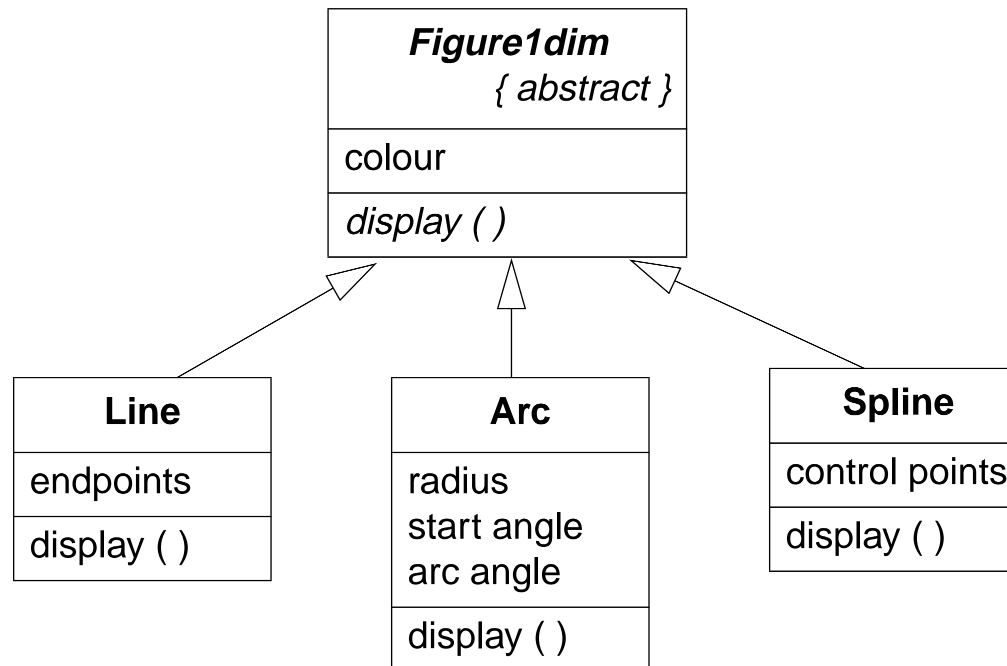
A qualified association uses a special qualifier value to identify the object at the other end of the association:

"The multiplicity attached to the target role denotes the possible cardinalities of the set of target objects selected by the pairing of a source object and a qualifier value."

NB: Qualifiers are part of the association, not the class

Inheritance

A subclass inherits the features of its superclasses:



What is Inheritance For?

New software often builds on old software by imitation, refinement or combination. Similarly, classes may be *extensions*, *specializations* or *combinations* of existing classes.

Inheritance supports:

Conceptual hierarchy:

- ❑ conceptually related classes can be organized into a specialization hierarchy
  - ☞ people, employees, managers
  - ☞ geometric objects ...

Software reuse:

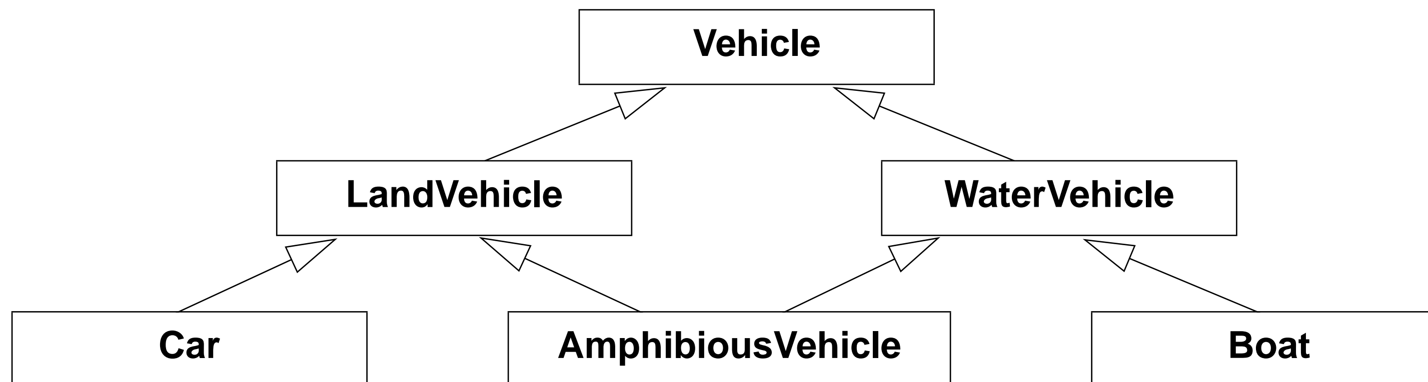
- ❑ related classes may share interfaces, data structures or behaviour
  - ☞ geometric objects ...

Polymorphism:

- ❑ objects of distinct, but related classes may be uniformly treated by clients
  - ☞ array of geometric objects

Multiple Inheritance

A class may inherit features from multiple superclasses:



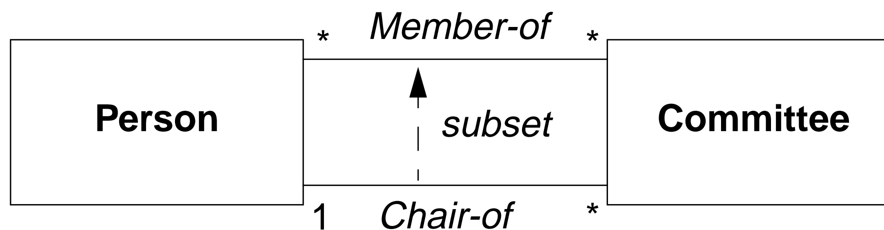
In Eiffel, features inherited from common parents are *shared* unless they have been renamed along one of the inheritance paths. Such features are considered *replicated*.

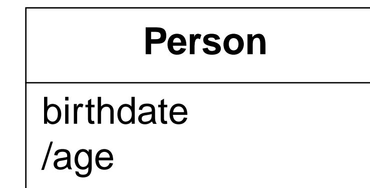
Other languages may adopt other rules to resolve inheritance conflicts.

Constraints

Constraints are restrictions on values attached to classes or associations.

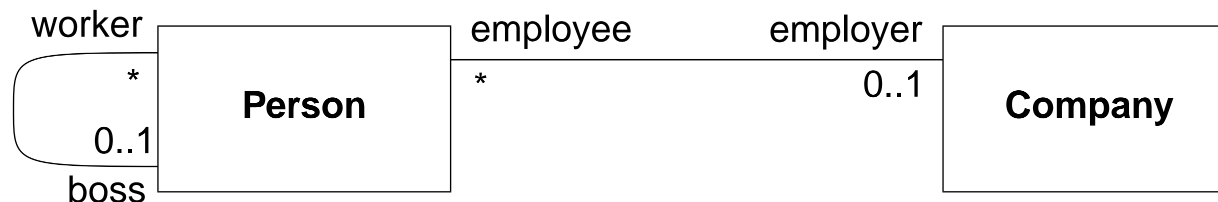
- Binary constraints may be shown as dashed lines between elements
- Derived values and associations can be marked with a “/”





{ age = currentDate - birthdate }

Constraints are specified between braces, either free or within a note:



Using the Notation

During Analysis:

- ❑ Capture classes visible to users
- ❑ Document attributes and responsibilities
- ❑ Identify associations and collaborations
- ❑ Identify conceptual hierarchies
- ❑ Capture all visible features

During Design:

- ❑ Specify contracts and operations
- ❑ Decompose complex objects
- ❑ Factor out common interfaces and functionalities

The graphical notation is only part of the analysis or design document. For example, a data dictionary cataloguing and describing all names of classes, roles, associations, etc. must be maintained throughout the project.

Summary

You should know the answers to these questions:

- ❑ How do you represent classes, objects and associations?
- ❑ How do you specify the visibility of attributes and operations to clients?
- ❑ How is a utility different from a class? How is it similar?
- ❑ Why do we need both named associations and roles?
- ❑ Why is inheritance useful in analysis? In design?
- ❑ How are constraints specified?

Can you answer the following questions?

- ✎ *Why would you want a feature to have class scope?*
- ✎ *Why don't you need to show operations when depicting an object?*
- ✎ *Why aren't associations drawn with arrowheads?*
- ✎ *How is aggregation different from any other kind of association?*
- ✎ *How are associations realized in an implementation language?*

5. Modelling Behaviour

- Use Case Diagrams
- Sequence Diagrams
- Collaboration Diagrams
- State Diagrams

Sources:

- *Unified Modeling Language — Notation Guide*, version 1.1, Rational Software Corporation, 1997.
- *Object-Oriented Development — The Fusion Method*, D. Coleman, et al., Prentice Hall, 1994.

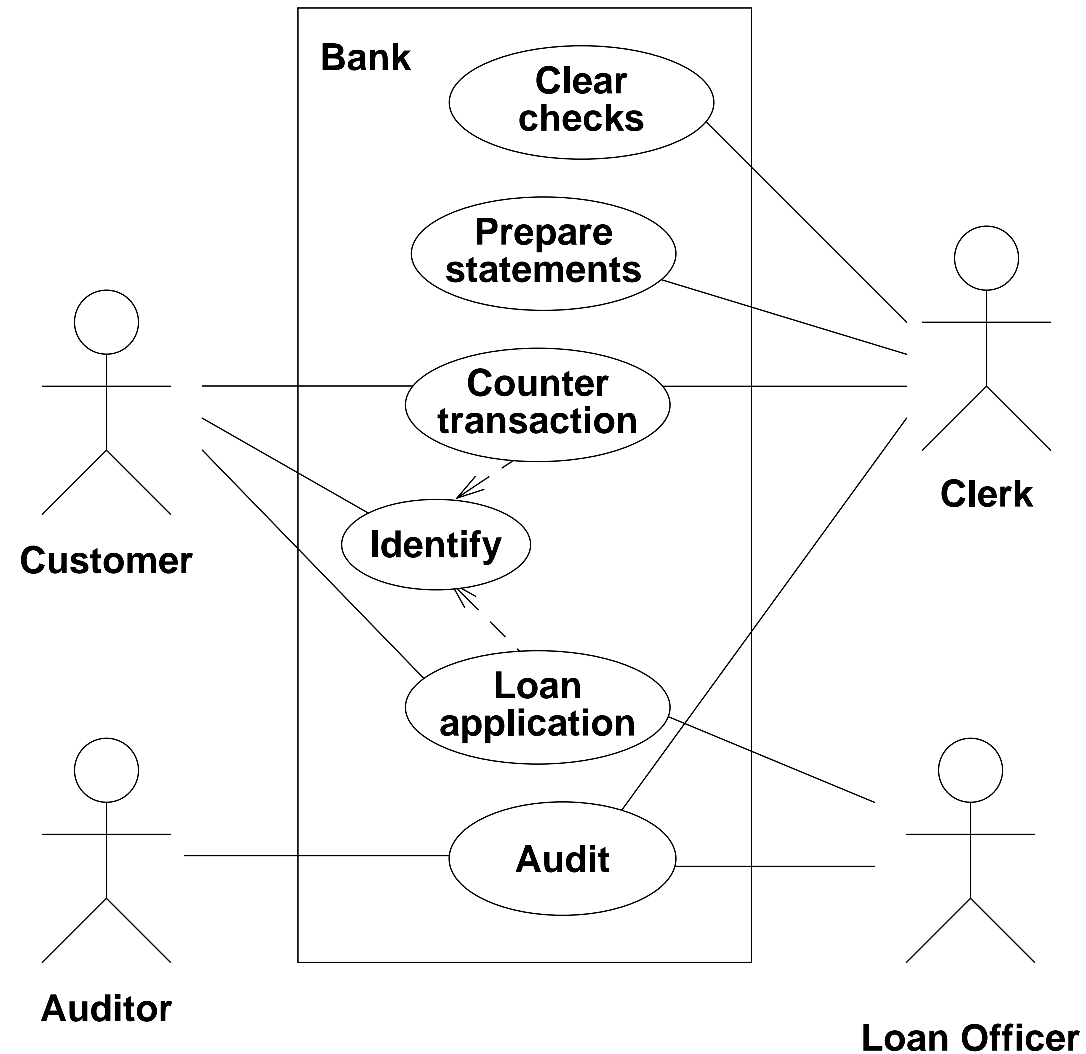
Use Case Diagrams

A *use case* is a generic description of an entire transaction involving several actors.

A *use case diagram* presents a set of use cases (ellipses) and the external actors that interact with the system.

Dependencies and associations between use cases may be indicated.

A *scenario* is an instance of a use case showing a typical example of its execution.



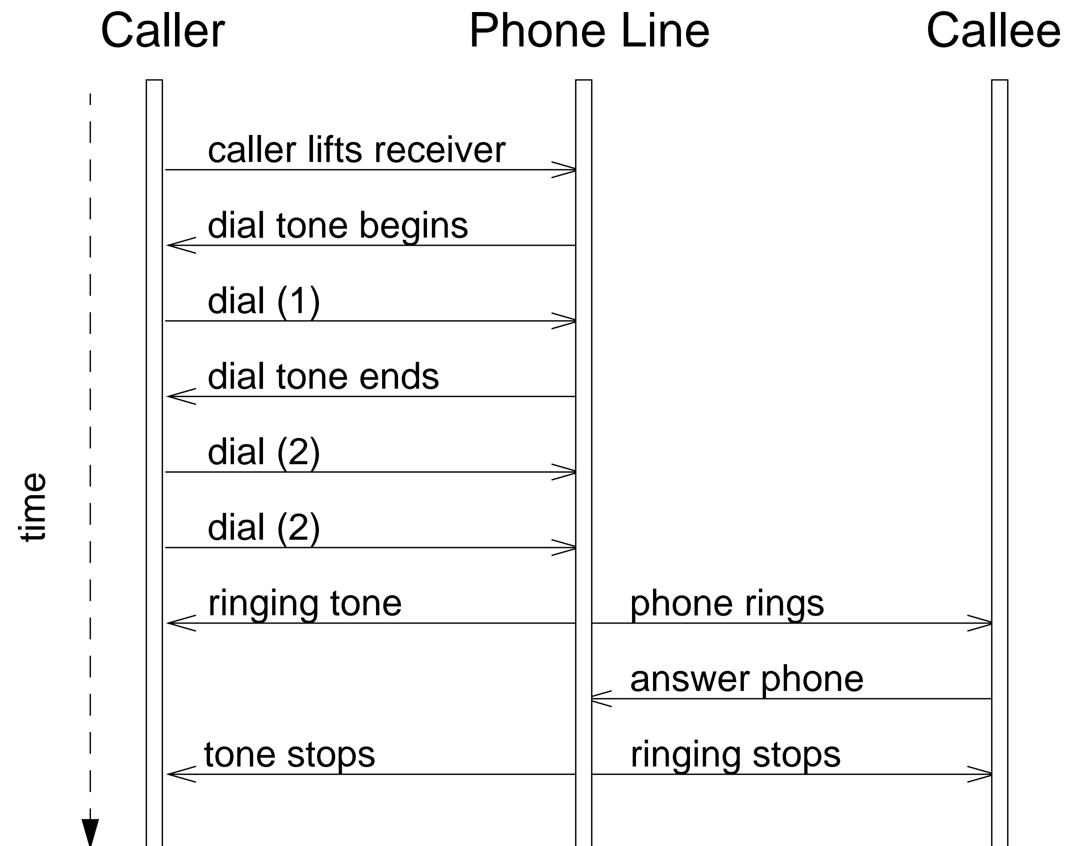
Sequence Diagrams

A *sequence diagram* depicts a scenario by showing the interactions among a set of objects in temporal order.

Objects (not classes!) are shown as vertical bars.

Events or message dispatches are shown as horizontal (or slanted) arrows from the send to the receiver.

Recall that a scenario describes a typical *example* of a use case, so conditionality is not expressed!



UML Message Flow Notation

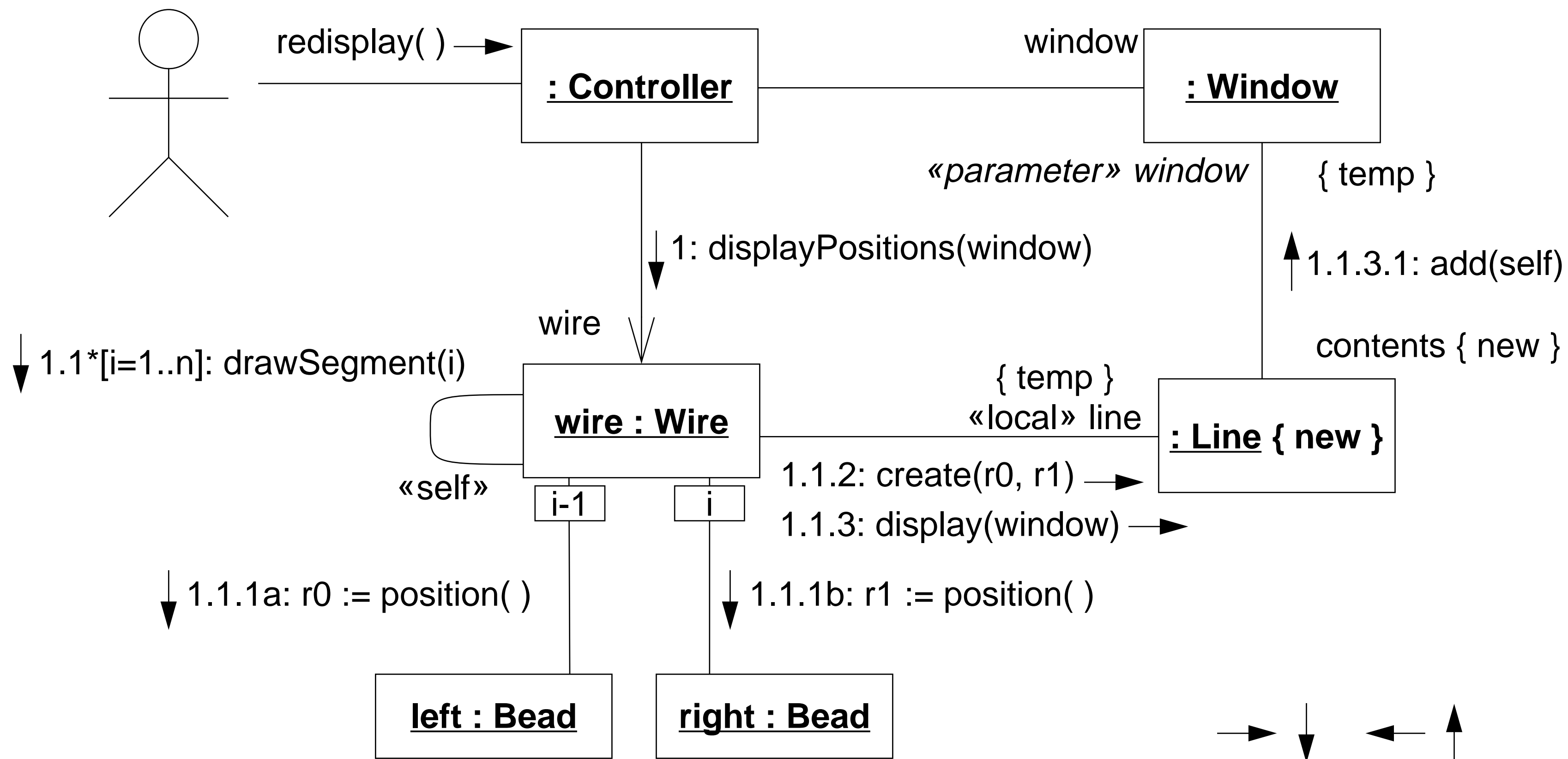
Filled solid arrowhead
procedure call or other nested control flow

Stick arrowhead
flat, sequential control flow (usually asynchronous)

Half-stick arrowhead
asynchronous control flow between objects within a procedural sequence

Collaboration Diagrams

Collaboration diagrams depict scenarios as flows of messages between objects:



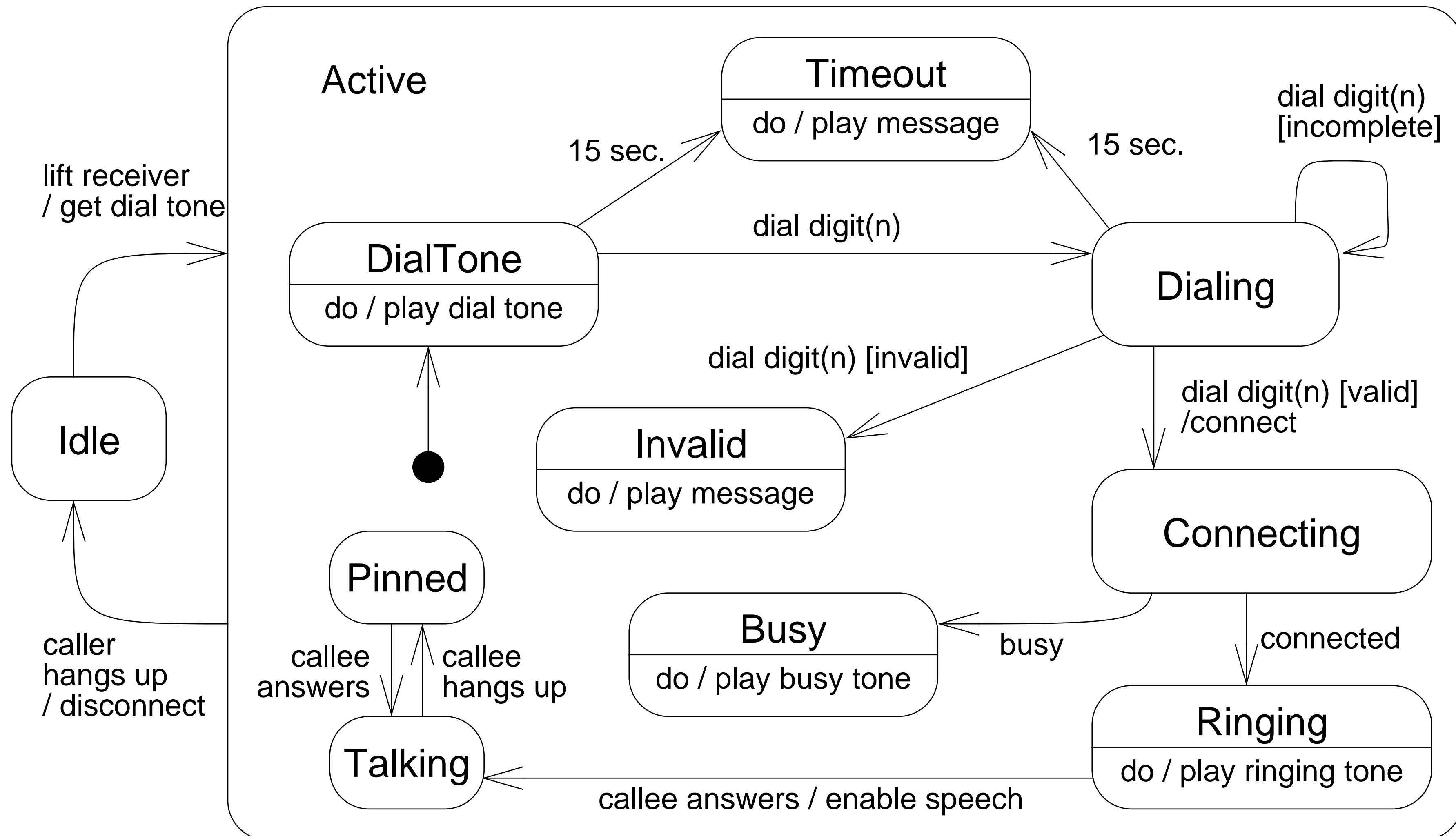
Message Labels

Messages from one object to another are labelled with text strings showing the *direction* of message flow and information indicating the message *sequence*.

Message labels:

1. Prior messages from other threads (e.g. “[A1.3, B6.7.1]”)
   - ☞ only need with concurrent flow of control
2. Dot-separated list of sequencing elements:
   - ☞ *sequencing* integer (e.g., “3.1.2” is invoked by “3.1” and follows “3.1.1”)
   - ☞ letter indicating *concurrent* threads (e.g., “1.2a” and “1.2b”)
   - ☞ *iteration* indicator (e.g., “1.1*[i=1..n]”)
   - ☞ *conditional* indicator (e.g., “2.3 [#items = 0]”)
3. Return value binding (e.g., “status :=”)
4. Message name
5. Argument list

State Diagrams



State Diagram Notation

A State Diagram describes the *temporal evolution* of an object of a given class in response to *interactions* with other objects inside or outside the system.

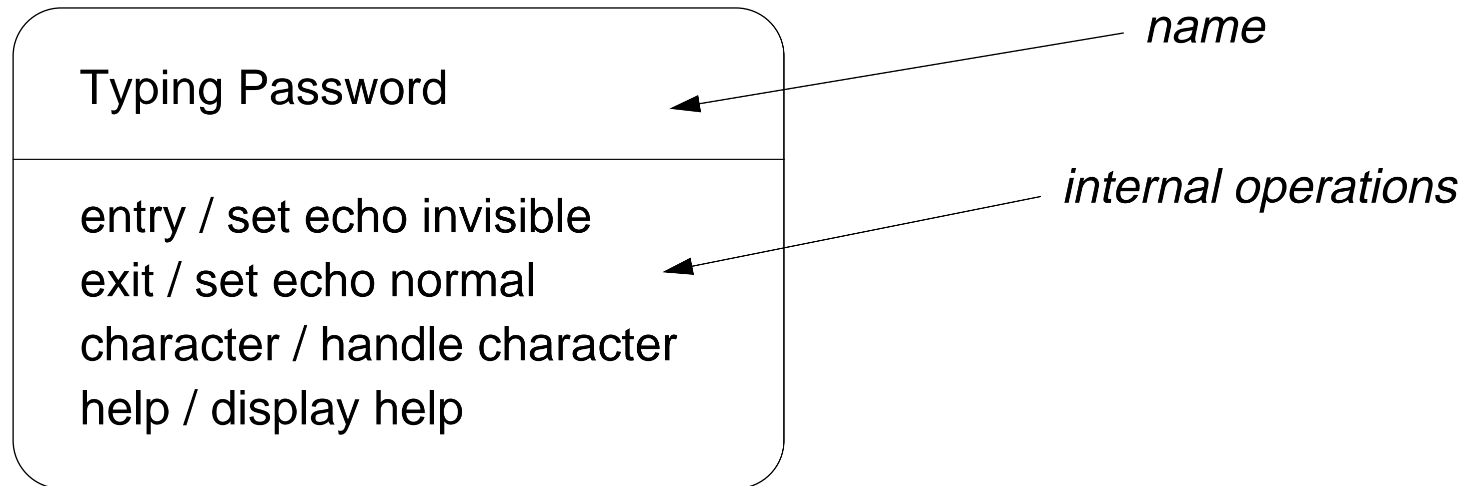
An *event* is a one-way (asynchronous) communication from one object to another:

- atomic (non-interruptible)
- includes events from hardware and real-world objects
  e.g., message receipt, input event, elapsed time, ...
- notation: **eventName(parameter: type, ...)**
- may cause object to make a *transition* between states

A *state* is a period of time during which an object is waiting for an event to occur:

- depicted as rounded box with (up to) three sections:
  - name — optional
  - state variables — **name: type = value** (valid only for that state)
  - triggered operations — internal transitions and ongoing operations
- may be nested

State Box with Regions



The **entry** event occurs whenever a transition is made into this state, and the **exit** operation is triggered when a transition is made out of this state.

The **help** and **character** events cause internal transitions with no change of state, so the entry and exit operations are not performed.

Transitions and Operations

Transitions:

- A response to an external event received by an object in a given state
- May invoke an operation, and cause object to change state
- May send an event to an external object
- Transition syntax (each part is optional):
  event (arguments)
  [condition]
  ^target.sendEvent (arguments)
  / operation (arguments)
- *External* transitions label arcs between states;
  internal transitions are part of the triggered operations of a state

Operations:

- Operations invoked by transitions are atomic *actions*
- *Entry* and *exit* operations can be associated with states

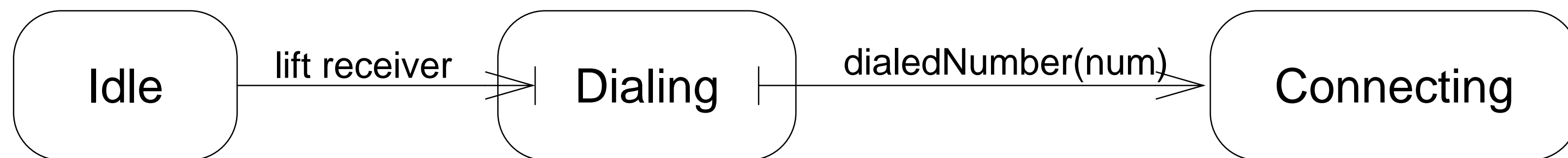
Activities:

- Ongoing operations while object is in a given state
- Modelled as internal transitions labelled with the pseudo-event **do**

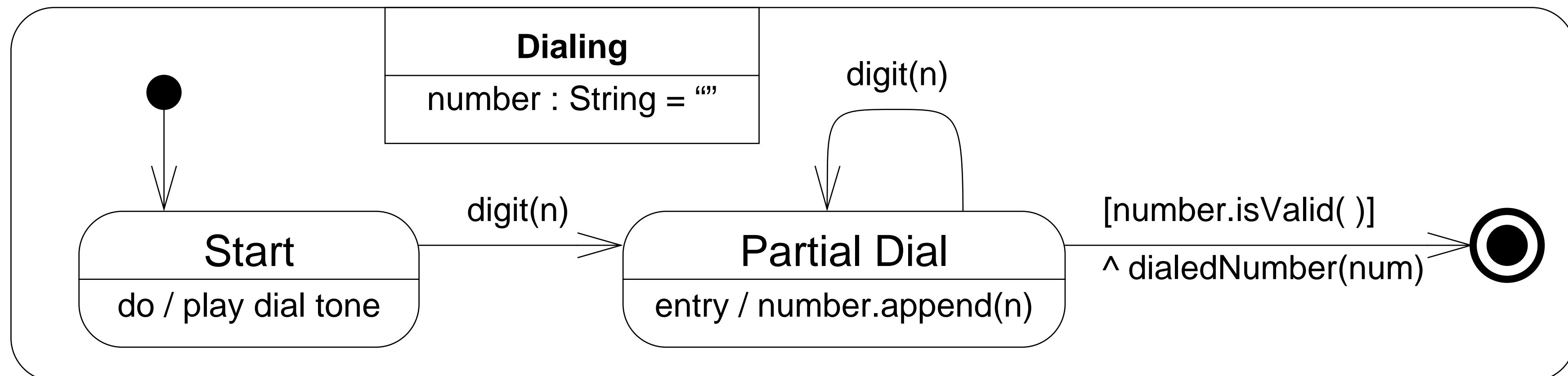
Composite States

Composite states may depicted either as high-level or low-level views.

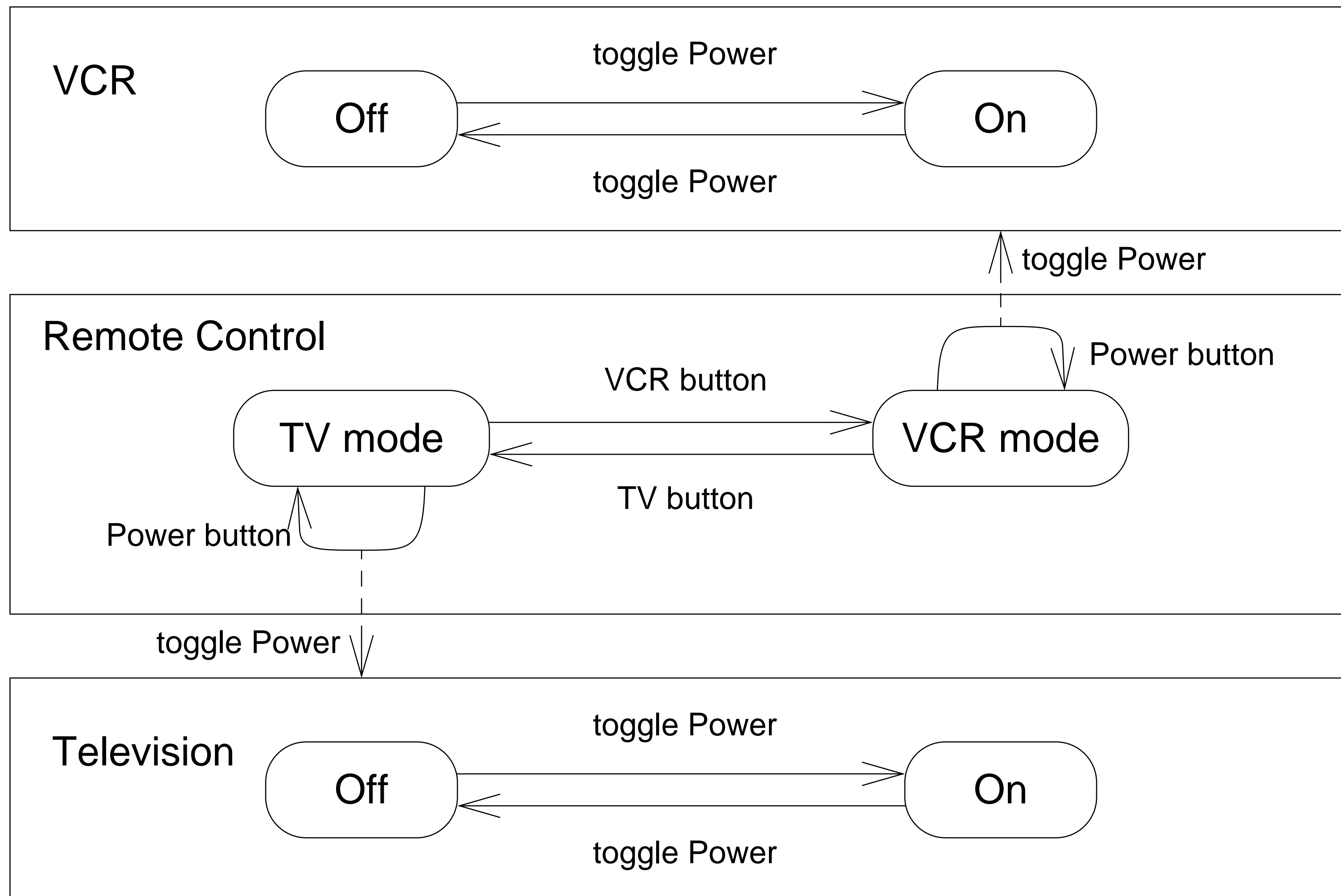
To indicate the presence of internal states, “stubbed transitions” may be used in the high-level view:



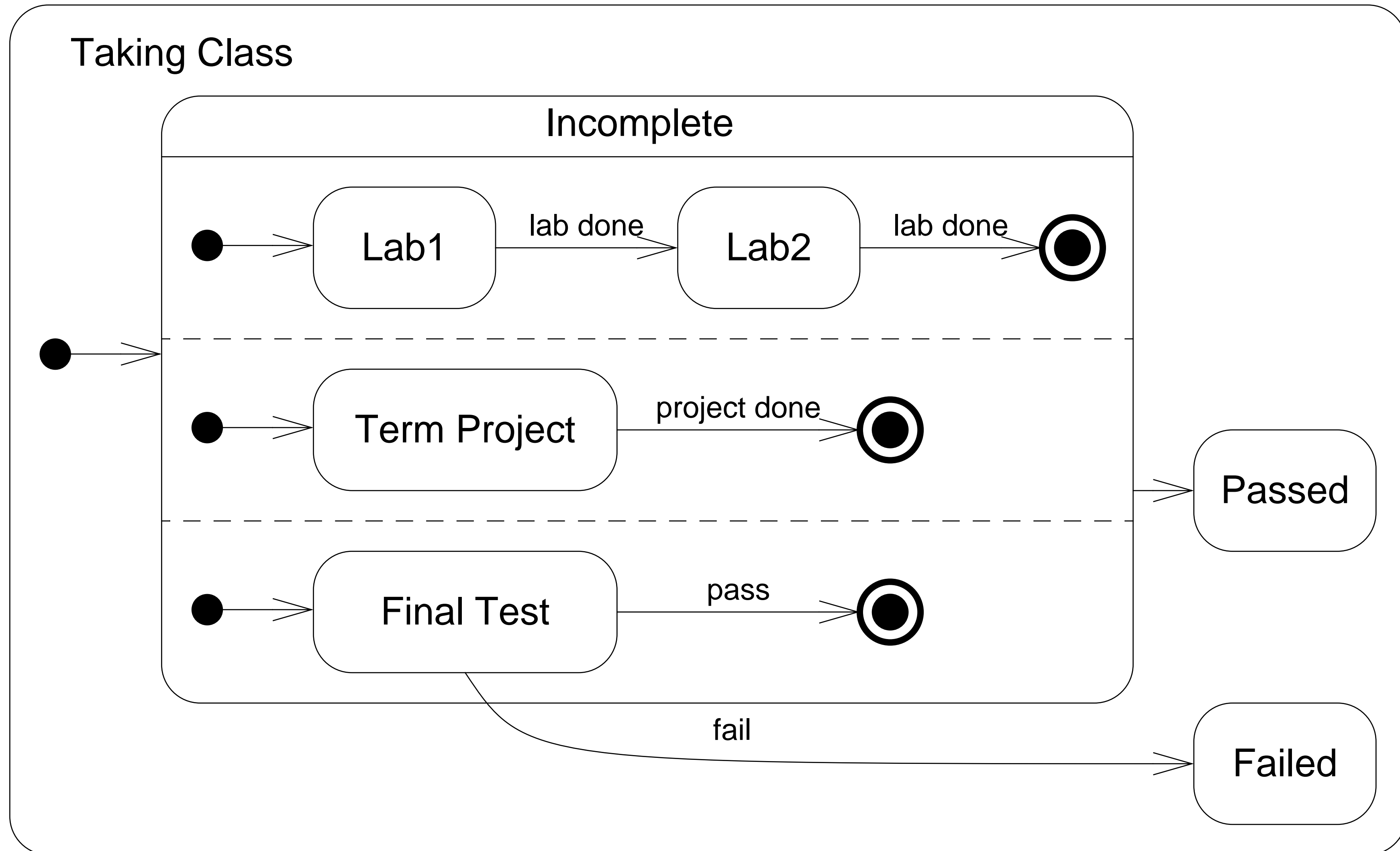
Starting and termination substates are shown as black spots and “bulls-eyes”:



Sending Events between Objects



Concurrent Substates



Branching and Merging

Entering concurrent states:

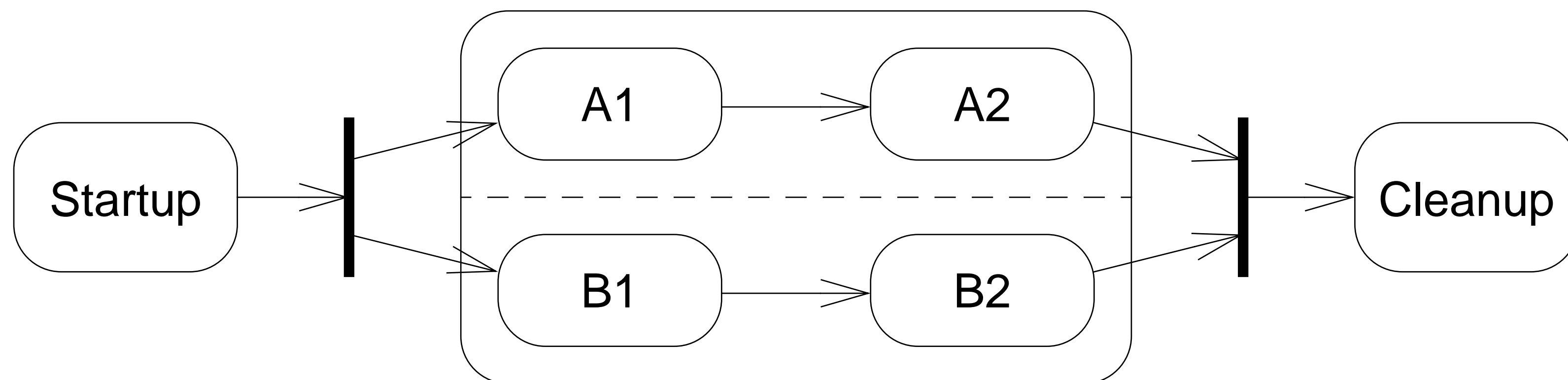
Entering a state with concurrent substates means that *each* of the substates is entered concurrently (one logical thread per substate).

Leaving concurrent states:

A labelled transition out of any of the substates terminates *all* of the substates.

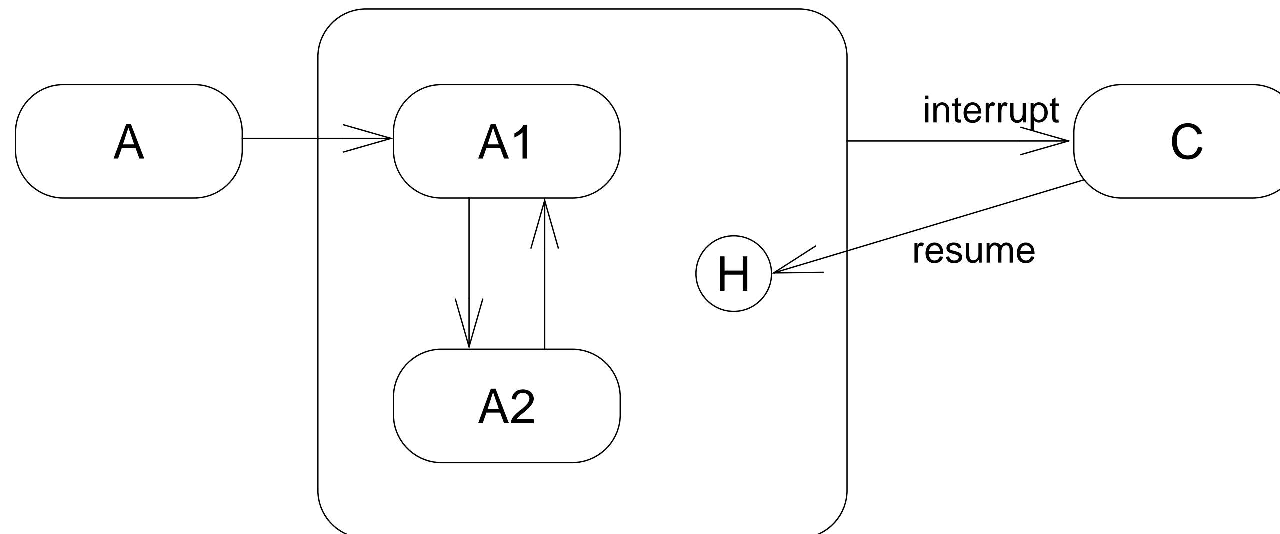
An unlabelled transition out of the overall state waits for all substates to terminate.

An alternative notation for explicit branching and merging uses a “synchronization bar”:



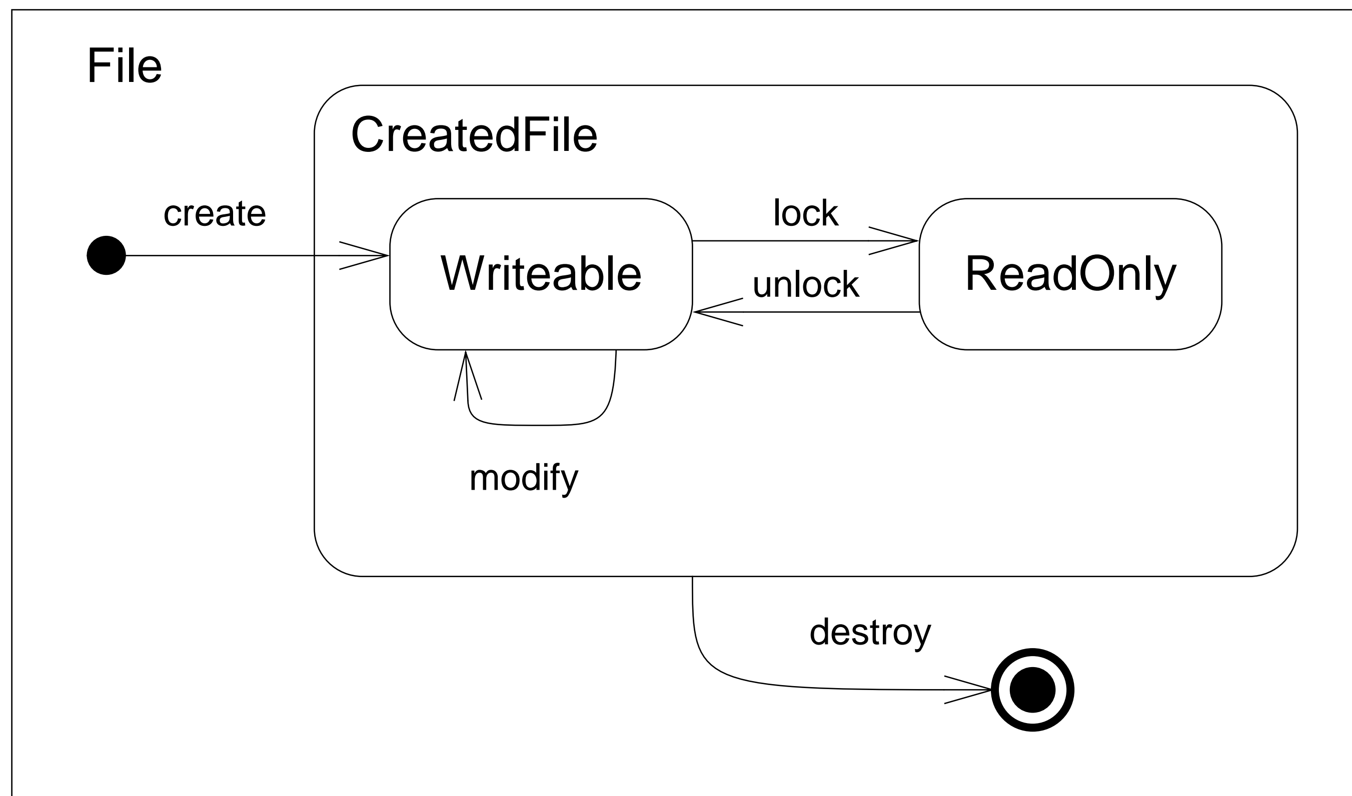
History Indicator

A “history indicator” can be used to indicate that the current composite state should be remembered upon an external transition. To return to the saved state, a transition should point explicitly to the history icon:



Creating and Destroying Objects

Creation and destruction of objects can be depicted by using the start and terminal symbols as top-level states:



Using the Notations

The diagrams introduced here complement class and object diagrams.

During Analysis:

- Use case, sequence and collaboration diagrams document use cases and their scenarios during requirements specification

During Design:

- Sequence and collaboration diagrams can be used to document implementation scenarios or refine use case scenarios
- State diagrams document internal behaviour of classes and must be validated against the specified use cases

Summary

You should know the answers to these questions:

- ❑ What is the purpose of a use case diagram?
- ❑ Why do scenarios depict objects but not classes?
- ❑ How can timing constraints be expressed in scenarios?
- ❑ How do you specify and interpret message labels in a scenario?
- ❑ How do you use nested state diagrams to model object behaviour?
- ❑ What is the difference between “external” and “internal” transitions?
- ❑ How can you model interaction between state diagrams for several classes?

Can you answer the following questions?

- ✎ *Can a sequence diagram always be translated to an collaboration diagram?*
- ✎ *Or vice versa?*
- ✎ *Why are arrows depicted with the message labels rather than with links?*
- ✎ *When should you use concurrent substates?*

6. Software Architecture

Overview:

- What is Software Architecture?
- Coupling and Cohesion
- Architectural styles:
  - ☞ Layered, Client-Server, Blackboard, Dataflow, ...

Sources:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- *Objects, Components and Frameworks with UML*, D. D'Souza, A. Wills, Addison-Wesley, 1999
- *Pattern-Oriented Software Architecture — A System of Patterns*, F. Buschmann, et al., John Wiley, 1996
- *Software Architecture: Perspectives on an Emerging Discipline*, M. Shaw, D. Garlan, Prentice-Hall, 1996

What is Software Architecture?

A neat-looking drawing of some boxes, circles, and lines, laid out nicely in Powerpoint or Word, does not constitute an architecture.

The architecture of a system consists of:

- the *structure(s) of its parts*
  - including design-time, test-time, and run-time hardware and software parts
- the *externally visible properties* of those parts
  - modules with interfaces, hardware units, objects
- the *relationships and constraints* between them

in other words:

- The set of design decisions about any system (or subsystem) that keeps its implementors and maintainers from exercising "needless creativity."

How Architecture Drives Implementation

- Use a *3-tier client-server* architecture: all business logic must be in the middle tier, presentation and dialogue on the client, and data services on the server; that way you can scale the application server processing independently of persistent store.
- Use *Corba* for all distribution, using Corba event channels for notification and the Corba relationship service; do not use the Corba messaging service as it is not yet mature.
- Use Collection Galore's *collections* for representing any collections; by default use their List class, or document your reason otherwise.
- Use *Model-View-Controller* with an explicit ApplicationModel object to connect any UI to the business logic and objects.

Sub-systems, Modules and Components

- A sub-system is a system in its own right whose operation is *independent* of the services provided by other sub-systems.
- A module is a system component that *provides services* to other components but would not normally be considered as a separate system.
- A component is an *independently deliverable unit of software* that encapsulates its design and implementation and offers interfaces to the out-side, by which it may be composed with other components to form a larger whole.

Cohesion

Cohesion is a measure of how well the parts of a component “belong together.”

Cohesion is *weak* if elements are bundled simply because they perform similar or related functions (e.g., java.lang.Math).

Cohesion is *strong* if all parts are needed for the functioning of other parts (e.g. java.lang.String).

Strong cohesion *promotes maintainability* and *adaptability* by limiting the scope of changes to small numbers of components.

There are many definitions and interpretations of cohesion.

Most attempts to formally define it are inadequate!

Coupling

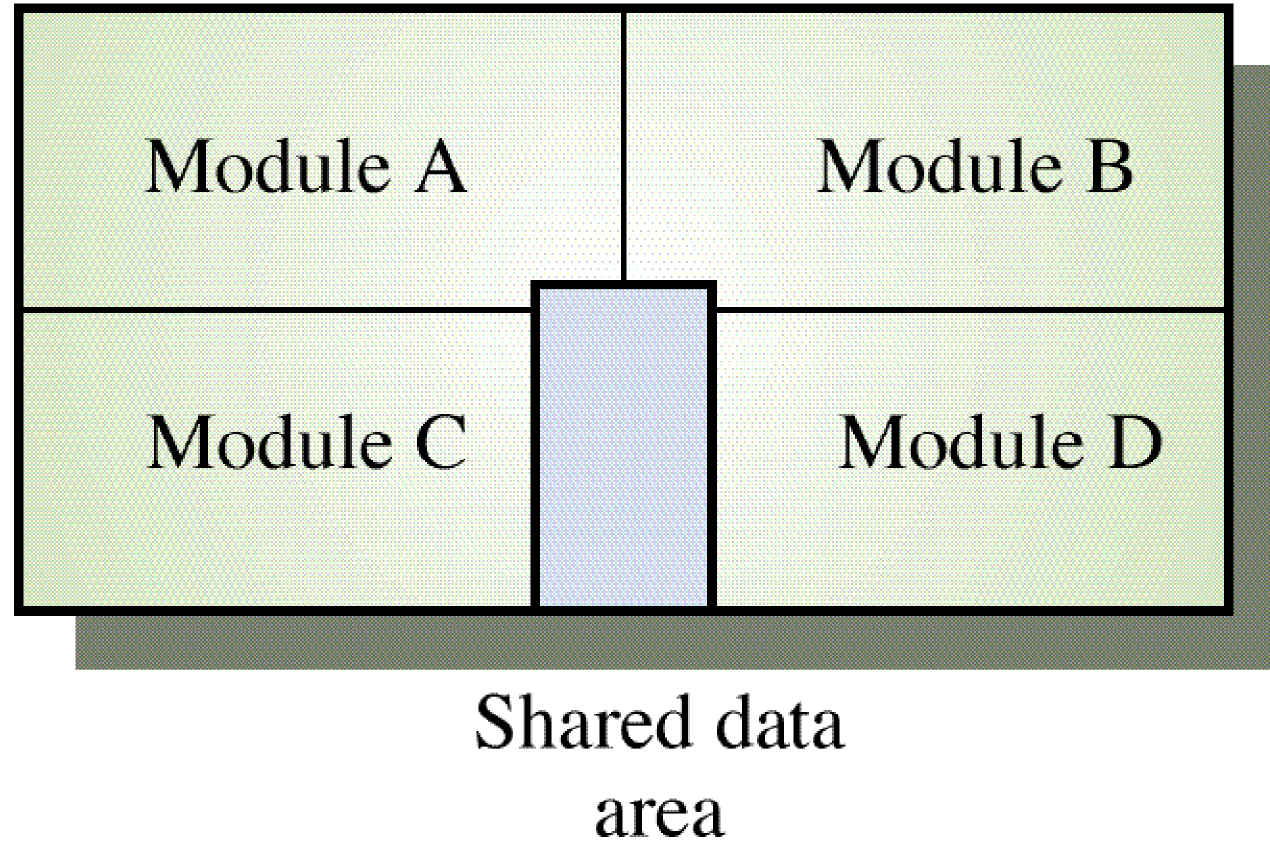
Coupling is a measure of the *strength of the interconnections* between system components.

Coupling is *tight* between components if they depend heavily on one another, (e.g., there is a lot of communication between them).

Coupling is *loose* if there are few dependencies between components.

Loose coupling *promotes maintainability* and *adaptability* since changes in one component are less likely to affect other ones.

Tight Coupling



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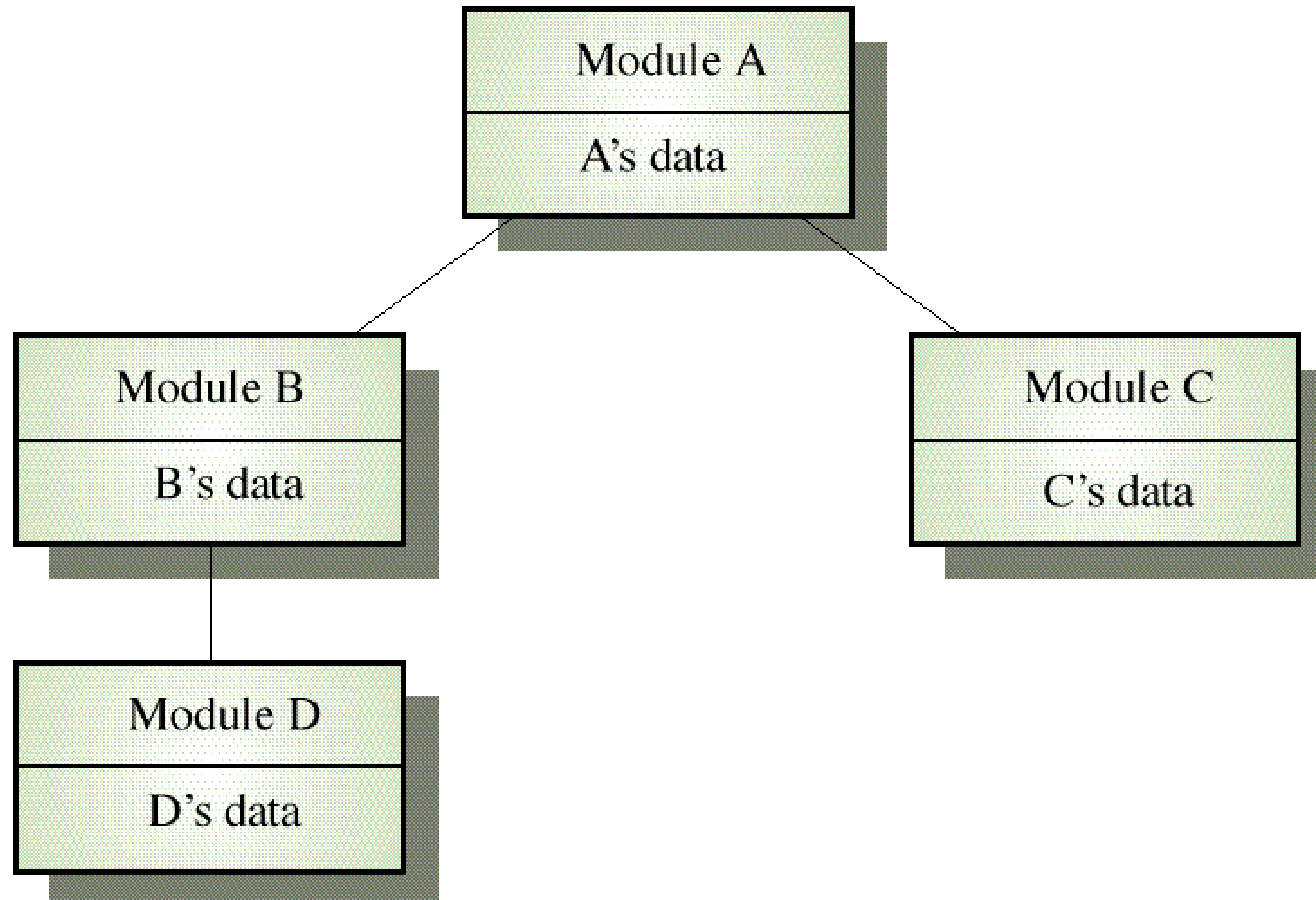
Loose Coupling



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Architectural Parallels

- Architects are the *technical interface* between the customer and the contractor building the system
- A *bad architectural design* for a building *cannot be rescued* by good construction — the same is true for software
- There are *specialized types* of building and software architects
- There are *schools* or *styles* of building and software architecture

An architectural style defines a family of systems in terms of a pattern of structural organization. More specifically, an architectural style defines a vocabulary of components and connector types, and a set of constraints on how they can be combined.

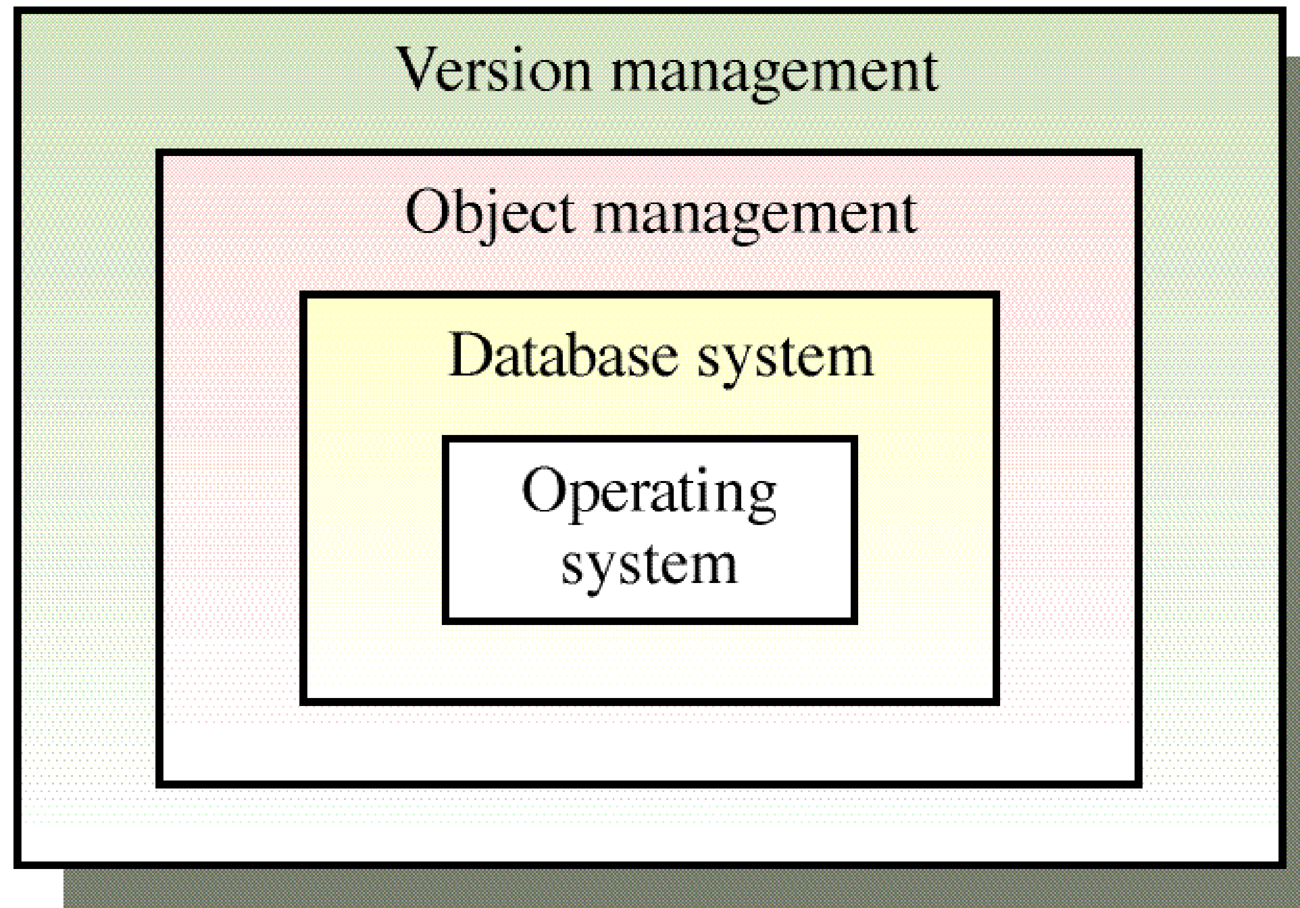
— Shaw and Garlan

Layered Architectures

A layered architecture organises a system into a set of layers each of which provide a set of services to the layer "above."

- ❑ Normally layers are *constrained* so elements only see
  - – other elements in the same layer, or
  - – elements of the layer below
- ❑ *Callbacks* may be used to communicate to higher layers
- ❑ Supports the *incremental* development of sub-systems in different layers.
  - ☞ When a layer interface changes, only the adjacent layer is affected

Abstract Machine Model



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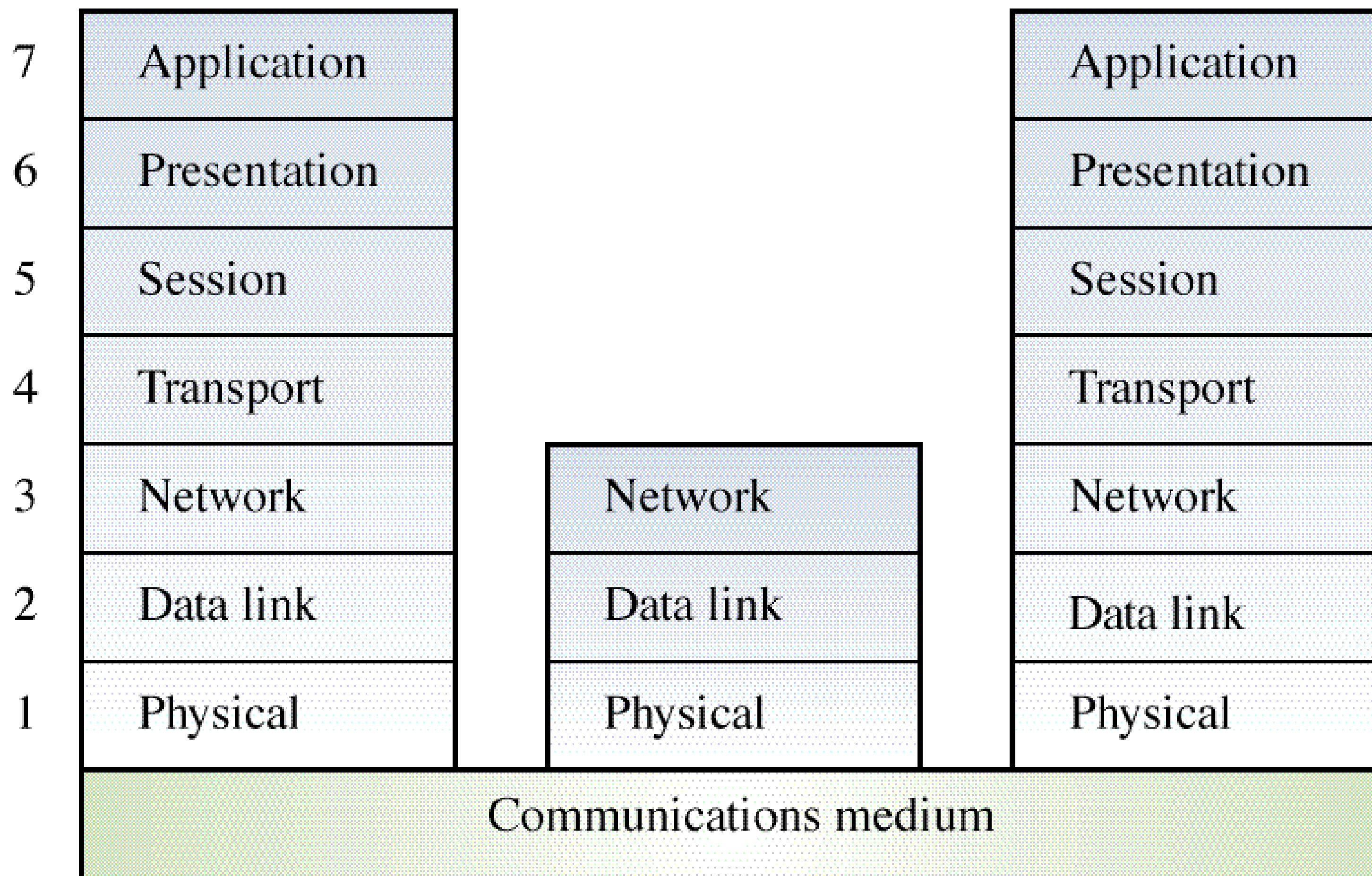
OSI Reference Model



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Client-Server Architectures

A client-server architecture distributes *application logic* and *services* respectively to a number of client and server sub-systems, each potentially running on a different machine and communicating through the *network* (e.g, by RPC).

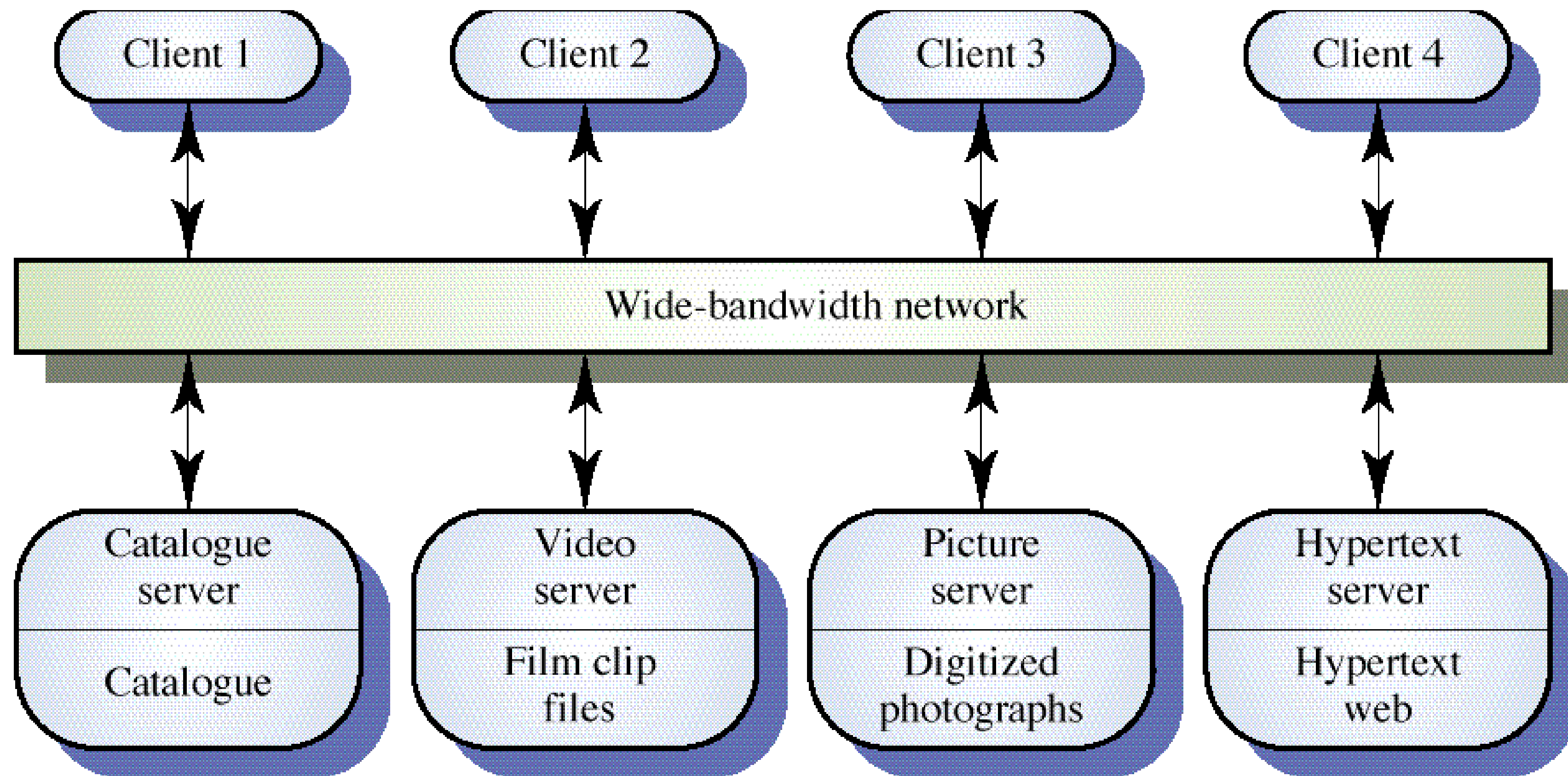
Advantages

- ❑ Distribution of data is straightforward
- ❑ Makes effective use of networked systems. May require cheaper hardware
- ❑ Easy to add new servers or upgrade existing servers

Disadvantages

- ❑ No shared data model so sub-systems use different data organisation. Data interchange may be inefficient
- ❑ Redundant management in each server
- ❑ May require a central register of names and services — it may be hard to find out what servers and services are available

Client-Server Architectures



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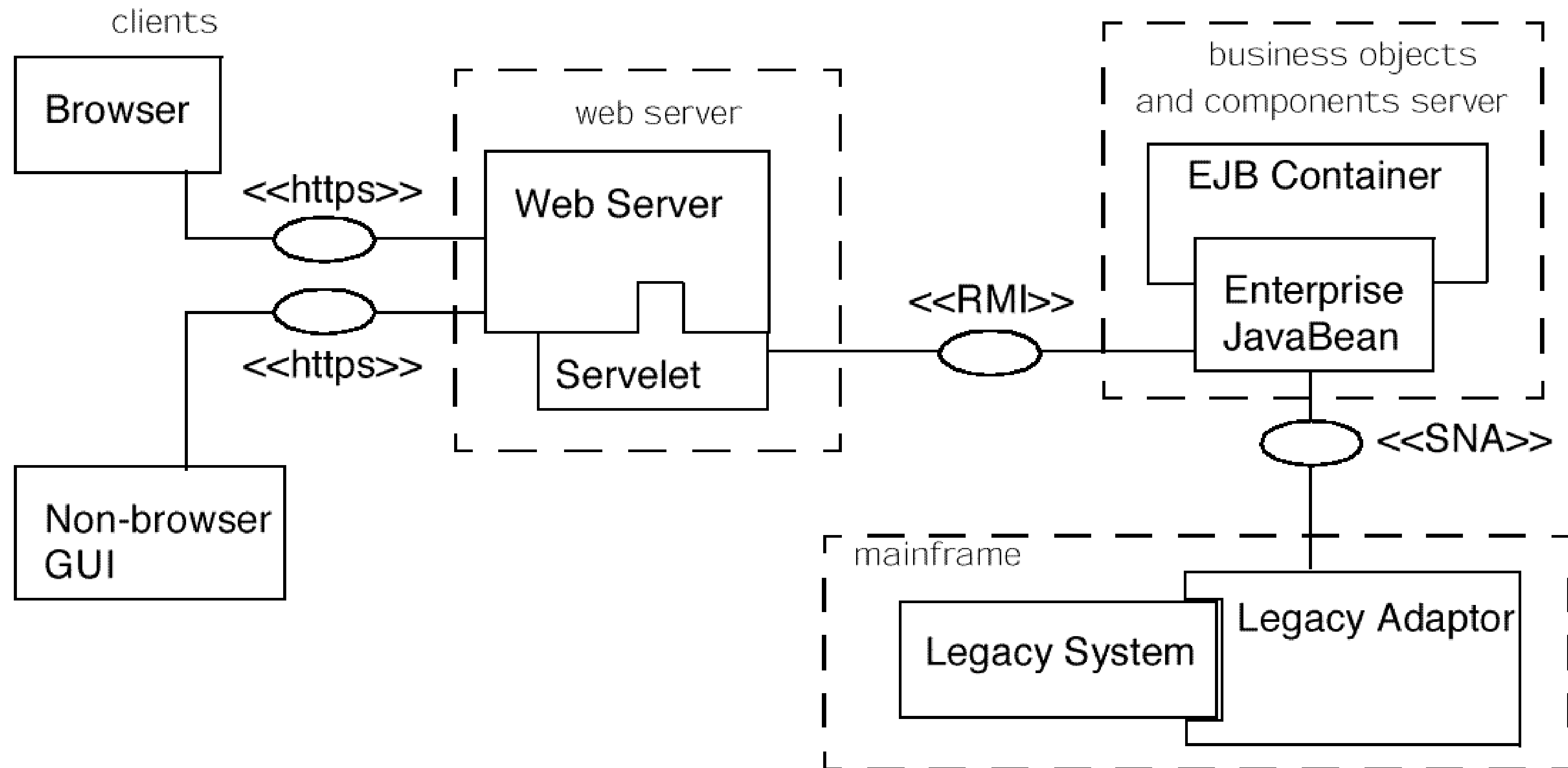
Four-Tier Architectures



Blackboard Architectures

A blackboard architecture *distributes application logic* to a number of independent sub-systems, but manages all data in a *single, shared repository* (or “blackboard”).

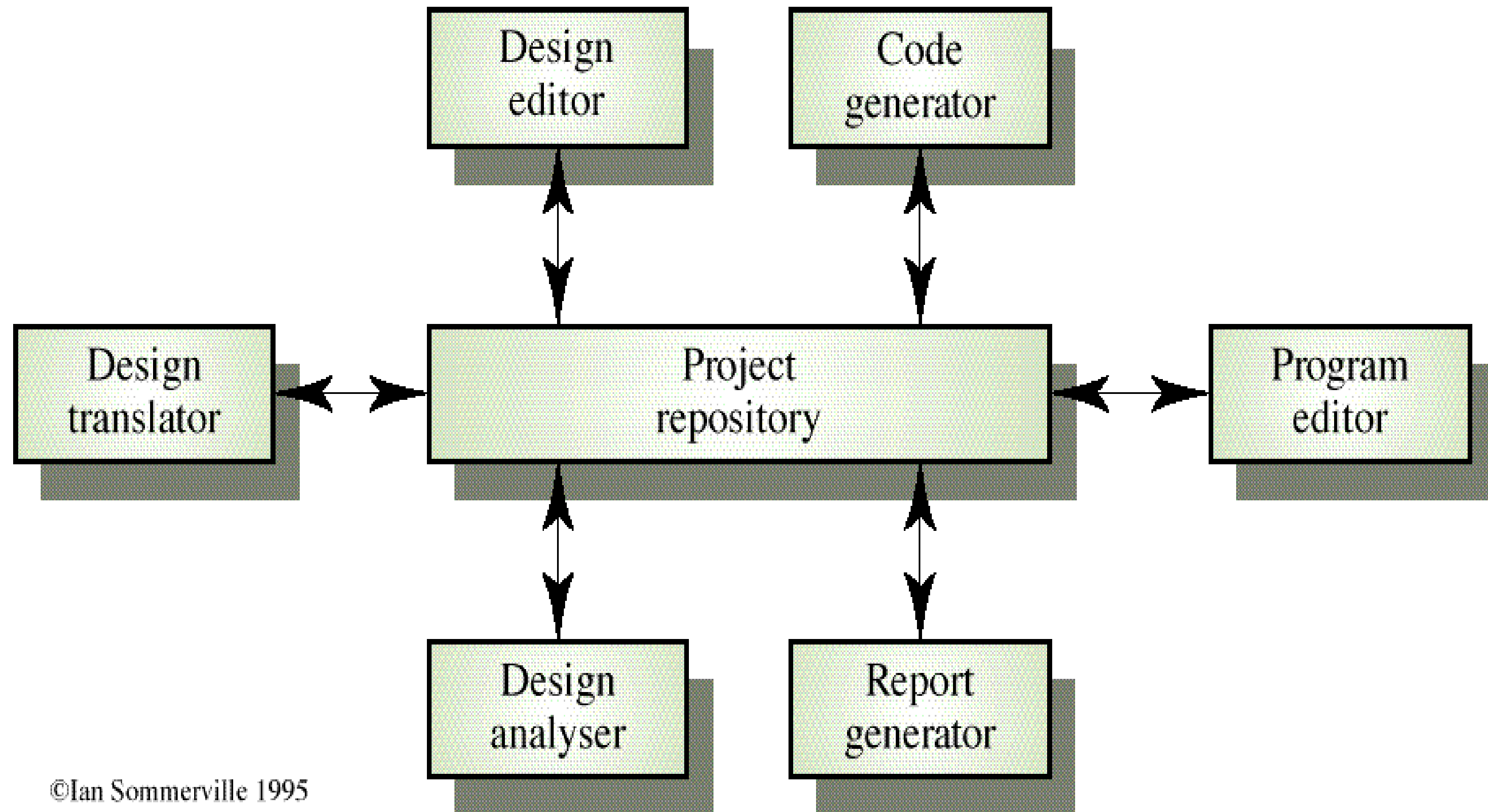
Advantages

- Efficient way to share large amounts of data
- Sub-systems need not be concerned with how data is produced, backed up etc.
- Sharing model is published as the repository schema

Disadvantages

- Sub-systems must agree on a repository data model
- Data evolution is difficult and expensive
- No scope for specific management policies
- Difficult to distribute efficiently

Repository Model



Event-driven Systems

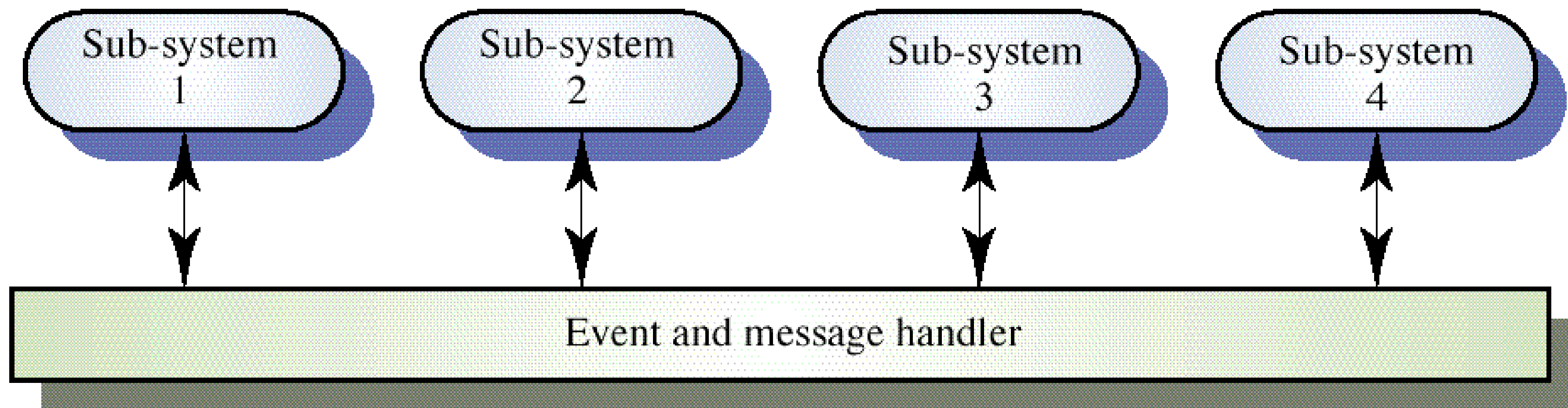
In an event-driven architecture components perform services in reaction to *external events* generated by other components.

- In *broadcast* models an event is broadcast to all sub-systems. Any sub-system which can handle the event may do so.
- In *interrupt-driven* models real-time interrupts are detected by an interrupt handler and passed to some other component for processing.

Broadcast model

- Effective in integrating sub-systems on different computers in a network
- Can be implemented using a *publisher-subscriber* pattern:
  - ☞ Sub-systems register an interest in specific events
  - ☞ When these occur, control is transferred to the subscribed sub-systems
- Control policy is not embedded in the event and message handler. Sub-systems decide on events of interest to them
- However, sub-systems don’t know if or when an event will be handled

Selective Broadcasting



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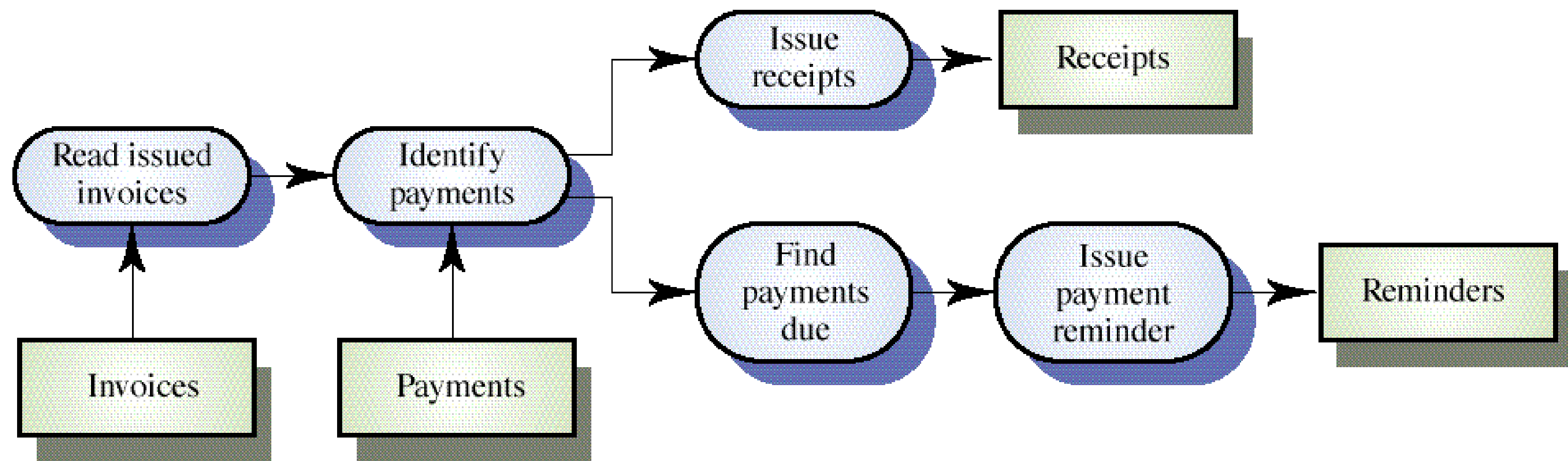
Dataflow Models

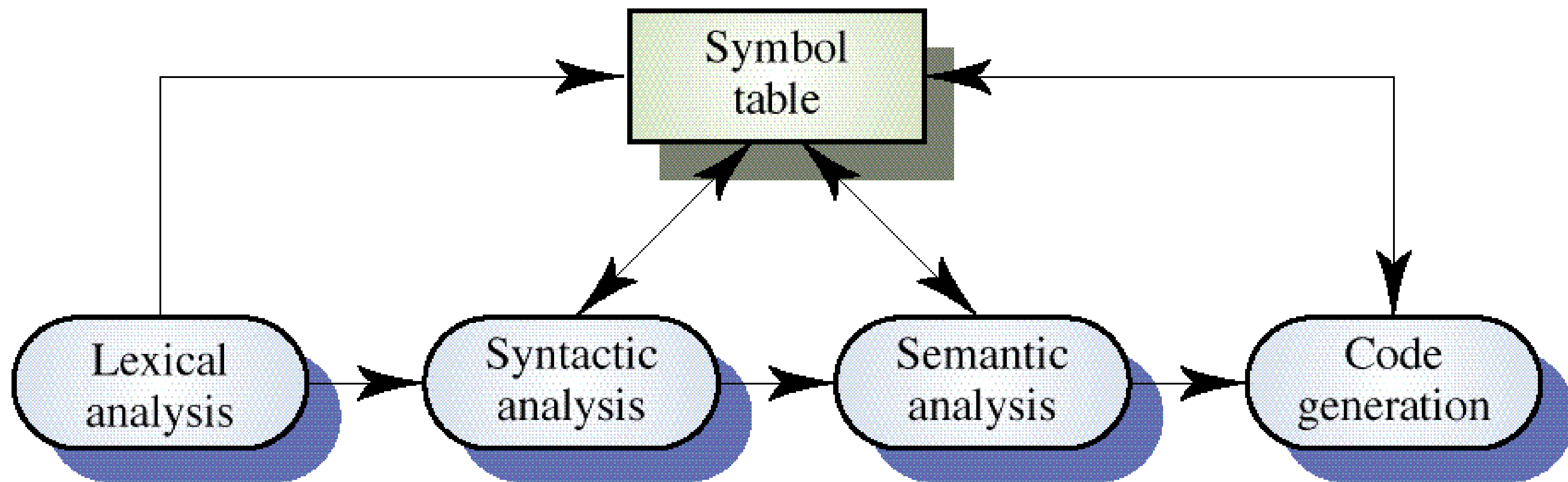
In a dataflow architecture each component performs *functional transformations* on its *input*s to produce *outputs*.

- ❑ Dataflows should be free of cycles
- ❑ The single-input, single-output variant is known as *pipes and filters*
  - ☞ e.g., UNIX (Bourne) shell
- ❑ Not really suitable for interactive systems

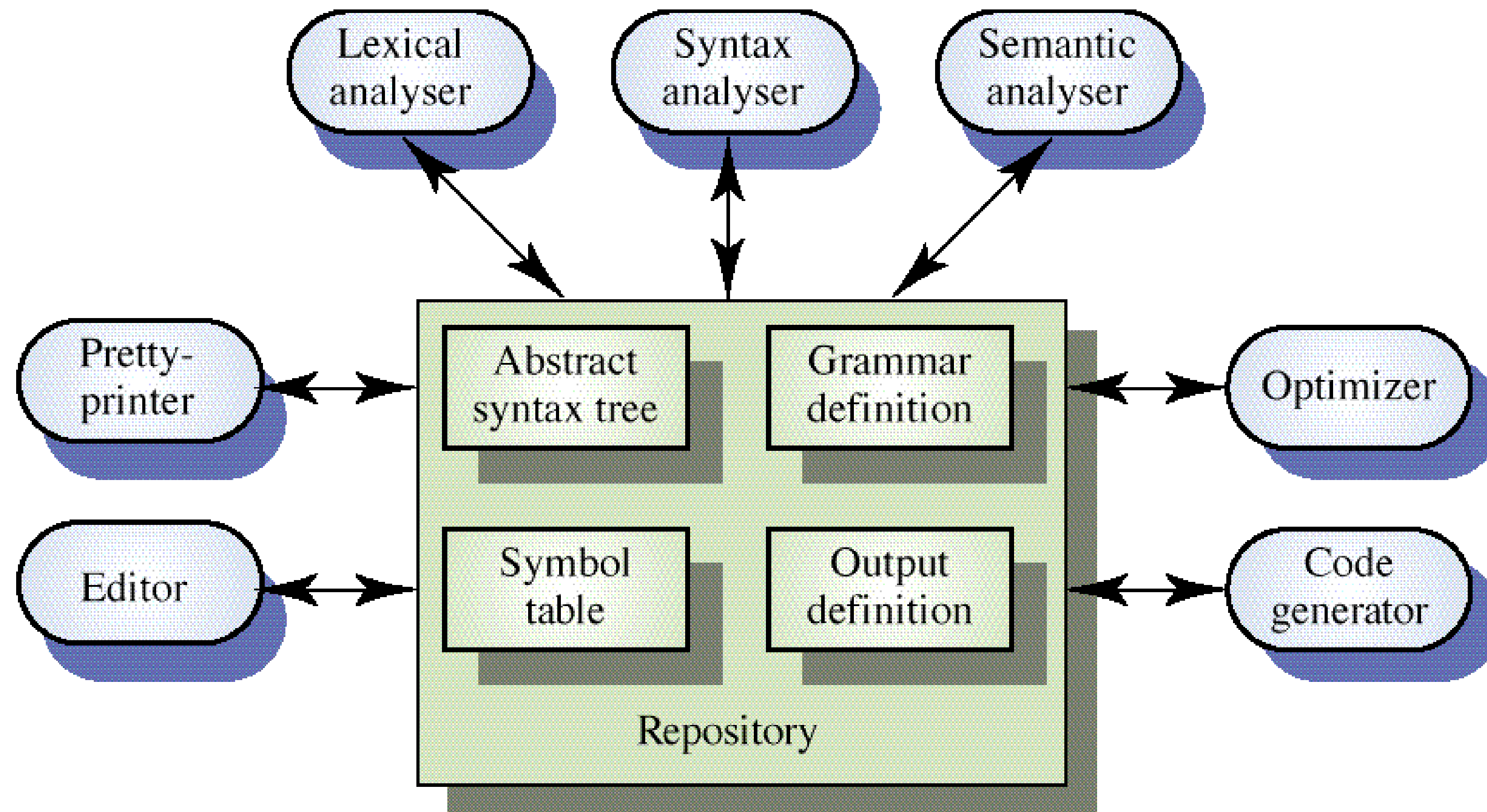
Invoice Processing System



Compilers as Dataflow Architectures



Compilers as Blackboard Architectures



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Summary

You should know the answers to these questions:

- ❑ How does software architecture *constrain* a system?
- ❑ How does choosing an architecture simplify design?
- ❑ What are *coupling* and *cohesion?*
- ❑ What is an *architectural style?*
- ❑ Why shouldn’t elements in a software layer “see” the layer above?
- ❑ What kinds of applications are suited to *event-driven* architectures?

Can you answer the following questions?

- ✎ *What is meant by a “fat client” or a “thin client” in a 4-tier architecture?*
- ✎ *What kind of architectural styles are supported by the Java AWT? by RMI?*
- ✎ *How do callbacks reduce coupling between software layers?*
- ✎ *How would you implement a dataflow architecture in Java?*
- ✎ *Is it easier to understand a dataflow architecture or an event-driven one?*
- ✎ *What are the coupling and cohesion characteristics of each architectural style?*

7. Responsibility-Driven Design

Overview:

- What is Object-Oriented Design?
- Finding Classes
- Identifying Responsibilities
- Finding Collaborations

Source:

- *Designing Object-Oriented Software*, R. Wirfs-Brock, B. Wilkerson, L. Wiener, Prentice Hall, 1990.

What is Object-Oriented Design?

"Object-oriented [analysis and] design is the process by which software requirements are turned into a detailed specification of objects. This specification includes a complete description of the respective roles and responsibilities of objects and how they communicate with each other."

- ❑ The result of the design process is not a final product:
  - ☞ design decisions may be revisited, even after implementation
  - ☞ design is not linear but iterative
- ❑ The design process is not algorithmic:
  - ☞ a design method provides guidelines, not fixed rules
  - ☞ "a good sense of style often helps produce clean, elegant designs — designs that make a lot of sense from the engineering standpoint"

✔ *Responsibility-driven design is an (analysis and) design technique that works well in combination with various methods and notations.*

Design Steps

The Initial Exploration

1. Find the classes in your system
2. Determine the responsibilities of each class
   - ☞ What are the client-server *contracts?*
3. Determine how objects collaborate with each other to fulfil their responsibilities
   - ☞ What are the client-server *roles?*

The Detailed Analysis

1. Factor common responsibilities to build class hierarchies
2. Streamline collaborations between objects
   - ☞ Is message traffic heavy in parts of the system?
   - ☞ Are there classes that collaborate with everybody?
   - ☞ Are there classes that collaborate with nobody?
   - ☞ Are there groups of classes that can be seen as subsystems?
3. Turn class responsibilities into fully specified signatures

Finding Classes

Start with requirements specification: what are the goals of the system being designed, its expected inputs and desired responses.

1. Look for noun phrases:
   - ☞ separate into obvious classes, uncertain candidates, and nonsense
2. Refine to a list of *candidate* classes. Some *guidelines* are:
   - ☞ *Model physical objects* — e.g. disks, printers
   - ☞ *Model conceptual entities* — e.g. windows, files
   - ☞ *Choose one word for one concept* — what does it *mean* within the system
   - ☞ *Be wary of adjectives* — does it really signal a separate class?
   - ☞ *Be wary of missing or misleading subjects* — rephrase in active voice
   - ☞ *Model categories of classes* — delay modelling of inheritance
   - ☞ *Model interfaces to the system* — e.g., user interface, program interfaces
   - ☞ *Model attribute values, not attributes* — e.g., Point vs. Centre

Drawing Editor Requirements Specification

The drawing editor is an interactive graphics editor. With it, users can create and edit drawings composed of lines, rectangles, ellipses and text.

Tools control the mode of operation of the editor. Exactly one tool is active at any given time.

Two kinds of tools exist: the selection tool and creation tools. When the selection tool is active, existing drawing elements can be selected with the cursor. One or more drawing elements can be selected and manipulated; if several drawing elements are selected, they can be manipulated as if they were a single element. Elements that have been selected in this way are referred to as the *current selection*. The current selection is indicated visually by displaying the control points for the element. Clicking on and dragging a control point modifies the element with which the control point is associated.

When a creation tool is active, the current selection is empty. The cursor changes in different ways according to the specific creation tool, and the user can create an element of the selected kind. After the element is created, the selection tool is made active and the newly created element becomes the current selection.

The text creation tool changes the shape of the cursor to that of an I-beam. The position of the first character of text is determined by where the user clicks the mouse button. The creation tool is no longer active when the user clicks the mouse button outside the text element. The control points for a text element are the four corners of the region within which the text is formatted. Dragging the control points changes this region. The other creation tools allow the creation of lines, rectangles and ellipses. They change the shape of the cursor to that of a crosshair. The appropriate element starts to be created when the mouse button is pressed, and is completed when the mouse button is released. These two events create the start point and the stop point.

The line creation tool creates a line from the start point to the stop point. These are the control points of a line. Dragging a control point changes the end point.

The rectangle creation tool creates a rectangle such that these points are diagonally opposite corners. These points and the other corners are the control points. Dragging a control point changes the associated corner.

The ellipse creation tool creates an ellipse fitting within the rectangle defined by the two points described above. The major radius is one half the width of the rectangle, and the minor radius is one half the height of the rectangle. The control points are at the corners of the bounding rectangle. Dragging control points changes the associated corner.

Drawing Editor: noun phrases

The drawing editor is an interactive graphics editor. With it, users can create and edit drawings composed of lines, rectangles, ellipses and text.

Tools control the mode of operation of the editor. Exactly one tool is active at any given time.

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Class Selection Rationale (I)

Model physical objects:

- ☞ ~~mouse button~~ [event or attribute]

Model conceptual entities:

- ☞ ellipse, line, rectangle
- ☞ Drawing, Drawing Element
- ☞ Tool, Creation Tool, Ellipse Creation Tool, Line Creation Tool, Rectangle Creation Tool, Selection Tool, Text Creation Tool
- ☞ text, Character
- ☞ Current Selection

Choose one word for one concept:

- ☞ Drawing Editor ⇒ ~~editor~~, ~~interactive graphics editor~~
- ☞ Drawing Element ⇒ ~~element~~
- ☞ Text Element ⇒ ~~text~~
- ☞ Ellipse Element, Line Element, Rectangle Element ⇒ ~~ellipse~~, ~~line~~, ~~rectangle~~

Class Selection Rationale (II)

Be wary of adjectives:

- Ellipse Creation Tool, Line Creation Tool, Rectangle Creation Tool, Selection Tool, Text Creation Tool — *all have different requirements*
- ~~bounding rectangle~~, ~~rectangle~~, ~~region~~ ⇒ Rectangle
  — *common meaning, but different from Rectangle Element*
- Point ⇒ ~~end point~~, ~~start point~~, ~~stop point~~
- Control Point — *more than just a coordinate*
- corner ⇒ ~~associated corner~~, ~~diagonally opposite corner~~
  — *no new behaviour*

Be wary of sentences with missing or misleading subjects:

- "The current selection is indicated visually by displaying the control points for the element." — *by what? Assume Drawing Editor ...*

Model categories:

- Tool, Creation Tool

Class Selection Rationale (III)

Model interfaces to the system:

- ☞ ~~user~~ — *don't need to model user explicitly*
- ☞ ~~cursor~~ — *cursor motion handled by operating system*

Model values of attributes, not attributes themselves:

- ☞ ~~height of the rectangle~~, ~~width of the rectangle~~
- ☞ ~~major radius~~, ~~minor radius~~
- ☞ ~~position~~ — *of first text character; probably Point attribute*
- ☞ ~~mode of operation~~ — *attribute of Drawing Editor*
- ☞ ~~shape of the cursor~~, ~~I-beam~~, ~~crosshair~~ — *attributes of Cursor*
- ☞ ~~corner~~ — *attribute of Rectangle*
- ☞ ~~time~~ — *an implicit attribute of the system*

Candidate Classes

Preliminary analysis yields the following candidates:

- Character
- Control Point
- Creation Tool
- Current Selection
- Drawing
- Drawing Editor
- Drawing Element
- Ellipse Creation Tool
- Ellipse Element
- Line Creation Tool
- Line Element
- Point
- Rectangle
- Rectangle Creation Tool
- Rectangle Element
- Selection Tool
- Text Creation Tool
- Text Element
- Tool

Expect the list to evolve as design progresses.

Class Cards

Use class cards to record candidate classes:

Class: Drawing	
superclasses	
subclasses	
responsibilities ...	*collaborations*

Write a short description of the purpose of the class on the back of the card

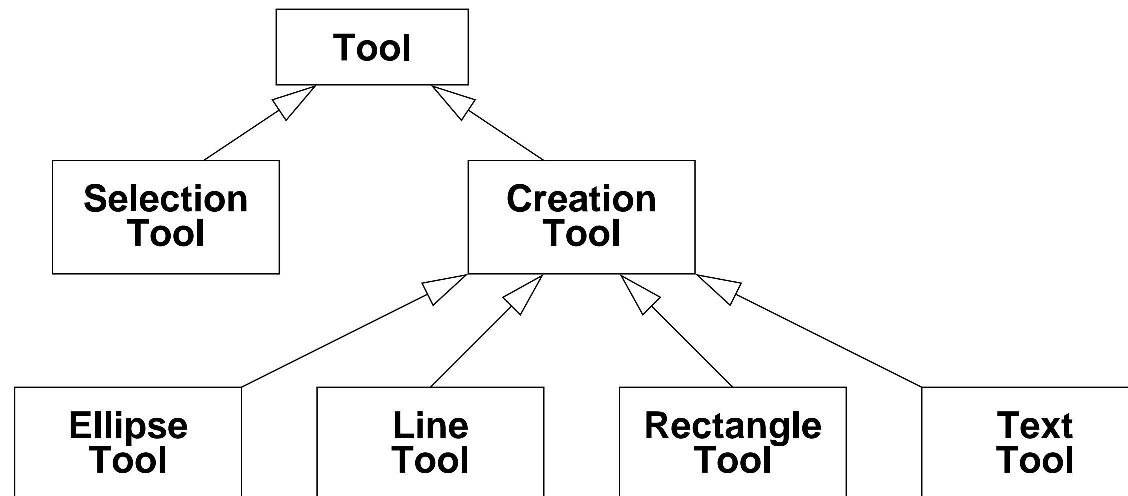
- ☞ compact, easy to manipulate, easy to modify or discard!
- ☞ easy to arrange, reorganize
- ☞ easy to retrieve discarded classes

Finding Abstract Classes

Abstract classes factor out common behaviour shared by other classes

They are *abstract* because they need not be completely implemented.

- ☞ group related classes with common attributes
- ☞ introduce abstract superclasses that represent the group
- ☞ “categories” are good candidates for abstract classes



✔ ***Warning:** beware of premature classification; your hierarchy will evolve*

Identifying and Naming Groups

If you have trouble *naming* a group:

- ☞ enumerate common attributes to derive the name
- ☞ divide into more clearly defined subcategories

Attributes of abstract classes should serve to distinguish subgroups

- ☞ Physical vs. conceptual
- ☞ Active vs. passive
- ☞ Temporary vs. permanent
- ☞ Generic vs. specific
- ☞ Shared vs. unshared

Classes may be missing because the specification is incomplete or imprecise

- ☞ editing ⇒ undoing ⇒ need for a Cut Buffer

Recording Superclasses

Record superclasses and subclasses on all class cards:

Class: Creation Tool	
Tool	
Ellipse Tool, Line Tool, Rectangle Tool, Text Tool	

Responsibilities

What are responsibilities?

- ☞ the knowledge an object maintains and provides
- ☞ the actions it can perform

Responsibilities represent the *public services* an object may provide to clients, not the way in which those services may be implemented

- ☞ specify *what* an object does, not *how* it does it
- ☞ don't describe the interface yet, only conceptual responsibilities

Identifying Responsibilities

- Study the requirements specification:
  - highlight verbs and determine which represent responsibilities
  - perform a walk-though of the system
    - exploring as many scenarios as possible
    - identify actions resulting from input to the system
- Study the candidate classes:
  - class names ⇒ roles ⇒ responsibilities
  - recorded purposes on class cards ⇒ responsibilities

Assigning Responsibilities

- Evenly distribute system intelligence
  - avoid procedural centralization of responsibilities
  - keep responsibilities close to objects rather than their clients
- State responsibilities as generally as possible
  - “draw yourself” vs. “draw a line/rectangle etc.”
- Keep behaviour together with any related information
  - principle of encapsulation
- Keep information about one thing in one place
  - if multiple objects need access to the same information
    (i) a new object may be introduced to manage the information, or
    (ii) one object may be an obvious candidate, or
    (iii) the multiple objects may need to be collapsed into a single one
- Share responsibilities among related objects
  - break down complex responsibilities

Relationships Between Classes

Additional responsibilities can be uncovered by examining relationships between classes, especially:

- The “Is-Kind-Of” Relationship:
  - classes sharing a common attribute often share a common superclass
  - common superclasses suggest common responsibilities
    e.g., to create a new Drawing Element, a Creation Tool must:
    1. accept user input — *implemented in subclass*
    2. determine location to place it — *generic*
    3. instantiate the element — *implemented in subclass*
- The “Is-Analogous-To” Relationship:
  - similarities between classes suggest as-yet-undiscovered superclasses
- The “Is-Part-Of” Relationship:
  - distinguish (don’t share) responsibilities of part and of whole

Difficulties in assigning responsibilities suggest:

- missing classes in design, or
- free choice between multiple classes

Recording Responsibilities

List responsibilities as succinctly as possible:

Class: Drawing	
Know which elements it contains	

Too many responsibilities to fit onto one card suggests over-centralization:

☞ Check if responsibilities really belong in a superclass, or if they can be distributed to cooperating classes.

Having more classes leads to a more flexible and maintainable design. If necessary, classes can later be consolidated.

Collaborations

What are collaborations?

- collaborations are client requests to servers needed to fulfil responsibilities
- collaborations reveal control and information flow and, ultimately, subsystems
- collaborations can uncover missing responsibilities
- analysis of communication patterns can reveal misassigned responsibilities

Finding Collaborations

For each responsibility:

1. Can the class fulfil the responsibility by itself?
2. If not, what does it need, and from what other class can it obtain what it needs?

For each class:

1. What does this class know?
2. What other classes need its information or results? Check for collaborations.
3. Classes that do not interact with others should be discarded. (Check carefully!)

Check for these relationships:

- ❑ The “Is-Part-Of” Relationship
- ❑ The “Has-Knowledge-Of” Relationship
- ❑ The “Depends-Upon” Relationship

Recording Collaborations

Collaborations exist only to fulfil responsibilities.

Enter the class name of the server role next to client's responsibility:

Class: Drawing	
Know which elements it contains	
Maintain ordering between elements	Drawing Element

Note *each* collaboration required for a responsibility.

Include also collaborations between peers.

Validate your preliminary design with another walk-through.

Summary

You should know the answers to these questions:

- ❑ What criteria can you use to identify potential classes?
- ❑ How can class cards help during analysis and design?
- ❑ How can you identify abstract classes?
- ❑ What are class responsibilities, and how can you identify them?
- ❑ How can identification of responsibilities help in identifying classes?
- ❑ What are collaborations, and how do they relate to responsibilities?

Can you answer the following questions?

- ✎ *When should an attribute be promoted to a class?*
- ✎ *Why is it useful to organize classes into a hierarchy?*
- ✎ *How can you tell if you have captured all the responsibilities and collaborations?*

8. Detailed Design

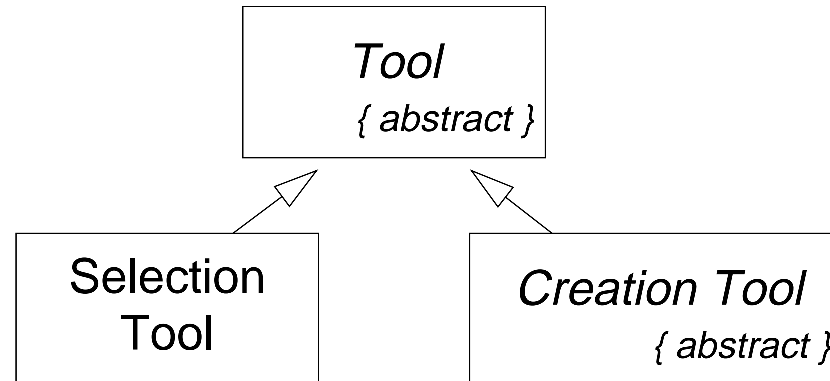
Overview:

- Structuring Inheritance Hierarchies
- Identifying Subsystems
- Specifying Class Protocols (Interfaces)

Source:

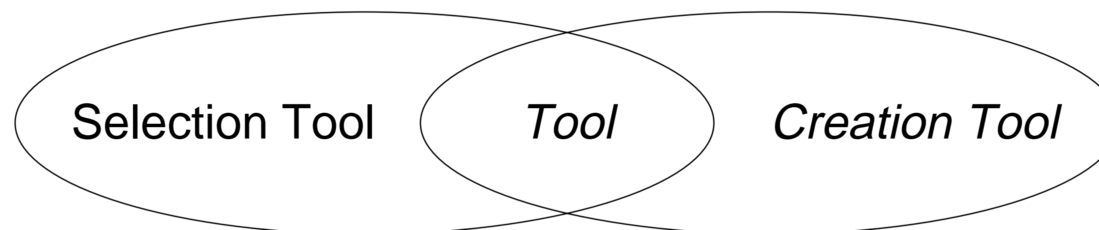
- *Designing Object-Oriented Software*, R. Wirfs-Brock, B. Wilkerson, L. Wiener, Prentice Hall, 1990

Sharing Responsibilities



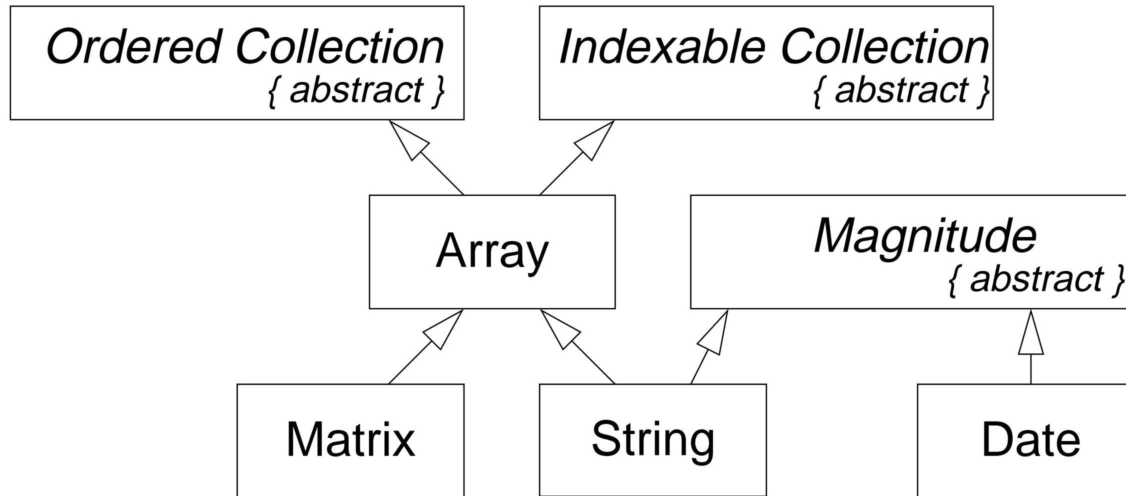
Concrete classes may be both instantiated and inherited from.
Abstract classes may only be inherited from. *Note on class cards and on class diagram.*

Venn Diagrams can be used to visualize shared responsibilities:



(Warning: not part of UML!)

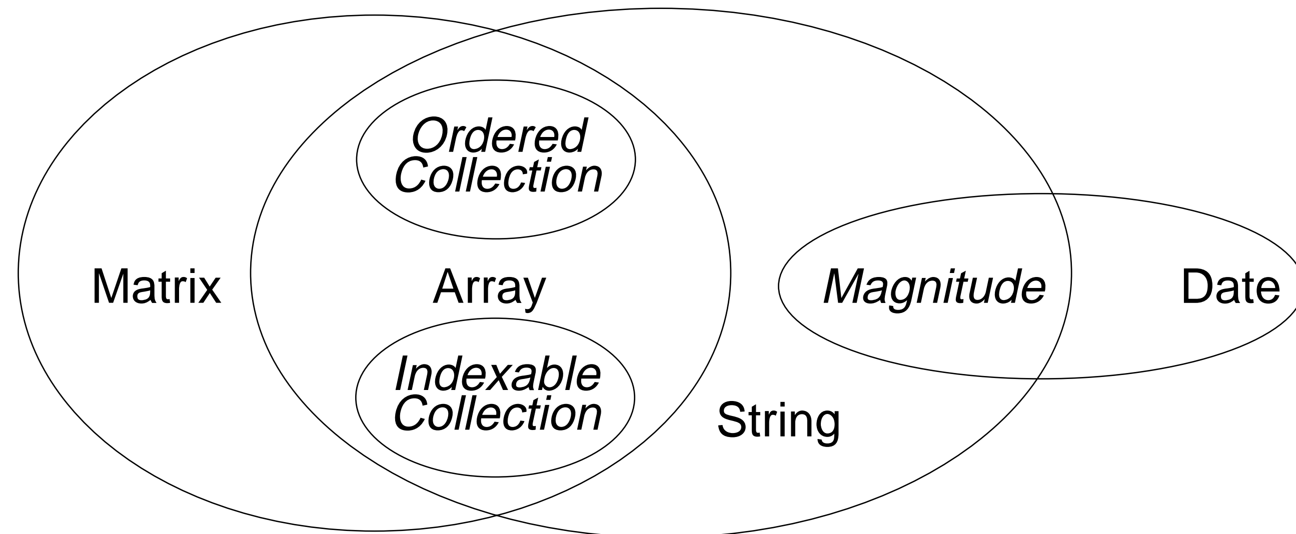
Multiple Inheritance



Decide whether a class will be instantiated to determine if it is abstract or concrete.

Responsibilities of subclasses are *larger* than those of superclasses.

Intersections represent common superclasses.



Building Good Hierarchies

Model a “kind-of” hierarchy:

- ☞ Subclasses should support all inherited responsibilities, and possibly more

Factor common responsibilities as high as possible:

- ☞ Classes that share common responsibilities should inherit from a common abstract superclass; introduce any that are missing

Make sure that abstract classes do not inherit from concrete classes:

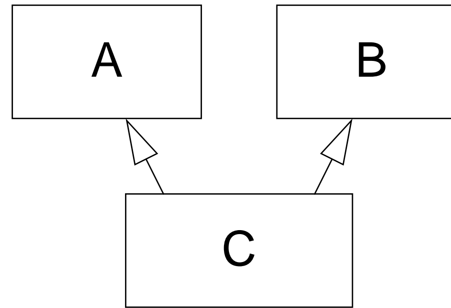
- ☞ Eliminate by introducing common abstract superclass: *abstract classes should support responsibilities in an implementation-independent way*

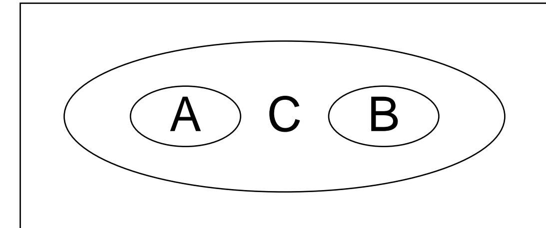
Eliminate classes that do not add functionality:

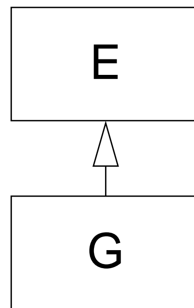
- ☞ Classes should either add new responsibilities, or a particular way of implementing inherited ones

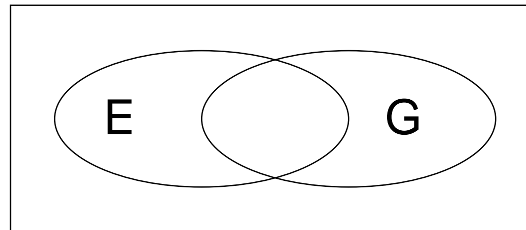
Building Kind-Of Hierarchies

Correctly Formed Subclass Responsibilities







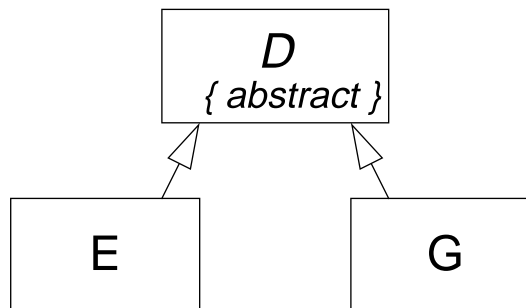


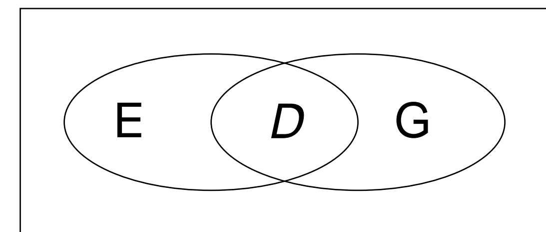
Incorrect Subclass/Superclass Relationships

Subclasses should assume *all* superclass responsibilities

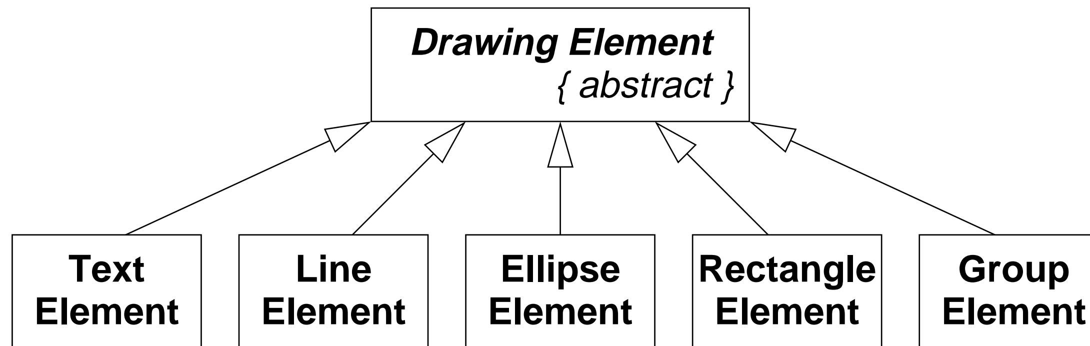
Revised Inheritance Relationships

Introduce abstract superclasses to encapsulate common responsibilities



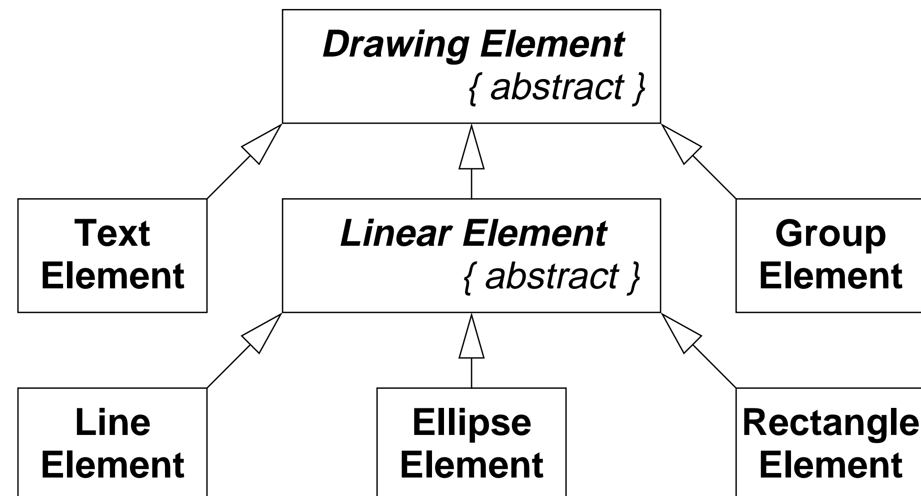


Refactoring Responsibilities



Lines, Ellipses and Rectangles are responsible for keeping track of the width and colour of the lines they are drawn with.

This suggests a common superclass.



Identifying Contracts

A *contract* defines a set of requests that a client can make of a server related to a cohesive set of closely-related responsibilities.

Contracts introduce another level of abstraction, and help to simplify your design.

- *Group* responsibilities used by the same clients:
  - ☞ conversely, separate clients suggest separate contracts
- *Maximize* the cohesiveness of classes:
  - ☞ unrelated contracts belong in subclasses
- *Minimize* the number of contracts:
  - ☞ unify responsibilities and move as high in the hierarchy as appropriate

Applying the Guidelines

1. Start by defining contracts at the top of your hierarchies
2. Introduce new contracts only for subclasses that add significant new functionality
   - ☞ do new responsibilities represent new functionality, or do they just specialize inherited functionality?
3. For each class card, assign responsibilities to an appropriate contract
   - ☞ briefly describe each contract and assign a unique number
   - ☞ number responsibilities according to the associated contract
4. For each collaboration on each class card, determine which contract represents it
   - ☞ model collaborations as associations in class diagrams (AKA “collaboration graphs”)

What are Subsystems?

Subsystems are groups of classes that collaborate to support a set of contracts.

- ❑ Subsystems simplify design by raising abstraction levels:
  - ☞ subsystems group logically related responsibilities, and encapsulate related collaborations
- ❑ Don’t confuse with superclasses:
  - ☞ subsystems group related responsibilities rather than factoring out common responsibilities

Find subsystems by looking for *strongly-coupled* classes:

- ☞ list the collaborations and identify strong inter-dependencies
- ☞ identify and highly frequently-travelled communication paths

Subsystems, like classes, also support contracts. Identify the services provided to clients *outside* the subsystem to determine the subsystem contracts.

Subsystem Cards

For each subsystem, record its name, its contracts, and, for each contract, the internal class or subsystem that supports it:

Subsystem: Drawing Subsystem	
Access a drawing	Drawing
Modify part of a drawing	Drawing Element
Display a drawing	Drawing

Class Cards

For each collaboration from an outside client, change the client's class card to record a collaboration with the subsystem:

Class: File	(*Abstract*)
Document File, Graphics File, Text File	
Knows its contents	
Print its contents	Printing Subsystem

Record on the subsystem card the delegation to the agent class.

Simplifying Interactions

Complex collaborations lead to unmaintainable systems.
Exploit subsystems to simplify overall structure.

- ❑ Minimize the number of collaborations a class has with other classes:
  - ☞ centralizing communications into a subsystem eases evolution
- ❑ Minimize the number of classes to which a subsystem delegates:
  - ☞ centralized subsystem interfaces reduce complexity
- ❑ Minimize the number of different contracts supported by a class:
  - ☞ group contracts that require access to common information

Checking Your Design:

- ☞ model collaborations as associations in class diagrams
- ☞ update class/subsystem cards and class hierarchies
- ☞ walk through scenarios:
  - ➪ Has coupling been reduced? Are collaborations simpler?

Protocols

A *protocol* is a set of signatures (i.e., method names, parameter types and return types) to which a class will respond.

- ☞ Generally, protocols are specified for public responsibilities
- ☞ Protocols for private responsibilities should be specified if they will be used or implemented by subclasses

1. Construct protocols for each class
2. Write a design specification for each class and subsystem
3. Write a design specification for each contract

Refining Responsibilities

Select method names carefully:

- ☞ Use a single name for each conceptual operation in the system
- ☞ Associate a single conceptual operation with each method name
- ☞ Common responsibilities should be explicit in the inheritance hierarchy

Make protocols as generally useful as possible:

- ☞ The more general it is, the *more* messages that should be specified

Define reasonable defaults:

1. Define the most general message with all possible parameters
2. Provide reasonable default values where appropriate
3. Define specialized messages that rely on the defaults

Specifying Your Design: Classes

Specifying Classes

1. Class name; abstract or concrete
2. Immediate superclasses and subclasses
3. Location in inheritance hierarchies and class diagrams
4. Purpose and intended use
5. Contracts supported (as server); inherited contracts and ancestor
6. For each contract, list responsibilities, method signatures, brief description and any collaborations
7. List private responsibilities; if specified further, also give method signatures etc.
8. Note: implementation considerations, possible algorithms, real-time or memory constraints, error conditions etc.

Specifying Subsystems and Contracts

Specifying Subsystems

1. Subsystem name; list all encapsulated classes and subsystems
2. Purpose of the subsystem
3. Contracts supported
4. For each contract, list the responsible class or subsystem

Formalizing Contracts

1. Contract name and number
2. Server(s)
3. Clients
4. A description of the contract

Summary

You should know the answers to these questions:

- ❑ How can you identify abstract classes?
- ❑ What criteria can you use to design a good class hierarchy?
- ❑ How can refactoring responsibilities help to improve a class hierarchy?
- ❑ What is the difference between contracts and responsibilities?
- ❑ What are subsystems (“categories”) and how can you find them?
- ❑ What is the difference between protocols and contracts?

Can you answer the following questions?

- ✎ *What use is multiple inheritance during design if your programming language does not support it?*
- ✎ *Why should you try to minimize coupling and maximize cohesion?*
- ✎ *How would you use Responsibility Driven design together with the Unified Modeling Language?*

9. User Interface Design

Overview:

- Interface design models
- Design principles
- Information presentation
- User Guidance
- Evaluation

Sources:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Third Edn., 1994.

Interface Design Models

Four different models occur in HCI design:

1. The design model expresses the *software design.*
2. The user model describes the *profile of the end users.*
   (i.e., novices vs. experts, cultural background, etc.)
3. The user's model is the end users' *perception of the system.*
4. The system image is the *external manifestation* of the system
   (look and feel + documentation etc.)

GUI Characteristics

Characteristic	*Description*
Windows	Multiple windows allow *different information* to be displayed *simultaneously* on the user's screen.
Icons	Usually icons represent *files* (including folders and applications), but they may also stand for *processes* (e.g., printer drivers).
Menus	Menus bundle and organize *commands* (eliminating the need for a command language).
Pointing	A pointing device such as a mouse is used for *selecting* choices from a menu or indicating items of interest in a window.
Graphics	Graphical elements can be *mixed with text* on the same display.

GUI advantages

- They are *easy to learn* and use.
  - Users without experience can learn to use the system quickly.
- The user may *switch attention* between tasks and applications.
  - Information remains visible in its own window when attention is switched.
- Fast, full-screen interaction is possible with immediate access to the entire screen

But

- A GUI is not automatically a good interface
  - Many software systems are never used due to poor UI design
  - A poorly designed UI can cause a user to make catastrophic errors

User Interface Design Principles

Principle	*Description*
User familiarity	Use terms and concepts *familiar to the user.*
Consistency	*Comparable* operations should be *activated in the same way.* Commands and menus should have the same format, etc.
Minimal surprise	If a command operates in a known way, the user *should be able to predict* the operation of comparable commands.
Feedback	Provide the user with visual and auditory feedback, maintaining *two-way communication.*
Memory load	*Reduce the amount of information* that must be remembered between actions. Minimize the memory load.
Efficiency	Seek *efficiency in dialogue, motion and thought.* Minimize keystrokes and mouse movements.
Recoverability	Allow users to *recover from their errors.* Include undo facilities, confirmation of destructive actions, 'soft' deletes, etc.
User guidance	Incorporate some form of *context-sensitive user guidance* and assistance.

Direct Manipulation

A direct manipulation interface presents the user with a model of the information space which is modified by direct action.

Examples

- forms (direct entry)
- WYSIWYG document editors

Advantages

- Users feel in control and are less likely to be intimidated by the system
- User learning time is relatively short
- Users get immediate feedback on their actions
  - ☞ mistakes can be quickly detected and corrected

Problems

- Finding the right user metaphor may be difficult
- It can be hard to navigate efficiently in a large information space.
- It can be complex to program and demanding to execute

Interface Models

Desktop metaphor.

- The model of an interface is a “desktop” with icons representing files, cabinets, etc.

Control panel metaphor.

- The model of an interface is a hardware control panel with interface entities including:
  - ☞ buttons, switches, menus, lights, displays, sliders etc.

Menu Systems

Menu systems allow users to make a *selection from a list* of possibilities presented to them by the system by pointing and clicking with a *mouse*, using *cursor keys* or by *typing* (part of) the name of the selection.

Advantages

- Users don’t need to remember command names
- Typing effort is minimal
- User errors are trapped by the interface
- Context-dependent help can be provided (based on the current menu selection)

Problems

- Actions involving logical *conjunction* (and) or *disjunction* (or) are awkward to represent
- If there are many choices, some menu *structuring* facility must be used
- Experienced users find menus *slower* than command language

Menu Structuring

- Scrolling menus
  - The menu can be scrolled to reveal additional choices
  - Not practical if there is a very large number of choices
- Hierarchical menus
  - Selecting a menu item causes the menu to be *replaced* by a sub-menu
- Walking menus
  - A menu selection causes another menu to be *revealed*
- Associated control panels
  - When a menu item is selected, a control panel pops-up with further options

Command Interfaces

With a command language, the user types commands to give instructions to the system

- May be implemented using *cheap terminals*
- *Easy to process* using compiler techniques
- Commands of *arbitrary complexity* can be created by command combination
- *Concise interfaces* requiring minimal typing can be created

Advantages

- Allow experienced users to *interact quickly* with the system
- Commands can be *scripted*

Problems

- Users have to *learn and remember* a command language
- Not suitable for *occasional* or inexperienced users
- An *error detection* and recovery system is required
- *Typing* ability is required

Information Presentation

Information display factors

- Is the user interested in *precise information* or *data relationships?*
- How *quickly* do information values *change?*
  Must the change be indicated immediately?
- Must the user take some *action* in response to a change?
- Is there a *direct manipulation* interface?
- Is the information *textual or numeric?* Are *relative values* important?

Jan	Feb	Mar	April	May	June
2842	2851	3164	2789	1273	2835

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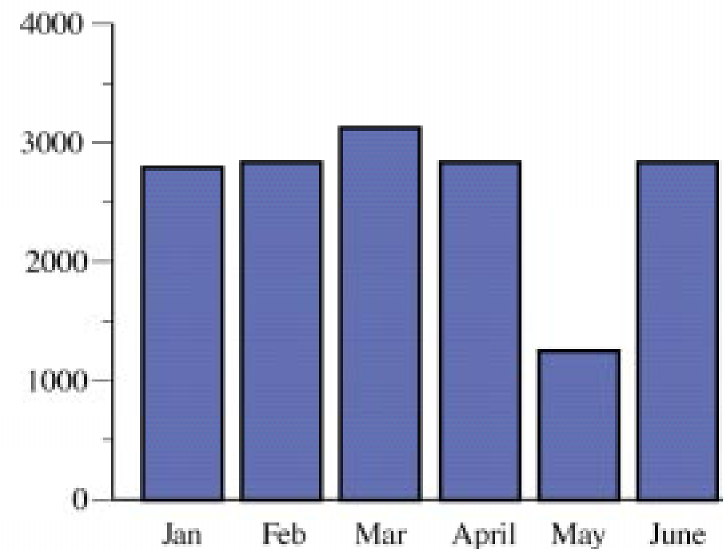


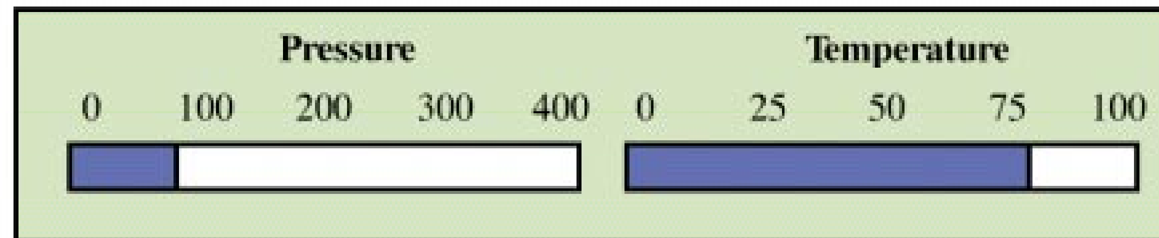
Analogue vs. Digital Presentation

Digital presentation

- Compact - takes up little screen space
- Precise values can be communicated

Analogue presentation

- Easier to get an 'at a glance' impression of a value
- Possible to show relative values
- Easier to see exceptional data values



Colour Displays

Colour can help the user *understand complex information structures.*

Colour use guidelines

- ❑ *Don't* use (only) colour to *communicate meaning!*
  - ☞ Open to *misinterpretation* (colour-blindness, cultural differences ...)
  - ☞ Design for *monochrome* then add colour
- ❑ Use colour coding to *support user tasks*
  - ☞ highlight exceptional events
  - ☞ allow users to control colour coding
- ❑ Use *colour change* to show *status change*
- ❑ Don't use *too many colours*
  - ☞ Avoid colour pairings which *clash*
- ❑ Use colour coding *consistently*

User Guidance

The user guidance system is *integrated with the user interface* to help users when they *need information* about the system or when they make some kind of *error.*

User guidance covers:

- ❑ System messages, including error messages
- ❑ Documentation provided for users
- ❑ On-line help

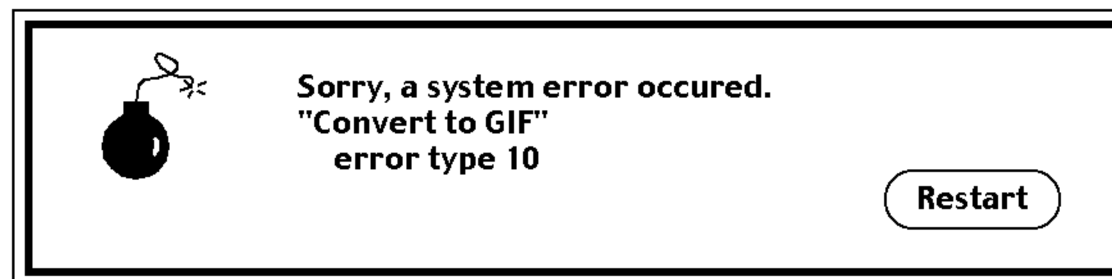
Design Factors in Message Wording

Context	The user guidance system should be aware of what the user is doing and should *adjust the output message to the current context.*
Experience	The user guidance system should provide both longer, *explanatory messages for beginners,* and more *terse messages for experienced users.*
Skill level	Messages should be *tailored to the user's skills* as well as their experience. I.e., depending on the *terminology* which is familiar to the reader.
Style	Messages should be *positive rather than negative.* They should never be insulting or try to be funny.
Culture	Wherever possible, the designer of messages should be *familiar with the culture* of the country (or environment) where the system is used. A suitable message for one culture might be unacceptable in another.

Error Message Guidelines

- Speak the user's language
- Give constructive advice for recovering from the error
- Indicate negative consequences of the error (e.g., possibly corrupted files)
- Give an audible or visual cue
- Don't make the user feel guilty!

Good and Bad Error Messages



Help System Design

Help? *means* “Please help. I want information.”
Help! *means* “HELP. *I'm in trouble.*”

Help information

- ❑ Should *not* simply be an on-line manual
  - ☞ Screens or windows don't map well onto paper pages
- ❑ Dynamic characteristics of display can *improve information presentation*
  - ☞ but people are not so good at reading screens as they are text.

Help system use

- ❑ *Multiple entry points* should be provided
  - ☞ the user should be able to get help from different places
- ❑ The help system should indicate *where the user is positioned*
- ❑ *Navigation and traversal* facilities must be provided

User Interface Evaluation

User interface design should be *evaluated* to assess its suitability and *usability*.

Usability attributes

Attribute	*Description*
Learnability	How long does it take a new user to become productive with the system?
Speed of operation	How well does the system response match the user's work practice?
Robustness	How tolerant is the system of user error?
Recoverability	How good is the system at recovering from user errors?
Adaptability	How closely is the system tied to a single model of work?

Summary

You should know the answers to these questions:

- ❑ What *models* are important to keep in mind in UI design?
- ❑ What is the principle of *minimal surprise?*
- ❑ What problems arise in designing a good *direct manipulation interface?*
- ❑ What are the trade-offs between *menu systems and command languages?*
- ❑ How can you use *colour* to improve a UI?
- ❑ In what way can a help system be *context sensitive?*

Can you answer the following questions?

- ✎ *Why is it important to offer “keyboard shortcuts” for equivalent mouse actions?*
- ✎ *How would you present the current load on the system? Over time?*
- ✎ *What is the worst UI you every used? Which design principles did it violate?*
- ✎ *What’s the worst web site you’ve used recently? How would you fix it?*
- ✎ *What’s good or bad about the MS-Word help system?*

10. Software Validation

Overview:

- Reliability, Failures and Faults
- Fault Tolerance
- Software Testing: Black box and white box testing
- Static Verification

Source:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.

Software Reliability, Failures and Faults

The *reliability* of a software system is a measure of how well it provides the services expected by its users, expressed in terms of software failures.

A software *failure* is an execution event where the software behaves in an unexpected or undesirable way.

A software *fault* is an erroneous portion of a software system which may cause failures to occur if it is run in a particular state, or with particular inputs.

Failure class	*Description*
Transient	Occurs only with certain inputs
Permanent	Occurs with all inputs
Recoverable	System can recover without operator intervention
Unrecoverable	Operator intervention is needed to recover from failure
Non-corrupting	Failure does not corrupt data
Corrupting	Failure corrupts system data

Programming for Reliability

Fault avoidance:

☞ development techniques to reduce the number of faults in a system

Fault tolerance:

☞ developing programs that will operate despite the presence of faults

Fault avoidance depends on:

1. A precise *system specification* (preferably formal)
2. Software design based on *information hiding* and *encapsulation*
3. Extensive validation *reviews* during the development process
4. An organizational *quality philosophy* to drive the software process
5. Planned *system testing* to expose faults and assess reliability

Common Sources of Software Faults

Several features of programming languages and systems are common sources of faults in software systems:

- ❑ *Goto statements* and other unstructured programming constructs make programs hard to understand, reason about and modify.
  - ☞ Use structured programming constructs
- ❑ *Floating point numbers* are inherently imprecise and may lead to invalid comparisons.
  - ☞ Fixed point numbers are safer for exact comparisons
- ❑ *Pointers* are dangerous because of aliasing, and the risk of corrupting memory
  - ☞ Pointer usage should be confined to abstract data type implementations
- ❑ *Parallelism* is dangerous because timing differences can affect overall program behaviour in hard-to-predict ways.
  - ☞ Minimize inter-process dependencies
- ❑ *Recursion* can lead to convoluted logic, and may exhaust (stack) memory.
  - ☞ Use recursion in a disciplined way, within a controlled scope
- ❑ *Interrupts* force transfer of control independent of the current context, and may cause a critical operation to be terminated.
  - ☞ Minimize the use of interrupts; prefer disciplined exceptions

Fault Tolerance

A fault-tolerant system must carry out four activities:

1. Failure detection:
   - ☞ detect that the system has reached a particular state or will result in a system failure
2. Damage assessment:
   - ☞ detect which parts of the system state have been affected by the failure
3. Fault recovery:
   - ☞ restore the state to a known, “safe” state (either by correcting the damaged state, or backing up to a previous, safe state)
4. Fault repair:
   - ☞ modify the system so the fault does not recur (!)

Approaches to Fault Tolerance

N-version Programming:

Multiple versions of the software system are implemented independently by different teams. The final system:

- runs all the versions in parallel,
- compares their results using a voting system, and
- rejects inconsistent outputs. (At least three versions should be available!)

Recovery Blocks:

A finer-grained approach in which a program unit contains a test to check for failure, and alternative code to back up and try in case of failure.

- alternatives are executed in sequence, not in parallel
- the failure test is independent (not by voting)

Defensive Programming

Failure detection:

- Use the *type system* as much as possible to ensure that state variables do not get assigned invalid values.
- Use *assertions* to detect failures and raise exceptions. Explicitly state and check all invariants for abstract data types, and pre- and post-conditions of procedures as assertions. Use exception handlers to recover from failures.
- Use *damage assessment* procedures, where appropriate, to assess what parts of the state have been affected, before attempting to fix the damage.

Fault recovery:

- Backward recovery: backup to a previous, consistent state
- Forward recovery: make use of redundant information to reconstruct a consistent state from corrupted data

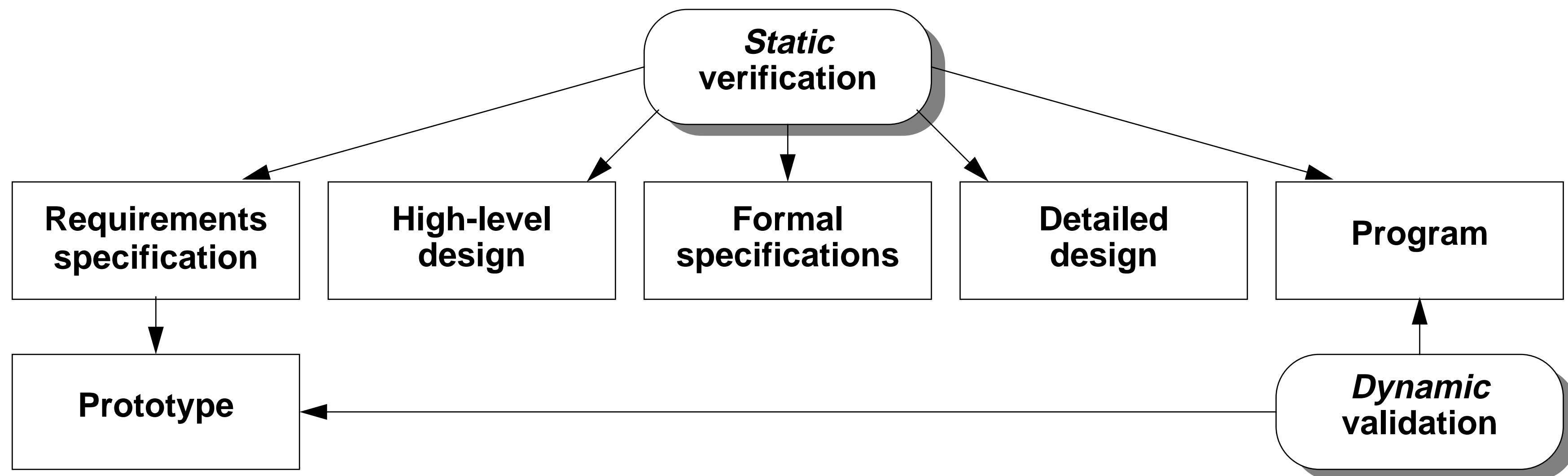
Verification and Validation

Validation:

- Are we building the right product?

Verification:

- Are we building the product right?



Static techniques include program inspection, analysis and formal verification.

Dynamic techniques include *statistical testing* and *defect testing* ...

The Testing Process

1. Unit testing:
   - ☞ Individual (stand-alone) components are tested to ensure that they operate correctly.
2. Module testing:
   - ☞ A collection of related components (a module) is tested as a group.
3. Sub-system testing:
   - ☞ The phase tests a set of modules integrated as a sub-system. Since the most common problems in large systems arise from sub-system interface mismatches, this phase focuses on testing these interfaces.
4. System testing:
   - ☞ This phase concentrates on (i) detecting errors resulting from unexpected interactions between sub-systems, and (ii) validating that the complete systems fulfils functional and non-functional requirements.
5. Acceptance testing (alpha/beta testing):
   - ☞ The system is tested with real rather than simulated data.

Testing is iterative! Regression testing is performed when defects are repaired.

Regression Testing

Regression testing means testing that everything that used to work *still works* after changes are made to the system!

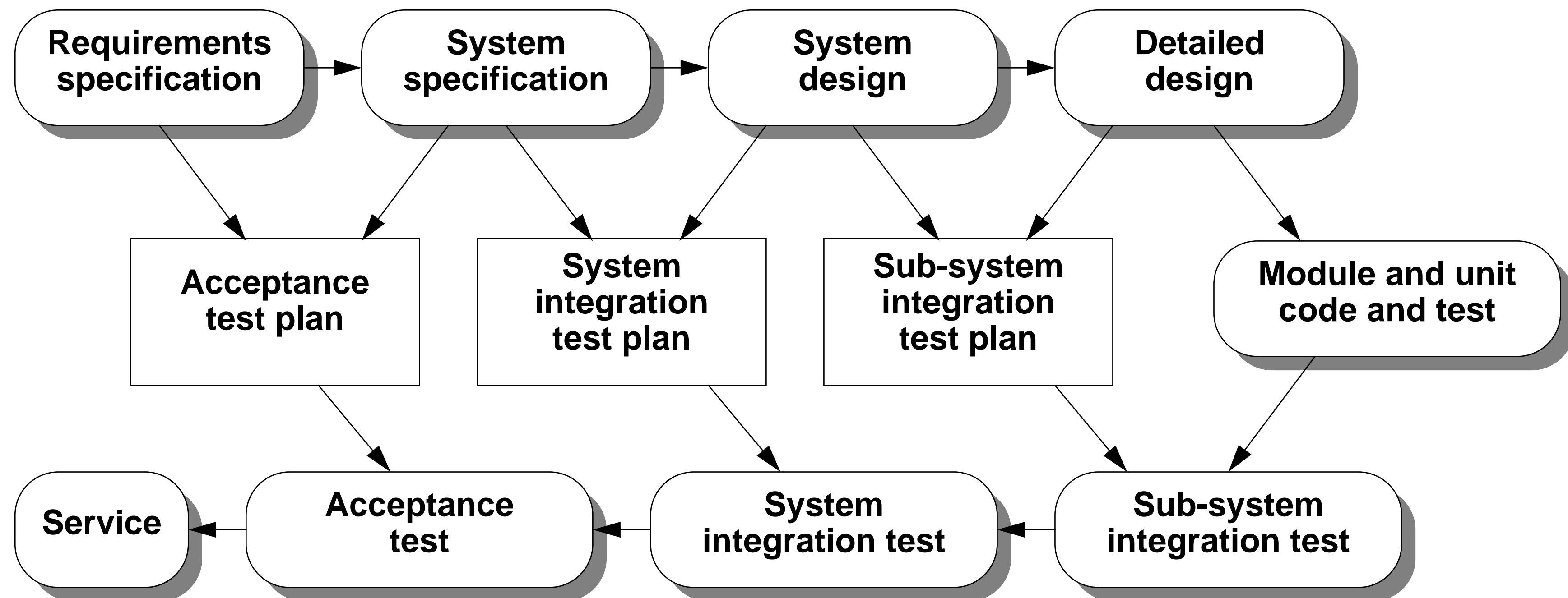
- tests must be *deterministic* and *repeatable*
- should test “all” functionality
  - every interface
  - all boundary situations
  - every feature
  - every line of code
  - everything that can conceivably go wrong!

It costs extra work to define tests up front, but they pay off in debugging & maintenance!

NB: Testing can only reveal the *presence* of defects, not their absence!

Test Planning

The preparation of the test plan should begin when the system requirements are formulated, and the plan should be developed in detail as the software is designed.



The plan should be revised regularly, and tests should be repeated and extended wherever iteration occurs in the software process.

Testing Strategies

Top-down Testing:

- ☞ Start with sub-systems, where modules are represented by “stubs”
- ☞ Similarly test modules, representing functions as stubs
- ☞ Coding and testing are carried out as a single activity
- ☞ Design errors can be detected early on, avoiding expensive redesign
- ☞ Always have a running (if limited) system
- ☞ BUT: may be impractical for stubs to simulate complex components

Bottom-up Testing:

- ☞ Start by testing units and modules
- ☞ Test drivers must be written to exercise lower-level components
- ☞ Works well for reusable components to be shared with other projects
- ☞ BUT: pure bottom-up testing will not uncover architectural faults till late in the software process

Typically a combination of top-down and bottom-up testing is best.

Defect Testing

Tests are designed to reveal the presence of defects in the system.
Testing should, in principle, be exhaustive, but in practice can only be representative.

Test data are inputs devised to test the system.
Test cases are input/output specifications for a particular function being tested.

Petschenik (1985) proposes:

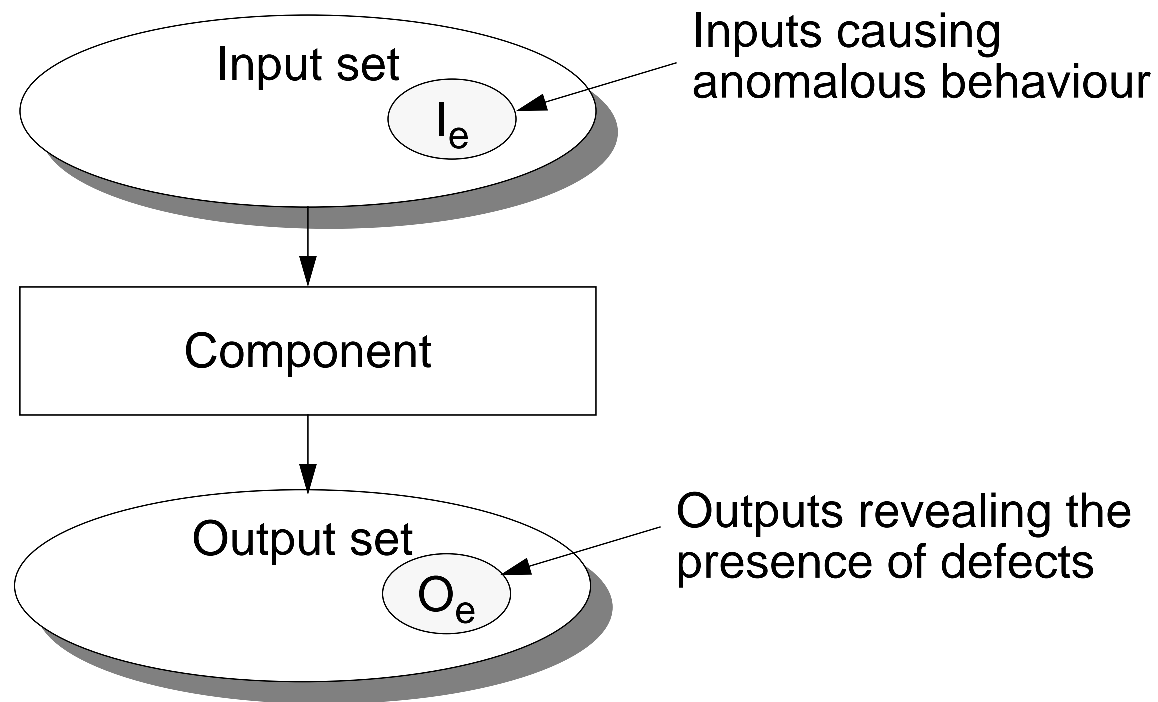
1. "Testing a system's capabilities is more important than testing its components."
   - ☞ Choose test cases that will identify situations that may prevent users from doing their job.

2. "Testing old capabilities is more important than testing new capabilities."
   - ☞ Always perform regression tests when the system is modified.

3. "Testing typical situations is more important than testing boundary value cases."
   - ☞ If resources are limited, focus on typical usage patterns.

Functional testing

Functional testing treats a component as a “*black box*” whose behaviour can be determined only by studying its inputs and outputs.



Test cases are derived from the *external* specification of the component.

Equivalence Partitioning

Test cases can be derived from a component's interface, by assuming that the component will behave similarly for all members of an equivalence partition.

Example:

```
private int[] _elements;
public boolean find(int key) { ... }
```

Check input partitions:

- Do the inputs fulfil the pre-conditions?
- Is the key in the array?
  - ☞ leads to (at least) 2x2 equivalence classes

Check boundary conditions:

- Is the array of length 1?
- Is the key at the start or end of the array?
  - ☞ leads to further subdivisions (not all combinations make sense)

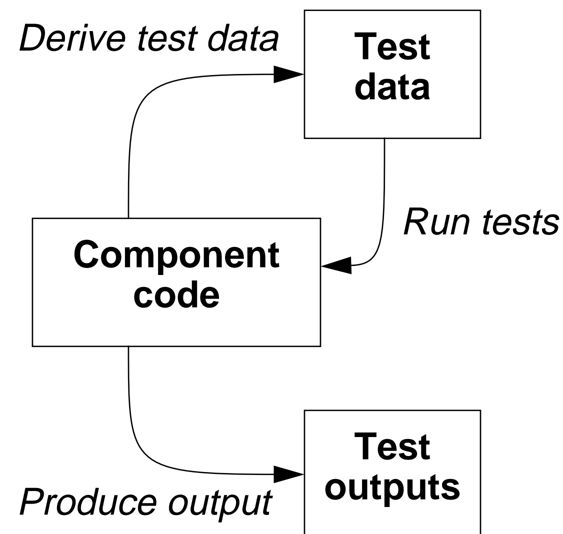
Test Cases and Test Data

Generate test data that cover all meaningful equivalence partitions.

Test Cases	*Test Data*
Array length 0	key = 17, elements = { }
Array not sorted	key = 17, elements = { 33, 20, 17, 18 }
Array size 1, key in array	key = 17, elements = { 17 }
Array size 1, key not in array	key = 0, elements = { 17 }
Array size > 1, key is first element	key = 17, elements = { 17, 18, 20, 33 }
Array size > 1, key is last element	key = 33, elements = { 17, 18, 20, 33 }
Array size > 1, key is in middle	key = 20, elements = { 17, 18, 20, 33 }
Array size > 1, key not in array	key = 50, elements = { 17, 18, 20, 33 }
...	

Structural Testing

Structural testing treats a component as a “white box” or “glass box” whose structure can be examined to generate test cases.



Path testing is a white-box strategy which exercises every independent execution path through a component.

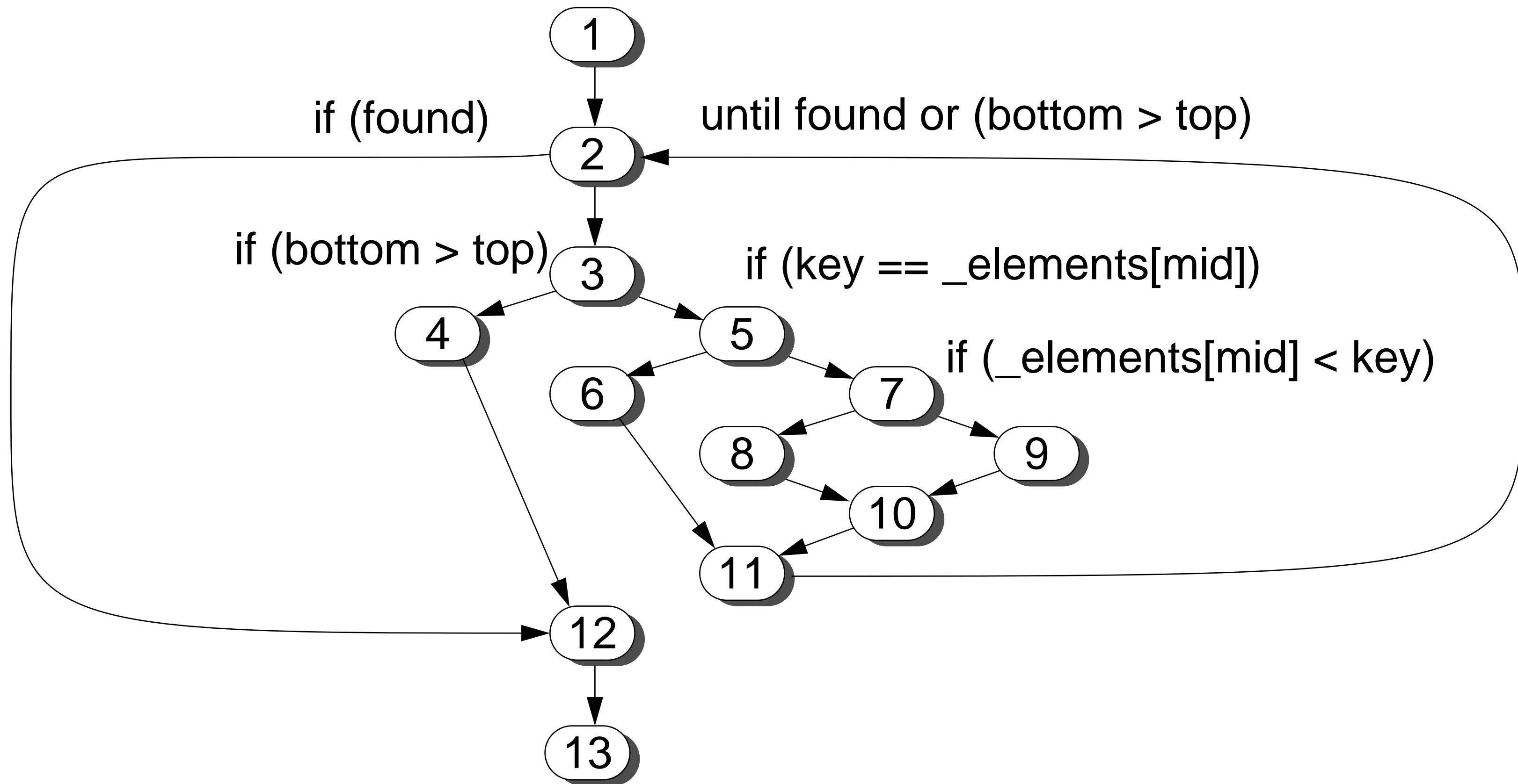
Binary Search Method

```
public boolean find(int key) throws assertionViolation { // (1)
   assert(isSorted()); // pre-condition
   if (isEmpty()) { return false; } // Trivially can't find key in an empty list
   int bottom = 0;
   int top = _elements.length-1;
   int lastIndex = (bottom+top)/2;
   int mid;
   boolean found = key == _elements[lastIndex];

   while ((bottom <= top) && !found) {                          // (2) (3)
      assert(bottom <= top); // loop invariant
      mid = (bottom + top) / 2;
      found = key == _elements[mid];
      if (found) {                                              // (5)
         lastIndex = mid;                                       // (6)
      } else {
         if (_elements[mid] < key) {                            // (7)
            bottom = mid + 1;                                   // (8)
         } else { top = mid - 1; }                              // (9)
      } // loop variant decreases: top - bottom
   }                                                            // (4)
   assert((key == _elements[lastIndex]) || !found); // post-condition
   return found;
}
```

Path Testing

A set of *independent paths* of a flow graph must cover all the edges in the graph:
e.g., {1,2,3,4,12,13}, {1,2,3,5,6,11,2,12,13}, {1,2,3,5,7,8,10,11,2,12,13}, {1,2,3,5,7,9,10,11,2,12,13}



Test cases should be chosen to cover all independent paths through a routine.

Statistical Testing

The objective of statistical testing is to determine the reliability of the software, rather than to discover software faults. Reliability may be expressed as:

- probability of failure on demand,
- rate of failure occurrence,
- mean time to failure,
- availability

Tests are designed to reflect the frequency of actual user inputs and, after running the tests, an estimate of the operational reliability of the system can be made:

1. *Determine usage patterns* of the system (classes of input and probabilities)
2. *Select or generate test data* corresponding to these patterns
3. *Apply the test cases*, recording execution time to failure
4. Based on a statistically significant number of test runs, *compute reliability*

Static Verification

Program Inspections:

- ❑ Small team systematically checks program code
- ❑ Inspection checklist often drives this activity
  - ☞ e.g., “Are all invariants, pre- and post-conditions checked?” ...

Static Program Analysers:

- ❑ Complements compiler to check for common errors
  - ☞ e.g., variable use before initialization

Mathematically-based Verification:

- ❑ Use mathematical reasoning to demonstrate that program meets specification
  - ☞ e.g., that invariants are not violated, that loops terminate, etc.

Cleanroom Software Development:

- ❑ Systematically use (i) incremental development, (ii) formal specification, (iii) mathematical verification, and (iv) statistical testing

Summary

You should know the answers to these questions:

- ❑ What is the difference between a *failure* and a *fault*?
- ❑ What kinds of failure classes are important?
- ❑ How can a software system be made fault-tolerant?
- ❑ How do assertions help to make software more reliable?
- ❑ What are the goals of software validation and verification?
- ❑ What is the difference between test cases and test data?
- ❑ How can you develop test cases for your programs?
- ❑ What is the goal of path testing?

Can you answer the following questions?

- ✎ *When would you combine top-down testing with bottom-up testing?*
- ✎ *When would you combine black-box testing with white-box testing?*
- ✎ *Is it acceptable to deliver a system that is not 100% reliable?*

11. Software Quality

Overview:

- What is quality?
- Quality Management activities
- ISO 9001
- Quality Reviews
- Product and Process Standards

Sources:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Third Edn., 1994.
- *Objects, Components and Frameworks with UML*, D. D'Souza, A. Wills, Addison-Wesley, 1999

What is Quality?

Software Quality is conformance to

- ❑ explicitly stated *functional and performance requirements*,
- ❑ explicitly documented *development standards*,
- ❑ *implicit characteristics* that are expected of all professionally developed software.

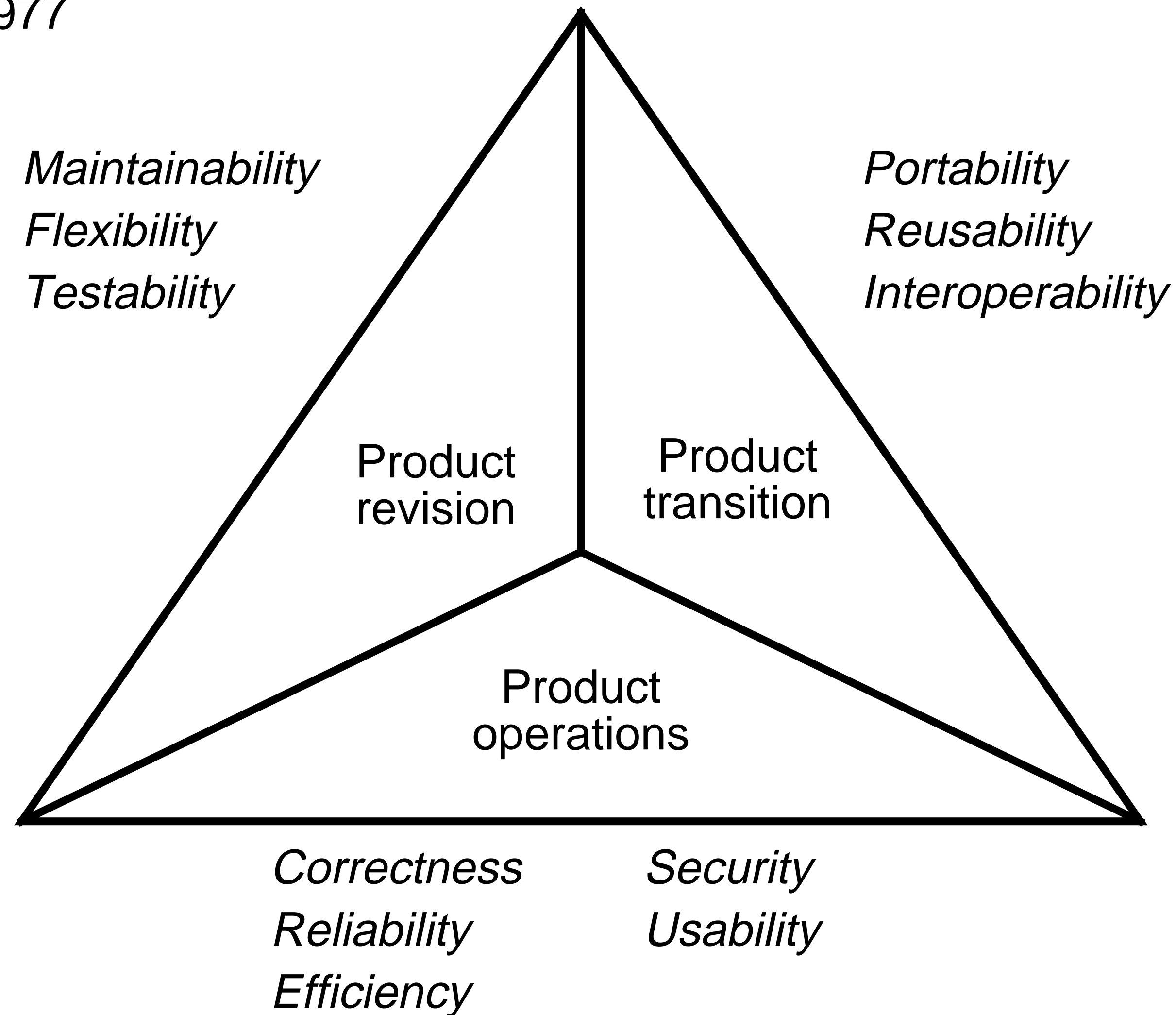
Problems:

- ❑ Software specifications are usually *incomplete* and often *inconsistent*
- ❑ There is tension between:
  - ☞ *customer* quality requirements (efficiency, reliability, etc.)
  - ☞ *developer* quality requirements (maintainability, reusability, etc.)
- ❑ Some quality requirements are hard to specify in an unambiguous way
  - ☞ *directly* measurable qualities (e.g., errors/KLOC),
  - ☞ *indirectly* measurable qualities (e.g., usability).

Quality management is not just about reducing defects!

Software Quality Factors

Ref: McCall 1977



Quality Management Activities

Quality assurance

- *Establish* organisational procedures and standards for quality

Quality planning

- *Select* applicable procedures and standards for a particular project and *modify* these as required

Quality control

- *Ensure* that procedures and standards are *followed* by the software development team

Quality management should be *separate from project management* to ensure independence

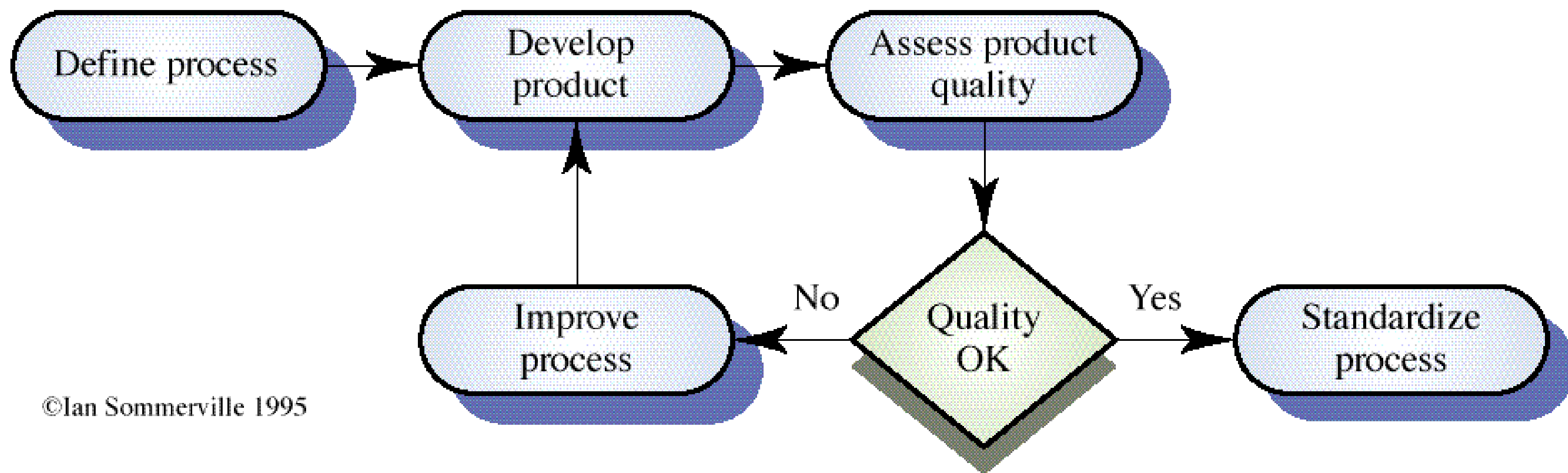
Quality Controls

Examples:

- *Code walk-through* of a module to check if it implements its functional specification correctly
  - ☞ Results in *minutes* documenting who participated, what was found ...
- *Acceptance test* to check if a function has been correctly implemented
  - ☞ Results in a *test record*
- *Examination* of a program for conformance to standards
  - ☞ Results in filled *form* or *checklist*
- *Running a tool* to check for adherence to portability standard
  - ☞ Results in *printout* of the tool

Process-based Quality

Quality management must include periodic *reviews of the quality system* itself!



ISO 9000

ISO 9000 is an *international set of standards for quality management* applicable to a range of organisations from manufacturing to service industries.

ISO 9001 is a *generic model of the quality process*, applicable to organisations which *design, develop and maintain products*

- ISO 9001 must be *instantiated* for each organisation
- ISO 9000-3 *interprets* ISO 9001 for the *software developer*

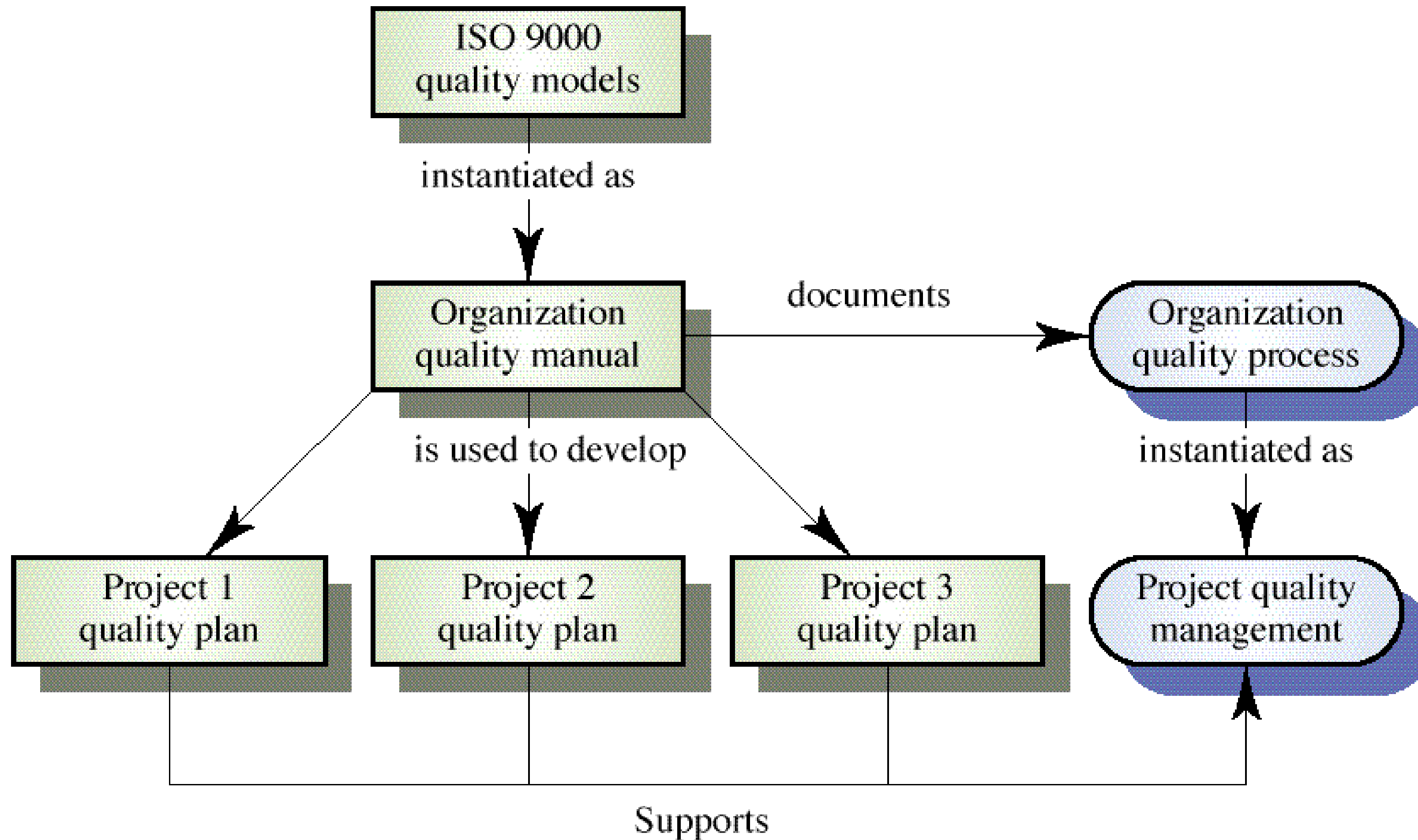
NB: ISO = International Organisation for Standardization

ISO 9001

Describes quality standards and procedures for developing products *of any kind*:

Management responsibility	*Quality system*
Control of non-conforming products	Design control
Handling, storage, packaging and delivery	Purchasing
Purchaser-supplied products	Product identification and traceability
Process control	Inspection and testing
Inspection and test equipment	Inspection and test status
Contract review	Corrective action
Document control	Quality records
Internal quality audits	Training
Servicing	Statistical techniques

ISO 9000 and Quality Management



ISO 9000 Certification

Software developers may request to be *certified* as being ISO 9000 compliant.

- Quality standards and procedures must be *documented* in an organisational quality manual
  - ☞ The quality system should be used for several months to detect problems
- An *external body* should *audit* the system for conformance to ISO 9000
  - ☞ Usually a company specializing in standards
- The system is submitted to an *accreditation body*
  - ☞ One for each country

Customers are increasingly demanding that suppliers be ISO 9000 certified ...

The Quality Plan

A quality plan should:

- set out *desired product qualities* and how these are assessed
  - ☞ define the most *significant* quality attributes
- define the *quality assessment process*
  - ☞ i.e., the *controls* used to ensure quality
- set out which *organisational standards* should be applied
  - ☞ may define new standards, i.e., if new tools or methods are used

Types of Review

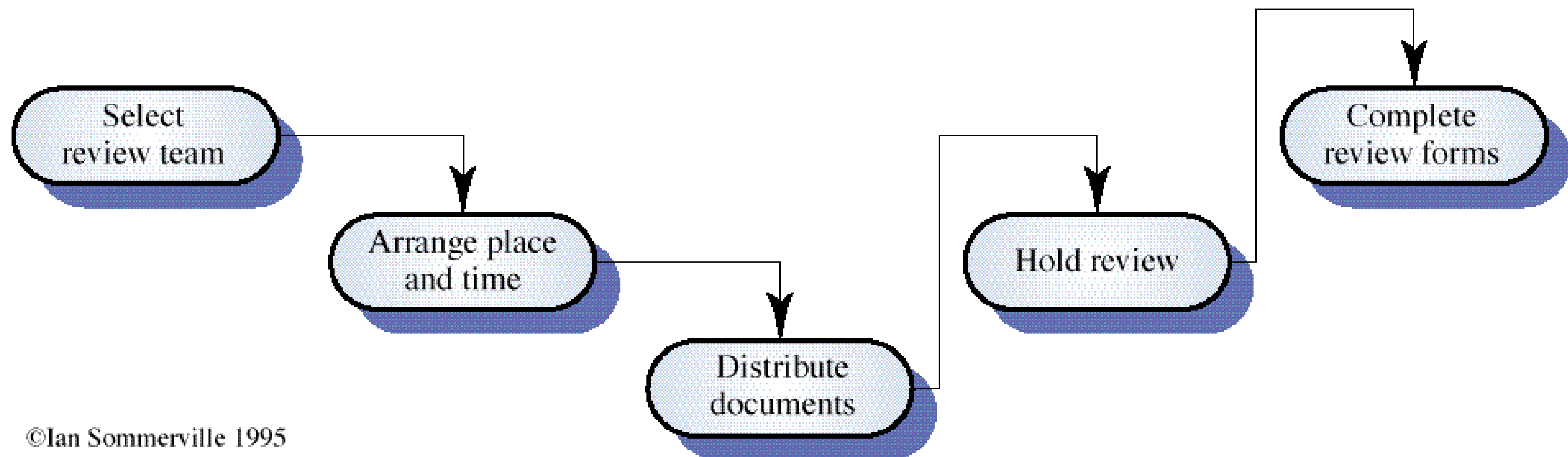
Review type	*Principal purpose*
Design or program inspections	To detect detailed errors in the design or code and to check whether standards have been followed. The review should be driven by a *checklist of possible errors*.
Progress reviews	To provide information for management about the overall progress of the project. This is both a process and a product review and is concerned with *costs, plans and schedules*.
Quality reviews	To carry out a technical analysis of product components or documentation to find *faults or mismatches* between the specification and the design, code or documentation. It may also be concerned with broader quality issues such as *adherence to standards* and *other quality attributes*.

Quality Reviews

A quality review is carried out by a group of people who carefully *examine* part or all of a *software system* and its associated *documentation*.

- Objective is the *discovery of system defects and inconsistencies*
- Review *teams* should be relatively *small* and *reviews* should be fairly *short*
- *Any documents* produced in the process may be reviewed
  - Code, designs, specifications, test plans, standards, etc. can all be reviewed.
- Review should be *recorded* and records maintained
  - Software or documents may be “signed off” at a review
  - Progress to the next development stage is thereby approved

The Review Process



Review Meetings and Minutes

Review meetings should:

- typically involve *3-5 people*
- require a maximum of *2 hours advance preparation*
- last *less than 2 hours*

The review report should summarize:

1. What was reviewed
2. Who reviewed it?
3. What were the findings and conclusions?

The review should conclude whether the product is:

1. *Accepted* without modification
2. *Provisionally accepted*, subject to corrections (no follow-up review)
3. *Rejected*, subject to corrections and follow-up review

Review Guidelines

1. Review the *product*, not the producer
2. Set an *agenda* and maintain it
3. *Limit debate* and rebuttal
4. *Identify problem areas*, but don’t attempt to solve every problem noted
5. Take *written notes*
6. *Limit* the number of participants and insist upon advance preparation
7. Develop a *checklist* for each product that is likely to be reviewed
8. *Allocate resources* and time schedule for reviews
9. Conduct meaningful *training* for all reviewers
10. *Review* your early *reviews*

Sample Review checklists (I)

Software Project Planning

1. Is software scope unambiguously defined and bounded?
2. Are resources adequate for scope?
3. Have risks in all important categories been defined?
4. Are tasks properly defined and sequenced?
5. Is the basis for cost estimation reasonable?
6. Have historical productivity and quality data been used?
7. Is the schedule consistent? ...

Requirements Analysis

1. Is information domain analysis complete, consistent and accurate?
2. Does the data model properly reflect data objects, attributes and relationships?
3. Are all requirements traceable to system level?
4. Has prototyping been conducted for the user/customer?
5. Are requirements consistent with schedule, resources and budget? ...

Sample Review checklists (II)

Design

1. Has modularity been achieved?
2. Are interfaces defined for modules and external system elements?
3. Are the data structures consistent with the information domain?
4. Are the data structures consistent with the requirements?
5. Has maintainability been considered? ...

Code

1. Does the code reflect the design documentation?
2. Has proper use of language conventions been made?
3. Have coding standards been observed?
4. Are there incorrect or ambiguous comments? ...

Testing

1. Have test resources and tools been identified and acquired?
2. Have both white and black box tests been specified?
3. Have all the independent logic paths been tested?
4. Have test cases been identified and listed with expected results?
5. Are timing and performance to be tested? ...

Review Results

Comments made during the review should be classified.

- ❑ No action.
  - ☞ No change to the software or documentation is required.
- ❑ Refer for repair.
  - ☞ Designer or programmer should correct an identified fault.
- ❑ Reconsider overall design.
  - ☞ The problem identified in the review impacts other parts of the design.

Requirements and specification errors may have to be referred to the client.

Product and Process Standards

Product standards define characteristics that all components should exhibit.
Process standards define how the software process should be enacted.

Product standards	*Process standards*
Design review form	Design review conduct
Document naming standards	Submission of documents
Procedure header format	Version release process
Java programming style standard	Project plan approval process
Project plan format	Change control process
Change request form	Test recording process

Problems

- ❑ Not always seen as relevant and up-to-date by software engineers
- ❑ May involve too much bureaucratic form filling
- ❑ May require tedious manual work if unsupported by software tools

Sample Java Code Conventions

4.2 Wrapping Lines

When an expression will not fit on a single line, break it according to these general principles:

- Break after a comma.
- Break before an operator.
- Prefer higher-level breaks to lower-level breaks.
- Align the new line with the beginning of the expression at the same level on the previous line.
- If the above rules lead to confusing code or to code that's squished up against the right margin, just indent 8 spaces instead.

10.3 Constants

Numerical constants (literals) should not be coded directly, except for -1, 0, and 1, which can appear in a for loop as counter values.

Documentation Standards

Documentation process standards define how documents should be developed, validated and maintained.

Document interchange standards define how documents are stored and interchanged between different documentation systems.

Document standards are concerned with document contents, structure, and appearance:

- *Identification:* how documents are uniquely identified
- *Structure:* standard structure for project documents
- *Presentation:* define fonts and styles, use of logos, etc.
- *Update:* how changes from previous versions are reflected in a document

Good and Bad Documentation

Bad signs

- No documentation
- All documents, no code exists
- All pictures
- Wall-sized documents
- Big thick formal documents

Good signs

- Clear document structure
- Mix of formal and informal
- Clear glossary

Summary

You should know the answers to these questions:

- ❑ Can a correctly functioning piece of software still have poor quality?
- ❑ Why should quality management be separate from project management?
- ❑ How could you use ISO 9000 to guide quality management?
- ❑ How should you organize and run a review meeting?
- ❑ What information should be recorded in the review minutes?

Can you answer the following questions?

- ✎ *How can you evaluate a quality assurance plan?*
- ✎ *Would you trust software developed by an ISO 9000 certified company?*
- ✎ *Why are coding standards important?*
- ✎ *What would you include in a documentation review checklist?*
- ✎ *How often should reviews by scheduled?*

12. Computer-Aided Software Engineering

Overview:

- ❑ What is CASE?
  - ☞ CASE tool functionality vs. process support
- ❑ Tools, Workbenches and Environments
  - ☞ Programming workbenches
  - ☞ Analysis and design workbenches
  - ☞ Testing workbenches
- ❑ Software Engineering Environments

Source:

- ❑ Software Engineering, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.

What is CASE?

"Computer-aided Software Engineering" refers to automated support for the software engineering process. There are mainly 3 levels of CASE technology:

1. Production-process support technology:
   - ☞ includes support for process activities such as specification, design, implementation, testing etc. (mature, and wide-spread)

2. Process management technology:
   - ☞ includes tools to support process modelling and process management (few products available)

3. Meta-CASE technology:
   - ☞ tools for generating CASE tools (not widely adopted)

CASE Tool Functionality

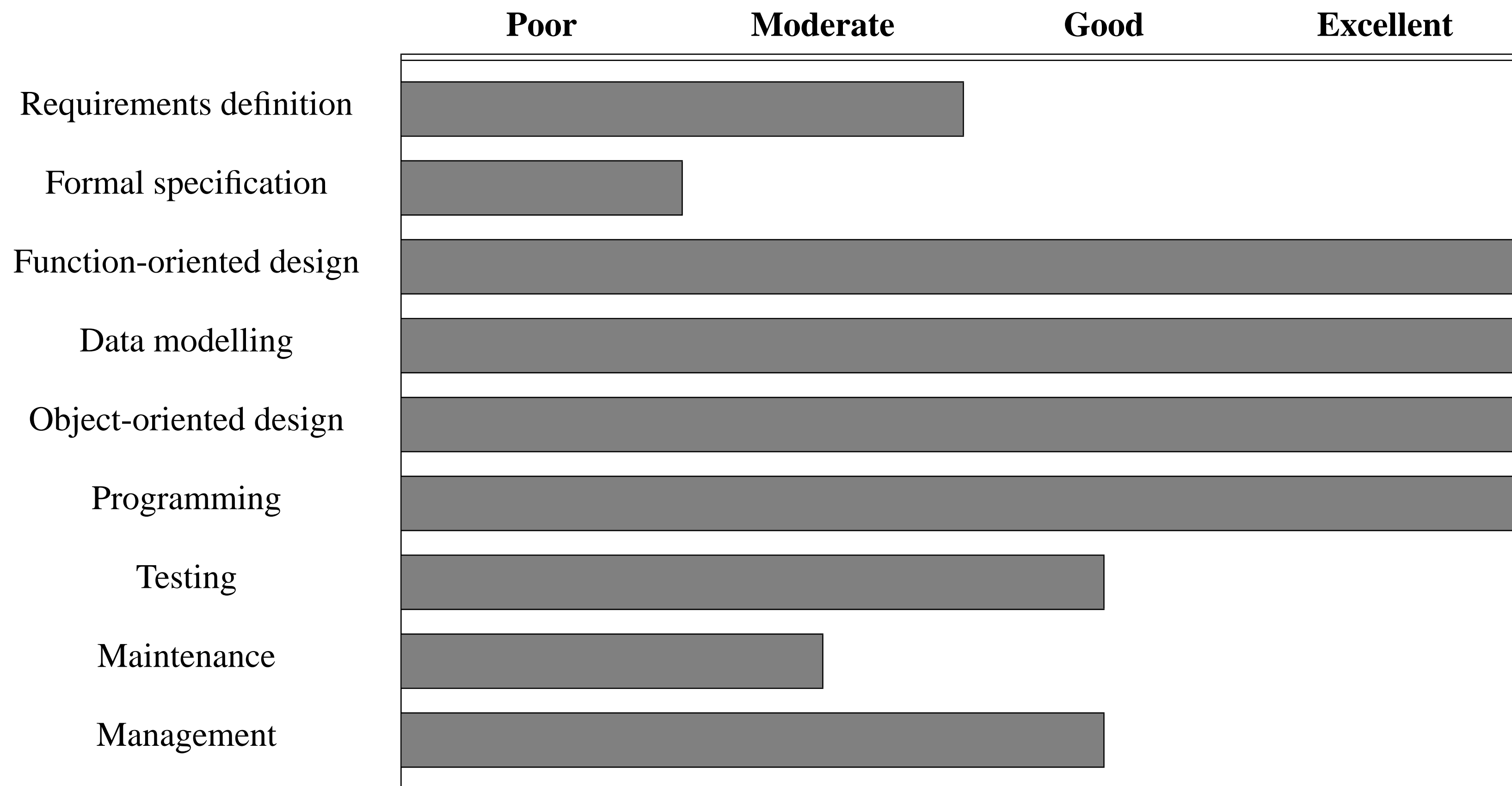
CASE tools can be classified by functionality or by their support for the software process.

Tool type	Examples
Management Tools	PERT tools, estimation tools
Editing tools	Text editors, diagram editors, word processors
Configuration management tools	Version management systems, change management systems
Prototyping tools	Very high-level languages, user interface generators
Method support tools	Design editors, data dictionaries, code generators
Language processing tools	Compilers, interpreters
Program analysis tools	Cross-reference generators, static analysers, dynamic analysers
Testing tools	Test data generators, file comparators
Debugging tools	Interactive debugging systems
Documentation tools	Page layout programs, image editors
Re-engineering tools	Cross-reference systems, program restructuring systems

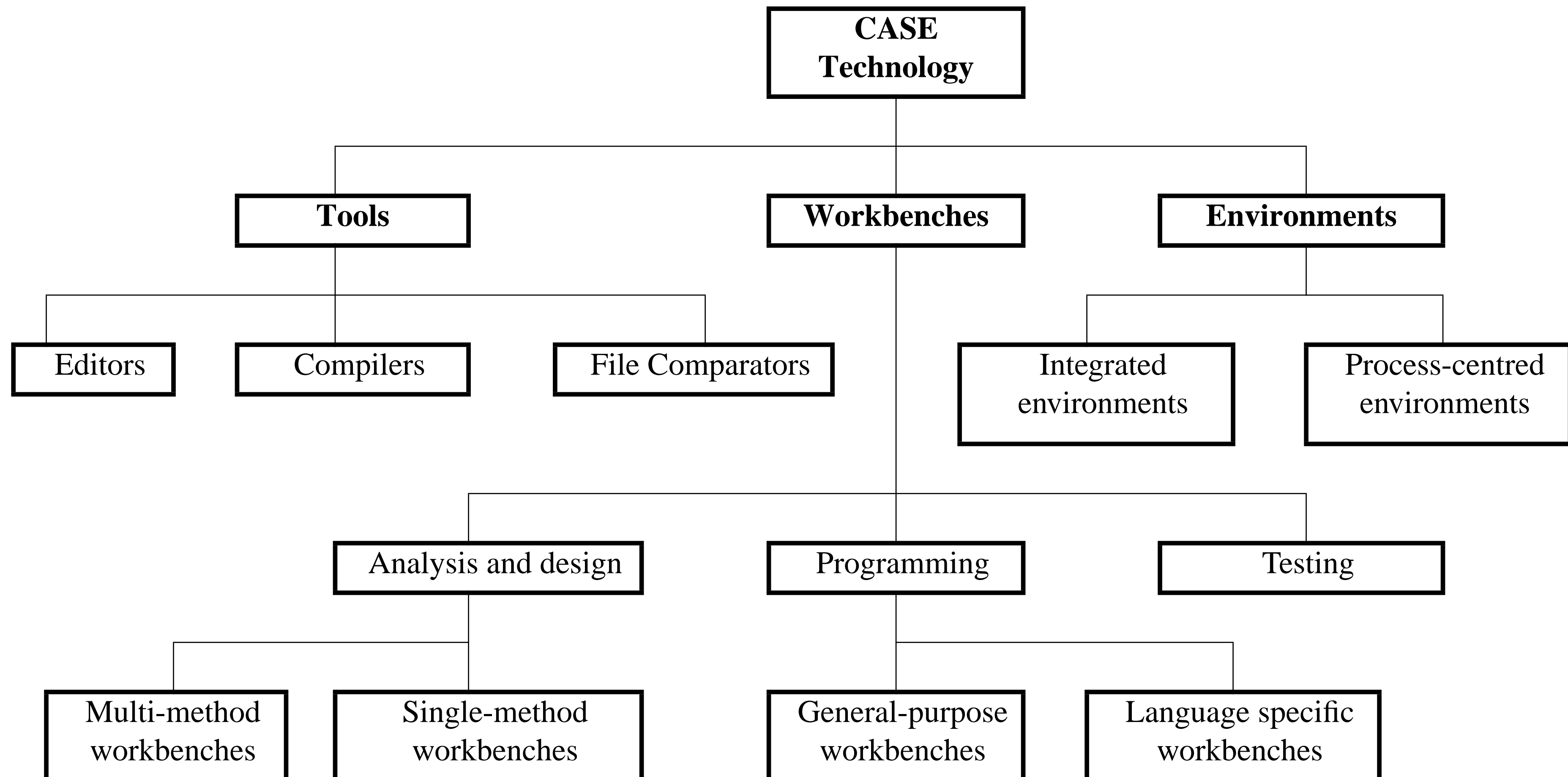
CASE Tool Process Support

Tools	Specification	Design	Implementation	Verification and Validation
Planning and Estimation	✓	✓	✓	✓
Text Editing	✓	✓	✓	✓
Document Preparation	✓	✓	✓	✓
Configuration Management	✓	✓	✓	✓
Prototyping	✓			✓
Diagram Editing	✓	✓		
Data Dictionary	✓	✓		
User Interface Management		✓	✓	
Method Support	✓	✓		
Language Processing			✓	✓
Program Analysis			✓	✓
Interactive Debugging			✓	✓
Program Transformation			✓	
Modelling and Simulation	✓			✓
Test Data Generation				✓

Quality of Tools Support



Tools, Workbenches and Environments

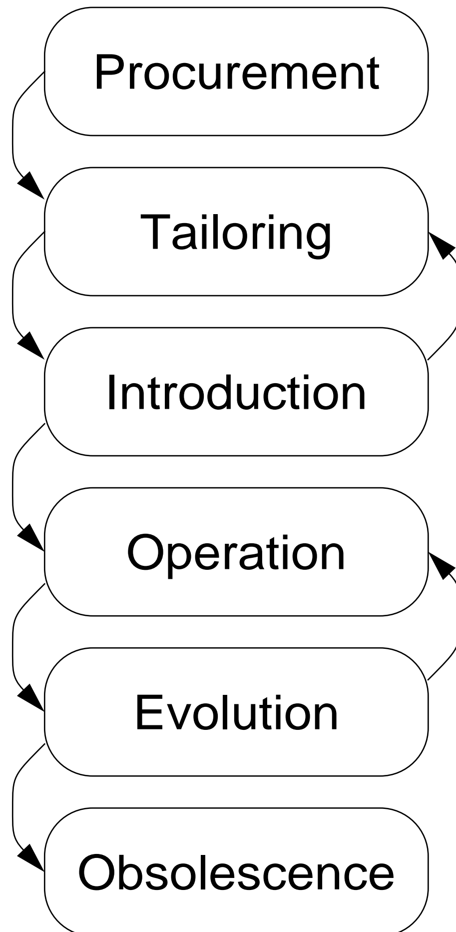


Integrated CASE

CASE systems can be integrated at various levels:(Wasserman 1990):

1. Platform integration
   - ☞ Tools run on the same hardware/operating system platform
2. Data integration
   - ☞ Tools operate using a shared data model
3. Presentation integration
   - ☞ Tools offer a common user interface
4. Control integration
   - ☞ Tools may activate and control the operation of other tools
5. Process integration
   - ☞ Tool usage is guided by an explicit process model and process engine

The CASE life cycle



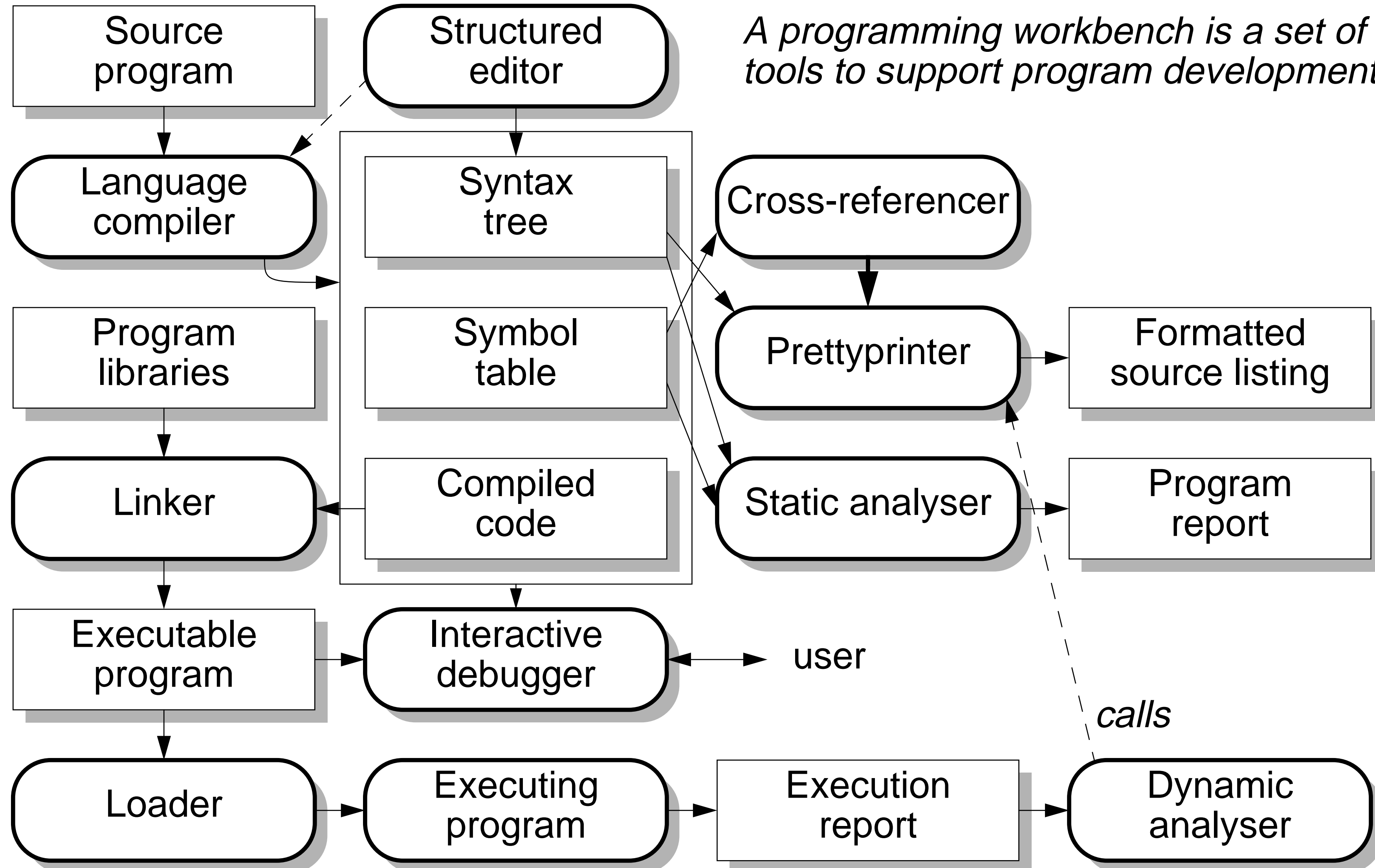
During CASE system *procurement*, current methods and standards, platform, application domain, security, and CASE system cost (including training and maintenance) must be considered.

CASE system *tailoring* involves installation, process model definition, tool integration, and documentation of the installation.

Introduction can be risky due to user resistance (CASE systems restrict freedom by imposing discipline), inadequate training, or even management resistance (changing tools and procedures increases risks for individual projects).

An *obsolete* CASE system cannot simply be scrapped, but must be phased out over a transition period.

Programming Workbenches



Static Program Analysers

Static program analysers scan the source code to detect possible faults and anomalies:

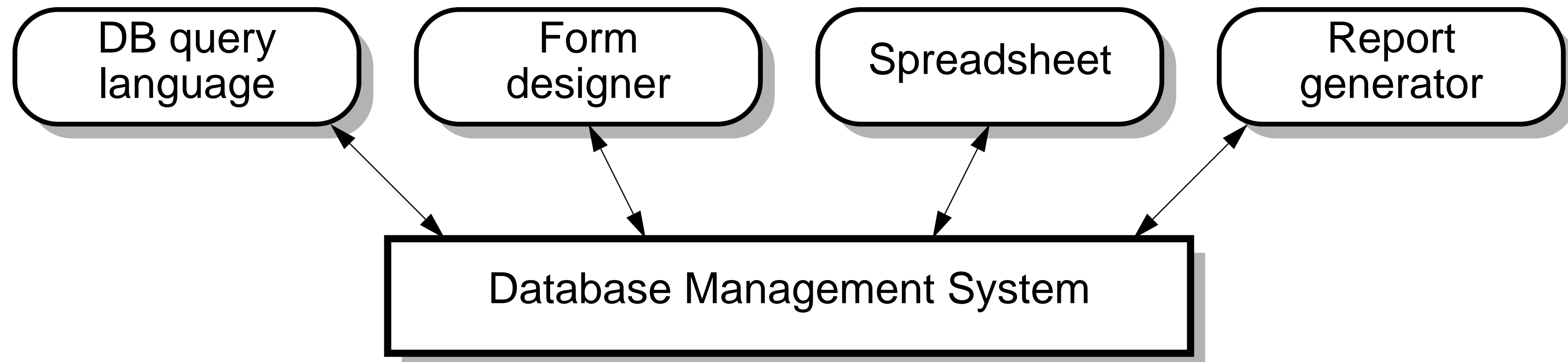
- ☞ Unreachable code
- ☞ Unconditional branches into loops
- ☞ Undeclared variables
- ☞ Variables used before initialization
- ☞ Variables declared and never used
- ☞ Variables written twice with no intervening assignment
- ☞ Parameter type mismatches
- ☞ Parameter number mismatches
- ☞ Uncalled functions and procedures
- ☞ Non-usage of function results
- ☞ Possible array bound violations
- ☞ Misuse of pointers

Stages of Static Analysis

1. Control flow analysis:
   - ☞ loops with multiple exit or entry points and unreachable code ...
2. Data use analysis:
   - ☞ use of uninitialized variables, declared but unused variables ...
3. Interface analysis:
   - ☞ consistency of procedure declarations and use, unused functions ...
4. Information flow analysis:
   - ☞ identifies dependencies of output variables on input
5. Path analysis:
   - ☞ identifies all possible paths through program

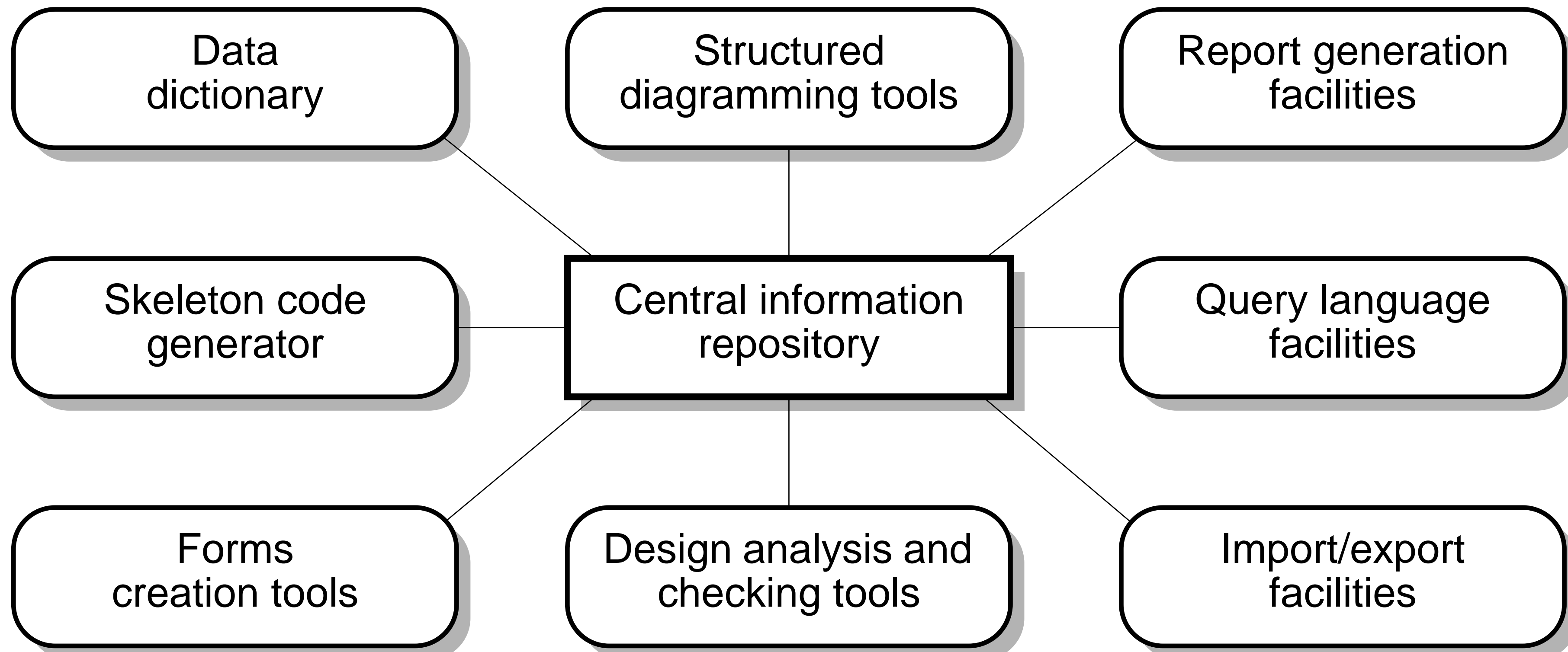
4GL Workbenches

A so-called “Fourth Generation Language” (4GL) is really a programming workbench for producing interactive applications that provide users with form and spreadsheet views on an underlying (relational) database.



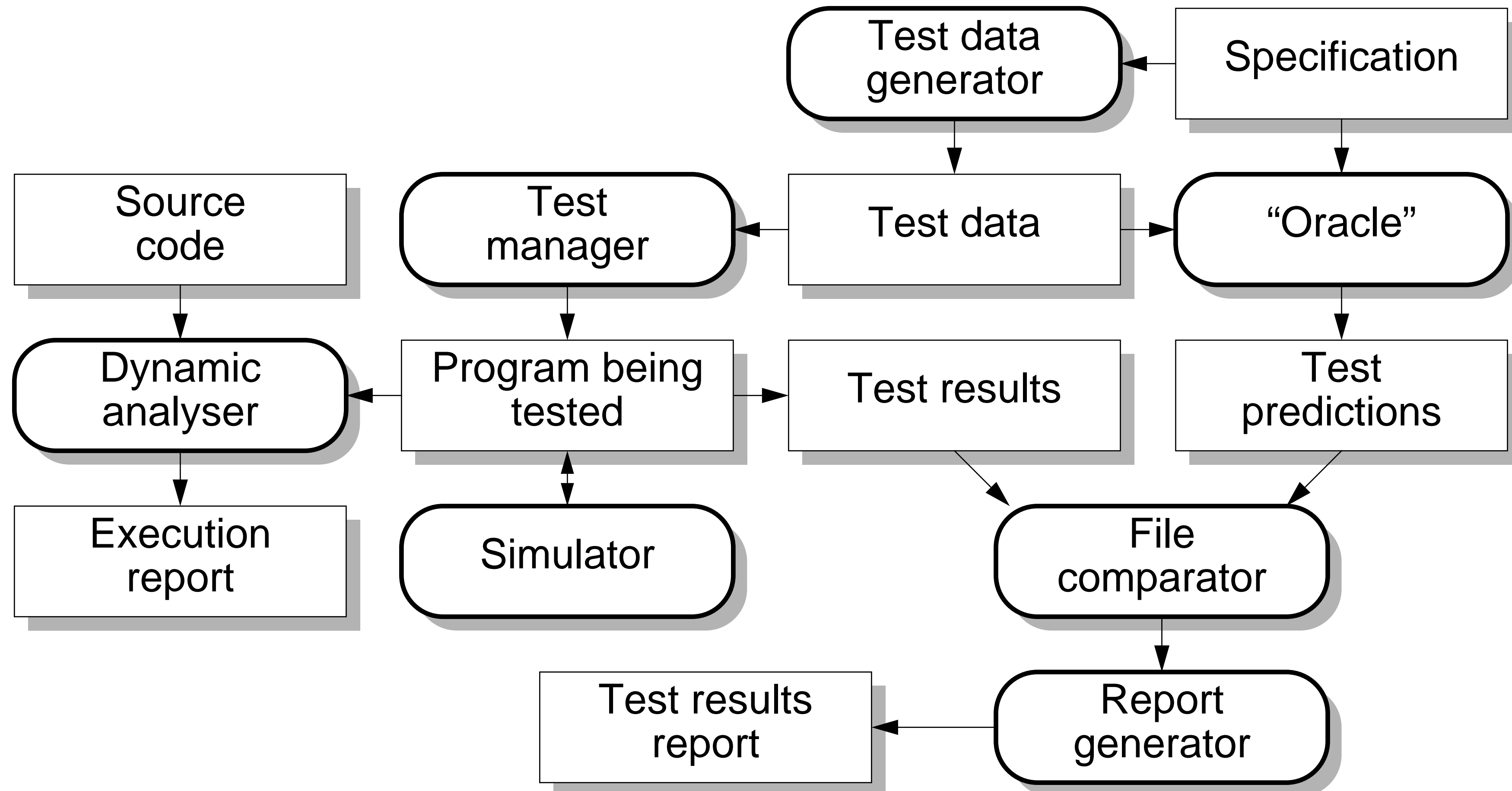
Analysis and Design Workbenches

Analysis and design workbenches support the *modelling* phases of the software process, usually by means of a graphical notation (e.g., dataflow, ER, UML etc.), and may or may not support a specific analysis and design method (e.g., JSD, Booch, etc.).



Testing Workbenches

Testing tends to be application and organization specific, so workbenches are typically developed in-house using standard tools.



Testing Tools

Test Data Generators:

- ☞ automatic generation of test inputs
- ☞ output analysis by “oracle” (i.e., prototype, parallel system, human)

File Comparators:

- ☞ automatically comparing old and new test results (e.g., UNIX “diff”)

Simulators:

- ☞ hardware — cost, availability, risk ...
- ☞ events — real-time, reproducibility, load ...

Dynamic Analysers:

- ☞ instrumentation statements are automatically added to program
- ☞ execution profiles are generated and analysed

Configuration Management Tools

Configuration management is concerned with the development of procedures and standards for managing an evolving software system product.

Tool examples:

Version Control — SCCS and RCS:

- ☞ check-out and check-in of components
- ☞ logging changes (who, where, when)
- ☞ changes converted to system “deltas” (can generate any version)
- ☞ “freezing” of versions as releases (possibly parallel ⇒ tree of versions)

System Building — Make:

- ☞ dependency specification
- ☞ rules for generation of intermediate files
- ☞ automatic re-generation of out-of-date files

Software Engineering Environments

A software engineering environment (SEE) is a set of hardware and software tools which can act in combination in an integrated way to provide support for the whole of the software process from initial specification through to testing and system delivery.

— Sommerville, 5th edn., p. 548

SEEs vs. CASEs:

- ❑ SEEs are fully integrated (all 5 levels)
- ❑ SEEs support development by teams and provide integrated configuration management
- ❑ SEEs support workbenches for a range of software development activities

Although there are presently no good examples of SEEs, the Portable Common Tool Environment (PCTE) has been widely adopted as a standard framework for SEEs ...

Summary

You should know the answers to these questions:

- ❑ What are the key features of a CASE environment?
- ❑ Which phases of the software lifecycle benefit from configuration management?
- ❑ In what different ways can CASE system be integrated?
- ❑ What are the risks in adopting a CASE system?
- ❑ What kinds of errors can be detected by static analysis?
- ❑ What is an “oracle” and how is it used?

Can you answer the following questions?

- ✎ *Why is the quality of tool support for project management not as good as for design and programming?*
- ✎ *Where does SNiFF+ fit into the CASE system classification?*
- ✎ *Is it better to use a single method A&D workbench or a multi-method one?*
- ✎ *Why is Meta-CASE technology not widely used?*
- ✎ *Why are there no good examples of SEEs in use?*

The 4GL-Component Framework **Delphi**

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What is Delphi?

- Delphi is a 4GL-object-oriented, visual programming environment for RAD Client/Server applications for Windows 95/NT.
- Delphi provides a library of reusable software components and several integrated development tools like experts.
- Delphi is (deceptively) easy to use. Within minutes, an advanced programmer can create real Windows applications.
- To write Delphi programs, it is not necessary to be a Windows programming expect, but at least one must be familiar with some fundamental Windows concepts.

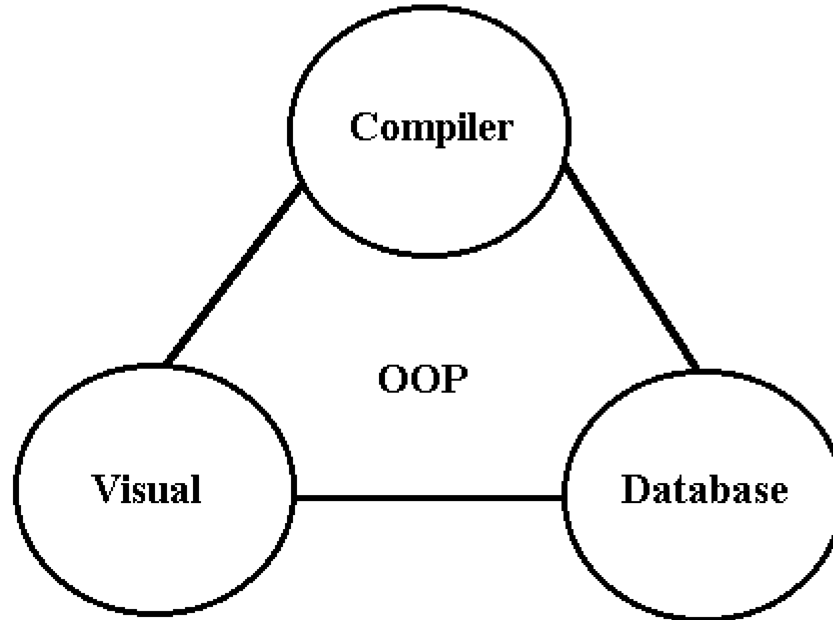
4GL-Environment

- A 4GL-environment integrates programming facilities, graphical user interfaces (GUI), and a database system in a single tool.
- The programming language used in these systems is usually object-oriented.
- The main purpose of these systems is to support application development for commercial problem domains as good as possible.
- A 4GL-environment is an end user tool that focuses on highest productivity.

Delphi - Goals and Objects

- Rapid Application Development environment for the Internet and Enterprise,
- Build large scale database solutions,
- Build high speed, native-code compiled, client and server applications for the Enterprise and the Internet,
- Reuse objects through-out the enterprise in a multi-tier environment.
- Simplifying distributed enterprise development through a one-step simultaneous support of COM and CORBA (Visibroker).

The environment

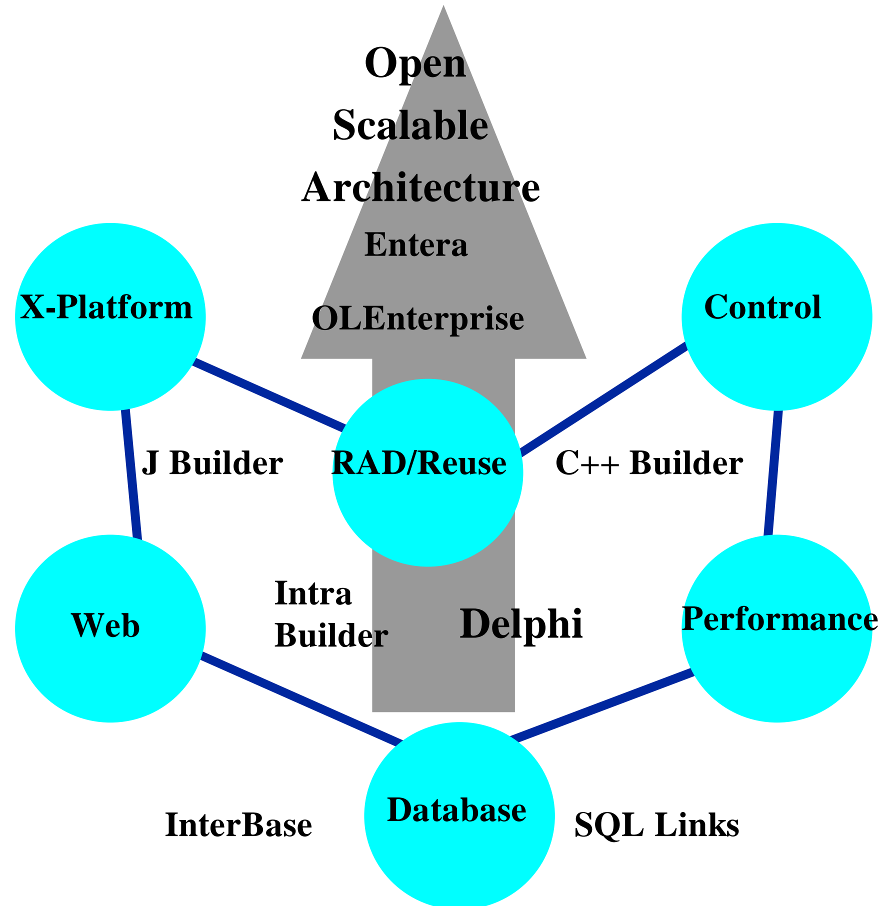


Delphi combines a RAD environment, high speed native code compiler, scalable database and reusable componentry to provide developer with the highest productivity.

The product family

JBuilder:
Scalable cross-platform web-applications

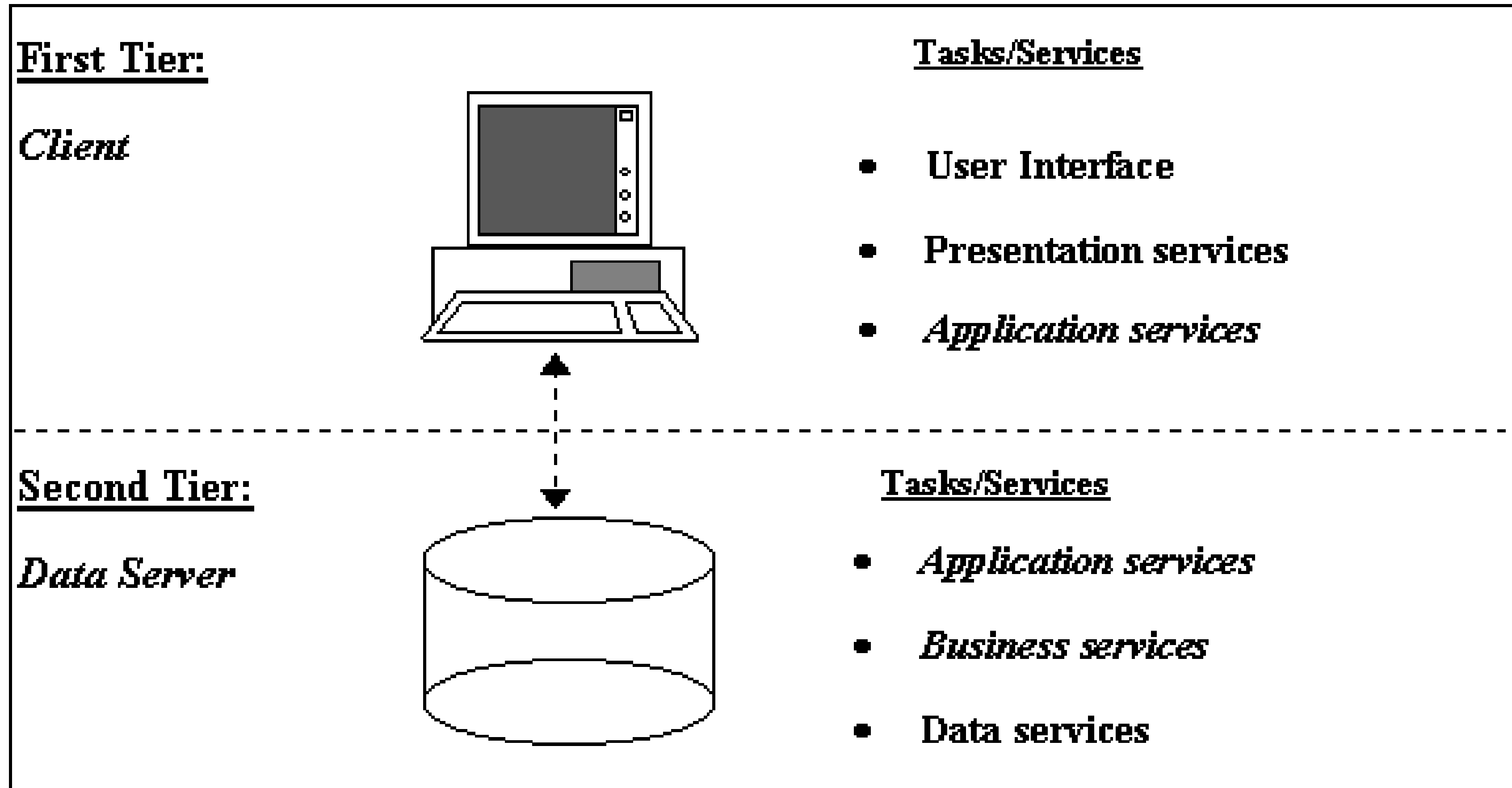
C++ Builder:
Critical business applications



Intra Builder:
Corporate Data-driven web-applications

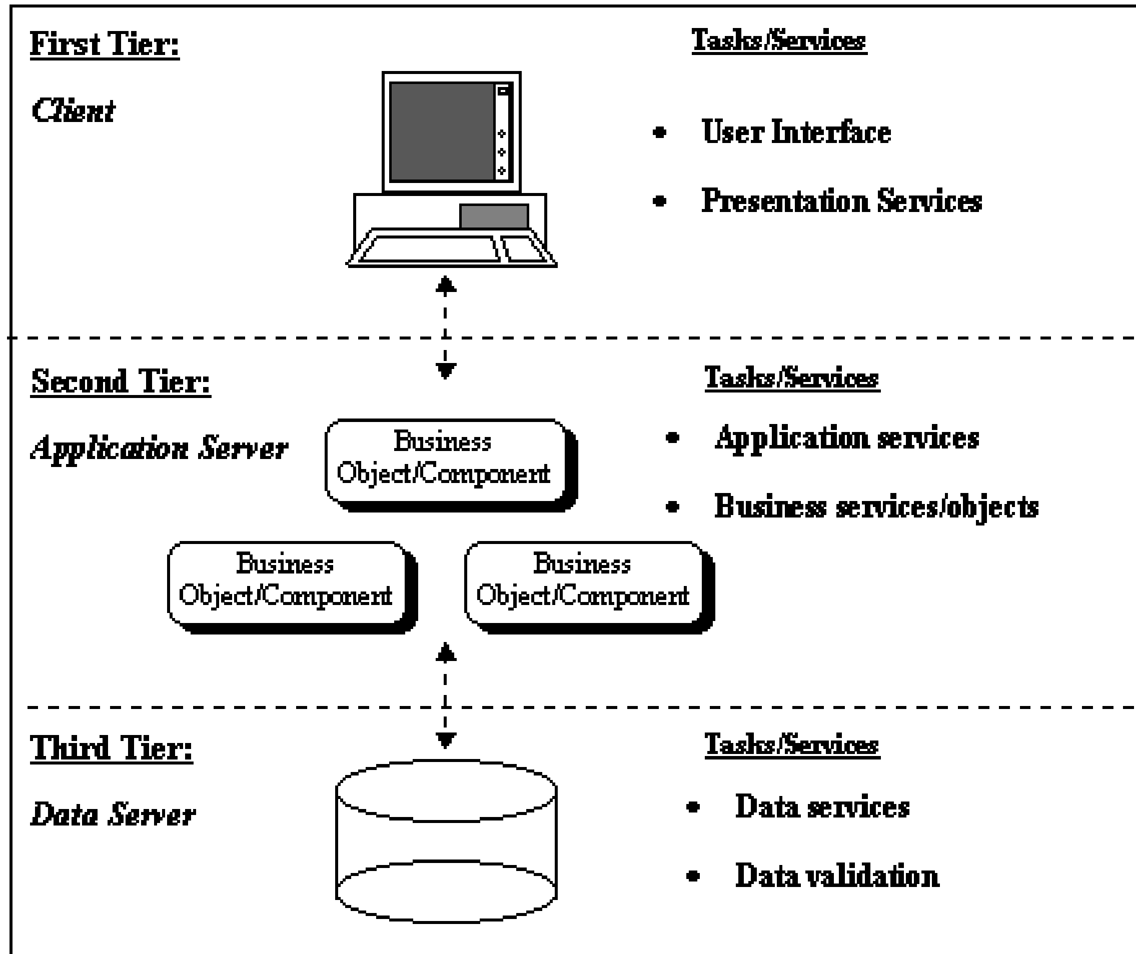
Delphi:
Scalable Windows applications

Two-tier Architecture



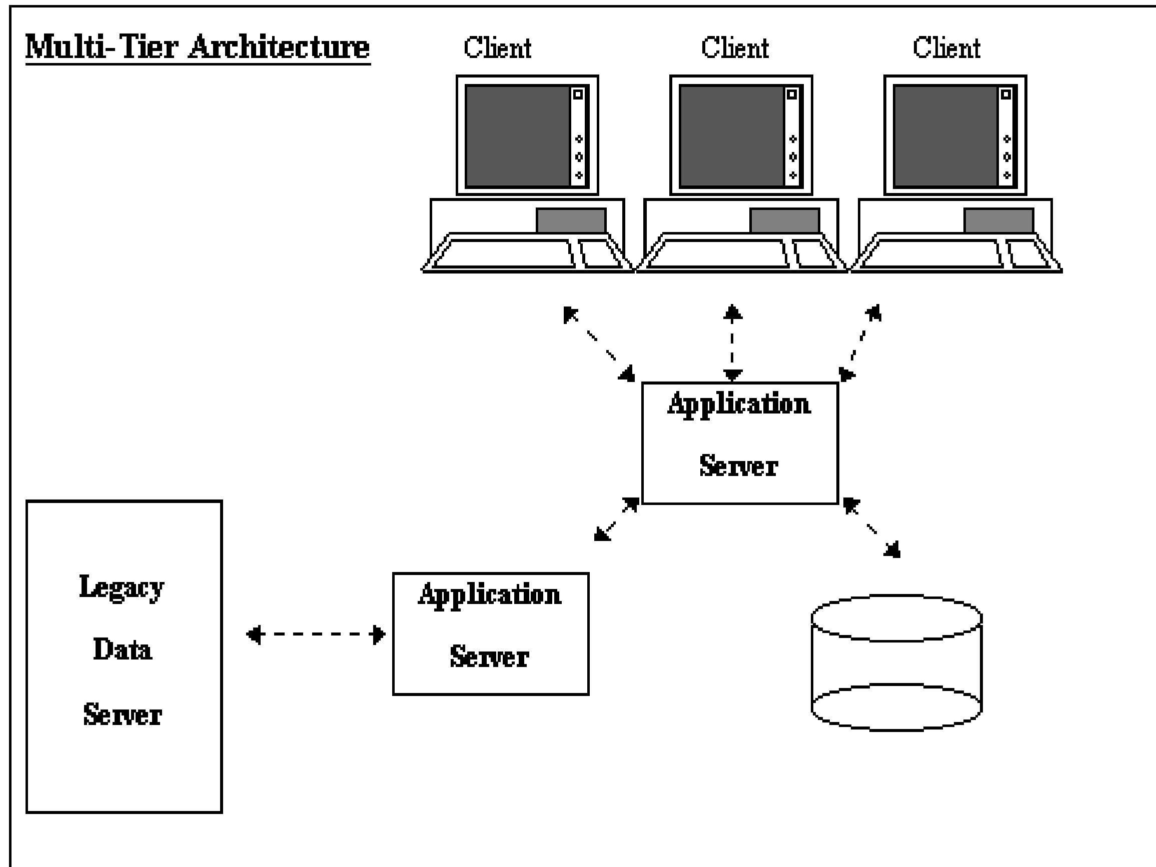
Provides basic separations of concerns.

Tree-tier Architecture



Offers a technology neutral method to develop client/server applications with vendors who employ standard interfaces which provide services for each logical tier.

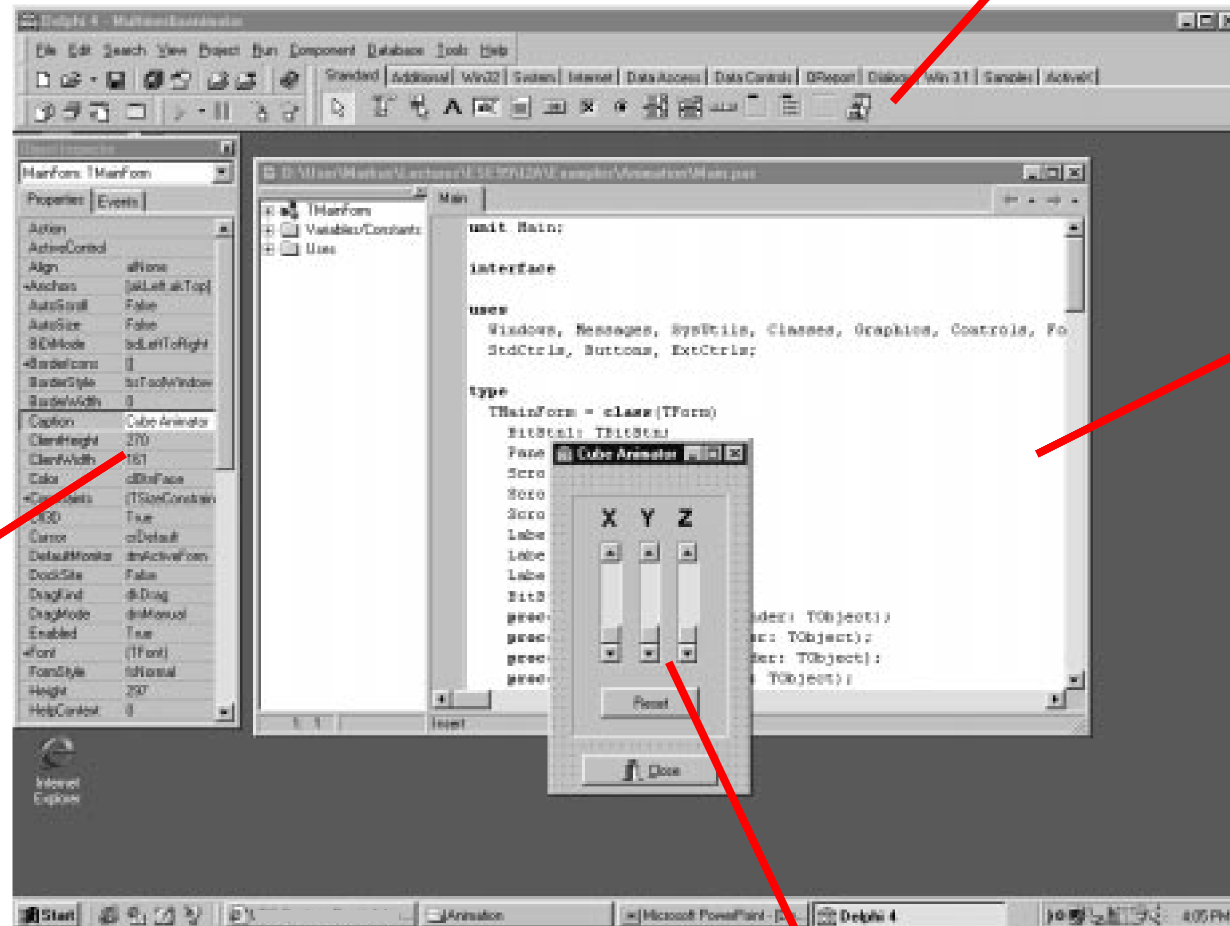
Multi-tier Architecture



A multi-tier, three-tier, or N-tier implementation employs a three-tier logical architecture superimposed on a distributed physical model. Application Servers can access other application servers in order to supply services to the client application as well as supply services for other application servers.

The Delphi IDE

Component Repository



Form
Editor

Object
Inspector

Application Form

Hello World

Steps:

- new application
- add label
- set alignment
- change font
- resize form
- run

Delphi Component Definition

- A component is an item that can be selected from the component palette and which can be manipulated by the form designer or the program code.
- A component is an object which class is derived from the class TComponent, TComponent defines the basic behaviour that must be fulfilled by every component.
- A component is an element which can be added to the Delphi environment. The complexity of a component can range from a simple extension of a standard component to a complex interface component for hard- and software.

Facts about Delphi

- Components + ObjectPascal = Application,
- Transparent integration of COM and CORBA components,
- Delphi components can easily be made a COM components,
- The JavaBeans model is derived from Delphi,
- Delphi has emerged a first component market.
- Delphi is a mixed-style programming environment; the user can or must use the textual or visual style of programming.
- Delphi components lack a binary standard like COM.

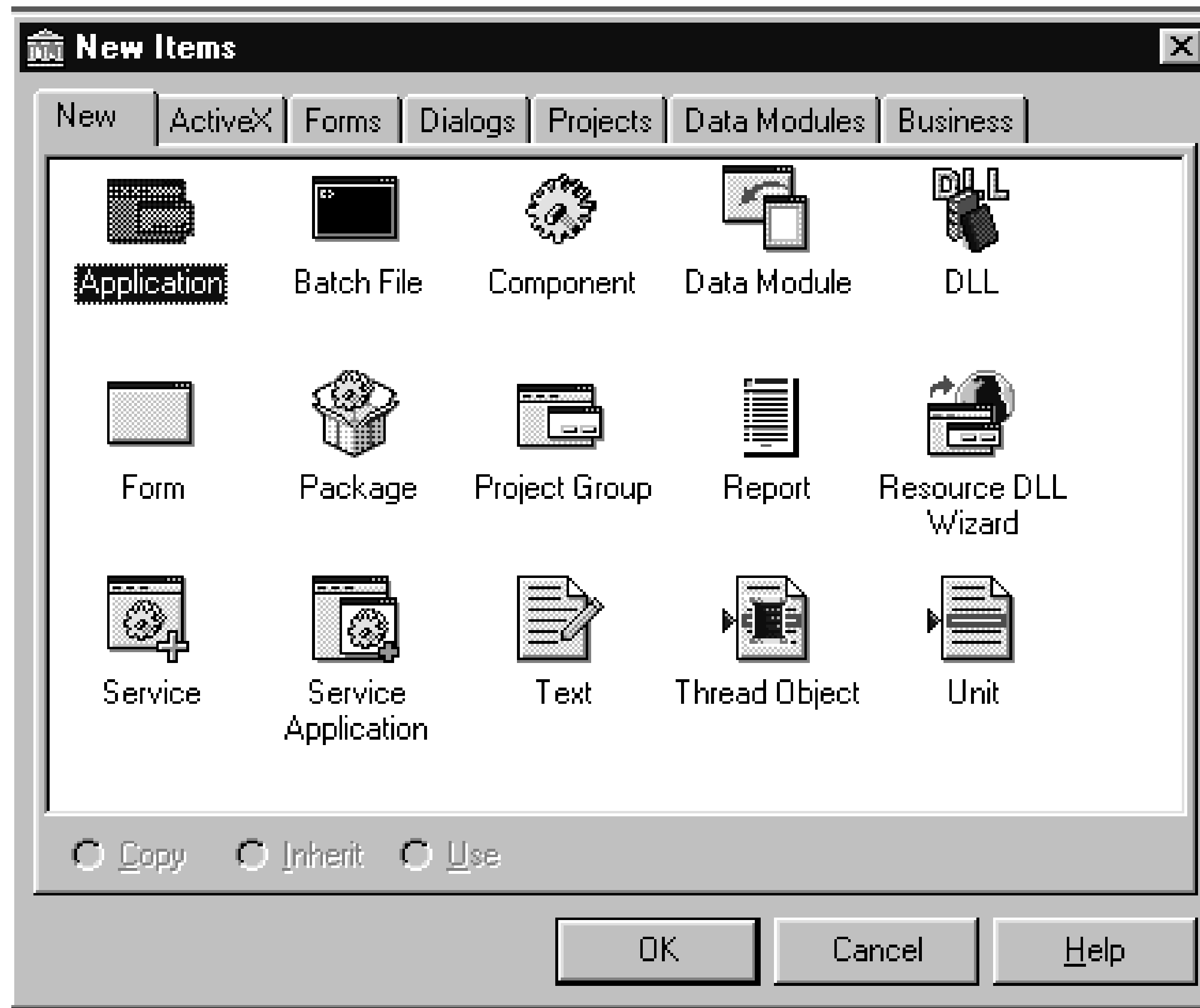
Working with Components

- All components are visible and configurable at design time.
- Visual components appear at runtime as designed.
- Non-visual components are invisible at runtime. These components provide a visual way of setting up properties.
- Only published properties can be changed at design time.
- Event handler provide a convenient way to add application specific code to your application.
- Understanding component properties and events is essential to effectively program with Delphi.

The Object Model

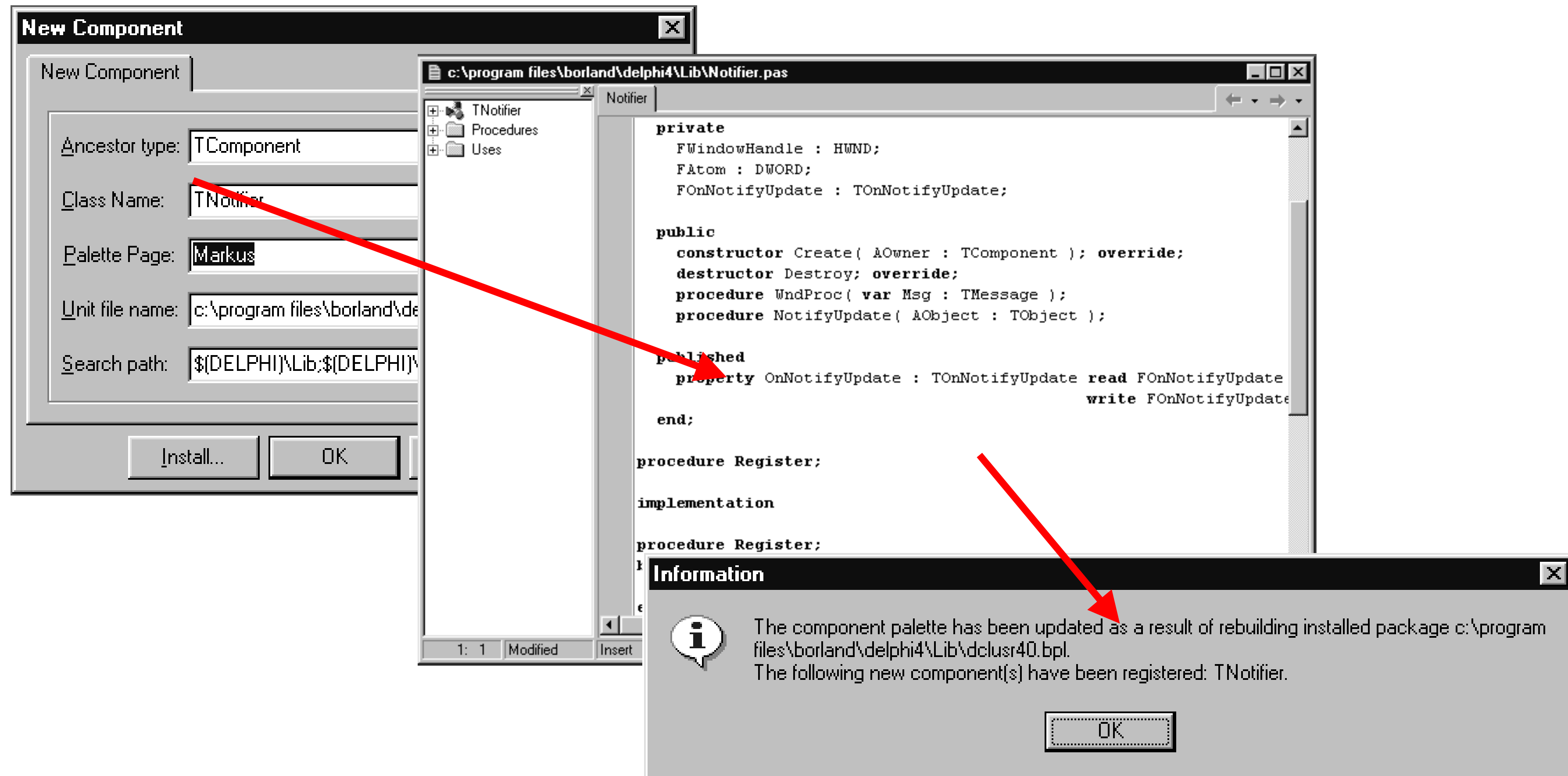
- The root class of every object is TObject.
- A class can have a private, protected, public, and published interface.
- The object model supports class-based features like class methods.
- Every object in Delphi is a dynamic instance - reference model.
- Delphi supports so-called method pointers.
- Type information is available at both design time and runtime.
- The object model provides a so-called property mechanism faking direct instance variable access.

Delphi's Object repository



Creating a new Component

- New component
- Implement component



- Test and install component

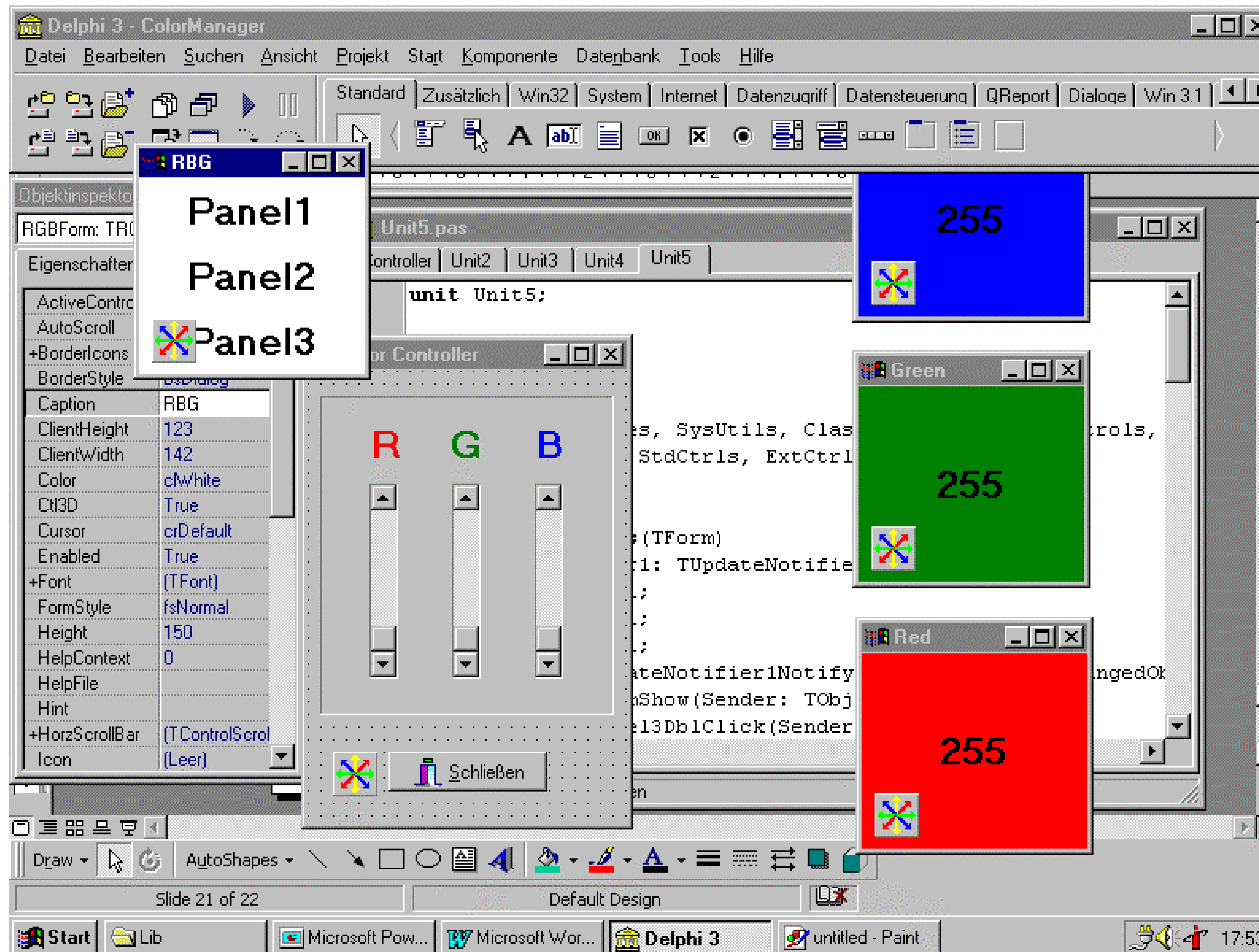
Publisher-Subscriber pattern I

```
TUpdateNotifier = class(TComponent)
private
  FWindowHandle : HWND;
  FAtom : DWORD;
  FOnNotifyUpdate : TOnNotifyUpdate;

public
  constructor Create( AOwner : TComponent ); override;
  destructor Destroy; override;
  procedure WndProc( var Msg : TMessage );
  procedure NotifyUpdate( AObject : TObject );

published
  property OnNotifyUpdate : TOnNotifyUpdate read FOnNotifyUpdate
                                            write FOnNotifyUpdate;
end;
```

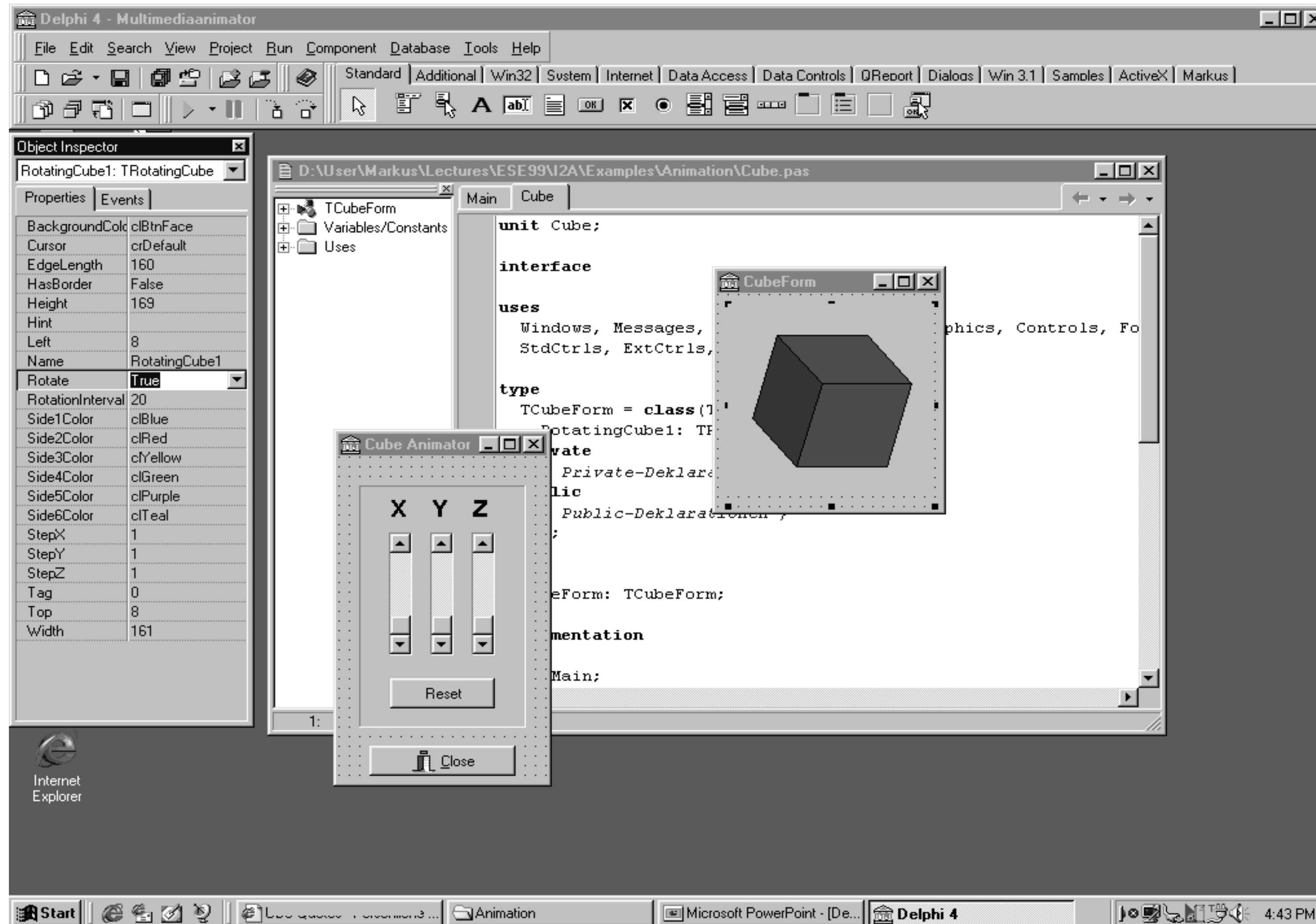
Publisher-Subscriber pattern II



Publisher-Subscriber pattern III

ColorManager

Rotating 3D Cube



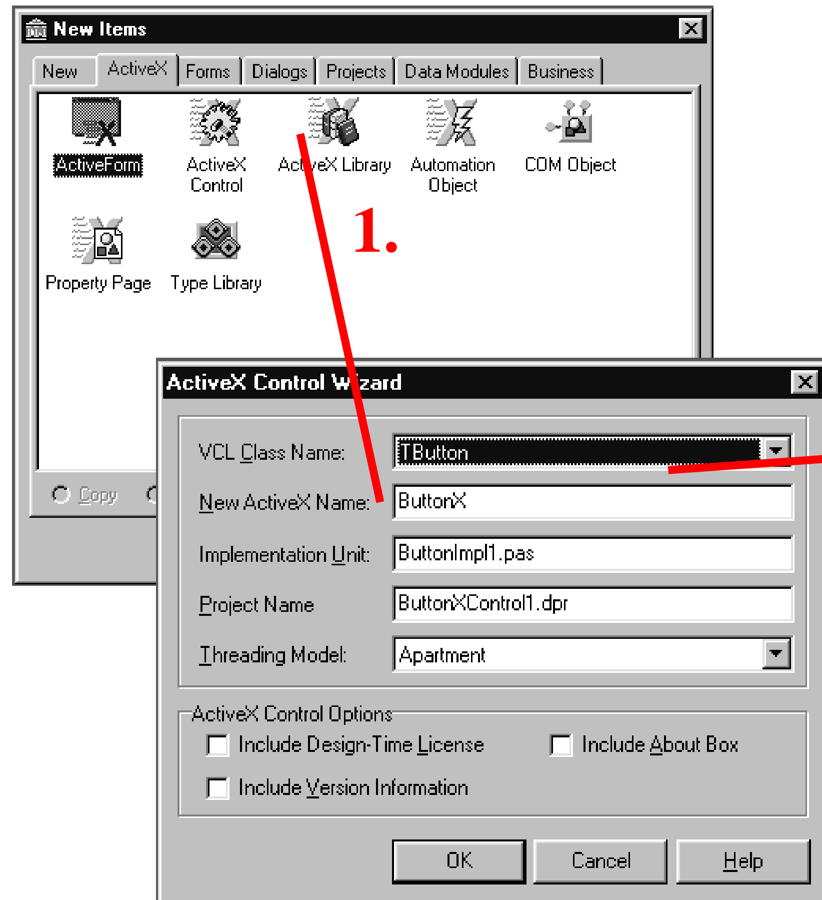
Rotating 3D Cube

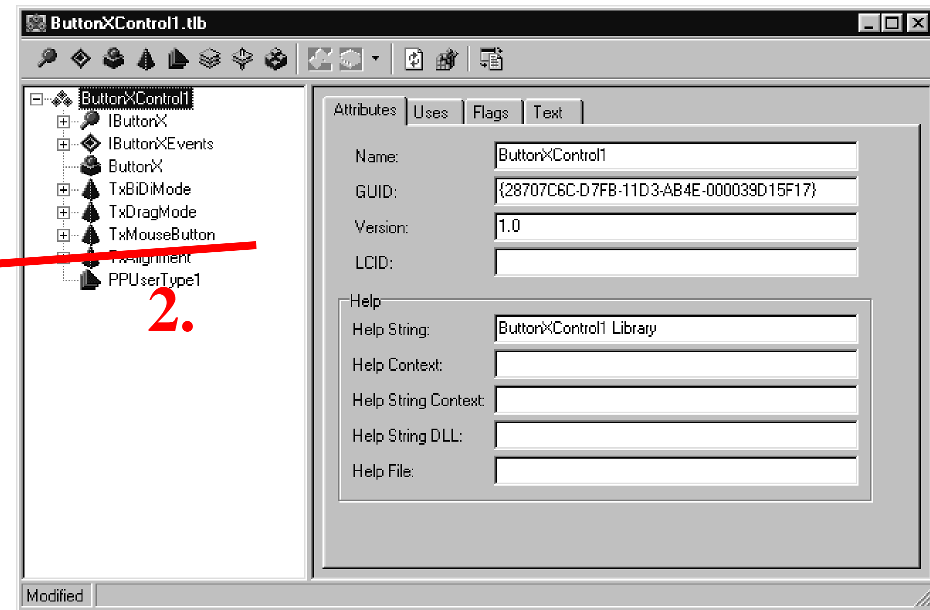
A rotating cube

One-Step ActiveX

New element:

Build-in COM support:



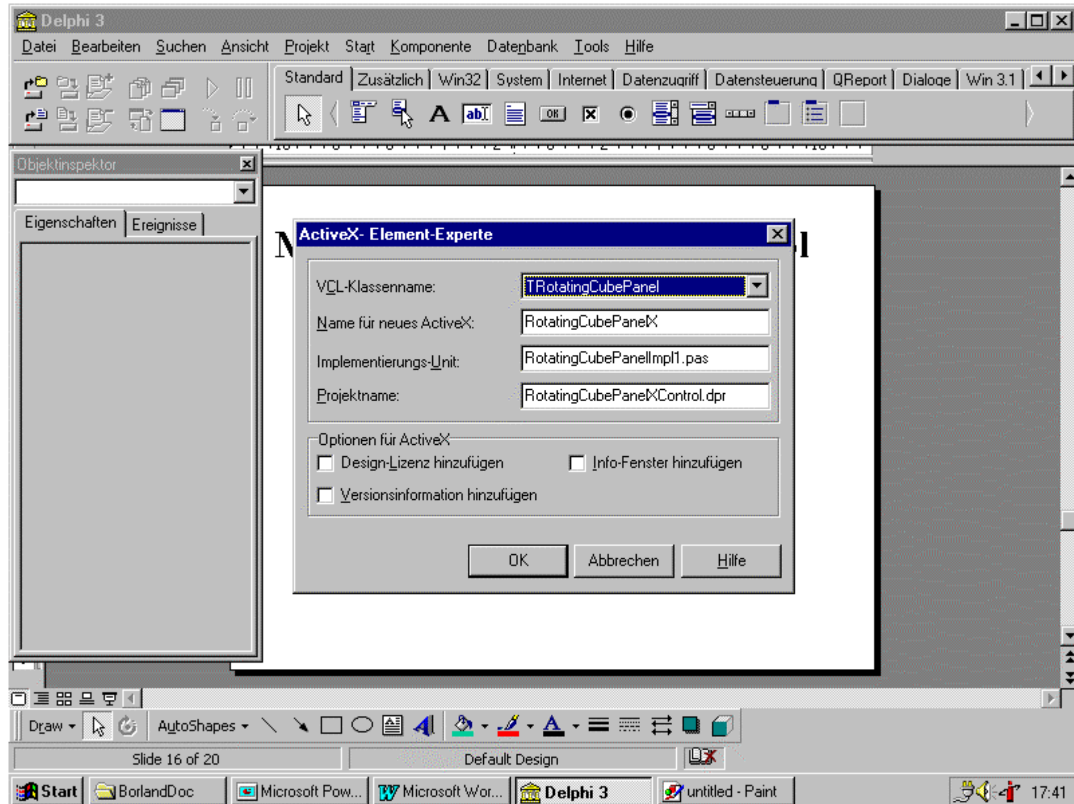


Derive from TWinControl

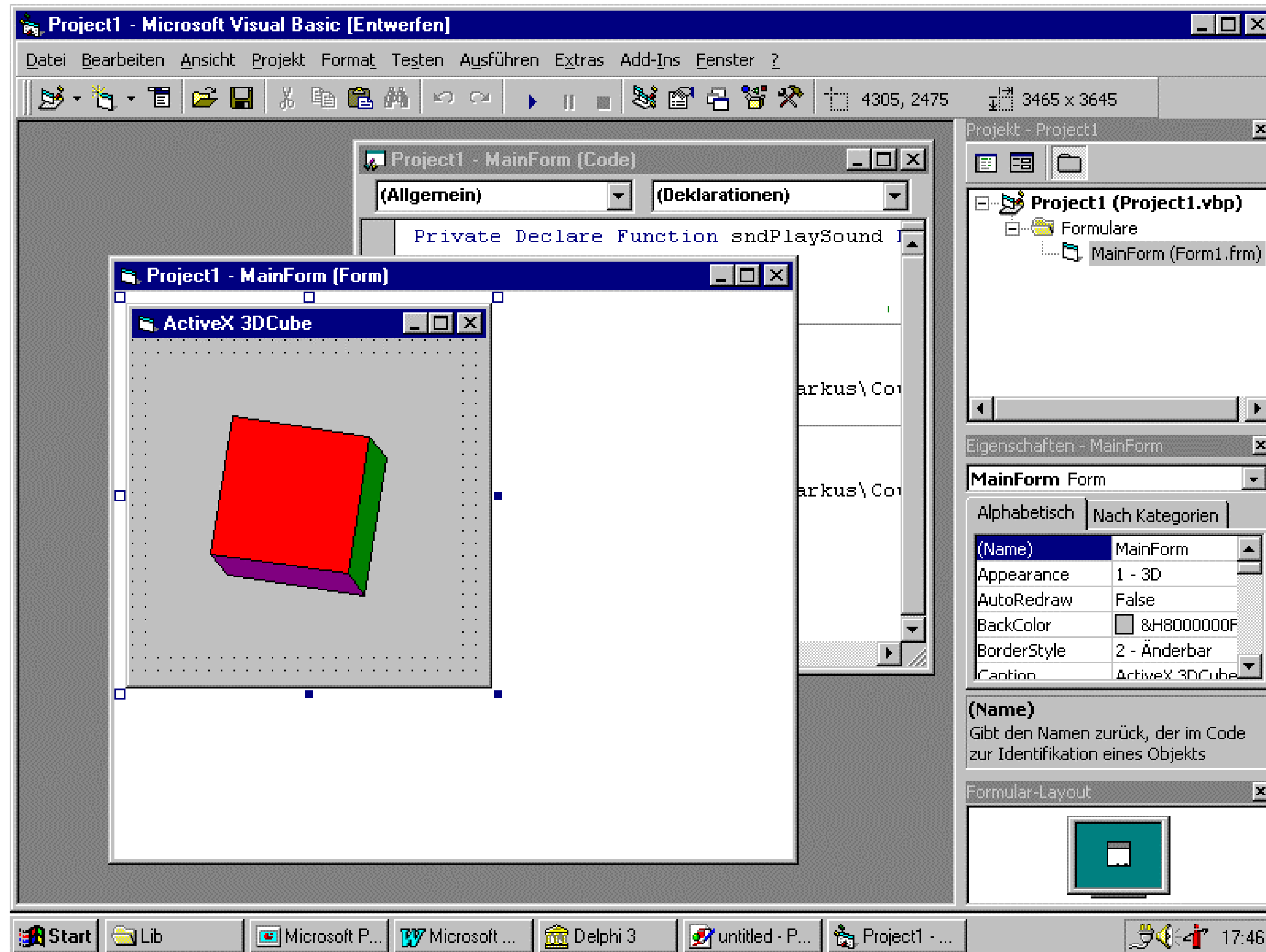
Make it into an ActiveX-control

Steps:

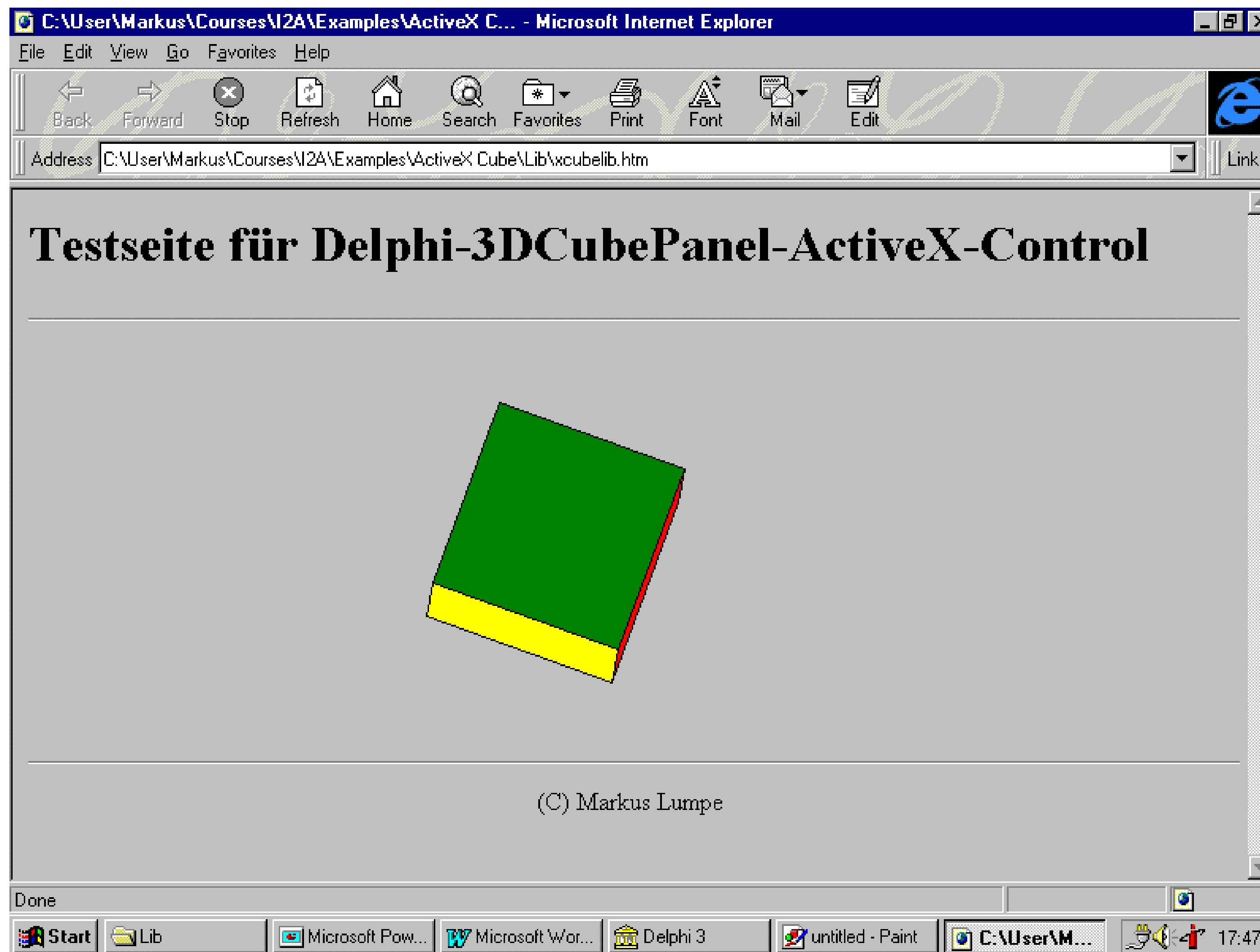
- Make cube component an window control
- Make new component a ActiveX-element
- Build OCX
- Register ActiveX-server



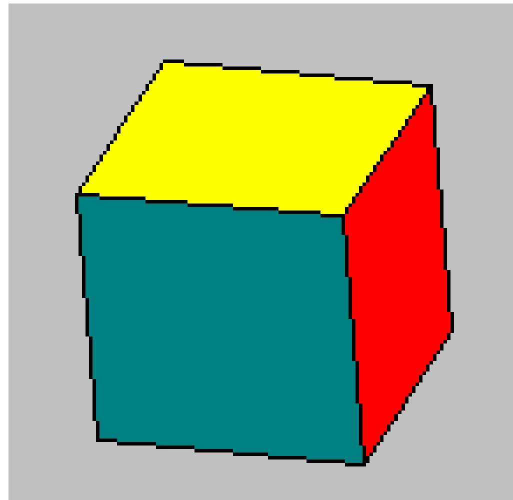
Use Delphi's ActiveX-control I



Use Delphi's ActiveX-control II



Use Delphi’s ActiveX-control III



What have you learned about Delphi?

- Delphi is a rapid application development environment,
- Delphi supports enterprise and internet client/server solutions,
- Delphi supports an open, scalable multi-tier architecture,
- Delphi provides support to create, manage, and deliver data over the web,
- Delphi provides support to create reusable objects,
- Delphi provides support to graphically display of any kind of data,
- Delphi supports one-step COM and CORBA development.

Questions