ESE

Einführung in Software Engineering

Prof. O. Nierstrasz

Wintersemester 2001/2002

Table of Contents

1. ESE — Einführung in Software Engineering

Lecturer	Prof. Oscar Nierstrasz Oscar.Nierstrasz@iam.unibe.ch Schützenmattstr. 14/103, Tel.631.4618
Assistants	Michele Lanza, Tel. 631.4868 Michael Locher, Mauricio Seeberger
Lectures	ExWi B7, Wednesdays @ 14h15-16h00
WWW	www.iam.unibe.ch/~scg/Teaching/ESE/

Principle Texts

- *Software Engineering*, I. Sommerville, Addison-Wesley, Sixth Edn., 2000.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Fourth Edn., 1997.
- *Designing Object-Oriented Software*, R. Wirfs-Brock, B. Wilkerson, L. Wiener, Prentice Hall, 1990.

Selected material courtesy of Prof. Serge Demeyer

Other Books

- *The Mythical Man-Month*, F. Brooks, Addison-Wesley, Anniversary Edition 1995.
- *Object-Oriented Software Construction*, B. Meyer, Prentice Hall, Second Edn., 1997.
- UML Distilled, M. Fowler with K. Scott, Addison Wesley, Second Edition, 2000
- *Objects, Components and Frameworks with UML*, D. D'Souza, A. Wills, Addison-Wesley, 1999
- *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

Schedule

1.	10 - 24	Introduction — The Software Lifecycle
2.	10 - 31	Project Management
3.	11 - 07	Requirements Collection
4.	11 - 14	Responsibility-Driven Design
5.	11 - 21	Detailed Design
6.	11 - 28	Modeling Objects and Classes
7.	12 - 05	Modeling Behaviour
8.	12 - 12	Software Architecture
9.	12 - 19	User Interface Design
10.	01 - 09	Software Validation
11.	01 - 16	Software Quality
12.	01 - 23	Software Metrics
13.	02 - 30	TBA ...
14.	02 - 06	*Final Exam*

Why Software Engineering?

A naive view: Problem Specification —*coding*→ Final Program

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?

What is Software Engineering? (I)

Some Definitions and Issues

"state of the art of developing quality software on time and within budget"

- Trade-off between perfection and physical constraints
  - ☞ SE has to deal with real-world issues
- State of the art!
  - ☞ Community decides on "best practice" + life-long education

What is Software Engineering? (II)

"multi-person construction of multi-version software"

— Parnas

- Team-work
  - ☞ Scale issue ("program well" is not enough) + Communication Issue
- Successful software systems must evolve or perish
  - ☞ Change is the norm, not the exception

What is Software Engineering? (III)

"software engineering is different from other engineering disciplines"

— Sommerville

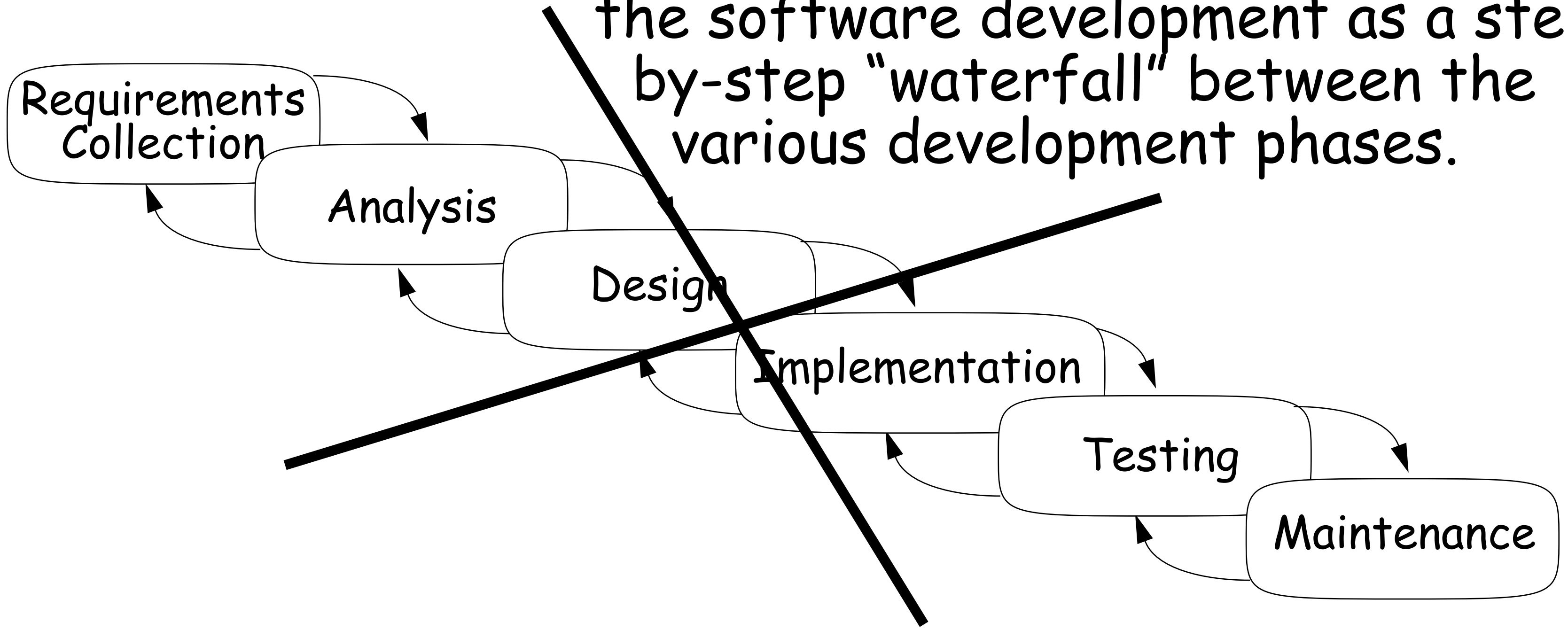
- Not constrained by physical laws
  - ☞ limit = human mind
- It is constrained by political forces
  - ☞ balancing stake-holders

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

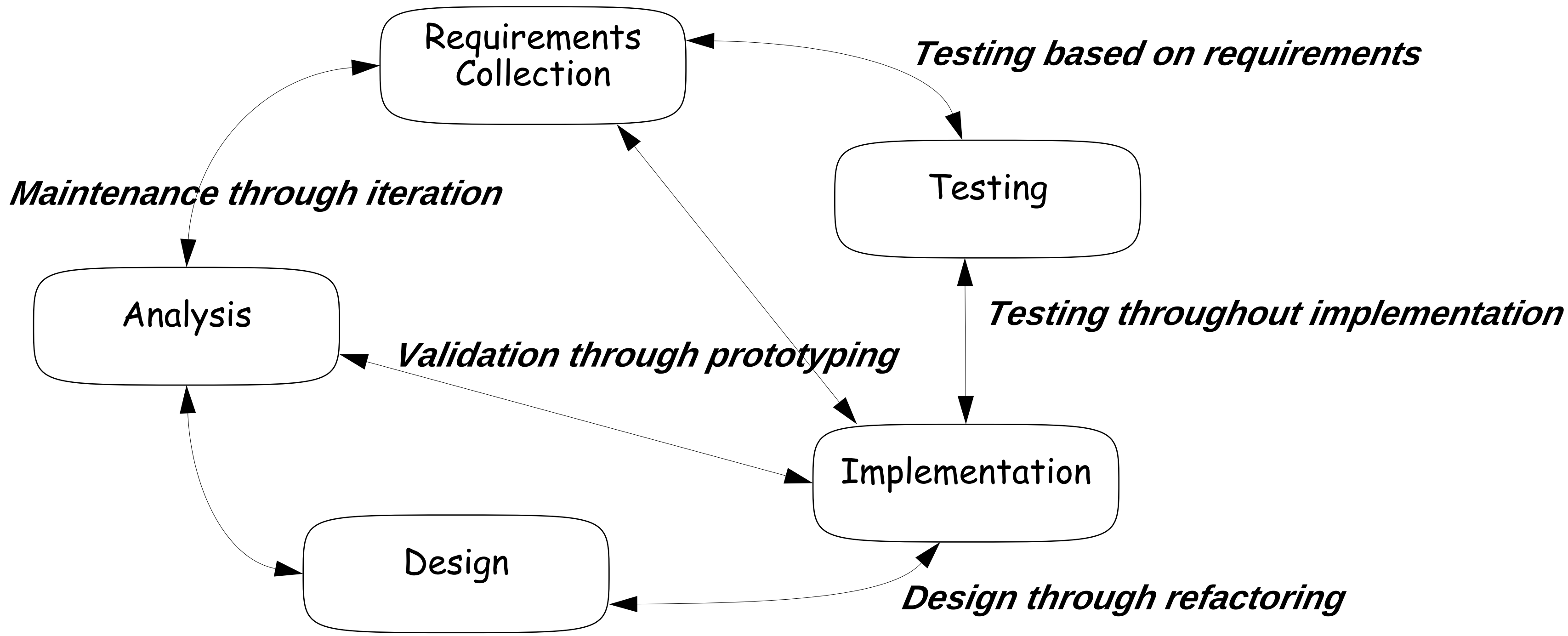
Problems with the Software Lifecycle

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.

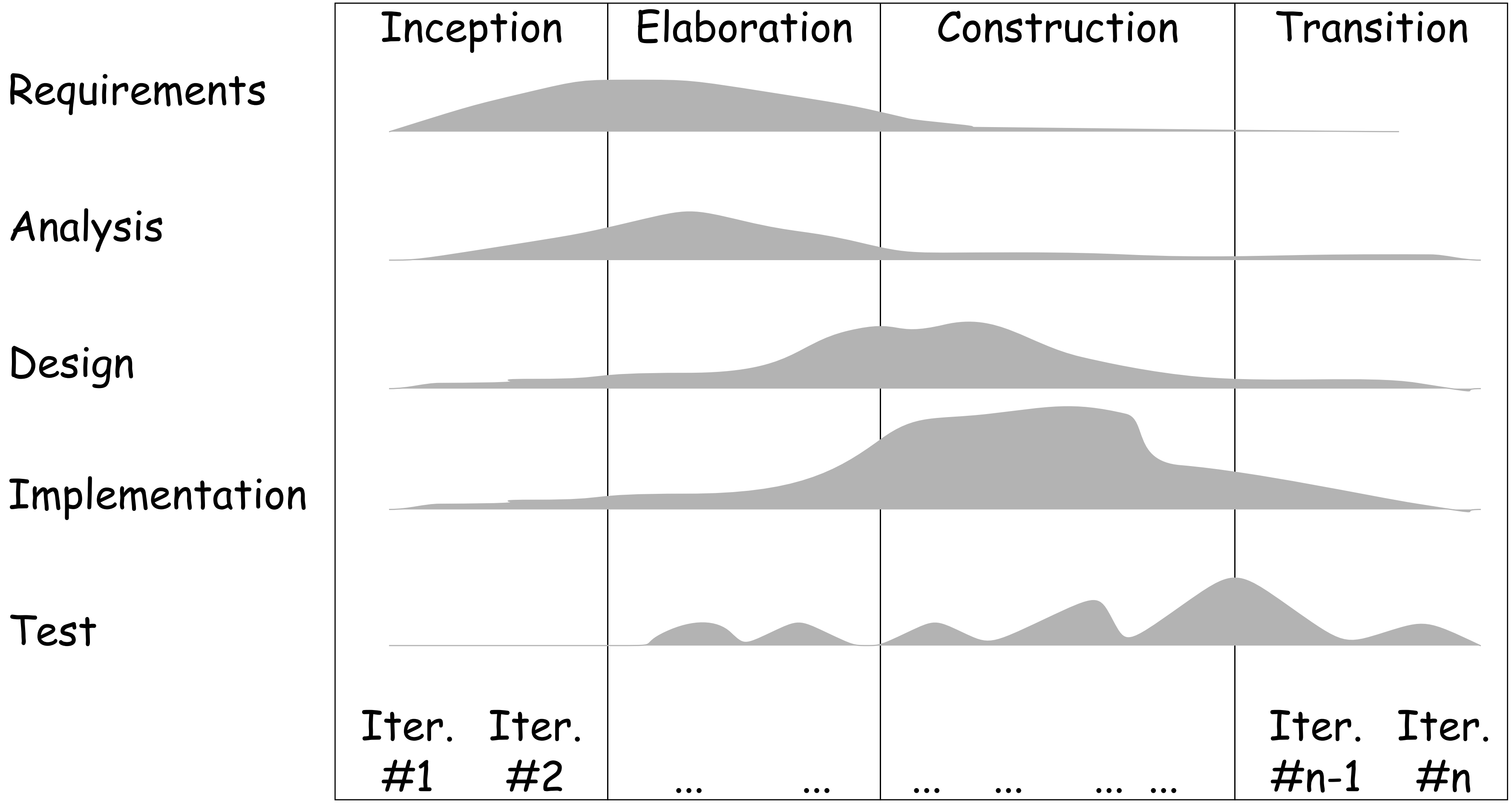
The later in the lifecycle errors are discovered, the more expensive they are to fix!

Iterative and Incremental Development

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.

The Unified Process

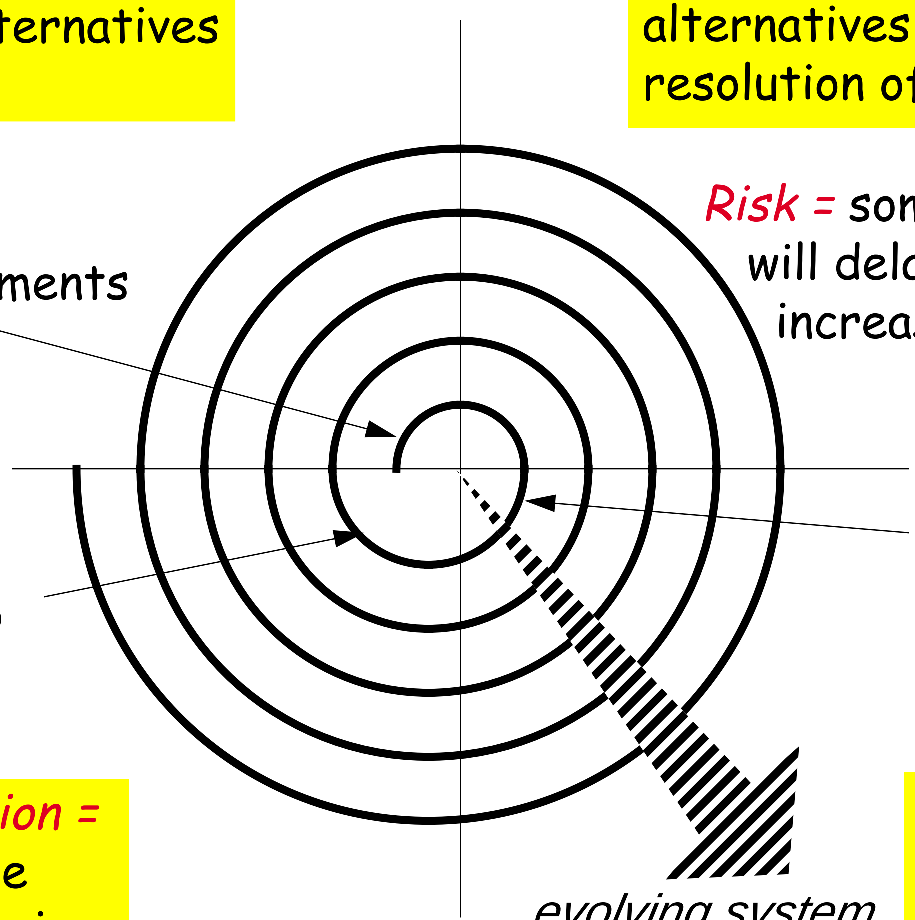


How do you plan the number of iterations?
How do you decide on completion?

Boehm's Spiral Lifecycle

Planning = determination of objectives, alternatives and constraints

Risk Analysis = Analysis of alternatives and identification/ resolution of risks



Customer Evaluation = Assessment of the results of engineering

Engineering = Development of the "next level" product

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*.

Changing requirements

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*.

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

Object-Oriented Analysis

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

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

Prototyping (I)

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

Prototyping (II)

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* and *operations* associated to 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

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
- ❑ Testing and implementation go hand-in-hand
  - ☞ Ideally, test case specification *precedes* design and implementation

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 activities

"Maintenance" entails:

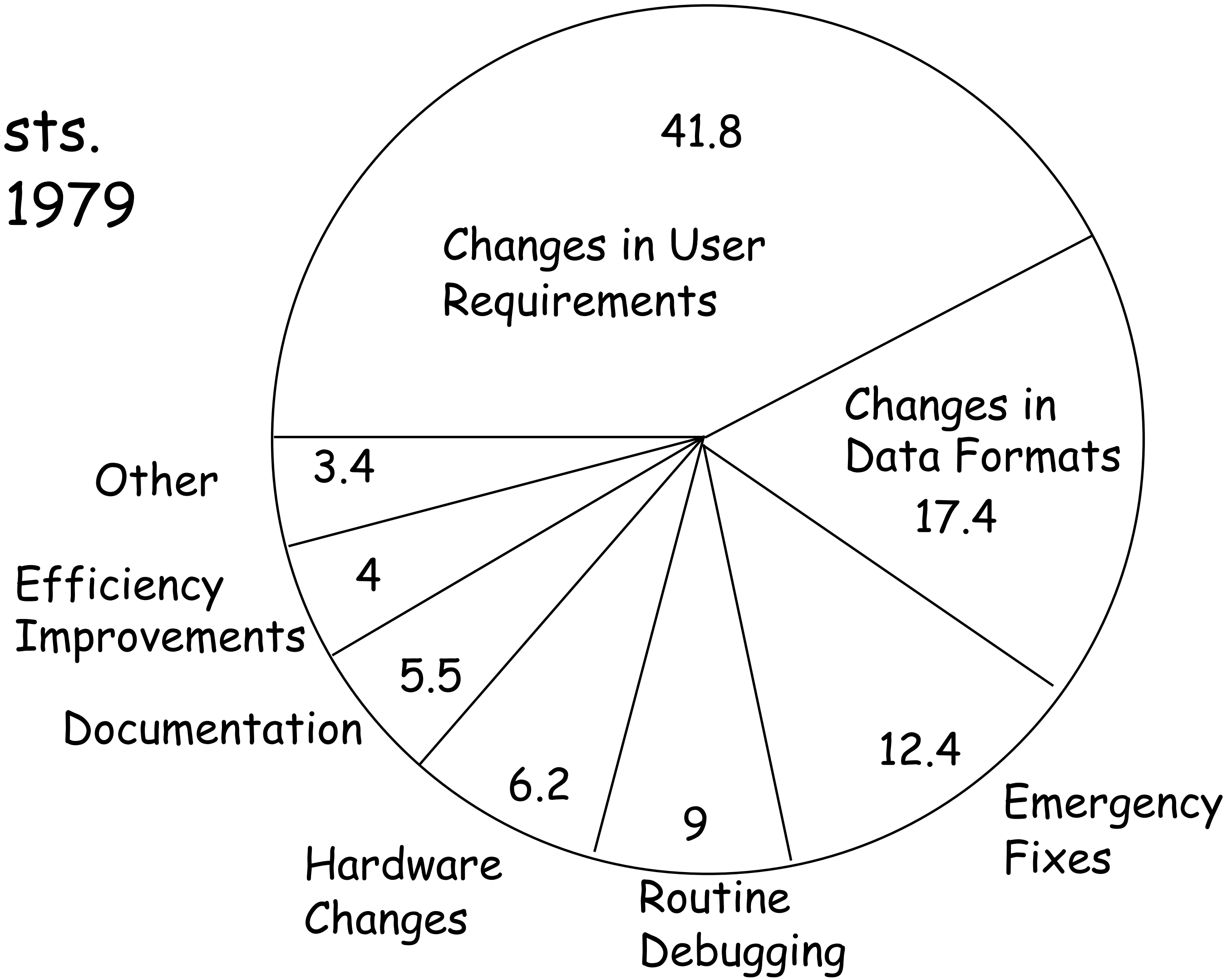
- configuration and version management
- reengineering (redesigning and refactoring)
- updating all analysis, design and user documentation

Repeatable, automated tests enable evolution and refactoring

Maintenance costs

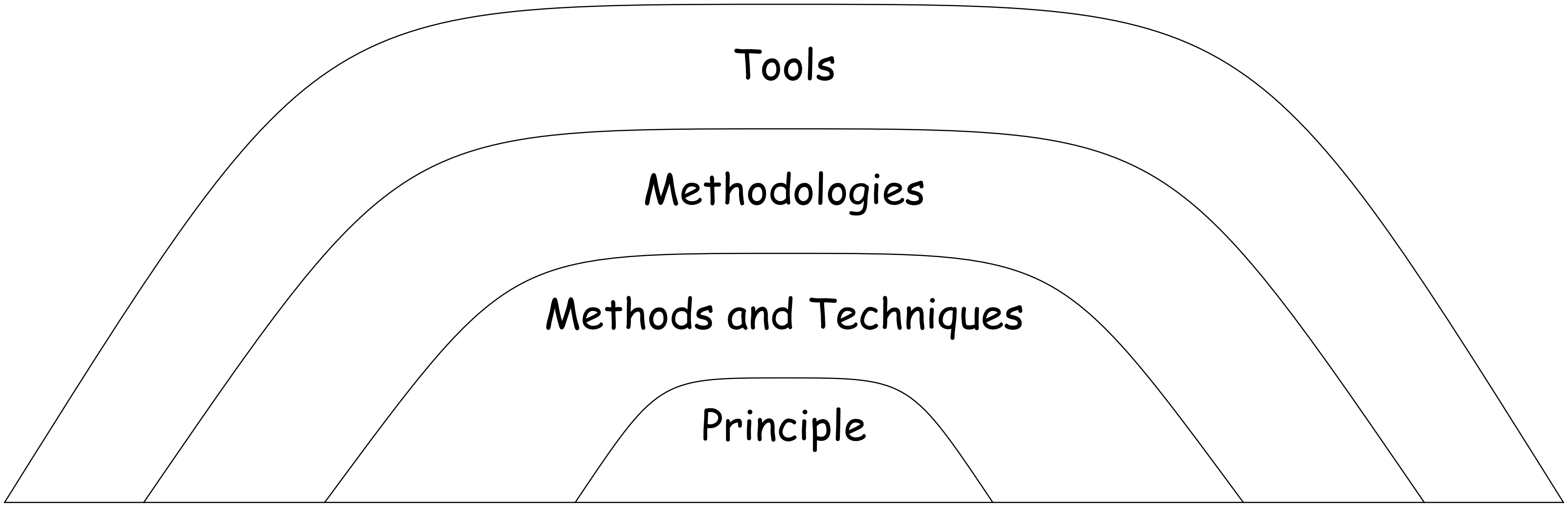
Breakdown of maintenance costs.

Source: Lientz 1979



Methods and Methodologies

Principle = general statement describing desirable properties
Method = general guidelines governing some activity
Technique = more technical and mechanical than method
Methodology = package of methods and techniques packaged



— *Ghezzi et al. 1991*

Object-Oriented Methods: a brief history

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 + ...
  - various UML-based methods (e.g. Catalysis)

What you should know!

- 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 these questions?

- What is the appeal of the “waterfall” model?
- 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:

- Risk management
- Scoping and estimation, planning and scheduling
- Dealing with delays
- Staffing, directing, teamwork

Sources:

- *Software Engineering*, I. Sommerville, Addison-Wesley, Sixth Edn., 2000.
- *Software Engineering — A Practitioner's Approach*, R. Pressman, Mc-Graw Hill, Third Edn., 1994.

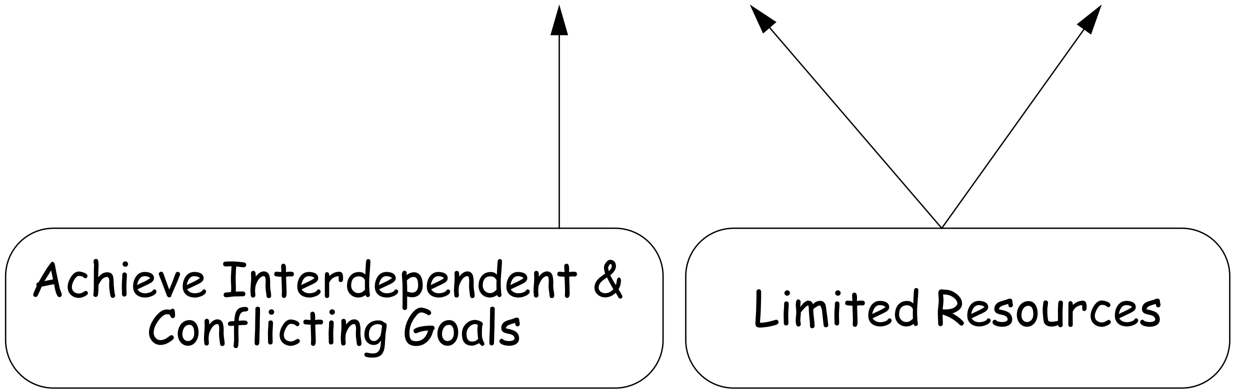
Recommended Reading

- *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, Addison Wesley, 1999

Why Project Management?

Almost all software products are obtained via *projects*.
(as opposed to manufactured products)

Project Concern = Deliver on time and within budget



The Project Team is the primary Resource!

What is Project Management?

Project Management = Plan the work and work the plan

Management Functions

- **Planning**: Estimate and schedule *resources*
- **Organization**: *Who* does *what*
- **Staffing**: *Recruiting* and *motivating* personnel
- **Directing**: Ensure team *acts as a whole*
- **Monitoring** (Controlling): Detect plan *deviations* + *corrective actions*

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 ...

Risk Management ..

Management must:

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

Risk Management Techniques

Risk Items	*Risk Management Techniques*
Personnel *shortfalls*	Staffing with top talent; *team building*; cross-training; pre-scheduling key people
Unrealistic schedules and budgets	Detailed multi-source cost & schedule estimation; *incremental development*; reuse; re-scoping
Developing the *wrong* software functions	User-surveys; *prototyping*; early users's manuals
Continuing stream of *requirements changes*	High change threshold; information hiding; *incremental development*

Risk Items	*Risk Management Techniques*
Real time *performance* shortfalls	Simulation; benchmarking; modeling; prototyping; *instrumentation*; *tuning*
Straining computer science *capabilities*	Technical analysis; cost-benefit analysis; *prototyping*; reference checking

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

Myth: 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.

Scope and Objectives

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*

Estimation Strategies

These strategies are simple but risky:

Expert judgement	*Consult* experts and *compare* estimates ☞ cheap, but unreliable
Estimation by analogy	*Compare* with *other projects* in the same application domain ☞ limited applicability
Parkinson's Law	Work expands to fill the *time available* ☞ pessimistic management strategy
Pricing to win	You *do what you can* with the budget available ☞ requires trust between parties

Estimation Techniques

"Decomposition" and "Algorithmic cost modeling" are used together

Decomposition	Estimate costs for *components* + *integration* ☞ top-down or bottom-up estimation
Algorithmic cost modeling	Exploit *database* of historical facts to map size on costs ☞ requires correlation data

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*

   ☞ else ask the customers to split/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 ask to reduce scope, customers complain some more but reduce scope anyway)

Planning and Scheduling

Good planning depends largely on project manager's intuition and experience!

- *Split* project into *tasks*.
  - ☞ Tasks into subtasks etc.
- For each task, *estimate* the *time*.
  - ☞ Define tasks small enough for reliable estimation.
- Significant tasks should end with a *milestone.*
  - ☞ *Milestone* = A verifiable goal that must be met after task completion
  - ☞ Clear unambiguous milestones are a necessity! ("80% coding finished" is a meaningless statement)
  - ☞ *Monitor* progress via *milestones*

...

Planning and Scheduling ...

- *Define dependencies* between project tasks
  - ☞ Total time depends on longest (= critical) path in activity graph
  - ☞ *Minimize* task *dependencies* to avoid delays
- *Organize* tasks *concurrently* to make optimal use of workforce

Planning is *iterative*

$\Rightarrow$ *monitor* and *revise* schedules during the project!

Myth: Deliverables and Milestones

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.

Deliverables and Milestones

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

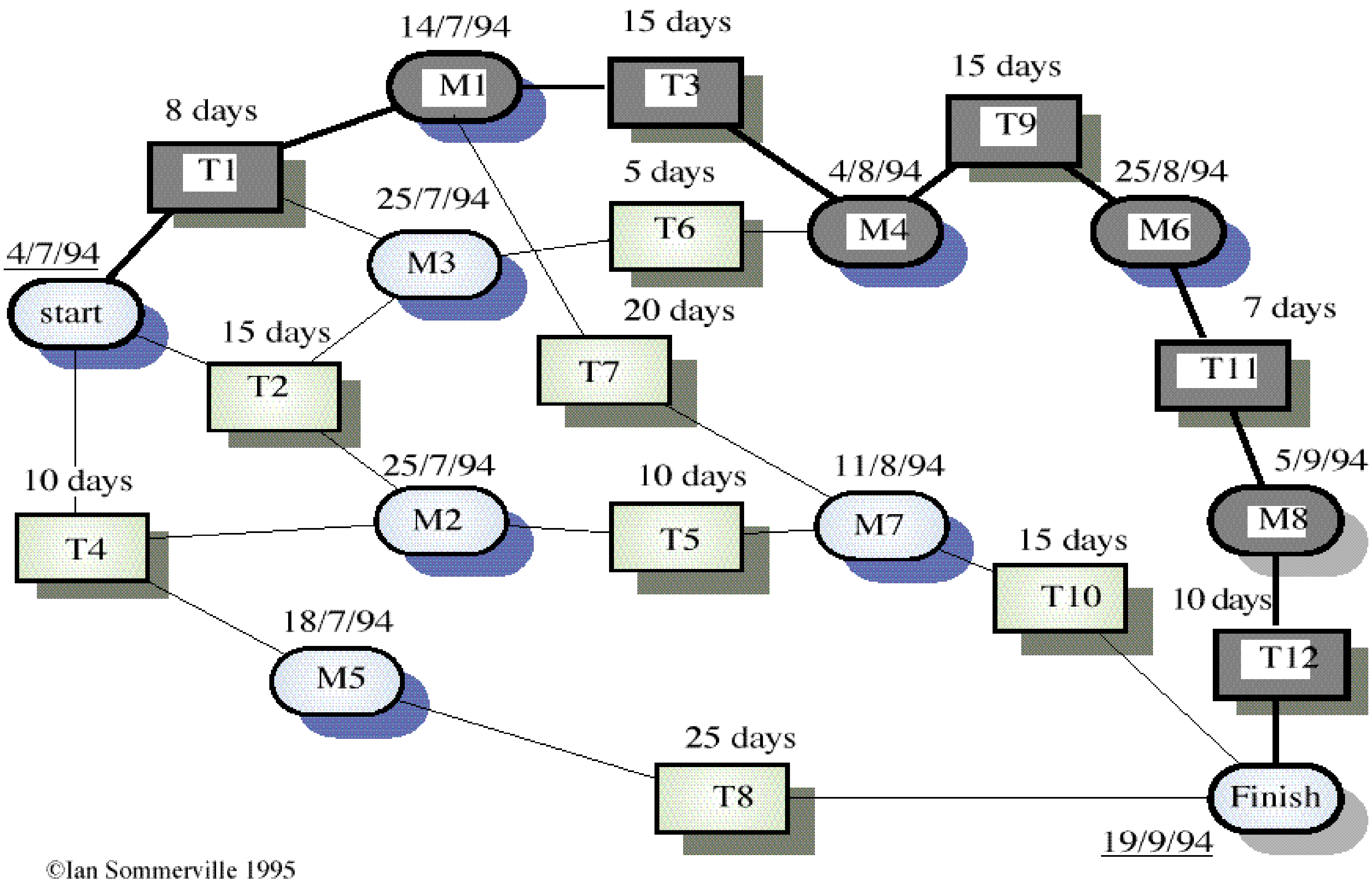
NB: Deliverables must evolve as the project progresses!

Example: Task Durations and Dependencies

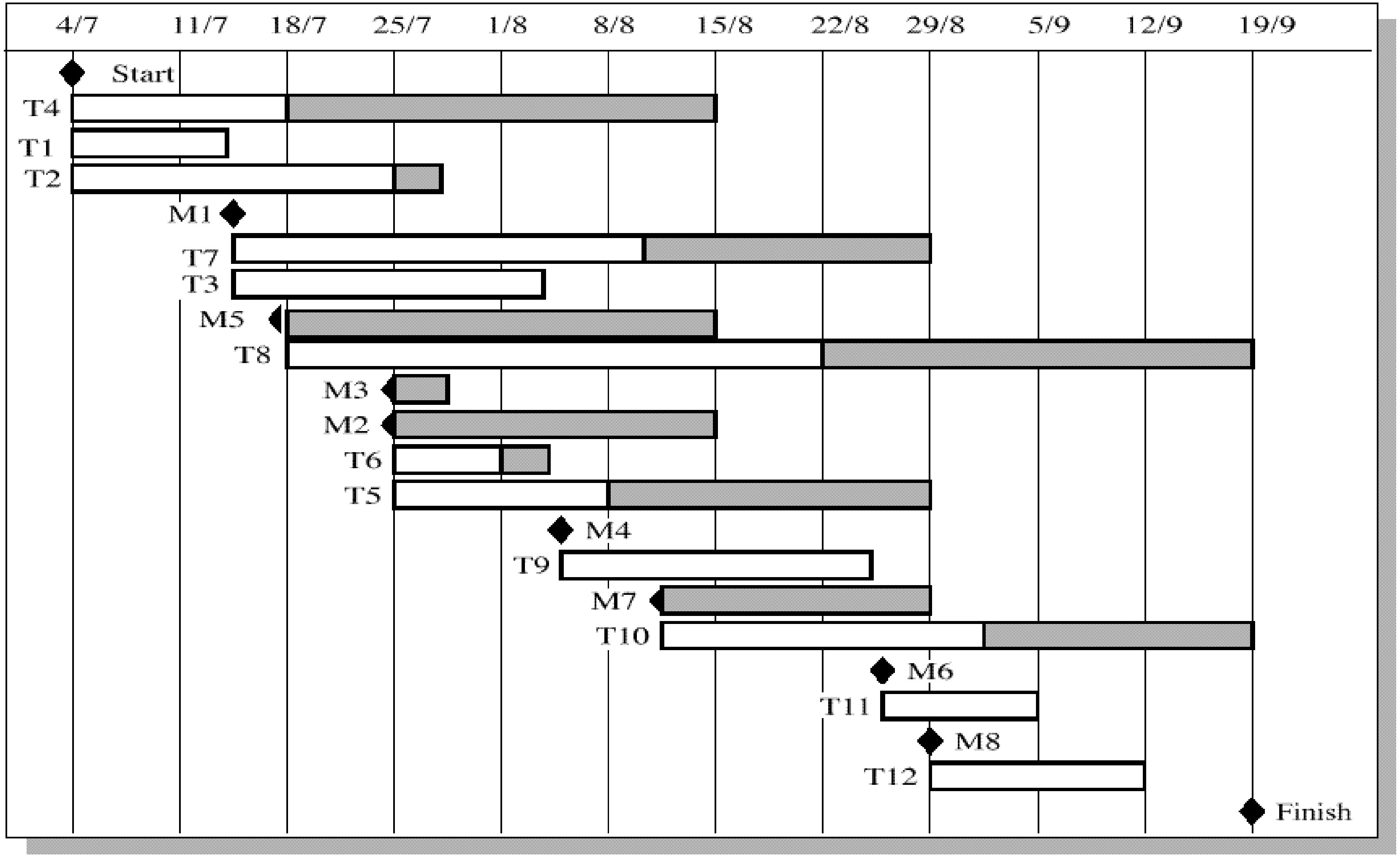
Task	Duration (days)	Dependencies
T1	8	
T2	15	
T3	15	T1
T4	10	
T5	10	T2, T4
T6	5	T1, T2
T7	20	T1
T8	25	T4
T9	15	T3, T6
T10	15	T5, T7
T11	7	T9
T12	10	T11

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

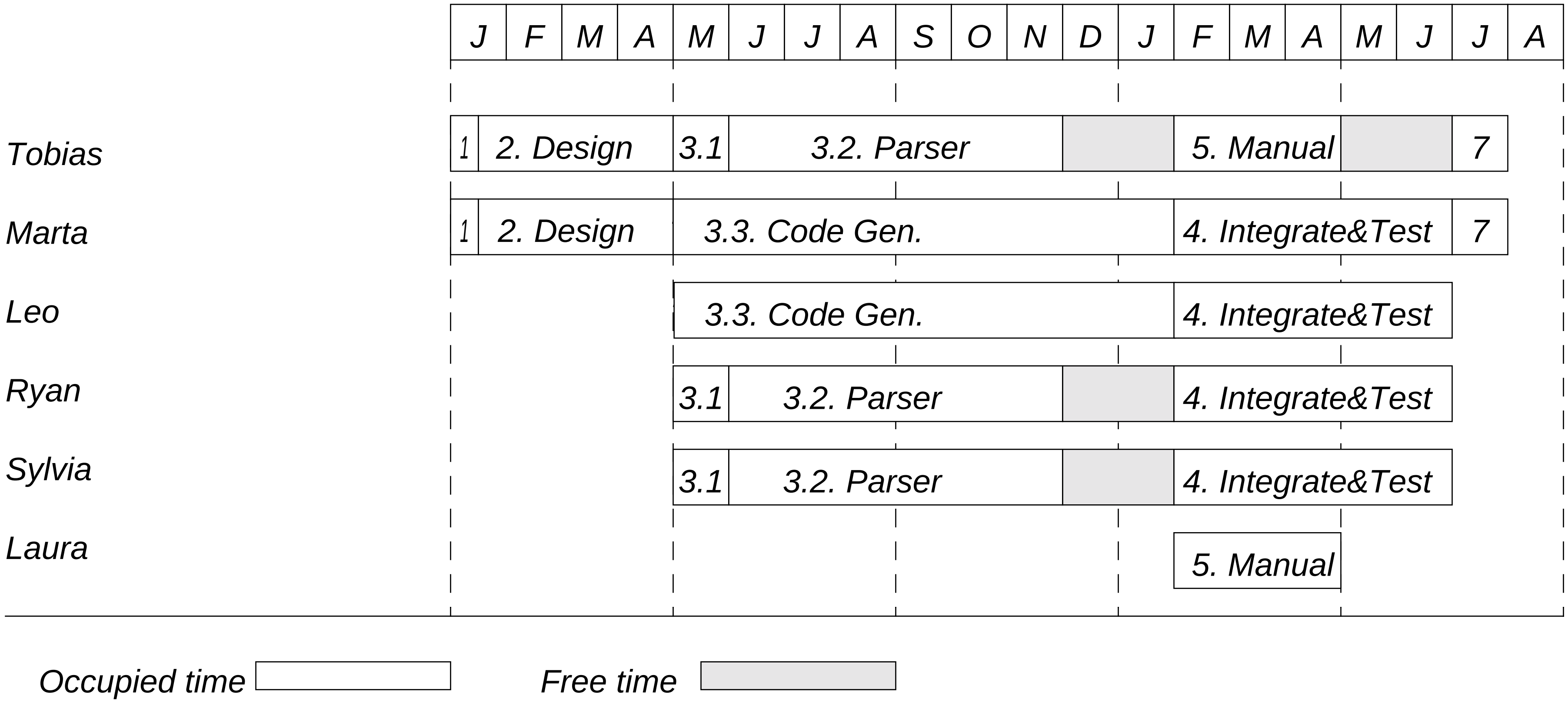
Pert Chart: Activity Network



Gantt Chart: Activity Timeline



Gantt Chart: Staff Allocation



(Overall tasks such as reviewing, reporting, ... are difficult to incorporate)

Myth: Delays

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
- Cutting back in testing and reviewing is *a recipe for disaster*
- *Working overnight?* Only short term benefits!

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*

Dealing with Delays

Spot potential delays as soon as possible
... then you have more time to recover

How to spot?

- Earned value analysis
  - planned time is the project budget
  - time of a completed task is *credited* to the project budget

...

Dealing with Delays ...

How to recover?

A combination of following 3 actions

- *Adding* senior staff for well-specified tasks
  - ☞ outside critical path to avoid communication overhead
- *Prioritize* requirements and deliver incrementally
  - ☞ deliver most important functionality on time
  - ☞ testing remains a priority (even if customer disagrees)
- *Extend* the deadline

Earned Value: Tasks Completed

The 0/100 Technique

- earned value := 0% when task not completed
- earned value := 100% when task completed
  - tasks should be rather *small*
  - gives a *pessimistic* impression

The 50/50 Technique

- earned value := 50% when task started
- earned value := 100% when task completed
  - tasks are rather *large*
  - may give an *optimistic* impression
- variant with 20/80

Earned Value ...

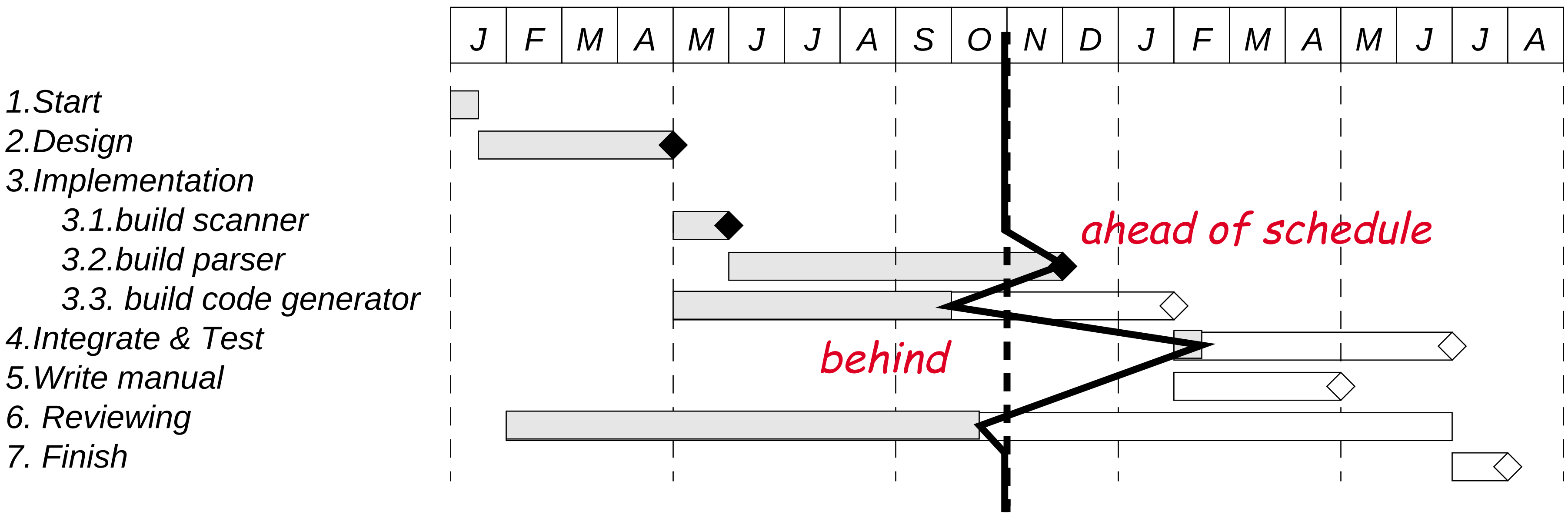
The Milestone Technique

- earned value := number of milestones completed / total number of milestones
  - tasks should be *large* with lots of intermediate milestones
  - better to split task in several subtasks and fall back on 0/100

Gantt Chart: Slip Line

Visualize slippage

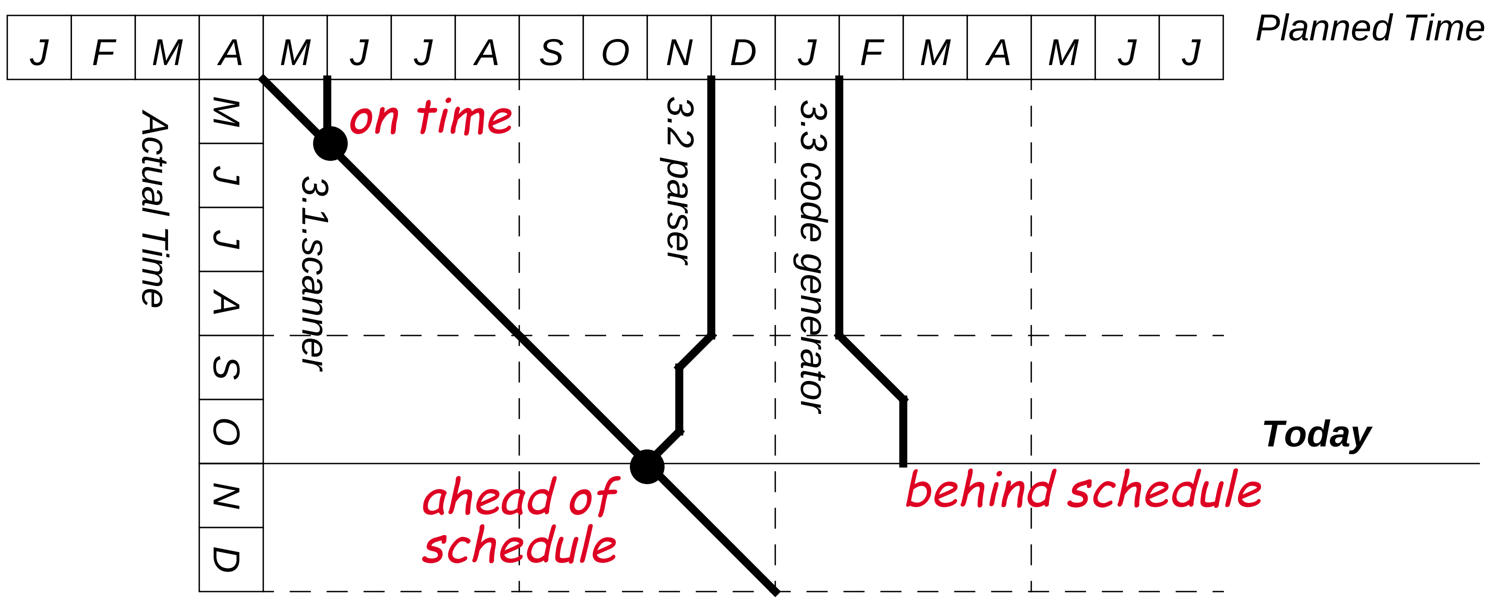
- Shade time line = portion of task completed
- Draw a *slip line* at current date, connecting endpoints of the shaded areas
  - bending to the right = *ahead* of schedule
  - to the left = *behind* schedule



Timeline Chart

Visualise slippage evolution

- downward lines represent planned completion time as they vary in current time
- bullets at the end of a line represent completed tasks



Slip Line vs. Timeline

Slip Line	Monitors *current slip status* of project tasks ❑ *many* tasks ❑ only for *1 point in time* ☞ include a few slip lines from the past to illustrate evolution
Timeline	Monitors how the slip status of project tasks *evolves* ❑ *few* tasks ☞ crossing lines quickly clutter the figure ☞ colours can be used to show more tasks ❑ *complete* time scale

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*

...

Chief Programmer Teams ...

- 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

Directing Teams

Managers serve their team

- Managers ensure that team has the *necessary information* and *resources*

"The manager's function is not to make people work, it is to make it possible for people to work"

— Tom DeMarco

Responsibility demands authority

- Managers must *delegate*
  - ☞ Trust your own people and they will trust you.

...

Directing Teams ...

Managers manage

- Managers *cannot* perform tasks on the *critical path*
  - ☞ Especially difficult for technical managers

Developers control deadlines

- A manager cannot meet a deadline to which the *developers* have not *agreed*

Conway's Law

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

What you should know!

- *How can prototyping help to reduce risk in a project?*
- *What are milestones, and why are they important?*
- *What can you learn from an activity network? An activity timeline?*
- *What's the difference between the 0/100; the 50/50 and the milestone technique for calculating the earned value.*
- *Why should programming teams have no more than about 8 members?*

Can you answer these 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?*
- *Would you consider bending slip lines as a good sign or a bad sign? Why?*
- *How would you select and organize the perfect software development team?*
- *What are good examples of Conway's Law in action?*

3. Requirements Collection

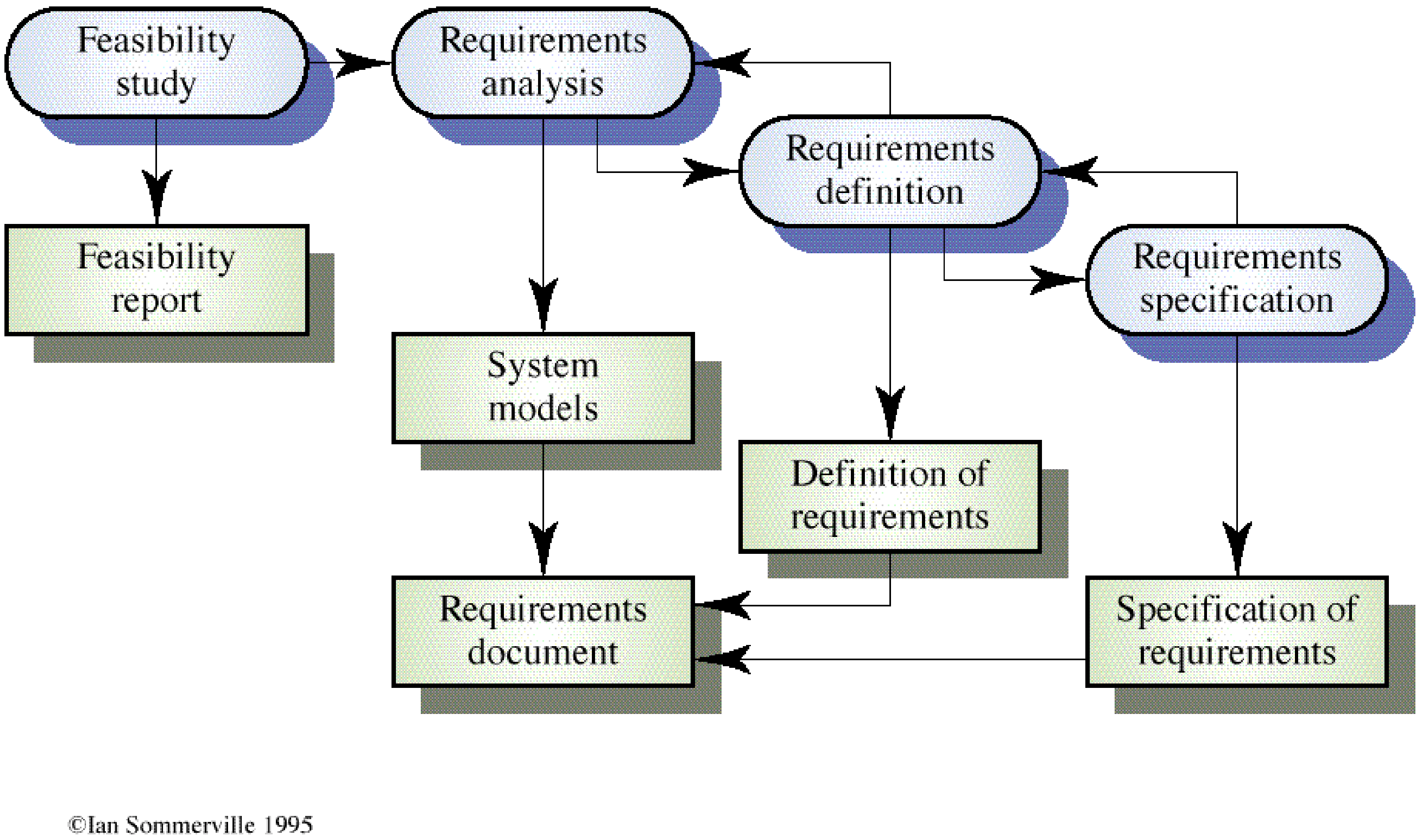
Overview:

- The Requirements Engineering Process
- Use cases and scenarios
- Functional and non-functional requirements
- Evolutionary and throw-away prototyping
- Requirements checking and reviews

Sources:

- *Software Engineering*, I. Sommerville, 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



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

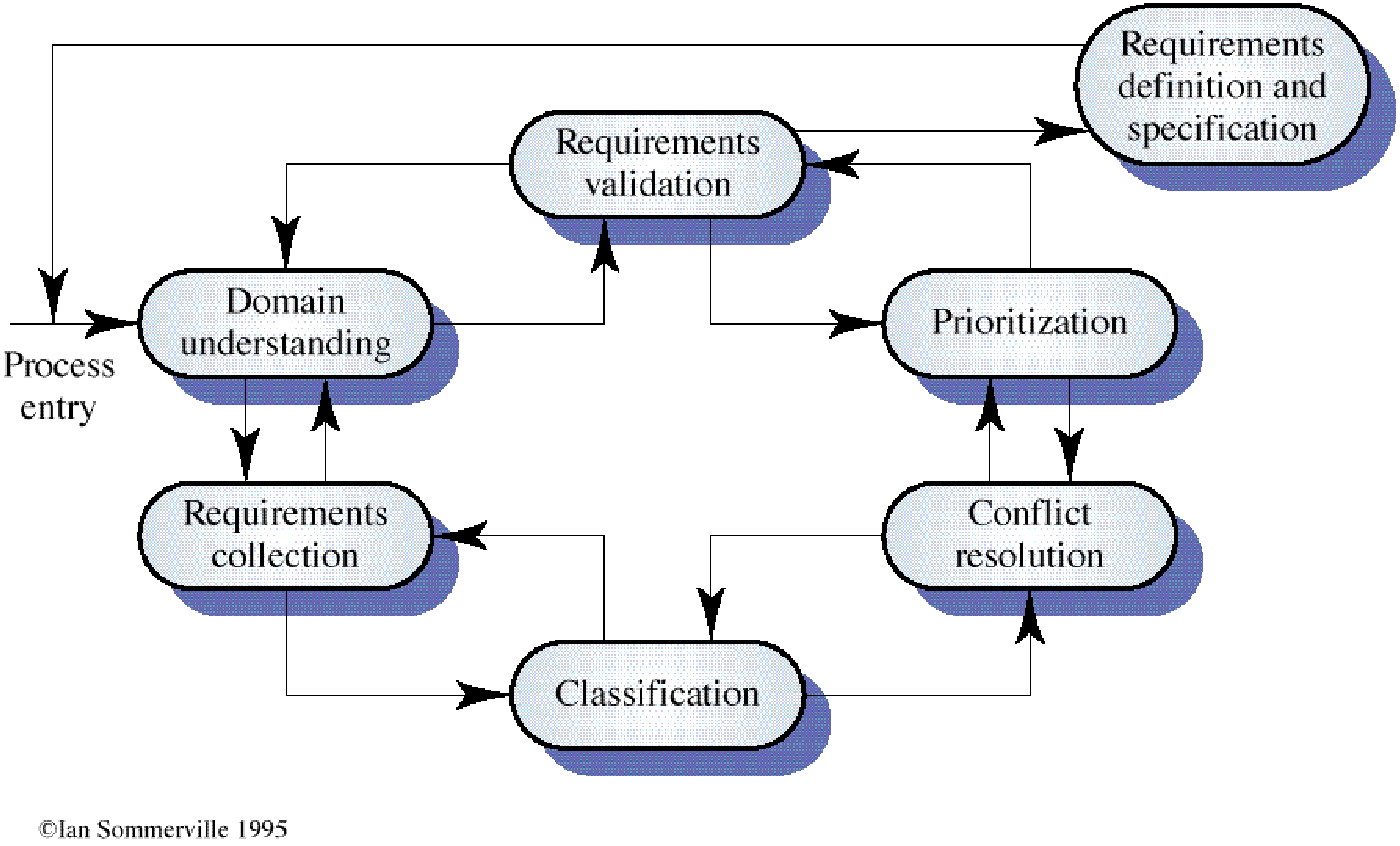
Various problems typically arise:

- 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



Use Cases and Viewpoints

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

☞ e.g., buy a DVD through the internet

A <u>*scenario*</u> is a *particular trace of action occurrences*, starting from a known initial state.

☞ e.g., connect to myDVD.com, go to the "search" page

...

Use Cases and Viewpoints ...

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

UML is an industry standard for documenting OO models.

Class Diagrams	visualize *logical structure* of system in terms of *classes*, *objects* and *relationships*
Use Case Diagrams	show external *actors* and *use cases* they participate in
Sequence Diagrams	visualize *temporal message ordering* of a *concrete* scenario of a use case
Collaboration Diagrams	visualize *relationships* of objects exchanging messages in a *concrete scenario*
State Diagrams	specify the *abstract states* of an object and the *transitions* between the states

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*

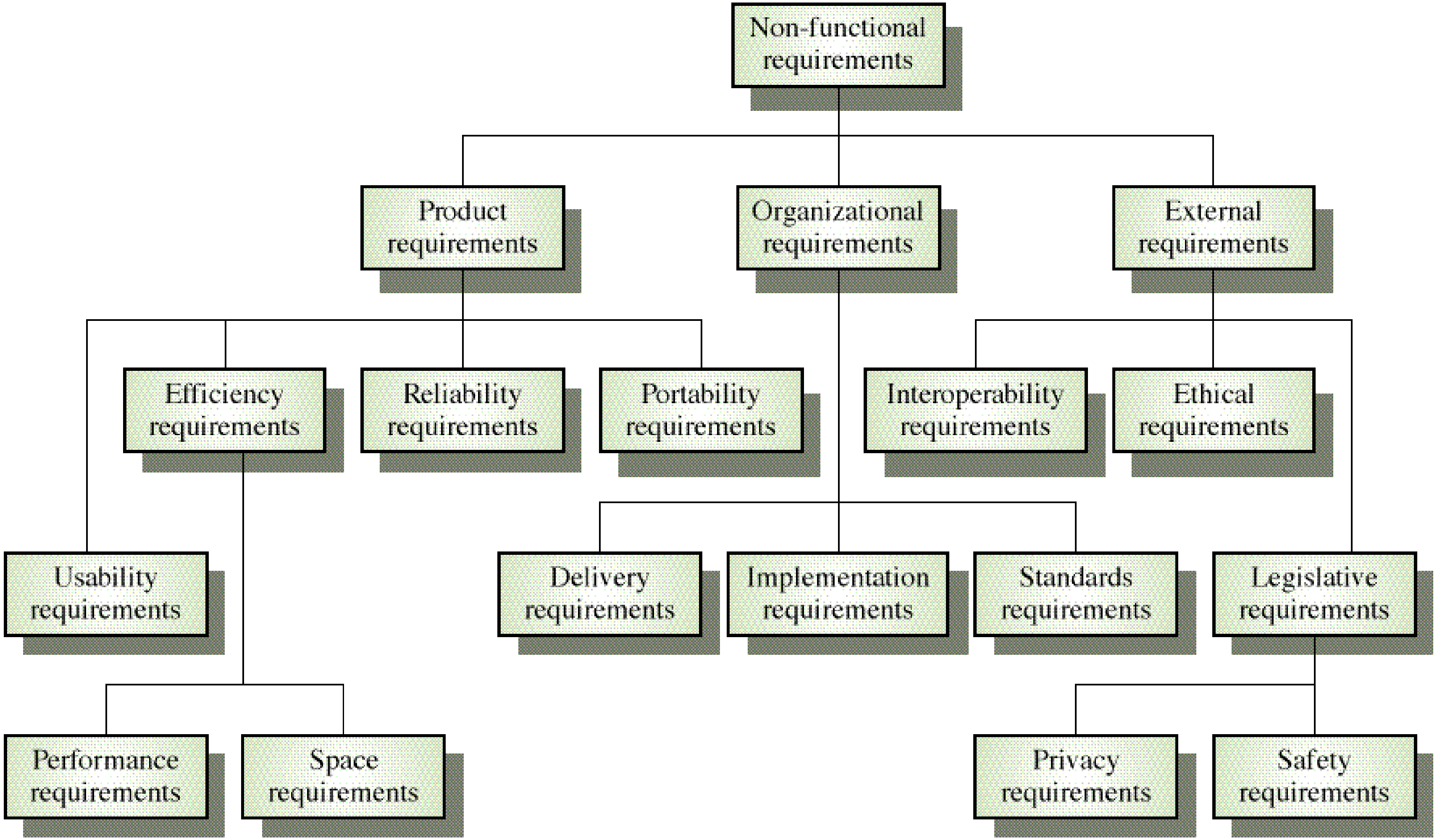
Non-functional requirements are *constraints* on the system or the development process

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

Non-functional Requirements

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.

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 Rate of errors made by trained users Number of help frames
Reliability	Mean time to failure Probability of unavailability Rate of failure occurrence

Property	*Measure*
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

- *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?

Traceability

To protect against changes you should be able to *trace back from every system component to the original requirement* that caused its presence.

	Comp 1	Comp 2	...	...	...	...	...	...	...	Comp m
Req 1				x			x			
Req 2	x									x
...										
...		x				x			x	
...										
...		x								
...					x					x
Req n										

Traceability ...

- A *software process* should help you keeping this virtual table up-to-date
- *Simple techniques* may be quite valuable (naming conventions, ...)

What you should know!

- 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. 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.

Why Responsibility-driven Design?

Functional Decomposition

> Decompose according to the *functions* a system is supposed to perform.

Functional Decomposition

- Good in a "waterfall" approach: stable requirements and one monolithic function

However

- *Naive:* Modern systems perform more than one function
- *Maintainability:* system functions evolve ⇒ redesign affect whole system
- *Interoperability:* interfacing with other system is difficult

Why Responsibility-driven Design? ...

Object-Oriented Decomposition

> Decompose according to the *objects* a system is supposed to manipulate.

Object-Oriented Decomposition

- Better for complex and evolving systems

However

- How to find the objects?

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."

What is Object-Oriented Design?

- 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.*

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

Finding Classes ...

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* — is it really 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.
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.

Class Selection Rationale

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

...

Class Selection Rationale ...

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 ...

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*

...

Class Selection Rationale ...

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

Model interfaces to the system:

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

...

Class Selection Rationale ...

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.

CRC Cards

Use CRC cards to record candidate classes:

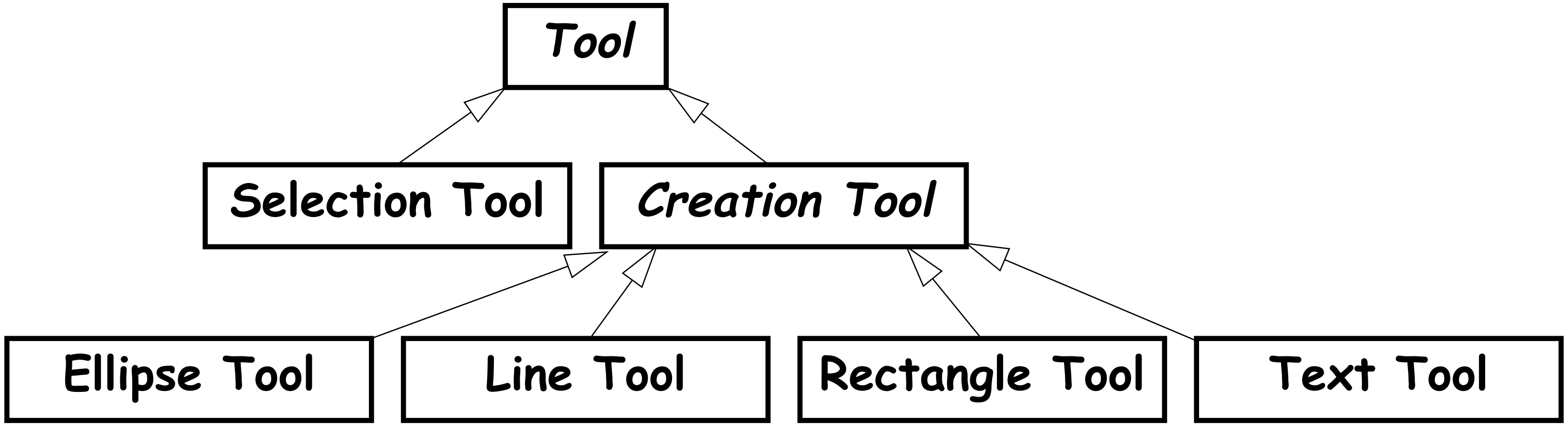
Class: Drawing	
<superclasses>	
<subclasses>	
<responsibilities ...>	*<collaborations>*

Write a short description 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



- *group* related classes with common attributes
- introduce *abstract superclasses* to 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*
- if you still cannot name it, *discard* the group and search for others.

...

Identifying and Naming Groups ...

Attributes of abstract classes should serve to distinguish subgroups

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

Ignore attributes that don't help to make distinctions.

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 (but 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

...

Assigning Responsibilities ...

- 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*

Relationships Between Classes ...

- 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 for one card suggests *over-centralization:*

☞ Try to *redistribute* to *superclasses* or *collaborators*

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!)

...

Finding Collaborations ...

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.

Put the server class next to the 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*.

What you should know!

- 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?*

5. Detailed Design

Overview:

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

Source:

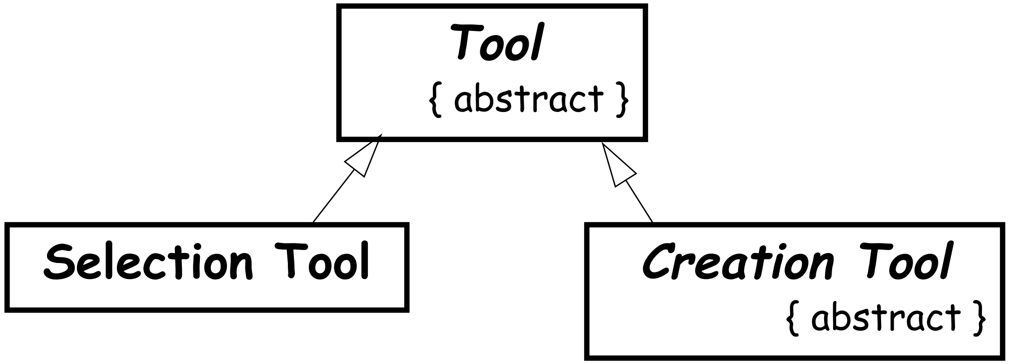
- *Designing Object-Oriented Software*, R. Wirfs-Brock, B. Wilkerson, L. Wiener, Prentice Hall, 1990

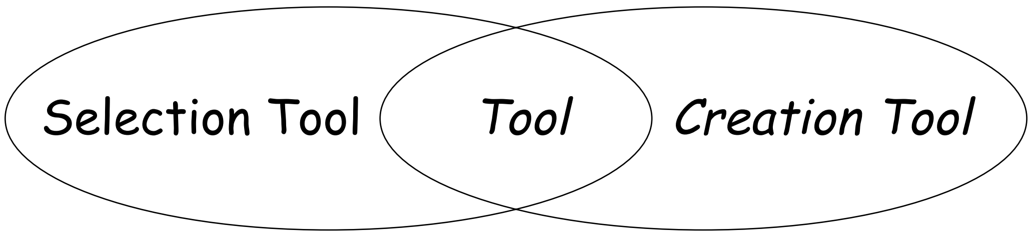
Sharing Responsibilities

Concrete classes may be both instantiated and inherited from.

Abstract classes may only be inherited from.

Note on class cards and on class diagram.

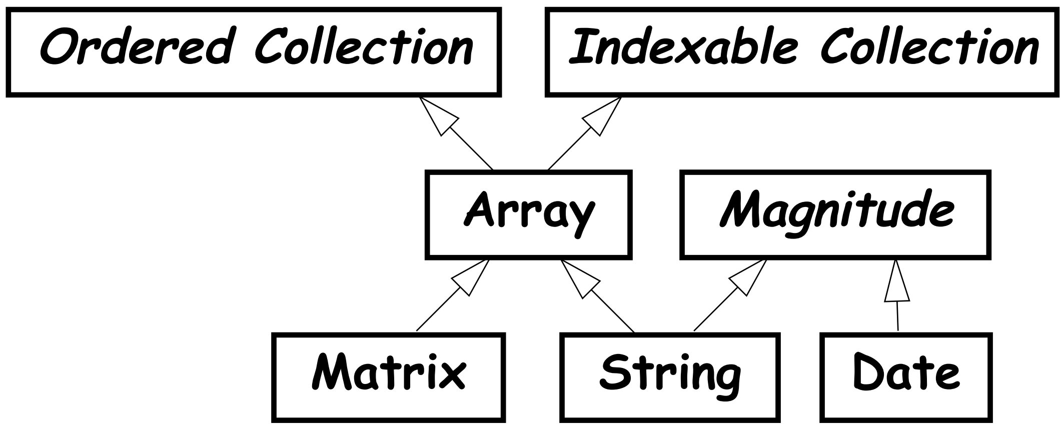




Venn Diagrams can be used to visualize shared responsibilities.

(Warning: not part of UML!)

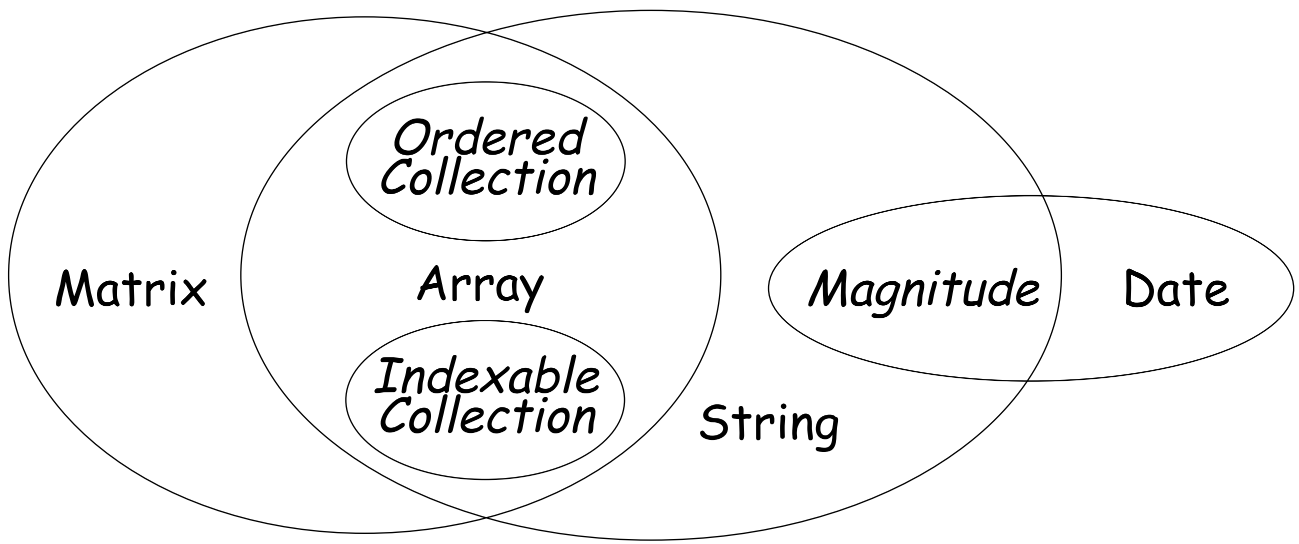
Multiple Inheritance



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

...

Building Good Hierarchies ...

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

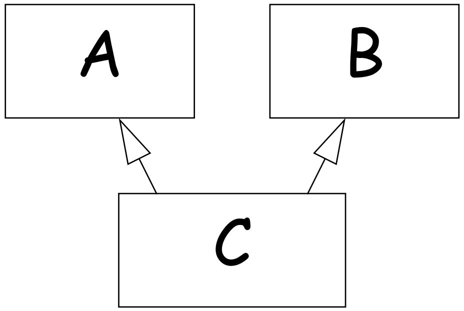
- Eliminate by introducing *common abstract superclass*: abstract classes should support responsibilities in an implementation-independent way

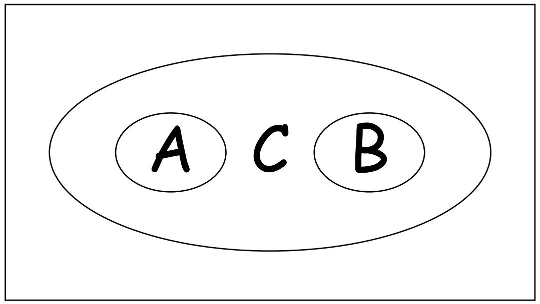
Eliminate classes that do not add functionality:

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

Building Kind-Of Hierarchies

Correctly Formed Subclass Responsibilities:





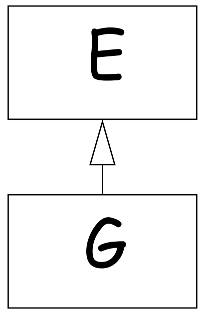
C assumes *all* the responsibilities of both A and B

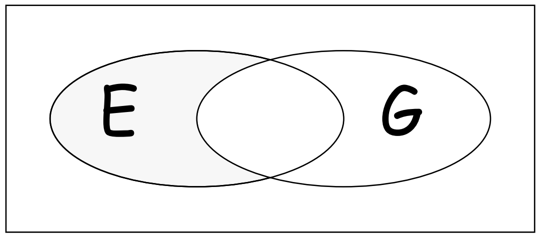
...

Building Kind-Of Hierarchies ...

Incorrect Subclass/Superclass Relationships

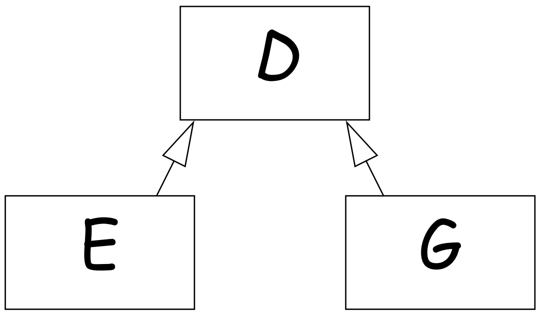
G assumes only *some* of the responsibilities inherited from E

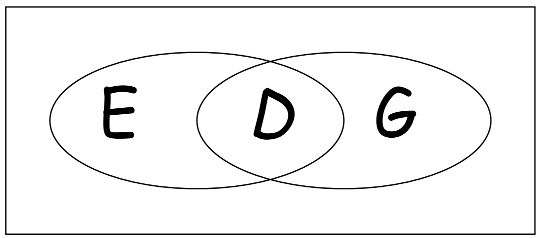




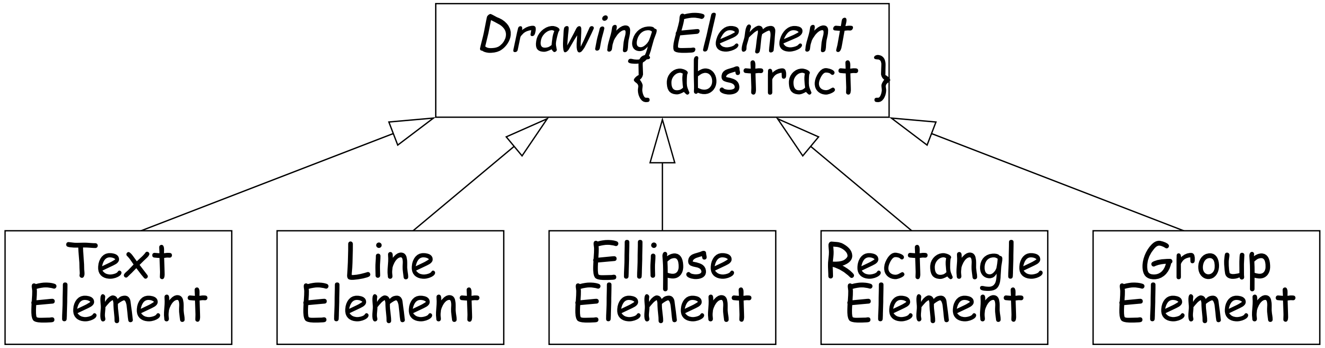
Revised Inheritance Relationships

Introduce *abstract superclasses* to encapsulate common responsibilities



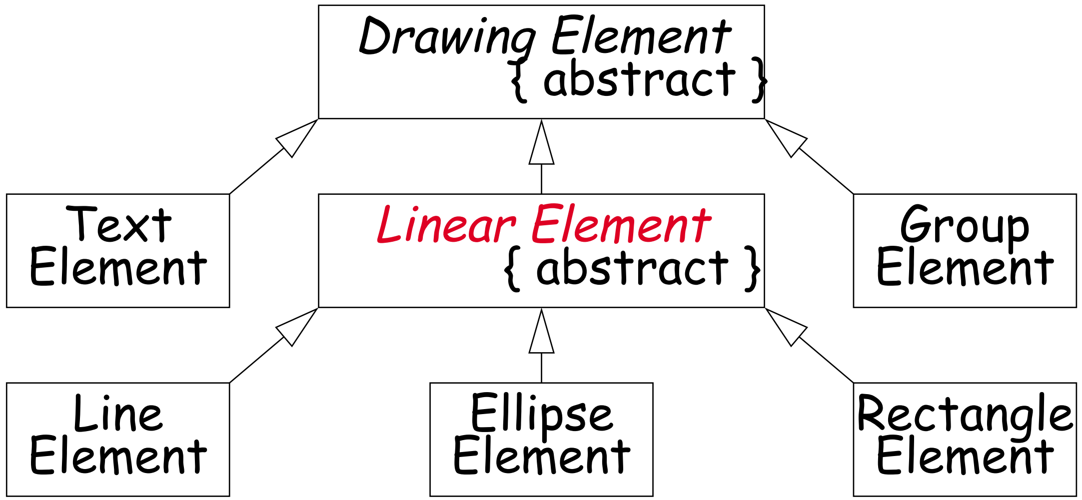


Refactoring Responsibilities



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.

...

Identifying Contracts ...

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?

...

Applying the Guidelines ...

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

Finding Subsystems

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

- list the collaborations and identify *strong inter-dependencies*
- identify *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*

NB: Also 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

...

Simplifying Interactions ...

- *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., an *interface*) 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

Defaults

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

What you should know!

- 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?*

6. Modeling Objects and Classes

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

Sources

- *Unified Modeling Language — Notation Guide*, version 1.3, Rational Software Corporation, 1997.
- *UML Distilled*, Martin Fowler, Kendall Scott, Addison-Wesley, Second Editon, 2000.

UML

What is UML?

- uniform notation: Booch + OMT + Use Cases (+ state charts)
  - ☞ UML is *not* a method or process
  - ☞ .. The *Unified Development Process* is

Why a Graphical Modeling Language?

- Software projects are carried out in *team*
- Team members need to *communicate*
  - ☞ ... sometimes even with the end users
- "One picture conveys a thousand words"
  - ☞ the question is only *which words*
  - ☞ Need for *different views* on the same software artifact

Why UML?

Why UML

- Represents de-facto *standard*
  - more tool support, more people understand your diagrams, less education
- Is reasonably *well-defined*
  - ... although there are interpretations and dialects
- Is *open*
  - stereotypes, tags and constraints to extend basic constructs
  - has a meta-meta-model for advanced extensions

UML History

- 1994: Grady Booch (Booch method) + James Rumbaugh (OMT) at Rational
- 1994: Ivar Jacobson (OOSE, use cases) joined Rational
  - ☞ "The three amigos"
- 1996: Rational formed a consortium to support UML
- January, 1997: UML1.0 submitted to OMG by consortium
- November, 1997: UML 1.1 accepted as OMG standard
  - ☞ However, OMG names it UML1.0
- December, 1998: UML task force cleans up standard in UML1.2
- June, 1999: UML task force cleans up standard in UML1.3
- ...: Major revision to UML2.0

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:

Polygon
centre: Point vertices: List of Point borderColour: Colour fillColour: Colour
display (on: Surface) rotate (angle: Integer) erase ( ) destroy ( ) select (p: Point): Boolean

A collapsed class view:

Polygon

Class with Package name:

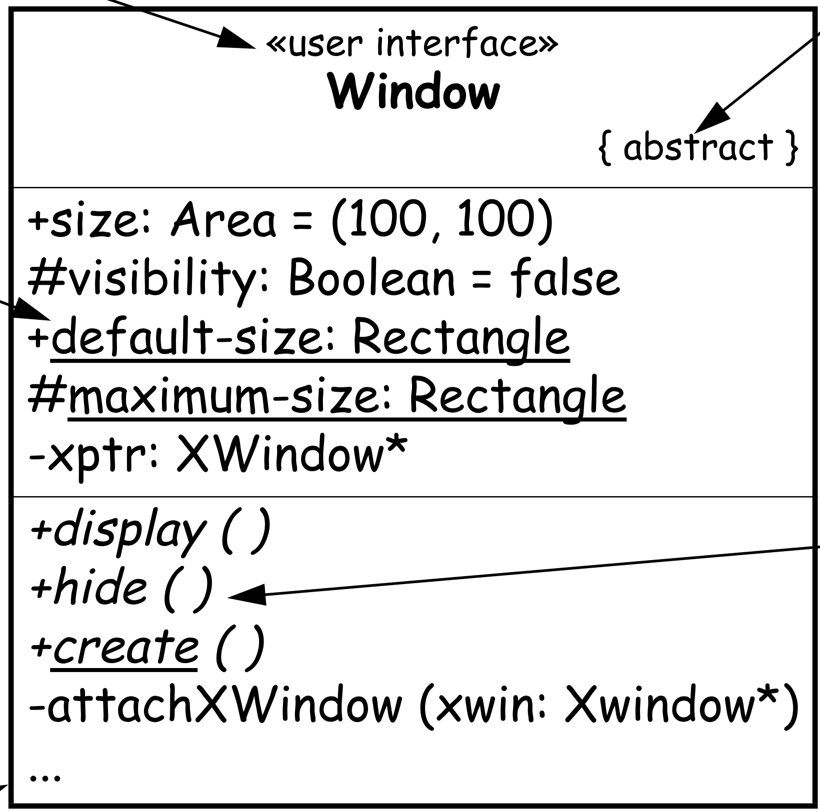
ZWindows::Window

Attributes and operations are also collectively called *features*.

Visibility and Scope of Features

Stereotype
(what "kind" of class is it?)

User-defined properties
(e.g., readonly, owner = "Pingu")



underlined attributes have *class scope*

+ = "public"
 # = "protected"
– = "private"

italic attributes are *abstract*

An ellipsis signals that further entries are not shown

Attributes and Operations

Attributes are specified as:

name: type = initialValue { property string }

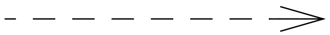
Operations are specified as:

name (param: type = defaultValue, ...) : resultType

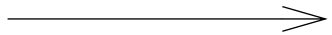
UML Lines and Arrows

Constraint
(usually annotated)

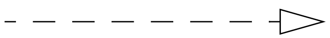
Association
e.g., «uses»



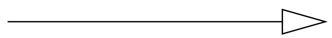
Dependency
e.g., «requires»,
«imports» ...



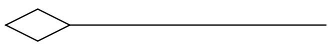
Navigable
association
e.g., part-of



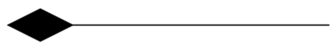
Realization
e.g., class/template,
class/interface



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



Aggregation
i.e., "consists of"

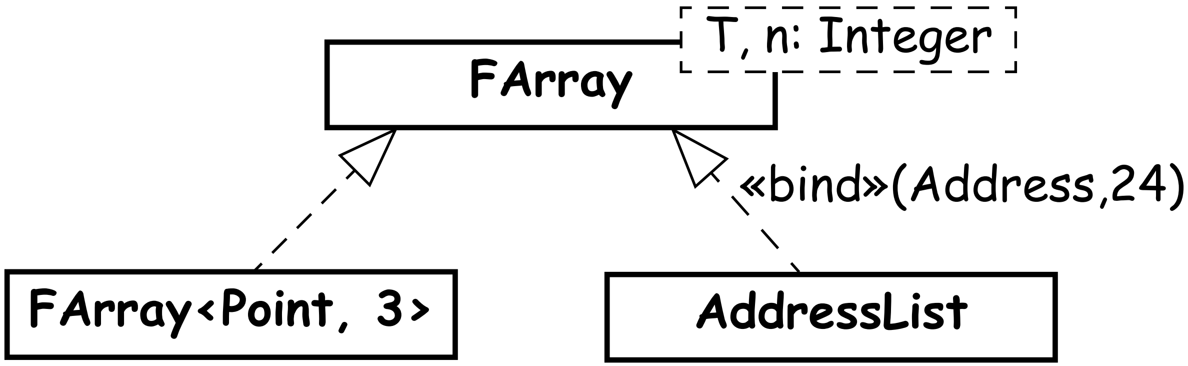


"Composition"
i.e., containment

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**).

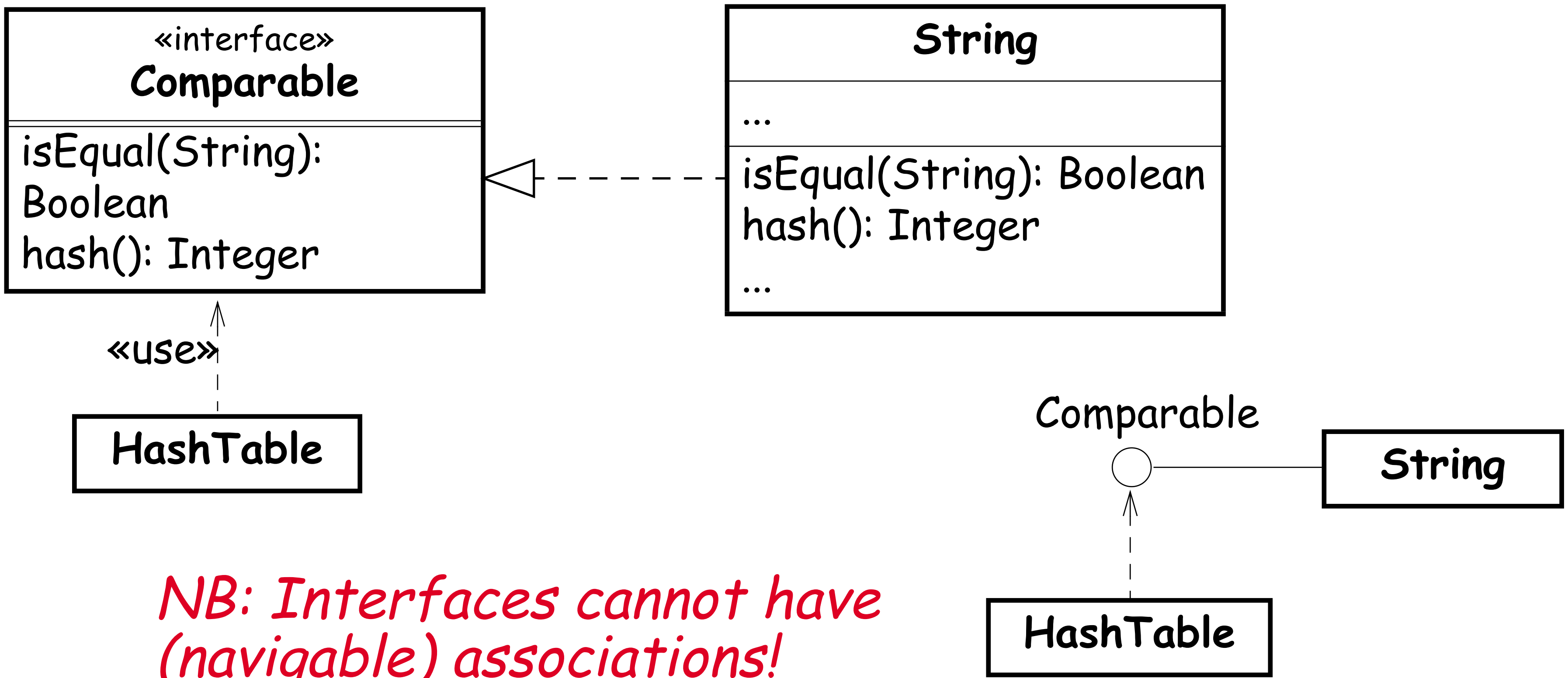


Instantiation of a class from a template can be shown by a dashed arrow (*Realization*).

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

Interfaces

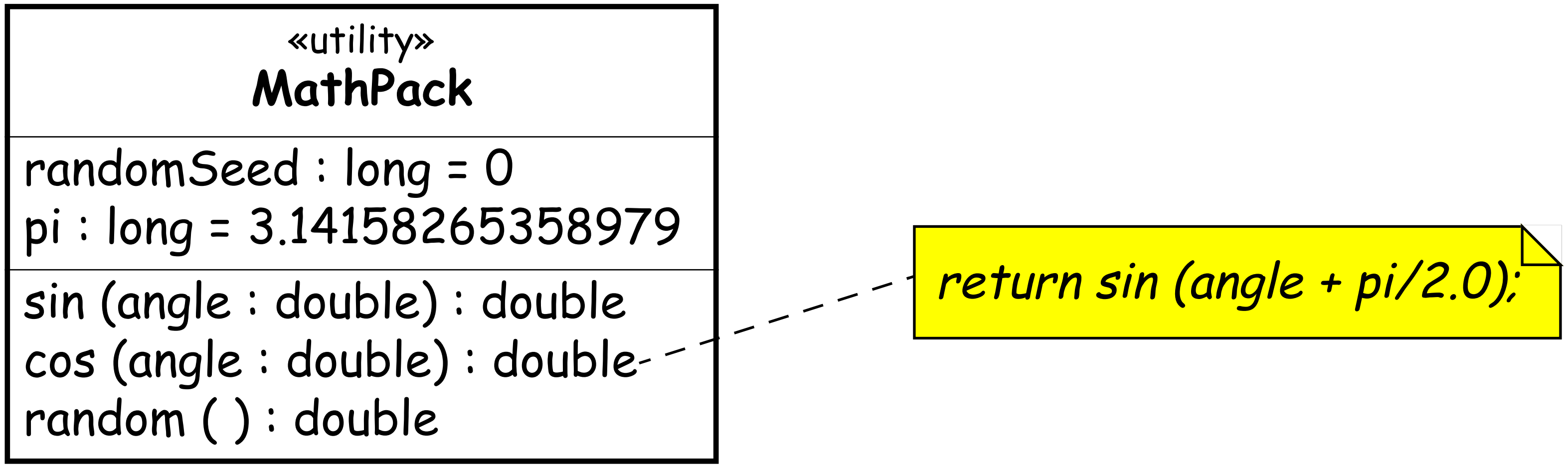
Interfaces, equivalent to abstract classes with no attributes, are represented as classes with the stereotype «interface» or, alternatively, with the "Lollipop-Notation":



NB: Interfaces cannot have (navigable) associations!

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.

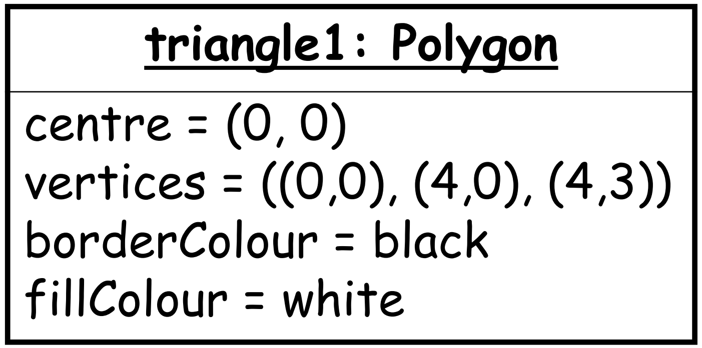


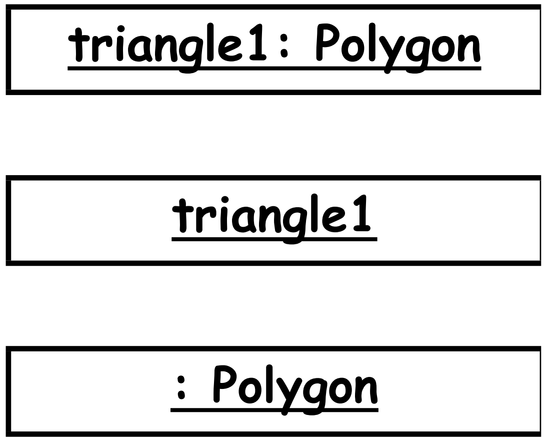
NB: A utility's attributes are already interpreted as being in class scope, so it is redundant to underline them.

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.

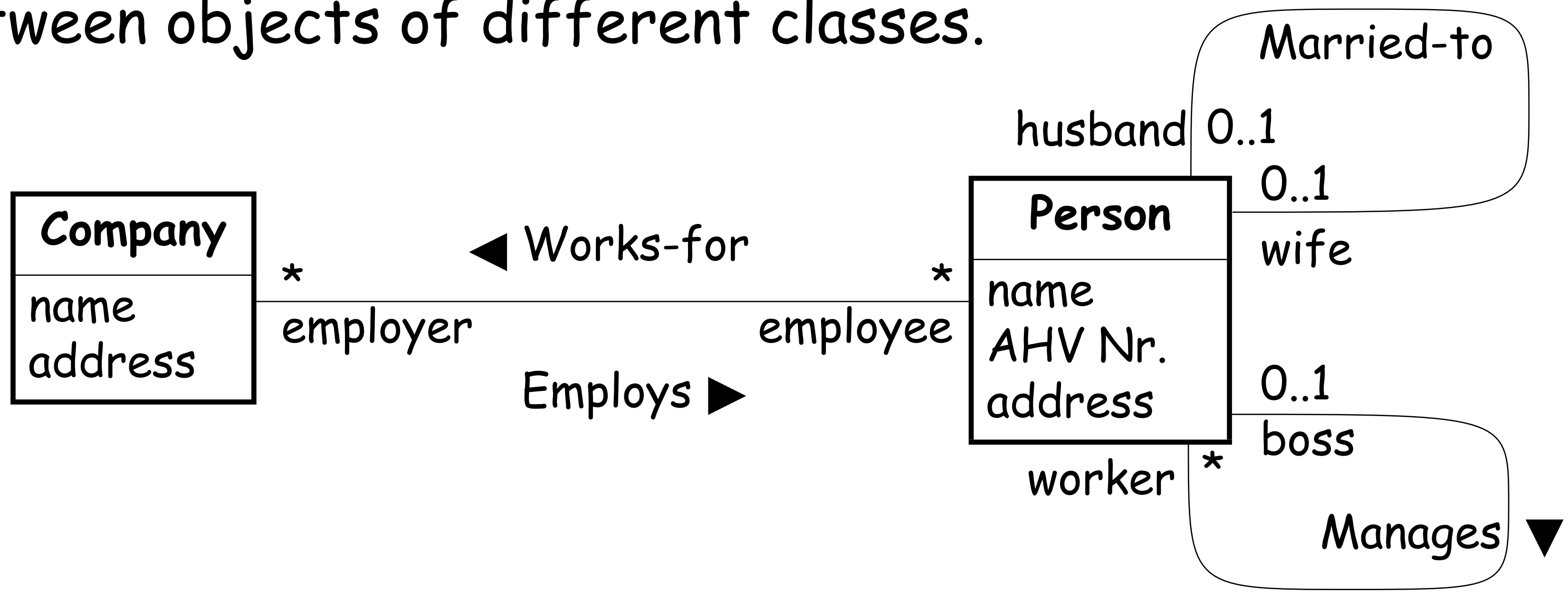




At least one of the name or the type must be present.

Associations

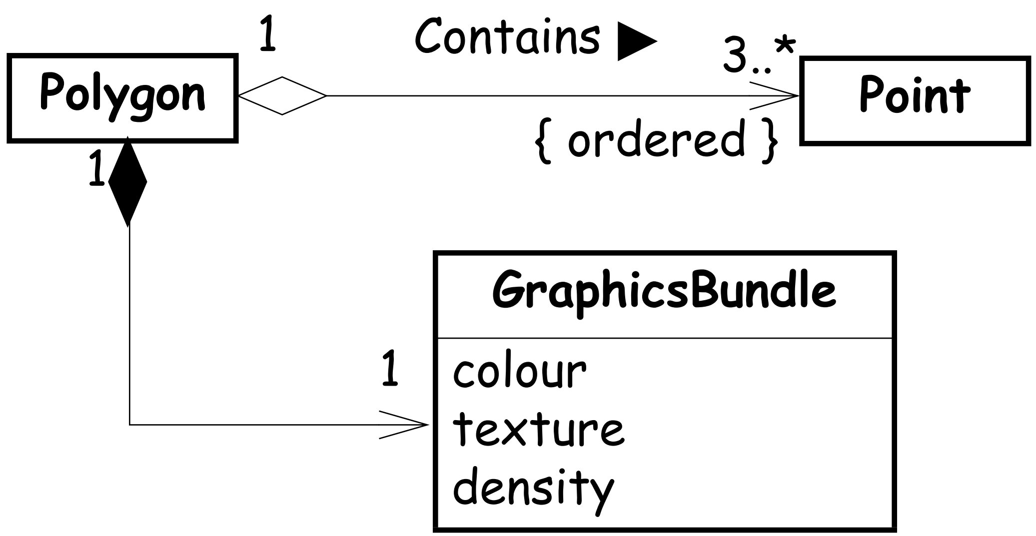
<u>*Associations*</u> represent *structural relationships* between objects of different classes.



- 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*:



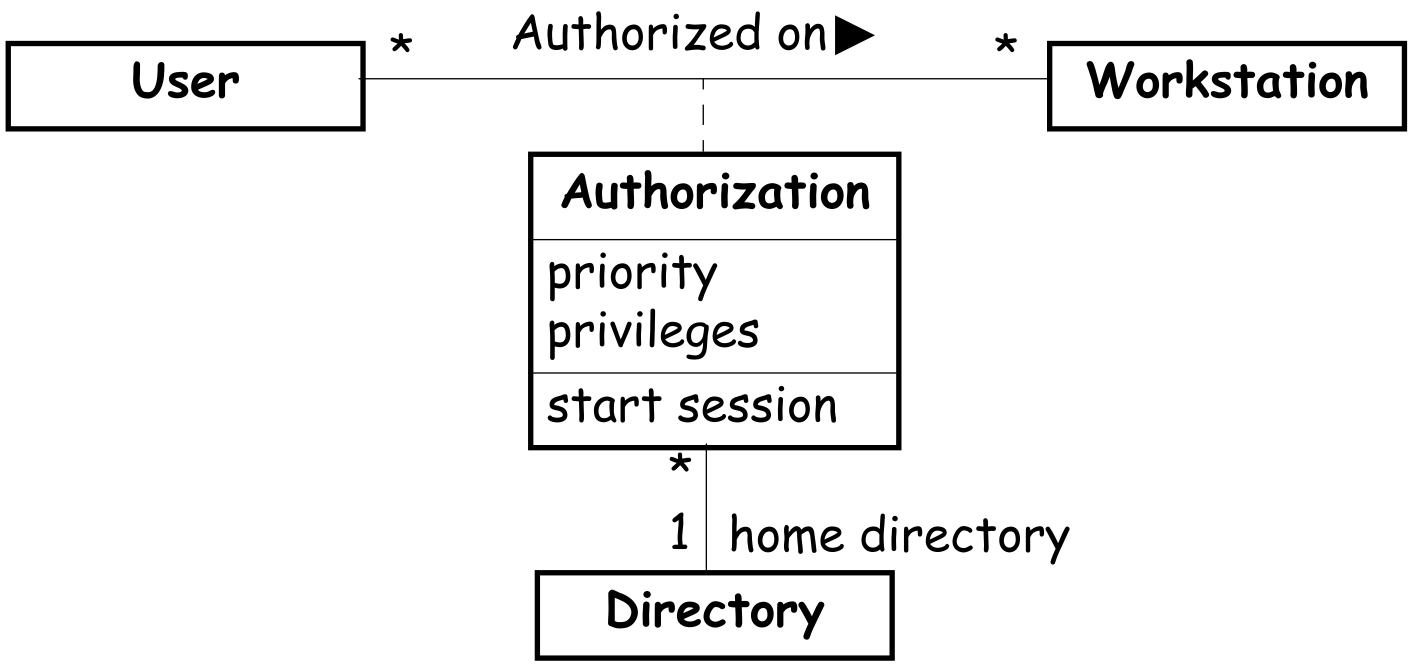
A *hollow* diamond indicates a *reference*; a *solid* diamond an *implementation*.

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

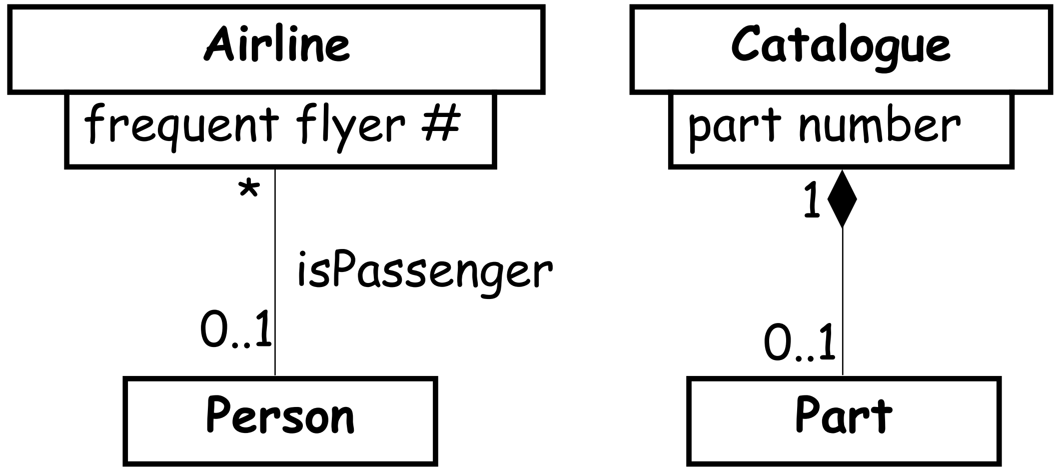
An association may be an instance of an *association class*:



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.

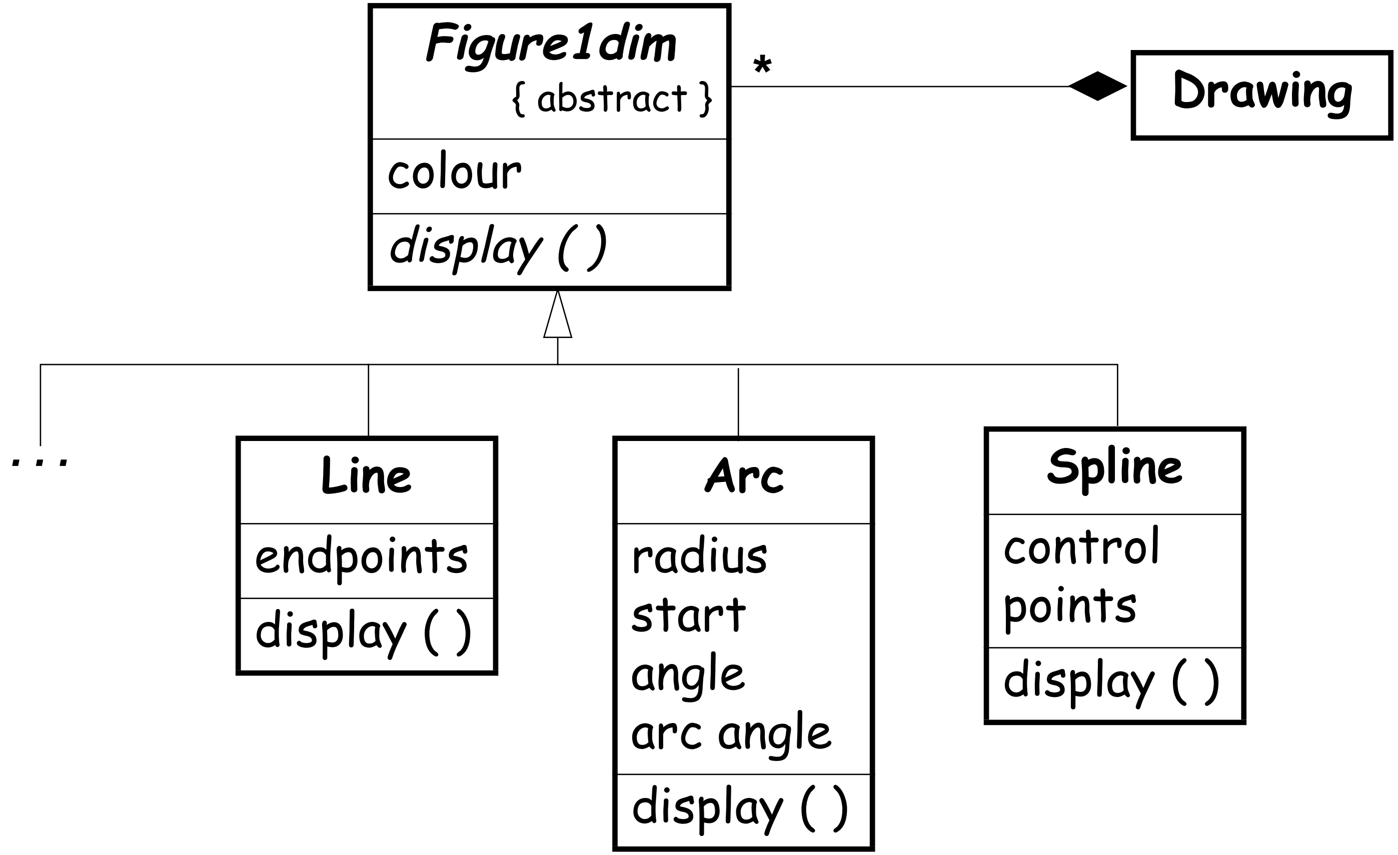


"The multiplicity attached to the target role denotes the possible cardinalities of the set of target objects selected by the pairing of a source object and a qualifier value."

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:

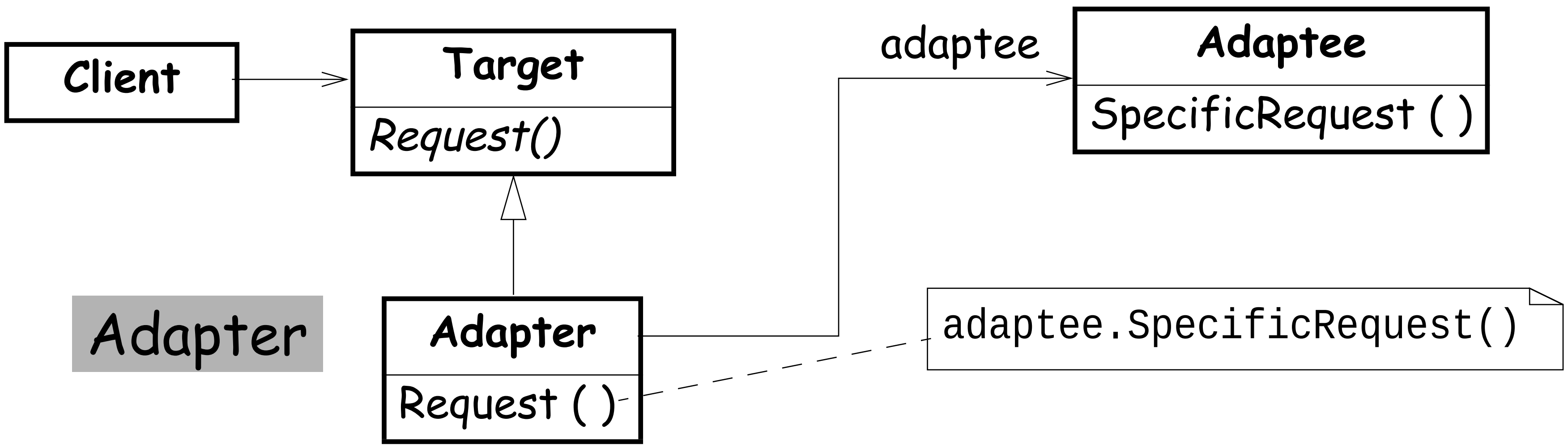
- related classes may *share* interfaces, data structures or behaviour
  - ☞ geometric objects ...

Polymorphism:

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

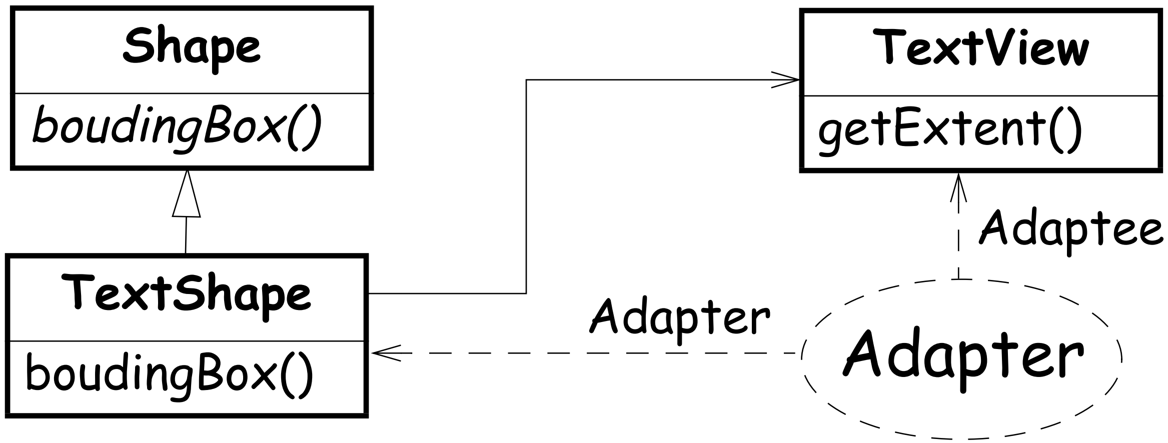
Design Patterns as Collaborations

Design Patterns can be represented as *"parameterized collaborations"*:



Instantiating Design Patterns

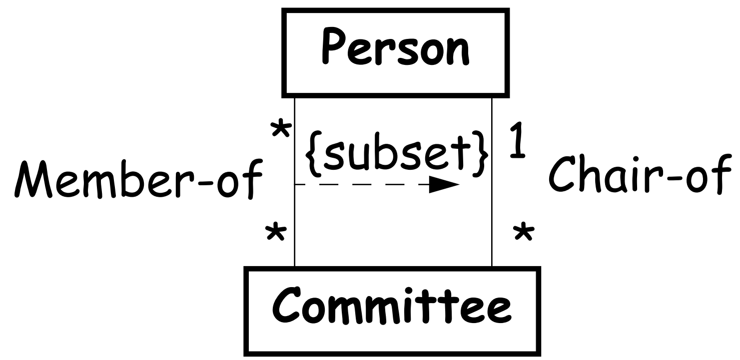
A Design Pattern in use (an *instantiation*) can be described with a *dashed oval*:



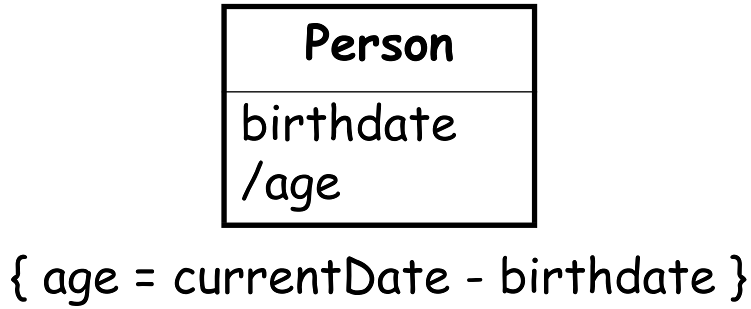
Constraints

<u>*Constraints*</u> are *restrictions* on values attached to classes or associations.

- *Binary constraints* may be shown as dashed lines between elements

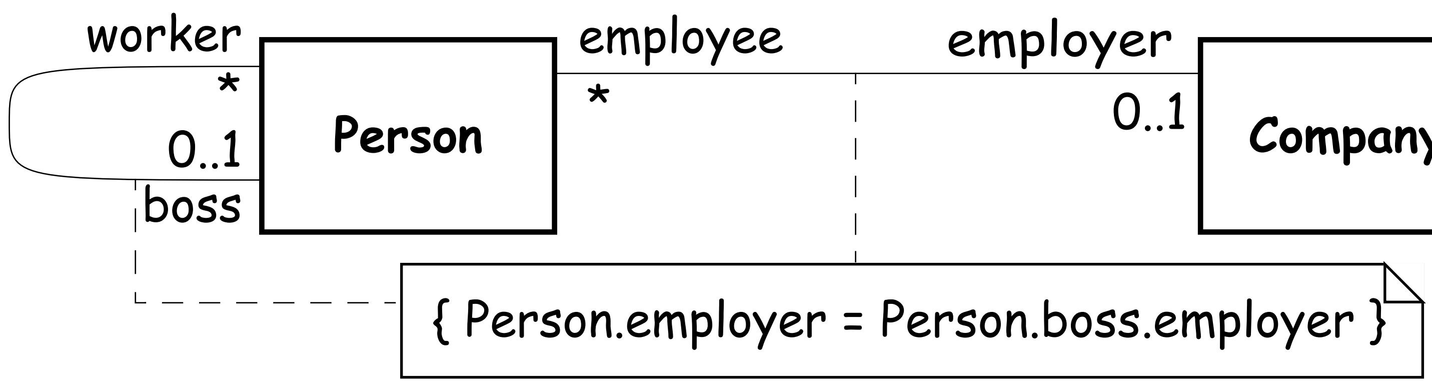


- *Derived values* and associations can be marked with a "/"



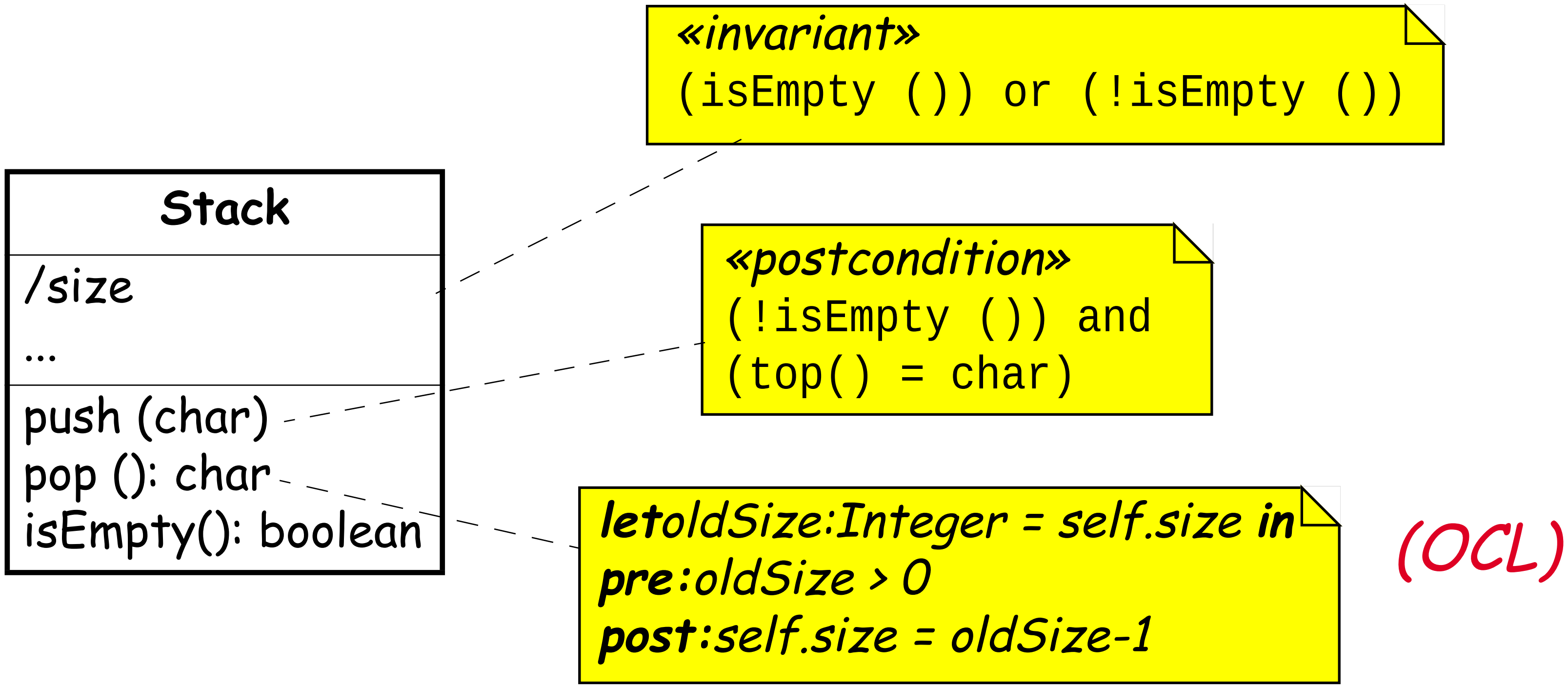
Specifying Constraints

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



Design by Contract in UML

Combine *constraints* with *stereotypes*:



NB: «invariant», «precondition», and «postcondition» are predefined in UML.

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*

...

Using the Notation ...

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.

What you should know!

- 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?*

7. Modeling Behaviour

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

Sources:

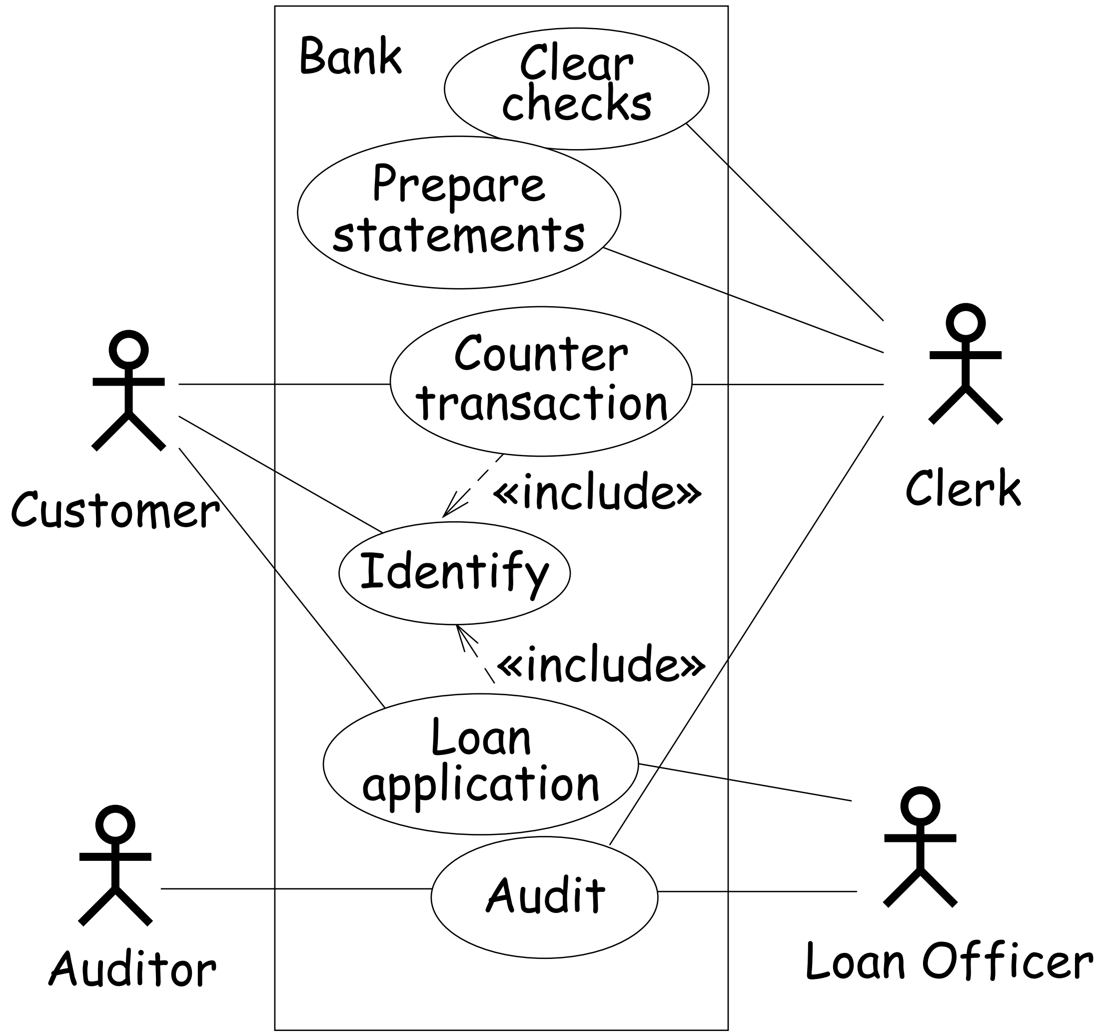
- *Unified Modeling Language — Notation Guide*, version 1.1, Rational Software Corporation, 1997.
- *Object-Oriented Development — The Fusion Method*, D. Coleman, et al., Prentice Hall, 1994.

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.



Scenarios

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

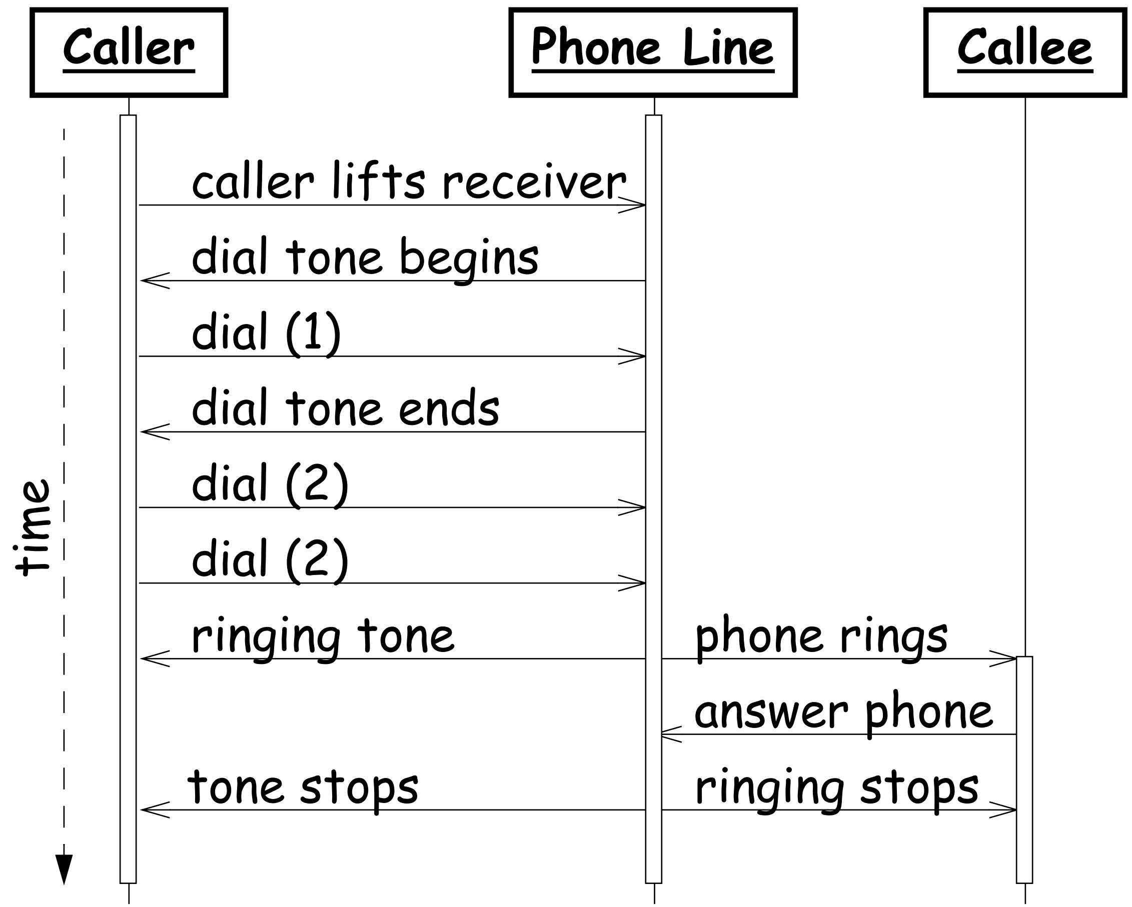
Scenarios can be presented in UML using either *sequence diagrams* or *collaboration diagrams*.

Note that a scenario only describes an *example* of a use case, so conditionality cannot be expressed!

Sequence Diagrams

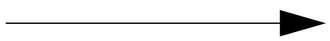
A *sequence diagram* depicts a scenario by showing the interactions among a set of objects in *temporal order*.

Objects (not classes!) are shown as *vertical bars*. *Events* or message dispatches are shown as horizontal (or slanted) *arrows* from the sender to the receiver.



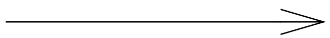
Temporal *constraints* between events may also be expressed.

UML Message Flow Notation



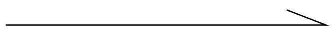
Filled solid arrowhead

procedure call or other nested control flow



Stick arrowhead

flat, *sequential* control flow

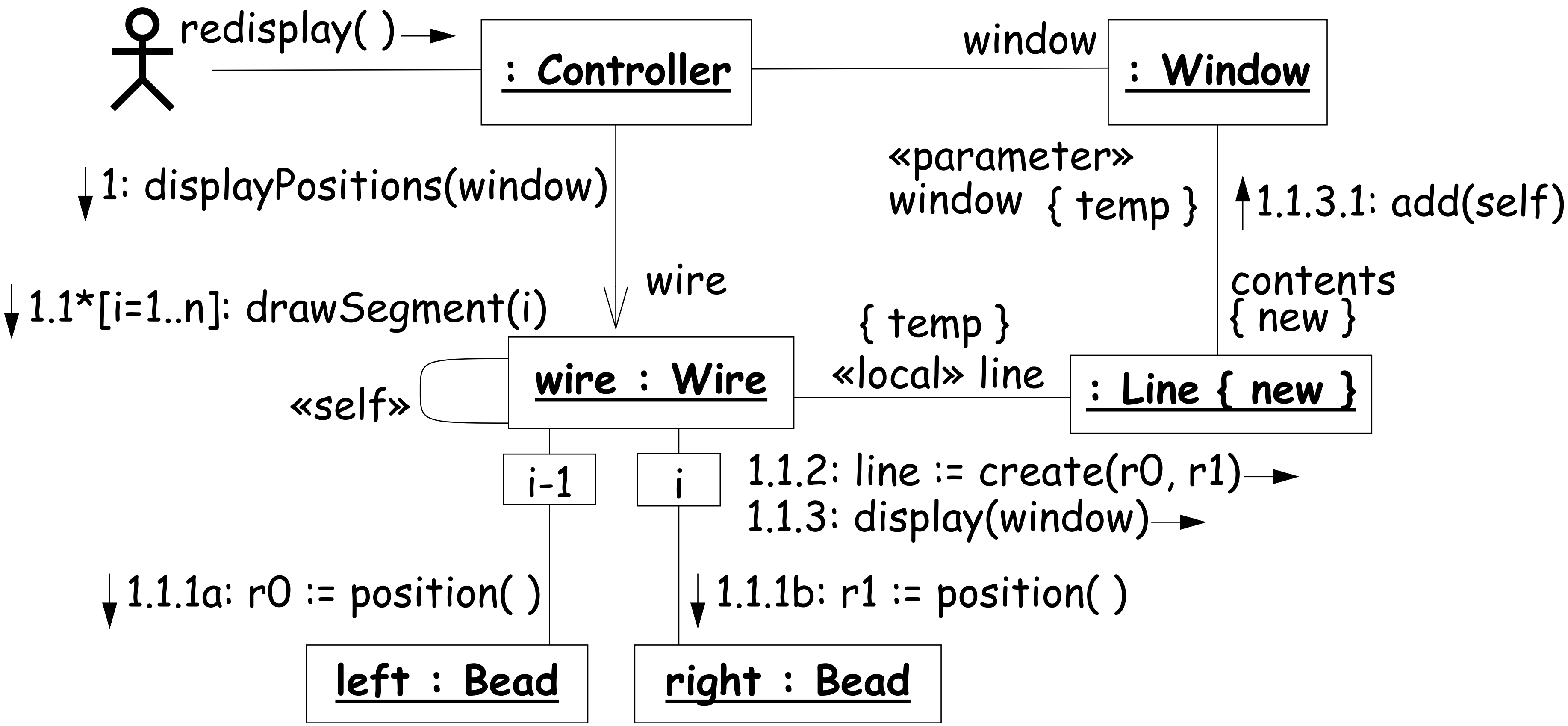


Half-stick arrowhead

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*.

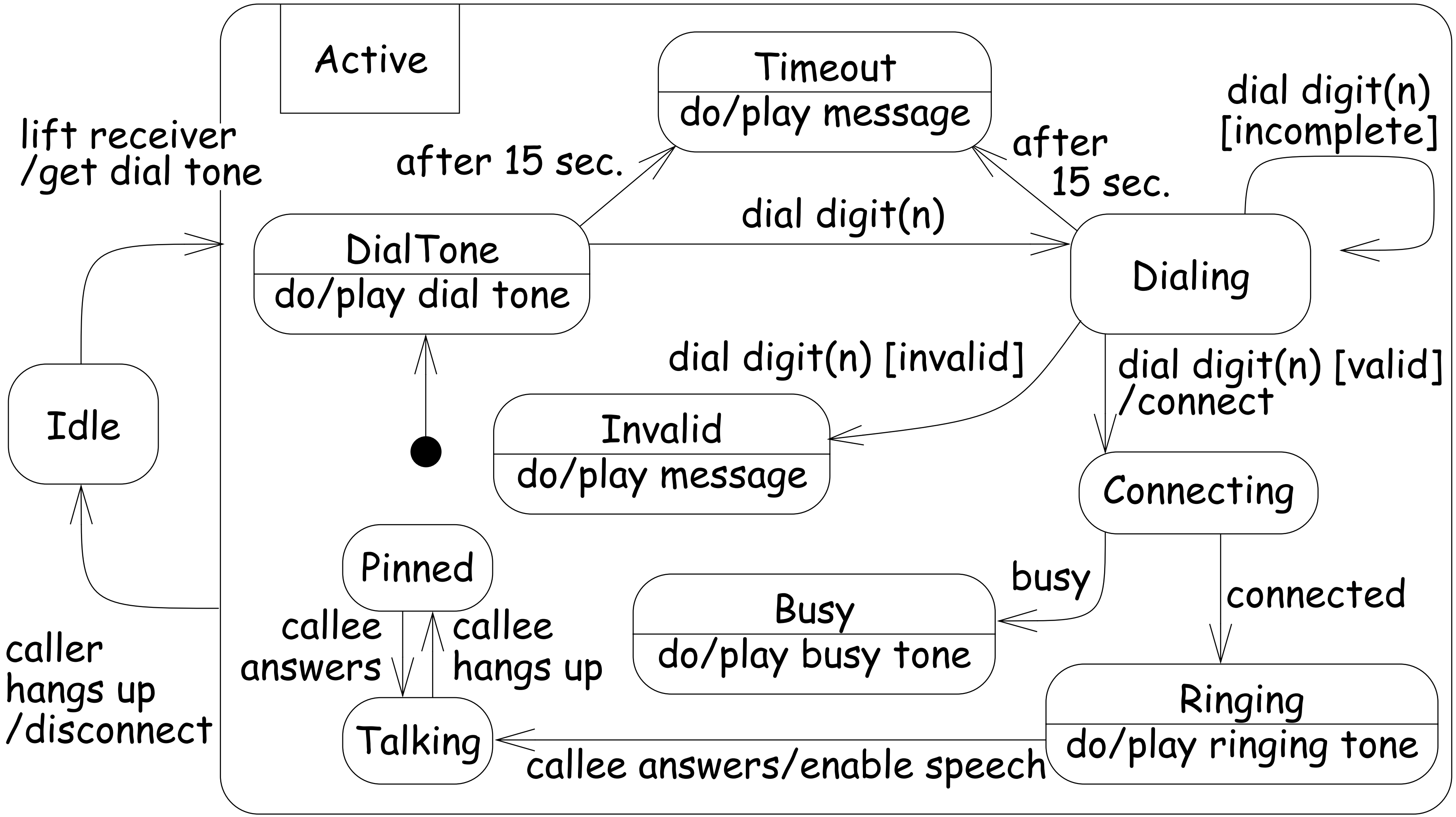
1. *Prior messages* from other threads (e.g. "[A1.3, B6.7.1]")
   - ☞ only needed with *concurrent* flow of control
2. *Dot-separated list* of sequencing elements
   - ☞ *sequencing* integer (e.g., "3.1.2" is invoked by "3.1" and follows "3.1.1")
   - ☞ letter indicating *concurrent* threads (e.g., "1.2a" and "1.2b")
   - ☞ *iteration* indicator (e.g., "1.1*[i=1..n]")
   - ☞ *conditional* indicator (e.g., "2.3 [#items = 0]")

...

Message Labels ...

3. *Return value* binding (e.g., “status :=”)
4. Message *name*
   ☞ event or operation name
5. Argument list

State Diagrams



State Diagram Notation

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

An <u>*event*</u> 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

...

State Diagram Notation ...

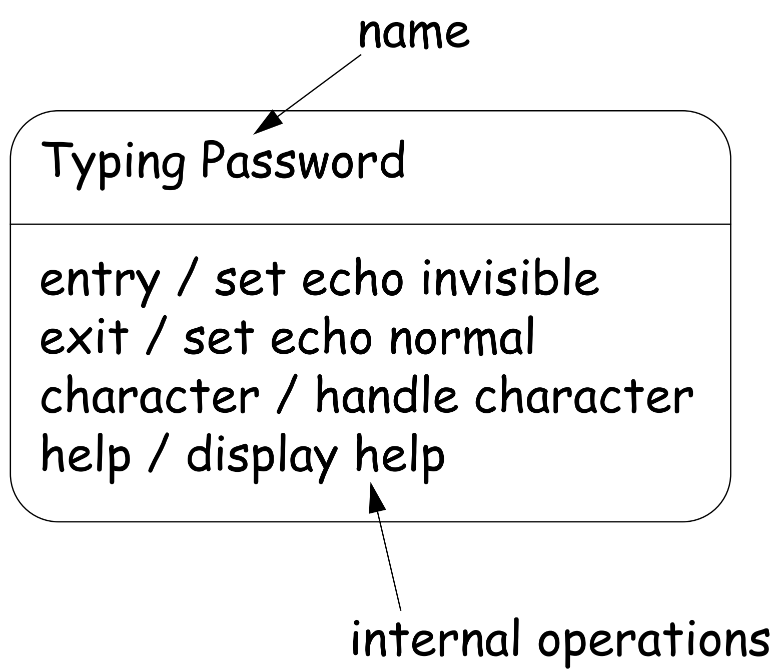
A *state* is a period of time during which an object is *waiting* for an event to occur:

- 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

A <u>*transition*</u> is an *response* to an external *event* received by an object in a given *state*

- May *invoke* an operation, and cause the object to *change state*
- May *send* an event to an external object
- Transition syntax (each part is optional):

  event(arguments) [condition]
  / ^target.sendEvent operation(arguments)
- *External* transitions label arcs between states
- *Internal* transitions are part of the triggered operations of a state

Operations and Activities

An *operation* is an *atomic action* invoked by a *transition*

- *Entry* and *exit* operations can be associated with states

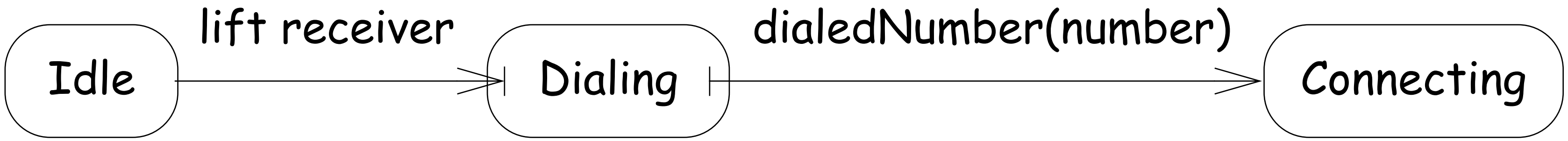
An *activity* is an *ongoing operation* that takes place while object is in a given state

- Modelled as "internal transitions" labelled with the pseudo-event **do**

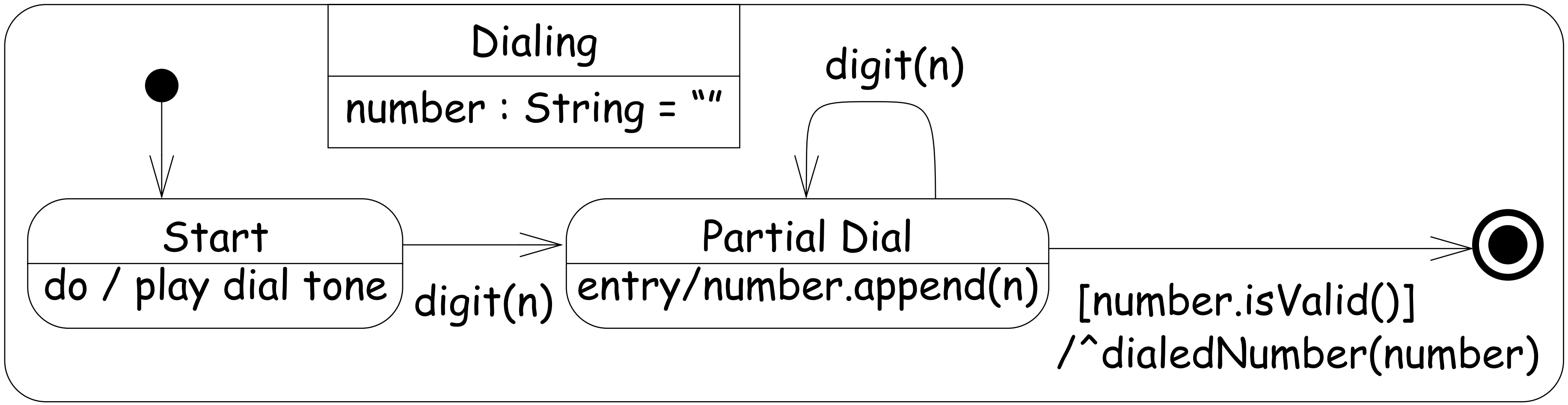
Composite States

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

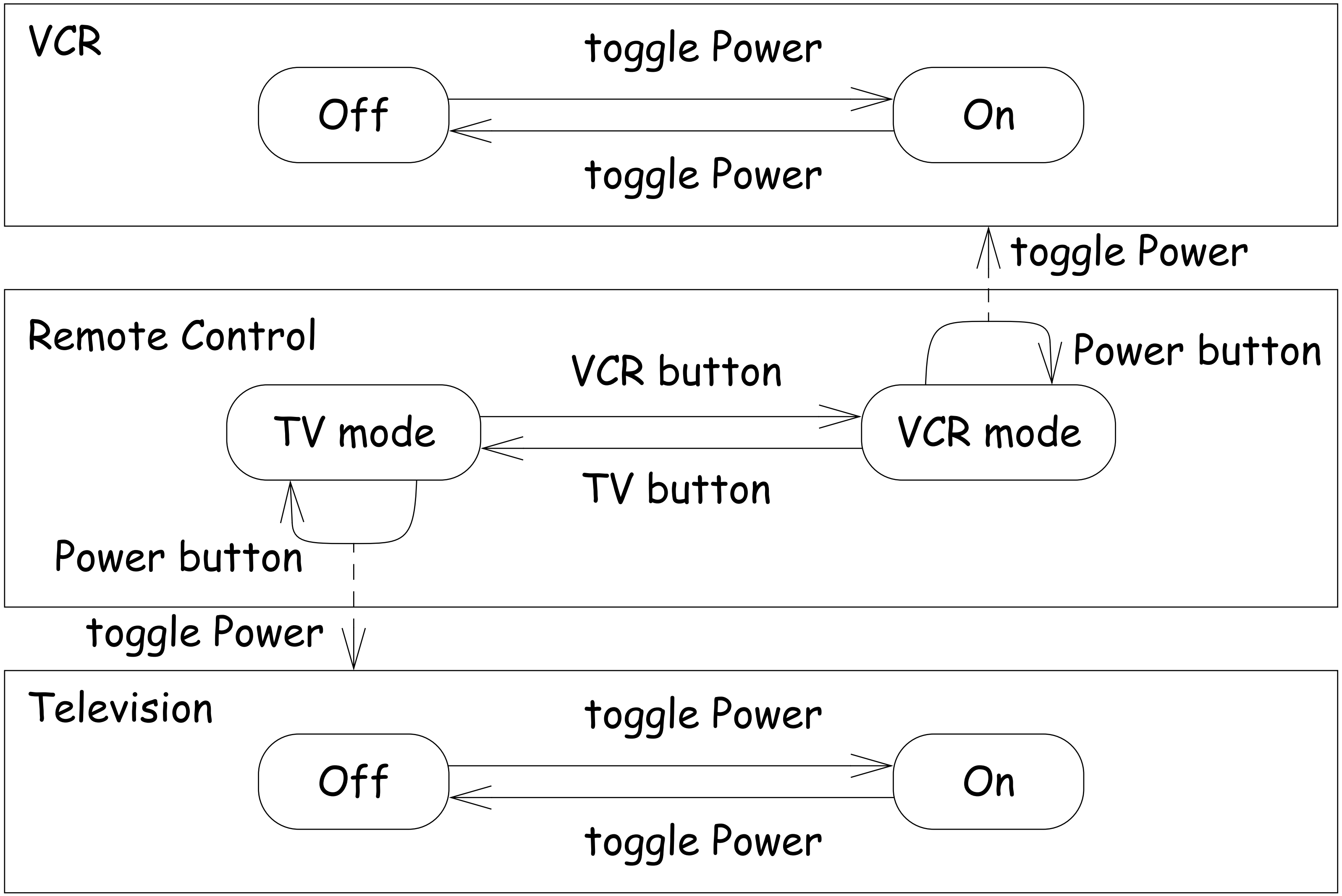
"Stubbed transitions" indicate the presence of internal states:



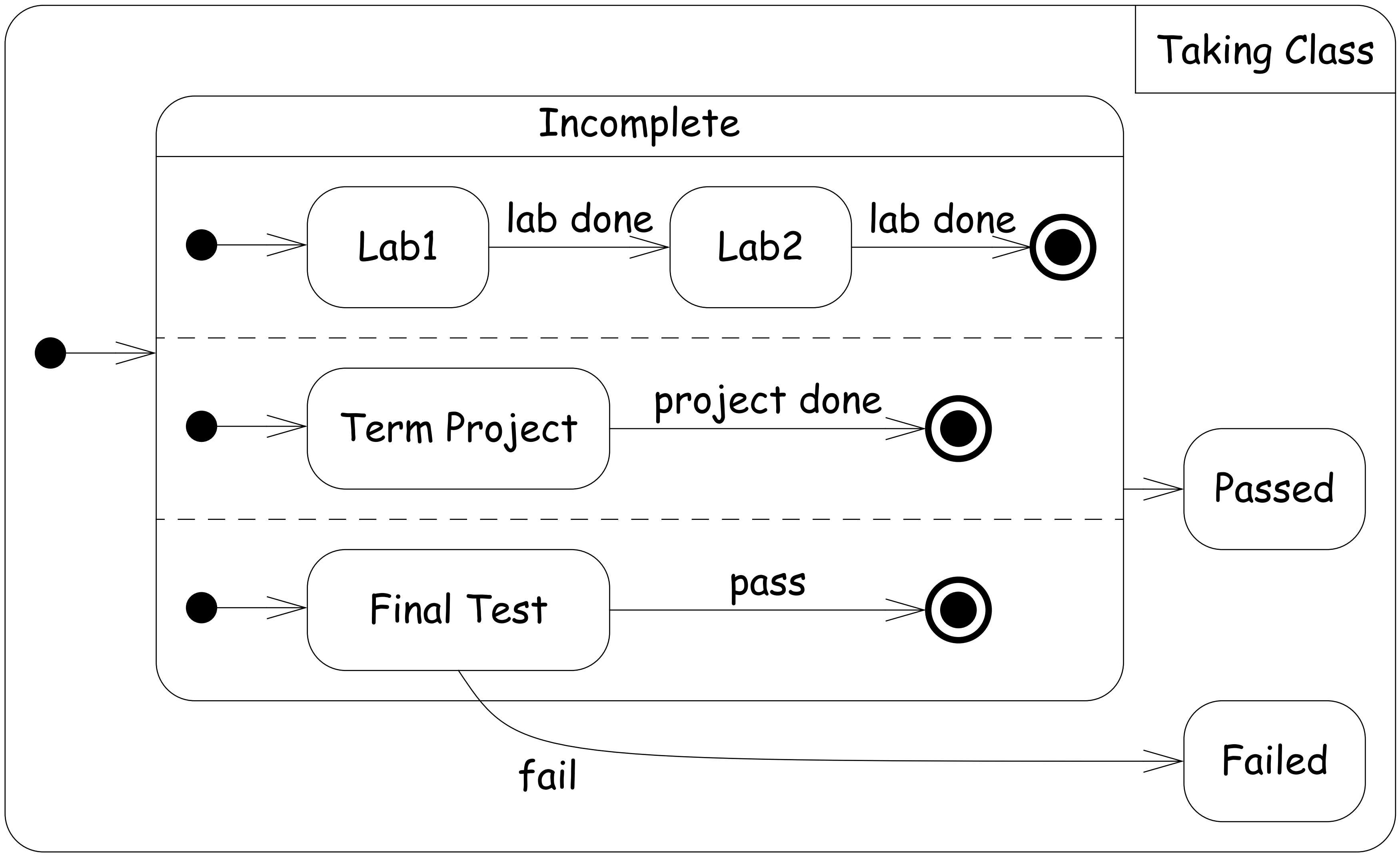
Initial and terminal substates are shown as black spots and "bulls-eyes":



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:

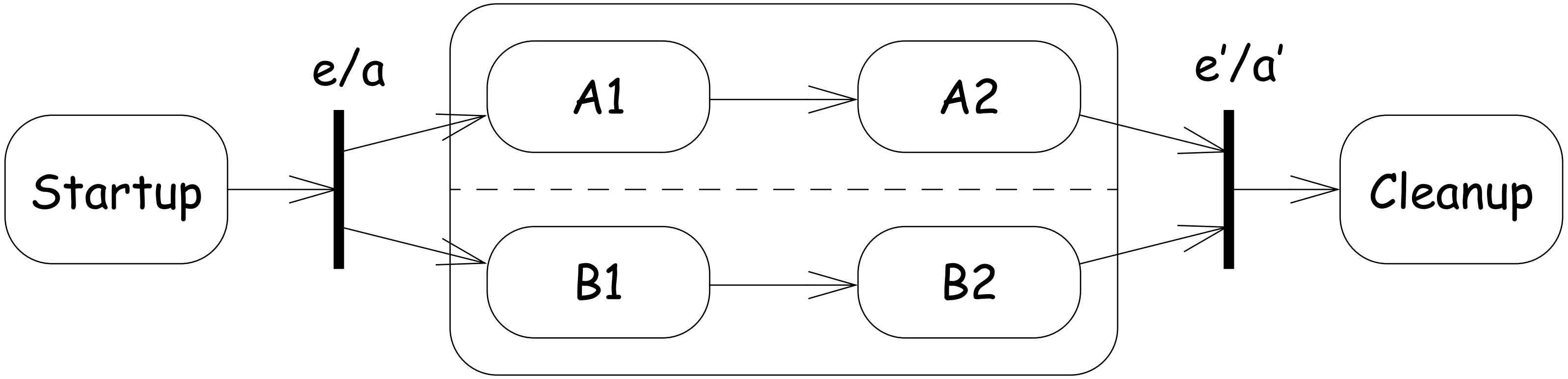
A *labelled transition* out of any of the substates *terminates all* of the substates.

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

...

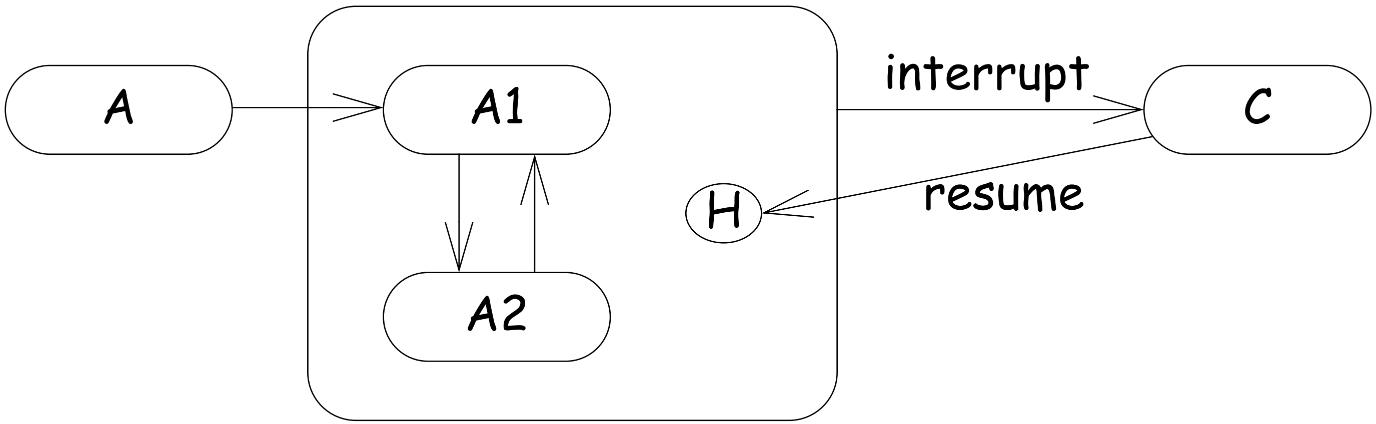
Branching and Merging ...

An alternative notation for explicit branching and merging uses a "*synchronization bar*":



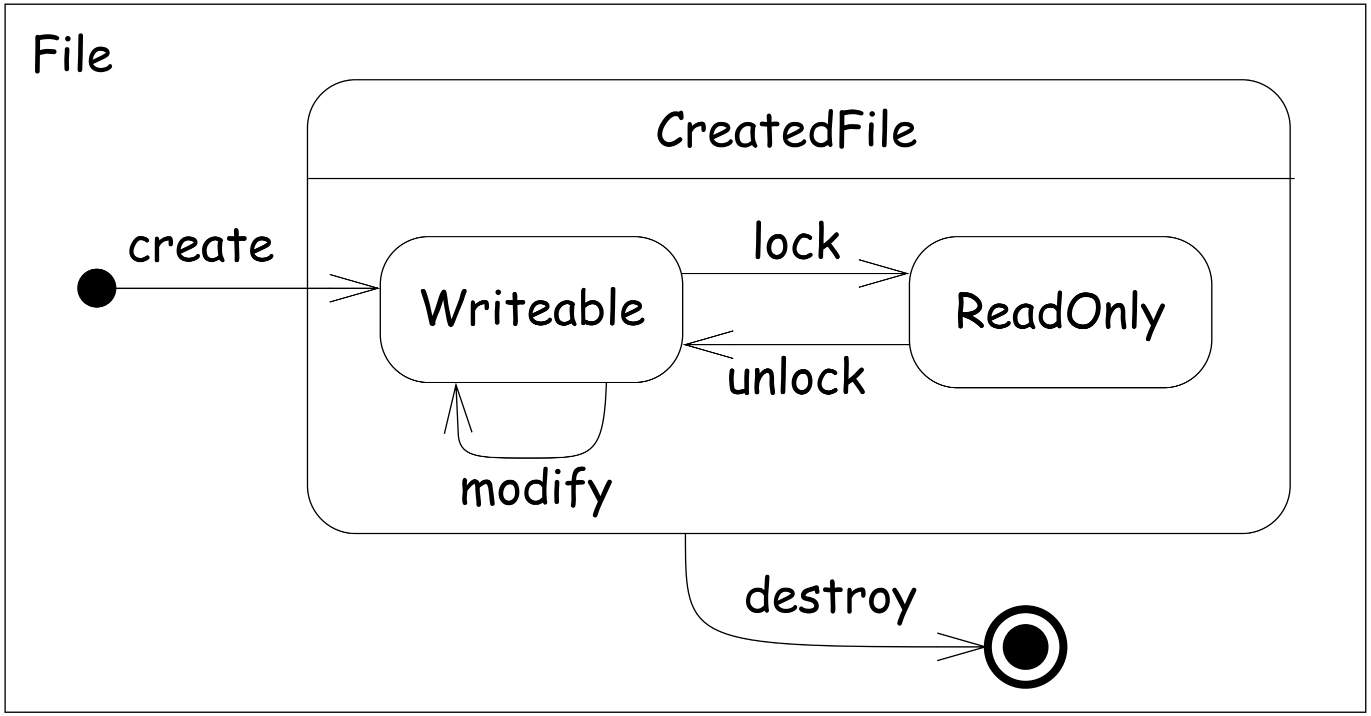
History Indicator

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

What you should know!

- *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?*

8. Software Architecture

Overview:

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

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.

— D'Souza & Wills

What is Software 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.

...

How Architecture Drives Implementation ...

- 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.

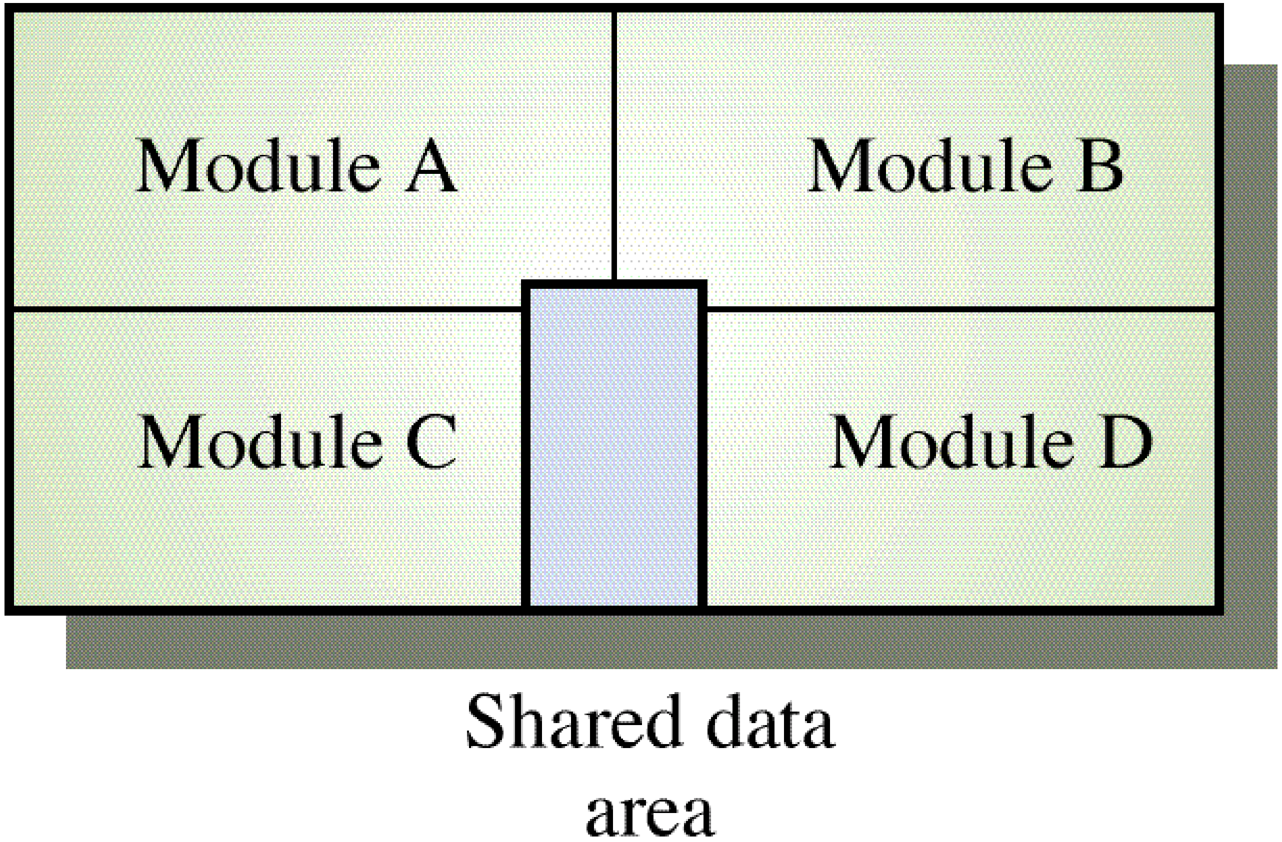
There are many definitions and interpretations of cohesion. *Most attempts to formally define it are inadequate!*

Coupling

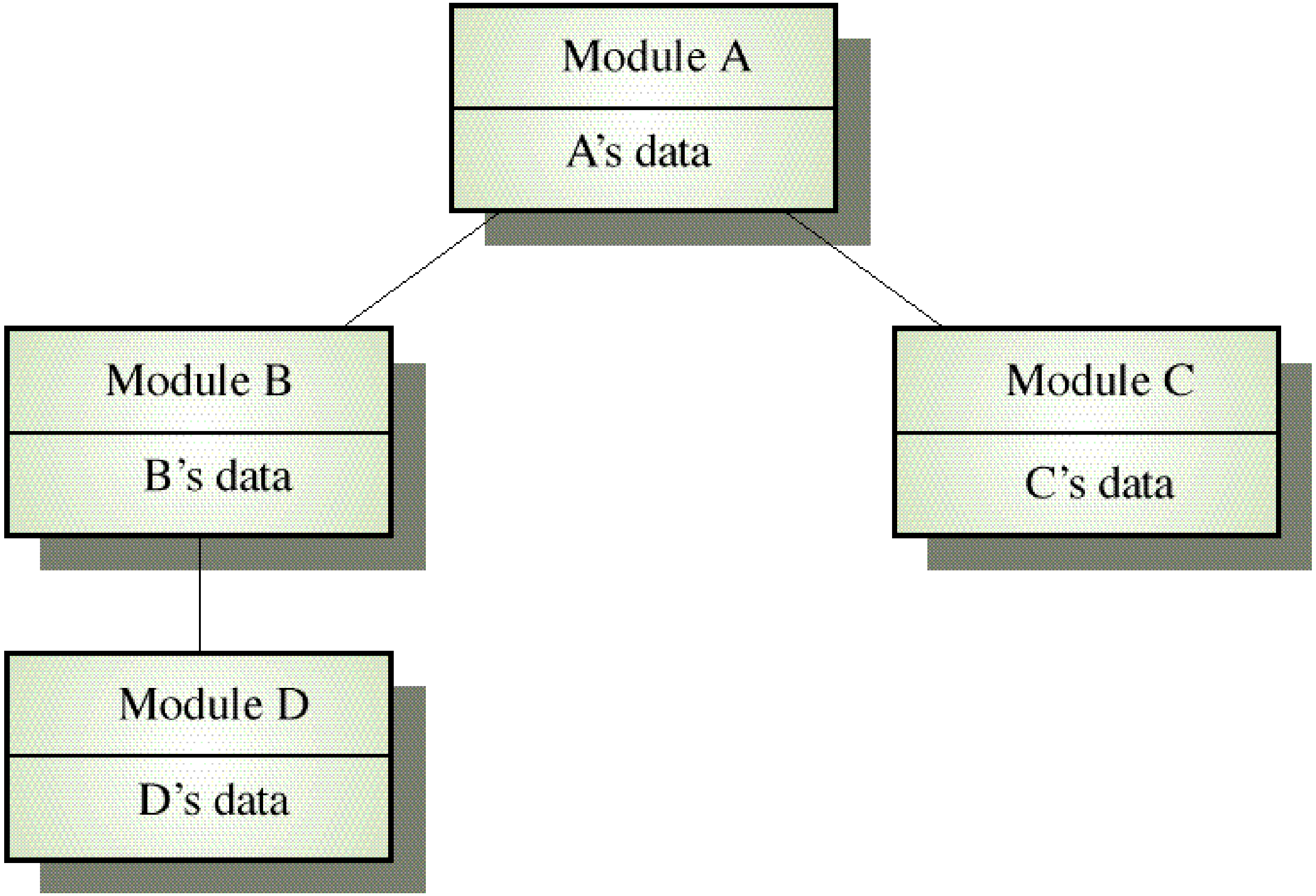
Coupling is a measure of the *strength of the interconnections* between system components.

- 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 others*.

Tight Coupling



Loose Coupling



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

Architectural Styles

An <u>architectural style</u> 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.

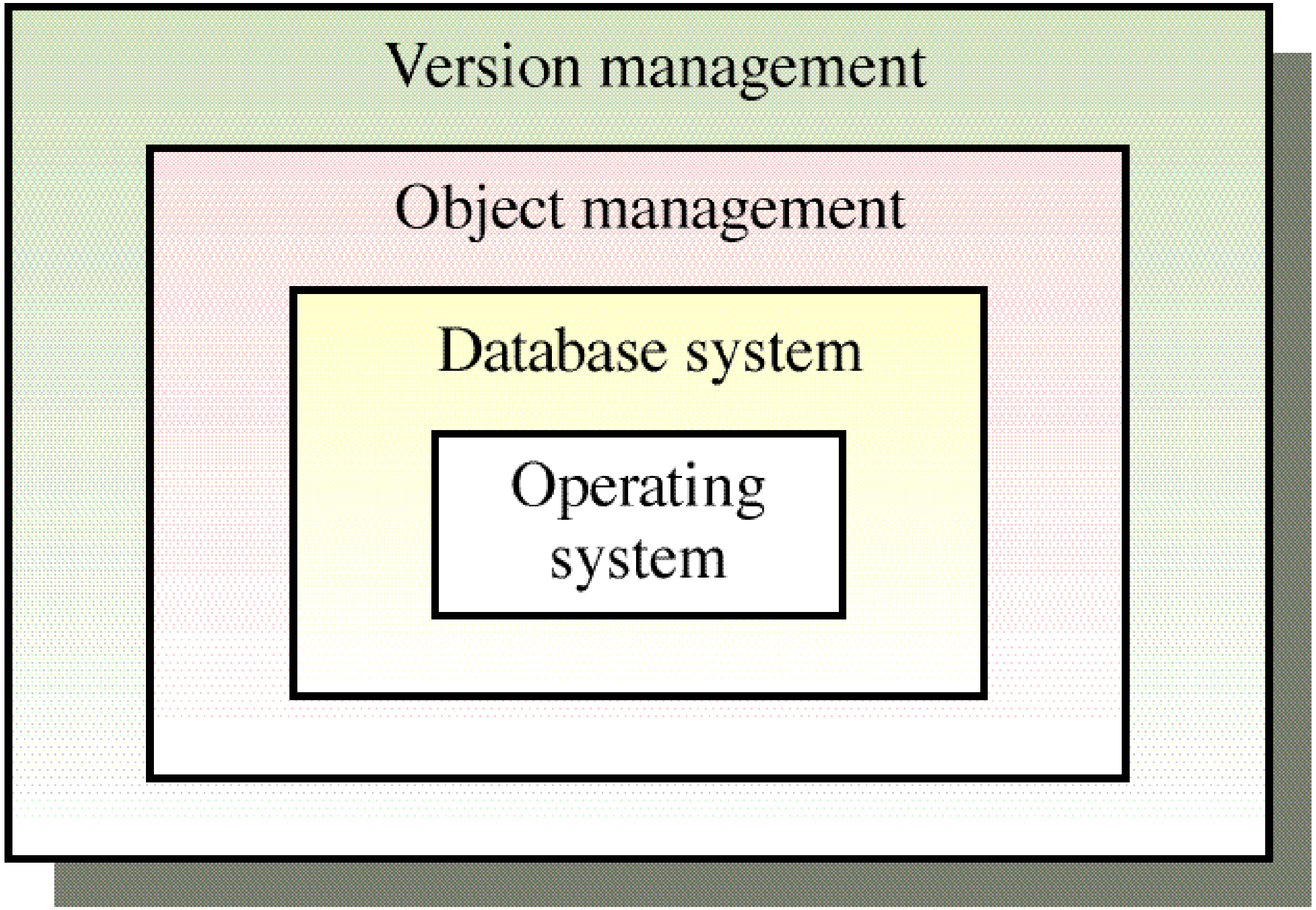
— Shaw and Garlan

Layered Architectures

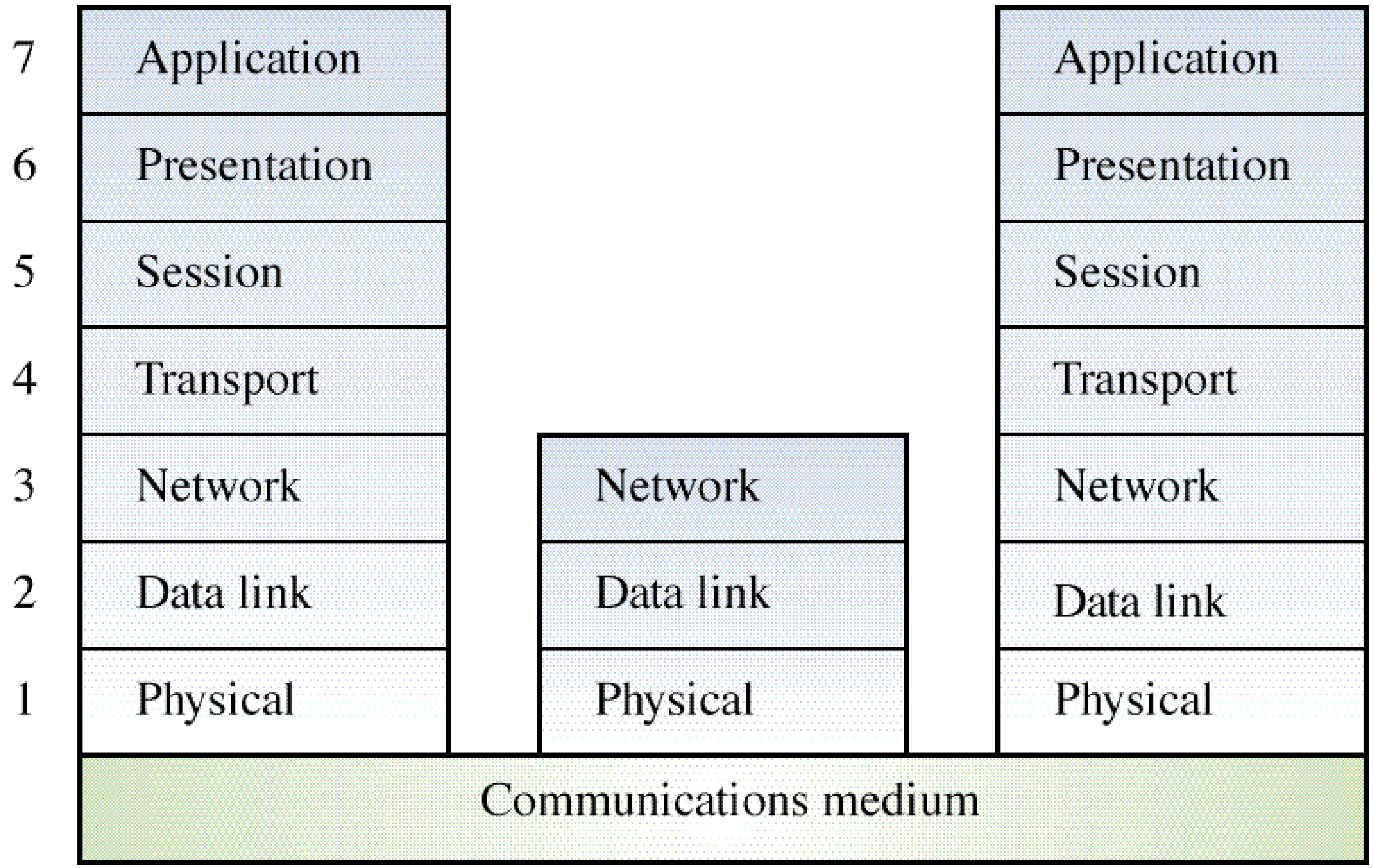
A *layered architecture* organises a system into a set of layers each of which *provide a set of services to the layer "above".*

- 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



OSI Reference Model



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

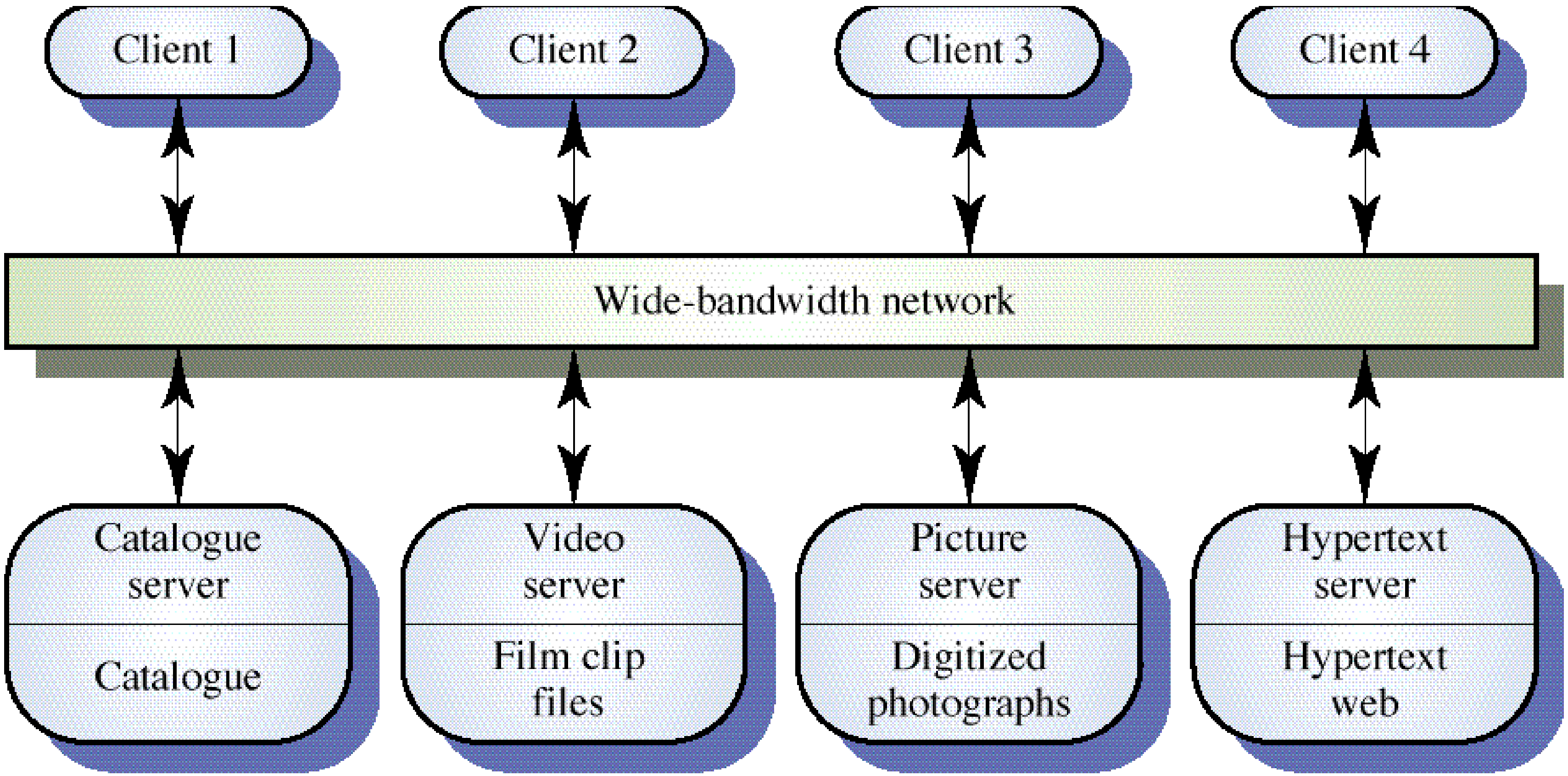
...

Client-Server Architectures ...

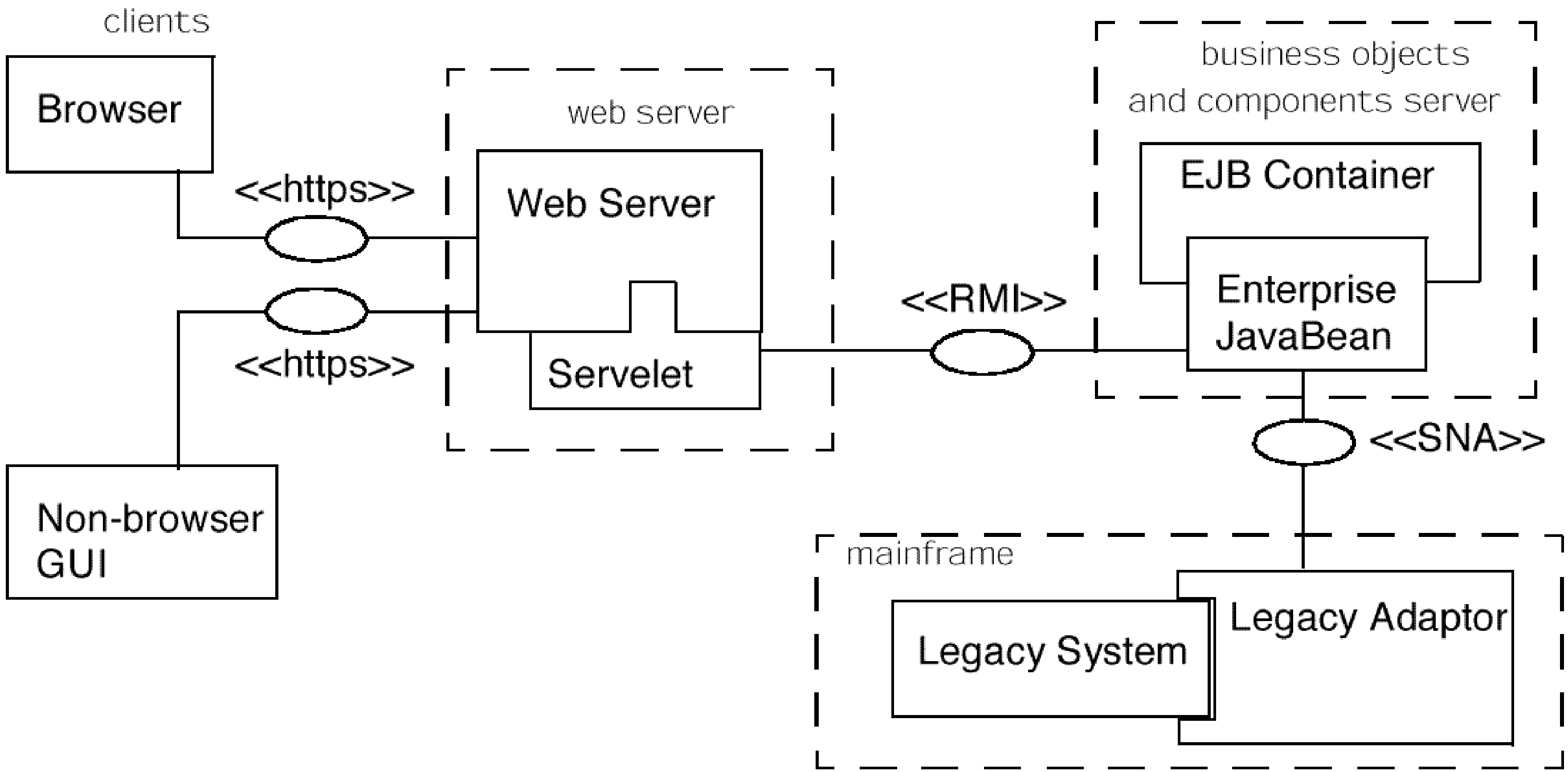
Disadvantages

- *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 registry* of names and services — it may be hard to find out what servers and services are available

Client-Server Architectures



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*

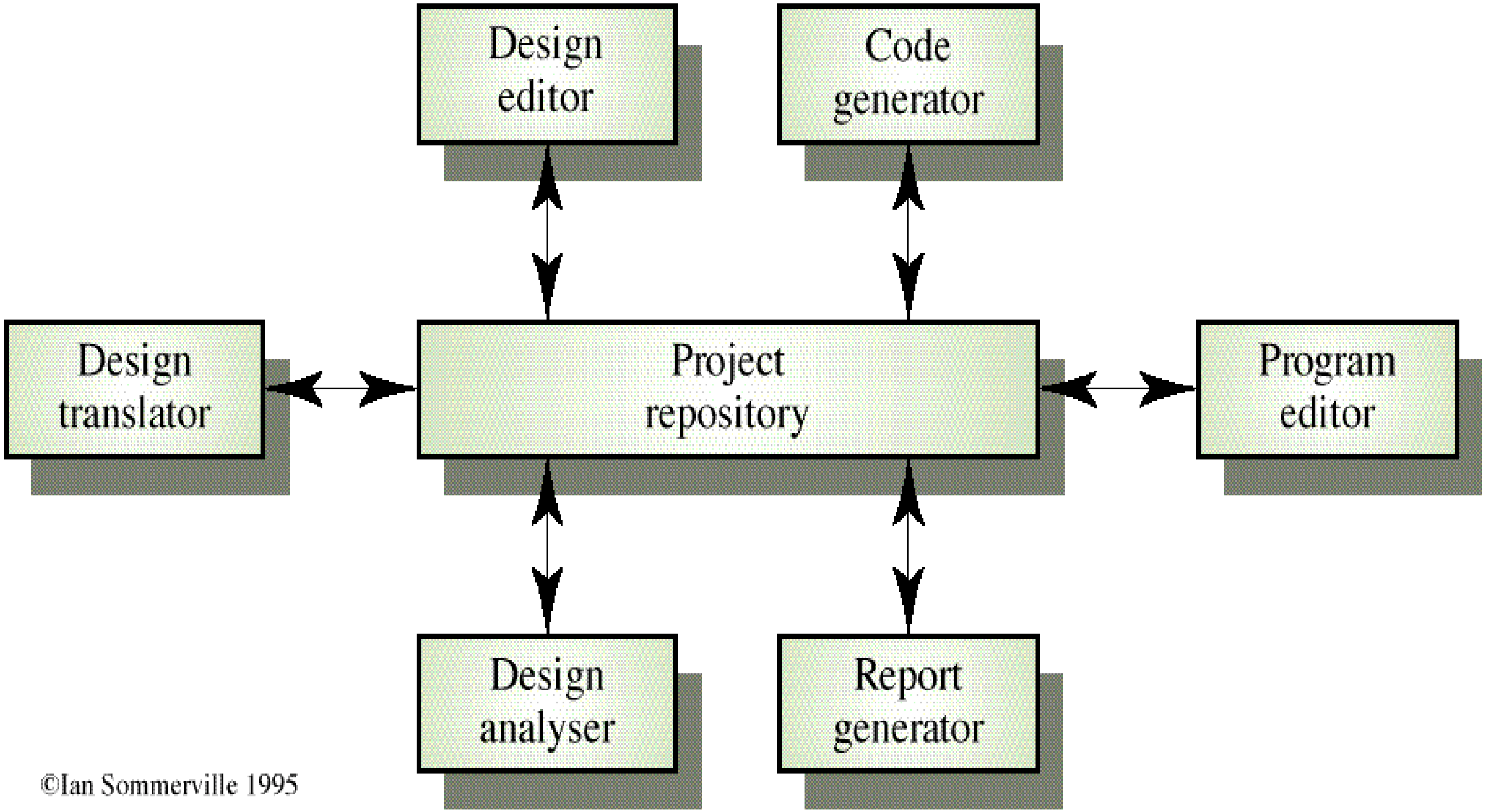
...

Blackboard Architectures ...

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

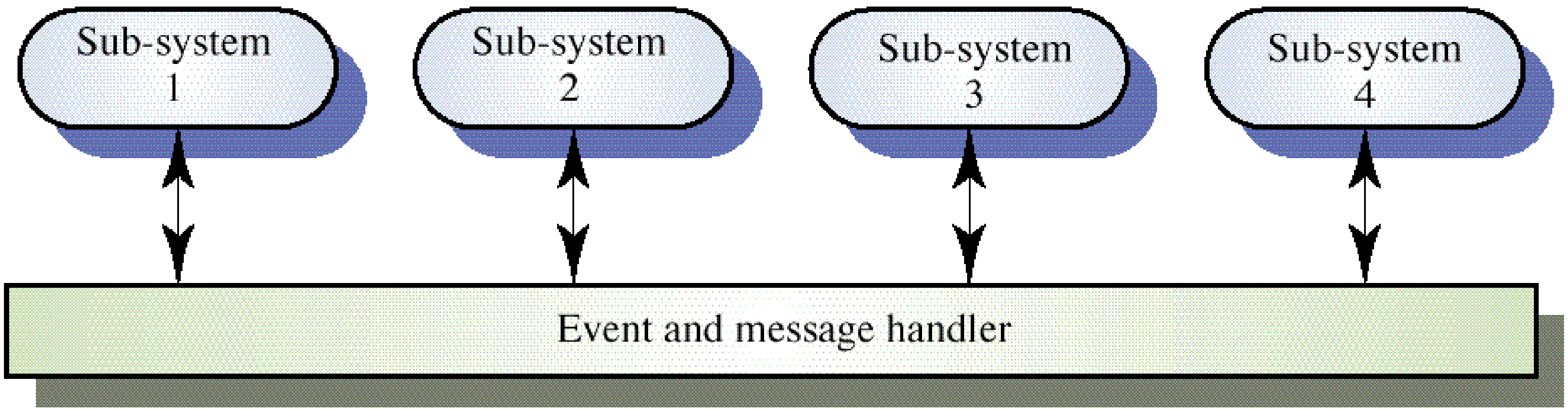
In an *event-driven architecture* components perform services in reaction to *external events* generated by other components.

- 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



Dataflow Models

In a _dataflow architecture_ each component performs *functional transformations* on its *inputs* to produce *outputs*.

- Highly effective for *reducing latency* in parallel or distributed systems
  - ☞ No call/reply overhead
  - ☞ But, fast processes must *wait* for slower ones
- *Not* really suitable for *interactive systems*
  - ☞ Dataflows should be *free of cycles*

...

Dataflow Models ...

Examples:

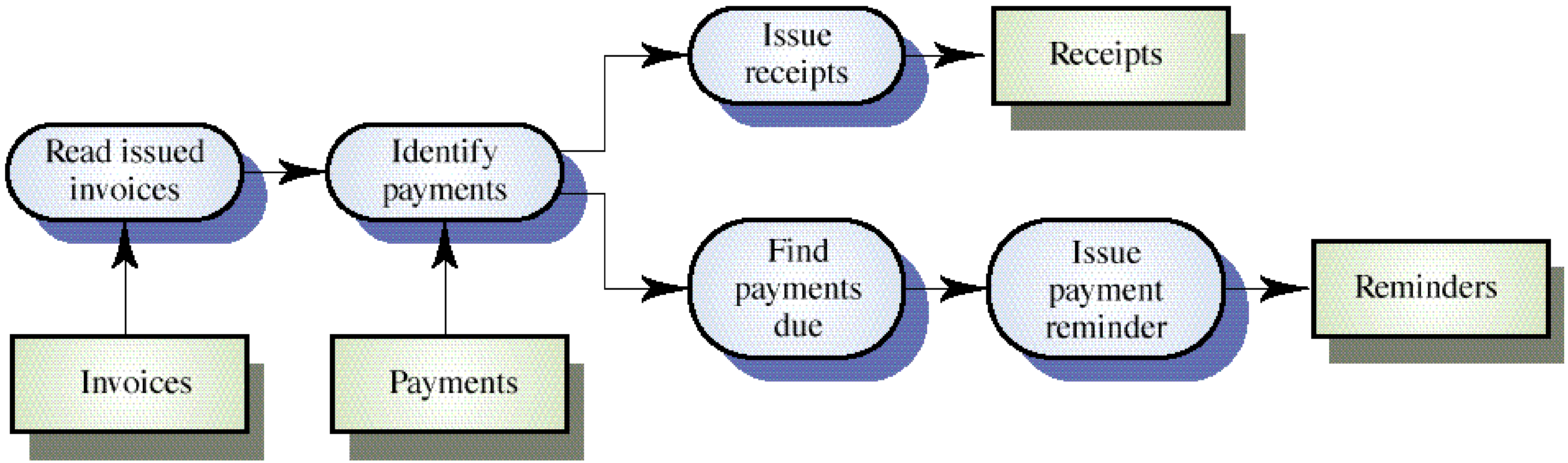
- The single-input, single-output variant is known as *pipes and filters*
  - ☞ e.g., UNIX (Bourne) shell

Data source	*Filter*	*Data sink*
`tar cf - .`	`gzip -9`	`rsh picasso dd`

  - ☞ e.g., CGI Scripts for interactive Web-content

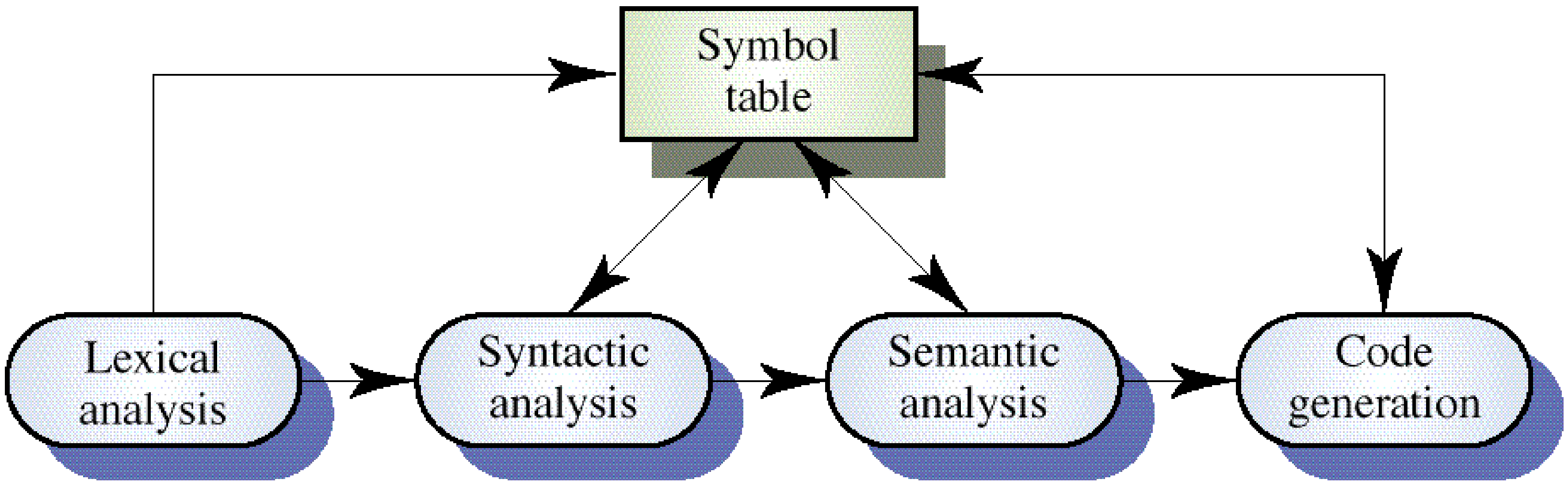
Data source	*Filter*	*Data sink*
`HTML Form`	`CGI Script`	`generated HTML page`

Invoice Processing System

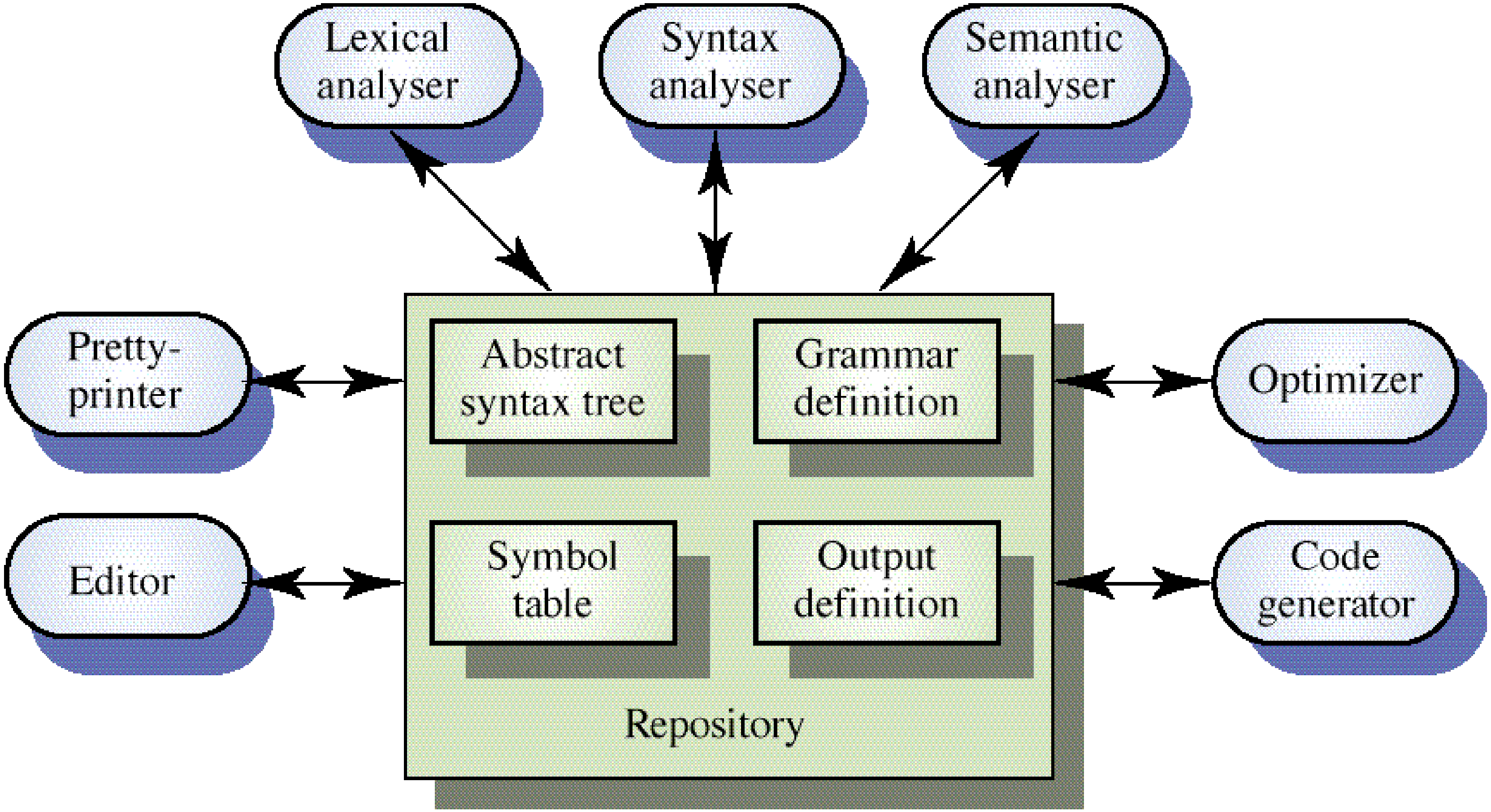


©Ian Sommerville 1995

Compilers as Dataflow Architectures

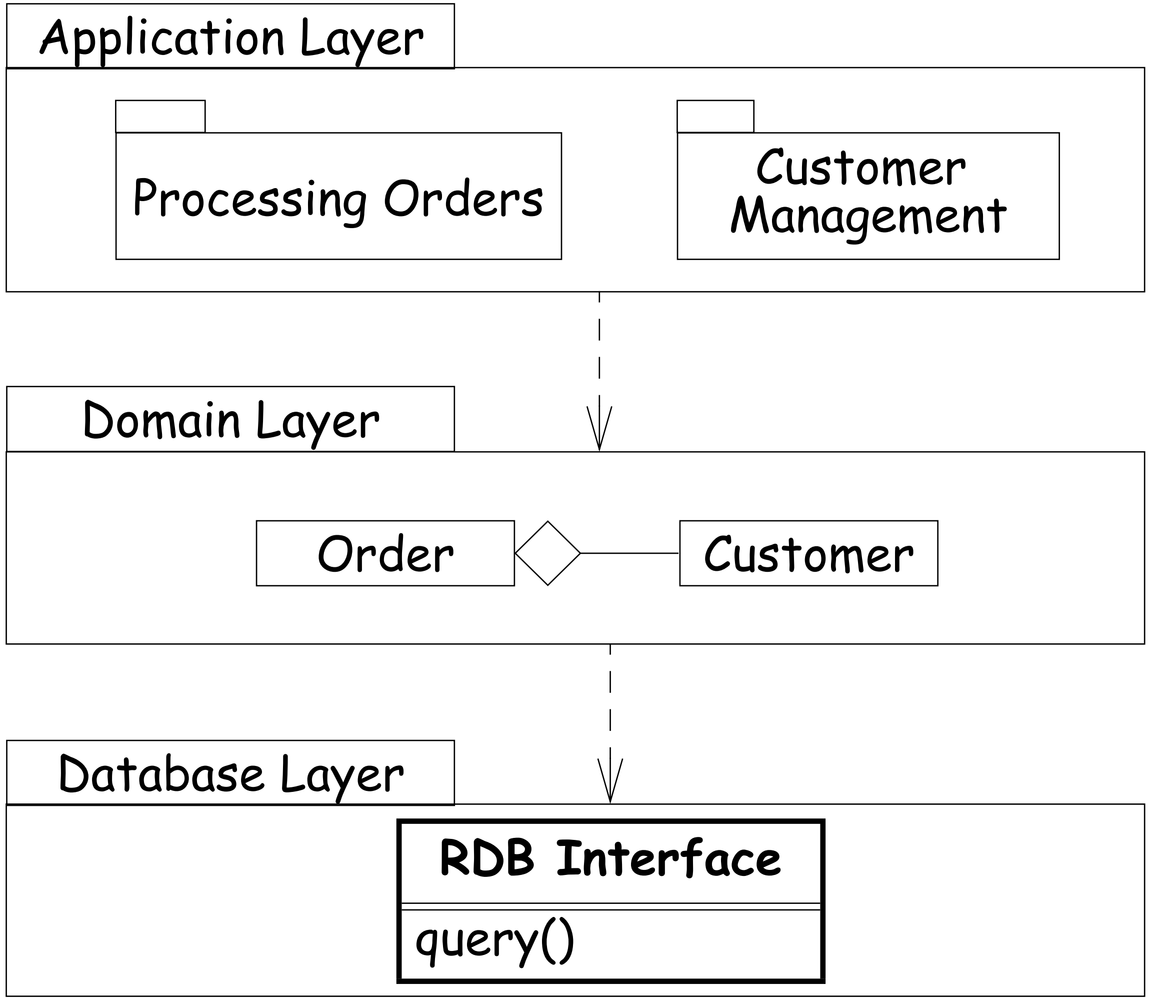


Compilers as Blackboard Architectures



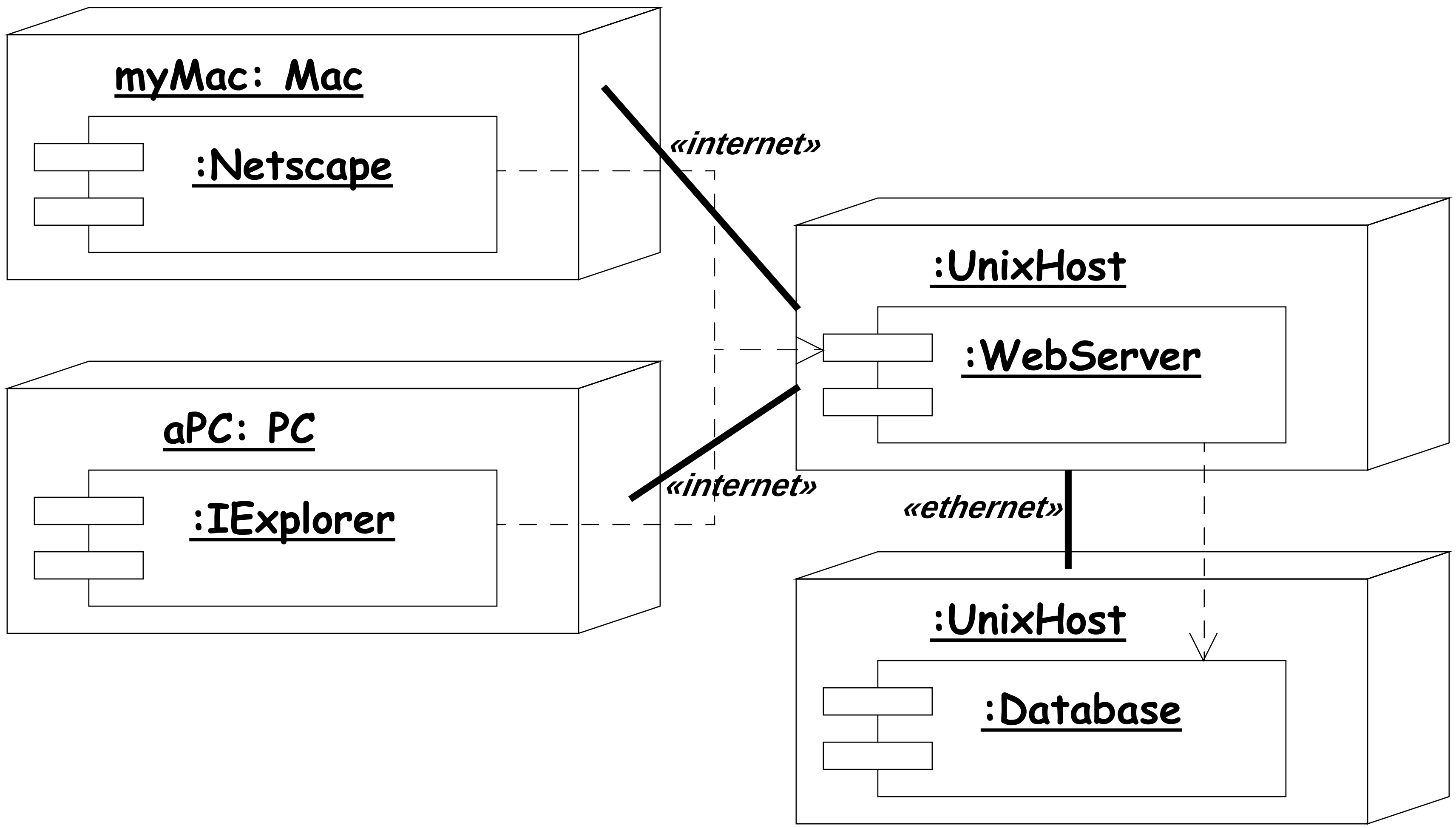
UML support: Package Diagram

Decompose system into *packages* (containing any other UML element, incl. packages)



UML support: Deployment Diagram

Physical layout of run-time components on hardware nodes.



What you should know!

- 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?*

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).

Characteristic	*Description*
Pointing	A pointing device such as a mouse is used for *commands* choices from a menu or indicating items of interest in a window.
Graphics	Graphical elements can be *commands* 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

...

GUI (dis) advantages ...

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*.

Principle	*Description*
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 and graphics editors

...

Direct Manipulation ...

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.

...

Menu Systems ...

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

...

Command Interfaces ...

Advantages

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

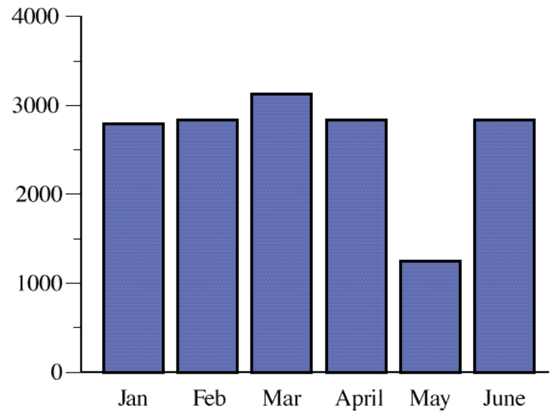
Problems

- 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 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



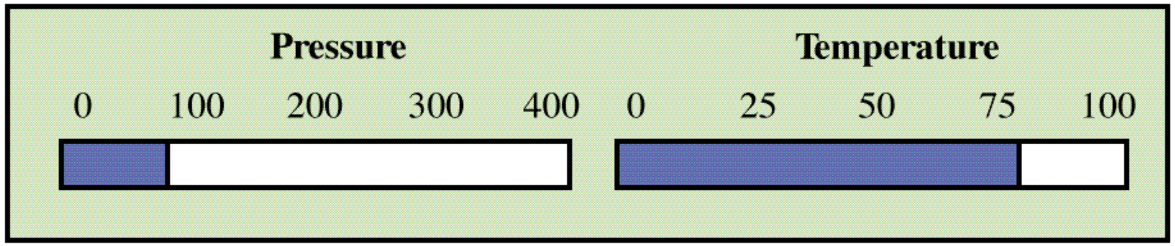
Analogue vs. Digital Presentation

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 Use Guidelines

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

- ❑ *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

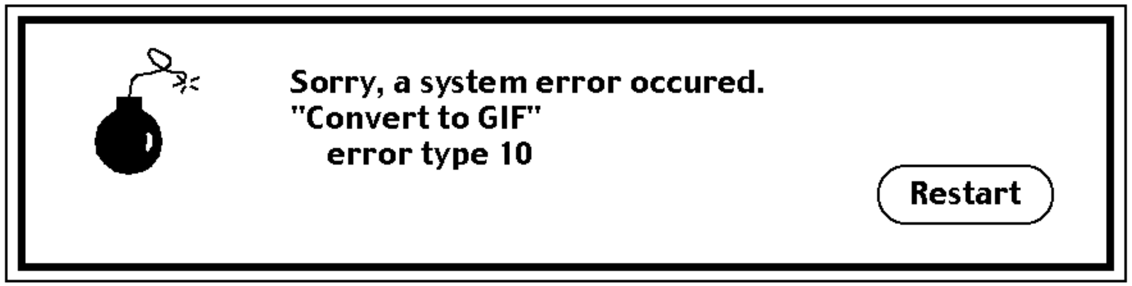
Context	The user guidance system should be aware of what the user is doing and should *adjust the output message to the current context*.
Experience	The user guidance system should provide both longer, *explanatory messages for beginners*, and more *terse messages for experienced users*.
Skill level	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?

What you should know!

- 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 short-cuts" 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.

Kinds of failures

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

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

...

Common Sources of Software Faults ...

- *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!)

...

Approaches to Fault Tolerance ...

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.

...

Defensive Programming ...

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

Verification:

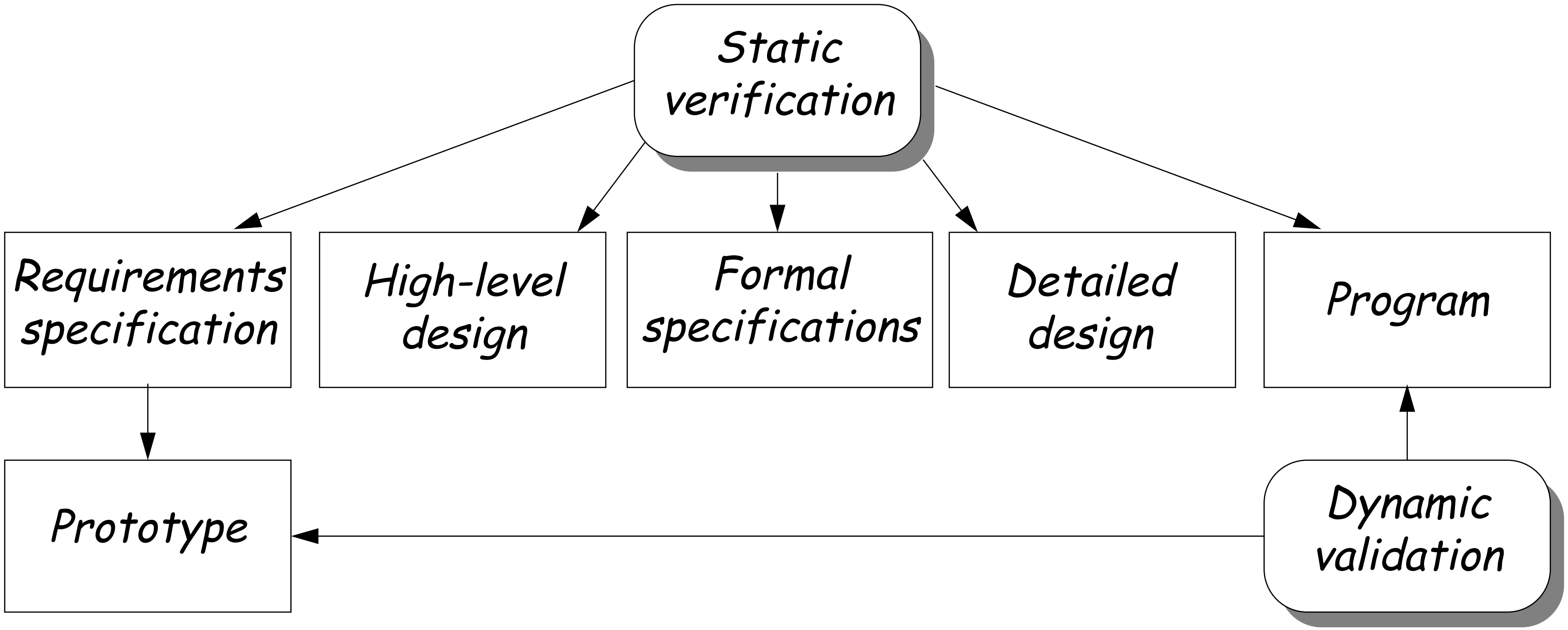
- Are we *building the product right*?
  - — i.e., does it conform to specs?

Validation:

- Are we building the *right product*?
  - — i.e., does it meet expectations?

...

Verification and Validation ...



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.

...

The Testing Process ...

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

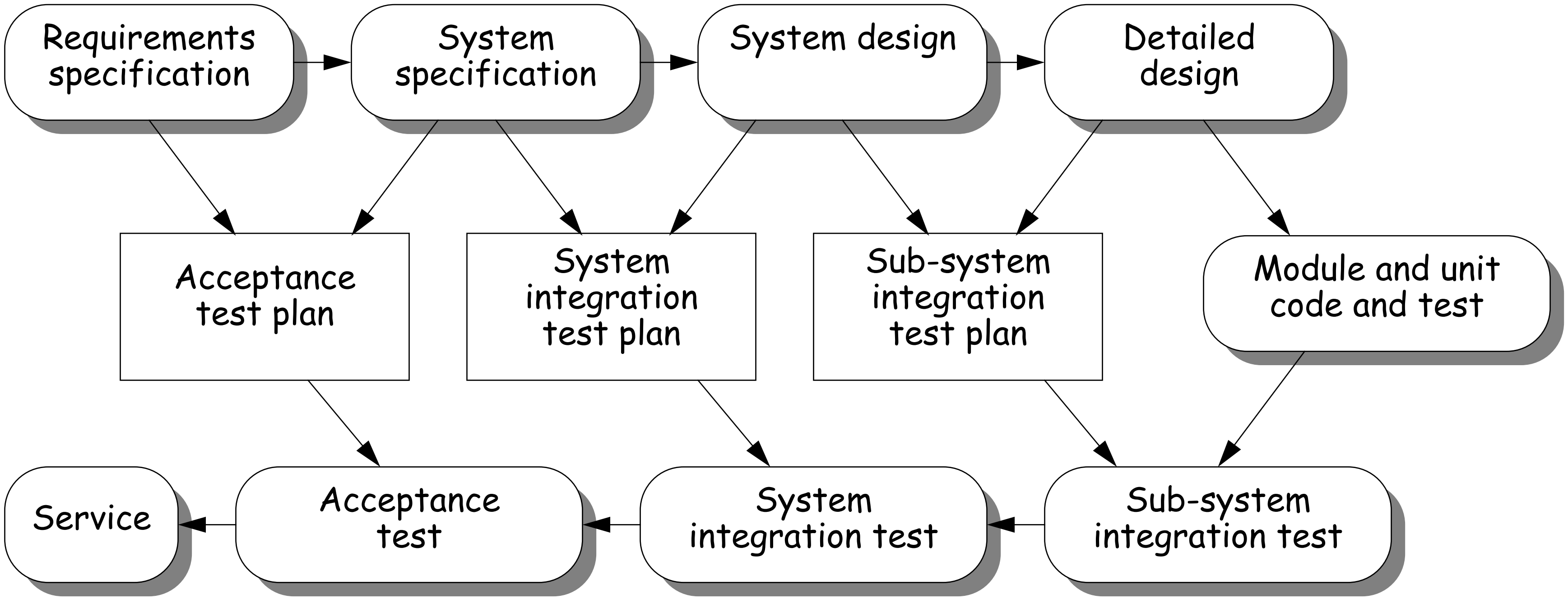
<u>*Regression testing*</u> means testing that everything that used to work *still works* after changes are made to the system!

- 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!

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* where the software process iterates.

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.

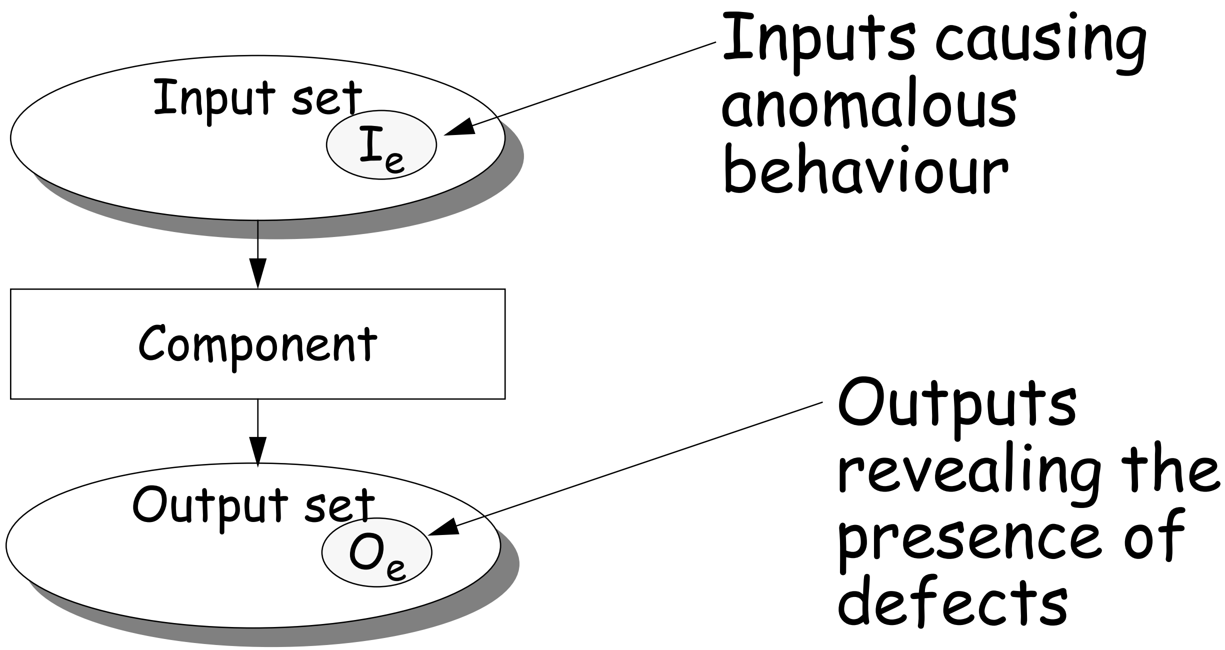
Defect Testing ...

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 (black box) testing

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



Coverage Criteria

Test cases are derived from the *external* specification of the component and should cover:

- all exceptions
- all data ranges (incl. invalid) generating different classes of output
- all boundary values

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* ...

Equivalence partitioning

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

Check input partitions:

- Do the inputs fulfil the *pre-conditions*?
  - ☞ is the array sorted, non-empty ...
- 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

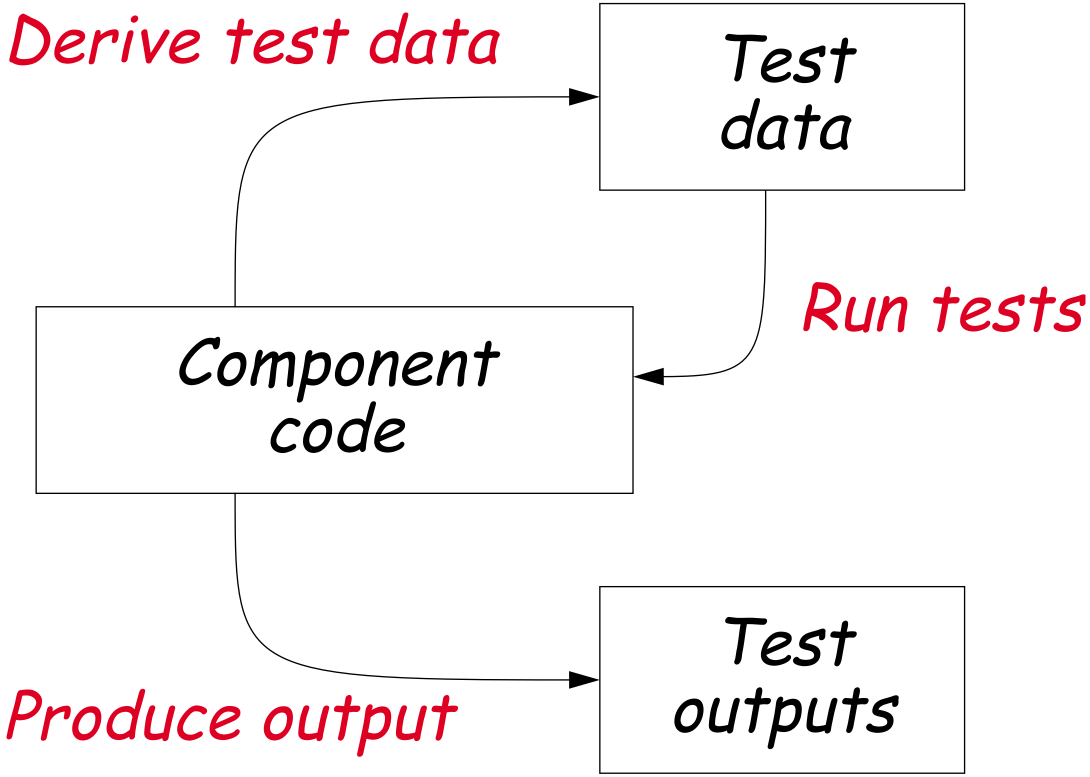
Generate test data that *cover all meaningful equivalence partitions*.

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 (white box) Testing

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

Derive test cases to *maximize coverage* of that structure, yet *minimize number of test cases*.



Coverage criteria

- every *statement* at least once
- all *portions of control flow* at least once
- all possible *values of compound conditions* at least once
- all portions of *data flow* at least once
- for all *loops* L, with n allowable passes:
  - (i) skip the loop;
  - (ii) 1 pass through the loop
  - (iii) 2 passes
  - (iv) m passes where $2 < m < n$
  - (v) n-1, n, n+1 passes

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

Binary Search Method

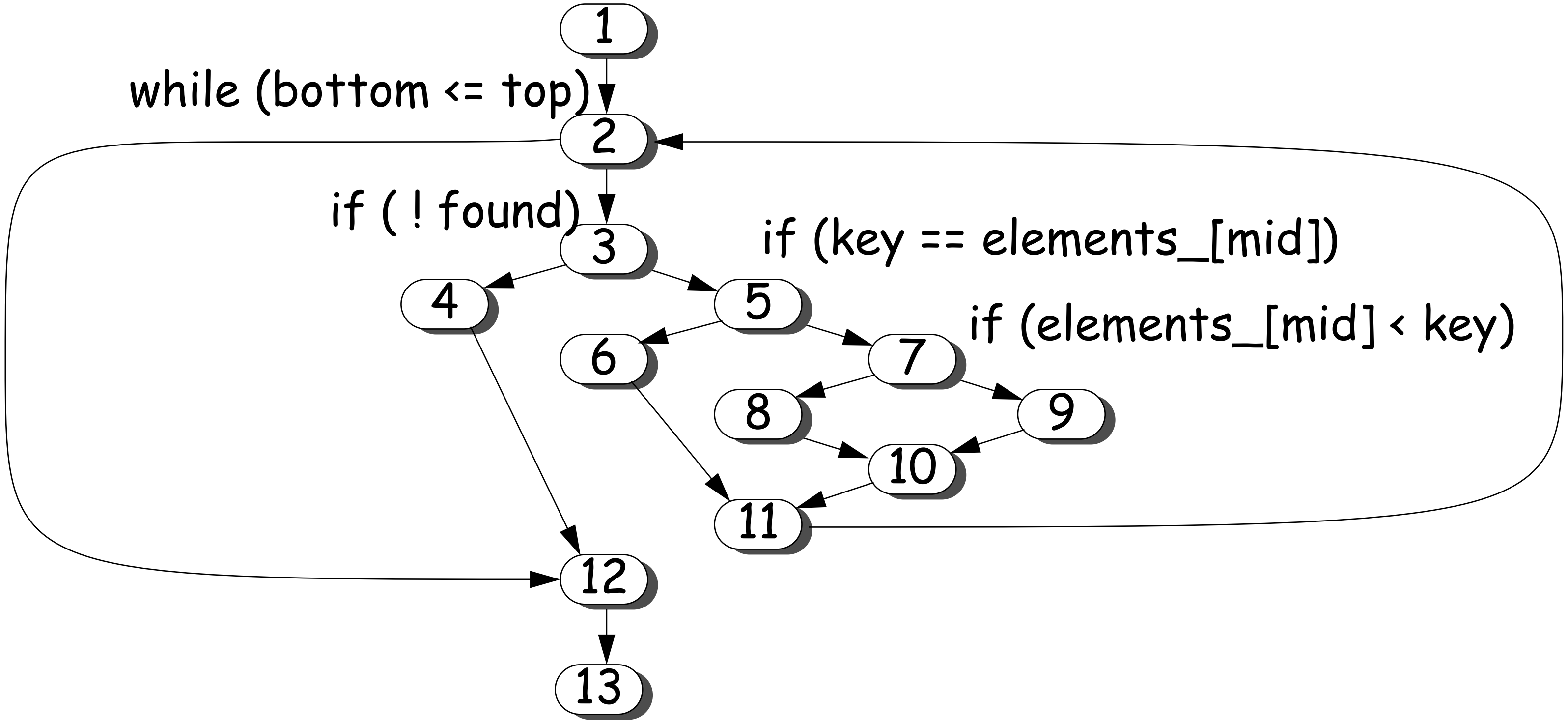
```
public boolean find(int key)
    throws assertionViolation {          // (1)
  assert(isSorted()); // pre-condition
  if (isEmpty()) { return false; }
  int bottom = 0;
  int top = elements_.length-1;
  int lastIndex = (bottom+top)/2;
  int mid;
  boolean found = key == elements_[lastIndex];

  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

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



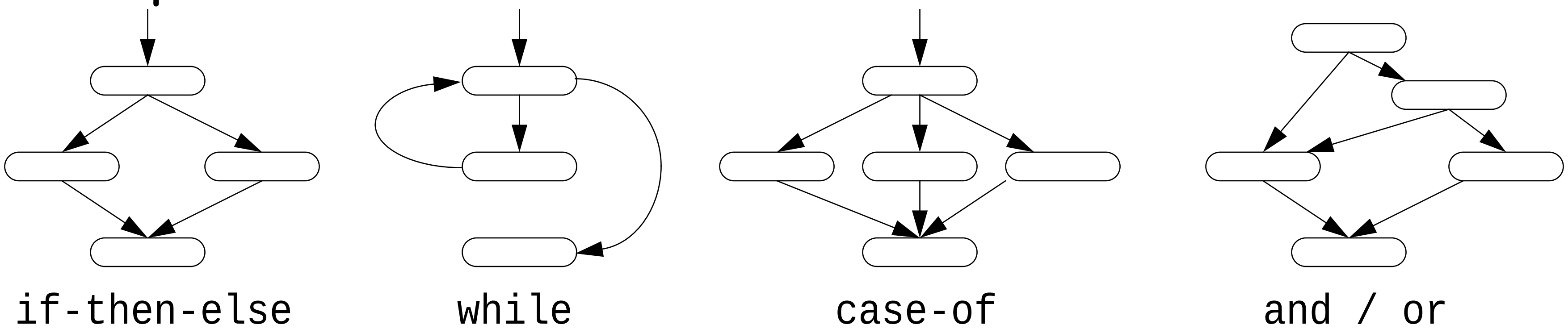
e.g., {1,2,12,13}, {1,2,3,4,12,13}, {1,2,3,5,6,11,2,12,13}, {1,2,3,5,7,8,10,11,2,12,13}, {1,2,3,5,7,9,10,11,2,12,13} ...

Basis Path Testing: The Technique

See [Press92a]

1. Draw a *control flow graph*

   Nodes represent nonbranching statements; edges represent control flow.



2. Compute the *Cyclomatic Complexity*

   = #(edges) - #(nodes) + 2 = number of conditions + 1

...

Basis Path Testing ...

3. Determine a set of *independent paths*

   Several possibilities. Upper bound = Cyclomatic Complexity

4. Prepare *test cases* that force each of these paths

   Choose values for all variables that control the branches.

   Predict the result in terms of values and/or exceptions raised

5. Write *test driver* for each test case

Condition Testing

For complex boolean expressions, Basis Path Testing is not enough! Input values {x = 3, y=4} and {x = 4, y=3} will exercise all paths, but consider {x = 3, y=3} ...

- *Condition Testing* exercises all logical conditions
- *Domain Testing*: for each occurrence of <, <=, =, <>, >= 3 tests

```
public int abs (int x, int y)
     throws assertionViolation {
   int result;
     if (x > y) {
        result = x - y;
     } else {
        result = y - x;
     }
   assert (result > 0); // post-condition
   return result;
}
```

Statistical Testing

The objective of *statistical testing* is to determine the *reliability* of the software, rather than to discover faults.

Reliability may be expressed as:

- *probability* of failure on demand
  - i.e., for safety-critical systems
- *rate* of failure occurrence
  - i.e., #failures/time unit
- *mean time* to failure
  - i.e., for a stable system
- *availability*
  - i.e., fraction of time, for e.g. telecom systems

Statistical Testing ...

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

...

Static Verification ...

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

When to Stop?

When are we done testing? When do we have enough tests?

Cynical Answers (sad but true)

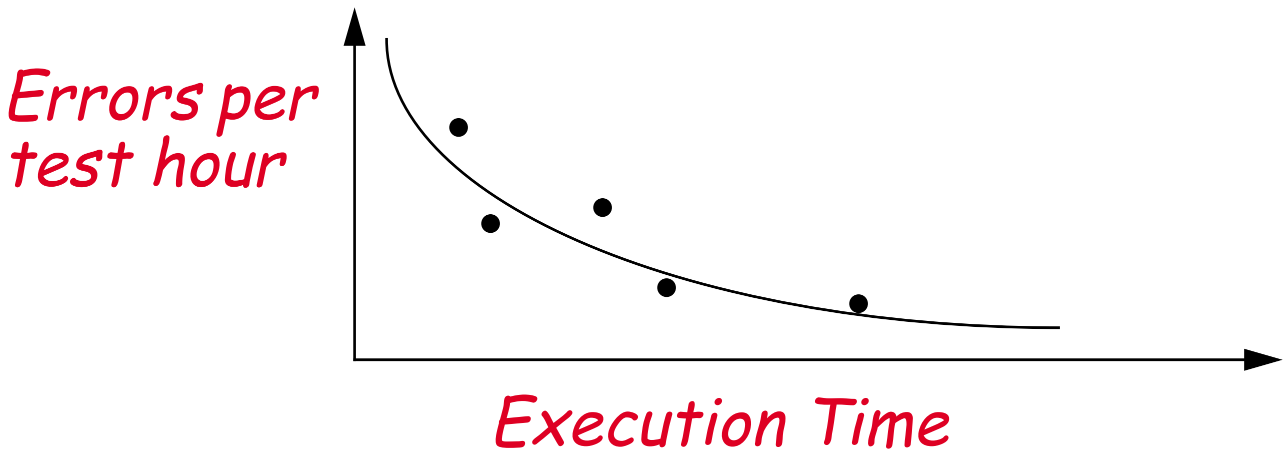
- ❑ You're never done: each run of the system is a new test
  - ☞ Each bug-fix should be accompanied by a new regression test
- ❑ You're done when you are out of time/money
  - ☞ Include testing in the project plan AND DO NOT GIVE IN TO PRESSURE
  - ☞ ... in the long run, tests save time

...

When to Stop? ...

Statistical Testing

- ❑ Test until you've reduced the failure rate to fall below the risk threshold
  - ☞ Testing is like an insurance company calculating risks



What you should know!

- 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 Attributes
- Quality Assurance: Planning and Reviewing
- Quality System and 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.
- *Fundamentals of Software Engineering*, C. Ghezzi, M. Jazayeri, D. Mandroli, Prentice-Hall 1991

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.

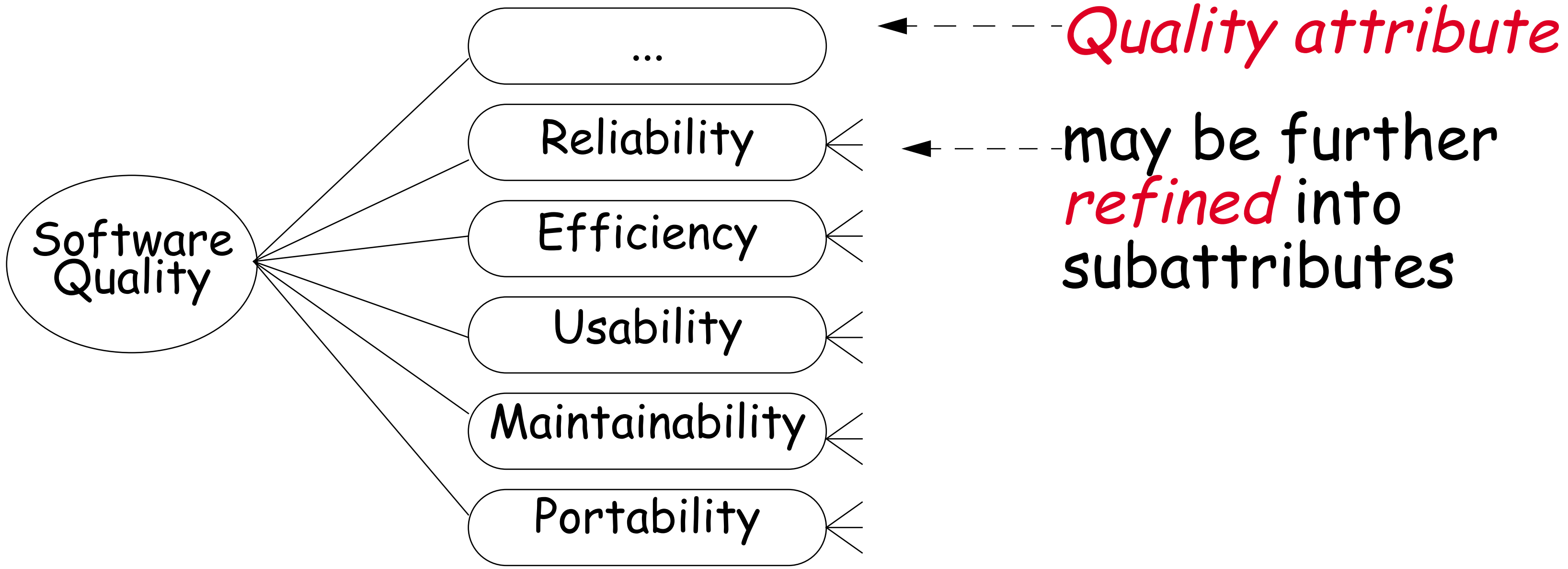
Problems with Software Quality

- 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!

Hierarchical Quality Model

Define quality via hierarchical quality model, i.e. number of *quality attributes* (a.k.a. quality factors, quality aspects, ...)



Choose quality attributes (and weights) depending on the project context

Quality Attributes

Quality attributes apply both to the product and the process.

- *product:* delivered to the customer
- *process:* produces the software product
- *resources:*
  (both the product and the process require resources)
  - ☞ Underlying assumption: a quality process leads to a quality product
    (cf. metaphor of manufacturing lines)

Quality Attributes ...

Quality attributes can be external or internal.

- *External:* Derived from the relationship between the environment and the system (or the process).
  (To derive, the system or process must *run*)
  - ☞ e.g. *Correctness*, *Reliability*, *Robustness*

- *Internal:* Derived immediately from the product or process description
  (To derive, it is sufficient to have the description)
  - ☞ Underlying assumption: internal quality leads to external quality
    (cfr. metaphor manufacturing lines)
  - ☞ e.g. *Efficiency*, *Usability*

Correctness, Reliability, Robustness

Correctness

- A system is <u>*correct*</u> if it *behaves according to its specification*
  - ☞ An *absolute* property (i.e., a system cannot be "almost correct")
  - ☞ ... in theory and practice *undecidable*

Reliability

- The user may rely on the system behaving properly
- <u>*Reliability*</u> is the *probability* that the system will operate as expected over a specified interval
  - ☞ A *relative* property (a system has a mean time between failure of 3 weeks)

Correctness, Reliability, Robustness ...

Robustness

- A system is *robust* if it behaves reasonably *even in circumstances that were not specified*
  - ☞ A *vague* property (once you specify the abnormal circumstances they become part of the requirements)

Efficiency, Usability

Efficiency. (Performance)

- *Use of resources* such as computing time, memory
  - Affects user-friendliness and scalability
  - Hardware technology changes fast!
  - (Remember: First do it, then do it right, then do it fast)

- For process, resources are manpower, time and money
  - relates to the "productivity" of a process

Efficiency, Usability ...

Usability. (User Friendliness, Human Factors)

- The *degree* to which the human users find the system (process) both "*easy to use*" and *useful*
  - Depends a lot on the target audience (novices vs. experts)
  - Often a system has various kinds of users (end-users, operators, installers)
  - Typically expressed in "amount of time to learn the system"

Maintainability

external product attributes (evolvability also applies to process)

Maintainability

- How easy it is to *change* a system after its initial release
  - ☞ *software entropy* ⇒ maintainability gradually decreases over time

Maintainability ...

Is often refined into ...

Repairability

- How much work is needed to *correct* a defect

Evolvability (Adaptability)

- How much work is needed to *adapt* to changing requirements (both system and process)

Portability

- How much work is needed to *port* to new environment or platforms

Verifiability, Understandability

internal (and *external*) product attribute

Verifiability

- How easy it is to *verify* whether desired attributes are there?
  - internally: e.g., verify requirements, code inspections
  - externally: e.g., testing, efficiency

Understandability

- How easy it is to *understand* the system
  - internally: contributes to maintainability
  - externally: contributes to usability

Productivity, Timeliness, Visibility

external process attribute (visibility also internal)

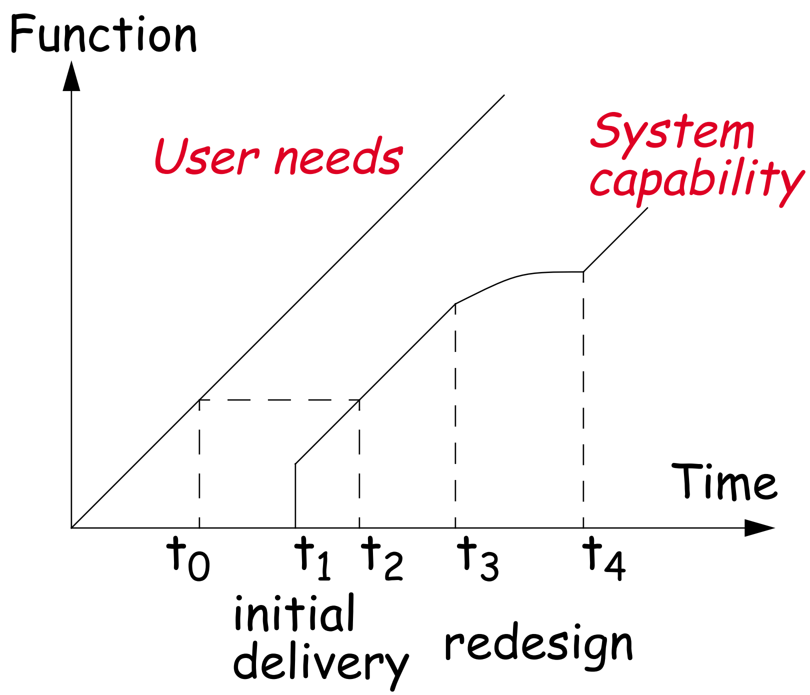
Productivity

- ❑ Amount of product produced by a process for a given number of resources
  - ☞ productivity among individuals varies a lot
  - ☞ often: productivity ($\sum$ individuals) < $\sum$ productivity (individuals)

Productivity, Timeliness, Visibility ...

Timeliness

- Ability to *deliver the product on time*
  - important for marketing (“short time to market”)
  - often a reason to sacrifice other quality attributes
  - incremental development may provide an answer



Productivity, Timeliness, Visibility ...

Visibility. (Transparency, Glasnost)

- Current process *steps* and project *status* are accessible
  - ☞ important for management
  - ☞ also deal with staff turn-over

Quality Control Assumption

Project Concern = Deliver on time and within budget

External (and Internal) Product Attributes

Process Attributes

Assumptions:

Internal quality ⇒ External quality

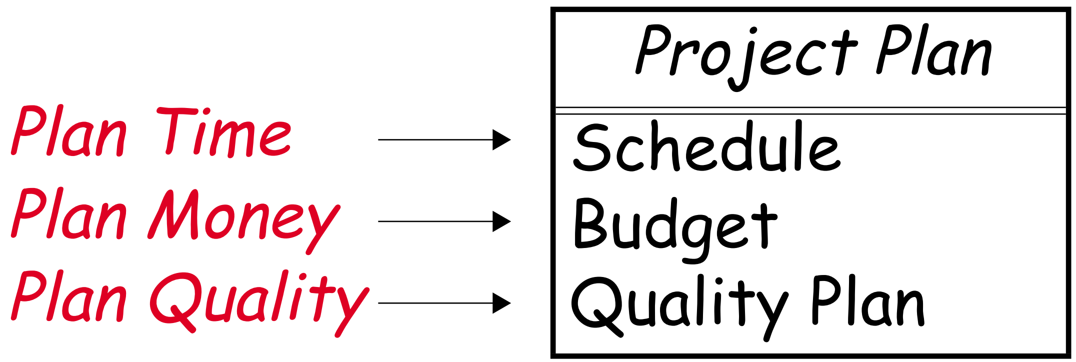
Process quality ⇒ Product quality

Control *during* project

Obtain *after* project

Otherwise, quality is mere coincidence!

The Quality Plan



The Quality Plan ...

A <u>*quality plan*</u> 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

NB: Quality Management should be separate from project management to ensure independence

Types of 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*.

Review type	*Principal purpose*
Formal Technical Reviews (a.k.a. design or program inspections)	Driven by *checklist* ❑ detect detailed errors in any product ❑ mismatches between requirements and product ❑ check whether standards have been followed.

Review type	*Principal purpose*
Progress reviews	Driven by *budgets*, *plans and schedules* ❑ check whether project runs according to plan ❑ requires precise milestones ❑ both a process and a product review

- Reviews 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*

Review Meetings

Review meetings should:

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

Review Minutes

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?

...

Sample Review Checklists (II)

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 (III)

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?

...

Sample Review Checklists (IV)

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*?

...

Sample Review Checklists (V)

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 conventions	Project plan approval process
Project plan format	Change control process
Change request form	Test recording process

Potential Problems with Standards

- 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.

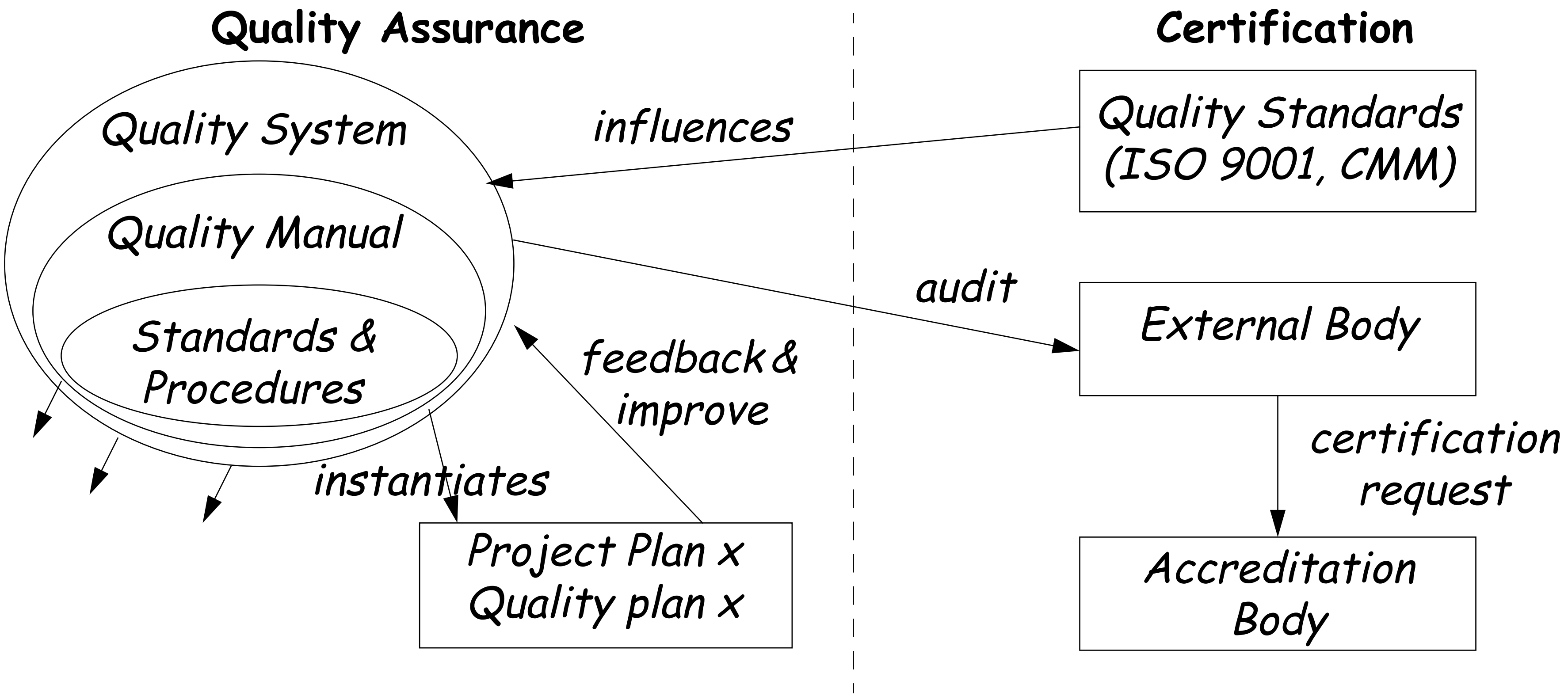
Sample Java Code Conventions ...

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.

Quality System

A Quality Plan should be an instance of an organization's *Quality System*



Customers may require an externally reviewed quality system

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 whose business processes range all the way from design and development, to production, installation and servicing;

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

ISO = International Organisation for Standardization

- ISO main site: http://www.iso.ch/
- ISO 9000 main site: http://www.tc176.org/

Capability Maturity Model (CMM)

The SEI process maturity model classifies how well contractors *manage software processes*

Quantitative data are necessary for improvement!

Level 5: Optimizing
Improvement is fed back into QA process

Level 4: Managed
QA Process + quantitative data collection

Level 3: Defined
QA process is defined and institutionalized

Level 2: Repeatable
Formal QA procedures in place

Quality depends on individual project managers!

Level 1: Initial (Ad Hoc)
No effective QA procedures, quality is luck

Quality depends on individuals!

What you should know!

- Can a correctly functioning piece of software still have poor quality?
- What's the difference between an external and an internal quality attribute?
- And between a product and a process attribute?
- Why should quality management be separate from project 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?

- *Why does a project need a quality plan?*
- *Why are coding standards important?*
- *What would you include in a documentation review checklist?*
- *How often should reviews be scheduled?*
- *Would you trust software developed by an ISO 9000 certified company?*
- *And if it were CMM level 5?*

12. Software Metrics

Overview:

- Measurement Theory
- GQM Paradigm
- Quantitative Quality Model
- Sample Quality Metrics

Sources:

- Software Engineering, I. Sommerville, Addison-Wesley, Fifth Edn., 1996.
- Software Engineering — A Practitioner's Approach, R. Pressman, Mc-Graw Hill, Third Edn., 1994.
- Norman E. Fenton, Shari l. Pfleeger, "Software Metrics: A rigorous & Practical Approach", Thompson Computer Press, 1996.

Why Metrics?

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 quantifies concepts

Date	Measurement	Comment
2000 BC	Rankings "hotter than"	By touching objects, people could compare temperature
1600 AD	Thermometer "hotter than"	A separate device is able to compare temperature
1720 AD	Fahrenheit scale	Quantification allows us to log temperature, study trends, predict phenomena (weather forecasting), ...
1742 AD	Celsius scale	
1854 AD	Kelvin scale	Absolute zero allows for more precise descriptions of physical phenomena

Measurement enables understanding, control and improvement

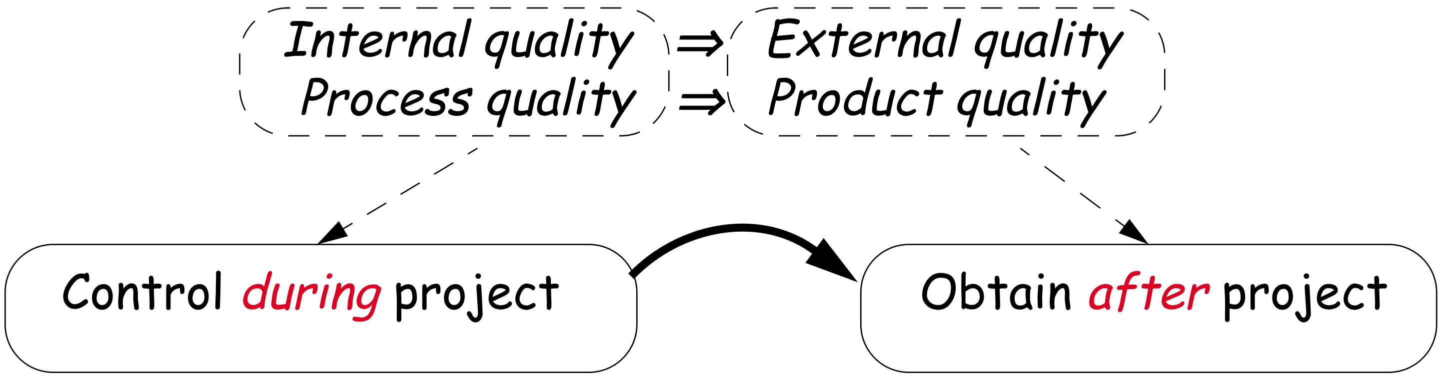
Why Software Metrics

Effort (and Cost) Estimation

- Measure early in the life-cycle to deduce later production efforts

Quality Assessment and Improvement

- *Control* software quality attributes during development
- *Compare* (and *improve*) software production processes
- Remember *Quality Assumptions*



What are Software Metrics?

Software metrics

- Any type of measurement which relates to a software system, process or related documentation
  - Lines of code in a program
  - the Fog index (calculates readability of a piece of documentation)

    0.4 *(# words / # sentences) +
    (percentage of words ≥ 3 syllables)
  - number of person-days required to implement a use-case

NB: "Software metrics" are not mathematical metrics, but rather measures

Direct and Indirect Measures

Direct Measures

- *Measured* directly in terms of the observed attribute (usually by counting)
  - Length of source-code, Duration of process, Number of defects discovered

Indirect Measures

- *Calculated* from other direct and indirect measures
  - Module Defect Density = Number of defects discovered / Length of source
  - Temperature is usually derived from the length of a liquid column

Possible Problems

Compare productivity in lines of code per time unit.

- Do we use the same units to compare?
  - What is a "line of code"? What is the "time unit"?
- Is the context the same?
  - Were programmers familiar with the language?
- Is "code size" really what we want to produce?
  - What about code quality?
- How do we want to interpret results?
  - Average productivity of a programmer?
    Programmer X is twice as productive as Y?
- What do we want to do with the results?
  - Do you reward "productive" programmers?
    Do you compare productivity of software processes?

Empirical Relations

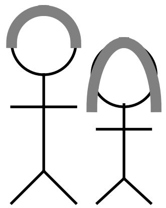
Empirical relations observe true/false relationships between (attributes of) real world entities.

Empirical relations are *complete*, i.e. defined for all possible combinations.

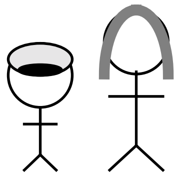
Examples

Empirical relationships between height attributes of persons

"is taller than" binary relationship

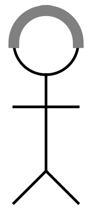


Frank "is taller than" Laura

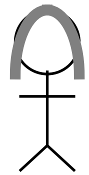


Joe "is not taller than" Laura

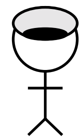
"is tall" unary relationship



Frank "is tall"

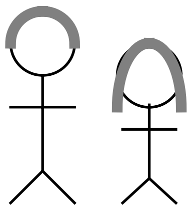


Laura "is tall"

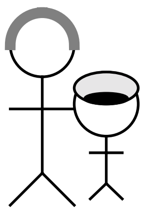


Joe "is not tall"

"is much taller than" binary relationship

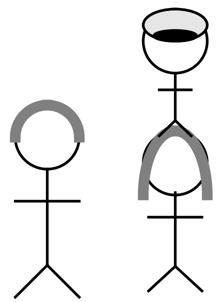


Frank "is not much taller than" Laura



Frank "is much taller than" Joe

"... is higher than ... + ..." ternary relationship



Frank "is not higher than" Joe on Laura's shoulders

Measurement Mapping

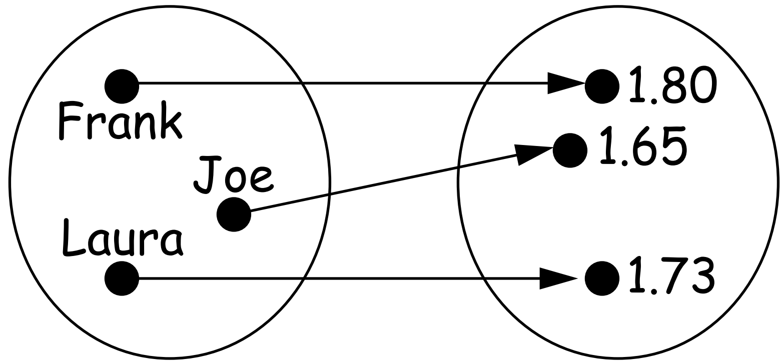
Measure & Measurement

A _measure_ is a function mapping

- an *attribute* of a real world entity (= the domain)

onto

- a *symbol* in a set with known mathematical relations (= the range).



Example: measure mapping "height" attribute of person on a number representing "height in meters".

A _measurement_ is then the symbol assigned to the real world attribute by the measure.

Purpose: *Manipulate symbol(s) in the range to draw conclusions about attribute(s) in the domain*

(Measures vs Metrics)

Mathematically, a *metric* is a function m measuring the *distance* between two objects such that:

1. $\forall$ x, m(x,x) = 0
2. $\forall$ x, y, m(x,y) = m(y,x)
3. $\forall$ x, y, z, m(x,z) $\leq$ m(x,y) + m(y,z)

So, technically "software metrics" is an abuse of terminology, and we should instead talk about "software measures".

Preciseness

To be *precise*, the definition of the measure must specify:

- *domain*: do we measure people's height or width?
- *range*: do we measure height in centimetres or inches?
- *mapping rules*: do we allow shoes to be worn?

Representation Conditions

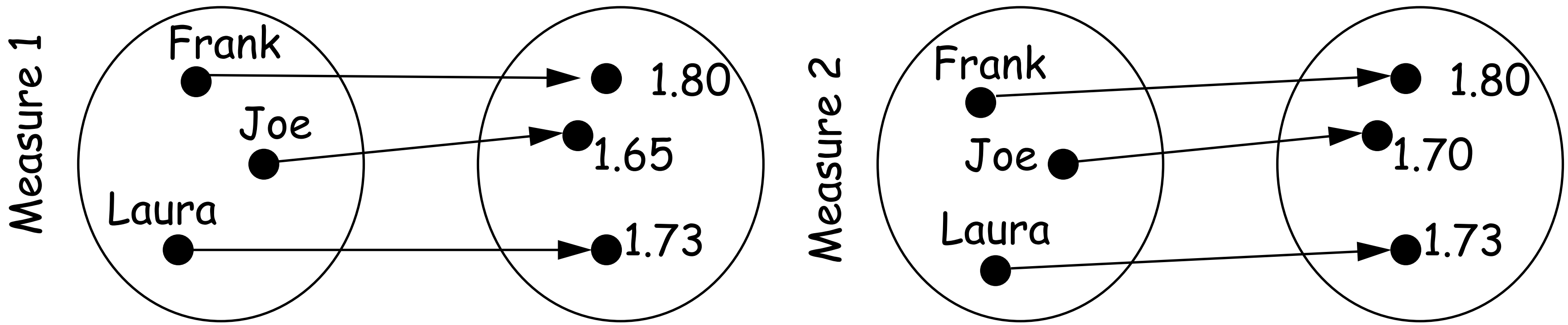
To be *valid*, a measure must satisfy the *representation condition*:

empirical relations (in domain) $\Leftrightarrow$ mathematical relations (in range)

In general, the more empirical relations, the more difficult it is to find a valid measure.

Representation Conditions ...

Empirical Relation		Measure 1		Measure 2	
is-taller-than		$x > y$		$x > y$	
Frank, Laura	true	1.80 > 1.73	true	1.80 > 1.73	true
Joe, Laura	false	1.65 > 1.73	false	1.70 > 1.73	false
is-much-taller-than		$x > y + .10$		$x > y + .10$	
Frank, Laura	false	1.80 > 1.73 + .10	false	1.80 > 1.73 + .10	false
Frank, Joe	true	1.80 > 1.65 + .10	true	*1.80 > 1.70 + .10*	*false*



GQM

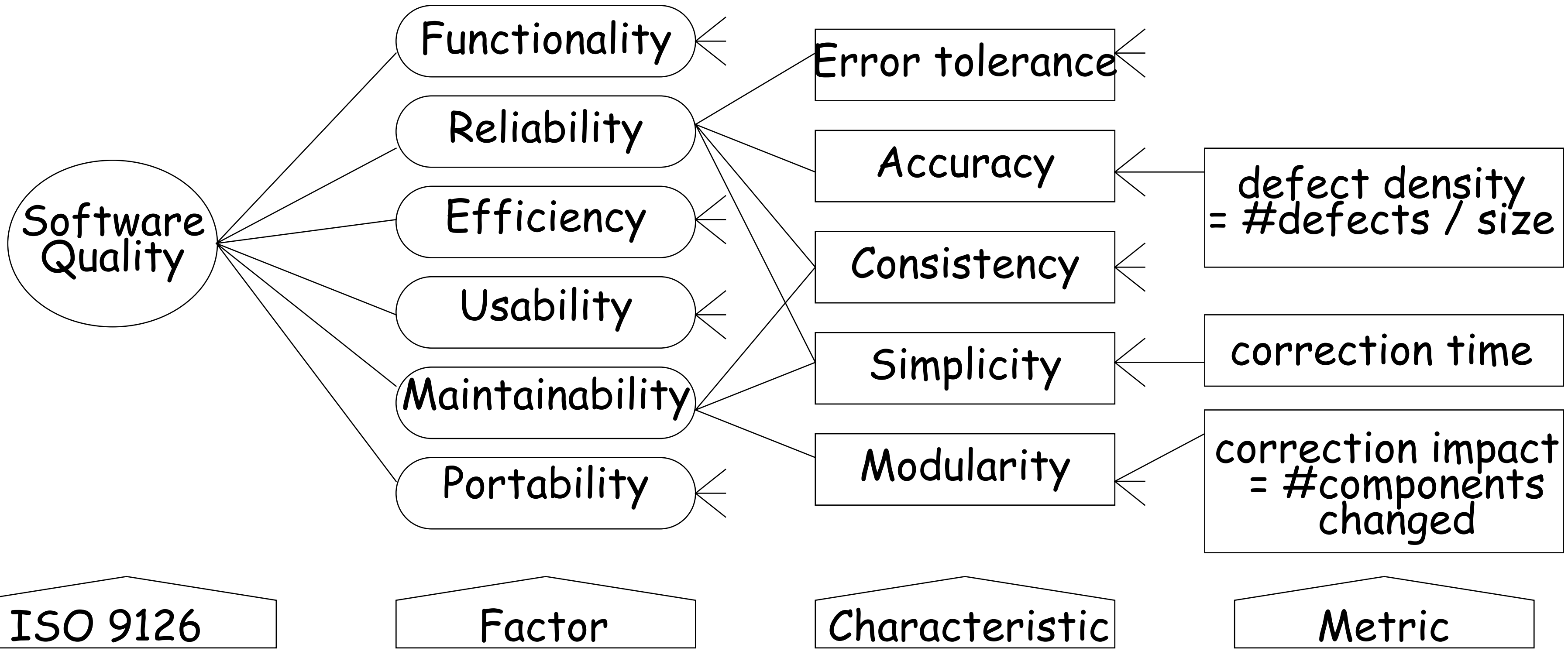
Goal - Question - Metrics approach. [Basili et al. 1984]

- Define *Goal*
  - e.g., “How effective is the coding standard XYZ?”
- Break down into *Questions*
  - “Who is using XYZ?”
  - “What is productivity/quality with/without XYZ?”
- Pick suitable *Metrics*
  - Proportion of developers using XYZ
  - Their experience with XYZ ...
  - Resulting code size, complexity, robustness ...

Quantitative Quality Model

Quality according to ISO 9126 standard

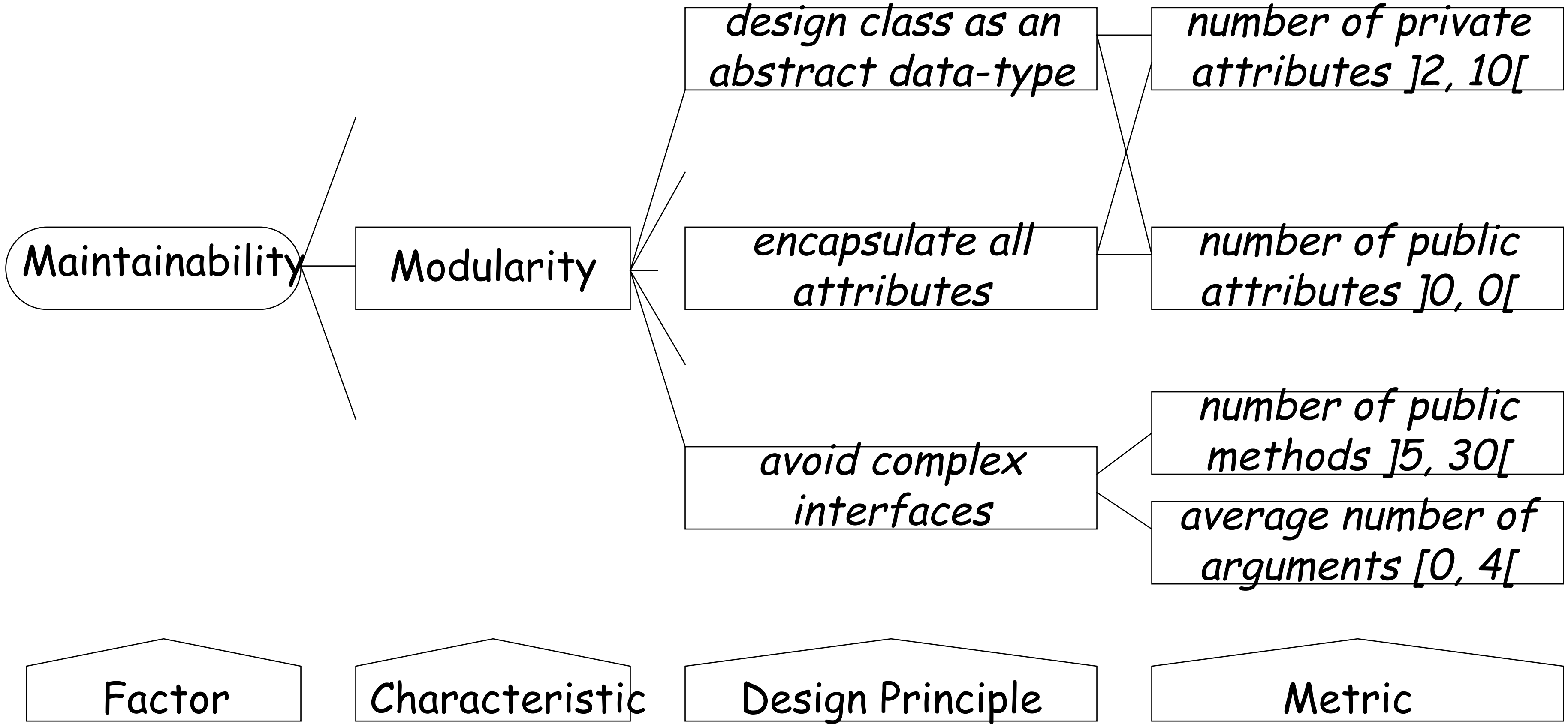
- Divide-and conquer approach via "hierarchical quality model"
- Leaves are simple metrics, measuring basic attributes



"Define your own" Quality Model

Define the quality model with the development team

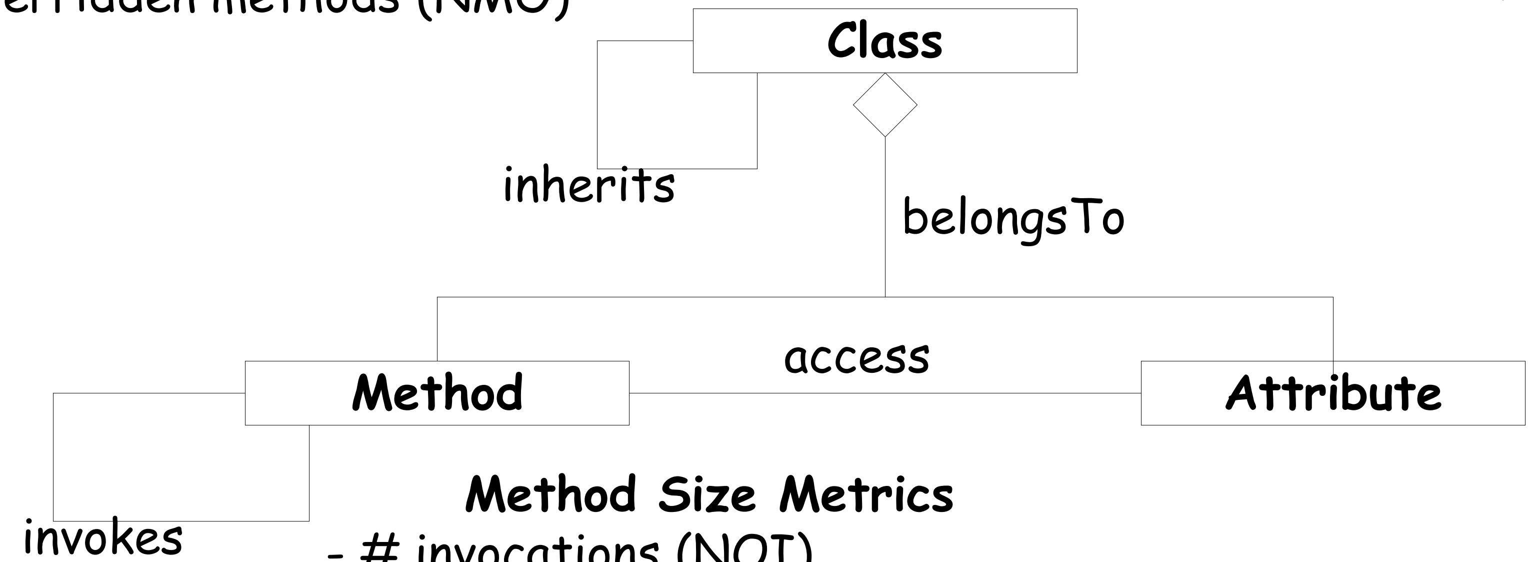
- Team chooses the characteristics, design principles, metrics ... and the *thresholds*



Sample Size (and Inheritance) Metrics

Inheritance Metrics
- hierarchy nesting level (HNL)
- # immediate children (NOC)
- # inherited methods, unmodified (NMI)
- #overridden methods (NMO)

Class Size Metrics
- # methods (NOM)
- # attributes, instance/class (NIA, NCA)
- # Σ of method size (WMC)



Method Size Metrics
- # invocations (NOI)
- # statements (NOS)
- # lines of code (LOC)
- # arguments (NOA)

These are Internal Product Metrics

Sample Coupling & Cohesion Metrics

These are Internal Product Metrics

Following definitions stem from [Chid91a], later republished as [Chid94a]

Coupling Between Objects (CBO)

CBO = number of other class to which given class is coupled

Interpret as "number of other classes a class requires to compile"

Lack of Cohesion in Methods (LCOM)

LCOM = number of disjoint sets (= not accessing same attribute) of local methods

Coupling & Cohesion Metrics

Beware!

Researchers disagree whether coupling/cohesion methods are *valid*

- ❑ Classes that are observed to be cohesive may have a high LCOM value
  - ☞ due to accessor methods
- ❑ Classes that are not much coupled may have high CBO value
  - ☞ no distinction between data, method or inheritance coupling

Sample External Quality Metrics (I)

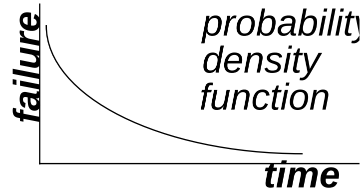
Productivity (Process Metric)

- functionality / time
- functionality in LOC or FP; time in hours, weeks, months
  - ☞ be careful to compare: the same unit does not always represent the same
- Does not take into account the quality of the functionality!

Sample External Quality Metrics (II)

Reliability (Product Metric)

- *mean time to failure* = mean of probability density function PDF



  - for software one must take into account the fact that repairs will influence the rest of the function ⇒ quite complicated formulas
- *average time between failures* = # failures / time
  - time in execution time or calendar time
  - necessary to calibrate the probability density function
- *mean time between failure* = MTTF + mean time to *repair*
  - to know when your system will be available, take into account *repair*

Sample External Quality Metrics (III)

Correctness (Product Metric)

- "a system is correct or not, so one cannot measure correctness"
- *defect density* = # known defects / product size
  - product size in LOC or FP
  - # known defects is a time based count!
- do NOT compare across projects unless you're data collection is sound!

Sample External Quality Metrics (IV)

Maintainability (Product Metric)

- #time to repair certain categories of changes
- "mean time to repair" vs. "average time to repair"
  - ☞ similar to "mean time to failure" and "average time between failures"
- beware for the units
  - ☞ categories of changes is subjective
  - ☞ time =?
    problem recognition time + administrative delay time + problem analysis time + change time + testing & reviewing time

Conclusion: Metrics for QA (I)

Question: *Can internal product metrics reveal which components have good/poor quality?*

Yes, but...

Not reliably

- false positives: “bad” measurements, yet good quality
- false negatives: “good” measurements, yet poor quality

Heavyweight

- Requires team to develop (customize?) a quantitative quality model
- Requires definition of thresholds (trial and error)

Difficult to interpret

- Requires complex combinations of simple metrics

...

However...

- *Cheap* once you have the quality model and the thresholds
- *Good focus* (± 20% of components are selected for further inspection)
  Note: focus on the most complex components first

Conclusion: Metrics for QA (II)

Question: *Can external product/process metrics reveal quality?*

Yes, ...

- ❑ More reliably then internal product metrics

However...

- ❑ Requires a *finished* product or process
- ❑ It is hard to achieve *preciseness*
  - ☞ even if measured in same units
  - ☞ beware to compare results from one project to another

What you should know!

- *What are the possible problems of metrics usage in software engineering? How does the metrics theory address them?*
- *What kind of measurement scale would you need to say "A specification error is worse than a design error"? And what if we want to say "A specification error is twice as bad as a design error?"*
- *What's the difference between "Mean time to failure" and "Average time between failures"? Why is the difference important?*

Can you answer the following questions?

- *During which phases in a software project would you use metrics?*
- *Why is it so important to have "good" product size metrics?*
- *Why do we prefer measuring Internal Product Attributes instead of External Product Attributes during Quality Control? What is the main disadvantage of doing that?*
- *Why are coupling/cohesion metrics important? Why then are they so rarely used?*

13. TBA ...