Software and Interface Design

Models, Tools & Processes

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Computer Science Tripos Part 1a

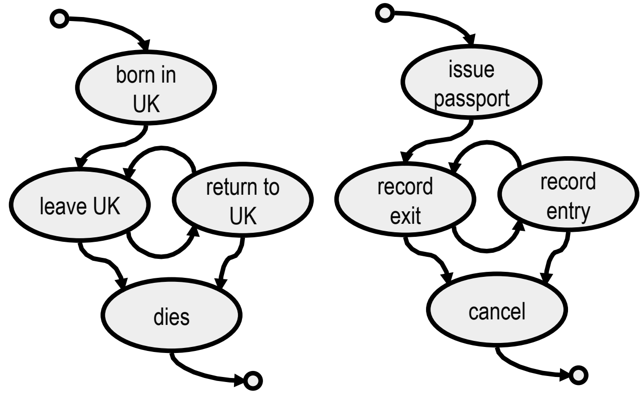
How hard can it be?

- State what the system should do
  - $\{D_1, D_2, D_3 \ldots\}$
- State what it shouldn't do
  - $\{U_1, U_2, U_3 \ldots\}$
- Systematically add features
  - that can be proven to implement D_n
  - while not implementing U_n

How hard can it be …

- The United Kingdom Passport Agency
  - http://www.parliament.the-stationery-office.co.uk/pa/cm199900/cmselect/cmpubacc/65/6509.htm
- 1997 contract for new computer system
  - aimed to improve issuing efficiency, on tight project timetable
  - project delays meant throughput not thoroughly tested
  - first live office failed the throughput criterion to continue roll-out
  - second office went live, roll out halted, but no contingency plan
  - rising backlog in early 1999, alongside increasing demand
  - passport processing times reached 50 days in July 1999
  - widespread publicity, anxiety and panic for travelling public
  - telephone service overloaded, public had to queue at UKPA offices
  - only emergency measures eventually reduced backlog
- So how hard can it be to issue a passport?
  - … let's try some simple definition

… to define this system?



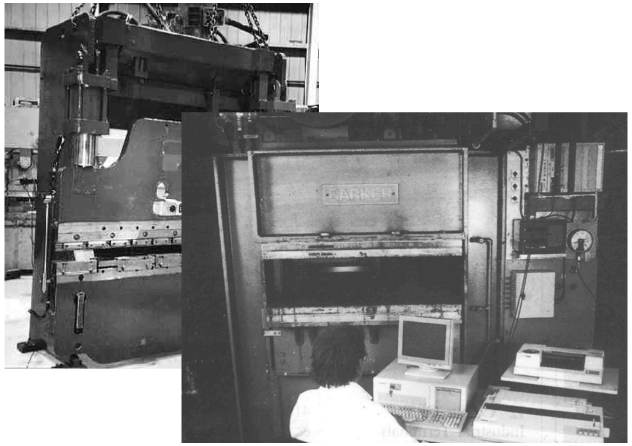
How hard can it be …

… to define a simple bureaucracy?

Why is the world complicated?

- Bureaucratic systems are complex because managers (people) always mess up
- What about physical systems, which don't rely on people to work?
  - Start with known characteristics of physical device.
  - Assemble behaviours to achieve function
  - This is how engineering products (bridges and aircraft) are designed.

How hard can it be …



… to define a physical system?

Design and uncertainty

- A good programmer should be able to:
  - Create a system that behaves as expected.
  - Behaves that way reliably.
- But a good designer must also:
  - Take account of the ***unexpected***.
- A well-designed software system is not the same as a well-designed algorithm.
  - If the requirements change or vary, you might replace the algorithm,
  - But it's seldom possible to replace a whole system.

What is the problem?

- The problem is ***not*** that we don't understand the computer.
- The problem ***is*** that we don't understand the problem!
- Does computer science offer any answers?
- The good news:
  - We've been working on it since 1968
- The bad news:
  - There is still no "silver bullet"!
    (from great IBM pioneer Fred Brooks)

Introduction

A design process based on knowledge

Pioneers – Bavarian Alps, 1968

- 1954: complexity of SAGE air-defence project was under-estimated by 6000 person-years …
  - … at a time when there were only about 1000 programmers in the whole world!
  - … "Software Crisis!"

- 1968: First meeting on "Software Engineering" convened in Garmisch-Partenkirchen.

Engineering = science + design

- Science: if we have enough knowledge, we can solve problems.
- Design: understanding the importance of what you ***don't*** know
  - dealing with uncertainty, lack of knowledge …
  - … but trying to be *systematically* ignorant!
- Design is a process, not a set of known facts
  - process of learning about a problem
  - process of describing a solution
  - at first with many gaps …
  - eventually in sufficient detail to build the solution

Learning by building models

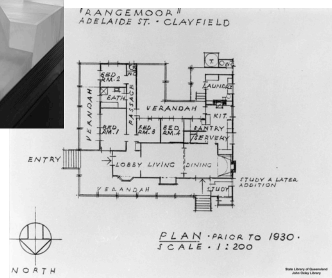
- The software design process involves gaining knowledge about a problem, and about its technical solution.
- We describe both the problem and the solution in a series of *design models*.
- Testing, manipulating and transforming those models helps us gather more knowledge.
- One of the most detailed models is written in a programming language.
  - Getting a working program is almost a side-effect of describing it!

What is a design model?

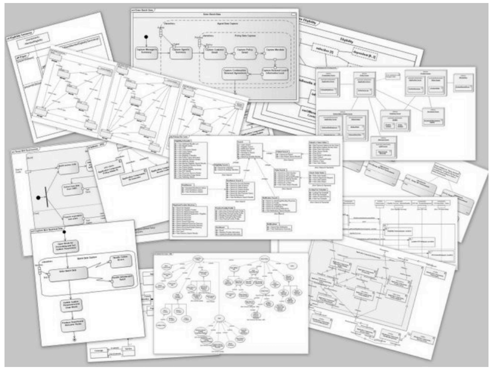
- A model is a description from which *detail has been removed:*
  - in a systematic manner,
  - and for a particular purpose.
- A model is a *simplification of reality*
  - intended to promote understanding.
- If we want to understand and analyse large and complex problems …
- … ***we have to use models.***

Design models – architecture

Model by Hans Rosbach



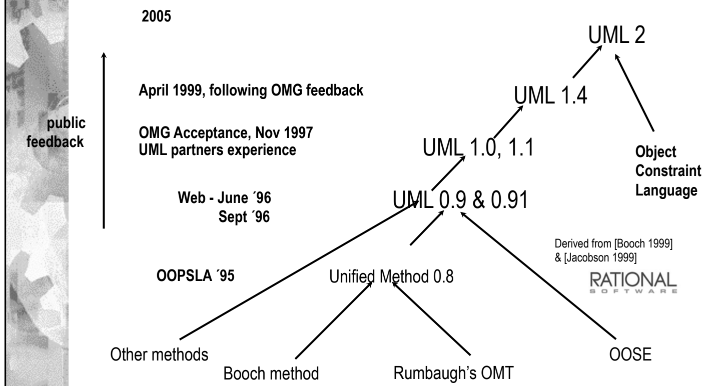
Design models – software



Unified Modeling Language

- **Use Case** diagrams - interactions with / interfaces to the system.
- **Class** diagrams - type structure of the system.
- **Collaboration** diagrams - interaction between instances
- **Sequence** diagrams - temporal structure of interaction
- **Activity** diagrams - ordering of operations
- **Statechart** diagrams - behaviour of individual objects
- **Component** and **Deployment** diagrams - system organisation

UML history & status



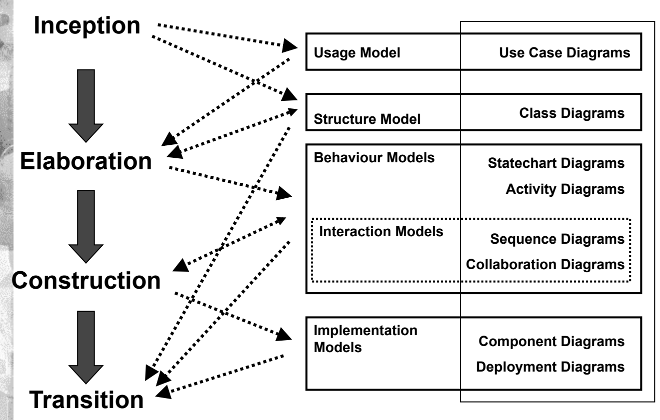
Derived from [Booch 1999] & [Jacobson 1999]

RATIONAL SOFTWARE

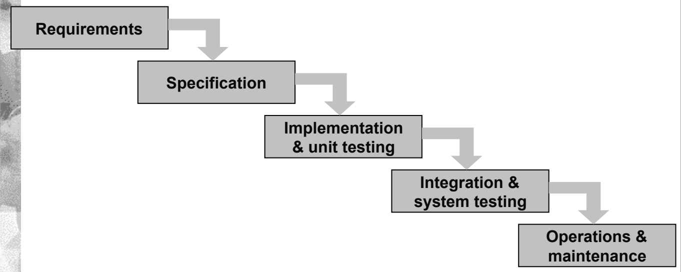
Outline for the rest of the course

- Roughly follows stages of the (UML-related) *Unified Software Development Process*
  - Inception
    - structured description of what system must do
  - Elaboration
    - defining classes, data and system structure
  - Construction
    - object interaction, behaviour and state
  - Transition
    - testing and optimisation
- Plus allowance for *iteration*
  - at every stage, and through all stages

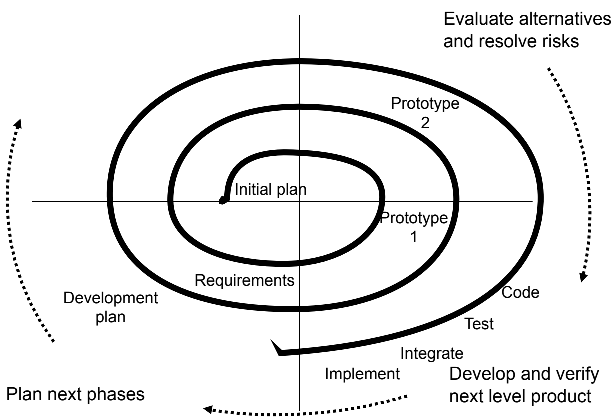
Unified Process vs. Models



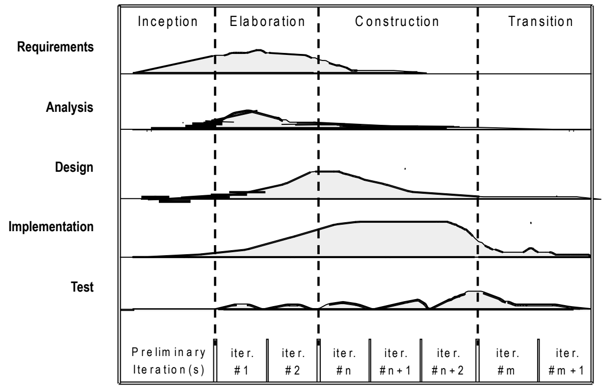
Old-style stages: the "waterfall"



Modern stages: the "spiral"



Effort distribution



Books

- ***Code Complete:*** A practical handbook of software construction
  - Steve McConnell, Microsoft Press 2004 (2nd edition)
- ***UML Distilled:*** A brief guide to the standard object modeling language
  - Martin Fowler, Addison-Wesley 2003 (3rd edition)
- Further:
  - *Interaction Design,* Rogers, Sharp & Preece
  - *Software Engineering,* Roger Pressman
  - *The Mythical Man-Month,* Fred Brooks
  - *The Design of Everyday Things,* Donald Norman
  - *Contextual Design,* Hugh Beyer & Karen Holtzblatt
  - *Software Pioneers,* Broy & Denert
  - *Educating the Reflective Practitioner*, Donald Schon

Supervision exercises

- Use design briefs from Part 1b Group Design Projects
  - http://www.cl.cam.ac.uk/teaching/ group-projects/design-briefs.html
- Choose a specific project to work on
- Carry out initial design phases, up to the point where you could start writing source code
  - Supervision 1: Inception phase + early elaboration
  - Supervision 2: Iterate and refine elaboration phase

Inception phase

structured description of system usage and function

Pioneers – Tom DeMarco

- Structured Analysis
  - 1978, Yourdon Inc
- Defined the critical technical role of the system analyst
  - Analyst acts as a middleman between users and (technical) developers
- Analyst's job is to construct a functional specification
  - data dictionary, data flow, system partitioning

How can you capture requirements?

Analysing requirements

- Analysis usually involves (re)negotiation of requirements between client and designer.
  - Once considered "*requirements capture*".
  - Now more often "*user-centred design*".
- An "interaction designer" often replaces (or works alongside) traditional systems analysts.
  - Professional interaction design typically combines research methods from social sciences with visual or typographic design skills (and perhaps CS).

Pioneers: Gould & Lewis (1985)

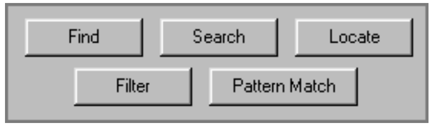
- The (then) radical alternative of User-Centred Design
- Early focus on users and tasks
  - Understand them by studying them
- Empirical measurement
  - Test user responses to prototypes
- Iterative design
  - Fix any problems and try again

Communicating requirements

- The need for user documentation

Documentation bugs

Interaction design bugs



From Interface Hall of Shame

The psychological approach

- Anticipate what will happen when someone tries to use the system.
  - Design a “conceptual model” that will help them (and you) develop shared understanding.
- The gulf of execution:
  - System users know ***what*** they want to achieve, but can’t work out ***how*** to do it.
- The gulf of evaluation:
  - Systems ***fail*** to give suitable feedback on what just happened, so users ***never learn*** what to do.
- See Norman: *Design of Everyday Things*.
  - Far more detail to come in Part II HCI course

The anthropological approach

- Carry out fieldwork:
  - Interview the users.
  - Understand the context they work in.
  - Observe the nature of their tasks.
  - Discover things by observation that they might not have told you in a design brief.
- Collaborate with users to agree:
  - What problem ought to be solved.
  - How to solve it (perhaps by reviewing sketches of proposed screens etc.).

Ethnographic field studies

- Understand real detail of user activity, not just official story, theories or rationalisations.
- Researchers work in the field:
  - Observing context of people's lives
  - Ideally participating in their activities
- Academic ethnography tends to:
  - Observe subjects in a range of *contexts*.
  - Observe over a substantial *period of time*.
  - Make full record of both *activities* and *artefacts*.
  - Use transcripts of video/audio recordings.

Interviews

- See Beyer & Holtzblatt, *Contextual Design*
- Field work usually includes interviews
  - ***Additional*** to requirements meetings with client
- Often conducted in the place of work during 'contextual enquiry' (as in Beyer & Holtzblatt)
  - emphasis on user tasks, not technical issues
- Plan questions in advance
  - ensure all important aspects covered

Structured models of work

- Division of labour and its coordination
  - *activities*, *methods* and *connections*
  - *measures*, *exceptions* and domain *knowledge*
- Plans and procedures
  - When do they succeed and fail?
  - Where paperwork meets computer work
- Local knowledge and everyday skills
  - Spatial and temporal organisation
  - Organisational memory
    - How do people learn to do their work?
    - Do formal/official methods match reality?

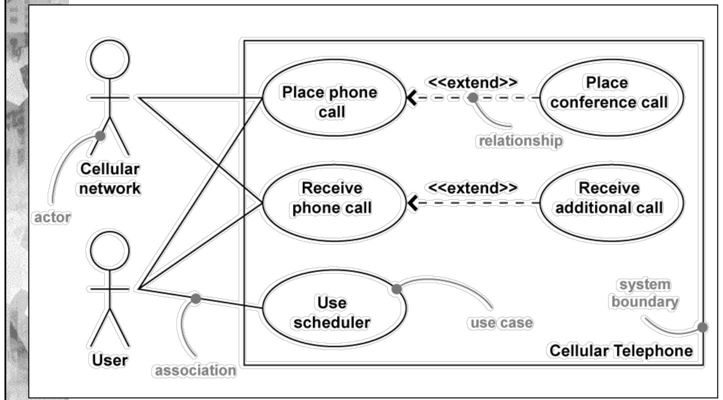
User Personas

- This is a way to 'distil' information about users
  - from field work, interviews, user studies etc
  - into a form that is more useful to design teams.
- Write fictional portraits of individuals representing various kinds of user
  - give them names, jobs, and personal history
  - often include photographs (from libraries ,actors)
- Help software engineers to remember that customers are not like them …
  - … or their friends …
  - … or anyone they've ever met!

Designing system-use scenarios

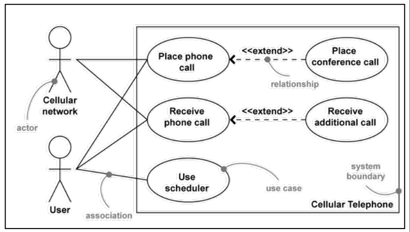
- Aim is to describe the human activity that the system has to carry out or support.
  - Known as use cases in UML/USDP
- Use cases help the designer to discover and record interactions between software objects.
- Can be refined as a group activity, based on personas, or in discussion with clients.
- May include mock-ups of screen designs, or physical prototypes.
- Organised and grouped in use case diagrams

UML Use Case diagram



UML Use Case diagram

- Actors
  - play system role
  - may not be people
- Use case
  - like a scenario
- Relationships
  - include
  - extend
  - generalisation



Deriving objects from a scenario

- The ***nouns*** in a description refer to ‘things’.
  - A source of classes and objects.
- The ***verbs*** refer to actions.
  - A source of interactions between objects.
  - Actions describe object behavior, and hence required methods.

Example of context description

The cinema booking system should store seat bookings for multiple theatres.

Each theatre has seats arranged in rows.

Customers can reserve seats and are given a row number and seat number.

They may request bookings of several adjoining seats.

Each booking is for a particular show (i.e., the screening of a given movie at a certain time).

Shows are at an assigned date and time, and scheduled in a theatre where they are screened.

The system stores the customers' telephone number.

Nouns

The cinema booking system should store seat bookings for multiple theatres.

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Verbs

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Extracted nouns & verbs

Cinema booking system
Stores (seat bookings)
Stores (telephone number)

Theatre
Has (seats)

Movie

Customer
Reserves (seats)
Is given (row number, seat number)
Requests (seat booking)

Time

Date

Seat booking

Show
Is scheduled (in theatre)

Seat

Seat number

Telephone number

Row

Row number

Scenario structure: CRC cards

- First described by Kent Beck and Ward Cunningham.
  - Later innovators of “agile” programming, and also the first wiki!
- Use simple index cards, with each cards recording:
  - A *class* name.
  - The class’s *responsibilities*.
  - The class’s *collaborators*.

Typical CRC card

Class name	**Collaborators**
Responsibilities	

Partial example

CinemaBookingSystem	*Collaborators*
Can find movies by title and day.	**Movie**
Stores collection of movies.	**Collection**
Retrieves and displays movie details.	
...	

Refinement of usage model

- Scenarios allow you to check that the problem description is clear and complete.
- Analysis leads gradually into design.
  - Talking through scenarios & class responsibilities leads to elaborated models.
- Spotting errors or omissions here will save considerable wasted effort later!
  - Sufficient time should be taken over the analysis.
  - CRC was designed to allow (in principle) review and discussion with analysts and/or clients.

Requirements documents

- Statement of organised user/system requirements - generally written in natural language
- ***Not*** a formal deliverable in USDP
  - But can be useful if a client wants waterfall-style contracts
- Agile processes are actively opposed to formal requirements documents
  - The requirements emerge as the system is implemented, in response to user requests and feedback
  - But in this case, cost control is essential!

Functional vs non-functional

- Functional – ***what*** the system will do
  - e.g. the cinema system shall provide a facility for accepting payments
  - e.g. the cinema system shall authenticate door entry
- Non-functional – ***how*** the system will do it (a constraint on how functions are implemented)
  - e.g. the cinema system shall authenticate a payment in 30 seconds or less
  - e.g. the cinema system shall use hard-copy tickets

Requirements prioritisation

MoSCoW criteria

- **M:** Must have - mandatory requirements that are fundamental to the system
- **S:** Should have - important requirements that could be omitted
- **C:** Could have - optional requirements
- **W:** Want to have - these requirements really can wait (i.e. bells & whistles)

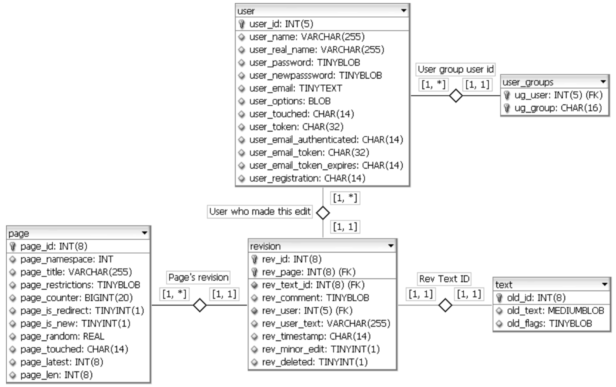
Elaboration

defining classes, data and system structure

Pioneers – Peter Chen

- Entity-Relationship Modeling
  - 1976, Massachusetts Institute of Technology
- User-oriented response to Codd’s theoretical definition of the relational database
  - Define attributes and values
  - Relations as associations between things
  - Things play a *role* in the relation.
- E-R Diagrams showed entity (box), relation (diamond), role (links).
- Object-oriented Class Diagrams show class (box) and association (links)

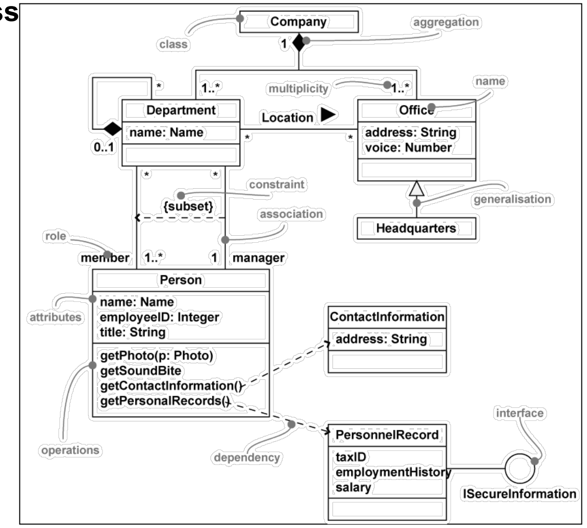
ER diagram (design of a wiki system)



From entities to objects

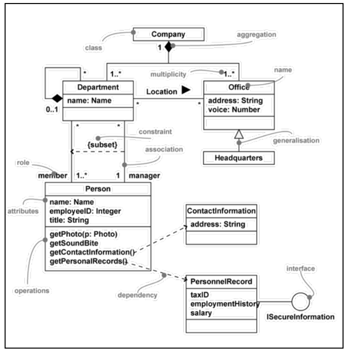
- objects
  - represent ‘things’ in some problem domain (example: “the red car down in the car park”)
- classes
  - represent all objects of a kind (example: “car”)
- operations
  - actions invoked on objects (Java “*methods”)*
- instance
  - can create many instances from a single class
- state
  - all the attributes (field values) of an instance

UML Class diagram



UML Class diagram

- Attributes
  - type and visibility
- Operations
  - signature and visibility
- Relationships
  - association
    - with multiplicity
    - potentially aggregation
  - generalisation



Class design from CRC cards

- Scenario analysis helps to clarify application structure.
  - Each card maps to a class.
  - Collaborations reveal class cooperation/object interaction.
- Responsibilities reveal public methods.
  - And sometimes fields; e.g. “Stores collection ...”

Refining class interfaces

- Replay the scenarios in terms of method calls, parameters and return values.
- Note down the resulting method signatures.
- Create outline classes with public-method stubs.
- Careful design is a key to successful implementation.

Dividing up a design model

- Abstraction
  - Ignore details in order to focus on higher level problems (e.g. aggregation, inheritance).
  - If classes correspond well to types in domain they will be easy to understand, maintain and reuse.
- Modularization
  - Divide model into parts that can be built and tested separately, interacting in well-defined ways.
  - Allows different teams to work on each part
  - Clearly defined interfaces mean teams can work independently & concurrently, with increased chance of successful integration.

Pioneers – David Parnas

- Information Hiding
  - 1972, Carnegie Mellon University
- How do you decide the points at which a program should be split into pieces?
  - Are small modules better?
  - Are big modules better?
  - What is the optimum boundary size?
- Parnas proposed the best criterion for modularization:
  - Aim to hide design decisions within the module.

Information hiding in OO models

- Data belonging to one object is hidden from other objects.
  - Know *what* an object can do, not *how* it does it.
  - Increases independence, essential for large systems and later maintenance
- Use Java visibility to hide implementation
  - Only methods intended for interface to other classes should be public.
  - Fields should be private – accessible only within the same class.
  - *Accessor* methods provide information about object state, but don't change it.
  - *Mutator* methods change an object's state.

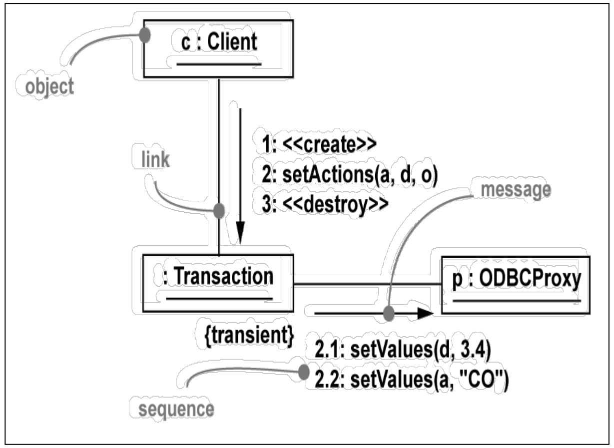
Cohesion in OO models

- Aim for high cohesion:
  - Each component achieves only "one thing"
- Method (functional) cohesion
  - Method only performs out one operation
  - Groups things that must be done together
- Class (type) cohesion
  - Easy to understand & reuse as a domain concept
- Causes of low, poor, cohesion
  - Sequence of operations with no necessary relation
  - Unrelated operations selected by control flags
  - No relation at all – just a bag of code

Construction

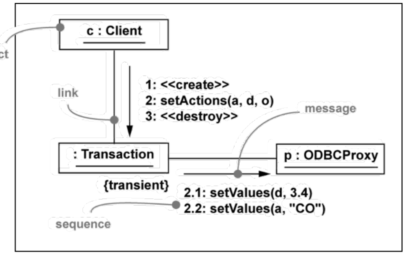
object interaction, behaviour and state

UML Collaboration diagram

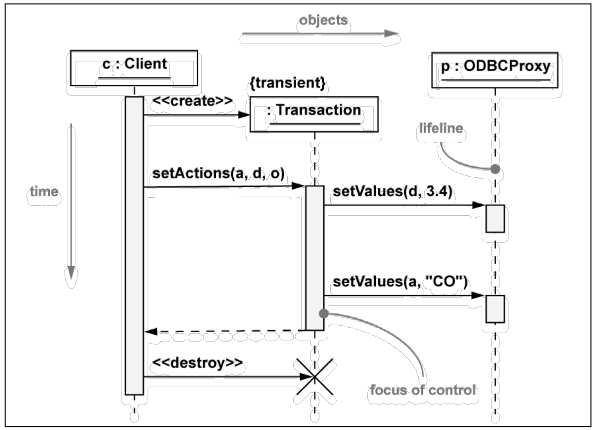


UML Collaboration diagram

- Objects
  - class instances
  - can be *transient*
- Links
  - from associations
- Messages
  - travel along links
  - numbered to show *sequence*

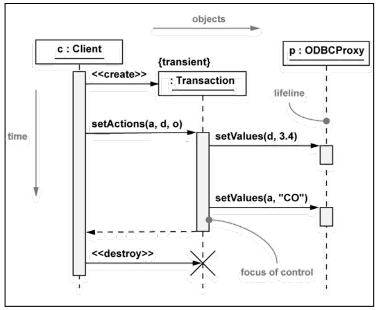


UML Sequence diagram



UML Sequence diagram

- Interaction again
  - same content as collaboration
  - emphasises time dimension
- Object lifeline
  - objects across page
  - time down page
- Shows focus of control



Loose coupling

- Coupling: links between parts of a program.
- If two classes depend closely on details of each other, they are *tightly coupled*.
- We aim for *loose coupling*.
  - keep parts of design clear & independent
  - may take several design iterations
- Loose coupling makes it possible to:
  - achieve reusability, modifiability
  - understand one class without reading others;
  - change one class without affecting others.
- Thus improves maintainability.

Responsibility-driven design

- Which class should I add a new method to?
  - Each class should be responsible for manipulating its own data.
  - The class that owns the data should be responsible for processing it.
- Leads to low coupling & "client-server contracts"
  - Consider every object as a server
  - Improves reliability, partitioning, graceful degradation

Interfaces as specifications

- Define method *signatures* for classes to interact
  - Include parameter and return types.
  - Strong separation of required functionality from the code that implements it (information hiding).
- Clients interact independently of the implementation.
  - But clients can choose from alternative implementations.

Causes of error situations

- Incorrect implementation.
  - Does not meet the specification.
- Inappropriate object request.
  - E.g., invalid index.
- Inconsistent or inappropriate object state.
  - E.g. arising through class extension.
- Not always programmer error
  - Errors often arise from the environment (incorrect URL entered, network interruption).
  - File processing often error-prone (missing files, lack of appropriate permissions).

Defensive programming

- Client-server interaction.
  - Should a server assume that clients are well-behaved?
  - Or should it assume that clients are potentially hostile?
- Significant differences in implementation required.
- Issues to be addressed
  - How much checking by a server on method calls?
  - How to report errors?
  - How can a client anticipate failure?
  - How should a client deal with failure?

Argument values

- Arguments represent a major 'vulnerability' for a server object.
  - Constructor arguments initialize state.
  - Method arguments often control behavior.
- Argument checking is one defensive measure.
- How to report illegal arguments?
  - To the user? ***Is*** there a human user? Can the user do anything to solve the problem? If not solvable, what should you suggest they do?
  - To the client object: return a diagnostic value, or throw an exception.

Example of diagnostic return

```
public boolean removeDetails(String key)
{
    if(keyInUse(key)) {
        ContactDetails details =
                        (ContactDetails) book.get(key);
        book.remove(details.getName());
        book.remove(details.getPhone());
        numberOfEntries--;
        return true;        <-- Diagnostic OK
    }
    else {
        return false;       <-- Diagnostic not OK
    }
}
```

Client response to diagnostic

- Either:
  - Test the return value.
    - Attempt recovery on error.
    - Avoid program failure.
  - Ignore the return value.
    - Cannot be prevented.
    - Likely to lead to program failure.
  - Exceptions are preferable.
- Clients should take note of error notifications.
  - Check return values.
  - Don't 'ignore' exceptions.
- Include code to attempt recovery.
  - Will often require a loop.

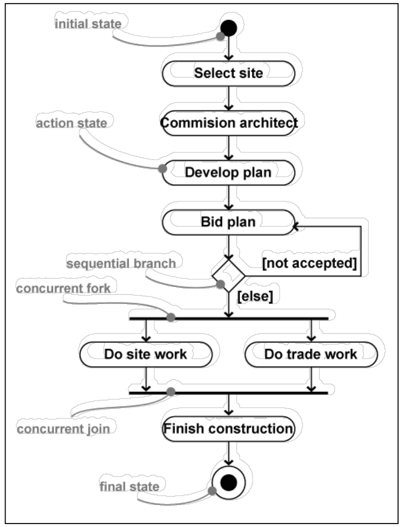
Error avoidance

- Clients can often use server query methods to avoid errors.
  - More robust clients mean servers can be more trusting.
  - Unchecked exceptions can be used.
  - Simplifies client logic.
- But there is a trade-off: the use of queries may increase client-server coupling.

Construction inside objects

object internals

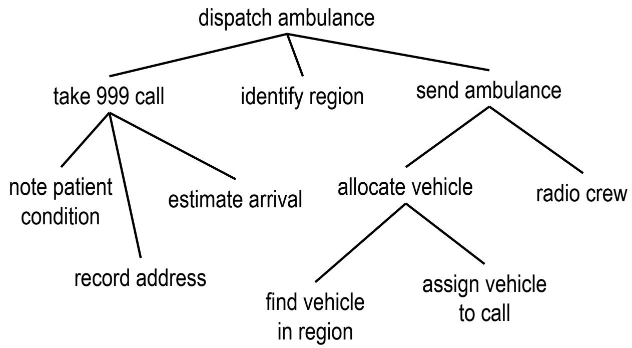
UML Activity diagram



Pioneers – Edsger Dijkstra

- Structured Programming
  - 1968, Eindhoven
- Why are programmers so bad at understanding dynamic processes and concurrency?
  - (ALGOL then – but still hard in Java today!)
- Observed that “GOTO” made things worse
  - Hard to describe what state a process has reached, when you don’t know which process is being executed.
- Define process as nested set of execution blocks, with fixed entry and exit points

Top-down design & stepwise refinement



Bottom-up construction

- Why?
  - Start with what you understand
  - Build complex structures from well-understood parts
  - Deal with concrete cases in order to understand abstractions
- Study of expert programmers shows that real software design work combines top-down and bottom up.

Modularity at code level

- Is this piece of code (class, method, function, procedure … “routine” in McConnell) needed?
- Define what it will do
  - What information will it hide?
  - Inputs
  - Outputs (including side effects)
  - How will it handle errors?
- Give it a good name
- How will you test it?
- Think about efficiency and algorithms
- Write as comments, then fill in actual code

Modularity in non-OO languages

- Separate source files in C
  - Inputs, outputs, types and interface functions defined by declarations in “header files”.
  - Private variables and implementation details defined in the “source file”
- Modules in ML, Perl, Fortran, …
  - Export publicly visible interface details.
  - Keep implementation local whenever possible, in interest of information hiding, encapsulation, low coupling.

Source code as a design model

- Objectives:
  - ***Accurately*** express logical structure of the code
  - ***Consistently*** express the logical structure
  - Improve ***readability***
- Good visual layout shows program ***structure***
  - Mostly based on white space and alignment
  - The compiler ignores white space
  - Alignment is the single most obvious feature to human readers.
- Like good typography in interaction design: but the "users" are other programmers!

Code as a structured model

```
public int Function_name (int parameter1, int parameter2)

// Function which doesn't do anything, beyond showing the fact
// that different parts of the function can be distinguished.

    int local_data_A;
    int local_data_B;

    // Initialisation section
    local_data_A = parameter1 + parameter2;
    local_data_B = parameter1 - parameter2;
    local_data_B++;

    // Processing
    while (local_data_A < 40) {
        if ( (local_data_B * 2) > local_data_A ) then {
            local_data_B = local_data_B - 1;
        } else {
            local_data_B = local_data_B + 1;
        }
        local_data_C = local_data_C + 1;
    }
    return local_data_C;
}
```

Expressing local control structure

```
while (local_data_C < 40) {
    form_initial_estimate(local_data_C);
    record_marker(local_data_B - 1);
    refine_estimate(local_data_A);
    local_data_C = local_data_C + 1;
} // end while
```

```
if ( (local_data_B * 2) > local_data_A ) then {
    // drop estimate
    local_data_B = local_data_B - 1;
} else {
    // raise estimate
    local_data_B = local_data_B + 1;
} // end if
```

Expressing structure within a line

- Whitespacealwayshelpshumanreaders
  - `newtotal=oldtotal+increment/missamount-1;`
  - `newtotal = oldtotal + increment / missamount - 1;`
- The compiler doesn't care – take care!
  - `x = 1  *  y+2  *  z;`
- Be conservative when nesting parentheses
  - `while ( (! error) && readInput() )`
- Continuation lines – exploit alignment

```
if ( ( aLongVariableName && anotherLongOne ) |
     ( someOtherCondition() ) )
   {
     …
   }
```

Naming variables: Form

- Priority: full and accurate (*not* just short)
  - Abbreviate for pronunciation (remove vowels)
    - e.g. CmptrScnce (leave first and last letters)
- Parts of names reflect conventional functions
  - Role in program (e.g. "count")
  - Type of operations (e.g. "window" or "pointer")
  - Hungarian naming (not really recommended):
    - e.g. pscrMenu, ichMin
- Even individual variable names can exploit typographic structure for clarity
  - **`xPageStartPosition`**
  - **`x_page_start_position`**

Naming variables: Content

- Data names describe domain, not computer
  - Describe what, not just how
  - **`CustomerName`** better than **`PrimaryIndex`**
- Booleans should have obvious truth values
  - **`ErrorFound`** better than **`Status`**
- Indicate which variables are related
  - **`CustName`**, **`CustAddress`**, **`CustPhone`**
- Identify globals, types & constants
  - C conventions: g_wholeApplet, T_mousePos
- Even temporary variables have meaning
  - **`Index`**, not **`Foo`**

Pioneers – Michael Jackson

- Jackson Structured Programming
  - 1975, independent consultant, London
- Describe program structure according to the structure of input and output streams
  - Mostly used for COBOL file processing
  - Still relevant to stream processing in Perl
- Data records (items in collection, elements in array) require a code loop
- Variant cases (subtypes, categories, enumerations) require conditional execution
- Switching between code and data perspectives helps to learn about design complexity and to check correctness.

Structural *roles* of variables

- Classification of what variables do in a routine
  - Don't confuse with data types (e.g. int, char, float)
- Almost all variables in simple programs do one of:
  - fixed value
  - stepper
  - most-recent holder

    } most common: 70 % of variables (fixed value, stepper, most-recent holder)
  - most-wanted holder
  - gatherer
  - transformation
  - one-way flag
  - follower
  - temporary
  - organizer

Fixed value

- Value is never changed after initialization
- Example: input radius of a circle, then print area
  - variable r is a *fixed value,* gets its value once, never changes after that.
- Useful to declare “final” in Java (see variable PI).

```
public class AreaOfCircle {

  public static void main(String[] args) {
      final float PI = 3.14F;
      float r;
      System.out.print("Enter circle radius: ");
      r = UserInputReader.readFloat();
      System.out.println(“Circle area is " + PI * r * r);
  }
}
```

Stepper

- Goes through a succession of values in some systematic way
  - E.g. counting items, moving through array index
- Example: loop where multiplier is used as a stepper.
  - outputs multiplication table, stepper goes through values from one to ten.

```
public class MultiplicationTable {

  public static void main(String[] args) {
      int multiplier;
      for (multiplier = 1; multiplier <= 10; multiplier++)
            System.out.println(multiplier + " * 3 = "
                  + multiplier * 3);
  }
}
```

Most-recent holder

- Most recent member of a group, or simply latest input value
- Example: ask the user for input until valid.
  - Variable s is a most-recent holder since it holds the latest input value.

```
public class AreaOfSquare {

  public static void main(String[] args) {
      float s = 0f;
      while (s <= 0) {
            System.out.print("Enter side of square: ");
            s = UserInputReader.readFloat();
      }
      System.out.println(“Area of square is " + s * s);
  }
}
```

Most-wanted holder

- The "best" (biggest, smallest, closest) of values seen.
- Example: find smallest of ten integers.
  - Variable smallest is a *most-wanted holder* since it is given the most recent value if it is smaller than the smallest one so far.
  - (i is a *stepper* and number is a *most-recent holder.*)

```
public class SearchSmallest {
  public static void main(String[] args) {
      int i, smallest, number;
      System.out.print("Enter the 1. number: ");
      smallest = UserInputReader.readInt();
      for (i = 2; i <= 10; i++) {
            System.out.print("Enter the " + i + ". number: ");
            number = UserInputReader.readInt();
            if (number < smallest) smallest = number;
      }
      System.out.println("The smallest was " + smallest);
  }
}
```

Gatherer

- Accumulates values seen so far.
- Example: accepts integers, then calculates mean.
  - Variable sum is a *gatherer* the total of the inputs is gathered in it.
  - (count is a *stepper* and number is a *most-recent holder*.)

```
public class MeanValue {

   public static void main(String[] argv) {
        int count=0;
        float sum=0, number=0;
        while (number != -999) {
                System.out.print("Enter a number, -999 to quit: ");
                number = UserInputReader.readFloat();
                if (number != -999) { sum += number; count++; }
        }
        if (count>0) System.out.println("The mean is " +
                                                sum / count);
   }
}
```

Transformation

- Gets every value by calculation from the value of other variable(s).
- Example: ask the user for capital amount, calculate interest and total capital for ten years.
  - Variable interest is a *transformation* and is always calculated from the capital.
  - (capital is a *gatherer* and i is a *counter*.)

```
public class Growth {
   public static void main(String[] args) {
        float capital, interest;   int i;
        System.out.print("Enter capital (positive or negative): ");
        capital = UserInputReader.readFloat();
        for (i = 1; i <=10; i++) {
                interest = 0.05F * capital;
                capital += interest;
                System.out.println("After "+i+" years interest is "
                        + interest + " and capital is " + capital);
        }
   }
}
```

One-way flag

- Boolean variable which, once changed, never returns to its original value.
- Example: sum input numbers and report if any negatives.
  - The *one-way flag* neg monitors whether there are negative numbers among the inputs. If a negative value is found, it will never return to false.
  - (number is a *most-recent holder* and sum is a *gatherer*.)

```
public class SumTotal {
   public static void main(String[] argv) {
        int number=1, sum=0;
        boolean neg = false;
        while (number != 0) {
                System.out.print("Enter a number, 0 to quit: ");
                number = UserInputReader.readInt();  sum += number;
                if (number < 0) neg = true;
        }
        System.out.println("The sum is " + sum);
        if (neg) System.out.println("There were negative numbers.");
   }
}
```

Follower

- Gets old value of another variable as its new value.
- Example: input twelve integers and find biggest difference between successive inputs.
  - Variable previous is a *follower*, following current.

```
public class BiggestDifference {
   public static void main(String[] args) {
      int month, current, previous, biggestDiff;
      System.out.print("1st: "); previous = UserInputReader.readInt();
      System.out.print("2nd: "); current = UserInputReader.readInt();
      biggestDiff = current - previous;
      for (month = 3; month <= 12; month++) {
        previous = current;
        System.out.print(month + "th: ");
        current = UserInputReader.readInt();
        if (current - previous > biggestDiff)
          biggestDiff = current - previous;
      }
      System.out.println("Biggest difference was " + biggestDiff);
   }
}
```

Temporary

- Needed only for very short period (e.g. between two lines).
- Example: output two numbers in size order, swapping if necessary.
  - Values are swapped using a *temporary* variable tmp whose value is later meaningless (no matter how long the program would run).

```
public class Swap {
   public static void main(String[] args) {
        int number1, number2, tmp;
        System.out.print("Enter num: ");
        number1 = UserInputReader.readInt();
        System.out.print("Enter num: ");
        number2 = UserInputReader.readInt();
        if (number1 > number2) {
                tmp = number1;
                number1 = number2;
                number2 = tmp;
        }
        System.out.println("Order is " + number1 + ","
                + number2 + ".");
   }
}
```

Organizer

- An array for rearranging elements
- Example: input ten characters and output in reverse order.
  - The reversal is performed in *organizer* variable word.
  - tmp is a *temporary* and i is a *stepper*.)

```
public class Reverse {
   public static void main(String[] args) {
        char[] word = new char[10];
        char tmp; int i;
        System.out.print("Enter ten letters: ");
        for (i = 0; i < 10; i++) word[i] =
                UserInputReader.readChar();
        for (i = 0; i < 5; i++) {
                tmp = word[i];
                word[i] = word[9-i];
                word[9-i] = tmp;
        }
        for (i = 0; i < 10; i++) System.out.print(word[i]);
        System.out.println();
   }
}
```

Verifying variables by role

- Many student program errors result from using the same variable in more than one role.
  - Identify role of each variable during design
- There are opportunities to check correct operation according to constraints on role
  - Check stepper within range
  - Check most-wanted meets selection criterion
  - De-allocate temporary value
  - Confirm size of organizer array is invariant
  - Use compiler to guarantee final fixed value
- Either do runtime safety checks (noting efficiency tradeoff), or use language features.

Type-checking as modeling tool

- Refine types to reflect meaning, not just to satisfy the compiler (C++ example below)
- Valid (to compiler), but incorrect, code:
  - `float totalHeight, myHeight, yourHeight;`
  - `float totalWeight, myWeight, yourWeight;`
  - `totalHeight = myHeight + yourHeight + myWeight;`
- Type-safe version:
  - `type t_height, t_weight: float;`
  - `t_height totalHeight, myHeight, yourHeight;`
  - `t_weight totalWeight, myWeight, yourWeight;`
  - `totalHeight = myHeight + yourHeight + myWeight;`

Compile error!

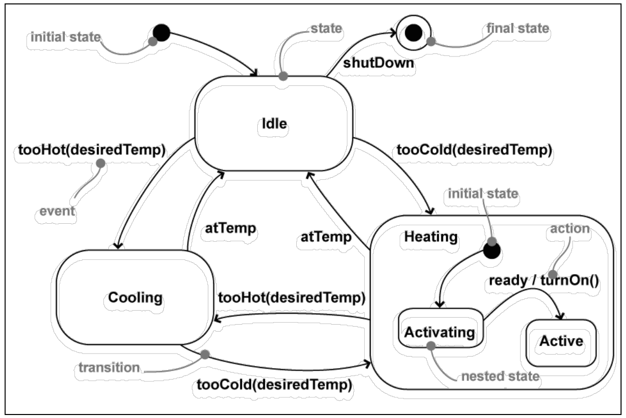
Language support for user types

- Smalltalk
  - All types are classes – consistent, but inefficient
- C++
  - Class overhead very low
  - User-defined types have no runtime cost
- Java
  - Unfortunately a little inefficient
  - But runtime inefficiency in infrequent calculations far better than lost development time.

Construction of data lifecycles

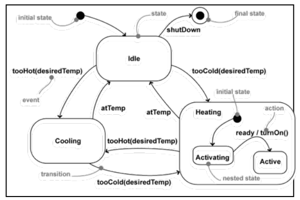
object state

UML Statechart diagram



UML Statechart diagram

- Lifecycle of an object from internal perspective
- Related to “state” design pattern
- Shares properties of finite state machine
  - … but transitions and states can be more complex.



Maintaining valid system state

- Pioneers (e.g. Turing) talked of proving program correctness using mathematics
- In practice, the best we can do is confirm that the state of the system is consistent
  - State of an object valid before and after operation
  - Parameters and local variables valid at start and end of routine
  - Guard values define state on entering & leaving control blocks (loops and conditionals)
  - Invariants define conditions to be maintained throughout operations, routines, loops.

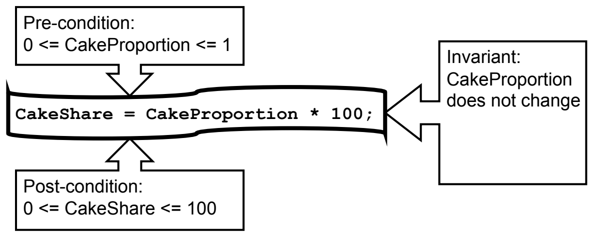
Pioneers – Tony Hoare

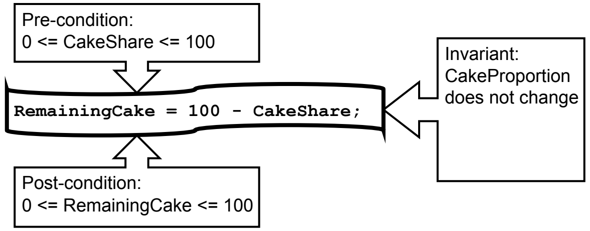
- Assertions and proof
  - 1969, Queen's University Belfast
- Program element behaviour can be defined
  - by a *post-condition* that will result …
  - … given a known *pre-condition*.
- If the previous and next states are accurately defined:
  - Individual elements can be composed
  - Program correctness is potentially provable
- This is the field of (Floyd-)Hoare logic

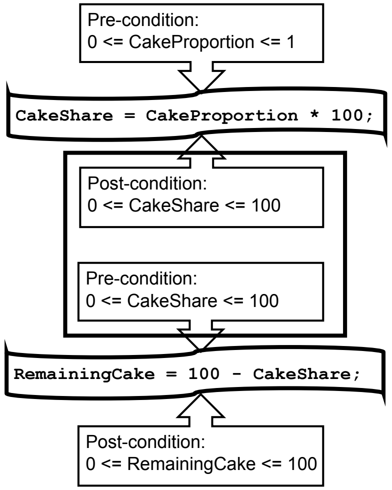
Basics of Hoare logic

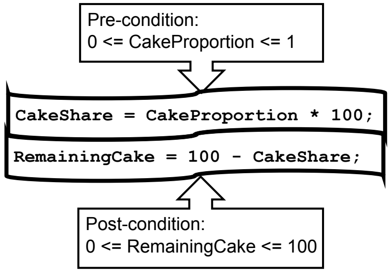
- How can you reason about the correctness of a program?
- Example
  - ***If*** a number is between 0 and 1
    - (e.g. a valid fraction of a whole)
  - … and you multiply it by 100 …
  - ***Then*** the result will be between 0 and 100
    - (e.g. a valid percentage)
- Note that a formal treatment comes in CST Part II

Pre- and post- conditions









Formal design models: Z notation

BirthdayBook

$known : \mathbb{P}\, NAME$

$birthday : NAME \rightarrow\!\!\!\!+ DATE$

$known = \mathrm{dom}\, birthday$

- Definitions of the *BirthdayBook* state space:
  - *known* is a set of NAMEs
  - *birthday* is a partial map from NAMEs to DATEs
- Invariants:
  - *known* must be the domain of *birthday*

Formal design models: Z notation

$$
\begin{array}{|l}
\textit{AddBirthday} \\
\hline
\Delta \textit{BirthdayBook} \\
\textit{name?} : \textit{NAME} \\
\textit{date?} : \textit{DATE} \\
\hline
\textit{name?} \notin \textit{known} \\
\textit{birthday}' = \textit{birthday} \cup \{\textit{name?} \mapsto \textit{date?}\} \\
\hline
\end{array}
$$

- An operation to change state
  - *AddBirthday* modifies the state of *BirthdayBook*
  - Inputs are a new *name* and *date*
  - Precondition is that *name* must not be previously known
  - Result of the operation, *birthday'* is defined to be a new and enlarged domain of the *birthday* map function

Formal design models: Z notation

$$
\begin{array}{|l}
\textit{Remind} \\
\hline
\Xi \textit{BirthdayBook} \\
\textit{today?} : \textit{DATE} \\
\textit{cards!} : \mathbb{P}\, \textit{NAME} \\
\hline
\textit{cards!} = \{\, n : \textit{known} \mid \textit{birthday}(n) = \textit{today?} \,\} \\
\hline
\end{array}
$$

- An operation to inspect state of *BirthdayBook*
  - This schema does not change the state of *BirthdayBook*
  - It has an output value (a set of people to send *cards* to)
  - The output set is defined to be those people whose birthday is equal to the input value *today*.

Advantages of formal models

- Requirements can be analysed at a fine level of detail.
- They are declarative (specify what the code should do, not how), so can be used to check specifications from an alternative perspective.
- As a mathematical notation, offer the promise of tools to do automated checking, or even proofs of correctness ("verification").
- They have been applied in some real development projects.

Disadvantages of formal models

- Notations that have lots of Greek letters and other weird symbols look scary to non-specialists.
  - Not a good choice for communicating with clients, users, rank-and-file programmers and testers.
- Level of detail (and thinking effort) is similar to that of code, so managers get impatient.
  - If we are working so hard,
    why aren't we just writing the code?
- Tools are available, but not hugely popular.
  - Applications so far in research / defence / safety critical
- Pragmatic compromise from UML developers
  - "Object Constraint Language" (OCL).
  - Formal specification of some aspects of the design, so that preconditions, invariants etc. can be added to models.

Language support for assertions

- Eiffel (pioneering OO language)
  - supported pre- and post-conditions on every method.
- C++ and Java support “assert” keyword
  - Programmer defines a statement that must evaluate to boolean true value at runtime.
  - If assertion evaluates false, exception is raised
- Some languages have debug-only versions, turned off when system considered correct.
  - Dubious trade-off of efficiency for safety.
- Variable roles could provide rigorous basis for fine-granularity assertions in future.

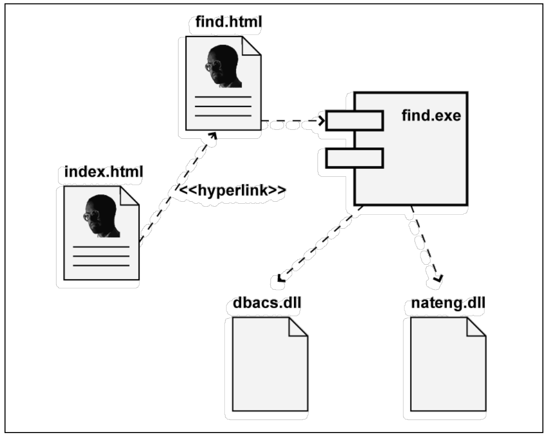
Defensive programming

- Assertions and correctness proofs are useful tools, but not always available.
- Defensive programming includes additional code to help ensure local correctness
  - Treat function interfaces as a contract
- Each function / routine
  - Checks that input parameters meet assumptions
  - Checks output values are valid
- System-wide considerations
  - How to report / record detected bugs
  - *Perhaps* include off-switch for efficiency

Construction using objects

components

UML Component diagram



Component documentation

- Your own classes should be documented the same way library classes are.
- Other people should be able to use your class without reading the implementation.
- Make your class a 'library class'!

Elements of documentation

Documentation for a class should include:

- the class name
- a comment describing the overall purpose and characteristics of the class
- a version number
- the authors' names
- documentation for each constructor and each method

Elements of documentation

The documentation for each constructor and method should include:

- the name of the method
- the return type
- the parameter names and types
- a description of the purpose and function of the method
- a description of each parameter
- a description of the value returned

- In Java, just use Javadoc

Transition

testing and optimisation

What is the goal of testing?

- A) To define the end point of the software development process as a managed objective?
- B) To prove that the programmers have implemented the specification correctly?
- C) To demonstrate that the resulting software product meets defined quality standards?
- D) To ensure that the software product won't fail, with results that might be damaging?

Testing and quality

- Wikipedia (2013)
  - "Software testing is the process used to assess the ***quality*** of computer software. It is an empirical technical investigation conducted to provide stakeholders with information about the ***quality*** of the product or service under test, with respect to the context in which it is intended to operate."
- Edsger Dijkstra
  - "Program testing can be used to show the ***presence*** of bugs, but ***never*** to show their absence"

Remember design as learning?

- Design is the process of learning about a problem and describing a solution
  - at first with many gaps …
  - eventually in sufficient detail to build it.
- We describe both the problem and the solution in a series of *design models*.
- Testing those models in various ways helps us gather more knowledge.
- Source code is simply the most detailed model used in software development.

Learning through testing

A bug is a system's way of telling you that you don't know something (P. Armour)

- Testing searches for the ***presence*** of bugs.
  - (not for the absence of bugs)
- Later: 'debugging' searches for the ***cause*** of bugs, once testing has found that a bug exists.
  - The manifestation of an bug as observable behaviour of the system may well occur some 'distance' from its cause.

Testing principles

- Look for violations of the interface contract.
  - Aim is to find bugs, ***not*** to prove that unit works as expected from its interface contract
  - Use positive tests (expected to pass) in the hope that they ***won't*** pass
  - Use negative tests (expected to fail) in the hope that they ***don't*** fail
- Try to test *boundaries* of the contract
  - e.g. zero, one, overflow, search empty collection, add to a full collection.

Unit testing priorities

- Concentrate on modules most likely to contain errors:
  - Particularly complex
  - Novel things you've not done before
  - Areas known to be error-prone
- Some habits in unit test ordering
  - Start with small modules
  - Try to get input/output modules working early
    - Allows you to work with real test data
  - Add new ones gradually
  - You probably want to test critical modules early
    - For peace of mind, not because you expect errors

How to do it: testing strategies

- Manual techniques
  - Software inspections and code walkthrough
- Black box testing
  - Based on specified unit interfaces, not internal structure, for test case design
- White box testing
  - Based on knowing the internal structure
- Stress testing
  - At what point will it fail?
- 'Random' (unexpected) testing
  - Remember the goal: most errors in least time

Pioneers – Michael Fagan

- Software Inspections
  - 1976, IBM
- Approach to design checking, including planning, control and checkpoints.
- Try to find errors in design and code by systematic *walkthrough*
- Work in teams including designer, coder, tester and moderator.

Software inspections

- A low-tech approach, relatively underused, but more powerful than appreciated.
- Read the source code in execution order, acting out the role of the computer
  - High-level (step) or low-level (step-into) views.
- An expert tries to find common errors
  - Array bound errors
  - Off-by-one errors
  - File I/O (and threaded network I/O)
  - Default values
  - Comparisons
  - Reference versus copy

Inspection by yourself

- Get away from the computer and 'run' a program by hand
- Note the current object state on paper
- Try to find opportunities for incorrect behaviour by creating incorrect state.
- Tabulate values of fields, including invalid combinations.
- Identify the state changes that result from each method call.

Black box testing

- Based on interface specifications for whole system or individual modules
- Analyse input ranges to determine test cases
- Boundary values
  - Upper and lower bounds for each value
  - Invalid inputs outside each bound
- Equivalence classes
  - Identify data ranges and combinations that are 'known' to be equivalent
  - Ensure each equivalence class is sampled, but not over-represented in test case data

White box testing

- Design test cases by looking at internal structure, including all possible bug sources
  - Test each independent path at least once
  - Prepare test case data to force paths
  - Focus on error-prone situations (e.g. empty list)
  - The goal is to find as many errors as you can
- Control structure tests:
  - conditions – take each possible branch
  - data flow – confirm path through parameters
  - loops – executed zero, one, many times
  - exceptions – ensure that they occur

Stress testing

- The aim of stress testing is to find out *at what point* the system will fail
  - You really *do* want to know what that point is.
  - You *have to keep going* until the system fails.
  - If it hasn't failed, you haven't done stress testing.
- Consider both volume and speed
- Note difference from *performance testing*, which aims to confirm that the system will perform as specified.
  - Used as a contractual demonstration
  - It's not an efficient way of finding errors

Random testing

- There are far more combinations of state and data than can be tested exhaustively
- Systematic test case design helps explore the range of possible system behaviour
  - But remember the goal is to make the system fail, not to identify the many ways it works correctly.
- Experienced testers have an instinct for the kinds of things that make a system fail
  - Usually by thinking about the system in ways the programmer did not expect.
  - Sometimes, just doing things at random can be an effective strategy for this.

Regression testing

- 'Regression' is when you go backwards, or things get worse
  - Regression in software usually results from re-introducing faults that were previously fixed.
  - Each bug fix has around 20% probability of reintroducing some other old problem.
  - Refactoring can reintroduce design faults
- So regression testing is designed to ensure that a new version gives the same answers as the old version did

Regression testing

- Use a large database of test cases
- Include all bugs reported by customers:
  - customers are much more upset by failure of an already familiar feature than of a new one
  - reliability of software is relative to a set of inputs, so better test inputs that users actually generate!
- Regression testing is boring and unpopular
  - test automation tools reduce mundane repetition
  - perhaps biggest single advance in tools for software engineering of packaged software

Test automation

- Thorough testing (especially regression testing) is time consuming and repetitive.
- Write special classes to test interfaces of other classes automatically
  - "test rig" or "test harness"
  - "test stubs" substitute for unwritten code, or simulate real-time / complex data
- Use standard tools to exercise external API, commands, or UI (e.g. mouse replay)
  - In commercial contexts, often driven from build and configuration tools.

Unit testing

- Each unit of an application may be tested.
  - Method, class, interface, package
- Can (should) be done *during* development.
  - Finding and fixing early lowers development costs (e.g. programmer time).
  - Build up a test suite of necessary harnesses, stubs and data files
- JUnit is often used to manage and run tests
  - you use this to check your practical exercises
  - www.junit.org

Other system tests

- Security testing
  - automated probes, or
  - a favour from your Russian friends
- Efficiency testing
  - test expected increase with data size
  - use code profilers to find hot spots
- Usability testing
  - essential to product success
  - often involves studying users

Testing efficiency: optimisation

- Worst error is using wrong algorithm
  - e.g. lab graduate reduced 48 hours to 2 minutes
  - Try different size data sets – does execution time vary as N, $2N$, N^2, N^3, N^4, k^N ...?
- If this is the best algorithm, and you know it scales in a way appropriate to your data, but still goes too slow for some reason, ask:
  - How often will this program / feature be run?
  - Hardware gets faster quickly
  - Optimisation may be a waste of ***your*** time

Testing efficiency: optimisation

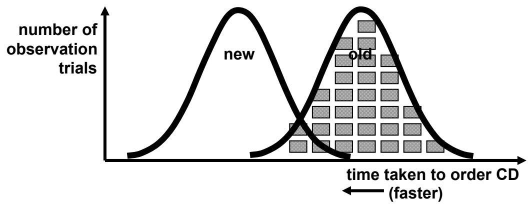
- When optimisation is required
  - First: check out compiler optimisation flags
  - For *some parts* of extreme applications
    - Use code profiler to find hotspots/bottlenecks
    - Most likely cause: overuse of some library/OS function
  - When pushing hardware envelope
    - Cache or pre-calculate critical data
    - Recode a function in C or assembler
    - Use special fast math tricks & bit-twiddling
    - Unroll loops (but compilers should do this)
- But if this is an interactive system …
  - … how fast will the user be?

User interface efficiency

- Usability testing can measure speed of use
  - How *long* did Fred take to order a book from Amazon?
  - How many *errors* did he make?
- But every observation is different.
  - Fred might be faster (or slower) next time
  - Jane might be consistently faster
- So we compare averages:
  - over a number of trials
  - over a range of people (experimental subjects)
- Results usually have a normal distribution

Experimental (A/B) interface testing

- Experimental *treatment* is some change that we expect to have an effect on usability:
  - Hypothesis: we expect new interface to be faster (& produce less errors) than old one



- Expected answer: *usually* faster, but not *always*

Hypothesis testing

- *Null hypothesis:*
  - What is the probability that this amount of difference in means could be random variation between samples?
  - Hopefully very low ($p < 0.01$, or 1%)
  - Use a statistical *significance test*, such as the *t-test*.

A/B testing for decisions

- e.g. Do more people click the “buy” button if it’s round or square?
  - It would be ridiculous to test every aspect of a design this way.
- But if you have a lot of users/data (e.g. you’re Google)
  - make different versions of a page
  - compare numbers of user choices from logs
- Difference might still result from random variation
  - Use the *binomial test* to see if the difference between versions is greater than chance
  - Remember coin-tossing experiments at school!

Usability testing in the field

- Brings advantages of ethnography / contextual task analysis to testing phase of product development.
- Case study: Intuit Inc.’s *Quicken* product
  - originally based on interviews and observation
  - follow-me-home programme after product release:
    - random selection of shrink-wrap buyers;
    - observation while reading manuals, installing, using.
  - Quicken success was attributed to the programme:
    - survived predatory competition, later valued at $15 billion.

Think-aloud testing

- Black-box testing for the user interface
- Observe and record a system user performing sample tasks
  - Could be using paper prototype or mockup
  - Ask them to think aloud while working
  - Record and capture their understanding
- Goal is to identify their mental model, so you can assess gulfs of execution/evaluation.
- Essential to find users *who don’t think the same way you do!*

Cognitive walkthrough

- White-box testing for the user interface
  - Like software inspection of your user theory
- No user involved – the design/test team follows a structured inspection process:
  - Break the user’s task down into subgoals
  - For each subgoal:
    - What is the user trying to achieve at this moment?
    - Can they see the control they need?
    - Is it labelled in a way that matches their goal?
    - Why would they choose the action you expect?
    - Does the feedback help them learn (even if correct)?

Philosophy of testing

Classic testing advice

- The Art of Software Testing
  - Glenford J. Myers
  - John Wiley, 1979
- Seven Principles of Software Testing
  - Bertrand Meyer, ETH Zürich and Eiffel Software
  - IEEE Computer, August 2008, 99-101

Myers' classic book

The Psychology and Economics of Program Testing 15

Table 2.1
Vital Program Testing Guidelines

Principle Number	*Principle*
1	A necessary part of a test case is a definition of the expected output or result.
2	A programmer should avoid attempting to test his or her own program.
3	A programming organization should not test its own programs.
4	Thoroughly inspect the results of each test.
5	Test cases must be written for input conditions that are invalid and unexpected, as well as for those that are valid and expected.
6	Examining a program to see if it does not do what it is supposed to do is only half the battle; the other half is seeing whether the program does what it is not supposed to do.
7	Avoid throwaway test cases unless the program is truly a throwaway program.
8	Do not plan a testing effort under the tacit assumption that no errors will be found.
9	The probability of the existence of more errors in a section of a program is proportional to the number of errors already found in that section.
10	Testing is an extremely creative and intellectually challenging task.

Myers' 10 principles

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Myers' 10 principles (cont.)

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Meyer's new classic article

SOFTWARE TECHNOLOGIES

Seven Principles of Software Testing

Bertrand Meyer, ETH Zürich and Eiffel Software

Testing is about producing failures.

While everyone knows the theoretical limitations of software testing, in practice we devote considerable effort to this task and would consider it foolish or down-

for testing, echoed in the Wikipedia definition (http://en.wikipedia.org/wiki/Software_testing): "Software testing is the process used to assess the quality of computer software. Software testing is an empirical technical investigation conducted to

have evidenced 550, 540, and 530 faults, the trend is encouraging, but the next run is unlikely to find no faults, or 100. (Mathematical reliability models allow more precise estimates, credible in the presence of a sound long-term data collection process.)

The only incontrovertible connection is negative, a falsification in the Popperian sense: A failed test gives us evidence of nonquality. In addition, if the test previously passed, it indicates regression and points to possible quality problems in the program and the development process. The most famous quote about testing expressed this memorably: "Program testing," wrote Edsger Dijkstra, "can be used to show the presence of bugs, but never to show their absence!"

Less widely understood (and probably not intended by Dijkstra) is what this means for testers: the best possible self-advertisement. Surely, any technique that uncovers faults holds great interest for all "stakeholders," from managers to developers and customers.

Rather than an indictment, we

Meyer's 7 Principles

- Principle 1: Definition
  - To test a program is to try to make it fail.
- Principle 2: Tests versus specs
  - Tests are no substitute for specifications.
- Principle 3: Regression testing
  - Any failed execution must yield a test case, to remain a permanent part of the project's test suite.

Meyer's 7 Principles (cont.)

- Principle 4: Applying 'oracles'
  - Determining success or failure of tests must be an automatic process.
- Principle 4 (variant): Contracts as oracles
  - Oracles should be part of the program text, as contracts. Determining test success or failure should be an automatic process consisting of monitoring contract satisfaction during execution.
- Principle 5: Manual and automatic test cases
  - An effective testing process must include both manually and automatically produced test cases.

Meyer's 7 Principles (cont.)

- Principle 6: Empirical assessment of testing strategies
  - Evaluate any testing strategy, however attractive in principle, through objective assessment using explicit criteria in a reproducible testing process.
- Principle 7: Assessment criteria
  - A testing strategy's most important property is the number of faults it uncovers as a function of time.

Fixing bugs – 'debugging'

- Treat debugging as a series of experiments
  - As with testing, debugging is about learning things
- Don't just make a change in the hope that it might fix a bug
  - Form a hypothesis of what is causing the unexpected behaviour
  - Make a change that is designed to test the hypothesis
  - If it works, good, if not, you've learned something
  - Either way, check what else you broke

Debugging strategy

- Your goal is to find and fix the error (gain information), not disguise the symptom
- Step 1: THINK
  - Which is the relevant data?
  - Why is it behaving that way?
  - Which part is correct, and which incorrect?
- Step 2: search and experiment
  - Backtrack from the place that is incorrect
  - Test on local state in each place
  - Try to localise changes

Print statements

- The most popular debugging technique.
- No special tools required.
- All programming languages support them.
- But often badly used …
  - Printing things at random in hope of seeing something wrong
- Instead:
  - Make a hypothesis about the cause of a bug
  - Use a print statement to test it
- Output may be voluminous
  - Turning off and on requires forethought.

Walkthroughs

- Read through the code, explaining what state changes will result from each line.
- Explain to someone else what the code is doing.
  - They might spot the error.
  - The process of explaining might help you to spot it for yourself (the cardboard software engineer)
- Can be done on-screen from source code, on paper (as in a software inspection), or using a debugger

Debuggers

- Usual features include:
  - Breakpoints
    - Similar to print statements – can be used to test state at a particular program point
  - Step-over or step-into methods/routines
    - Identify specific routine or statement responsible for unexpected effect.
  - Call sequence (stack) inspectors
    - Explore parameters preceding unexpected effect
  - Object and variable state inspectors
    - Also continuous “watch” windows.
- However, debuggers are both language-specific and environment-specific.

If all else fails …

- Sleep on it.

Iterative Development

within any design phase or any combination of phases

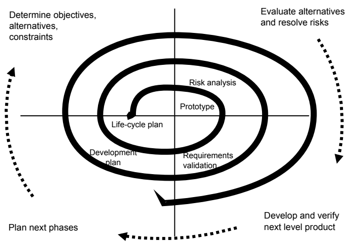
The economics of phase tests

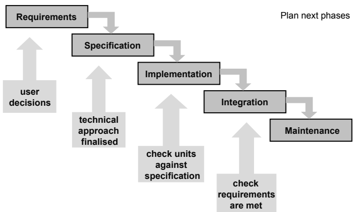
Relative cost to fix an fault [Boehm 1980]

Phase in which found	**Cost ratio**
requirements	1
design	3-6
coding	10
development testing	15-40
acceptance testing	30-70
operation	40-1000

… & these figures are considered conservative!

Waterfall vs Spiral





Prototyping

- Supports early investigation of a system.
  - Early problem identification.
- Incomplete components can be simulated.
  - e.g. always returning a fixed result.
  - May want to avoid random or time-dependent behavior which is difficult to reproduce.
- Allows early interaction with clients
  - Perhaps at inception phase of project
  - Especially (if feasible) with actual users!
- In product design, creative solutions are discovered by building many prototypes

Prototyping product concepts

- Emphasise appearance of the interface, create some behaviour with scripting functions:
  - Visio – diagrams plus behaviour
  - Animation tools – movie sequence
  - JavaScript – simulate application as web page
  - PowerPoint – 'click-through' prototype
- Cheap prototypes are good prototypes
  - More creative solutions are often discovered by building more prototypes.
  - Glossy prototypes can be mistaken for the real thing – either criticised more, or deployed!

Prototypes without programming

- Low-fidelity prototypes (or mockups)
  - Paper-and-glue simulation of interface
  - User indicates action by pointing at buttons on the paper "screen"
  - Experimenter changes display accordingly
- "*Wizard of Oz*" simulation method
  - Computer user interface is apparently operational
  - Actual system responses are produced by an experimenter in another room.
  - Can cheaply assess effects of "intelligent" interfaces

Software continues changing

- Even after project completion!
- There are only two options for software:
  - Either it is continuously maintained …
  - … or it dies.
- Software that cannot be maintained will be thrown away.
  - Not like a novel (written then finished).
  - Software is extended, corrected, maintained, ported, adapted…
- The work will be done by different people over time (often decades).

Versioning

- More on version and configuration management next year.
  - Versioning is about communicating change
- e.g. *semantic versioning* on open source projects:
  - 1.3.15 => MAJOR.MINOR.PATCH.
  - MAJOR version when you make incompatible API changes,
  - MINOR version when you add functionality in a backwards-compatible manner, and
  - PATCH version when you make backwards-compatible bug fixes.

User-centred Design

- Focus on ‘end-users’, not just specifications from contract and/or client
- Use ethnographic methods at inception stage
- Design based on user conceptual models
- Early prototyping to assess conceptual model
- Contextual evaluation to assess task relevance
- Frequent iteration

Agile methods (e.g. XP)

- Deliver working software from the outset
- Collect user stories describing features
- Design leader prioritises implementation
- Build functional increments in “sprints”
- Refactor as required
- Stop when the money runs out
- Some tension with user-centred processes
- Many proprietary alternatives!

Extreme Programming (1)

- From Portland Smalltalk group (Beck & Cunningham)
  - Software development as collaboration
  - Invented patterns, wikis, agile methods
- Customers work on-site with developers
  - No project manager, but a “coach”
- *User stories* are written on little cards
  - “A promise to have a conversation”
  - But you *must* talk to the customer
    - Don’t rely on documents
    - Show them the working system instead

Extreme Programming (2)

- Technical practices included:
  - Iterations and releases are timeboxed
    - Planning game to estimate and negotiate
  - Test-driven development:
    - start with an example of how the program works
  - Pair programming
    - share your code with others *all the time*
    - learning percolates around the team
- Management:
  - A simple daily stand-up for team awareness

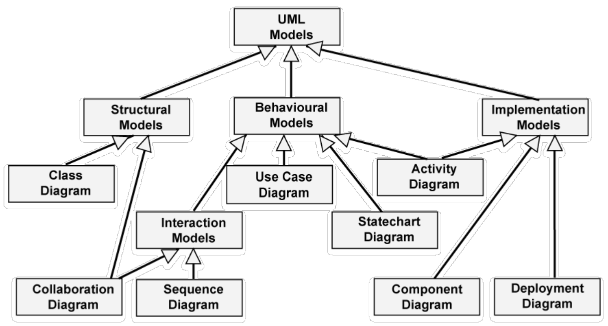
Scrum: agile management

- Project roles:
  - Product owner = “single wringable neck”
  - Development team members
  - Scrum master = an expert on process
- Manage the backlog
  - List of items (user stories) to be implemented
- Plan by timeboxed “sprints”
  - Do something, then plan some more
- Not just technical
  - Scrum could be a way of managing anything

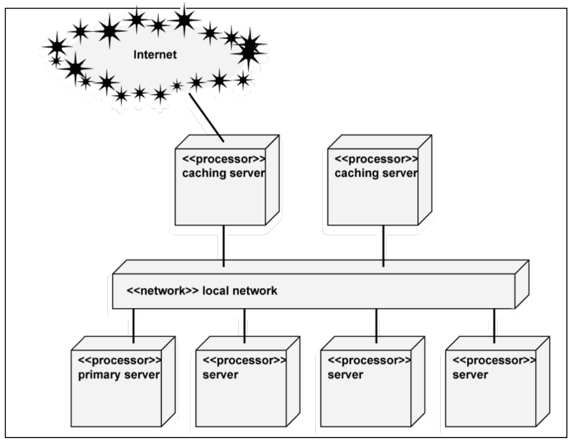
Participatory Design

- Users become partners in the design team
  - Originated in Scandinavian printing industry
  - Now used in developing world, with children, …
- PICTIVE method
  - Users generate scenarios of use in advance
  - Low fidelity prototyping tools (simple office supplies) are provided for collaborative session
  - The session is videotaped for data analysis
- CARD method
  - Cards with screen-dumps on them are arranged on a table to explore workflow options

UML review: Modelling for uncertainty



Eventually … a Deployment diagram



The ‘quick and dirty’ version of USDP

- Plan using general UML phase principles
- Make sure you visit / talk to end-users
  - show them pictures of proposed screens
- Write use case “stories”
  - note the parts that seem to be common
- Keep a piece of paper for each class
  - write down attributes, operations, relationships
  - lay them out on table, and “talk through” scenarios
- Think about object multiplicity and lifecycle
  - collections, state change, persistence
- Test as early as possible

Software Design: beyond “correct”

The requirements for design conflict and cannot be reconciled. All designs for devices are in some degree failures, either because they flout one or another of the requirements or because they are compromises, and compromise implies a degree of failure ... quite specific conflicts are inevitable once requirements for economy are admitted; and conflicts even among the requirements of use are not unknown. It follows that all designs for use are arbitrary. The designer or his client has to choose in what degree and where there shall be failure. … It is quite impossible for any design to be the “logical outcome of the requirements” simply because, the requirements being in conflict, their logical outcome is an impossibility.

David Pye, *The Nature and Aesthetics of Design* (1978).