UNIVERSITÄT BERN

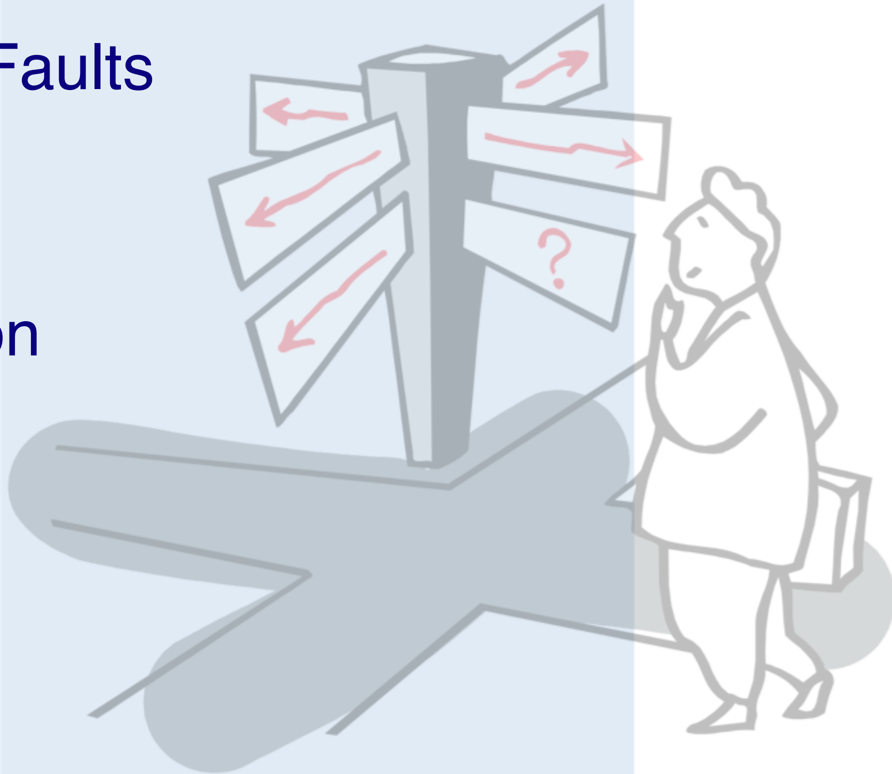
# ESE
*Einführung in Software Engineering*

## 5. Software Validation

Prof. O. Nierstrasz

# Roadmap

> Reliability, Failures and Faults
> Fault Avoidance
> Fault Tolerance
> Verification and Validation
> The Testing process
  — Black box testing
  — White box testing
  — Statistical testing

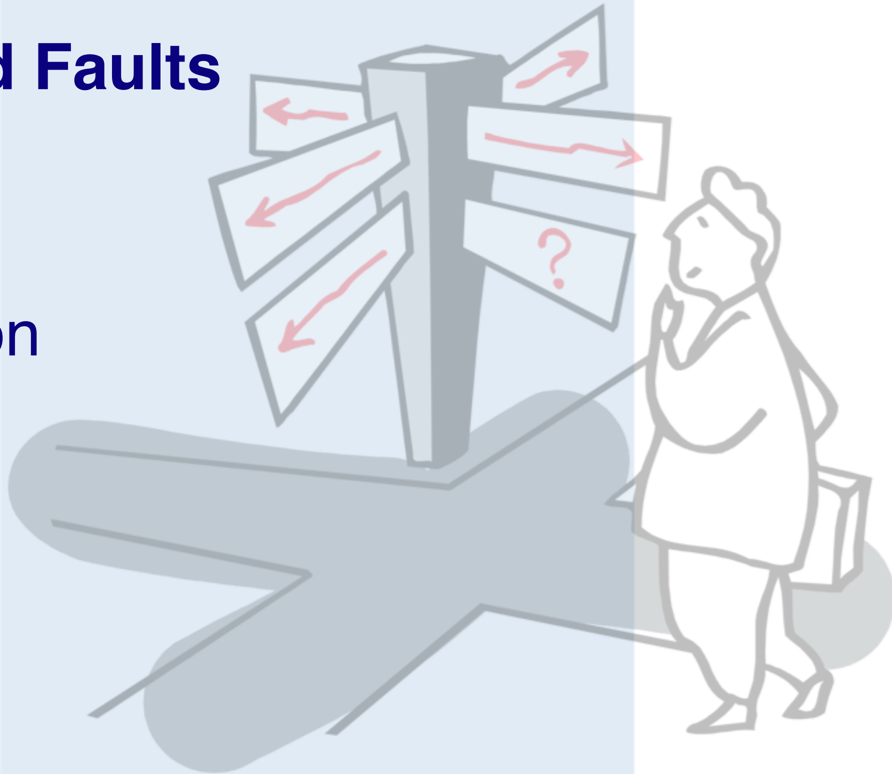


# Source

> *Software Engineering*, I. Sommerville, 7th Edn., 2004.

# Roadmap

> **Reliability, Failures and Faults**
> Fault Avoidance
> Fault Tolerance
> Verification and Validation
> The Testing process
  — Black box testing
  — White box testing
  — Statistical testing



# 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.

© Oscar Nierstrasz

# 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 |

© Oscar Nierstrasz

# 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*

© Oscar Nierstrasz

# Roadmap

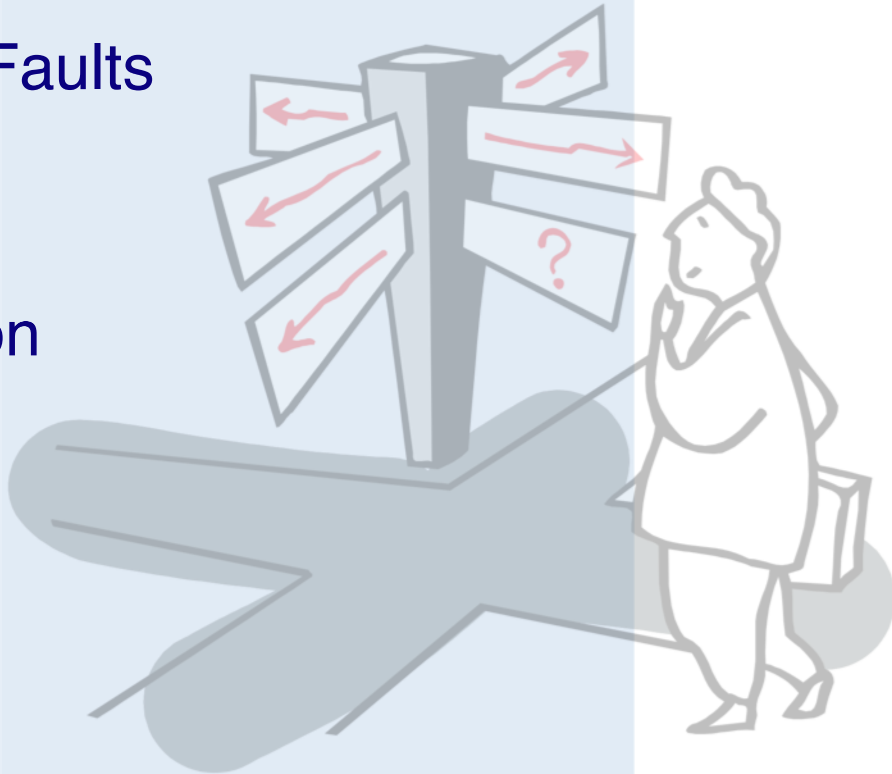
> Reliability, Failures and Faults

> **Fault Avoidance**

> Fault Tolerance

> Verification and Validation

> The Testing process
  — Black box testing
  — White box testing
  — Statistical testing



# 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

© Oscar Nierstrasz

# 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

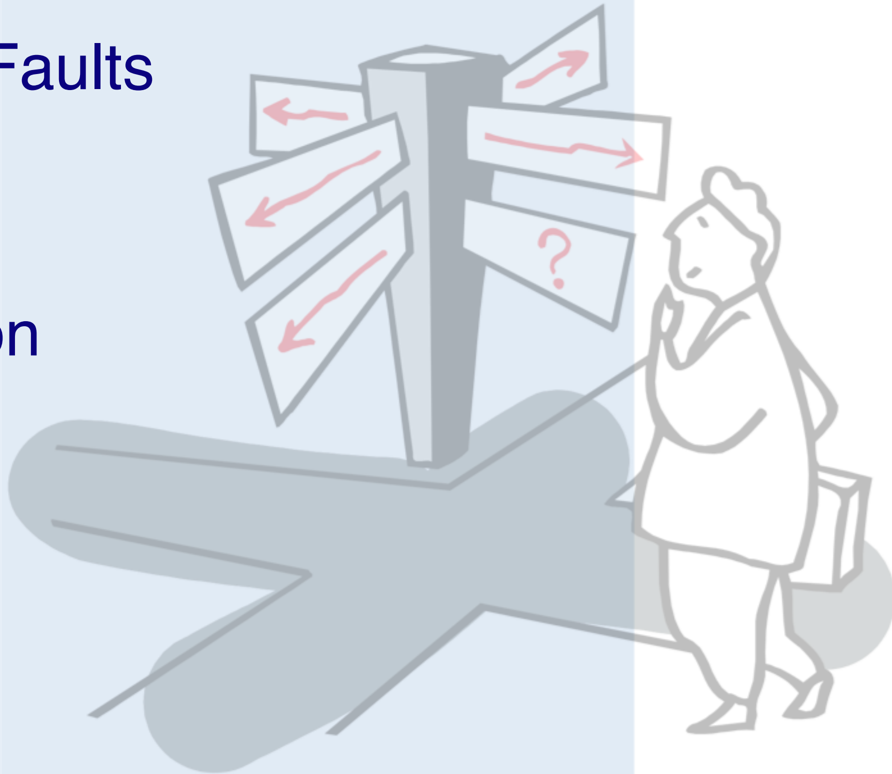
> ***Recursion*** can lead to *convoluted logic*, and may exhaust (stack) memory.
>
> — Use recursion in a disciplined way, within a controlled scope

> ***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

© Oscar Nierstrasz

# Roadmap

> Reliability, Failures and Faults
> Fault Avoidance
> **Fault Tolerance**
> Verification and Validation
> The Testing process
  — Black box testing
  — White box testing
  — Statistical testing



# 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 (!)

© Oscar Nierstrasz

# 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!)

© Oscar Nierstrasz

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

***Fault recovery:***

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

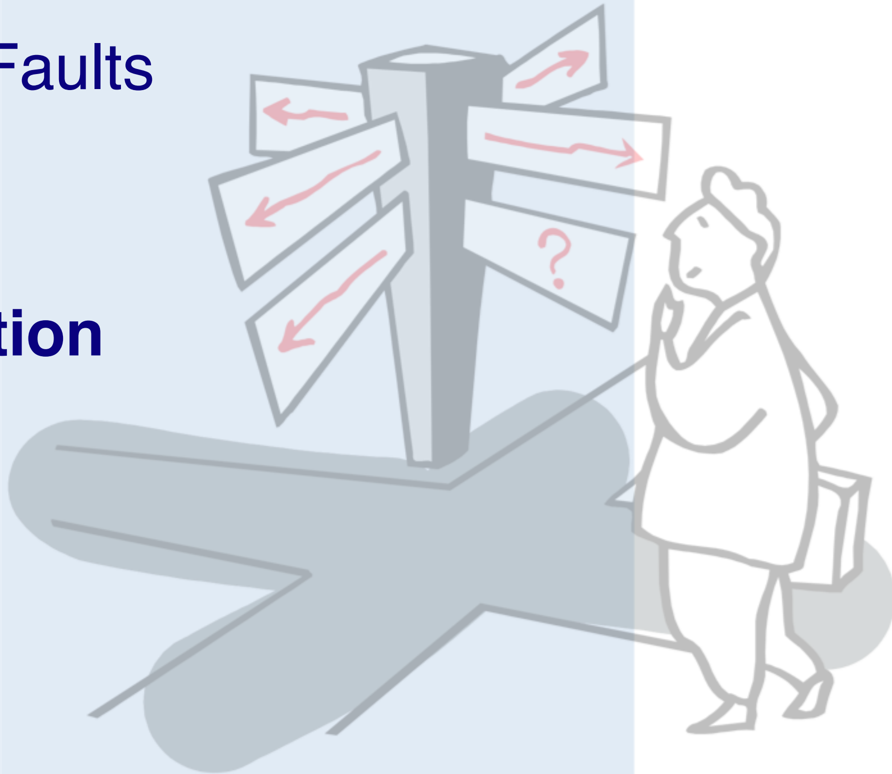
# Examples

- Concurrency control
  - Pessimistic (locking)
    - *Java synchronization; rcs*
  - Optimistic (check for conflict before commit)
    - *Cvs, subversion*
- Fault recovery
  - Change logs (rollback and replay)
    - *Smalltalk image and changes*

© Oscar Nierstrasz

# Roadmap

> Reliability, Failures and Faults
> Fault Avoidance
> Fault Tolerance
> **Verification and Validation**
> The Testing process
— Black box testing
— White box testing
— Statistical testing



# Verification and Validation

***Verification:***

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

***Validation:***

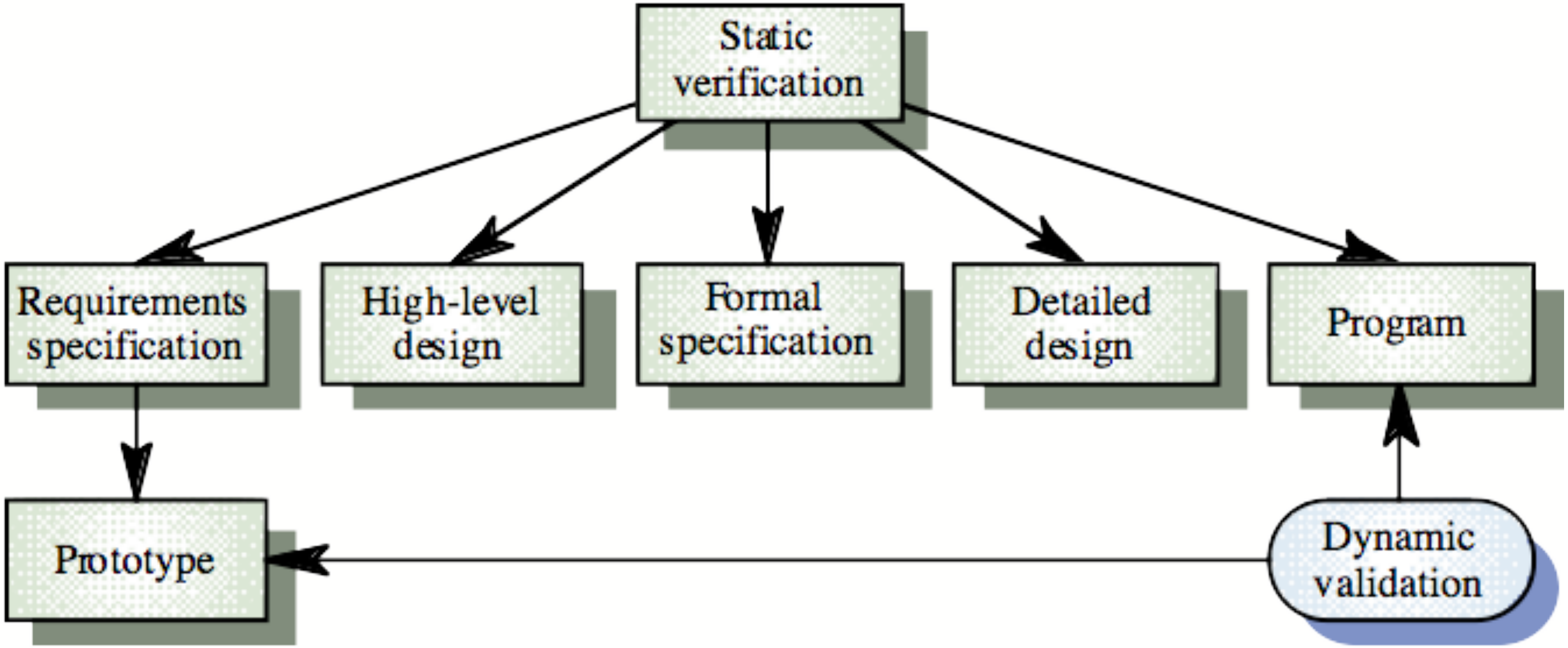
- Are we building the *right product*?
  - — i.e., does it meet expectations?

© Oscar Nierstrasz

# Verification and Validation ...

*Static techniques* include program inspection, analysis and formal verification.

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




© Ian Sommerville 2000

# Static Verification

***Program Inspections:***

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

***Static Program Analysers:***

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

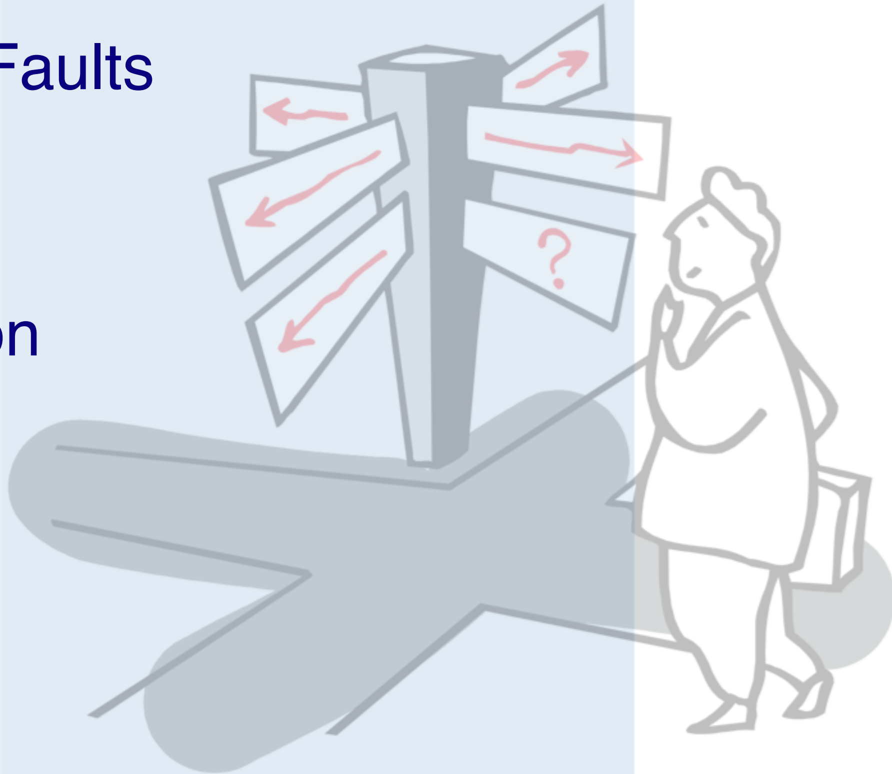
***Mathematically-based Verification:***

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

© Oscar Nierstrasz

# Roadmap

- Reliability, Failures and Faults
- Fault Avoidance
- Fault Tolerance
- Verification and Validation
- **The Testing process**
  - Black box testing
  - White box testing
  - Statistical testing



© Oscar Nierstrasz

# 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.

© Oscar Nierstrasz

# 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.*

© Oscar Nierstrasz

# Regression testing

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

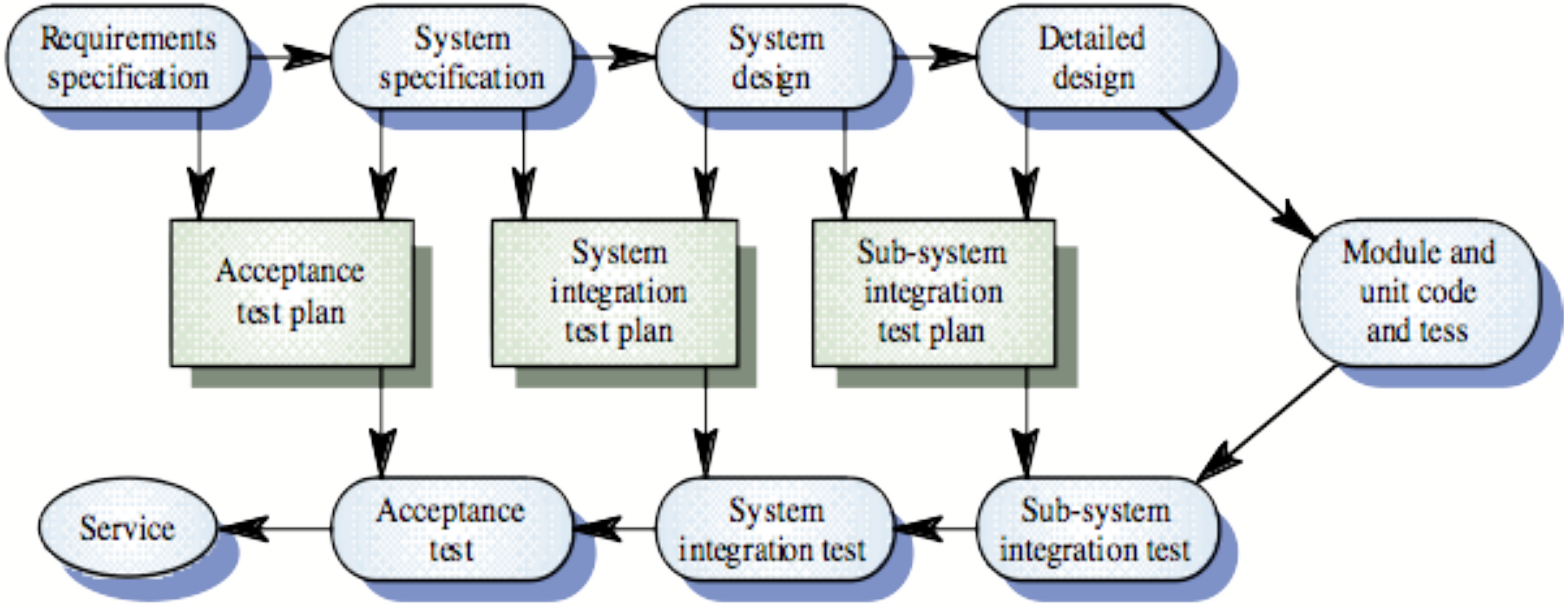
- tests must be *deterministic* and *repeatable*
- should test "all" functionality
  - every interface
  - all boundary situations
  - every feature
  - every line of code
  - everything that can conceivably go wrong!

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

© Oscar Nierstrasz

# 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.

© Ian Sommerville 2000

# 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

© Oscar Nierstrasz

# 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.*

© Oscar Nierstrasz

# Testing vs Correctness

> “Program testing can be a very effective way to show the presence of bugs, but is hopelessly inadequate for showing their absence.”
>
> — *Edsger Dijkstra, The Humble Programmer, ACM Turing lecture, 1972*

© Oscar Nierstrasz

# 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.

© Oscar Nierstrasz

# Defect Testing ...

*Petschenik (1985) proposes:*

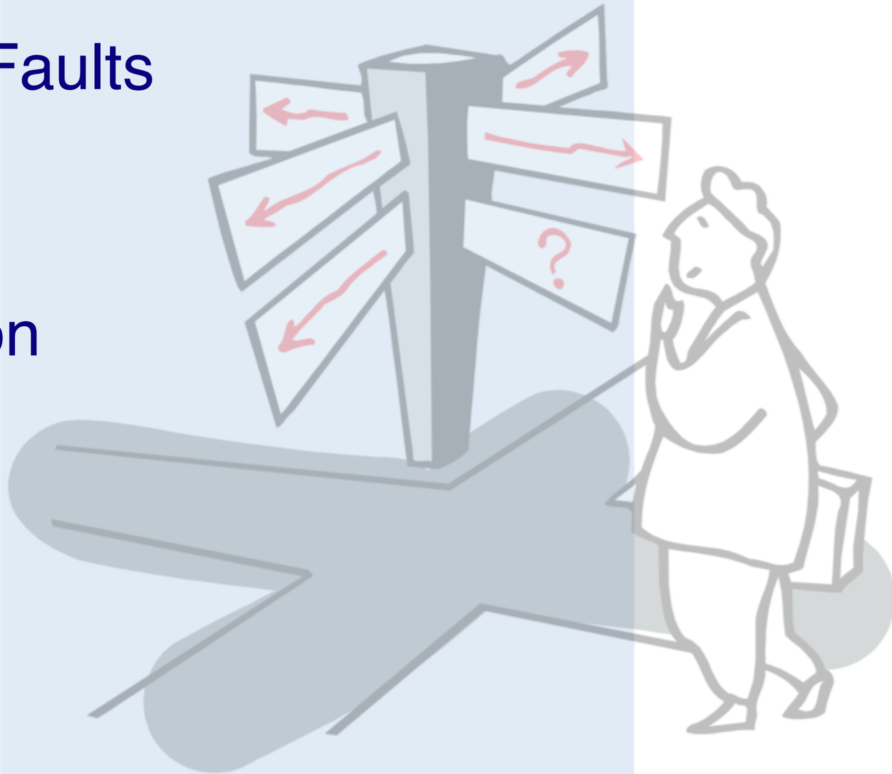
1. "Testing a system's *capabilities* is more important than testing its components."
   — Choose test cases that will identify situations that may prevent users from doing their job.

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

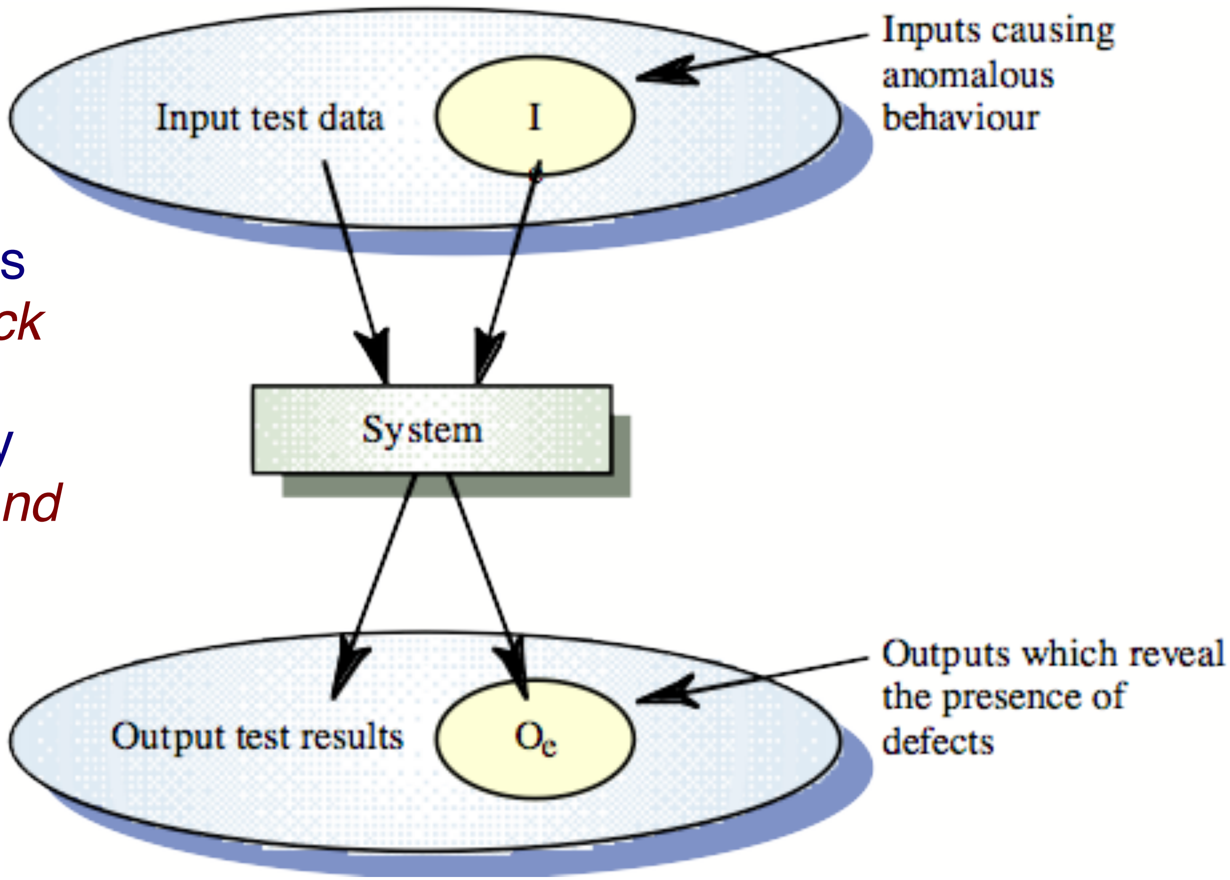
3. "Testing *typical situations* is more important than testing boundary value cases."
   — If resources are limited, focus on typical usage patterns.

# Roadmap

- > Reliability, Failures and Faults
- > Fault Avoidance
- > Fault Tolerance
- > Verification and Validation
- > The Testing process
  - — **Black box testing**
  - — White box testing
  - — Statistical testing



# 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*.

© Ian Sommerville 2000

# 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* ...

© Oscar Nierstrasz

# Equivalence partitioning

```
public static void search(int key, int [] elemArray, Result r)
    { … }
```

***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)

© Oscar Nierstrasz

# 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 } |
| ... | |

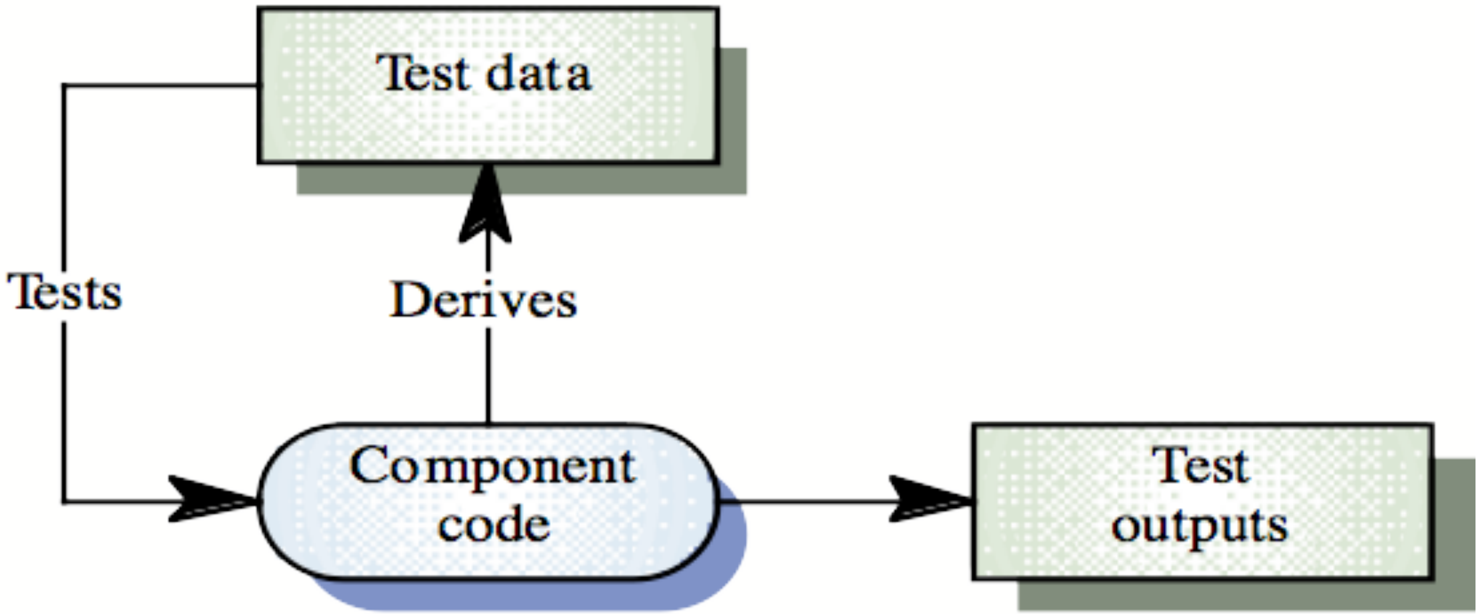
# Roadmap

> Reliability, Failures and Faults
> Fault Avoidance
> Fault Tolerance
> Verification and Validation
> The Testing process
  — Black box testing
  — **White box testing**
  — Statistical testing

# 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 the number of test cases*.




© Ian Sommerville 2000

# 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.

© Oscar Nierstrasz

```
class BinSearch {
// This is an encapsulation of a binary search function that takes an array of
// ordered objects and a key and returns an object with 2 attributes namely
// index - the value of the array index
// found - a boolean indicating whether or not the key is in the array
// An object is returned because it is not possible in Java to pass basic types by
// reference to a function and so return two values
// the key is -1 if the element is not found
    public static void search (int key, int [] elemArray, Result r)
    {
      int bottom = 0;
      int top = elemArray.length - 1;
      int mid;
      r.found = false; r.index = -1;                                            (1)
      while ( bottom <= top)                                                    (2)
      {
          mid = (top + bottom) / 2;
          if (elemArray [mid] == key)                                           (3)
          {
              r.index = mid;                                                    (8)
              r.found = true;
              return ;                                                          -> (9)
          } // if part
          else
          {
              if (elemArray [mid] < key)                                (4)
                  bottom = mid + 1;                                             (5)
              else
                  top = mid -i;                                         (6)
          }                                                             (7)
      } //while loop
    } //search                                                                  (9)
} //BinSearch
```

© Ian Sommerville 2000

# Program flow graphs

> Each branch is shown as a separate path and loops are shown by arrows looping back to the loop condition node

> The number of tests to test all control statements equals the *cyclomatic complexity*

*Cyclomatic complexity = Number of edges - Number of nodes +2*

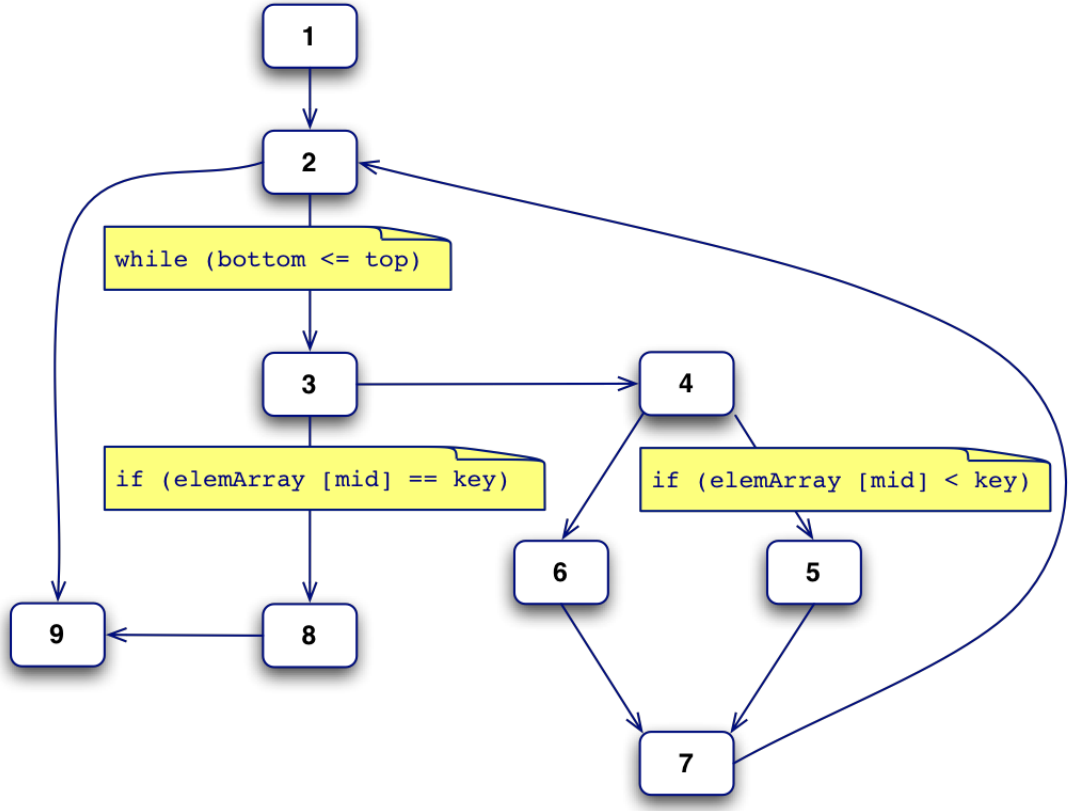
© Oscar Nierstrasz

# Path Testing

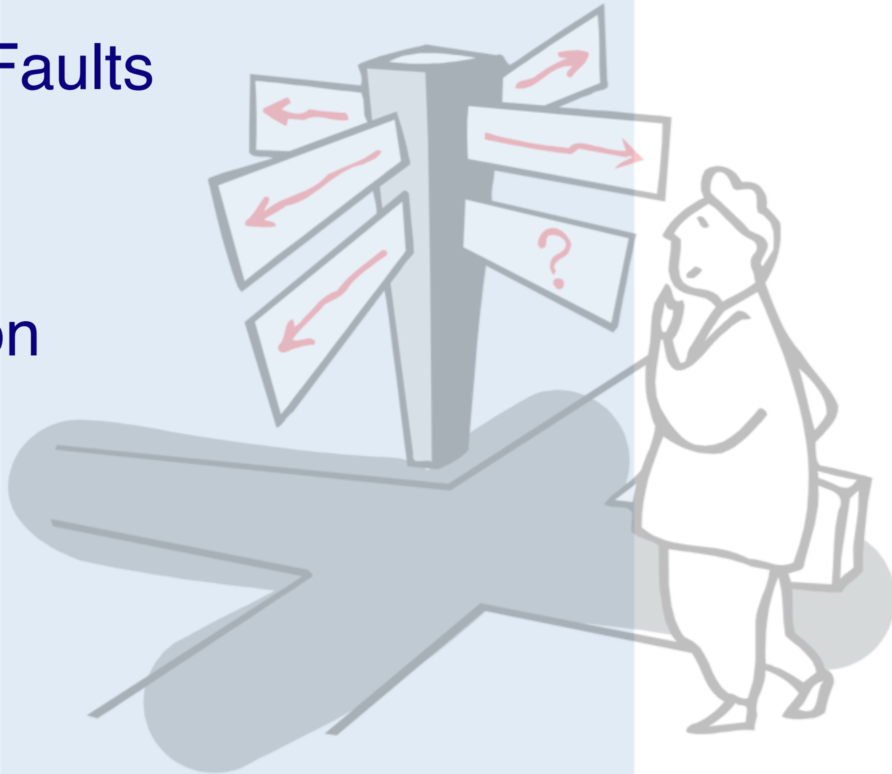
Test cases should be chosen to cover all *independent paths* through a routine:

- 1, 2, 9
- 1, 2, 3, 8, 9
- 1, 2, 3, 4, 5, 7, 2, 9
- 1, 2, 3, 4, 6, 7, 2, 9

*(Each path traverses at least one new edge)*



# Roadmap




- Reliability, Failures and Faults
- Fault Avoidance
- Fault Tolerance
- Verification and Validation
- The Testing process
  - Black box testing
  - White box testing
  - **Statistical testing**

# 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

© Oscar Nierstrasz

# 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*

# When to Stop?

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

***Cynical Answers (sad but true)***

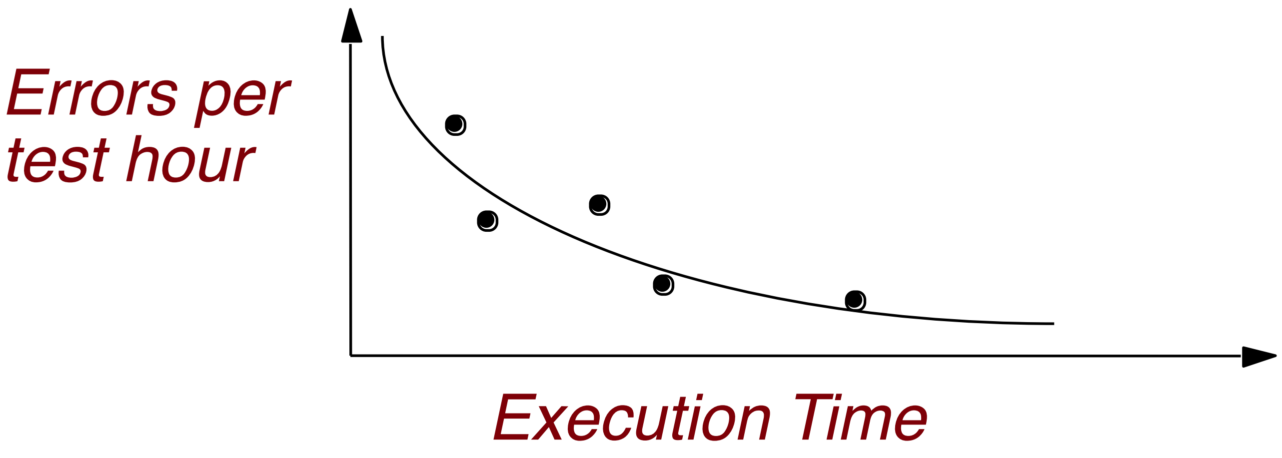
- You're *never done*: each run of the system is a new test
  - Each bug-fix should be accompanied by a new regression test
- You're done when you are out of time/money
  - Include testing in the project plan and *do not give in to pressure*
  - ... in the long run, tests save time

© Oscar Nierstrasz

# 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?

© Oscar Nierstrasz

# 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?

© Oscar Nierstrasz

# License

> http://creativecommons.org/licenses/by-sa/3.0/

creative commons
COMMONS DEED

**Attribution-ShareAlike 3.0 Unported**

***You are free:***

**to Share** — to copy, distribute and transmit the work
**to Remix** — to adapt the work

***Under the following conditions:***

**Attribution.** You must attribute the work in the manner specified by the author or licensor (but not in any way that suggests that they endorse you or your use of the work).

**Share Alike.** If you alter, transform, or build upon this work, you may distribute the resulting work only under the same, similar or a compatible license.

For any reuse or distribution, you must make clear to others the license terms of this work. The best way to do this is with a link to this web page.

Any of the above conditions can be waived if you get permission from the copyright holder.

Nothing in this license impairs or restricts the author's moral rights.