Software Testing

Eunseok Lee, Prof.
School of Information and Communication
Sungkyunkwan University

Objectives

- Understand the stages of testing from **testing during development** to **acceptance testing** by system customers;
- Have been introduced to techniques that help you choose test cases that are geared to discovering program defects;
- Understand test-first development, where you design tests before writing code and run these tests automatically;
- Know the important difference between components, system and release testing and be aware of user testing processes and techniques

Topics covered

1. Development testing
2. Test-driven development
3. Release testing
4. User testing

Program testing

- Testing is intended to show that a program does what it is intended to do and to discover program defects before it is put into use.
- When you test software, you execute a program using artificial data.
- You check the results of the test run for *errors*, *anomalies* or *information* about the program's non-functional attributes.
- Can reveal the presence of errors NOT their absence.
- Testing is part of a more general verification and validation process.

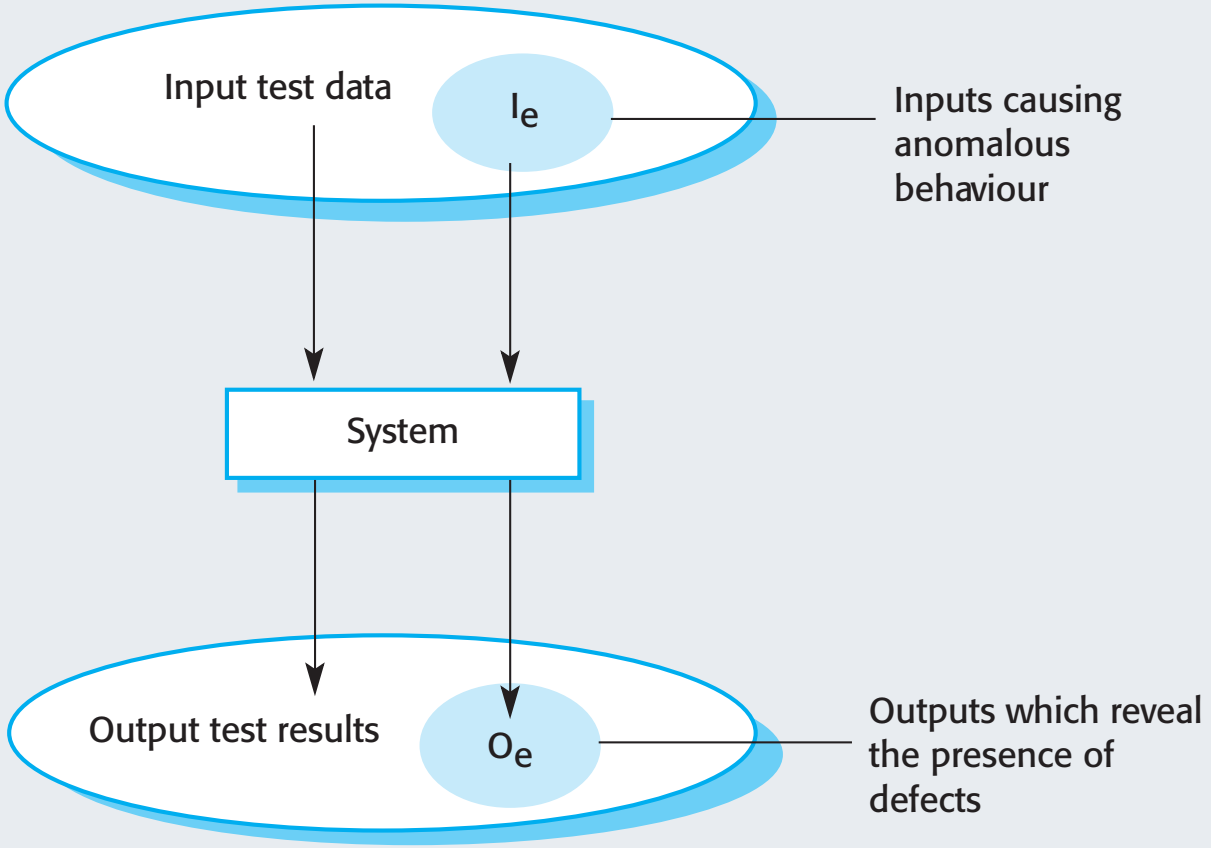
Program testing goals

- **To demonstrate to the developer and the customer that the software meets its requirements.**
  - For **custom software**, this means that there should be at least *one test for every requirement* in the requirements document. For **generic software** products, it means that there should be *tests for all of the system features, plus combinations* of these features, that will be incorporated in the product release.
- **To discover situations in which the behavior of the software is incorrect, undesirable or does not conform to its specification.**
  - **Defect testing** is concerned with rooting out undesirable system behavior such as system crashes, unwanted interactions with other systems, incorrect computations and data corruption.

Validation and defect testing

- **The first goal leads to validation testing**
  - You expect the system to perform correctly using a given set of test cases that reflect the system's expected use.
  - A successful test shows that the system operates as intended.
- **The second goal leads to defect testing**
  - The test cases are designed *to expose defects*. The test cases in defect testing can be deliberately obscure and need not reflect how the system is normally used.
  - A successful test is a test that makes the system perform incorrectly and so exposes a defect in the system.

An input-output model of program testing



Verification vs validation

- **Verification**:
  "**Are we building the product right**".
  - The software should conform to its specification.

- **Validation**:
  "**Are we building the right product**".
  - The software should do what the user really requires.

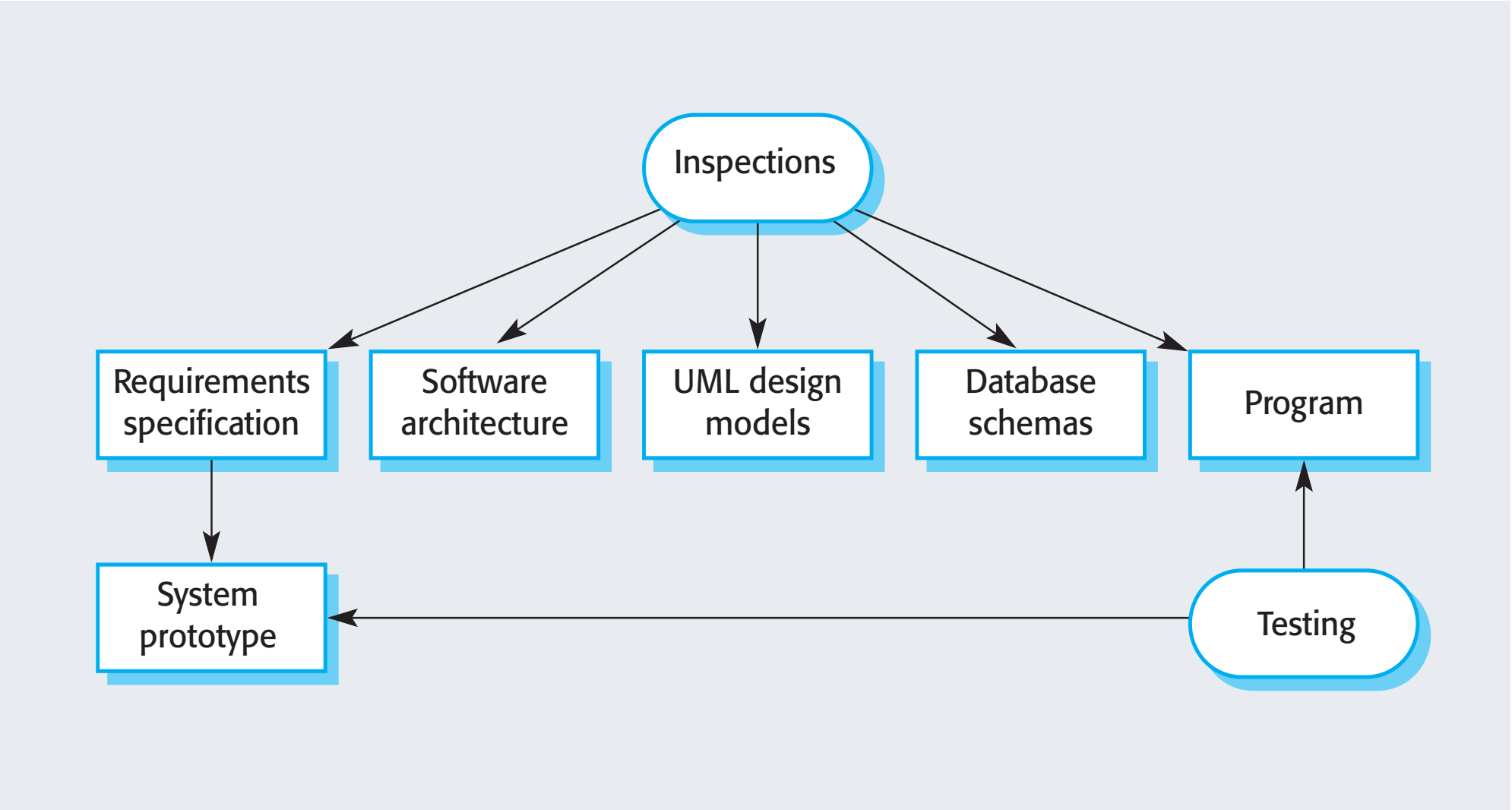
V & V confidence

- **Aim of V & V is to establish confidence that the system is 'fit for purpose'.**
- **Depends on system's purpose, user expectations and marketing environment**
  - Software purpose
    - The level of confidence depends on how critical the software is to an organization.
  - User expectations
    - Users may have low expectations of certain kinds of software.
  - Marketing environment
    - Getting a product to market early may be more important than finding defects in the program.

Inspections and testing

- **Software inspections. Concerned with analysis of the static system representation to discover problems (static verification)**
  - May be supplement by tool-based document and code analysis.
- **Software testing. Concerned with exercising and observing product behaviour (dynamic V & V)**
  - The system is executed with test data and its operational behaviour is observed.

Inspections and testing



Software inspections

- These involve **people examining** the **source representation** with the aim of discovering anomalies and defects.
- Inspections **not require execution** of a system so may be used before implementation.
- They may be applied to any representation of the system (requirements, design, configuration data, test data, etc.).
- They have been shown to be an effective technique for discovering program errors.

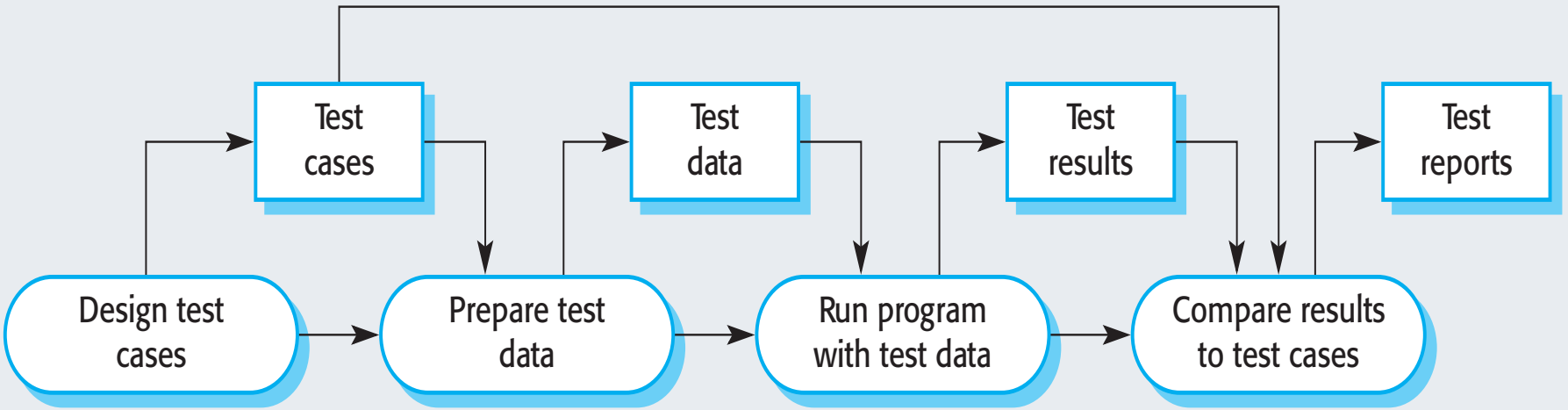
Advantages of inspections

- During testing, **errors can mask (hide) other errors**. Because inspection is a static process, you don't have to be concerned with interactions between errors.
- **Incomplete versions** of a system can be inspected *without additional costs*. If a program is incomplete, then you need to develop specialized test harnesses to test the parts that are available.
- As well as searching for program defects, an inspection can also consider broader **quality attributes of a program**, such as ***compliance with standards***, ***portability*** and ***maintainability***.

Inspections and testing

- Inspections and testing are *complementary* and not opposing verification techniques.
- Both should be used during the V & V process.
- Inspections can check conformance with a specification but not conformance with the customer's real requirements.
- Inspections cannot check non-functional characteristics such as **performance**, **usability**, etc.

A model of the software testing process



Stages of testing

- Development testing, where the system is tested during development to discover bugs and defects.
- Release testing, where a separate testing team test a complete version of the system before it is released to users.
- User testing, where users or potential users of a system test the system in *their own environment*.

1. Development testing

- Development testing includes all testing activities that are carried out by the team developing the system.
  - **Unit testing**, where individual program units or object classes are tested. Unit testing should focus on testing the ***functionality*** of objects or methods.
  - **Component testing**, where several individual units are integrated to create composite components. Component testing should focus on testing ***component interfaces***.
  - **System testing**, where some or all of the components in a system are integrated and the system is tested ***as a whole***. System testing should focus on testing ***component interactions***.

1.1 Unit testing

- **Unit testing is the process of testing individual units in isolation.**
- **It is a *defect testing* process.**

- **Units may be:**
  - Individual functions or methods within an object
  - Object classes with several attributes and methods
  - Composite components with defined interfaces used to access their functionality.

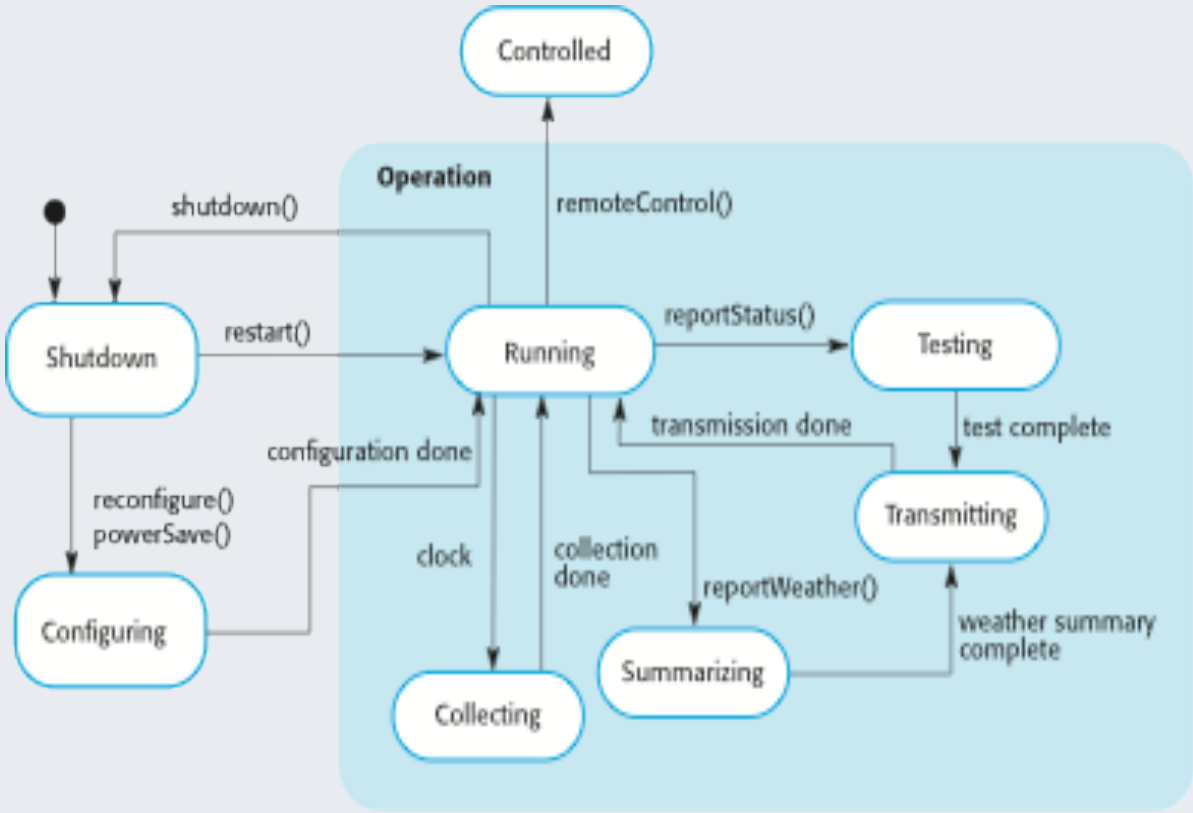
Object class testing

- **Complete test coverage of a class involves**
  - Testing all operations associated with an object
  - Setting and interrogating all object attributes
  - Exercising the object in all possible states.

- **Inheritance makes it more difficult to design object class tests as the information to be tested is not localized.**

The weather station object interface

WeatherStation
identifier
reportWeather ( ) reportStatus ( ) powerSave (instruments) remoteControl (commands) reconfigure (commands) restart (instruments) shutdown (instruments)



Weather station testing

- Need to define test cases for reportWeather, calibrate, test, startup and shutdown.
- Using a state model, identify sequences of state transitions to be tested and the event sequences to cause these transitions
- **For example:**
  - Shutdown -> Running-> Shutdown
  - Configuring-> Running-> Testing -> Transmitting -> Running
  - Running-> Collecting-> Running-> Summarizing -> Transmitting -> Running

Automated testing

- Whenever possible, unit testing should be automated so that tests are run and checked without manual intervention.
- In automated unit testing, you make use of a test automation framework (such as JUnit) to write and run your program tests.
- Unit testing frameworks provide generic test classes that you extend to create specific test cases. They can then run all of the tests that you have implemented and report, often through some GUI, on the success or otherwise of the tests.

Automated test components

- A **setup part**, where you initialize the system with the test case, namely the inputs and expected outputs.
- A **call part**, where you call the object or method to be tested.
- An **assertion part** where you compare the result of the call with the expected result. If the assertion evaluates to true, the test has been successful, if false, then it has failed.

Fault localizer by SE lab, SKKU

	Test Cases																
mid() { int x,y,z,m;	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	2,1,3	Tarantula	portion	rank	AMPLE	portion	rank	Ochiai	portion	Jaccard	portion
1: read("Enter 3 numbers:",x,y,z);	●	●	●	●	●	●	0.5	11.99%	7	0	0.00%	13	0.48	14.29%	0.17	14.29%
2: m = z;	●	●	●	●	●	●	0.5	11.99%	7	0	0.00%	13	0.48	14.29%	0.17	14.29%
3: if (y<z)	●	●	●	●	●	●	0.5	11.99%	7	0	0.00%	13	0.48	14.29%	0.17	14.29%
4: if (x<y)	●	●			●	●	0.63	15.11%	3	0.4	12.50%	5	0.48	14.29%	0.17	14.29%
5: m = y;		●					0.0	0.00%	13	0.2	6.25%	8	0	0.00%	0	0.00%
6: else if (x<z)	●				●	●	0.71	17.03%	2	0.6	18.75%	2	0.48	14.29%	0.17	14.29%
7: m = y; // *** bug ***	●					●	0.83	19.90%	1	0.8	25.00%	1	0.48	14.29%	0.17	14.29%
8: else			●	●			0.0	0.00%	13	0.4	12.50%	5	0	0.00%	0	0.00%
9: if (x>y)			●	●			0.0	0.00%	13	0.4	12.50%	5	0	0.00%	0	0.00%
10: m = y;			●				0.0	0.00%	13	0.2	6.25%	8	0	0.00%	0	0.00%
11: else if (x>z)				●			0.0	0.00%	13	0.2	6.25%	8	0	0.00%	0	0.00%
12: m = x;							0.0	0.00%	13	0	0.00%	13	0	0.00%	0	0.00%
13: print("Middle number is:",m);	●	●	●	●	●	●	0.5	11.99%	7	0	0.00%	13	0.48	14.29%	0.17	14.29%
} Pass/Fail Status	P	P	P	P	P	F	4.2	100.00%		3.2	100.00%		3.36	100.00%	1.19	100.00%

SELab. Fault Localizer

File Analysis

statement	code	Pass	Fail	1	2	3	4	5	6	Tarantular-...	Rank	Ochiai-sus	Jaccard-sus
1	int m;	5	1	1.0	1.0	1.0	1.0	1.0	-1.0	0.5	4.0	0.40824828	0.16666667
2	System.out.println("input numbers: " + x + ", " + y + ", "...	5	1	1.0	1.0	1.0	1.0	1.0	-1.0	0.5	4.0	0.40824828	0.16666667
3	m = z;	5	1	1.0	1.0	1.0	1.0	1.0	-1.0	0.5	4.0	0.40824828	0.16666667
4	if(y<z){	5	1	1.0	1.0	1.0	1.0	1.0	-1.0	0.5	4.0	0.40824828	0.16666667
5	if(x<y){	3	1	1.0	1.0	0.0	0.0	1.0	-1.0	0.625	3.0	0.5	0.25
6	m = y;	1	0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0
7	else if(x<z){	2	1	1.0	0.0	0.0	0.0	1.0	-1.0	0.71428573	2.0	0.57735026	0.33333334
8	m = y;	1	1	1.0	0.0	0.0	0.0	0.0	-1.0	0.8333333	1.0	0.70710677	0.5
9	else {	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0
10	if(x>y){	2	0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	9.0	0.0	0.0
11	m = y;	1	0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0
12	else if(x>z){	1	0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	9.0	0.0	0.0
13	m = x;	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0
14	System.out.println("Middle number is: " + m);	5	1	1.0	1.0	1.0	1.0	1.0	-1.0	0.5	4.0	0.40824828	0.16666667
15	Test Output:			3.0	2.0	2.0	5.0	4.0	1.0				
16	Expected Output:			3.0	2.0	2.0	5.0	4.0	2.0				
17	Test Result:			1.0	1.0	1.0	1.0	1.0	0.0				

1.2 Choosing unit test cases

- The test cases should show that, when used as expected, the component that you are testing does what it is supposed to do.
- If there are defects in the component, these should be revealed by test cases.
- **This leads to 2 types of unit test case:**
  - The first of these should reflect normal operation of a program and should show that the component works as expected.
  - The other kind of test case should be based on testing experience of where common problems arise. It should use abnormal inputs to check that these are properly processed and do not crash the component.

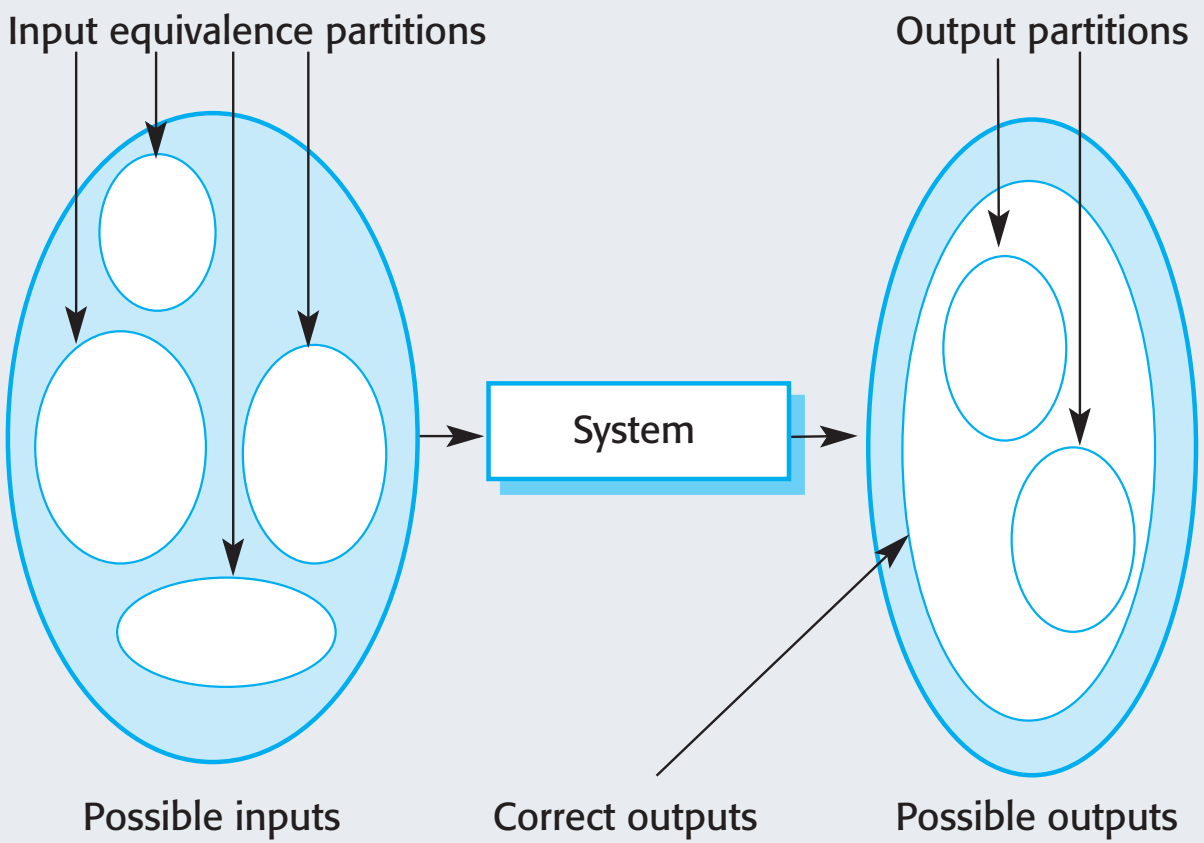
Testing strategies

- **Partition testing, where you identify groups of inputs that have common characteristics and should be processed in the same way.**
  - You should choose tests from within each of these groups.
- **Guideline-based testing, where you use testing guidelines to choose test cases.**
  - These guidelines reflect previous experience of the kinds of errors that programmers often make when developing components.

(1)Partition testing

- Partitions are **groups of data that have common characteristics**.
- Input data and output results of a program fall into different classes that have common characteristics, such as positive, negative numbers and menu selections.
- Each of these classes is an equivalence partition or domain where the program behaves in an equivalent way for each class member.
- Test cases should be chosen from each partition.

Equivalence partitioning



Test case design in partition testing

(1)Identifying all partitions for a system or components

- >Input equivalence partitions
- All of the set members should be processed in an equivalent way
- >Output equivalence partitions
- Program outputs that have common characteristics.

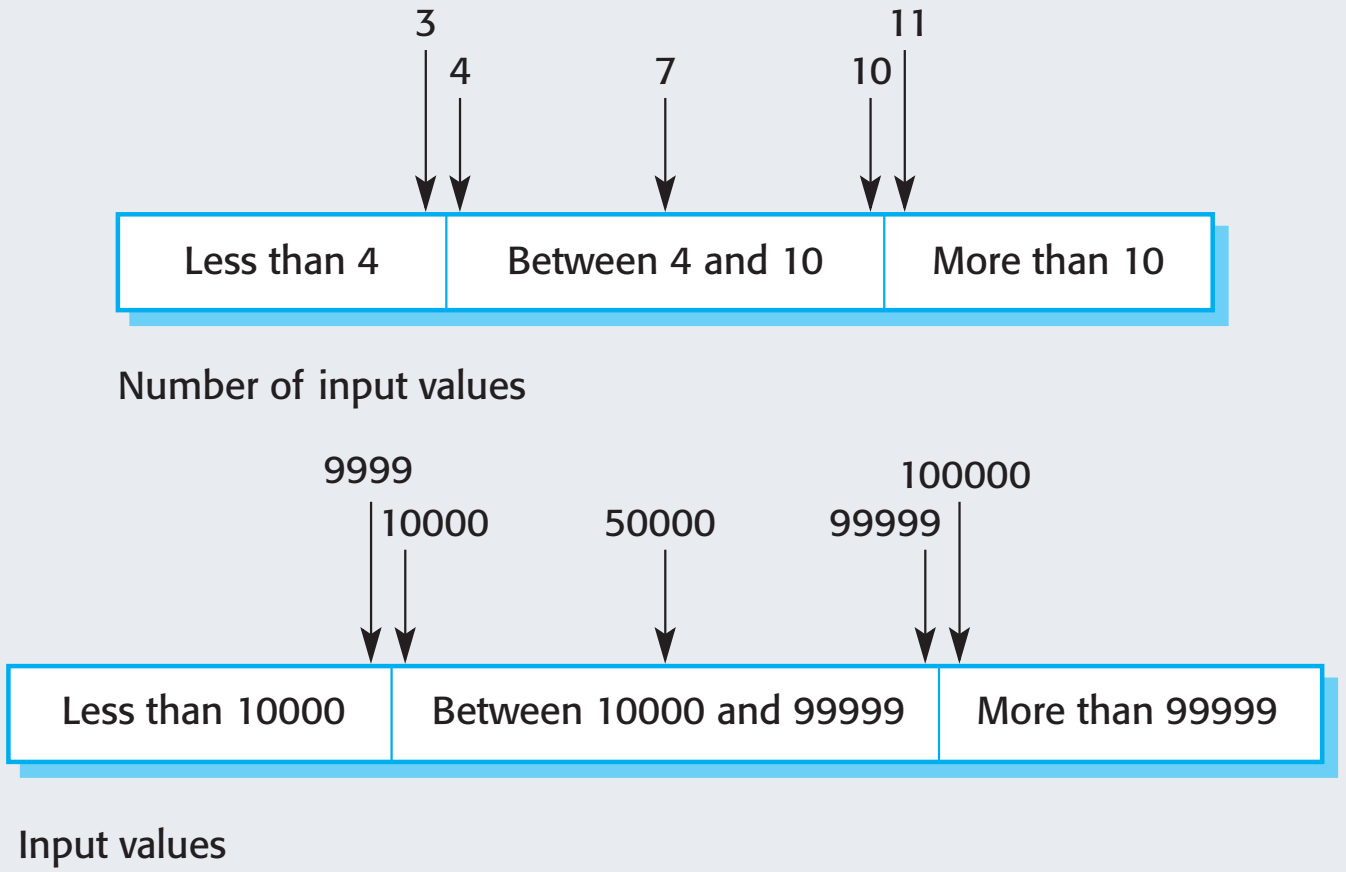
(2)Choose test cases from each of these partitions

- >Choose test cases on the **boundaries** of the partitions plus cases close to the **mid-point** of the partition

- You identify partitions by using the specification or user documentation.

ex) Program specification states that the program accepts 4 to 10 inputs that are five-digit integers greater than 10,000.

Equivalence partitions



(2)Testing guidelines (sequences)

- Test software with sequences which have only a single value.
- Use sequences of different sizes in different tests.
- Derive tests so that the first, middle and last elements of the sequence are accessed.
- Test with sequences of zero length.

Sequence	**Element**
Single value	In sequence
Single value	Not in sequence
More than 1 value	First element in sequence
More than 1 value	Last element in sequence
More than 1 value	Middle element in sequence
More than 1 value	Not in sequence

Input sequence (T)	**Key** (Key)	**Output** (Found, L)
17	17	true, 1
17	0	false, ??
17, 29, 21, 23	17	true, 1
41, 18, 9, 31, 30, 16, 45	45	true, 7
17, 18, 21, 23, 29, 41, 38	23	true, 4
21, 23, 29, 33, 38	25	false, ??

General testing guidelines

- Choose inputs that force the system **to generate all error messages**
- Design inputs that cause **input buffers to overflow**
- Repeat the **same input** or series of inputs numerous times
- Force **invalid outputs** to be generated
- Force computation results to be **too large** or **too small**.

Key points

- Testing can only show the *presence of errors* in a program. It cannot demonstrate that there are no remaining faults.
- Development testing is the responsibility of the software *development team*. A separate team should be responsible for testing a system before it is released to customers.
- Development testing includes unit testing, in which you test individual objects and methods component testing in which you test related groups of objects and system testing, in which you test partial or complete systems.

Software Testing

Part 2

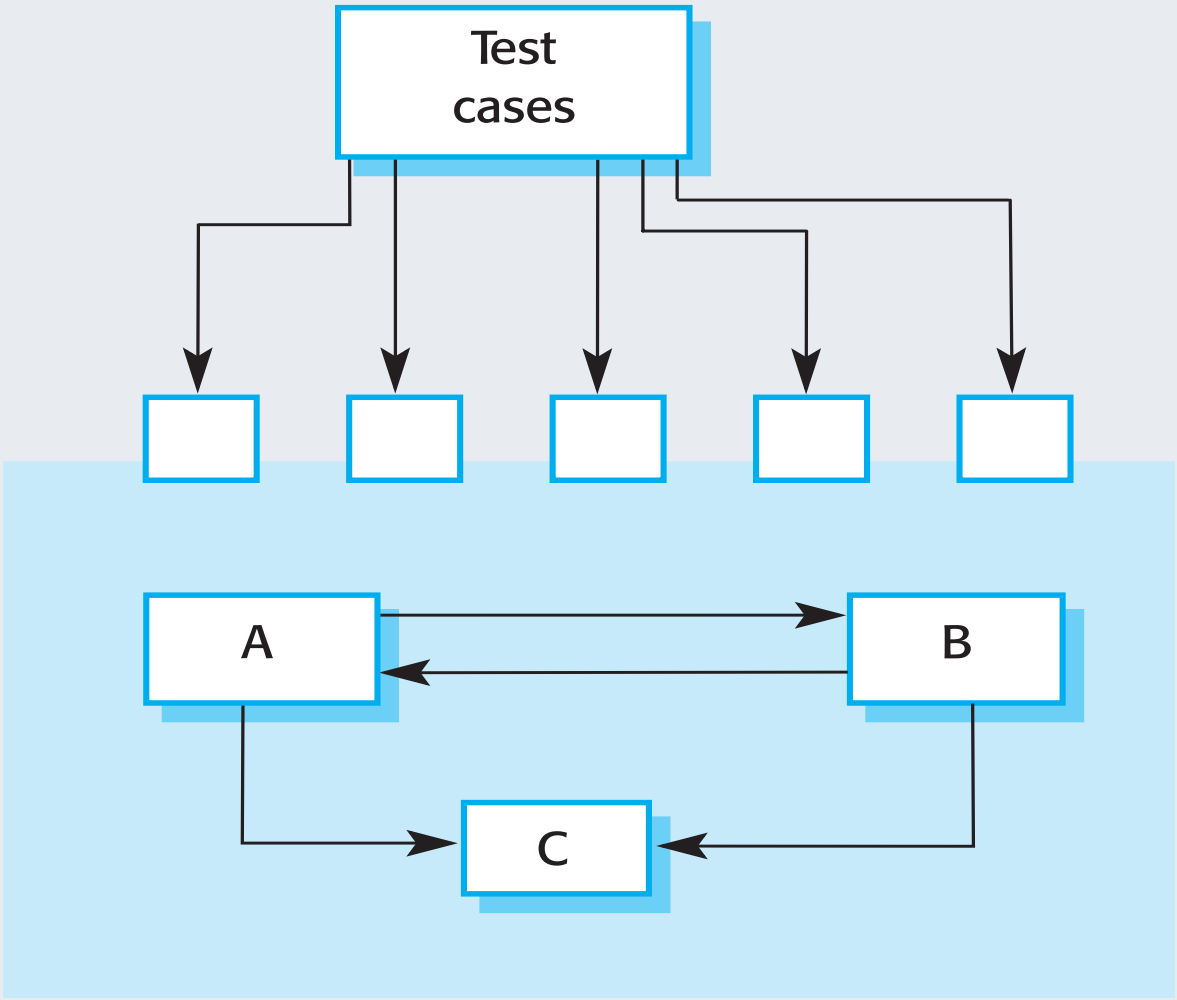
1.3 Component testing

- Software components are often ***composite components*** that are made up of several interacting objects.
- You access the functionality of these objects through the defined **component interface.**
- Testing composite components should therefore focus on showing that the **component interface behaves according to its specification.**
  - You can assume that unit tests on the individual objects within the component have been completed.

Interface testing

- Objectives are to detect faults due to **interface errors** or **invalid assumptions** about interfaces.
- **Interface types**
  - Parameter interfaces Data passed from one component to another. ex)Methods in an object.
  - Procedural interfaces Sub-system encapsulates a set of procedures to be called by other sub-systems. ex)Object and reusable components have this form of interface.
  - Message passing interfaces Sub-systems request services from other sub-systems. ex)client-server system
  - Shared memory interfaces Block of memory is shared between procedures or functions. ex)Embedded systems with sensors-processors

Interface testing



Interface errors

- **Interface misuse**
  - A calling component calls another component and makes an error in its use of its interface e.g. parameters in the wrong order.
- **Interface misunderstanding**
  - A calling component embeds assumptions about the behaviour of the called component which are incorrect.
- **Timing errors**
  - The called and the calling component operate at different speeds and out-of-date information is accessed.

Interface testing guidelines

- Design tests so that parameters to a called procedure are at the **extreme ends of their ranges**.
- Always test pointer parameters with **null pointers**.
- Design tests which cause the **component to fail**.
- Use **stress testing** in message passing systems.
- In shared memory systems, **vary the order** in which components are activated.

1.4 System testing

- System testing during development involves *integrating* components to create a version of the system and then ***testing the integrated system***.
- The focus in system testing is testing the **interactions between components**.
- System testing checks that components are **compatible**, **interact correctly** and **transfer** the right data at the right time across their interfaces.
- System testing tests the **emergent behavior** of a system.

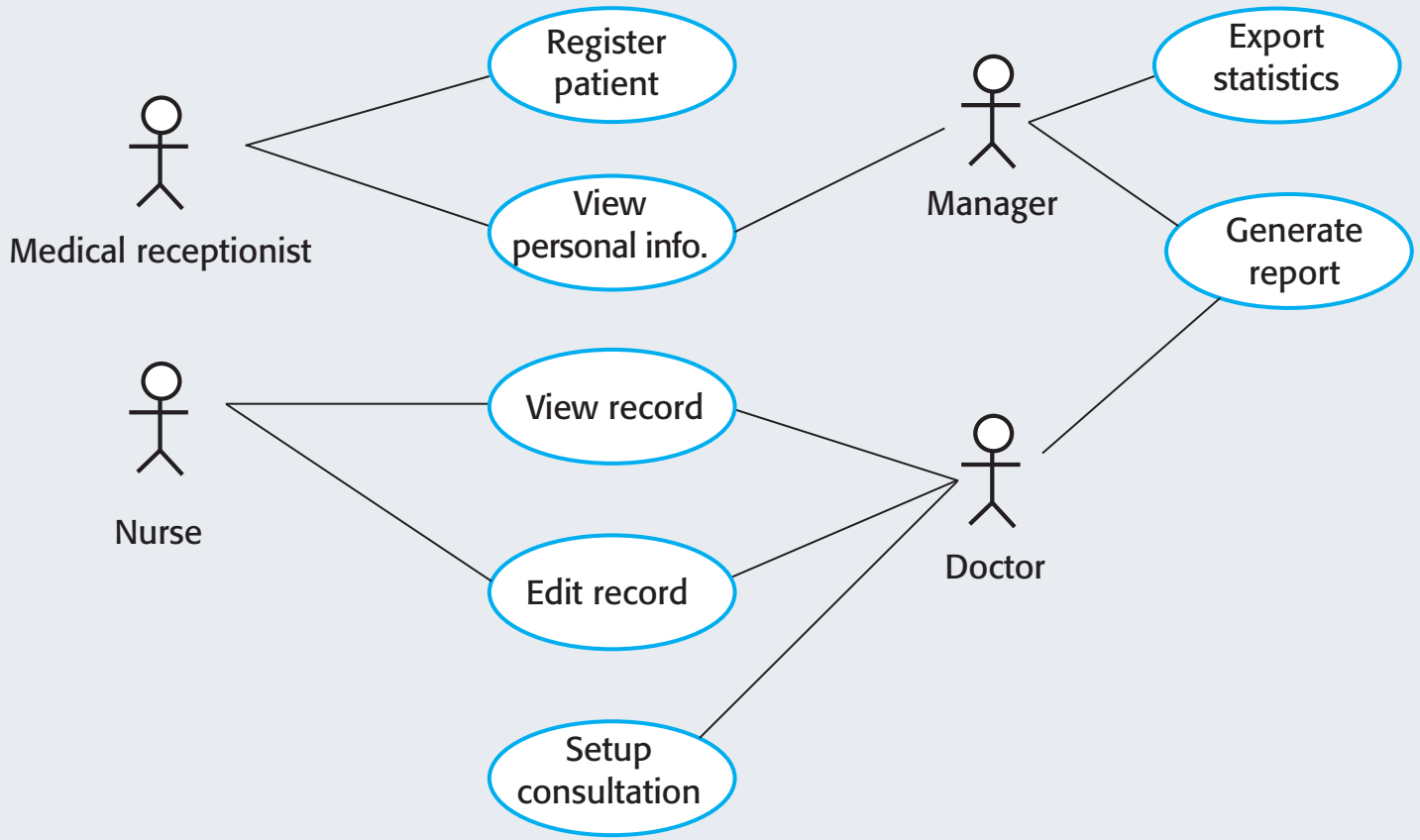
System and component testing

- During system testing, *reusable components* that have been separately developed and *off-the-shelf systems* may be **integrated** with *newly developed components*. The **complete system is then tested**.
- Components developed by different team members or sub-teams may be integrated at this stage. System testing is a ***collective*** rather than an individual process.
  - In some companies, system testing may involve a **separate testing team** with no involvement from designers and programmers.

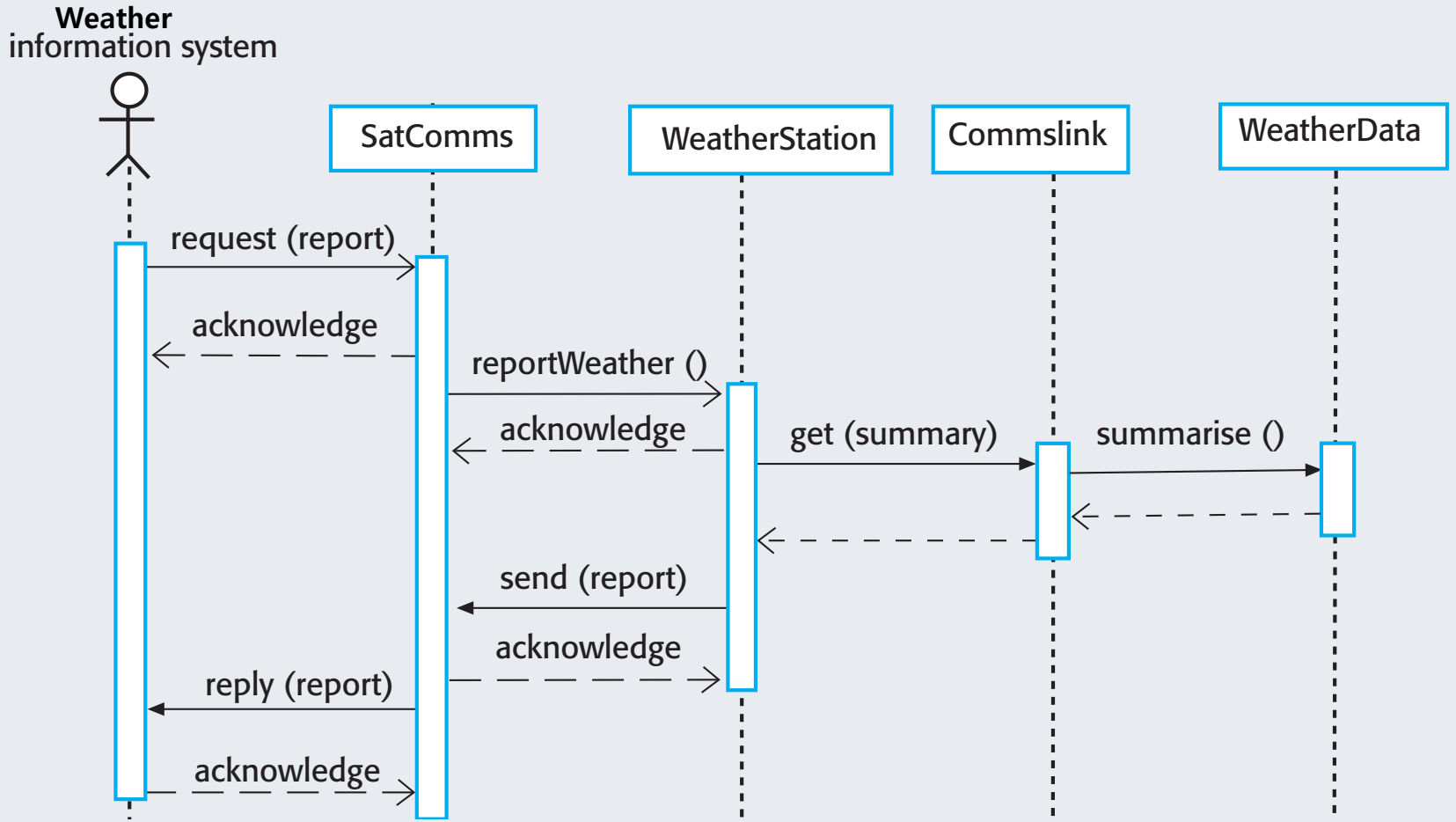
Use-case testing

- The use-cases developed to identify system interactions can be used as a **basis for system testing**.
- Each use case usually involves several system components so testing the use case forces these interactions to occur.
- The sequence diagrams associated with the use case documents the components and interactions that are being tested.

Use cases for the MHC-PMS



Collect weather data sequence chart



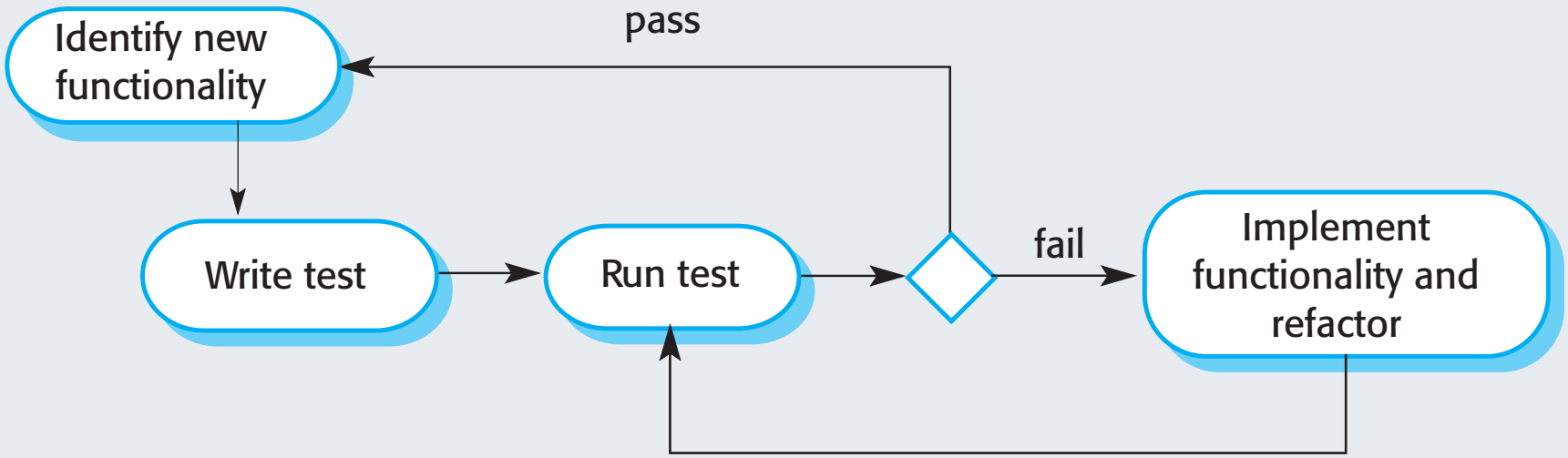
Testing policies

- Exhaustive system testing is impossible so **testing policies** which **define the required system test coverage** may be developed.
- **Examples of testing policies:**
  - All system functions that are accessed through menus should be tested.
  - Combinations of functions (e.g. text formatting) that are accessed through the same menu must be tested.
  - Where user input is provided, all functions must be tested with both correct and incorrect input.

2. Test-driven development

- Test-driven development (TDD) is an approach to program development in which you **inter-leave testing and code development**.
- Tests are written before code and **'passing' the tests** is the critical driver of development.
- You develop code ***incrementally***, along with a test for that increment. You don't move on to the next increment until the code that you have developed passes its test.
- TDD was introduced as part of **agile methods** such as Extreme Programming. However, it can also be used in plan-driven development processes.

Test-driven development



TDD process activities

- Start by **identifying the increment** of functionality that is required. This should normally be small and implementable in a few lines of code.
- **Write a test** for this functionality and **implement** this as an automated test.
- **Run the test**, **along with all other tests** that have been implemented. Initially, you have not implemented the functionality so the new test will fail.
- **Implement** the functionality and **re-run** the test.
- Once all tests run successfully, you move on to implementing the next chunk of functionality.

Benefits of test-driven development

- **Code coverage**
  - Every code segment that you write has at least one associated test so all code written has at least one test.
- **Regression testing**
  - A regression test suite is developed incrementally as a program is developed.
- **Simplified debugging**
  - When a test fails, it should be obvious where the problem lies. The newly written code needs to be checked and modified.
- **System documentation**
  - The tests themselves are a form of documentation that describe what the code should be doing.

Regression testing

- Regression testing is testing the system to **check that changes have not 'broken' previously working code**.
- In a manual testing process, regression testing is expensive but, with automated testing, it is simple and straightforward. All tests are rerun every time a change is made to the program.
- Tests must run 'successfully' before the change is committed.

3. Release testing

- Release testing is the **process of testing a particular release of a system** that is intended for use outside of the development team.
- The primary goal of the release testing process is to **convince the supplier** of the system that it is good enough for use.
  - Release testing, therefore, has to show that the system delivers its specified ***functionality***, ***performance*** and ***dependability***, and **that it does not fail *during normal use***.
- Release testing is usually a **black-box testing** process where tests are only derived from the ***system specification***.

Release testing and system testing

- **Release testing** is a form of **system testing.**
- **Important differences:**
  - A ***separate team*** that has not been involved in the system development, should be responsible for release testing.
  - **System testing** by the development team should focus on discovering bugs in the system (**defect testing**). The objective of **release testing** is to check that the system meets its requirements and is good enough for external use (**validation testing**).

3.1 Requirements based testing

- Requirements-based testing involves **examining each requirement** and **developing a test** or **tests for it.**
- **MHC-PMS requirements:**
  - If a patient is known to be allergic to any particular medication, then prescription of that medication shall result in a warning message being issued to the system user.
  - If a prescriber chooses to ignore an allergy warning, they shall provide a reason why this has been ignored.

Requirements tests

- Set up a patient record with no known allergies. Prescribe medication for allergies that are known to exist. Check that a warning message is not issued by the system.
- Set up a patient record with a known allergy. Prescribe the medication to that the patient is allergic to, and check that the warning is issued by the system.
- Set up a patient record in which allergies to two or more drugs are recorded. Prescribe both of these drugs separately and check that the correct warning for each drug is issued.
- Prescribe two drugs that the patient is allergic to. Check that two warnings are correctly issued.
- Prescribe a drug that issues a warning and overrule that warning. Check that the system requires the user to provide information explaining why the warning was overruled.

3.2 Features tested by scenario

- Authentication by logging on to the system.
- Downloading and uploading of specified patient records to a laptop.
- Home visit scheduling.
- Encryption and decryption of patient records on a mobile device.
- Record retrieval and modification.
- Links with the drugs database that maintains side-effect information.
- The system for call prompting.

A usage scenario for the MHC-PMS

Kate is a nurse who specializes in mental health care. One of her responsibilities is to visit patients at home to check that their treatment is effective and that they are not suffering from medication side -effects.
On a day for home visits, Kate logs into the MHC-PMS and uses it to print her schedule of home visits for that day, along with summary information about the patients to be visited. She requests that the records for these patients be downloaded to her laptop. She is prompted for her key phrase to encrypt the records on the laptop.

One of the patients that she visits is Jim, who is being treated with medication for depression. Jim feels that the medication is helping him but believes that it has the side -effect of keeping him awake at night. Kate looks up Jim's record and is prompted for her key phrase to decrypt the record. She checks the drug prescribed and queries its side effects. Sleeplessness is a known side effect so she notes the problem in Jim's record and suggests that he visits the clinic to have his medication changed. He agrees so Kate enters a prompt to call him when she gets back to the clinic to make an appointment with a physician. She ends the consultation and the system re-encrypts Jim's record.

After, finishing her consultations, Kate returns to the clinic and uploads the records of patients visited to the database. The system generates a call list for Kate of those patients who she has to contact for follow-up information and make clinic appointments.

3.3 Performance testing

- **Part of release testing** may involve testing the **emergent properties** of a system, such as *performance* and *reliability*.
- Tests should reflect the **profile of use** of the system.
- Performance tests usually involve planning a series of tests where the load is steadily increased until the system performance becomes unacceptable.
- **Stress testing** is a **form of performance testing** where the system is deliberately overloaded to test its failure behavior.

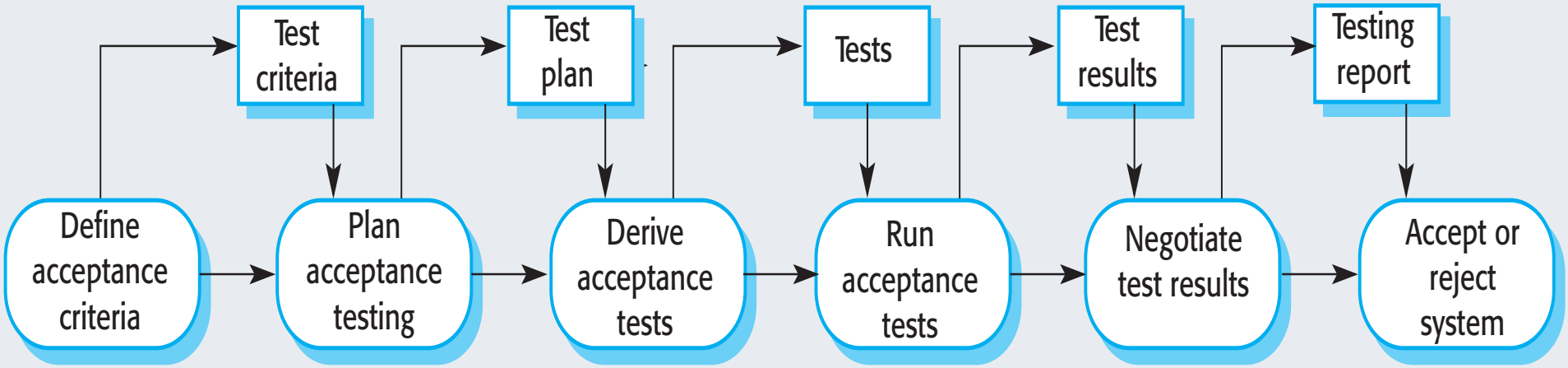
4. User testing

- **User** or **customer testing** is a stage in the testing process in which users or customers provide input and advice on system testing.
- User testing is essential, even when comprehensive system and release testing have been carried out.
  - The reason for this is that influences from the user's working environment have a major effect on the reliability, performance, usability and robustness of a system. These cannot be replicated in a testing environment.

Types of user testing

- **Alpha testing**
  - Users of the software work with the development team to test the software *at the developer's site*.
- **Beta testing**
  - A release of the software is made available to users to allow them to experiment and to raise problems that they discover with the system developers.
- **Acceptance testing**
  - Customers test a system to decide whether or not it is ready to be accepted from the system developers and deployed in the customer environment. Primarily for **custom systems**.

The acceptance testing process



Agile methods and acceptance testing

- In agile methods, the **user/customer is part of the development team** and is responsible for making decisions on the acceptability of the system.
- Tests are defined by the user/customer and are integrated with other tests in that they are run automatically when changes are made.
- There is **no separate acceptance testing** process.
- Main problem here is **whether or not the embedded user is 'typical'** and can represent the interests of all system stakeholders.

Key points

- When testing software, you should try to '**break' the software** by using experience and guidelines to choose types of test case that have been effective in discovering defects in other systems.
- Wherever possible, you should **write automated tests**. The tests are embedded in a program that can be run every time a change is made to a system.
- **Test-first development** is an approach to development where tests are written before the code to be tested.
- **Scenario testing** involves inventing a **typical usage scenario** and using this to derive test cases.
- **Acceptance testing** is a user testing process where the aim is to decide if the software is good enough to be deployed and used in its operational environment.