EAST WEST UNIVERSITY

CSE412
Software Engineering

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Topic 5

Software Reliability Engineering

Topics covered

- Availability and reliability
- Reliability requirements
- Fault-tolerant architectures
- Programming for reliability
- Reliability measurement

Software reliability

- In general, software customers expect all software to be dependable. However, for non-critical applications, they may be willing to accept some system failures.
- Some applications (critical systems) have very high reliability requirements and special software engineering techniques may be used to achieve this.
  - Medical systems
  - Telecommunications and power systems
  - Aerospace systems

Faults, errors and failures

Term	Description
Human error or mistake	Human behavior that results in the introduction of faults into a system. For example, in the wilderness weather system, a programmer might decide that the way to compute the time for the next transmission is to add 1 hour to the current time. This works except when the transmission time is between 23.00 and midnight (midnight is 00.00 in the 24-hour clock).
System fault	A characteristic of a software system that can lead to a system error. The fault is the inclusion of the code to add 1 hour to the time of the last transmission, without a check if the time is greater than or equal to 23.00.
System error	An erroneous system state that can lead to system behavior that is unexpected by system users. The value of transmission time is set incorrectly (to 24.XX rather than 00.XX) when the faulty code is executed.
System failure	An event that occurs at some point in time when the system does not deliver a service as expected by its users. No weather data is transmitted because the time is invalid.

Faults and failures

- Failures are a usually a result of system errors that are derived from faults in the system
- However, faults do not necessarily result in system errors
  - The erroneous system state resulting from the fault may be transient and ‘corrected’ before an error arises.
  - The faulty code may never be executed.
- Errors do not necessarily lead to system failures
  - The error can be corrected by built-in error detection and recovery
  - The failure can be protected against by built-in protection facilities. These may, for example, protect system resources from system errors

Fault management

- Fault avoidance
  - The system is developed in such a way that human error is avoided and thus system faults are minimised.
  - The development process is organised so that faults in the system are detected and repaired before delivery to the customer.
- Fault detection
  - Verification and validation techniques are used to discover and remove faults in a system before it is deployed.
- Fault tolerance
  - The system is designed so that faults in the delivered software do not result in system failure.

Availability and reliability

- Reliability
  - The probability of failure-free system operation over a specified time in a given environment for a given purpose
- Availability
  - The probability that a system, at a point in time, will be operational and able to deliver the requested services
- Both of these attributes can be expressed quantitatively e.g. availability of 0.999 means that the system is up and running for 99.9% of the time.

Reliability and specifications

- Reliability can only be defined formally with respect to a system specification i.e., a failure is a deviation from a specification.
- However, many specifications are incomplete or incorrect – hence, a system that conforms to its specification may ‘fail’ from the perspective of system users.
- Furthermore, users don’t read specifications so don’t know how the system is supposed to behave.
- Therefore, perceived reliability is more important in practice.

Reliability in use

- Removing X% of the faults in a system will not necessarily improve the reliability by X%.
- Program defects may be in rarely executed sections of the code so may never be encountered by users. Removing these does not affect the perceived reliability.
- Users adapt their behaviour to avoid system features that may fail for them.
- A program with known faults may therefore still be perceived as reliable by its users.

System reliability requirements

- Functional reliability requirements define system and software functions that avoid, detect or tolerate faults in the software and so ensure that these faults do not lead to system failure.
- Software reliability requirements may also be included to cope with hardware failure or operator error.

✧ Reliability is a measurable system attribute so non-functional reliability requirements may be specified quantitatively. These define the number of failures that are acceptable during normal use of the system or the time in which the system must be available.

Reliability metrics

- Reliability metrics are units of measurement of system reliability.
- System reliability is measured by counting the number of operational failures, where appropriate, relating these to the demands made on the system and the time that the system has been operational.
- A long-term measurement program is required to assess the reliability of critical systems.
- Metrics
  - Probability of failure on demand (POFOD)
  - Rate of occurrence of failures/Mean time to failure (ROCOF/MTTF)
  - Availability (AVAIL)

Probability of failure on demand (POFOD)

- This is the probability that the system will fail when a service request is made. Useful when demands for service are intermittent and relatively infrequent.
- Appropriate for protection systems where services are demanded occasionally and where there are serious consequence if the service is not delivered.
- Relevant for many safety-critical systems with exception management components
    - **Emergency shutdown system in a chemical plant.**

Rate of fault occurrence (ROCOF)

- Reflects the rate of occurrence of failure in the system.
- **ROCOF of 0.002 means 2 failures are likely in each 1000 operational time units e.g., 2 failures per 1000 hours of operation.**
- Relevant for systems where the system must process a large number of similar requests in a short time
    - **Credit card processing system, airline booking system.**
- Reciprocal of ROCOF is Mean time to Failure (MTTF)
    - Relevant for systems with long transactions i.e. where system processing takes a long time (e.g. CAD systems). MTTF should be longer than expected transaction length.

Availability

- Measure of the fraction of the time that the system is available for use.
- Takes repair and restart time into account
- **Availability of 0.998 means software is available for 998 out of 1000-time units**.
- Relevant for non-stop, continuously running systems
  - **telephone switching systems, railway signalling systems.**

Availability specification

Availability	Explanation
0.9	The system is available for 90% of the time. This means that, in a 24-hour period (1,440 minutes), the system will be unavailable for 144 minutes.
0.99	In a 24-hour period, the system is unavailable for 14.4 minutes.
0.999	The system is unavailable for 84 seconds in a 24-hour period.
0.9999	The system is unavailable for 8.4 seconds in a 24-hour period. Roughly, one minute per week.

Non-functional reliability requirements

- Non-functional reliability requirements are specifications of the required reliability and availability of a system using one of the reliability metrics (POFOD, ROCOF or AVAIL).
- Quantitative reliability and availability specification has been used for many years in safety-critical systems but is uncommon for business-critical systems.
- However, as more and more companies demand 24/7 service from their systems, it makes sense for them to be precise about their reliability and availability expectations.

Benefits of reliability specification

- The process of deciding the required level of the reliability helps to clarify what stakeholders really need.
- It provides a basis for assessing when to stop testing a system. You stop when the system has reached its required reliability level.
- It is a means of assessing different design strategies intended to improve the reliability of a system.
- If a regulator has to approve a system (e.g., all systems that are critical to flight safety on an aircraft are regulated), then evidence that a required reliability target has been met is important for system certification.

Specifying reliability requirements

- Specify the availability and reliability requirements for different types of failure. There should be a lower probability of high-cost failures than failures that don’t have serious consequences.
- Specify the availability and reliability requirements for different types of system service. Critical system services should have the highest reliability but you may be willing to tolerate more failures in less critical services.
- Think about whether a high level of reliability is really required. Other mechanisms can be used to provide reliable system service.

ATM reliability specification

- Key concerns
  - To ensure that their ATMs carry out customer services as requested and that they properly record customer transactions in the account database.
  - To ensure that these ATM systems are available for use when required.
- Database transaction mechanisms may be used to correct transaction problems so a low-level of ATM reliability is all that is required
- Availability, in this case, is more important than reliability

ATM availability specification

- System services
  - The customer account database service;
  - The individual services provided by an ATM such as ‘withdraw cash’, ‘provide account information’, etc.
- The database service is critical as failure of this service means that all of the ATMs in the network are out of action.
- You should specify this to have a high level of availability.
  - Database availability should be around 0.9999, between 7 am and 11pm.
  - This corresponds to a downtime of less than 1 minute per week.

ATM availability specification

- For an individual ATM, the key reliability issues depends on mechanical reliability and the fact that it can run out of cash.
- A lower level of software availability for the ATM software is acceptable.
- The overall availability of the ATM software might therefore be specified as 0.999, which means that a machine might be unavailable for between 1 and 2 minutes each day.

Insulin pump reliability specification

- Probability of failure (POFOD) is the most appropriate metric.
- Transient failures that can be repaired by user actions such as recalibration of the machine. A relatively low value of POFOD is acceptable (say 0.002) – one failure may occur in every 500 demands.
- Permanent failures require the software to be re-installed by the manufacturer. This should occur no more than once per year. POFOD for this situation should be less than 0.00002.

Fault tolerance

- In critical situations, software systems must be fault tolerant.
- Fault tolerance is required where there are high availability requirements or where system failure costs are very high.
- Fault tolerance means that the system can continue in operation in spite of software failure.
- Even if the system has been proved to conform to its specification, it must also be fault tolerant as there may be specification errors, or the validation may be incorrect.

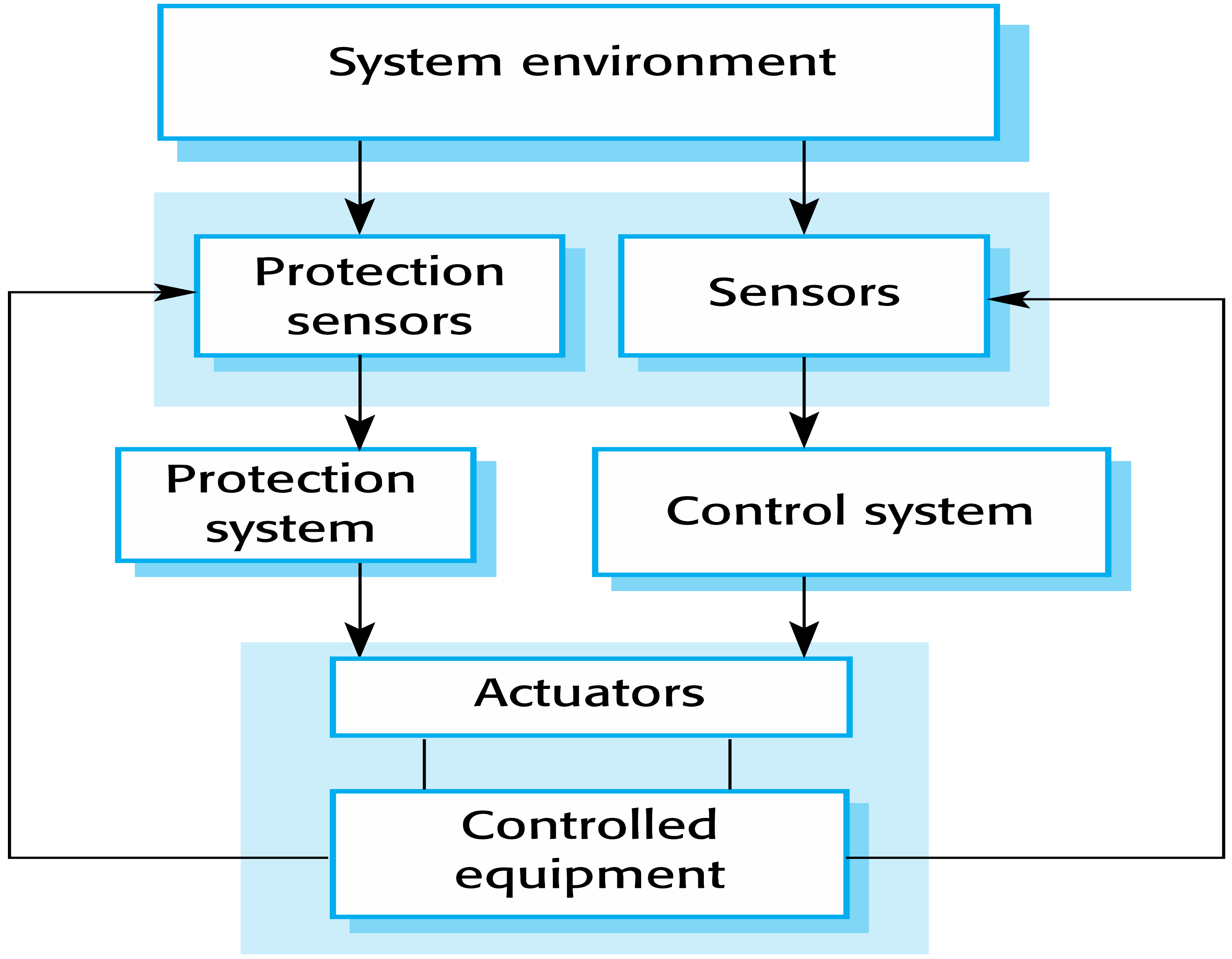
Fault-tolerant system architectures

- Fault-tolerant systems architectures are used in situations where fault tolerance is essential. These architectures are generally all based on redundancy and diversity.
- Examples of situations where dependable architectures are used:
  - Flight control systems, where system failure could threaten the safety of passengers
  - Reactor systems where failure of a control system could lead to a chemical or nuclear emergency
  - Telecommunication systems, where there is a need for 24/7 availability.

Protection systems

- A specialized system that is associated with some other control system, which can take emergency action if a failure occurs.
  - System to stop a train if it passes a red light
  - System to shut down a reactor if temperature/pressure are too high
- Protection systems independently monitor the controlled system and the environment.
- If a problem is detected, it issues commands to take emergency action to shut down the system and avoid a catastrophe.

Protection system architecture



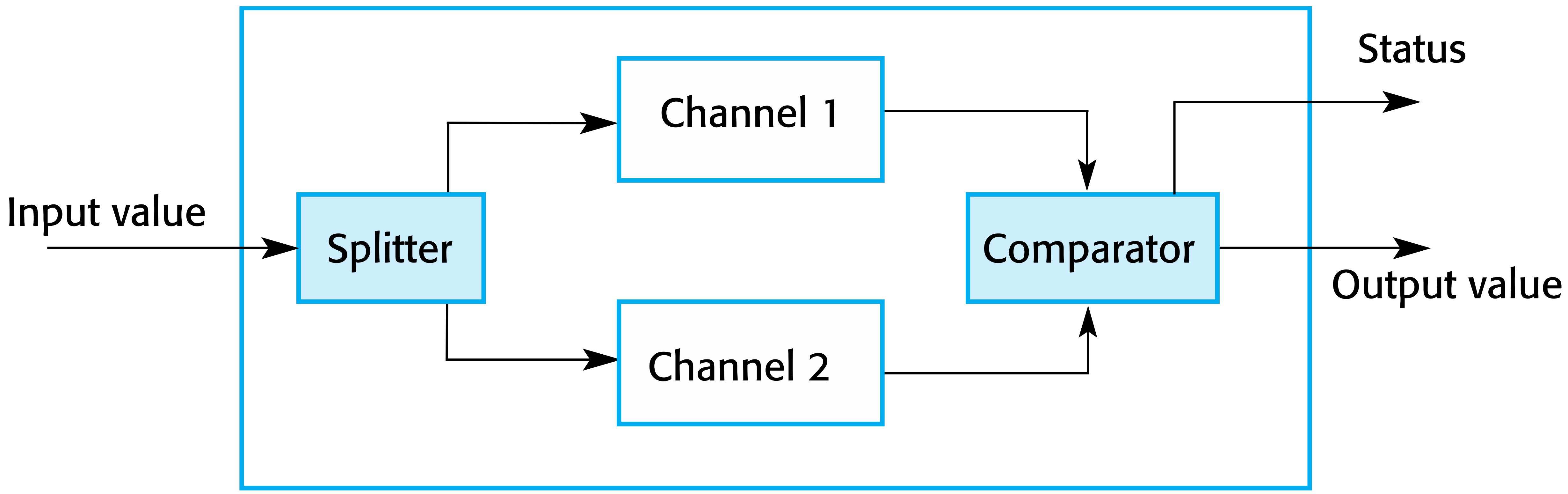
Protection system functionality

- Protection systems are redundant because they include monitoring and control capabilities that replicate those in the control software.
- Protection systems should be diverse and use different technology from the control software.
- They are simpler than the control system so more effort can be expended in validation and dependability assurance.
- Aim is to ensure that there is a low probability of failure on demand for the protection system.

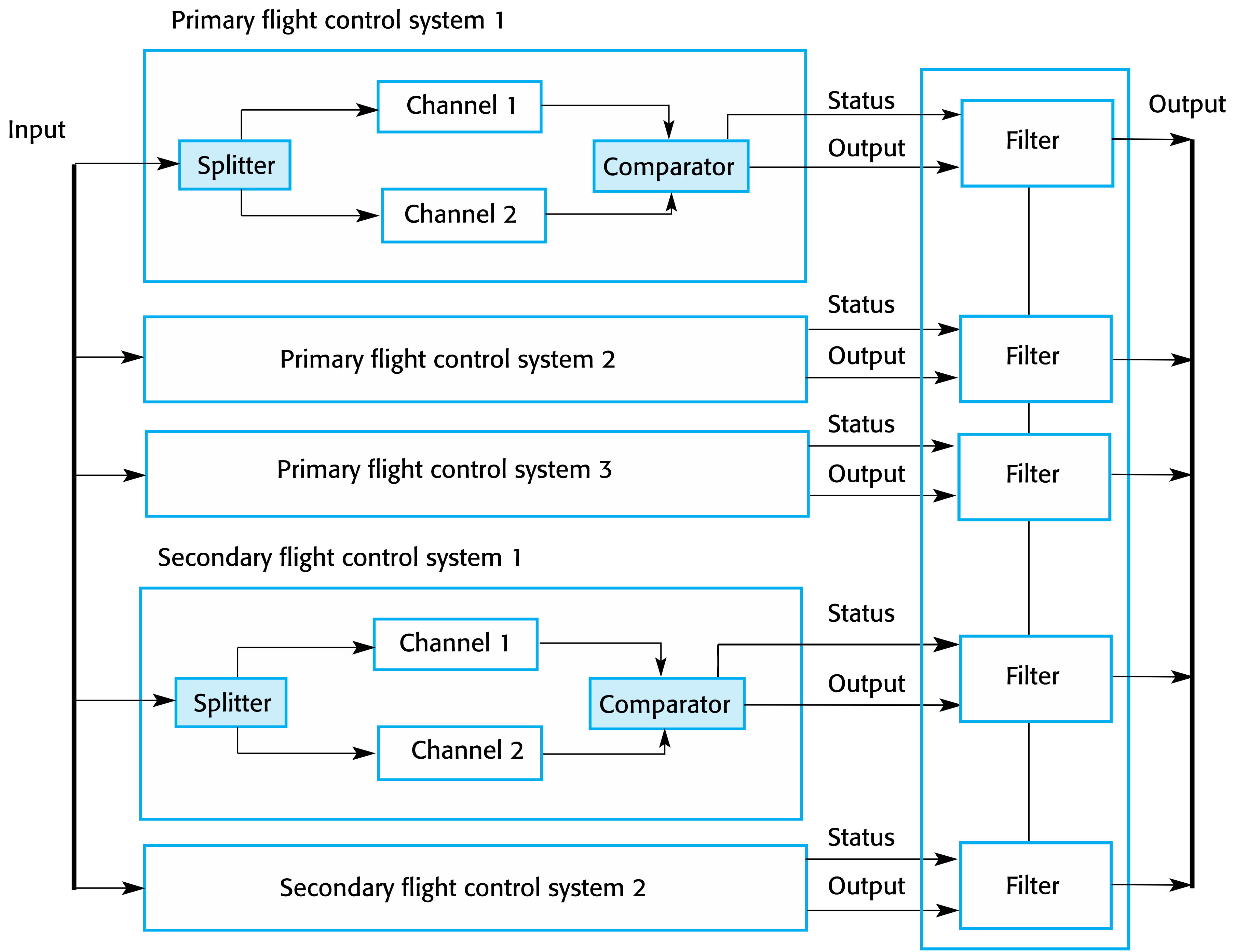
Self-monitoring architectures

- Multi-channel architectures where the system monitors its own operations and takes action if inconsistencies are detected.
- The same computation is carried out on each channel and the results are compared. If the results are identical and are produced at the same time, then it is assumed that the system is operating correctly.
- If the results are different, then a failure is assumed and a failure exception is raised.

Self-monitoring architecture



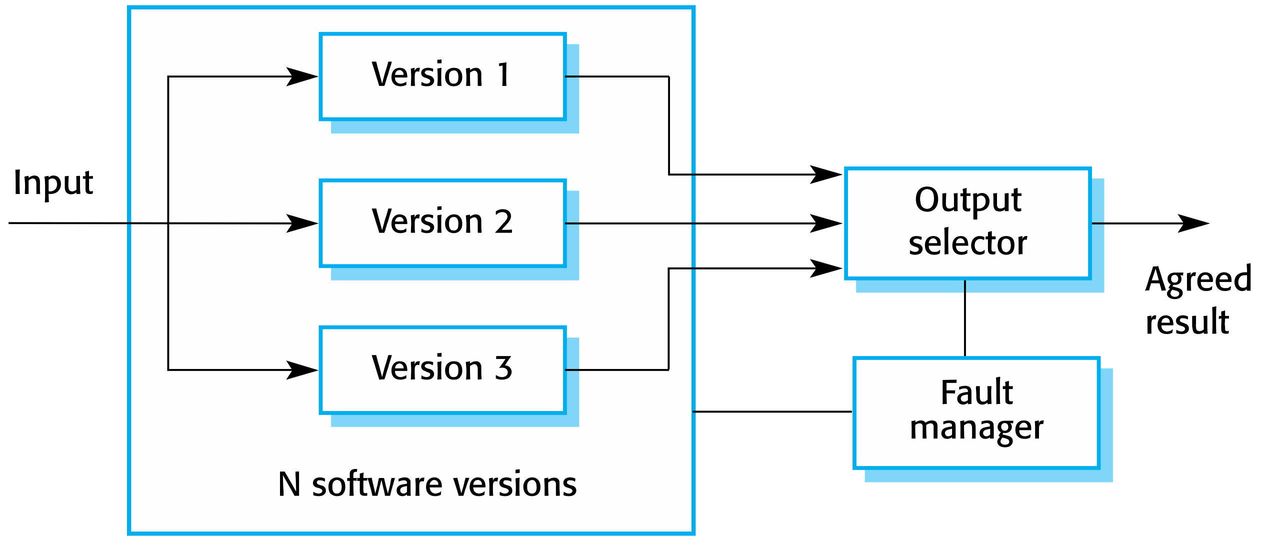
Airbus flight control system architecture



N-version programming

- Multiple versions of a software system carry out computations at the same time. There should be an odd number of computers involved, typically 3.
- The results are compared using a voting system and the majority result is taken to be the correct result.
- Approach derived from the notion of triple-modular redundancy, as used in hardware systems.
- The different system versions are designed and implemented by different teams. It is assumed that there is a low probability that they will make the same mistakes. The algorithms used should but may not be different.
- There is some empirical evidence that teams commonly misinterpret specifications in the same way and chose the same algorithms in their systems.

N-version programming



Software diversity

- Approaches to software fault tolerance depend on software diversity where it is assumed that different implementations of the same software specification will fail in different ways.
- It is assumed that implementations are-
  - Independent
  - do not include common errors
- Strategies to achieve diversity
  - Different programming languages
  - Different design methods and tools
  - Explicit specification of different algorithms