FACULDADE ENGENHARIA
Departamento de Informática

Qualidade de Software
(14450)

Quality Attributes and Measurement

(adapted from lecture notes of the “DIT 635 - Software Quality and Testing” unit,
delivered by Professor Gregory Gay, at the Chalmers and the University of Gothenburg, 2022)

Today's Goals

- ✧ Discuss software quality in more detail.
  - **Quality attributes**
    - Dependability, availability, performance, scalability, and security.
- ✧ How we build evidence that the system is good enough to release.
- ✧ How to assess whether each attribute is met.

Software Quality

- We all want **high-quality** software.
  - We don’t all agree on the definition of quality.
- Quality encompasses both **what** the system does and **how** it does it.
  - How *quickly* it runs.
  - How *secure* it is.
  - How *available* its services are.
  - How easily it *scales* to more users.
- Quality is hard to measure and assess objectively.

Quality Attributes

- Describe **desired properties** of the system.
- Developers prioritize attributes and design system that meets chosen thresholds.
- Most relevant for this course: **dependability**
  - Ability to *consistently* offer correct functionality, even under *unforeseen* or *unsafe* conditions.

Quality Attributes

- ✧ **Performance**
  - Ability to meet timing requirements. When events occur, the system must respond quickly.
- ✧ **Security**
  - Ability to protect information from unauthorized access while providing service to authorized users.
- ✧ **Scalability**
  - Ability to “grow” the system to process more concurrent requests.

Quality Attributes

- ✧ **Availability**
  - Ability to carry out a task when needed, to minimize “downtime”, and to recover from failures.
- ✧ **Modifiability**
  - Ability to enhance software by fixing issues, adding features, and adapting to new environments.
- ✧ **Testability**
  - Ability to easily identify faults in a system.
  - Probability that a fault will result in a visible failure.

Quality Attributes

✧ Interoperability

- Ability to exchange information with and provide functionality to other systems.

✧ Usability

- Ability to enable users to perform tasks and provide support to users.
- How easy it is to use the system, learn features, adapt to meet user needs, and increase confidence and satisfaction in usage.

Other Quality Attributes

- ✧ Resilience
- ✧ Supportability
- ✧ Portability
- ✧ Development Efficiency
- ✧ Time to Deliver
- ✧ Tool Support

Quality Attributes

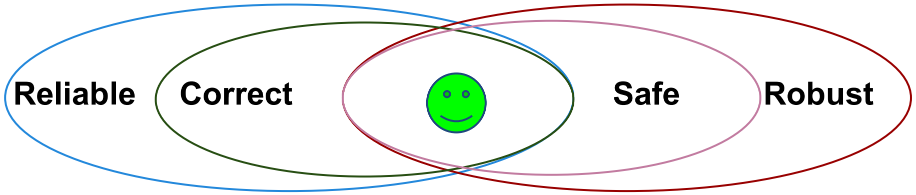
- These qualities **often conflict**.
  - Fewer subsystems improves performance, but hurts modifiability.
  - Redundant data helps availability, but lessens security.
  - Localizing safety-critical features ensures safety, but degrades performance.
- Important to decide what is important, and set a threshold on when it is “good enough”.

Our Focus

- ✧ Dependability
- ✧ Availability
- ✧ Performance
- ✧ Scalability
- ✧ Security
- ✧ **(Others important - but not enough time for all!)**

When is Software Ready for Release?

- Provide evidence that the system is *dependable*.
- The goal of dependability is to establish four things about the system:
  - That it is **correct**.
  - That it is **reliable**.
  - That it is **safe**.
  - That is is **robust**.



Correctness

- ✧ A program is **correct** if it is always consistent with its specification.
- ✧ Depends on quality and detail of requirements.
  - Easy to show with respect to a weak specification.
  - Often impossible to prove with a detailed specification.
- ✧ Correctness is rarely provably achieved.

Reliability

- ✧ Statistical approximation of correctness.
- ✧ The likelihood of correct behavior from some period of observed behavior.
  - Time period, number of system executions
- ✧ Measured relative to a specification and usage profile (expected pattern of interaction).
  - Dependent on how the system is used by a type of user.

Dependence on Specifications

- ✧ Correctness and reliability:
  - Success relative to the strength of the specification.
    - **Hard to meaningfully prove anything for strong spec.**
  - Severity of a failure is not considered.
    - **Some failures are worse than others.**
- ✧ Safety revolves around **a restricted specification**.
- ✧ Robustness revolves around **everything not specified.**

Safety

- ✧ Safety is the **ability to avoid hazards**.
  - Hazard = defined undesirable situation.
  - Generally serious problems.
- ✧ Relies on a specification of hazards.
  - Defines what the hazard is, how it will be avoided in the software.
  - We prove or show evidence that the hazard is avoided.
  - Only concerned with hazards, so proofs often possible.

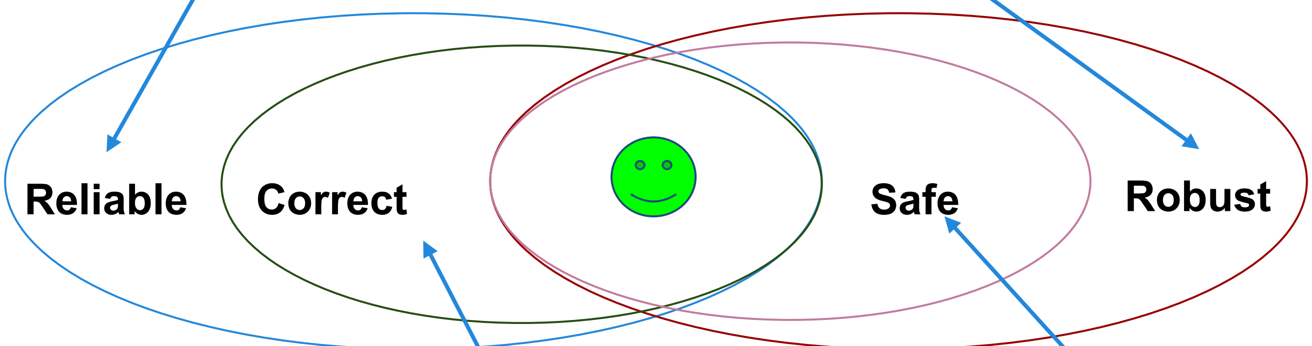
Robustness

- ✧ Software that is "correct" may fail when the assumptions of its design are violated.
  - *How* it fails matters.
- ✧ **Software that "gracefully" fails is robust.**
  - Design the software to counteract unforeseen issues or perform graceful degradation of services.
    - Look at how a program could fail and handle those situations.
  - Cannot be proved, but is a goal to aspire to.

Dependability Property Relations

Reliable, but not correct. Catastrophic failures can occur.

Robust, but not safe. Catastrophic failures can occur.



Correct, but not safe. Specification is inadequate

Safe, but not correct. Annoying failures can occur.

Measuring Dependability

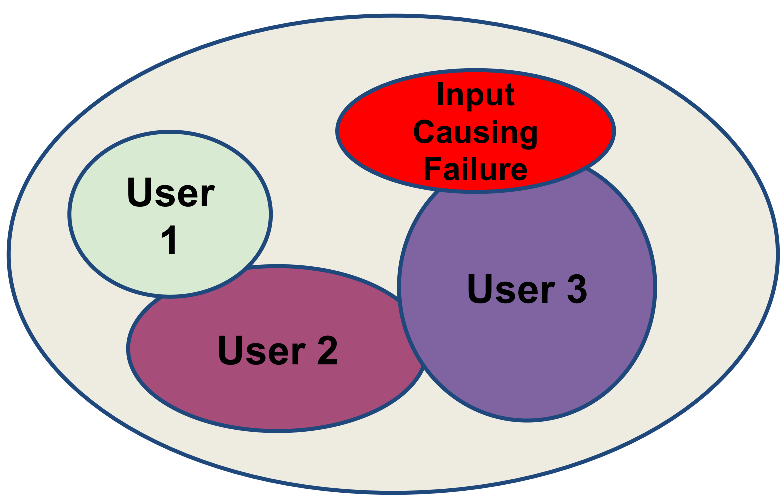
- ✧ Must establish criteria for when the system is dependable enough to release.
  - Correctness hard to prove conclusively.
  - Robustness/Safety important, but do not demonstrate functional correctness.
  - **Reliability is the basis for arguing dependability.**
    - Can be measured.
    - Can be demonstrated through sufficient volume of testing.

What is Reliability?

- ✧ Probability of failure-free operation for a **specified time** in a **specified environment** for a **given purpose**.
  - Depends on system and type of user.
- ✧ How well users ***think*** the system provides services they require.

Improving Reliability

- ✧ **Improved when faults in the most frequently-used parts of the software are removed.**
  - Removing X% of faults != X% improvement in reliability.
    - In one study, removing 60% of faults led to 3% improvement.
  - Removing faults with serious consequences is the top priority.



Reliability is Measurable

- ✧ Reliability can be defined and measured.
- ✧ Reliability requirements can be specified:
  - Non-functional requirements define number of failures that are acceptable during normal use or time in which system is allowed to be unavailable.
  - Functional requirements define how the software avoids, detects, and tolerates failures.

How to Measure Reliability

- ✧ Hardware metrics often aren't suitable for software.
  - Based on component failures and the need to repair or replace a component once it has failed.
  - In hardware, the design is assumed to be correct.
- ✧ Software failures are always design failures.
  - Often, the system is available even though a failure has occurred.
  - Metrics consider **failure rates**, **uptime**, and **time between failures**.

Metric 1: Availability

- Can the software carry out a task when needed?
  - Encompasses **reliability** and **repair**.
    - Does the system tend to show correct behavior?
    - Can the system recover from an error?
- The ability to mask or repair faults such that cumulative outages do not exceed a required value over a time interval.
  - **Both a reliability measurement AND an independent quality attribute.**

Metric 1: Availability

✧ Measured as **(uptime) / (total time observed)**

- Takes repair and restart time into account.
- Does not consider incorrect computations.
- Only considers crashes/freezing.
- 0.9 = down for 144 minutes a day.
  - 0.99 =14.4 minutes
  - 0.999 = 84 seconds
  - 0.9999 = 8.4 seconds

Availability

- Improvement requires understanding nature of failures that arise.
- Failures can be prevented, tolerated, removed, or forecasted.
  - How are failures detected?
  - How frequently do failures occur?
  - What happens when a failure occurs?
  - How long can the system be out of operation?
  - When can failures occur safely?
  - Can failures be prevented?
  - What notifications are required when failure occurs?

Availability Considerations

- ✧ Time to repair is the time until the failure is no longer observable.
  - Can be hard to define. Stuxnet caused problems for months. How does that impact availability?
- ✧ Software can remain partially available more easily than hardware.
- ✧ If code containing fault is executed, but system is able to recover, there was no failure.

Metric 2: Probability of Failure on Demand (POFOD)

- ✧ Likelihood that a request will result in a failure
- ✧ **(failures/requests over observed period)**
  - POFOD = 0.001 means that 1 out of 1000 requests fail.
- ✧ Used in situations where a failure is serious.
  - Independent of frequency of requests.
  - 1/1000 failure rate sounds risky, but if one failure per lifetime, may be good.

Metric 3: Rate of Occurrence of Fault (ROCOF)

- ✧ Frequency of occurrence of unexpected behavior.
- ✧ **(number of failures / total time observed)**
  - ROCOF of 0.02 means 2 failures per 100 time units.
  - Often given as “N failures per M seconds/minutes/hours”
- ✧ Most appropriate metric when requests are made on a regular basis (such as a shop).

Metric 4: Mean Time Between Failures (MTBF)

- ✧ Average length of time between observed failures.
  - Only considers time where system operating.
  - Requires the timestamp of each failure and the timestamp of when the system resumed service.
- ✧ Used for systems with long user sessions, where crashes can cause major issues.
  - E.g., saving requires resource (disc/CPU/memory) consumption.

Probabilistic Availability

- ✧ (alternate definition)
- ✧ Probability that system will provide a service within required bounds over a specified time interval.
  - **Availability = MTBF / (MTBF + MTTR)**
    - MTBF: Mean time between failures.
    - MTTR: Mean time to repair

Reliability Metrics

- ✧ Availability: **(uptime) / (total time observed)**
- ✧ POFOD: **(failures/ requests over period)**
- ✧ ROCOF: **(failures / total time observed)**
- ✧ MTBF: **Average time between observed failures.**
- ✧ MTTR: **Average time to recover from failure.**

Reliability Examples

✧ Provide software with 10000 requests.

- Wrong result on 35 requests, crash on 5 requests.
- What is the POFOD?

- 40 / 10000 = 0.0004
- Run the software for 144 hours

  (6 million requests). Software failed on 6 requests.

  What is the ROCOF? The POFOD?
- ROCOF = 6/144 = 1/24 = 0.04
- POFOD = 6/6000000 = (10^{-6})

Reliability Examples

- ✧ You advertise a piece of software with a ROCOF of 0.001 failures per hour.
  - However, it takes 3 hours (on average) to get the system up again after a failure.
  - What is availability per year?

- Failures per year:

  approximately 8760 hours per year (24*365)

  0.001 * 8760 = 8.76 failures per year

- Availability

  8.76 * 3 = 26.28 hours of downtime per year.

  Availability = 0.997 ((8760 - 26.28)/8760)

Additional Examples

- ✧ Want availability of at least 99%, POFOD of less than 0.1, and ROCOF of less than 2 failures per 8 hours.
  - After 7 full days, 972 requests were made.
  - Product failed 64 times (37 crashes, 27 bad output).
  - Average of 2 minutes to restart after each failure.
- ✧ What is the availability, POFOD, and ROCOF?
- ✧ Can we calculate MTBF?
- ✧ Is the product ready to ship? If not, why not?

Additional Examples

- ✧ Want availability of at least 99%, POFOD of less than 0.1, and ROCOF of less than 2 failures per 8 hours.
  - After 7 full days, 972 requests were made.
  - Product failed 64 times (37 crashes, 27 bad output).
  - Average of 2 minutes to restart after each failure.
- ✧ **ROCOF: 64/168 hours**
  - **= 0.38/hour**
  - **= 3.04/8 hour work day**

Additional Examples

- Want availability of at least 99%, POFOD of less than 0.1, and ROCOF of less than 2 failures per 8 hours.
  - After 7 full days, 972 requests were made.
  - Product failed 64 times (37 crashes, 27 bad output).
  - Average of 2 minutes to restart after each failure.
- **POFOD: 64/972 = 0.066**
- **Availability: Down for (37*2) = 74 minutes / 168 hrs**
  - **= 74/10089 minutes = 0.7% of the time = 99.3%**

Additional Examples

✧ Can we calculate MTBF?

- No - need timestamps. We know how long they were down (on average), but not when each crash occurred.

✧ Is the product ready to ship?

- No. Availability/POFOD are good, but ROCOF is too high.

Reliability Economics

- ✧ May be cheaper to accept unreliability and pay for failure costs.
- ✧ Depends on social/political factors and system.
  - Reputation for unreliability may hurt more than cost of improving reliability.
  - Cost of failure depends on risks of failure.
    - Health risks or equipment failure risk requires high reliability.
    - Minor annoyances can be tolerated.

Performance

- ✧ Ability to meet timing requirements.
- ✧ Characterize pattern of input events and responses
  - Requests served per minute.
  - Variation in output time.
- ✧ Driving factor in software design.
  - Often at expense of other quality attributes.
  - **All** systems have performance requirements.

Performance Measurements

- ✧ **Latency:** The time between the arrival of the stimulus and the system's response to it.
- ✧ **Response Jitter:** The allowable variation in latency.
- ✧ **Throughput:** Usually number of transactions the system can process in a unit of time.
- ✧ **Deadlines in processing:** Points where processing must have reached a particular stage.
- ✧ **Number of events not processed** because the system was too busy to respond.

Measurements - Latency

- ✧ Time it takes to complete an interaction.
- ✧ **Responsiveness:** how quickly system responds to routine tasks.
  - Key consideration: user productivity.
  - How responsive is the user's device? The system?
  - Measured probabilistically (... 95% of the time)
  - Under a load of 350 update transactions per minute, 90% of "open account" requests should return a reply to the calling program within 10 seconds.

Measurements - Latency

- **Turnaround time** = time to complete larger tasks.
  - Can task be completed in available time?
  - Impact on system while running?
  - Can partial results be produced?
  - Ex: Assuming a daily throughput of 850,000 requests, the process should take no longer than 4 hours, including writing results to a database.
  - Ex: It must be possible to resynchronize monitoring stations and reset database within 5 minutes.

Measurements - Response Jitter

- ✧ Response time is non-deterministic.
  - If non-determinism can be controlled, this is OK.
    - 10s +- 1s, great!
    - 10s +- 10 minutes, bad!
- ✧ Defines how much variation is allowed.
  - Places boundaries on when task can be completed.
  - If boundaries violated, quality is compromised.
  - Ex: “All writes to the database must be completed within 120 to 150 ms.”

Measurements - Throughput

- ✧ The workload a system can handle in a time period.
  - Shorter the processing time, higher the throughput.
  - As load increases (and throughput rises), response time for individual transactions tends to increase.
    - With 10 concurrent users, request takes 2s.
    - With 100 users, request takes 4s.

Measurements - Throughput

- Possible to end up in situation where throughput goals conflict with response time goals.
  - With 10 users, each can perform 20 request per minute (throughput: 200/m).
  - With 100 users, each can perform 12 per minute (throughput: 1200/m - but at cost to response time).

Measurements - Deadlines

- ✧ Some tasks must take place as scheduled.
- ✧ If times are missed, the system will fail.
  - In a car, fuel must ignite when cylinder is in position.
  - Places a deadline on when the fuel must ignite.
- ✧ Deadlines can be used to place boundaries on when events must complete.

Measurements - Missed Events

- ✧ If the system is busy, input may be ignored.
  - Or, queued until too late to matter.
- ✧ Can track how many input events are ignored because the system is too slow to respond.
  - Set upper bound on how many events can be missed in a defined timeframe.

Scalability

- ✧ Ability to process increasing number of requests.
  - While meeting performance requirements.
- ✧ Horizontal scalability (“scaling out”)
  - Adding more resources to logical units.
    - Adding another server to a cluster.
    - “elasticity” (add or remove VMs from a pool)
- ✧ Vertical scalability (“scaling up”)
  - Adding more resources to a physical unit.
    - Adding memory to a single computer.

Scalability

- ✧ How can we effectively utilize additional resources?
- ✧ Requires that additional resources:
  - Result in performance improvement.
  - Did not require undue effort to add.
  - Did not disrupt operations.
- ✧ The system must be designed to scale
  - (i.e., designed for concurrency).

Assessing Scalability

- ✧ Ability to address more requests is often part of **performance** assessment.
- ✧ Assessing scalability directly measures impact of adding or removing resources.
- ✧ Response measures reflect:
  - Changes to performance.
  - Changes to availability.
  - Load assigned to existing and new resources.

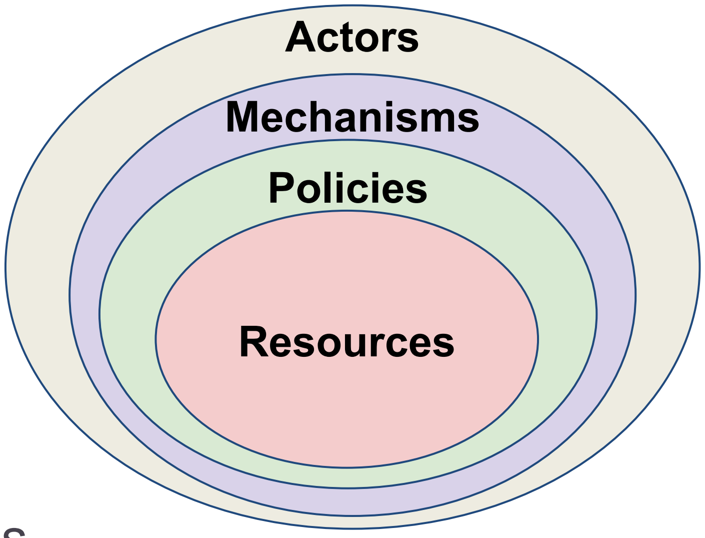
Security

- ✧ Ability to protect data and information from unauthorized access...
  - **… while still providing access to people and systems that are authorized.**
- ✧ Can we protect software from attacks?
  - Unauthorized access attempts.
  - Attempts to deny service to legitimate users.

Security

✧ Processes that allow owners of resources to control access.

- Who: Actors (systems or users).
- Resources are sensitive elements, operations, and data of the system.
- Policies define legitimate access to resourced.
- Enforced by security mechanisms used by actors to gain access to resources.



Security Characterization (CIA)

- ✧ Confidentiality
  - ▪ Data and services protected from unauthorized access.
    - A hacker cannot access your tax returns on an IRS server.
- ✧ Integrity
  - ▪ Data/services not subject to unauthorized manipulation.
    - Your grade has not changed since assigned.
- ✧ Availability
  - ▪ The system will be available for legitimate use.
    - A DDOS attack will not prevent your purchase.

Supporting CIA

- ✧ Authentication: Verifies identities of all parties.
- ✧ Nonrepudiation: Guarantees that sender cannot deny sending, and recipient cannot deny receiving.
- ✧ Authorization: Grants privilege of performing a task.

Security Approaches

- Achieving security relies on:
  - Detecting attacks.
  - Resisting attacks.
  - Reacting to attacks.
  - Recovering from attacks.
- Objects being protected are:
  - Data at rest.
  - Data in transit.
  - Computational processes.

Security is Risk Management

- **Not simply secure/not secure.**
  - All systems will be compromised.
  - Try to avoid attack, prevent damage, and quickly recover.
  - Balance risks against cost of guarding against them.
  - Set realistic expectations!

Assessing Security

- ✧ Measure of system's ability to protect data from unauthorized access while still providing service to authorized users.
- ✧ Assess how well system responds to attack.
  - Stimuli are attacks from external systems/users or demonstrations of policies (log-in, authorization).
  - Responses: auditing, logging, reporting, analyzing.

Assessing Security

- ✧ No universal metrics for measuring “security”.
- ✧ Present specific attack types and specify how system responds.
- ✧ Response assessed by appropriate metrics.
  - Time to identify attacker.
  - Amount of data protected.
  - Time to stop attack.

Key Points (1 of 3)

- ✧ Dependability is one of the most important software characteristics.
  - Aim for correctness, reliability, safety, robustness.
  - Often assessed using reliability.
- ✧ Reliability depends on the pattern of usage of the software. Different users will interact differently.
- ✧ Reliability measured using ROCOF, POFOD, Availability, MTBF

Key Points (2 of 3)

- ✧ Availability is the ability of the system to be available for use, especially after a failure.
- ✧ Performance is about management of resources in the face of demand to achieve acceptable timing.
  - Usually measured in terms of throughput and latency.
- ✧ Scalability is the ability to “grow” the system to process an increasing number of requests.
  - While still meeting performance requirements.

Key Points (3 of 3)

- ✧ Security is the ability to protect data and information from unauthorized access…
  - … while still providing access to people and systems that are authorized.
- ✧ Security is not “measured”, but requires defining attacks and actions to prevent or reduce impact of risk, then assessing those actions.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