Software Testing Techniques for User Acceptance and Systems Integration Testing

Software Quality

Outline

- Factors in Project Success & Failure
- A Case Study, The Initial Launch of HealthCare.gov
- Software Reliability
- The Spectrum of Software Quality
- Cost of Software Defects
- Software Verification and Validation (V&V)
- Software Testing in Development Life Cycle

Factors in Project Success & Failure

Software Crisis

- Many software-related failures: auto-pilot systems, air traffic control systems, banking systems, IRS.
  - On January 15, 1990, the AT&T long-distance telephone network broke down, interrupting long-distance telephone services in US for over 8 hours. [Missing **break** in a **switch** statement.]
  - On June 4, 1996, the maiden flight of the new and improved Ariane 5 rocket exploded 37 seconds after lift-off.
  - On June 8, 2001, a software problem caused the NYSE to shut down the entire trading floor for over an hour.
  - On May 27, 2017, a software problem caused a disruption for 75,000 passengers in British Airways
  - February 2020: Heathrow disruption, More than 100 flights were disrupted after it was hit by technical issues
  - Many, many, many more.

What is the problem?

Software Projects have a terrible track record

A 1995 Standish Group study (CHAOS) [see notes] found that only 16.2% of IT projects were successful in meeting scope, time, and cost goals (on-time & on-budget) [Things have improved a bit since.]

Over 31% of IT projects were canceled [never seeing completion], costing over $81 billion in the U.S. alone

- They never worked
- Too late for the market window

Most projects are

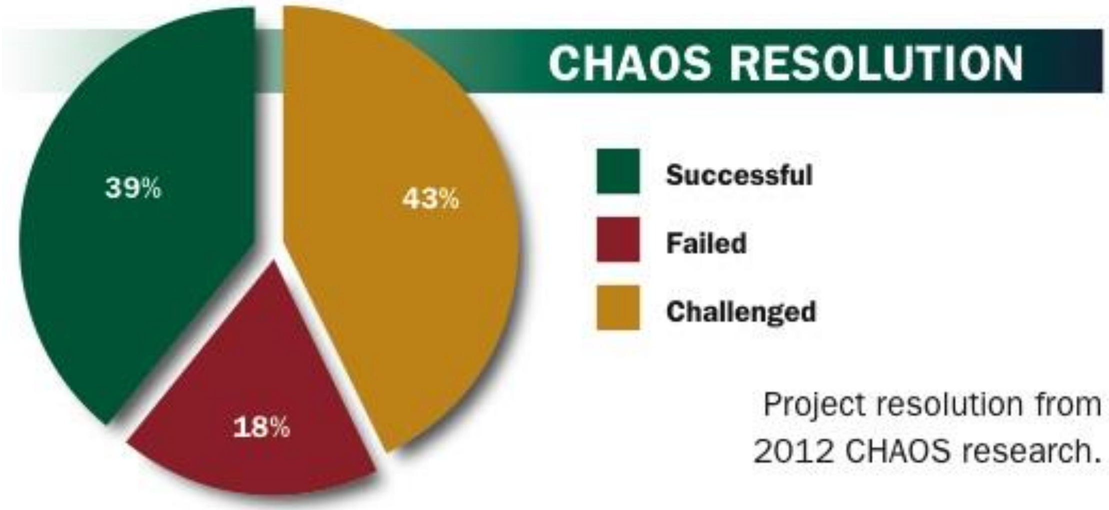
- Late in delivery
- Missing functionality
- Have major defects (bugs)
- Did not do what the customer wanted
- Hard to maintain and support

Chaos Report 2012

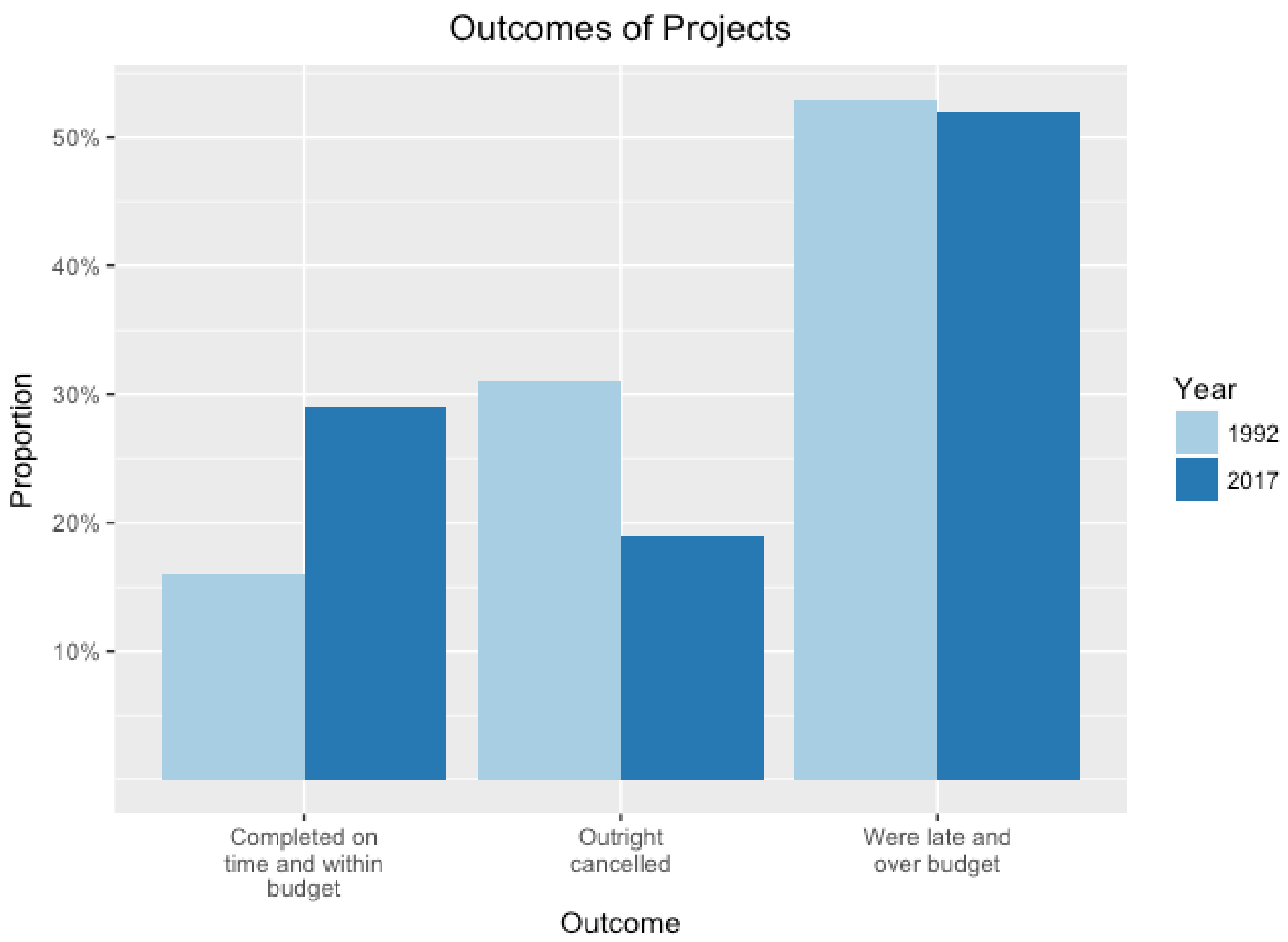
Project Success: Type 1. The project is completed on-time and on-budget, with all features and functions as initially specified. (2012: 39%)

Project Challenged: Type 2. The project is completed and operational but over-budget, over the time estimate, and offers fewer features and functions than originally specified. (2012: 43%)

Project Impaired: Type 3.
The project is canceled at some point
during the development cycle.
(2012: 18%) (Are ALL impaired projects failures???)



1992-2017



Outcomes of Projects
50%
40%
30%
20%
10%
Proportion
Completed on time and within budget
Outright cancelled
Were late and over budget
Outcome
Year
1992
2017

A Case Study
The Initial Launch of HealthCare.gov (2013)

ACA – HealthCare.gov

- ACA signed into law on March 23, 2010
- HealthCare.gov is a healthcare exchange website.
  - "One-stop shopping sites for health insurance"
  - CBO forecast: 7 million users during the first year
- Development contracts awarded in September 2011
  - No-bid, cost-plus contracts
  - Pre-certified private contractors
- HealthCare.gov launched on October 1, 2013
  - Serious technological problems

HealthCare.gov – The Launch Problems

- Performance: response time (landing page) > 8s
  - “Maddeningly long wait times"
- Navigation: broken UI
- Stability: intermittent crashes, availability ≈ 43%
- Functionality: incorrect and incomplete data
- Error rate (per page) ≈ 6%
- Scalability: < 1,100 concurrent users
- Enrollment completion rate < 30%

HealthCare.gov – The Contractors & The Cost

- The lead contractor: CGI Group
  - At least 47 private companies involved
  - Including QSSI, Equifax, Serco
- Coordinated by the Centers for Medicare and Medicaid Services (CMS)
- Total budget: $293 million
  - CGI: $196 million (2013). $112 million paid Oct. 2013
  - QSSI: $85 million
- Estimated actual cost: > $500 million by Oct. 2013

HealthCare.gov – The Failures – Software Eng.

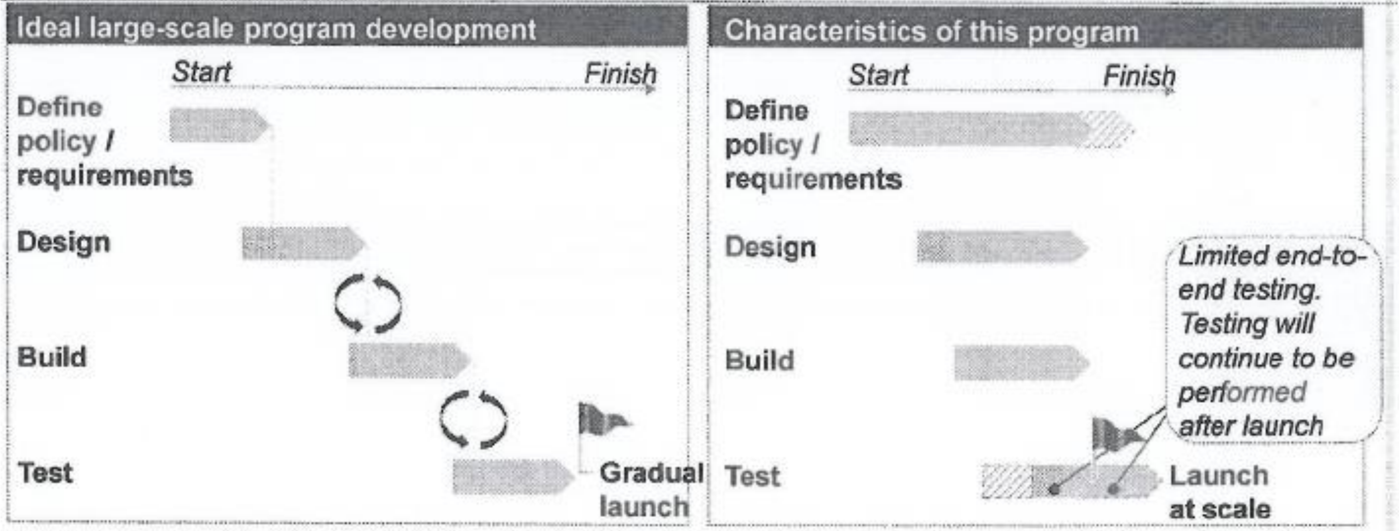
- **Inadequate Testing**
  - “This system just wasn't tested enough.” – CMS
  - Full test began T -2 weeks (time before launch).
  - Final “pre-flight checklist” T -1 week: 41 of 91 functions fail.
  - No “end-to-end” test as late as T -4 days
  - Stress tests T -1 day: performance degradation with only 1,100 concurrent users. (50,000-60,000 expected)
  - Final top-to-bottom security tests not finished.
  - No integration test. No beta test.

HealthCare.gov – The Failures – Software Eng.

- **Evolving, Rolling Requirements**
  - Regulations and policies were still in flux when contracts awarded in 2011.
  - The specifications for the project were delayed repeatedly.
  - The regulations and policies were modified repeatedly until summer 2013.
  - Repeated changes result in design changes.
  - CGI did not start coding until Spring 2013
- **Failure to Effectively Manage Changes**
  - "Write-down-all-the-requirements-then-build-to-those-requirements"
  - Did not adopt an agile development approach.
  - Committed to an all-or-nothing launch date.

Case Study: HealthCare.gov– McKinsey "Red Team" Assessment

Programs of this type ideally have a sequential planning, design, and implementation process with significant testing and revision



Description of ideal situation:

- Clear articulation of requirements & success metrics
- Minimized dependency on third parties
- Sequential requirements, design, build, and testing
- Iteration and revision between phases
- End-to-end integrated operations and IT testing
- Limited initial launch

Current situation:

- Evolving requirements
- Multiple definitions of success
- Significant dependency on external parties/ contractors
- Parallel "stacking" of all phases
- Insufficient time and scope of end-to-end testing
- Launch at full volume

CMS has been working to mitigate challenges resulting from program characteristics

CMS

Confidential and Proprietary — Pre-decisional Information

4

Case Study: HealthCare.gov: The Failures – Management

- Management expertise is in getting contracts not delivering projects.
- Project quality is sacrificed for the sake of appearances.
- Seriously substandard staffing and under staffing
  - CGI. Three months before launch, only 10 developers were working on a crucial part of the site , and of those, only one was "at a high enough skill level.”
- Lack of coordination among contractors
  - Unclear responsibilities. Fragmented authority.

Case Study: HealthCare.gov: The Failures – Gov. & Policies

- Government IT projects
  - Most are over budget and/or behind schedule.
  - “Write-down-all-the-requirements-then-build-to-those-requirements” is outdated.
- IT procurement policies
  - Cost-plus contract, no-bid contracts
  - “The firms that typically get contracts are the firms that are good at getting contracts, not typically good at executing on them.”

Case Study: HealthCare.Gov – Dec. 2013

- 400+ bug fixes, by the end of Nov. 2013
  - "Operate smoothly for most users." – W.H.
- Availability > 90%
- Response time (landing page) < 1s
- Error rate (per page) < 1%
- Completion rate ≈ 80%
- System capacity ≈ 50,000 concurrent users
- Sign-ups
  - 27,000 in Oct, 110,000 in Nov, 975,000 in Dec

Case Study: HealthCare.Gov – April 2014

- Issues on data accuracy and completeness
  - Estimated 10-15% of sign-ups missing
  - Other inaccuracies have been reported
- CGI work during repair continue to be substandard
  - Half of the software fixes failed. – *CMS*
- CGI contract has been terminated. (Jan. 10, 2014)
- March 31, 2014 (last day to sign up), site went down
- April 1, 2014. 7.1 million signed up – *W.H.*

Case Study: HealthCare.Gov – Aftermath

- *Accenture* took over in Jan. 2014 as the lead contractor for development and maintenance: $175M
- Cost of building the system – *GAO*, July 2014
  - $834M through Feb. 2014
    - Total estimated cost: > $2B
  - "CMS undertook the development of HealthCare.gov without effective planning or oversight practices"
  - Also found "increased and unnecessary risk of unauthorized access, use, disclosure, modification or loss" of information
  - CMS only withheld $267,000 in requested fees, 2% of the contract, from CGI.

Case Study: HealthCare.Gov – 2015 Enrollment Cycle

- Enrollment for 2015 (37 states)
  - Nov 15, 2014 – February 15, 2015.
  - Outages on the first day
  - More smooth operation thereafter
- February, 2015
  - ~ 11.4 million sign-ups (~8.6 million re-enrollments)
    - Open enrollment extensions: March 15 – April 30
  - ~800,000 received incorrect tax information,
    - Incorrect amount on 1095-A Form

Case Study: HealthCare.gov: The Lessons Learned

- Adopt software engineering best practices
  - Agile software development. Testing early.
  - Software quality assurance and testing. Testing throughout.
- Adopt management best practices
  - Clear responsibility and accountability
  - Performance metrics and progress tracking
- Revamp government IT procurement policies
  - Current system is antiquated, and has failed.
  - Bring government IT to the 21st century.

Software Reliability

Metrics of Software Quality – Performance & Scalability

- Performance
  - The ability to complete requested functions or services within the expected time span by the users.
  - e.g., average response time for a given task
- Scalability
  - The capacity of a system to handle increasing load or demand.
  - e.g., # of concurrent users, # of transactions per second, # of requests per second

Product Quality Metrics

- Two key metrics for intrinsic product quality are Mean Time To Failure (**MTTF**) and availability
- **MTTF** is most often used with safety critical systems such as air traffic control systems, avionics, and weapons
- **Availability** is the probability that a system will work as required when required during the period of a mission.
- Both are correlated, but different in the same way that failures and defects are different

Metrics of Software Quality – Mean Time Between Failures

- Mean time between failures (MTBF)
  - Average of intervals between consecutive failures.
- Mean time to failures (MTTF)
  - Average amount of time a system operates before it fails
- Mean time to repair (MTTR)
  - Average time to repair/restart the system and get it back to running
- MTBF is a simple measure of reliability

$$MTBF = MTTF + MTTR$$

Metrics of Software Quality – Availability & Reliability

- Availability
  - The probability of a system to be available.
  - The fraction of time the system is available.

$$\frac{\text{available time (“up time”)}}{\text{total time}}$$

- Reliability
  - The probability of a system to operate without failures.
  - The fraction of all attempted operations that complete *successfully.*

$$\frac{\text{\# of successful operations}}{\text{\# of total operations attempted}}$$

Software Availability

- Software availability is the probability that a program is operating according to requirements at a given point in time and is defined as

$$\text{Availability} = \left[\text{MTTF}/(\text{MTTF} + \text{MTTR})\right] \times 100\%$$

- Consider 5 nines availability (99.999%); what does this mean?
  - 5 minutes of down time per year

[See Availability (system) – https://en.wikipedia.org/wiki/Availability_(system)]

Metrics of Software Quality – Error Rate & Completion Rate

- Reliability depends on the *unit* of operation
  - An operation may consists of multiple steps
  - Reliability ≠ Completion rate
- Error rate (per page)
  - The fraction of pages (unit of operation) that time out or fail
- Completion rate
  - The fraction of all attempted operations that *eventually* complete the operation
  - Completion ≠ Success

Integration & System Testing

- Integration testing
  - To expose defects in the interfaces and the interactions between integrated sub-systems.
- System (“end-to-end”) testing
  - Test of an integrated system to determine whether it meets the specification.

Acceptance & Beta Testing

- Acceptance testing
  - To determine whether or not a system satisfies the user needs and requirements.
  - To enable the user, customers, or other authorized entity to determine whether or not to accept the system.
- Beta testing
  - One form of acceptance testing
  - Performed by *real* users in their own environment
  - Perform actual tasks without interference.

The Spectrum of Software Quality

What is Quality?

Some possible definitions:

- Quality = zero defects (Crosby)
- The totality of features and characteristics of a product or service that bear on its ability to satisfy specified or implied needs. (ISO)
- Quality = fitness for purpose (Juran)
- Quality n., the degree of excellence (OED)

Software System Qualities

- Correctness
- Availability
- Reliability
- Performance
- Scalability
- Efficiency
- Safety
- Usability
- Security
- Robustness
- Maintainability
- Reusability
- Portability
- Interoperability

On Expected Behavior – Correctness vs. Reliability

- Correctness
  - Whether a system is consistent with its *specification*.
- Reliability
  - The probability of a system to operate without failures.
  - Relative to its *specification* and a *usage profile*.
  - Statistical approximation to correctness

    100% reliable ≈ correct

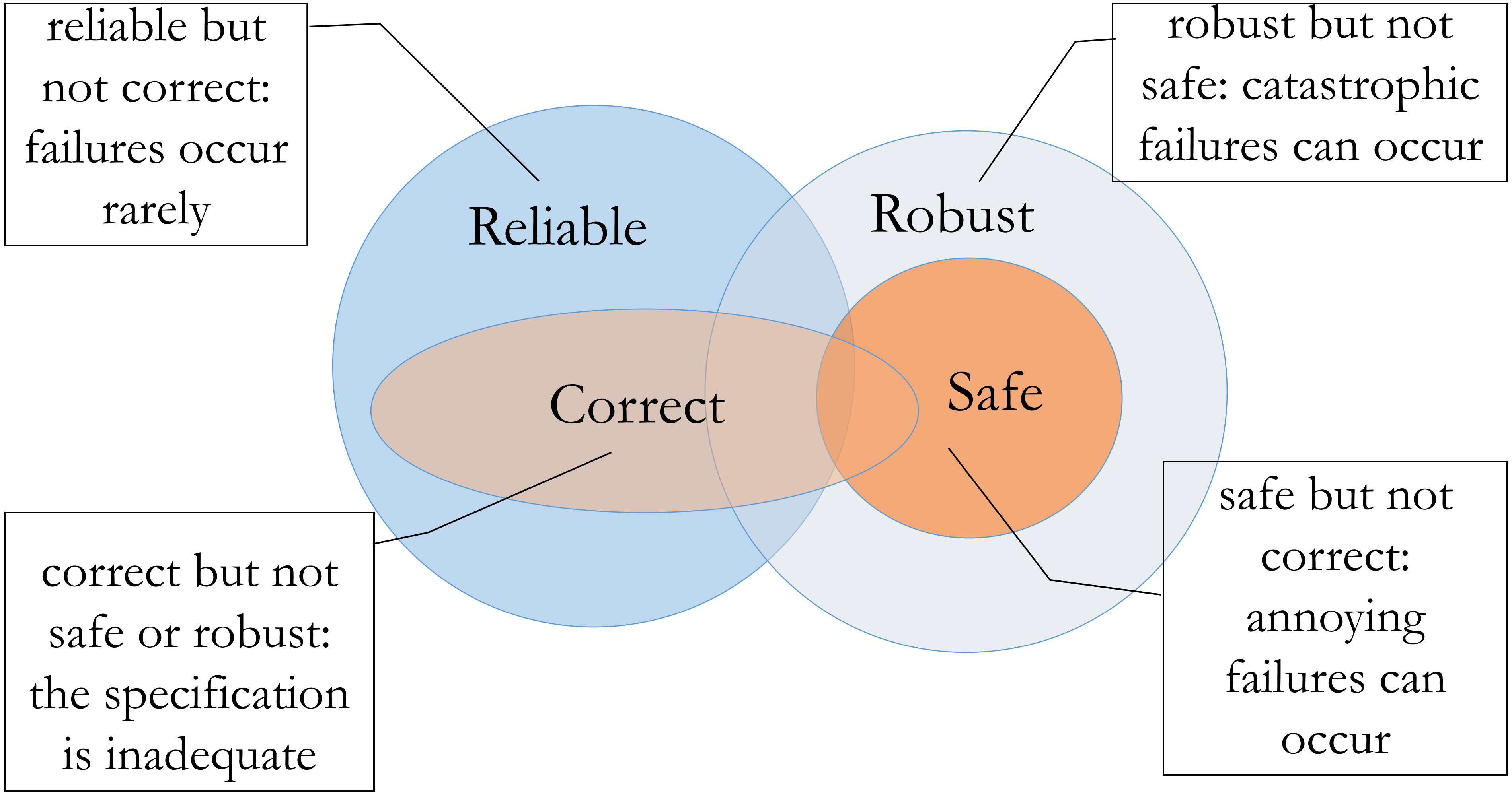
On Exceptional Behavior – Safety vs. Robustness

- Safety
  - The ability of a software system to prevent certain undesirable behaviors, i.e., *hazards*.
- Robustness
  - The ability of a software system to *fail or degrade gracefully* outside its normal operating parameters.
  - Acceptable (degraded) behavior under extreme conditions.

Correctness

- Correctness is an all-or-nothing proposition.
- A program cannot be mostly correct or somewhat correct or 30% correct, it is absolutely correct on all possible behaviors or else it is not correct.
- It is very easy to achieve correctness, since every program is correct with respect to some (very bad) specification.
- Correctness is a goal to aim for, but is rarely provably achieved.

Relationship Among the Qualities



Performance Related Qualities

- Performance
  - The ability to complete requested functions or services within the expected time span by the users.
- Scalability
  - The capacity of a system to handle increasing load or demand.
- Efficiency
  - The ability to make maximum and efficient use of system resources.

Usability & Security

- Usability
  - The ability for the users to use all the features of the system without special efforts.
- Security
  - The ability to maintain integrity of the system operation and the data.

Internal Qualities

- Maintainability
  - The ability to make changes, enhance, adapt, and evolve a software system over a long period of time.
- Reusability
  - The ability to use parts of the system in different project without special effort on the part of the developers
- Portability
  - The ability to port a software system to a different platform or operating environment

Software Quality

Conformance to customers’ requirements

Quality

- For software, two kinds of quality may be encountered:
  - **Quality of design** encompasses requirements, specifications, and the design of the system.
  - **Quality of conformance** is an issue focused primarily on implementation.
  - user satisfaction = compliant product + good quality + delivery within budget and schedule

Cost of Quality

- Prevention costs include
  - Quality planning
  - Formal technical reviews
  - Test equipment
  - Training
- Internal failure costs include
  - Rework
  - Repair
  - Failure mode analysis
- External failure costs are
  - Complaint resolution
  - Product return and replacement
  - Help line support
  - Warranty work

Customers’ Expectations

- What’s wrong with “performance to customers’ expectations” rather than requirements?
- Often hear people say “We must exceed the customers’ expectations!”
- What’s the basic problem with this?
- The result is?

Software Quality

- Conformance to explicitly stated functional and performance requirements, explicitly documented development standards, and implicit characteristics that are expected of all professionally developed software.
- Quality must be defined and measured if improvements are to be achieved
- In the narrowest sense, it is commonly recognized as the lack of “bugs” in the product
- Also, the most basic meaning of conformance to requirements because if the software contains too many functional defects, the basic requirement of providing the desired function is not met
- How is this usually expressed?

Application to Software

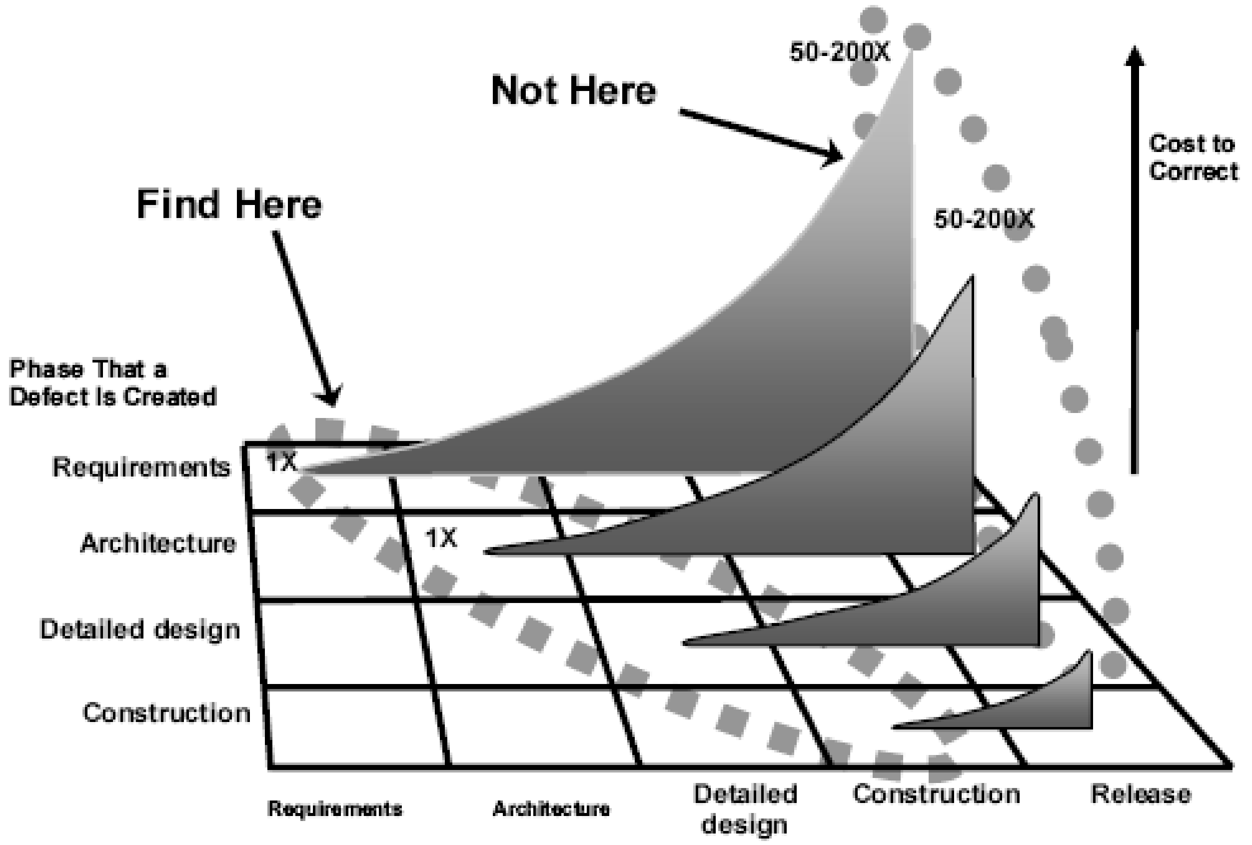
- Simplistically, software product quality is lack of “bugs” in the product
- Why is this problematical for software systems?
  - Correct operation is not sufficient – performance?
  - Usability by the end-user
  - Software specifications

Cost of Software Defects

Saving Time and Money

- Even experienced software engineers inject a defect about every ten lines of code
- The cost of finding and fixing defects increases at every step in the development process
- The defect find & fix times range from 3 minutes in code reviews to 25 minutes in inspections and 1400 minutes in system testing
- For accurate plans and reliable commitments, you must insist on what?

Cost of Software Defects



Source: Steve McConnell

Estimated Cost of Fixing Defects

		Time detected				
		spec	design	code	test	post-release
Time introduced	spec	1×	3×	5–10×	15×	30–100×
	design	-	1×	10×	20×	30–100×
	code	-	-	1×	10×	20–50×

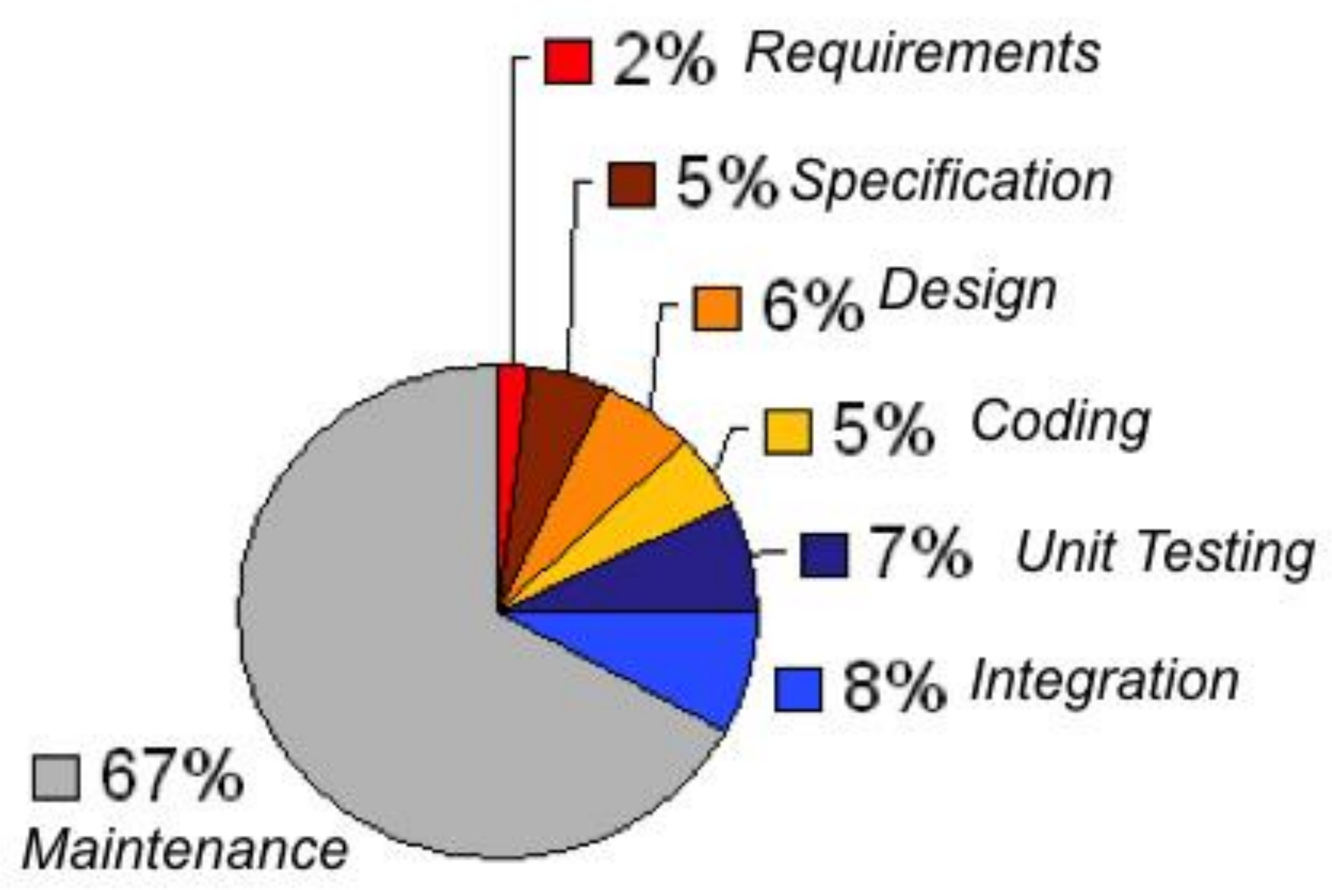
The earlier a defect is discovered, the lower the cost of fixing the defect.

Distribution of Defects – Time Introduced and Fixed

Time introduced (%)	Time detected (%)					
	spec design	code unit test	integration system test	beta test	post-release	Total
specification design	3.5	10.5	35	6	15	70
code unit test	-	6	9	2	3	20
integration system test	-	-	6.5	1	2.5	10
Total	3.5	16.5	50.5	9	20.5	100%

- Majority of defects are introduced early
- Majority of defects are discovered late.

Cost by Development Phases



Software Verification and Validation (V&V)

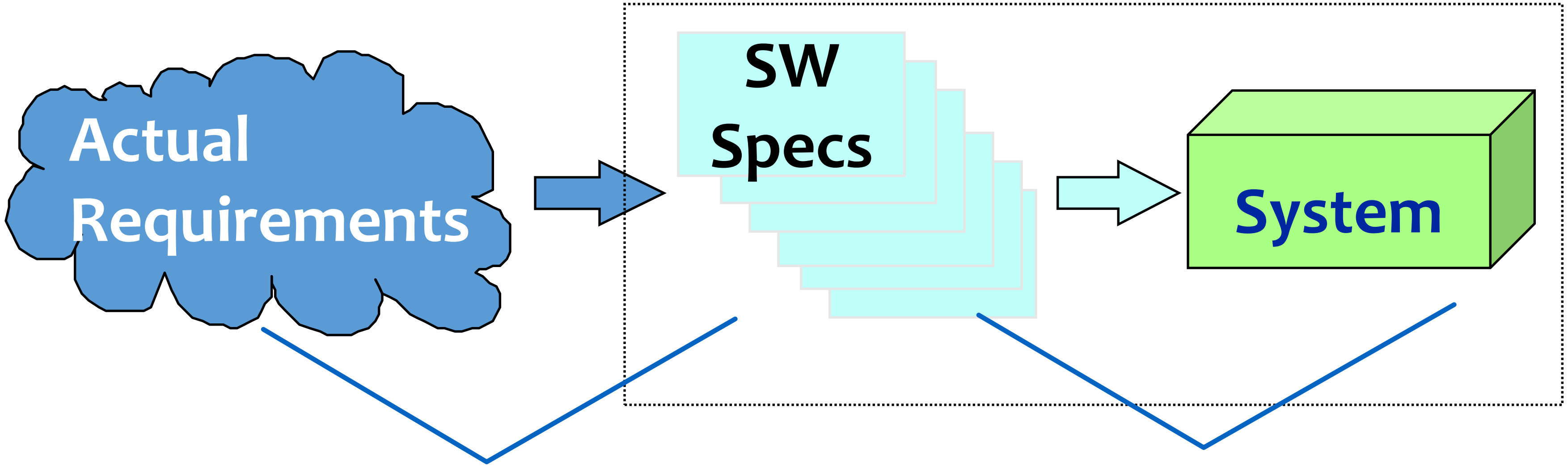
Verification and Validation

- **Verification**
  Does the software system meet the requirements specifications?

  Are we building the software right?
- **Validation**
  Does the software system meet the user's real needs?

  Are we building the right software?

Validation vs. Verification



Validation

Includes

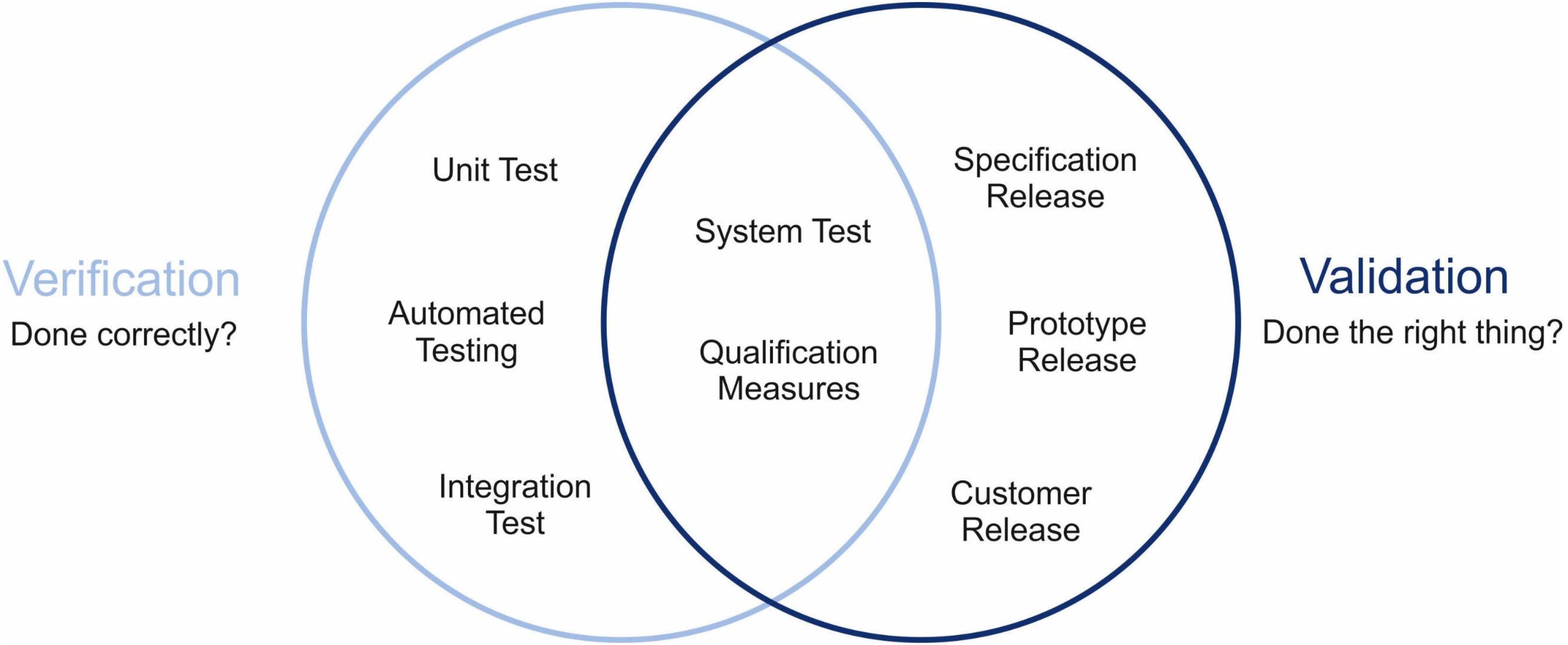
- usability testing
- user feedback

Verification

Includes

- testing (mostly)
- inspections
- static analysis

Validation vs. Verification



Software Testing in V&V

- Testing can be done for verification and validation
- Verification:

    To find defects by executing a program in a test or simulated environment

    - e.g., functional test, integration test
- Validation:

    To find defects by executing a program in a real environment or with real users

    - e.g., usability test, beta test

Software Testing in Development Life Cycle

Software Qualities and Process

- Qualities cannot be added after development
  - Quality results from a set of inter-dependent activities
  - Analysis and testing are crucial but far from sufficient.
- Testing is not a phase, but a lifestyle
  - Testing and analysis activities occur from early in requirements engineering through delivery and subsequent evolution.
  - Quality depends on every part of the software process
- An essential feature of software processes is that software test and analysis is thoroughly integrated and not an afterthought

The Quality Process

- Quality process: set of activities and responsibilities
  - focused primarily on ensuring adequate dependability
  - concerned with project schedule or with product usability
- The quality process provides a framework for
  - selecting and arranging activities
  - considering interactions and trade-offs with other important goals.

Testing Activities in Life Cycle

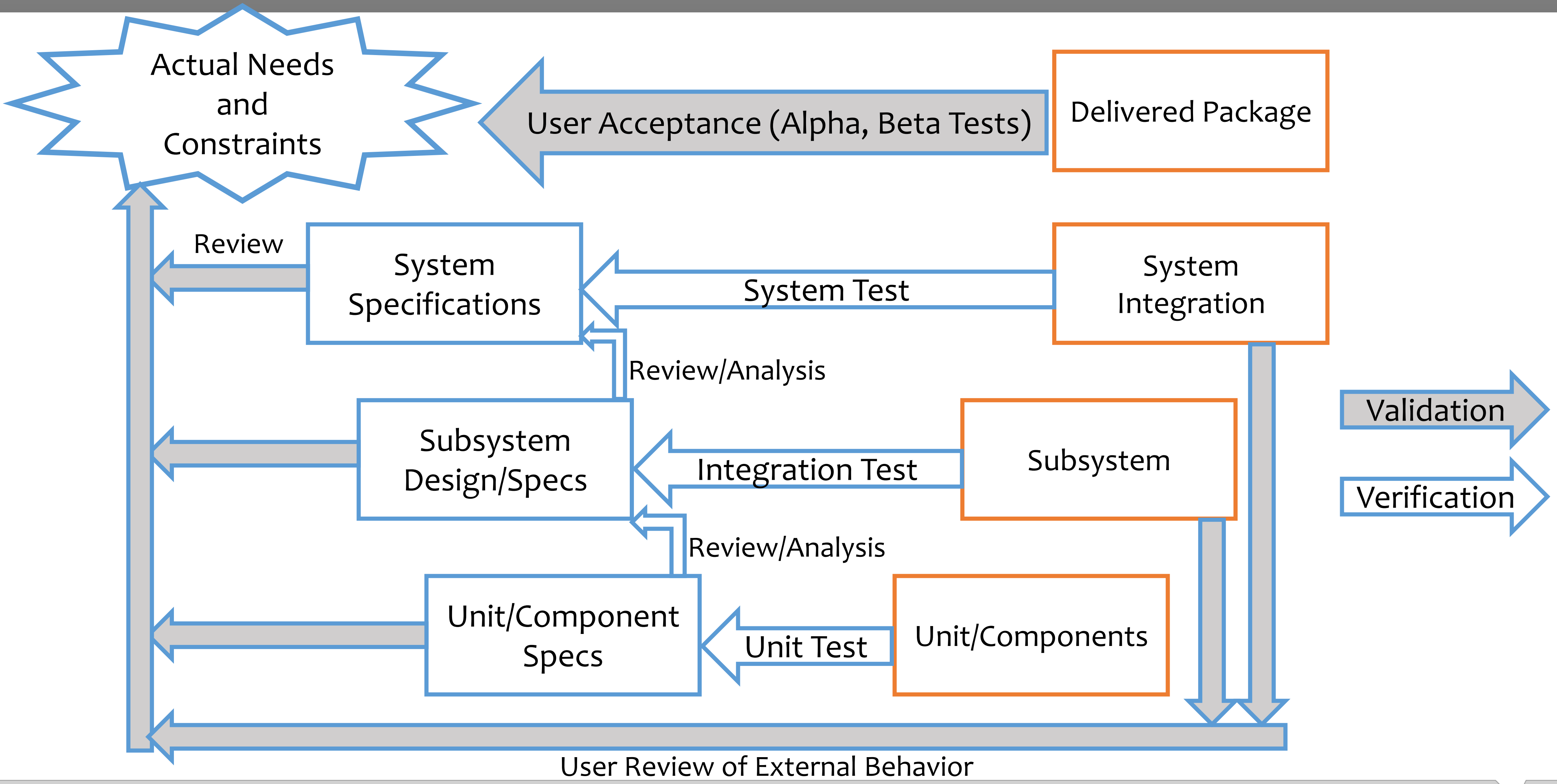
- For every development activity there is a corresponding testing activity
  - Development phases, development levels
- Each test level has objectives specific to that level
- Test design should start as early as possible
  - as soon as relevant documents are available

- Applicable to waterfall and agile development model

Levels of Granularity of Testing

- Unit (component, module) testing
- Integration testing
- System testing
- Acceptance testing

The V-Model of – Validation & Verification



Unit Testing

- Testing of individual software unit/module/components
  - Synonymous to *module testing*, *component testing*
- Focus on the functions of the unit
  - functionality, correctness, accuracy
- Usually carried out by the developers of the unit
- Basis for unit testing
  - component specifications
  - detailed design and code

Integration Testing

- Testing performed to expose defects in the *interfaces* and in the *interactions between* integrated components or sub-systems.
- Focus on the interactions between modules
- Usually carried out by the developers of the sub-systems involved
- Basis for integration testing
  - system design and architecture
  - subsystem and interface specification

Regression Testing

- Used when a large amount of testing is needed and the changes, while small, can affect many parts of the system.
- Best example is in compiler development:
  - Collect selected examples of code that exercise each part of the compiler
  - Add new examples when a bug is detected
  - Run the compiler over the entire collection and capture the output
  - After any change of the code within the compiler, repeat the run
  - Compare with the baseline results

System Testing

- Testing of an integrated system to verify that it meets the specification.
  - A.k.a. the *end-to-end test*
- Verify functional and *non-functional* requirements
- Carried out by the developers and *independent testers*
- Basis for system testing
  - software requirement *specification*
  - functional *specification*

Acceptance Testing

- Test the whole system to ensure that it meets the *requirements*
- Focus on customer acceptance
- Carried out by *independent testers* and the *customers*
- Basis for acceptance testing
  - system and user requirements
  - use cases, business processes, risk analysis

Acceptance Testing & Criteria

- Acceptance testing

  Formal testing with respect to user needs, requirements, and business processes conducted to determine whether or not a system satisfies the *acceptance criteria* and to enable the user, customers or other authorized entity to determine whether or not to accept the system.

- Acceptance criteria

  The *exit criteria* that a component or system must satisfy in order to be accepted by a user, customer, or other authorized entity.

Acceptance Testing Techniques

- Random (statistical) testing
- Alpha testing
- Beta testing

Acceptance Testing – Random Test

- Random test (statistical test)
  - Test cases are selected randomly, possibly using a pseudo-random number generation algorithm, to match an *operation profile,* or *usage profile.*
- Not the same as *ad hoc* testing

Acceptance Testing – Alpha Test

- Simulated operational testing.
- Performed by personnel *acting as* potential users/customers.
- Carried out in a *controlled* environment.
- Observed by the development organization.

Acceptance Testing – Beta Test

- Operational testing to determine whether or not a component or system satisfies the user/customer needs and fits within the business processes.
- Performed by *real* users in their own environment.
- Perform actual tasks without interference or close monitoring

Summary: Key Concepts

- Spectrum of software qualities
- Metrics of quality attributes
- Cost of software defects
- V-model of validation and verification
- Levels of granularity of testing
  - Unit, integration, system, acceptance test
  - Regression test