CISC/CMPE 327 Software Quality Assurance

Queen's University, 2019-fall

Lecture #27 Software Product Metric

Software Product Metrics

- Today's topic is product metrics, the measurements we can make of the actual software product itself
  - External product metrics
    - Defect metrics
  - Internal product metrics
    - Size metrics
    - Complexity metrics

External Product Metrics

- Measures of the Software in its Environment
  - External metrics are those we can apply only by observing the software product in its environment (e.g., by running it)
  - Includes many measures, but particularly:
    - Failure rate (number of failures per unit time)
    - Availability rate (percent of time system is "up")
    - Defect rate (number of defects per size of code)

Reliability

- Definition of Reliability
  - Reliability is the probability that a system will execute without failure in a given environment over a given period of time
  - Implications:
    - No single number for a given program
      - Depends on how the program is used (its environment)
    - Use probability to model our uncertainty
    - Time dependent

Reliability Metrics (recall)

- Probability of failure on demand (POFOD)
  - The probability that a demand for service from a system will result in a system failure
  - POFOD = 0.001 means that there is a 1/1000 chance that a failure will occur when a demand is made
- Rate of occurrence of failures (ROCOF)
  - The probable number of failures likely to be observed in a certain time period (e.g., 1 hour)
  - Reciprocal of ROCOF is the mean time to failure
    - ROCOF of 2 failures/h, mean time to failure = 30 min

Reliability: Definition of Failure

- Formal view:
  - Any deviation from specified behaviour
- Engineering view:
  - Any deviation from required, specified, or expected behaviour
    - Required (by environment)
    - Expected (by user)

Errors, Faults, and Failures

- Definitions
  - a (human) error is a mistake or oversight on the part of a designer or programmer, which may cause…
  - a fault, which is a mistake in the software, which in turn may cause…
  - a failure when the program is run in certain situations
- Defect: usually defined as a fault or a failure
  - Defects = Faults + Failures
  - but sometimes **only** Faults, or **only** Failures

Defect Density Metric

- Defect Density
  - a standard reliability metric

    DD = (Number of defects found) / (System size)

  - Size is often measured in KLOC (1000s of lines of code), so units of defect density are defects found per 1000 lines
  - Widely used as an indicator of software quality

Predictive Power of Defect Density

- However..
  - Unfortunately, faults are not a good predictor of failures, and vice versa
  - 35% of faults cause only about 1% of failures, and 35% of failures are caused by only about 2% of faults

Predictive Power of Defect Density

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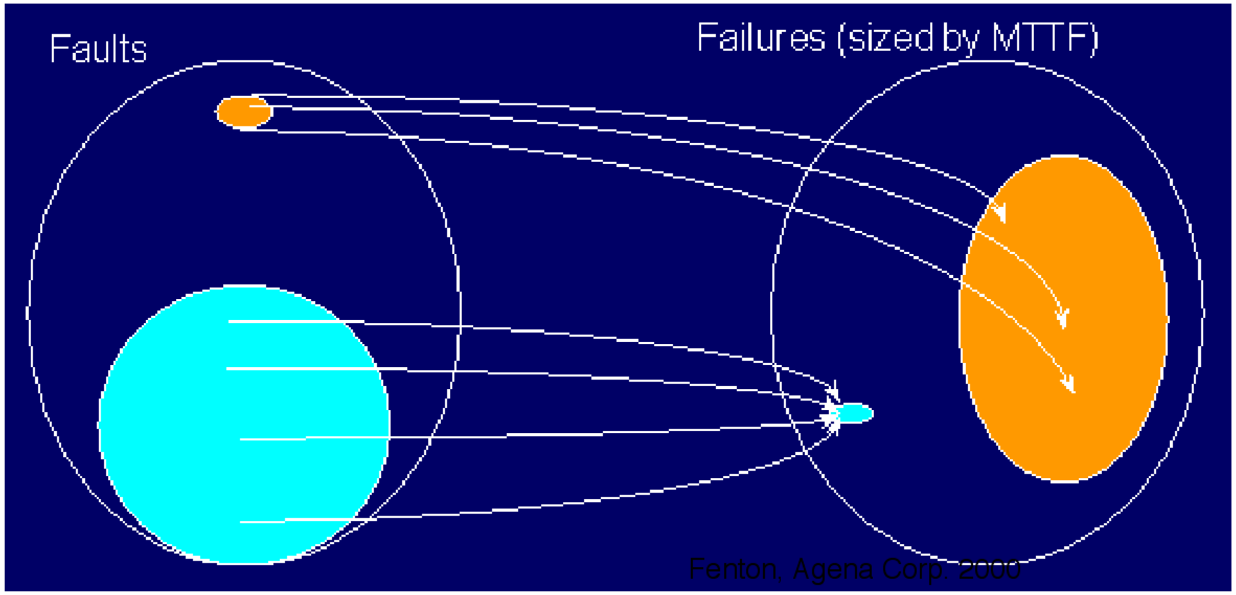

– This finding makes historical defect density look like not such a good predictor of quality

A Process Metric Using Defects

- Effectiveness of Defect Detection
  - Defect statistics can also be used for evaluating and improving software process
  - For example, defect metrics have been used to show the effectiveness of inspection vs. testing

Testing Type	Defects found per hour
Regular use	0.210
Black box	0.282
White box	0.322
Reading/Inspections	1.057

Internal Product Metrics

- Measures of the Product Itself
  - The vast majority of metrics in practice are internal product metrics, measures of the software code, design, or functionality, independent of its environment
  - The U.S. military lists literally hundreds of measures of code alone
  - These measures are easy to make and easy to automate, but it's not always clear which attributes of the program they characterize (if any)

Code Metrics

- Software Size
  - The simplest and most enduring product metric is the size of the product, measured using a count of the number of lines of source code (LOC), most often quoted in 1000's (KLOC)
  - Used in a number of other indirect measures, such as:
    - Productivity (LOC / effort)
    - Effort or cost estimation (Effort = *f*(LOC))
    - Quality assessment or estimation (defects / LOC)
  - Many similar measures are also used:
    - KDSI (1000's of delivered source instructions)
    - NLOC (non-comment lines of code)
    - Number of characters of source or bytes of object code

Problems with LOC Measures

- What Attribute is Measured?
  - LOC really measures length of a program (a physical characteristic), not size (a logical characteristic)
  - Mistakenly used as a surrogate for measures of what we're really interested in
    - Effort, complexity, functionality
  - Does not take into account redundancy or reuse
  - Cannot be compared across different programming languages
  - Can only be measured at end of development cycle

Problems with LOC Measures

- How many lines of code are there?
- How many statement lines of code?

```
for (i=0; i<100; ++i) printf("hello %d\n", i);
```

```
printf("hello 0\n");
printf("hello 1\n");
printf("hello 2\n");
printf("hello 3\n");
... 96 more lines ...
```

```
printf("hello 0\nhello 1\nhello 2\nhello 3\n   ...99\n");
```

Better Size Measures

- Fundamental Size Attributes of Software
  - Length: The physical size of the software
    - LOC will do as measure
  - Functionality: The capabilities provided to the user by the software
    - How big or rich is the set of functions provided?
    - Somewhat tricky unless we are comparing subsets and supersets—but sometimes we are:
      - version 1.0: features 1 through 50
      - version 1.1: features 1 through 56
      - version 2.0: features 1 through 100
      - version 2.0 $\supseteq$ version 1.1 $\supseteq$ version 1.0
  - Complexity: How complex is this software?

“Lines of code metrics distort the true economic case by so much that their use for economic studies involving more than one programming language might be classified as professional malpractice.

“The only situation where LOC metrics behave reasonably well is when two projects utilize the same programming language.”

—Capers Jones,

Applied Software Measurement (2008)

Better Size Measures

- Complexity: How complex is this software?
  - Problem complexity: Measures the complexity of the underlying problem
  - Algorithmic complexity: Measures the complexity or efficiency of the solution implemented by the software
  - Structural complexity: Measures the structure of the program used to implement the algorithm (includes control structure, modular structure, data flow structure, and architectural structure)
  - Cognitive complexity: Measures the effort to understand the software

Code Complexity Metrics

- Better Measures of Source Code
  - Need something closer to cognitive complexity
    ⇒ work on complexity metrics for code
  - Early work measured characteristics such as:
    - Number/density of decision (if) statements
    - Number/depth of blocks/loops
    - Number/average length of methods/classes
  - Best-known and accepted source code complexity measures are:
    - Halstead's "Software Science" metrics
    - McCabe's "Cyclomatic Complexity" and "Data Complexity”

"Software Science" Metrics (Halstead 1977)

- Operators and Operands
  - Operators: Reserved language words and language operators
    - Examples: **if**, **return**, **this**, +, !=, >>, etc..
  - Operands: Identifiers, type names, and character, numeric, or string constants
    - Examples: int, bool, void, x, y, 1, "Hello", etc..

"Software Science" Metrics (Halstead 1977)

- Operators and Operands
  - Program source code considered as a sequence of "tokens", each of which is either an operator or an operand
    - η_1 = number of unique (different) operators
    - η_2 = number of unique (different) operands
    - N_1 = total number of operator uses
    - N_2 = total number of operand uses
  - Length of program $N = N_1 + N_2$
  - Vocabulary of program $\eta = \eta_1 + \eta_2$

"Software Science" Metrics (Halstead 1977)

- The Software Science Predictive Theory
  - Using η_1, η_2, N_1, and N_2 as a basis, Halstead formulated a theory of software complexity and effort
  - Theory 1: An estimate of program length N is

    $N \approx \eta_1 \log \eta_1 + \eta_2 \log \eta_2$

  - Theory 2: Effort E required to create program P is

    $E = (\eta_1 N_2 N \log N) / (2 \eta_2)$ = Volume * Difficulty

  - Theory 3: Time T required to create program P is

    $T = E / 18$ seconds

McCabe's "Cyclomatic Complexity" Metric

- Flow Graphs Again
  - If the control flow graph G of program P has e edges and n nodes, then the cyclomatic complexity v of P is:
    - $v(P) = e - n + 2$
  - v(P) is the number of linearly independent paths in G
    - Example: $e = 16$, $n = 13$ $v(P) = 16 - 13 + 2 = 5$
  - McCabe proposed that for each module of code (e.g., method) P, $v(P) < 10$

McCabe's "Cyclomatic Complexity" Metric

- Flow Graphs Again
  - If all decisions are **two-way** (no switch statements), can simplify
  - Let n_{Dec} be the number of **decision nodes**, such as an *if*, an *else-if*, or the start (or end) of a *while* loop, with 2 out-edges
  - Let n_{NoDec} be the number of **non-decision nodes**, such as the body of an *if-then* with no *else*, with 1 out-edge (except the last node, which has 0 out-edges)
  - Every node is either a decision or a non-decision node, so

$$n = n_{\text{Dec}} + n_{\text{NoDec}}$$

  - Then McCabe's formula $e - n + 2$ becomes

$$\begin{aligned}
& e - (n_{\text{Dec}} + n_{\text{NoDec}}) + 2 \\
= \; & (2\,n_{\text{Dec}} + 1\,n_{\text{NoDec}} - 1) - (n_{\text{Dec}} + n_{\text{NoDec}}) + 2 \\
= \; & 2\,n_{\text{Dec}} + 1\,n_{\text{NoDec}} - 1 - n_{\text{Dec}} - n_{\text{NoDec}} + 2 \\
= \; & 1\,n_{\text{Dec}} + 1 \cdot 0 \quad - 1 \qquad + 2 \\
= \; & n_{\text{Dec}} - 1 + 2 \\
= \; & n_{\text{Dec}} + 1
\end{aligned}$$

Other Flowgraph Metrics

- Flowgraph Complexity of Software
  - McCabe is just one of many flowgraph-based complexity metrics, all with the advantage that they are independent of programming language
  - Others measure things like:
    - Maximum path length
    - Number/interaction of cycles
    - Maximum number of alternative paths (a.k.a. width or "fan-out")
  - All can be automatically computed once the flowgraph is known (and it can be automatically computed too)

Other Flowgraph Metrics

- Flowgraph Complexity of Software
  - Flowgraph decomposition, which partitions flowgraphs into independent one-node-in / one-node-out subgraphs, provides a rigorous general theory of structured programming
    - And it can also be automatically computed!

Summary

- Software Product Metrics
  - Failures and faults are the basis of defect density metrics, widely used as an indicator of software quality
  - Code metrics began with simple size (LOC), but have evolved to try to encompass the notion of cognitive code complexity
  - Flow graphs form the basis of many code complexity metrics
- References
  - Kan ch. 6.1–6.3 Defect Removal Effectiveness
  - Kan ch. 10 Complexity Metrics and Models

- Next time
  - Software Process Metrics