Software Metrics

Software Engineering

Definitions

- *Measure* - quantitative indication of extent, amount, dimension, capacity, or size of some attribute of a product or process.
  - Number of errors
- *Metric* - quantitative measure of degree to which a system, component or process possesses a given attribute. “A handle or guess about a given attribute.”
  - Number of errors found per person hours expended

Why Measure Software?

- Determine quality of the current product or process
- Predict qualities of a product/process
- Improve quality of a product/process

Example Metrics

- Defects rates
- Errors rates
- Measured by:
  - individual
  - module
  - during development
- Errors should be categorized by origin, type, cost

Metric Classification

- Products
  - Explicit results of software development activities.
  - Deliverables, documentation, by products
- Processes
  - Activities related to production of software
- Resources
  - Inputs into the software development activities
  - hardware, knowledge, people

Product vs. Process

- Process Metrics-
  - Insights of process paradigm, software engineering tasks, work product, or milestones.
  - Lead to long term process improvement.
- Product Metrics-
  - Assesses the state of the project
  - Track potential risks
  - Uncover problem areas
  - Adjust workflow or tasks
  - Evaluate teams ability to control quality

Types of Measures

- Direct Measures (internal attributes)
  - Cost, effort, LOC, speed, memory
- Indirect Measures (external attributes)
  - Functionality, quality, complexity, efficiency, reliability, maintainability

Size Oriented Metrics

- Size of the software produced
- Lines Of Code (LOC)
- 1000 Lines Of Code KLOC
- Effort measured in person months
- Errors/KLOC
- Defects/KLOC
- Cost/LOC
- Documentation Pages/KLOC
- LOC is programmer & language dependent

LOC Metrics

- Easy to use
- Easy to compute
- Can compute LOC of existing systems but cost and requirements traceability may be lost
- Language & programmer dependent

Function Oriented Metrics

- Function Point Analysis [Albrecht ’79, ’83]
- International Function Point Users Group (IFPUG)
- Indirect measure
- Derived using empirical relationships based on countable (direct) measures of the software system (domain and requirements)

Computing Functions Points

- Number of user inputs
  - Distinct input from user
- Number of user outputs
  - Reports, screens, error messages, etc
- Number of user inquiries
  - On line input that generates some result
- Number of files
  - Logical file (database)
- Number of external interfaces
  - Data files/connections as interface to other systems

Compute Function Points

- FP = Total Count * [0.65 + .01*Sum(F_i)]
- Total count is all the counts times a weighting factor that is determined for each organization via empirical data
- F_i (i=1 to 14) are complexity adjustment values

Complexity Adjustment

- Does the system require reliable backup and recovery?
- Are data communications required?
- Are there distributed processing functions?
- Is performance critical?
- Will the system run in an existing heavily utilized operational environment?
- Does the system require on-line data entry?
- Does the online data entry require the input transaction to be built over multiple screens or operations?

Complexity Adjustment (cont)

- Are the master files updated on line?
- Are the inputs, outputs, files, or inquiries complex?
- Is the internal processing complex?
- Is the code designed to be reusable?
- Are conversions and installations included in the design?
- Is the system designed for multiple installations in different organizations?
- Is the application designed to facilitate change and ease of use by the user?

Using FP

- Errors per FP
- Defects per FP
- Cost per FP
- Pages of documentation per FP
- FP per person month

FP and Languages

Language	**LOC/FP**
Assembly	320
C	128
COBOL	106
FORTRAN	106
Pascal	90
C++	64
Ada	53
VB	32
SQL	12

Using FP

- FP and LOC based metrics have been found to be relatively accurate predictors of effort and cost
- Need a baseline of historical information to use them properly
- Language dependent
- Productivity factors: People, problem, process, product, and resources
- FP can not be reverse engineered from existing systems easily

Complexity Metrics

- LOC - a function of complexity
- Language and programmer dependent
- Halstead's Software Science (entropy measures)
  - n_1 - number of distinct operators
  - n_2 - number of distinct operands
  - N_1 - total number of operators
  - N_2 - total number of operands

Example

```
if (k < 2)
{
  if (k > 3)
    x = x*k;
}
```

- Distinct operators: if ( ) { } > < = * ;
- Distinct operands: k 2 3 x
- $n_1 = 10$
- $n_2 = 4$
- $N_1 = 13$
- $N_2 = 7$

Halstead's Metrics

- Amenable to experimental verification [1970s]
- Length: $N = N_1 + N_2$
- Vocabulary: $n = n_1 + n_2$
- Estimated length: $\hat{N} = n_1 \log_2 n_1 + n_2 \log_2 n_2$
  - Close estimate of length for well structured programs
- Purity ratio: $PR = \hat{N}/N$

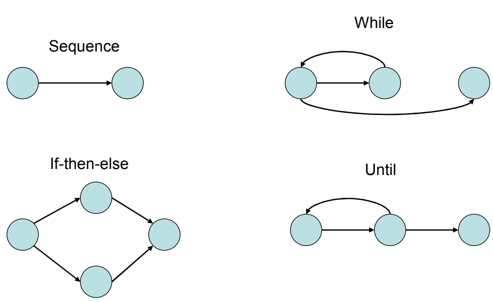
Program Complexity

- Volume: $V = N \log_2 n$
  - Number of bits to provide a unique designator for each of the n items in the program vocabulary.
- Program effort: E=V/L
  - L = V*/V
  - V* is the volume of most compact design implementation
  - This is a good measure of program understandability

McCabe's Complexity Measures

- McCabe's metrics are based on a control flow representation of the program.
- A program graph is used to depict control flow.
- Nodes represent processing tasks (one or more code statements)
- Edges represent control flow between nodes

Flow Graph Notation



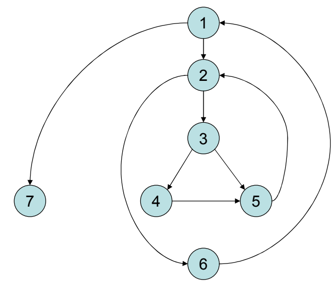
Cyclomatic Complexity

- Set of independent paths through the graph (basis set)
- V(G) = E – N + 2
  - E is the number of flow graph edges
  - N is the number of nodes
- V(G) = P + 1
  - P is the number of predicate nodes

Example

```
i = 0;
while (i<n-1) do
  j = i + 1;
  while (j<n) do
    if A[i]<A[j] then
      swap(A[i], A[j]);
  end do;
  i=i+1;
end do;
```

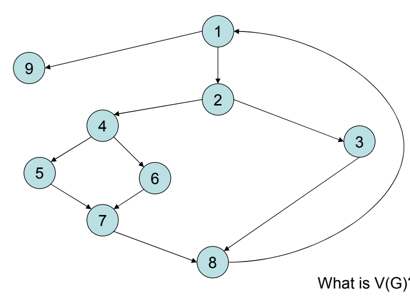
Flow Graph



Computing V(G)

- V(G) = 9 – 7 + 2 = 4
- V(G) = 3 + 1 = 4
- Basis Set
  - 1, 7
  - 1, 2, 6, 1, 7
  - 1, 2, 3, 4, 5, 2, 6, 1, 7
  - 1, 2, 3, 5, 2, 6, 1, 7

Another Example



What is V(G)?

Meaning

- V(G) is the number of (enclosed) regions/areas of the planar graph
- Number of regions increases with the number of decision paths and loops.
- A quantitative measure of testing difficulty and an indication of ultimate reliability
- Experimental data shows value of V(G) should be no more then 10. Testing is very difficulty above this value.

McClure's Complexity Metric

- Complexity = C + V
  - C is the number of comparisons in a module
  - V is the number of control variables referenced in the module
- Similar to McCabe's but with regard to control variables.

Metrics and Software Quality

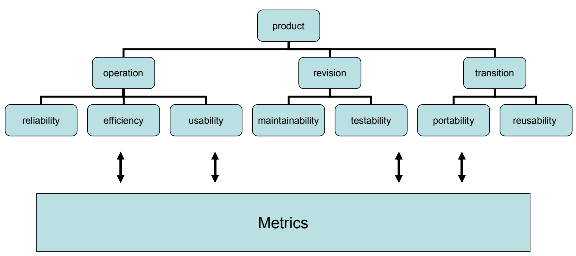
FURPS

- Functionality - features of system
- Usability – aesthesis, documentation
- Reliability – frequency of failure, security
- Performance – speed, throughput
- Supportability – maintainability

Measures of Software Quality

- Correctness
  - Defects/KLOC
  - Defect is a verified lack of conformance to requirements
  - Failures/hours of operation
- Maintainability
  - Mean time to change
  - Change request to new version (Analyze, design etc)
  - Cost to correct
- Integrity
  - Fault tolerance, security & threats
- Usability
  - Training time, skill level necessary to use, Increase in productivity, subjective questionnaire or controlled experiment

Quality Model



High level Design Metrics

- Structural Complexity
- Data Complexity
- System Complexity
- Card & Glass '80

- Structural Complexity S(i) of a module i.
  - $S(i) = f_{out}^2(i)$
  - Fan out is the number of modules immediately subordinate (directly invoked).

Design Metrics

- Data Complexity D(i)
  - $D(i) = v(i)/[f_{out}(i)+1]$
  - v(i) is the number of inputs and outputs passed to and from i.
- System Complexity C(i)
  - $C(i) = S(i) + D(i)$
  - As each increases the overall complexity of the architecture increases.

System Complexity Metric

- Another metric:
  - $length(i) * [f_{in}(i) + f_{out}(i)]^2$
  - Length is LOC
  - Fan in is the number of modules that invoke i.
- Graph based:
  - Nodes + edges
  - Modules + lines of control
  - Depth of tree, arc to node ratio

Coupling

- Data and control flow
  - d_i – input data parameters
  - c_i input control parameters
  - d_o output data parameters
  - c_o output control parameters
- Global
  - g_d global variables for data
  - g_c global variables for control
- Environmental
  - w fan in number of modules called
  - r fan out number modules that call module

Metrics for Coupling

- $M_c = k/m$, $k=1$

  - $m = d_i + ac_i + d_o + bc_o + g_d + cg_c + w + r$
  - a, b, c, k can be adjusted based on actual data

Component Level Metrics

- Cohesion (internal interaction)
- Coupling (external interaction)
- Complexity of program flow

- Cohesion – difficult to measure
  - Bieman ’94, TSE 20(8)
  - Data slice – from a program slice

Using Metrics

- The Process
  - Select appropriate metrics for problem
  - Utilized metrics on problem
  - Assessment and feedback

- Formulate
- Collect
- Analysis
- Interpretation
- Feedback

Metrics for the Object Oriented

- Chidamber & Kemerer '94 TSE 20(6)
- Metrics specifically designed to address object oriented software
- Class oriented metrics
- Direct measures

Weighted Methods per Class

$$WMC = \sum_{i=1}^{n} c_i$$

- c_i is the complexity (e.g., volume, cyclomatic complexity, etc.) of each method
- Must normalize
- What about inherited methods?
  - Be consistent

Depth of Inheritance Tree

- DIT is the maximum length from a node to the root (base class)
- Lower level subclasses inherit a number of methods making behavior harder to predict
- However, more methods are reused in higher DIT trees.

Number of Children

- NOC is the number of subclasses immediately subordinate to a class
- As NOC grows, reuse increases
- But the abstraction may be diluted

Coupling between Classes

- CBO is the number of collaborations between two classes
- As collaboration increases reuse decreases
- CRC – lists the number of collaborations
  - Classes, Responsibilities, and Collaborations

Response for a Class

- RFC is the number of methods that could be called in response to a message to a class
- Testing effort increases as RFC increases

Lack of Cohesion in Methods

- LCOM – poorly described in Pressman
- Class C_k with n methods $M_1, \ldots M_n$
- I_j is the set of instance variables used by M_j

LCOM

- There are n such sets $I_1, \ldots, I_n$
  - $P = \{(I_i, I_j) \mid (I_i \cap I_j) = \varnothing\}$
  - $Q = \{(I_i, I_j) \mid (I_i \cap I_j) \neq \varnothing\}$
- If all n sets I_i are $\varnothing$ then $P = \varnothing$
- LCOM = $|P| - |Q|$, if $|P| > |Q|$
- LCOM = 0 otherwise

Example LCOM

- Take class C with M_1, M_2, M_3
- $I_1 = \{a, b, c, d, e\}$
- $I_2 = \{a, b, e\}$
- $I_3 = \{x, y, z\}$
- $P = \{(I_1, I_3), (I_2, I_3)\}$
- $Q = \{(I_1, I_2)\}$

- Thus LCOM = 1

Explanation

- LCOM is the number of empty intersections minus the number of non-empty intersections
- This is a notion of degree of similarity of methods.
- If two methods use common instance variables then they are similar
- LCOM of zero is not maximally cohesive
- $|P| = |Q|$ or $|P| < |Q|$

Class Size

- CS
  - Total number of operations (inherited, private, public)
  - Number of attributes (inherited, private, public)

- May be an indication of too much responsibility for a class

Number of Operations Overridden

- NOO

- A large number for NOO indicates possible problems with the design
- Poor abstraction in inheritance hierarchy

Number of Operations Added

- NOA

- The number of operations added by a subclass
- As operations are added it is farther away from super class
- As depth increases NOA should decrease

Specialization Index

$$SI = [NOO * L] / M_{total}$$

- L is the level in class hierarchy
- M_{total} is the total number of methods

- Higher values indicate class in hierarchy that does not conform to the abstraction

Method Inheritance Factor

$$MIF = \frac{\sum_{i=1}^{n} M_i(C_i)}{\sum_{i=1}^{n} M_a(C_i)} .$$

- $M_i(C_i)$ is the number of methods inherited and not overridden in C_i
- $M_a(C_i)$ is the number of methods that can be invoked with C_i
- $M_d(C_i)$ is the number of methods declared in C_i

MIF

- $M_a(C_i) = M_d(C_i) + M_i(C_i)$
- All that can be invoked = new or overloaded + things inherited

- MIF is [0,1]
- MIF near 1 means little specialization
- MIF near 0 means large change

Coupling Factor

CF= $$\frac{\sum_i \sum_j is\_client(C_i, C_j)}{(TC^2 - TC)}$$.

- is_client(x,y) = 1 iff a relationship exists between the client class and the server class. 0 otherwise.
- (TC^2-TC) is the total number of relationships possible (Total Classes^2 – diagonal)
- CF is [0,1] with 1 meaning high coupling

Polymorphism Factor

PF = $$\frac{\sum_i M_o(C_i)}{\sum_i [M_n(C_i) * DC(C_i)]}$$.

- M_n() is the number of new methods
- M_o() is the number of overriding methods
- DC() number of descendent classes of a base class
- The number of methods that redefines inherited methods, divided by maximum number of possible distinct polymorphic situations

Operational Oriented Metrics

- Average operation size (LOC, volume)
- Number of messages sent by an operator
- Operation complexity – cyclomatic
- Average number of parameters/operation
  - Larger the number the more complex the collaboration

Encapsulation

- Lack of cohesion
- Percent public and protected
- Public access to data members

Inheritance

- Number of root classes
- Fan in – multiple inheritance
- NOC, DIT, etc.