Software Metrics

Any measurement which relates to a software system, process, or related documentation

Outline

- Properties of Metrics
- Analysis Metrics
- Design Metrics
- Implementation Metrics
- Documentation Metrics

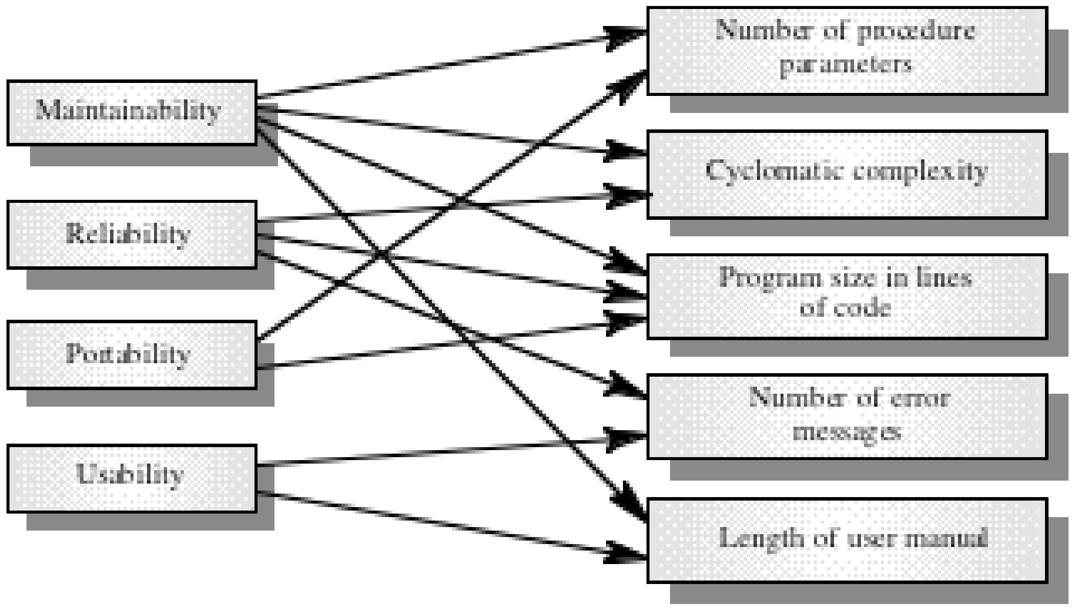
Software metrics

- Any type of measurement which relates to a software system, process, or related documentation, e.g.
  - Lines of code in a program
  - The Fog index
  - Person-days required to develop a component
- Allow the software and the software process to be quantified
- Measures of the software process or product
- Should be captured automatically if possible

Metrics assumptions

- A software property can be measured
- The relationship exists between what we can measure and what we want to know
- This relationship has been formalized and validated
- It may be difficult to relate what can be measured to desirable quality attributes

Internal and external attributes



Properties of Metrics

- Simple and Computable
- Empirically and Intuitively Persuasive
- Consistent and Objective
- Programming Language Independent

Data accuracy

- Don't collect unnecessary data. The questions to be answered should be decided in advance and the required data identified.
- Tell people why the data is being collected. It should not be part of personnel evaluation.
- Don't rely on memory. Collect data when it is generated, not after a project has finished and, if possible, automatically.

Measurement analysis

- Not always obvious what data means. Analyzing collected data is very difficult.
- Professional statisticians should be consulted if available.
- Data analysis must take local circumstances into account.

Analysis Metrics

- Attempt to estimate costs early in the development process:
  - Cocomo
  - Function Points

Cocomo

- Effort (in person-months) as a function of lines-of-code where b and c are constants determined by historical data dependent on the project type:

$$\text{Initial effort} = b * KLOC^{c}$$

Cocomo Project Types

- Organic (b=2.4, c=1.05)
  - A relatively small team develops software in a known environment. Those involved generally have significant experience with projects of this type. These tend to be small projects.
- Embedded (b=3.0, c=1.12)
  - These projects involve the development where the intended environment poses significant constraints. The product is "embedded" in an environment which is inflexible.
- Semidetached (b=3.6, c=1.20)
  - The team may show a mixture of experience and inexperienced people. The project may be larger than that in the organic type.

Cocomo Cost Drivers

Factors used to adjust initial effort estimate:

Cost Drivers	Rating					
	very low	low	nominal	high	very high	extra high
Product Attributes						
Reliability	.75	.88	1.00	1.15	1.40	
Data base		.94	1.00	1.08	1.16	
Product Complexity	.70	.85	1.00	1.15	1.30	1.65
Computer Attributes						
Execution Time			1.00	1.11	1.30	1.66
Main Storage			1.00	1.06	1.21	1.56
Virtual Machine Volatility		.87	1.00	1.15	1.30	
Computer Turnaround Time		.87	1.00	1.07	1.15	
Personnel Attributes						
Analyst Capabilities	1.46	1.19	1.00	.86	.71	
Applications Experience	1.29	1.13	1.00	.91	.82	
Programmer Capability	1.42	1.17	1.00	.86	.70	
Virtual Machine Experience	1.21	1.10	1.00	.90		
Prog. Lang. Experience	1.14	1.07	1.00	.95		
Project Attributes						
Use of modern prog. Tech.	1.24	1.10	1.00	.91	.82	
Use of Software Tools	1.24	1.10	1.00	.91	.83	
Development Schedule	1.23	1.08	1.00	1.04	1.10	

Cocomo problems

- Empirical studies show high (e.g. 600%) estimation errors.
  - Breaking into subsystems may help
- How is initial *size* parameter obtained?
  - Why are cost driver multipliers given to three-digit accuracy?
- Does not address factors such as application domain, methodologies, CASE tools, code reuse, etc.
  - Probably requires calibration

Function/Feature Points (1)

Compute weighted function count, FC:

		Weighting Factors		
Type	**Description**	**Simple**	**Average**	**Complex**
Input (I)	User Input	3	4	6
Output (O)	User Output	4	5	7
Inquiry (E)	User Inputs that Control Execution	3	4	6
Logical Internal (L)	Internal Data maintained by the system	7	10	15
Interfaces (F)	Data output to another program	5	7	10

Function/Feature Points (2)

Compute *value adjustment factor*, VAF, as the sum of 14 characteristics on a six point scale (0 = no influence to 5 = strong influence).

- Data Communications
- Distributed Function
- Performance
- Heavily Used Configuration
- Transaction Rate
- On-line Data Entry
- End-user Efficiency
- On-line Update
- Complex Processing
- Re-usability
- Installation Ease
- Operational Ease
- Multiple Sites
- Facilitate Change

Function/Feature Points (3)

- FP = FC * VAF
- Counts and weights are subjective
  - Based on top level data flow diagrams
  - Studies show median difference between raters approximately 12%
- Studies show good correlation with FP's
  - System size
  - Development effort
- But the studies are limited to MIS applications
  - No good studies on scientific, mathematical, communications, telecomm, real-time, etc.

Design Metrics

- Cohesion
- Coupling
- Complexity

Product Quality

- A quality metric should be a predictor of product quality.
- Design quality metrics concerned with measuring the cohesion, coupling, or complexity of a design are supposed to correlate with quality.
- The relationship between these metrics and quality as judged by a human may hold in some cases but it is not clear whether or not it is generally true.

Cohesion

- A measures of how strongly the elements within a module are related. The stronger the better.

Types of Cohesion

- Object
- Functional
- Sequential
- Communicational
- Procedural
- Temporal
- Logical
- Coincidental

Critique

- Difficult to apply in practice.
- Tedious to apply manually and impossible to automate.
- Informal

Coupling

- A measure of the degree of independence between modules. When there is little interaction between two modules, the modules are described as loosely coupled. When there is a high degree of interaction the modules are described as tightly coupled.

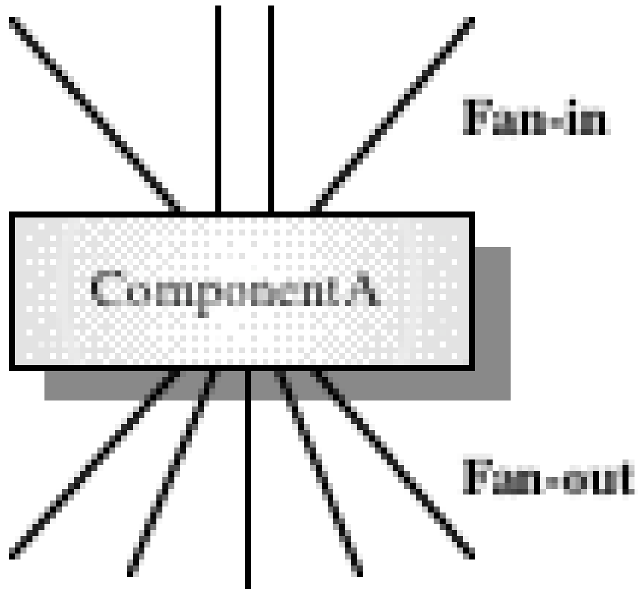
Types of Coupling

1. **Content Coupling**: One module refers to or changes the internals of another module.
2. **Common Coupling**: Two modules share the same global data areas.
3. **Control Coupling**: Data from one module is used to direct the order of instruction execution in another.
4. **Data Coupling**: Two modules communicate via a variable or array that is passed directly as a parameter between the two modules. The data is used in problem related processing, not for program control purposes.

Coupling metrics

- Associated with Yourdon's 'Structured Design'/ Measures 'fan-in and fan-out' in a structure chart.
- High fan-in (number of calling functions) suggests high coupling because of module dependencies.
- High fan-out (number of calls) suggests high coupling because of control complexity.

Structural fan-in and fan-out



Informational fan-in/fan-out

- The approach based on the calls relationship is simplistic because it ignores data dependencies.
- Informational fan-in/fan-out takes into account:
  - Number of local data flows + number of global data structures updated.
  - Data-flow count subsumes calls relation. It includes updated procedure parameters and procedures called from within a module.
- Complexity = Length * $(\text{Fan-in} * \text{Fan-out})^2$
  - Length is any measure of program size such as LOC.

Validation of Fan-in/fan-out

- Some studies with Unix found that informational fan-in/fan-out allowed complex and potentially faulty components to be identified.
- Some studies suggest that size and number of branches are as useful in predicting complexity than informational fan-in/fan-out.
- Fan-out on its own also seemed to be a good quality predictor.
- The whole area is still a research area rather than practically applicable.

CK Metrics for OO Designs

- Proposed by Chidamber and Kemerer
- Weighted Methods per Class (WMC)
  - A weighted sum of all the methods in a class.
  - How to weight the methods is a matter of debate. Some authors have used method length, cyclomatic complexity, or weighted all methods equally.
- Coupling Between Object classes (CBO)
  - A count of the number of other classes to which a given class is coupled. A class is coupled to another if it sends messages to objects or invokes constructors of the other class.
  - Inherited couplings are included in the count.

CK Metrics (2)

- Depth of Inheritance Tree (DIT)
  - Length of the longest path from a given class to the root class of the inheritance hierarchy.
- Number of Children (NOC)
  - The number of immediate subclasses.
- Response for a Class (RFC)
  - The count of the maximum number of methods that can be potentially invoked in response to a single message received by an object of a particular class.

CK Metrics (3)

- Lack of Cohesion of Methods (LCOM)
  - A count of the number of method-pairs whose *similarity* is zero minus the count of method pairs whose similarity is not zero.
  - Similarity refers to the number of instance variables by the methods.

CK Metrics Validation

- As of 2004, there have been about 10 empirical studies on the CK Metrics.
- Most studies have found correlations between one or more of the CK metrics and defects or maintenance cost.
- Studies are inconsistent as to which of the metrics are useful.
- One study found that size overwhelmed the effect of all metrics on defects.
- CK metrics do not take into account certain other factors (e.g. encapsulation, polymorphism) that effect complexity.

Implementation Metrics

- Design metrics are also applicable to programs.
- Other metrics include:
  - Length. The size of the program source code.
  - Cyclomatic complexity. The complexity of program control.
  - Length of identifiers.
  - Depth of conditional nesting.
- Anomalous metric values suggest a component may contain an above average number of defects or may be difficult to understand.

Lines of Code

- Lines of code (LOC or KLOC) is typically correlated with effort. Boehm, Walston-Felix, and Halstead all indicate Effort as a function of lines of code.
- Support
  - Easy to Determine
  - Easy to Automate
  - Easy to Enforce

LOC - Objections

- Some programmers write more verbose programs than others.
- Difficult to compare programs written in different languages.
- Some lines are more complex than others.
- What constitutes a line of code?

LOC - What is a line of code?

Physical Source Lines of Code

Statement Type	Includes	Excludes
Executable	x	
Declarations	x	
Compiler Directives	x	
Comments on their own lines		x
Assertions (Pre/Postconditions)		x
Program, procedure and function banners		x
Blank Lines		x
Blank Comments		x

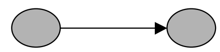
Lines of Documentation

Statement Type	Includes	Excludes
Comments on their own lines	x	
Assertions (Pre/Postconditions)	x	
Comments with source lines		x
Program, procedure and function banners	x	
Blank Lines		x
Blank Comments		x

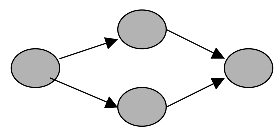
Cyclomatic Complexity

- Based on determining how complicated the control flow a program (procedure or function) is.
- The control flow is represented as directed graph.
- CC = Number(edges) - Number(nodes) + 1

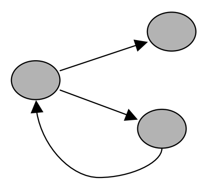
Cyclomatic Complexity (2)



Sequence: CC = 0



If-else: CC = 1



While loop: CC = 1

Program metrics utility

- Lines of code is simple, but experiments indicate it is a good predictor of problems.
- Cyclomatic complexity is a measure of control structure complexity, but has two drawbacks:
  - It is inaccurate for data-driven programs as it is only concerned with control constructs.
  - It places the same weight on nested and non-nested loops. Deeply nested structures, however, are usually harder to understand.

Reliability metrics

- Probability of failure-free operation for a specified time in a specified environment for a given purpose.
- This means quite different things depending on the system and the users of that system.
- Informally, reliability is a measure of how well system users think it provides the services they require.

Software reliability

- Cannot be defined objectively
  – Reliability measurements which are quoted out of context are not meaningful
- Requires operational profile for its definition
  – The operational profile defines the expected pattern of software usage
- Must consider fault consequences
  – Not all faults are equally serious. System is perceived as more unreliable if there are more serious faults

Failures and faults

- A failure corresponds to unexpected run-time behavior observed by a user of the software.
- A fault is a static software characteristic which causes a failure to occur.
- Faults need not necessarily cause failures. They only do so if the faulty part of the software is used.
- If a user does not notice a failure, is it a failure? Remember most users don’t know the software specification.

Reliability metrics

- Probability of failure on demand
  - This is a measure of the likelihood that the system will fail when a service request is made.
  - POFOD = 0.001 means 1 out of 1000 service requests result in failure.
  - Relevant for safety-critical or non-stop systems.
- Rate of failure occurrence (ROCOF)
  - ROCOF of 0.02 means 2 failures are likely in each 100 operational time units.
  - Relevant for operating systems, transaction processing systems.

Reliability metrics

- Mean time between failure
  - Measure of the time between observed failures.
  - MTBF is the reciprocal of ROCOF if the system is not being changed during operation.
- Availability
  - Measure of how likely the system is available for use. Takes repair/restart time into account.
  - Availability of 0.998 means software is available for 998 out of 1000 time units.
  - Relevant for continuously running systems e.g. telephone switching systems.

Time units

- Time units in reliability measurement must be carefully selected. Not the same for all systems.
- Raw execution time (for non-stop systems).
- Calendar time (for systems which have a regular usage pattern e.g. systems which are always run once per day).
- Number of transactions (for systems which are used on demand).

Failure consequences

- Reliability measurements do NOT take the consequences of failure into account
- Transient faults may have no real consequences but other faults may cause data loss or corruption and loss of system service
- May be necessary to identify different failure classes and use different measurements for each of these

Documentation quality metrics

- Readability of documentation is important.
- Gunnings Fog index is a simple measure of readability.
  - Based on length of sentences and number of syllables in a word
- However, this can be misleading when applied to technical documentation.

Key points

- Metrics gather information about both process and product.
- Quality metrics should be used to identify potentially problematical components.
- Lack of commonality across software process between organizations makes universal metrics difficult to develop.
- Metrics probably need to be calibrated to particular application domains and development organizations.

Key points

- Metrics still have a limited value and are not widely collected.
- Relationships between what we can measure and what we want to know are not well-understood.