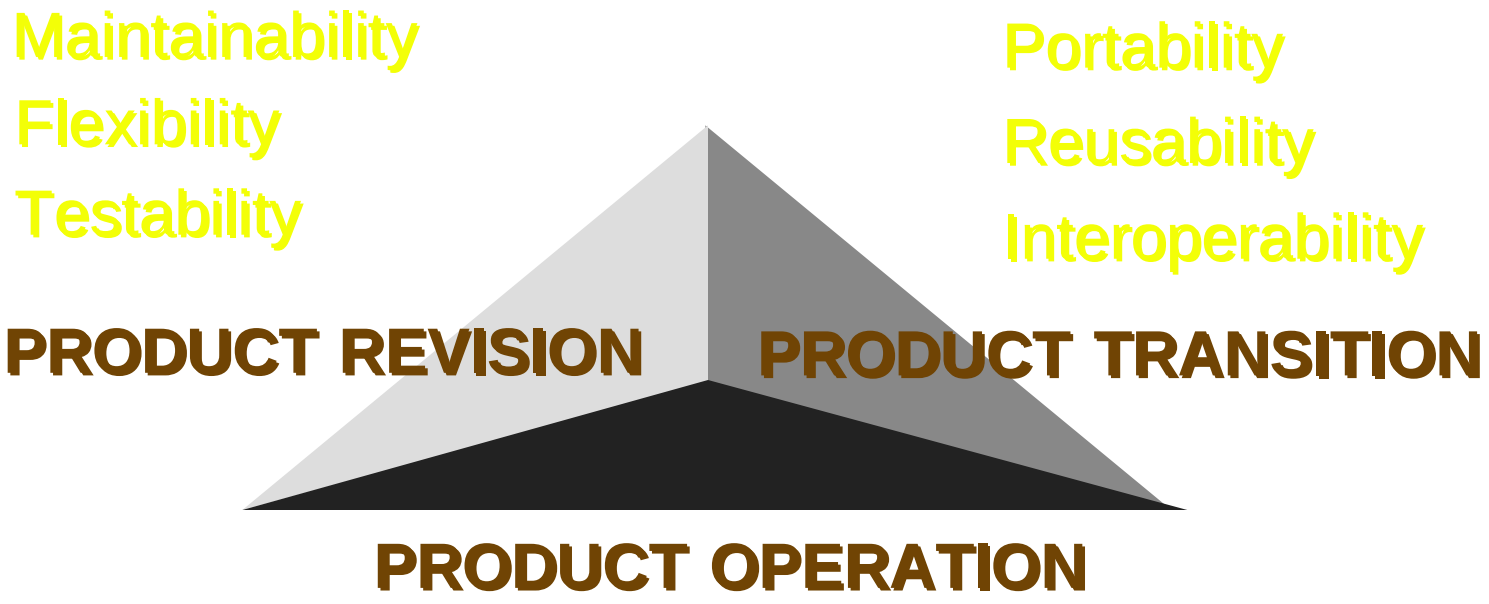
Product Metrics for Software

McCall's Triangle of Quality



A Comment

McCall's quality factors were proposed in the early 1970s. They are as valid today as they were in that time. It's likely that software built to conform to these factors will exhibit high quality well into the 21st century, even if there are dramatic changes in technology.

Measures, Metrics and Indicators

- A *measure* provides a quantitative indication of the extent, amount, dimension, capacity, or size of some attribute of a product or process
- The IEEE glossary defines a *metric* as "a quantitative measure of the degree to which a system, component, or process possesses a given attribute."
- An *indicator* is a metric or combination of metrics that provide insight into the software process, a software project, or the product itself

Measurement Principles

- The objectives of measurement should be established before data collection begins;
- Each technical metric should be defined in an unambiguous manner;
- Metrics should be derived based on a theory that is valid for the domain of application (e.g., metrics for design should draw upon basic design concepts and principles and attempt to provide an indication of the presence of an attribute that is deemed desirable);
- Metrics should be tailored to best accommodate specific products and processes

Measurement Process

- *Formulation*. The derivation of software measures and metrics appropriate for the representation of the software that is being considered.
- *Collection.* The mechanism used to accumulate data required to derive the formulated metrics.
- *Analysis*. The computation of metrics and the application of mathematical tools.
- *Interpretation*. The evaluation of metrics results in an effort to gain insight into the quality of the representation.
- *Feedback.* Recommendations derived from the interpretation of product metrics transmitted to the software team.

Goal-Oriented Software Measurement

- The Goal/Question/Metric Paradigm
  - (1) establish an explicit measurement *goal* that is specific to the process activity or product characteristic that is to be assessed
  - (2) define a set of *questions* that must be answered in order to achieve the goal, and
  - (3) identify well-formulated *metrics* that help to answer these questions.
- Goal definition template
  - Analyze {the name of activity or attribute to be measured}
  - for the purpose of {the overall objective of the analysis}
  - with respect to {the aspect of the activity or attribute that is considered}
  - from the viewpoint of {the people who have an interest in the measurement}
  - in the context of {the environment in which the measurement takes place}.

Metrics Attributes

- *simple and computable.* It should be relatively easy to learn how to derive the metric, and its computation should not demand inordinate effort or time
- *empirically and intuitively persuasive*. The metric should satisfy the engineer's intuitive notions about the product attribute under consideration
- *consistent and objective*. The metric should always yield results that are unambiguous.
- *consistent in its use of units and dimensions*. The mathematical computation of the metric should use measures that do not lead to bizarre combinations of unit.
- *programming language independent*. Metrics should be based on the analysis model, the design model, or the structure of the program itself.
- *an effective mechanism for quality feedback*. That is, the metric should provide a software engineer with information that can lead to a higher quality end product

Collection and Analysis Principles

- Whenever possible, data collection and analysis should be automated;
- Valid statistical techniques should be applied to establish relationship between internal product attributes and external quality characteristics
- Interpretative guidelines and recommendations should be established for each metric

Analysis Metrics

- Function-based metrics: use the function point as a normalizing factor or as a measure of the "size" of the specification
- Specification metrics: used as an indication of quality by measuring number of requirements by type

Function-Based Metrics

- The *function point metric* (FP), first proposed by Albrecht, can be used effectively as a means for measuring the functionality delivered by a system.
- Function points are derived using an empirical relationship based on countable (direct) measures of software's information domain and assessments of software complexity
- Information domain values are defined in the following manner:
  - number of external inputs (EIs)
  - number of external outputs (EOs)
  - number of external inquiries (EQs)
  - number of internal logical files (ILFs)
  - Number of external interface files (EIFs)

Function Points

Information Domain Value	Count	Weighting factor	simple	average	complex	
External Inputs (EIs)		3	3	4	6	=
External Outputs (EOs)		3	4	5	7	=
External Inquiries (EQs)		3	3	4	6	=
Internal Logical Files (ILFs)		3	7	10	15	=
External Interface Files (EIFs)		3	5	7	10	=
Count total						

$$VAF = 0.65 + [(\sum_{i=1}^{14} Ci) / 100]$$

where: Ci = degree of influence for each General System Characteristic
i = is from 1 to 14 representing each GSC.
$\sum$ = is summation of all 14 GSC's.

Weighted factor for IF/OF

	1 to 19 DET	20 to 50 DET	51 or more DET
1 RET	Low	Low	Average
2 to 5 RET	Low	Average	High
6 or more RET	Average	High	High

Weighted factor for EI

	1 to 4 DET	5 to 15 DET	16 or more DET
0 to 1 FTR	Low	Low	Average
2 FTRs	Low	Average	High
3 or more FTRs	Average	High	High

Weighted factor for EO/EQ

	1 to 5 DET	6 to 19 DET	20 or more DET
0 to 1 FTR	Low	Low	Average
2 to 3 FTRs	Low	Average	High
4 or more FTRs	Average	High	High

GENERAL SYSTEM CHARACTERISTICS

General System Characteristic		Brief Description
1.	Data communications	How many communication facilities are there to aid in the transfer or exchange of information with the application or system?
2.	Distributed data processing	How are distributed data and processing functions handled?
3.	Performance	Did the user require response time or throughput?
4.	Heavily used configuration	How heavily used is the current hardware platform where the application will be executed?
5.	Transaction rate	How frequently are transactions executed daily, weekly, monthly, etc.?
6.	On-Line data entry	What percentage of the information is entered On-Line?
7.	End-user efficiency	Was the application designed for end-user efficiency?
8.	On-Line update	How many ILF's are updated by On-Line transaction?

GENERAL SYSTEM CHARACTERISTICS

9.	Complex processing	Does the application have extensive logical or mathematical processing?
10.	Reusability	Was the application developed to meet one or many user's needs?
11.	Installation ease	How difficult is conversion and installation?
12.	Operational ease	How effective and/or automated are start-up, back up, and recovery procedures?
13.	Multiple sites	Was the application specifically designed, developed, and supported to be installed at multiple sites for multiple organizations?
14.	Facilitate change	Was the application specifically designed, developed, and supported to facilitate change?

Data Communications

Score As	Descriptions to Determine Degree of Influence
0	Application is pure batch processing or a standalone PC.
1	Application is batch but has remote data entry *or* remote printing.
2	Application is batch but has remote data entry *and* remote printing.
3	Application includes online data collection or TP (teleprocessing) front end to a batch process or query system.
4	Application is more than a front-end, but supports only one type of TP communications protocol.
5	Application is more than a front-end, and supports more than one type of TP communications protocol.

Distributed Data Processing

Score As	Descriptions To Determine Degree of Influence
0	Application does not aid the transfer of data or processing function between components of the system.
1	Application prepares data for end user processing on another component of the system such as PC spreadsheets and PC DBMS.
2	Data is prepared for transfer, then is transferred and processed on another component of the system (not for end-user processing).
3	Distributed processing and data transfer are online and in one direction only.
4	Distributed processing and data transfer are online and in both directions.
5	Processing functions are dynamically performed on the most appropriate component of the system.

Performance

Score As	Descriptions To Determine Degree of Influence
0	No special performance requirements were stated by the user.
1	Performance and design requirements were stated and reviewed but no special actions were required.
2	Response time or throughput is critical during peak hours. No special design for CPU utilization was required. Processing deadline is for the next business day.
3	Response time or throughput is critical during all business hours. No special design for CPU utilization was required. Processing deadline requirements with interfacing systems are constraining.
4	In addition, stated user performance requirements are stringent enough to require performance analysis tasks in the design phase.
5	In addition, performance analysis tools were used in the design, development, and/or implementation phases to meet the stated user performance requirements.

Heavily Used Configuration

Score As	Descriptions To Determine Degree of Influence
0	No explicit or implicit operational restrictions are included.
1	Operational restrictions do exist, but are less restrictive than a typical application. No special effort is needed to meet the restrictions.
2	Some security or timing considerations are included.
3	Specific processor requirements for a specific piece of the application are included.
4	Stated operation restrictions require special constraints on the application in the central processor or a dedicated processor.
5	In addition, there are special constraints on the application in the distributed components of the system.

Architectural Design Metrics

- Architectural design metrics
  - Structural complexity = g(fan-out)
  - Data complexity = f(input & output variables, fan-out)
  - System complexity = h(structural & data complexity)
- HK metric: architectural complexity as a function of fan-in and fan-out
- Morphology metrics: a function of the number of modules and the number of interfaces between modules

Metrics for OO Design-I

- Whitmire [WHI97] describes nine distinct and measurable characteristics of an OO design:
  - Size
    - Size is defined in terms of four views: population, volume, length, and functionality
  - Complexity
    - How classes of an OO design are interrelated to one another
  - Coupling
    - The physical connections between elements of the OO design
  - Sufficiency
    - "the degree to which an abstraction possesses the features required of it, or the degree to which a design component possesses features in its abstraction, from the point of view of the current application."
  - Completeness
    - An indirect implication about the degree to which the abstraction or design component can be reused

Metrics for OO Design-II

- Cohesion
  - The degree to which all operations working together to achieve a single, well-defined purpose
- Primitiveness
  - Applied to both operations and classes, the degree to which an operation is atomic
- Similarity
  - The degree to which two or more classes are similar in terms of their structure, function, behavior, or purpose
- Volatility
  - Measures the likelihood that a change will occur

Distinguishing Characteristics

Berard [BER95] argues that the following characteristics require that special OO metrics be developed:

- Localization—the way in which information is concentrated in a program
- Encapsulation—the packaging of data and processing
- Information hiding—the way in which information about operational details is hidden by a secure interface
- Inheritance—the manner in which the responsibilities of one class are propagated to another
- Abstraction—the mechanism that allows a design to focus on essential details

Class-Oriented Metrics

Proposed by Chidamber and Kemerer:

- weighted methods per class
- depth of the inheritance tree
- number of children
- coupling between object classes
- response for a class
- lack of cohesion in methods

Class-Oriented Metrics

Proposed by Lorenz and Kidd [LOR94]:

- class size
- number of operations overridden by a subclass
- number of operations added by a subclass
- specialization index

Class-Oriented Metrics

The MOOD Metrics Suite

- Method inheritance factor
- Coupling factor
- Polymorphism factor

Operation-Oriented Metrics

Proposed by Lorenz and Kidd [LOR94]:

- average operation size
- operation complexity
- average number of parameters per operation

Component-Level Design Metrics

- Cohesion metrics: a function of data objects and the locus of their definition
- Coupling metrics: a function of input and output parameters, global variables, and modules called
- Complexity metrics: hundreds have been proposed (e.g., cyclomatic complexity)

Interface Design Metrics

- Layout appropriateness: a function of layout entities, the geographic position and the "cost" of making transitions among entities

Code Metrics

- Halstead's Software Science: a comprehensive collection of metrics all predicated on the number (count and occurrence) of operators and operands within a component or program
  - It should be noted that Halstead's "laws" have generated substantial controversy, and many believe that the underlying theory has flaws. However, experimental verification for selected programming languages has been performed (e.g. [FEL89]).

Metrics for Testing

- Testing effort can also be estimated using metrics derived from Halstead measures
- Binder [BIN94] suggests a broad array of design metrics that have a direct influence on the "testability" of an OO system.
  - Lack of cohesion in methods (LCOM).
  - Percent public and protected (PAP).
  - Public access to data members (PAD).
  - Number of root classes (NOR).
  - Fan-in (FIN).
  - Number of children (NOC) and depth of the inheritance tree (DIT).