Chapter 15
Product Metrics

Moonzoo Kim
CS Division of EECS Dept.
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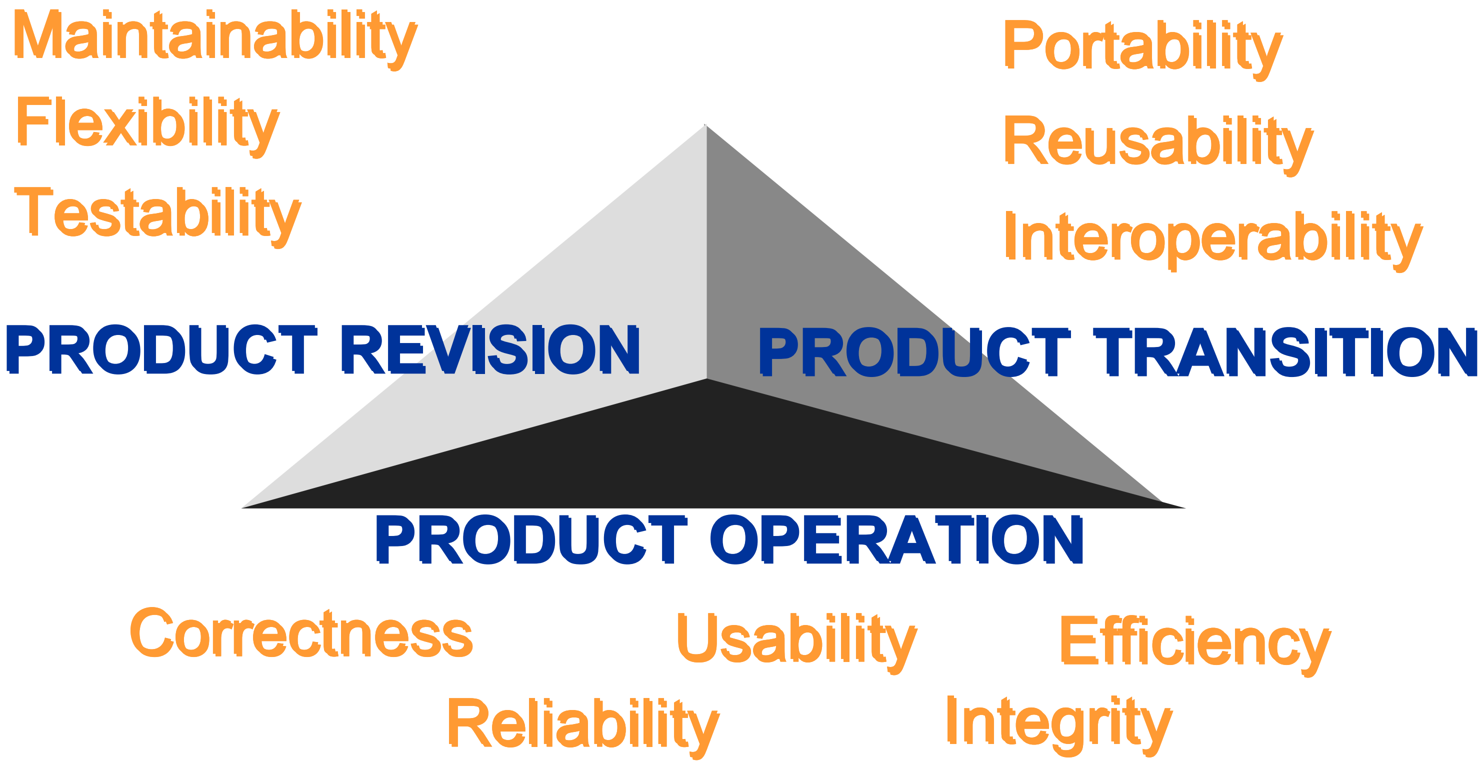
Overview of Ch15. Product Metrics

- 15.1 Software Quality
- 15.2 A Framework for Product Metrics
- 15.3 Metrics for the Analysis Model
  - Function point metrics
- 15.4 Metrics for the Design Model
  - Architectural design metrics
  - Metrics for OO design
  - Class-oriented metrics
  - Component-level design metrics
  - Operation oriented metrics
- 15.5 Metrics for Source Code
- 15.6 Metrics for Testing
- 15.7 Metrics for Maintenance

McCall’s Triangle of Quality (1970s)



ISO 9126 Quality Factors
- Functionality, reliability, usability, efficiency, maintainability, portability

Measures, Metrics and Indicators

- A SW engineer collects measures and develops metrics so that indicators will be obtained
  - A *measure* provides a quantitative indication of the extent, amount, dimension, capacity, or size of some attribute of a product or process
  - The IEEE defines a *metric* as “a quantitative measure of the degree to which a system, component, or process possesses a given attribute.”
    - IEEE Standard Glossary of Software Engineering Terminology (IEEE Std 610.12-1990)
  - An *indicator* is a metric or combination of metrics that provide insight into the software process, a software project, or the product itself
- Ex. Moonzoo Kim
  - Measure: height=170cm, weight=65 kg
  - Metric: fat metric= 0.38 (=weight/height)
  - Indicator: normal health condition (since fat metric < 0.5)

Measurement Principles

- The objectives of measurement should be established before data collection begins
  - Ex. It might be useless to measure a number of words in a C file.
- Each technical metric should be defined in an unambiguous manner
  - Ex. For measuring a total line number of a C program
    - Including comments? Including empty lines?
- Metrics should be derived based on a theory that is valid for the domain of application
  - Metrics for design should draw upon basic design concepts and principles and attempt to provide an indication of the presence of a desirable attribute
  - 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.

- *Example of Formulation*
  To check whether a give software is *hot-spotted* (i.e. has intensive loops)
- *Example of Collection*
  Instrument a source program/binary to count how many time a given statement is executed in one second
- *Example of Analysis*.
  Using Excel/MatLab to get average numbers of executions of statements
- *Example of Interpretation*.
  If there exist statements which were executed more than 10^8, on a 3 Ghz machine, then the program is hot-spotted
- *Example of Feedback*.
  Try to optimize those hot-spotted statements. Or those hot-spotted statement might have logical flaws

Goal-Oriented Software Measurement

- The Goal/Question/Metric Paradigm
  - establish an explicit measurement *goal*
  - define a set of *questions* that must be answered to achieve the goal
  - 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}.

Ex> Goal definition for SafeHome

- **Analyze** the Safehome SW architecture
- **for the purpose of** evaluating architectural components
- **with respect to** the ability to make Safehome more extensible
- **from the viewpoint of** the SW engineers performing the work
- **in the context of** produce enhancement over the next 3 years
- Questions
  - Q1: Are architectural components characterized in a manner that compartmentalizes function and related data?
    - Answer: 0 … 10
  - Q2: Is the complexity of each component within bounds that will facilitate modification and extension?
    - Answer: 0 … 1

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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.

  ex. MZ measure of a software complexity: kg x m^2
- *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

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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
  - Ex. Fat metric greater than 0.5 indicates obesity. A person who has more than 0.7 fat metric should consult a doctor.

Metrics for the Analysis Model

- These metrics examine the analysis model with the intent of predicting the "size" of the resultant system
- Size can be one indicator of design complexity
- Size can always an indicator of increased coding, integration, and testing efforts
- Example
  - Function-based metrics
  - Metrics for specification quality

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Function-Based Metrics

- The *function point metric* (FP), first proposed by Albrecht [ALB79], 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)
    - often used to update internal logical files
  - number of external outputs (EOs)
  - number of external inquiries (EQs)
  - number of internal logical files (ILFs)
  - Number of external interface files (EIFs) (

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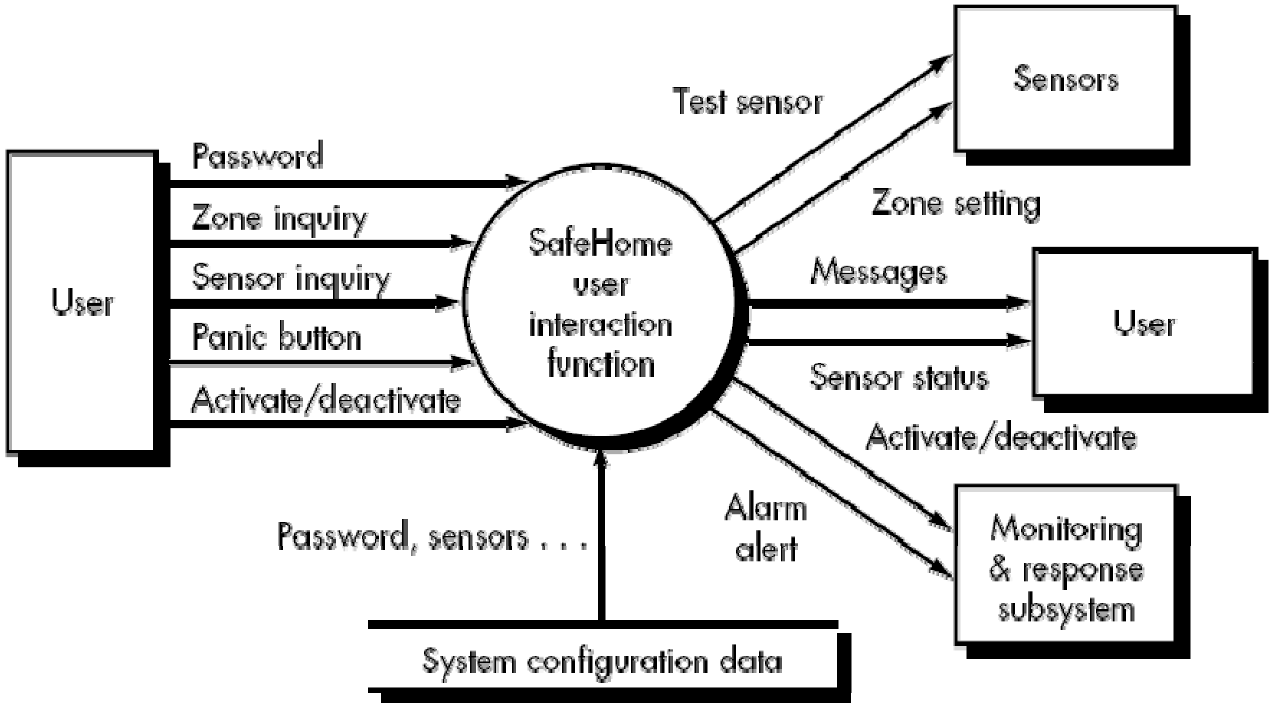
Function Points

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 →							

$FP = \text{count total} \times (0.65 + 0.01 \times \sum(F_i))$

where Fi's are value adjustment factors based on responses to the 14 questions (473 pg of SEPA)



Measurement parameter	Count		Simple	Average	Complex		
			Weighting Factor				
Number of user inputs	3	×	3	4	6	=	9
Number of user outputs	2	×	4	5	7	=	8
Number of user inquiries	2	×	3	4	6	=	6
Number of files	1	×	7	10	15	=	7
Number of external interfaces	4	×	5	7	10	=	20
Count total						→	50

Value Adjustment Factors (F_i)

- Following questions should be answered using a scale that ranges from 0 (not important) to 5 (absolutely essential)
  - Does the system require reliable backup and recovery?
  - Are specialized data communications required to transfer information to or from the application?
  - 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 on-line data entry require the input transaction to be built over multiple screens or operations?

Usage of Function Points

- Assume that
  - past data indicates that one FP translates into 60 lines of code
  - 12 FPs are produced for each person-month of effort
  - Past projects have found an average of 3 errors per FP during analysis and design reviews
  - 4 errors per FP during unit and integration testing
- These data can help SW engineers assess the completeness of their review and testing activities.
- Suppose that Safehome has 56 FPs
  - 56 =50 x [0.65 +0.01 x $\sum(\mathbf{F_i})$ (= 46)]
- Safehome will be
  - Expected size: 60 lines * 56 =3360 lines
  - Expected required man-month: 1/12 MM * 56 = 4.7 MM
  - Total analysis/design errors expected: 3 * 56 = 168 errors
  - Total testing errors expected: 4 * 56 = 224 errors

Metrics for the Design Model

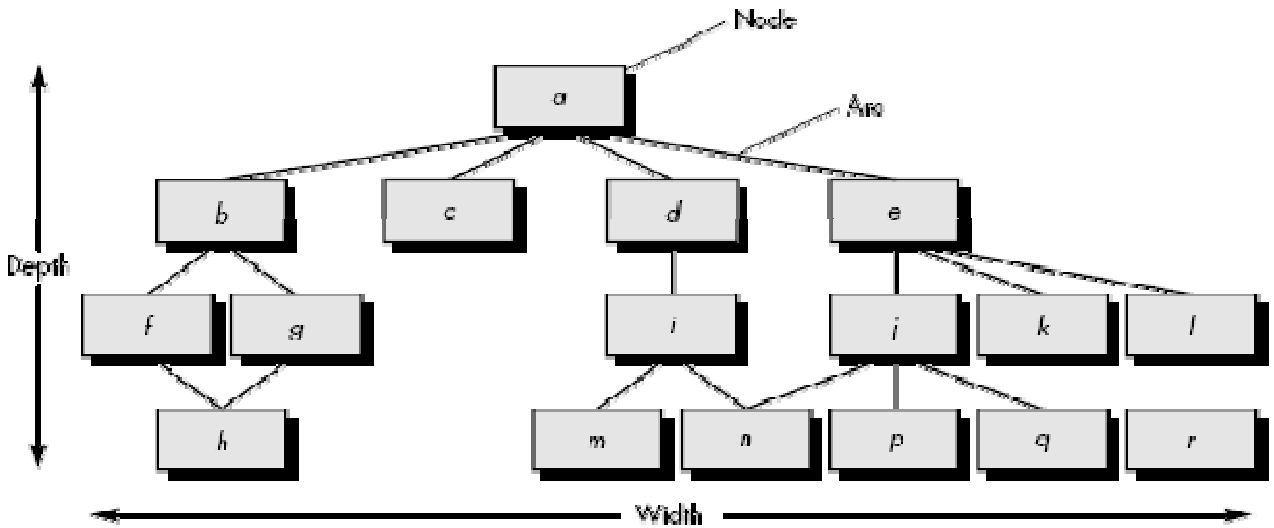
- The design of engineering products (i.e. a new aircraft, a new computer chip, or a new building) is conducted with well-defined design metrics for various design qualities
  - Ex 1. Quality does matter, see AMD's success in 2000~2006.
  - Ex 2. Pentium X should have
    - Heat dispense ratio < 100 Kcal/s
    - Should operate 99.99% time correctly at 10 Ghz
    - Should consume less than 100 watts/h electric power
- The design of complex software, however, often proceeds with virtually no metric measurement
  - Although design metric is not perfect, design without metric is not acceptable.

Architectural Design Metrics

- Architectural design metrics put emphasis on the effectiveness of modules or components within the architecture
  - These metrics are “black box”
- Architectural design metrics
  - Structural complexity of a module m= (# of fan-out of module m)^2
    - Fan-out is the number of modules immediately subordinate to the module
      - i.e. the # of modules that are directly invoked by the module
  - Data complexity = (# of input & output variables)/ (fan-out+1)
  - System complexity = structural complexity + data complexity

Morphology Metrics

- Morphology metrics: a function of the number of modules and the number of interfaces between modules
  - Size = n + a
  - Depth = the longest path from the root node to a leaf node
  - Width =maximum # of nodes at any one level of the architecture
  - Arc-to-node ratio



Metrics for OO Design-I

- Whitmire [WHI97] describes nine distinct and measurable characteristics of an OO design:
  - Size
    - Size is defined in terms of the following four views:
    - Population: a static count of OO entities such as classes
    - Volume: a dynamic count of OO entities such as objects
    - Length: a measure of a chain of interconnected design elements
    - Functionality: value delivered to the customer
  - Complexity
    - How classes of an OO design are interrelated to one another
  - Coupling
    - The physical connections between elements of the OO design
      - The # of collaborations between classes
  - Sufficiency
    - "the degree to which an abstraction possesses the features required of it, ... from the point of view of the current application."
    - Whether the abstraction (class) possesses the features required of it

Metrics for OO Design-II

- Completeness
  - An indirect implication about the degree to which the abstraction or design component can be reused
- 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:

- 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

- Localization

  the way in which information is concentrated in a program

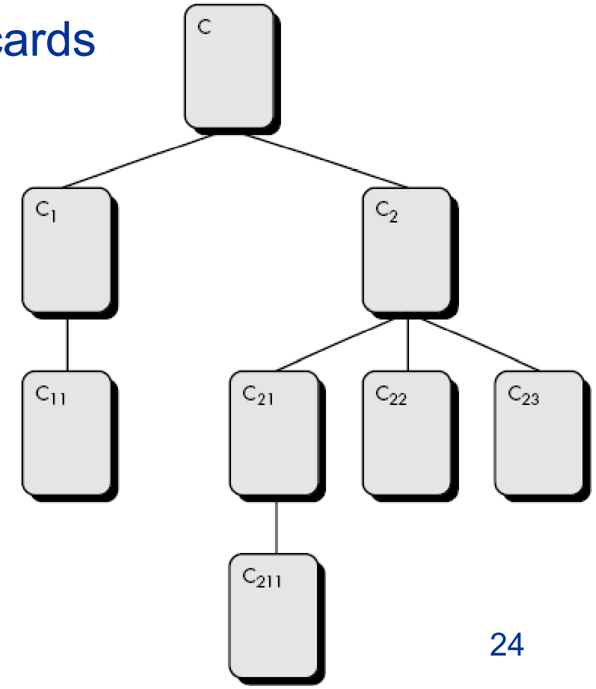
Class-Oriented Metrics

Proposed by Chidamber and Kemerer (CK metrics):

- Weighted methods per class $\sum(C_i)$ where C_i is a normalized complexity for method i
  - **The # of methods and their complexity are reasonable indicators of the amount of effort required to implement and test a class**
  - **As the # of methods grows for a given class, it is likely to become more application specific -> less reusability**
  - **Counting the # of methods is not trivial**
- Depth of the inheritance tree
  - As DIT grow, potential difficulties when attempting to predict the behavior of a class

Class-Oriented Metrics

- Number of children (NOC)
  - As NOC grows, more reuse, but the abstraction of the parent class is diluted
  - As NOC grows, the amount of testing will also increase
- Coupling between object classes (CBO)
  - CBO is the # of collaborations listed on CRC index cards
  - As CBO increases, reusability decreases
- Response for a class (RFC)
  - A set of methods that can be executed in response to a request
  - As RFC increases, test sequence grows
- Lack of cohesion in methods (LCOM)
  - A # of methods that access same attributes



Applying CK Metrics (pg483-484)

- **The scene:**
  - Vinod's cubicle.
- **The players:**
  - Vinod, Jamie, Shakira, Ed

    members of the *SafeHome* software engineering team, who are continuing work on component-level design and test case design.
- **The conversation:**
- **Vinod:** Did you guys get a chance to read the description of the CK metrics suite I sent you on Wednesday and make those measurements?
- **Shakira:** Wasn't too complicated. I went back to my UML class and sequence diagrams, like you suggested, and got rough counts for DIT, RFC, and LCOM. I couldn't find the CRC model, so I didn't count CBO.
- **Jamie (smiling):** You couldn't find the CRC model because I had it.
- **Shakira:** That's what I love about this team, superb communication.
- **Vinod:** I did my counts . . . did you guys develop numbers for the CK metrics?

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- (Jamie and Ed nod in the affirmative.)
- **Jamie:** Since I had the CRC cards, I took a look at CBO, and it looked pretty uniform across most of the classes. There was one exception, which I noted.
- **Ed:** There are a few classes where RFC is pretty high, compared with the averages . . . maybe we should take a look at simplifying them.
- **Jamie:** Maybe yes, maybe no. I'm still concerned about time, and I don't want to fix stuff that isn't really broken.
- **Vinod:** I agree with that. Maybe we should look for classes that have bad numbers in at least two or more of the CK metrics. Kind of two strikes and you're modified.
- **Shakira (looking over Ed's list of classes with high RFC):** Look, see this class? It's got a high LCOM as well as a high RFC. Two strikes?
- **Vinod:** Yeah I think so . . . it'll be difficult to implement because of complexity and difficult to test for the same reason. Probably worth designing two separate classes to achieve the same behavior.
- **Jamie:** You think modifying it'll save us time?
- **Vinod:** Over the long haul, yes.

Class-Oriented Metrics

The MOOD Metrics Suite

- Method inheritance factor (MIF) MIF = $\sum \mathbf{M_i(C_i)} / \sum \mathbf{M_a(C_i)}$
  - $M_i(C_i)$ = the # of methods inherited (and not overridden) in C_i
  - $M_a(C_i) = M_d(C_i) + M_i(C_i)$
  - $M_d(C_i)$ = the # of methods declared in the class C_i
- Coupling factor CF = $\sum \sum \mathbf{is\_client(C_i,C_j)} / \mathbf{(T_c^2 - T_c)}$
  - **Is_client = 1 if and only if a relationship exists between the client class C_c and C_s (C_c != C_s)**
  - **High CF makes trouble to understandability, maintainability and reusability.**

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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

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)

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Operation-Oriented Metrics

Proposed by Lorenz and Kidd [LOR94]:

- average operation size
  # of messages sent by the operation
- operation complexity
- average number of parameters per operation

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).

Metrics for Maintenance

- IEEE Std 982.1-1998 Software Maturity Index (SMI)
  - $SMI = [M_T - (F_a + F_c + F_d)]/M_T$
    - M_t = # of modules in the current release
    - F_c = # of modules in the current release that have been changed
    - F_a = # of modules in the current release that have been added
    - F_d = # of modules from the preceding release that were deleted in the current release