Measuring Object Oriented Design

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Measurement in day-to-day activities

- What’s the temperature today?
- How much time did it take to travel?
- Was it a comfortable journey?
- Are you joking?
- How cold is it at Bangalore?
- How many participants in SoDA?
- Was the morning tea too sweet?
- How popular is soda amongst the students as compared to tea?
- Which is the best team in the world?

Measurement

- Fundamental in any engineering discipline
- Software Engineering is no exception

- If you can measure, you can predict
- If you can measure, you can control
- If you can measure, you can compare
- If you can measure, you can improve
- You can estimate, cost, plan, investigate, assess …
- And if you can measure, you can relax too!

Quality

- Is there a definition for quality?
- How do you spot it?
- How do you measure it?
- Quantification of Quality
  - Quantification process is subjective
  - Once quantified, the measure is objective

Some example uses of metrics

- Selecting Data structures and algorithms
- Choosing over alternative implementations
- Adjust/refactor designs based on coupling and cohesion
- Use defect rates for process improvement
- Use effort and productivity metrics to assess the use of a technology or tool
- For improving understandability, maintainability, testability of software

Some basics of measurement theory

- How do we understand a given quality (or *attribute*)?
- By comparing samples
  - Example: height
    - We say person A is <u>taller than</u> person B.
    - Person C's wife is not that <u>much taller than</u> him.
  - We understand the <u>taller than</u> relation through comparison
  - We do not use numbers
- *<u>Taller than</u>* is an **empirical** relation for attribute *height* and not a **numerical** relation
- *When there is difference of opinion, we take consensus*
- Empirical relations on a set need not be binary
  - <u>is tall</u>
- We can map the empirical world to numerical world or formal relational world ➔ measurement
- E.g. $>$ relation on height in cms

Measurement: Quantifying Quality

- Are there any restrictions to be followed when this mapping is done?

- The mapping must be such that the numerical relation preserves and is preserved by the empirical relation

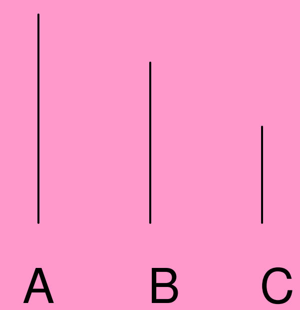
- i.e. as in
  - A is taller than B if and only if H(A) > H(B)
  - A is tall if and only if H(A) > 70
  - A is much taller than B if and only if H(A) > H(B)+15

Quantification

- Define following mappings from empirical to numerical world
  - A is taller than B if and only if H(A) > H(B)
  - A is tall if and only if H(A) > 70
  - A is much taller than B if and only if H(A) > H(B)+15
- Now given
    - sticks A,B,C and
    - H(A)=84   H(B)=72 H(C)=42

  We can say
  - A is taller than B and H(A) > H(B)

  And so on



- The interpretation

Different relational properties

- Reflexive: aRa for all a’s in the set
- Irreflexive: not aRa for all a’s
- Non-reflexive: It is not reflexive
- Symmetric: aRb → bRa for all a’s and b’s
- Asymmetric: aRb → not bRa
- Antisymmetric: aRb and bRa → a=b
- Transitive: aRb and bRc → aRc

Measurement scales

- Nominal
  - Specs fault, design fault, coding fault
- Ordinal
  - Trivial, simple, moderate, complex, incomprehensible
- Interval
  - Temperature Celsius/Fahrenheit , relative time
- Ratio
  - Length, weight, time intervals, temperature Kelvin
- Absolute
  - counts

Nominal scale

- Empirical system consists of only different classes
- There is no ordering among the classes
  - Numbering of classes is okay
  - but that is only to distinguish them and no notion of magnitude is associate
    - i.e. classes are not ordered, and even if they are numbered from 1 to n, that is only for identification
    - Civil engg students 001, cse students 002, Mech students 003

Ordinal Scale

- Empirical system consists of classes
- Classes are ordered with respect to the attribute
  - Any mapping that preserves the ordering is acceptable
  - The number represents ranking only
  - Hence no functions such as addition, subtraction

Good, very good, excellent, exceptional

Interval Scale

- It is more powerful than nominal or ordinal
- Captures the size of the intervals that separate classes
  - Preserves orders as with ordinal
  - Preserves differences but not ratios
    - Addition, subtraction is accepted
    - Multiplication and division is not

Temperature change: 20C to 21C at mumbai
is same as 30C to 31C in chennai

But we cannt say it is 2/3rd as hot in mumbai as in chennai

We cannot say delhi is 50% hotter than mumbai

Ratio Scale

- Preserves ordering
- Preserves the size of intervals between entities
- And ratios between entities
- Has a 0 element representing lack of the attribute
- Measurement mapping starts at 0 and increases in equal units (intervals)
- All arithmetic can be performed
  - Length of an object

Absolute scale

- Measurement is made by counting the number of elements in the set
  - There is only one possible measurement mapping, i.e. the count
  - All arithmetic is useful
    - Number of project engineers

Measurement in software (Product)

- Measuring specification
  - Internal attributes: size, reuse, modularity, redundancy, functionality, syntactic correctness
  - External attributes: comprehensibility, maintainability

Measurement in software (Product)

- Measuring designs
  - Internal attributes: size, reuse, modularity, coupling, cohesiveness, functionality
  - External attributes: quality, complexity, maintainability

Measurement in software (Product)

- Measuring code
  - Internal attributes: size, reuse, modularity, coupling, structured-ness
  - External attributes: reliability, usability, maintainability

Measurement in software (Processes)

- Measuring process stages
  - Time, efforts, number of changes made, number of faults
  - Cost, stability, cost-effectiveness

Measurement in software (Resources)

- Measuring personnel, s/w, hardware, offices
  - Size, price, temperature level, light in office, speed, memory size
  - Productivity, experience, usability, utilization, availability

Measuring size - length

- LoC
  - But explain how blank lines, comments, data declarations, lines containing more language statements are handled
- NCLoC
  - Non commented lines (or ELoC-effective LoC)
  - But for storage requirements this may be needed
- Or use LOC=NCLoc+CLOC (non-commented + commented lines of code measured separately)

- Ratio CLOC/LOC : density of comments

Measuring size - length

- ES: number of executable statements
  - Separate statements on same line are still distinct
  - Ignores comments, declarations, headings
- DSI: number of delivered source instructions
  - Like ES, but includes data definitions, and headings

Measuring size - length

- Halstead's ideas
- Given program P:
  - u1 no of unique operators
  - u2 no of unique operands
  - n1 total occurrences of operators
  - n2 total occurrences of operands
- n = Length of P = n1 + n2
- u = Vocabulary of P = u1 + u2
- v = Volume of P = n * $\log_2$ u

  = number of mental comparisons needed to write a program of length n
- Potential volume v* = volume of minimum size implementation of P
- L = Program level of P = v*/v
- D= Difficulty level of P = i/L

Weyuker's axioms for software complexity measures

- P, Q, R — program bodies
- |P| — complexity of P wrt some hypothetical measure
- |P| is non-negative
- For any P,Q
  - |P|<=|P| or |Q|<=|P|
- Complexities can be compared and ordered

Weyuker’s axiom 1

- There exists p and q such that
  - |P| is not equal to |P|
- Tries to stress that a measure in which all programs are equally complex is not really a measure

Weyuker's axiom 2

- Let c be a nonnegative number
- There are only finitely many programs of complexity equal to c
- This says that measure is not sensitive enough if it divides all programs into just a few complexity classes

Weyuker's axiom 3

- There are distinct programs P and Q such that |P| = |Q|
- i.e. the measure should not assign unique value to every program and thus should not be too fine level

Weyuker's axiom 4

- There exist programs p and q such that

  They are equivalent but |P| not= |Q|

- i.e. even when 2 programs do the same thing, their implementation complexity vaies

Weyuker’s axiom 5

- For all Ps and Qs,
  - |P| <= |P;Q| and
  - |Q| not= |P;Q|
- Components of the program are no more complex than program itself

Weyuker's axiom 6

- Whether or not the concatenation of a given program body with another should always affect the complexity of the resultant program in a uniform way?
- There exist p,q,r such that
  - Complexity of p and q are same: |P|=|Q|
  - Complexity of P;R not same as complexity of Q;R
    - |P;R| not=|Q;R|
  - i.e. R may not interact same with p and q

Weyuker's axiom 7

- There are two program bodies P and Q such that
  - Q is formed by permuting the order of statements of P and |P| not= |Q|
- Program complexity should be responsive to order of statements, and hence interaction among statements

Weyuker's axiom 8

- If P is a renaming of Q then |P|=|Q|

- This is in terms of Psychological complexity (actually relabeling of variables)

Weyuker's axiom 9

- There exist P, Q such that
  - $|P| + |Q| < |P;Q|$
- Complexity of a program formed by concatenating 2 program bodies can be greater than sum of their individual complexities

Weyuker’s axioms have been criticized

- E.g. consider KNOT measure = total no of points at which control flow crosses
- It is 0 for all structured programs and it does measure unstructredness of programs
- But property 1 states that every program should not have the same value else it is not a metric

Some Criticism on Weyuker's axioms

- Property 5 asserts that adding code cannot decrease complexity.
- This reflects a view that program size is key factor in complexity
- And also that low comprehensibility is not a key factor
- It's widely believed that we understand a program more easily as we see more of it
- Whereas, axiom 6 has to do with comprehensibility and little to do with size
- Thus they cannot be both satisfied by a single measure
- Zuse concluded 5 needs ratio scale, and 6 excludes it
- Useless metrics may be created satisfying all the properties

Object Oriented Metrics

- Why do we need them?
- In non-OO software complexity is in structure of code itself, larger portion of code is imperative
- In OO code, complexity lies in interaction between objects, a large portion of code is declarative, OO models real life objects: classes, objects, inheritance, encapsulation, message passing

CK Metric suit

- Chidamber and Kemerer's suit for object oriented systems
  - Weighed methods per class (WMC)
  - Depth of inheritance tree (DIT)
  - Number of children (NOC)
  - Coupling between object classes (CBO)
  - Response for a class (RFC)
  - Lack of cohesion in methods (LCOM)

Weighted methods per class (WMC) metric

- Every class has methods M1…Mn defined in the class
- C1…Cn are complexities of methods

Then

WMC = sum of all Ci's from C1 to Cn

Weighted methods per class (WMC) metric

- Method complexity is left undefined
- Scale used for it must be at least interval scale so that summation is possible

Weighted methods per class (WMC) metric

- **Viewpoints**

- No. of methods and complexity of methods is a predictor for time and efforts for a class
- Larger the no of methods, greater the impact on subclasses
- Classes with large no. of methods will have less reuse and will be application specific

Depth of inheritance tree (DIT)

- It's a metric for a class
- Maximum length from node to the root of the tree
- May be in presence of multiple inheritance
- Measures how many ancestor classes can potentially affect this class

Depth of inheritance tree (DIT)

- **Viewpoints**

- The deeper the class, greater the number of methods it will have, making it more complex
- Deeper tree indicates more design complexity as more classes and methods are involved

Number of Children (NOC)

- Number of immediate subclasses
- Measures how many subclasses will inherit the parent class
- **Viewpoint**
  - Greater the no. of children, greater the reuse
  - Greater the no. of children, greater the possibility of improper abstraction of the class: it could be a misuse of subclassing
  - No. of children measure efforts needed on testing a class

Coupling between objects (CBO)

- Count of no. of other classes to which it is coupled
- Objects are coupled if one of them acts on the other
- **Viewpoint**
  - Excessive coupling shows decline in modularity
  - More independent a class is, easier it is to reuse
  - Less coupling promotes modularity and encapsulation
  - Indicates how complex the testing could be

Coupling between objects (CBO)

- Classes responsible for managing interfaces have a high CBO
  - Classes that connect subsystems
- Usable by senior managers and project managers
  - to track integrity of a system
  - to check whether components are developing unnecessary interconnections

Response for a class (RFC)

- RFC = |Response Set RS|

- RS is a set of methods that can potentially be executed in response to a message received by an object of that class

Response for a class (RFC)

- **Viewpoint**
- Larger the number of methods invoked from a class, greater the complexity
- Worst case RS values will assist in testing estimation
- Large RFC needs greater understanding by the tester and in debugging

Lack of cohesion in methods (LCOM)

- Consider class C with methods M1..Mn
- Let Vi be set of instance variables used by method Mi
- There are such n sets Vi…Vn
- Let Pi’s be set of all tuples (Vi, Vj) such that the intersections of Vi and Vj are null
- Let Qi’s be set of all tuples (Vi, Vj) such that the intersections of Vi and Vj are non-null
- LCOM = IP|-|Q| if |P| > |Q|
  - 0 otherwise

Lack of cohesion in methods (LCOM)

- The degree of similarity is between 2 methods is given by the interaction of Vi and Vj
- LCOM is count of no. of method pairs whose similarity measure is 0, minus the count of no of method pairs whose similarity measure is not 0.
- The larger the no of similar methods, more cohesive is the class
- If none of the methods use any instance variable, they will have no similarity and LCOM value will be 0.

Lack of cohesion in methods (LCOM)

- **Viewpoint**
- Cohesiveness of methods within a class is desirable. It promotes encapsulation
- Lack of cohesion implies classes need splitting or splitting into subclasses
- Design flaws may be detected
- Low cohesion increases complexity and errors
- Can be used to identify classes that are trying to achieve many different objectives

Schroeder’s compilation of metrics

- Categories of metrics
  - System size
    - E.g. how many function calls and objects?
  - Class or method size
    - Small classes typically better than large ones
  - Coupling and inheritance
    - Number of types of relations: interdependence
  - Class of method internals
    - How complex code of a class is

System Size

- Lines of code LOC
- Total function calls TFC
- Number of classes NOC
- Number of windows NOW
  - (size of user interfaces on the system)

Class/Method Size

- LOC and function calls per class/method
- Number of methods per class
- Public method count per class
- Number of attributes per class
- Number of instance attributes per class

Coupling and Inheritance

- Class fan-in
  - Number of classes that depend on a given class
- Class fan-out
  - Number of classes on which a class depends
- Class inheritance level: no. of direct ancestors
- Number of children per class

Class and method internals

- No. of global/shared references per class
  - Break encapsulation
    - Use sparingly if unavoidable
- Method complexity
  - No of different execution paths within a block of code (cyclomatic complexity)
- Number of public attributes per class
- Lack of cohesion among methods

Class and method internals

- Class specialization index
  - Extent to which subclasses override (replace) the behavior of their ancestor classes
  - More the specialization, abstraction may be said to be inappropriate
  - Extending class behavior with new methods vs. heavy overriding
- Percent of commented methods
  - Documentation
- Number of parameters per method
  - Higher the number, complex the interface

MOOD Metrics

- Method hiding factor (MHF)
- Attribute hiding factor (AHF)
- Method inheritance factor (MIF)
- Polymorphism factor (PF)
- Coupling factor (CF)

Method hiding factor

- Invisibility of a method=percentage of total classes from which the method is not visible
- Numerator: sum of invisibilities of all methods in all classes
- Denominator: total number of methods defined in the system under consideration
- Very low: insufficient abstraction
- High value: little functionality

Attribute factor

- Numerator: sum of invisibilities of all attributes in all classes
- Invisibility: percentage of total classes from which attribute is not visible
- Denominator: total number of attributes defined in the system under consideration
- Very low: inefficient design
- Ideally all attributes are hidden

Polymorphism factor

- Actual number of possible different polymorphic situations

- Numerator: actual amount of polymorphism
- Denominator: maximum attainable polymorphism

Back to basic 2 issues

- Basic properties of measurement
- How to quantify quality