ESE
Einführung in Software Engineering

12. Software Metrics

Prof. O. Nierstrasz
Roadmap

> What are metrics? Why do we need them?
> Metrics for cost estimation
> Metrics for software quality evaluation
> Object-Oriented metrics in practice
Sources


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Why Metrics?

*When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science.*

— Lord Kelvin
### Why Measure Software?

<table>
<thead>
<tr>
<th>Why Measure Software?</th>
<th>Measure Correlation Between Specifications and Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimate cost and effort</strong></td>
<td>measure correlation between specifications and final product</td>
</tr>
<tr>
<td><strong>Improve productivity</strong></td>
<td>measure value and cost of software</td>
</tr>
<tr>
<td><strong>Improve software quality</strong></td>
<td>measure usability, efficiency, maintainability ...</td>
</tr>
<tr>
<td><strong>Improve reliability</strong></td>
<td>measure mean time to failure, etc.</td>
</tr>
<tr>
<td><strong>Evaluate methods and tools</strong></td>
<td>measure productivity, quality, reliability ...</td>
</tr>
</tbody>
</table>

“You cannot control what you cannot measure” — De Marco, 1982
“What is not measurable, make measurable” — Galileo
What are Software Metrics?

**Software metrics**

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

— Lines of code in a program
— the Fog index (calculates readability of a piece of documentation)

\[
0.4 \times \left( \frac{\text{# words}}{\text{# sentences}} \right) + \left( \% \text{ words} \geq 3 \text{ syllables} \right)
\]

— number of person-days required to implement a use-case
Mathematically, a **metric** is a function $m$ measuring the **distance between two objects** such that:

1. $\forall x, m(x,x) = 0$
2. $\forall x, y, m(x,y) = m(y,x)$
3. $\forall x, y, z, m(x,z) \leq m(x,y) + m(y,z)$

So, technically “software metrics” is an abuse of terminology, and we should instead talk about “software measures”.
**Direct and Indirect Measures**

**Direct Measures**
- *Measured* directly in terms of the observed attribute (usually by counting)
  - Length of source-code, Duration of process, Number of defects discovered

**Indirect Measures**
- *Calculated* from other direct and indirect measures
  - Module Defect Density = Number of defects discovered / Length of source
  - Temperature (usually derived from the length of a liquid column)
**Measure & Measurement**

A **measure** is a function mapping an **attribute** of a real world entity (= the domain) onto a **symbol** in a set with known mathematical relations (= the range).

A **measurement** is the symbol assigned to the real world attribute by the measure.

**Example:** measure mapping height attribute of person on a number representing height in meters.

**Purpose:** *Manipulate symbol(s) in the range to draw conclusions about attribute(s) in the domain*
Preciseness

To be **precise**, the definition of the measure must specify:

> **domain:** do we measure people’s height or width?
> **range:** do we measure height in centimetres or inches?
> **mapping rules:** do we allow shoes to be worn?
## Possible Problems

**Example:** Compare productivity in lines of code per time unit.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do we use the same units to compare?</td>
<td>What is a “line of code”?</td>
</tr>
<tr>
<td></td>
<td>What is the “time unit”?</td>
</tr>
<tr>
<td>Is the context the same?</td>
<td>Were programmers familiar with the language?</td>
</tr>
<tr>
<td>Is “code size” really what we want to produce?</td>
<td>What about code quality?</td>
</tr>
<tr>
<td>How do we want to interpret results?</td>
<td>Average productivity of a programmer?</td>
</tr>
<tr>
<td></td>
<td>Programmer X is twice as productive as Y?</td>
</tr>
<tr>
<td>What do we want to do with the results?</td>
<td>Do you reward “productive” programmers?</td>
</tr>
<tr>
<td></td>
<td>Do you compare productivity of software processes?</td>
</tr>
</tbody>
</table>
Goal — Question — Metrics approach
[Basili et al. 1984]

> Define Goal
  — e.g., “How effective is the coding standard XYZ?”

> Break down into Questions
  — “Who is using XYZ?”
  — “What is productivity/quality with/without XYZ?”

> Pick suitable Metrics
  — Proportion of developers using XYZ
  — Their experience with XYZ ...
  — Resulting code size, complexity, robustness ...
Validity and reliability

> A good metric is both **valid** (*measures what it is intended to measure*) and **reliable** (*yields consistent results*)

Some Desirable Properties of Metrics

- Valid and reliable (consistent)
- Objective, precise
- Intuitive
- Robust (failure-tolerant)
- Automatable and economical (practical)
- …

Caveat: Attempts to define formally desirable properties have been heavily disputed …

Roadmap

> What are metrics? Why do we need them?
> **Metrics for cost estimation**
> Metrics for software quality evaluation
> Object-Oriented metrics in practice
Cost estimation objectives

Cost estimation and planning/scheduling are closely related activities

Goals
> To establish a budget for a software project
> To provide a means of controlling project costs
> To monitor progress against the budget
   — comparing planned with estimated costs
> To establish a cost database for future estimation
## Estimation techniques

<table>
<thead>
<tr>
<th>Method</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expert judgement</strong></td>
<td>cheap, but risky!</td>
</tr>
<tr>
<td><strong>Estimation by analogy</strong></td>
<td>limited applicability</td>
</tr>
<tr>
<td><strong>Parkinson's Law</strong></td>
<td>unlimited risk!</td>
</tr>
<tr>
<td><strong>Pricing to win</strong></td>
<td>i.e., you do what you can with the money</td>
</tr>
<tr>
<td><strong>Top-down estimation</strong></td>
<td>may miss low-level problems</td>
</tr>
<tr>
<td><strong>Bottom-up estimation</strong></td>
<td>may underestimate integration costs</td>
</tr>
<tr>
<td><strong>Algorithmic cost modelling</strong></td>
<td>requires correlation data</td>
</tr>
</tbody>
</table>

*Each method has strengths and weaknesses!*  
Estimation should be based on several methods
Algorithmic cost modelling

> Cost is estimated as a *mathematical function of product, project and process attributes* whose values are estimated by project managers.
> The function is derived from a study of *historical costing data*.
> Most commonly used product attribute for cost estimation is *LOC* (code size).
> Most models are basically similar but with different attribute values.
Measurement-based estimation

A. Measure
Develop a system model and measure its size

B. Estimate
Determine the effort with respect to an empirical database of measurements from similar projects

C. Interpret
Adapt the effort with respect to a specific Development Project Plan
Lines of Code as a measure of system size?

> Easy to measure; but *not well-defined* for modern languages
  — *What’s a line of code?*

> A *poor indicator of productivity*
  — Ignores software reuse, code duplication, benefits of redesign
  — The lower level the language, the more productive the programmer!
  — The more verbose the programmer, the higher the productivity!
Function points

*Function Points (Albrecht, 1979)*

- Based on a combination of program characteristics:
  - external inputs and outputs
  - user interactions
  - external interfaces
  - files used by the system

- A weight is associated with each of these

- The function point count is computed by multiplying each raw count by the weight and summing all values

- Function point count modified by complexity of the project
Function points

Good points, bad points

> Can be measured already after design
> FPs can be used to estimate LOC depending on the average number of LOC per FP for a given language
> LOC can vary wildly in relation to FP
> FPs are very subjective — depend on the estimator. They cannot be counted automatically
Programmer productivity

A measure of the rate at which individual engineers involved in software development produce software and associated documentation

Productivity metrics

- Size-related measures based on some output from the software process. This may be lines of delivered source code, object code instructions, etc.
- Function-related measures based on an estimate of the functionality of the delivered software. Function-points are the best known of this type of measure
Programmer productivity ...

**Productivity estimates**

- Real-time embedded systems, 40-160 LOC/P-month
- Systems programs, 150-400 LOC/P-month
- Commercial applications, 200-800 LOC/P-month

**Quality and productivity**

- *All metrics based on volume/unit time are flawed because they do not take quality into account*
  - Productivity may generally be increased at the cost of quality
  - It is not clear how productivity/quality metrics are related
The COCOMO model

> Developed at TRW, a US defence contractor

> Based on a *cost database* of more than 60 different projects

> Exists in three stages

1. *Basic* — Gives a “ball-park” estimate based on product attributes
2. *Intermediate* — Modifies basic estimate using project and process attributes
3. *Advanced* — Estimates project phases and parts separately
Basic COCOMO Formula

Effort = C × PM^S × M

— Effort is measured in person-months
— C is a *complexity factor*
— PM is a product metric (size or functionality, usually KLOC)
— exponent S is close to 1, but increasing for large projects
— M is a multiplier based on process, product and development attributes (~ 1)
## COCOMO Project classes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Effort Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic mode</td>
<td>small teams, familiar environment, well-understood applications, no difficult non-functional requirements (EASY)</td>
<td>(\text{Effort} = 2.4 \text{ (KDSI)} \times M^{1.05})</td>
</tr>
<tr>
<td>Semi-detached mode</td>
<td>Project team may have experience mixture, system may have more significant non-functional constraints, organization may have less familiarity with application (HARDER)</td>
<td>(\text{Effort} = 3 \text{ (KDSI)} \times M^{1.12})</td>
</tr>
<tr>
<td>Embedded</td>
<td>Hardware/software systems, tight constraints, unusual for team to have deep application experience (HARD)</td>
<td>(\text{Effort} = 3.6 \text{ (KDSI)} \times M^{1.2})</td>
</tr>
</tbody>
</table>

KDSI = Kilo Delivered Source Instructions
COCOMO assumptions and problems

- Implicit productivity estimate
  - Organic mode = 16 LOC/day
  - Embedded mode = 4 LOC/day
- Time required is a function of total effort *not team size*
- Not clear how to adapt model to *personnel availability*

http://en.wikipedia.org/wiki/Fair_use
COCOMO assumptions and problems ...

> **Staff required** can’t be computed by dividing the development time by the required schedule

> The number of people working on a project varies depending on the *phase of the project*

> The more people who work on the project, the *more total effort* is usually required (!)

> Very *rapid build-up* of people often correlates with *schedule slippage*
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Quantitative Quality Model

**Quality according to ISO 9126 standard**
> Divide-and conquer approach via “hierarchical quality model”
> Leaves are simple metrics, measuring basic attributes

![Diagram showing the Qualitative Quality Model with ISO 9126 factors, software quality attributes, and metrics.](image)
“Define your own” Quality Model

Define the quality model with the development team

Team chooses the characteristics, design principles, metrics ... and the thresholds

- Modularity
  - design class as an abstract data-type
  - number of private attributes \([2, 10]\]
  - number of public attributes \([0, 0]\]
  - avoid complex interfaces
  - number of public methods \([5, 30]\]
  - average number of arguments \([0, 4]\)

- Maintainability
  - Characteristic
  - Metric

- Factor
  - Design Principle
Sample Size (and Inheritance) Metrics

Inheritance Metrics
- hierarchy nesting level (HNL)
- # immediate children (NOC)
- # inherited methods, unmodified (NMI)
- # overridden methods (NMO)

Class Size Metrics
- # methods (NOM)
- # attributes, instance/class (NIA, NCA)
- # S of method size (WMC)

Method Size Metrics
- # invocations (NOI)
- # statements (NOS)
- # lines of code (LOC)
- # arguments (NOA)
Sample Coupling & Cohesion Metrics

The following definitions stem from [Chid91a], later republished as [Chid94a]

**Coupling Between Objects (CBO)**
CBO = number of other classes to which given class is coupled
Interpret as “number of other classes a class requires to compile”

**Lack of Cohesion in Methods (LCOM)**
LCOM = number of disjoint sets (= not accessing same attribute) of local methods
Beware!

*Researchers disagree whether coupling/cohesion methods are valid*

- Classes that are observed to be cohesive may have a high LCOM value
  - due to accessor methods
- Classes that are not much coupled may have high CBO value
  - no distinction between data, method or inheritance coupling
**Sample Quality Metrics (I)**

*Productivity (Process Metric)*

> functionality / time

> functionality in LOC or FP; time in hours, weeks, months

— be careful to compare: the same unit does not always represent the same

> Does not take into account the quality of the functionality!
Sample Quality Metrics (II)

**Reliability (Product Metric)**

> **mean time to failure**
>  
> mean of probability density function PDF
>  
> — for software one must take into account the fact that repairs will influence the rest of the function ⇒ quite complicated formulas

> **average time between failures** = # failures / time
>  
> — time in execution time or calendar time
>  
> — necessary to calibrate the probability density function

> **mean time between failure** = MTTF + mean time to repair
>  
> — to know when your system will be available, take into account repair
Correctness \textit{(Product Metric)}

> “a system is correct or not, so one cannot measure correctness”

> \textbf{defect density} = \# known defects / product size
>  \quad — product size in LOC or FP
>  \quad — \# known defects is a time based count!

> \textit{do not compare across projects} unless your data collection is sound!
Sample Quality Metrics (IV)

**Maintainability (Product Metric)**

> #time to repair certain categories of changes
>  “mean time to repair” vs. “average time to repair”
>     — similar to “mean time to failure” and “average time between failures”
>  beware of the units
>     — “categories of changes” is subjective
>     — time =?
>         problem recognition time + administrative delay time + problem analysis
>         time + change time + testing & reviewing time
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Michele Lanza and Radu Marinescu, *Object-Oriented Metrics in Practice*, Springer-Verlag, 2006
Pattern: Study the Exceptional Entities

**Problem**
— How can you quickly gain insight into complex software?

**Solution**
— *Measure* software entities and *study the anomalous ones*

**Steps**
— Use simple metrics
— Visualize metrics to get an overview
— Browse the code to get insight into the anomalies
System Complexity View

Nodes = Classes
Edges = Inheritance Relationships

Width = Number of Attributes
Height = Number of Methods
Color = Number of Lines of Code
Detection strategy

A detection strategy is a metrics-based predicate to identify candidate software artifacts that conform to (or violate) a particular design rule.
Filters and composition

> A **data filter** is a predicate used to focus attention on a *subset of interest* of a larger data set

  — Statistical filters
    - *i.e.*, top and bottom 25% are considered outliers
  — Other relative thresholds
    - *i.e.*, other percentages to identify outliers (*e.g.*, top 10%)
  — Absolute thresholds
    - *i.e.*, fixed criteria, independent of the data set

> A useful detection strategy can often be expressed as a *composition* of data filters
God Class

> A God Class centralizes intelligence in the system
  — Impacts understandability
  — Increases system fragility
ModelFacade (ArgoUML)

- 453 methods
- 114 attributes
- over 3500 LOC
- all methods and all attributes are static
Feature Envy

Methods that are more interested in data of other classes than their own [Fowler et al. 99]
ClassDiagramLayouter

layout

weightAndPlaceClasses()

ClassDiagramLayouter

ClassDiagramNode
Data Class

> A Data Class provides data to other classes but little or no functionality of its own
Data Class (2)

- Class has many public data
  - NOAP + NOAM > MANY
- Complexity of class is not very high
  - WMC < VERY HIGH

AND

OR
- Class reveals many attributes and is not complex
- More than a few public data
  - NOAP + NOAM > FEW
- Complexity of class is not high
  - WMC < HIGH

AND
Property
A change in an operation implies many (small) changes to a lot of different operations and classes.
Project
What you should know!

- What is a measure? What is a metric?
- What is GQM?
- What are the three phases of algorithmic cost modelling?
- What problems arise when using LOC as a software metric?
- What are the key ideas behind COCOMO?
- What’s the difference between “Mean time to failure” and “Average time between failures”? Why is the difference important?
Can you answer the following questions?

> During which phases in a software project would you use metrics?
> Is the Fog index a “good” metric?
> How would you measure your own software productivity?
> Why are coupling/cohesion metrics important? Why then are they so rarely used?
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