Course "Softwareprozesse"

Software Measurement

Lutz Prechelt
Freie Universität Berlin, Institut für Informatik
http://www.inf.fu-berlin.de/inst/ag-se/

- Measure, measurement
- Scale type
- Validity, reliability, precision
- Product measures
  - size (LOC, FP)
  - quality
- Process measures
  - productivity
  - process quality
- Measurement application examples
- Goal-Question-Metric (GQM)
Learning objectives

- What are measures? What is measurement?
- What are the difficulties of measurement?
- Measurement in the software process
- What would we like to measure?
- What measures are common?
- Examples of more specialized measures?
Metrics and measurement

What is it about?
• Measurement is assigning a symbolic **value** to an object in order to characterize a certain **attribute** of that object

Why is it of interest?
• Measurement is useful **abstraction**: It sometimes allows talking about a complex situation in a way that is simple, yet precise and objective

What will we look at?
• Base ideas (measurement, scale type, validity, inference)
• Common mistakes
• Example metrics (product, process)
Definitions

• **Measurement**
  - The process $P$ of using a measure $M$
  - for assigning a value $V$ to some object $X$
  - in order to characterize attribute $A$ of $X$.

• **Measure ("Maß")**
  - A specific rule $M$ for measuring $A$: $A_M(X) = V$
  - Each measure is on a particular scale (see below)
  - Different measures may exist for the same attribute
    - These can be equivalent (differ in scale (**measurement unit**) only)
    - non-equivalent but similar (use the same basic approach)
    - or non-compatible (differ in their approach to characterizing $A$)

• **Metric ("Metrik")**
  - Mathematics: A measure of distance between points
  - Software Engineering: A synonym for measure
    - Actually, 'metric' is more common, probably because 'measure' also means 'Maßnahme'
Example measurements

- $\text{Number}_{\text{Wheels}}(\text{Car X}) = 4$
  - absolute scale

- $\text{Height}_{\text{feet}}(\text{Room X}) = 9.8 \text{ ft}$
  $\text{Height}_{\text{meter}}(\text{Room X}) = 3 \text{ m}$
  - ratio scale

- $\text{Temperature}_{\text{Centigrade}}(\text{Room X}) = 22 ^\circ \text{C}$
  $\text{Temperature}_{\text{Fahrenheit}}(\text{Room X}) = 72 ^\circ \text{F}$
  - difference scale

- Grade(Student X) = "very good"
  Grade(Student X) = "top group"
  - ordinal scale
  (absolute)
  (relative)
A word of warning: scale types

- An advantage of quantitative data is that it can be processed using mathematical operations ("inference")
  - This can allow easy summarization or can provide additional insights

- However, not all computations (inferences) are valid for all kinds of quantitative data
  - The data must be on a sufficient scale type
    - otherwise, an operation may be invalid and may make no sense
  - See the next slide
The scale types

- **Nominal/categorical scale** (named values)
  - Qualitative data: The values are just names
  - Example: Design method A, design method B
  - Inference: mode
    - (the most frequent value)

- **Ordinal scale** (rank scale)
  - Ordered nominal data: One value is larger than another, but we cannot characterize the size of the difference
  - Inference: comparison, median
  - Example: very good, good, OK, not so good, bad

- **Difference scale** (interval scale)
  - Inference: difference, mean
    - but 0 is not equal to 'nothing'
  - Example: degrees centigrade

- **Ratio scale** ("Verhältnisskala")
  - We can compute ratios: 20 is twice as much as 10
    - Note: But we cannot compare apples to oranges (or meters to watts)!
  - Most physical quantities, including absolute temperature (Kelvin)

- **Absolute scale**
  - 1 is also special (counting)
What often goes wrong with scale types

- "Oh, 20 degrees. That's twice as warm as yesterday."
  - A difference scale is not a ratio scale
  - 20 degrees centigrade is 293 Kelvin. That is only 3.5% more than 283 Kelvin.

- When something qualitative is measured using an ordinal scale
  - e.g. "How well did you like using the tool?"
    very well, well, OK, not so well, did not like it
  - Often such scales are coded with numbers: 5, 4, 3, 2, 1
  - Wrong: "average satisfaction was 3.8"
  - Even worse: "average satisfaction in group B was 30% higher than in group A"
    - This is utter nonsense! (What assumption does it imply?)
    - Assume you would have coded using 605, 604, 603, 602, 601? Or 605, 604, 22, 0, -888?
What sometimes goes wrong with scale types

- Even if you do have a ratio scale, things may go wrong:

```
GOLD HILL

EST.  1859
ELEV.  8463
POP.   118
TOTAL  10440
```

Exercise: Which scales are present here?
Characteristics of measures and measurements

- **Validity**
  - For a measure: How well does the measure really characterize the intended attribute?
  - For a measurement procedure: How well do specific measurements really approximate the true measurement value?
    - How exact is it? (Accuracy)
  - See next slides

- **Reliability**
  - How well do multiple measurements of the same object agree?
  - e.g. repeated measurements of IQ

- **Precision**
  - How fine is the maximal resolution of differences in the attribute?
  - e.g. measurement of time in minutes, seconds, or milliseconds
Validity of a measure

- **Simple attributes** (such as physical quantities) can be characterized completely and precisely by a single measure
  - e.g. the length
- All such measures of one attribute are equivalent and valid
  - they just use different measurement units
  - which can be converted by fixed formulae

- **Complex attributes**, however, have no single measure
  - e.g. the quality of a piece of software
- Many different measures can be invented for such attributes
- They are not equivalent
- They measure different aspects of the attribute or are different representatives (proxies) of the attribute
  - They can be more or less "good" measures of the attribute
  - This goodness is called "validity" (Validität, Gültigkeit)
Validity example: Stress

- Attribute to be measured: Current level $S$ of stress of a person
  - (stress is not a well-defined state)
- Possible proxies:
  - Rate of heartbeat
  - Blood pressure
  - Muscle tone (Muskeltonus)
  - Skin temperature
  - Skin electrical resistance
- None of these alone is a very valid measure of stress
- However, they can be combined to form a fairly valid measure
  - This is used for instance in the Polygraph (Lügendetektor)
Validity example: Size of software

- Attribute to be measured:
  The size $S$ of a piece of software
  - (software size is not a well-defined attribute)
- Possible proxies:
  - Length of source code
    - In statements? In lines? In bytes?
    - In lines, but ignoring comments, empty lines, brace-only lines, ...
  - Length of object code
    - Using which compiler? Which settings?
  - Memory requirements
    - But: Does my sort program get bigger when it sorts a longer input sequence?
  - Functionality
    - Sensible idea! But: Unit? Measured how?
- Validity depends on purpose of measurement
What would we like to measure?

1. Attributes of the product:
   - Software size
   - Software quality
   - Software value

2. Attributes of the process:
   - Productivity (process efficiency)
   - Process quality

3. Predictors of any of these
Measuring software size

- Software size is of interest because it is a major factor for all process attributes relating to effort, such as
  - productivity
  - implementation/test/maintenance effort
- However, it is an elusive property. Sensible, valid measures of size are difficult to obtain.

- The most common measures are
  - Function points (at reqmts. level)
  - Number of pages of requirements (at reqmts. level)
  - Number of interfaces/modules/classes (at design level)
  - Lines-of-code (LOC) (at code level)
Measuring size: Function Points (FP)

- **Idea:**
  - Sum up the requirements, weighted by kind and complexity, in a standardized way to measure SW size

- **Advantages:**
  - Size can be determined early in the process
  - The measure is independent of language, technology, design style, superfluous functionality etc.

- **Function point rules:**
  - Count the number of input dialog screens ("inputs"), view/report screens ("outputs"), connections to other programs ("interfaces"), blocks of internal program state ("files")
  - Weigh each as "simple", "medium", or "complex" (according to well-defined criteria), each giving a fixed number of points
  - Sum up all these points

<table>
<thead>
<tr>
<th>FTR’s</th>
<th>DATA ELEMENTS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5</td>
<td>6-19</td>
<td>&gt; 19</td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>Low</td>
<td>Low</td>
<td>Ave</td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>Low</td>
<td>Ave</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>&gt; 3</td>
<td>Ave</td>
<td>High</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>
Function points are fairly well-defined
  - Detailed definitions exist for the requirement kinds and complexity classes
    - Even for SW changes (as opposed to new development)
  - Once the productivity (FP/personmonth) is known, FPs provide a good basis for project estimation

But:
  - Function points are valid only for certain kinds of system
    - Straightforward information systems whose internal processing is simple
      - The basic idea can be adapted to some other domains, though
  - Counting FPs is a manual process
    - Except if the requirements are structured along FP counting rules
Measuring size: Lines-of-Code (LOC)

- **Idea:**
  - Length of source code is a reasonable representative of size

- **Advantages:**
  - Can be measured automatically

- **Common definition:**
  - Count all lines containing program code (declaration/statement)
    - i.e., ignore empty lines and comment-only lines
  - Names: LOC (lines of code), KLOC (1000 LOC), SLOC (source LOC), NCSLOC (non-comment SLOC)

- **What to watch out for:**
  - Depends on programming language
  - Depends on formatting style
  - Heavily depends on program design
  - Should comments count or not?
  - Have code generators been used?

PF07resultsTR, Figure 10.5: Reused Modified, Reused, Manually written, Generated Modified, Generated
LOC: Dependence on language and program design

Each point is a different program by a different programmer, but all programs have the same functionality!
Measuring software quality

- Measuring quality is the holy grail of SW measurement
- Quality is not one attribute but many
  - e.g. efficiency, modifiability, readability, correctness, robustness, etc.
- All of them can only be measured after specifying context and assumptions
  - e.g. the workload or the expected changes
- Some of them can then be measured
  - e.g. efficiency by benchmarking
    - again several aspects: runtime, throughput, memory consumption, network traffic, energy consumption, etc.
  - e.g. learnability by a beginner experiment
    - measure task completion time, correctness, and success rates of beginners after receiving a well-defined training or instruction
- others are by-and-large impractical to measure
  - e.g. modifiability: How to generalize from one change to all?
Measuring quality: Quantify where possible

• Quality attributes are very important for software project agreements/contracts
• Therefore, all quality attributes that can be operationalized should really be defined and measured: "Quantify quality"
  • " Poor quantification is better than none" (Tom Gilb)
    • at least it can be; because it allows for systematic progress
• Definitions could be part of the contract
• Measurements can be part of the acceptance test
• They will often involve human beings and subjectivity, but that is acceptable if statistical averaging is used
  • e.g. test learnability by measuring a group of 20 random representative users
  • See course "Empirische Bewertung in Informatik"
• Definitions will change as you learn how to measure better

Tom Gilb
Note: Quality and complexity attribute scales

There are a number of important attributes of software for which no good ratio scales are known

In particular:

- Quality
  - And all quality attributes such as comprehensibility, usability, portability, maintainability, etc.

- Complexity

- These are frequent places of scale type mis-use
  - So watch out what you are doing
  - e.g. reducing the number of defects by half is not doubling the correctness
    - correctness is bounded by 1 and does probably not have a sensible ratio scale (as opposed to reliability, which has one)
Measure quality: defects

- Most quality measures are costly to evaluate
  - They require much additional effort
- Hence, most projects take a much simplified approach: They count defects only
  - Hence they only measure correctness and measure it indirectly:
    - Some defects lead to frequent failures, others to rare ones or none;
    - Some failures have high impact, others are negligible
- Defects can be counted in various situations:
  - during inspections
  - during testing
  - after delivery ("field defects")
- Defects can be classified in various ways
  - See separate lecture
Measuring productivity

- Increasing productivity is one of the main goals of software engineering
- In general terms, productivity is output per input
  - For SW engineering: Amount (or value) of SW produced per effort invested
- Effort can be measured reasonably well
  - see next slide
- We have discussed measuring the amount (size) of SW before: This is a vague concept!
- Value would be a good replacement for amount
  - but is difficult to measure as well
  - see lecture "economical view of SE"
Measuring productivity: effort

When measuring effort, take into account:

• Which tasks to measure:
  • usually design, coding, testing,
  • perhaps also requirements.
  • What about learning and training time?
    • technology, domain, specific requirements
  • What about overhead?
    • typically 10-30% of work time of engineering staff

• Whose effort to include:
  • only software engineering staff
  • or also: administrative support (secretary),
    customer contact (sales, customer support),
    technical project support (system administration),
    customers' participation.
Possible levels of productivity

Very, very, very roughly (these are examples only!):

• Individual programmer, small program, known technology and domain:
  • Coding only: 100 LOC/hour
  • Design/code/test: 30 LOC/hour
  • Overall: 60 LOC/personhour

• 5-person team, 50 KLOC project, known technology and domain:
  • Overall: 6 LOC/personhour
  • i.e., this project takes 9 months

• 20-person team, 100 KLOC project, unproven technology, embedded SW, known domain:
  • Overall: 1 LOC/personhour
  • i.e., this project takes 29 months!

• These values can vary over rather wide range
  • and are influenced by many factors, see next slide for examples
Example: Productivity study

- 29 projects from Hewlett Packard (median size 70 KLOC)
- MacCormack et al., IEEE Software, September 2003

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Mean</th>
<th>Median</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defect rate</td>
<td>Average no. of customer-reported defects per month per million lines of new code over first 12 months</td>
<td>18.8</td>
<td>7.1</td>
<td>23.1</td>
<td>0.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Productivity</td>
<td>New LOC developed per person-day</td>
<td>26.4</td>
<td>17.6</td>
<td>24.0</td>
<td>0.7</td>
<td>85.0</td>
</tr>
<tr>
<td>Functional specification</td>
<td>Percentage of functional specification that was complete before team started coding</td>
<td>55%</td>
<td>55%</td>
<td>32%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Design specification</td>
<td>Percentage of detailed design specification complete before team started coding</td>
<td>20%</td>
<td>10%</td>
<td>26%</td>
<td>0%</td>
<td>80%</td>
</tr>
<tr>
<td>Design review</td>
<td>Binary: 1 if design reviews were performed during development, 0 if not</td>
<td>0.79</td>
<td>1</td>
<td>0.41</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Code review</td>
<td>Binary: 1 if the number of people who typically reviewed another person’s code was one or more, 0 if none</td>
<td>0.52</td>
<td>1</td>
<td>0.51</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Subcycles</td>
<td>Binary: 1 if development was divided into separate subcycles, 0 if not</td>
<td>0.76</td>
<td>1</td>
<td>0.43</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Early prototype</td>
<td>Percentage of final product’s functionality contained in the first prototype</td>
<td>38%</td>
<td>40%</td>
<td>24%</td>
<td>0%</td>
<td>90%</td>
</tr>
<tr>
<td>Daily builds</td>
<td>Binary: 1 if design changes were integrated into code base and compiled daily; 0 if not</td>
<td>0.32</td>
<td>0</td>
<td>0.48</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Regression test</td>
<td>Binary: 1 if someone ran an integration or regression test when checking code into the build; 0 if not</td>
<td>0.55</td>
<td>1</td>
<td>0.51</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Example: Productivity study results

Results of the study:

• Several of the development practices investigated have a large impact on either productivity or product quality:
  • System SW has much higher defect rates
  • Automated tests upon each check-in correlate with greatly improved resulting quality, as do design reviews
  • Daily builds correlate with greatly increased productivity

• (Note: The study only indicates correlation, not causation!)

<table>
<thead>
<tr>
<th>Model</th>
<th>Defect rate</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>16.36</td>
<td>34.9****</td>
</tr>
<tr>
<td>Systems</td>
<td>14.87**</td>
<td></td>
</tr>
<tr>
<td>Early prototype†</td>
<td>0.48***</td>
<td>−0.42***</td>
</tr>
<tr>
<td>Daily builds</td>
<td></td>
<td>16.89**</td>
</tr>
<tr>
<td>Regression test</td>
<td>−12.64**</td>
<td></td>
</tr>
<tr>
<td>Design review</td>
<td>−19.65**</td>
<td></td>
</tr>
<tr>
<td>R-squared (adjusted)</td>
<td>74.6%</td>
<td>52.8%</td>
</tr>
<tr>
<td>F-ratio</td>
<td>15</td>
<td>11.1</td>
</tr>
<tr>
<td>Df</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>
Measuring process quality

• For process improvement, we are not only interested in product quality, but also in the quality of the process that produced it

• Common measures of process quality:
  • Productivity (as seen above)
  • Inspection yield
    • What fraction of all defects present in a document is found by an inspection?
  • Defect insertion
    • How often do defect corrections introduce new defects?
  • Schedule accuracy/predictability
    • Tasks: How much too long how often?
    • When does replanning occur (early/late)?
  • Churn
    • What fraction of documents (e.g. code files) is changed frequently? How frequently?
  • etc.
Example: A qualitative process compliance measure

- Marek Leszak, Dewayne Perry, Dieter Stoll: "Classification and evaluation of defects in a project retrospective", J. of Systems and Software 61(3), April 2002
- Define a 3-level ordinal measure of QA process compliance
  - levels green, yellow, red
  - based on process compliance with respect to unit test, code review, design review, integration test
Example: A qualitative process compliance measure (2)

- and use it to compare defect densities
Measurement in the software process

- All measurement must be made for a specific, well-understood purpose
  - i.e., in order to reach a process-related goal
- Otherwise, the measurements will probably not be useful

- Further, the process must support the measurement
- Otherwise
  - measurement cost will often be high
  - data quality may be low (mistakes, lack of precision, gaps)

- An approach for designing and arranging goal-directed, well-supported measurement programmes is called **GQM**
  - see next slide
Goal-Question-Metric (GQM)


- Step 1(G): Establish the goals of the data collection
  - e.g. "Understand our software changes and change process"

- Step 2(Q): Formulate questions of interest
  - e.g. "What is the distribution of change reasons?", "What is the distribution of changes over system components?", "How large are individual changes?", "How much effort is needed for individual changes?"

- Step 3(M): Define concrete measurements (metrics)
  - categorial ones, e.g. change reason classes, subtask types
  - quantitative ones, e.g. number of files modified, person hours
GQM (2)

• Step 4(M): Implement the measurement
  • Manual measurement: develop a data collection form
  • Automated measurement: implement data collection software
  • Introduce the process change that includes the measurement

• Step 5(M): Collect and validate data
  • Validate as soon as possible
    • Initially all data, later samples of data
  • Validate even automatically collected data

• Step 6(Q): Analyze data
  • Analyze measurement data in order to answer questions

• And then(G):
  • Progress towards your goal,
  • perhaps modify measurements
Summary

- Measurement is assigning values to attributes of objects
  - There are different scale types for the values: Beware!
- Quality attributes of measures: validity, reliability, precision
  - For most of the interesting attributes of SW and SW processes, it is very difficult to define highly valid measures!
- Common measures of software size:
  - Lines-of-code, Function points
- Common measures of software quality are often based on number of defects
- Most measures of productivity are dubious,
  - because they are based on size rather than value
- Process measures are often more interesting than product measures
Thank you!