Quality Management of Software and Systems

Software Measurement

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Motivation
Measurement

- *„When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.“*
  (Lord Kelvin, Popular Lectures and Addresses, 1889)
- *„Was man messen kann, das existiert auch!“*
  (Max Planck, 1858 - 1947)

Motivation
Measurements in Software Development

- Substitutes quantitative and reproducible statements for qualitative and usually intuitive statements about software
- Example
  - Qualitative, intuitive
    - The developer states: ‘I have fully tested my software module.’
  - Quantitative, reproducible
    - ‘My test tools states a branch coverage of **57% (70 of 123 branches)** at the moment. In our company modules are considered sufficiently tested with a branch coverage of **95%**. Thus, I have to test at least **47** additional branches with an estimated additional effort of **1.5 days** based on experiences with similar modules.’

Motivation
Measuring Quality in Software Development

- Today, software is used in application domains, where quantitative statements are common or necessary
  - Contracts: 'We stipulate a minimum availability of 99.8%!'
  - Safety proof of a rail system for the Eisenbahnbundesamt: 'What is the residual risk of software failures?'
  - Is the estimated number of residual faults sufficiently small to release the products?
  - Is the possibility of software faults in controllers causing a failure in our upper class limousine sufficiently small?
  - We need a failure free mission time of four weeks. Is this possible?

Motivation
Measuring Quality in Software Development: Problems

- Most quality characteristics not directly measurable!
  - Number of faults
  - Availability
  - Reliability
  - Safety
  - ...
- Quality characteristics may be
  - Determined experimental (e.g., reliability)
  - Calculated from directly measurable characteristics (e.g., number of faults)

Software Quality Experiments
Stochastic Analysis of Software Reliability: Situation

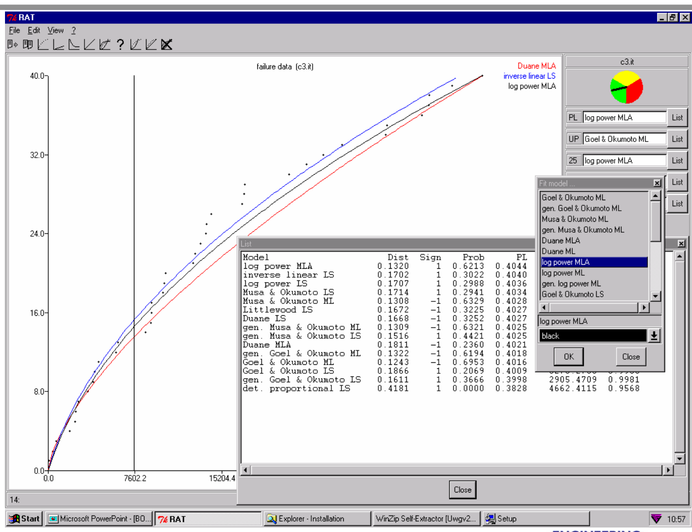
- Independent research area since approximately 30 years
- Sparse influence to software development in practice
- Mathematical foundation partly too complex
- A lot of different stochastic reliability models
- A priori selection of a model not possible
- Determination of model parameters necessary
- Theory application to practice needs powerful tool support

Software Quality Experiments
Stochastic Analysis of Software Reliability: Theory

$$m(t) = E(N(t))$$

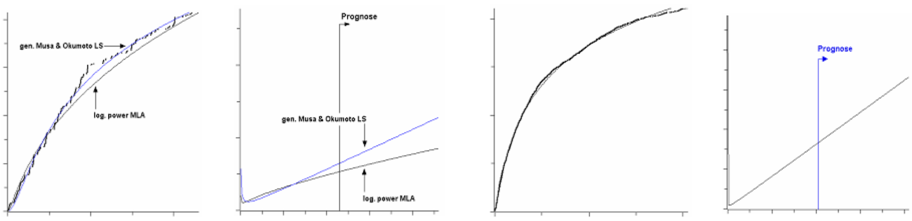
- Musa and Goel-Okumoto model, respectively $m(t) = a(1 - e^{-bt})$
- Generalized Goel-Okumoto model $m(t) = a(1 - e^{-bt^c})$
- Musa-Okumoto model $m(t) = a\ln(bt + 1)$
- Generalized Musa-Okumoto model $m(t) = a\ln(bt^c + 1)$
- Duane and Crow model, respectively $m(t) = at^b$
- Log model $m(t) = a\ln(bt)$
- Log power model $m(t) = a\ln^b(t + 1)$
- Generalized log power model $m(t) = a\ln^b(ct + 1)$
- Yamada S-shape model $m(t) = a(1 - (1 + bt)e^{-bt})$
- Generalized Yamada S-shape model $m(t) = a(1 - (1 + ct)e^{-bt})$
- Geometric Moranda and deterministic proportional model, resp. $m(t) = a + b\ln(t + 1)$
- Littlewood model $m(t) = c(t + a)^{-b}$
- Inverse linear model $m(t) = a(\sqrt{bt + 1} - 1)$

Software Quality Experiments
Stochastic Analysis of Software Reliability: Practical Method of Resolution

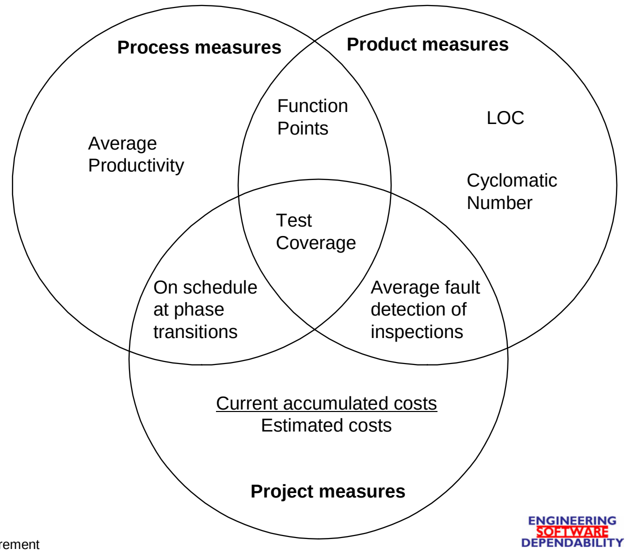


Software Quality Experiments
Stochastic Analysis of Software Reliability: Practical Method of Resolution

- ☐ Numerous application domains (traffic engineering, medical engineering, telecommunication, ...)



Software Measures
Applying Measures

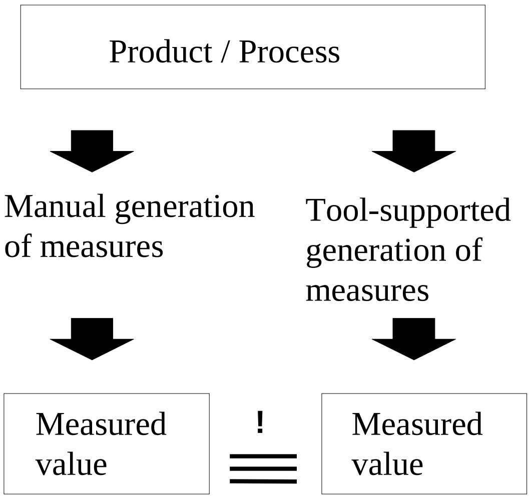


Software Measures
Requirements of Measures

- Simplicity
  - Is the result so simple that it could be easily interpreted?
- Adequacy
  - Covers the measure the desired characteristic?
- Robustness
  - Is the value of the measure stable against manipulations of minor importance?
- Timeliness
  - Can the measure be collected in sufficient time to allow a reaction to the process?
- Analyzability
  - Is the measure statistically analyzable (e.g., numeric domain) (For this requirement the type of the measure scale is crucial)

Software Measures
Requirements of Measures: Reproducibility

- Normally, a measure is reproducible, independent of the generation mechanism, if it is defined in a precise way



Software Measures
Requirements of Measures: Reproducibility

- Examples
  - McCabe's cyclomatic number: e-n+2

    e = Number of edges in a CFG; n = Number of nodes in a CFG; CFG = Control flow graph
    - Completely reproducible
  - Lines of Code (LOC)

    Count empty lines? Count lines with comment?
    - Completely reproducible, if adequately defined
  - Function Points: manual evaluation of complexities needed
    - Not completely reproducible in principle
  - Understandability
    - Poor reproducibility

Software Measures
Evaluation of Measures

- A recommendation of lower and upper bounds for measures is difficult
- Which values are 'normal' must be determined by experience
- A deviation from usual values may indicate a problem, not necessarily, though

Software Measures
Calibration of Measures and Models

- The correlation between measures and relevant characteristics demands a calibration, which has to be adapted to changing situations if necessary
- Empirical and theoretical models can be distinguished
- Example
  - Theoretical effort model (cp. Halstead-Measures)
    $E = \dots size^2 \dots$

    The square correlation between effort and size was identified by theoretical considerations
  - Empirical effort model: E = ... size^1.347 ...

    The exponent of 1.347 was determined by statistical data analysis

Measuring Scales

- While expressing abstract characteristics as numerical value, it is necessary to figure out which operations can be reasonably performed on the values
- Example
  - Measuring length
    - Board *a* has a length of one meter. Board *b* has a length of two meters. Thus, board *b* is two times as long as board *a*.
    - This statement makes sense
  - Measuring temperature
    - Today, we have 20°C. Yesterday it was 10°C. Hence, today it is twice as hot as yesterday
    - That is wrong. The correct answer would be: Today is approximately 3.5 % warmer than yesterday
  - Obviously, there is a difference between the temperature scale in °C and the length in meters, which leads to operations not applicable to the temperature scale

Measuring Scales

- Nominal scale
  - Free labeling of specific characteristics
  - Inventory numbers of library books (DV 302, PH 002, CH 056, ...)
  - Names of different requirements engineering methods (SA; SADT, OOA; IM, ...)
- Ordinal scale
  - Mapping of an ordered attribute's aspect to an ordered set of measurement values, such that the order is preserved
  - Mapping of patient arrivals to the waiting list in a medical practice
- Interval scale
  - A scale, which is still valid if transformations like g(x) = ax + b, with a > 0 are applied
  - Temperature scales in degree Celsius or Fahrenheit. If F is a temperature in the Fahrenheit scale, the temperature in the Celsius scale can determined as follows: C = $^5/_9$ (F - 32). The relations between temperatures are preserved

Measuring Scales

- Rational scale
  - Scale, where numerical values can be related to each other (percental statements make sense)
  - Length in meters (It is twice as far from a to b than from c to d)
  - Temperature in Kelvin
- Absolute scale
  - Scale, providing the only possibility to measure circumstances
  - Counting

Cyclomatic Complexity

- Common measure of complexity
- Often surrounded with an aura of an ‘important’ key measure
- Originated from graph theory (strongly connected graphs) and thus relating to control flow graphs and programs
- Calculation: e – n + 2
  (e = Number of edges, n = Number of nodes)
- Easy to calculate as it depends strongly on the number of decisions within the program
- Suited as complexity measure, if the number of decisions predicate the complexity of the program
- Probably the most common measure in analysis and testing tools

Cyclomatic Complexity

- Cyclomatic number is a measure of the structural complexity of programs
- Calculation based on the control flow graph
- Cyclomatic number v(G) of a graph is: v(G) = e - n + 2

  (e – Number of edges, n – Number of nodes)

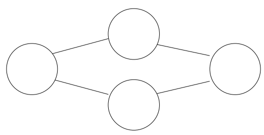
Cyclomatic Complexity

- Cyclomatic complexity of graphs

Sequence

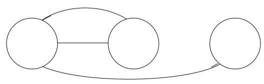
v(G) = 1-2+2 = 1

Selection



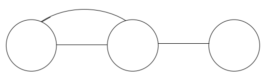
v(G) = 4-4+2 = 2

Pre-test loop



v(G) = 3-3+2 = 2

Post-test loop



v(G) = 3-3+2 = 2

Current Impact of Software Measurements

- Efficient software measurements are important for the following areas
  - Flat management structures
  - Standardizations with respect to software developments
  - Achieving a high Capability Maturity Level (Assessments)

Current Impact of Software Measurements
Software Measurements and Flatter Management Structures

- Trend for software management towards flat structures
  - One manager supervises significant more developer than before
  - Provision and summarization of information not through middle management, but automated measurement systems
  - Management intervention only necessary if measurement values indicates problematic situations

➔ Efficient measurement is an important requirement

Current Impact of Software Measurements
Software Measurements and Software Development Standards

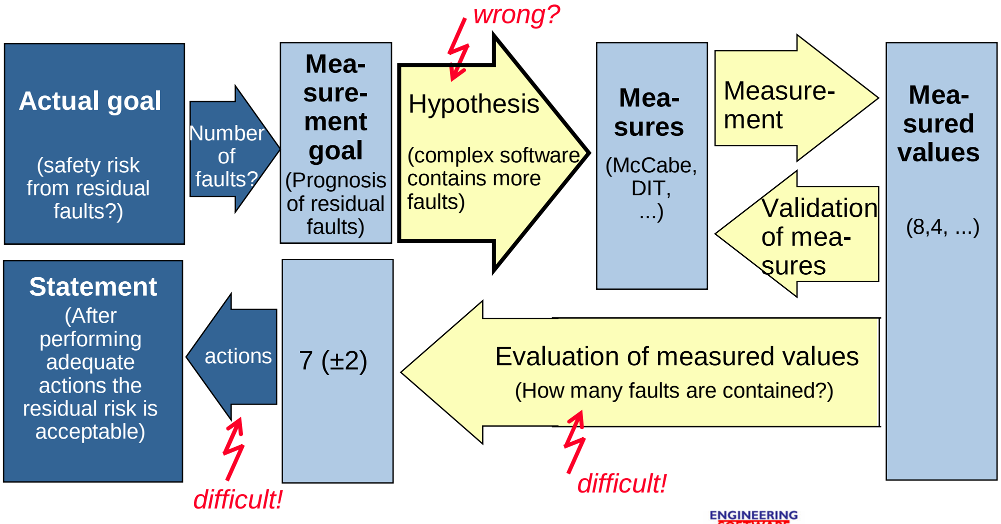
- Standards become more and more important for the software development (e.g., ISO 9001)
  - Quality proof for potential customers
  - Marketing argument; differentiation from not certified competitors
  - Important with respect to product liability
  - In some domains requirement for the contract
  - All standards attach importance to systematic procedures, transparency, and control of the development process

  ➔This can be proved by adequate measures

Current Impact of Software Measurements
Software Measurements and the Capability Maturity Model

- Capability Maturity Model assigns the maturity of a software development process to one of five levels. The possible levels are: 1-initial, 2-repeatable, 3-defined, 4-managed, 5-optimized
- Reaching level 4 or 5 is only possible if a measurement system exists and is used that provides the following tasks
  - Measurement of productivity and quality
  - Evaluation of project based on this measurements
  - Detection of deviations
  - Arrange corrective activities if deviations occur
  - Identification and control of project risks
  - Prognosis of project progress and productivity

Software Quality Measurement
Chain of Reasoning



Software Quality Measurement
Popular Hypotheses in Theory and Practice

	/Fenton, Ohlsson 00/	/Basili, et al. 96/	/Cartwright, Shepperd 00/	/Basili, Perricone 84/	/Abreu, Melo 96/
Few modules contain the majority of faults	++	++	(+)	++	/
Few modules generate the majority of failures	++	/	/	/	/
Many faults during the module test means many faults during the system test	+	/	/	/	/
Many faults during the test means many failures during usage	--	/	/	/	/
Fault density of corresponding phases are constant between releases	+	/	/	/	/
Size measures are adequate for the fault prediciton	+	/	+	-	/

++: strong conformation; +: light conformation; 0: no statement;
-: light refusal; -- strong refusal; /: not evaluated; ?: unclear

Software Quality Measurement
Popular Hypotheses in Theory and Practice: Findings I

- Faults are not uniformly distributed among software modules, but concentrated in few modules
- This modules generate the majority of all problems
- Larger module size does not necessarily mean more faults
- Many discovered problems during the tests does not mean that the software shows a lack of quality during practice
- There seem to be rules guaranteeing that subsequent developments provide similar results
- **Question**
  - **How can the few modules that contain the majority of faults be discovered?**

Software Quality Measurement
Popular Hypotheses in Theory and Practice

	/Fenton, Ohlsson 00/	/Basili, et al. 96/	/Cartwright, Shepperd 00/	/Basili, Perricone 84/	/Abreu, Melo 96/
Code complexity measures are better means for fault prediction	Better than size measures: -	WMC: +	WMC: /	Better than size measures: -	MHF: +
		DIT: ++	DIT: ++		AHF: 0
		RFC: ++	RFC: /		MIF: +
		NOC: ?	NOC: ?		AIF: (+)
		CBO: ++	CBO: /		POF: +
		LCOM: 0	LCOM: /		COF: ++

- Object-oriented measures
  - WMC (*Weighted Methods per Class*)
  - DIT (*Depth of Inheritance Tree*)
  - NOC (*Number Of Children*)
  - CBO (*Coupling Between Object-classes*)
  - RFC (*Response For a Class*)
  - LCOM (*Lack of Cohesion on Methods*)
  - MHF: *Method Hiding Factor*
  - AHF: *Attribute Hiding Factor*
  - MIF: *Method Inheritance Factor*
  - AIF: *Attribute Inheritance Factor*
  - POF: *Polymorphism Factor*
  - COF: *Coupling Factor*

Software Quality Measurement
Popular Hypotheses in Theory and Practice: Findings II

- Several simple complexity measures (e.g., McCabes cyclomatic number) are not better than size measures (e.g., LOC)
- Specific complexity measures display a good quality of fault prediction
- **Conclusion**
  - **A suitable combination of adequate complexity measures enables a directed identification of faulty modules**

Software Quality Measurement
Popular Hypotheses in Theory and Practice

	/Fenton, Ohlsson 00/	/Basili, et al. 96/	/Cartwright, Shepperd 00/	/Basili, Perricone 84/	/Abreu, Melo 96/
Model-based *(Shlaer-Mellor)* measures are suited for fault prediction	/	/	Events: ++	/	/
Model-based measures are not suited for size prediction	/	/	States: ++	/	/

Software Quality Measurement
Popular Hypotheses in Theory and Practice: Findings III

- It is possible to derive measures from software design to predict code size and fault numbers at an early stage

Software Quality Measurement
Conclusions

- Statistic methods for deriving software reliability are theoretically funded and applicable in practice
- Several plausible hypotheses are empirically falsified, but there is evidence that
  - Faults concentrates in few modules
  - This modules can be identified through measurements of
    - Code complexity
    - Complexity of design models
- Prediction of faults based on single measures (so called univariate analysis) is not possible. A suitable combination of measures (so called multivariate analyses) can produce reliable propositions
- It can be anticipated, that prediction models can be generated based on finished projects, as the similarity between subsequent projects is empirically supported

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Literature

- Halstead M.H., Elements of Software Science, New York: North-Holland 1977
- Zuse H., Software Complexity - Measures and Methods, Berlin, New York: De Gruyter 1991

ENGINEERING SOFTWARE DEPENDABILITY