Softwaretechnik / Software-Engineering

Lecture 2: Software Metrics

2016-04-21

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Is Software Development Always Successful? No.

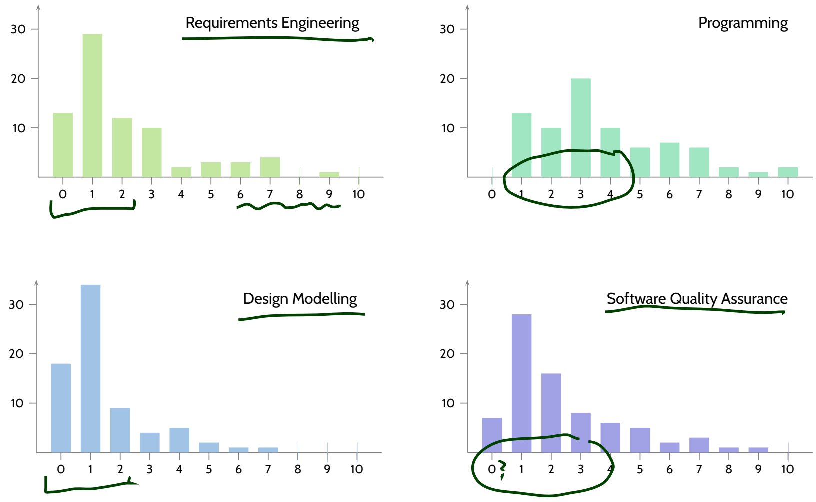

Ariane 5, V88


Therac-25


Toll Collect

- self-driving car, 2016; wrong strategy in traffic situation; crash, no injury
- game distribution platform, 2015; unintentional `rm -rf /`; damage not quantified
- car, 2015; security issue, remote exploit; 1.4 Mio. cars recalled
- car, 2014; unintended acceleration, stack overflows; people injured and killed
- photocopier, 2013; unintentional lossy compression; no damage known
- tiltrotor aircraft, 2000; hydraulic failure not handled; 4 killed
- credit card failures, 2000; incompatibility of new EMV chip; parties ruined
- spacecraft lander, 1998; landing gear operation in flight; 100s Mio. $
- war vessel, 1997; uncontrolled ship by division by 0; no damage
- plane landing, 1993; environment assumptions problem; 2 killed, 54 injured
- ambulance management, 1992; management issues, poor QA; 46 killed
- missile defense, 1991; integer overflow; 28 killed
- telephone infrastructure, 1990; erronously entered mode; 9h no phones, 75 + 100 Mio. $
- defense system, 1979; random bits, false rocket attack announced; no harm
- weather balloons, 1971; poor protocol design; 72 weather-balloons and data lost
- …

Survey: Previous Experience



Expectations

- none, because mandatory course
- **overall**
  - ✔ well-structured lectures
  - (✔) praxis oriented
  - ✘ practical knowledge about planning, designing and testing software
  - ✔ improve skills in scientific work
  - (✔) more about scientific methods
- **other courses**
  - ✘ more on how courses are linked together
  - ✘ skills we need to organise SoPra
  - ✔ maybe transfer knowledge in SoPra
- **"real world"**
  - ✔ vocabulary and methods in professional software development
  - ✔ learn how things work in a company, to easier integrate into teams, e.g., communication
- **kinds of software**
  - ✔ embedded systems and software
  - ✘ how to combine HW and SW parts

Introduction	L 1:	18.4., Mon
Scales, Metrics, Costs	L 2:	21.4., Thu
	L 3:	25.4., Mon
	T 1:	28.4., Thu
Development	L 4:	2.5., Mon
	-	5.5., Thu
Process	L 5:	9.5., Mon
	L 6:	12.5., Thu
	-	16.5., Mon
	-	19.5., Thu
	T 2:	23.5., Mon
	-	26.5., Thu
Requirements Engineering	L 7:	30.5., Mon
	L 8:	2.6., Thu
	L 9:	6.6., Mon
	T 3:	9.6., Thu
Architecture & Design	L10:	13.6., Mon
	L 11:	16.6., Thu
	L12:	20.6., Mon
	T 4:	23.6., Thu
Software Mondelling	L13:	27.6., Mon
	L14:	30.6., Thu
	L15:	4.7., Mon
	T 5:	7.7., Thu
Quality Assurance (Testing, Formal Verification)	L16:	11.7., Mon
	L17:	14.7., Thu
	L18:	18.7., Mon
Wrap-Up	L19:	21.7., Thu

Expectations Cont'd

- **software development**
  - ✔ understand how software development practically works
  - ✔ developing, maintaining software at bigger scale
  - ✔ aspects of software development
- **software project management**
  - ✔ learn what is important to plan
  - ✔ how to structure the process of a project
  - ✔ how to keep control of project, measure success
  - ✘ which projects need full-time project manager
  - ✘ which kind of documentation is really necessary
  - ✘ want to get better in leading a team; how to lead team of engineers
- **cost estimation**
  - ✔ how to estimate time and effort
  - (✘) formal methods for better planning of projects
  - ✘ tools which help planning
- **quality**
  - ✔ learn ways how to judge quality based on the requirements
  - ✔ avoid mistakes during software development
  - ✔ make better programs, or make programs more efficiently

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Expectations Cont'd

- **requirements**
  - ✔ formal ways to specify requirements
  - ✔ learn techniques to reduce misunderstandings
  - ✔ understand types of requirements
  - (✔) learn how requirements are to be stated
  - (✔) how to create requirements/specification document
- **design**
  - ✔ techniques for design
  - ✔ predict potential risks and crucial design errors
  - (✘) come up with good design, learn how to design
  - (✘) practical knowledge on application of design patterns
  - ✘ how to structure, compose components, how to define interfaces
  - ✘ standards for keeping parts of project compatible
  - ✘ how to guarantee a particular reliability
- **Implementation**
  - (✔) modular programming, better documentation of big projects
  - ✘ more of computers and programming, write faster better programs
  - ✘ strengths and weaknesses of standards, training in their application
  - ✘ improve coding skills
  - ✘ how to increase (software) performance

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Expectations Cont'd

- **code quality assurance**
  - ✔ methods for testing to guarantee high level of quality
  - (✔) how to conduct most exhaustive test as possible in reasonable time
  - ✔ formal methods like program verification
  - ✘ learn about practical implementation of these tools

- **extra information**
  - "will work as teacher"
  - "want to work on medical software"
  - "want to work in automotive industry"
  - "worked as software-engineer"

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Topic Area Project Management: Content

VL 2	• **Software Metrics**
	• Properties of Metrics
⋮	• Scales
	• Examples
VL 3	• **Cost Estimation**
	• Deadlines and Costs
⋮	• Expert's Estimation
	• Algorithmic Estimation
VL 4	• **Project Management**
	• Project
⋮	• Process and Process Modelling
	• Procedure Models
VL 5	• Process Models
	• **Process Metrics**
⋮	• CMMI, Spice

Content

- **Software Metrics**
  - Motivation
  - Vocabulary
  - Requirements on Useful Metrics
  - Excursion: Scales
  - Example: LOC
  - Other Properties of Metrics
  - Subjective and Pseudo Metrics
  - Discussion
- **Cost Estimation**
  - Deadlines and Costs
  - Expert's Estimation
  - Algorithmic Estimation

Software Metrics

Engineering vs. Non-Engineering

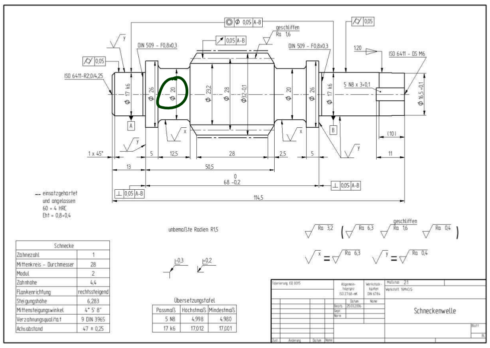
	workshop (technical product)	studio (artwork)
Mental prerequisite	the existing and available technical know-how	artist's inspiration, among others
Deadlines	can usually be planned with sufficient precision	cannot be planned due to dependency on artist's inspiration
Price	oriented on cost, thus calculable	determined by market value, not by cost
Norms and standards	exist, are known, and are usually respected	are rare and, if known, not respected
Evaluation and comparison	can be conducted using objective, quantified criteria	is only possible subjectively, results are disputed
Author	remains anonymous, often lacks emotional ties to the product	considers the artwork as part of him/herself
Warranty and liability	are clearly regulated, cannot be excluded	are not defined and in practice hardly enforceable

(Ludewig and Lichter, 2013)

Motivation

- Goal: **specify**, and **systematically compare** and **improve** industrial products.
- Approach: **precisely** describe and **assess** the products (and the process of creation).

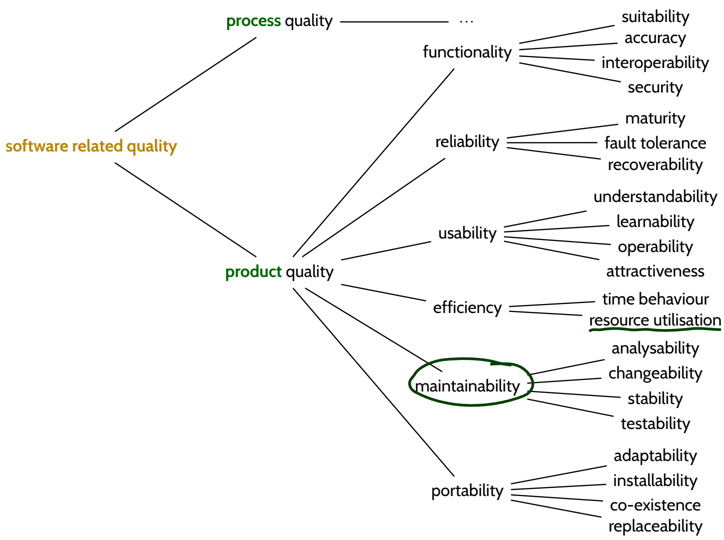
- This is common practice for **material goods**:



- Not so obvious (and common) for **immaterial goods**, like **software**.
  It should be common: **objective measures** are central to engineering approaches.

Why "no so obvious" for software?

- Recall, e.g., **quality** (ISO/IEC 9126-1:2000 (2000)):



Vocabulary

metric – A quantitative measure of the degree to which a system, component, or process posesses a given attribute.
See: quality metric. **IEEE 610.12 (1990)**

quality metric –

(1) A quantitative measure of the degree to which an item possesses a given quality attribute.

(2) A function whose inputs are software data and whose output is a single numerical value that can be interpreted as the degree to which the software possesses a given quality attribute. **IEEE 610.12 (1990)**

Software Metrics: Motivation and Goals

Important **motivations** and **goals** for using software metrics:

- **specify** quality requirements
- **assess** the quality of products and processes
- **quantify** experience, progress, etc.
- **predict** cost/effort, etc.
- support **decisions**

Software metrics can be used:

- **prescriptive**, e.g., "all prodecures must not have more then N parameters", or
- **descriptive**, e.g., "procedure P has N parameters".

  A **descriptive** metric can be

  - **diagnostic**, e.g., "the test effort was N hours", or
  - **prognostic**, e.g., "the expected test effort is N hours".

  Note: **prescriptive** and **prognostic** are different things.

- **Examples**: support decisions by **diagnostic** measurements:
  (i) Measure time spent per procedure, then "optimize" most time consuming procedure.
  (ii) Measure attributes which indicate architecture problems, then re-factor accordingly.

Requirements on Useful Metrics

Definition. A **software metric** is a function $m : P \to S$ which assigns to each **proband** $p \in P$ a **valuation yield** ("Bewertung") $m(p) \in S$. We call S **scale**.

In order to be useful, a (software) metric should be:

differentiated	worst case: same valuation yield for all probands
comparable	ordinal scale, better: rational (or absolute) scale ($\rightarrow$ in a minute)
reproducible	multiple applications of a metric to the same proband should yield the same valuation
available	valuation yields need to be in place when needed
relevant	wrt. overall needs
economical	worst case: doing the project gives a perfect prognosis of project duration – at a high price; **irrelevant** metrics are not economical (if not available for free)
plausible	($\rightarrow$ pseudo-metric)
robust	developers cannot arbitrarily manipulate the yield; antonym: **subvertible**

Excursion: Scales

Scales and Types of Scales

Scales S are distinguished by supported **operations**:

	$=, \neq$	$<, >$ (with transitivity)	$\min$, $\max$	percen-tiles, e.g. median	Δ	propor-tion	natural 0 (zero)
nominal scale	✔	✘	✘	✘	✘	✘	✘
ordinal scale	✔	✔	✔	✔	✘	✘	✘
interval scale (with units)	✔	✔	✔	✔	✔	✘	✘
rational scale (with units)	✔	✔	✔	✔	✔	✔	✔
absolute scale	a rational scale where S comprises the key figures itself						

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interval scale (with units)	✔	✔	✔	✔	✔	✘	✘
rational scale (with units)	✔	✔	✔	✔	✔	✔	✔
absolute scale	a rational scale where S comprises the key figures itself						

Examples: **Nominal Scale**

- nationality, gender, car manufacturer, geographic direction, train number, …
- **Software engineering example**: programming language ($S = \{\texttt{Java}, \texttt{C}, \dots\}$)

$\rightarrow$ There is no (natural) order between elements of S; the lexicographic order can be imposed ("$\texttt{C} < \texttt{Java}$"), but is not related to the measured information (thus not natural).

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interval scale (with units)	✔	✔	✔	✔	✔	✘	✘
rational scale (with units)	✔	✔	✔	✔	✔	✔	✔
absolute scale	a rational scale where S comprises the key figures itself						

Examples: **Ordinal Scale**

- strongly agree $>$ agree $>$ disagree $>$ strongly disagree; Chancellor $>$ Minister (administrative ranks);
- leaderboard (finishing number tells us that 1st was faster than 2nd, but not how much faster)
- types of scales, …
- **Software engineering example**: CMMI scale (maturity levels 1 to 5) ($\rightarrow$ later)

$\rightarrow$ There is a (natural) **order** between elements of M,
but no (natural) notion of **distance** or **average**.

Scales and Types of Scales

Scales S are distinguished by supported **operations**:

	$=, \neq$	$<, >$ (with transitivity)	$\min$, $\max$	percen-tiles, e.g. median	Δ	propor-tion	natural 0 (zero)
nominal scale	✔	✘	✘	✘	✘	✘	✘
ordinal scale	✔	✔	✔	✔	✘	✘	✘
interval scale (with units)	✔	✔	✔	✔	✔	✘	✘
rational scale (with units)	✔	✔	✔	✔	✔	✔	✔
absolute scale	a rational scale where S comprises the key figures itself						

Examples: **Interval Scale**

- temperature in Fahrenheit
  - "today it is 10°F warmer than yesterday" ($\Delta(\vartheta_{\text{today}}, \vartheta_{\text{yesterday}}) = 10$°F)
  - "100°F is twice as warm as 50°F": …? No. Note: the zero is arbitrarily chosen.
- **Software engineering example**: time of check-in in revision control system

$\rightarrow$ There is a (natural) notion of difference $\Delta : S \times S \rightarrow \mathbb{R}$, but no (natural) proportion and 0.

Scales and Types of Scales

Scales S are distinguished by supported **operations**:

	$=, \neq$	$<, >$ (with transitivity)	min, max	percentiles, e.g. median	Δ	proportion	natural 0 (zero)
nominal scale	✔	✘	✘	✘	✘	✘	✘
ordinal scale	✔	✔	✔	✔	✘	✘	✘
interval scale (with units)	✔	✔	✔	✔	✔	✘	✘
rational scale (with units)	✔	✔	✔	✔	✔	✔	✔
absolute scale	a rational scale where S comprises the key figures itself						

Examples: **Rational Scale**

- age ("twice as old"); finishing time; weight; pressure; price; speed; distance from Freiburg...
- **Software engineering example**: runtime of a program for given inputs.

$\rightarrow$ The (natural) zero induces a meaning for proportion m_1/m_2.

Scales and Types of Scales

Scales S are distinguished by supported **operations**:

	$=, \neq$	$<, >$ (with transitivity)	min, max	percentiles, e.g. median	Δ	proportion	natural 0 (zero)
nominal scale	✔	✘	✘	✘	✘	✘	✘
ordinal scale	✔	✔	✔	✔	✘	✘	✘
interval scale (with units)	✔	✔	✔	✔	✔	✘	✘
rational scale (with units)	✔	✔	✔	✔	✔	✔	✔
absolute scale	a rational scale where S comprises the key figures itself						

Examples: **Absolute Scale**

- seats in a bus, number of public holidays, number of inhabitants of a country, ...
- "average number of children per family: 1.203" – what is a 0.203-child?
  The absolute scale has been **used as** a rational scale (makes sense for certain purposes if done with care).
- **Software engineering example**: number of known errors.

$\rightarrow$ An absolute scale has a **median**, but in general not an average **in** the scale.

Something for the Mathematicians...

Recall:

Definition. [*Metric Space (math.)*]

Let X be a set. A function $d : X \times X \to \mathbb{R}$ is called **metric** on X if and only if, for each $x, y, x \in X$,

(i) $d(x, y) \geq 0$ (non-negative)

(ii) $d(x, y) = 0 \iff x = y$ (identity of indiscernibles)

(iii) $d(x, y) = d(y, x)$ (symmetry)

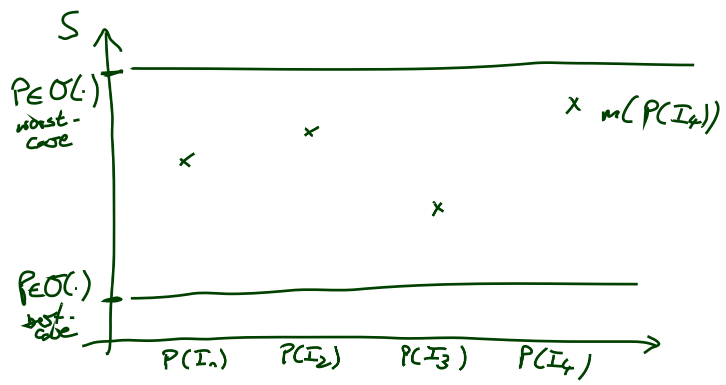
(iv) $d(x, z) \leq d(x, y) + d(y, z)$ (triangle inequality)

(X, d) is called **metric space**.

$\rightarrow$ different from all scales discussed before;
a metric space requires more than a rational scale.

$\rightarrow$ definitions of, e.g., IEEE 610.12, may use standard (math.) names for different things

Something for Comp. Scientist

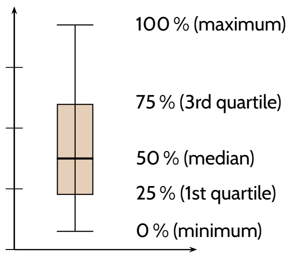


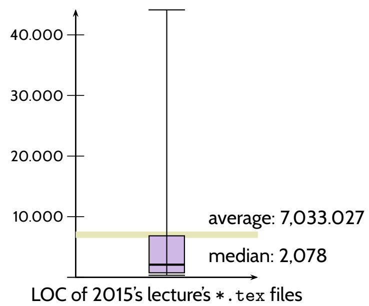
Median and Box-Plots

	M_1	M_2	M_3	M_4	M_5
LOC	127	213	152	139	13297

- **arithmetic average**: 2785.6
- **median**: 127, 139, **152**, 213, 13297

- a **boxplot** visualises 5 aspects of data at once
  (whiskers sometimes defined differently, with "outliers"):

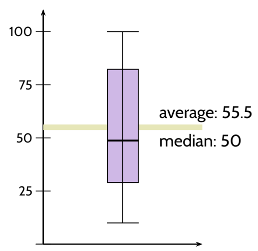




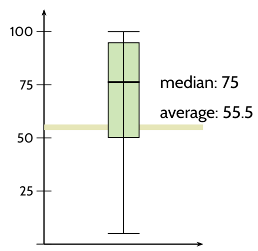
Example: Project Management

m: commits took place at n-th day of project.

Team A:
$10, 20, 30, 40, 50, 60, 70, 80, 90, 100$



Team B:
$5, 50, 60, 75, 80, 85, 95, 100$



Team B: "Oh, this SoPra was so stressful…Could we have done something about that?"

Back From Excursion: Scales

Requirements on Useful Metrics

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comparable	ordinal scale, better: rational (or absolute) scale
reproducible	multiple applications of a metric to the same proband should yield the same valuation
available	valuation yields need to be in place when needed
relevant	wrt. overall needs
economical	worst case: doing the project gives a perfect prognosis of project duration – at a high price; **irrelevant** metrics are not economical (if not available for free)
plausible	($\rightarrow$ pseudo-metric)
robust	developers cannot arbitrarily manipulate the yield; antonym: **subvertible**

Example: Lines of Code (LOC)

```
/* https://de.wikipedia.org/wiki/
 * Liste_von_Hallo-Welt-Programmen/
 * H%C3%B6here_Programmiersprachen#Java */

class Hallo {
␣
␣public static void
␣main( String[] args ) {
␣  System.out.print(
␣    "Hallo␣Welt!" ); // no newline
␣}
}
```

$LOC_{tot} = 12$
$LOC_{ne} = 11$
$LOC_{pars} = 7$

dimension	unit	measurement procedure
program size	LOC_{tot}	number of lines in total
net program size	LOC_{ne}	number of non-empty lines
code size	LOC_{pars}	number of lines with not only comments and non-printable
delivered program size	DLOC_{tot}, DLOC_{ne}, $\text{DLOC}_{\text{pars}}$	like LOC, only code (as source or compiled) given to customer

(Ludewig and Lichter, 2013)

differentiated	✓
comparable	✓
reproducible	✓
available	✓
relevant	?
economical	✓
plausible	(✓)
robust	?

More Examples

characteristic ('Merkmal')	positive example	negative example
differentiated	program length in LOC	CMM/CMMI level below 2
comparable	cyclomatic complexity	review (text)
reproducible	memory consumption	grade assigned by inspector
available	number of developers	number of errors in the code (not only known ones)
relevant	expected development cost; number of errors	number of subclasses (NOC)
economical	number of discovered errors in code	highly detailed timekeeping
plausible	cost estimation following COCOMO (to a certain amount)	cyclomatic complexity of a program with pointer operations
robust	grading by experts	almost all pseudo-metrics

(Ludewig and Lichter, 2013)

Other Properties of Metrics

Kinds of Metrics: ISO/IEC 15939:2011

> **base measure** – measure defined in terms of an attribute and the method for quantifying it. **ISO/IEC 15939 (2011)**

Examples:

- lines of code, hours spent on testing, ...
-

> **derived measure** – measure that is defined as a function of two or more values of base measures. **ISO/IEC 15939 (2011)**

Examples:

- average/median lines of code, productivity (lines per hour), ...
-

Kinds of Metrics: by Measurement Procedure

	objective metric	pseudo metric	subjective metric
Procedure	measurement, counting, poss. normed	computation (based on measurements or assessment)	review by inspector, verbal or by given scale
Advantages	exact, reproducible, can be obtained automatically	yields relevant, directly usable statement on not directly visible characteristics	not subvertable, plausible results, applicable to complex characteristics
Disadvantages	not always relevant, often subvertable, no interpretation	hard to comprehend, pseudo-objective	assessment costly, quality of results depends on inspector
Example, general	body height, air pressure	body mass index (BMI), weather forecast for the next day	health condition, weather condition ("bad weather")
Example in Software Engineering	size in LOC or NCSI; number of (known) bugs	productivity; cost estimation following COCOMO	usability; severeness of an error
Usually used for	collection of simple base measures	predictions (cost estimation); overall assessments	quality assessment; error weighting

(Ludewig and Lichter, 2013)

Pseudo-Metrics

Pseudo-Metrics

Some of the **most interesting aspects** of software development projects are **hard or impossible** to measure directly, e.g.:

- how **maintainable** is the software?
- how much **effort** is needed until completion?
- how is the **productivity** of my software people?
- do all modules do **appropriate error handling**?
- is the **documentation** sufficient and well usable?

Due to **high relevance**, people **want to measure** despite the difficulty in measuring. Two main approaches:

	differentiated	comparable	reproducible	available	relevant	economical	plausible	robust
Expert review, grading	(✔)	(✔)	(✘)	(✔)	✔!	(✘)	✔	✔
Pseudo-metrics, derived measures	✔	✔	✔	✔	✔!	✔	✘	✘

Note: not every derived measure is a pseudo-metric:

- **average LOC per module**: derived, **not pseudo** $\rightarrow$ we really measure average LOC per module.
- measure **maintainability** in average LOC per module: derived, **pseudo**
  $\rightarrow$ we don't really **measure** maintainability; average-LOC is only **interpreted** as maintainability.
  Not robust if easily subvertible (see exercises).

Pseudo-Metrics Example

Example: **productivity** (derived).

- Team T develops software S with LOC $N = 817$ in $t = 310$h.
- Define **productivity** as $p = N/t$, here: ca. 2.64 LOC/h.
- Pseudo-metric: measure **performance**, **efficiency**, **quality**, … of teams by **productivity** (as defined above).
- team may write

```
x
:=
y
+
z;
```

instead of `x := y + z;`

$\rightarrow$ 5-time productivity increase, but real efficiency actually decreased.

$\rightarrow$ not (at all) plausible.

$\rightarrow$ clearly **pseudo**.

McCabe Complexity

complexity –

(1) The degree to which a system or component has a design or implementation that is difficult to understand and verify. Contrast with: simplicity.

(2) Pertaining to any of a set of structure-based metrics that measure the attribute in (1). **IEEE 610.12 (1990)**

Definition. [*Cyclomatic Number [graph theory]*]

Let $G = (V, E)$ be a graph comprising **vertices** V and **edges** E.

The **cyclomatic number** of G is defined as number of edges

$$v(G) = |E| - |V| + 1.$$

Intuition: minimum number of edges to be removed to make G cycle free.

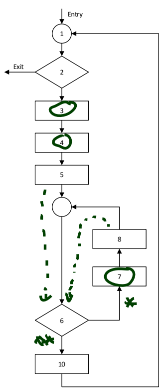
McCabe Complexity Cont'd

Definition. [*Cyclomatic Complexity [McCabe, 1976]*]

Let $G = (V, E)$ be the **Control Flow Graph** of program P.

Then the **cyclomatic complexity** of P is defined as $v(P) = |E| - |V| + p$ where p is the number of entry or exit points.

```
void insertionSort(int[] array) {
  for (int i = 2; i < array.length; i++) {
    tmp = array[i];
    array[0] = tmp;
    int j = i;
    while (j > 0 && tmp < array[j-1]) {
      array[j] = array[j-1];
      j--;
    }
    array[j] = tmp;
  }
}
```



Number of edges: $|E| = 11$
Number of nodes: $|V| = 6 + 2 + 2 = 10$
External connections: $p = 2$

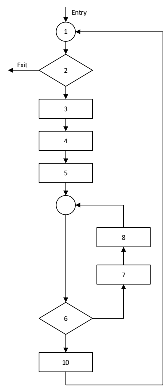
$\rightarrow v(P) = 11 - 10 + 2 = 3$

McCabe Complexity Cont'd

Definition. [*Cyclomatic Complexity [McCabe, 1976]*]
Let $G = (V, E)$ be the **Control Flow Graph** of program P.
Then the **cyclomatic complexity** of P is defined as $v(P) = |E| - |V| + p$ where p is the number of entry or exit points.

- **Intuition**: number of paths, number of decision points.
- **Interval scale** (not absolute, no zero due to $p > 0$); **easy to compute**
- Somewhat **independent** from programming language.
- **Plausibility**:
  + loops and conditions are harder to understand than sequencing.
  – doesn't consider data.
- **Prescriptive** use:

  "For each procedure, either limit cyclomatic complexity to [agreed-upon limit] or provide written explanation of why limit exceeded."



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