Softwaretechnik / Software-Engineering

Lecture 3: More Metrics & Cost Estimation

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Topic Area Project Management: Content

VL 2
- **Software Metrics**
  - Properties of Metrics
  - Scales
  - Examples

VL 3
- **Cost Estimation**
  - "(Software) Economics in a Nutshell"
  - Expert's Estimation
  - Algorithmic Estimation

VL 4
- **Project Management**
  - Project
  - Process and Process Modelling
  - Procedure Models
  - Process Models

VL 5
- **Process Metrics**
  - CMMI, Spice

Content

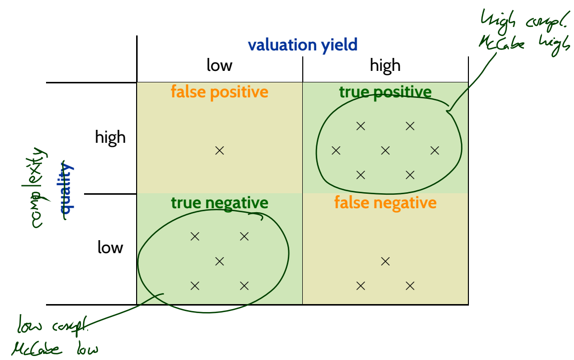
Kinds of Metrics: by Measurement Procedure

	objective metric	pseudo metric	subjective metric
Procedure	measurement, counting, possibly standardised	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 by 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)

Recall: Can Pseudo-Metrics be Useful?

- Pseudo-metrics **can be useful** if there is a (good) correlation (with few false positives and few false negatives) between valuation yields and the property to be measured:



- This may strongly depend on **context information**:
  - If LOC was (or could be made) non-subvertible (→ tutorials), then LOC/day **could be** a useful measure for, e.g., project progress.

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Subjective Metrics

	example	problems	countermeasures
Statement	"The specification **is** available."	Terms may be ambiguous, conclusions are hardly possible.	Allow only certain statements, characterise them precisely.
Assessment	"The module is implemented in a **clever** way."	Not necessarily comparable.	Only offer particular outcomes; put them on an (at least ordinal) scale.
Grading	"Readability is graded **4.0**."	Subjective; grading not reproducible.	Define criteria for grades; give examples how to grade; practice on existing artefacts

(Ludewig and Lichter, 2013)

The Goal-Question-Metric Approach

Information Overload!?

Now we have mentioned **nearly** 60 attributes one could measure…

Which ones **should** we measure?

It depends…

relevant plausible available differentiated economical comparable reproducible robust

One approach: **Goal-Question-Metric** (GQM).

Goal-Question-Metric (Basili and Weiss, 1984)

The three steps of **GQM**:

(i) **Define** the **goals** relevant for a project or an organisation.
(ii) From each goal, **derive questions** which need to be answered to check whether the goal is reached.
(iii) For each question, **choose** (or develop) **metrics** which contribute to finding answers.

Being **good** wrt. to a certain metric is (in general) not an asset on its own.
We usually want to optimise wrt. **goals**, not wrt. **metrics**.
In particular critical: pseudo-metrics for quality.

Software and process measurements may yield **personal data** ("personenbezogene Daten").
Their collection may be regulated by laws.

Example: A Metric for Maintainability

- Goal: assess **maintainability**.
- One approach: **grade** the following aspects, e.g., with scale $S = \{0, \dots, 10\}$.
  (Some aspects may be objective, some subjective (conduct review))

- **Norm Conformance**
  - n_1: size of units (modules etc.)
  - n_2: labelling
  - n_3: naming of identifiers
  - n_4: design (layout)
  - n_5: separation of literals
  - n_6: style of comments
- **Locality**
  - l_1: use of parameters
  - l_2: information hiding
  - l_3: local flow of control
  - l_4: design of interfaces
- **Readability**
  - r_1: data types
  - r_2: structure of control flow
  - r_3: comments
- **Testability**
  - t_1: test driver
  - t_2: test data
  - t_3: preparation for test evaluation
  - t_4: diagnostic components
  - t_5: dynamic consistency checks
- **Typing**
  - y_1: type differentiation
  - y_2: type restriction

- **Define**: $m = \frac{n_1 + \dots + y_2}{20}$ (**with weights**: $m_g = \frac{g_1 \cdot n_1 + \dots + g_{20} \cdot y_2}{G}$, $G = \sum_{i=1}^{20} g_i$).
- **Procedure**:
  - Train reviewers on existing examples.
  - Do not over-interpret results of first applications.
  - Evaluate and adjust before putting to use, adjust regularly.

(Ludewig and Lichter, 2013)

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Development of a pseudo-metrics:

(i) Identify **aspect** to be represented.
(ii) Devise a **model** of the aspect.
(iii) Fix a **scale** for the metric.
(iv) Develop a **definition** of the pseudo-metric, i.e., how to compute the metric.
(v) Develop **base measures** for all parameters of the definition.
(vi) **Apply** and **improve** the metric.

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(Ludewig and Lichter, 2013)

And Which Metrics Should One Use?

Often useful: collect some basic measures **in advance**
(in particular if collection is cheap / automatic), e.g.:

- **size**…

  … of newly **created** and **changed code**, etc.
  (automatically provided by revision control software),

- **effort**…

  … for **coding**, **review**, **testing**, **verification**, **fixing**, **maintenance**, etc.

- **errors**…

  … at least errors **found** during quality assurance, and errors **reported** by customer
  (can be recorded via standardised revision control messages)

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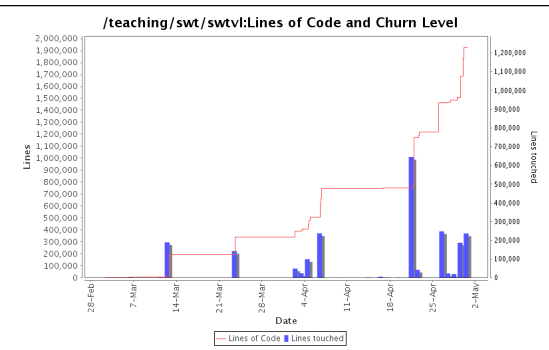

LOC and changed lines over time (obtained by `statsvn`(1).

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Measures derived from such basic measures may **indicate problems ahead** early enough
and buy time to take appropriate counter-measures. E.g., track

- **error rate** per release, **error density** (errors per LOC),
- average effort for error **detection** and **correction**,
- etc.

over time. In case of **unusual values**: investigate further (maybe using additional metrics).

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Tool support for software metrics, e.g., SonarCube.

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Content

- **Software Metrics**
  - Subjective Metrics
  - Goal-Question-Metric Approach
- **Cost Estimation**
  - "(Software) Economics in a Nutshell"
  - Cost Estimation
    - Expert's Estimation
      - The Delphi Method
    - Algorithmic Estimation
      - COCOMO
      - Function Points

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Content

"(Software) Economics in a Nutshell"

Costs

"Next to '**Software**', '**Costs**' is one of the terms occurring most often in this book."
Ludewig and Lichter (2013)

A first approximation:

cost ('Kosten')	all disadvantages of a solution
benefit ('Nutzen') (or: negative costs)	all benefits of a solution.

Note: costs / benefits can be subjective – and not necessarily quantifiable in terms of money...

Super-ordinate goal of many projects:

- **Minimize overall costs**, i.e. **maximise difference** between benefits and costs.
  (Equivalent: minimize sum of positive and negative costs.)

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Costs vs. Benefits: A Closer Look

The benefit of a software is determined by the advantages achievable using the software; it is influenced by:

- the degree of coincidence between **product** and **requirements**,
- additional services, comfort, flexibility etc.

Some other examples of cost/benefit pairs: (inspired by Jones (1990))

Costs	Possible Benefits
Labor during development (e.g., develop new test machinery)	Use of result (e.g., faster testing)
New equipment (purchase, maintenance, depreciation)	Better equipment (maintenance; maybe revenue from selling old)
New software purchases	(Other) use of new software
Conversion from old system to new	Improvement of system, maybe easier maintenance
Increased data gathering	Increased control
Training for employees	Increased productivity

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Costs: Economics in a Nutshell

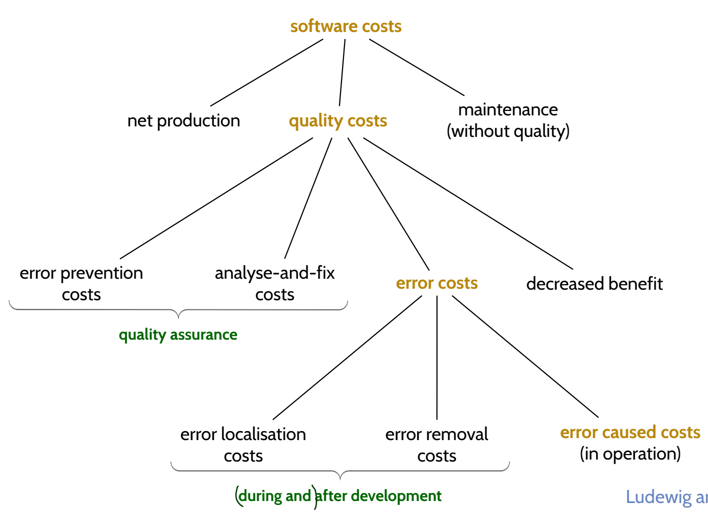
Distinguish **current cost** ('laufende Kosten'), e.g.

- **wages**,
- (business) **management**, **marketing**,
- **rooms**,
- **computers**, **networks**, **software** as part of infrastructure,
- …

and **project-related cost** ('projektbezogene Kosten'), e.g.

- additional **temporary personnel**,
- **contract costs**,
- **expenses**,
- **hardware and software** as part of product or system,
- …

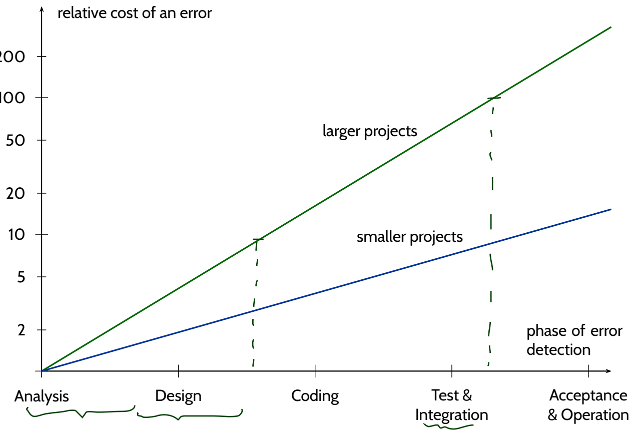
Software Costs in a Narrower Sense



Ludewig and Lichter (2013)

Software Engineering – the establishment and use of sound engineering principles to obtain economically software that is reliable and works efficiently on real machines. **F. L. Bauer (1971)**

Discovering Fundamental Errors Late Can Be Expensive



Relative error costs over latency according to investigations at IBM, etc.
By (Boehm, 1979); Visualisation: Ludewig and Lichter (2013).

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Cost Estimation

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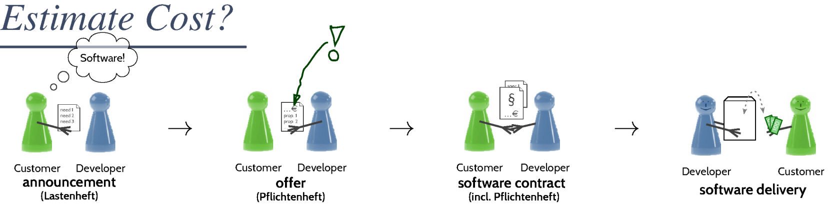
Content

Why Estimate Cost?



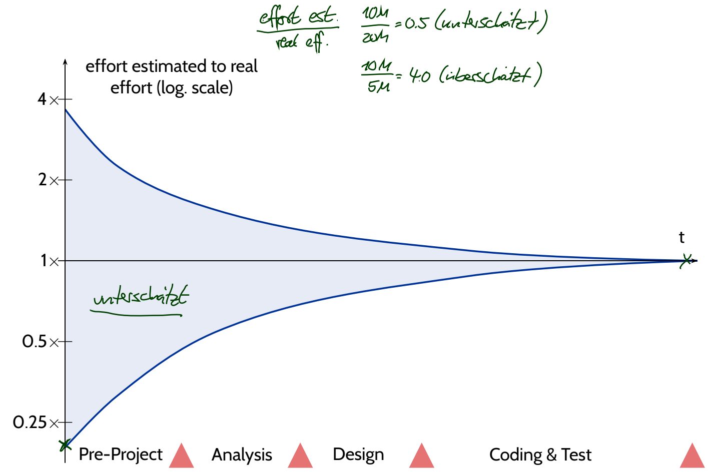
Lastenheft **(Requirements Specification)** Vom Auftraggeber festgelegte Gesamtheit der Forderungen an die Lieferungen und Leistungen eines Auftragnehmers innerhalb eines Auftrages.
(Entire demands on deliverables and services of a developer within a contracted development, created by the customer.) **DIN 69901-5** (2009)

- Developer can **help with writing** the requirements specification, in particular if customer is lacking technical background.

Pflichtenheft **(Feature Specification)** Vom Auftragnehmer erarbeitete Realisierungsvorgaben aufgrund der Umsetzung des vom Auftraggeber vorgegebenen Lastenhefts.
(Specification of how to realise a given requirements specification, created by the developer.)
DIN 69901-5 (2009)

- One way of getting the feature specification: **a pre-project** (may be subject of a designated contract).
- Tricky: one and the same content can serve both purposes; then only the title defines the purpose.

The “Estimation Funnel”



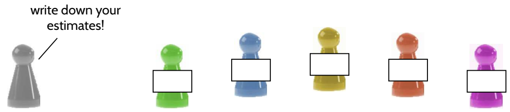
Uncertainty with estimations (following (Boehm et al., 2000), p. 10).

Visualisation: Ludewig and Lichter (2013)

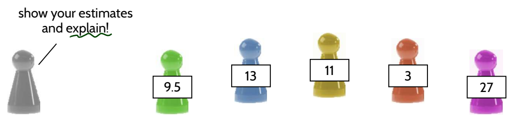
Expert’s Estimation

One approach: the **Delphi** method.

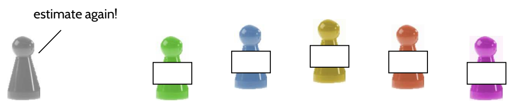
- Step 1:



- Step 2:



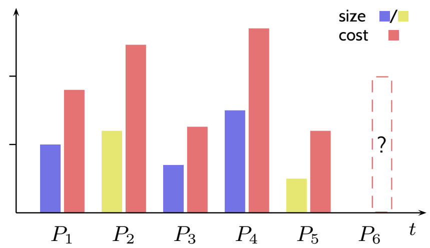
- Step 3:



- Then take the median, for example.

Algorithmic Estimation

Algorithmic Estimation: Principle



Assume:

- Projects $P_1, \dots, P_5$ took place in the past,
- Sizes S_i, costs C_i, and kinds k_i ($0 =$ blue-ish, $1 =$ yellow-ish) have been measured and recorded.

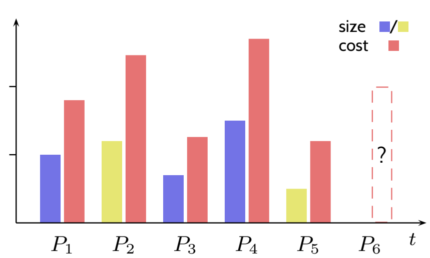
Question: What is the cost of the new project P_6?

Approach:

(i) Try to **find a function** f such that $f(S_i, k_i) = C_i$, for $1 \leq i \leq 5$.
(ii) **Estimate size** $\tilde{S}_6$ and **kind** $\tilde{k}_6$.
(iii) Estimate **cost** C_6 as $\tilde{C}_6 = f(\tilde{S}_6, \tilde{k}_6)$.

(In the artificial example above, $f(S, k) = S \cdot 1.8 + k \cdot 0.3$ would work, i.e.
if P_6 is of kind yellow (thus $\tilde{k}_6 = 1$) and size estimate is $\tilde{S}_6 = 2.7$ then estimate C_6 as $f(\tilde{S}_6, \tilde{k}_6) = 5.16$.)

Algorithmic Estimation: Principle



Approach, more general:

(i) **Identify** (measurable) **factors** $F_1, \dots, F_n$ which influence overall cost, like size in LOC.
(ii) Take a big sample of data from previous projects.
(iii) Try to **come up with a formula** f such that $f(F_1, \dots, F_n)$ matches previous costs.
(iv) **Estimate** values for $F_1, \dots, F_n$ for a new project.
(v) **Take** $f(\tilde{F}_1, \dots, \tilde{F}_n)$ **as cost estimate** $\tilde{C}$ for the new project.
(vi) Conduct new project, **measure** $F_1, \dots, F_n$ and cost C.
(vii) **Adjust** f if C is too different from $\tilde{C}$.

Note:

- The need for (expert's) estimation does not go away: one needs to estimate $\tilde{F}_1, \dots, \tilde{F}_n$.
- Rationale: it is often easier to estimate technical aspects than to estimate cost directly.

Algorithmic Estimation: COCOMO

Algorithmic Estimation: COCOMO

- **Co**nstructive **Co**st **Mo**del:
  Formulae which fit a huge set of archived project data (from the late 70's).
- Flavours:
  - COCOMO 81 (Boehm, 1981): variants **basic**, **intermediate**, **detailed**
  - COCOMO II (Boehm et al., 2000)
- All flavours are based on estimated program size S measured in DSI (Delivered Source Instructions) or kDSI (1000 DSI).
- Factors like security requirements or experience of the project team are mapped to values for parameters of the formulae.
- COCOMO examples:
  - textbooks like Ludewig and Lichter (2013) (most probably made up)
  - an exceptionally large example:
    COCOMO 81 for the Linux kernel (Wheeler, 2006) (and follow-ups)

COCOMO 81

Characteristics of the Type				a	b	Software Project Type
Size	Innovation	Deadlines/ Constraints	Dev. Environment			
Small (<50 KLOC)	Little	Not tight	Stable	3.2	1.05	Organic
Medium (<300 KLOC)	Medium	Medium	Medium	3.0	1.12	Semi-detached
Large	Greater	Tight	Complex HW/ Interfaces	2.8	1.20	Embedded

Basic COCOMO:

- **effort required**: $E = a \cdot (S/kDSI)^b$ [PM (person-months)]
- **time to develop**: $T = c \cdot E^d$ [months]
- **headcount**: $H = E/T$ [FTE (full time employee)]
- **productivity**: $P = S/E$ [DSI per PM] (← use to check for plausibility)

Intermediate COCOMO:

$$E = M \cdot a \cdot (S/kDSI)^b \quad \text{[person-months]}$$

$$M = RELY \cdot CPLX \cdot TIME \cdot ACAP \cdot PCAP \cdot LEXP \cdot TOOL \cdot SCED$$

COCOMO 81: Some Cost Drivers

$$M = RELY \cdot CPLX \cdot TIME \cdot ACAP \cdot PCAP \cdot LEXP \cdot TOOL \cdot SCED$$

	factor	very low	low	normal	high	very high	extra high
RELY	required software reliability	0.75	0.88	1	1.15	1.40	
CPLX	product complexity	0.70	0.85	1	1.15	1.30	1.65
TIME	execution time constraint			1	1.11	1.30	1.66
ACAP	analyst capability	1.46	1.19	1	0.86	0.71	
PCAP	programmer capability	1.42	1.17	1	0.86	0.7	
LEXP	programming language experience	1.14	1.07	1	0.95		
TOOL	use of software tools	1.24	1.10	1	0.91	0.83	
SCED	required development schedule	1.23	1.08	1	1.04	1.10	

- **Note**: what, e.g., "extra high" TIME means, may depend on project context. (Consider data from previous projects.)

COCOMO II (Boehm et al., 2000)

Consists of

- **Application Composition Model** – project work is configuring components, rather than programming
- **Early Design Model** – adaption of **Function Point** approach (in a minute); does not need completed architecture design
- **Post-Architecture Model** – improvement of **COCOMO 81**; needs completed architecture design, and size of components estimatable

COCOMO II: Post-Architecture

$$E = 2.94 \cdot S^X \cdot M$$

- **Program size**: $S = (1 + REVL) \cdot (S_{new} + S_{equiv})$
  - **requirements volatility** $REVL$: e.g., if new requirements make 10% of code unusable, then $REVL = 0.1$
  - S_{new}: estimated size minus size w of **re-used code**,
  - $S_{equiv} = w/q$, if writing new code takes q-times the effort of re-use.
- **Scaling factors**:

  $X = \delta + \omega, \quad \omega = 0.91, \quad \delta = \frac{1}{100} \cdot (PREC + FLEX + RESL + TEAM + PMAT)$

factor		very low	low	normal	high	very high	extra high
PREC	**precedentness** (experience with similar projects)	6.20	4.96	3.72	2.48	1.24	0.00
FLEX	**development flexibility** (development process fixed by customer)	5.07	4.05	3.04	2.03	1.01	0.00
RESL	**Architecture/risk resolution** (risk management, architecture size)	7.07	5.65	4.24	2.83	1.41	0.00
TEAM	**Team cohesion** (communication effort in team)	5.48	4.38	3.29	2.19	1.10	0.00
PMAT	**Process maturity** (see CMMI)	7.80	6.24	4.69	3.12	1.56	0.00

COCOMO II: Post-Architecture Cont'd

$$M = RELY \cdot DATA \cdot \cdots \cdot SCED$$

group	factor	description
Product factors	RELY	required software reliability
	DATA	size of database
	CPLX	complexity of system
	RUSE	degree of development of reusable components
	DOCU	amount of required documentation
Platform factors	TIME	execution time constraint
	STOR	memory consumption constraint
	PVOL	stability of development environment
Team factors	ACAP	analyst capability
	PCAP	programmer capability
	PCON	continuity of involved personnel
	APEX	experience with application domain
	PLEX	experience with development environment
	LTEX	experience with programming language(s) and tools
Project factors	TOOL	use of software tools
	SITE	degree of distributedness
	SCED	required development schedule

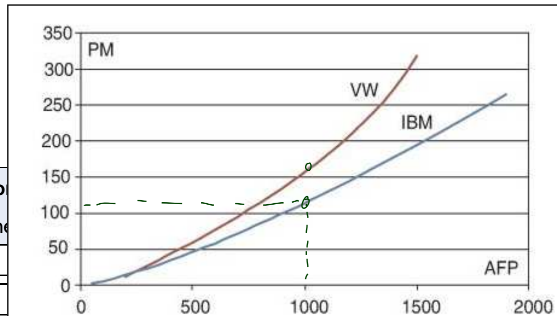
(also in COCOMO 81, new in COCOMO II)

Algorithmic Estimation: Function Points

Type	Complexity low	Complexity medium	Complexity high	Sum
input	____ $\cdot 3 =$	____ $\cdot 4 =$	____ $\cdot 6 =$	
output	____ $\cdot 4 =$	____ $\cdot 5 =$	____ $\cdot 7 =$	
query	____ $\cdot 3 =$	____ $\cdot 4 =$	____ $\cdot 6 =$	
user data	____ $\cdot 7 =$	____ $\cdot 10 =$	____ $\cdot 15 =$	
reference data	____ $\cdot 5 =$	____ $\cdot 7 =$	____ $\cdot 10 =$	
Unadjusted function points	UFP			
Value adjustment factor	VAF			
Adjusted function points	AFP = UFP · VAF			

$$VAF = 0.65 + \frac{1}{100} \cdot \sum_{i=1}^{14} GSC_i, \quad 0 \leq GSC_i \leq 5.$$

Algorithmic Estimation: Function Points



IBM and VW curve for the conversion from AFPs to PM according to (Noth and Kretzschmar, 1984) and (Knöll and Busse, 1991).

Type	low	Co…		
input	____ $\cdot 3 =$			
output	____ $\cdot 4 =$			
query	____ $\cdot 3 =$			
user data	____ $\cdot 7 =$			
reference data	____ $\cdot 5 =$	____ $\cdot 7 =$	____ $\cdot 10 =$	
Unadjusted function points	UFP			
Value adjustment factor	VAF			
Adjusted function points	AFP = UFP · VAF			

$$VAF = 0.65 + \frac{1}{100} \cdot \sum_{i=1}^{14} GSC_i, \quad 0 \leq GSC_i \leq 5.$$

Discussion

Ludewig and Lichter (2013) says:

- **Function Point** approach used in practice,
  in particular for **commercial software** (business software?).
- **COCOMO** tends to overestimate in this domain;
  needs to be adjusted by corresponding factors.

In the end, it's **experience**, **experience**, **experience**:

> "Estimate, document, estimate better." (Ludewig and Lichter, 2013)

Suggestion: start to explicate your experience **now**.

- **Take notes on your projects**:
  (e.g., Softwarepraktikum, Bachelor Projekt, Master Bacherlor's Thesis, Master Projekt, Master's Thesis, ...)
  - timestamps, size of program created, number of errors found, number of pages written, ...
- **Try to identify factors**: what hindered productivity, what boosted productivity, ...
- Which **detours and mistakes** were **avoidable** in hindsight? How?

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Tell Them What You've Told Them...

- **Goal-Question-Metric** approach:
  - Define goals, derive questions, choose metrics.
  - Evaluate and adjust.

  Recall: It's about the **goal**, not the metrics.
- For **software costs**, we can distinguish
  - net production, quality costs, maintenance.

  Software engineering is about being **economic** in all three aspects.
- Why estimate?
  - **Requirements specification** ('Lastenheft')
  - **Feature specification** ('Pflichtenheft')

  The latter (plus budget) is usually part of **software contracts**.
- Approaches:
  - **Expert's Estimation**
  - **Algorithmic Estimation**: COCOMO, Function Points
    → estimate cost **indirectly**, by estimating more **technical aspects**.

  In the end, it's **experience** (and **experience** (and **experience**)).

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