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

VL 5
- Process Metrics
  - CMMI, Spice
### Kinds of Metrics: by Measurement Procedure

<table>
<thead>
<tr>
<th></th>
<th>objective metric</th>
<th>pseudo metric</th>
<th>subjective metric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Procedure</strong></td>
<td>measurement, counting, possibly standardised</td>
<td>computation (based on measurements or assessment)</td>
<td>review by inspector, verbal or by given scale</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>exact, reproducible, can be obtained automatically</td>
<td>yields relevant, directly usable statement on not</td>
<td>not subvertable, plausible results, applicable to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>directly visible characteristics</td>
<td>complex characteristics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>assessment costly, quality of results depends</td>
</tr>
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<td></td>
<td></td>
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<td>on inspector</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>health condition, weather condition (&quot;bad</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>weather&quot;)</td>
</tr>
<tr>
<td><strong>Example, general</strong></td>
<td>body height, air pressure</td>
<td>body mass index (BMI), weather forecast for the</td>
<td>usability: severity of an error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>next day</td>
<td></td>
</tr>
<tr>
<td><strong>Example in Software</strong></td>
<td>size in LOC or NCSI; number of (known) bugs</td>
<td>productivity; cost estimation by COCOMO</td>
<td>quality assessment: error weighting</td>
</tr>
<tr>
<td>Engineering**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Usually used for</strong></td>
<td>collection of simple base measures</td>
<td>predictions (cost estimation); overall assessments</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Ludewig and Lichter, 2013)</td>
</tr>
</tbody>
</table>
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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<tr>
<td></td>
<td></td>
<td></td>
<td>characteristics</td>
</tr>
<tr>
<td>disadvantages</td>
<td>not always relevant,</td>
<td>hard to comprehend,</td>
<td>assessment costly,</td>
</tr>
<tr>
<td></td>
<td>often subvertable,</td>
<td>pseudo-objective</td>
<td>quality of results depends</td>
</tr>
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<td>no interpretation</td>
<td></td>
<td>on inspector</td>
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</tbody>
</table>

(Ludewig and Lichter, 2013)
<table>
<thead>
<tr>
<th>example</th>
<th>problems</th>
<th>countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statement</strong></td>
<td>“The specification is available.”</td>
<td>Terms may be ambiguous, conclusions are hardly possible. Allow only certain statements, characterise them precisely.</td>
</tr>
<tr>
<td><strong>Assessment</strong></td>
<td>“The module is implemented in a clever way.”</td>
<td>Not necessarily comparable. Only offer particular outcomes; put them on an (at least ordinal) scale.</td>
</tr>
<tr>
<td><strong>Grading</strong></td>
<td>“Readability is graded 4.0.”</td>
<td>Subjective; grading not reproducible. Define criteria for grades; give examples how to grade; practice on existing artefacts</td>
</tr>
</tbody>
</table>

(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…

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

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**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 $S = \{0, \ldots, 10\}$.
  (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:** $m = \frac{n_1 + \cdots + n_6}{20}$ \hspace{1cm} (with weights: $m_g = \frac{g_1 \cdot n_1 + \cdots + g_6 \cdot n_6}{G}$, $G = \sum_{i=1}^{20} g_i$).

- **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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And Which Metrics Should One Use?

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

- **size**…
  - … of newly \textit{created} and \textit{changed code}, etc.
    (automatically provided by revision control software).

- **effort**…
  - … for \textit{coding}, \textit{review}, \textit{testing}, \textit{verification}, \textit{fixing}, \textit{maintenance}, etc.

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

**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).

Tool support for software metrics, e.g., SonarCube.
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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“(Software) Economics in a Nutshell”
“Next to ‘Software’, ‘Costs’ is one of the terms occurring most often in this book.”

Ludewig and Lichter (2013)

A first approximation:

<table>
<thead>
<tr>
<th>cost ('Kosten')</th>
<th>all disadvantages of a solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>benefit ('Nutzen')</td>
<td>all benefits of a solution.</td>
</tr>
<tr>
<td>(or: negative costs)</td>
<td></td>
</tr>
</tbody>
</table>

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))

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

software costs
  
  net production
  
  quality costs
    
    quality assurance
      
      error prevention costs
        
        analyse-and-fix costs
          
          error costs
            
            decreased benefit
              
              error localisation costs
                
                error removal costs
                  
                  error caused costs
                    (in operation)
                      
                      during and after development

Ludewig and Lichter (2013)

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*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.

Cost Estimation
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    - COCOMO
    - Function Points

---

**Why Estimate Cost?**

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

  - **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]

  - **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.
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:** write down your estimates!
- **Step 2:** show your estimates and explain!
- **Step 3:** estimate again!

Then take the median, for example.

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**Algorithmic Estimation**
Assume:
• Projects $P_1, \ldots, P_5$ took place in the past.
• Sizes $S_i$, costs $C_i$, and kinds $k_i$ ($0 = \text{blue-ish}, 1 = \text{yellow-ish}$) 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 $\tilde{C}_6$ 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 $f(\tilde{S}_6, \tilde{k}_6) = 5.16$.)

Approach, more general:
(i) Identify (measurable) factors $F_1, \ldots, F_n$ 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 $f(F_1, \ldots, F_n)$ matches previous costs.
(iv) Estimate values for $F_1, \ldots, F_n$ for a new project.
(v) Take $f(\tilde{F}_1, \ldots, \tilde{F}_n)$ as cost estimate $\tilde{C}$ for the new project.
(vi) Conduct new project, measure $F_1, \ldots, F_n$ 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 $\tilde{F}_1, \ldots, \tilde{F}_n$.
• Rationale: it is often easier to estimate technical aspects than to estimate cost directly.
Algorithmic Estimation: COCOMO

- **Constructive Cost Model:**
  - 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)
### Characteristics of the Type

<table>
<thead>
<tr>
<th>Size</th>
<th>Innovation</th>
<th>Deadlines/Constraints</th>
<th>Dev. Environment</th>
<th>a</th>
<th>b</th>
<th>Software Project Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (&lt;50 KLOC)</td>
<td>Little</td>
<td>Not tight</td>
<td>Stable</td>
<td>3.2</td>
<td>1.05</td>
<td>Organic</td>
</tr>
<tr>
<td>Medium (&lt;300 KLOC)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>3.0</td>
<td>1.12</td>
<td>Semi-detached</td>
</tr>
<tr>
<td>Large</td>
<td>Greater</td>
<td>Tight</td>
<td>Complex HW/Interfaces</td>
<td>2.8</td>
<td>1.20</td>
<td>Embedded</td>
</tr>
</tbody>
</table>

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

**Intermediate COCOMO:**

\[
E = M \cdot a \cdot \left( \frac{S}{kDSI} \right)^b \] [person-months]

\[
M = \text{RELY} \cdot \text{CPLX} \cdot \text{TIME} \cdot \text{ACAP} \cdot \text{PCAP} \cdot \text{LEXP} \cdot \text{TOOL} \cdot \text{SCED}
\]

### COCOMO 81: Some Cost Drivers

\[
M = \text{RELY} \cdot \text{CPLX} \cdot \text{TIME} \cdot \text{ACAP} \cdot \text{PCAP} \cdot \text{LEXP} \cdot \text{TOOL} \cdot \text{SCED}
\]

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

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

- **Scaling factors**:
  \[ X = \delta + \omega, \quad \omega = 0.91, \quad \delta = \frac{1}{100} \cdot (\text{PREC} + \text{FLEX} + \text{RESL} + \text{TEAM} + \text{PMAT}) \]

<table>
<thead>
<tr>
<th>factor</th>
<th>very low</th>
<th>low</th>
<th>normal</th>
<th>high</th>
<th>very high</th>
<th>extra high</th>
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<tbody>
<tr>
<td>PREC</td>
<td>6.20</td>
<td>4.96</td>
<td>3.72</td>
<td>2.48</td>
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<tr>
<td>FLEX</td>
<td>5.07</td>
<td>4.05</td>
<td>3.04</td>
<td>2.03</td>
<td>1.01</td>
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<tr>
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<tr>
<td>TEAM</td>
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<td>3.29</td>
<td>2.19</td>
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<td>6.24</td>
<td>4.69</td>
<td>3.12</td>
<td>1.56</td>
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</table>
$$M = \text{RELY} \cdot \text{DATA} \cdot \cdots \cdot \text{SCED}$$

<table>
<thead>
<tr>
<th>group</th>
<th>factor</th>
<th>description</th>
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</thead>
<tbody>
<tr>
<td>Product factors</td>
<td>RELY</td>
<td>required software reliability</td>
</tr>
<tr>
<td></td>
<td>DATA</td>
<td>size of database</td>
</tr>
<tr>
<td></td>
<td>CPLX</td>
<td>complexity of system</td>
</tr>
<tr>
<td></td>
<td>RUSE</td>
<td>degree of development of reusable components</td>
</tr>
<tr>
<td></td>
<td>DOCU</td>
<td>amount of required documentation</td>
</tr>
<tr>
<td>Platform factors</td>
<td>TIME</td>
<td>execution time constraint</td>
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<tr>
<td></td>
<td>STOR</td>
<td>memory consumption constraint</td>
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<tr>
<td></td>
<td>PVOL</td>
<td>stability of development environment</td>
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<tr>
<td>Team factors</td>
<td>ACAP</td>
<td>analyst capability</td>
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<tr>
<td></td>
<td>PCAP</td>
<td>programmer capability</td>
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<td>continuity of involved personnel</td>
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<td></td>
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<tr>
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<td>TOOL</td>
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<td></td>
<td>SITE</td>
<td>degree of distributedness</td>
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<tr>
<td></td>
<td>SCED</td>
<td>required development schedule</td>
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</tbody>
</table>

(also in COCOMO 81, new in COCOMO II)

Algorithmic Estimation: Function Points
**Algorithmic Estimation: Function Points**

<table>
<thead>
<tr>
<th>Type</th>
<th>Complexity</th>
<th>Sum</th>
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<tbody>
<tr>
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<td>low</td>
<td>medium</td>
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<tr>
<td>input</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>output</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>query</td>
<td>(3)</td>
<td>(4)</td>
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<tr>
<td>user data</td>
<td>(7)</td>
<td>(10)</td>
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<tr>
<td>reference data</td>
<td>(5)</td>
<td>(7)</td>
</tr>
</tbody>
</table>

Unadjusted function points (UFP)

Value adjustment factor (VAF)

Adjusted function points (AFP) = UFP \cdot VAF

\[
VAF = 0.65 + \frac{1}{100} \sum_{i=1}^{14} GSC_i, \\
0 \leq GSC_i \leq 5.
\]
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?

---


- **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)).
References


