Softwaretechnik / Software-Engineering

Lecture 3: More Metrics & Cost Estimation

2017-05-08

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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

- **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
## Kinds of Metrics: by Measurement Procedure

<table>
<thead>
<tr>
<th>objective metric</th>
<th>pseudo metric</th>
<th>subjective metric</th>
</tr>
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<tbody>
<tr>
<td><strong>Procedure</strong></td>
<td>measurement, counting, possibly standardised</td>
<td>computation (based on measurements or assessment)</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>exact, reproducible, can be obtained automatically</td>
<td>yields relevant, directly usable statement on not directly visible characteristics</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>not always relevant, often subvertable, no interpretation</td>
<td>hard to comprehend, pseudo-objective</td>
</tr>
<tr>
<td><strong>Example, general</strong></td>
<td>body height, air pressure</td>
<td>body mass index (BMI), weather forecast for the next day</td>
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<td><strong>Example in Software Engineering</strong></td>
<td>size in LOC or NCSI; number of (known) bugs</td>
<td>productivity; cost estimation by COCOMO</td>
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<tr>
<td><strong>Usually used for</strong></td>
<td>collection of simple base measures</td>
<td>predictions (cost estimation); overall assessments</td>
</tr>
</tbody>
</table>

(Ludewig and Lichter, 2013)
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><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>
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<td>exact, reproducible, can be obtained automatically</td>
<td>yields relevant, directly usable statement on not directly visible characteristics</td>
<td>not subvertable, plausible results, applicable to complex characteristics</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>not always relevant, often subvertable, no interpretation</td>
<td>hard to comprehend, pseudo-objective</td>
<td>assessment costly, quality of results depends on inspector</td>
</tr>
<tr>
<td><strong>Example, general</strong></td>
<td>body height, air pressure</td>
<td>body mass index (BMI), weather forecast for the next day</td>
<td>health condition, weather condition (“bad weather”)</td>
</tr>
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<td><strong>Example in Software Engineering</strong></td>
<td>size in LOC or NCSI; number of (known) bugs</td>
<td>productivity; cost estimation by COCOMO</td>
<td>usability; severeness of an error</td>
</tr>
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<td><strong>Usually used for</strong></td>
<td>collection of simple base measures</td>
<td>predictions (cost estimation); overall assessments</td>
<td>quality assessment; error weighting</td>
</tr>
</tbody>
</table>

(Ludewig and Lichter, 2013)
## Subjective Metrics

<table>
<thead>
<tr>
<th></th>
<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.</td>
<td>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.</td>
<td>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.</td>
<td>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
Now we have mentioned nearly 60 attributes one could measure…

Which ones should we measure?

It depends…

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 $S = \{0, \ldots, 10\}$.
  (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:** $m = \frac{n_1 + \cdots + n_6}{20}$  
  (with weights: $m_g = \frac{g_1 \cdot n_1 + \cdots + g_20 \cdot y_2}{G}$, $G = \sum_{i=1}^{20} g_i$).

- **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:**

1. Identify aspect to be represented.
2. Devise a model of the aspect.
3. Fix a scale for the metric.
4. Develop a definition of the pseudo-metric, i.e., how to compute the metric.
5. Develop base measures for all parameters of the definition.
6. Apply and improve the metric.

**Procedure:**

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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
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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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“(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><strong>cost</strong> (‘Kosten’)</th>
<th>all disadvantages of a solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>benefit</strong> (‘Nutzen’) (or: negative costs)</td>
<td>all benefits of a solution.</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.)
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>
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<tbody>
<tr>
<td>Labor during development</td>
<td>Use of result</td>
</tr>
<tr>
<td>(e.g., develop new test machinery)</td>
<td>(e.g., faster testing)</td>
</tr>
<tr>
<td>New equipment (purchase, maintenance,</td>
<td>Better equipment</td>
</tr>
<tr>
<td>depreciation)</td>
<td>(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>
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</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,
- ...

\[\text{business administration, project leader involved}\]
Software Costs in a Narrower Sense

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)
Relative error costs over latency according to investigations at IBM, etc.

By (Boehm, 1979); Visualisation: Ludewig and Lichter (2013).
Cost Estimation
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**Why Estimate Cost?**

1. **Customer announcement (Lastenheft)**
2. → **Developer**
3. → **Customer offer (Pflichtenheft)**
4. → **Customer software contract (incl. Pflichtenheft)**
5. → **Developer software delivery**

### 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”

- effort estimated to real effort (log. scale)

\[
\frac{\text{effort est.}}{\text{real eff.}} = \frac{10M}{20M} = 0.5 \text{ (unterschätzt)}
\]

\[
\frac{10M}{5M} = 4.0 \text{ (überschätzt)}
\]

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

Visualisation: Ludewig and Lichter (2013)
Expert’s Estimation
**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.
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 = 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 $F_1, \ldots, F_n$ 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
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]

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

<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>1</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>
</tr>
</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** – 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**: \( S = (1 + \text{REVL}) \cdot (S_{\text{new}} + S_{\text{equiv}}) \)

- **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>
</tr>
</thead>
<tbody>
<tr>
<td>PREC precedence (experience with similar projects)</td>
<td>6.20</td>
<td>4.96</td>
<td>3.72</td>
<td>2.48</td>
<td>1.24</td>
<td>0.00</td>
</tr>
<tr>
<td>FLEX development flexibility (development process fixed by customer)</td>
<td>5.07</td>
<td>4.05</td>
<td>3.04</td>
<td>2.03</td>
<td>1.01</td>
<td>0.00</td>
</tr>
<tr>
<td>RESL Architecture/risk resolution (risk management, architecture size)</td>
<td>7.07</td>
<td>5.65</td>
<td>4.24</td>
<td>2.83</td>
<td>1.41</td>
<td>0.00</td>
</tr>
<tr>
<td>TEAM Team cohesion (communication effort in team)</td>
<td>5.48</td>
<td>4.38</td>
<td>3.29</td>
<td>2.19</td>
<td>1.10</td>
<td>0.00</td>
</tr>
<tr>
<td>PMAT Process maturity (see CMMI)</td>
<td>7.80</td>
<td>6.24</td>
<td>4.69</td>
<td>3.12</td>
<td>1.56</td>
<td>0.00</td>
</tr>
</tbody>
</table>
\[ M = \text{RELY} \cdot \text{DATA} \cdot \ldots \cdot \text{SCED} \]

<table>
<thead>
<tr>
<th>group</th>
<th>factor</th>
<th>description</th>
</tr>
</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>
</tr>
<tr>
<td></td>
<td>STOR</td>
<td>memory consumption constraint</td>
</tr>
<tr>
<td></td>
<td>PVOL</td>
<td>stability of development environment</td>
</tr>
<tr>
<td>Team factors</td>
<td>ACAP</td>
<td>analyst capability</td>
</tr>
<tr>
<td></td>
<td>PCAP</td>
<td>programmer capability</td>
</tr>
<tr>
<td></td>
<td>PCON</td>
<td>continuity of involved personnel</td>
</tr>
<tr>
<td></td>
<td>APEX</td>
<td>experience with application domain</td>
</tr>
<tr>
<td></td>
<td>PLEX</td>
<td>experience with development environment</td>
</tr>
<tr>
<td></td>
<td>LTEX</td>
<td>experience with programming language(s) and tools</td>
</tr>
<tr>
<td>Project factors</td>
<td>TOOL</td>
<td>use of software tools</td>
</tr>
<tr>
<td></td>
<td>SITE</td>
<td>degree of distributedness</td>
</tr>
<tr>
<td></td>
<td>SCED</td>
<td>required development schedule</td>
</tr>
</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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
<td>medium</td>
</tr>
<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>
</tr>
<tr>
<td>user data</td>
<td>~·7 =</td>
<td>~·10 =</td>
</tr>
<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: \( AFP = UFP \cdot VAF \)

\[
VAF = 0.65 + \frac{1}{100} \cdot \sum_{i=1}^{14} GSC_i,
\]

\[
0 \leq GSC_i \leq 5.
\]
### Algorithmic Estimation: Function Points

<table>
<thead>
<tr>
<th>Type</th>
<th>Complexity</th>
<th>UFP</th>
<th>VAF</th>
<th>AFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td>low</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>output</td>
<td>medium</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>query</td>
<td>low</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>user data</td>
<td>high</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reference data</td>
<td>high</td>
<td>5</td>
<td>0.7</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unadjusted function points</th>
<th>UFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value adjustment factor</td>
<td>VAF</td>
</tr>
<tr>
<td>Adjusted function points</td>
<td>AFP = UFP · VAF</td>
</tr>
</tbody>
</table>

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

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


