ETH Zürich
Chair of Software Engineering

Software Architecture

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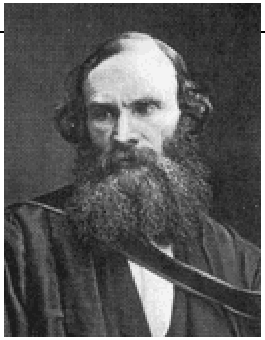
ETH Zurich, February-May 2011

Lecture 12: Metrics, Models & Cost Estimation

Measurement



"To measure is to know"

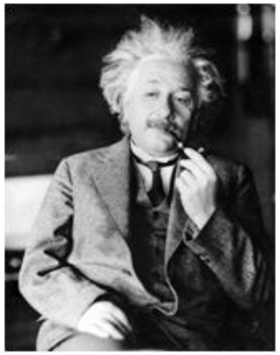
"When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of *Science*, whatever the matter may be. "

"If you cannot measure it, you cannot improve it."

Lord Kelvin

"You can't control what you can't measure"

Tom de Marco



"Not everything that counts can be counted, and not everything that can be counted counts."

Albert Einstein (attributed)

Why measure software?

Understand issues of software development

Make decisions on basis of facts rather than opinions

Predict conditions of future developments

The purpose of this lecture

Learn techniques to

- **Measure** factors of interest, mostly
  - Cost
  - Faults
- **Estimate** these factors, in particular cost, in advance

Some estimation techniques

1. Count
2. Determine from goals
3. Use individual expert judgment
4. Use collective expert judgment
5. Rely on analogy
6. Estimate from proxies
7. Apply model
8. Decompose and recompose
9. Calibration from historical data
10. Use tools
11. Combine approaches

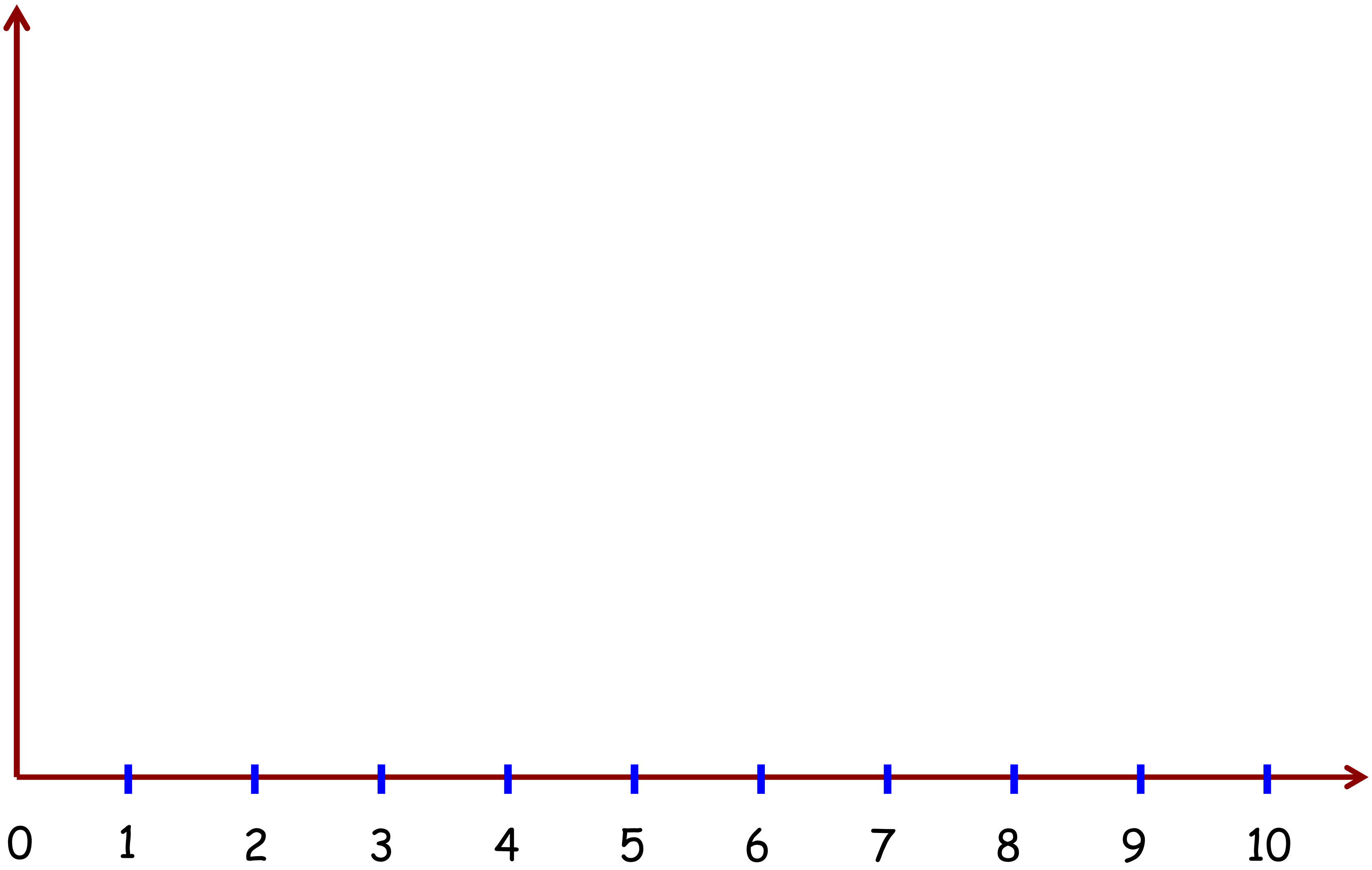
How good an estimator are you?

(From: Steve McConnell, *Software Estimation*, Microsoft Press, 2006)

For each of the following values, give a range that gives you a 90% chance of containing the correct answer

	Low	*High*
Surface temperature of the sun (*°C*)		
Latitude of Shanghai (*degrees*)		
Area of the Asian continent (*sq km*)		
Year of Alexander the Great's birth		
US currency in circulation, 2004 (*$*)		
Total volume of Great Lakes (*liters* or *cubic km*)		
Worldwide box office receipts for *Titanic* (*$*)		
Length of coastline of Pacific Ocean (*km*)		
Book titles published in US since 1776		
Weight of heaviest blue whale recorded (*tons*)		

Results



Some estimation techniques

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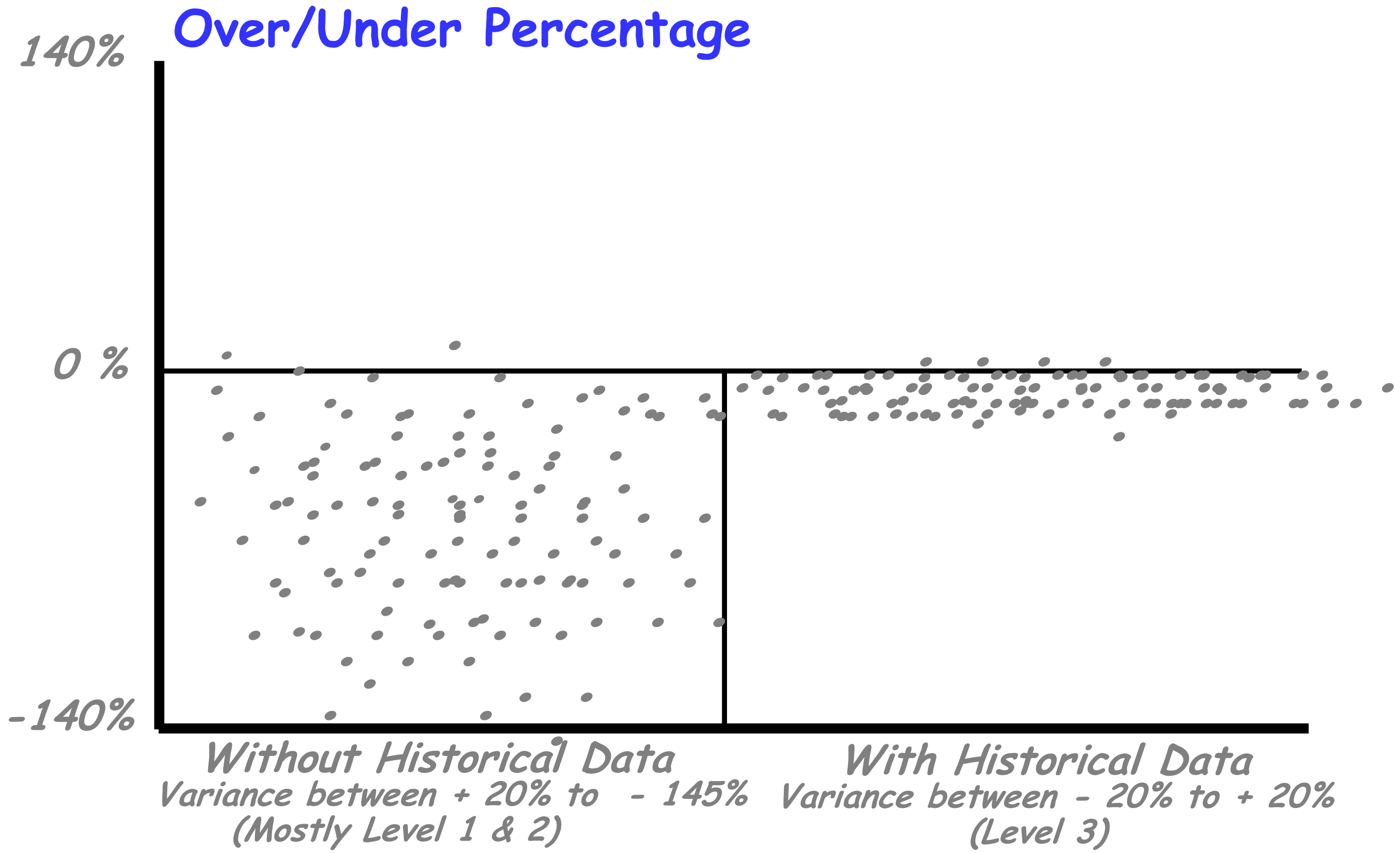
Absolute and relative measurements



(Based on 120 projects in Boeing Information Systems)

Reference: John D. Vu. "Software Process Improvement Journey:From Level 1 to Level 5." 7th SEPG Conference, San Jose, March 1997.

Software metrics: methodological guidelines

Measure only for a clearly stated purpose

Specifically: software measures should be connected with quality and cost

Assess the validity of measures through controlled, credible experiments

Apply software measures to software, not people

GQM (see next)

GQM (Goal/Question/Metric) (Basili et al.)

Process for a measurement campaign:

1. Define goal of measurement

   Analyze… with the purpose of … the … from the point of view of … in the context of …

   Example: Analyze testing phase with the purpose of estimating the costs from the point of view of the manager in the context of Siemens Train Division's embedded systems group

2. Devise suitable set of questions

   Example: do faults remain that can have major safety impact?

3. Associate metric with every question

Example: software quality

External quality factors:

- Correctness
- Robustness
- Ease of use
- Security
- …

Compare:

- *"This program is much more reliable than the previous development"*
- *"There are 67 outstanding faults, of which 3 are 'blocking' and 12 'serious'. The new fault rate for the past three months has been two per week."*

What to measure in software: examples

Effort measures

- Development time
- Team size
- Cost

Quality measures

- Number of failures
- Number of faults
- Mean Time Between Failures

Difficulty of cost control

Many industry projects late and over budget, although situation is improving

Cost estimation still considered black magic by many; does it have to be?

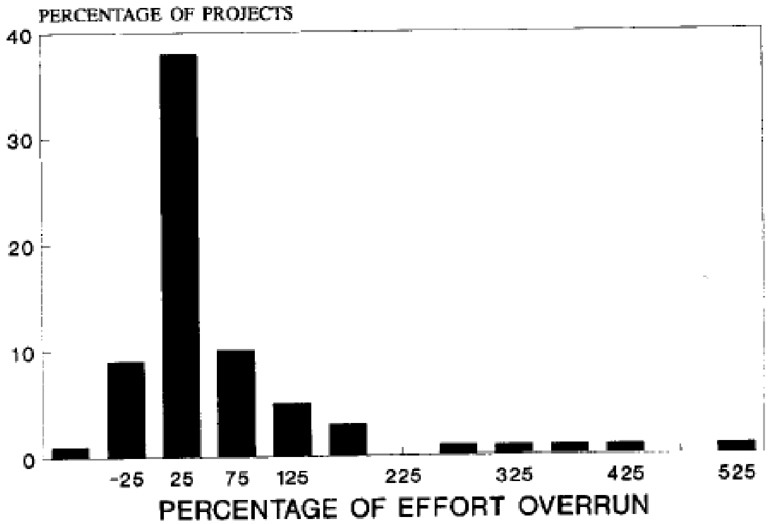


Fig. 1. Distribution of relative effort overruns [7].

Source: van Genuchten (1991)
Average overrun: 22%

Note: widely cited Standish "Chaos" report has been shown not to be credible

Difficulty of effort measurement: an example

(after Ghezzi/Jazayeri/Mandrioli)

Productivity:

- Software professional: a few tens of lines of code per day
- Student doing project: much more!

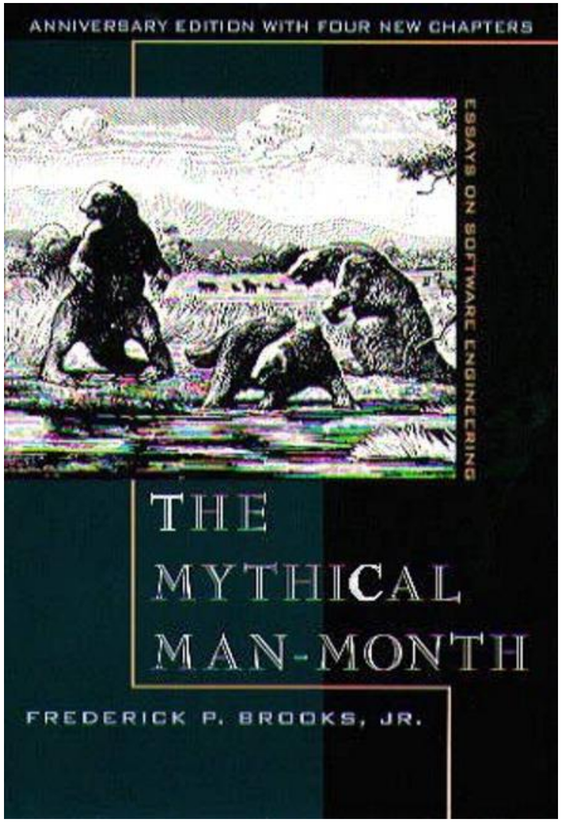
Discrepancy due to: other activities (meetings, administration, …); higher-quality requirements; application complexity; need to understand existing software elements; communication time in multi-person development; higher standards (testing, documentation).

Effort measurement

Standard measure: person-month (or "man-month")

Even this simple notion is not without raising difficulties:

- Programmers don't just program
- *m* persons x *n* months is not interchangeable with *n* persons x *m* months



Brooks: "The Mythical Man-Month"

Project parameters

Elements that can be measured in advance, to be fed into cost model

Candidates:

- Lines of code (LOC, KLOC, SLOC..) and other internal measures
- Function points, application points and other external measures

Some metrics apply to all programs, others to O-O programs only

Complexity models

Aim: estimate complexity of a software system

Examples:

- Lines of code
- Function points
- Halstead's volume measure: $N \log \eta$, where N is program length and η the program vocabulary (operators + operands)
- McCabe's cyclomatic number: $C = e - n + 2p$, where n is number of vertices in control graph, e the number of edges, and p the number of connected components

Traditional internal code metrics

Source Lines of Code (SLOC)

Comment Percentage (CP)

McCabe Cyclomatic Complexity (CC)

Source lines of code (SLOC)

Definition: count number of lines in program

Conventions needed for: comments; multi-line instructions; control structures; reused code.

Pros as a cost estimate parameter:

- Appeals to programmers
- Fairly easy to measure on final product
- Correlates well with other effort measures

Cons:

- Ambiguous (several instructions per line, count comments or not …)
- Does not distinguish between programming languages of various abstraction levels
- Low-level, implementation-oriented
- Difficult to estimate in advance.

Source lines of code

A measure of the number of physical lines of code

Different counting strategies:

- Blank lines
- Comment lines
- Automatically generated lines

EiffelBase has 63,474 lines, Vision2 has 153,933 lines, EiffelStudio (Windows GUI) has 1,881,480 lines in all compiled classes.

Code used in examples given here and below are got from revision 68868 in Origo subversion server.

Comment percentage

Ratio of the number of commented lines of code divided by the number of non-blank lines of code.

Critique:

If you need to comment your code, you better refactor it.

Software Metrics using EiffelStudio

With material by

Yi Wei & Marco Piccioni

May 2011

What to measure

Product properties

- Lines of Code
- Number of classes
- Cohesion & Coupling
- Conformance of code to OO principles

Process properties

- Man-month spent on software
- Number of bugs introduced per hour
- Ratio of debugging/developing time
- CMM, PSP

Metrics tool in EiffelStudio

A code quality checking tool with seamlessly working style:

Coding – Metricing – Problem solving – Coding

Highly customizable:

Define your own metrics to match particular requires

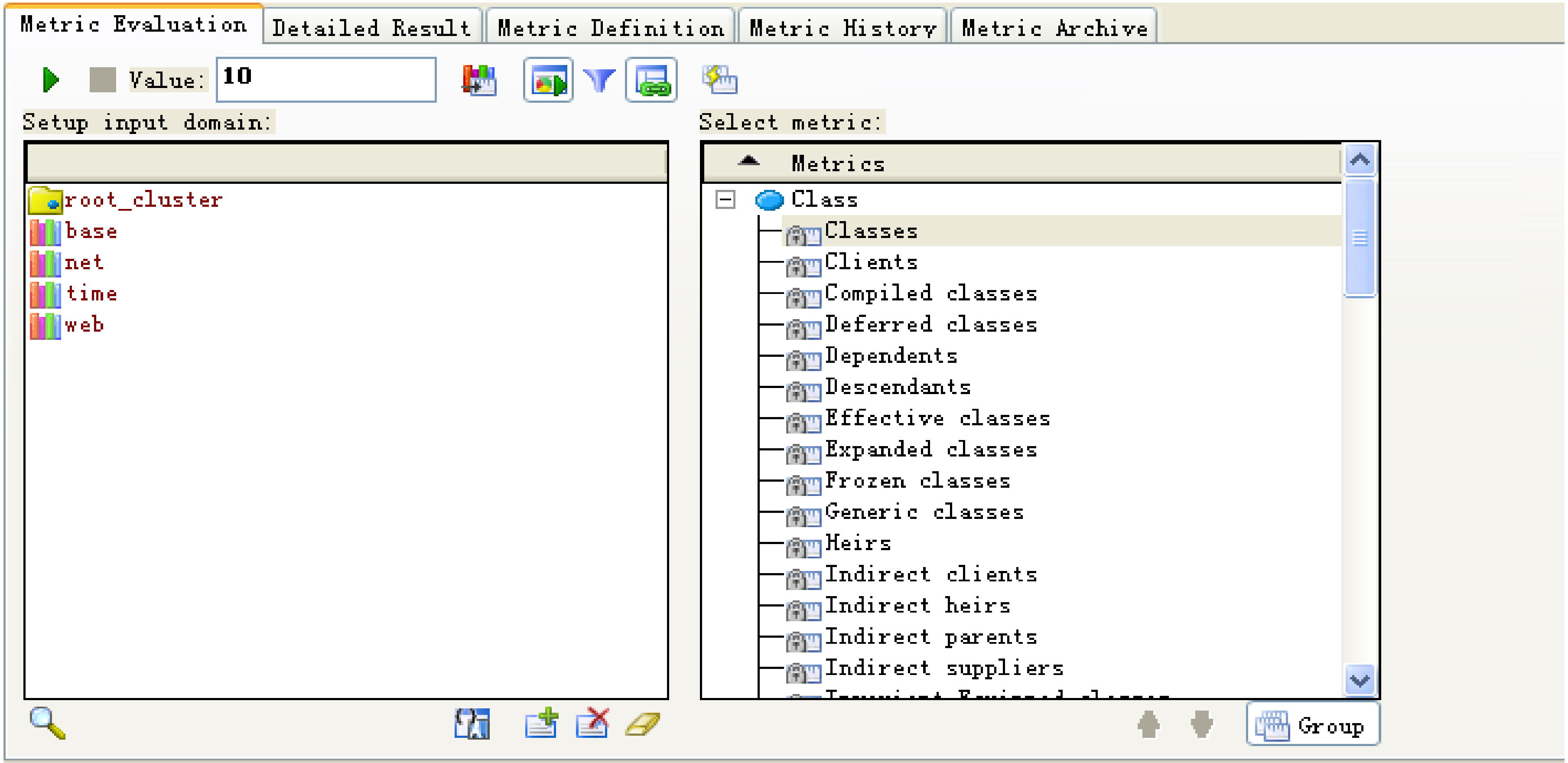
Metric archive comparison:

Compare measurement of your software to others

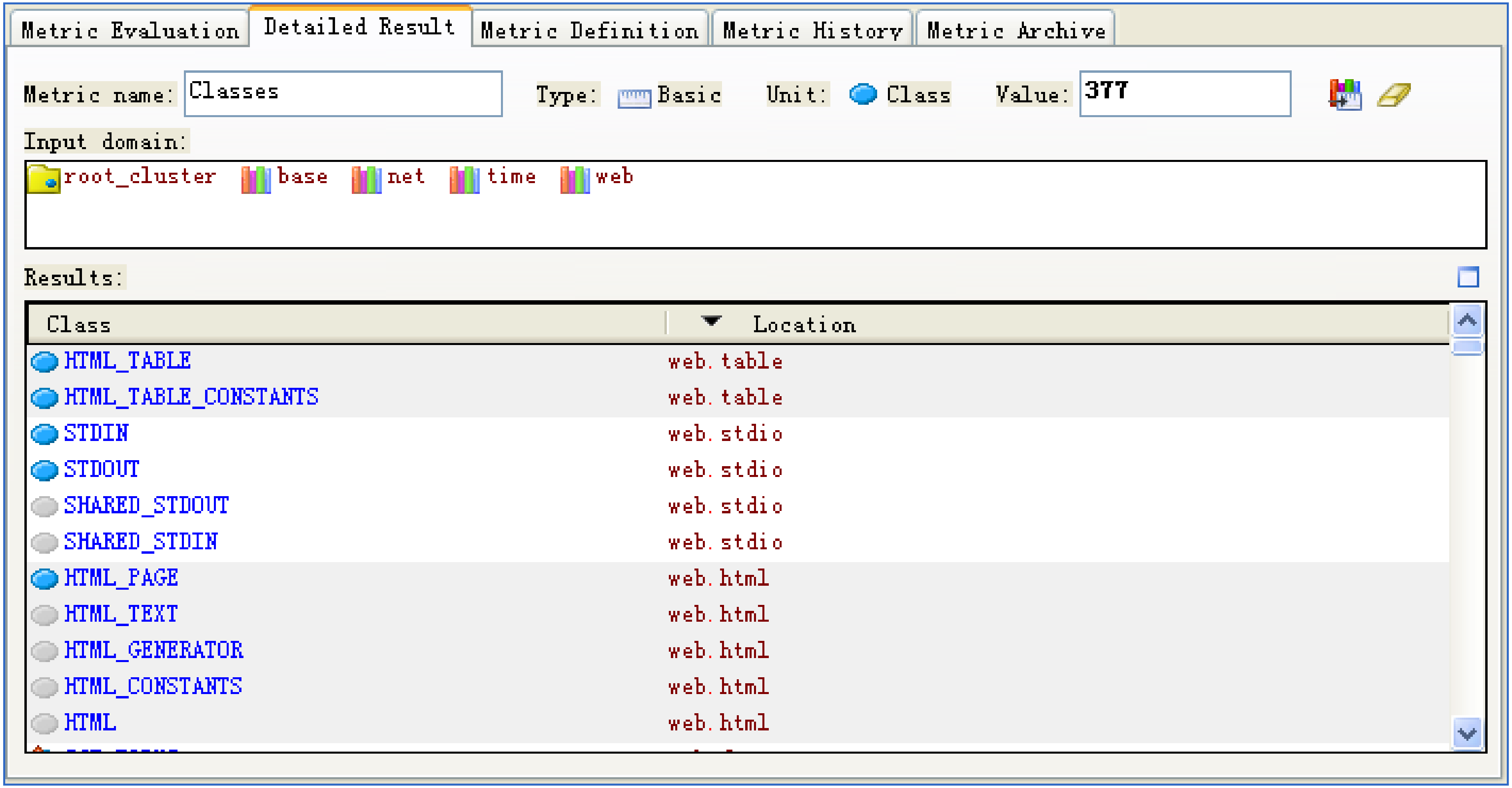
Automatic metric quality checking:

Get warned when some quality criterion are not met

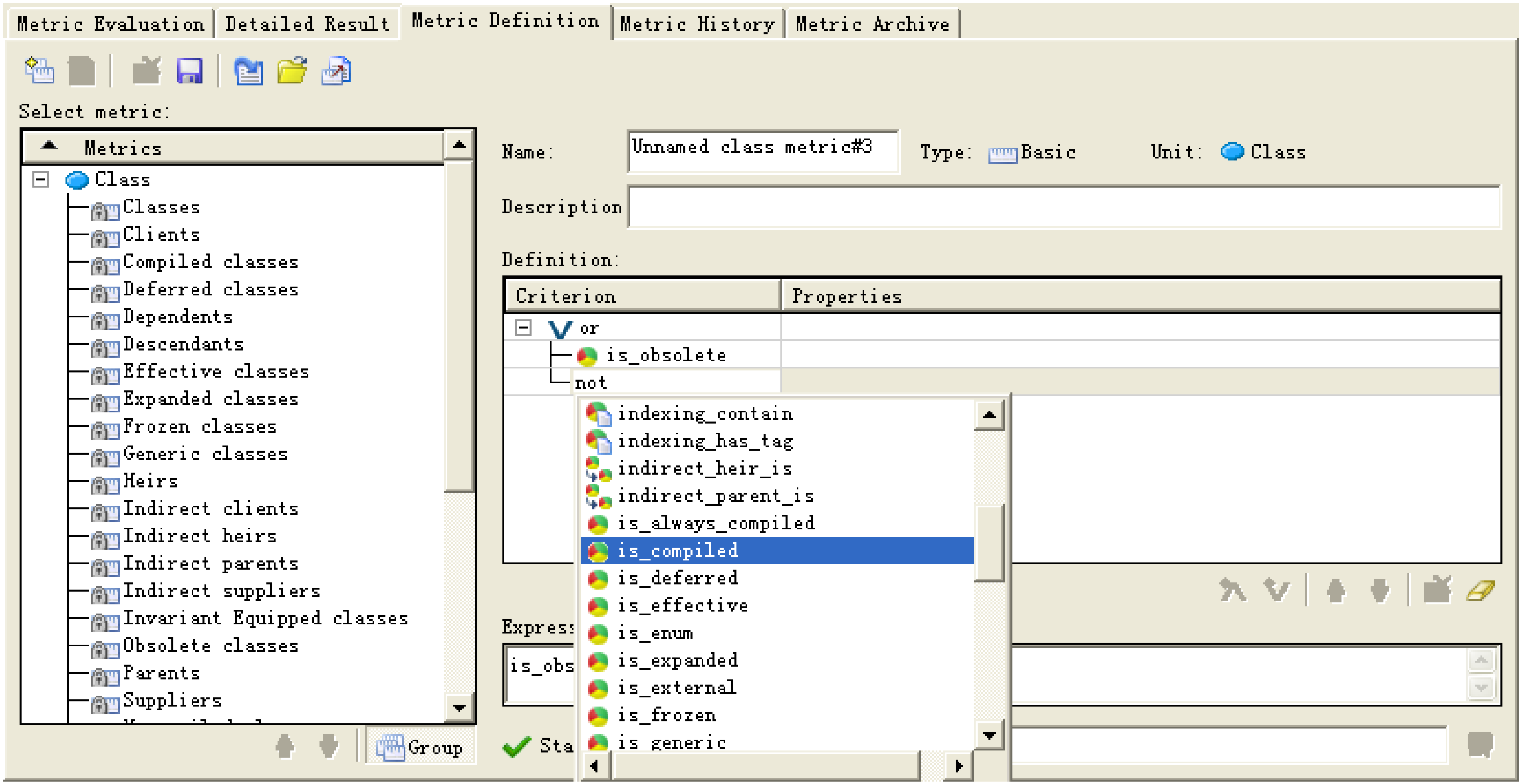
Metrics tool: evaluate metric



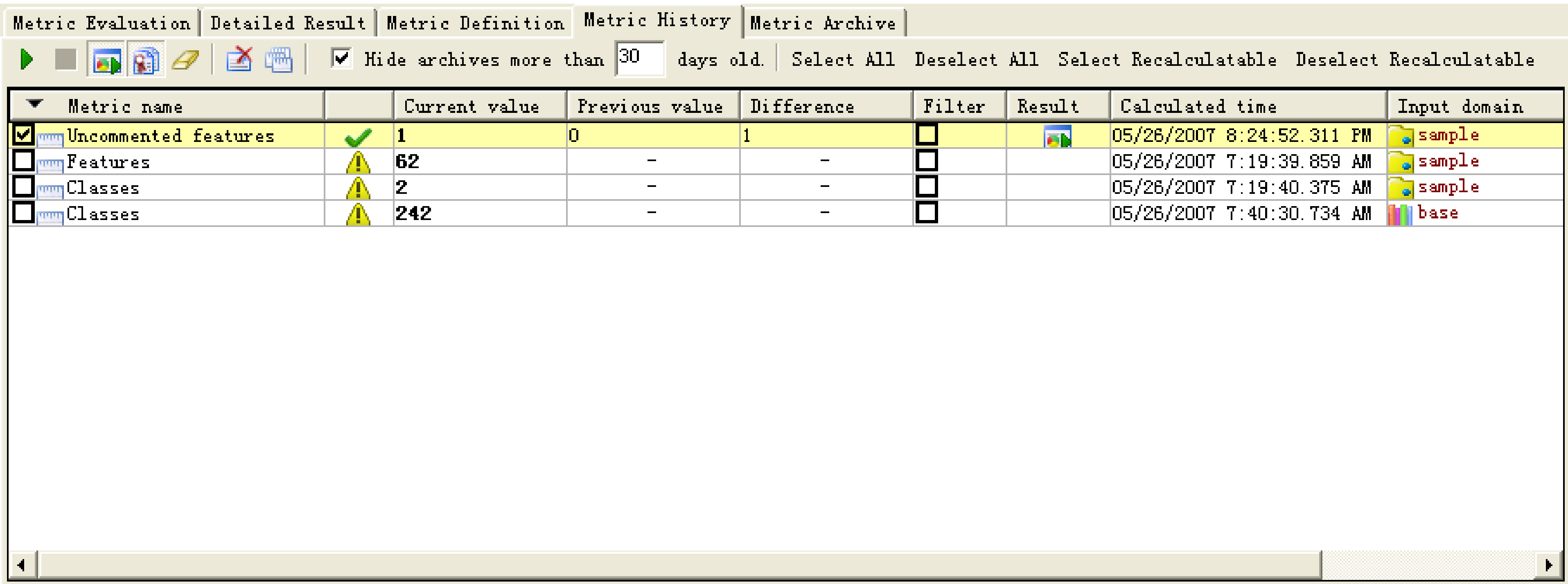
Metrics tool: investigate result



Metrics tool: define new metric

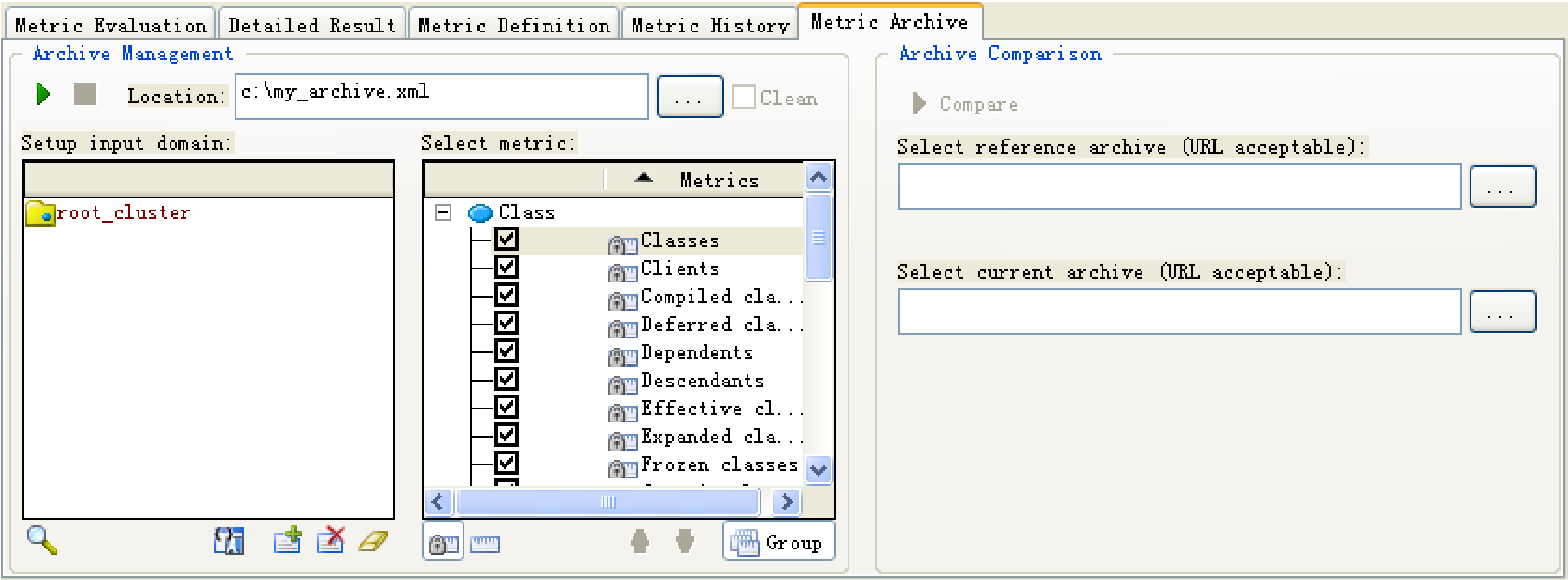


Metrics tool: metric History



Metric name		Current value	Previous value	Difference	Filter	Result	Calculated time	Input domain
Uncommented features		1	0	1			05/26/2007 8:24:52.311 PM	sample
Features		62	-	-			05/26/2007 7:19:39.859 AM	sample
Classes		2	-	-			05/26/2007 7:19:40.375 AM	sample
Classes		242	-	-			05/26/2007 7:40:30.734 AM	base

Metrics tool: archive



McCabe cyclomatic complexity

A measure based on a connected graph of the module (shows the topology of control flow within the program)

Definition

$M = E - N + P$ where

M = cyclomatic complexity

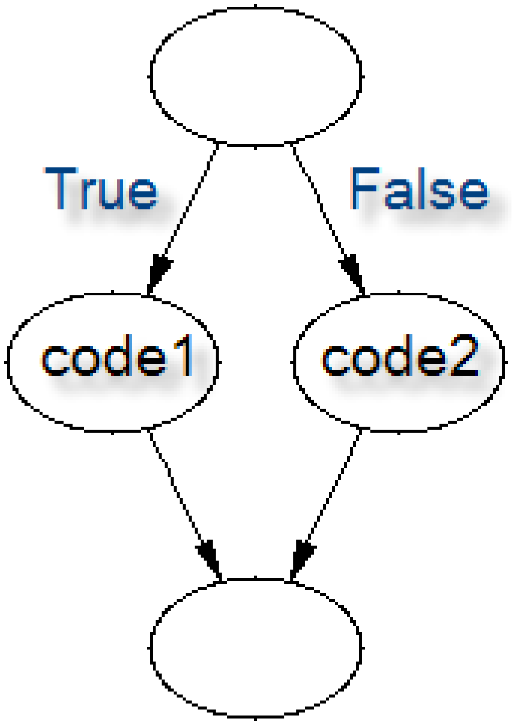
E = the number of edges of the graph

N = the number of nodes of the graph

P = the number of connected components.

Example of cyclomatic complexity

```
if condition then
        code 1
else
        code 2
end
```



$E = 4$, $N = 4$, $P = 2$,

$M = 4 - 4 + 2 = 2$

External metric: function points

Definition: one end-user business function

Five categories (and associated weights):

- Inputs (4)
- Outputs (5)
- Inquiries (4)
- Files (10)
- Interfaces to other systems (7)

Pros as a cost estimate parameter:

- Relates to functionality, not just implementation
- Experience of many years, ISO standard
- Can be estimated from design
- Correlates well with other effort measures

Cons:

- Oriented towards business data processing
- Fixed weights

Application points

Definition: high-level effort generators

Examples: screen, reports, high-level modules

Pro as a cost estimate parameter:

- Relates to high-level functionality
- Can be estimated very early on

Con:

- Remote from actual program

Some metrics for O-O programs

Weighted Methods Per Class (WMC)

Depth of Inheritance Tree of a Class (DIT)

Number of Children (NOC)

Coupling Between Classes (CBO)

Response for a Class (RFC)

Weighted methods per class

Sum of the complexity of each feature contained in the class.

Feature complexity: (e.g. cyclomatic complexity)

When feature complexity assumed to be 1,

WMC = number of features in class

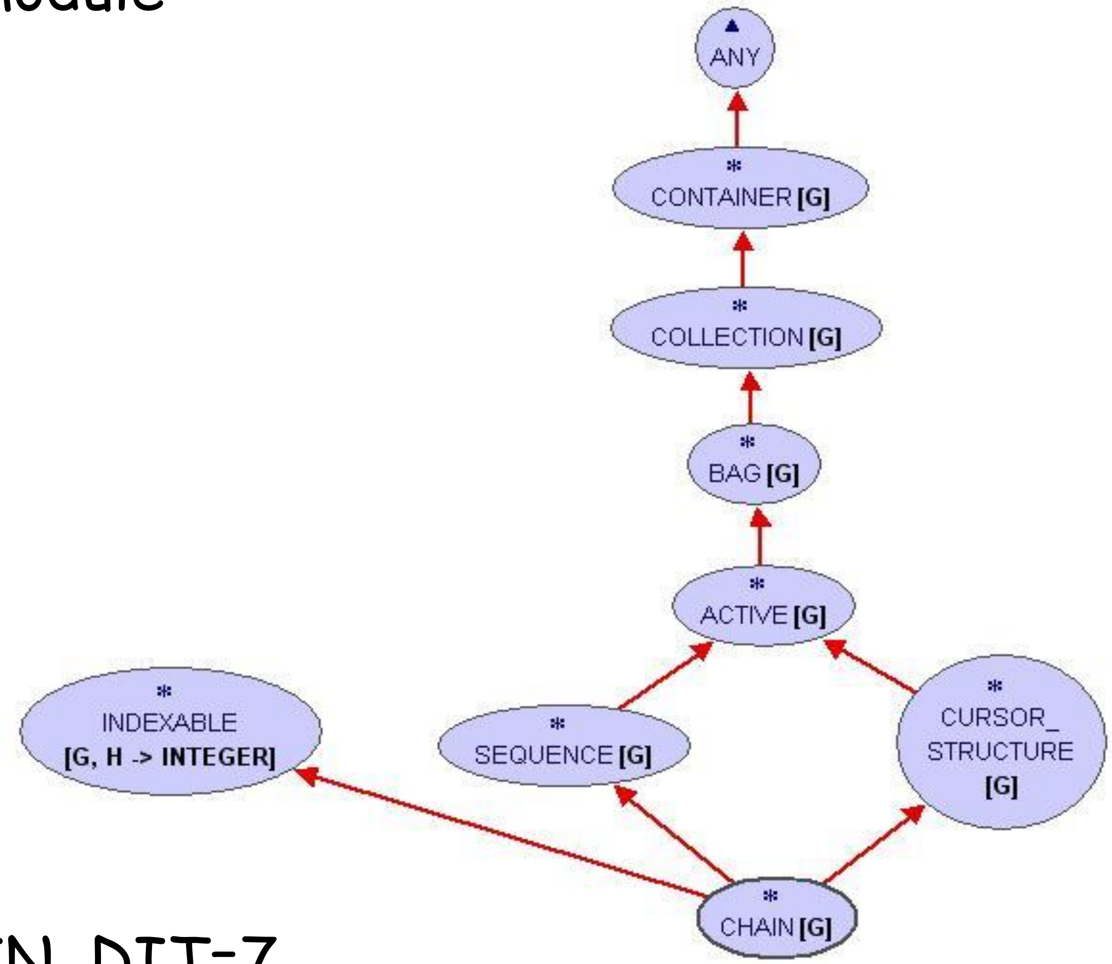
In Eiffel base, there are 5,341 features,

In Vision2 (Windows), there are 10,315 features,

In EiffelStudio (Windows GUI), there are 89,630 features.

Depth of inheritance tree of a class

Length of the longest path of inheritance ending at the current module



for CHAIN, DIT=7

Number of children

Number of immediate subclasses of a class.

In Eiffel base, there are 3 classes which have more than 10 immediate subclasses:

ANY

COMPARABLE

HASHABLE

And of course, ANY has most children.

Coupling between classes

Number of other classes to which a class is coupled, i.e., suppliers of a class.

In Eiffel base, there are 3 classes which directly depend on more than 20 other classes, they are:

STRING_8
STRING_32
TUPLE

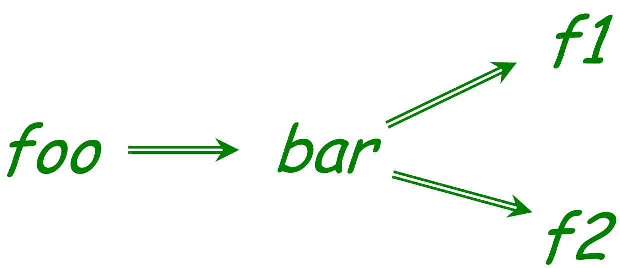
Class SED_STORABLE_FACILITIES indirectly depends on 91 other classes.

Response for a class (RFC)

Number of features that can potentially be executed in a feature, i.e., transitive closure of feature calls.

```
foo do
        bar
end

bar
        f1
        f2
end
```



RFC=3

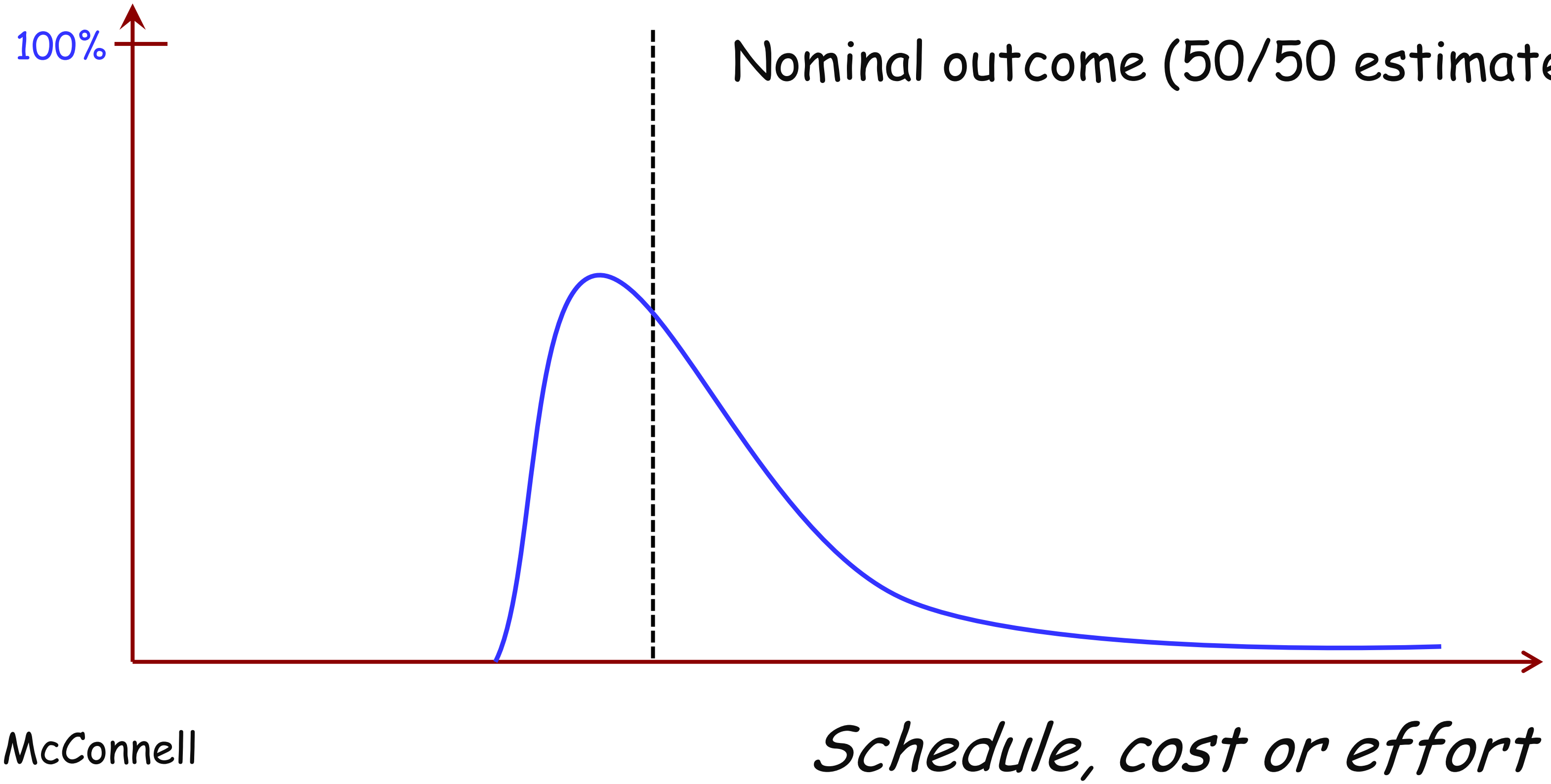
Cost estimation techniques

(This part of the material comes for a large part from Steve McConnell, *Sofware Estimation*, Microsoft Press, 2006, and B.W. Boehm et al., *Software Cost Estimation with Cocomo II*, Addison-Wesley, 2000)

Estimating costs

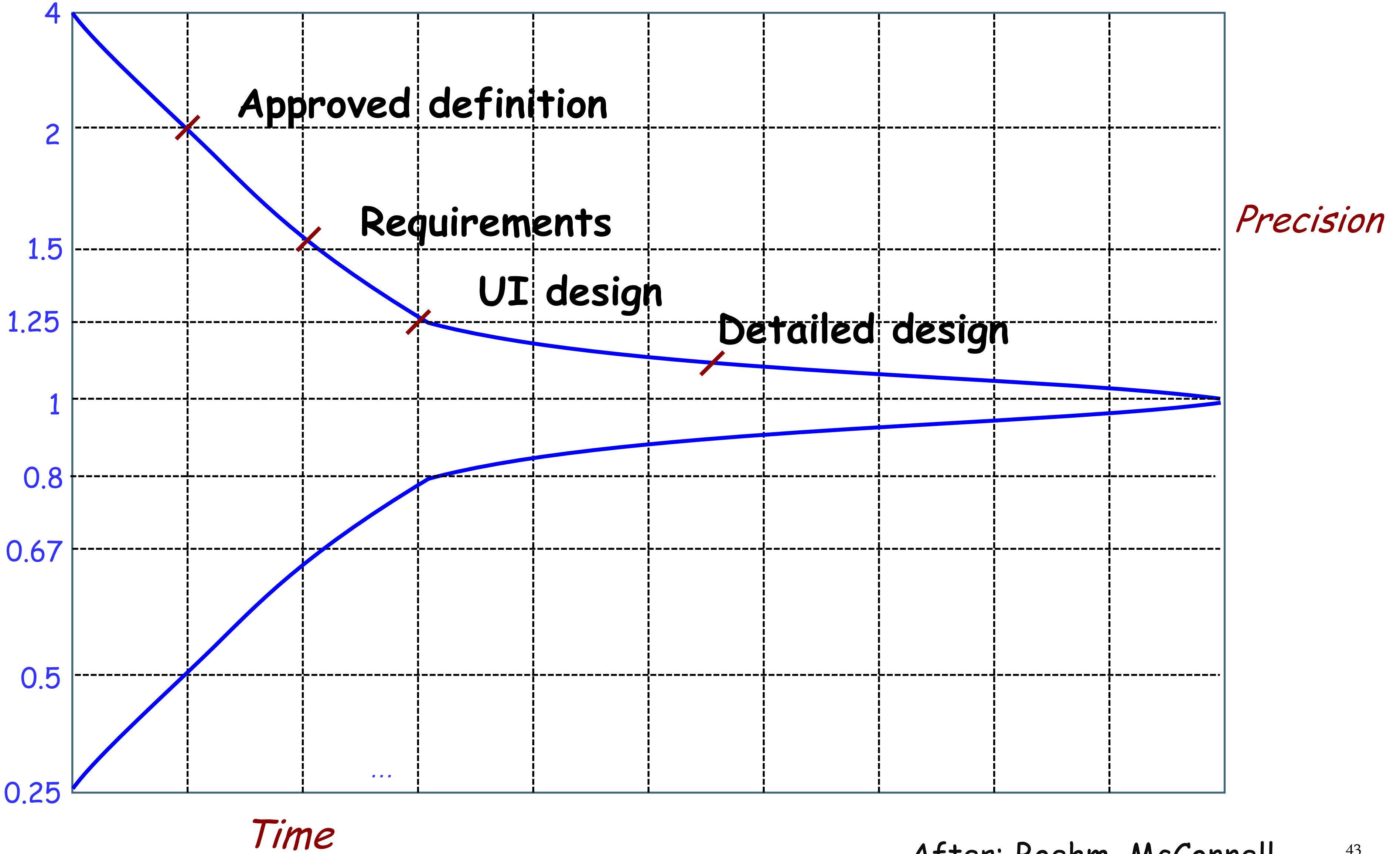
Any estimate has an associated probability

A typical probability distribution:



From: McConnell

The cone of uncertainty



After: Boehm, McConnell

Limits to the cone model

You get a cone that narrows itself (not a cloud) only if the project is well controlled and the estimates are regularly and effectively updated.

With these qualifications, the cone model is superior to single-point estimates

Sources of uncertainty

1 The development process

2 Unstable requirements

3 Unaccounted activities

4 Optimism

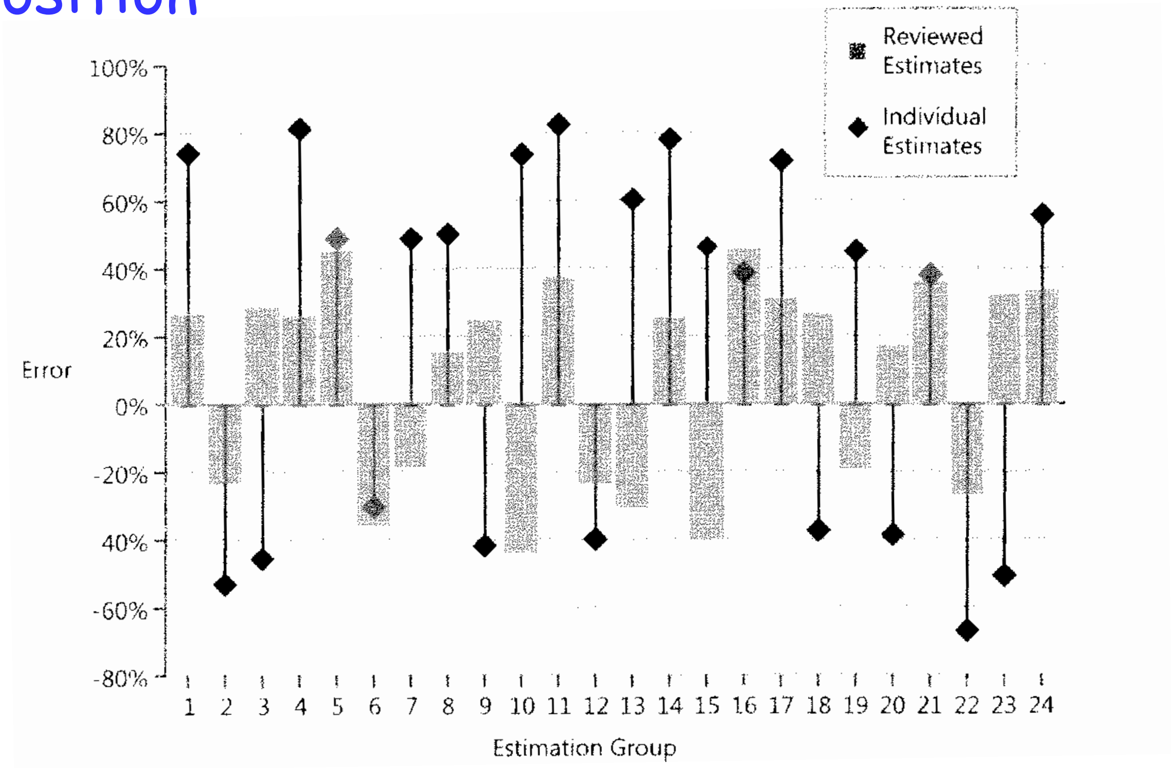
5 Bias

6 Unsupported precision

Using individual expert judgment

Practical advice:

- Never use off-the-cuff estimate
- Require low and high estimates
- Require decomposition



Source: McConnell

Using group judgment

Techniques:

- Individual first, then compare
- Discuss differences (do not just compute average)
- Arrive at consensus

Wideband Delphi (Boehm)

1. The Delphi coordinator presents each estimator with the specification and an estimation form.
2. Estimators prepare initial estimates individually. (Optionally, this step can be performed after step 3.)
3. The coordinator calls a group meeting in which the estimators discuss estimation issues related to the project at hand. If the group agrees on a single estimate without much discussion, the coordinator assigns someone to play devil's advocate.
4. Estimators give their individual estimates to the coordinator anonymously.
5. The coordinator prepares a summary of the estimates on an iteration form (shown in Figure 13-2) and presents the iteration form to the estimators so that they can see how their estimates compare with other estimators' estimates.
6. The coordinator has estimators meet to discuss variations in their estimates.
7. Estimators vote anonymously on whether they want to accept the average estimate. If any of the estimators votes "no," they return to step 3.
8. The final estimate is the single-point estimate stemming from the Delphi exercise. Or, the final estimate is the range created through the Delphi discussion and the single-point Delphi estimate is the expected case.

Effectiveness of Wideband Delphi (McConnell)

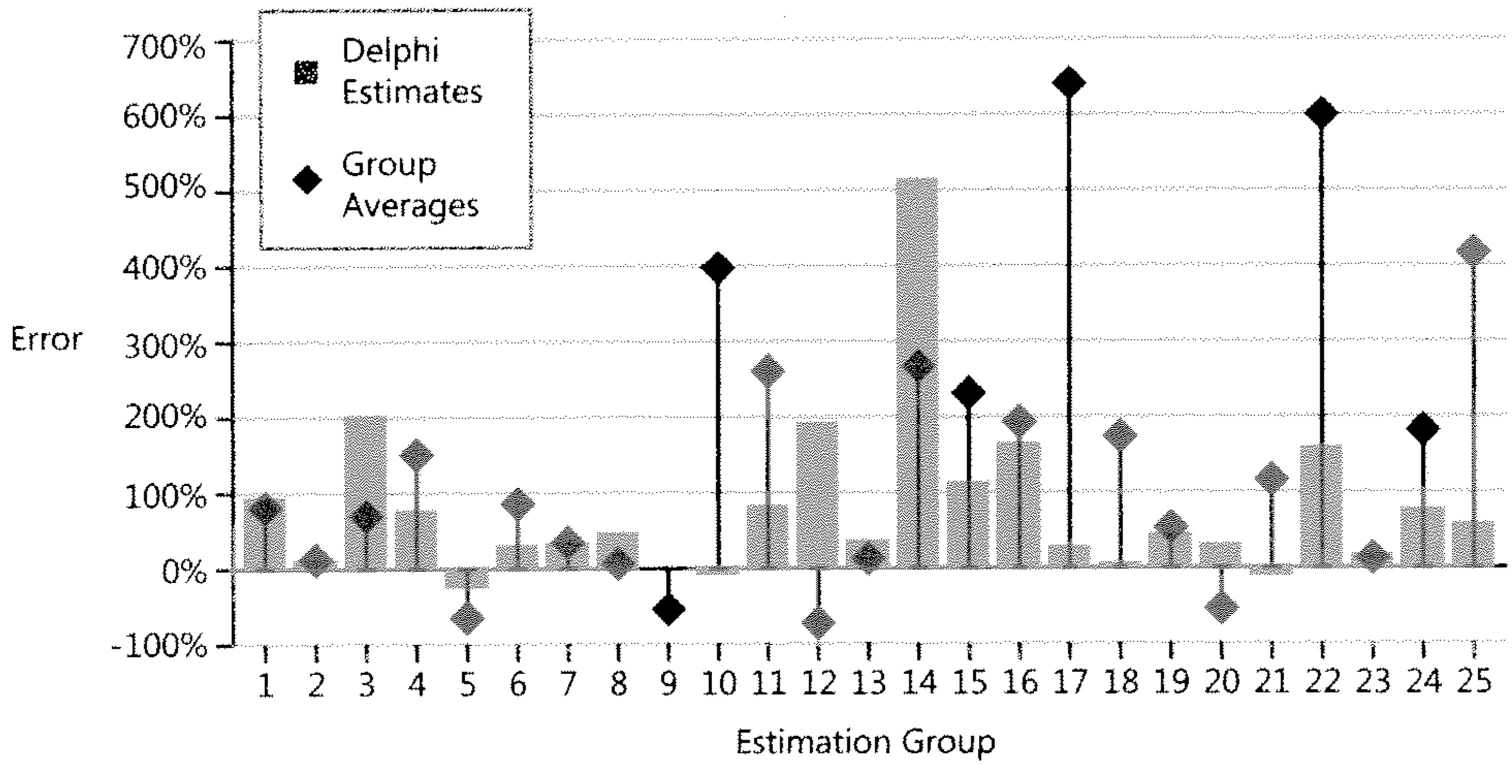


Figure 13-4 Estimation accuracy of simple averaging compared to Wideband Delphi estimation. Wideband Delphi reduces estimation error in about two-thirds of cases.

Source: McConnell

Effectiveness of Wideband Delphi (McConnell)

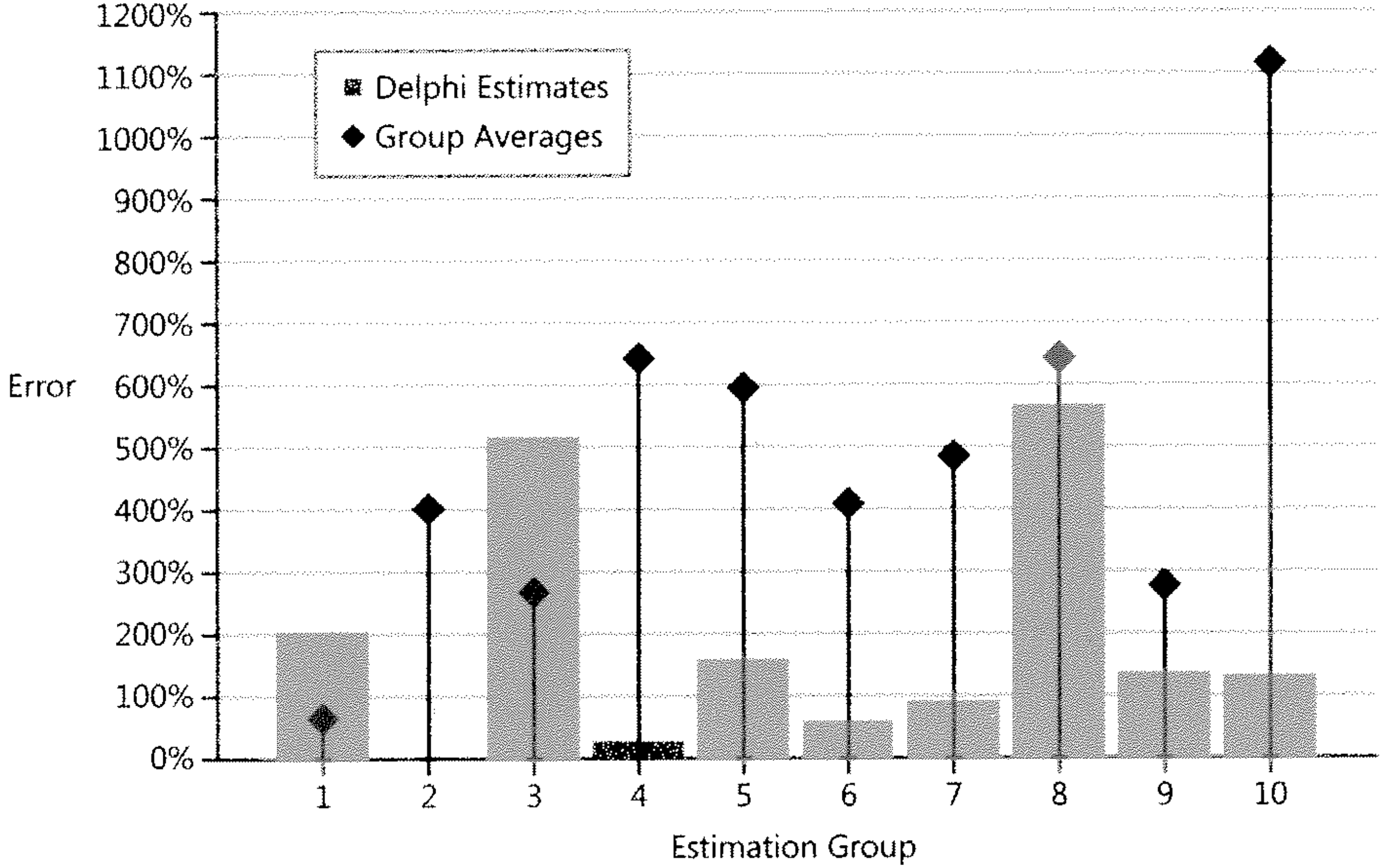


Figure 13-5 Wideband Delphi when applied to terrible initial estimates. In this data set, Wideband Delphi improved results in 8 out of 10 cases.

Source: McConnell

Decompose and recompose

Basic idea: find a division of the task into subtasks (function-based or step-based), estimate the subtasks, and combine the results.

Advantage: errors may compensate each other

Risk: accumulation of optimistic estimates

Advice: enforce best-case and worst-case estimate for each subtask

Estimation by analogy

Steps:

- 1 Get detailed data (size, effort, cost) for similar project
- 2 Compare size of old and new projects (measures: tables, screens, Web pages, reports, clusters, classes…)
- 3 Estimate size of new project
- 4 Estimate effort (or other parameter) for new project
- 5 Check for inconsistent comparison assumptions

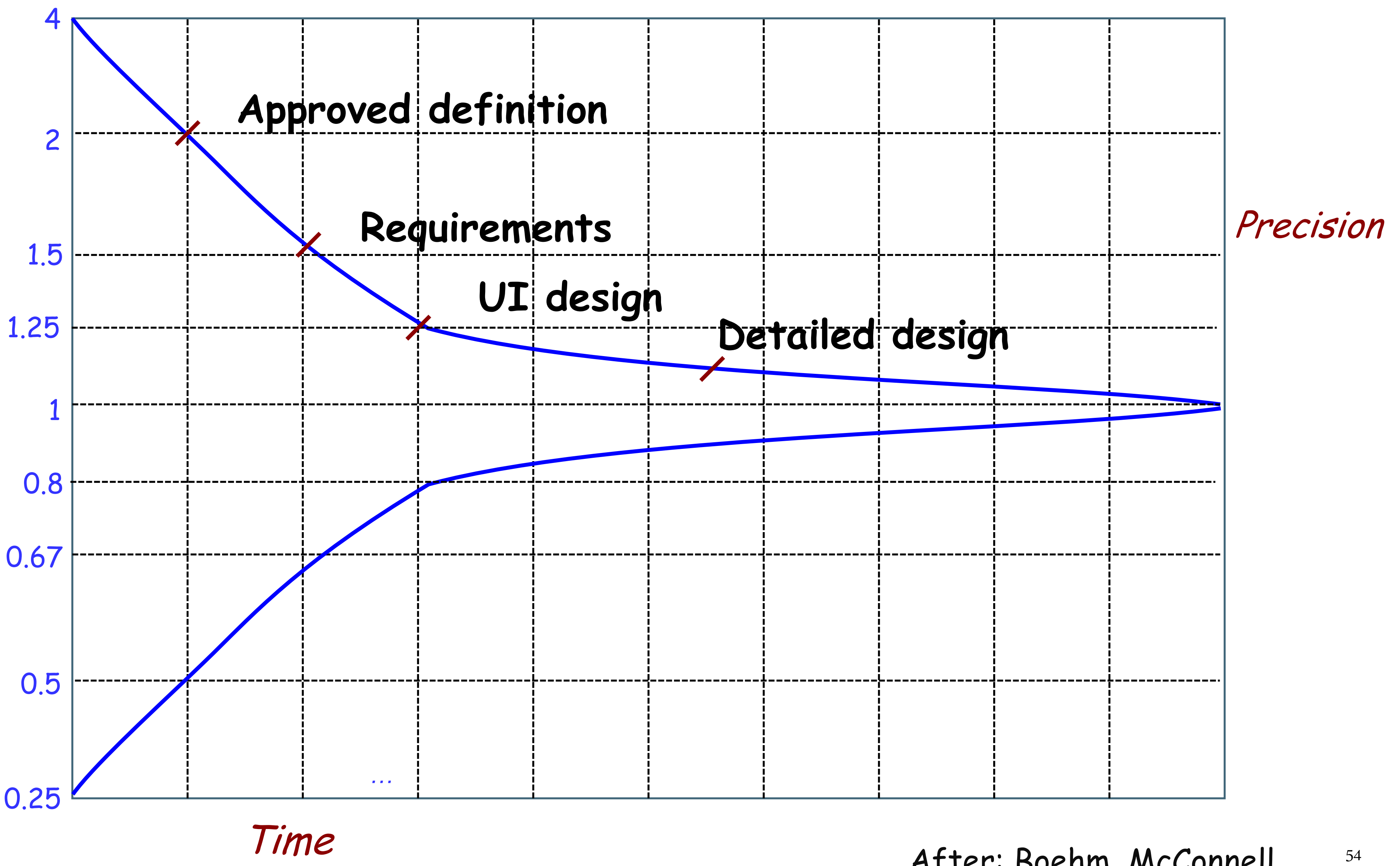
Estimation by proxy

Examples of proxies:

- Screens
- Static Web pages
- Dynamic Web pages
- (Relational) database pages
- Reports
- Business rules
- Story points (requirements features)

Estimating proxy values': "T-Shirt sizing"

The cone of uncertainty



After: Boehm, McConnell

Cost models

How do you estimate the cost of a project, *before* starting the project?

Cost models

Purpose: estimate in advance the effort attributes (development time, team size, cost) of a project

Problems involved:

- Find the appropriate parameters defining the project (making sure they are measurable in advance)
- Measure these parameters
- Deduce effort attributes through appropriate mathematical formula

Best known model: COCOMO (B. W. Boehm)

Cost models: COCOMO

Basic formula:

$$Effort = A * Size^{B} * M$$

A: 2.94 (early design)

B: 0.91 to 1.23 (depending on novelty, risk, process…)

M: Cost driver estimation

For Size, use:

- Action points at stage 1 (requirements)
- Function points at stage 2 (early design)
- Function points and SLOC at stage 3 (post-architecture)

COCOMO cost drivers (examples)

Early design:

- Product reliability & complexity
- Required reuse
- Platform difficulty
- Personnel capability
- Personnel experience
- Schedule
- Support facilities

Postarchitecture:

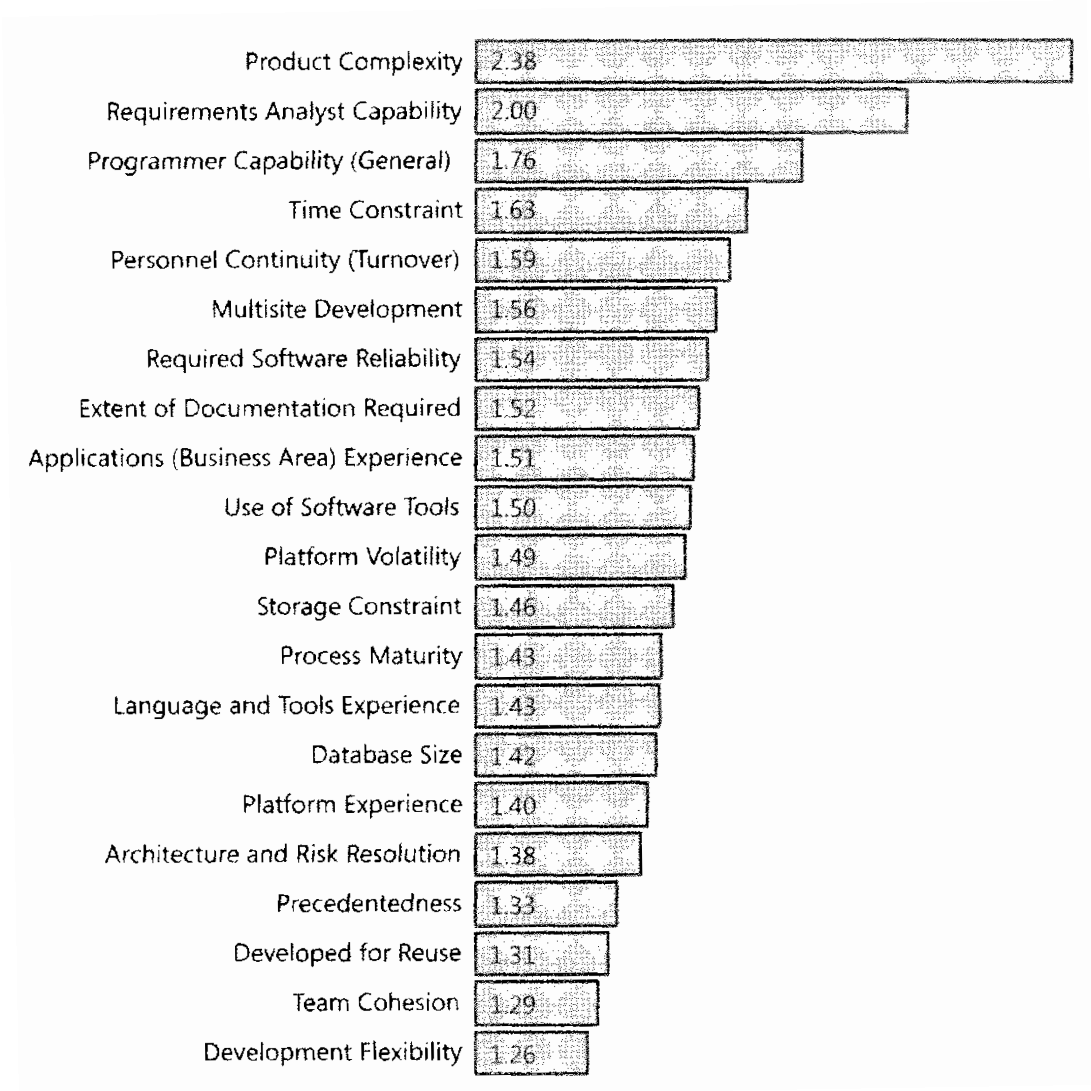
- Product reliability & complexity
- Database size
- Documentation needs
- Required reuse
- Execution time & storage constraints
- Platform volatility
- Personnel experience & capability
- Use of software tools
- Schedule
- Multisite development

COCOMO cost drivers

Factor	Very Low	Low	Nominal	High	Very High	Extra High	Influence
Applications (Business Area) Experience	1.22	1.10	1.00	0.88	0.81		1.51
Database Size		0.90	1.00	1.14	1.28		1.42
Developed for Reuse		0.95	1.00	1.07	1.15	1.24	1.31
Extent of Documentation Required	0.81	0.91	1.00	1.11	1.23		1.52
Language and Tools Experience	1.20	1.09	1.00	0.91	0.84		1.43
Multisite Development	1.22	1.09	1.00	0.93	0.86	0.78	1.56
Personnel Continuity (turnover)	1.29	1.12	1.00	0.90	0.81		1.59
Platform Experience	1.19	1.09	1.00	0.91	0.85		1.40
Platform Volatility		0.87	1.00	1.15	1.30		1.49
Product Complexity	0.73	0.87	1.00	1.17	1.34	1.74	2.38
Programmer Capability (general)	1.34	1.15	1.00	0.88	0.76		1.76
Required Software Reliability	0.82	0.92	1.00	1.10	1.26		1.54
Requirements Analyst Capability	1.42	1.19	1.00	0.85	0.71		2.00
Storage Constraint			1.00	1.05	1.17	1.46	1.46
Time Constraint			1.00	1.11	1.29	1.63	1.63
Use of Software Tools	1.17	1.09	1.00	0.90	0.78		1.50

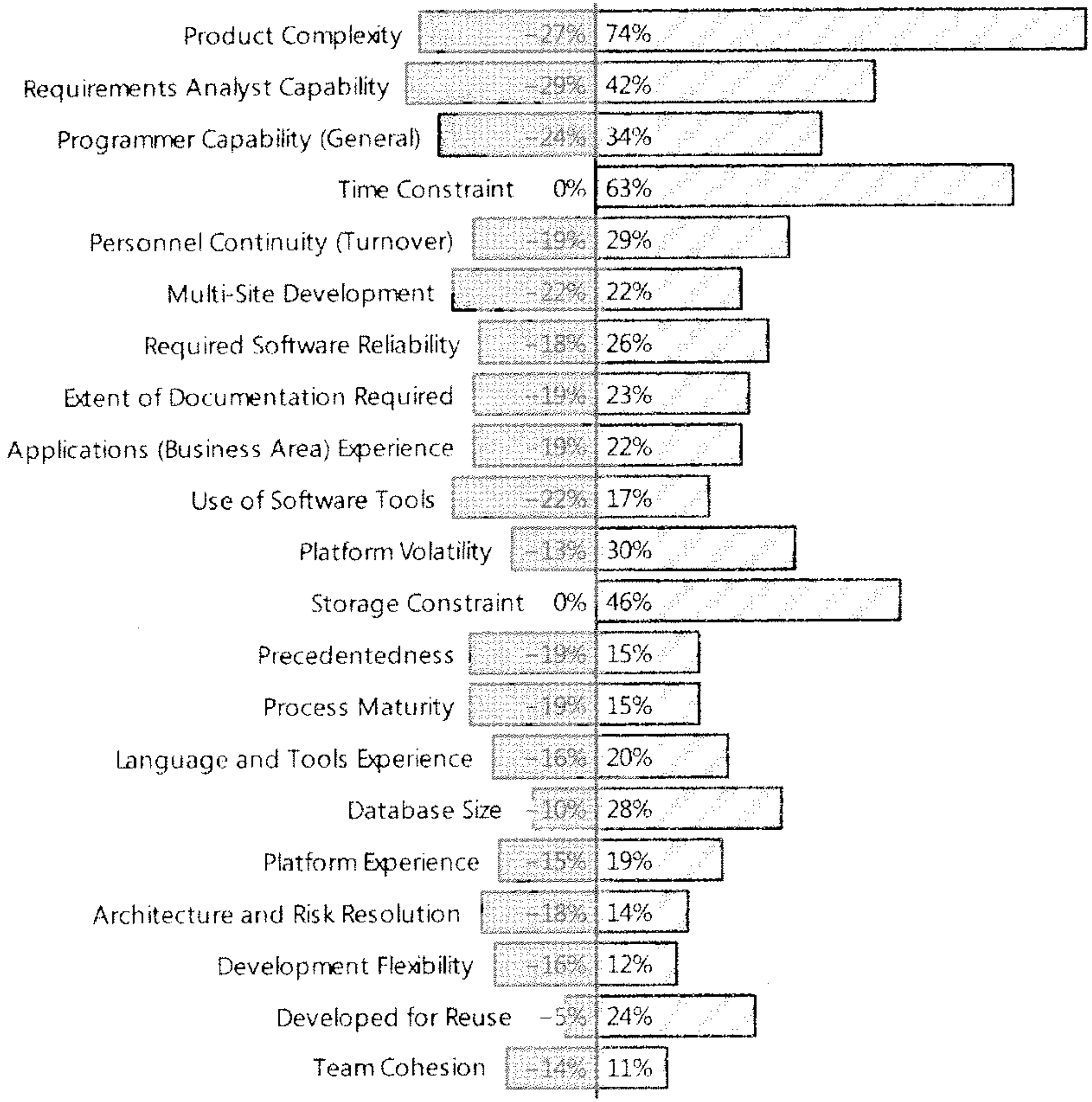
Source: Boehm, McConnell

COCOMO cost drivers



Source: Boehm, McConnell

COCOMO cost drivers



Source: Boehm, McConnell

About cost models

Easy to criticize, but seem to correlate well with measured effort in well-controlled environments

Useful only in connection with long-running measurement and project tracking policy; cf CMMI, PSP/TSP

Worth a try if you are concerned with predictability and cost control

Reliability models

Goal: to estimate the reliability – essentially, the likelihood of faults – in a system.

Basis: observed failures

Source: hardware reliability studies; application to software has been repeatedly questioned, but the ideas seem to hold

Reliability models: basic parameters

Interfailure times

Average: Mean Time To Failure: MTTF

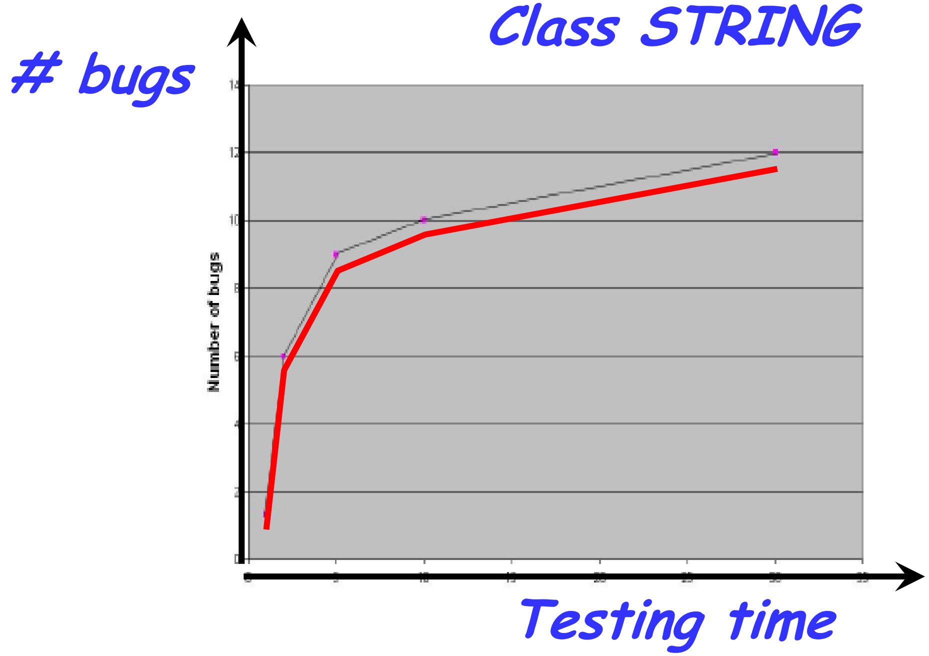
Mean Time To Repair: MTTR

- Do we stop execution to repair?
- Can repair introduce new faults?

Relability: R

$$R = \frac{MTTF}{1 + MTTF}$$

MTTF: the AutoTest experience

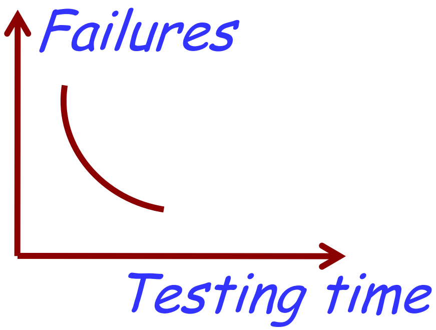


Apparent shape (conjecture only):

$$b = a - b / t$$

Reliability models

Attempt to predict the number of remaining faults and failures



Example: Motorola's zero-failure testing

$$Failures\ (t) = a\ e^{-b\ (t)}$$

Desired failure density (e.g. 1 failure per 10,000 SLOC)

Testing hours to last failure

Zero-failure test hours:

$$\frac{[\ln (f\ /\ (0.5 + f)]\ *\ h}{\ln [(0.5 + f)\ /\ tf + f)]}$$

Test failures so far

Software metrics: methodological guidelines

Measure only for a clearly stated purpose

Specifically: software measures should be connected with quality and cost

Assess the validity of measures through controlled, credible experiments

Apply software measures to software, not people

GQM (see below)

Metrics for software engineering

An assessment:

- Many software attributes are quantifiable
- They include both project and product attributes
- Models are available to estimate the values
- Models and metrics are only useful as part of a long-term measurement policy (see CMMI, PSP/TSP, but usable in many other contexts)
- Tools are available to support the metrics and models