Lecture 2: Metrics and Measurement

17-313: Foundations of Software Engineering
Claire Le Goues

Administrivia

- Reminder: change your zoom display name to be your name! And, please add a profile pic!
- Assignment 1 is released. It is due ~~Thu Sept 5, 11:59 pm (one week!).~~ Tuesday, Sept 15!
  - I'm *really* sorry: we set dates before we added Friday recitations. I'm reshuffling the schedule to reflect this, the website will be updated soon.
  - This is an individual assignment; we will compose groups this week. But: a comment on talking with your friends…
  - Get started early, ask for help, and check the #homework-techsupport channel; chances are decent your questions have been asked by others! Office hours will be scheduled.
- Reading for next Tuesday will be posted shortly.
- If you haven't filled out the schedule survey, do so after class.

Learning Goals

- Use measurements as a decision tool to reduce uncertainty
- Understand difficulty of measurement; discuss validity of measurements
- Provide examples of metrics for software qualities and process
- Understand limitations and dangers of decisions and incentives based on measurements

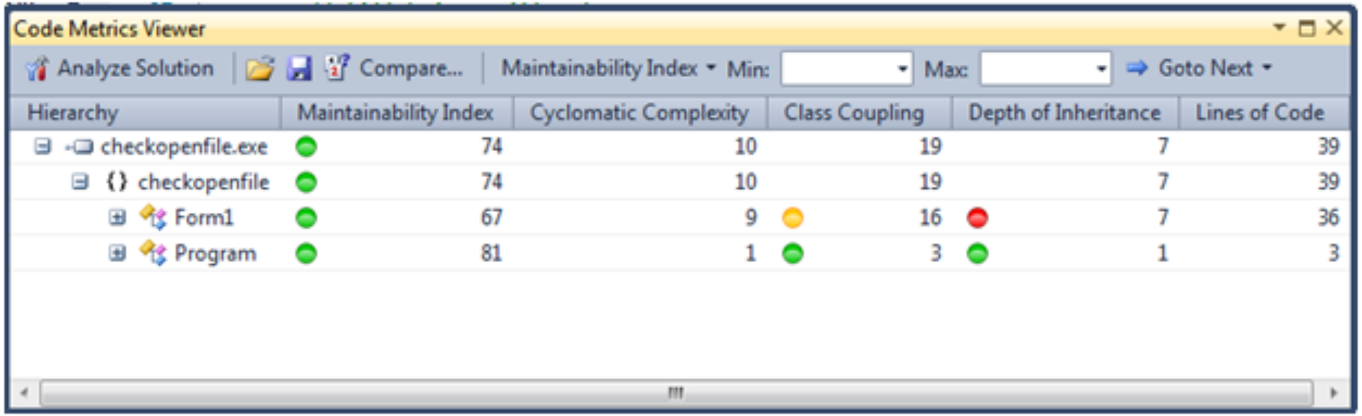
Software Engineering: Principles, practices (technical and non-technical) for **confidently** building **high-quality** software.

What does this mean?
How do we know?
→ *Measurement* and metrics are **key** concerns**.**

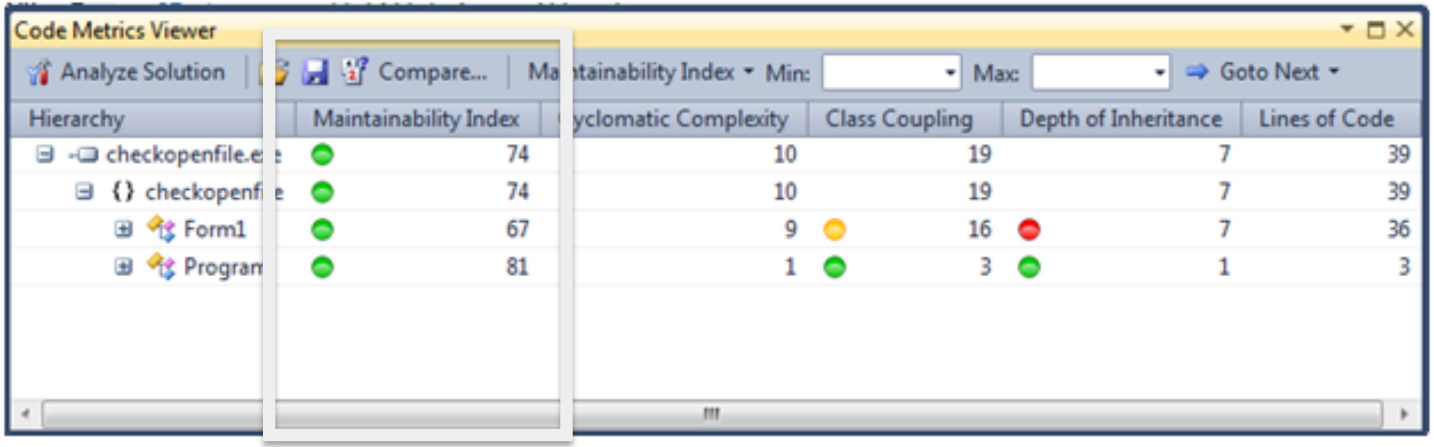
CASE STUDY:
THE MAINTAINABILITY INDEX

Visual Studio since 2007

“Maintainability Index calculates an index value between 0 and 100 that represents the relative ease of maintaining the code. A **high value means better maintainability**. Color coded ratings can be used to quickly identify trouble spots in your code. A **green rating is between 20 and 100** and indicates that the code has good maintainability. A **yellow rating is between 10 and 19** and indicates that the code is moderately maintainable. A **red rating is a rating between 0 and 9** and indicates low maintainability.”



Hierarchy	Maintainability Index	Cyclomatic Complexity	Class Coupling	Depth of Inheritance	Lines of Code
⊟ checkopenfile.exe	🟢 74	10	19	7	39
⊟ { } checkopenfile	🟢 74	10	19	7	39
⊞ Form1	🟢 67	9	🟡 16	🔴 7	36
⊞ Program	🟢 81	1	🟢 3	🟢 1	3



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Progran	🟢 81	1	🟢 3	🟢 1	3

- Index between 0 and 100 representing the relative ease of maintaining the code.
- Higher is better. Color coded by number:
  - Green: between 20 and 100
  - Yellow: between 10 and 19
  - Red: between 0 and 9.

From Visual Studio, since 2007

Design rational (from MSDN blog)

- "We noticed that as code tended toward 0 it was clearly hard to maintain code and the difference between code at 0 and some negative value was not useful."
- "The desire was that if the index showed red then we would be saying with a high degree of confidence that there was an issue with the code."

http://blogs.msdn.com/b/codeanalysis/archive/2007/11/20/maintainability-index-range-and-meaning.aspx

The Index

Maintainability Index =

MAX(0,(171 –

5.2 * log(Halstead Volume) –

0.23 * (Cyclomatic Complexity) –

16.2 * log(Lines of Code)

)*100 / 171)

Lines of Code

- Easy to measure

```
> wc –l file1 file2…
```

LOC	projects
450	Expression Evaluator
2.000	Sudoku, Functional Graph Library
40.000	OpenVPN
80-100.000	Berkeley DB, SQLlight
150-300.000	Apache, HyperSQL, Busybox, Emacs, Vim, ArgoUML
500-800.000	gimp, glibc, mplayer, php, SVN
1.600.000	gcc
6.000.000	Linux, FreeBSD
45.000.000	Windows XP

Normalizing Lines of Code

- Ignore comments and empty lines
- Ignore lines < 2 characters
- Pretty print source code first
- Count statements (logical lines of code)

```
for (i = 0; i < 100; i += 1) printf("hello"); /* How many lines of code is this? */
```

```
/* How many lines of code is this? */

for (
            i = 0;
            i < 100;
            i += 1
   ) {
            printf("hello");
}
```

Normalization per Language

Language	Statement factor (productivity)	Line factor
C	1	1
C++	2.5	1
Fortran	2	0.8
Java	2.5	1.5
Perl	6	6
Smalltalk	6	6.25
Python		6.5

Source: http://www.codinghorror.com/blog/2005/08/are-all-programming-languages-the-same.html u.a.

Halstead Volume

- Introduced by Maurice Howard Halstead in 1977
- Halstead Volume =
  number of operators/operands *
  log2(number of distinct
  operators/operands)
- Approximates size of elements and vocabulary

Halstead Volume - Example

```
main() {
        int a, b, c, avg;
        scanf("%d %d %d", &a, &b, &c);
        avg = (a + b + c) / 3;
        printf("avg = %d", avg);
}
```

Operators/Operands: main, (), {}, int, a, b, c, avg, scanf, (), "…", &, a, &, b, &, c, avg, =, a, +, b, +, c, (), /, 3, printf, (), "…", avg

Cyclomatic Complexity

- Proposed by McCabe 1976
- Based on control flow graph, measures linearly independent paths through a program
    - ~= number of decisions
    - Number of test cases needed to achieve branch coverage

M = edges of CFG – nodes of CFG + 2*end points

```
if (c1) {
                f1();
 } else {
                f2();
 }
 if (c2) {
                f3();
 } else {
                f4();
 }
```

Origins

- 1992 Paper at the International Conference on Software Maintenance by Paul Oman and Jack Hagemeister

$$171 - 5.2\,ln(\text{HV}) - 0.23\,\text{CC} - 16.2\,ln(\text{LOC}) + 50.0\,sin\sqrt{2.46 * \text{COM}}$$

COM = percentage of comments

- Developers rated a number of HP systems in C and Pascal
- Statistical regression analysis to find key factors among 40 metrics

PAUSE: discuss for 6 minutes

- What do you think of this index? Vote using emoji on the Slack post in #lectures
- Post a comment to #lectures with (1) the Andrew IDs of the people in your breakout room, (2) positives/negatives of the metric, and (3) would you use it, why or why not?

Thoughts?

- Metric seems attractive
- Easy to compute
- Often seems to match intuition

- Parameters seem almost arbitrary, calibrated in single small study code (few developers, unclear statistical significance)
- All metrics related to size: just measure lines of code?
- Original 1992 C/Pascal programs potentially quite different from Java/JS/C# code

http://avandeursen.com/2014/08/29/think-twice-before-using-the-maintainability-index/

MEASUREMENT FOR DECISION MAKING IN SOFTWARE DEVELOPMENT

What is Measurement?

- Measurement is the empirical, objective assignment of numbers, according to a rule derived from a model or theory, to attributes of objects or events with the intent of describing them. – Craner, Bond, “Software Engineering Metrics: What Do They Measure and How Do We Know?”
- A quantitatively expressed reduction of uncertainty based on one or more observations. – Hubbard, “How to Measure Anything …”

Software quality metric

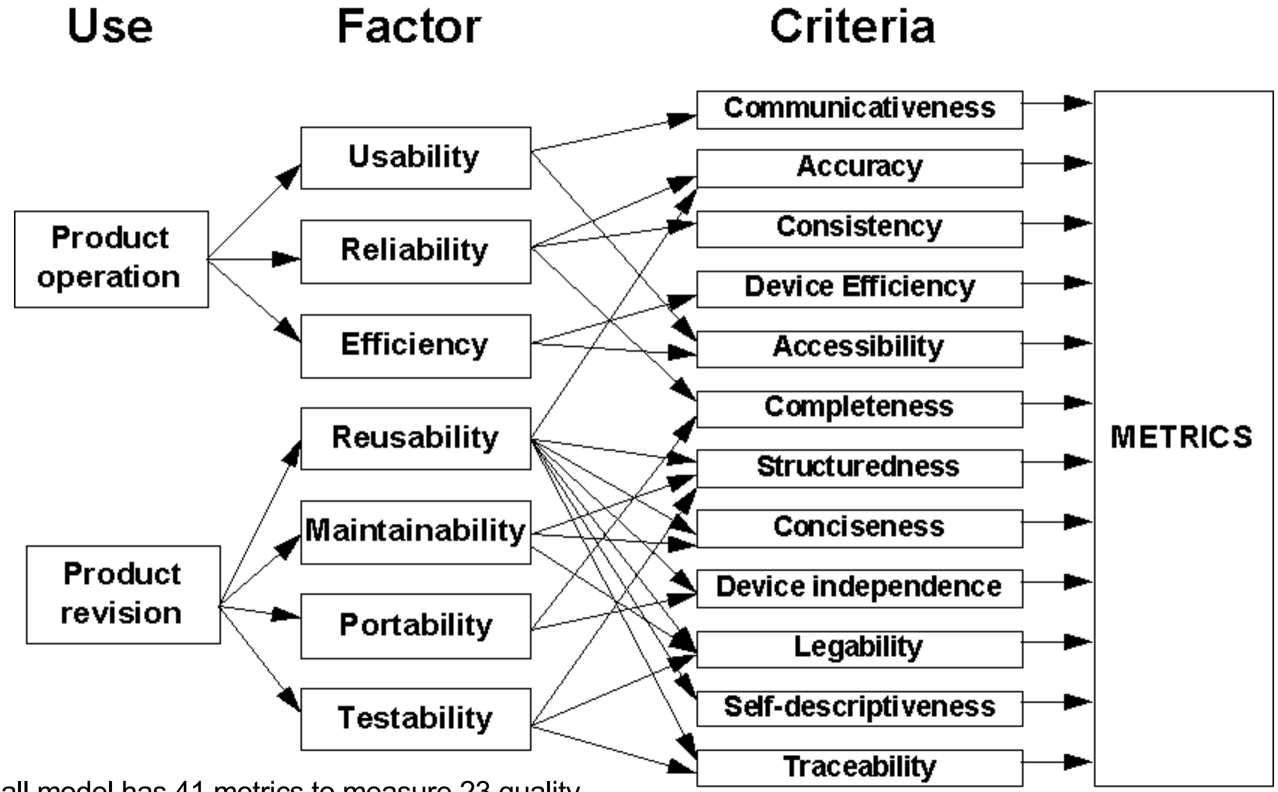
- IEEE 1061 says:
- “A software quality metric is a function whose inputs are software data and whose output is a single numerical value that can be interpreted as the degree to which software processes a given attribute that affects its quality.”

TEMPTATION OF SOFTWARE METRICS

Software Quality Metrics

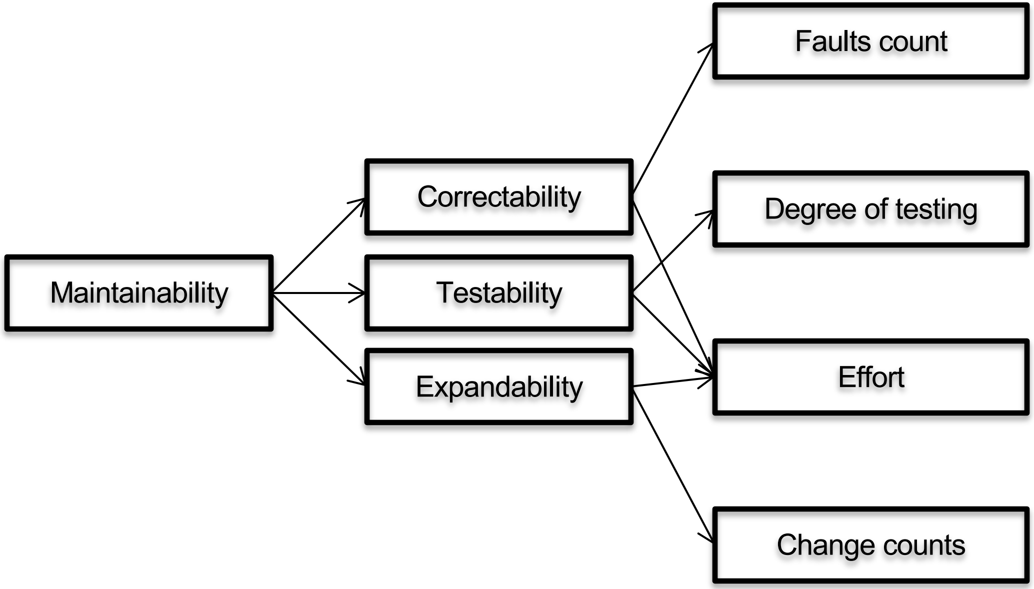
- IEEE 1061 definition: “A software quality metric is a function whose inputs are software data and whose output is a single numerical value that can be interpreted as the degree to which software processes a given attribute that affects its quality.”
- Metrics have been proposed for many quality attributes; may define own metrics

External attributes: Measuring Quality



McCall model has 41 metrics to measure 23 quality criteria from 11 factors

Decomposition of Metrics



Maintainability

Correctability

Testability

Expandability

Faults count

Degree of testing

Effort

Change counts

Closure time
Isolate/fix time
Fault rate

Statement coverage
Test plan completeness

Resource prediction
Effort expenditure

Change effort
Change size
Change rate

Object-Oriented Metrics

- Number of Methods per Class
- Depth of Inheritance Tree
- Number of Child Classes
- Coupling between Object Classes
- Calls to Methods in Unrelated Classes
- …

Other quality metrics?

- Comment density
- Test coverage
- Component balance (system breakdown optimality and component size uniformity)
- Code churn (number of lines added, removed, changed in a file)
- …

What software qualities do we care about? (examples)

- Scalability
- Security
- Extensibility
- Documentation
- Performance
- Consistency
- Portability
- Installability
- Maintainability
- Functionality (e.g., data integrity)
- Availability
- Ease of use

What process qualities do we care about? (examples)

- On-time release
- Development speed
- Meeting efficiency
- Conformance to processes
- Time spent on rework
- Reliability of predictions
- Fairness in decision making

- Measure time, costs, actions, resources, and quality of work packages; compare with predictions
- Use information from issue trackers, communication networks, team structures, etc…

Everything is measurable

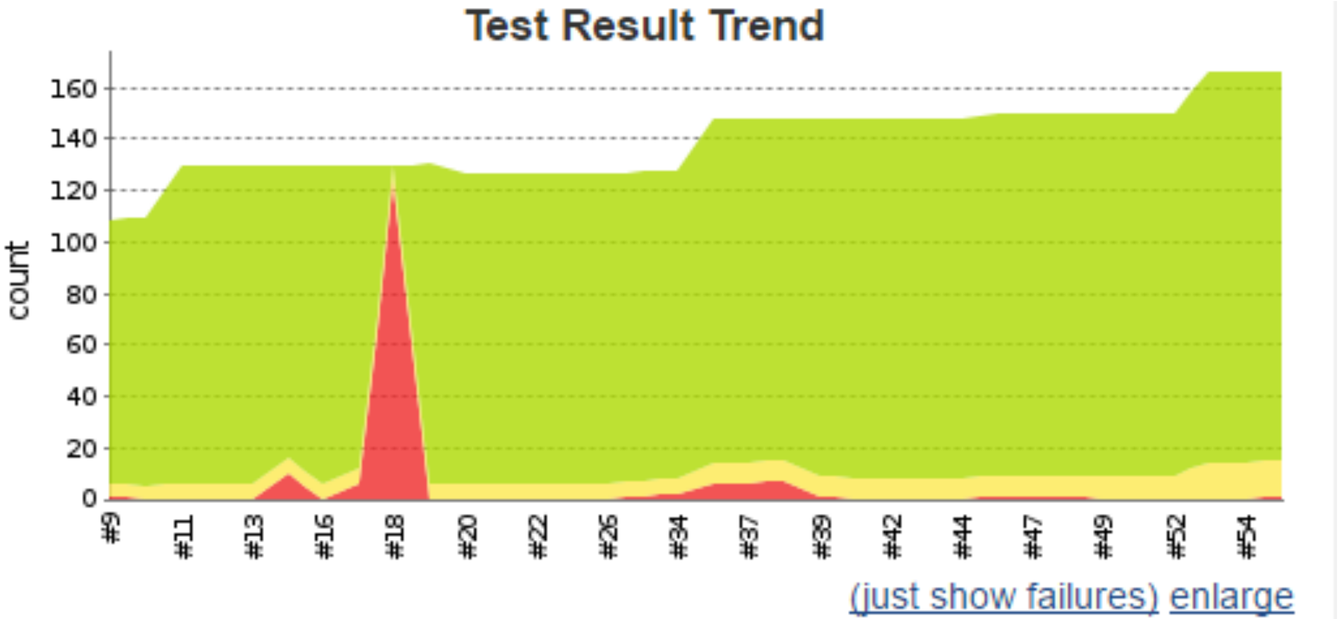
- If X is something we care about, then X, by definition, must be detectable.
  - How could we care about things like “quality,” “risk,” “security,” or “public image” if these things were totally undetectable, directly or indirectly?
  - If we have reason to care about some unknown quantity, it is because we think it corresponds to desirable or undesirable results in some way.
- If X is detectable, then it must be detectable in some amount.
  - If you can observe a thing at all, you can observe more of it or less of it
- If we can observe it in some amount, then it must be measurable.

D. Hubbard, How to Measure Anything, 2010

Measurement for Decision Making

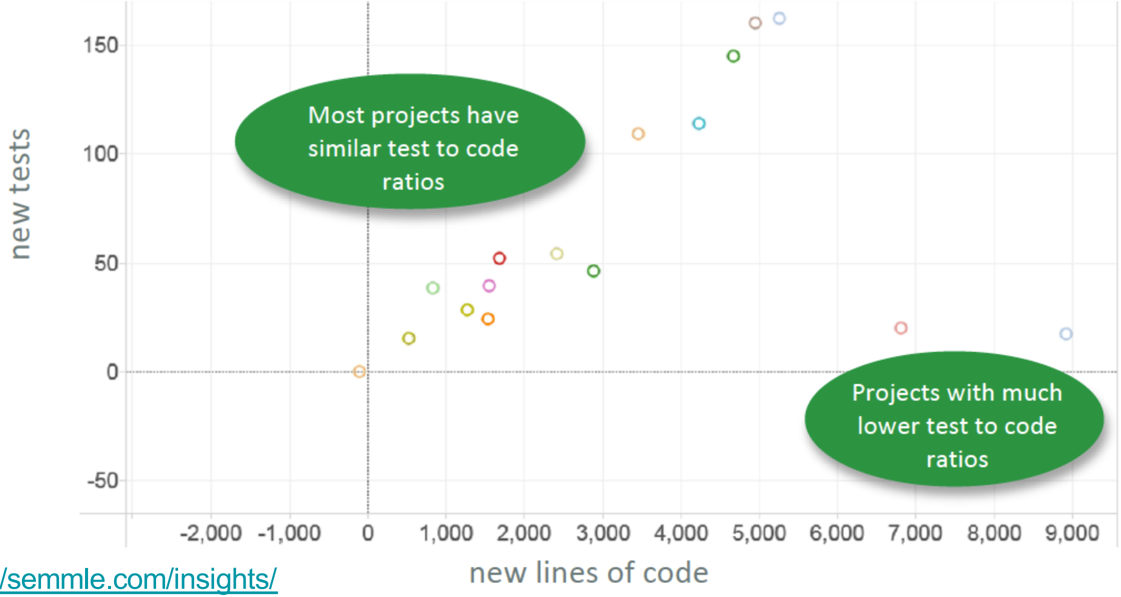
- Fund project?
- More testing?
- Fast enough? Secure enough?
- Code quality sufficient?
- Which feature to focus on?
- Developer bonus?
- Time and cost estimation? Predictions reliable?

Trend analyses



Benchmark-Based Metrics

- Monitor many projects or many modules, get typical values for metrics
- Report deviations



https://semmle.com/insights/

Questions to consider.

- What properties do we care about, and how do we measure it?
- What is being measured? Does it (to what degree) capture the thing you care about? What are its limitations?
- How should it be incorporated into process? Check in gate? Once a month? Etc.
- What are potentially negative side effects or incentives?

MEASUREMENT IS DIFFICULT

The streetlight effect

- A known observational bias.
- People tend to look for something only where it's easiest to do so.
    - If you drop your keys at night, you'll tend to look for it under streetlights.

DANGER

What could possibly go wrong?

- Bad statistics: A basic misunderstanding of measurement theory and what is being measured.
- Bad decisions: The incorrect use of measurement data, leading to unintended side effects.
- Bad incentives: Disregard for the human factors, or how the cultural change of taking measurements will affect people.

Measurements validity

- Construct – Are we measuring what we intended to measure?
- Predictive – The extent to which the measurement can be used to explain some other characteristic of the entity being measured
- External validity – Concerns the generalization of the findings to contexts and environments, other than the one studied

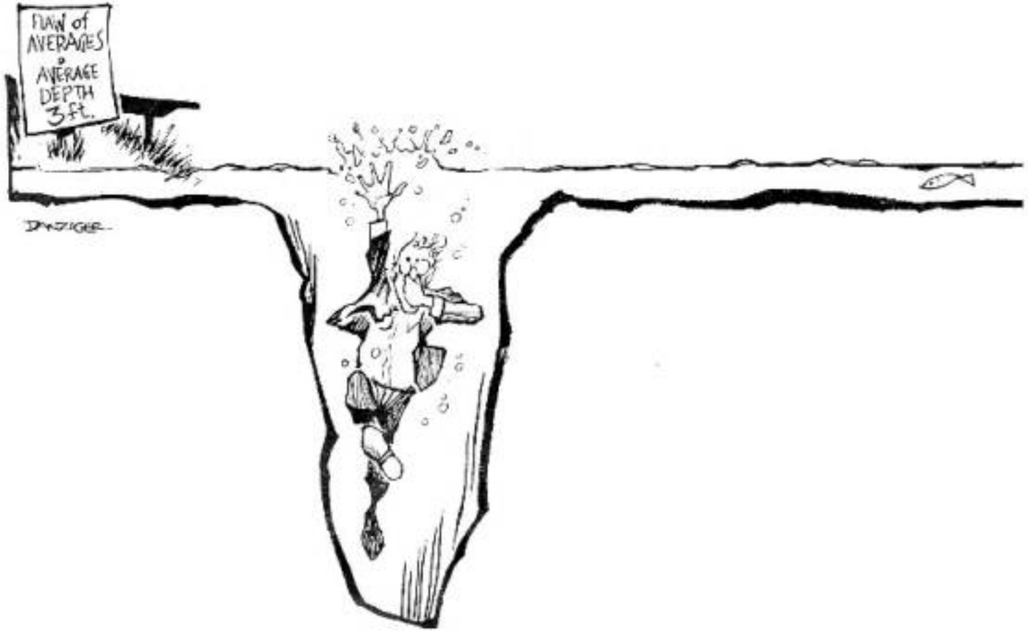
Lies, damned lies, and...

- In 1995, the UK Committee on Safety of Medicines issued the following warning: "third-generation oral contraceptive pills increased the risk of potentially life-threatening blood clots in the legs or lungs twofold -- that is, by 100 percent”

...statistics

- “...of every 7,000 women who took the earlier, second-generation oral contraceptive pills, about one had a thrombosis; this number increased to two among women who took third-generation pills...”
- “...The absolute risk increase was only one in 7,000, whereas the relative increase (among women who developed blood clots) was indeed 100 percent.”

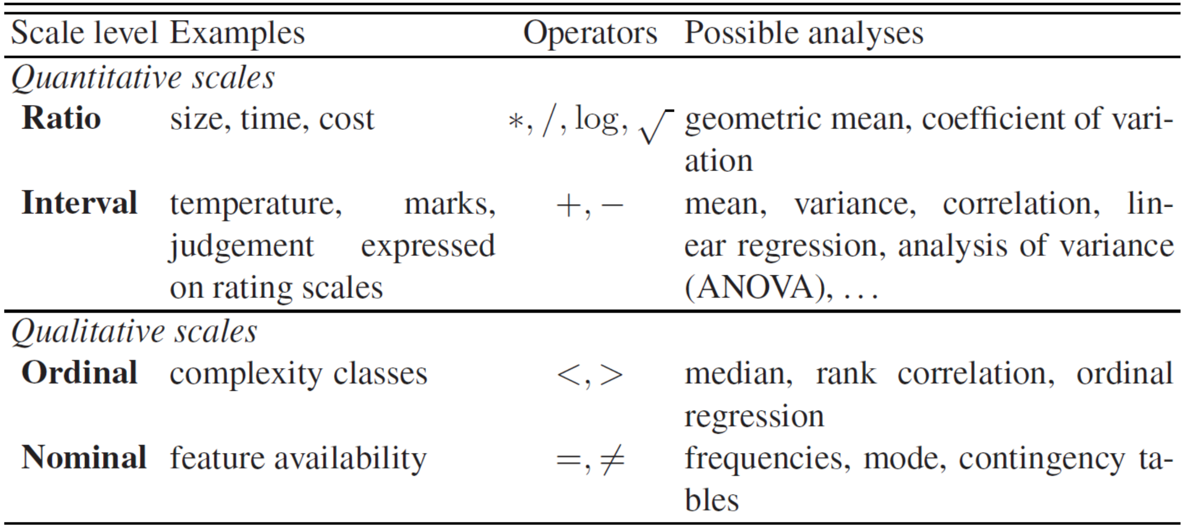
Understanding your data



Measurement scales

- Scale: the type of data being measured.
- The scale dictates what sorts of analysis/arithmetic is legitimate or meaningful.
- Your options are:
    - Nominal: categories
    - Ordinal: order, but no magnitude.
    - Interval: order, magnitude, but no zero.
    - Ratio: Order, magnitude, and zero.
    - Absolute: special case of ratio.

Summary of scales



Scale level	Examples	Operators	Possible analyses
Quantitative scales			
Ratio	size, time, cost	$*, /, \log, \sqrt{}$	geometric mean, coefficient of variation
Interval	temperature, marks, judgement expressed on rating scales	$+, -$	mean, variance, correlation, linear regression, analysis of variance (ANOVA), …
Qualitative scales			
Ordinal	complexity classes	$<, >$	median, rank correlation, ordinal regression
Nominal	feature availability	$=, \neq$	frequencies, mode, contingency tables

Nominal/categorical scale

- Entities classified with respect to a certain attribute. Categories are jointly exhaustive and mutually exclusive.
  - No implied order between categories!
- Categories can be represented by labels or numbers; however, they do not represent a magnitude, arithmetic operation have no meaning.
- Can be compared for identity or distinction, and measurements can be obtained by counting the frequencies in each category. Data can also be aggregated.

Entity	Attribute	Categories
Application	Purpose	E-commerce, CRM, Finance
Application	Language	Java, Python, C++, C#
Fault	Source	assignment, checking, algorithm, function, interface, timing

Ordinal scale

- Ordered categories: maps a measured attribute to an ordered set of values, but no information about the magnitude of the differences between elements.
- Measurements can be represented by labels or numbers, BUT: if numbers are used, *they do not represent a magnitude.*
  - ○ Honestly, try not to do that. It eliminates temptation.
- You cannot: add, subtract, perform averages, etc (arithmetic operations are out).
- You can: compare with operators (like “less than” or “greater than”), create ranks for the purposes of rank correlations (Spearman’s coefficient, Kendall’s τ).

Entity	Attribute	Values
Application	Complexity	Very Low, Low, Average, High, Very High
Fault	Severity	1 – Cosmetic, 2 – Moderate, 3 – Major, 4 – Critical

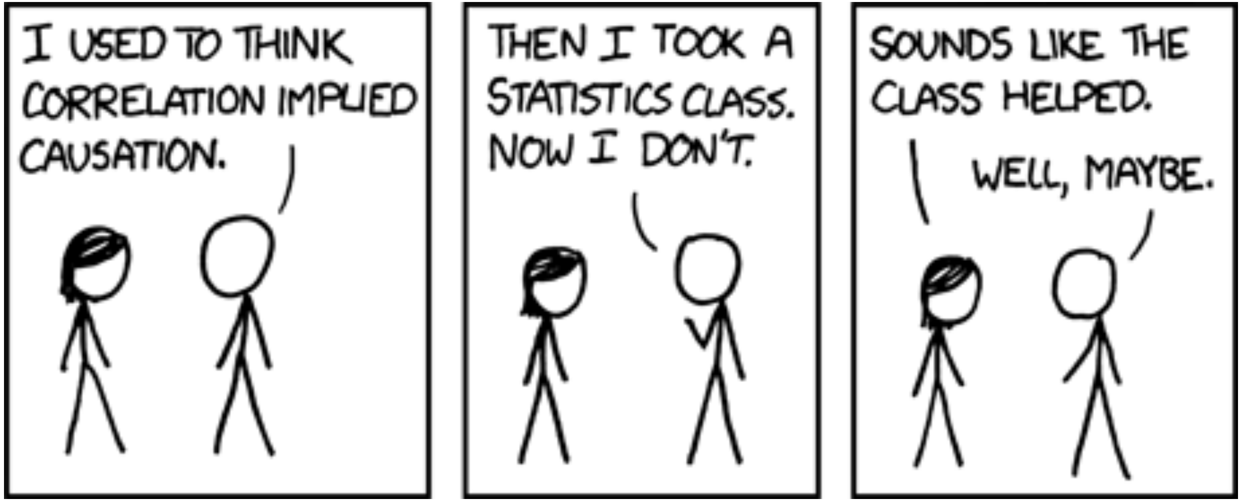
Interval scale

- Has order (like ordinal scale) and magnitude.
    - The intervals between two consecutive integers represent equal amounts of the attribute being measured.
- Does NOT have a zero: 0 is an arbitrary point, and doesn't correspond to the absence of a quantity.
- Most arithmetic (addition, subtraction) is OK, as are mean and dispersion measurements, as are Pearson correlations. Ratios are not meaningful.
    - Ex: The temperature yesterday was 64 oF, and today is 32 oF. Is today twice as cold as yesterday?
- Incremental variables (quantity as of today – quantity at an earlier time) and preferences are commonly measured in interval scales.

Ratio scale

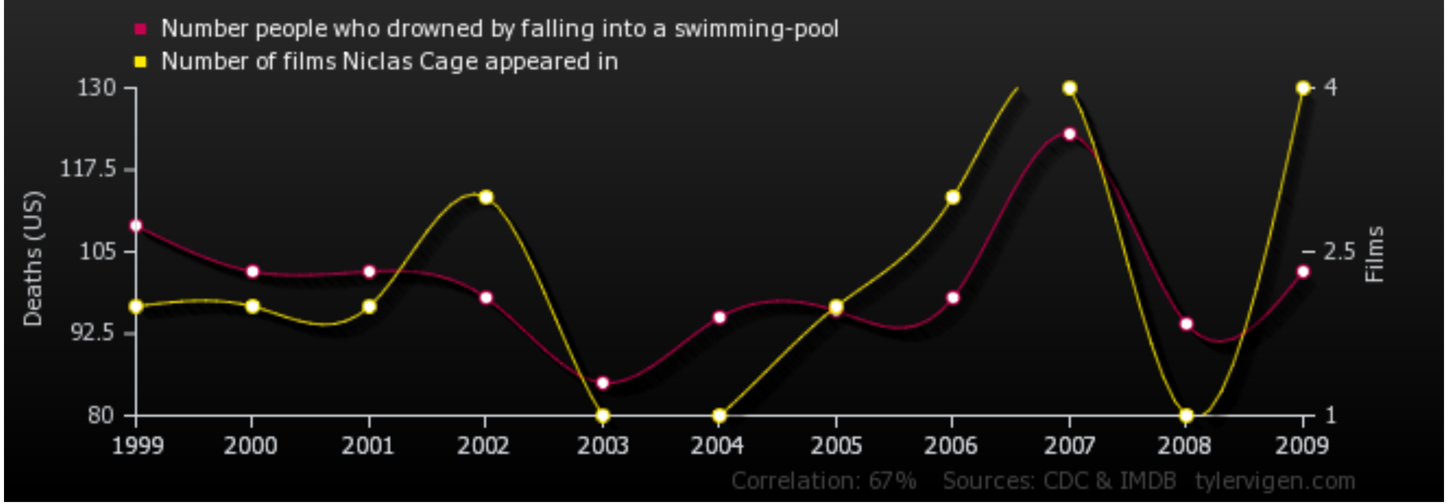
- An interval scale that has a true zero that actually represents the absence of the quantity being measured.
- All arithmetic is meaningful.
- Absolute scale is a special case, measurement simply made by counting the number of elements in the object.
    - Takes the form “number of occurrences of X in the entity.”

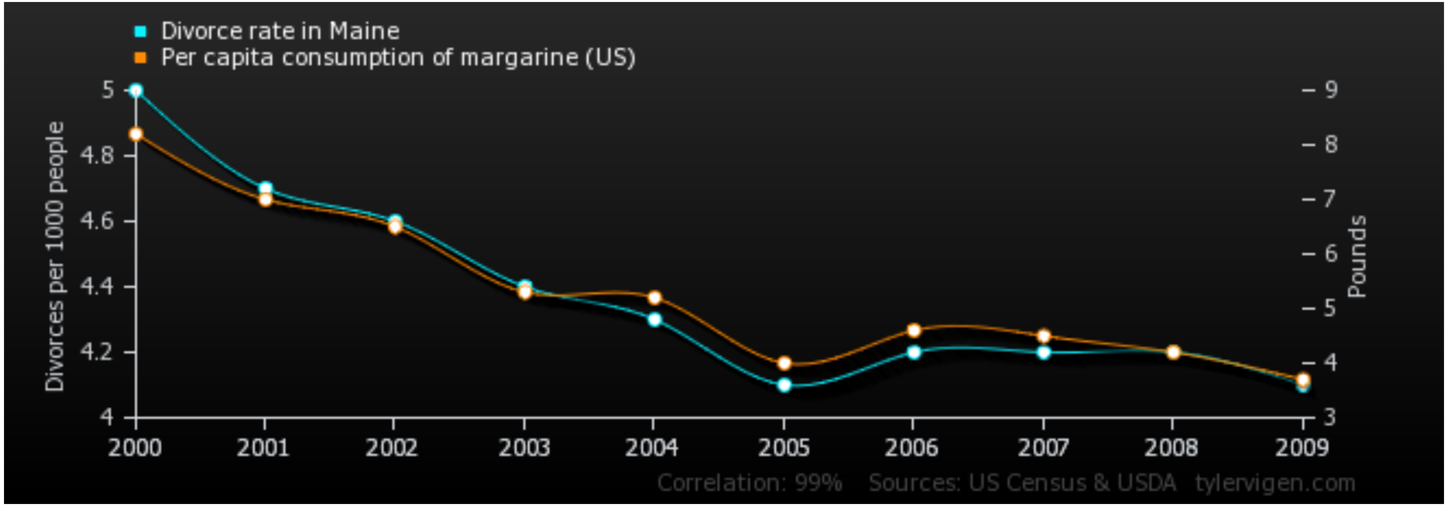
Entity	Attribute	Values
Project	Effort	Real numbers
Software	Complexity	Cyclomatic complexity


I USED TO THINK CORRELATION IMPLIED CAUSATION.
THEN I TOOK A STATISTICS CLASS. NOW I DON'T.
SOUNDS LIKE THE CLASS HELPED.
WELL, MAYBE.

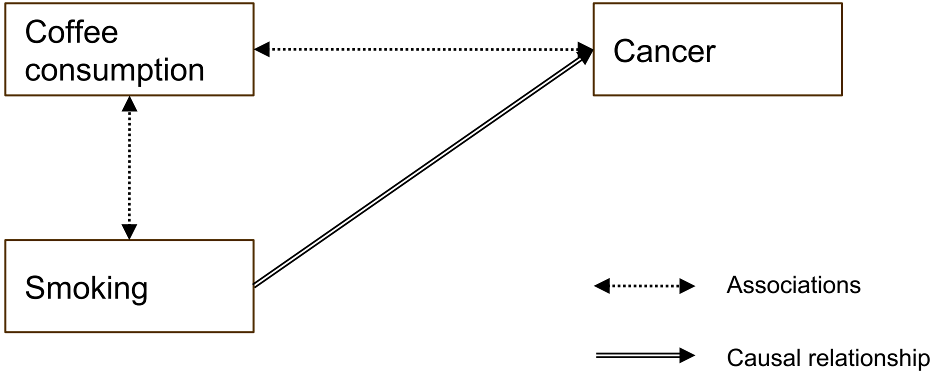
http://xkcd.com/552/

- For causation
  - Provide a theory (from domain knowledge, independent of data)
  - Show correlation
  - Demonstrate ability to predict new cases (replicate/validate)


Number people who drowned by falling into a swimming-pool
Number of films Niclas Cage appeared in
Deaths (US)
130
117.5
105
92.5
80
Films
4
2.5
1
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Correlation: 67%
Sources: CDC & IMDB
tylervigen.com


Divorce rate in Maine
Per capita consumption of margarine (US)
Divorces per 1000 people
5
4.8
4.6
4.4
4.2
4
Pounds
9
8
7
6
5
4
3
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Correlation: 99%
Sources: US Census & USDA
tylervigen.com

Confounding variables



- If you look only at the coffee consumption → cancer relationship, you can get very misleading results
- Smoking is a confounder

Effect of Class Size on the Validity of Object-oriented Metrics

- “Only four, out of twenty-four commonly used object-oriented metrics, were actually useful in predicting the quality of a software module when the effect of the module size was accounted for.”
- Khaled El Emam, Saida Benlarbi, and Nishith Goel ,September 1999

The McNamara Fallacy

- There seems to be a general misunderstanding to the effect that a mathematical model cannot be undertaken until every constant and functional relationship is known to high accuracy. This often leads to the omission of admittedly highly significant factors (most of the “intangibles” influences on decisions) because these are unmeasured or unmeasurable. To omit such variables is equivalent to saying that they have zero effect… Probably the only value known to be wrong…
    - J. W. Forrester, Industrial Dynamics, The MIT Press, 1961

McNamara fallacy

- Measure whatever can be easily measured.
- Disregard that which cannot be measured easily.
- Presume that which cannot be measured easily is not important.
- Presume that which cannot be measured easily does not exist.

https://chronotopeblog.com/2015/04/04/the-mcnamara-fallacy-and-the-problem-with-numbers-in-education/

Defect Density

- Defect density = Known bugs / line of code
- System spoilage = time to fix post-release defects /
  total system development time
- Post-release vs pre-release
- What counted as defect? Severity? Relevance?
- What size metric used?
- What quality assurance mechanisms used?
- Little reference data publicly available;
  typically 2-10 defects/1000 lines of code

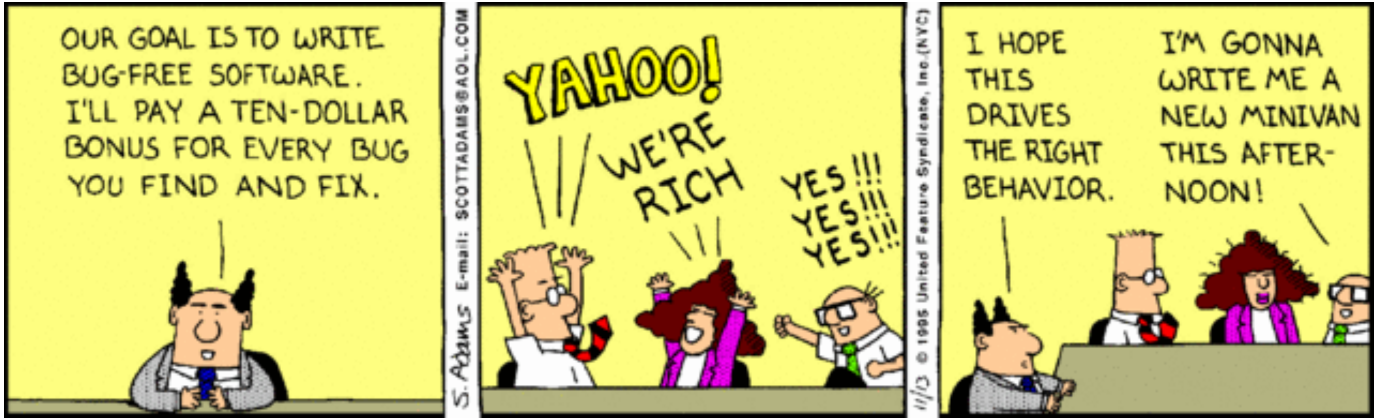
DISCUSSION: MEASURING USABILITY?

Example: Measuring usability.

- Automated measures on code repositories
- Use or collect process data
- Instrument program (e.g., in-field crash reports)
- Surveys, interviews, controlled experiments, expert judgment
- Statistical analysis of sample

METRICS AND INCENTIVES

Goodhart’s law: “When a measure becomes a target, it ceases to be a good measure.”

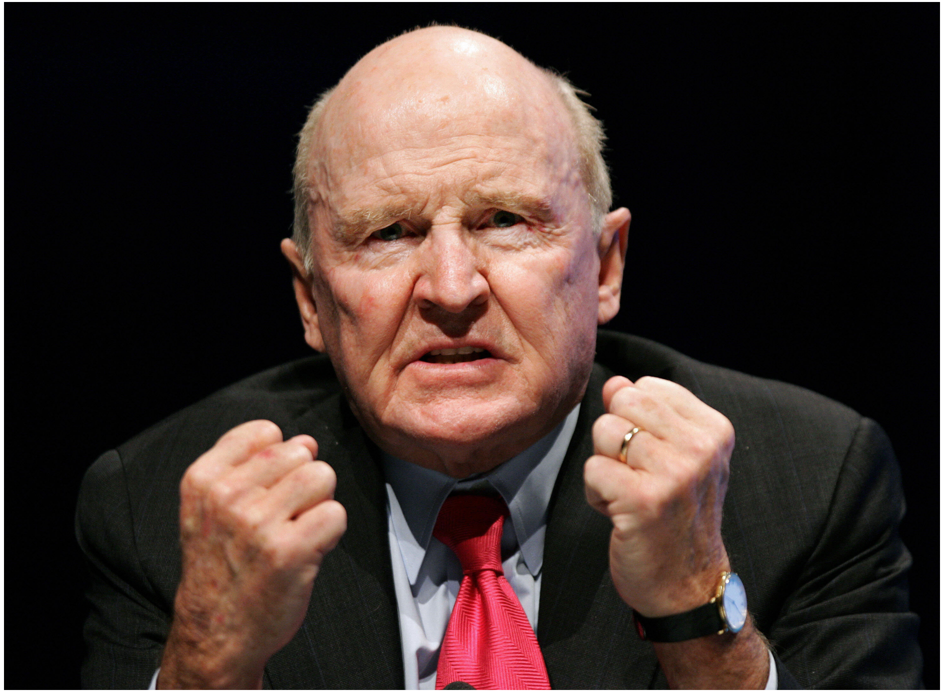

OUR GOAL IS TO WRITE BUG-FREE SOFTWARE. I'LL PAY A TEN-DOLLAR BONUS FOR EVERY BUG YOU FIND AND FIX.
S. Adams E-mail: SCOTTADAMS@AOL.COM
YAHOO!
WE'RE RICH
YES!!! YES!!!! YES!!!
11/13 © 1995 United Feature Syndicate, Inc.(NYC)
I HOPE THIS DRIVES THE RIGHT BEHAVIOR.
I'M GONNA WRITE ME A NEW MINIVAN THIS AFTER-NOON!

http://dilbert.com/strips/comic/1995-11-13/

Productivity Metrics

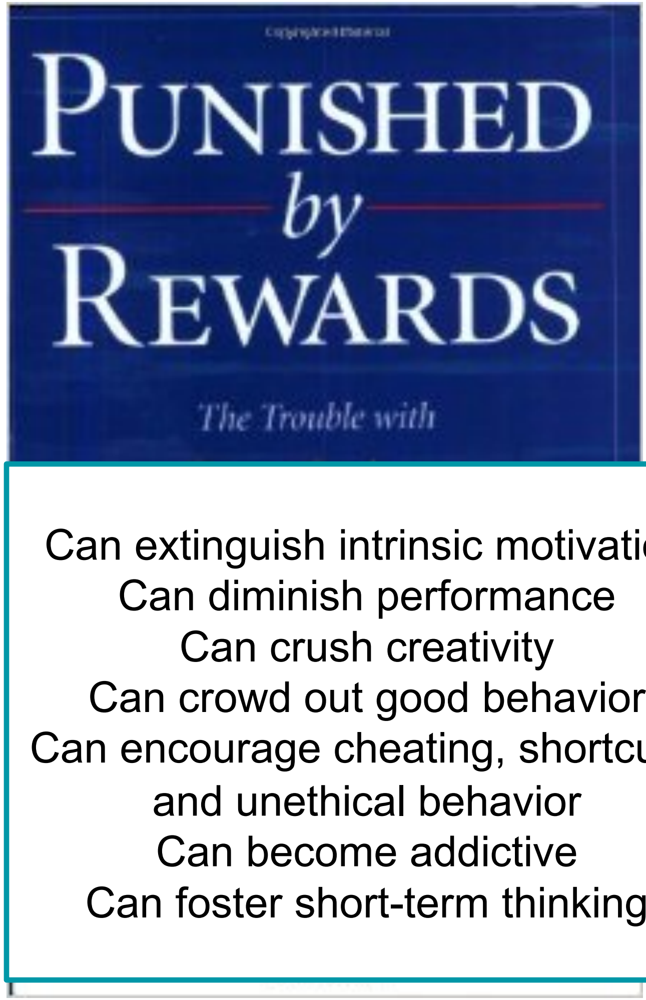
- Lines of code per day?
    - Industry average 10-50 lines/day
    - Debugging + rework ca. 50% of time
- Function/object/application points per month
- Bugs fixed?
- Milestones reached?

Stack Ranking

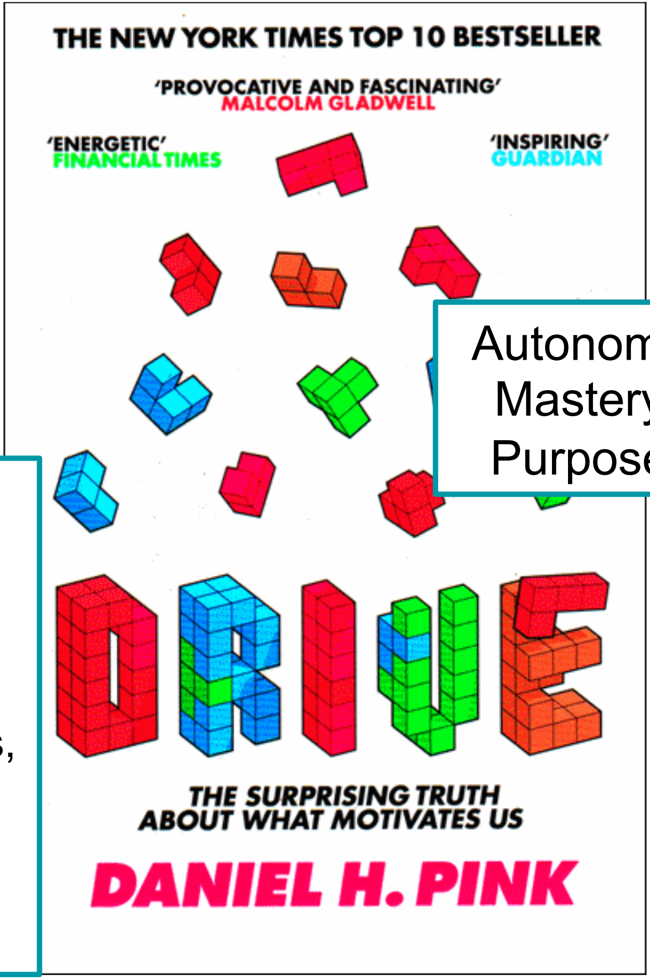


Incentivizing Productivity

- What happens when developer bonuses are based on
  - Lines of code per day?
  - Amount of documentation written?
  - Low number of reported bugs in their code?
  - Low number of open bugs in their code?
  - High number of fixed bugs?
  - Accuracy of time estimates?



Can extinguish intrinsic motivation
Can diminish performance
Can crush creativity
Can crowd out good behavior
Can encourage cheating, shortcuts,
and unethical behavior
Can become addictive
Can foster short-term thinking


THE NEW YORK TIMES TOP 10 BESTSELLER
'PROVOCATIVE AND FASCINATING'
MALCOLM GLADWELL
'ENERGETIC'
FINANCIAL TIMES
'INSPIRING'
GUARDIAN
DRIVE
THE SURPRISING TRUTH ABOUT WHAT MOTIVATES US
DANIEL H. PINK

Autonomy
Mastery
Purpose

Warning

- Most software metrics are controversial
  - Usually only plausibility arguments, rarely rigorously validated
  - Cyclomatic complexity was repeatedly refuted and is still used
  - “Similar to the attempt of measuring the intelligence of a person in terms of the weight or circumference of the brain”
- Use carefully!
- Code size dominates many metrics
- Avoid claims about human factors (e.g., readability) and quality, unless validated
- Calibrate metrics in project history and other projects
- Metrics can be gamed; you get what you measure

(Some) strategies

- Metrics tracked using tools and processes (process metrics like time, or code metrics like defects in a bug database).
- Expert assessment or human-subject experiments (controlled experiments, talk-aloud protocols).
- Mining software repositories, defect databases, especially for trend analysis or defect prediction.
  - Some success e.g., as reported by Microsoft Research
- Benchmarking (especially for performance).

BONUS SLIDES

Factors in a successful measurement program

- Set solid measurement objectives and plans.
- Make measurement part of the process.
- Gain a thorough understanding of measurement.
- Focus on cultural issues.
- Create a safe environment to collect and report true data.
- Cultivate a predisposition to change.
- Develop a complementary suite of measures.

Carol A. Dekkers and Patricia A. McQuaid, "The Dangers of Using Software Metrics to (Mis)Manage", 2002.

Kaner’s questions when choosing a metric

1. What is the purpose of this measure?
2. What is the scope of this measure?
3. What attribute are you trying to measure?
4. What is the attribute’s natural scale?
5. What is the attribute’s natural variability?
6. What instrument are you using to measure the attribute, and what reading do you take from the instrument?
7. What is the instrument’s natural scale?
8. What is the reading’s natural variability (normally called measurement error)?
9. What is the attribute’s relationship to the instrument?
10. What are the natural and foreseeable side effects of using this instrument?

Cem Kaner and Walter P. Bond. “Software Engineering Metrics: What Do They Measure and How Do We Know?” 2004

Summary

- Measurement is difficult but important for decision making
- Software metrics are easy to measure but hard to interpret, validity often not established
- Many metrics exist, often composed; pick or design suitable metrics if needed
- Careful in use: monitoring vs incentives
- Strategies beyond metrics

Further Reading on Metrics

- Sommerville. Software Engineering. Edition 7/8, Sections 26.1, 27.5, and 28.3
- Hubbard. How to measure anything: Finding the value of intangibles in business. John Wiley & Sons, 2014. Chapter 3
- Kaner and Bond. Software Engineering Metrics: What Do They Measure and How Do We Know? METRICS 2004
- Fenton and Pfleeger. Software Metrics: A rigorous & practical approach. Thomson Publishing 1997

Microsoft Survey (2014)

- "Suppose you could work with a team of data scientists and data analyists who specialize in studying how software is developed.
  Please list up to five questions you would like them to answer. Why do you want to know? What would you do with the answers?"

Andrew Begel and Thomas Zimmermann. "Analyze this! 145 questions for data scientists in software engineering." *ICSE*. 2014.

Top Questions

- How do users typically use my application?
- What parts of a software product are most used and/or loved by customers?
- How effective are the quality gates we run at checkin?
- How can we improve collaboration and sharing between teams?
- What are best key performance indicators (KPIs) for monitoring services?
- What is the impact of a code change or requirements change to the project and tests?

Top Questions

- What is the impact of tools on productivity?
- How do I avoid reinventing the wheel by sharing and/or searching for code?
- What are the common patterns of execution in my application?
- How well does test coverage correspond to actual code usage by our customers?
- What kinds of mistakes do developers make in their software? Which ones are the most common?
- What are effective metrics for ship quality?

Bottom Questions

- Which individual measures correlate with employee productivity (e.g., employee age, tenure, engineering skills, education, promotion velocity, IQ)?
- Which coding measures correlate with employee productivity (e.g., lines of code, time it take to build the software, a particular tool set, pair programming, number of hours of coding per day, language)?
- What metrics can be used to compare employees?
- How can we measure the productivity of a Microsoft employee?
- Is the number of bugs a good measure of developer effectiveness?
- Can I generate 100% test coverage?