Unreproducible tests

Successes, failures, and lessons in testing and verification

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Presented at ICST
20 April 2012

Reproducibility:
The linchpin of verification

A test should behave deterministically

- For detecting failures
- For debugging
- For providing confidence

A proof must be independently verifiable

Tool support: test frameworks, mocking, capture-replay, proof assistants, …

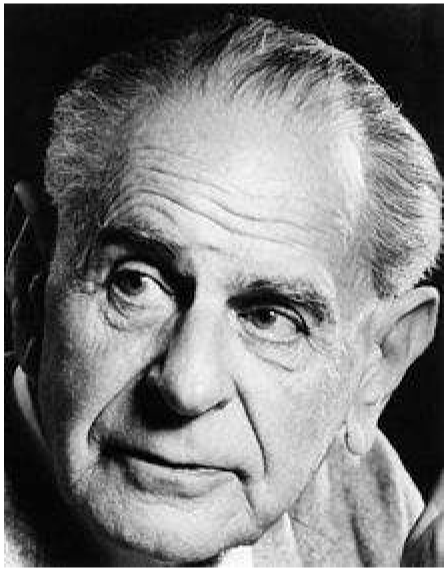
Reproducibility:
The linchpin of research

Research:

- A search for scientific truth
- Should be testable (falsifiable) -Karl Popper

Example: evaluation of a tool or methodology

Bad news: Much research in testing and verification fails this scientific standard



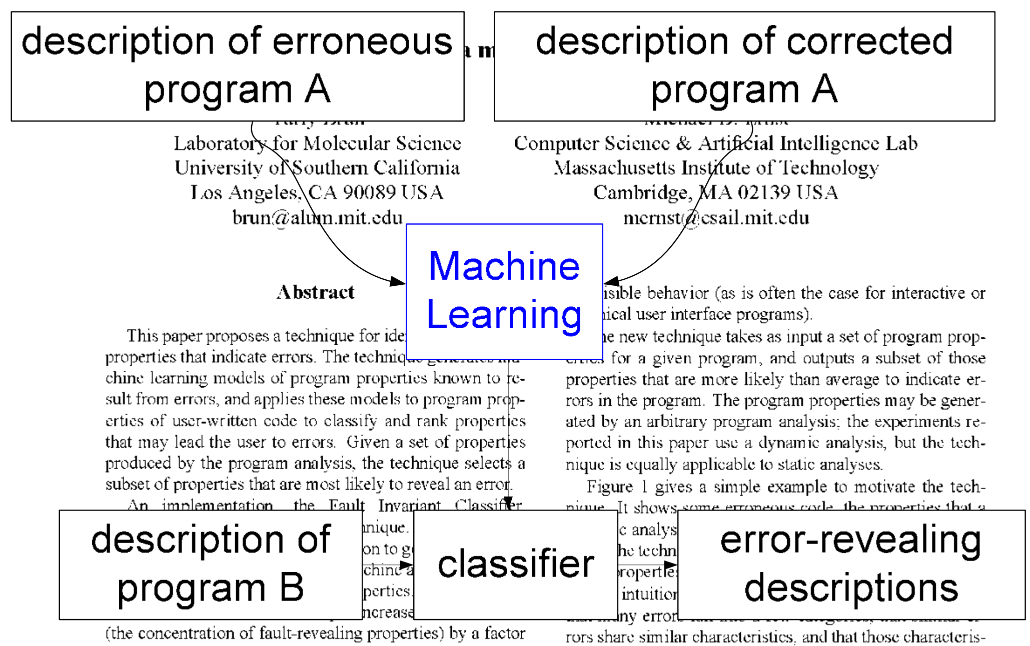
Industrial practice is little better

"Variability and reproducibility in software engineering: A study of four companies that developed the same system", Anda et al., 2008

A personal embarrassment

"Finding Latent Code Errors via Machine Learning over Program Executions", ICSE 2004

- Indicates bug-prone code
- Outperforms competitors; 50x better than random
- Solves open problem
- Innovative methods
- >100 citations



What went wrong

- Tried lots of machine learning techniques
  - Went with the one that worked
  - Output is actionable, but no explanatory power
  - Explanatory models were baffling
- Unable to reproduce
  - Despite availability of source code & experiments
- No malfeasance, but not enough care

How can we prevent such problems?

Outline

- Examples of non-reproducibility
- Causes of non-reproducibility
- Is non-reproducibility a problem?
- Achieving reproducibility

Random vs. systematic test generation

- Random is worse

  [Ferguson 1996, Csallner 2005, ...]
- Random is better

  [Dickinson 2001, Pacheco 2009]
- Mixed

  [Hamlet 1990, D'Amorim 2006, Pacheco 2007, Qu 2008]

Test coverage

- Test-driven development improves outcomes [Franz 94, George 2004]
- Unit testing ROI is 245%-1066% [IPL 2004]
- Abandoned in practice [Robinson 2011]

Type systems

- Static typing is better
  - [Gannon 1977, Morris 1978, Pretchelt 1998]
  - the Haskell crowd
- Dynamic typing is better
  - [Hanenburg 2010]
  - the PHP/Python/JavaScript/Ruby crowd
- Many attempts to combine them
  - Soft typing, inference
  - Gradual/hybrid typing

Programming styles

- Introductory programming classes:
  - Objects first [Kolling 2001, Decker 2003, …]
  - Objects later [Reges 2006, …]
  - Makes no difference [Ehlert 2009, Schulte 2010, …]
- Object-oriented programming
- Functional languages
  - Yahoo! Store originally in Lisp
  - Facebook chat widget originally in Erlang

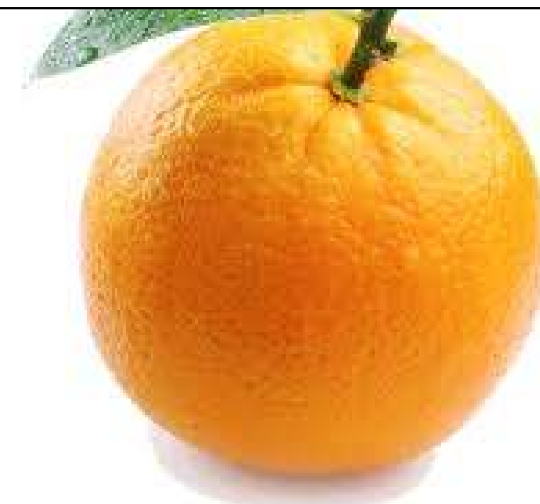
More examples

- Formal methods from the beginning [Barnes 1997]
- Extreme programming [Beck 1999]
- Testing methodologies

Causes of non-reproducibility

1. Some other factor dominates the experimental effect

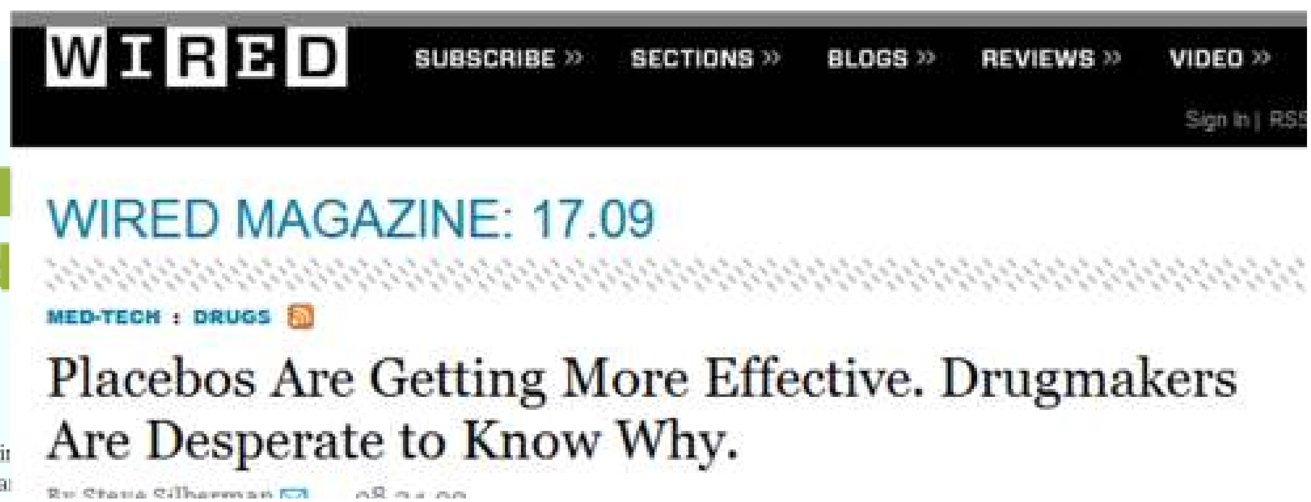
Threats to validity
- construct (correct measurements & statistics)
- internal (alternative explanations & confounds)
- external (generalize beyond subjects)
- reliability (reproduce)



People

- Abilities
- Knowledge
- Motivation

We can learn a lot even from studies of college students



Other experimental subjects

(besides people)

- “Subsetting the SPEC CPU2006 benchmark suite” [Phansalkar 2007]
- “Experiments with subsetting benchmark suites” [Vandierendonck 2005]
- “The use and abuse of SPEC” [Hennessey 2003]

space program

Siemens suite

Implementation

- Every evaluation is of an implementation
  - Tool, instantiation of a process such as XP or TDD, etc.
  - You hope it generalizes to a technique
- Your tool
  - Tuned to specific problems or programs
- Competing tool
  - Strawman implementation
    - Example: random testing
  - Tool is mismatched to the task
    - Example: clone detection [ICSE 2012]
  - Configuration/setup
    - Example: invariant detection

Interpretation of results

- Improper/missing statistical analysis
- Statistical flukes
  - needs to have an explanation
  - tried too many things
- Subjective bias

Biases

- Hawthorne effect (observer effect)
- Friendly users, underestimate effort
- Sloppiness
- Fraud
  - (Compare to sloppiness)

Reasons not to totemize reproducibility

Reproducibility is not always paramount

Reproducibility inhibits innovation

- Reproducibility adds cost
  - Small increment for any project
- Don’t over-engineer
  - If it’s not tested, it is not correct
  - Are your results important enough to be correct?
- Expectation of reproducibility affects research
  - Reproducibility is a good way to get your paper accepted

Our field is young

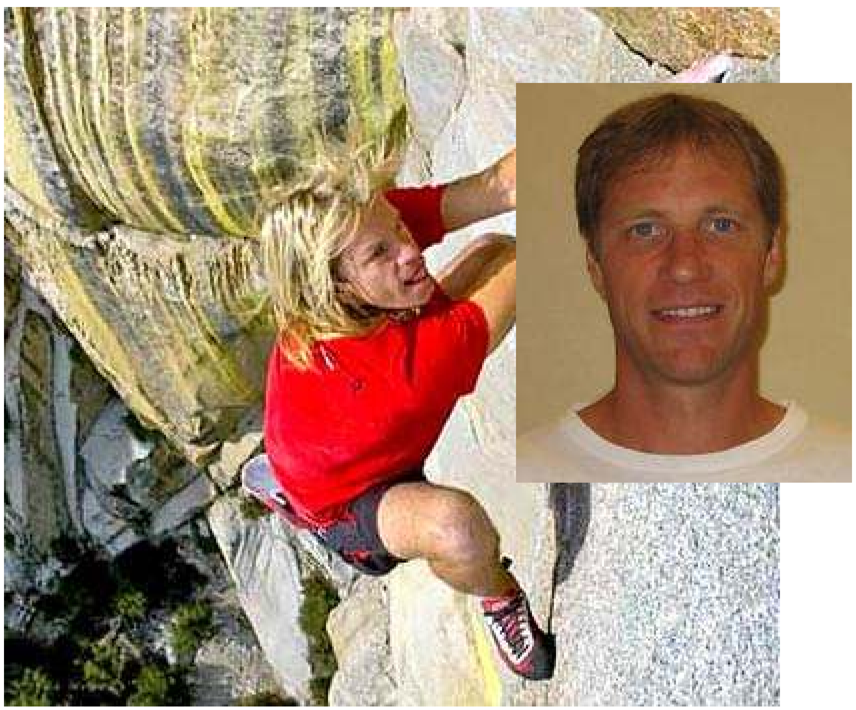
- It takes decades to transition from research to practice
  - True but irrelevant
- Lessons and generalizations will appear in time
  - **How** will they appear?
  - Do we want them to appear faster?
- The field is still developing & learning
  - Statistics? Study design?

A novel idea
is worthy of dissemination…

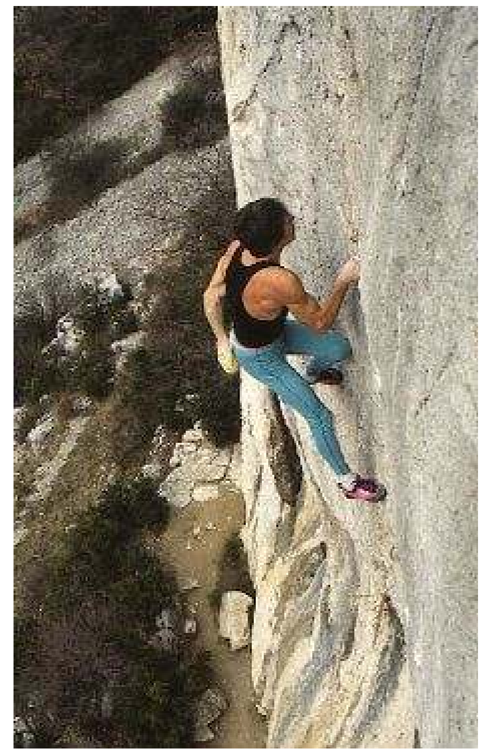
… without evaluation

… without artifacts

Possibly true, but irrelevant



"Results, not ideas."
-Craig Chambers



Positive deviance

- A difference in outcomes indicates:
  - an important factor
  - a too-general question
- Celebrate differences and seek lessons in them
  - Yes, but start understanding earlier

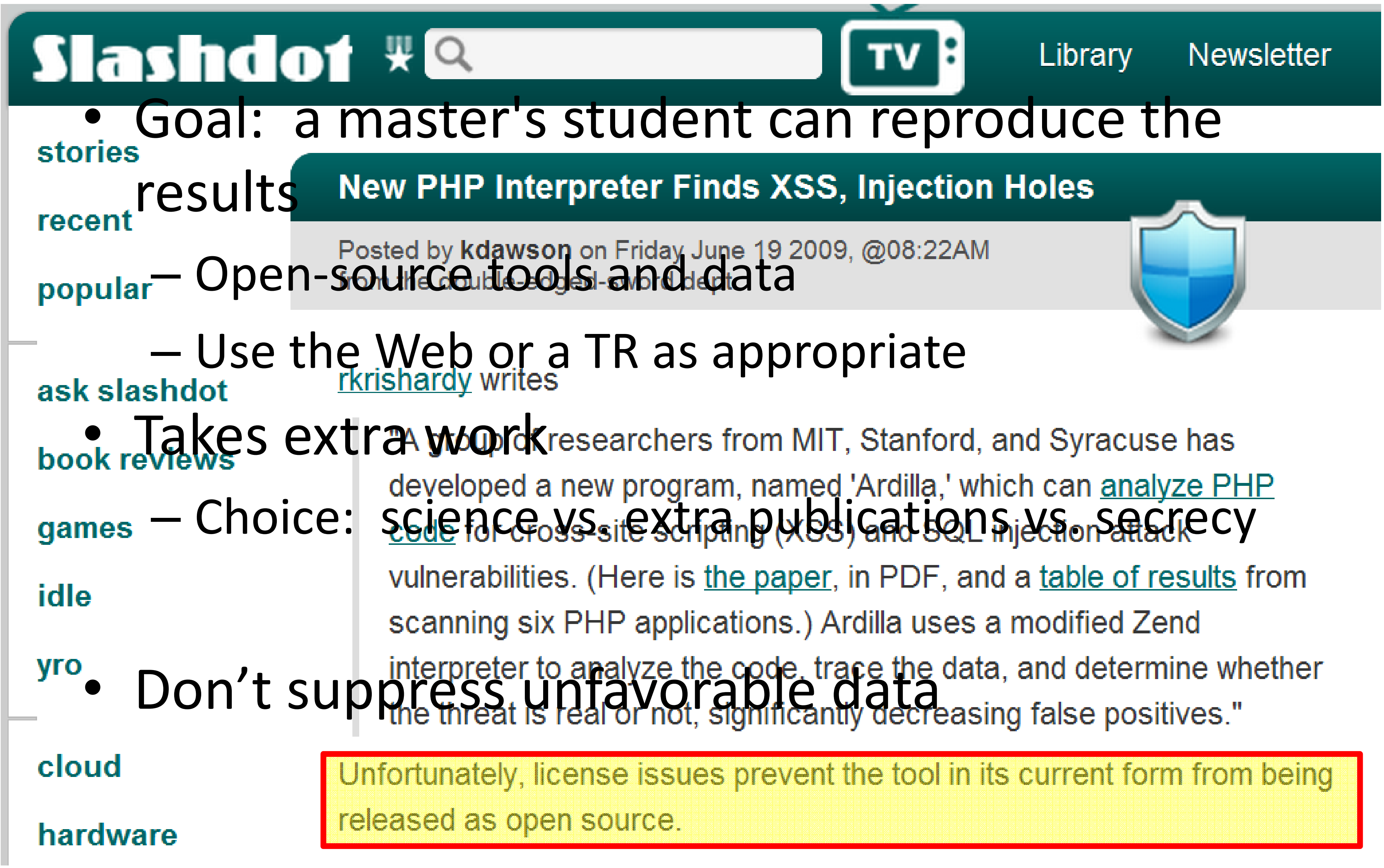
How to achieve reproducibility

Definitions

- **Reproducible**: an independent party can
  - follow the same steps, and
  - obtain similar results
- **Generalizable**: similar results, in a different context
- **Credible**: the audience believes the results

Give all the details

- Goal: a master's student can reproduce the results
  - Open-source tools and data
  - Use the Web or a TR as appropriate
- Takes extra work
  - Choice: science vs. extra publications vs. secrecy
- Don't suppress unfavorable data



Admit non-generalizability

- You cannot to control for every factor
- What do you expect to generalize?
- **Why?**
- Did you try it?
  - Did you test your hypothesis?

“Threats to validity” section considered dangerous

“Our experiments use a suite of 7 programs and may not generalize to other programs.”

Often omits the real threats – cargo-cult science

It's better to discuss as you go along

Summarize in conclusions

Explain yourself

- No “I did it” research
- Explain each result/effect
  - or admit you don’t know
- What was hard or unexpected?
- Why didn’t others do this before?

- Make your conclusions actionable

Research papers are software too

- "If it isn't tested, it's probably broken."

- Have you tested your code?
- Have you tested generalizability?

- Act like your results matter

Automate/script everything

There should be no manual steps (Excel, etc.)

Except during exploratory analysis

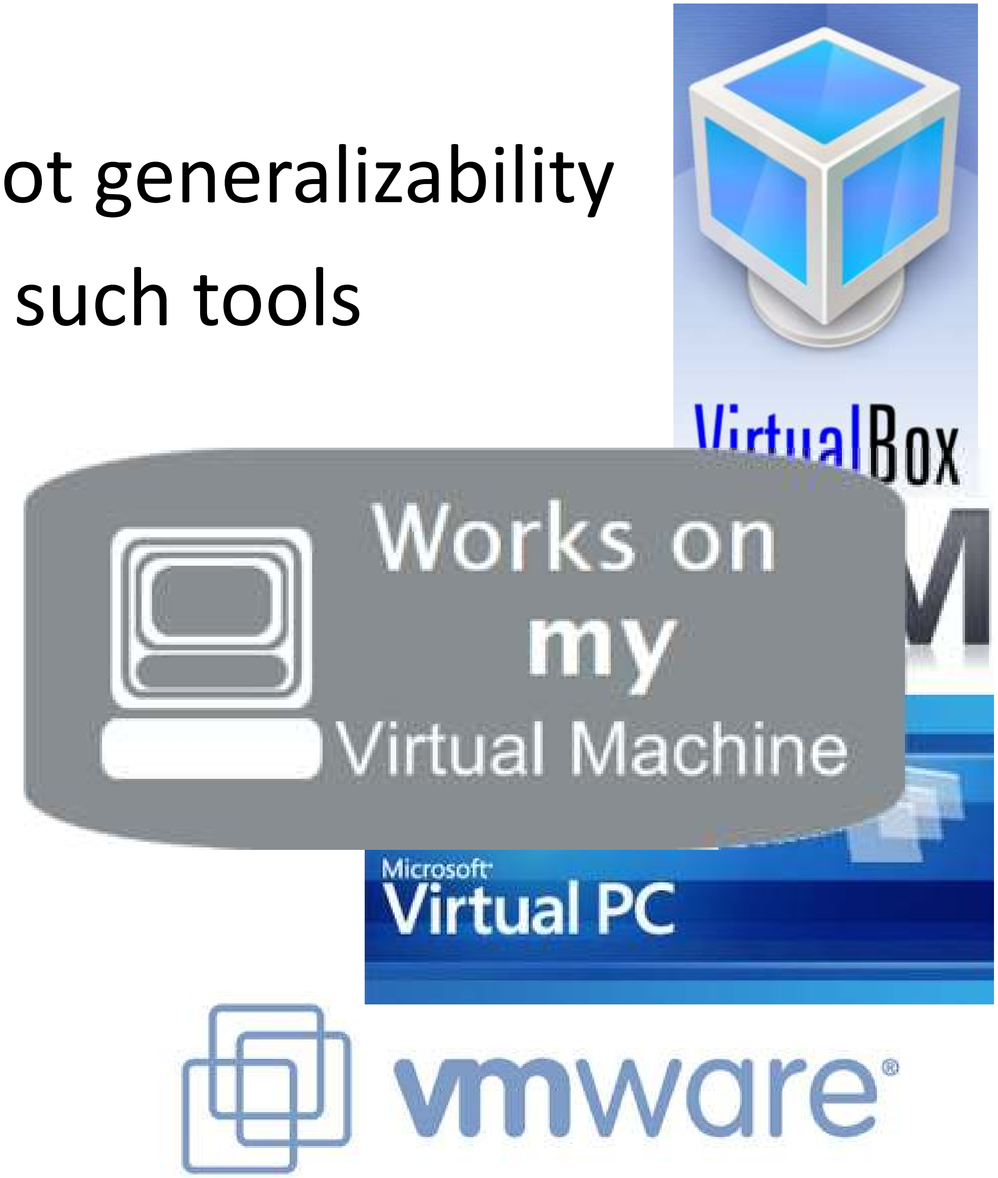
- Prevents mistakes
- Enables replication
- Good if data changes

This costs no extra time in the long run

(Do you believe that? *Why?*)

Packaging a virtual machine

- Reproducibility, but not generalizability
- Hard to combine two such tools
- Partial credit



Measure and compare

- Actually measure
  - Compare to other work
  - Reuse data where possible
- Report statistical results, not just averages
- Explain differences

Look for measureable and repeatable effects

- 1% programmer productivity would matter!
- It won't be visible

Focus

- Don't bury the reader in details
- Don't report irrelevant measures
- Not every question needs to be answered
- Not every question needs to be answered numerically

Usability

- Is your setup only usable by the authors?
- Do you want others to extend the work?
- Pros and cons of realistic engineering
  - Engineering effort
  - Learning from users
  - Re-use (citations)

Reproducibility, not reproduction

- Not every research result must be reproduced
- All results should be reproducible

- Your research answers some specific (small) question
- Seek reproducibility in that context

Blur the lines

- Researchers should be practitioners
  - design, write, read, and test code!
  - and more besides, of course
- Practitioners should be open to new ways of working
  - Settling for “best practices” is settling for mediocrity

We are doing a great job

Research in testing and verification:

- Thriving research community
- Influence beyond this community
- Great ideas
- Practical tools
- Much good evaluation
- Transformed industry
- Helped society

We can do <u>better</u>

"If I have seen further it is by standing on the shoulders of giants."

-Isaac Newton