Photo credit: Dave DiCello

17-803 Empirical Methods

Bogdan Vasilescu, Institute for Software Research

The Role of Theory

Tuesday, February 9, 2021

Outline for Today

- The role of theory
- Literature reviews (next class)

I. The Role of Theory

- Easterbrook, S., Singer, J., Storey, M. A., & Damian, D. (2008). Selecting empirical methods for software engineering research. In Guide to advanced empirical software engineering (pp. 285-311). Springer, London.
- Varpio, L., Paradis, E., Uijtdehaage, S., & Young, M. (2020). The distinctions between theory, theoretical framework, and conceptual framework. Academic Medicine, 95(7), 989-994.

- Topic: using AI to generate programming source code from natural language
- 9 months into his PhD
- Has built a tool
- Needs an evaluation plan

Meet Stu Dent

Stu Dent idea by Steve Easterbrook

Stu's Evaluation Plan

- Controlled experiment using an IDE plugin
  - Independent variable: Stu's "NL2Code" vs. writing code "from scratch"
  - Dependent variables: correctness, speed, subjective assessment
  - Tasks: various Python
  - Subjects: CS grad students
  - Hypotheses:
    - H1: "Code written using NL2Code is more often correct than code written from scratch."
    - H2: "Subjects complete tasks faster when using NL2Code than when writing code from scratch."
    - H3: "Subjects prefer using the snippets from NL2Code over writing code from scratch."
- Results:
  - H1 & H2 & H3 rejected*
  - Subjects found NL2Code unintuitive

* True story: https://arxiv.org/abs/2101.11149

Slide idea by Steve Easterbrook

Threats to Validity

- What is correctness? How is it measured (subjective?)? How is speed measured?
  - "Construct validity"
- How familiar were the subjects with the NL2Code plugin?
  - "Internal validity"
- Were the tasks representative? Grad student subjects as sample of what population? Are they representative?
  - "External validity"
- Subjects knew NL2Code was Stu's own tool
  - "Theoretical reliability"
- … much more on threats to validity throughout the semester

What Went Wrong?

- What was the research question?
  - Is tool A (NL2Code) better than tool B (from scratch)?
- What would count as an answer?
- What use would the answer be?
  - How is it a “contribution to knowledge”?
- How does this evaluation related to the existing literature?

Slide by Steve Easterbrook

Compare to Medical Trials

Why would we expect it to be better?

Why do we need to know?

What will we do with the answer?

Is drug A better than drug B?

Better at doing what?

Better in what way?

Better in what situations?

Slide by Steve Easterbrook

Why would we expect
it to be better?

You gotta have a theory!

Slide by Steve Easterbrook

What Is a Theory?

- A theory is a set of propositions that are logically related, expressing the relation(s) among several different constructs and propositions.

- Characteristics:
  - Identifies and defines constructs / phenomena;
  - Makes assertions about their nature;
  - Makes assertions about the causal relationships between them;
  - Explains *why* certain relationships occur (good theories).

- Theories are the building blocks of scientific knowledge.
  - They explain how and why certain phenomena occur, and allow predictions to be made.
  - The more data supporting the theory, the stronger it becomes.

What Is a Theory?

- Theories can be:
  - descriptive (i.e., naming and characterizing a phenomenon),
  - explanatory (i.e., clarifying the relationships between phenomena),
  - emancipatory (i.e., articulating the oppression of a people),
  - disruptive (i.e., extending existing knowledge or refuting it), or
  - predictive (i.e., predicting an outcome based on specific inputs).

- Theories can also have different levels of explanatory power:
  - Grand theories: highly abstract; broad natural or social patterns (e.g., Marxist theories of society)
  - Mid-range theories: address more specific aspects of human interactions (e.g., signaling theory)
  - Microtheories: focus on individual-level phenomena (see microsociology)

Theories Explaining Phenomena Can Compete

- Different theories can address different aspects of a phenomenon, each offering different insights into the phenomenon.

- Different theories can even address the same aspect of a phenomenon.
  - Theories that are simpler, or more elegant are preferred.

- Read broadly!

Definitions:
“Theory” vs “Theoretical Framework” vs “Conceptual Framework”

What Is a Theoretical Framework?

- A theoretical framework is a logically developed and connected set of concepts and premises—developed from one or more theories—that a researcher creates to scaffold a study.
- To create a theoretical framework, the researcher must define any concepts and theories that will provide the grounding of the research, unite them through logical connections, and relate these concepts to the study that is being carried out.
  - In short, a theoretical framework is a reflection of the work the researcher engages in to use a theory in a given study.

What Is a Conceptual Framework?

- A conceptual framework is the justification for why a given study should be conducted.
- The conceptual framework
  - (1) describes the state of known knowledge, usually through a literature review;
  - (2) identifies gaps in our understanding of a phenomenon or problem; and
  - (3) outlines the methodological underpinnings of the research project.
- It is constructed to answer two questions:
  - "Why is this research important?" and
  - "What contributions might these findings make to what is already known?"

How do these concepts relate to the qualitative/quantitative divide?

When and how to use a theory, a theoretical framework, or a conceptual framework?

Theory for Positivists vs Constructivists

- Positivists expect their theories to have strong predictive power.
  - e.g., generalized models of cause-and-effect as the basis for theories.

- Constructivists expect theories to strengthen their understanding of complex situations.
  - e.g., frequent use of categorizations and analogies.

How Objectivist Deductive Researchers Use Theory

- A theory as the starting point for the research project.
- The theory offers testable components:
  - the cause-and-effect relationships that can be examined,
  - the concepts that should be operationalized,
  - the variables that are relevant to control.
- These testable components are used to generate specific hypotheses which are the foundation for a study.

How Objectivist Deductive Researchers Use Theory

- The theory is part of the object of research.
  - simultaneously test a hypothesis derived from theory and the accompanying theory underlying that hypothesis.
- The theory must:
  - (1) be testable;
  - (2) be open to being falsified.
- New knowledge: evidence to support, refine, or challenge a theory.
- Linear progression: theory –> hypothesis development –> data collection –> interpretation of findings –> refinement of theory / generation of new causal explanations.

How Objectivist Deductive Researchers Use a Theoretical Framework

- This is the work to render a theory operational, testable, and able to be used to predict, test a hypothesis, or explain a phenomenon.
- Steps:
  - identify the theory
  - articulate why the current context is a legitimate area of study for that theory
  - shape the constructs of interest
  - articulate the specific language and assumptions of the research question
  - identify the variables and conditions of interest
  - orient the approach to analysis.
- You need one to:
  - Be able to put the theory to the test.
  - Be able to unite findings across research contexts.

How Objectivist Deductive Researchers Use a Conceptual Framework

- Typical structure:
  - a description of relevant literature,
  - a summary of the relevant theory,
  - an explanation of why this theory could be informative to this context,
  - a specific research question that likely contains a hypothesis,
  - a rationale for the research methodology adopted, and
  - a series of outcomes or variables of interest.
- A conceptual framework is finalized before the study and is rarely modified once data collection has started.

How Subjectivist Inductive Researchers Use Theory

- (1) Theory as the product of research.
  - Grounded Theory: generating theory from the data; most fully inductive.
- (2) One or more theories informing the research process.
  - theory shapes every stage of the research process, including research questions, data collection, etc.
  - theory refinement / development may be a major research output.
- (3) Theory as an interpretive tool.
  - chosen during data analysis processes to shape the final study interpretations and conclusions.
  - may have to modify the data collection and analysis partway as new theory becomes relevant.

- All three are equally valid.
  - But make early, explicit decision as to when and how to use theory (impacts development of the theoretical framework).

How Subjectivist Inductive Researchers Use a Conceptual Framework

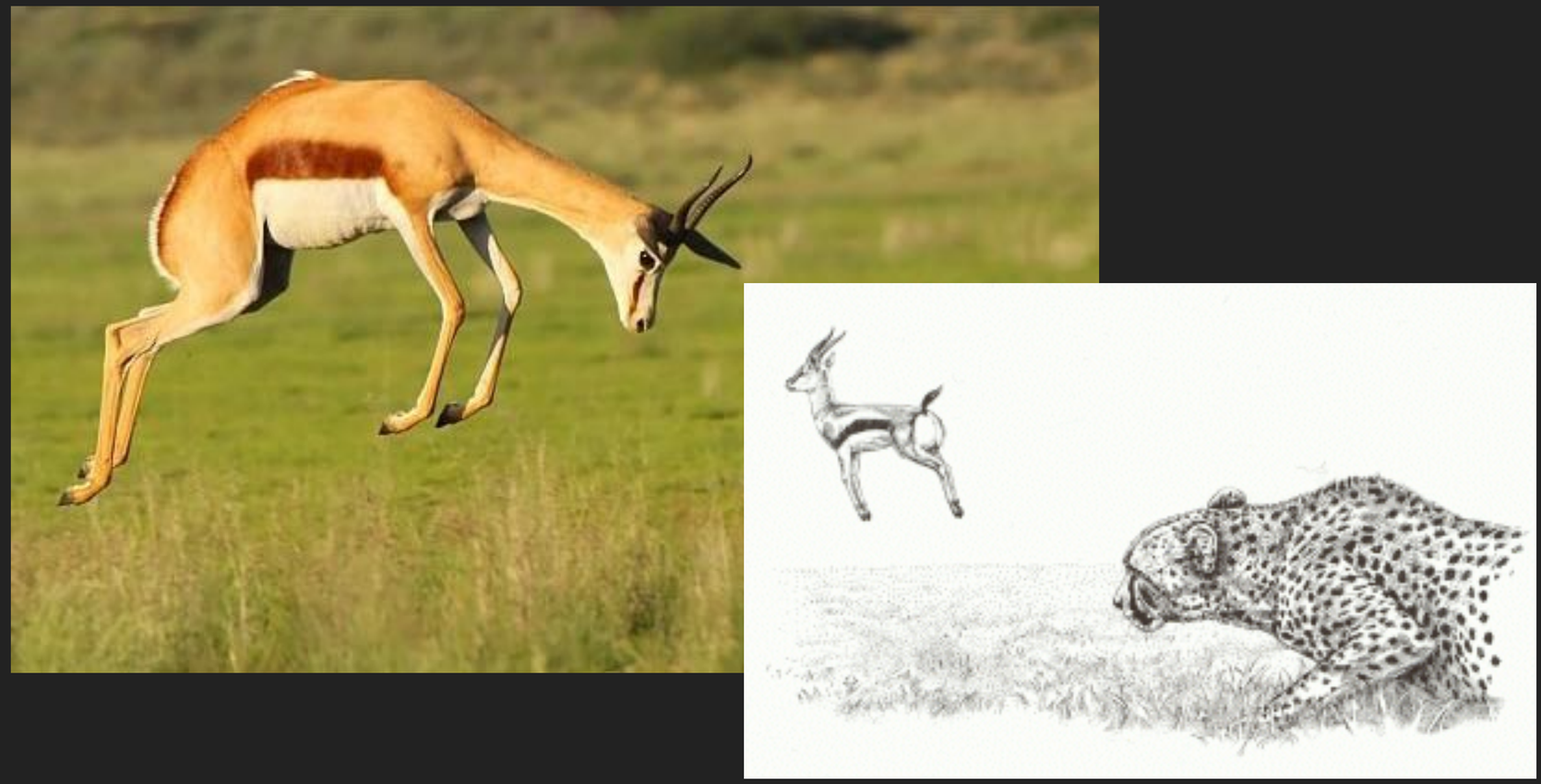
- Typical structure:
  - a description of relevant literature,
  - a summary of relevant theory (first two study designs),
  - an explanation of why the research should be carried out in the selected context,
  - research question(s), and
  - justification for the research methodology selected.
- The conceptual framework may evolve during a study as new ideas, insights, and knowledge are developed.

Example Borrowed Theory on Signaling (Positivist Stance / Deductive Strategy)

Signals

- Original idea from evolutionary biology
- Visible clues that imply hidden quality
- Types of signals
  - Assessment: visible clue cannot be produced without hidden quality
  - Conventional: meaning is agreed upon, will continue to exist only if enforced by norms

Stotting as Honest Signal



Peacock Tail Feathers as Handicap Signal

Avoid Colorful Snakes

a) Eastern coral snake (poisonous)

Avoid Colorful Snakes

a) Eastern coral snake (poisonous)

(b) Scarlet king snake (nonpoisonous)

Cheater!

Conventional Signals

STRUDEL

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Hi there! I'm an Assistant Professor in CMU's School of Computer Science and a member of the Institute for Software Research. My students and I form the Socio-Technical Research Using Data Excavation Lab (STRUDEL).

I'm most active in the software engineering research community, where I have co-chaired the MSR 2020 Data Showcase, have been serving on program committees for the major software engineering venues (including ICSE, FSE, and ASE; thanks for the Distinguished Reviewer Award at ASE 2018!), am an Associate Editor for the ACM Transactions on Software Engineering and Methodology, and am co-chairing the SIGSOFT Initiative on Data-driven Introspection, among others.

On the internets I'm sometimes referred to as a "*prominent female professor from a gender studies department, that no one ever audits and that gets to peer review herself*". I also suffer from *cognitive dissonance* as a scientist who uses LaTeX.

Prospective Students

If you're a motivated student looking for a PhD position, check out the Software Engineering and Societal Computing programs at CMU, which most of my current students are part of. Applications are due early/mid December. Please feel free to reach out to me before applying, to introduce yourself and describe your research interests.

Conventional Signals – Trustworthy?

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Fake CV? Chances are your company will catch you out

Submit

Mishita Mehra, ET Bureau Jan 8, 2012, 02.27AM IST

Tags: Sunday ET | Steve Jobs | resume | Fake CV | CV | company

Did you say deception? It is not even a lie, not in the lowly, how-can-you-do-this sort of way. Call it an exaggeration, if you must - the stretched truth that boosts your resume. So what if you forget the 'assistant' in your designation and just write manager or add a few thousands to your current pay. Or extend a job tenure to cover three months of vegetating before the TV - even Steve Jobs needed his psychedelic breaks, didn't he?

RELATED ARTICLES

Check on job applicants gets deeper as hiring activity goes...

November 28, 2009

There Are Many Signals on a Platform Like GitHub

Built-in (GitHub)

request / request

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Simplified HTTP request client.

2,190 commits | 17 branches | 130 releases | 273 contributors | Apache-2.0

Custom

README.md

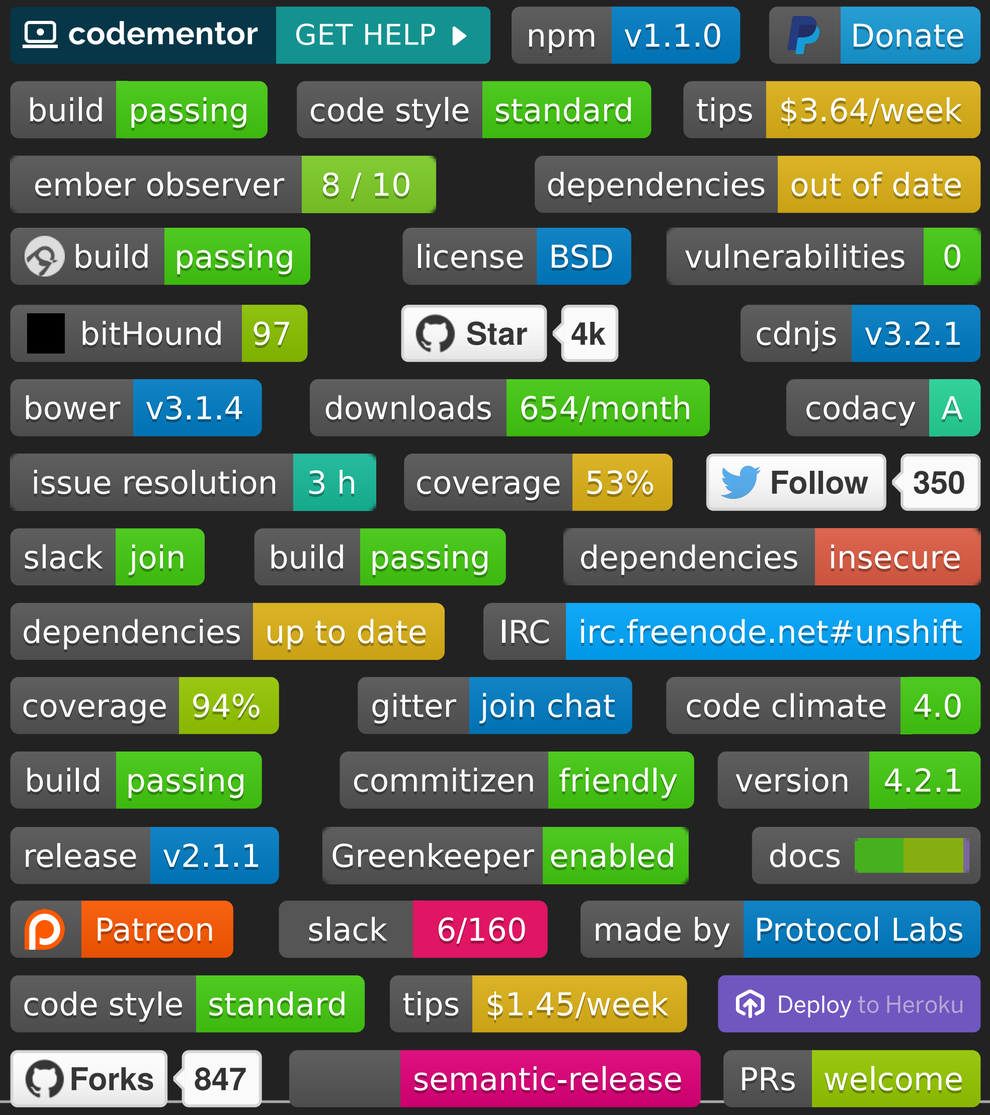
Request - Simplified HTTP client

npm install request
22 dependencies version 2.81.0
22,431 dependents updated 6 months ago
1,275 ★

build passing | coverage 92% | coverage 93% | dependencies up to date | vulnerabilities 0 | gitter join chat

Types of Badges

- Quality assurance
  - Build status, test coverage, static analysis, …
- Dependency management
  - Version tracking, vulnerability tracking, …
- Information
  - *npm* version, license, coding style, release strategy, commit message conventions, …
- Popularity
  - npm downloads, GitHub stats, Twitter, …
- Support
  - chat & collaboration, issue stats, …
- Misc:
  - Paypal, donations, Gittip, …



Types of Badges

- Quality assurance
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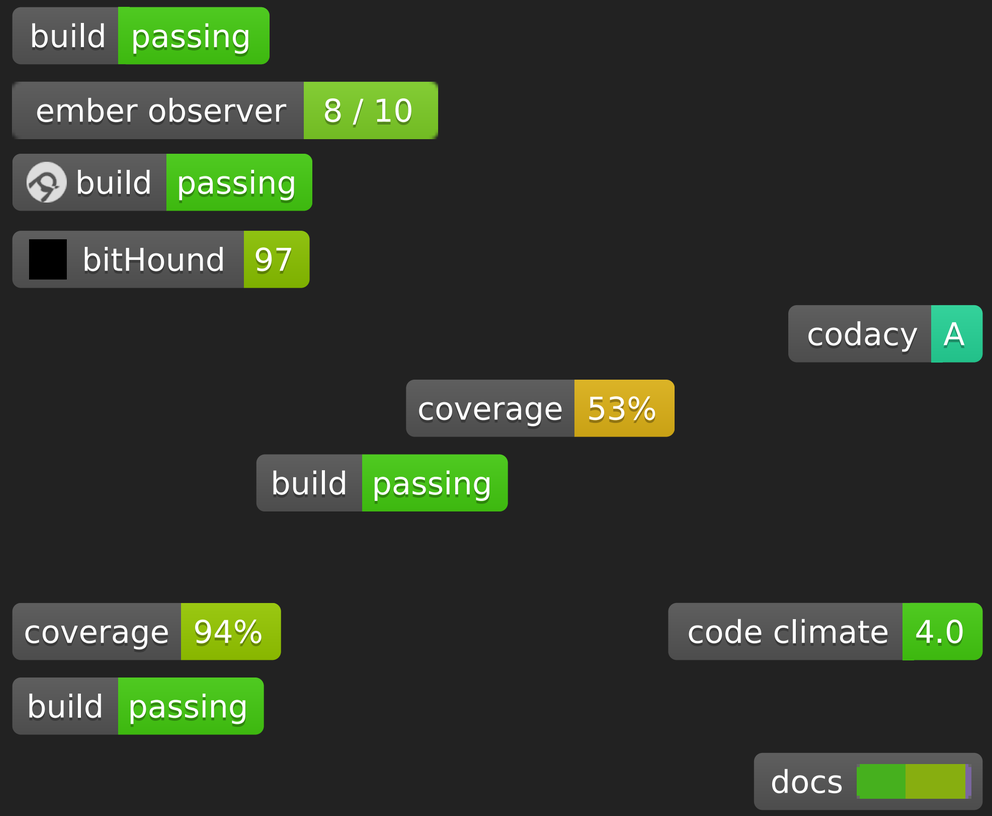
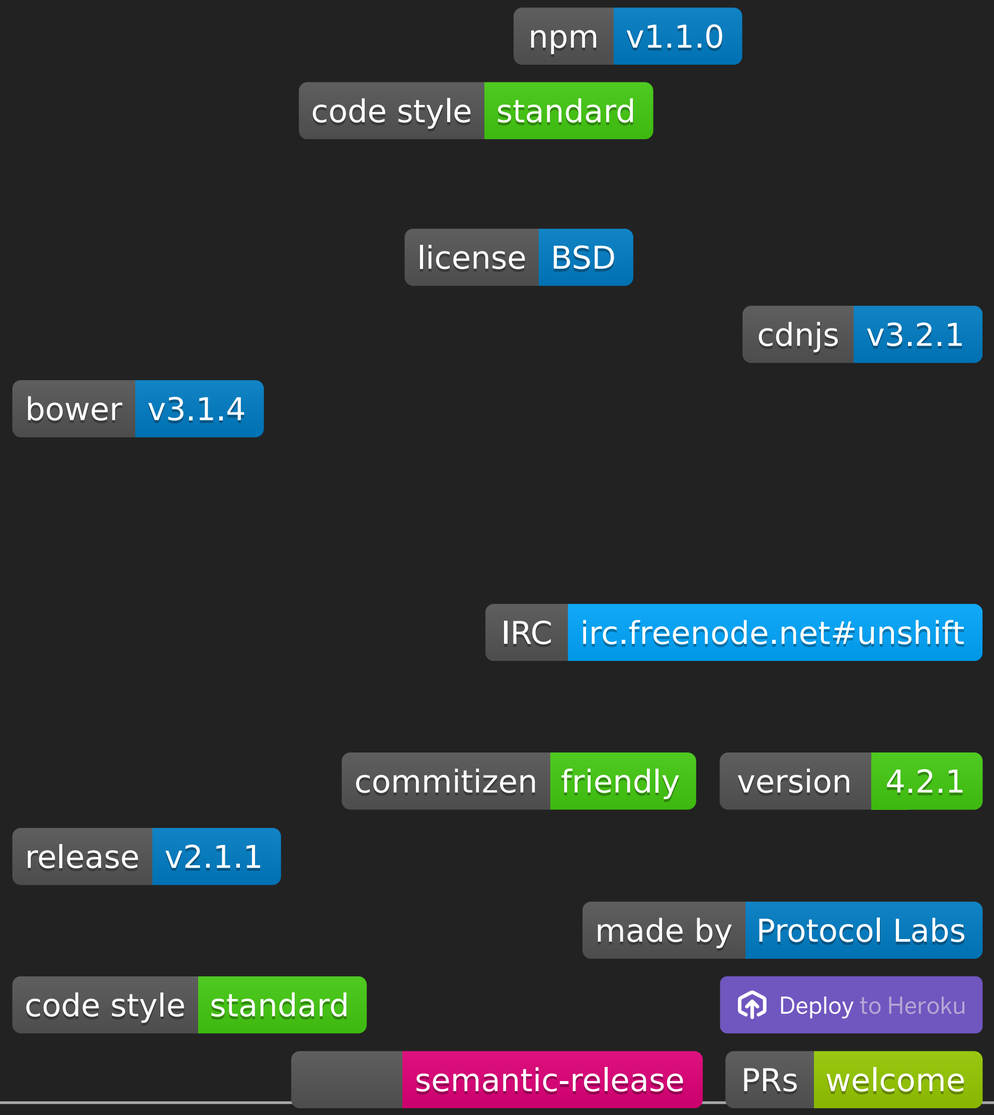


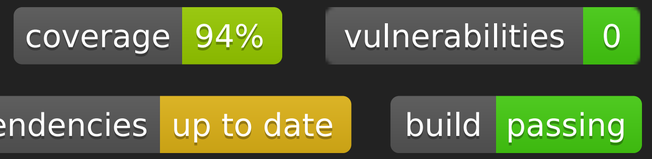
Types of Badges

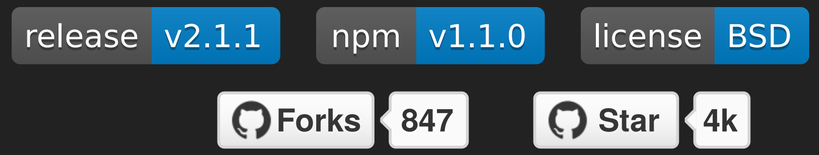
- Quality assurance
  - Build status, test coverage, static analysis, …
- Dependency management
  - Version tracking, vulnerability tracking, …
- Information
  - *npm* version, license, coding style, release strategy, commit message conventions, …

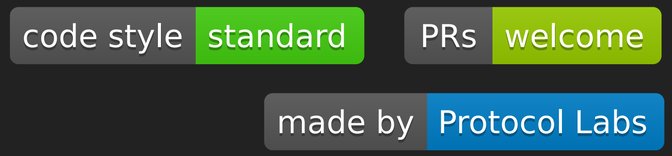


Conventional Signal Vs Assessment Signal Badges

Badges vary widely in production cost

- Expensive: 

- Cheap: 

- No cost: 

Can You Trust Them?

seanmonstar / intel

Watch 10 | Star 191 | Fork 29

Code | Issues 11 | Pull requests 0 | Projects 0 | Wiki | Insights

I need more intel! http://seanmonstar.github.io/intel/

224 commits | 3 branches

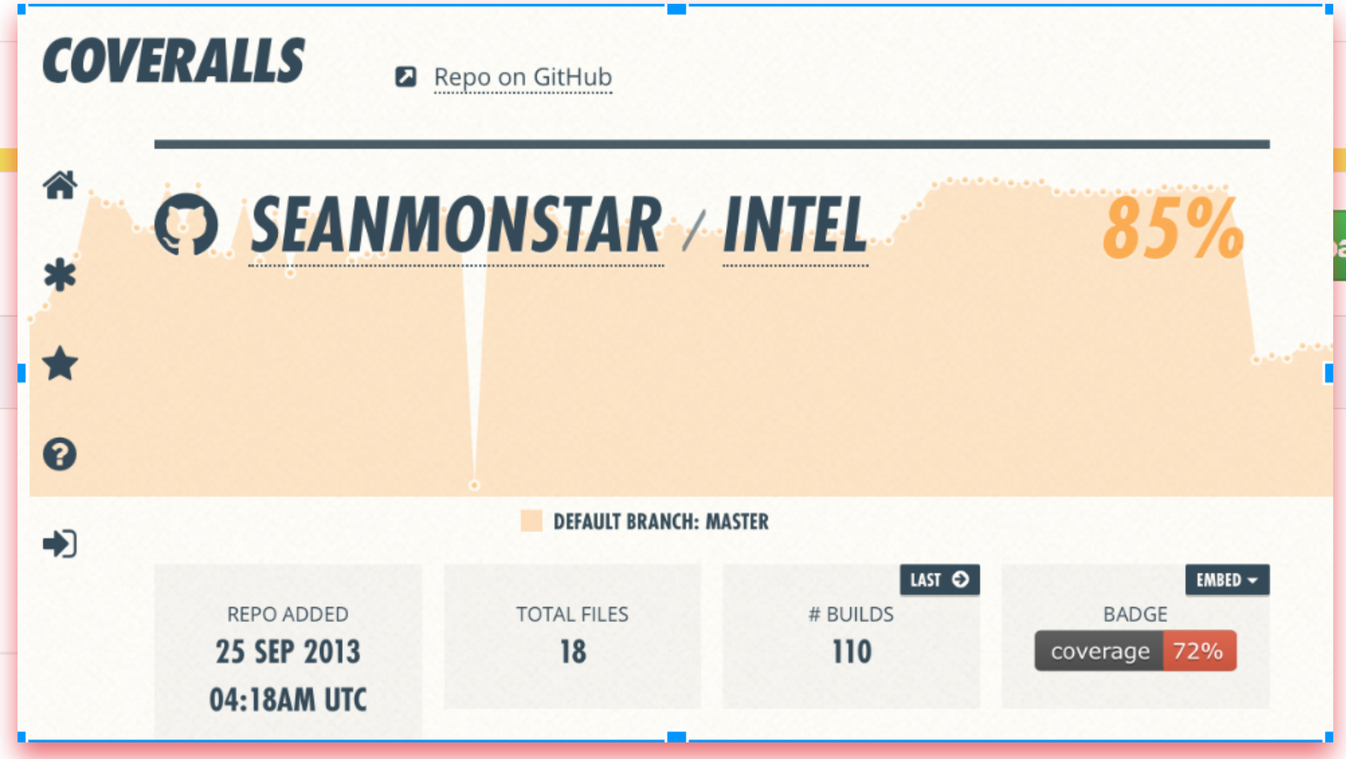
Branch: master | New pull request

README.md

intel

build passing | coverage 100% | npm package 1.2.0

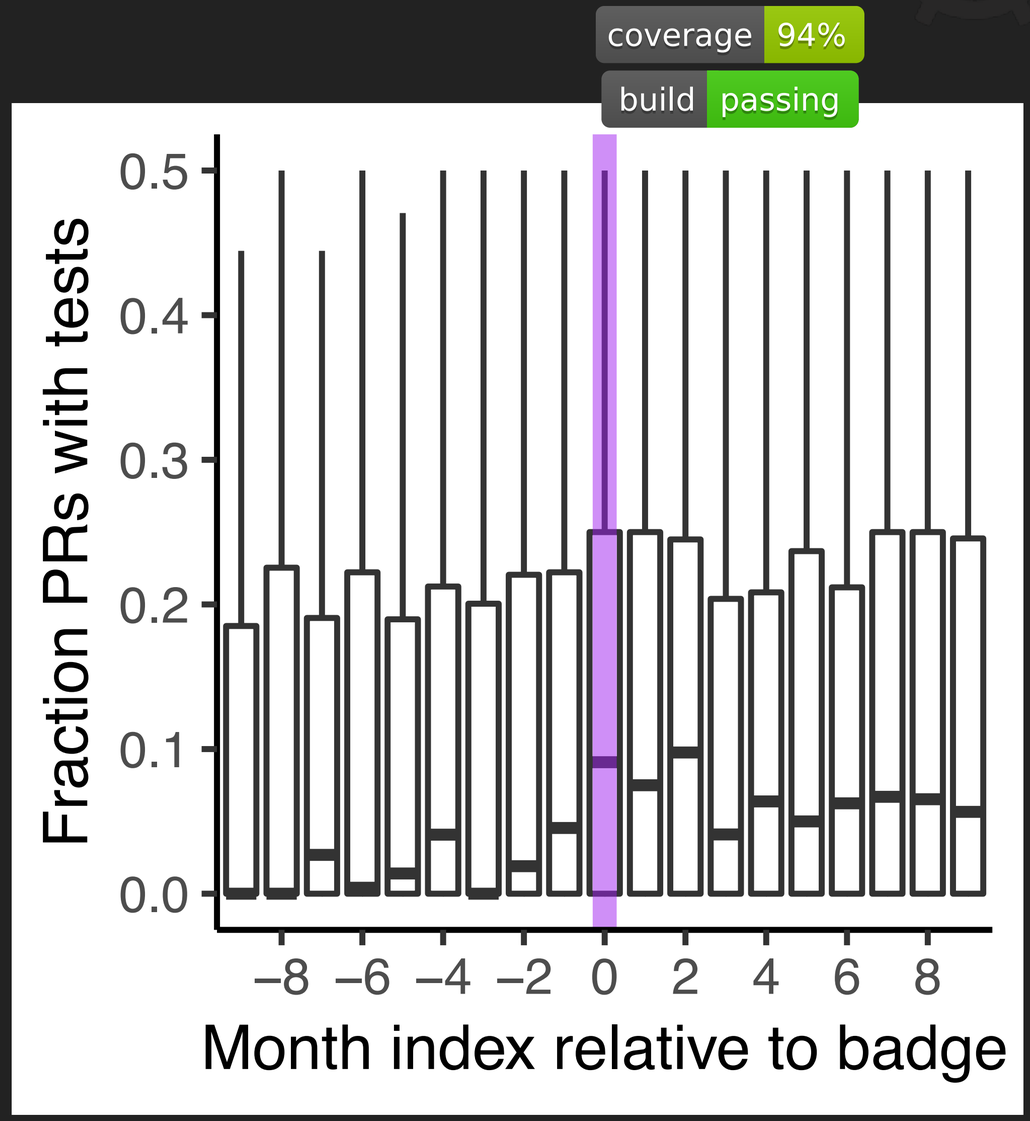
An abbreviation of intelligence. In this case, the acquirement of information.



Signals of PR Quality

- Hyp: The adoption of a quality-assurance badge, and even more so of a coverage badge, encourages more external contributors to include tests.

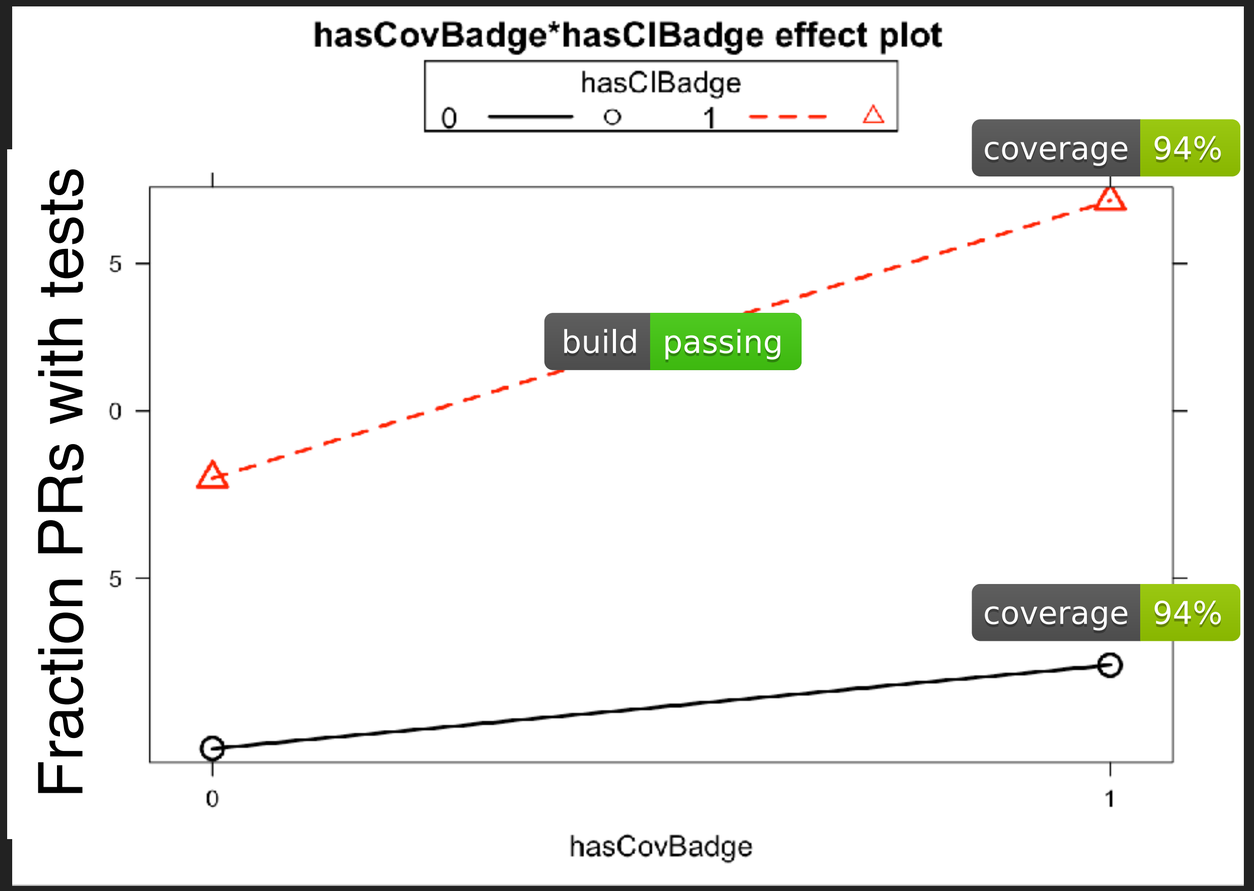
Increase in the monthly fraction of PRs containing tests after adopting QA badge



Signals of PR Quality

- Hyp: The adoption of a quality-assurance badge, and even more so of a coverage badge, encourages more external contributors to include tests.

Coverage and CI badges interact, amplifying each other's effects.

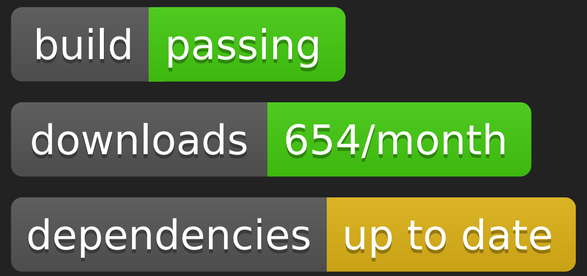


Take-Aways (1)

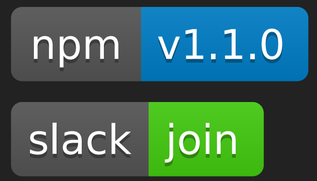
- Open source developers rely on, and respond to, signals
  - We add both qualitative and quantitative evidence for badges

Take-Aways (2)

- Harder to fake badges provide more reliable signals
  - As signaling theory predicts

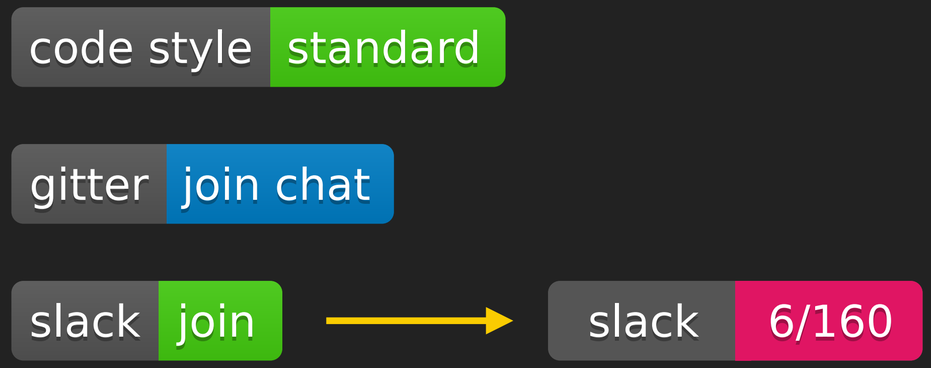


VS



Take-Aways (2)

- Harder to fake badges provide more reliable signals
  - As signaling theory predicts
- Redesign badges as assessment signals



“Meh, doesn’t apply to me, I’m primarily building tools in my research”

Why Build a Tool?

- Build a Tool to Test a Theory
  - Tool is part of the experimental materials needed to conduct your study
- Build a Tool to Develop a Theory
  - Theory emerges as you explore the tool
- Build a Tool to Explain your Theory
  - Theory as a concrete instantiation of (some aspect of) the theory

Slide by Steve Easterbrook

Stu's Theory

- Background assumptions
  - Tasks can be completed by piecing together code snippets involving popular libraries / APIs
  - Many such example code snippets are available in NL2Code's trained data
  - …
- Basic theory (brief summary)
  - Programmers decompose tasks into a sequence of (small) steps. At every step, they know conceptually what must be done next, but (a) do not know how to create a concrete implementation of their idea, or (b) would rather not have to type it in. The NL2Code AI could help speed up task completion especially in the (b) scenario; otherwise, with (a) users might not recognize which NL2Code search result to use, if multiple, or know how to integrate that snippet into their program. Possible speedups would occur primarily because users risk getting distracted when they switch context going outside of their IDEs, and not because of the time it would take to write down source code (because programmers mostly copy paste code from Stack Overflow anyway; they rarely write code from scratch). …

Stu's Theory

- Some possible derived hypotheses:
  - For tasks where programmers have extensive prior experience (i.e., they could have written solutions from scratch), using NL2Code should reduce task completion times.
  - The more steps (e.g., API calls) are involved in implementing a solution to a task, the more NL2Code should speed up task completion times.
  - …

Summary

- In any empirical study, theories become a "lens" through which the world is observed and interpreted, whether or not they are explicitly acknowledged.
  - Real-world phenomena too rich / complex to study without that much filtering.

- Quantitative methods:
  - Theory to decide which variables to isolate and measure, and which to ignore or exclude.
- Qualitative methods:
  - Theory to focus data analysis / interpretation.

Summary

- Without the theory, we have no way of making sense of the accumulation of empirical results.
  - An individual study can never offer conclusive results.

- Theories support analytical generalization
  - Provide a deeper understanding of our empirical results
  - ...and hence how they apply more generally
  - Much more powerful than statistical generalization

All Methods Are Flawed

- E.g. Laboratory Experiments
  - Cannot study large scale software development in the lab!
  - Too many variables to control them all!
- E.g. Case Studies
  - How do we know what's true in one project generalizes to others?
  - Researcher chose what questions to ask, hence biased the study
- E.g. Surveys
  - Self-selection of respondents biases the study
  - Respondents tell you what they think they ought to do, not what they actually do
- ...etc...

Slide by Steve Easterbrook

Strategies To Overcome Weaknesses

- Theory-building
  - Testing a hypothesis is pointless (single flawed study!)…
  - …unless it builds evidence for a clearly stated theory
- Empirical induction
  - Series of studies over time…
  - Each designed to probe more aspects of the theory
  - …together build evidence for a clearly stated theory
- Mixed-methods research
  - Use multiple methods to investigate the same research question
  - Each method compensates for the flaws of the others
  - …together build evidence for a clearly stated theory

Slide by Steve Easterbrook

Credits

- Graphics:
  - Dave DiCello photography (cover)
- Content:
  - Easterbrook, S., Singer, J., Storey, M. A., & Damian, D. (2008). Selecting empirical methods for software engineering research. In Guide to advanced empirical software engineering (pp. 285-311). Springer, London.
  - Varpio, L., Paradis, E., Uijtdehaage, S., & Young, M. (2020). The distinctions between theory, theoretical framework, and conceptual framework. Academic Medicine, 95(7), 989-994.
  - Trockman, A., Zhou, S., Kästner, C., & Vasilescu, B. (2018). Adding sparkle to social coding: an empirical study of repository badges in the npm ecosystem. In Proceedings of the 40th International Conference on Software Engineering (pp. 511-522).