What is Software Engineering Research?

Welcome – Summer 2019

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isr institute for SOFTWARE RESEARCH

Summer REUs in SE at CMU

- Work with CMU faculty and researchers
  - Contribute to new SE knowledge

- As part of a community
  - Mailing lists: reuse-students@cs.cmu.edu, software-group@cs.cmu.edu
  - Slack: reuse-2019
  - SE brown bag lunches
    - Wednesday at noon (usually in Newell Simon 4305)
  - ISR "Birthday Celebration" lunches – June 18 and July 16
  - Other activities

- Weekly seminar series – SSSG
  - Research (and meta-research) talks
  - Reading papers

Software Engineering at Carnegie Mellon

Goal: new knowledge
- about the engineered world (as-is)
- about how to improve that world

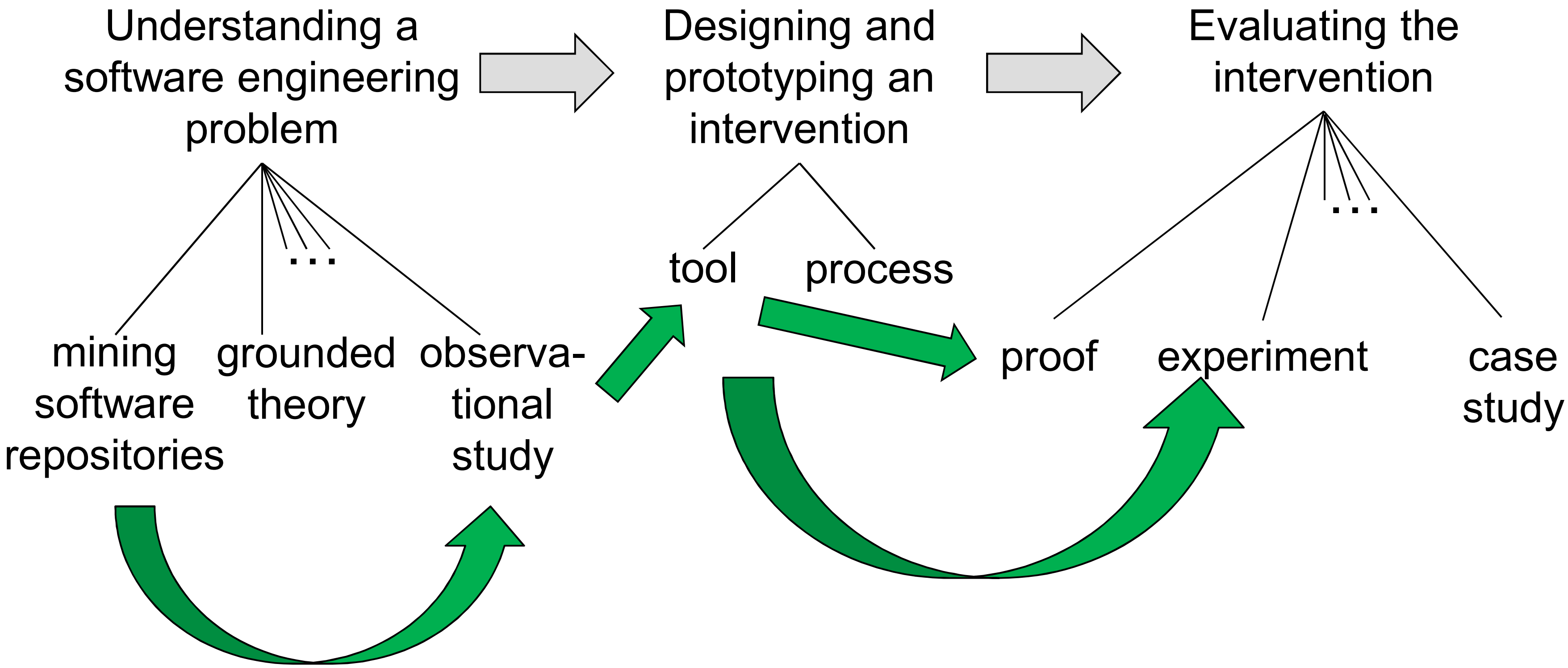
Software engineering is the branch of computer science
that creates practical, cost-effective solutions
to computing and information processing problems,
preferentially by applying scientific knowledge,
developing software systems in the service of mankind

- from "Software Engineering for the 21st Century: A basis for rethinking the curriculum" by the CMU SE Faculty (Mary Shaw, editor).

Engineering is about cost-effectiveness

SE is an applied science

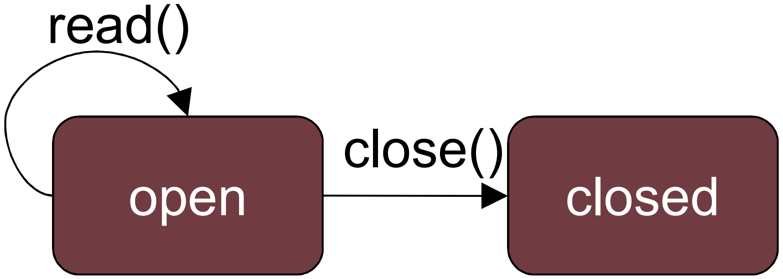
One Model of SE Research


Understanding a software engineering problem
Designing and prototyping an intervention
Evaluating the intervention
mining software repositories
grounded theory
…
observa-tional study
tool
process
proof
experiment
…
case study

One path through the model:
research on *object protocols*

Background: Protocols

- APIs often define **object protocols**
- Protocols restrict possible orderings of method calls
  - Violations result in error or undefined behavior



```
package java.io;

class FileReader {
   int read() { … }
   …
   /** Closes the stream and releases any system resources associated with it. Once the stream has been
   closed, further read(), ready(), mark(), reset(), or skip() invocations will throw an IOException.
   Closing a previously closed stream has no effect. **/
   void close() { … }
}
```

- We have developed a language, PLAID, that builds protocols into the type system and object model
  - now Obsidian does too!

Study 1: How Common Are Protocols?

- Approach: Quantitative Code Corpus Study
  - Used the Java standard library, plus many apps, frameworks
  - Tool identifies code pattern likely to indicate protocol
  - Weed out false positives via manual comparison to definition of what a protocol is
  - Categorized the protocols found

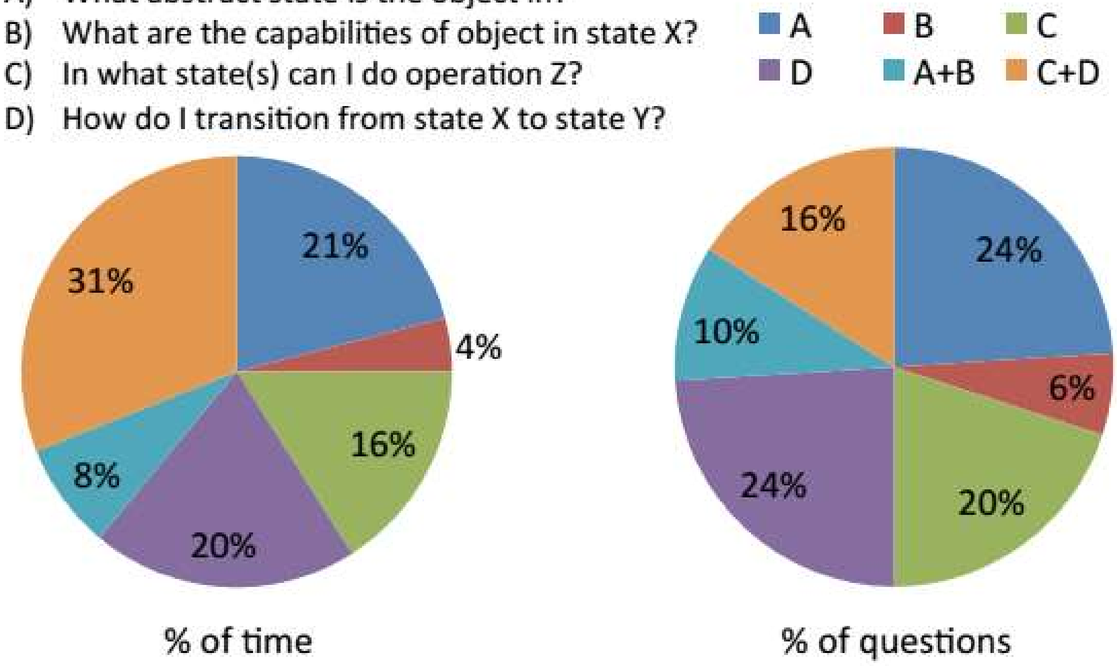
- Results
  - At least 7.2% of types define protocols
    - Compare: 2.5% of types define generics
  - At least 13.3% of classes use protocols
  - Identified 7 categories covering 98% of protocols

An Empirical Study of Object Protocols in the Wild. Nels E. Beckman, Duri Kim, and Jonathan Aldrich. In *Proceedings of the European Conference on Object-Oriented Programming (ECOOP '11)*, 2011.

Study 2: Protocol Programming Barriers

- Question: What barriers do programmers face when using APIs with protocols?
- Approach: Observational lab study of professional programmers
  - Programmers did mined protocol tasks (from another study) while thinking aloud
  - We assigned programmer time to quotes they uttered
  - Using open coding, we categorized the quotes
  - **Results:** programmers spent 70-80% of their time asking 4 kinds of questions:

A) What abstract state is the object in?
B) What are the capabilities of object in state X?
C) In what state(s) can I do operation Z?
D) How do I transition from state X to state Y?



Observations:
- Primarily a qualitative study
- However, we did gather some quantitative data

Intervention: The PLAID Language

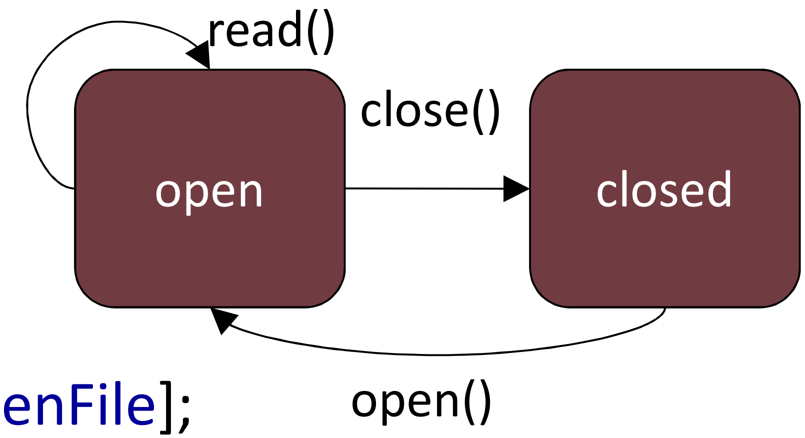
```
state File {
   val String filename;
}
state ClosedFile = File with {
   method void open() [ClosedFile>>OpenFile];
}
state OpenFile = File with {
   private val CFile fileResource;

   method int read();
   method void close() [OpenFile>>ClosedFile];
}
```

State transition

Different representation

New methods



Implementing Typestate Changes

```
method void open() [ClosedFile>>OpenFile] {
    this <- OpenFile {
        fileResource = fopen(filename);
    }
}
```

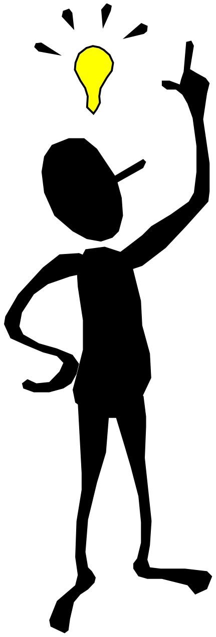
Typestate change primitive – like Smalltalk *become*

Values must be specified for each new field

Side note: we're now building on these ideas in the Obsidian language

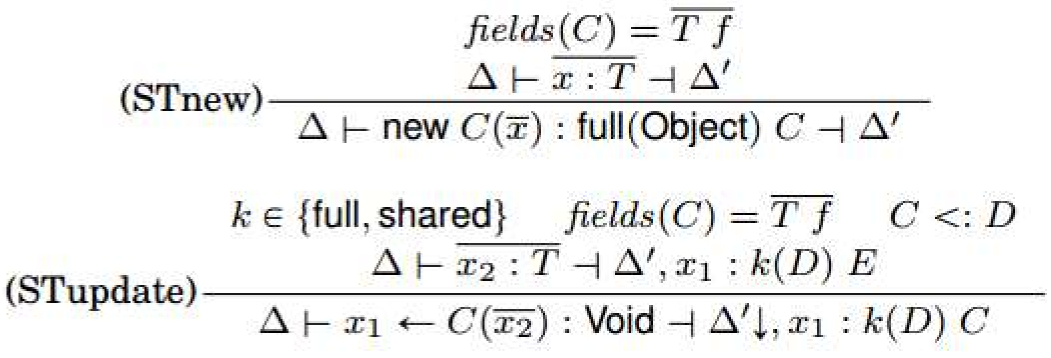
Why Typestate in the Language?

- The world has state – so should programming languages
  - egg -> caterpillar -> butterfly; sleep -> work -> eat -> play; hungry <-> full
- Language influences thought [Sapir '29, Whorf '56, Boroditsky '09]
  - Language support encourages engineers to **think** about states
    - Better designs, better documentation, more effective reuse
- Improved library specification and verification
  - Typestates define when you can call read()
  - Make constraints that are only implicit today, explicit
- Expressive modeling
  - If a field is not needed, it does not exist
  - Methods can be overridden for each state
- Simpler reasoning
  - Without state: fileResource non-**null** if File is open, **null** if closed
  - With state: fileResource always non-**null**
    - But only exists in the FileOpen state



Theory: Plaid’s Type System is Safe

- Typestate checks should ensure protocol objects are accessed safely
- Formal model of language, type system
- **Theorem:** a well-typed program won’t call a method from the wrong state



$$\text{(STnew)}\ \dfrac{\begin{array}{c} \mathit{fields}(C) = \overline{T\ f} \\ \Delta \vdash \overline{x : T} \dashv \Delta' \end{array}}{\Delta \vdash \mathsf{new}\ C(\overline{x}) : \mathsf{full}(\mathsf{Object})\ C \dashv \Delta'}$$

$$\text{(STupdate)}\ \dfrac{\begin{array}{c} k \in \{\mathsf{full}, \mathsf{shared}\} \quad \mathit{fields}(C) = \overline{T\ f} \quad C <: D \\ \Delta \vdash \overline{x_2 : T} \dashv \Delta', x_1 : k(D)\ E \end{array}}{\Delta \vdash x_1 \leftarrow C(\overline{x_2}) : \mathsf{Void} \dashv \Delta'\!\downarrow, x_1 : k(D)\ C}$$

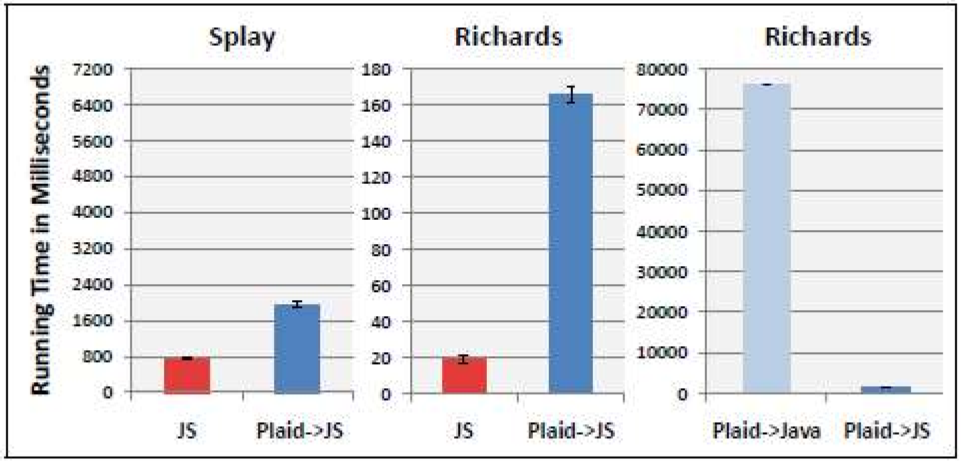
Two typing rules in a formal model of Plaid

Foundations of Typestate-Oriented Programming. Ronald Garcia, Éric Tanter, Roger Wolff, and Jonathan Aldrich. *Transactions on Programming Languages and Systems* 36(4) article 12, 2014.

This paper also explored *gradual typestate*, leading to our gradual verification project!

Implementation: Plaid can be Efficient

- Typestate requires changing behavior at run time
  - How can we make this object model efficient?
- New compilation approach
  - Associate state-based metadata with each object
  - Update methods following metadata on state change
- Prototyped in JavaScript
  - Performance comparison to native JS and to naïve Plaid compiler



- Efficient Implementation of the Plaid Language. Sarah Chasins. *Systems, Programming, Languages, and Applications: Software for Humanity (SPLASH)*, 2011.

Study 3: Effect of Protocol Documentation

- We wanted to know if Plaid can help programmers program more effectively with protocols
  - But that's a hard question to measure directly, due to learning effects, tool quality, etc.
- Proxy: Plaid's design enables new forms of `javadoc`-like documentation. Does the documentation help?
  - `plaiddoc`: shows state space, organizes methods by state, shows state pre- and post-conditions
- Approach: controlled laboratory experiment
  - 20-participant between-subjects study
  - Task: answer questions identified in study 2b, above

Structuring Documentation to Support State Search: A Laboratory Experiment about Protocol Programming. Joshua Sunshine, James Herbsleb, and Jonathan Aldrich. *Proc. European Conference on Object-Oriented Programming*, 2014.

Study 3: Effect of Protocol Documentation

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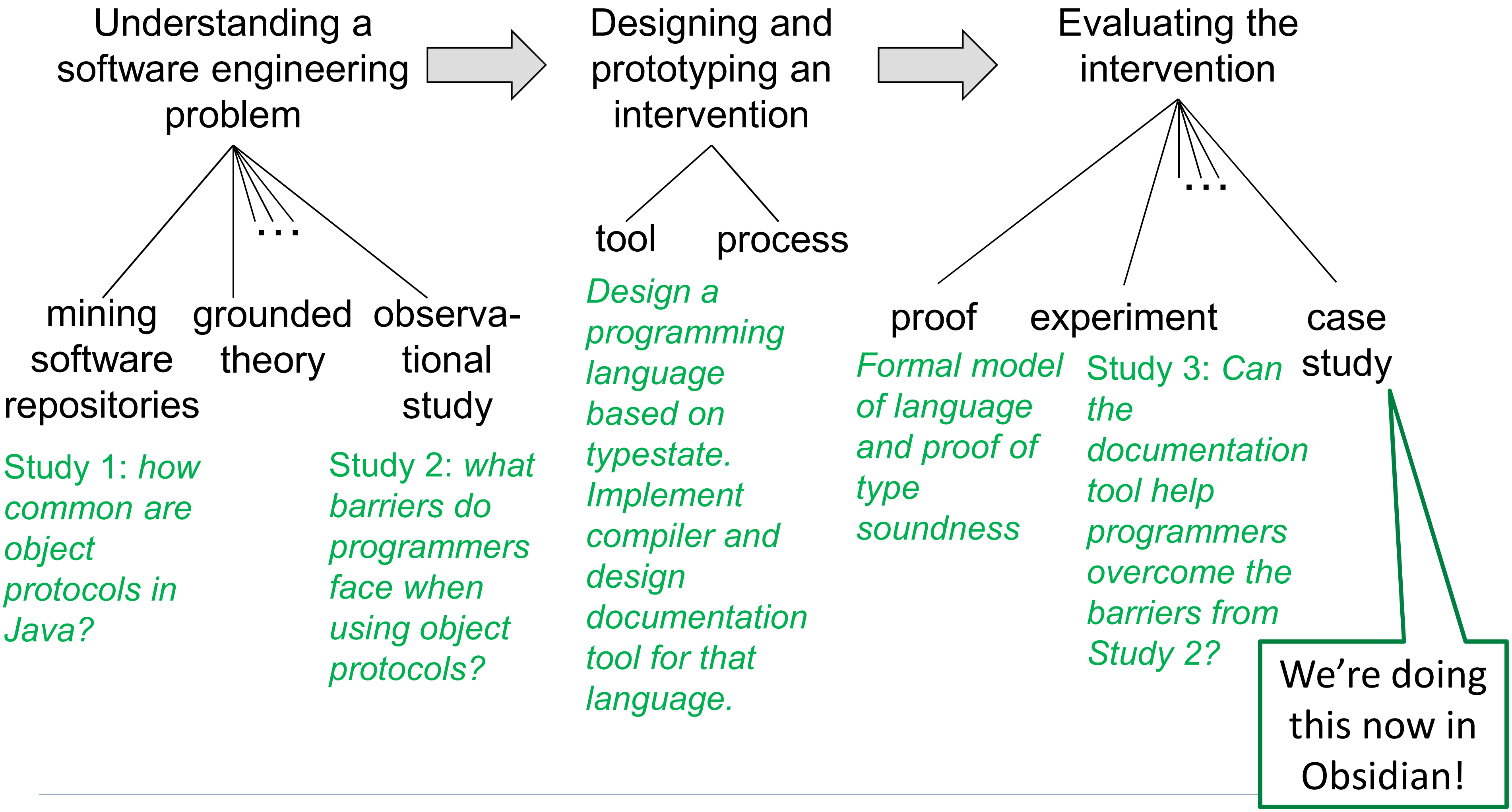
- Approach: controlled laboratory experiment
    - 20-participant between-subjects study
    - Task: answer questions identified in study 2b, above
    - **Results:**
        - `plaiddoc` participants were **2.2x faster** (p < 0.001)
        - `javadoc` participants were **7.9x more likely to make errors** (p=0.002)

One Model of SE Research



Understanding a software engineering problem → Designing and prototyping an intervention → Evaluating the intervention

Understanding a software engineering problem

- mining software repositories
- grounded theory
- …
- observational study

Study 1: *how common are object protocols in Java?*

Study 2: *what barriers do programmers face when using object protocols?*

Designing and prototyping an intervention

- tool
- process

Design a programming language based on typestate. Implement compiler and design documentation tool for that language.

Evaluating the intervention

- proof
- experiment
- …
- case study

Formal model of language and proof of type soundness

Study 3: *Can the documentation tool help programmers overcome the barriers from Study 2?*

We're doing this now in Obsidian!

If you like the REU, what might be next?

CMU SE Ph.D. Alumni Careers (examples)

Thomas LaToza

Assistant Professor, George Mason

SE/HCI research on how humans interact with code and designing new ways to build software

Chris Scaffidi

Associate Professor,

Oregon State

Research on helping end-users create software; directs OSU's master's in SE

Josh Sunshine

Systems Scientist

Carnegie Mellon

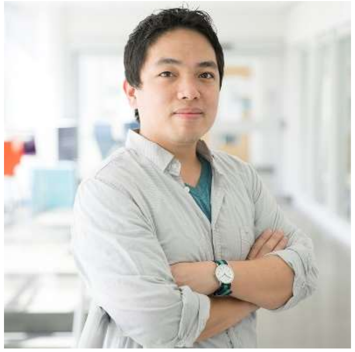
SE/PL research, especially on the usability of reusable software components

Ciera Jaspan

Tech Lead Manager, Google

Engineering Productivity Research

Research on developer productivity at Google; regularly publishes at ICSE, OOPSLA



Jason Tsay

IBM Research AI

Research in AI Engineering: how to improve experiences of data scientists, developers who work in AI

Owen Cheng

Senior Software Engineer, Uber Advanced Technology Group

SE Research – Careers and Ph.D.

- University professor
  - Pursue *your* own research agenda – be your own boss!
  - Teach and mentor students in research
  - Even service tasks are rewarding – running programs, organizing conferences
- Industry researcher
  - Explore the most cutting edge ideas in a real environment
  - See those ideas have an immediate impact on products
- For either, you need a Ph.D. in CS…or SE!
  - Primary focus is research
  - Typically takes 5-6 years
    - Master's degree is not a prerequisite
  - Tuition and stipend are provided
  - Just as fun as an REU in SE!
- CMU among the best places to study CS/SE

Ph.D. Applications

- Primary criterion: promise to do successful independent research
  - You will get practice this summer!

- Apply in December 2019 for Fall 2020 (etc.)

- Documentation: Recommendations, research & industry experience, statement, test scores, grades

Our SE PhD Curriculum

- Research (always ≥ 50% time)
  - Project work
  - Thesis
- Coursework
  - Core SE course
  - Core areas
    - Design/Engineering
    - Symbolic modeling and analysis
    - Behavioral science
    - Society/Bus./Policy
  - 2 Electives
- Practicum
  - Reflection on practice

- Skills
  - Speaking and writing
- Teaching
  - TA two courses
- Community engagement
  - Weekly research seminar
  - Volunteer service
- Experience
  - Prior industrial experience
  - Internships during the program

The Ph.D. is a New World

- Research is your #1 job!
  - Starts immediately when you arrive

- Course grades (mostly) don't matter: learning does

- Nature of the work differs
  - You will be given ill-defined problems, and have to define them
  - Critical thinking and interpretation dominate fact-finding
  - Much of the feedback you get will be informal

- Challenging and fun
  - A chance to make a lasting contribution to scientific knowledge
  - One of the best periods in my life—also true for many students here!