Program Analysis, in Industry and Academia

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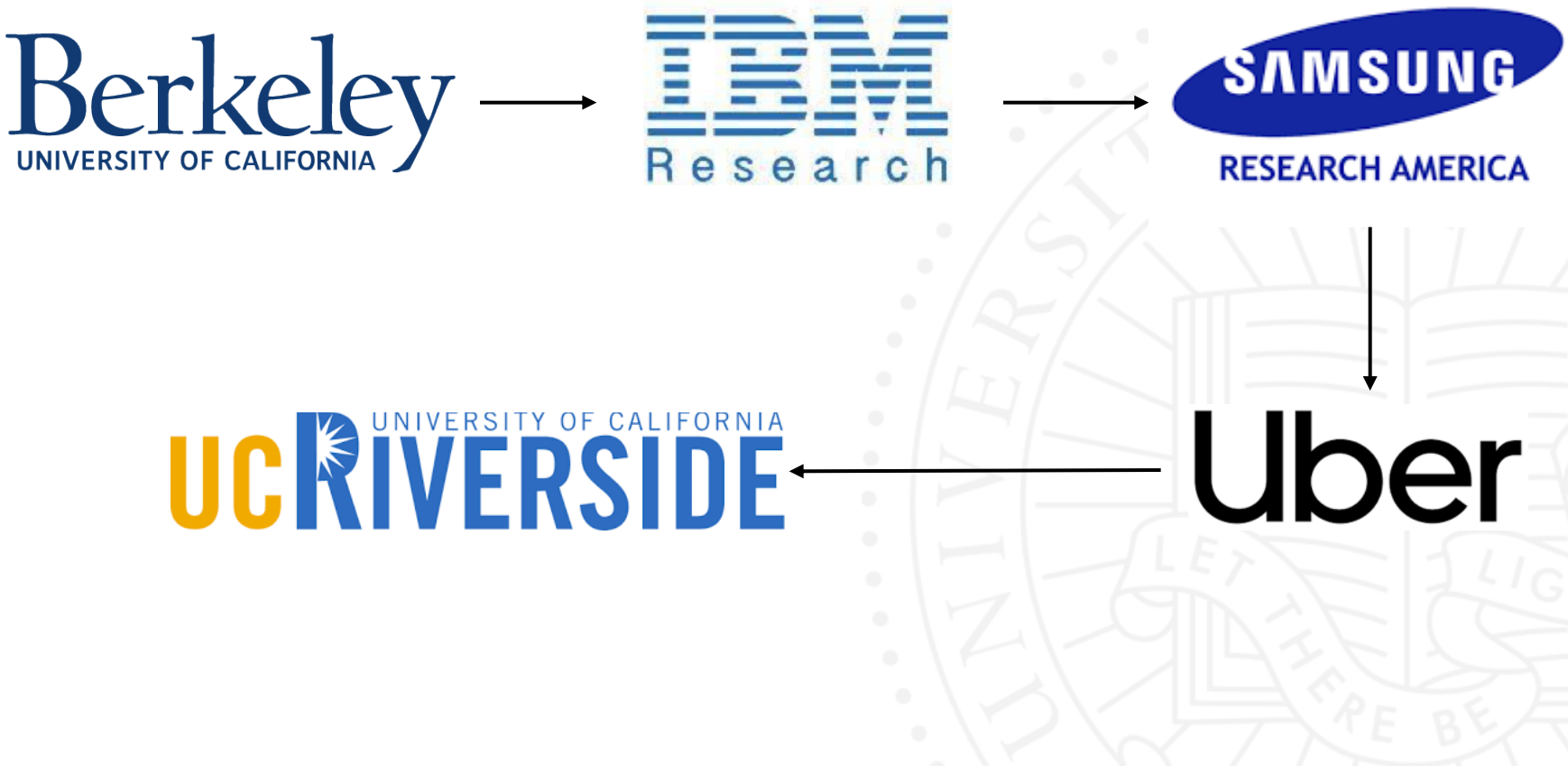
My Journey


Berkeley
UNIVERSITY OF CALIFORNIA
IBM Research
SAMSUNG
RESEARCH AMERICA
Uber
UC RIVERSIDE UNIVERSITY OF CALIFORNIA

This talk

- My personal journey in industrial research / industry / academia
  - For a great overview of CS PhD jobs, see Kathleen Fisher's PLMW@PLDI'19 talk: http://bit.ly/careerOptions

- **My focus**: program analysis at scale
  - Static analysis
  - Type systems and type inference

Grad School

2002-2007

Ras Bodik
(my advisor)

Problem Space: Pointer Analysis

- Finds values for pointer variables
- Crucial building block
  - "What gets called by `x.m()`?"
  - "What code uses `untrustedInput()`?"
- Others formulated C pointer analysis as a CFL-reachability problem
- Ras's suggestion (~January 2003): Java pointer analysis using CFL-reachability

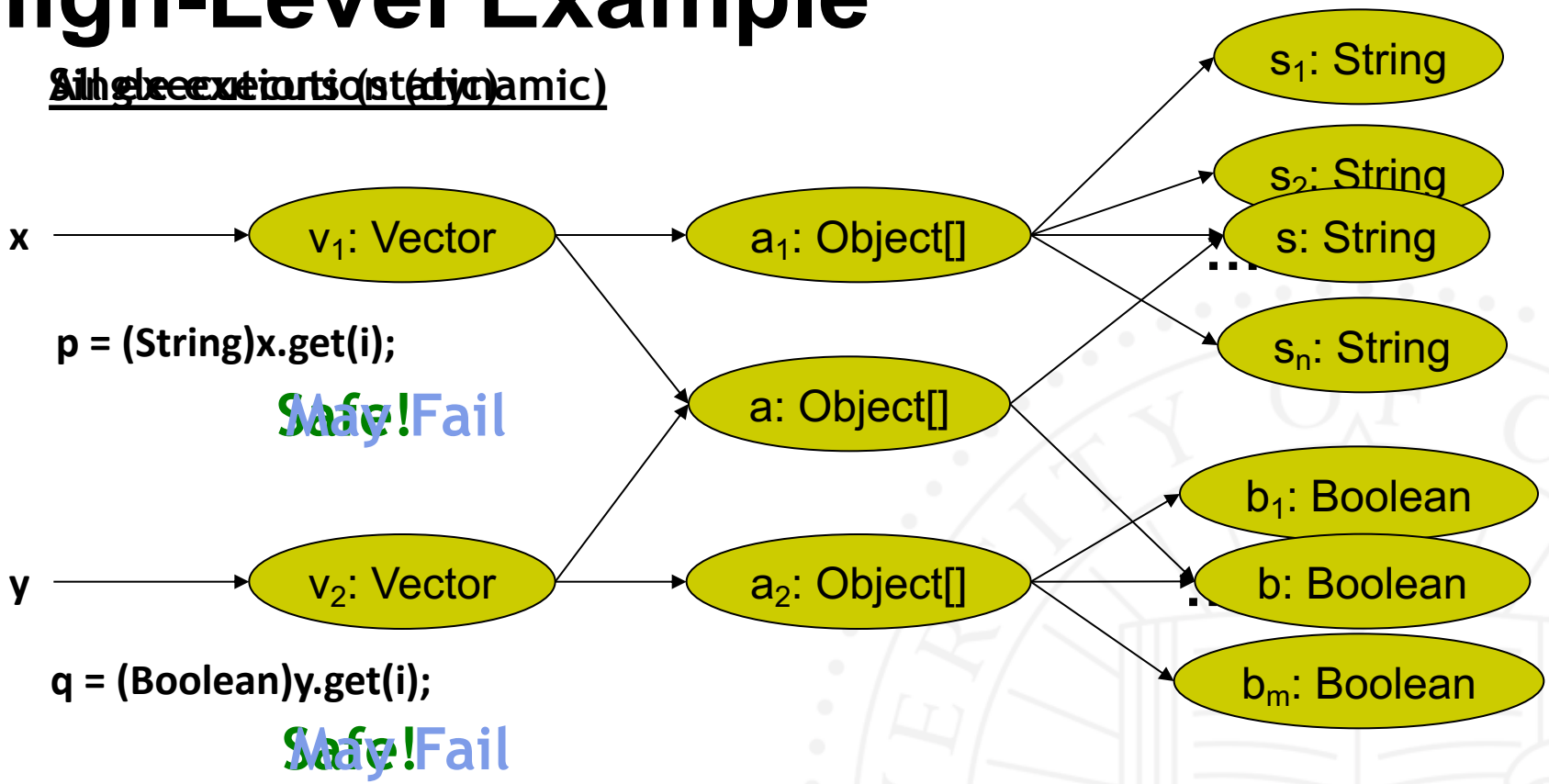
Target programs: Benchmarks

- Standard suites used in performance papers
  - SpecJVM98
  - Dacapo
- Tried to use "real-world" clients
  - E.g., proving safety of downcasts
  - Atypical for pointer analysis papers at the time
- "Large" programs
  - Hundreds of thousands of lines (with libraries)
  - I learned later they weren't that big…

Making progress

- Took a while (> 1 year) to ramp up
  - Understanding the (extensive) literature
  - Learning the engineering "tricks"
- A few false starts, paper rejections
  - Spent multiple months on an idea that didn't work
- **Insight**: Java analysis has a "balanced parentheses" structure
- Led to a refinement-based technique with improved scalability and precision

High-Level Example



- Must merge some objects (decidability)
- Too much merging: precision loss
- Too little merging: space explosion (typically exponential)
- Our technique: unmerge through refinement

Branching out

- Idea: balanced parentheses for slicing
- Implemented with Steve Fink from IBM
  - Ras had long collaborated with IBM
  - Used newly open-source WALA framework
- Wrote a fun paper ("Thin Slicing")
- Realized how much I enjoy close collaboration...

IBM Research

2008-2013

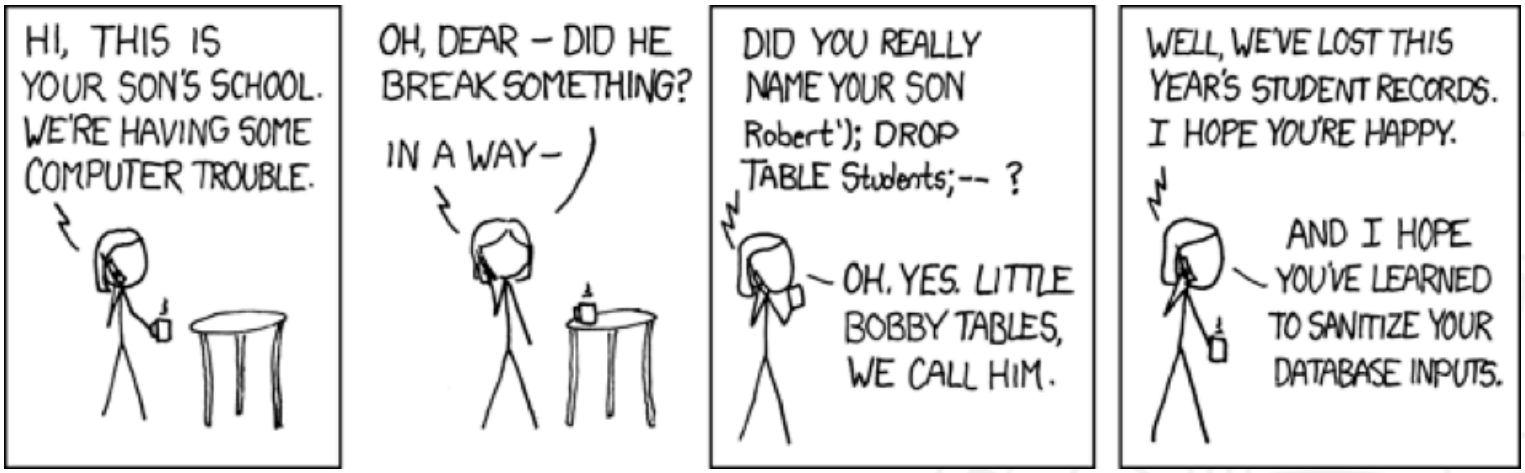
Balance in Industrial Research

- Some work should "pay the bills"
  - Applying research results to a product
  - Lower risk (but still publishable!)
  - Tangible impact
- Other work should be forward looking
  - Speculative, but with a story for eventual impact
  - Sometimes turns into "pay the bills" work
- I really enjoyed this balance!
  - Get to have a portfolio of impact

Information flow vulnerabilities

- Untrusted data used in sensitive operation
  - E.g., SQL injection
- Leaking of confidential data
  - E.g., showing exception stack traces

(paying the bills)

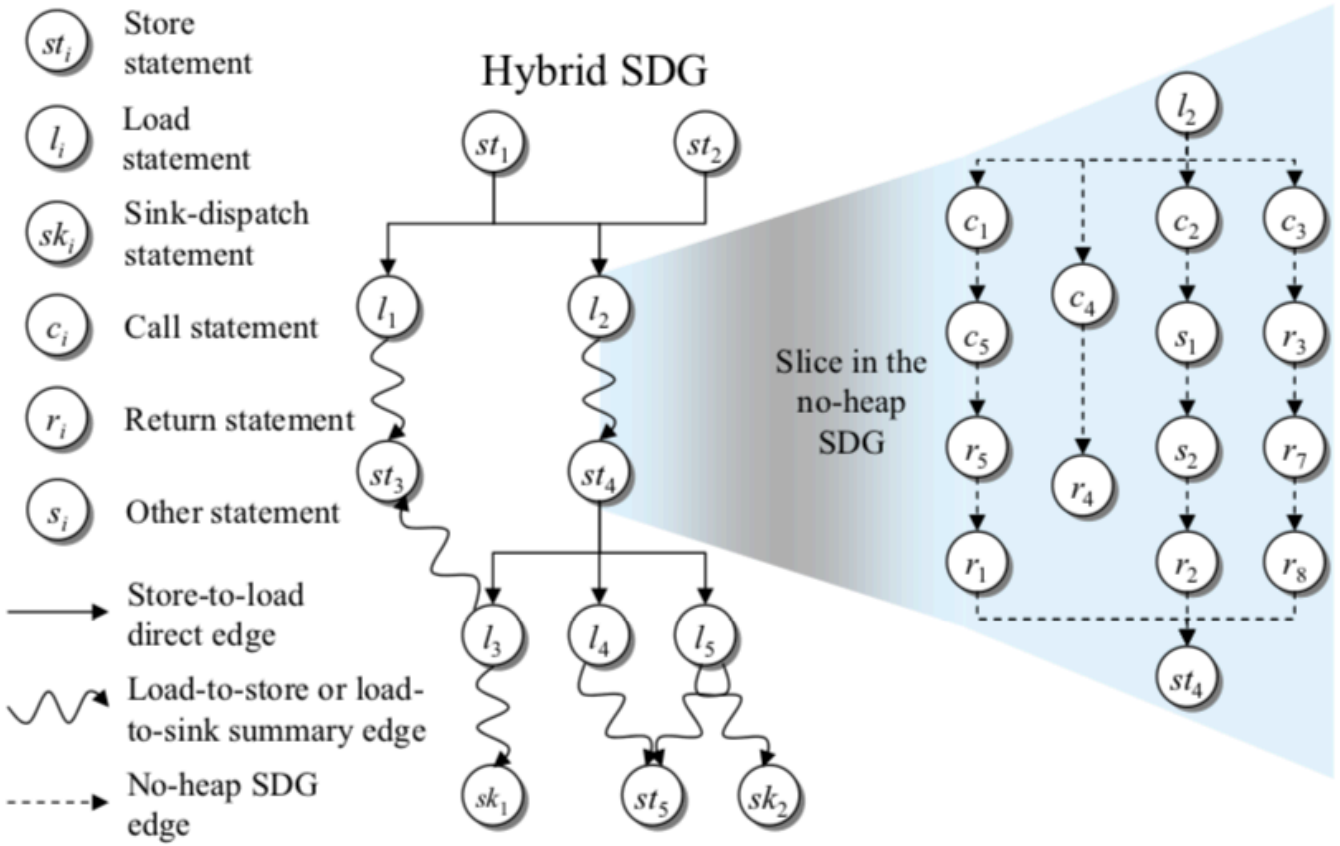


https://www.xkcd.com/327/

Target programs: Customer code

- Much different than what I saw in grad school
- Enormous!
  - Dozens of library jars in classpath
  - Even building class hierarchy had to be optimized
- Often based on complex frameworks
  - No `main()` method in application
  - Framework calls into app based on XML config
  - Hard to analyze!

Technique: hybrid thin slicing



The real world

- Many heuristics needed for huge programs
  - Cutoffs, timeouts, etc.
  - Hard to build robustly
- Frameworks led to many missed issues
- Tools sell by doing well in "proof-of-concept"
  - Sales engineer tries tool on customer code
  - Find some bugs, don't miss obvious ones
  - "Verifying" the code not relevant
- So, design analysis to work well in PoCs

Eventual approach

- No whole-program pointer analysis!
- Use simple class hierarchy + local tracking of data flow and aliasing
- Built a sophisticated tool F4F to make modeling of frameworks easier
- Successful product (still sold today)

Shifting gears: JavaScript

- ~2011, heard from Julian Dolby about challenges in analyzing JavaScript web apps
- We started studying challenges in core static analysis for JavaScript
- Forward looking: no particular customer

Reflective code

Java: `x.f = y`

If no `f` field, compile error

JavaScript: `x[e] = y`

If field doesn't exist, create it!

Disaster for pointer analysis

Used in real world 😐

```
var e = “blur,focus,load”.split(“,”);
// e is [“blur”,”focus”,”load”]
for (var i=0;i<e.length;i++) {
  var o = e[i];
  jQuery.fn[o] = function() { … };
  jQuery.fn[“un”+o] = function() { … };
  jQuery.fn[“one”+o] = function() { … };
}
```

Techniques

- Improvements to traditional pointer analysis
  - Correlation tracking
  - Dynamic determinacy analysis
- Scalable, approximate (unsound) call graphs
  - Used to pay the bills! AppScan JS analysis

Samsung Research

2013-2016

Shifting gears: Performance

TIZEN™

- A push for running JS / web apps on devices
- Performance was lagging behind
  - Dynamic features hard to optimize
  - Hard to run JIT, GC with resource constraints
- Goal: ahead-of-time compilation for JS

Target programs: web apps

- Often, not much client code
  - Many had < 10,000 LoC
- But, relied on complex frameworks
  - And web browser itself is complex!
- When optimizing, **can't be unsound**

Technique: type inference

- Defined a type system for a rich subset of JS
  - Enabled efficient code generation
- Defined a (global) type inference algorithm, to handle extant code
- Built a full compiler backend (compiled to C)

$$\boxed{X_R, \Gamma \vdash e : X \mid C}$$

$$\textsc{C-Int}\ \frac{\mathsf{fresh}\ X}{X_R, \Gamma \vdash n : X \mid X^{\mathsf{r}} \equiv \mathsf{int}} \qquad \textsc{C-Var}\ \frac{\Gamma(x) = X}{X_R, \Gamma \vdash x : X \mid \emptyset} \qquad \textsc{C-This}\ \frac{}{X_R, \Gamma \vdash \mathsf{this} : X_R \mid \emptyset}$$

$$\textsc{C-VarDecl}\ \frac{X_R, \Gamma\,[x \mapsto X_1] \vdash e_1 : Y_1 \mid C_1 \qquad \mathsf{fresh}\ X_1 \qquad X_R, \Gamma\,[x \mapsto X_1] \vdash e_2 : X \mid C_2}{X_R, \Gamma \vdash \mathsf{let}\ x = e_1\ \mathsf{in}\ e_2 : X \mid C_1 \wedge C_2 \wedge Y_1^{\mathsf{r}} <: X_1^{\mathsf{r}} \wedge Y_1^{\mathsf{w}} <: X_1^{\mathsf{w}}}$$

$$\textsc{C-VarUpd}\ \frac{x : X_1 \in \Gamma \qquad X_R, \Gamma \vdash e_1 : X \mid C_1}{X_R, \Gamma \vdash x := e_1 : X \mid C_1 \wedge X^{\mathsf{r}} <: X_1^{\mathsf{r}} \wedge X^{\mathsf{w}} <: X_1^{\mathsf{w}}} \qquad \textsc{C-Null}\ \frac{\mathsf{fresh}\ X}{X_R, \Gamma \vdash \mathsf{null} : X \mid X^{\mathsf{w}} <: \langle\,\rangle}$$

$$\textsc{C-MethDecl}\ \frac{\mathsf{fresh}\ Y_R, Y_1, X \quad \mathsf{has\_this}(e) \quad Y_R, \Gamma\,[x \mapsto Y_1] \vdash e : Y_2 \mid C}{X_R, \Gamma \vdash \mathsf{function}\ (x)\ \{e\} : X \mid C \wedge Y_R^{\mathsf{w}} <: \langle\,\rangle \wedge \mathsf{concrete}(Y_R) \wedge \mathsf{notproto}(Y_R) \wedge X^{\mathsf{r}} \equiv ([Y_R]\ Y_1 \Rightarrow Y_2)}$$

$$\textsc{C-MethApp}\ \frac{\mathsf{fresh}\ X_M, Y_R, X_3, X \qquad X_R, \Gamma \vdash e_1 : X_1 \mid C_1 \qquad X_R, \Gamma \vdash e_2 : X_2 \mid C_2}{\begin{array}{l} X_R, \Gamma \vdash e_1.a\,(e_2) : X \mid \quad C_1 \wedge C_2 \wedge X_1^{\mathsf{r}} <: \langle a : X_M \rangle \wedge X_M^{\mathsf{r}} \equiv ([Y_R]\ X_3 \Rightarrow X) \wedge \mathsf{strip}(X_M) \wedge \mathsf{concrete}(X_1) \\ \qquad\qquad \wedge\ \mathsf{concrete}(Y_R) \wedge Y_R^{\mathsf{w}} <: \langle\,\rangle \wedge \mathsf{notproto}(Y_R) \wedge X_2^{\mathsf{r}} <: X_3^{\mathsf{r}} \wedge X_2^{\mathsf{w}} <: X_3^{\mathsf{w}} \end{array}}$$

$$\textsc{C-ObjEmp}\ \frac{}{X_R, \Gamma \vdash \{\cdot\} : X \mid \mathsf{proto}(X) \wedge X^{\mathsf{r}} \equiv \langle\,\rangle \wedge X^{\mathsf{mr}} \equiv \langle\,\rangle} \qquad \textsc{C-Attr}\ \frac{\mathsf{fresh}\ X \quad X_R, \Gamma \vdash e : X_1 \mid C}{X_R, \Gamma \vdash e.a : X \mid C \wedge X_1^{\mathsf{r}} <: \langle a : X \rangle \wedge \mathsf{notmethod}(X)}$$

$$\textsc{C-AttrUpd}\ \frac{\mathsf{fresh}\ X_f \quad X_R, \Gamma \vdash e_1 : X_b \mid C_1 \quad X_R, \Gamma \vdash e : X_v \mid C_2}{X_R, \Gamma \vdash e_1.a := e : X_v \mid C_1 \wedge C_2 \wedge X_b^{\mathsf{w}} <: \langle a : X_f \rangle \wedge X_v^{\mathsf{r}} <: X_f^{\mathsf{r}} \wedge X_v^{\mathsf{w}} <: X_f^{\mathsf{w}} \wedge \mathsf{attach}(X_b, X_f, X_v)}$$

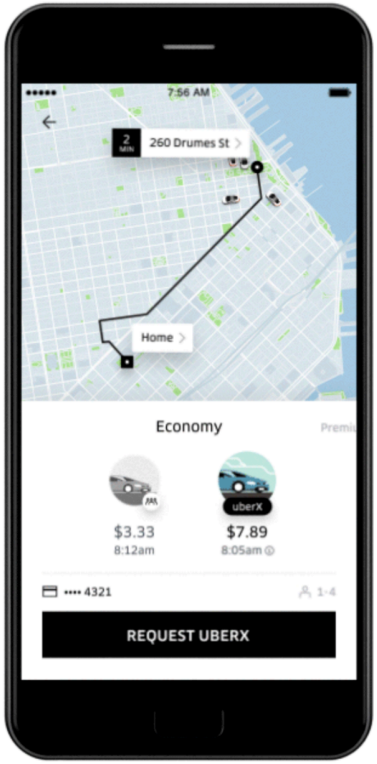
$$\textsc{C-ObjLit}\ \frac{\mathsf{fresh}\ X \qquad \forall i \in 1..n.\ \mathsf{fresh}\ X_i \qquad \forall i \in 1..n.\ X_R, \Gamma \vdash e_i : Y_i \mid C_i \quad X_R, \Gamma \vdash e_p : X_p \mid C_p}{\begin{array}{l} X_R, \Gamma \vdash \{a_1 : e_1, \ldots, a_n : e_n\}\ \mathsf{proto}\ e_p : X \mid \quad C_p \wedge \bigwedge_i (C_i \wedge Y_i^{\mathsf{r}} <: X_i^{\mathsf{r}} \wedge Y_i^{\mathsf{w}} <: X_i^{\mathsf{w}} \wedge \mathsf{attach}(X, X_i, Y_i)) \\ \qquad\qquad \wedge\ X^{\mathsf{w}} \equiv \langle a_1 : X_1, \ldots, a_n : X_n \rangle \wedge X^{\mathsf{r}} <: X_p^{\mathsf{r}} \wedge X_p^{\mathsf{r}} <: X^{\mathsf{r}} \setminus \{a_1, \ldots, a_n\} \\ \qquad\qquad \wedge\ \mathsf{proto}(X) \wedge \mathsf{proto}(X_p) \wedge X^{\mathsf{mr}} <: X_p^{\mathsf{mr}} \wedge X^{\mathsf{mw}} <: X_p^{\mathsf{mw}} \end{array}}$$

Figure 8: Constraint generation.

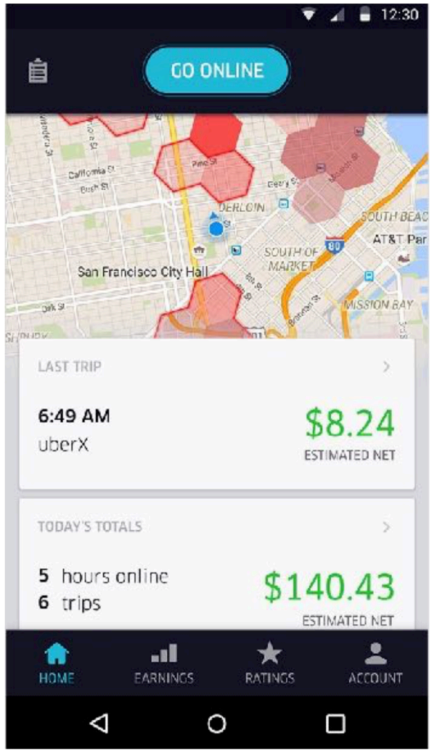
Uber

2017-2018

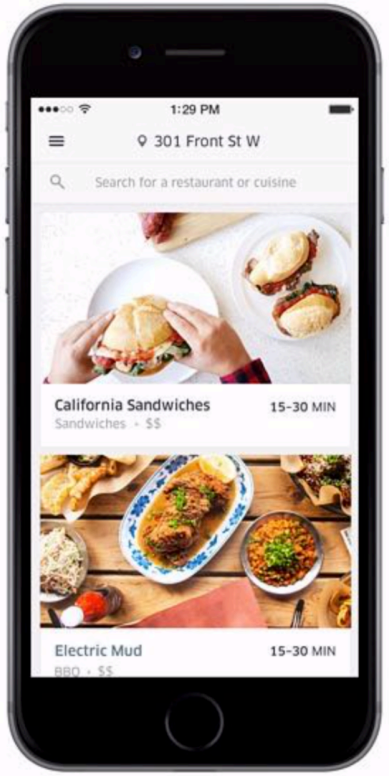
Uber Apps



Rider



Driver



Eats

iOS and Android

App reliability: crucial

Rider app crash: can't get home

Driver app crash: can't earn

Using apps involves payments

Apps take significant time to patch

Target programs: our own code

- We can rewrite code to work well with tool!
- Goal: integrate with development process
  - Fast, modular analysis
  - Understandable error messages
- Can require reasonable annotation burden

Technique: Pluggable Types

- Idea: add extra type checking to compiler
  - Leveraging source code annotations
- Pioneered by Checker Framework
- **NullAway**: fast, practical NPE prevention
  - Engineered for speed
  - Soundness tradeoffs to reduce annotations
  - Runs on every Android build at Uber
  - https://github.com/uber/NullAway, https://arxiv.org/abs/1907.02127

Example: Nullability

```
static void log(Object x) {
  System.out.println(x.toString());
}
static void foo() {
  log(null); Error: cannot pass null to @NonNull
}              parameter x
```

Example: Nullability

```
static void log(@Nullable Object x) {
  System.out.println(x.toString());
}
static void foo() {
  log(null);
}
```

Error: de-referencing x may yield NPE

Example: Nullability

```
static void log(@Nullable Object x) {
  if (x == null) return;
  System.out.println(x.toString());
}
static void foo() {
  log(null);
}
```

Other Uber projects

- Type-based detection of multithreading bugs
  - Specialized to stream APIs
  - Also running on every Android build
- Optimization of Swift protocols
  - 12% speedup in app startup
  - Upstreamed to Apple
- Auto-deletion of stale feature flags
  - Stale flags hurt reliability, code readability
  - Hundreds of flags removed

UC Riverside

2019-present

What's next?

- I still like to pay the bills!
  - Make time for open-source hacking
  - Polish tools, within reason
- Invest in teaching / advising
- Research: greater risk / time horizon
- Find good collaborators!
  - Students, faculty (Riverside / elsewhere), industry

Tips

- Be aware of “adjacent” areas
  - Read broadly (papers, Hacker News, …)
  - Make time for it
- Networking and visibility matters!
  - Talk to people
  - Do open source, give talks (with video)
- Value in different perspectives on a problem
  - The “right”, academic solution
  - Dealing with existing code as-is
  - Working with developers

Thanks!