Moving Fast with High Reliability: Program Analysis at Uber

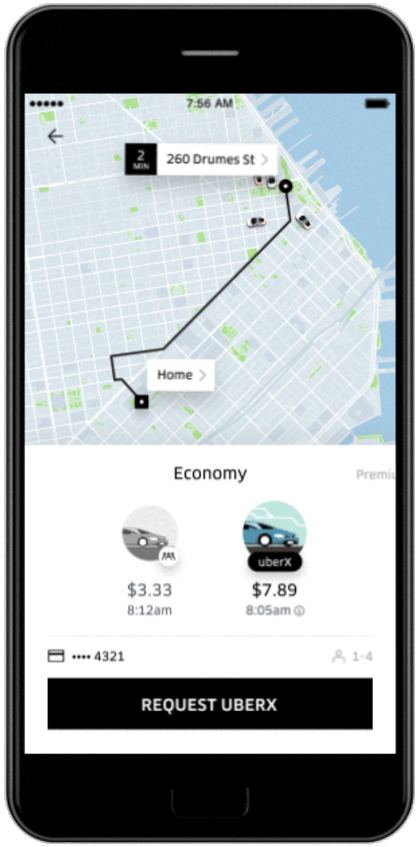
Manu Sridharan

Software Reliability Workshop

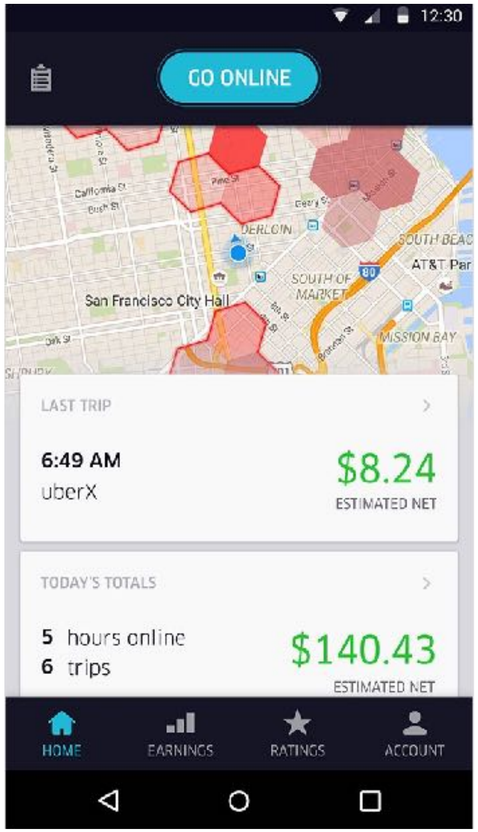
ETH Zurich

OCTOBER 14, 2017

Uber Apps



Rider

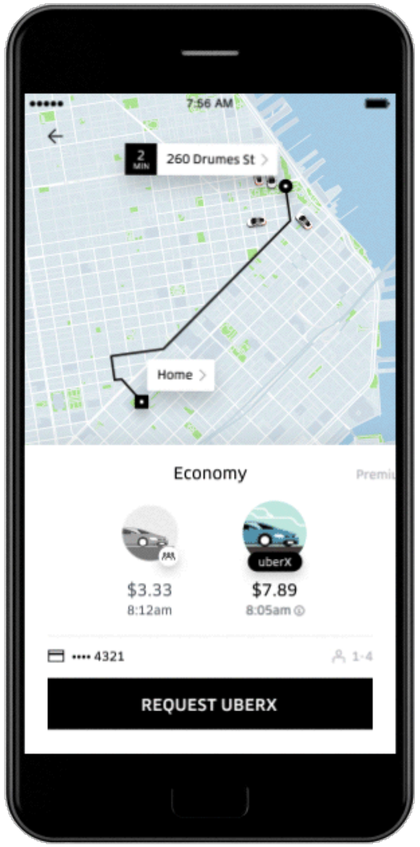


Driver

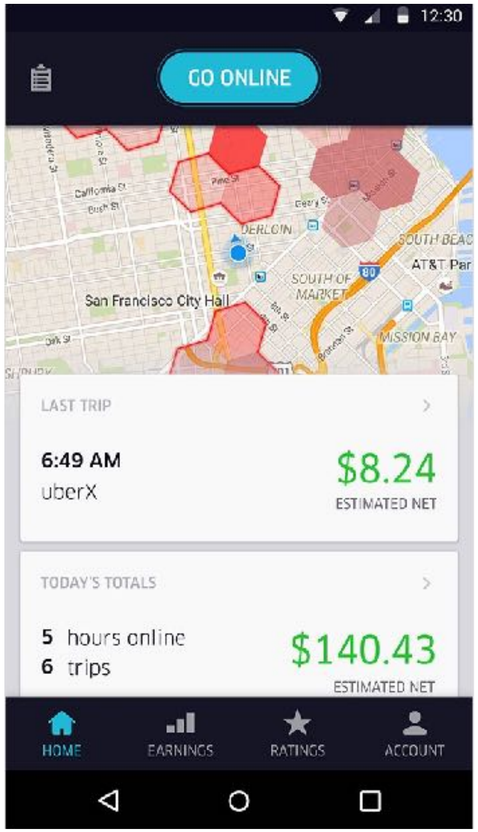
Eats

iOS and Android

Uber Apps



Rider



Driver

Eats

iOS and Android

Uber cares *a lot* about reliability

Rider crash: can’t get home

Driver crash: can’t earn

Using our apps involves a payment

Apps take significant time to patch

“Transportation as reliable as running water, everywhere, for everyone”

Uber needs to move fast

Hundreds of developers working simultaneously

- Hundreds of commits per day

Millions of lines of code

Goal: Let builders build

- Let developers stay in the flow
- Let developers work independently

How can Uber move fast *and* keep reliability high?

Modularity in Design *and* Analysis

Modularity in Design *and* Analysis

App design emphasizes modularity

- Features can be developed and disabled independently
- Enables developers to move fast

Modularity in Design *and* Analysis

App design emphasizes modularity

- Features can be developed and disabled independently
- Enables developers to move fast

Analysis can both enforce *and* leverage design

- Leverage code modularity for greater scalability / precision
- Modular analysis avoids pollution from unrelated code

Modularity in Design *and* Analysis

App design emphasizes modularity

- Features can be developed and disabled independently
- Enables developers to move fast

Analysis can both enforce *and* leverage design

- Leverage code modularity for greater scalability / precision
- Modular analysis avoids pollution from unrelated code

Strong willingness to adjust design to help analysis

Remainder of this talk

Remainder of this talk

Designing for analyzability

Remainder of this talk

Designing for analyzability

Case studies

Remainder of this talk

Designing for analyzability

Case studies

Future projects / open problems

Designing for Analyzability

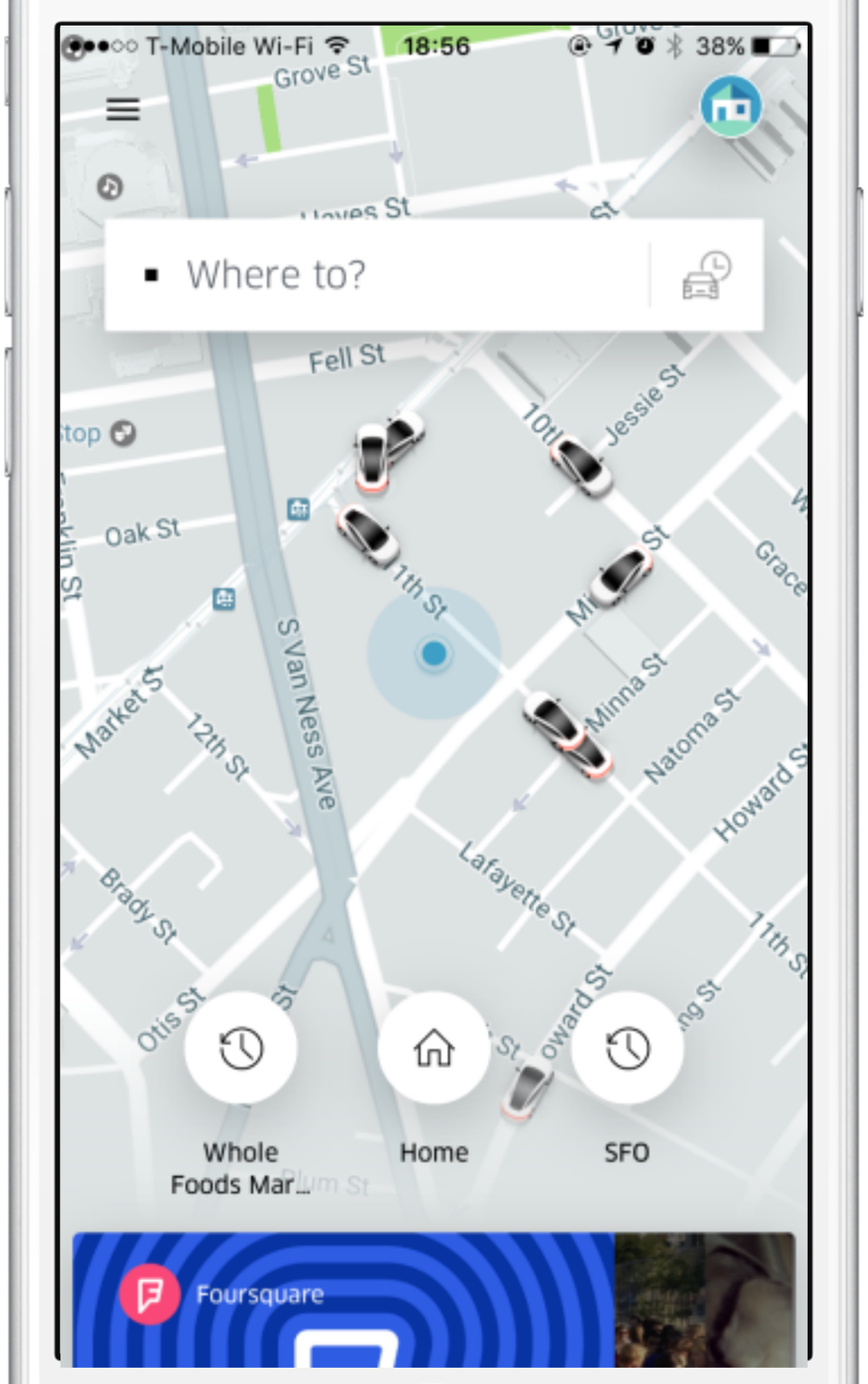
Rewritten Rider App

In 2016, Uber built new rider apps
from scratch

Key goals included:

- High availability of core flows, without slowing feature development
- Maximal decoupling of features

These goals help static analysis!



Plugins

Plugins: Motivation

Isolate core flows from other features

- Core flow: getting a ride
- Non-core: account settings

Plugins can be disabled remotely

- Reduces risk in feature experimentation

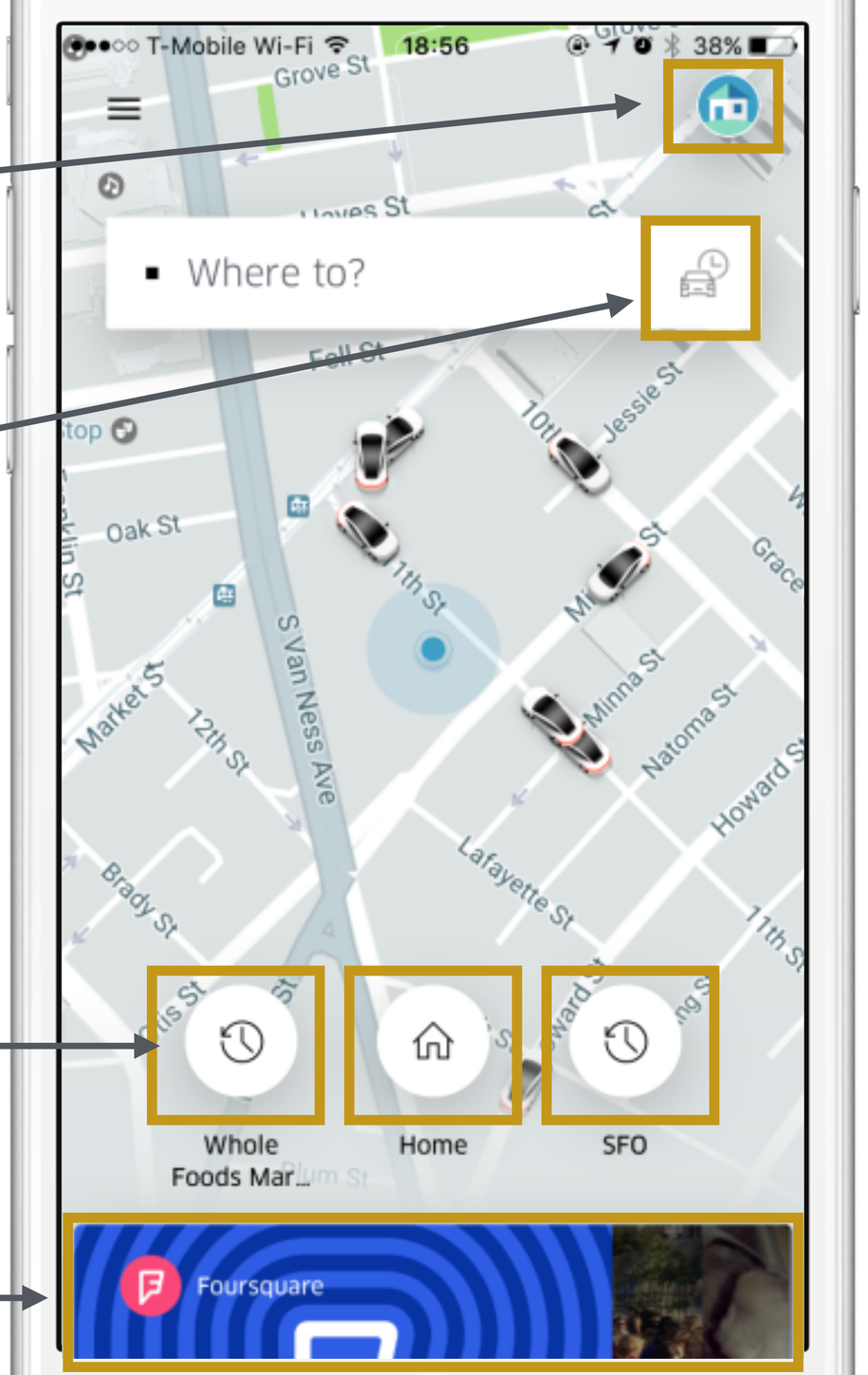
Plugin examples

Profiles

Scheduled rides

Location shortcuts

Feed



Plugins: Under the Hood

Core code defines plugin points

- Changes get extra manual review

Core can only reference non-core via plugins

- Enforced via naming conventions + linting

80% of code in plugins

Core flows tested with all plugins disabled

Deep Scope Hierarchies

Scoping of app state

Scoping of app state

Some state needs to be shared between features

- The map
- User account information when logged in

Scoping of app state

Some state needs to be shared between features

- The map
- User account information when logged in

Storing in global state leads to bugs

- Subtle dependencies creep in between features

Scoping of app state

Some state needs to be shared between features

- The map
- User account information when logged in

Storing in global state leads to bugs

- Subtle dependencies creep in between features

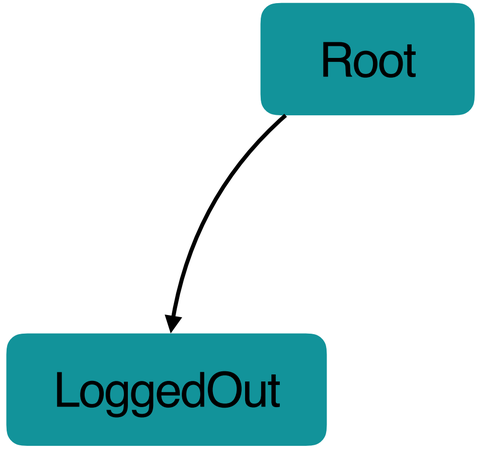
Must manage object lifetimes carefully to avoid leaks

- E.g., after trip, need to promptly discard trip state
- In old app, fragile reset() methods

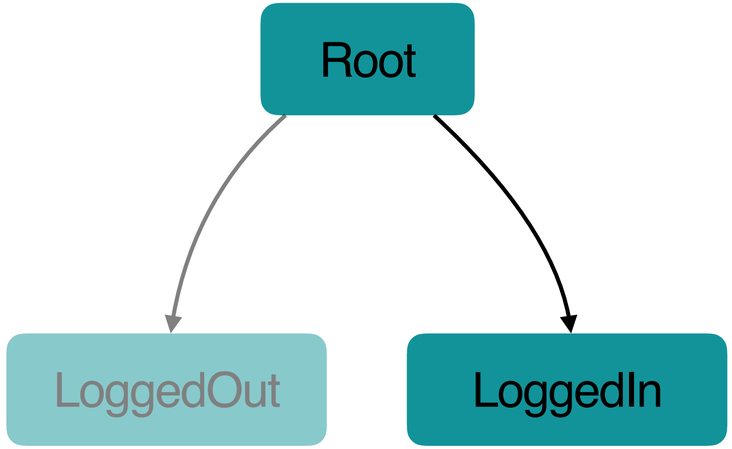
Deep Scope Hierarchies

Deep Scope Hierarchies

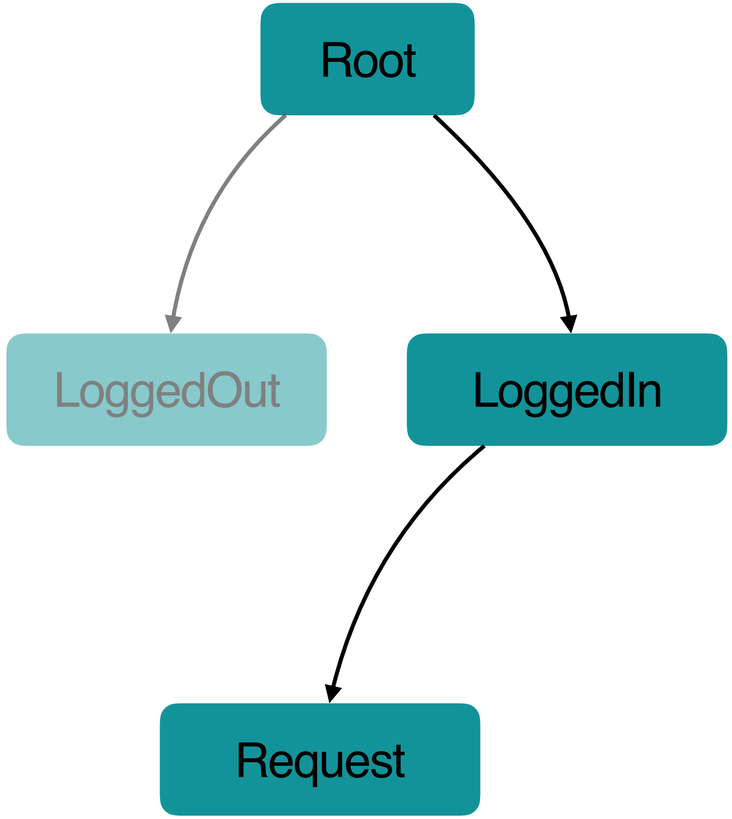
Deep Scope Hierarchies



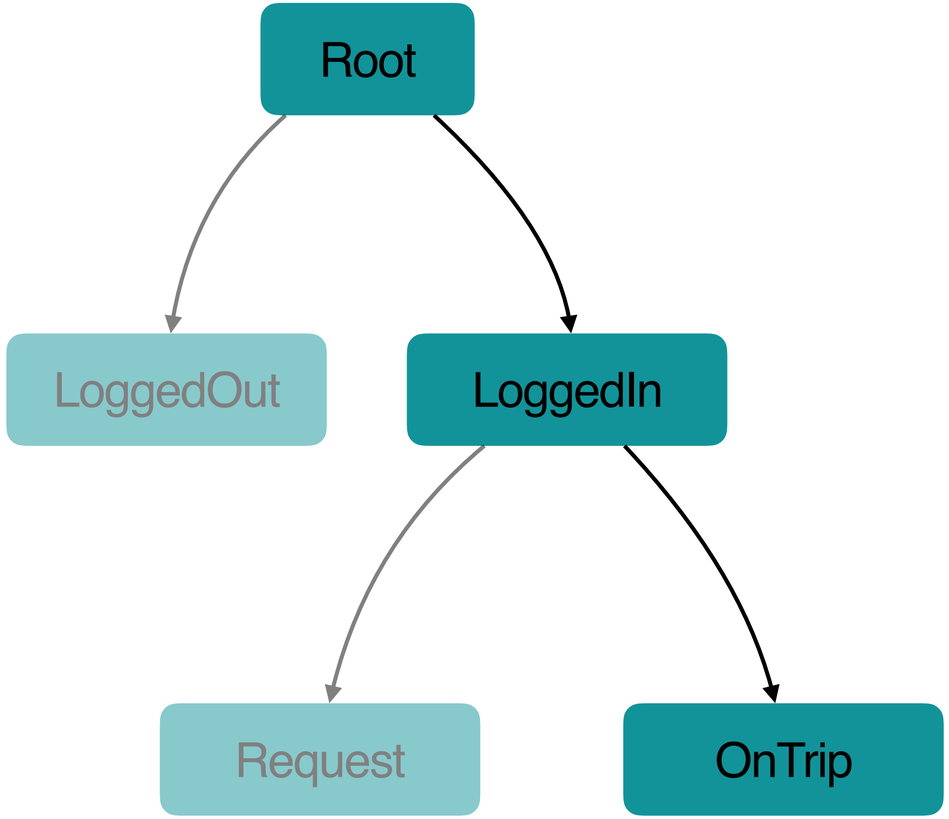
Deep Scope Hierarchies



Deep Scope Hierarchies

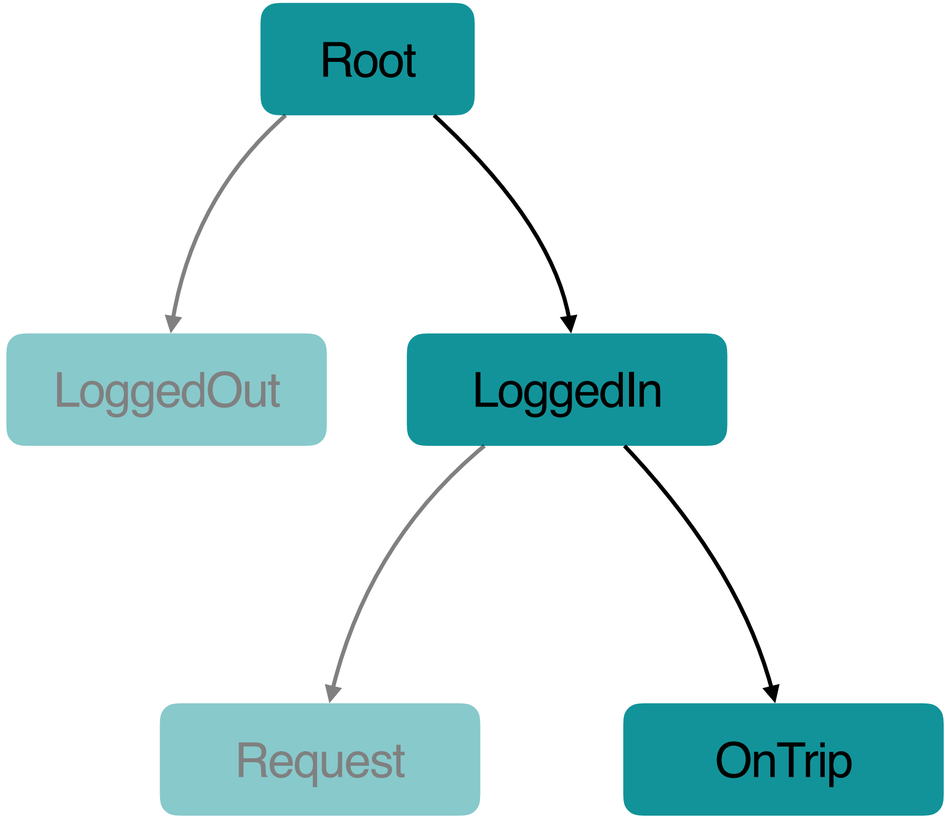


Deep Scope Hierarchies



Deep Scope Hierarchies

Parent creates / destroys child scopes

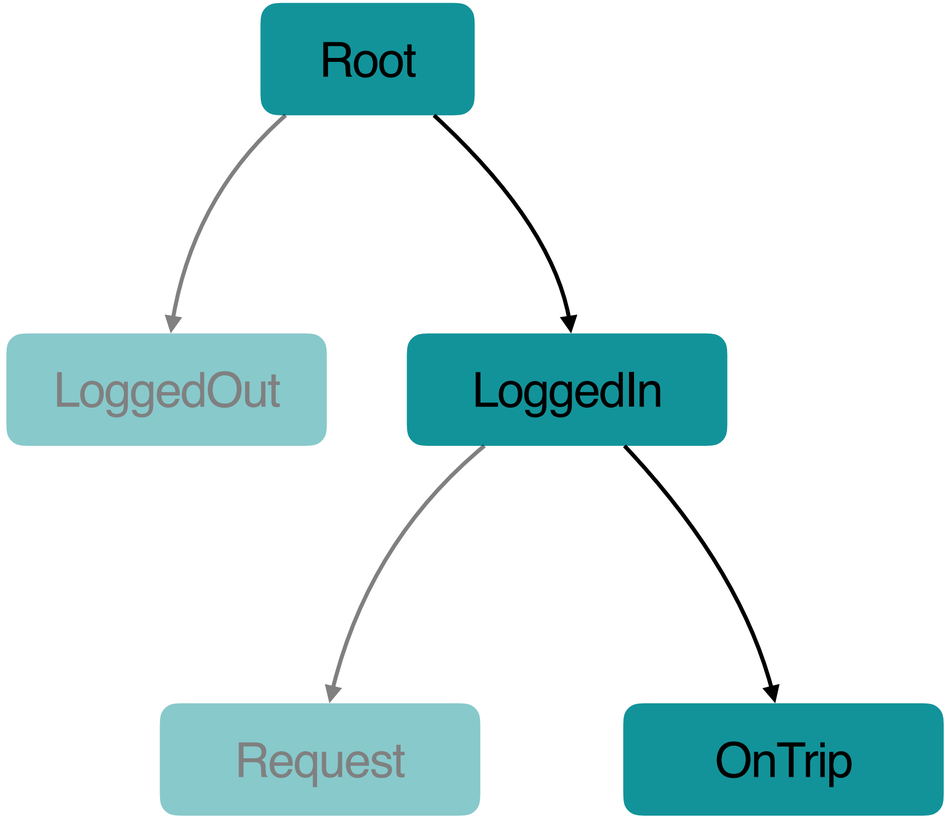


Deep Scope Hierarchies

Parent creates / destroys child scopes

State must be *explicitly shared* from parent to child

- *Statically* prohibited from accessing sibling state

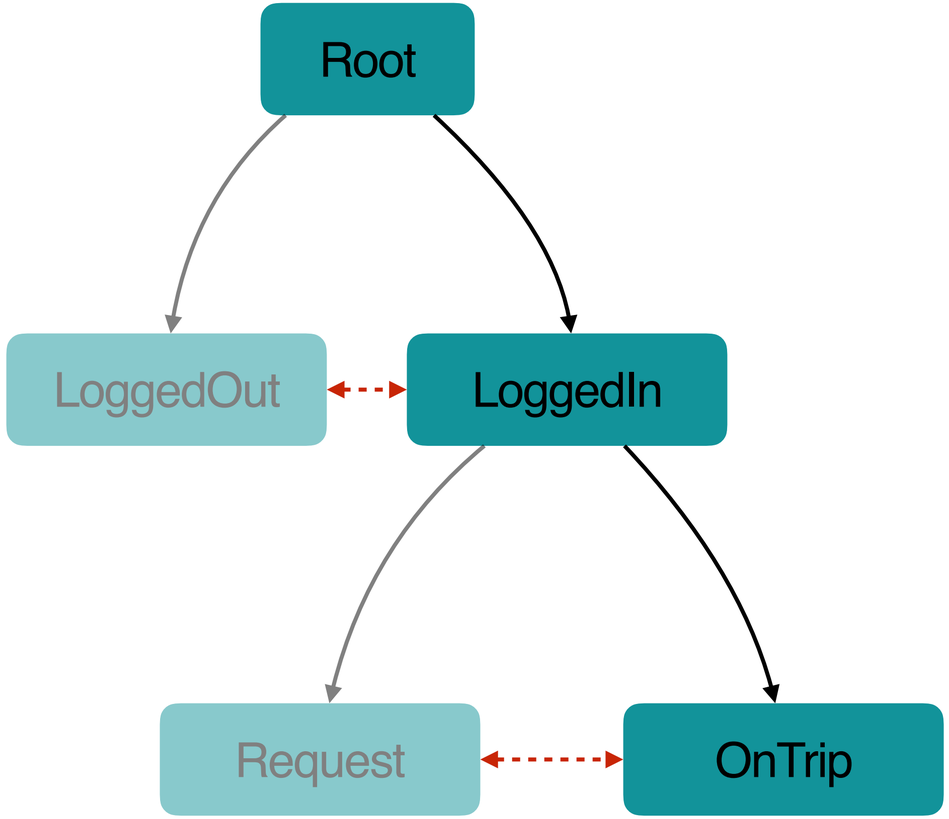


Deep Scope Hierarchies

Parent creates / destroys child scopes

State must be *explicitly shared* from parent to child

- *Statically* prohibited from accessing sibling state



Deep Scope Hierarchies

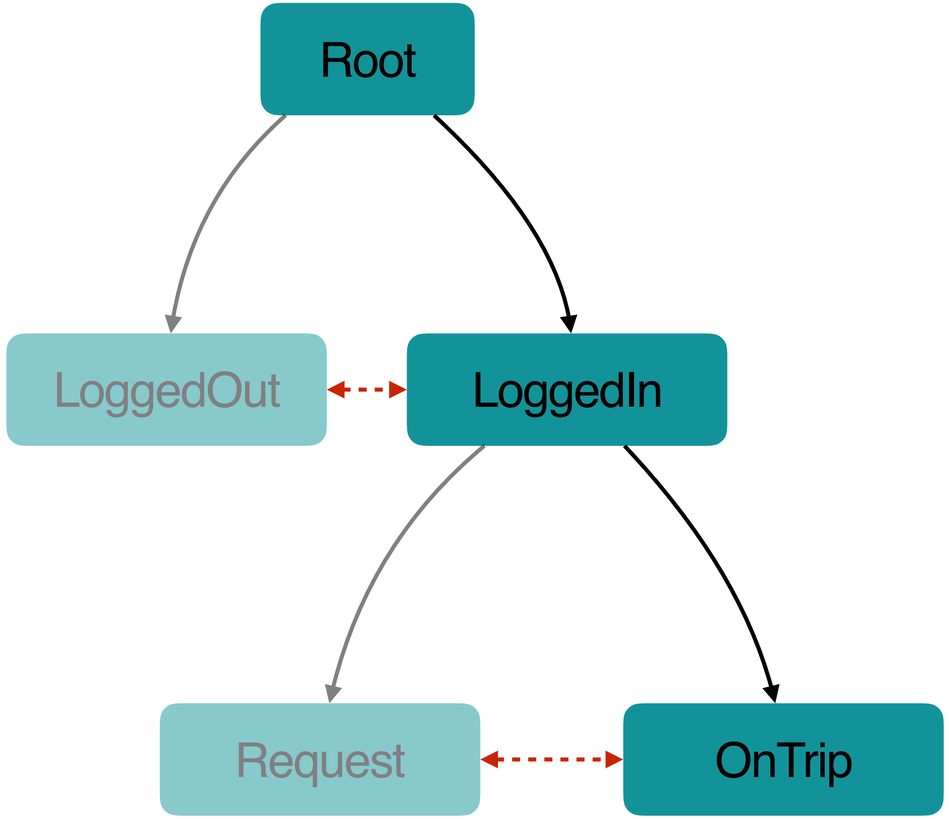
Parent creates / destroys child scopes

State must be *explicitly shared* from parent to child

- *Statically* prohibited from accessing sibling state

Object lifetimes tied to scopes

- No more reset() methods
- Helps prevent leaks



Deep Scope Hierarchies

Parent creates / destroys child scopes

State must be *explicitly shared* from parent to child

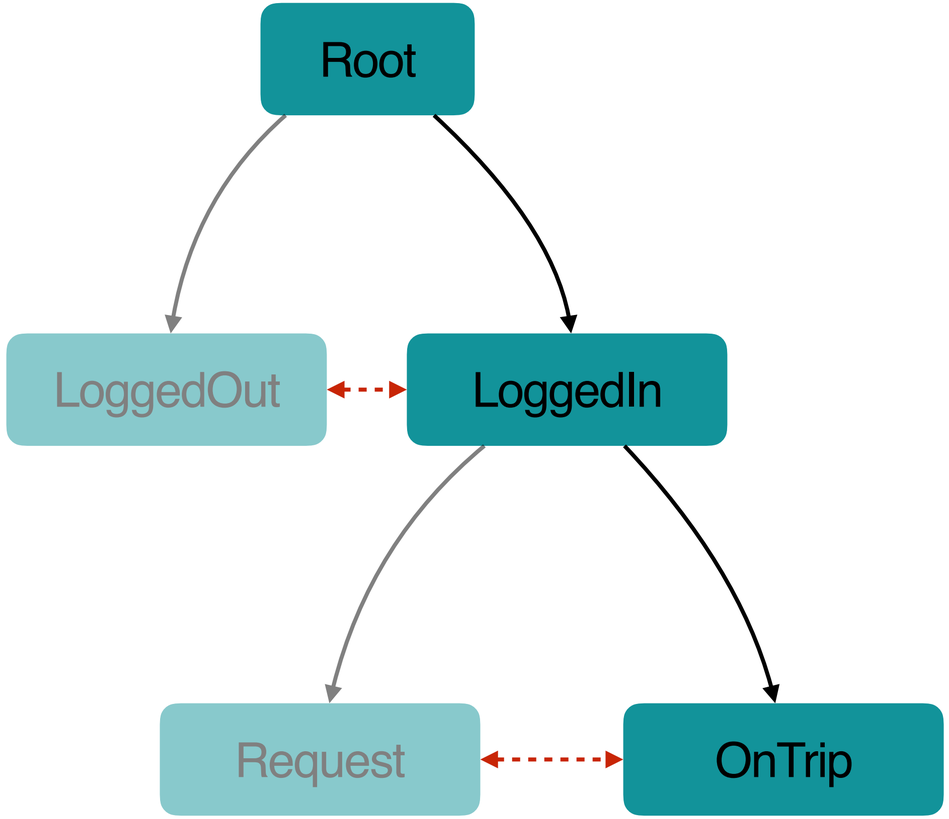
- *Statically* prohibited from accessing sibling state

Object lifetimes tied to scopes

- No more reset() methods
- Helps prevent leaks

Based on new RIB framework

- Router-Interactor-Builder (refinement of MVC)
- Builders manage state sharing, Routers manage tree structure



Implications

Decoupling: Good for Moving Fast

Features stay independent

- A challenge with so much shared app state

Well-defined contracts

- Between features, via RIB tree
- Between core and optional code, via plugins

Result: developers stay sane

Decoupling: Good for Analysis!

Decoupling: Good for Analysis!

Better whole program analysis

- Less pollution from imprecise data flow

Decoupling: Good for Analysis!

Better whole program analysis

- Less pollution from imprecise data flow

Modular verification!

- Of core code, via plugins
- Of individual features, via deep scopes

Decoupling: Good for Analysis!

Better whole program analysis

- Less pollution from imprecise data flow

Modular verification!

- Of core code, via plugins
- Of individual features, via deep scopes

May require specifications at boundaries

- Can we infer them?

Decoupling: Good for Analysis!

Better whole program analysis

- Less pollution from imprecise data flow

Modular verification!

- Of core code, via plugins
- Of individual features, via deep scopes

May require specifications at boundaries

- Can we infer them?

Big opportunity!

Nullness Checking for Android

Principles for bug checkers

Principles for bug checkers

Block the build

All reports must be addressed.

Precision is critical

Principles for bug checkers

Block the build

All reports must be addressed.

Precision is critical

Run checks early

Aim for instant IDE feedback.

Performance is critical

Principles for bug checkers

Block the build

All reports must be addressed.
Precision is critical

Run checks early

Aim for instant IDE feedback.
Performance is critical

Annotations are OK

Makes errors more understandable, analyses more performant

NullPointerException Background

```
Exception in thread "main" java.lang.NullPointerException
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.visit(JDTJava2CAstTranslator.java:1480)
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.visitNode(JDTJava2CAstTranslator.java:2901)
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.visit(JDTJava2CAstTranslator.java:1462)
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.visitNode(JDTJava2CAstTranslator.java:2887)
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.visitNodeOrNodes(JDTJava2CAstTranslator.java:2959)
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.createBlock(JDTJava2CAstTranslator.java:1275)
    at com.ibm.wala.cast.java.translator.jdt.JDTJava2CAstTranslator.visit(JDTJava2CAstTranslator.java:1280)
    …
```

Major source of Android app crashes

In mid-2015, Facebook released Infer (http://fbinfer.com/), with static detection of NPEs

Uber aggressively adopted Infer to “eradicate” NPEs

Type-Based NPE Prevention

Type-Based NPE Prevention

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

Type-Based NPE Prevention

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

Type-Based NPE Prevention

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

Type-Based NPE Prevention

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

Error: de-referencing x may yield NPE

Type-Based NPE Prevention

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

Type-Based NPE Prevention

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

Type-Based NPE Prevention

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

As in Eradicate (http://fbinfer.com/docs/eradicate.html),

Checker Framework (https://checkerframework.org/)

NullAway

Eradicate: huge success, but significant running time

- Only ran on submit queue (final stage of CI)

Error Prone (http://errorprone.info/): custom checkers within Java compiler

Efficient: Re-use work that compiler has already done

- E.g., AST construction, type analysis

NullAway: Eradicate-like checking in Error Prone

Experience with NullAway

Runs on **all builds** instead of just submit queue

- < 10% overhead
- Devs get much faster feedback

Found hundreds of new issues

- Greater flexibility in handling third-party jars

Open source! https://github.com/uber/NullAway

Soundness?

Analysis is not sound

- Not even soundy! (http://soundiness.org)
- Contrast with Checker Framework

Holes: multithreading, initialization, arrays, mutation, …

In practice, gaps have been in library models

RAVE (https://github.com/uber-common/rave) ensures nullness assumptions valid for data from disk/network

Recent enhancement: stream handling

Recent enhancement: stream handling

```
class Data { int age() { ... }; }
class Person { @Nullable Data data() { ... }; }
Stream<Person> pplStream = ...;
int ageSum = pplStream
        .filter((p) -> p.data() != null)
        .mapToInt((p) -> p.data().age())
        .sum();
```

Recent enhancement: stream handling

```
class Data { int age() { ... }; }
class Person { @Nullable Data data() { ... }; }
Stream<Person> pplStream = ...;
int ageSum = pplStream
        .filter((p) -> p.data() != null)
        .mapToInt((p) -> p.data().age()) Error: de-referencing p.data() may yield NPE
        .sum();
```

Recent enhancement: stream handling

```
class Data { int age() { ... }; }
class Person { @Nullable Data data() { ... }; }
Stream<Person> pplStream = ...;
int ageSum = pplStream
        .filter((p) -> p.data() != null)
        .mapToInt((p) -> p.data().age())
        .sum();
```

Result: `Stream<{ p | p.data() != null}>`

Recent enhancement: stream handling

```
class Data { int age() { ... }; }
class Person { @Nullable Data data() { ... }; }
Stream<Person> pplStream = ...;
int ageSum = pplStream
        .filter((p) -> p.data() != null)
        .mapToInt((p) -> p.data().age())
        .sum();
```

Result: `Stream<{ p | p.data() != null}>`

Multithreading

Multithreading

Multithreading

Many nasty bugs possible

- Data races
- Accessing UI off main thread

Multithreading

Many nasty bugs possible

- Data races
- Accessing UI off main thread

Most multithreading via ReactiveX

- Functional reactive programming for asynchronous streams
- Very structured use of threads

Multithreading

Many nasty bugs possible

- Data races
- Accessing UI off main thread

Most multithreading via ReactiveX

- Functional reactive programming for asynchronous streams
- Very structured use of threads

```
sourceObservable()
    .observeOn(COMPUTATION)
    .map(x -> expensive(x))
    .observeOn(MAIN)
    .subscribe(i -> display(i));
```

Multithreading

Many nasty bugs possible

- Data races
- Accessing UI off main thread

Most multithreading via ReactiveX

- Functional reactive programming for asynchronous streams
- Very structured use of threads

Opportunity: specialized analyses!

```
sourceObservable()
    .observeOn(COMPUTATION)
    .map(x -> expensive(x))
    .observeOn(MAIN)
    .subscribe(i -> display(i));
```

Rx Thread Checker

```
sourceObservable()
    .observeOn(COMPUTATION)
    .map(x -> expensive(x))
    .subscribe(i -> display(i));
```

Rx Thread Checker

```
sourceObservable()
    .observeOn(COMPUTATION)
    .map(x -> expensive(x))
    .subscribe(i -> display(i));
```

Off-main-thread UI access

Rx Thread Checker

```
sourceObservable()
    .observeOn(COMPUTATION)
    .map(x -> expensive(x))
    .subscribe(i -> display(i));
```

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

```
sourceObservable()
     .observeOn(COMPUTATION)
     .map(x -> expensive(x))
     .subscribe(i -> display(i));
```


```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

```
sourceObservable()
     .observeOn(COMPUTATION)
     .map(x -> expensive(x))
     .subscribe(i -> display(i));

     @UIEffect
```

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

Thread types for Observables (Checker Framework)

```
sourceObservable()
     .observeOn(COMPUTATION)
     .map(x -> expensive(x))
     .subscribe(i -> display(i));
```

`@UIEffect`

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

Thread types for Observables (Checker Framework)

```
sourceObservable() @MainThread
    .observeOn(COMPUTATION)
    .map(x -> expensive(x))
    .subscribe(i -> display(i));

    @UIEffect
```

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

Thread types for Observables (Checker Framework)

```
sourceObservable() @MainThread
    .observeOn(COMPUTATION) @ComputeThread
    .map(x -> expensive(x))
    .subscribe(i -> display(i));

    @UIEffect
```

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

Thread types for Observables (Checker Framework)

```
sourceObservable() @MainThread
    .observeOn(COMPUTATION) @ComputeThread
    .map(x -> expensive(x)) @ComputeThread
    .subscribe(i -> display(i));

    @UIEffect
```

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

Thread types for Observables (Checker Framework)

```
sourceObservable() @MainThread
    .observeOn(COMPUTATION) @ComputeThread
    .map(x -> expensive(x)) @ComputeThread
    .subscribe(i -> display(i)); Error: UI effect off main thread
```

`@UIEffect`

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Rx Thread Checker

Thread types for Observables (Checker Framework)

```
sourceObservable() @MainThread
    .observeOn(COMPUTATION) @ComputeThread
    .map(x -> expensive(x)) @ComputeThread
    .subscribe(i -> display(i)); Error: UI effect off main thread
```

`@UIEffect`

Enforced with effect analysis (Gordon et al., ECOOP'13)

```
@UIEffect
void display(i) { … }
```

Actively deploying across Android codebase

Future work: extend to enforce side-effect freedom

Other projects / open problems

Performance: Speed and Memory

Micromax Spark

Performance: Speed and Memory

Need to run smoothly on *all* devices

- Many low-end devices in growth markets

Micromax Spark

Performance: Speed and Memory

Need to run smoothly on *all* devices

- Many low-end devices in growth markets

How to attack with analysis?

- Statically detect slow code on main thread
- Give visibility into UI-blocking network requests
- Reduce OutOfMemoryErrors (statically enforce scope hierarchies)

Micromax Spark

Performance: Speed and Memory

Need to run smoothly on *all* devices

- Many low-end devices in growth markets

How to attack with analysis?

- Statically detect slow code on main thread
- Give visibility into UI-blocking network requests
- Reduce OutOfMemoryErrors (statically enforce scope hierarchies)

A challenge with new features going in constantly!

Micromax Spark

Infrastructure: Swift

Future of iOS development

Uber has invested heavily

- New rider app written entirely in Swift
- Google “swift with a hundred engineers”
- Same architecture! Plugins + deep scopes + Rx

Little analysis infrastructure available

- We released NEAL for linting: https://github.com/uber/NEAL

Cross-platform analyses? Swift-specific?

And more…

Verification of startup code

Preventing code duplication

Test generation / selection

Dead code elimination

Conclusions

Need high app reliability

Need developers to move fast

Approach: modular app design + program analysis

- Analysis helps enforce design
- Design increases analysis effectiveness
- Tons of opportunities

Relevant resources

Blog posts

App architecture: https://eng.uber.com/new-rider-app/

Scope hierarchies: https://eng.uber.com/deep-scope-hierarchies/

Plugins: https://eng.uber.com/plugins/

Open source

NullAway: https://github.com/uber/NullAway

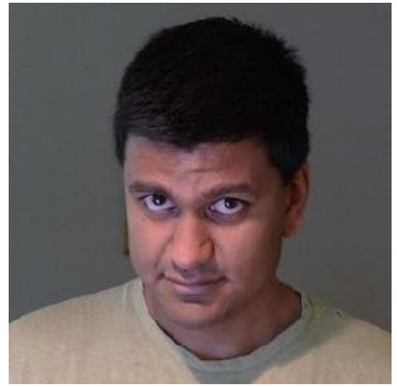
NEAL: https://github.com/uber/NEAL

Uber Programming Systems Group

Raj Barik

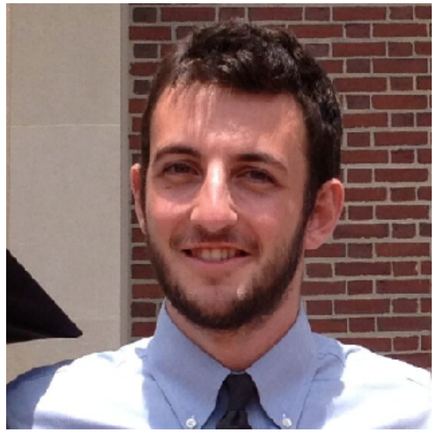
Lazaro Clapp

Murali Krishna Ramanathan



Manu Sridharan

Adam Welc



Benno Stein (Intern)

Thank you

UBER