Fine-grained Deterministic Parallelization of Static Analyses

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Joint work with
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Background

- Associate professor at KTH (2014–2018 assistant professor)
- 2005–2014 ***Scala language team***
  - 2012–2014 Typesafe, Inc. (now Lightbend, Inc.)
- Co-author Scala language specification
- Focus on ***asynchronous, concurrent and distributed programming***
  - Creator of Scala actors, co-author of Scala's futures and async/await
  - *Topics:* programming models, compilers, type systems, semantics

The Problem

- Increasing importance of static analysis
  - Bug finding, security analysis, taint tracking, etc.
- Precise and powerful analyses have ***long running times***
  - Infeasible to integrate into nightly builds, CI, IDE, …
  - ***Parallelization difficult:*** advanced static analyses not data-parallel
- Scaling static analyses to ever-growing software systems requires ***maximizing utilization of multi-core CPUs***

The Approach

Ongoing work on checking correctness

- Novel ***concurrent programming model***
  - Generalization of futures/promises
  - Guarantees deterministic outcomes *(if used correctly)*
- Implemented in Scala
  - Statically-typed, integrates functional and object-oriented programming
  - Supported backends: JVM, JavaScript (+ experimental native backend)
- Integrated with OPAL, a state-of-the-art ***JVM bytecode analysis framework***

Example

- Two key concepts: ***cells*** and ***handlers***
- Cell completers permit ***writing***, cells only ***reading*** (concurrently)

```
val completer1 = CellCompleter[...]
val completer2 = CellCompleter[...]
val cell1 = completer1.cell
val cell2 = completer2.cell

cell2.when(cell1) { update =>
  if (update.value == Impure) FinalOutcome(Impure)
  else NoOutcome
}
completer1.putFinal(Impure)
```

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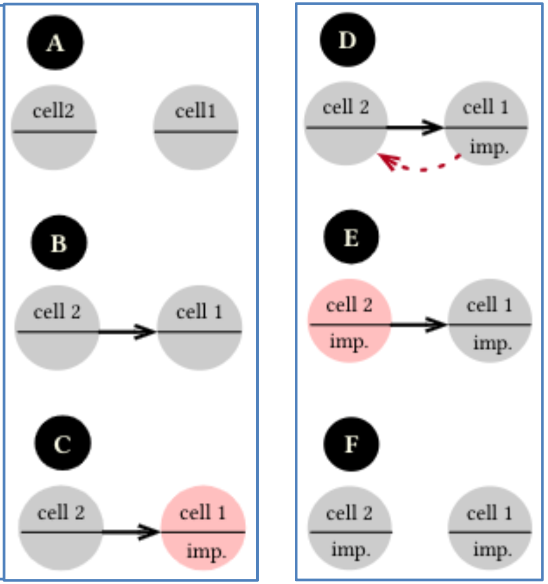
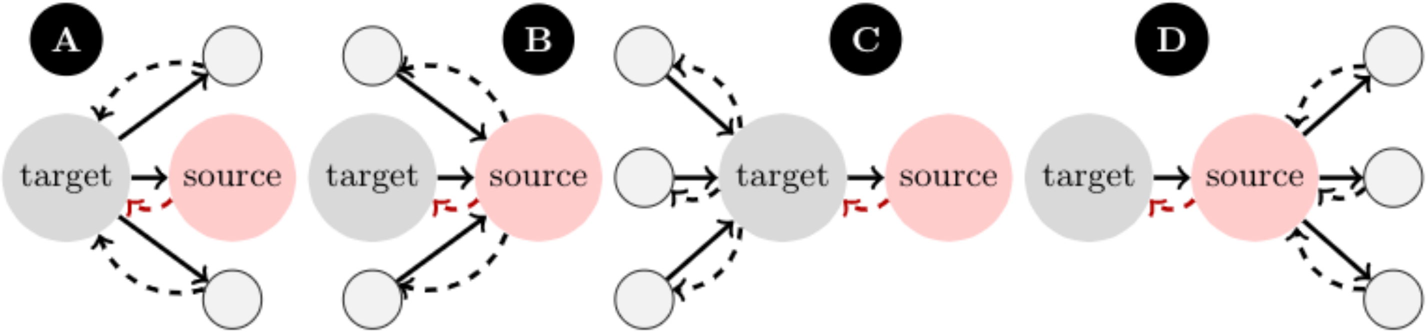
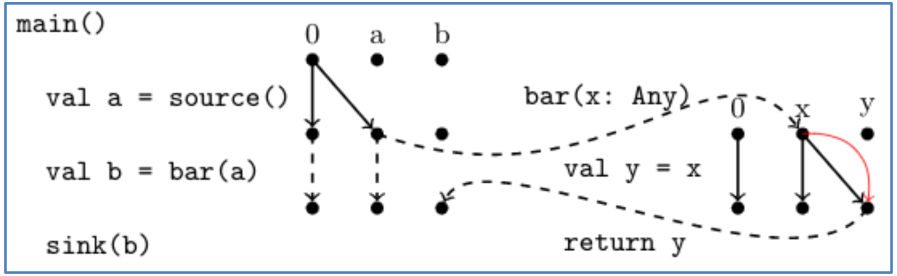


Scheduling Strategies

- ***Priorities for message propagations*** depending on number of dependencies of source/target nodes and dependees/dependers



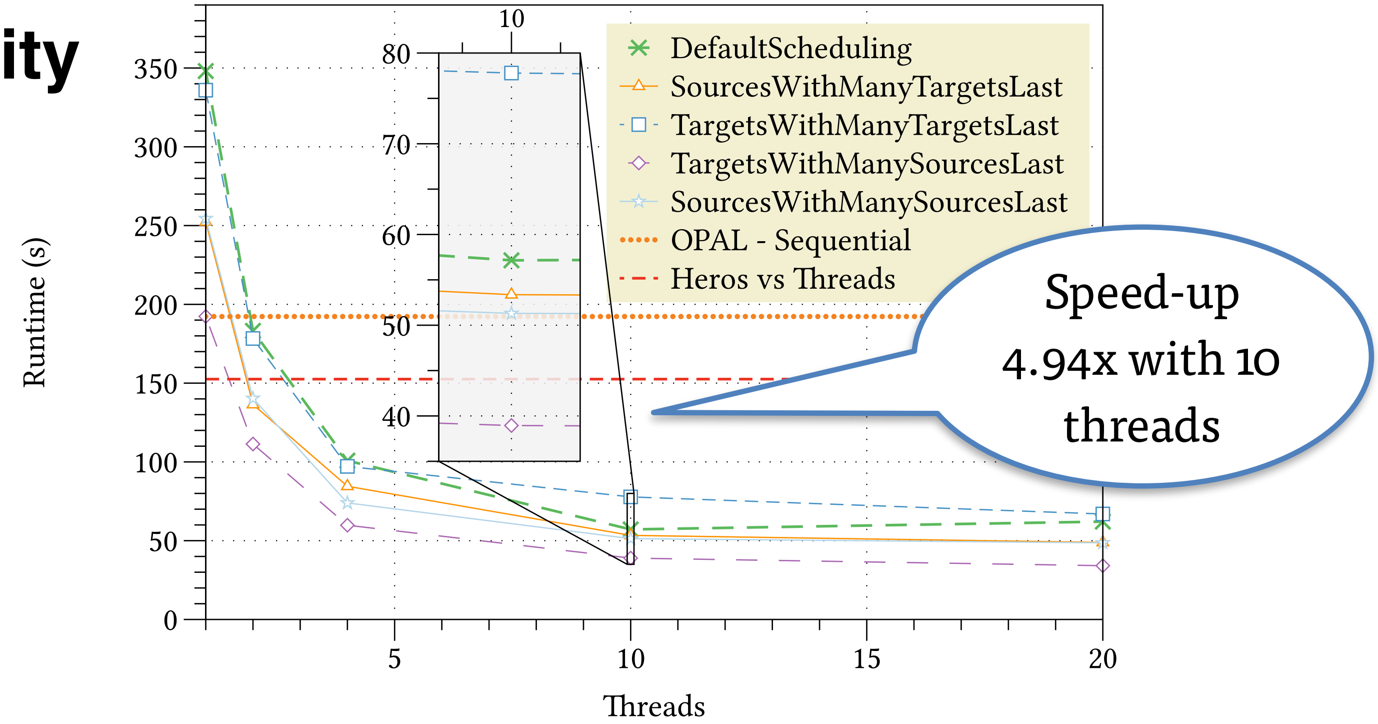
Experimental Evaluation



- Implementation of IFDS[1] analysis framework
- Use IFDS framework to implement ***taint analysis***
  - search for methods in JDK with return type `Object` or `Class` with String parameter that is later used in an invocation of `Class.forName`

[1] Interprocedural Finite Distributive Subset

Scalability



Analysis executed on Intel(R) Core(TM) i9-7900X CPU @ 3.30GHz (10 cores) with 128 GB RAM running Ubuntu 18.04.1 and OpenJDK 1.8_212

Scheduling Strategies

Table 2. Performance of different scheduling strategies. Percentages show speedup of each strategy compared to (a) default strategy and (b) slowest strategy.

Strategy	Run time [s]	Speedup (a)	Speedup (b)
DefaultScheduling	57.15	0.00%	26.54%
SourcesWithManyTargetsLast	53.37	6.62%	31.40%
TargetsWithManySourcesLast	38.94	31.86%	49.94%
TargetsWithManyTargetsLast	77.79	-36.12%	0.00%
SourcesWithManySourcesLast	51.30	10.23%	34.05%

- Using suitable scheduling strategy has big impact on execution time
- Best strategy ***49.94% faster than worst*** strategy, ***31.86% faster than default***

Conclusion

- Deterministic concurrent programming model
  - Supporting pluggable, domain-specific scheduling strategies
- Implemented as a library for Scala
- Experimental results for state-of-the-art IFDS-based taint analysis:
  - Speed-up of 4.94x using 10 threads
  - Significant gains using analysis-specific scheduling strategies
- Open-source code available on GitHub: https://github.com/phaller/reactive-async