Incremental Type Checking for Free

Using Scope Graphs to Derive Incremental Type Checkers

Aron Zwaan Hendrik van Antwerpen Eelco Visser†

Nov 14, 2023

Delft University of Technology

Overview

- Writing type checkers: Hard
- Generate using Statix DSL

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Name & Type Specification

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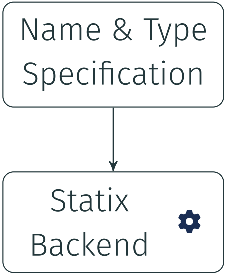

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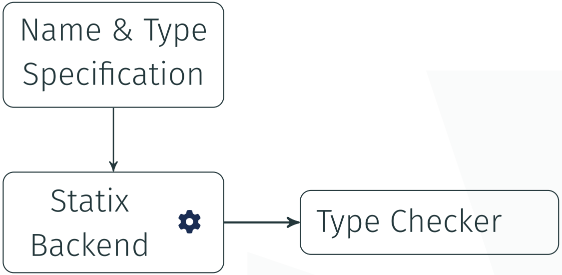

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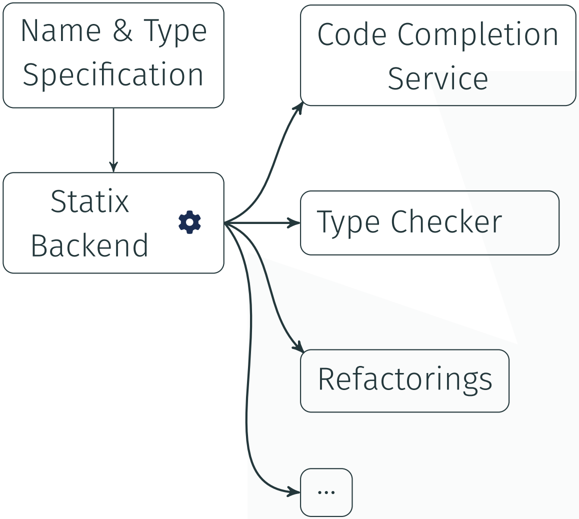

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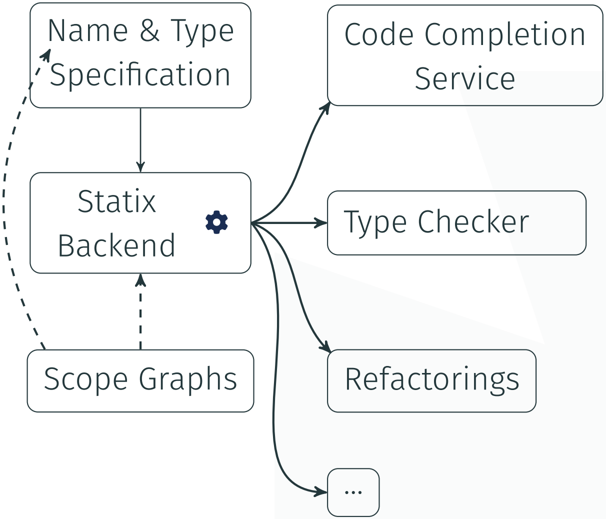

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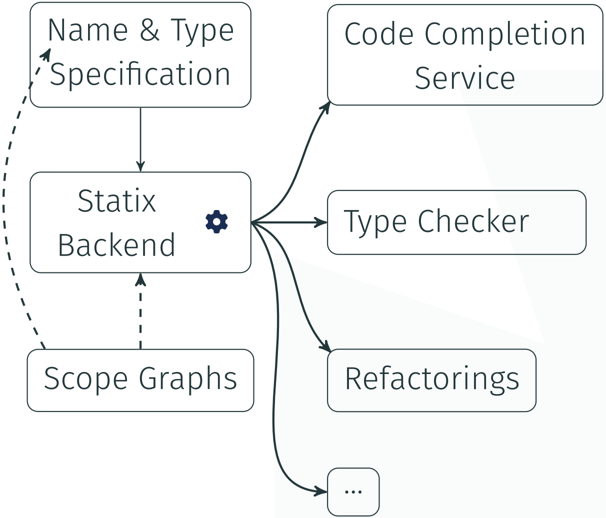
  2. Consistent
  3. Allows reasoning



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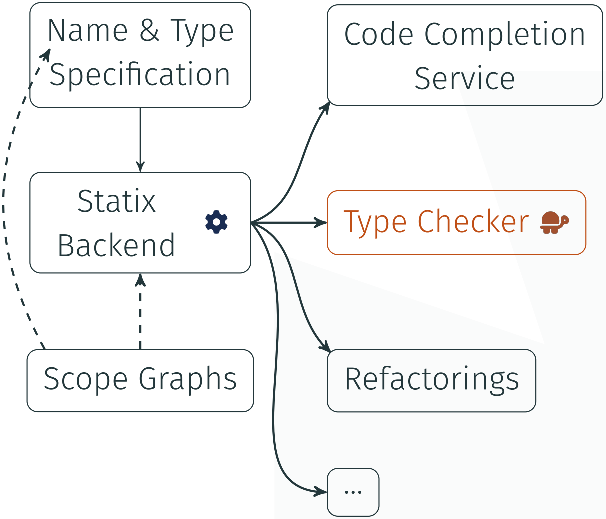

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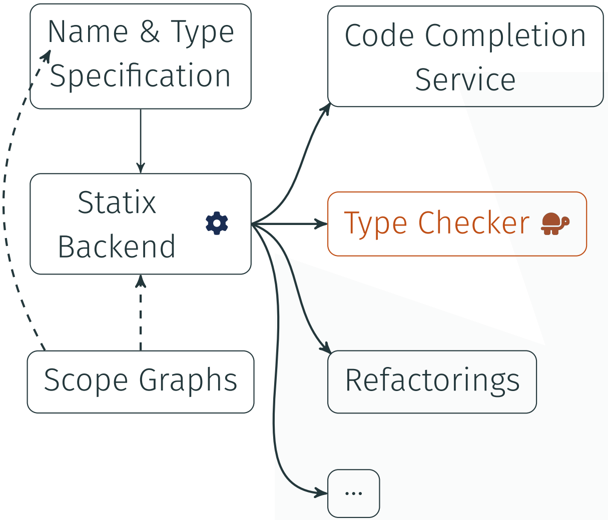

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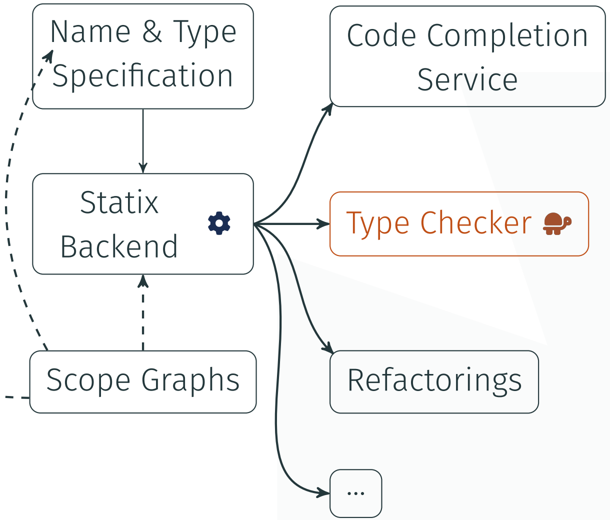

Statix Rules

$$\frac{}{\vdash n : \textbf{int}}$$

$$\frac{\vdash c : \textbf{bool} \quad \vdash e_1 : \mathrm{T} \quad \vdash e_2 : \mathrm{T}}{\vdash \textbf{if}\ c\ \textbf{then}\ e_1\ \textbf{else}\ e_2 : \mathrm{T}}$$

```
typeOfExpr: Expr -> Type

typeOfExpr(Int(n)) = INT().

typeOfExpr(If(c, e1, e2)) = T :-
  typeOfExpr(c) == BOOL(),
  typeOfExpr(e1) == T,
  typeOfExpr(e2) == T.
```

Scope Graphs

```
class A {

}
```

```
class B extends A {

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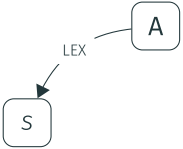

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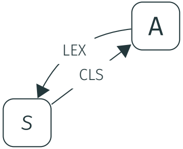

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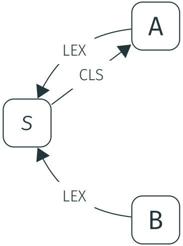

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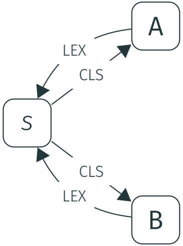

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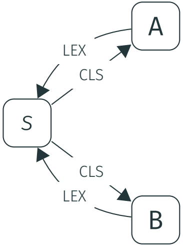

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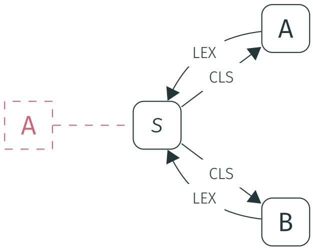

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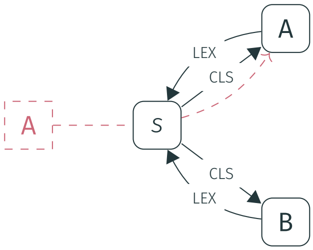

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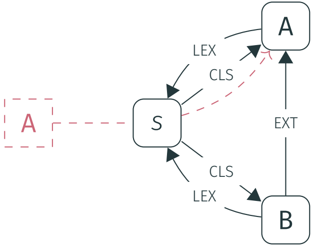

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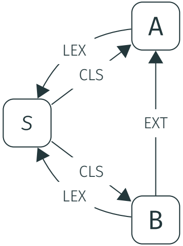

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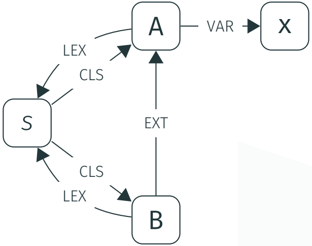

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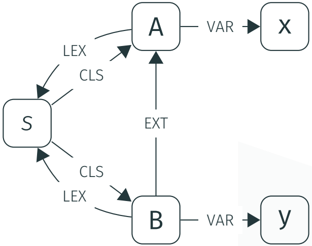

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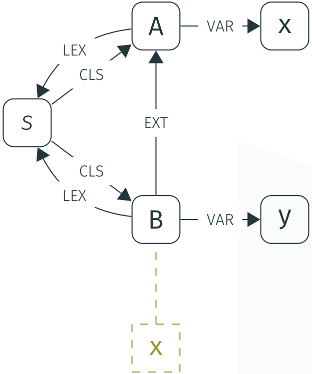

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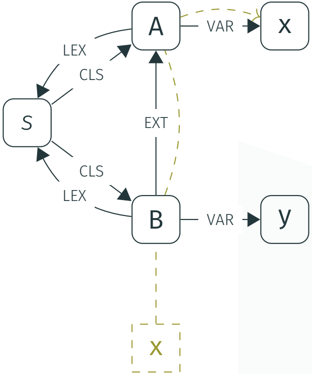

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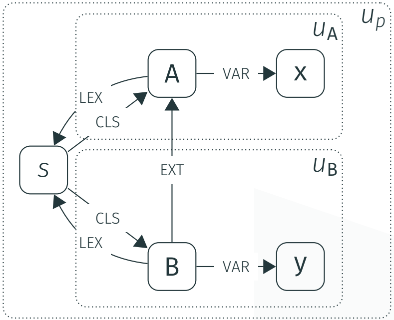

Scope Graphs in Statix

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declOk(s, Class(name, ext, body)) :-
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  query CLS
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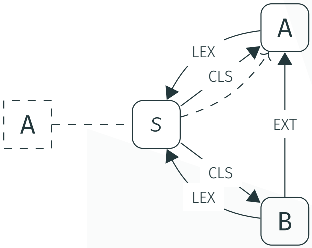

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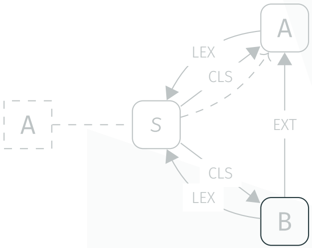

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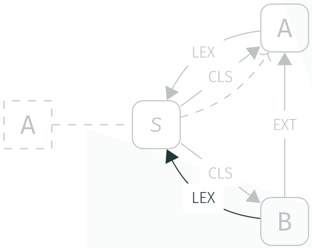

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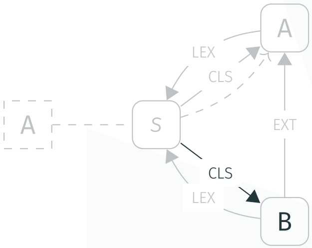

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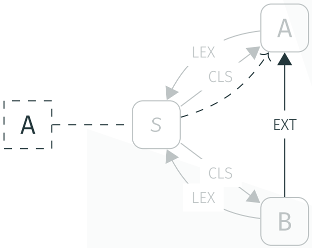

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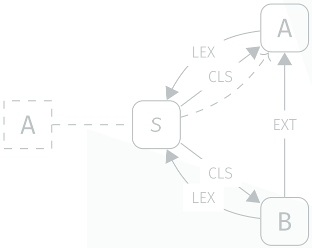

Problem & Solution Setup

- Problem: Performance
- Ideally: Generate *incremental* type checkers
- Challenge: tracking (mutual) dependencies
- Key Insight: Query $\sim$ Dependency
- Solution: using scope graph diffing

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if AST changed then
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class B {
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class C extends B {
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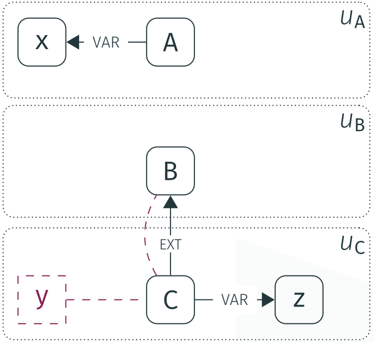

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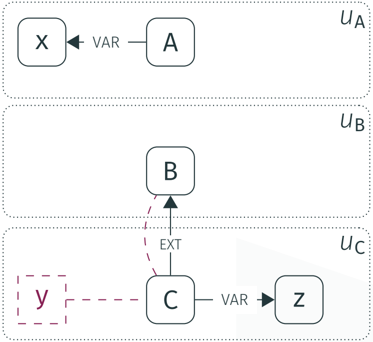

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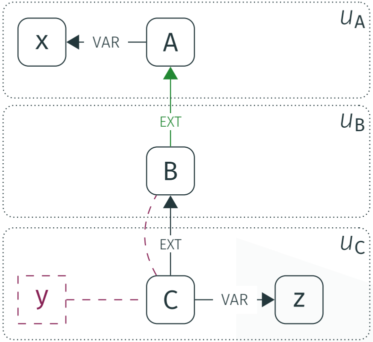

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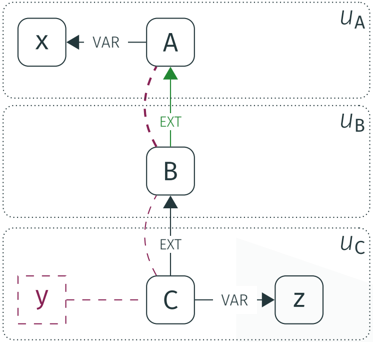

New scope A becomes reachable

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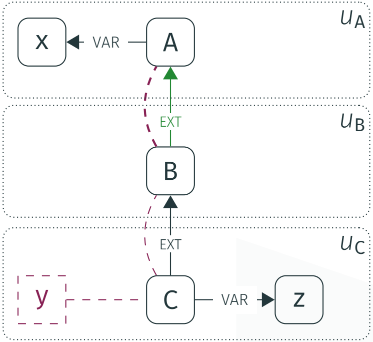

No new results in A, thus no reanalysis.

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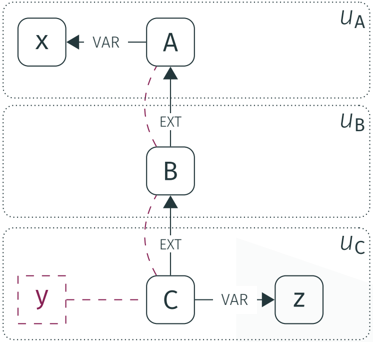

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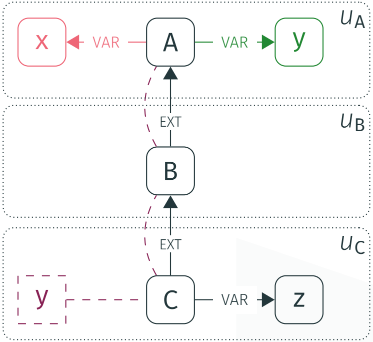

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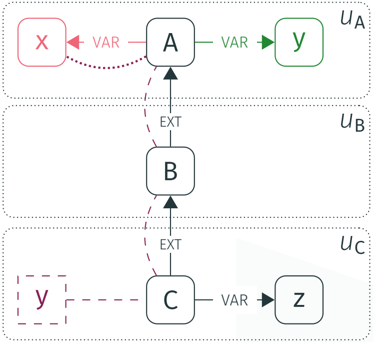

Scope x becomes unreachable

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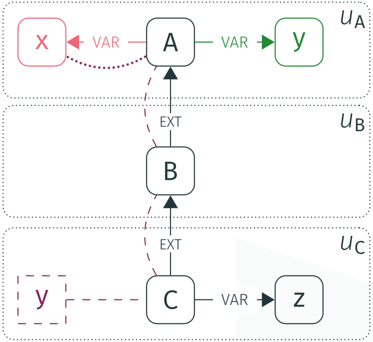

No old results in x, thus no reanalysis.

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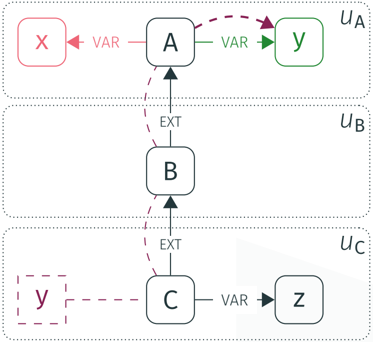

Scope y becomes reachable

Verifying Queries

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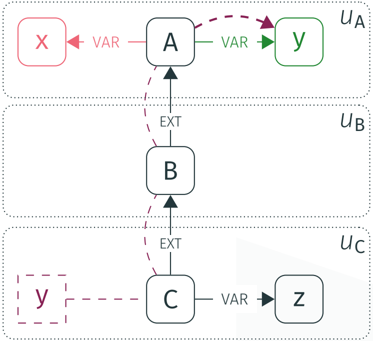

New results in y, reanalyze unit C.

Also in the paper

- Partial reanalysis
- Mutually recursive dependencies
- Non-deterministic scope identities

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Fast analysis response times in IDEs are essential for a good editor experience. Incremental type-checking can provide that in a scalable fashion. However, existing techniques are not reusable between languages. Moreover, mutual and dynamic dependencies preclude traditional approaches to incrementality. This makes finding automatic approaches to incremental type-checking a challenging but important open question.

In this paper, we present a technique that automatically derives incremental type-checkers from type system specifications written in the Statix meta-DSL. We use name resolution queries in scope graphs (a generic model of name binding embedded in Statix) to derive dependencies between compilation units. A novel *query confirmation* algorithm finds queries for which the answer changed due to an edit in the program. Only units with such queries require reanalysis. The effectiveness of this algorithm is improved by (1) splitting the type-checking task into a *context-free* and a *context-sensitive* part, and (2) reusing a generic mechanism to resolve mutual dependencies. This automatically yields incremental type-checkers for any Statix specification.

Compared to non-incremental parallel execution, we achieve speedups up to 147x on synthetic benchmarks, and up to 21x on real-world projects, with initial overheads below 10%. This suggests that our framework can provide efficient incremental type-checking to the wide range of languages supported by Statix.

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CCS Concepts: • **Software and its engineering** → **Incremental compilers**; • **Theory of computation** → **Program analysis**; Program semantics.

Additional Key Words and Phrases: type-checker, incremental type-checking, scope graphs, type systems, name binding, reference resolution, Statix

ACM Reference Format:
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1 INTRODUCTION

Many useful features of an IDE, such as inline error messages, code navigation and refactorings, use information from a type-checker. To provide an optimal editor experience, this type information needs to be available fast [Chaudhuri et al. 2017]. Unfortunately, as type-checking can be computationally expensive, fast editor response times are non-trivial to achieve on larger projects. To retain short feedback times for large projects, we need approaches to type-checking that have execution times proportional to the size of a change to a project, rather than to the project size

[†]Eelco worked on this paper until his untimely passing on April 5, 2022.

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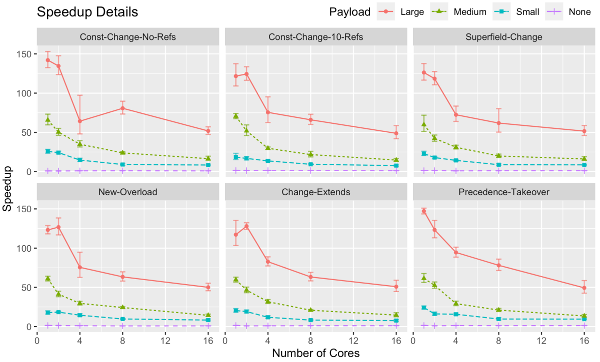
Proc. ACM Program. Lang., Vol. 6, No. OOPSLA2, Article 140. Publication date: October 2022.

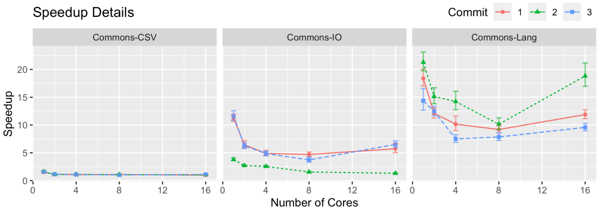
Evaluation

- Java
- Synthetic Projects
  - 1 – 100 classes
  - 20 methods
  - 5 invocations
- Synthethic Changes



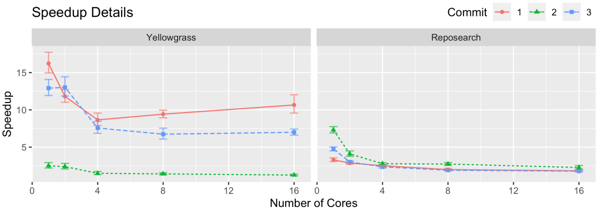
Evaluation

- Java
- Commons CSV, IO, Lang3
- Commit Sampling



Evaluation

- WebDSL
- Internal Applications
- Commit Sampling



Conclusion

Scope graphs allow effortless type checker incrementalization.