Towards Interactive Abstract Interpretation for Multithreaded Programs

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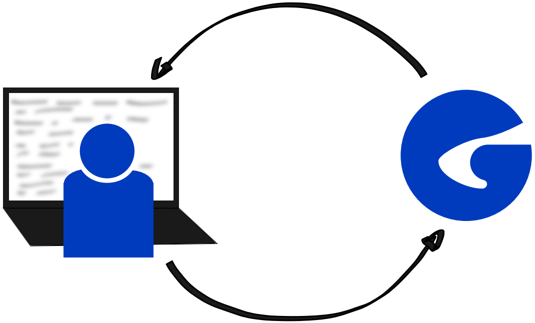
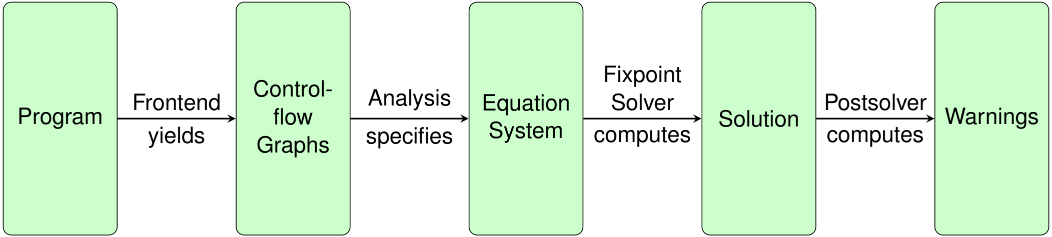
Provide Abstract Interpretation During Development



Abstract interpretation: Expensive Fixpoint Computation



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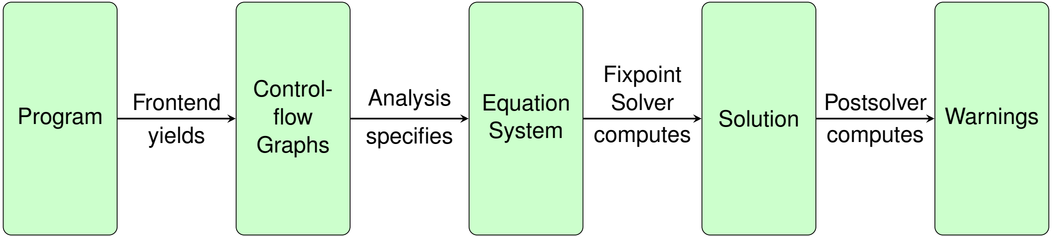
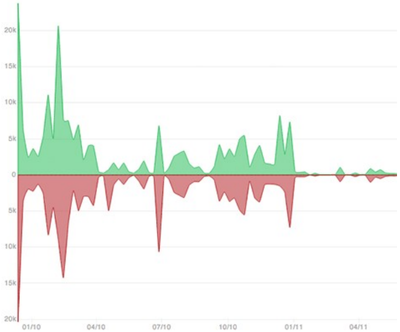


Observation: Software development is incremental



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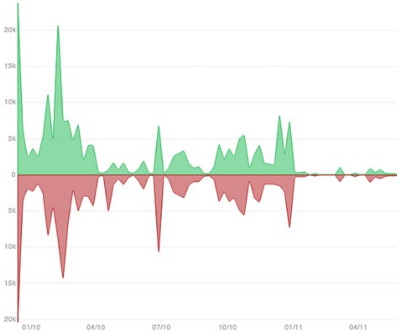

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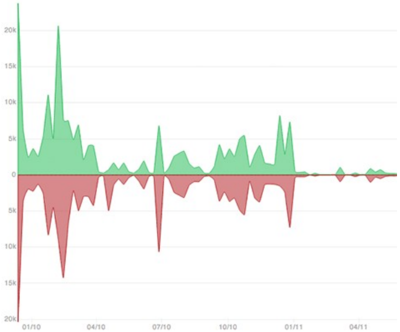

- Software development is **incremental**
- Single commits usually make **small changes**

Idea: Static analysis should be incremental, too!

Re-analyze only the increments

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The **top-down solver** TD already tracks dependencies

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- set of `stable` unknowns
- set of `called` unknowns – those are currently active
- influence relationship between unknowns
- mapping from unknowns to abstract values
- when unknown changes, it is *destabilized*
  — remove all unknowns from `stable` that depend on it and are not `called`.

Example program

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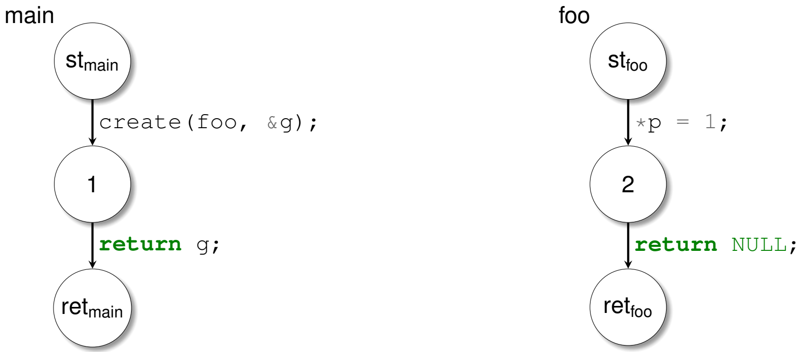

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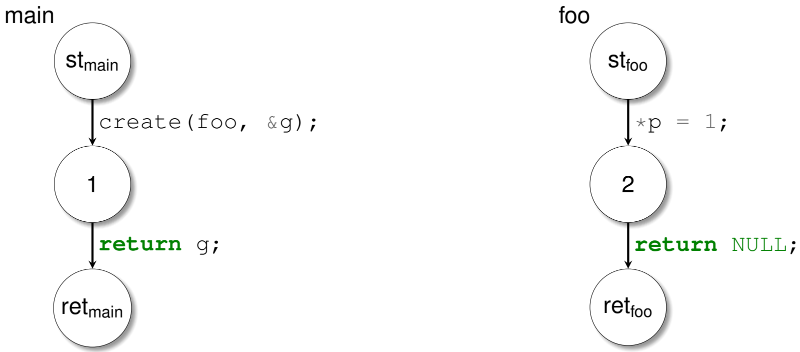

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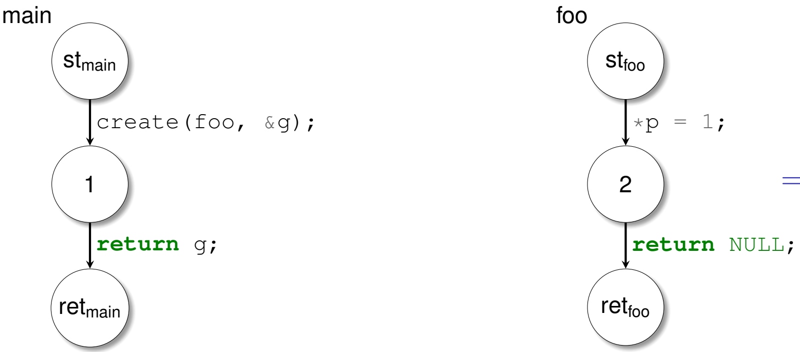

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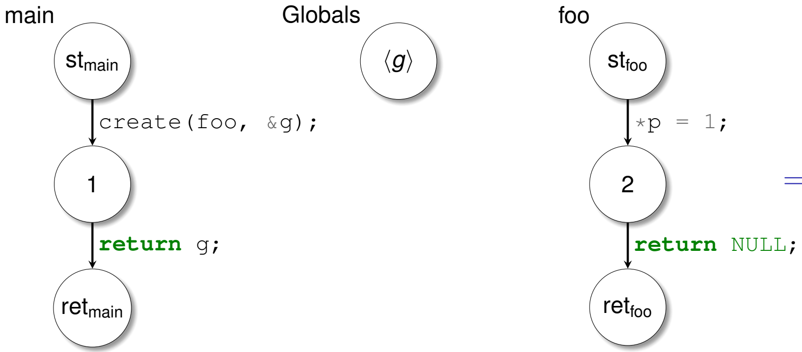

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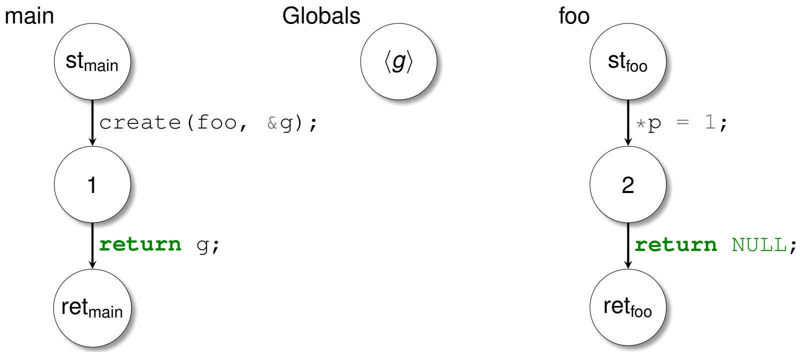
Example Run of Top-Down Solver



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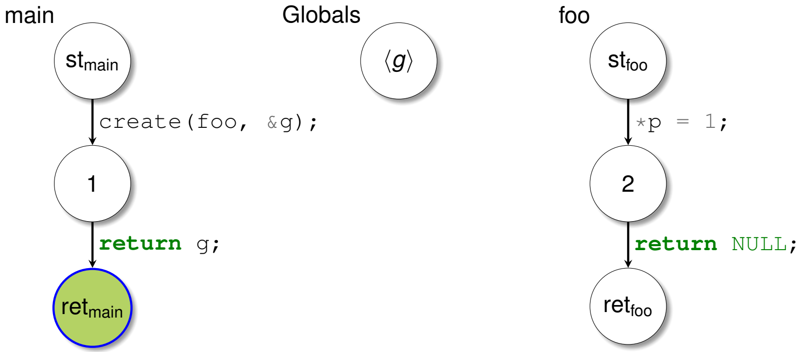

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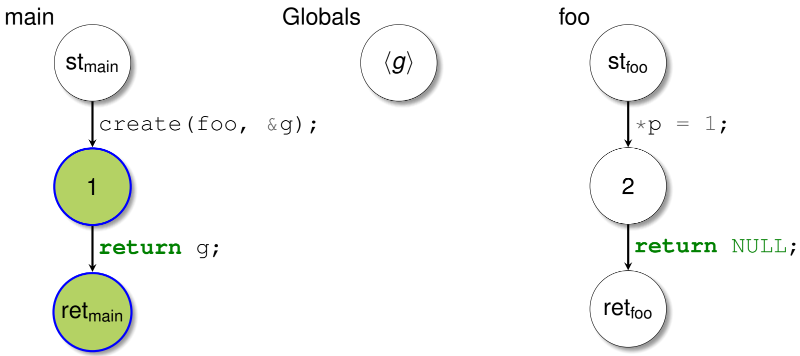

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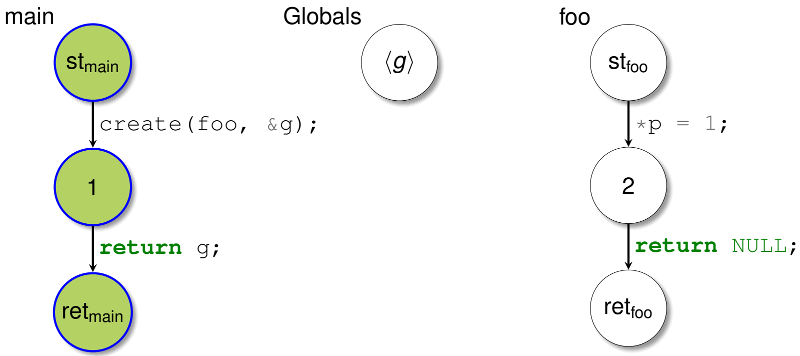

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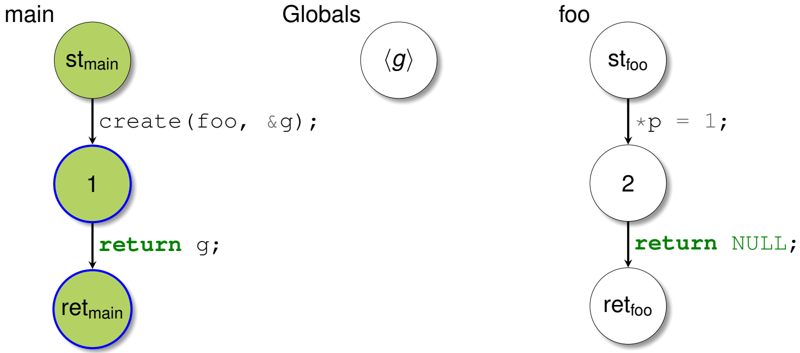

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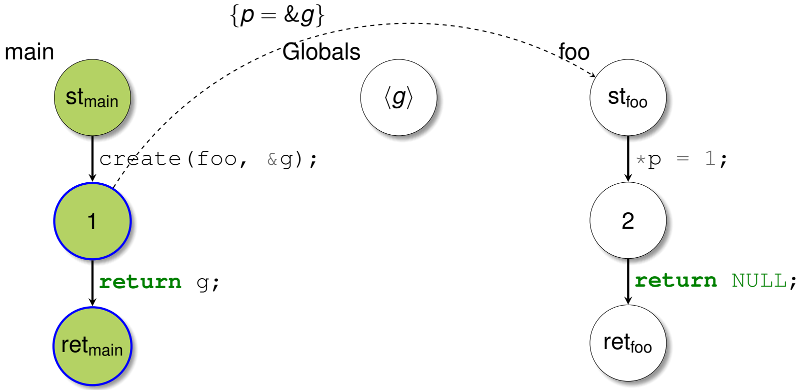

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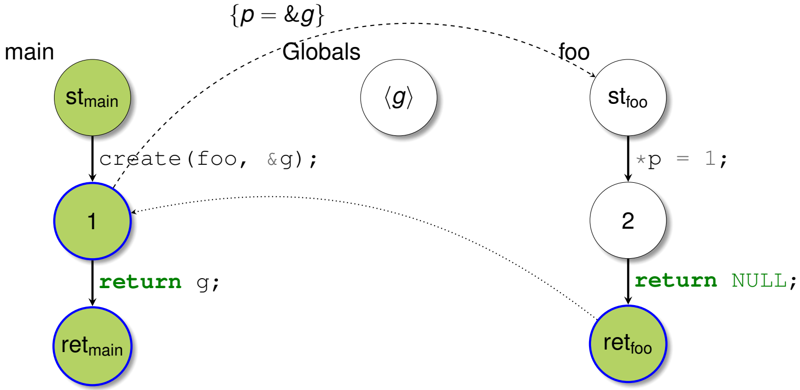

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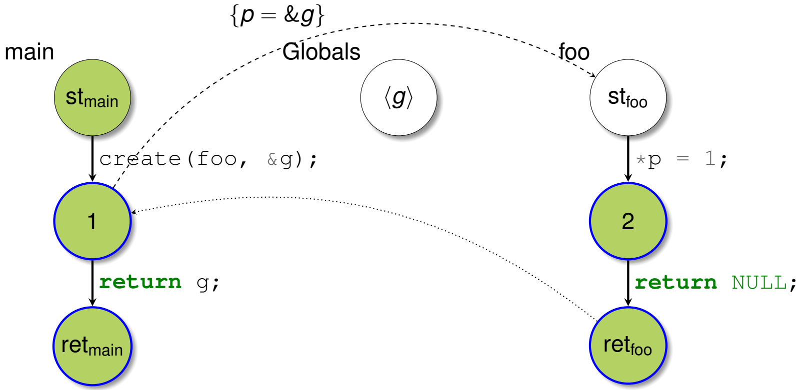

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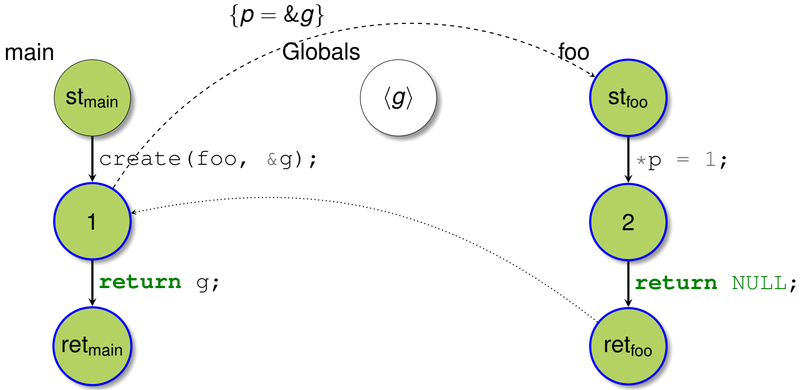

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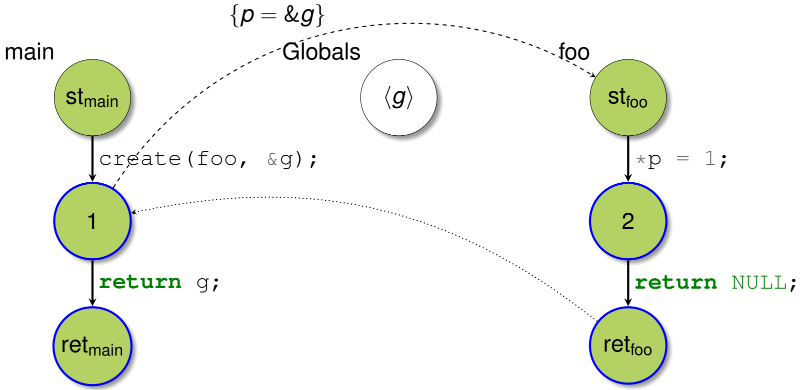

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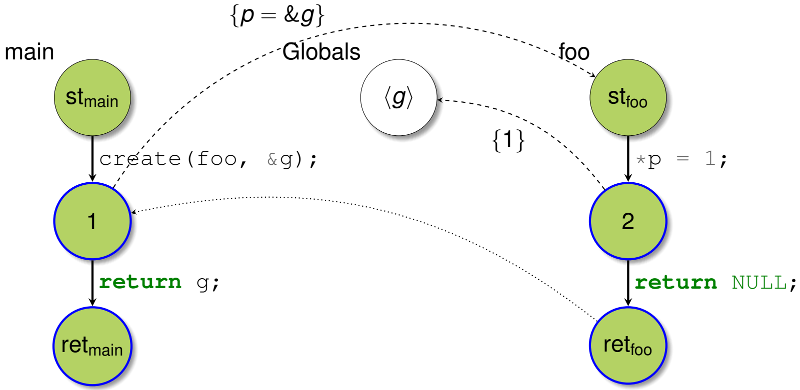

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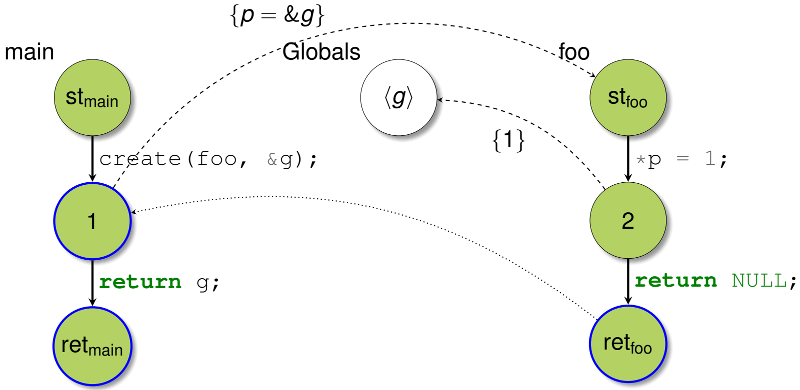

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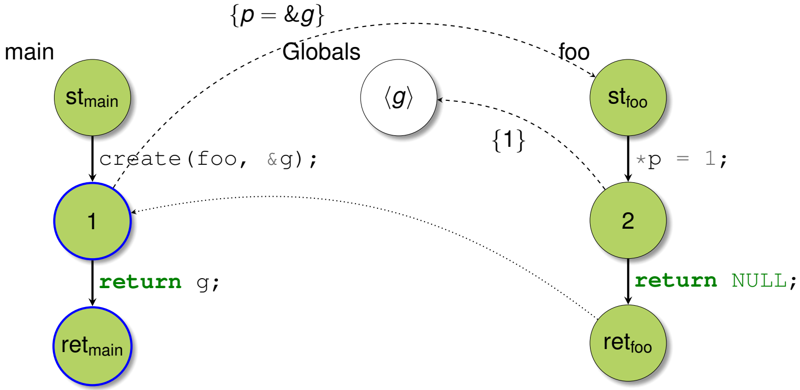

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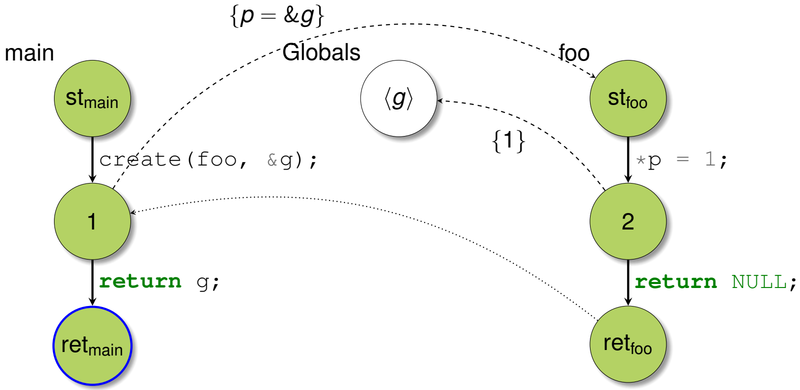

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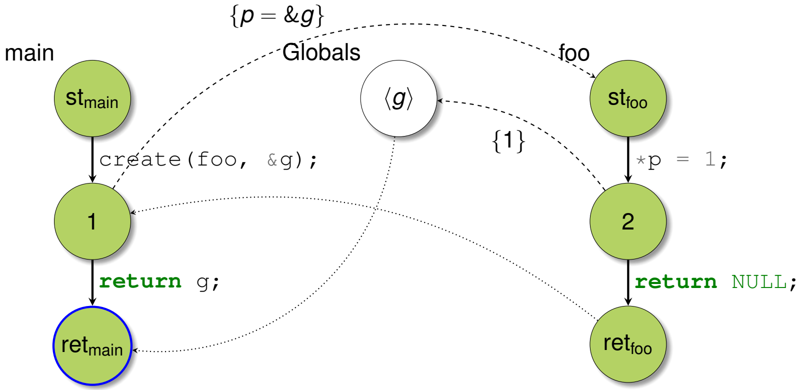

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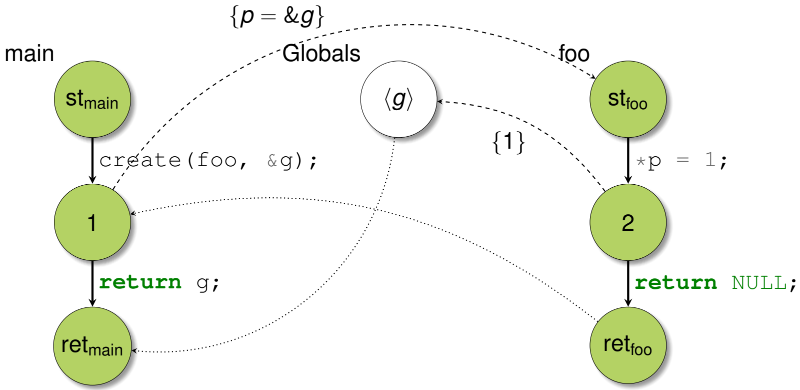

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- widening/narrowing

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- widening/narrowing
- **mixed flow-sensivitity**, i.e., may collect **flow-insensitive information** while performing a **flow-sensitive** analysis otherwise

Change in example program

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        *p = 2;
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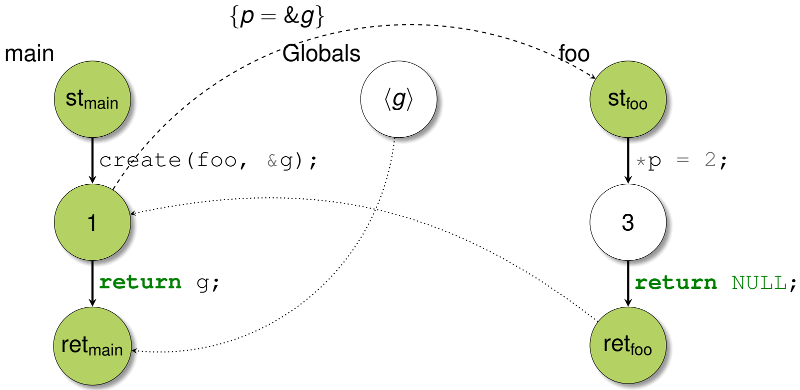
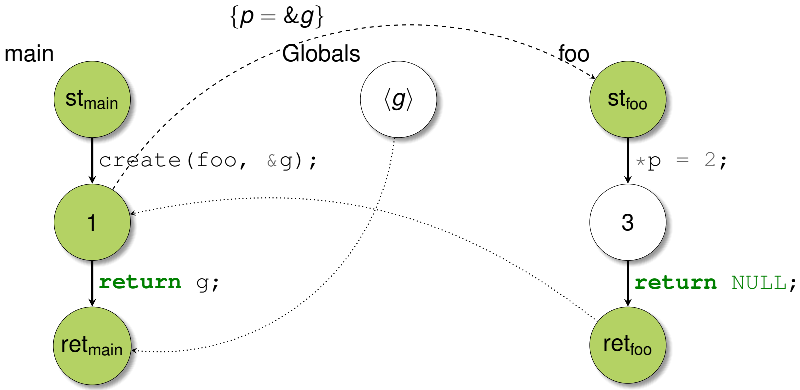
Incremental Abstract Interpretation



1. Load old results

Incremental Abstract Interpretation



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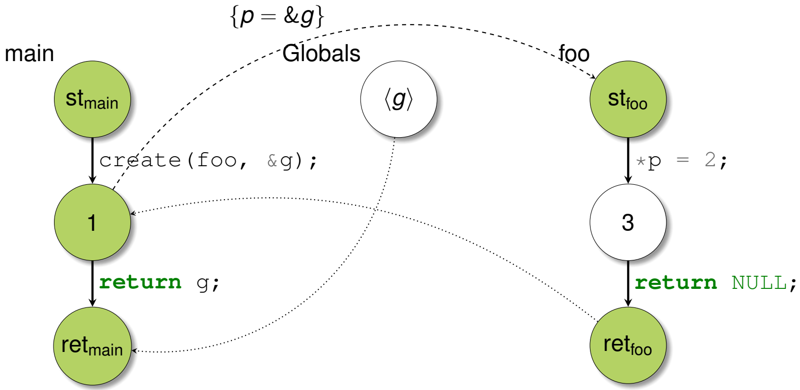

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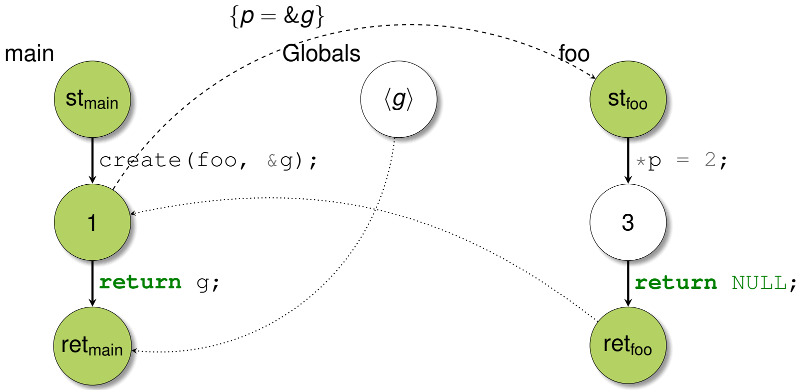

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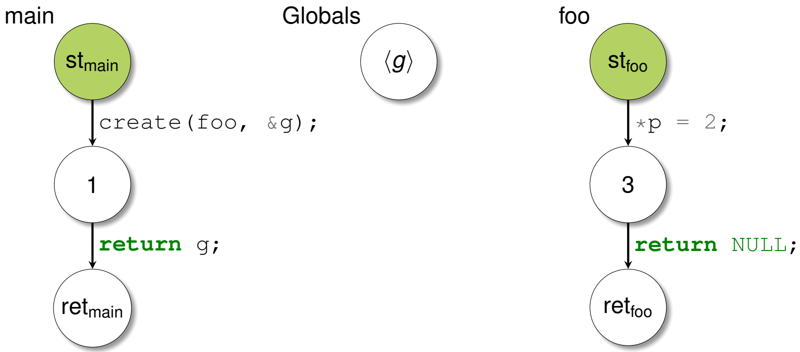

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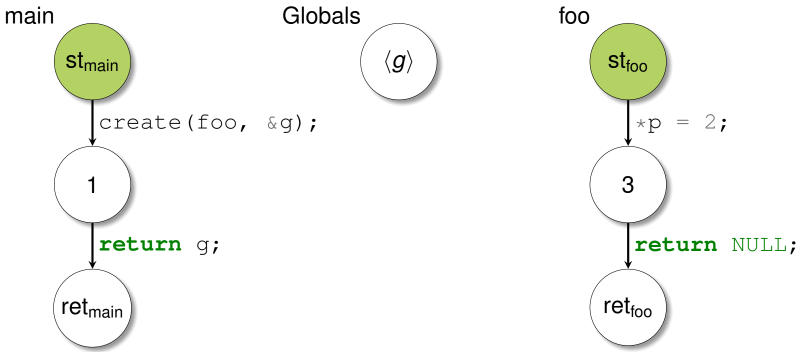

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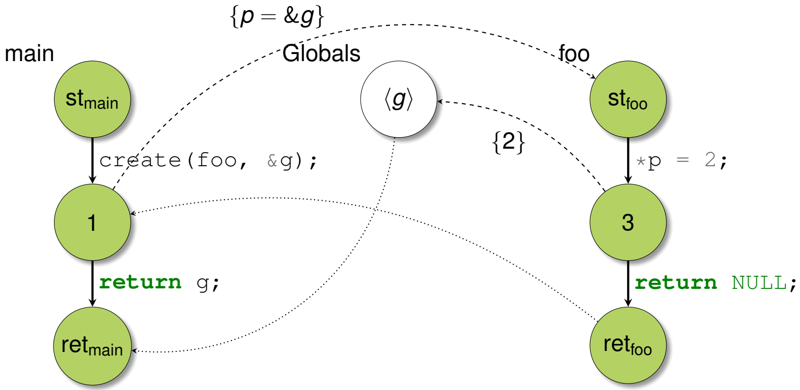

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Incremental Abstract Interpretation

- **Reluctant Destabilization**
- Incremental Warning Generation

- Update rules for globals

- IDE Integration

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$\Longrightarrow$ Change has no impact outside of `foo`!

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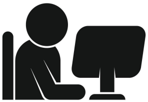
3. Solve end point of `main`. If all changes were local, the end point of `main` is stable, so nothing to do.

Incremental Abstract Interpretation

- Reluctant Destabilization
- **Incremental Warning Generation**

- Update rules for globals



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Observation: Warnings can be reused as well

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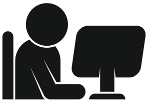
Incremental Warning Generation

- Keep track of unknowns never destabilized during incremental run
- Warnings generated at these unknowns can be reused

Incremental Abstract Interpretation

- Reluctant Destabilization
- Incremental Warning Generation

- **Update rules for globals**



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$\Longrightarrow$ Flow-insensitive unknowns will contain artifacts from earlier programs.

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  - Restart flow-insensitive unknowns by setting them to $\perp$
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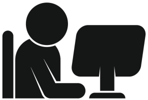
  - Destabilize all unknowns that cause a side effect

- Update Rules and Abstract Garbage Collection
  - Remember where contributions came from
  - Δ upon re-evaluation
  - Completely remove contributions from dead contexts

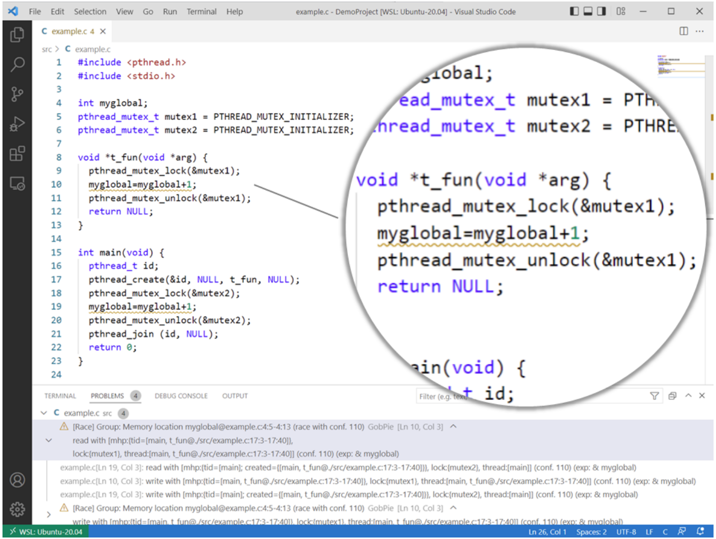
- Reluctant Destabilization
- Incremental Warning Generation

- Update rules for globals



- **IDE Integration**

Integrated into VS Code



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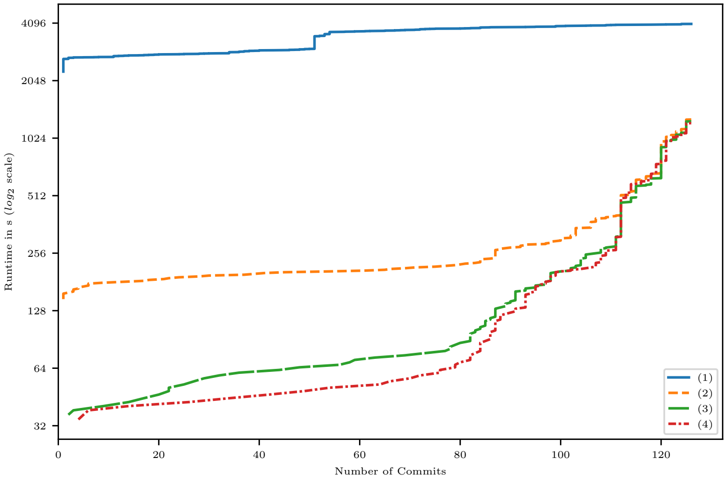
- Intervals & exclusion sets
- Accesses & data-race detection

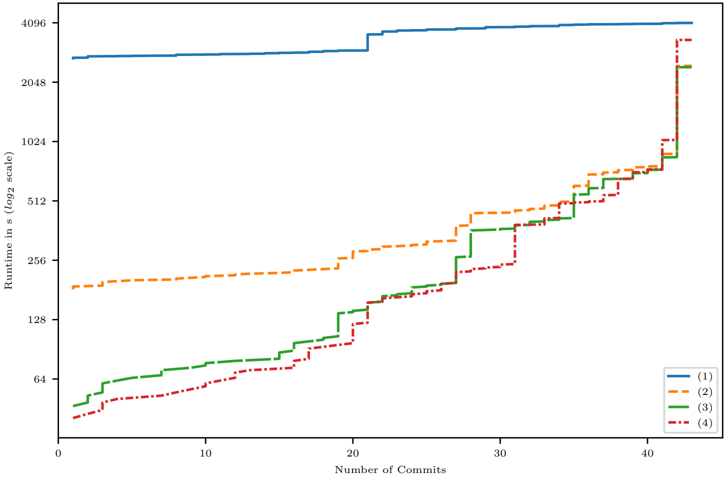
Results on ZSTANDARD



Analysis runtimes on commits with $\leq$ 50 lines of code changed. Configurations:

- non-incremental
- incremental
- + incremental warning generation
- + reluctant destabilization

Results on ZSTANDARD



Analysis runtimes on commits with $>$ 50 lines of code changed. Configurations:

- non-incremental
- incremental
- + incremental warning generation
- + reluctant destabilization

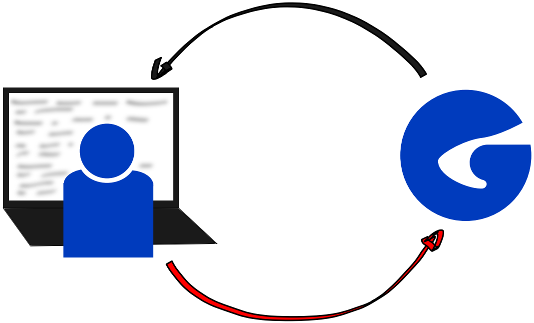
Our previous work

- [Seidl et al., Chrisfest'20]: Incremental Abstract Interpretation
- [Erhard et al., STTT'23]: Interactive Abstract Interpretation: Reanalyzing Multithreaded C Programs for Cheap
- [Stemmler et al., PLDI'25]: Taking out the Toxic Trash: Recovering Precision in Mixed Flow-Sensitive Static Analyses

GOBLINT

/goblint/analyzer

Vision: Interactive Abstract Interpretation During Development



From Incremental to Interactive

Consider not only changes to the input program

From Incremental to Interactive

Consider not only changes to the input program,
but also **user interaction**!

From Incremental to Interactive

Consider not only changes to the input program,
but also **user interaction**!

(one may think of it as changing the analysis specification)

Expert Developer Diane

Expert Developer Diane

- Coarse results immediately, refine in the background
- While fixing the most salient warning, the analysis may be able to show less salient warnings spurious

Expert Developer Diane

- Surface semantic information

Expert Developer Diane

- Surface semantic information
  - complete call-graph

Expert Developer Diane

- Surface semantic information
  - complete call-graph
  - dead branches

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  - ...

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- Surface semantic information
  - complete call-graph
  - dead branches
  - (non-)nullness of arguments
  - ...

- Static analysis as treasure trove of information usually hidden from Diane

Expert Developer Diane

- To drill-down on warnings locally enable

Expert Developer Diane

- To drill-down on warnings locally enable
  - (more) context-sensitivity

Expert Developer Diane

- To drill-down on warnings locally enable
  - (more) context-sensitivity
  - (more) path-sensitivity

Expert Developer Diane

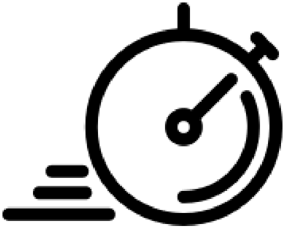
- To drill-down on warnings locally enable
  - (more) context-sensitivity
  - (more) path-sensitivity
  - (more) concurrency-sensitivity

Expert Developer Diane

- To drill-down on warnings locally enable
  - (more) context-sensitivity
  - (more) path-sensitivity
  - (more) concurrency-sensitivity
  - (more) expressive abstract domains

... and beyond soundness:

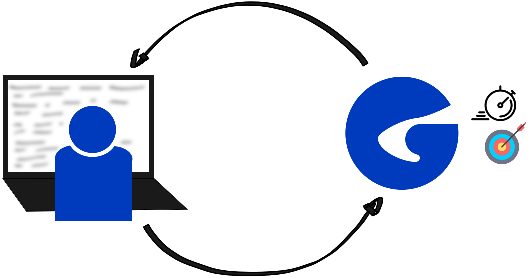
- Ask Diane why some alarm is false (e.g., "these two pointers can never alias")
- Refine analysis relying on this information.



...while limiting recomputation!

Thank you!

- Precise incremental abstract interpretation of multi-threaded programs
- Ideas and ingredients for interactive abstract interpretation



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