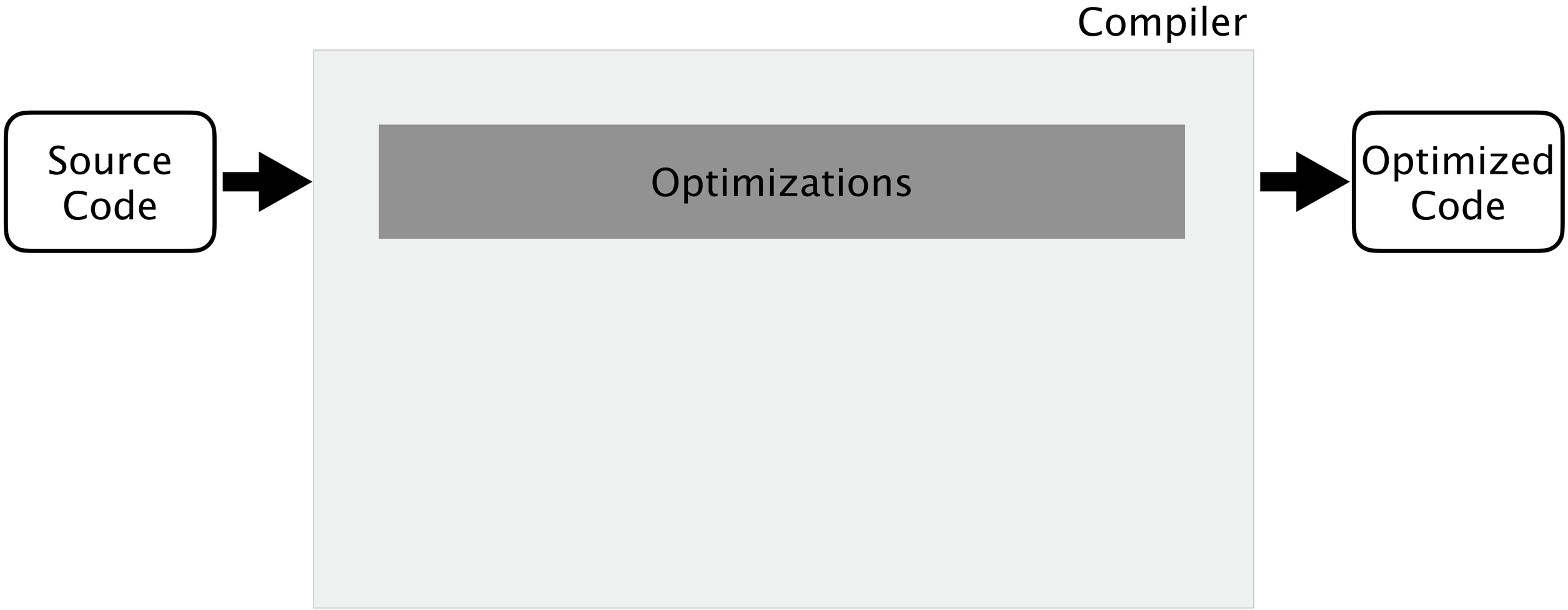
SCAF: A Speculation-Aware Collaborative Dependence Analysis Framework

Sotiris Apostolakis, Ziyang Xu, Zujun Tan, Greg Chan, Simone Campanoni[†], and David I. August

PLDI 2020

[†]Northwestern University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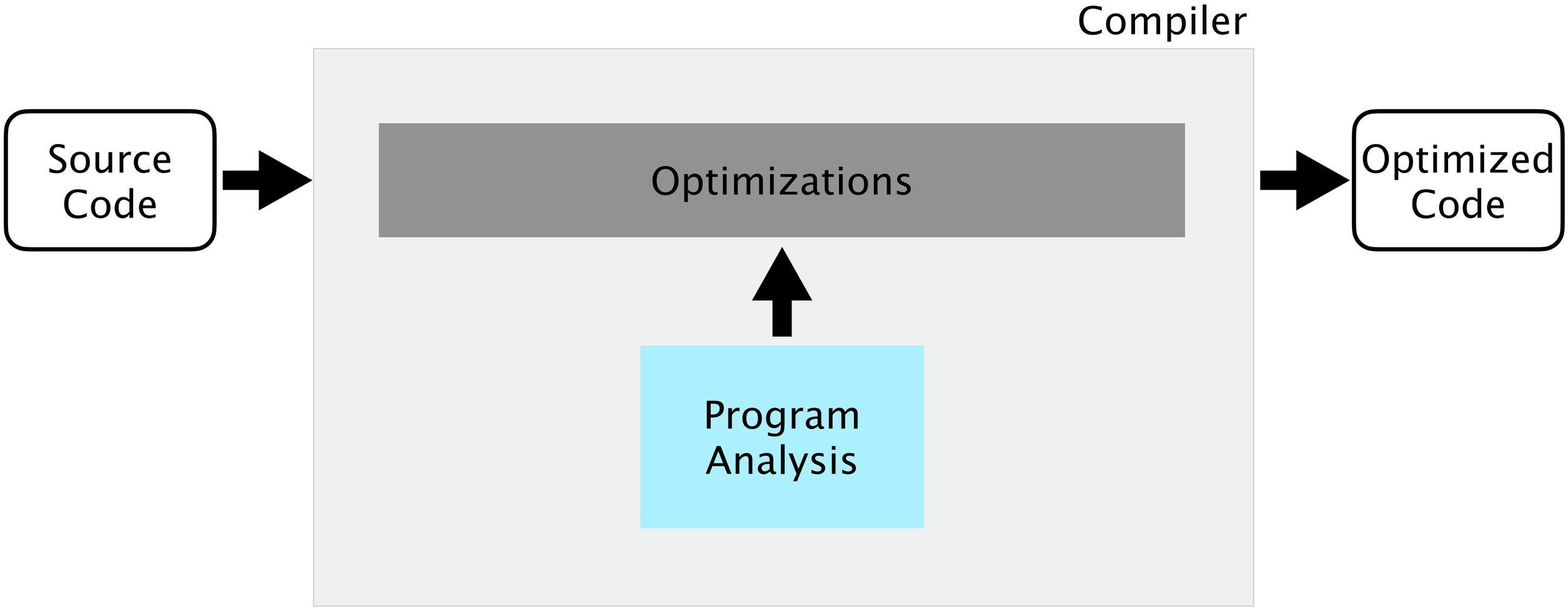
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- insufficiently precise in practice [Hind, PASTE'01]
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- conservatively respects all possible inputs
  Many real dependences rarely occur in practice.

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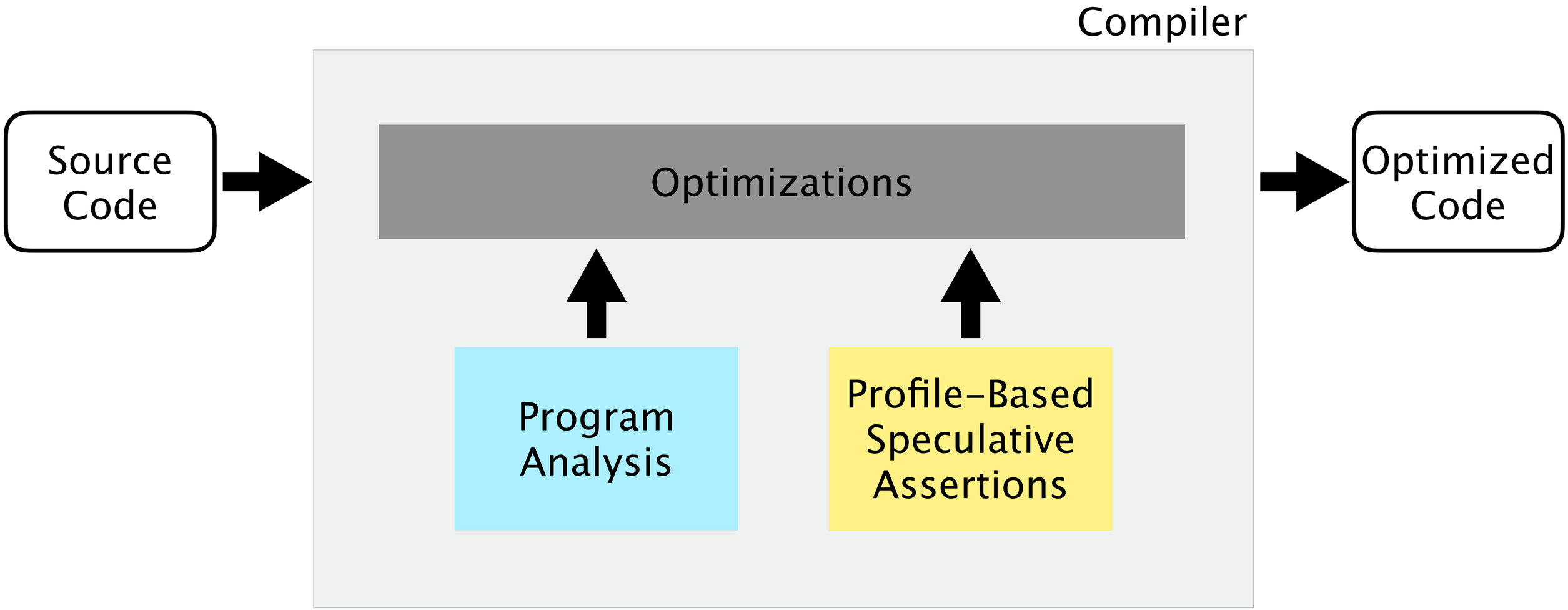
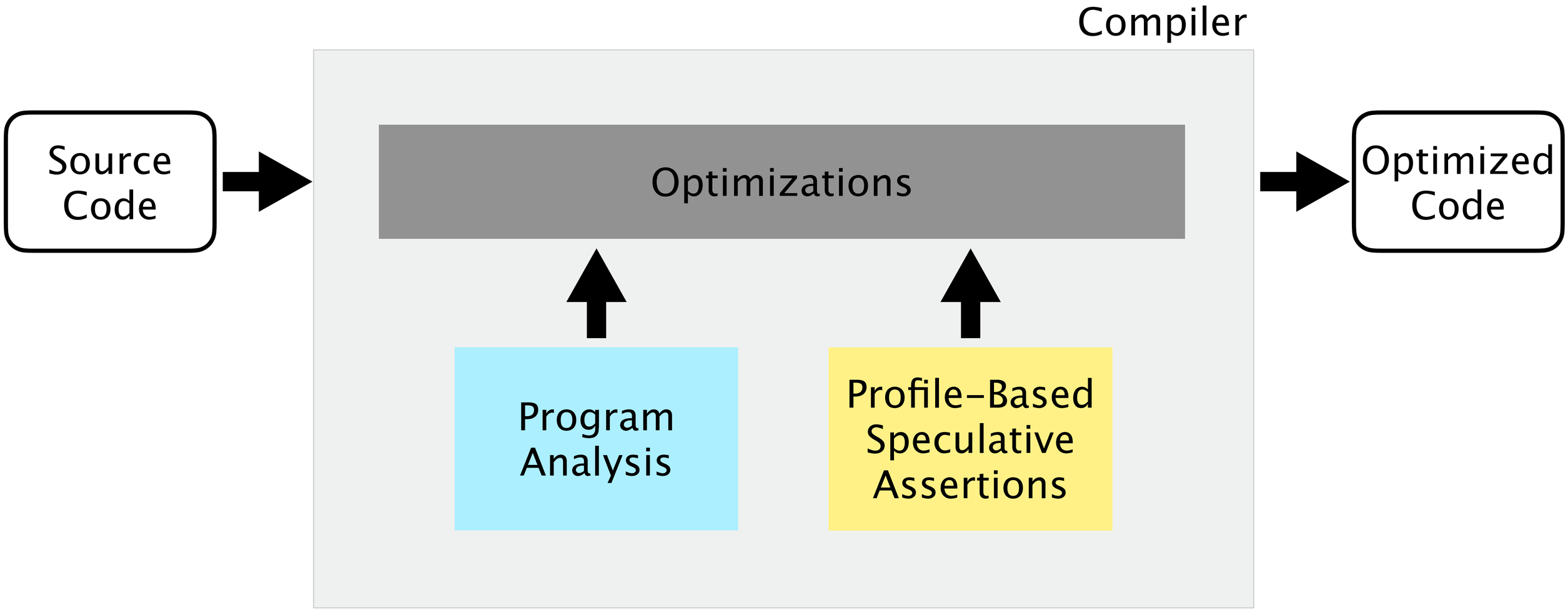


State-of-the-art [1,2,3,4] does not fully leverage speculation



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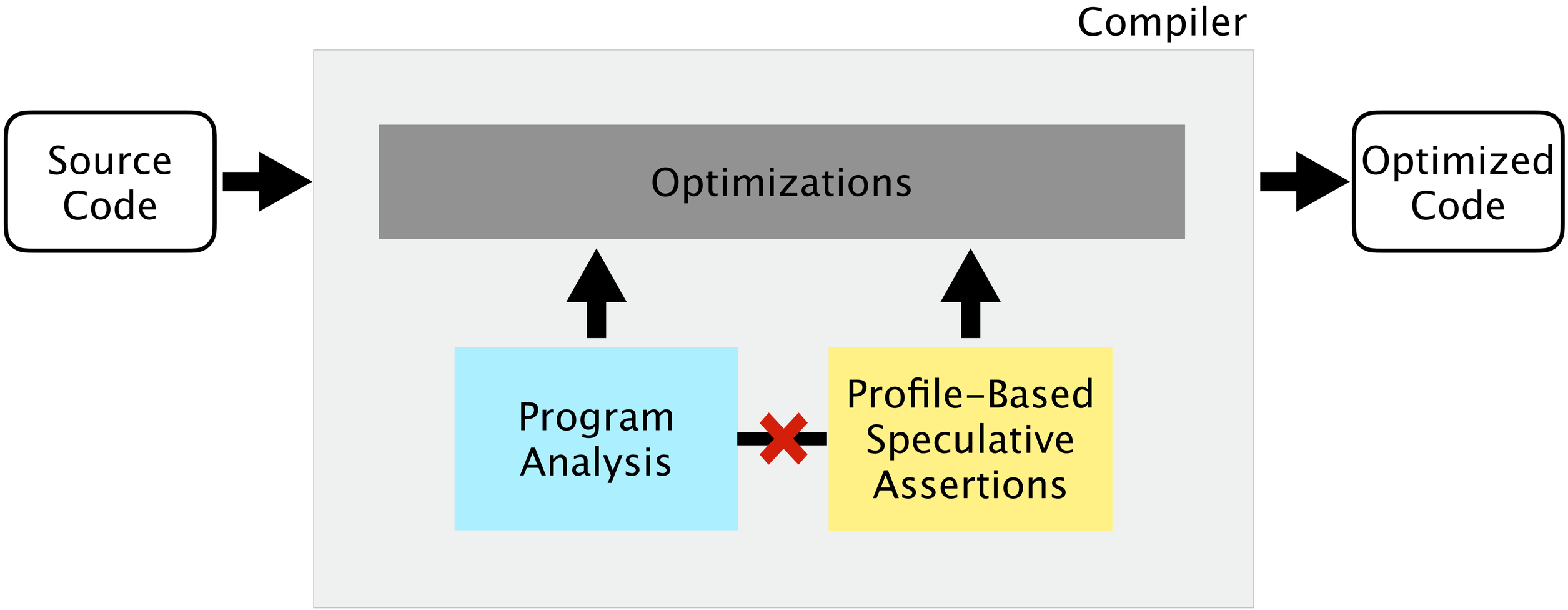

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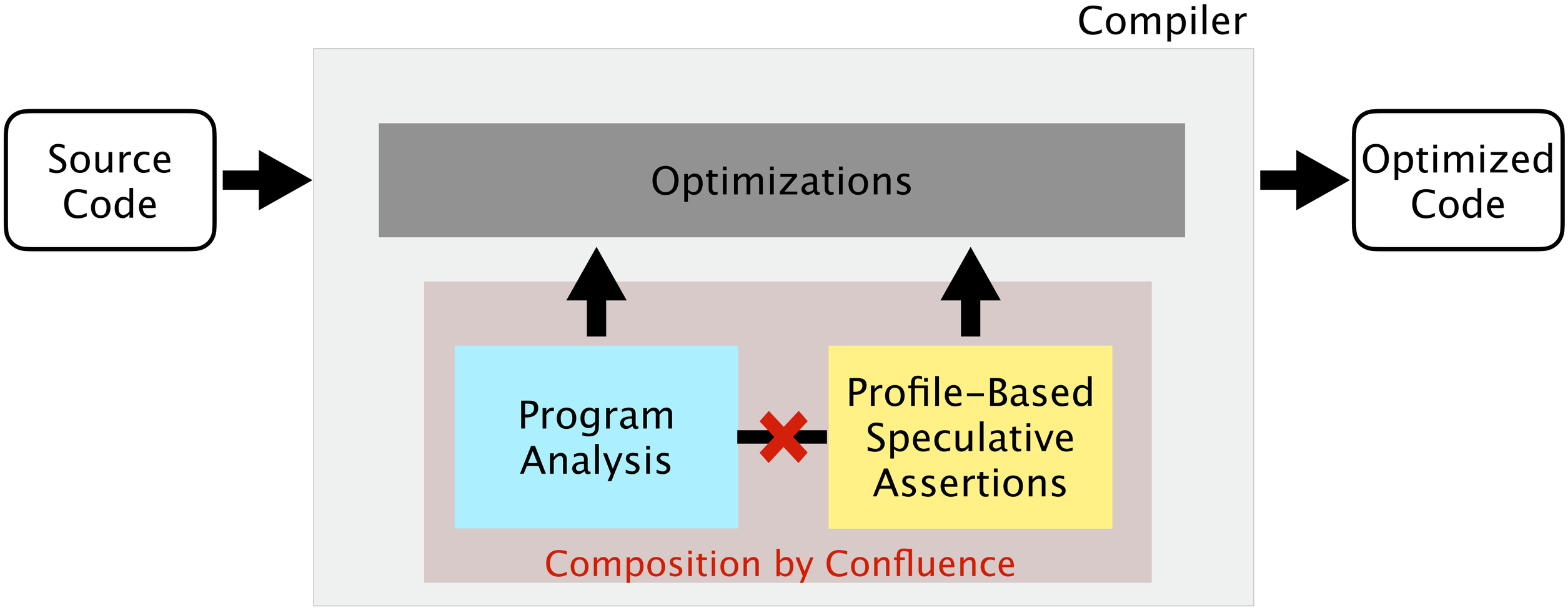

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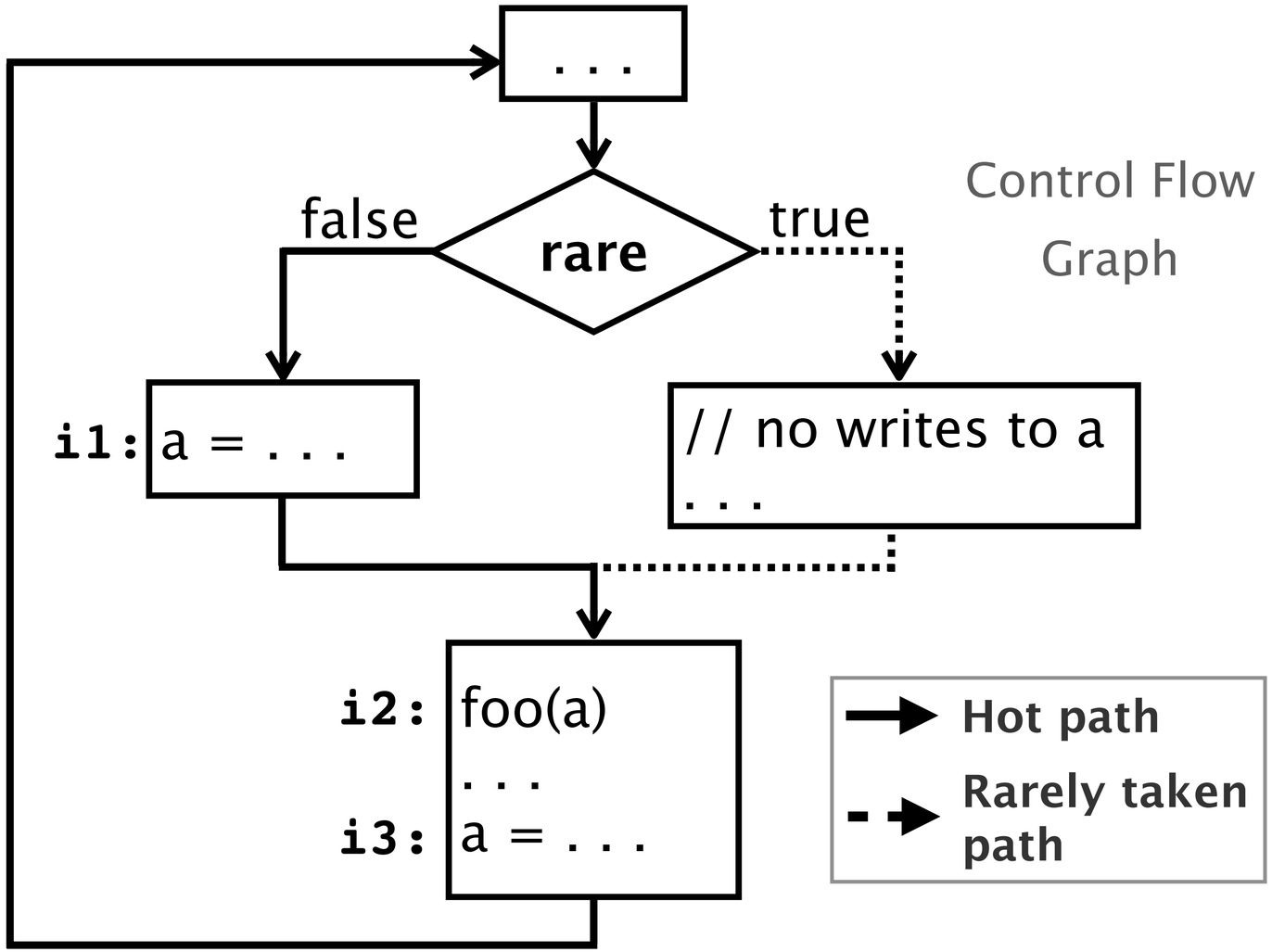

Control Flow Graph

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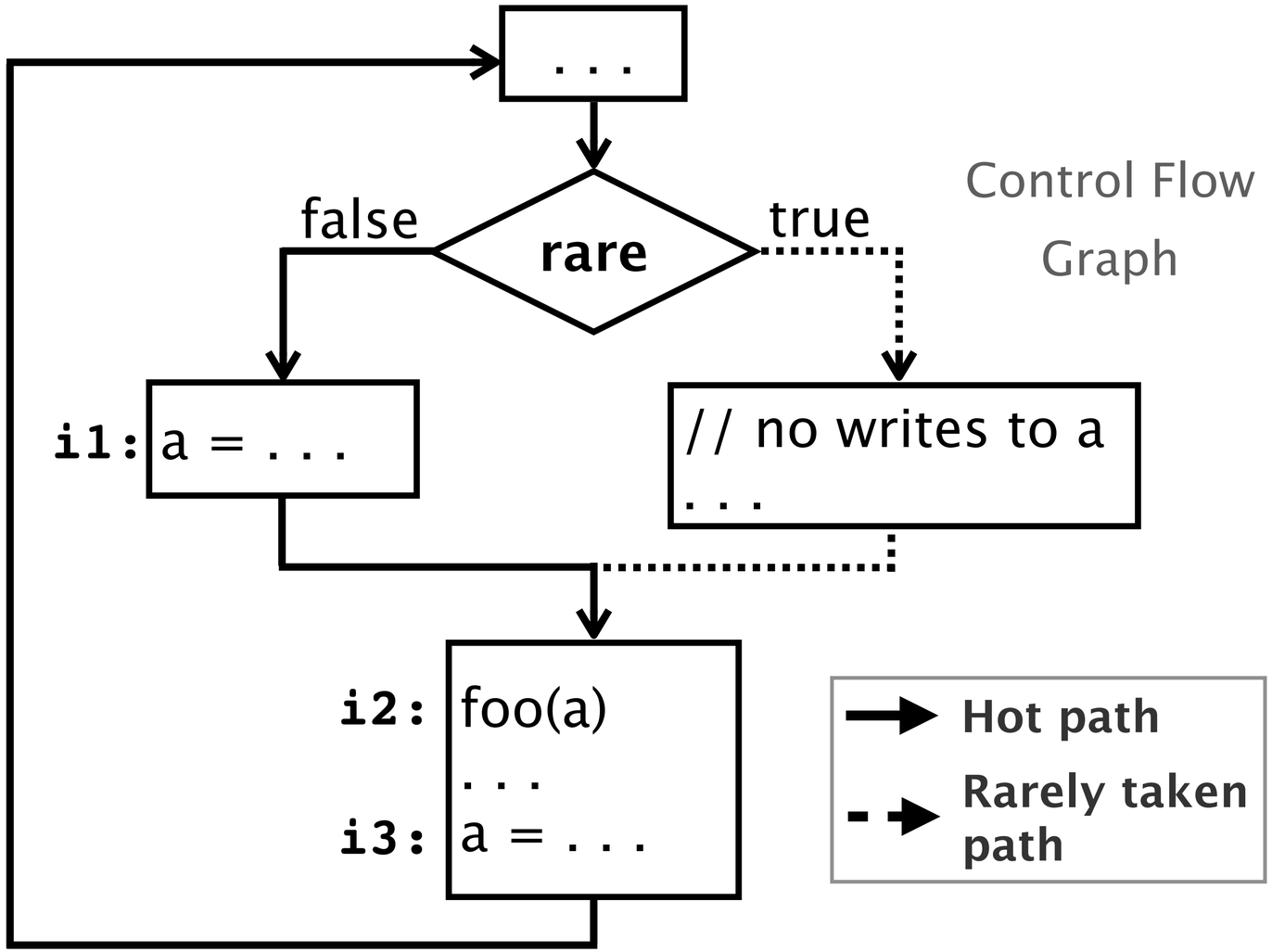

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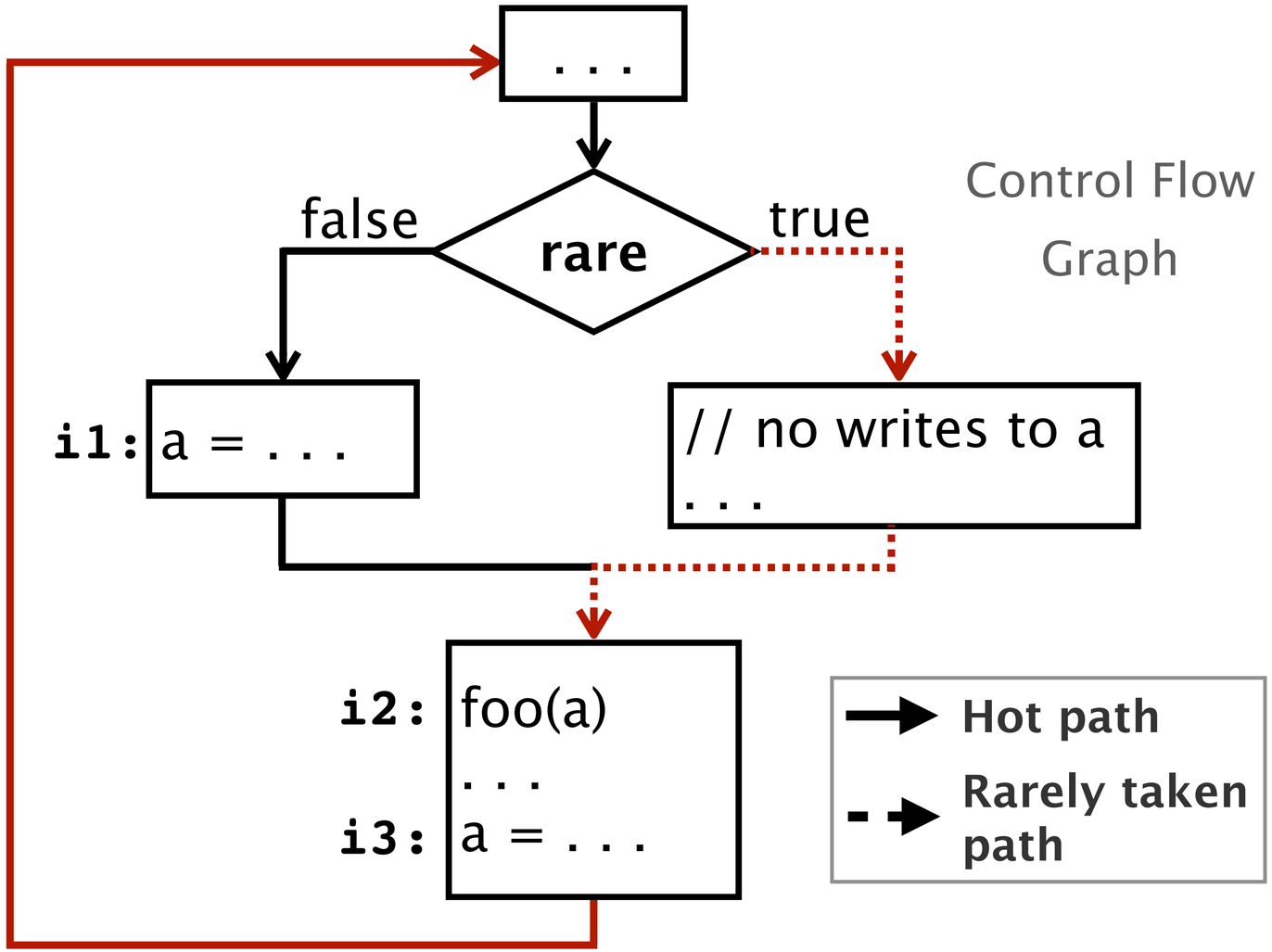

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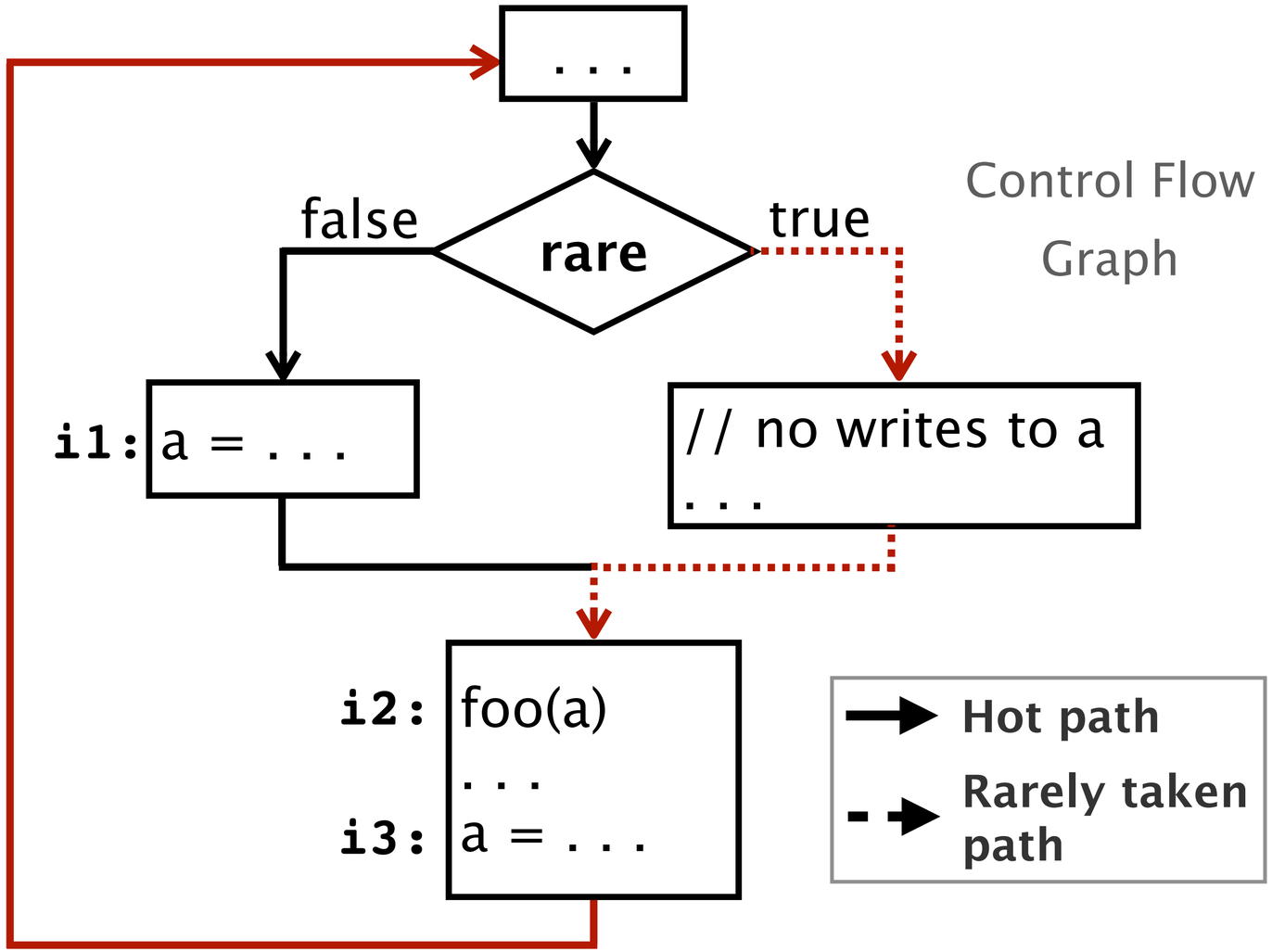

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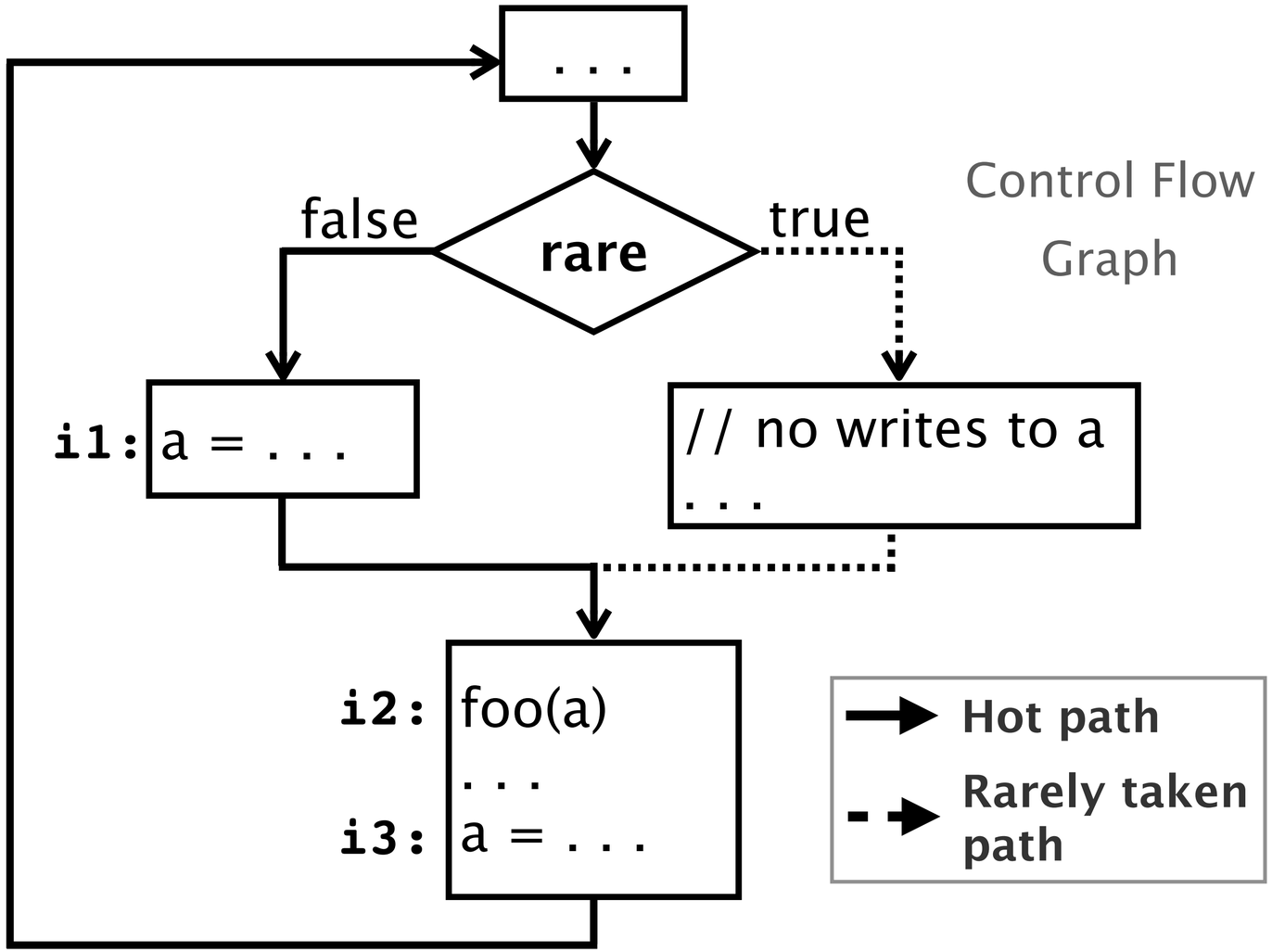

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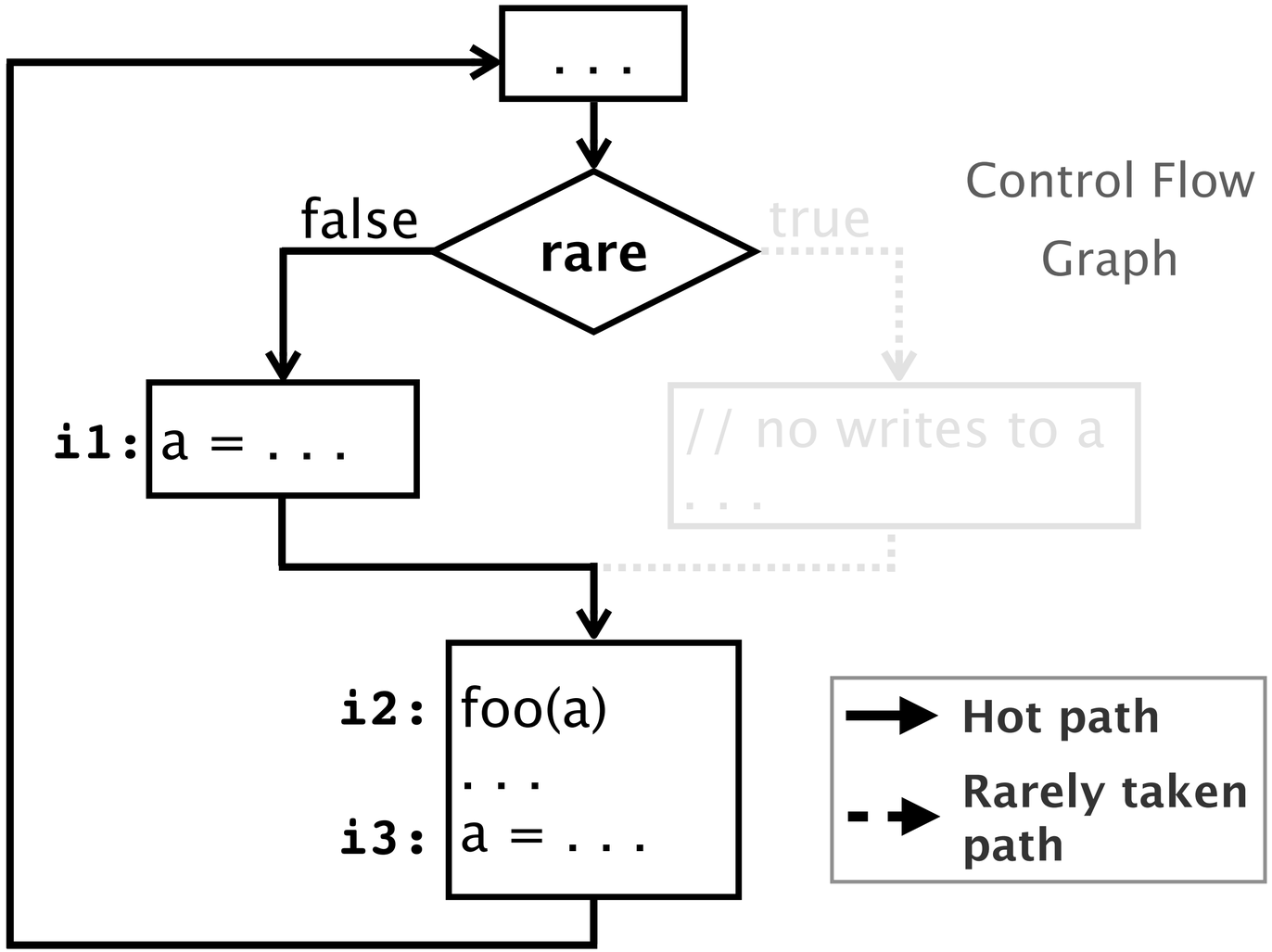

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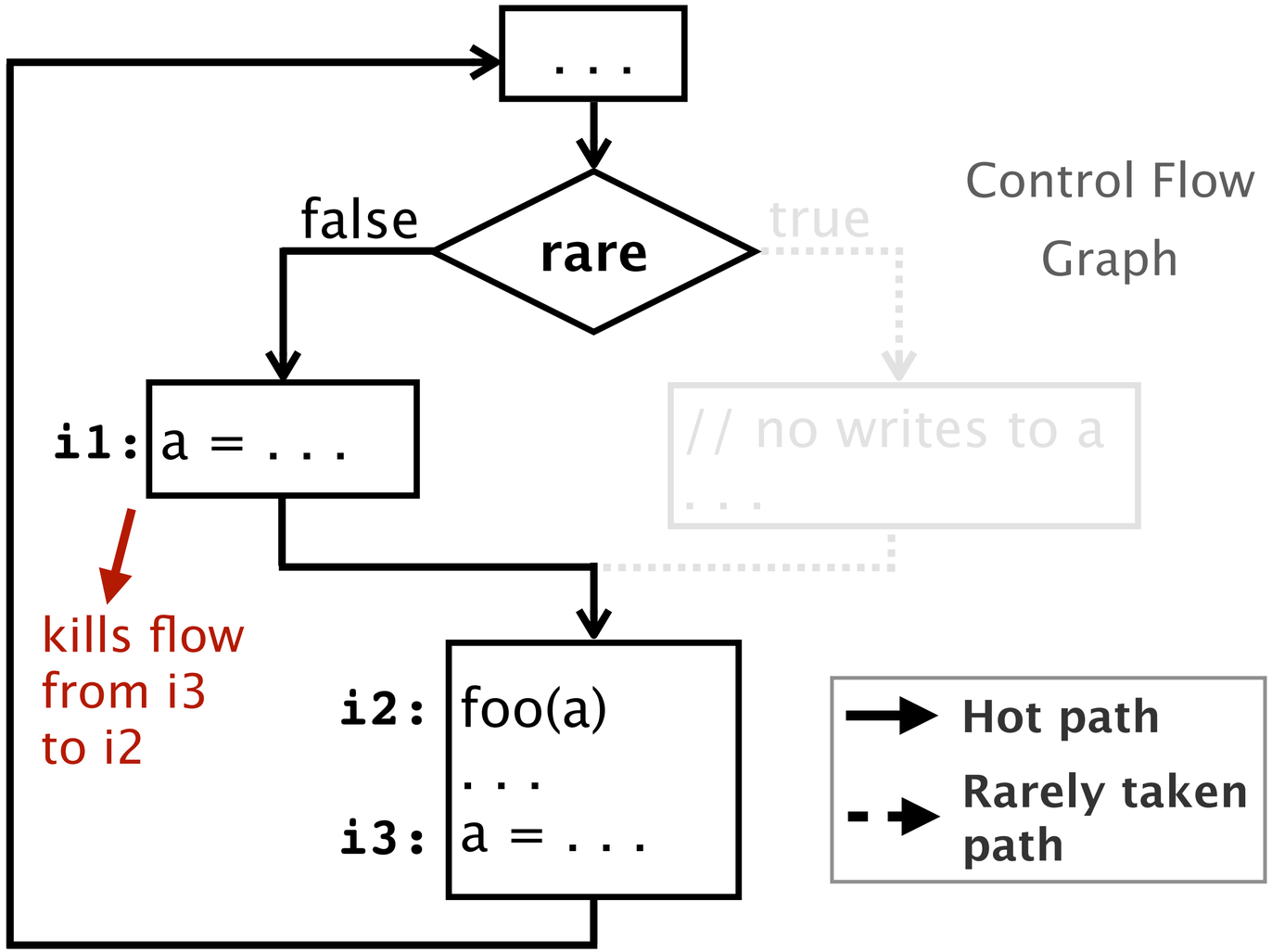

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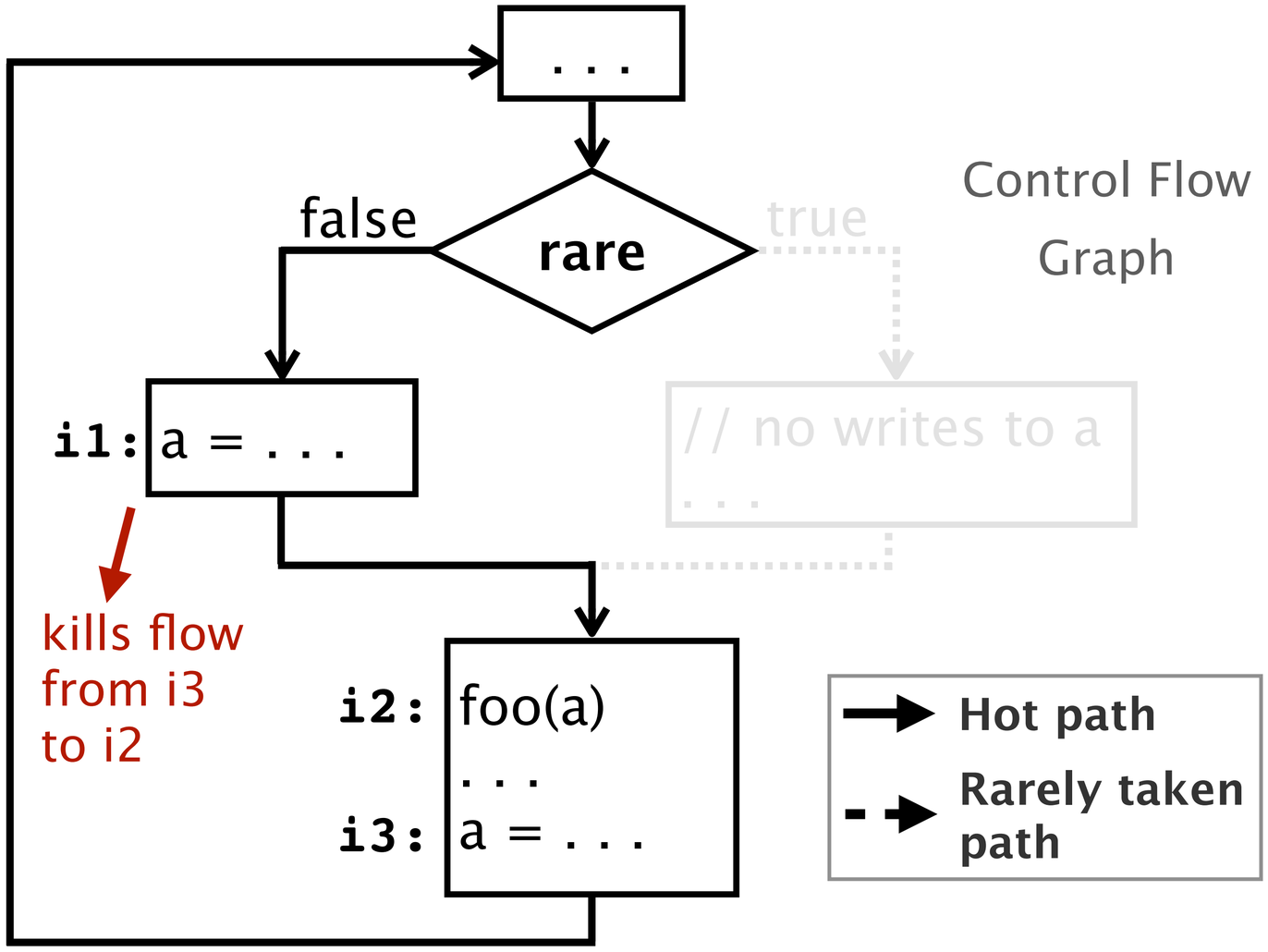
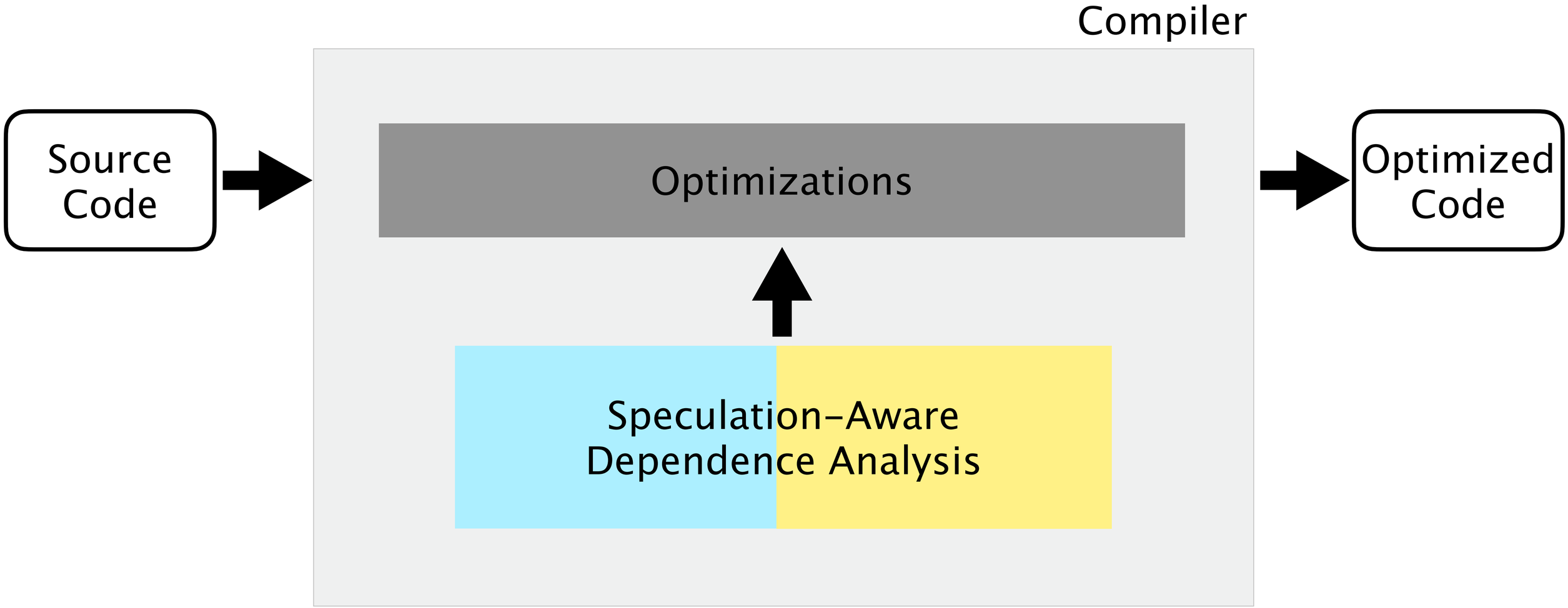
Memory analysis and speculation combined can assert its absence.



Monolithic Integration [1,2,3]



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Proposed Approach: Composition by Collaboration

Proposed Approach is both Modular & Collaborative

Approaches	Supported Forms of Collaboration		Memory Analysis Decoupled from Speculation
	Among Speculative Techniques	Between Memory Analysis and Speculative Techniques	
Monolithic Integration [1,2,3]	✗	✓	✗
Composition by Confluence [4,5,6,7]	✗	✗	✓
Composition by Collaboration (**This Work**)	✓	✓	✓

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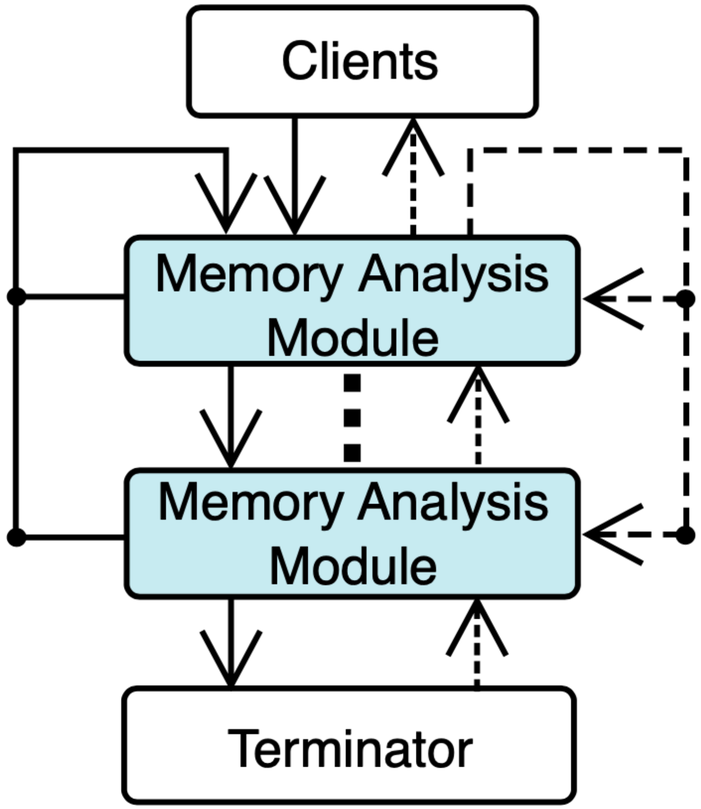
CAF*: Collaborative Dependence Analysis Framework



CAF*

Collaborative resolution of analysis queries by simple analysis algorithms

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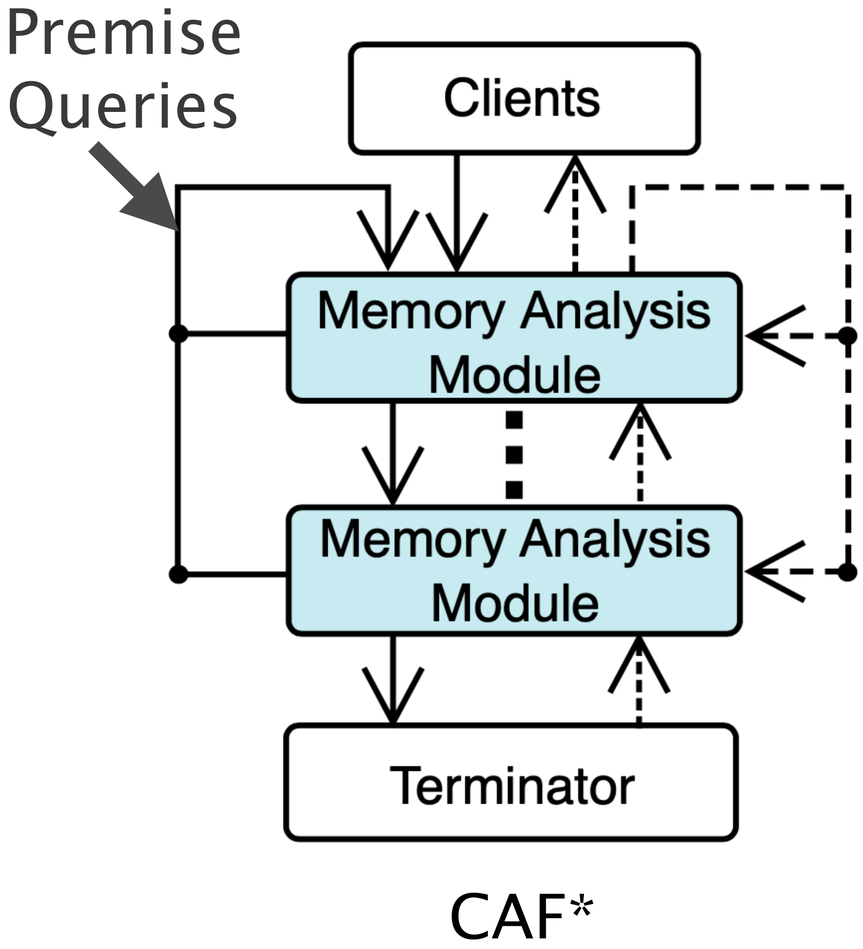

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Collaborative resolution of analysis queries by simple analysis algorithms

Isolate propositions beyond ones module's logic as premise queries.

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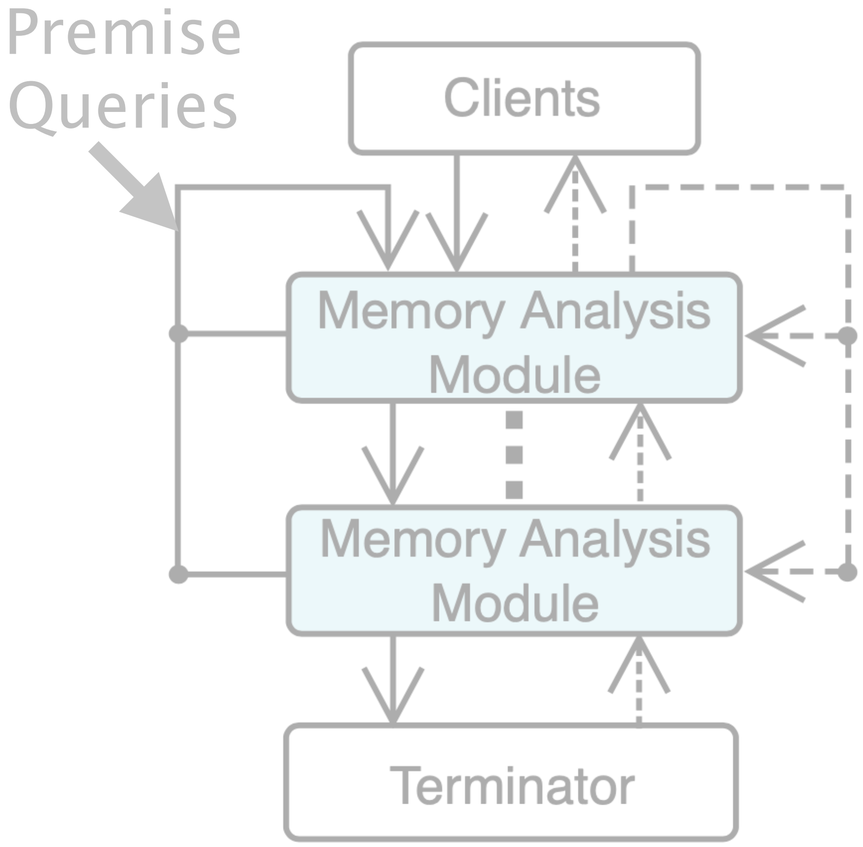

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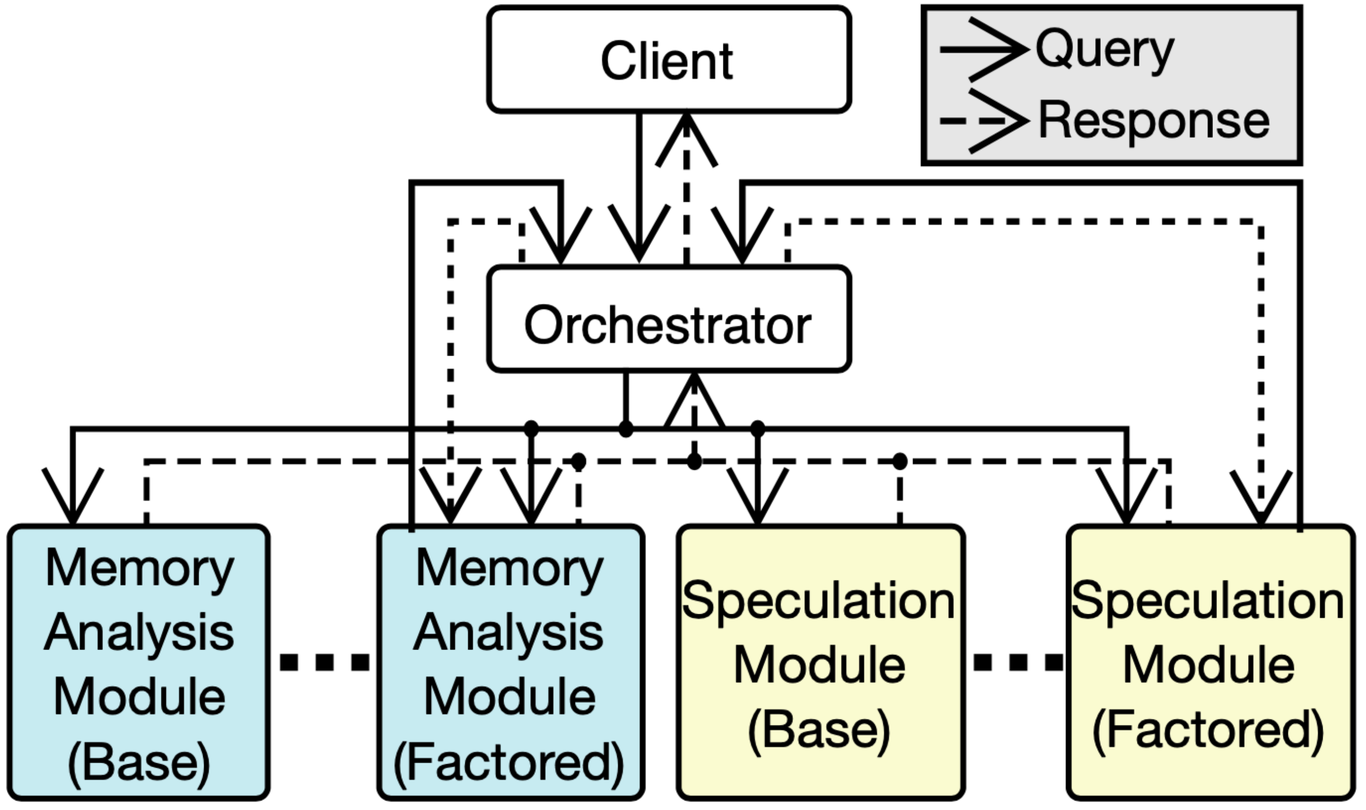

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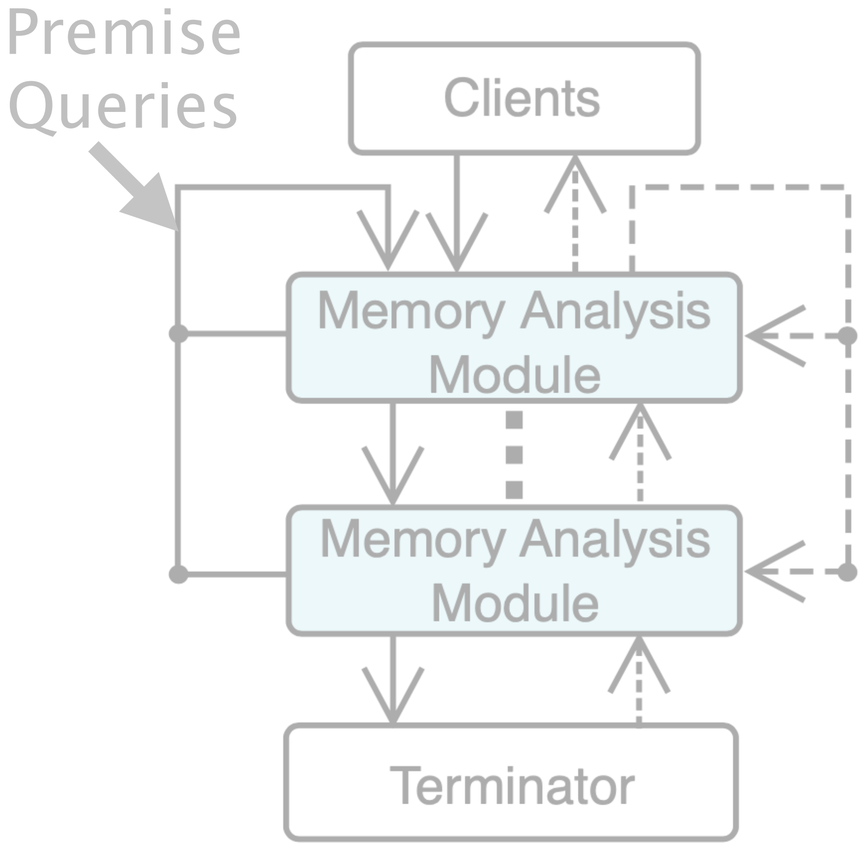

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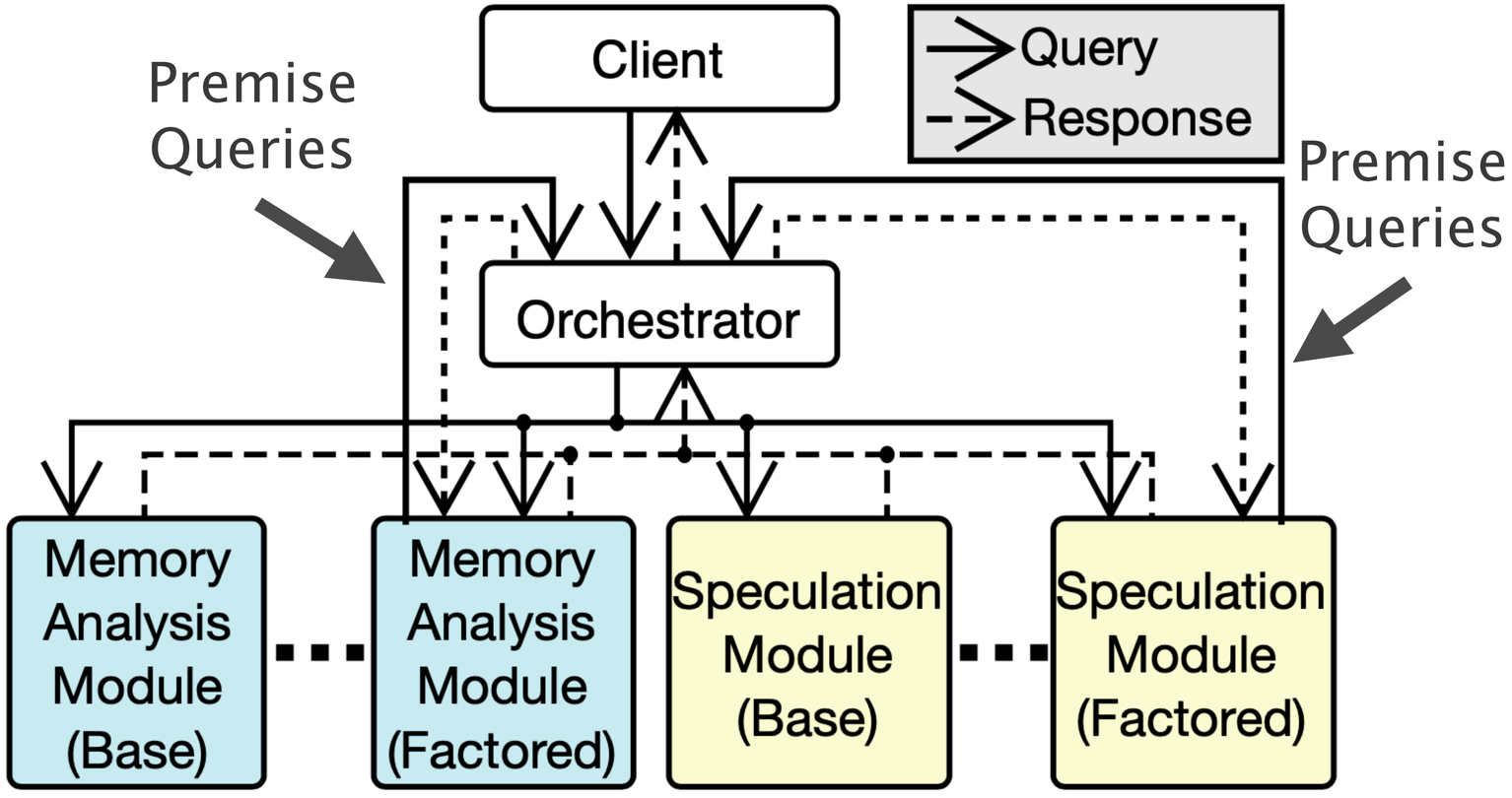

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Desired result parameter for quick bail-out

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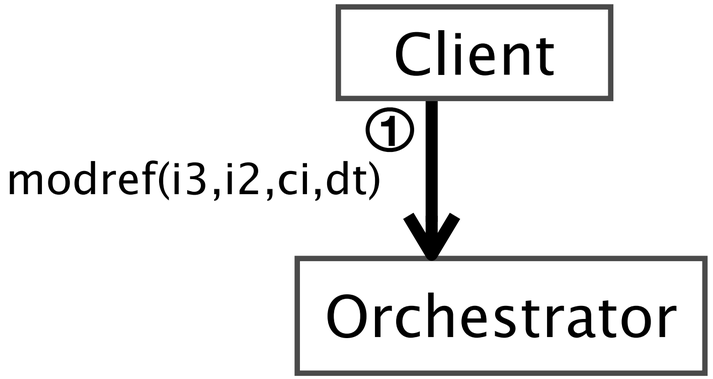

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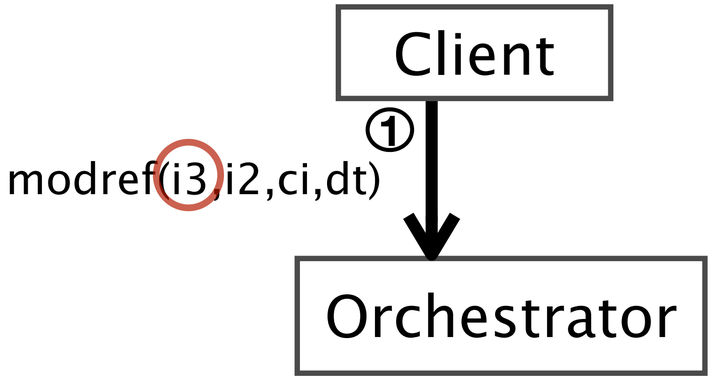

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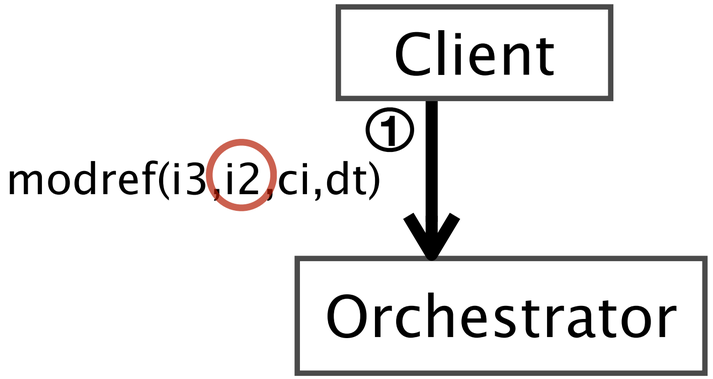

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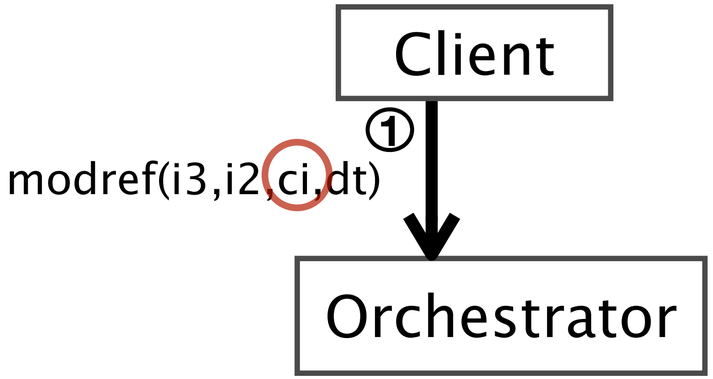

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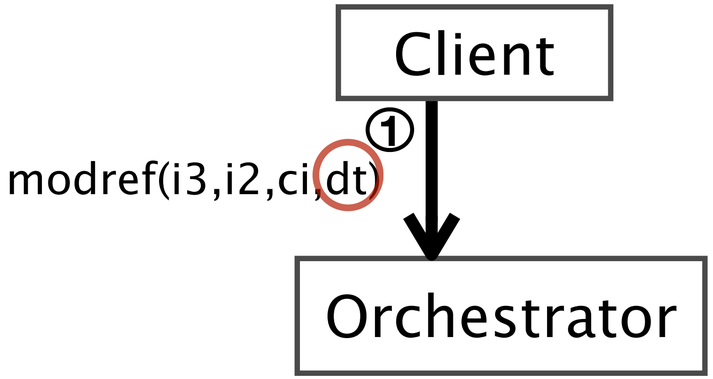

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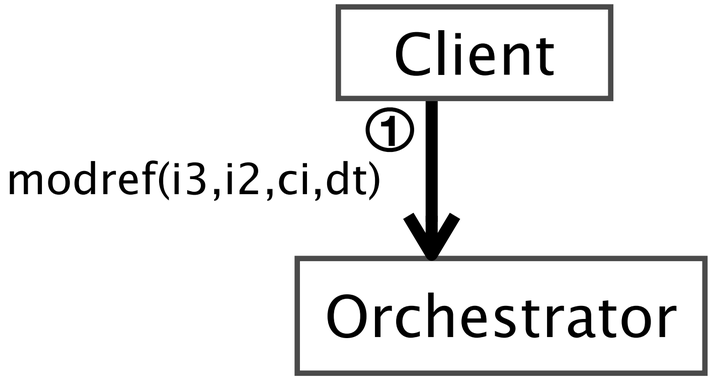

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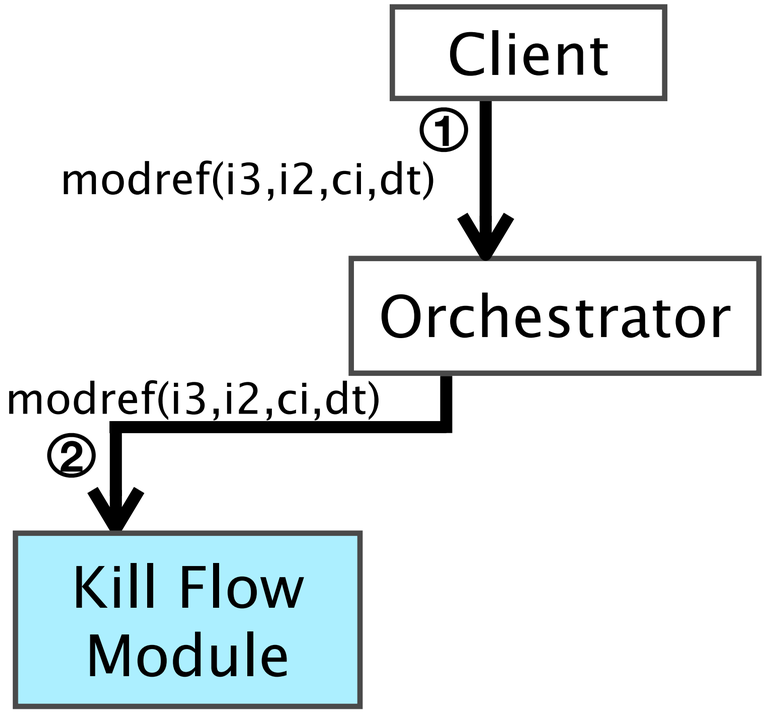

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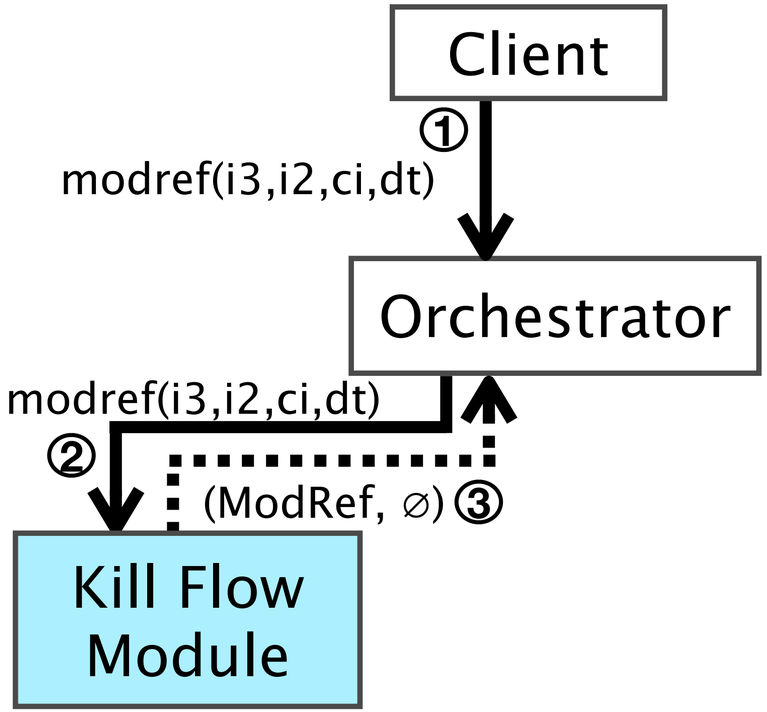

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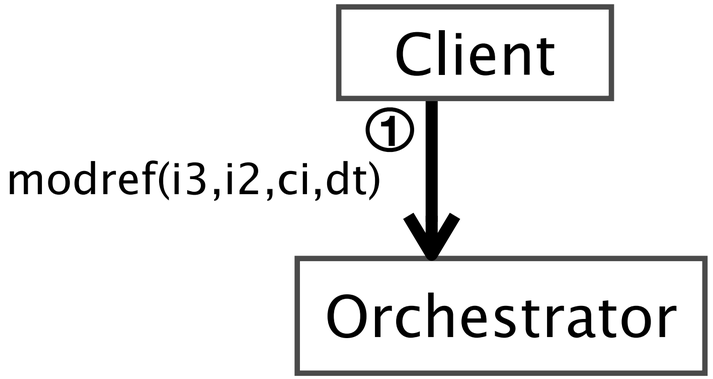

Kill Flow Module

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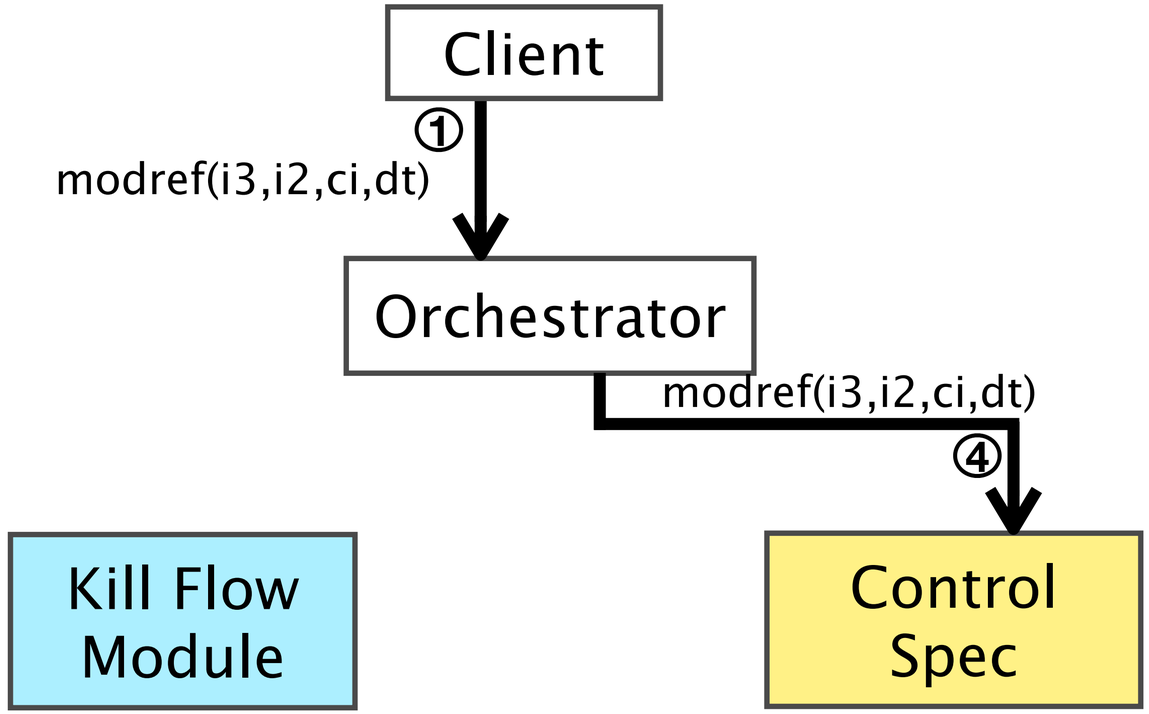

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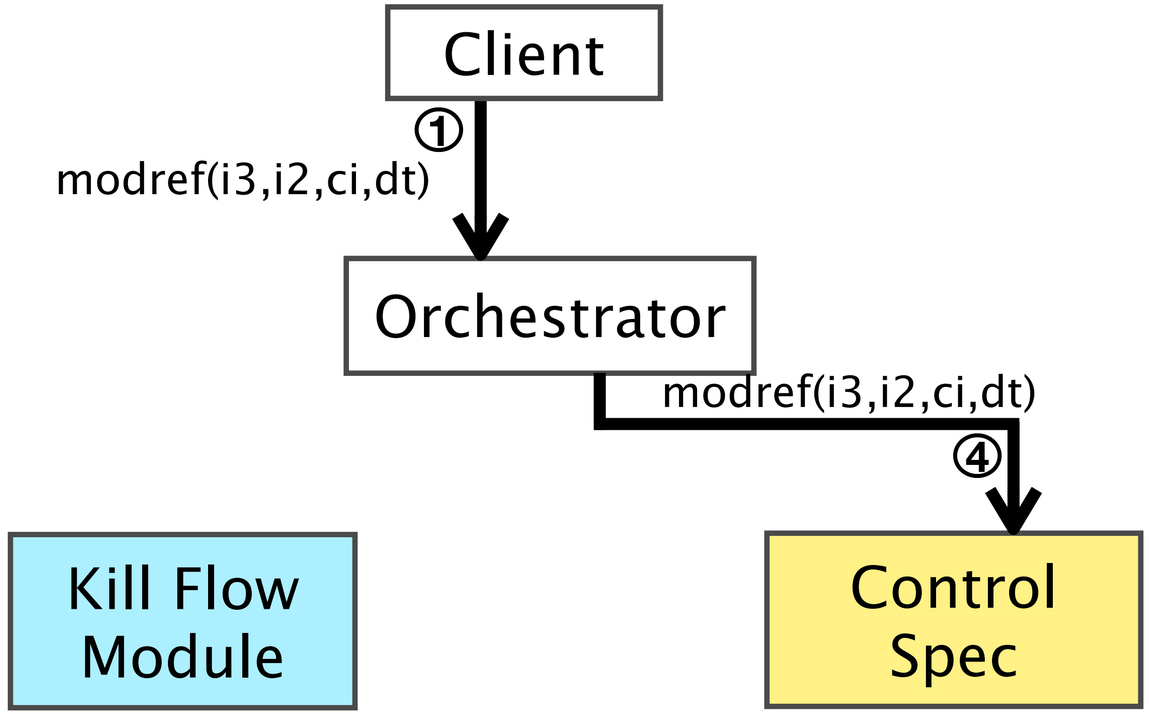

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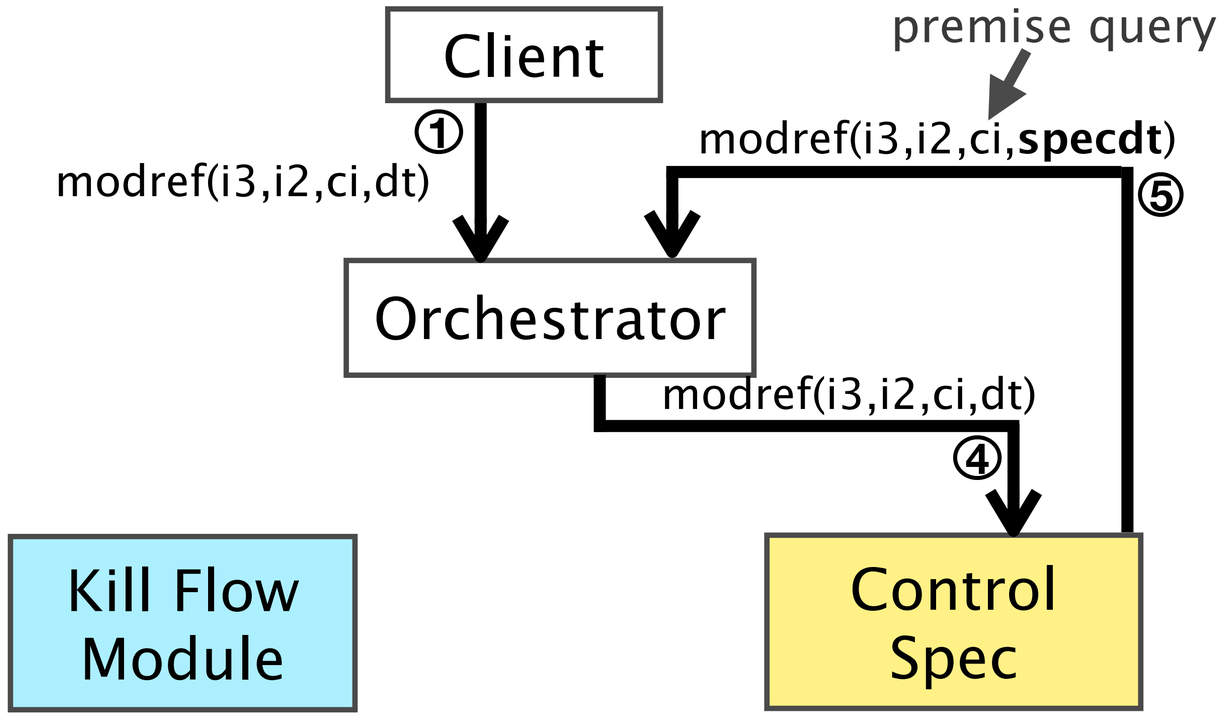

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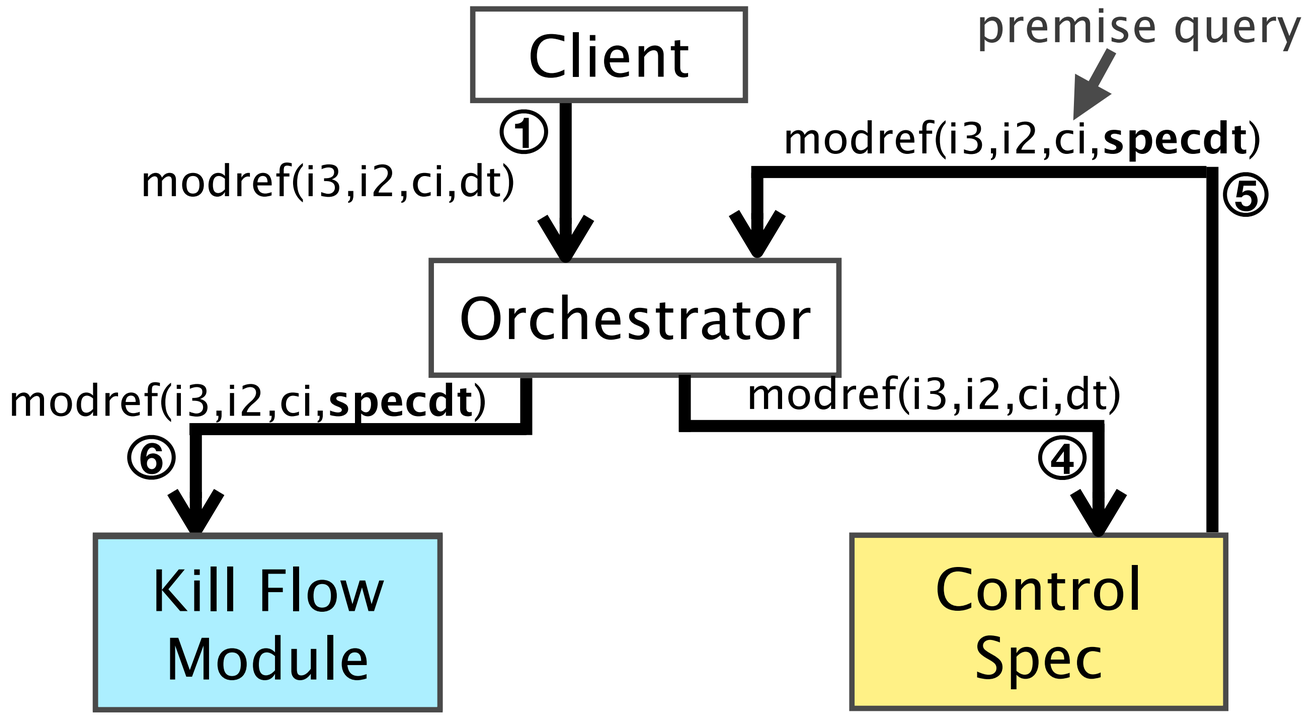

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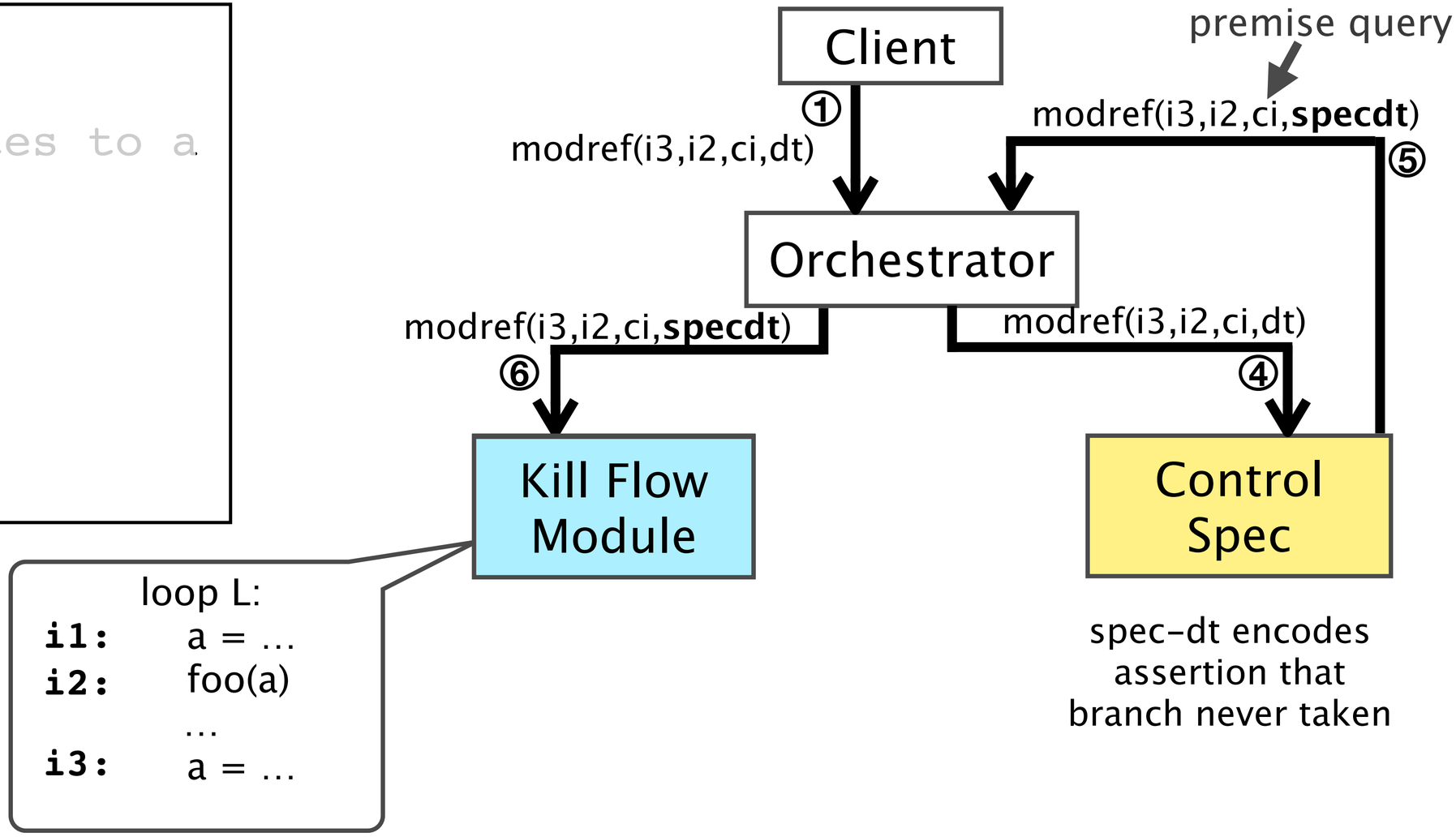

View of loop based on spec-dt

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i3:   a = ...
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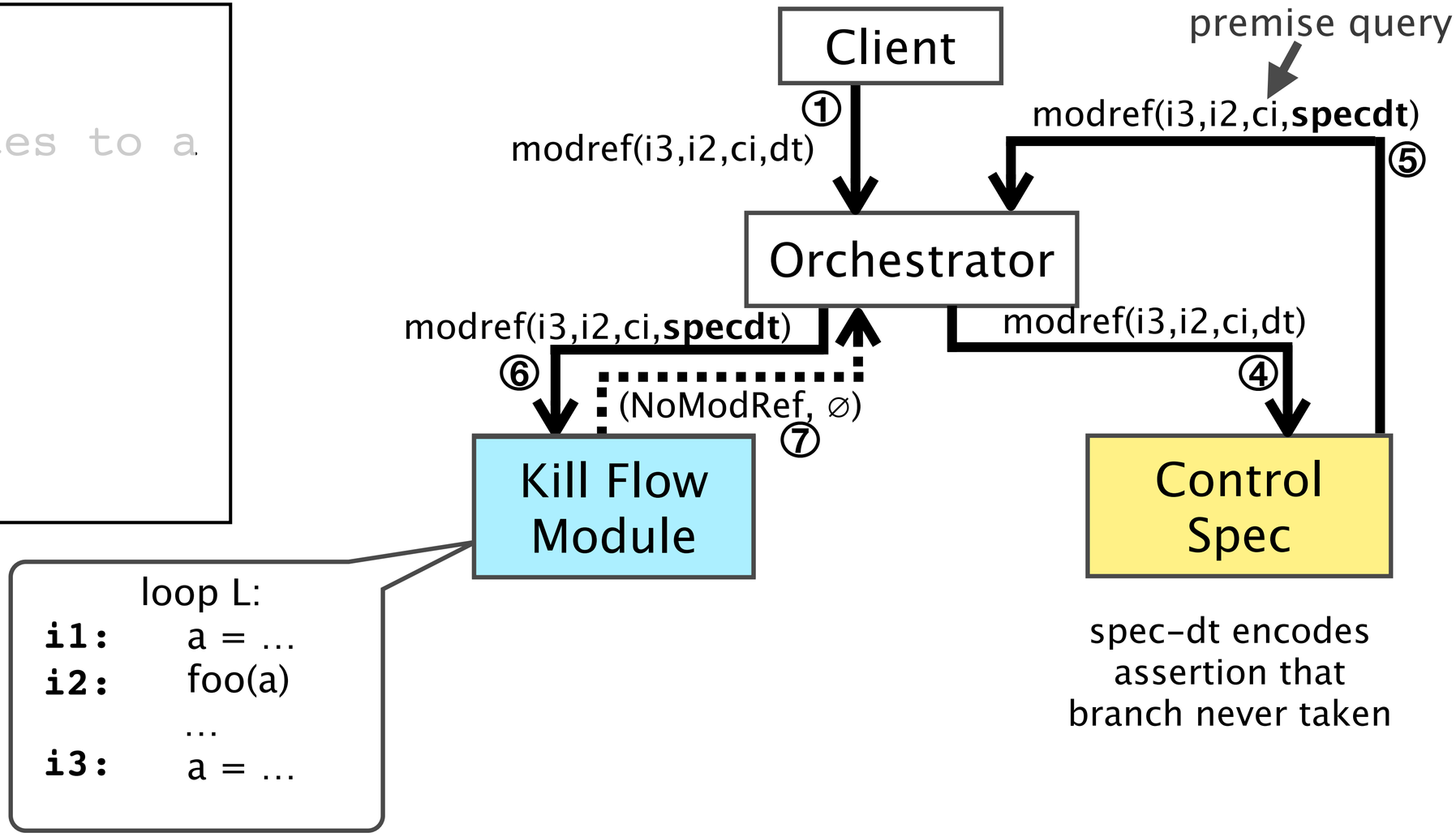
Is there a cross-iter data flow from i3 to i2?



View of loop based on spec-dt

SCAF in action

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   loop L:
      if (rare)
        // no writes to a
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      else
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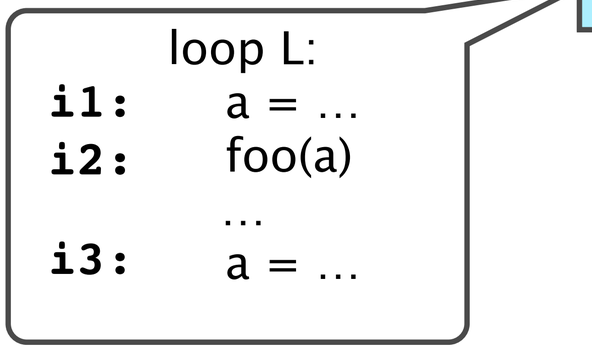

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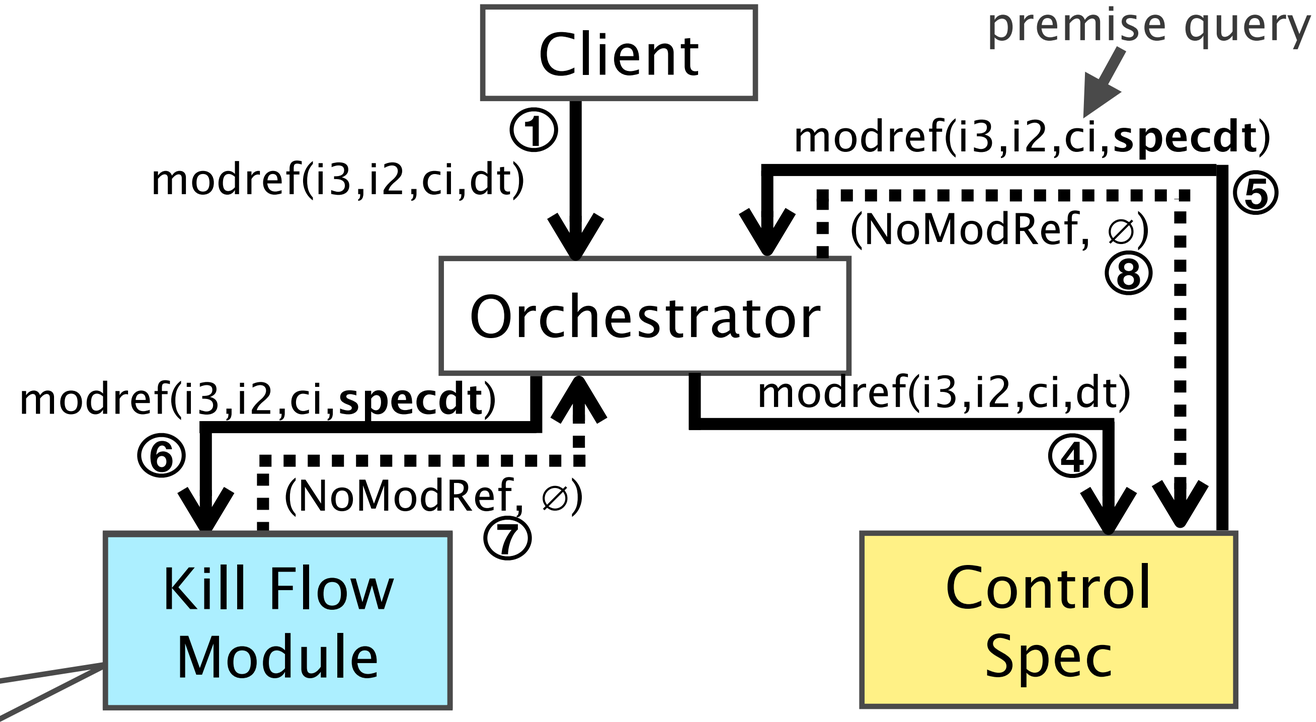

spec-dt encodes assertion that branch never taken

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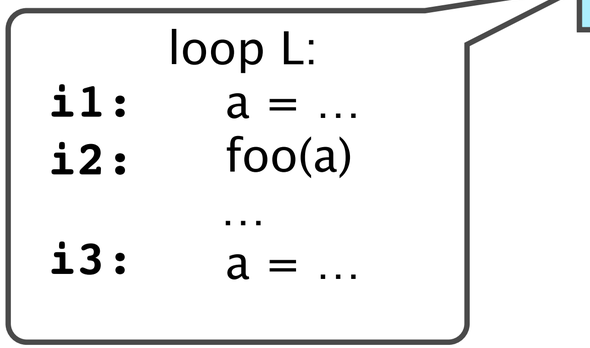
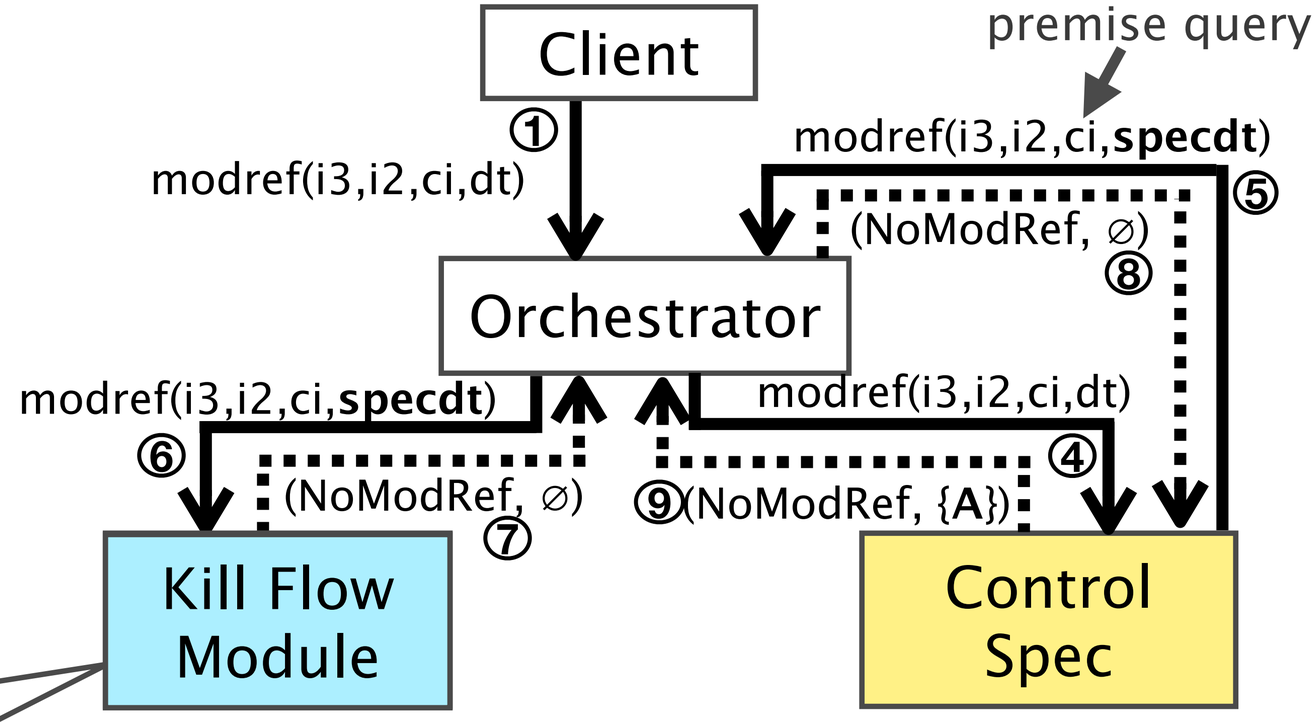


View of loop based on spec-dt



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Speculation assertion **A:** branch never taken

SCAF in action

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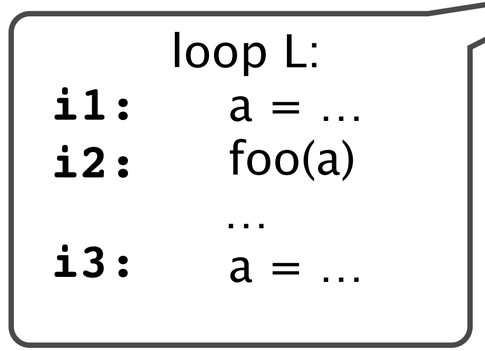
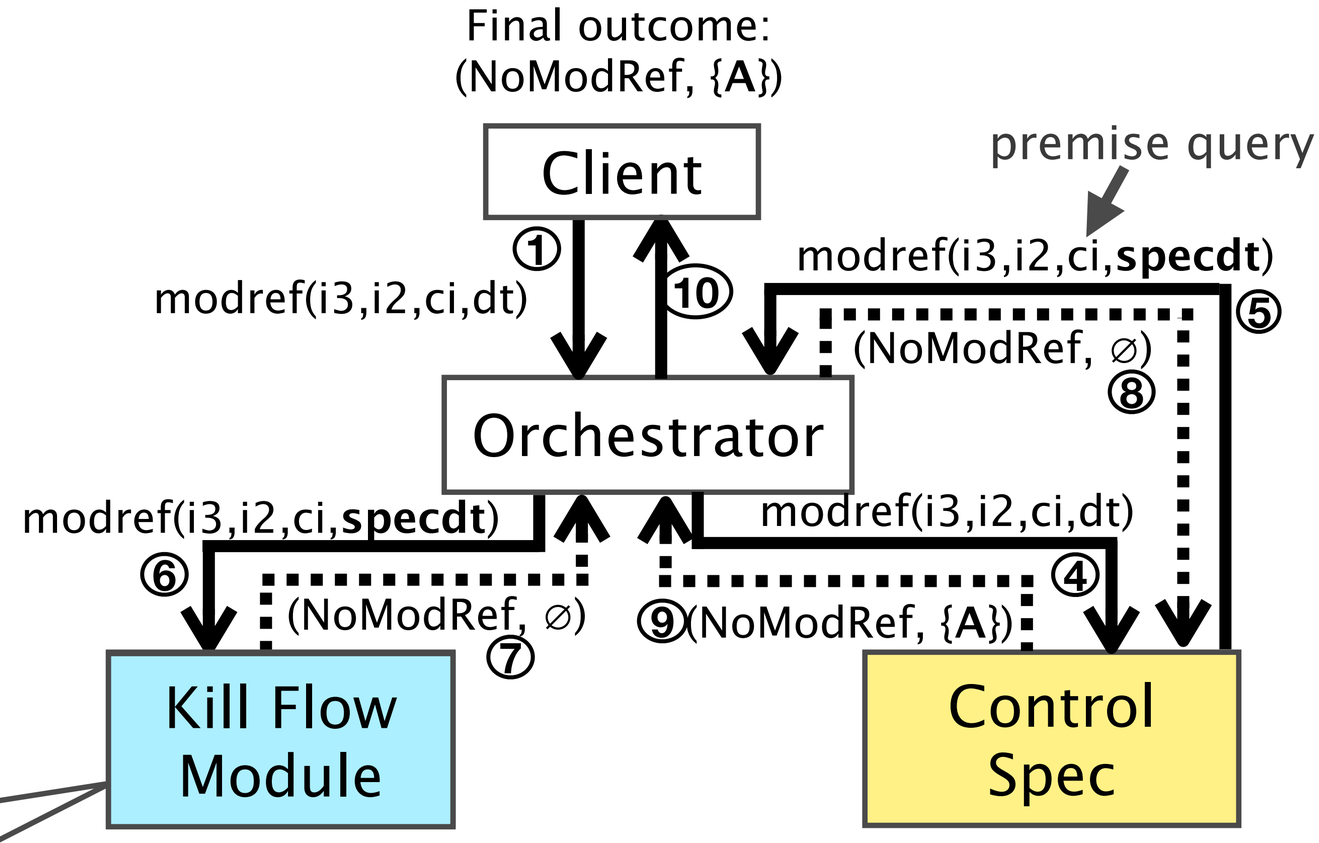


View of loop based on spec-dt



spec-dt encodes assertion that branch never taken

Speculation assertion **A:** branch never taken

SCAF’s Evaluation Methodology

SCAF's Evaluation Methodology

Empirically Evaluated Claim

SCAF reduces the need for memory speculation

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Benchmarks

16 C/C++ benchmarks from SPEC CPU

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Empirically Evaluated Claim

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Benchmarks

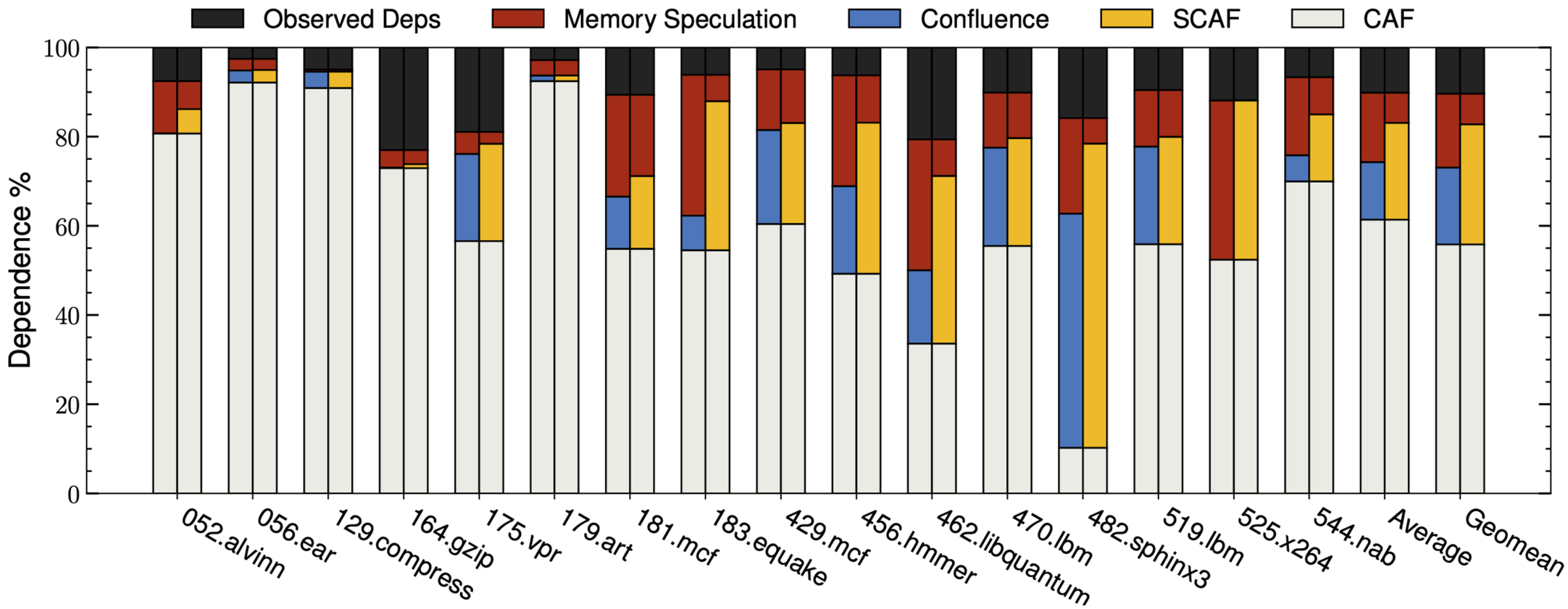
16 C/C++ benchmarks from SPEC CPU

State-of-art Baseline

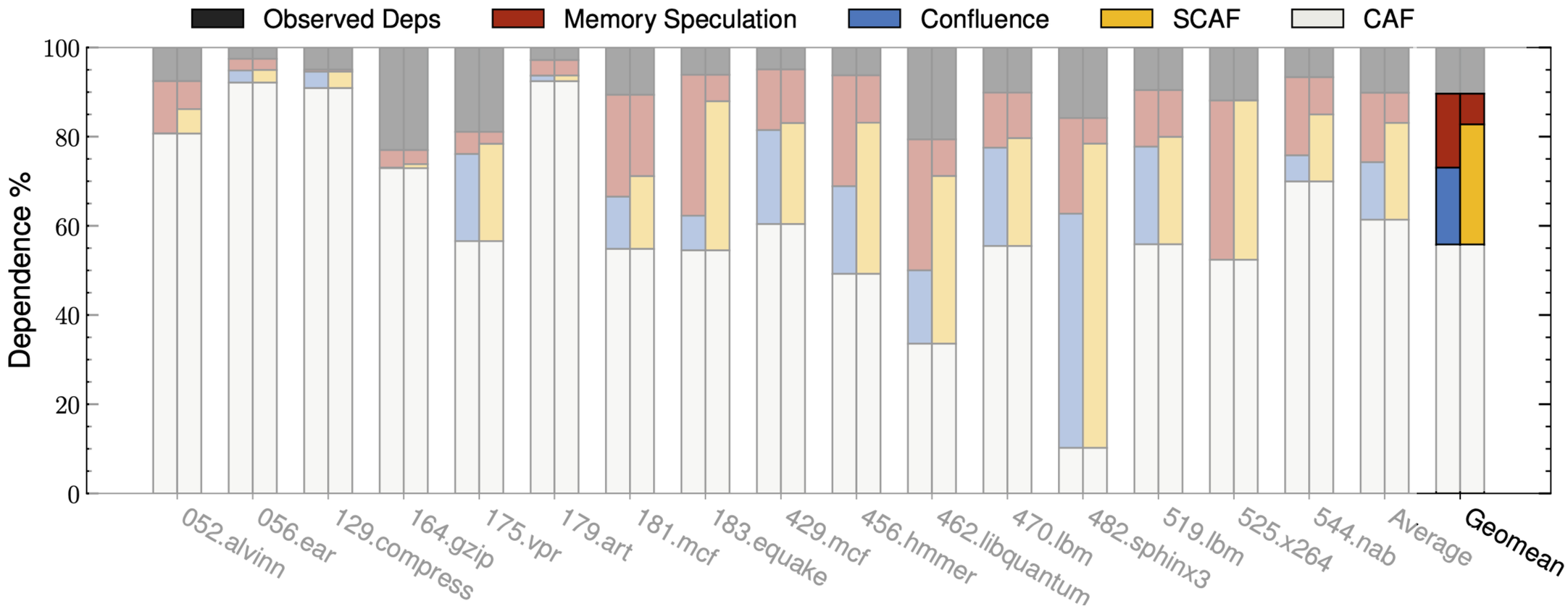
Composition by Confluence: analysis results are the confluence of results of individual components [1,2,3,4]

[1]Johnson et al., PLDI '12 [2]Kim et al., CGO '12 [3]Mehrara et al., PLDI '09 [4]Vachharajani et al., PACT '07

SCAF reduces need for expensive memory speculation



SCAF reduces need for expensive memory speculation



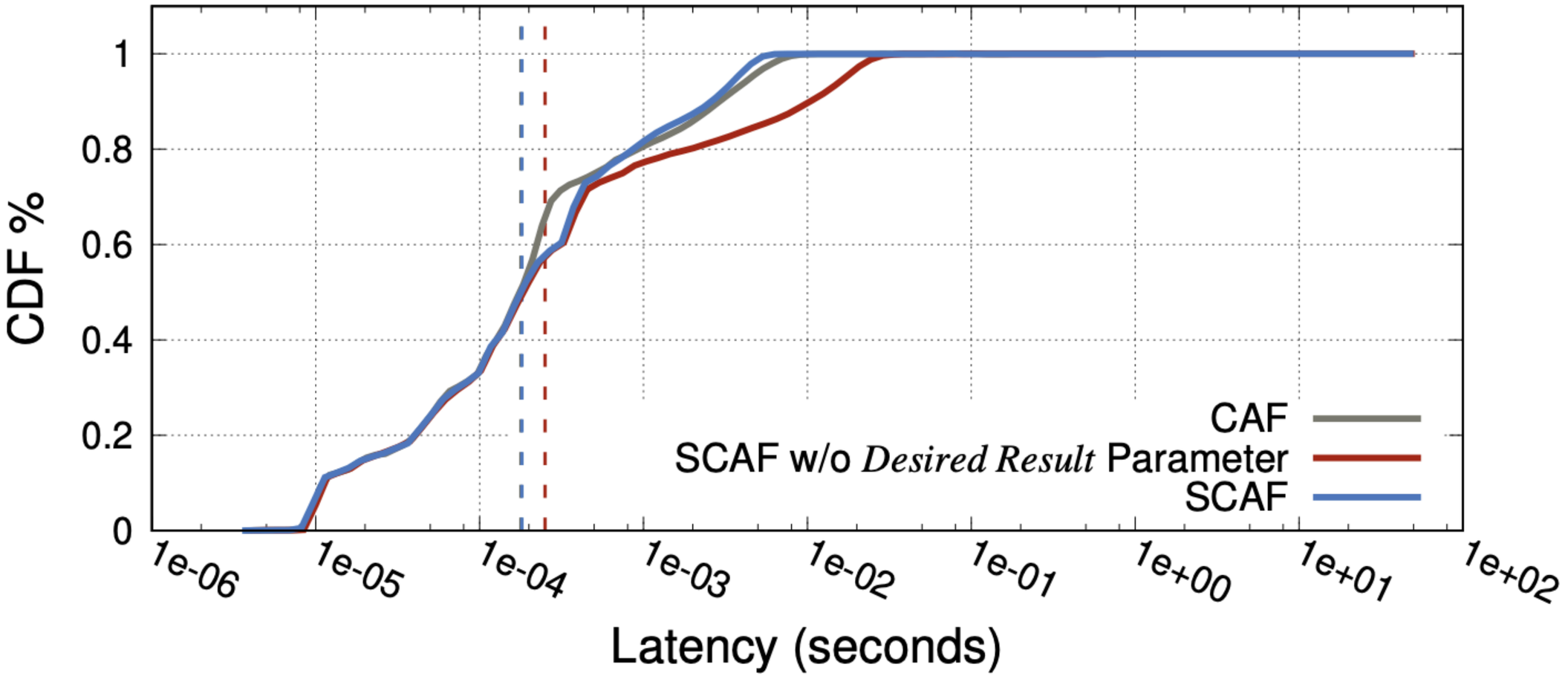
SCAF enables various Forms of Beneficial Collaboration

	Benchmark Coverage	Loop Coverage
Among Speculation Modules	87.5%	53.6%
Between Memory Analysis and Speculation Modules	93.8%	42.9%
All	100.0%	66.1%

Beneficial Collaboration: two or more modules collaboratively resolve more queries than in isolation

New Desired Result Parameter reduces Query Latency

28 % geomean reduction



Conclusion

- SCAF is a modular and collaborative dependence analysis framework that computes the full impact of speculation on memory dependence analysis
- SCAF dramatically reduces, compared to the state-of-the-art, the need for expensive-to-validate memory speculation.
- SCAF is essential for memory analysis sensitive clients and a necessary step toward robust automatic parallelization

Artifact available: https://doi.org/10.5281/zenodo.3751586