INTERPROCEDURAL SPECIALIZATION OF HIGHER-ORDER DYNAMIC LANGUAGES WITHOUT STATIC ANALYSIS

ECOOP
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Université de Montréal

INTRODUCTION

- Research on JIT compilation
  - Dynamic languages
  - Dynamic techniques

- *LC*: Research oriented Scheme compiler
  - Scheme and Functional Programming Workshop 2014 & 2015
  - https://github.com/bsaleil/lc

INTRODUCTION

- Dynamic languages
  - Work done at compilation ↓
  - Work done at execution ↑
- Dynamic type checking
  - Ensures safety of the primitives :)
  - Impact on performance :(

DYNAMIC TYPE CHECKING

- Example

```
(define (sum-to-10 x)
  (if (> x 10)
      0
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4 type checks in this code

- How can we remove them ?

INTERPROCEDURAL SPECIALIZATION

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INTERPROCEDURAL SPECIALIZATION

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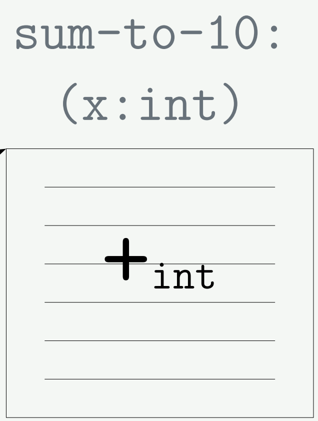

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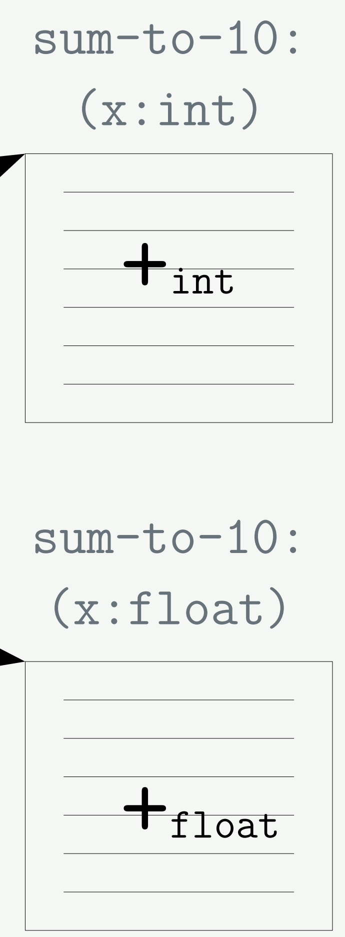

RUNNING EXAMPLE: HIGHER ORDER FUNCTION

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(define (make-sumer n)
  (letrec ((f (lambda (x)      ← Closure that captures n
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(define sum-to-10 (make-sumer 10))
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; 6 + 7 + 8 + 9 + 10
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→ Static analysis (e.g. *0*-CFA)

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INTERPROCEDURAL SPECIALIZATION

INTERPROCEDURAL SPECIALIZATION OF HIGHER-ORDER LANGUAGES

INTERPROCEDURAL SPECIALIZATION OF HIGHER-ORDER DYNAMIC LANGUAGES

INTERPROCEDURAL SPECIALIZATION OF HIGHER-ORDER DYNAMIC LANGUAGES WITHOUT STATIC ANALYSIS

Interprocedural Specialization of Higher-Order Dynamic Languages Without Static Analysis

→ Basic Block Versioning (BBV)

- *Simple and Effective Type Check Removal through Lazy Basic Block Versioning*
  Maxime Chevalier-Boisvert and Marc Feeley, ECOOP 2015
- Lazy intraprocedural code specialization (JIT)
- No static analysis
- Dynamic languages (JavaScript, Scheme, …)

NAIVE COMPILATION

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5 checks needed

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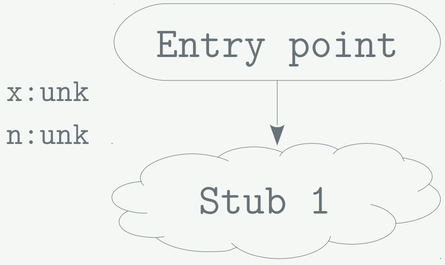

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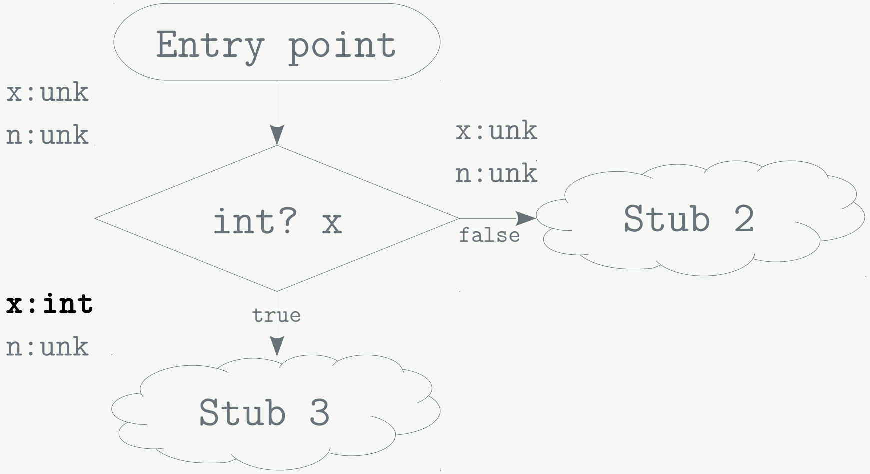

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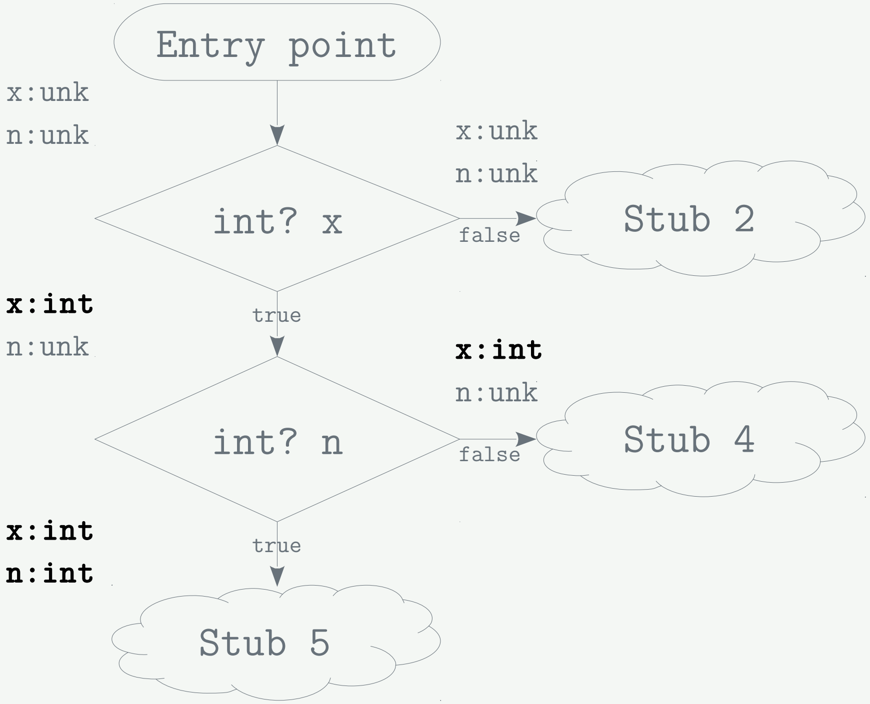

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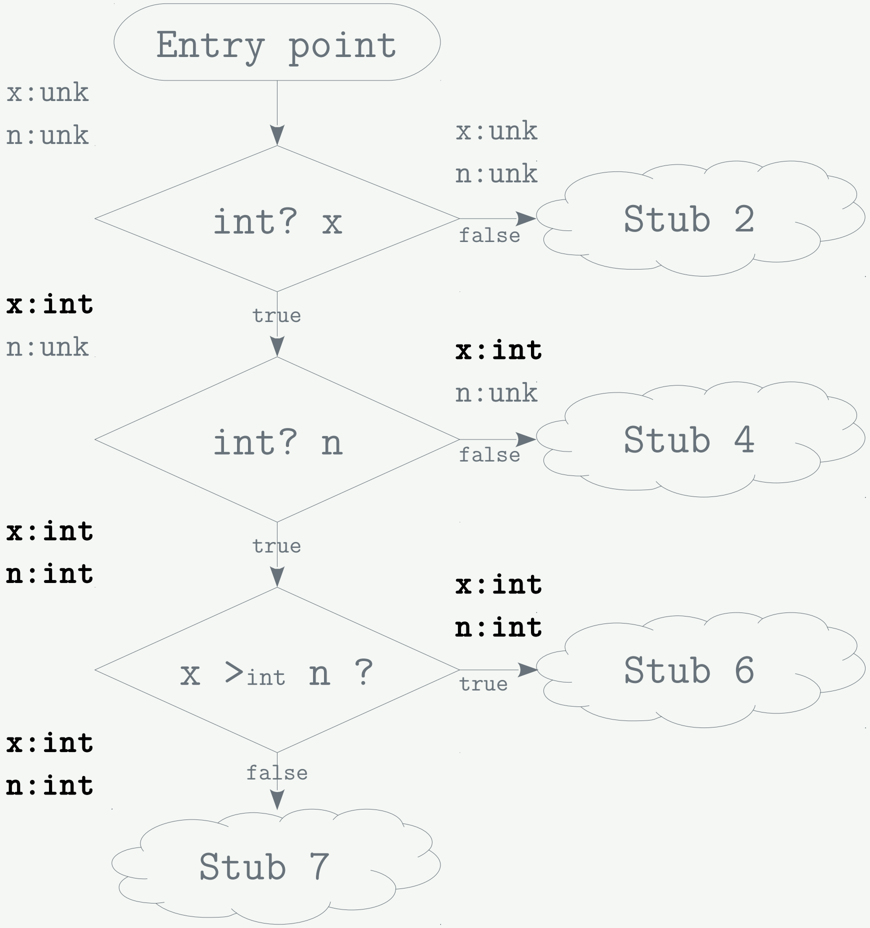

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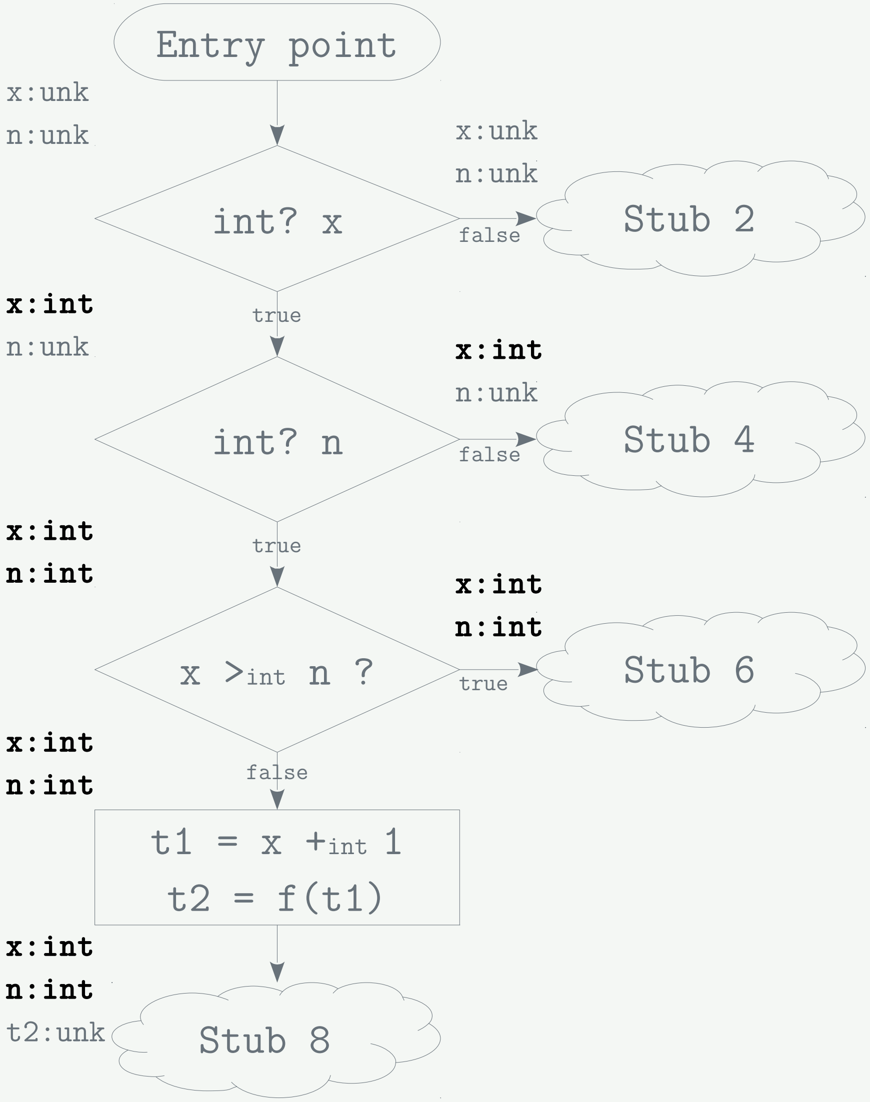

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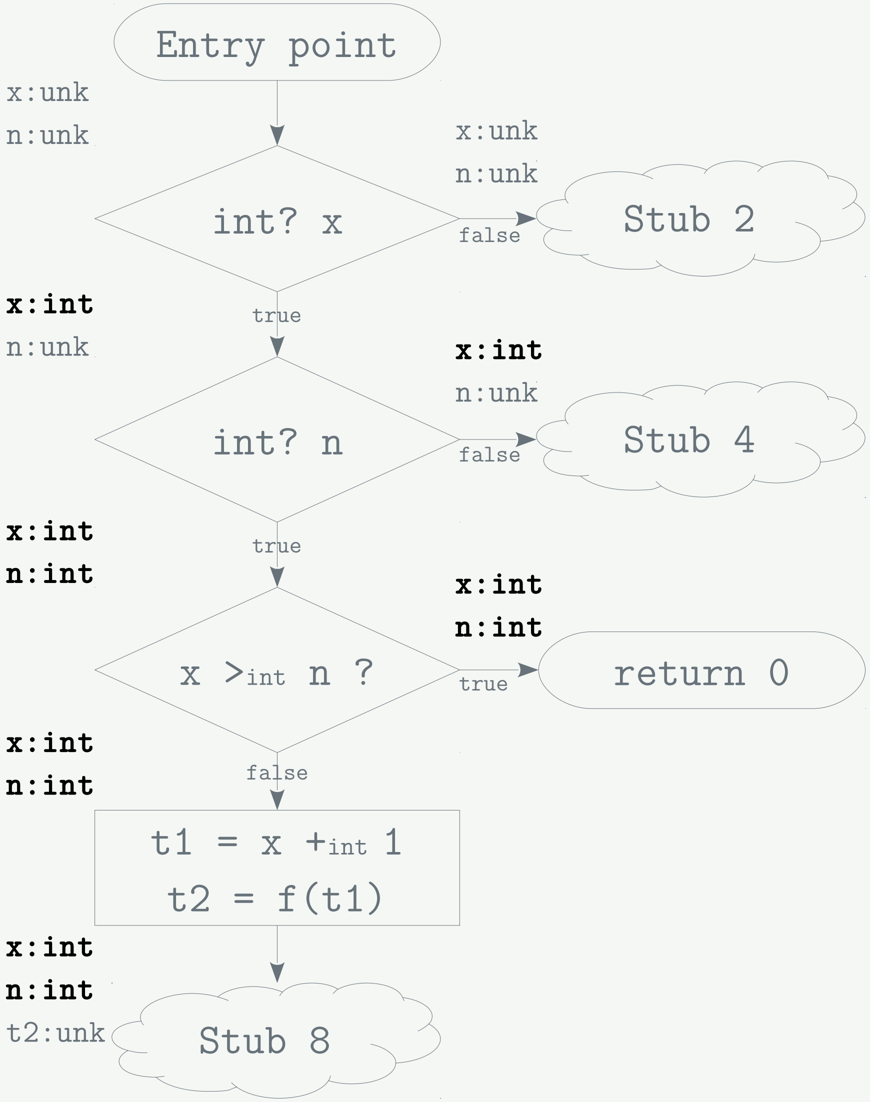

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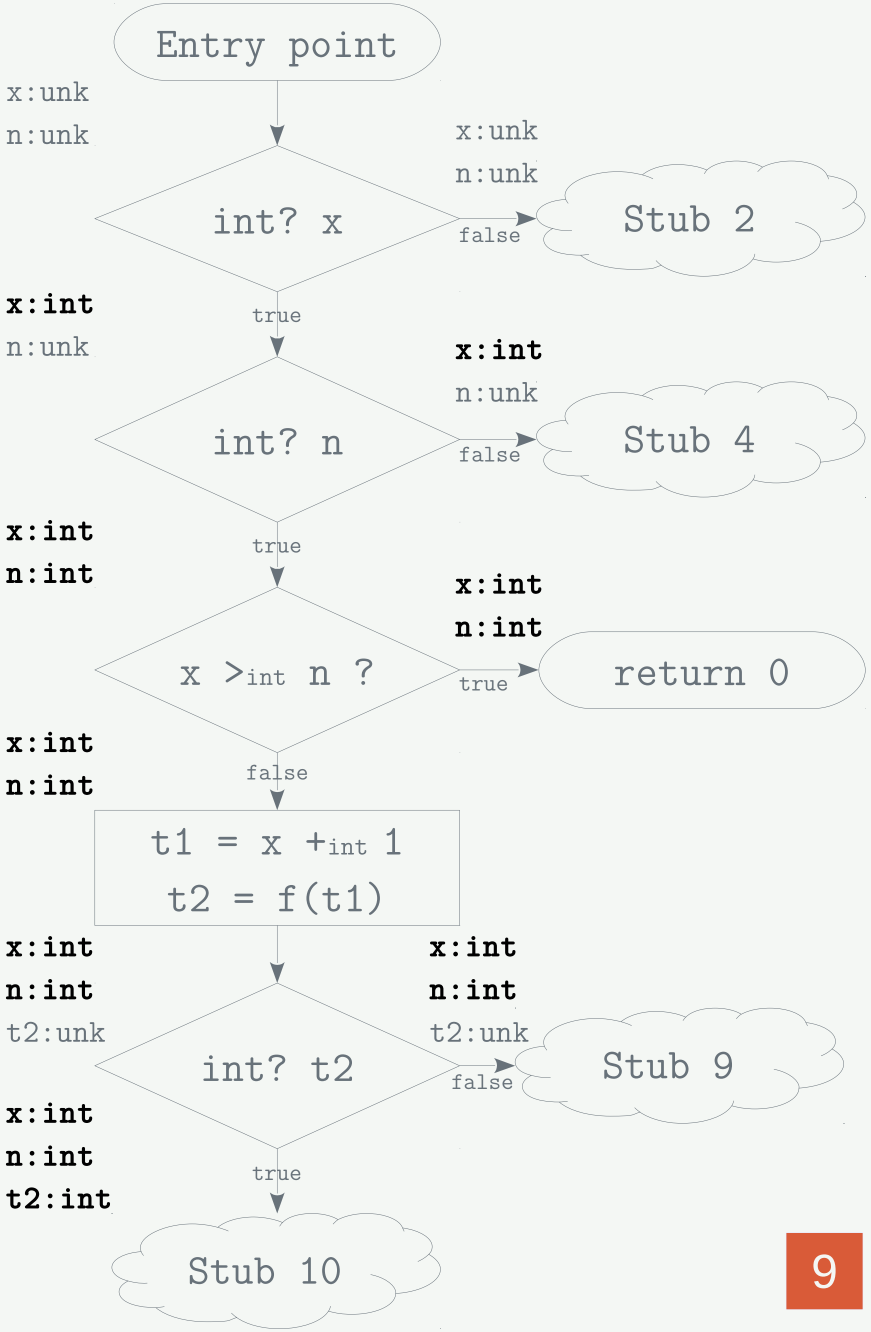

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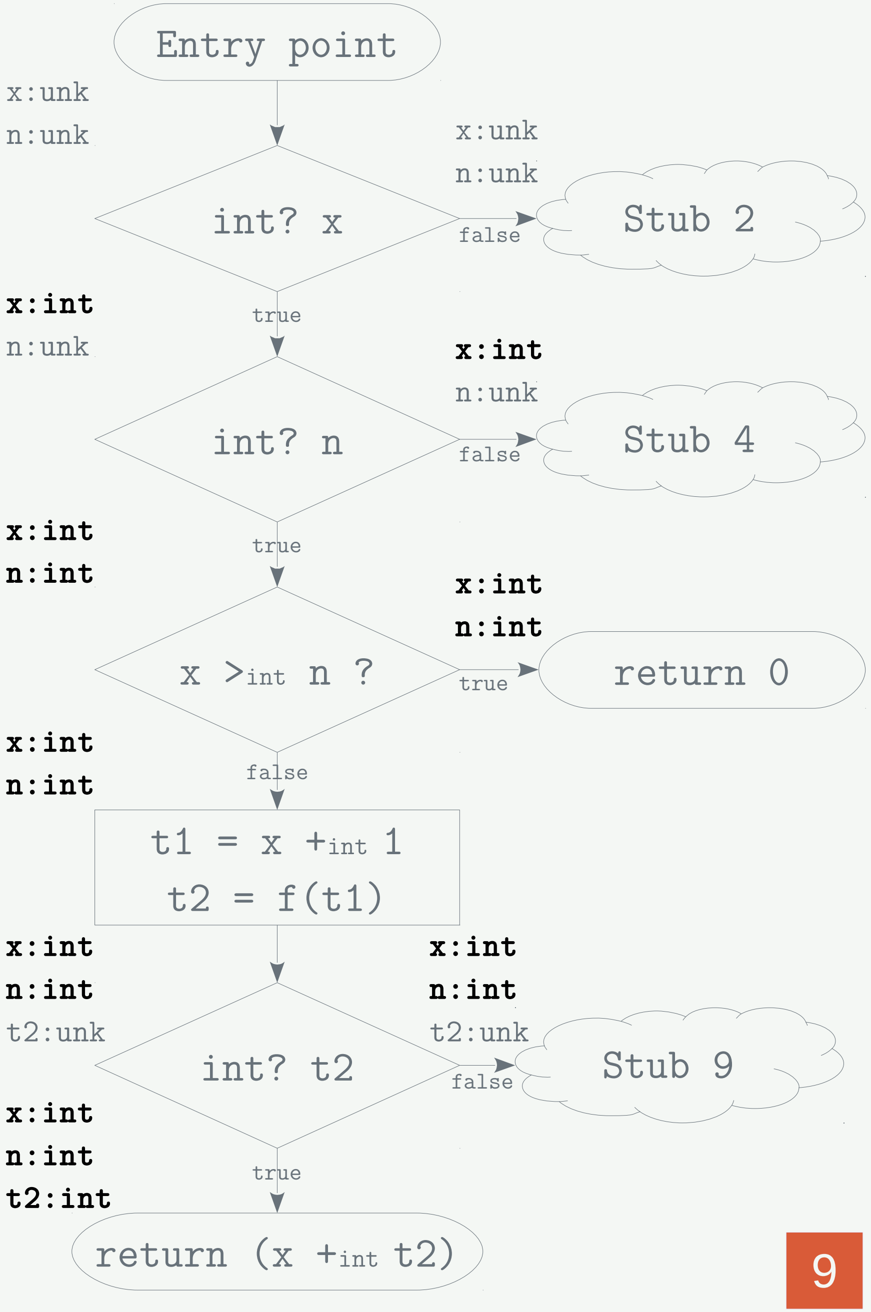

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3 checks needed
(2 removed)

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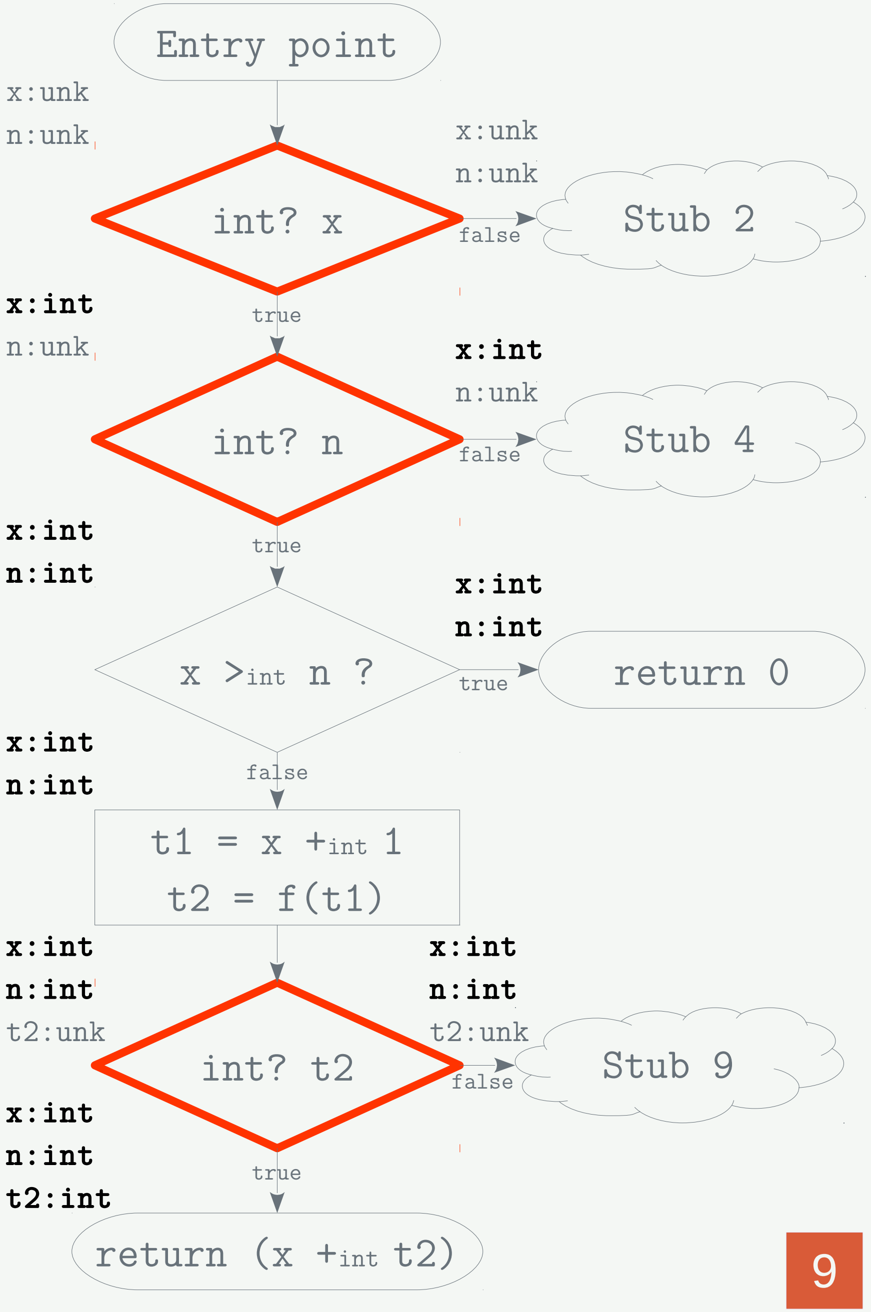

OUR WORK: INTERPROCEDURAL EXTENSIONS

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```

1 check needed
(4 removed)

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```

no checks needed
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- Propagate the types through function calls
  → no check on x
- Propagate the types through function returns
  → no check on the returned value
- Specialize the code using captured information
  → no check on n

OUR WORK: INTERPROCEDURAL EXTENSIONS

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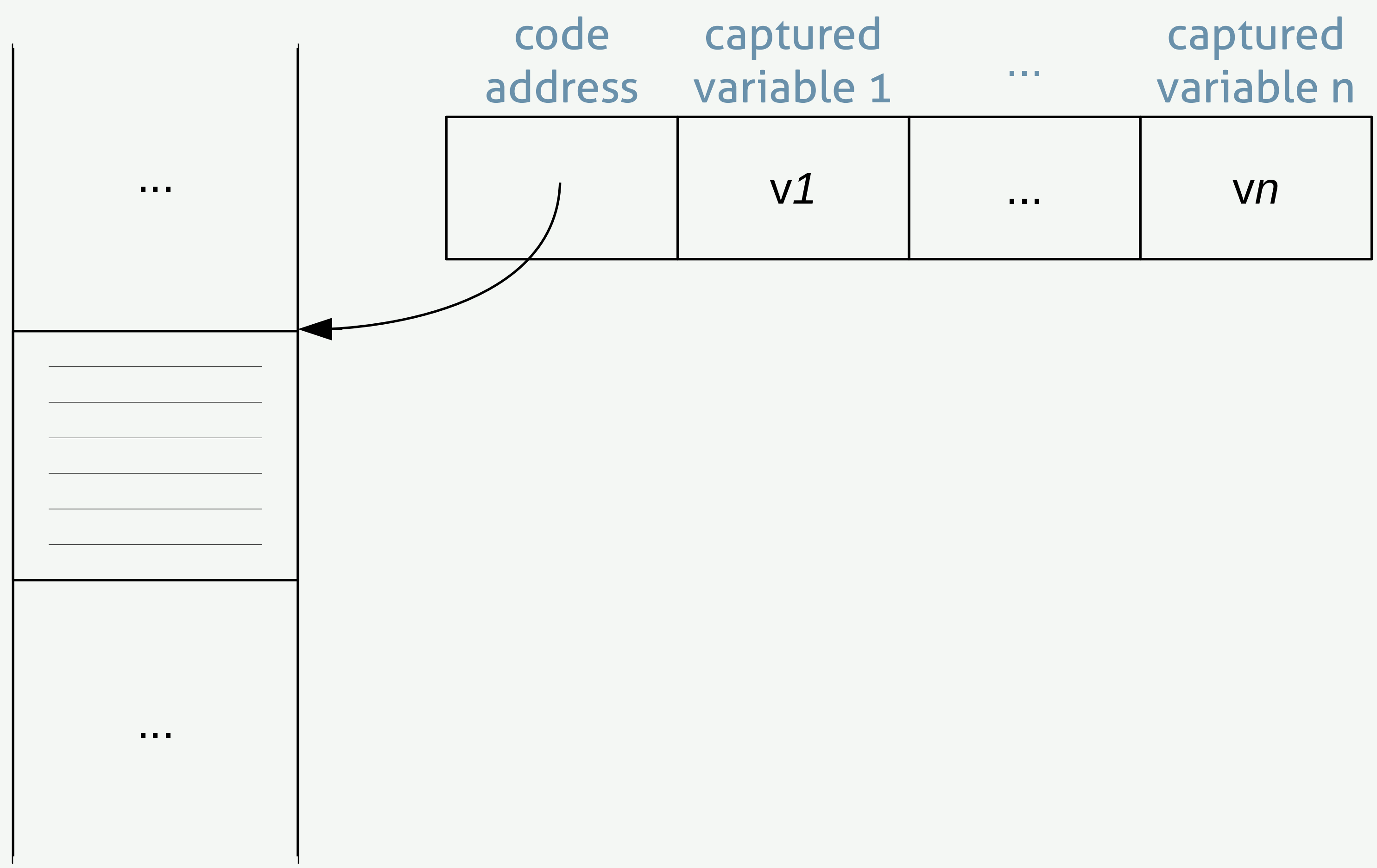
IMPLEMENTATION

Closure representation extension

FLAT CLOSURE REPRESENTATION



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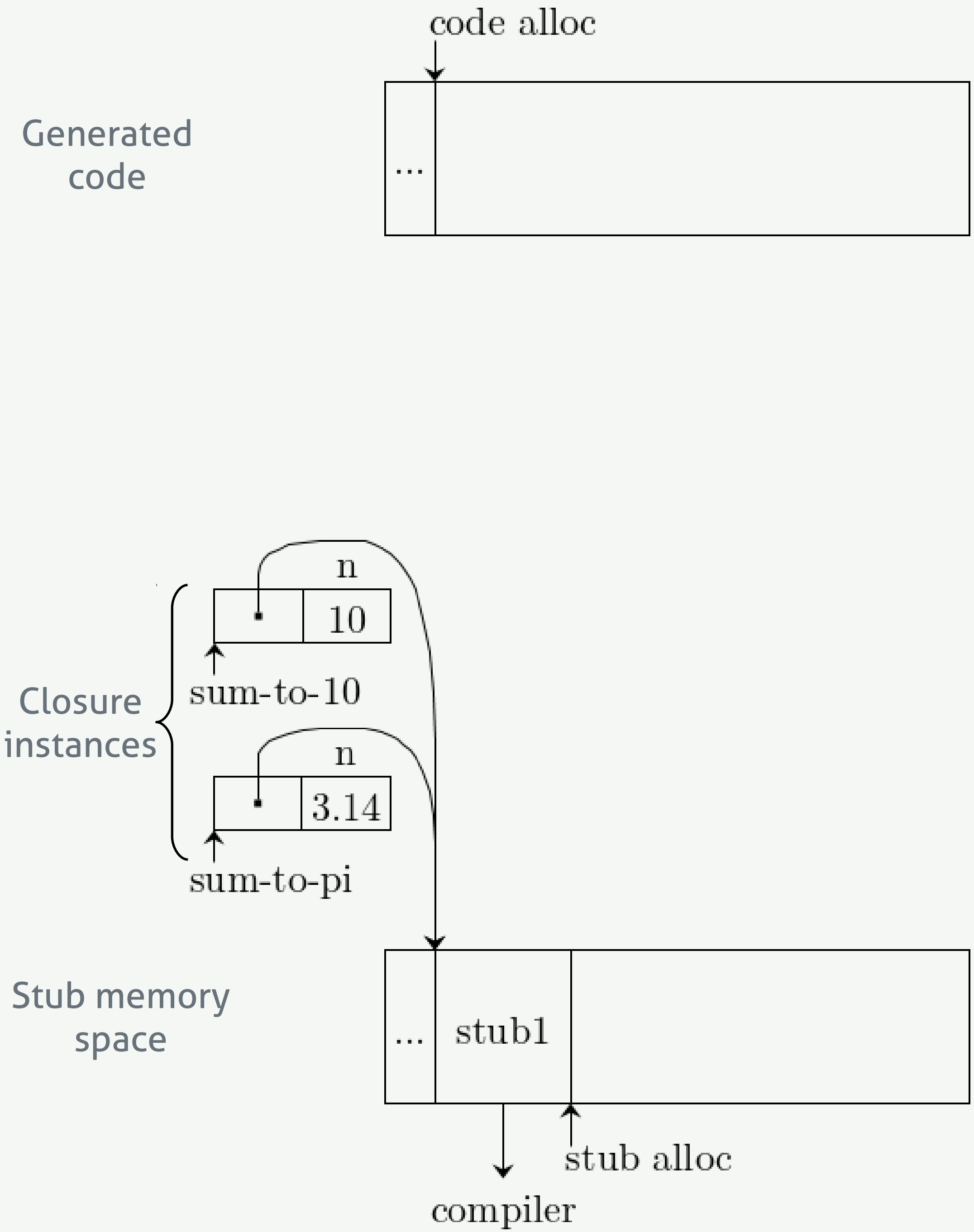


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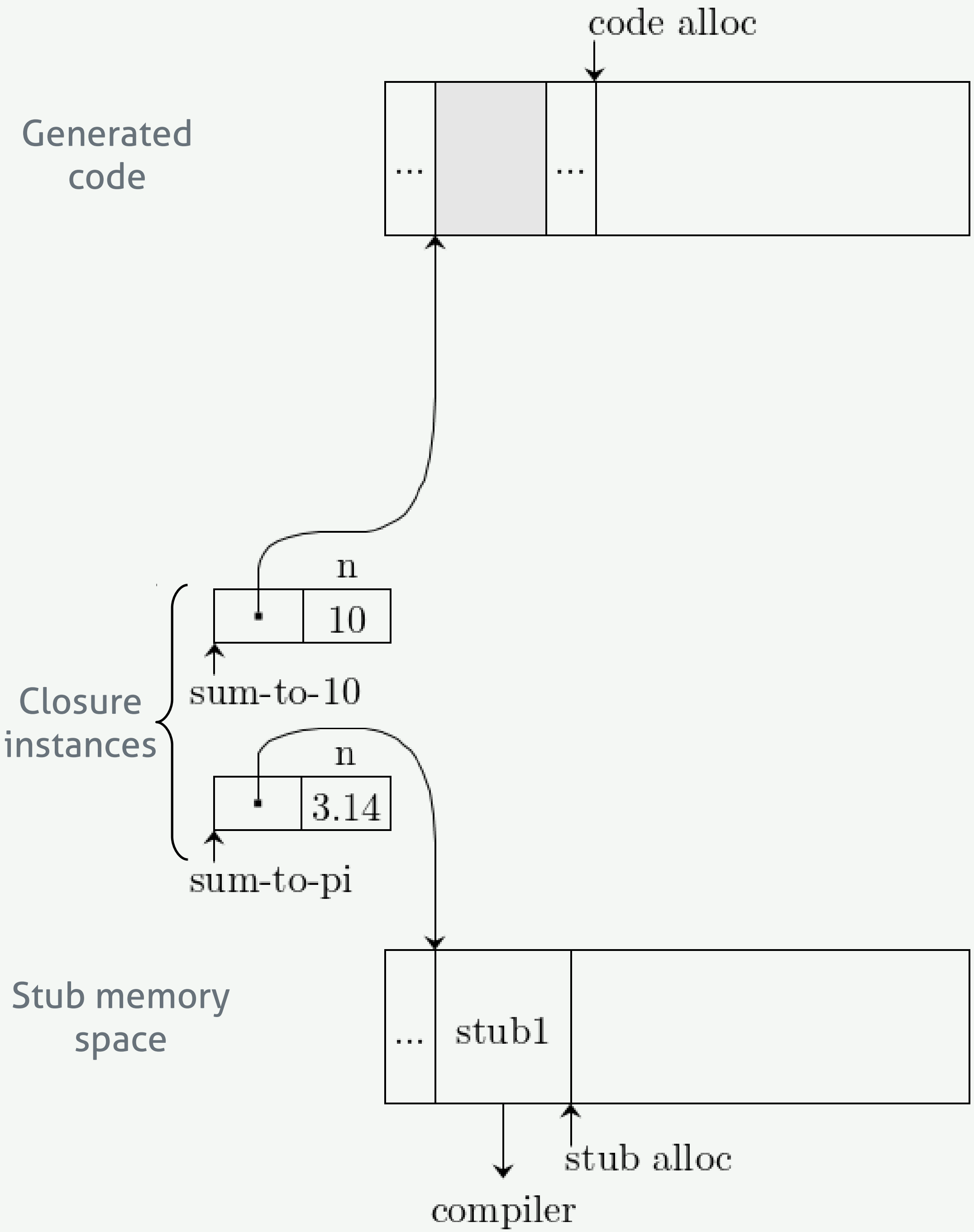


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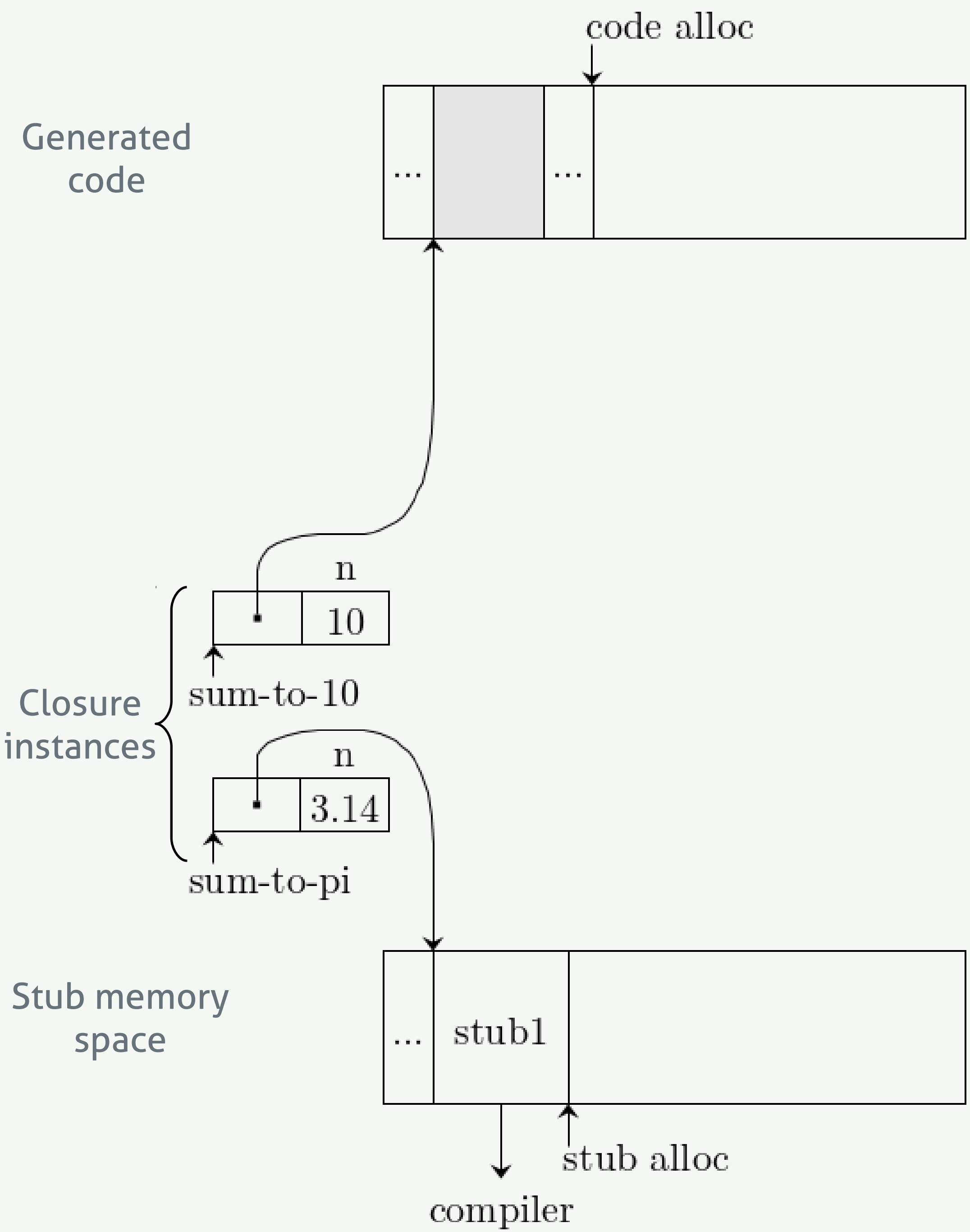


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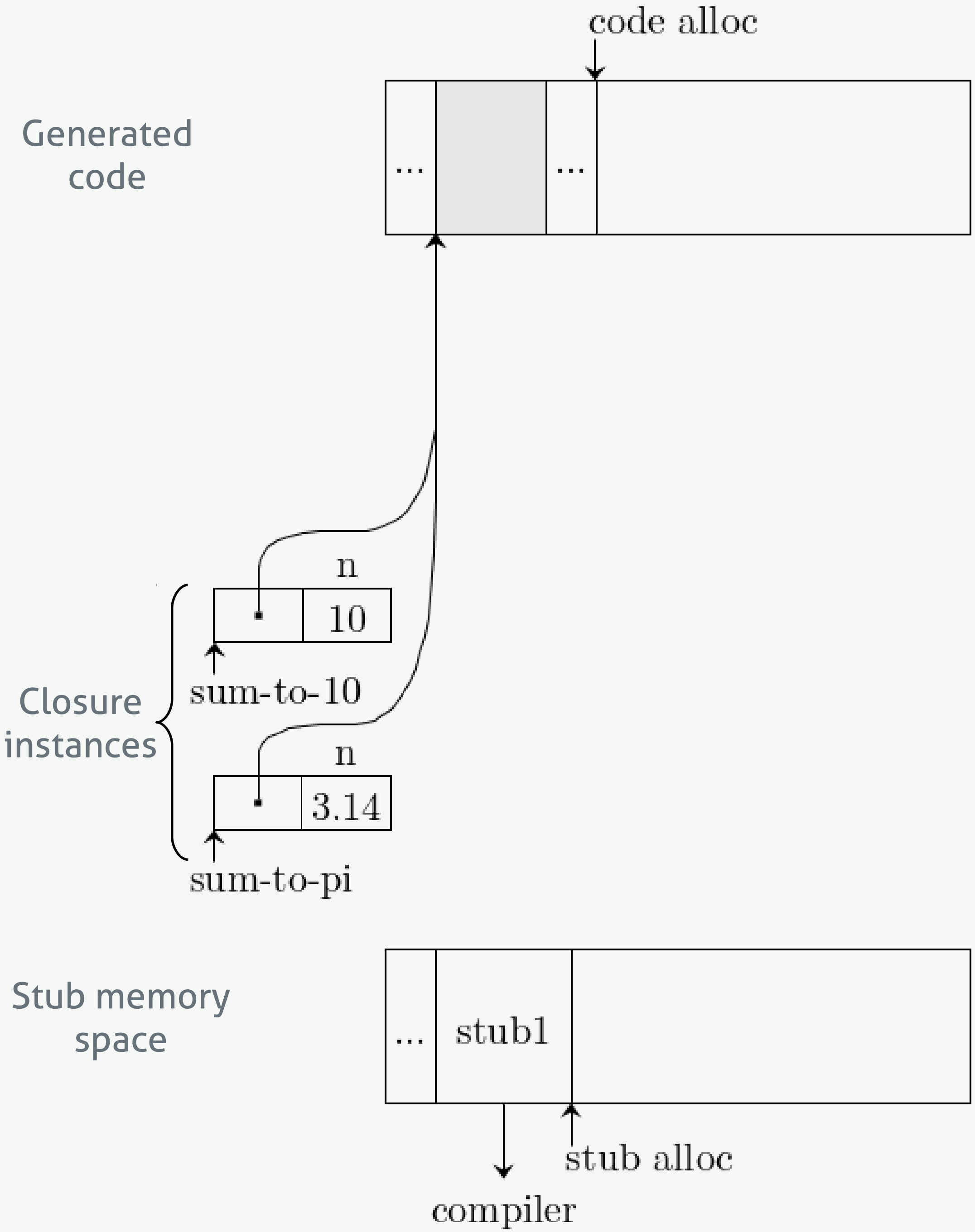


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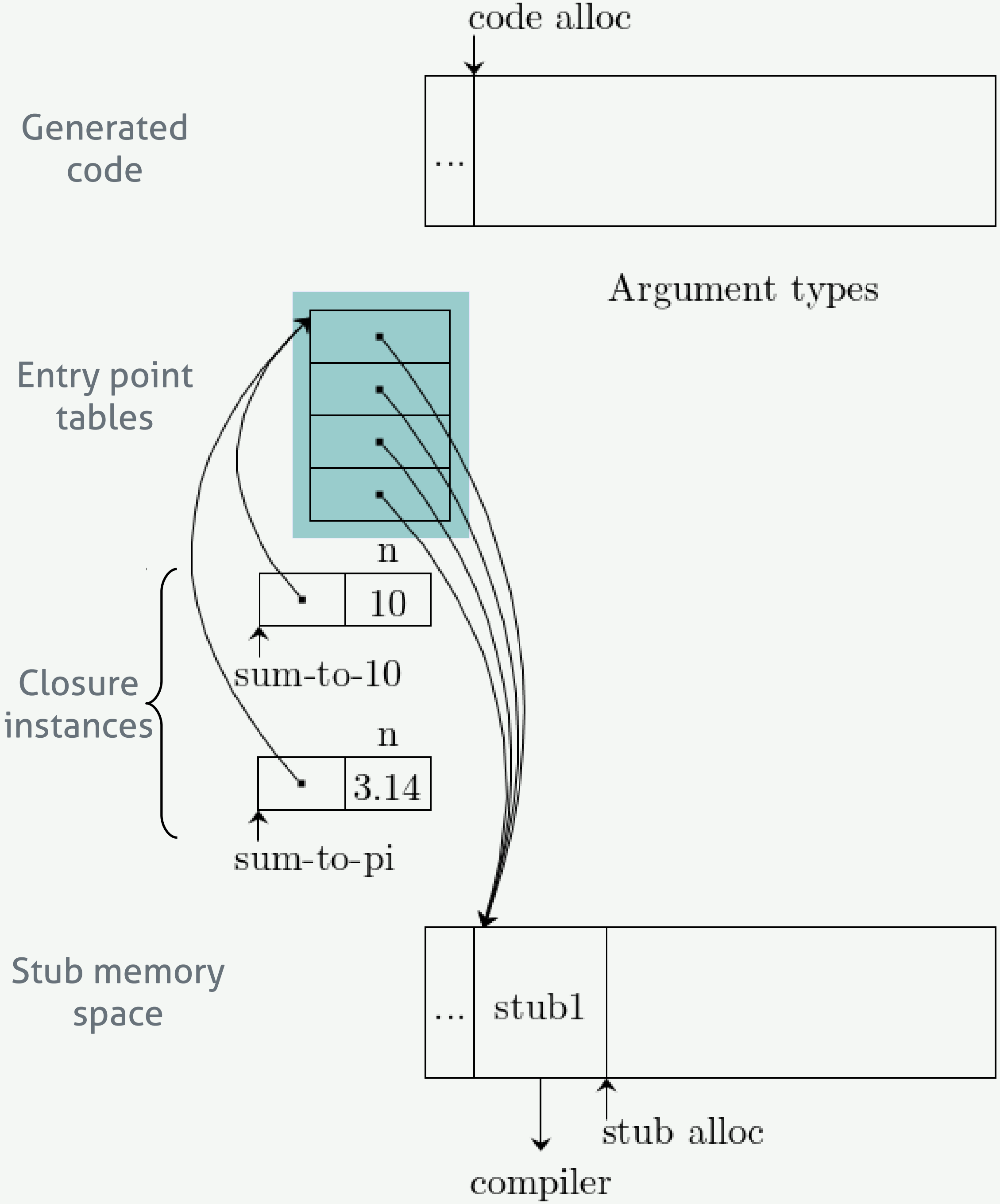


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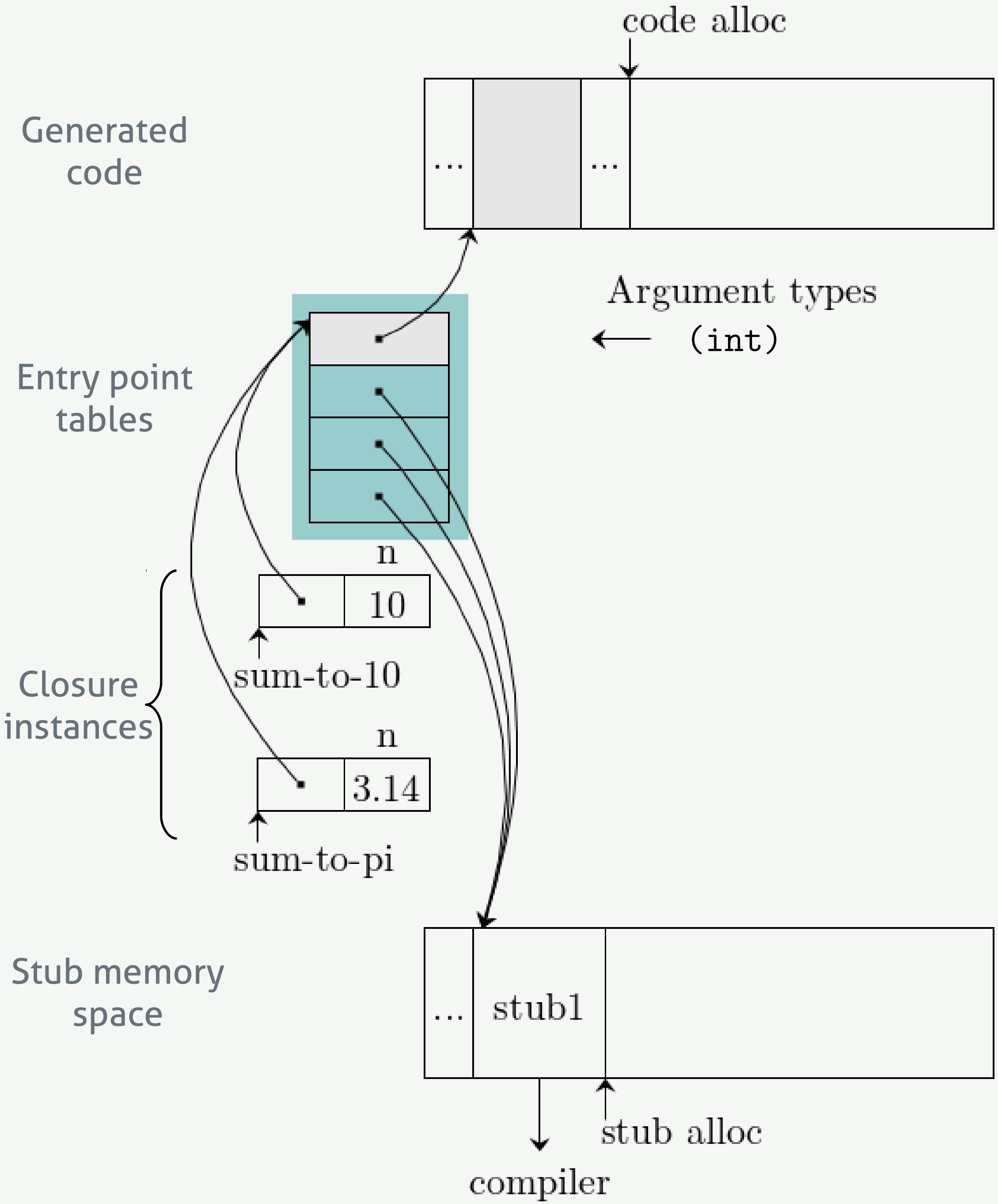


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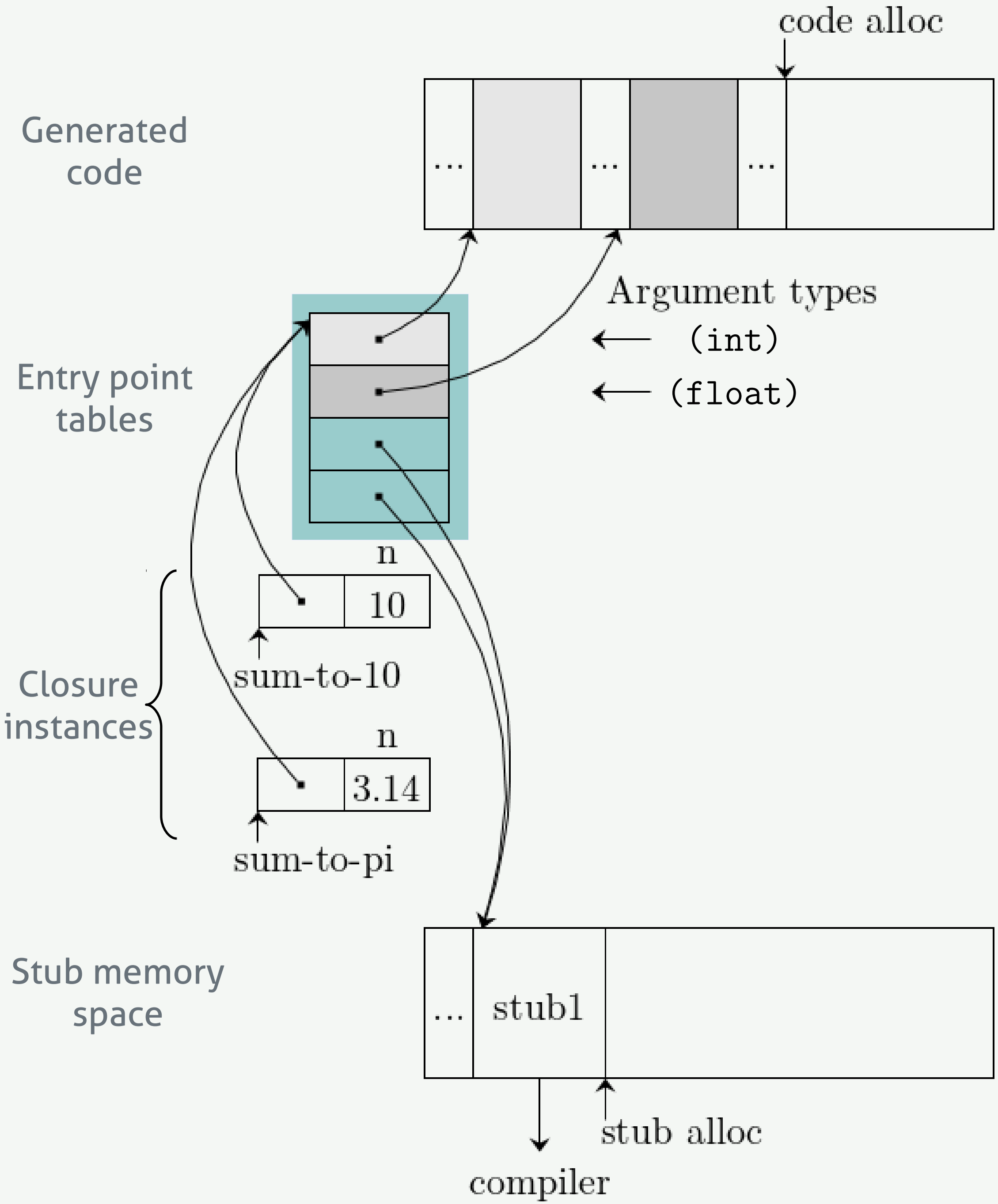


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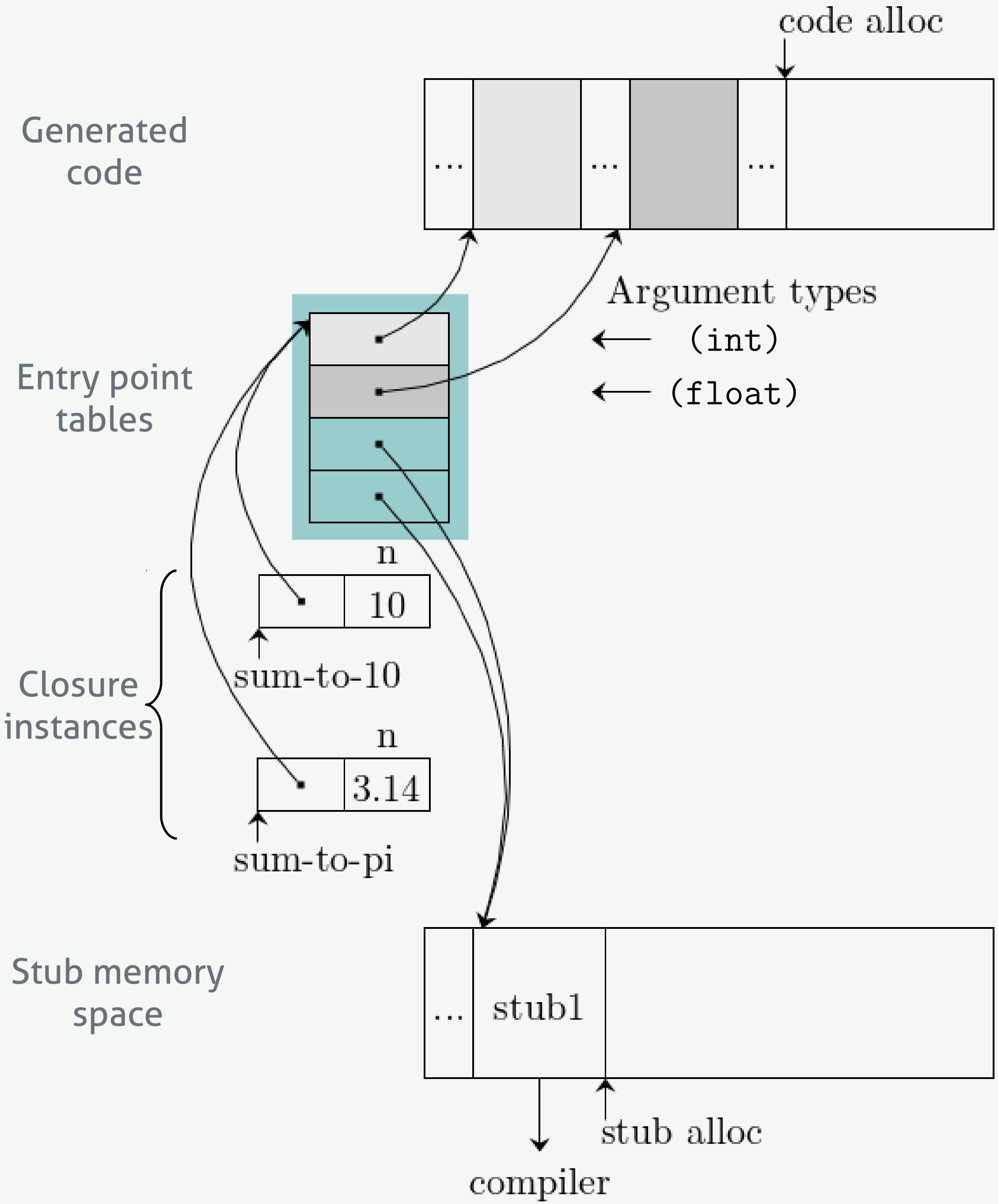
IMPLEMENTATION: FLAT CLOSURE EXTENSION

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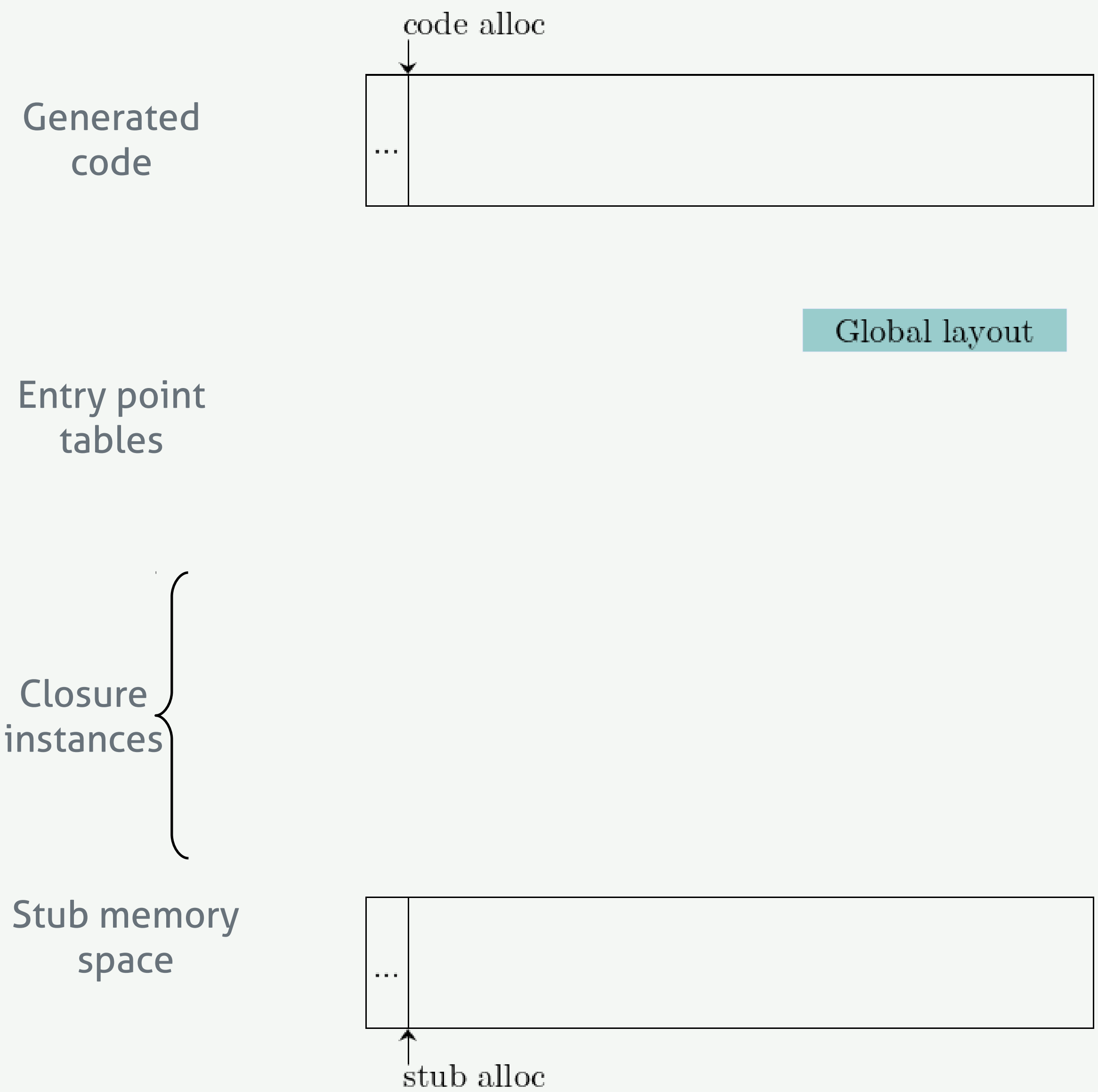
IMPLEMENTATION

Dynamic dispatch

IMPLEMENTATION: DYNAMIC DISPATCH

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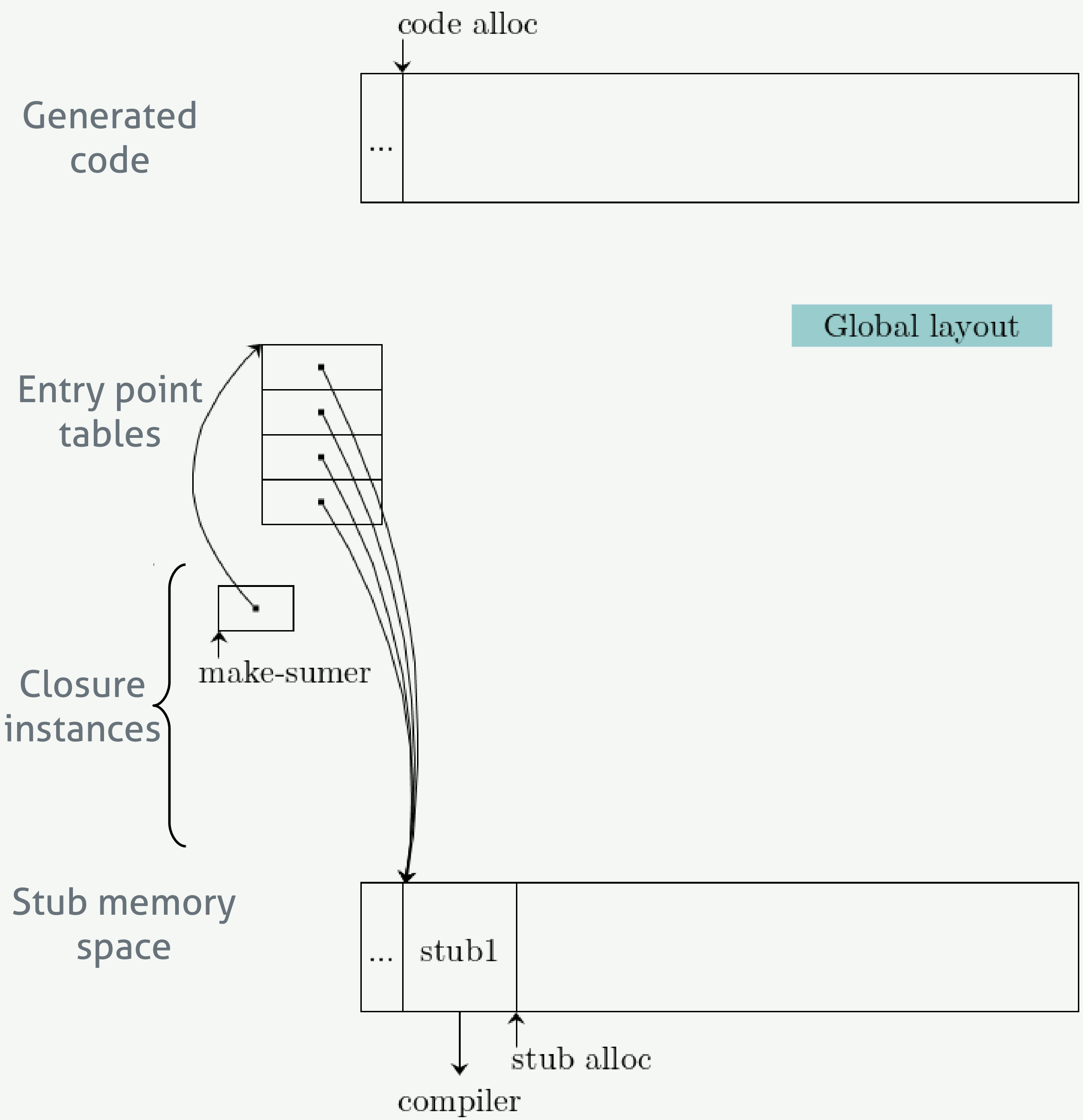


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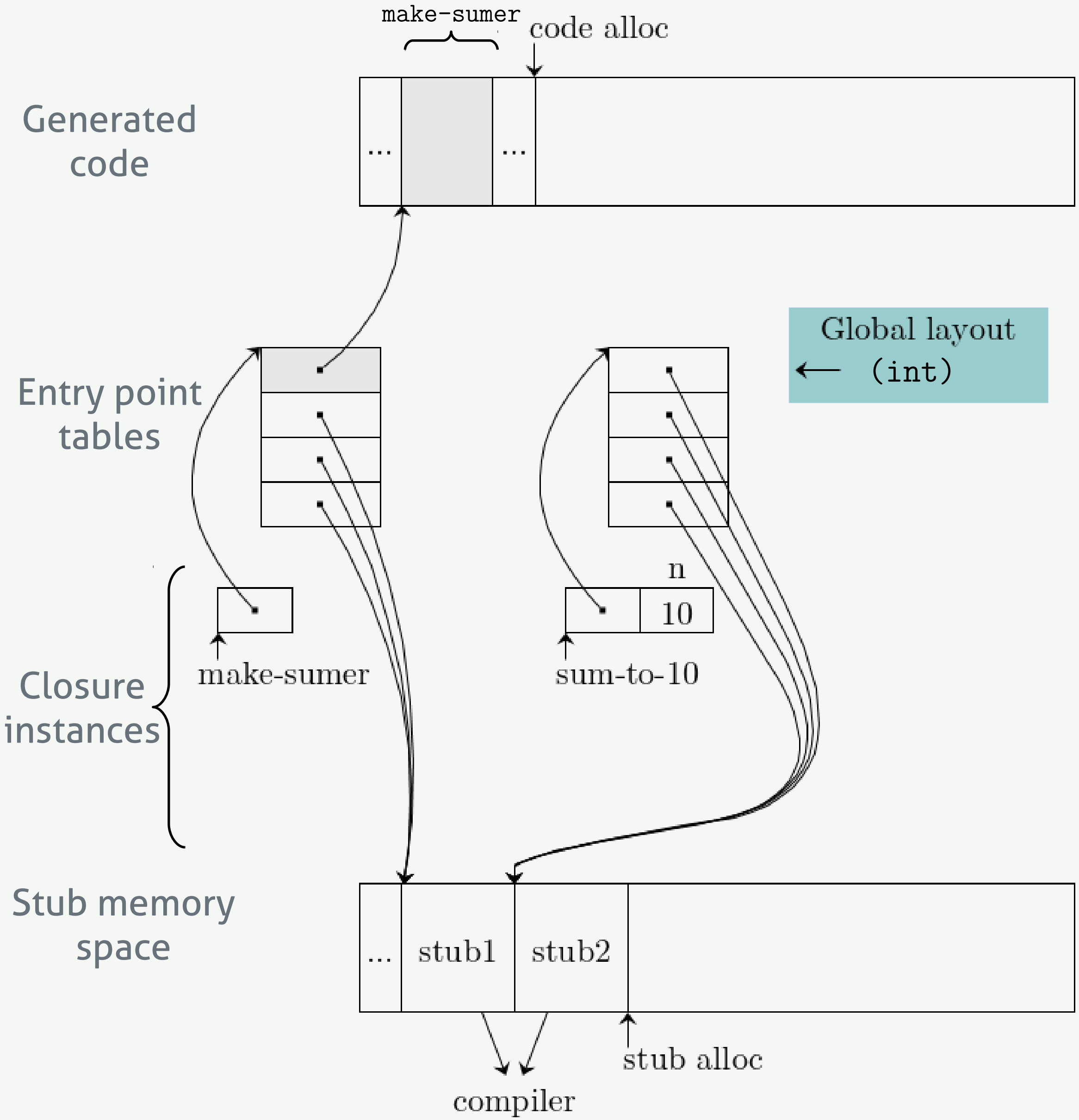


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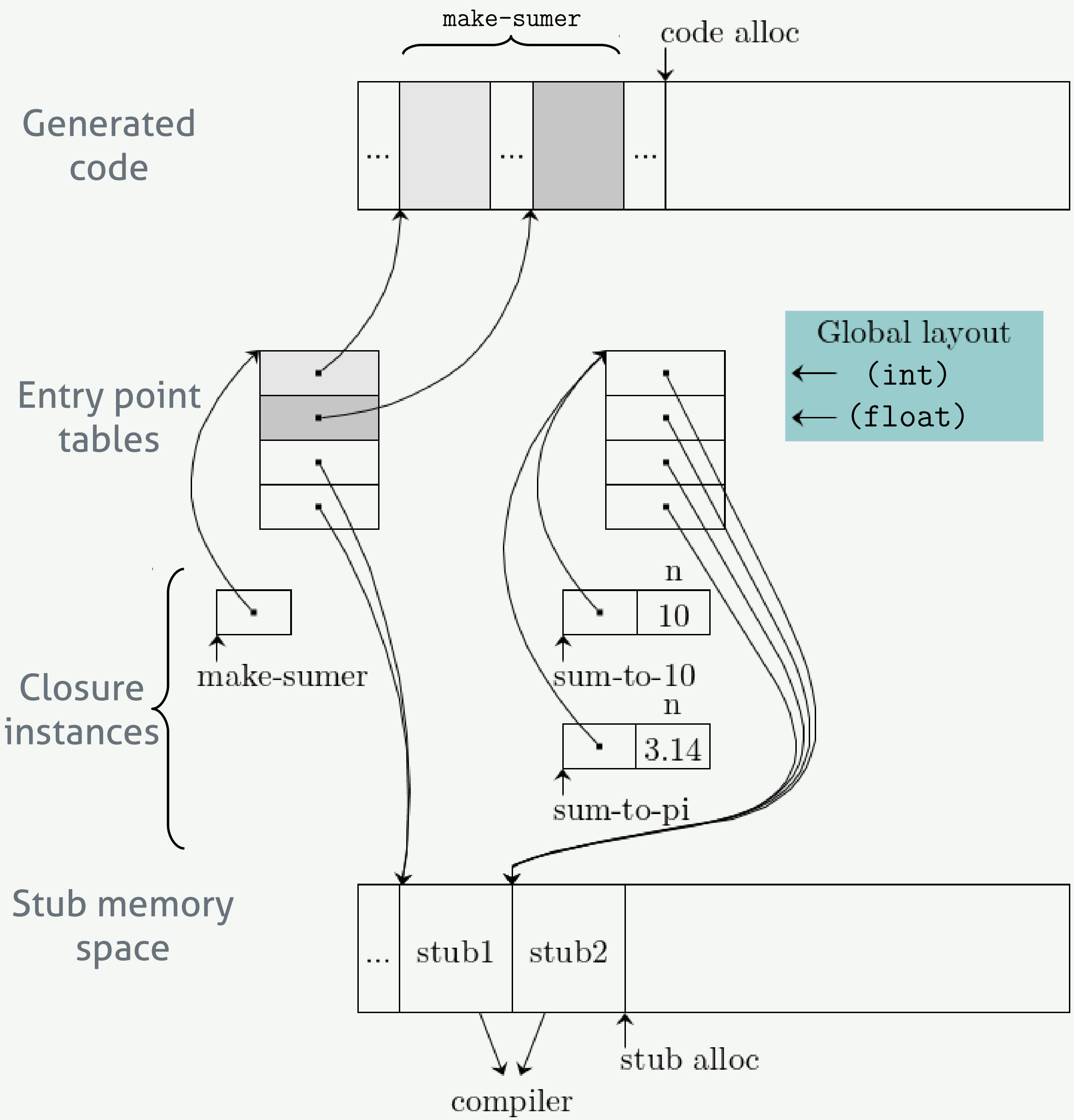


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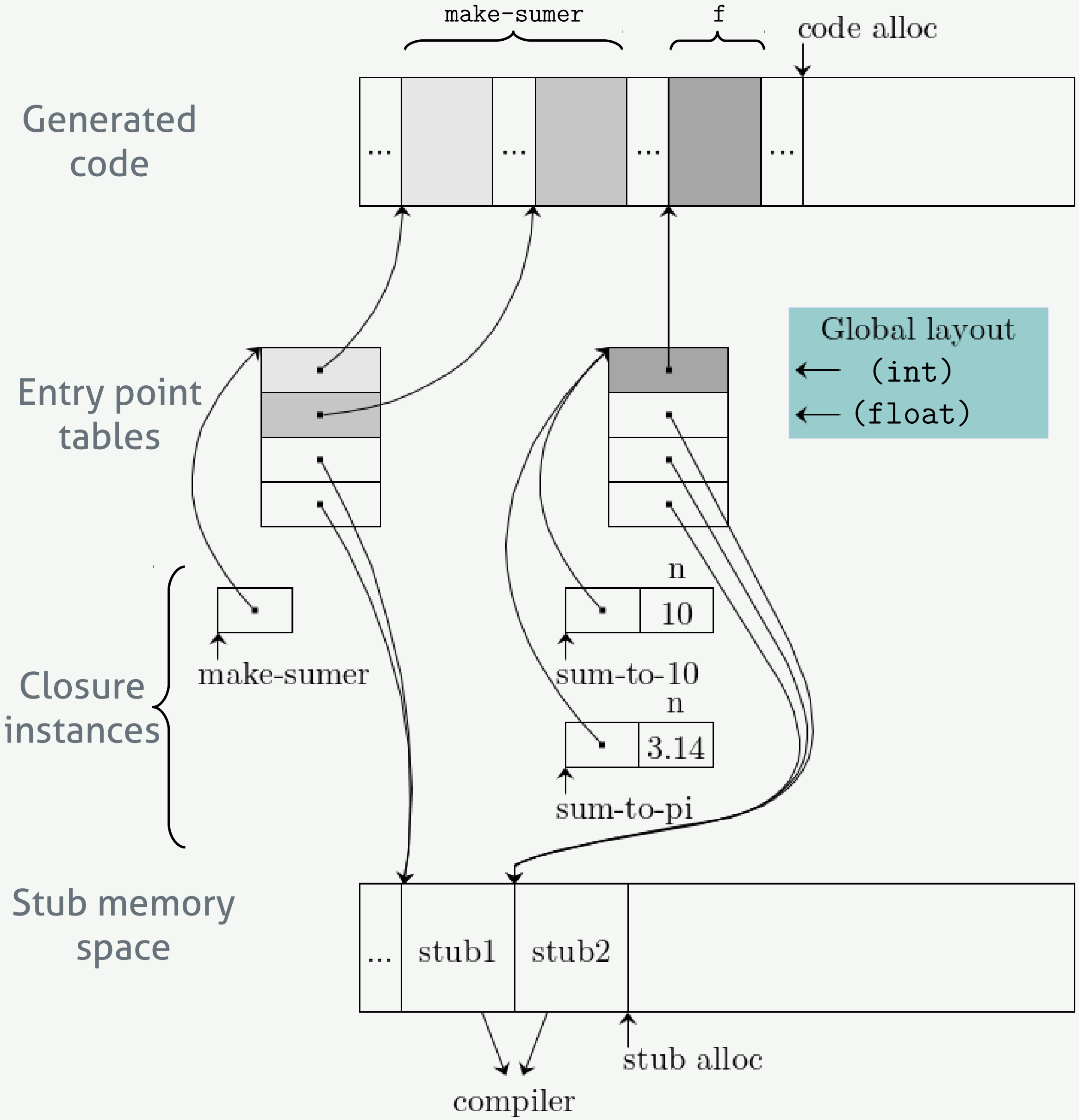


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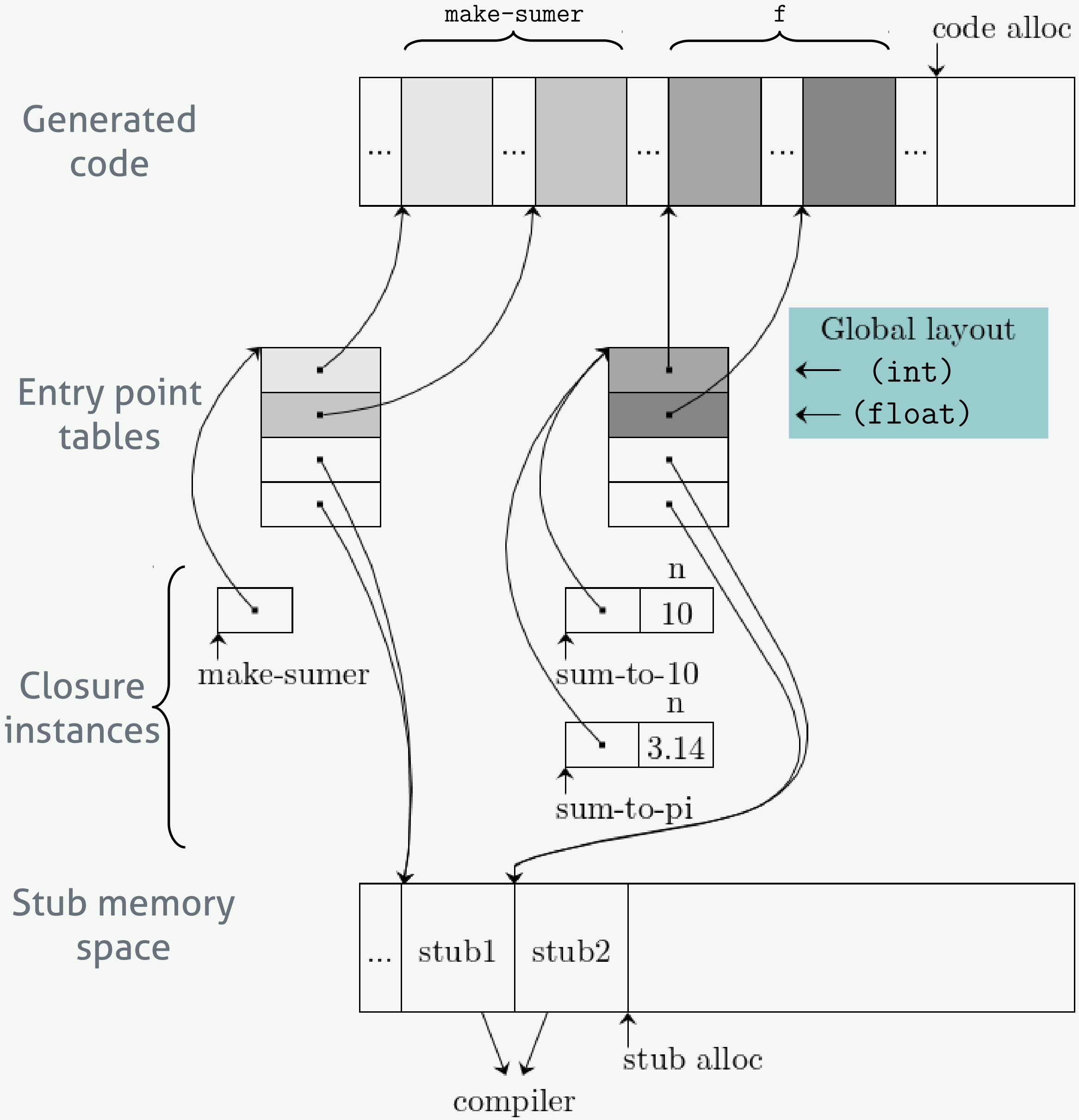


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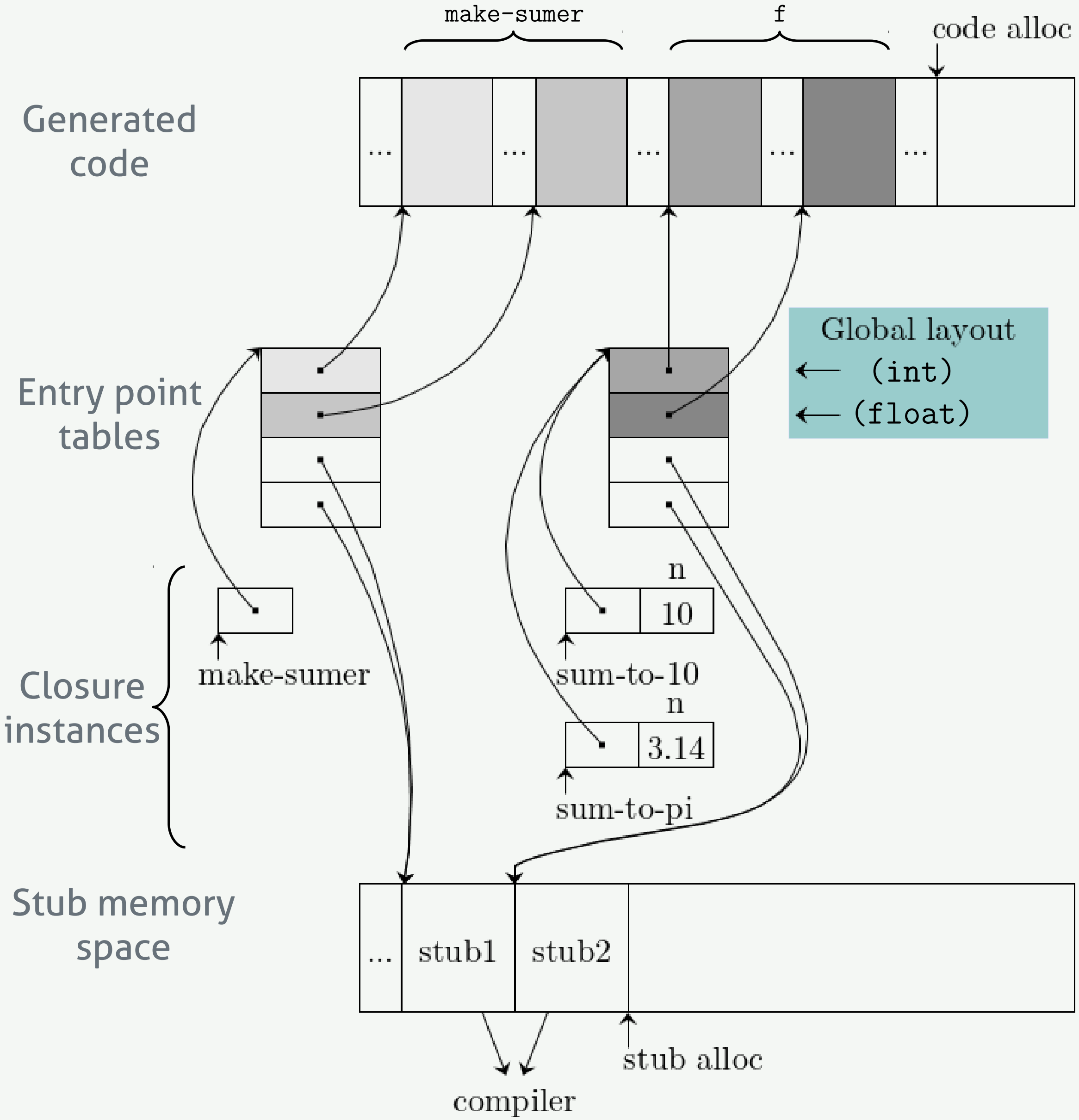


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IMPLEMENTATION

Captured information

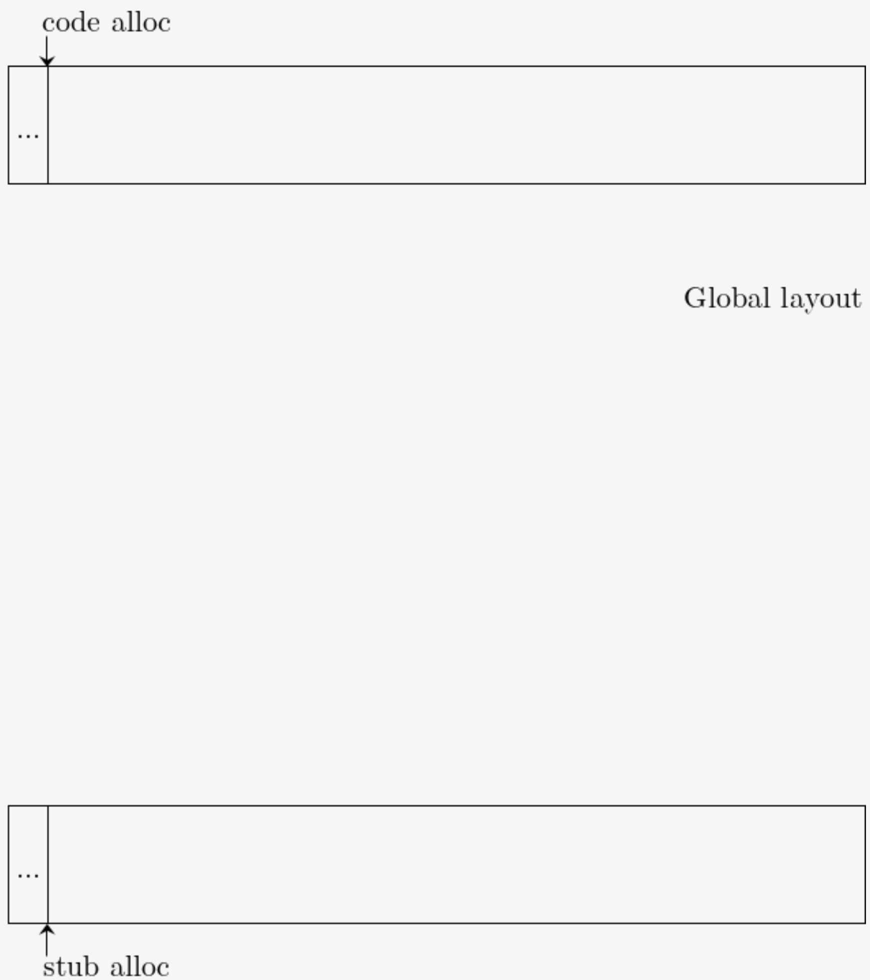
IMPLEMENTATION: CAPTURED INFORMATION

Generated code

Entry point tables

Closure instances

Stub memory space

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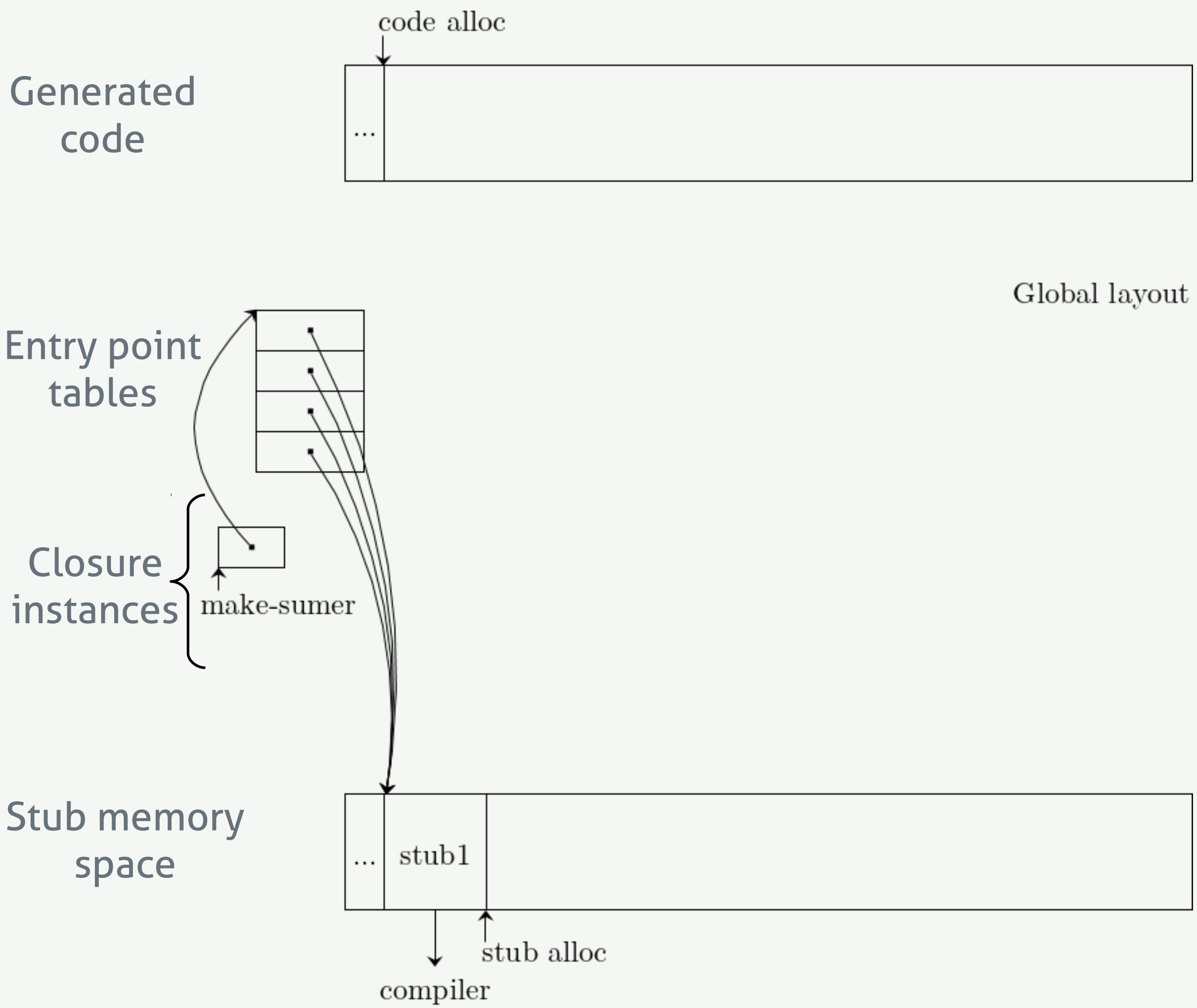


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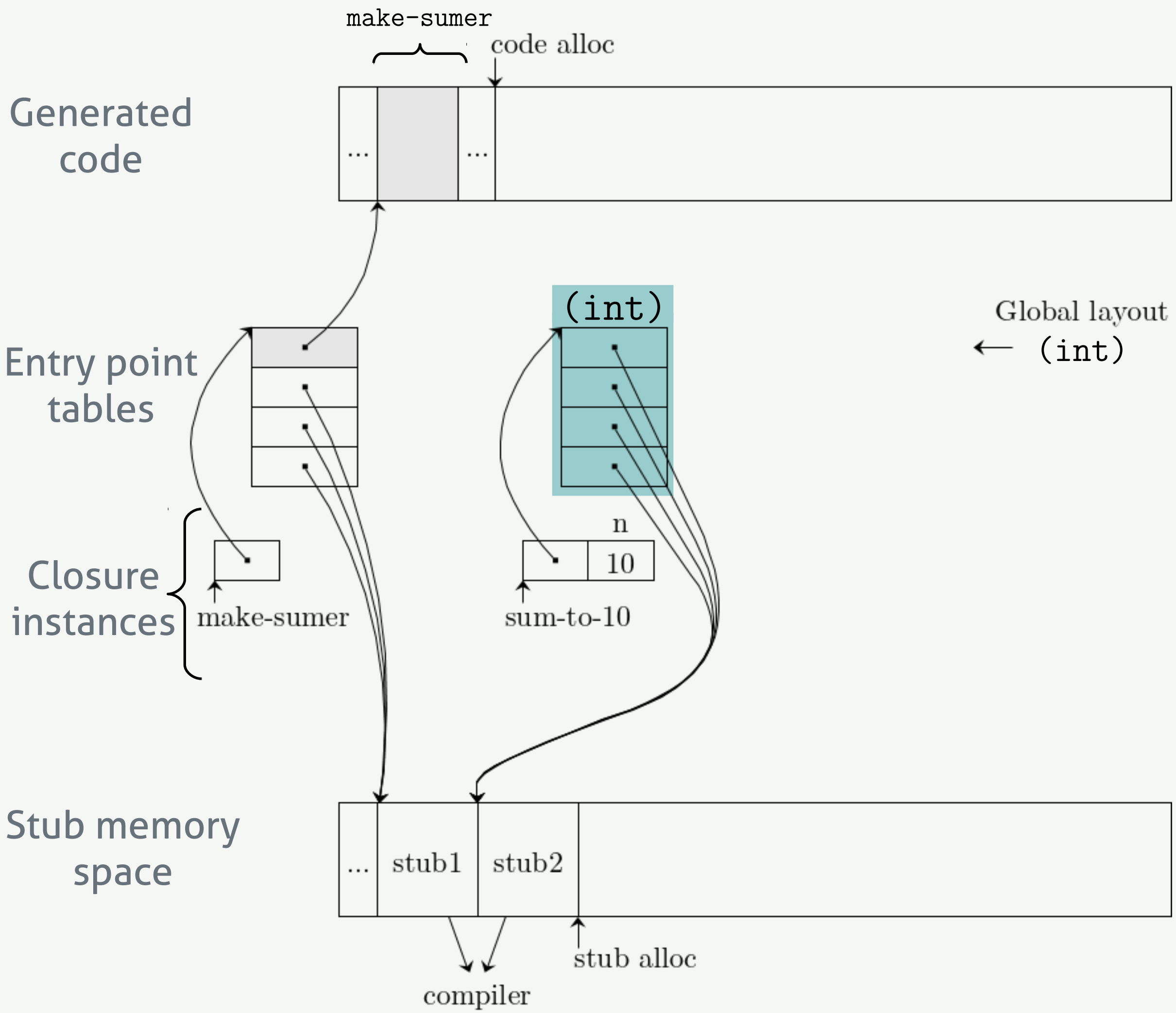


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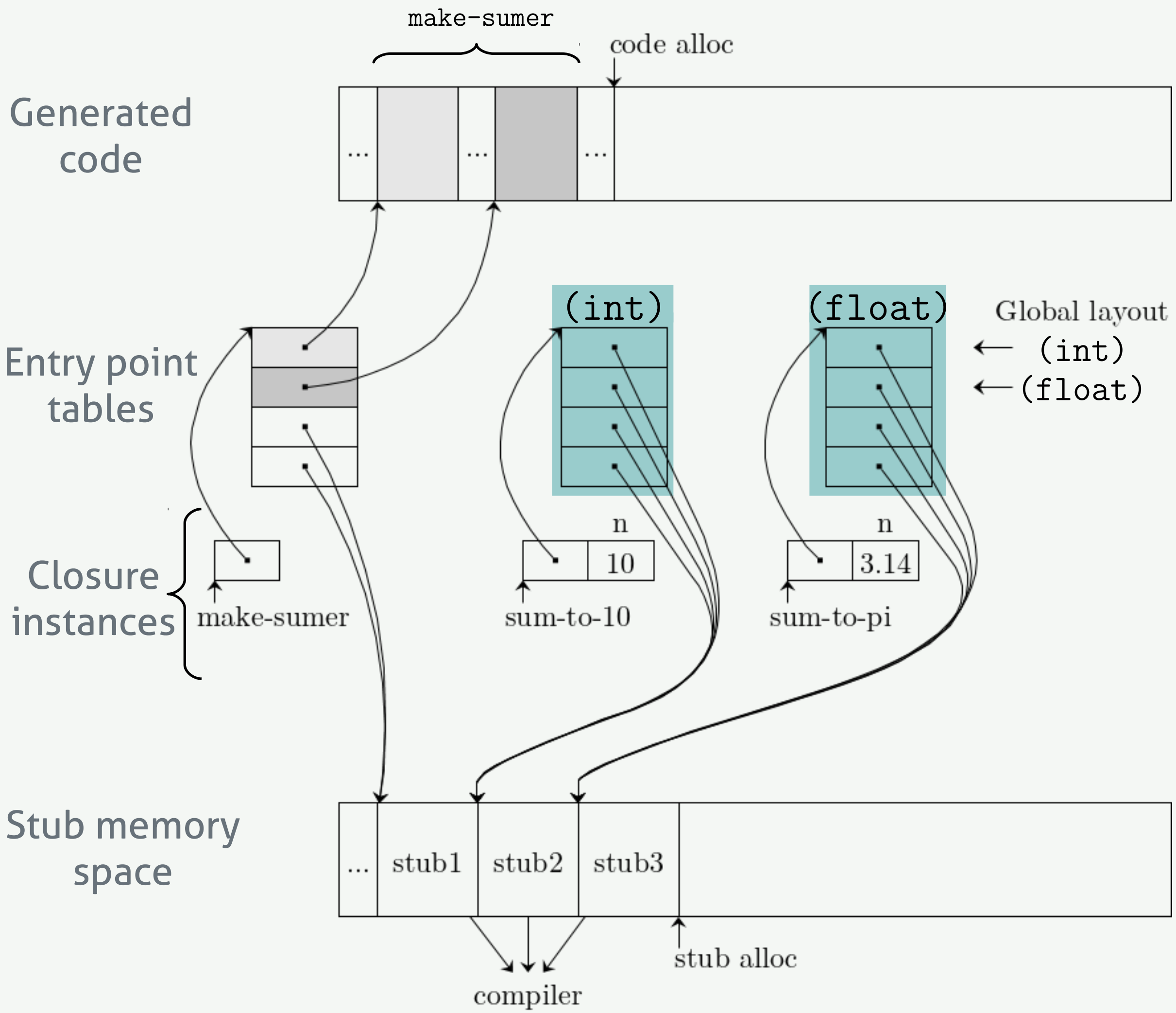


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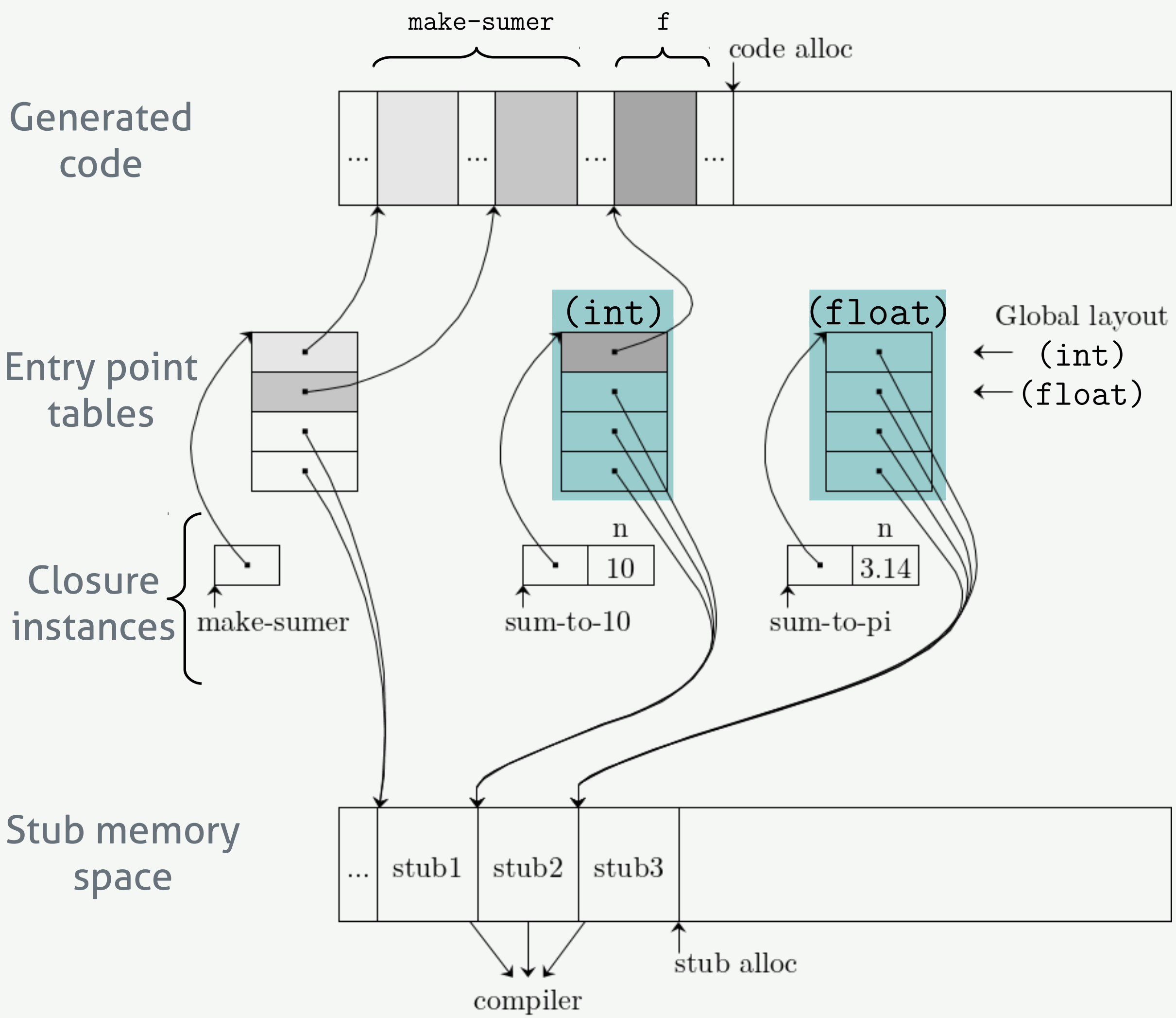


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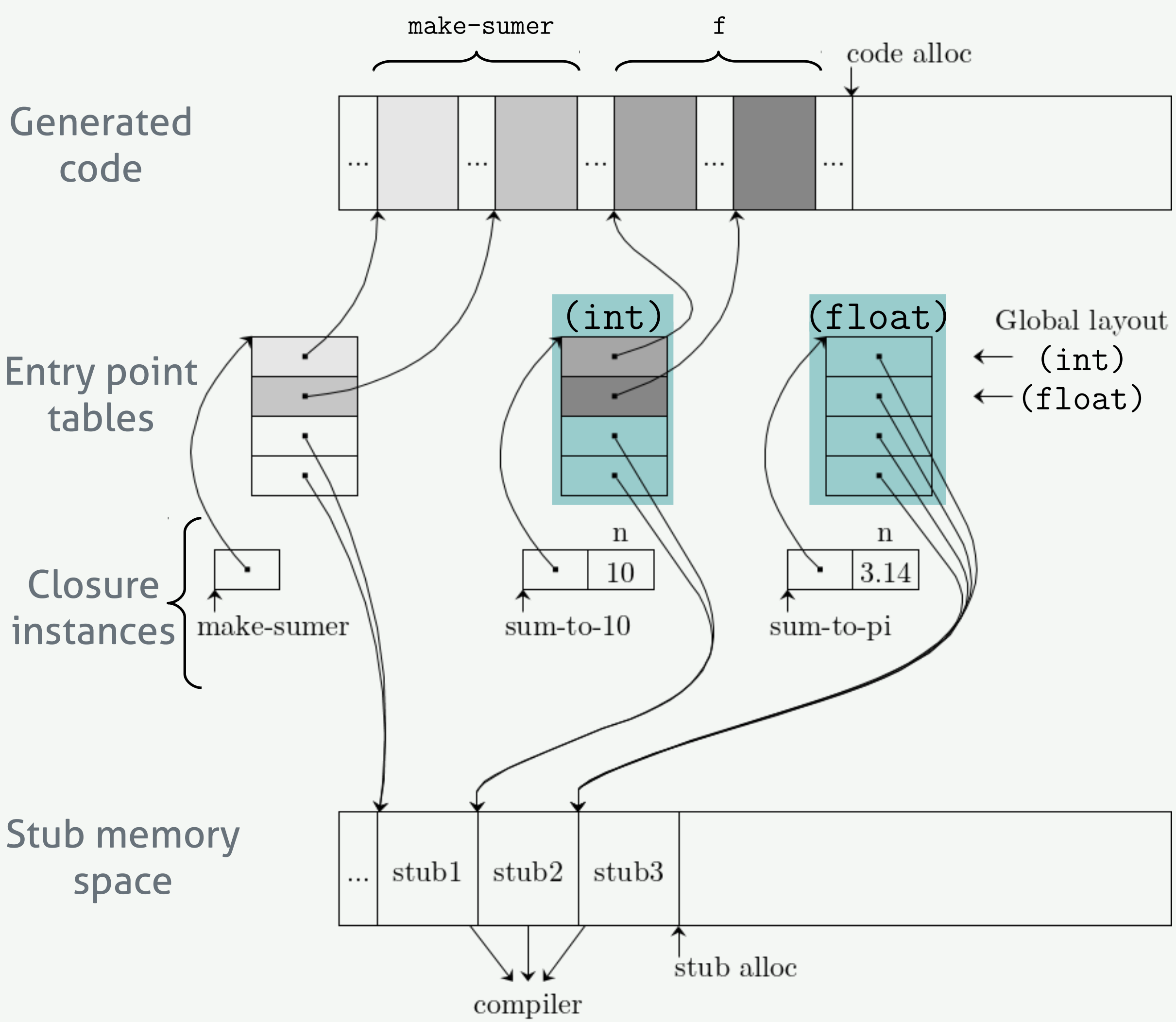


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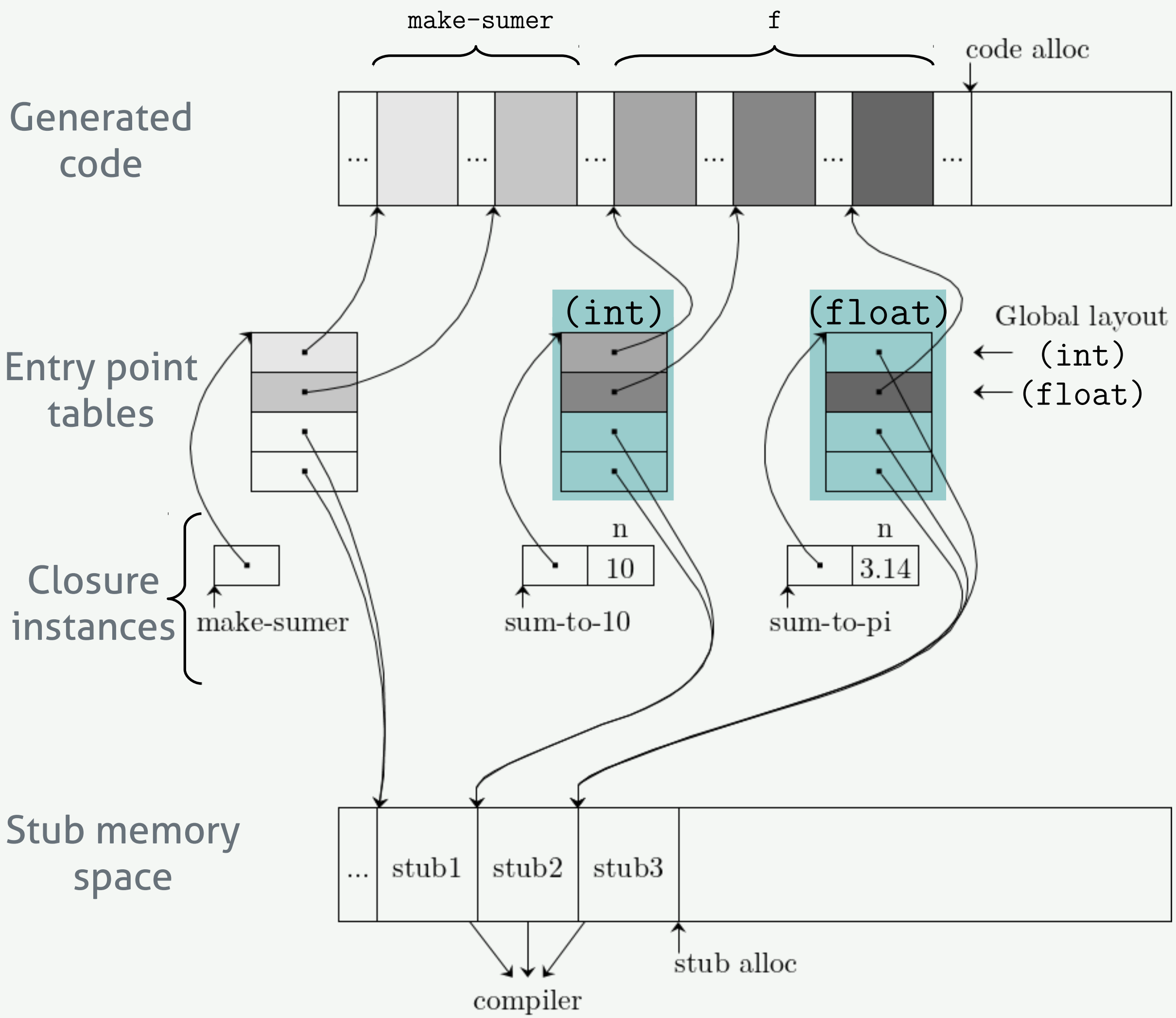


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IMPLEMENTATION

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→ Function return is a call to the continuation
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  → Function return is a call to the continuation
  → Conceptually same implementation !

  - Propagated types → Type of the returned value
  - Captured types → Type of the local variables

RESULTS

RESULTS

- 35 benchmarks: Standard Scheme benchmarks

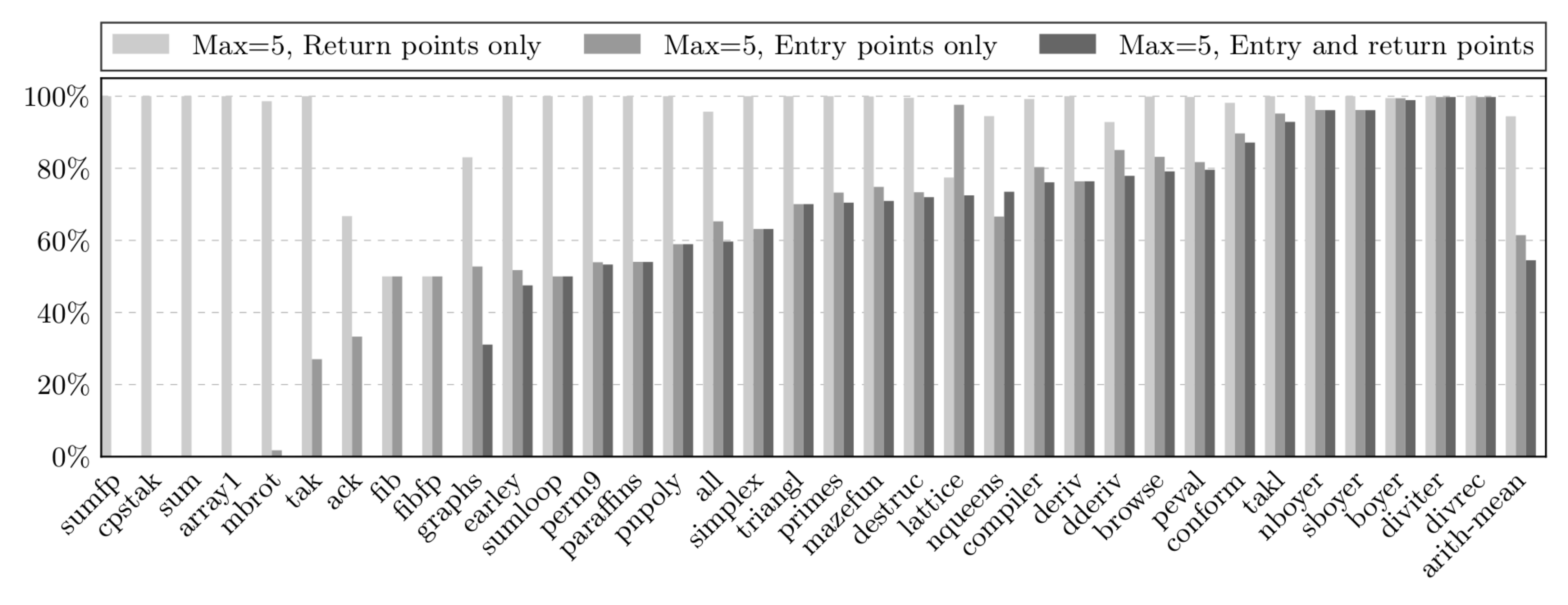
- Configurations

  - **Intraprocedural BBV**
  - Interprocedural: function specialization
  - Interprocedural: continuation specialization
  - **Interprocedural: function and continuation specialization**

- Metrics

  - Number of type checks
  - Generated code size
  - Execution / Compilation / Total time

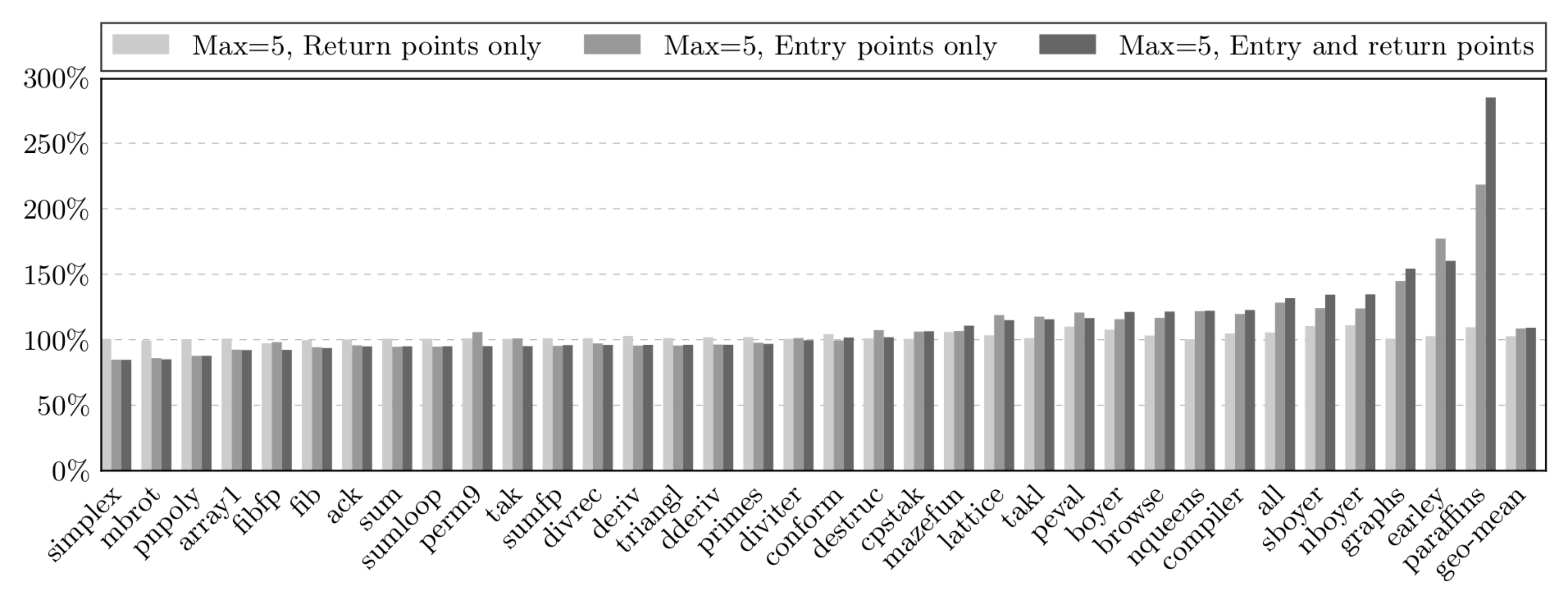
NUMBER OF TYPE CHECKS



- Number of executed type checks relative to pure intraprocedural specialization

- No checks for 9 benchmarks
- Significantly fewer checks for most of the benchmarks

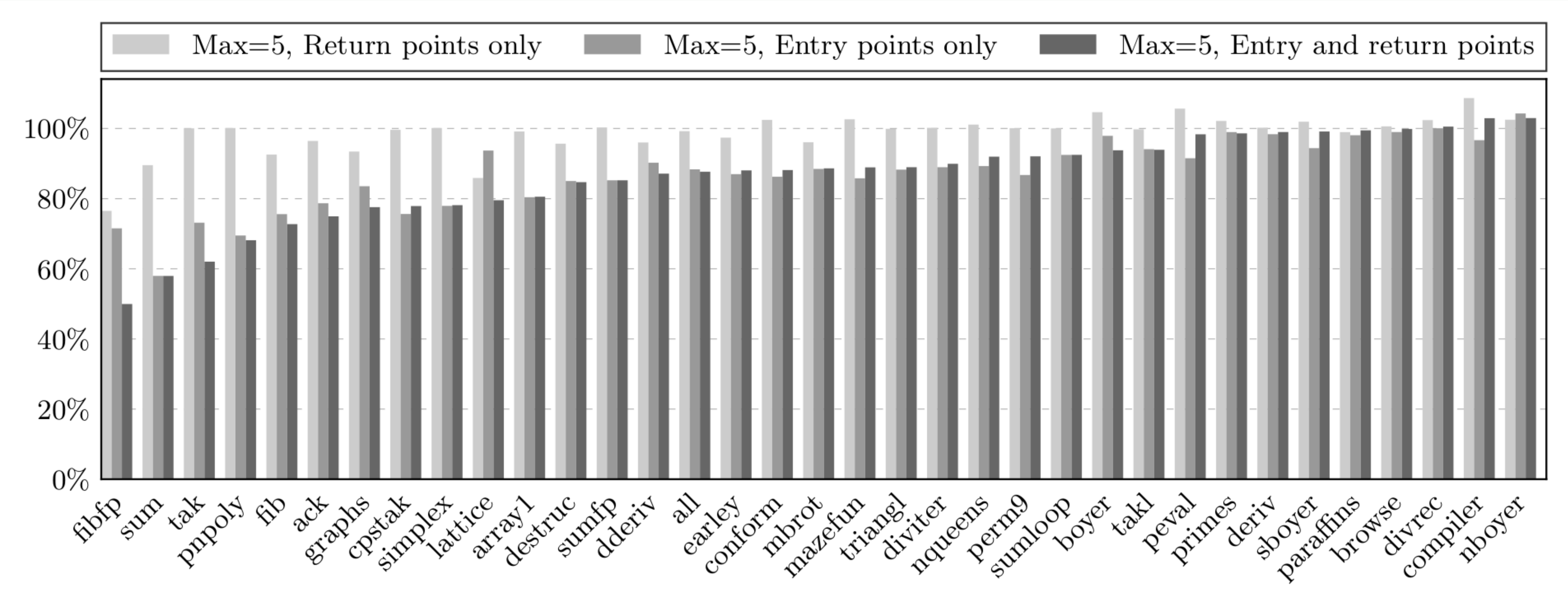
CODE SIZE



- Generated code size relative to pure intraprocedural specialization

- Less code generated for half of the benchmarks
- Just 9% more code generated on average

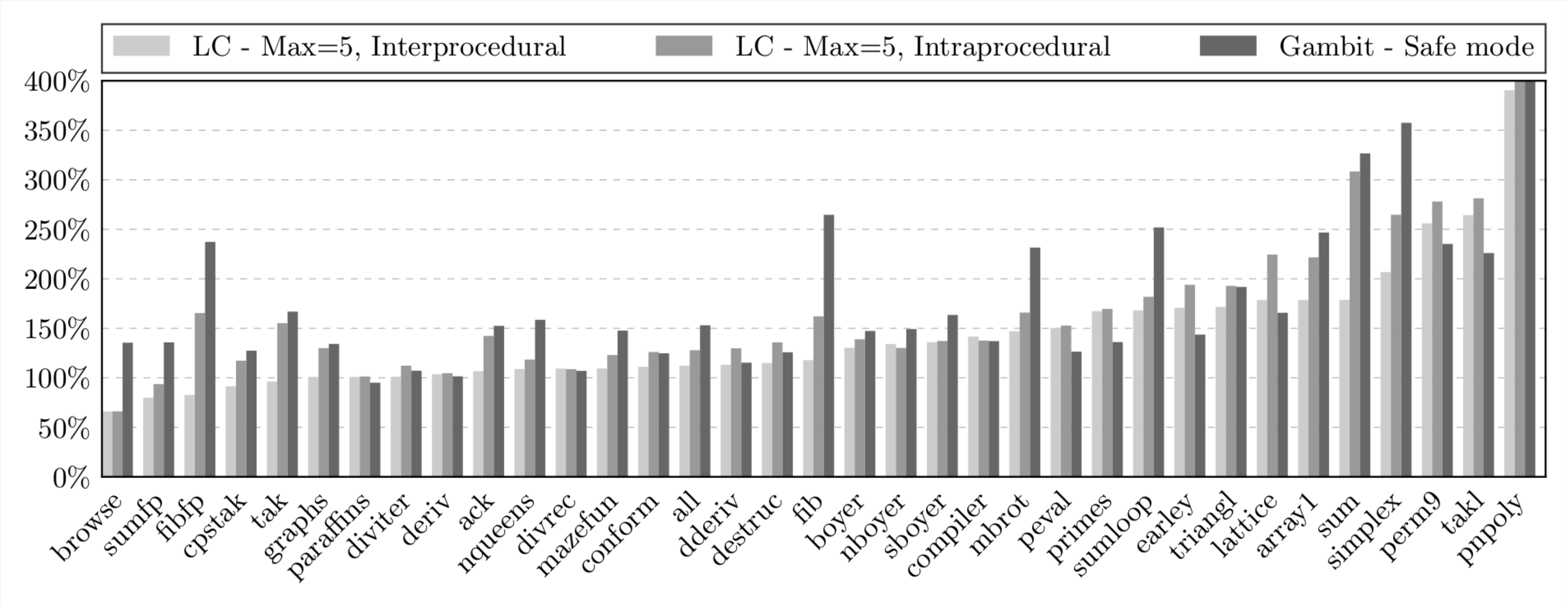
EXECUTION TIME



- Execution time relative to pure intraprocedural specialization

- Almost all benchmarks are faster
- No benchmark is significantly slower
- Up to 2x faster

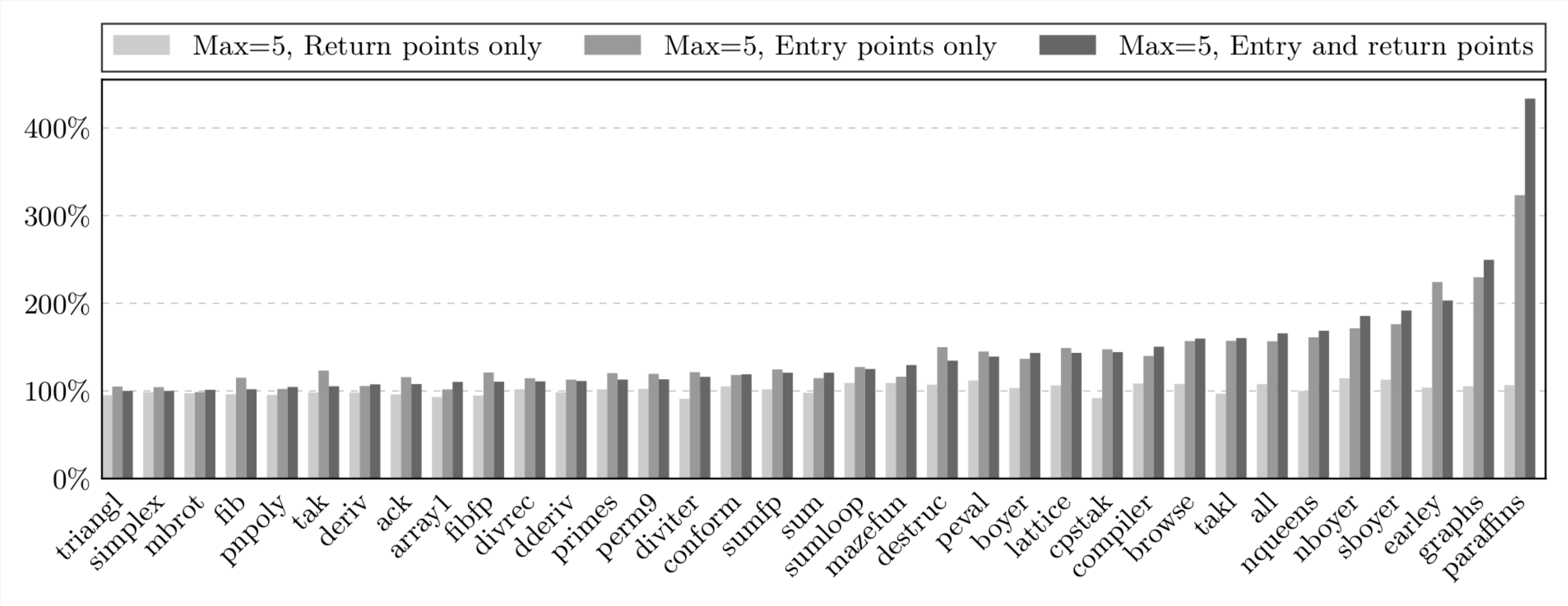
EXECUTION TIME (VS GAMBIT)



- Execution time relative to the execution time of the code generated by the Gambit Scheme compiler with dynamic checks turned off (capped at 400%)

- Faster than Gambit with dynamic checks turned on
- Varies from 0.5x to 4x (6x slower with Gambit executing all the checks)

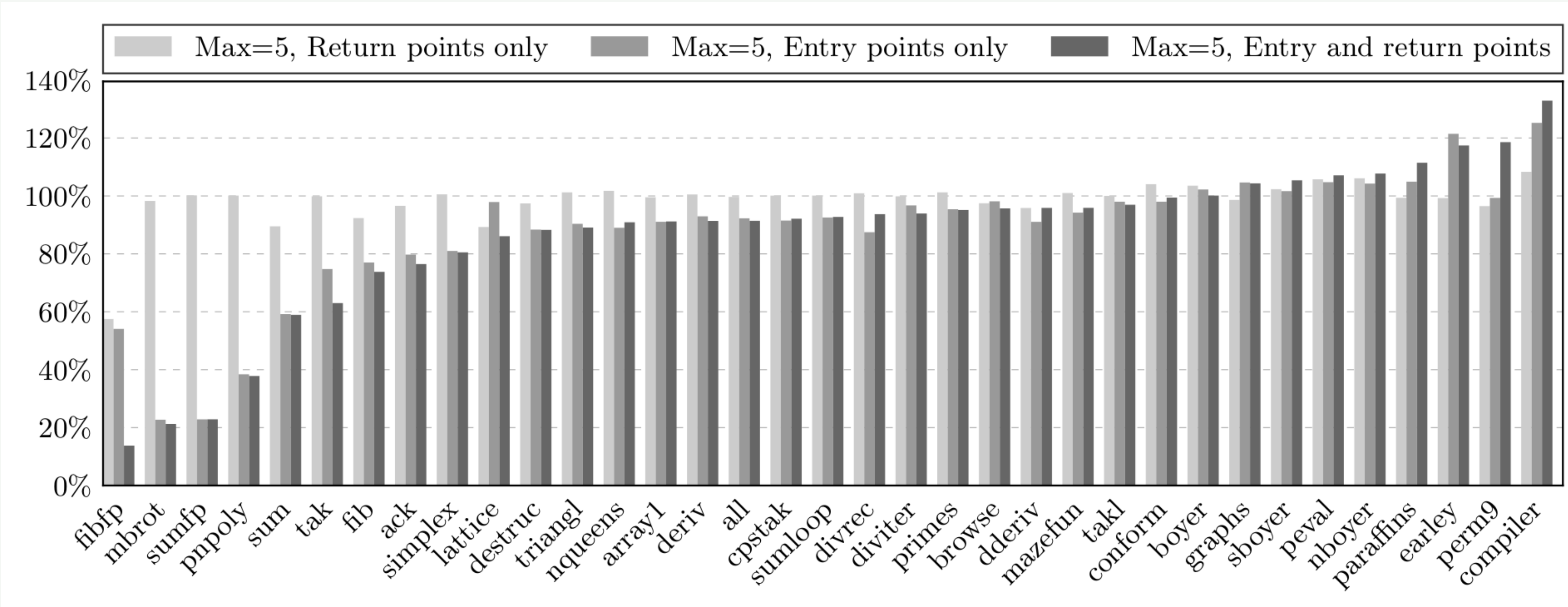
COMPILATION TIME



- Compilation time relative to pure intraprocedural BBV

- Compilation time increase for most of the benchmarks
- Mostly small increase in compilation time, but up to 4x

TOTAL TIME



- Total time relative to pure intraprocedural BBV

- Large speedup for floating point (avoids boxing)
- Most of the benchmarks are faster
- From 0.14x to 1.33x

CONCLUSION

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- Lazy interprocedural specialization
- Works well
  - Checks removed (up to 100%)
  - Faster code (up to 50%)
- Simple
  - Simple to implement
  - Does not require complex architecture

Future Work

- Propagating other properties
  - Value (e.g. `x = 10`)
  - Variable relationship (e.g. `x < y`)
- Function identity and return address propagation
  - Dynamic function inlining
- Register allocation information
  - Arguments
  - Returned value