Identification of unnecessary object allocations using static escape analysis

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Motivating Example

- OOP encourages frequent object creation —> Abundance of short-lived objects.
- The impact on memory management and garbage collector.

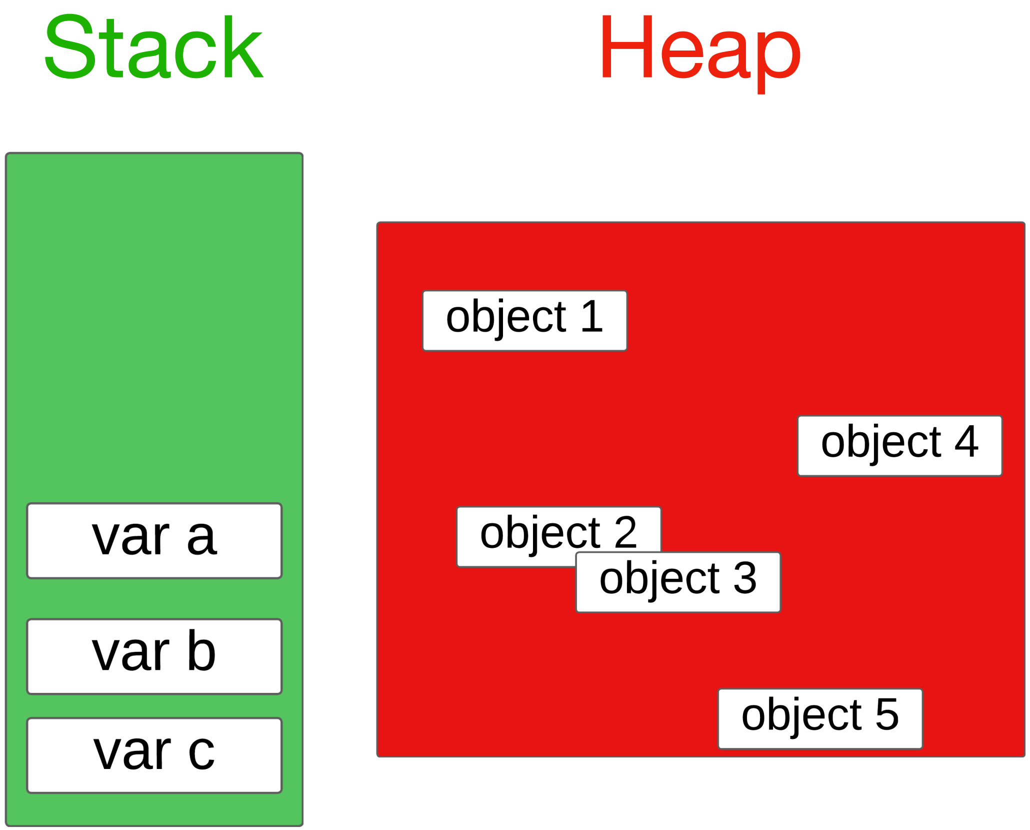
```
carFactory
    | cars res|

    cars := OrderedCollection
new.
    1 to: 100000 do: [ :i |
        cars add: (Car
            name: ‘ … ‘
            model:’ … ’
              ].
 ^ cars sum: [:aCar | aCar
price]
```

What is the impact of this code ?

Can we optimise it?

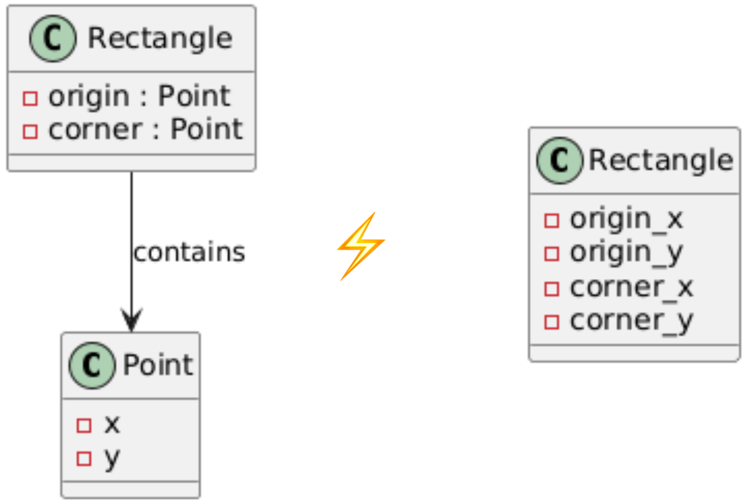
Possible Optimisations

- Stack allocation
- Object inlining
- ….



Possible Optimisations

- Stack allocation
- **Object inlining**
- ....



Rectangle origin: 1@1 corner: 2@2

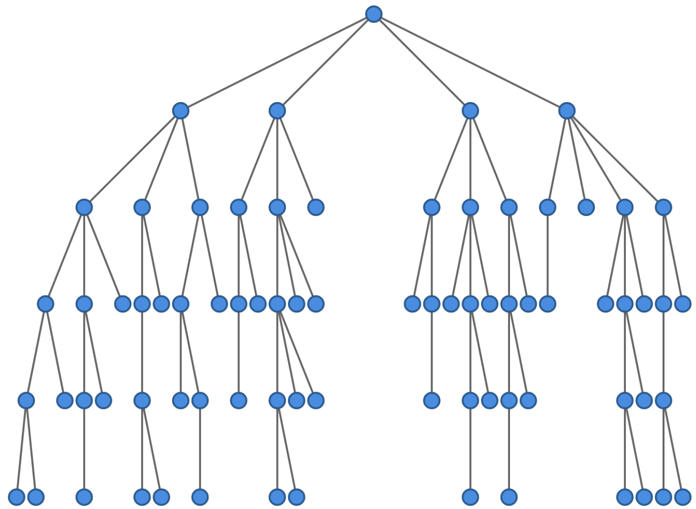
How to identify objects that can be inlined/stack allocated?

Challenges of dynamically-typed language analysis

- Dynamically-typed languages contain highly polymorphic call sites

- Prevalent use of reflection and block closure

- Large call graphs



Large call graphs

67% selectors have multiple Implementors

Characterizing escaping objects

Non-escaping object: lifetime is bound to its allocation context

methodWithNonEscaping

Mybuilder new

Build.

Escape analysis identifies, at compile-time, objects that are not reachable outside of a given execution context.

An escaping object

methodWithEscaping

```
o := Object new.
aGlobal := Array new: 7.
^ o
```

Our escape causes

- *Assignments* to *instance variables* of heap-allocated objects
- *Assignments* to *global/shared* variables
- *Return* to the top level of the call stack
- *Arguments* of blocks

Known selectors that cause escape

- Reflective, primitive, ffis e.g. #perform:with:
- Collection constructors, e.g. #with:,…
- Block evaluation e.g. #value:

Selectors to skip

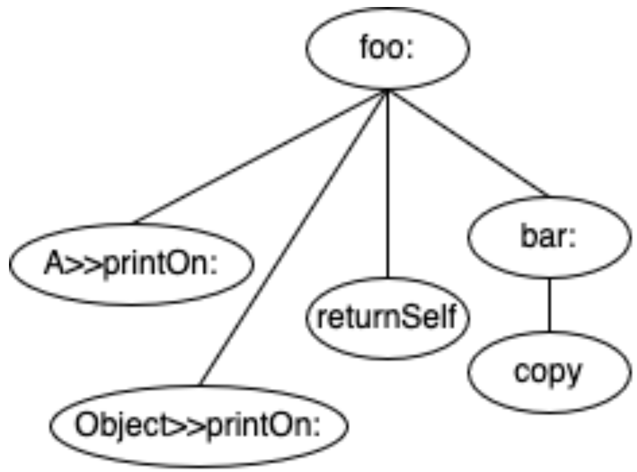
- Object creation
- Exception handling and control flow
- Testing methods
- Error messages and halts
- asString asSymbol printString

Our approach

- Context-sensitive, flow-insensitive escape analysis for Pharo
- Builds a points-to graph to track references to heap-allocated objects
- Applies escape constraints on the points-to graph
- Interprocedurality to handle method calls

Need for interprocedural analysis

```
A >> foo: arg
    | tmp st st1 |
    tmp := Object new.
    st := Stream new.
    self bar: tmp.
    st1 := st returnSelf.
    tmp printOn: st
A >> bar: anObject
        ^ anObject
copy
```



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    tmp printOn: st

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        ^ anObject
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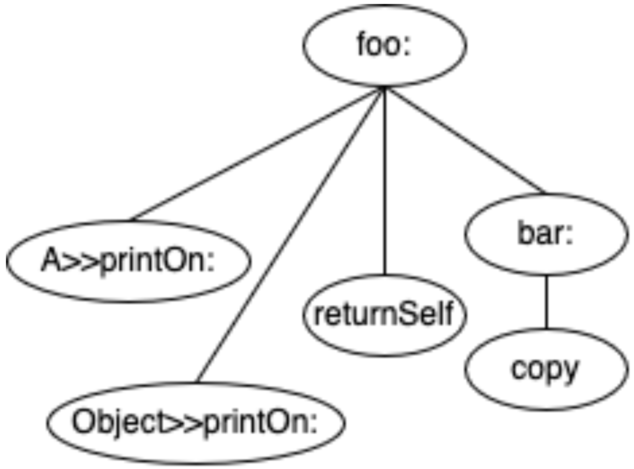
```

Call Edge



Need for interprocedural analysis

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```
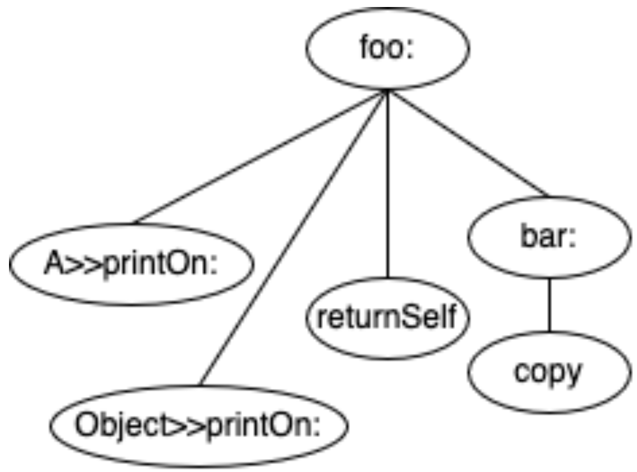

Return Edge

Call Edge



Points-to Analysis

```
A >> foo: arg
    | tmp st st1 |
    tmp := Object new.
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    self bar: tmp.
    st1 := st returnSelf.
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```
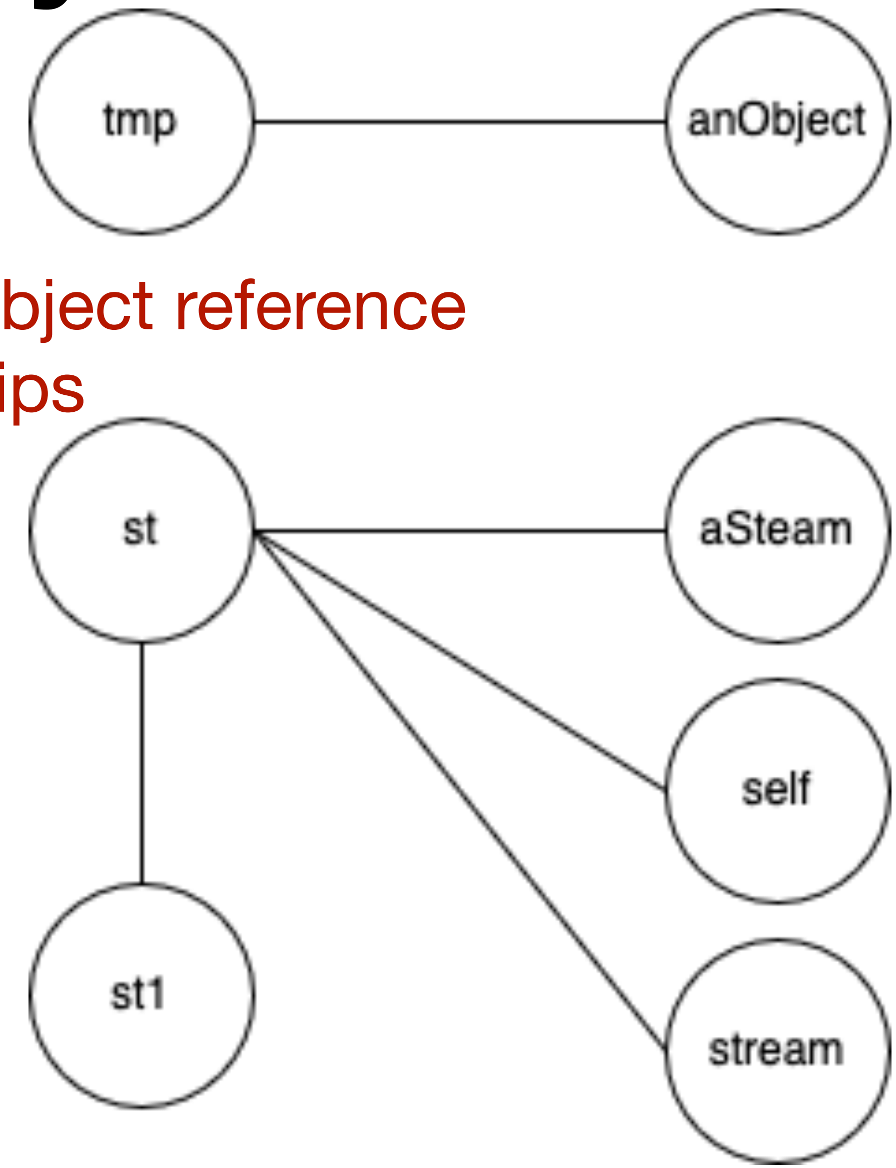

Capture object reference relationships



Addressing our challenges

- Call site memoization
- Call graph node skipping
- Type propagation
- Graph depth and breadth heuristic limitations

Call site Memoization

- Save and reuse analysis summaries for call sites based on:
  - Arguments monitoring status (tracked or not) and type information
  - Selector identity

```
A >> foo: arg
   | tmp st st1 |
   tmp := Object new.
   st := Stream new.
   self bar: tmp.
   st1 := st returnSelf.
➡  st1 bar: st.
   tmp printOn: st
A >> bar: anObject
        ^ anObject
copy
```

Call graph node skipping

When a representation of a method includes only escaping variables to track, there is no further information to extract —> Safe to skip.

Type propagation

- The analyzer models all possible implementor methods for a message

- We propagation variables types starting from allocation site and leverage to reduce scope of implementors

Call graph complexity limitation

- Open world assumption
- Limit the depth of graph exploration
- Limit Working list size (#visited methods)

Results

Anecdotal evidence

```
AIAstar >> heuristicFrom: startModel to: endModel
    | dijkstra addEdges pathD parameters |
    …
    parameters := OrderedCollection new.
    parameters add: startModel model.
    parameters add: endModel model.
    dijkstra start: parameters first.
    dijkstra end: parameters second.
    …
```

Depth impact on analysis

Depth	Analysis time	Candidates
1	9 min 14 s (39 ms)	54
2	47 min 41 s (204 ms)	189
3	3 h 29 min (895 ms)	199
4	27 h 11 min (270712995 ms)	203
≥5	> 27 h	—

Table 2: Average *SubMethods* Depth of call graph. Runtime and resulting positive candidates – fixed number of input methods.

- 203 candidates
- Depth = 3 was found to be a stable point for a reasonable execution time.

Time to perform analysis

Total methods	Analysis time	Candidates
4 800	6 min 32 s	103
7 200	12 min 32 s	138
9 600	16 min 35 s	147
12 000	19 min 46 s	158
14 400	1 h 32 min 43 s	166
16 800	35 min 57 s	173
19 200	41 min 10 s	177
21 600	46 min 48 s	182
24 000	2 h 35 min 38 seconds	189

Table 3: Runtime and resulting positive candidates - variable number of input methods for maximum depth of 2 for the call graph

How many special methods encountered

Depth	FFI	Primitives	Reflection
1	0	226	32
2	1458	15196	14582

Type Propagation Evaluation

Depth n	Analysis time w/ TP	Analysis time w/o TP	Candidates w/ TP	Candidates w/o TP
1	5 s	7 s	12	12
2	20 s	56 s	43	38
3	1 min 1 s	2 min 9 s	48	38
4	1 min 53 s	3 min 30s	49	39
5	3 min 33 s	1 h 1 min	48	37
6	7 min 50 s	18 min 09 s	48	39
7	14 min 39 s	45 min 1 s	48	37
8	48 min 40 s	—	48	—
9	10 h 1 min	—	47	—

Table 4: Analysis time and candidate counts across depths, with and without type propagation (tp: Type propagation).

False negatives:

Objects marked as escaping by static analyzer
But non-escaping during execution

- Objects returned from a constructor or factory
- Objects assigned to instance variables of non-escaping objects

Perspective

- Analyze individual fields of objects rather than treating the entire object as an indivisible unit.
- Analyse beyond Assignments to Instance Variables.
- Adding the abstract interpretation (partially evaluate some messages if we have all their argument values)
- Towards analysing external projects.

Summary

- Many short-lived objects in OOP
- Context-sensitive, flow-insensitive, interprocedural escape analysis for Pharo
- Builds an points-to graph to track references to heap-allocated objects
- Conservative escape conditions to make faster analysis
- Limited results (203 out of 24000~ allocation)