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Partial Escape Analysis and Scalar Replacement for Java

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VM Research Group, Oracle Labs

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Partial Escape Analysis and Scalar Replacement for Java

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Graal?

http://openjdk.java.net/projects/graal/

graal-dev@openjdk.java.net

```
$ hg clone http://hg.openjdk.java.net/graal/graal
$ cd graal
$ ./mx build
$ ./mx ideinit
$ ./mx vm <arguments>
```

- Graal Resources

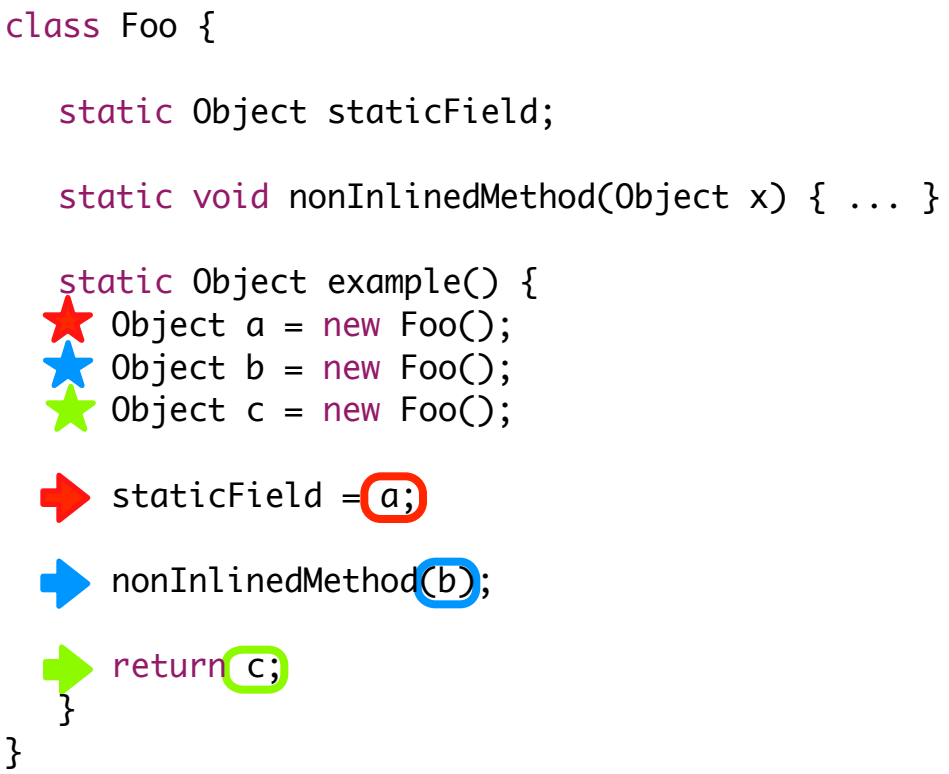
https://wiki.openjdk.java.net/display/Graal/

graal-dev@openjdk.java.net

Escape Analysis

- Escape Analysis:
  Analyzes where references to new objects flow

- Looks for “escapes”
  - Method call parameters
  - Static fields
  - Return value
  - Throws
  - …



Escape Analysis - Optimization Opportunities

- Allocated object is scope/method local
  - Scalar Replacement: replace fields with local variables
- Allocated object is thread local
  - Lock Removal: no other thread can see the object, no locking required
  - Stack Allocation: automatic stack management, destroyed on return
- Allocated object escapes
  - Escapes to other threads/methods, no optimizations possible

Escape Analysis - Example

```
public static Car getCached(int hp, String name) {
     Car car = new Car(hp, name, null);
     Car cacheEntry = null;
     for (int i = 0; i < cache.length; i++) {
          if (car.hp == cache[i].hp &&
                car.name == cache[i].name) {
               cacheEntry = cache[i];
               break;
          }
     }
     if (cacheEntry != null) {
          return cacheEntry;
     } else {
          return null;
     }
}
```

Escape Analysis - Example

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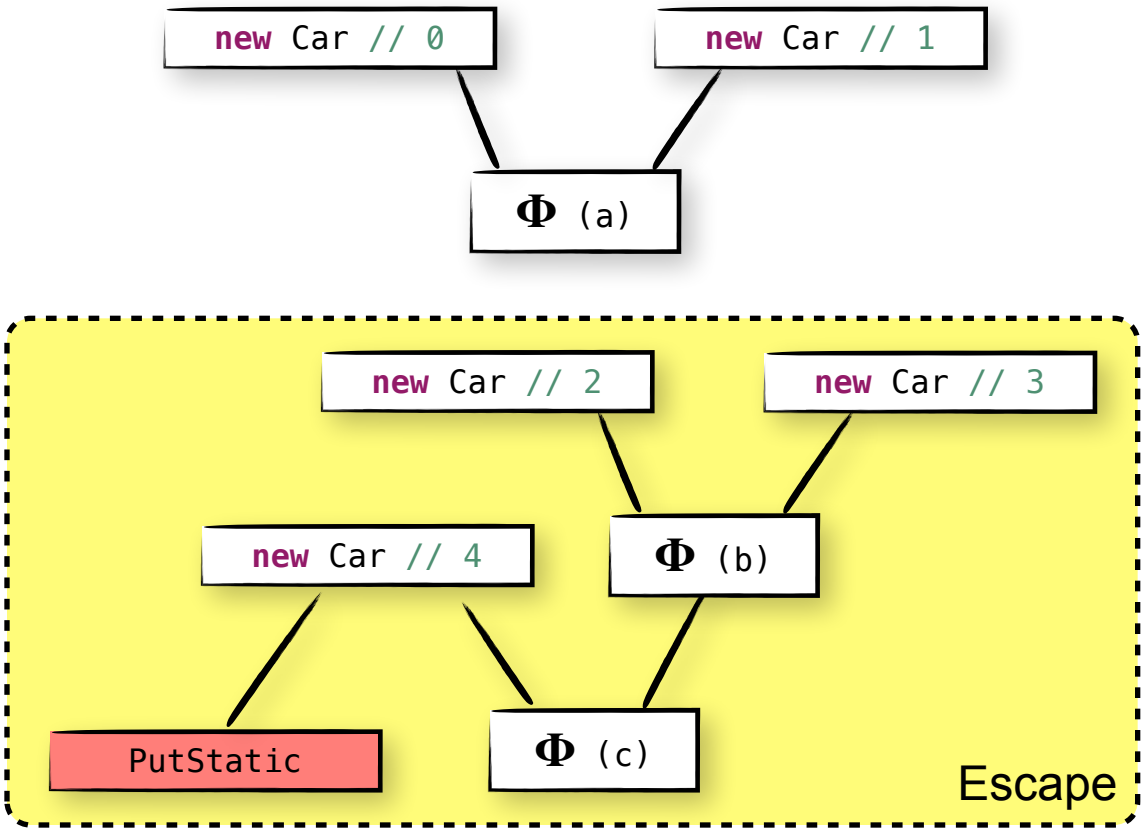
               break;
          }
     }
     if (cacheEntry != null) {
          return cacheEntry;
     } else {
          return null;
     }
}
```

- `new Car(...)` does not escape
- Allocation is removed
- Field loads replaced with values

Escape Analysis - e.g. Equi-Escape Sets

```
Car a, b, c;
if (...) {
     a = new Car(...) // 0
} else {
     a = new Car(...) // 1
}
if (...) {
     b = new Car(...) // 2
} else {
     b = new Car(...) // 3
}
if (...) {
     tmp = new Car(...) // 4
     staticField = tmp;
     c = tmp;
} else {
     c = b;
}
```



Thomas Kotzmann and Hanspeter Mössenböck. 2005. Escape analysis in the context of dynamic compilation and deoptimization. In *Proceedings of the 1st ACM/USENIX international conference on Virtual execution environments* (VEE '05).

Partial Escape Analysis

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            cacheEntry = cache[i];
            break;
        }
    }
    if (cacheEntry != null) {
        return cacheEntry;
    } else {
        addToCache(car);
        return car;
    }
}
```

Partial Escape Analysis

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public static Car getCached(int hp, String name) {
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               cacheEntry = cache[i];
               break;
          }
     }
     if (cacheEntry != null) {
          return cacheEntry;
     } else {
          Car car = new Car(hp, name, null);
          addToCache(car);
          return car;
     }
}
```

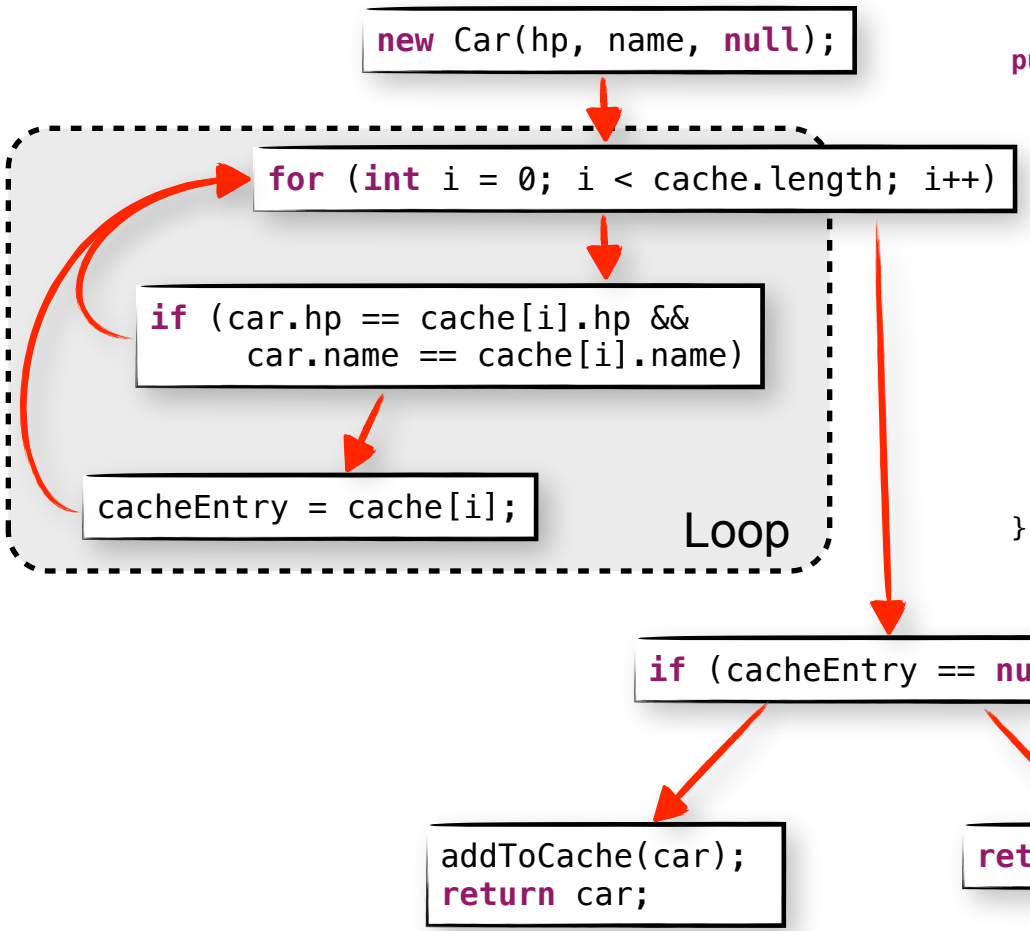
probability: ?%

- `new Car(...)` escapes at:
  - `addToCache(car);`
  - `return car;`
- Might be a very unlikely path
- No allocation in frequent path

Partial Escape Analysis

- Escape Analysis (EA): either remove allocation or not
- Partial Escape Analysis (PEA): push allocations into infrequent paths
  - Which often allows removal of other object allocations
- PEA is (inherently) control-flow sensitive
  - Analysis performs iteration over CFG

Partial Escape Analysis - Iteration

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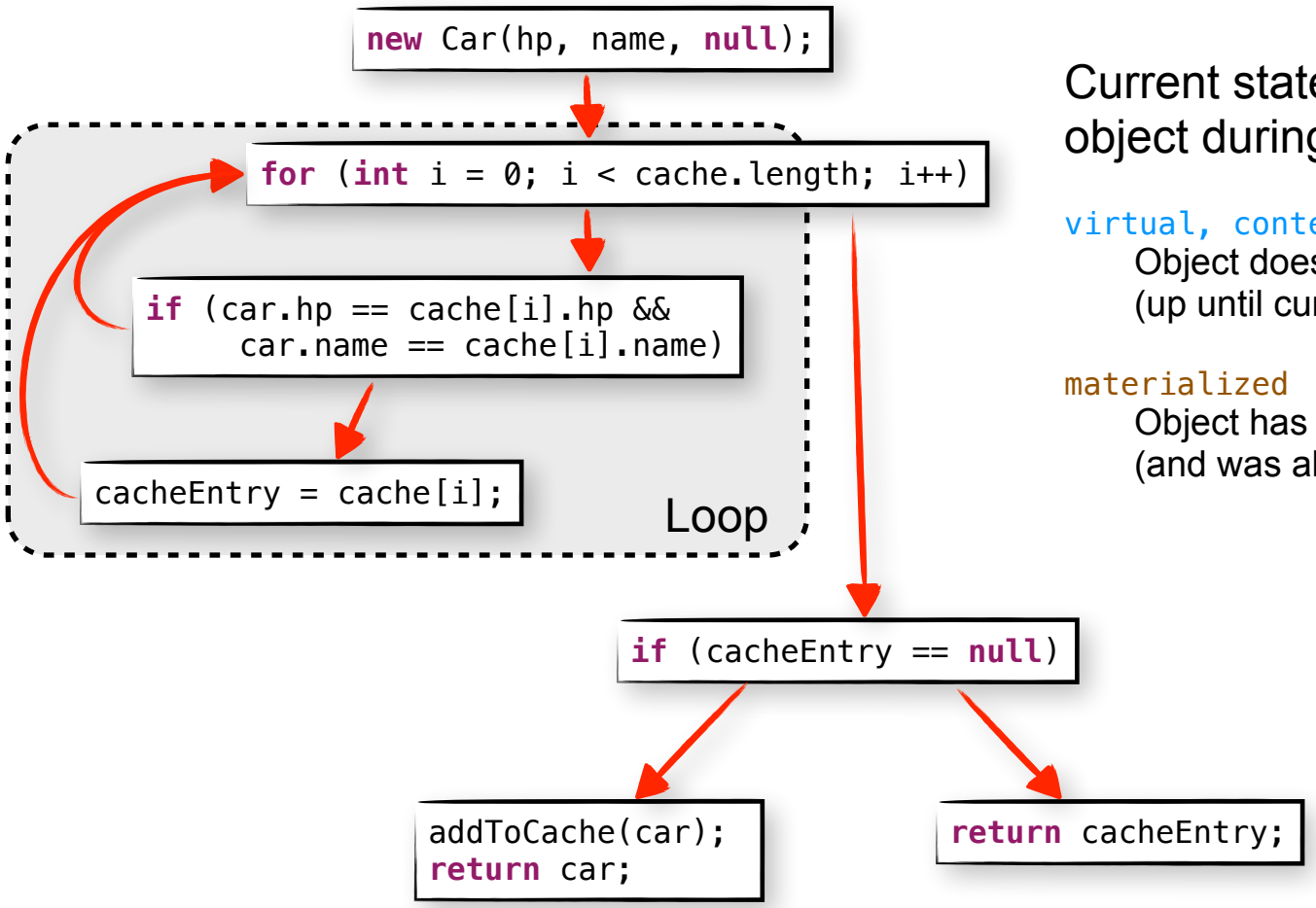
Partial Escape Analysis - Iteration

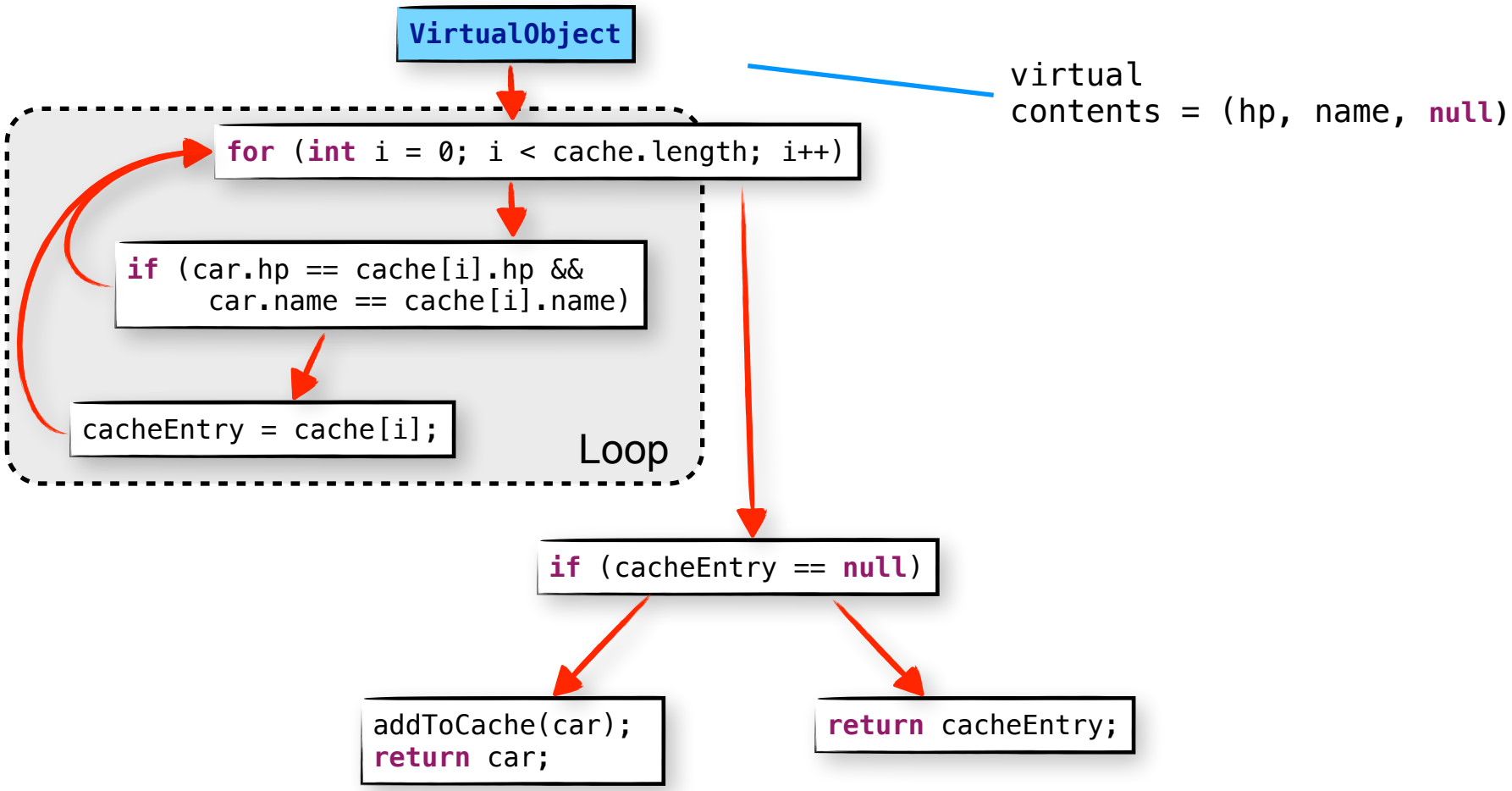


Current state of Escape Analyzed object during CFG iteration:

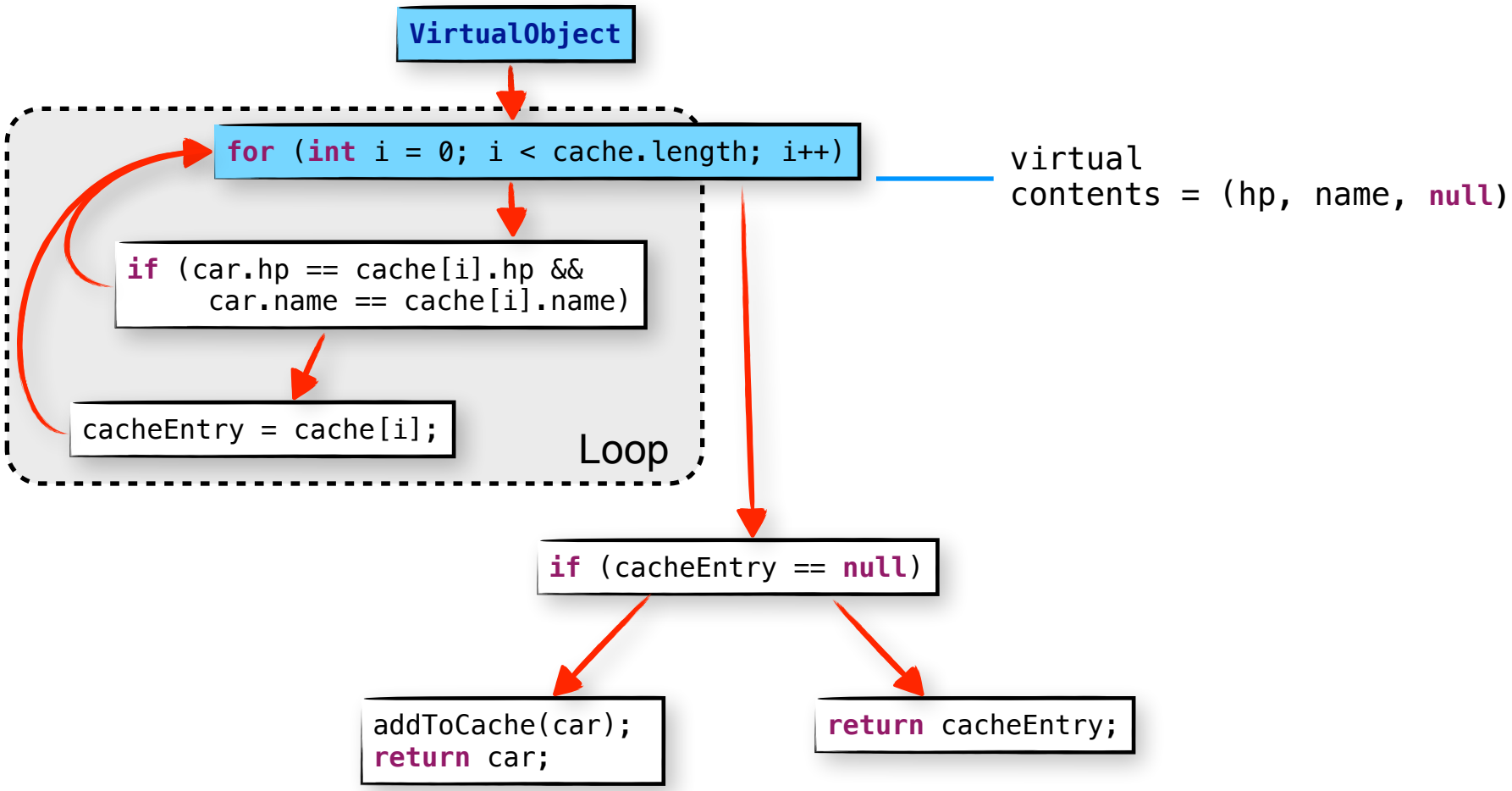
`virtual, contents = (...)`
Object does not escape
(up until current point)

`materialized`
Object has escaped
(and was allocated)

Partial Escape Analysis - Iteration



Partial Escape Analysis - Iteration



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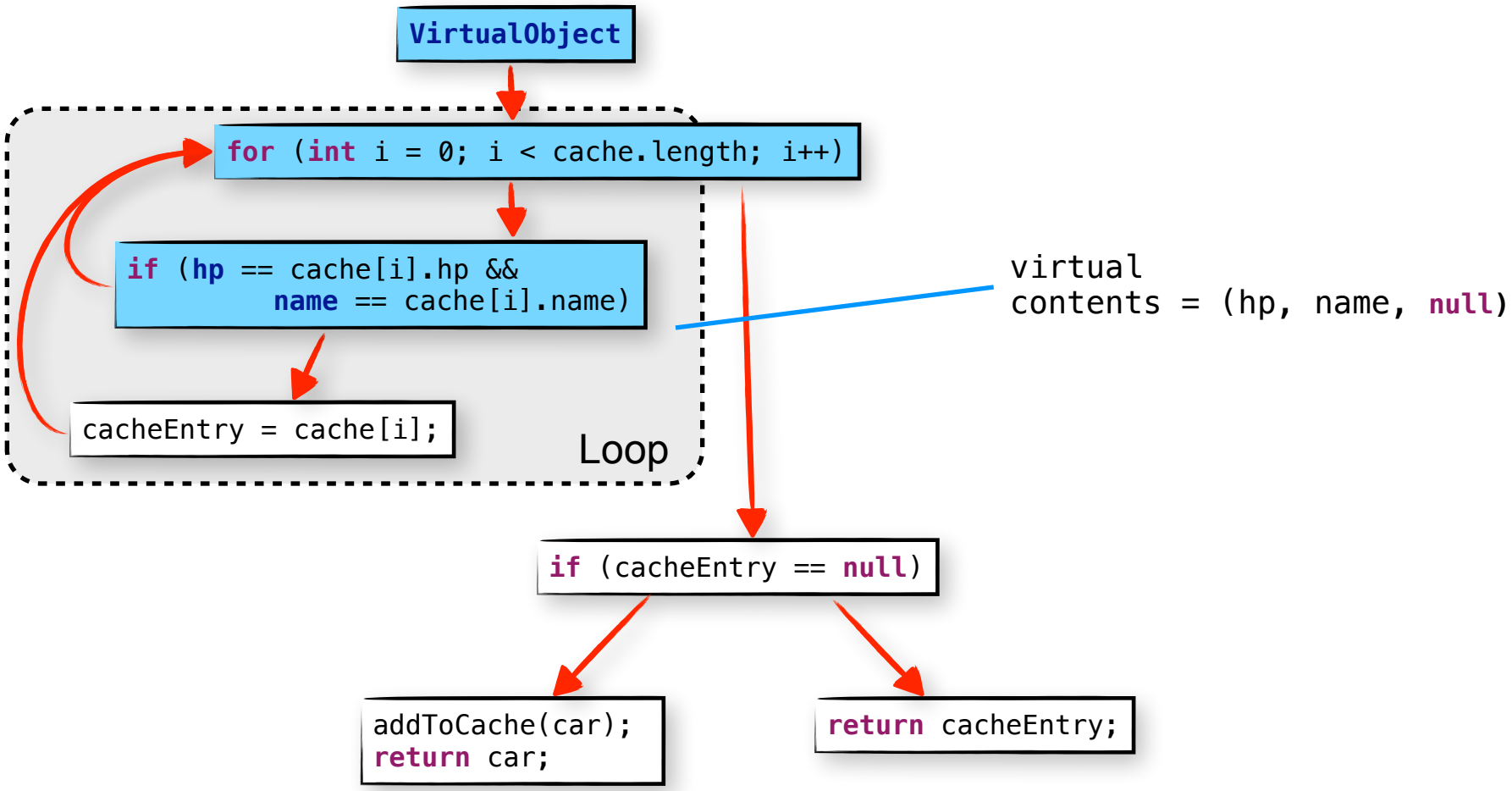

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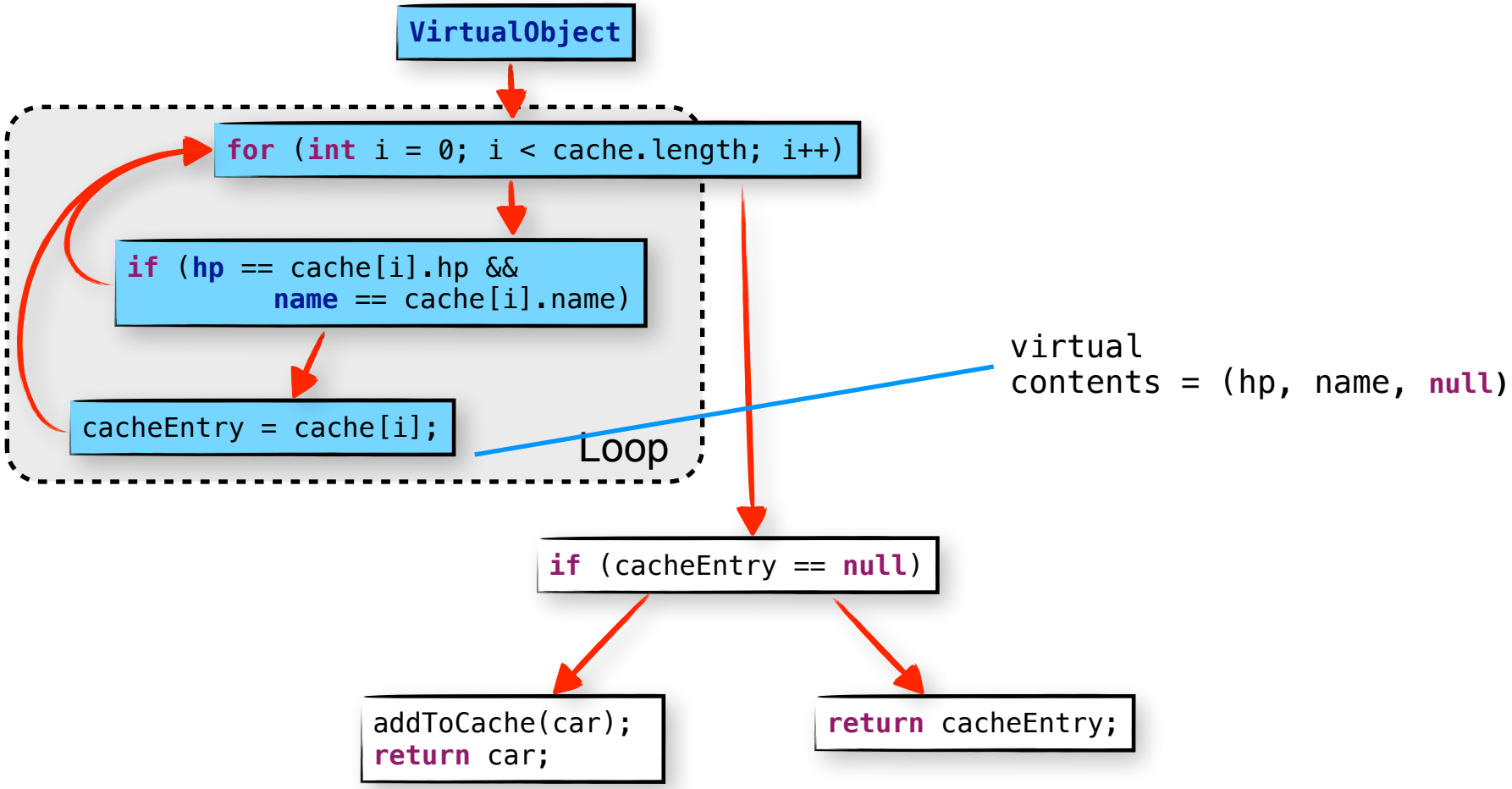

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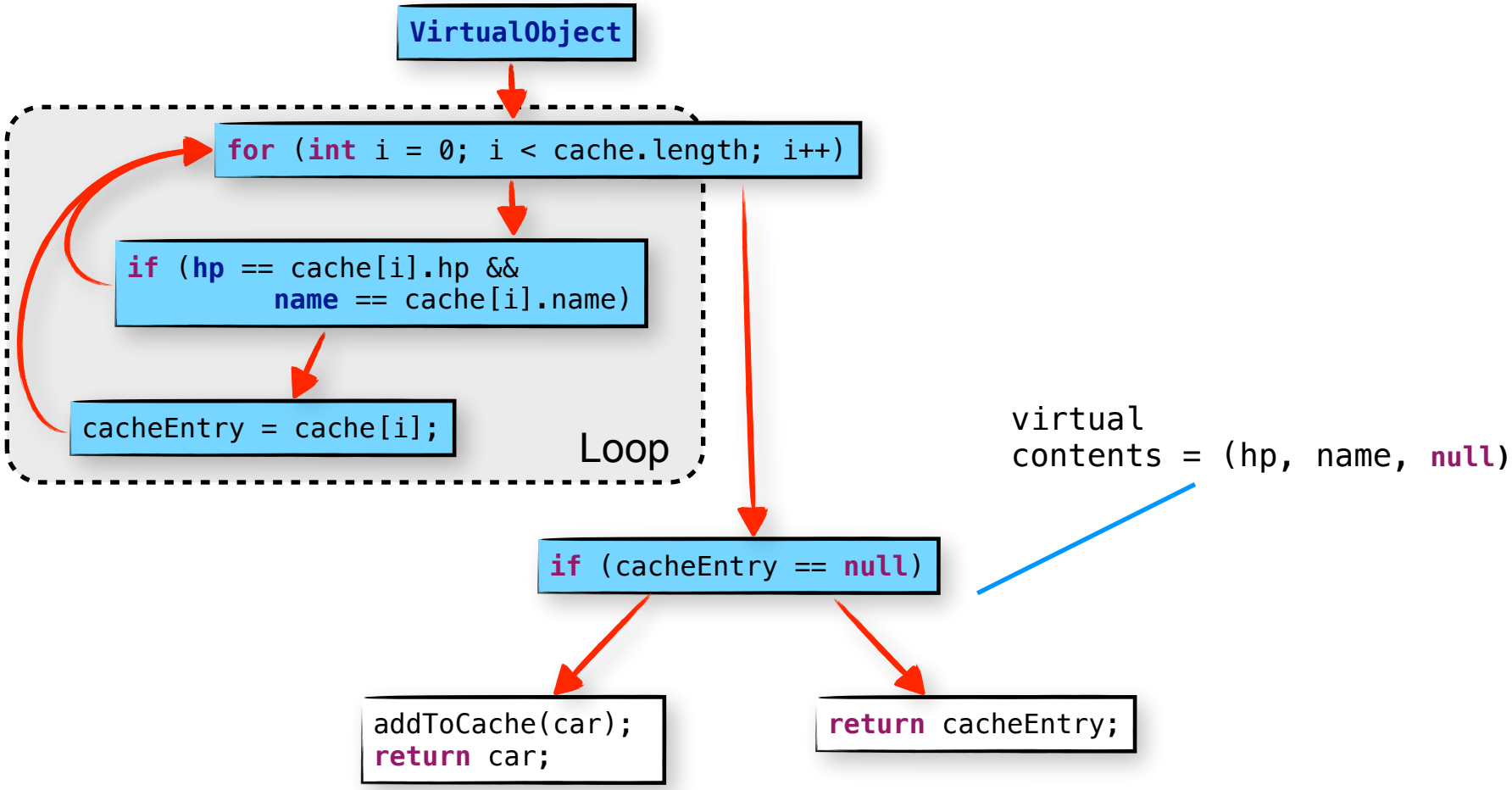

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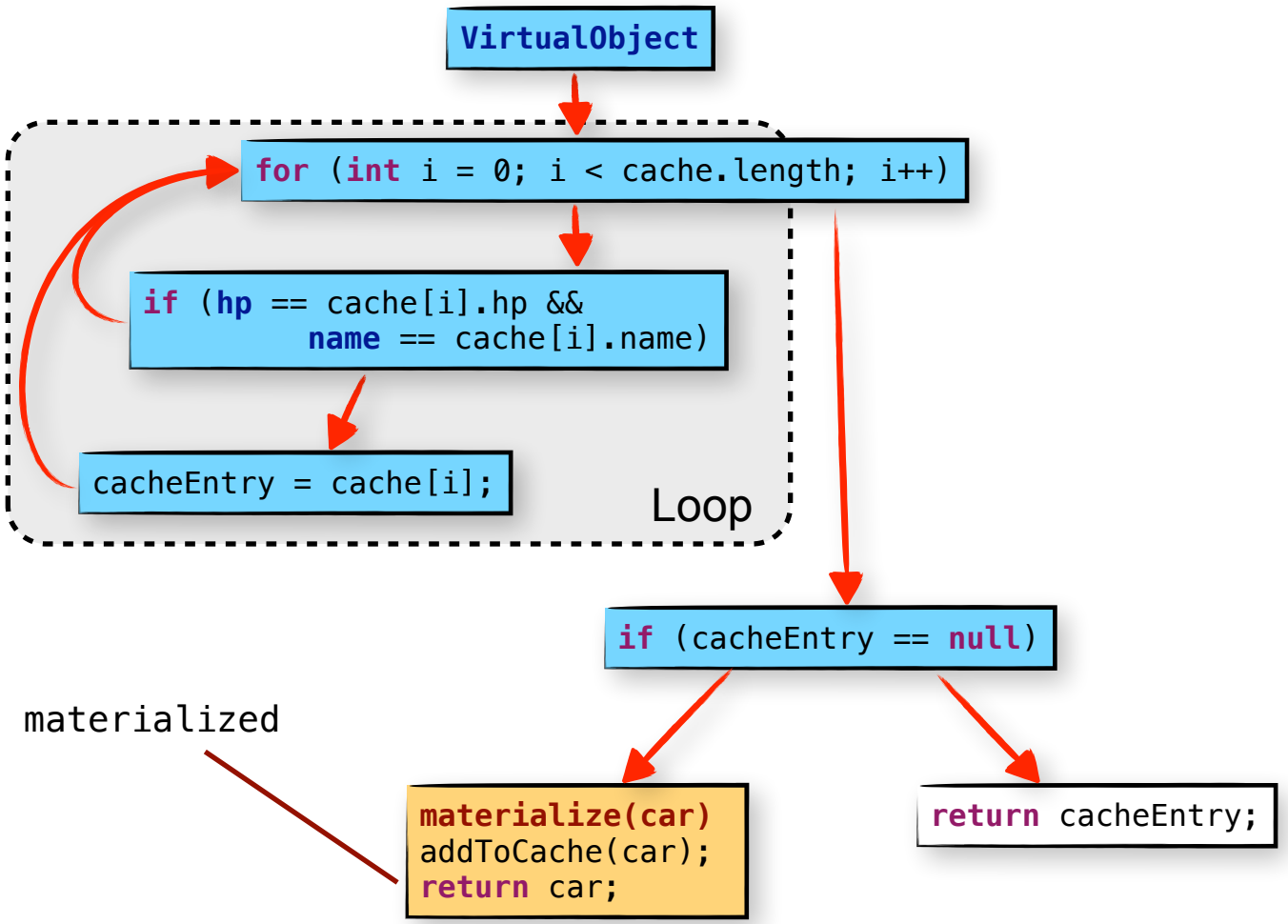

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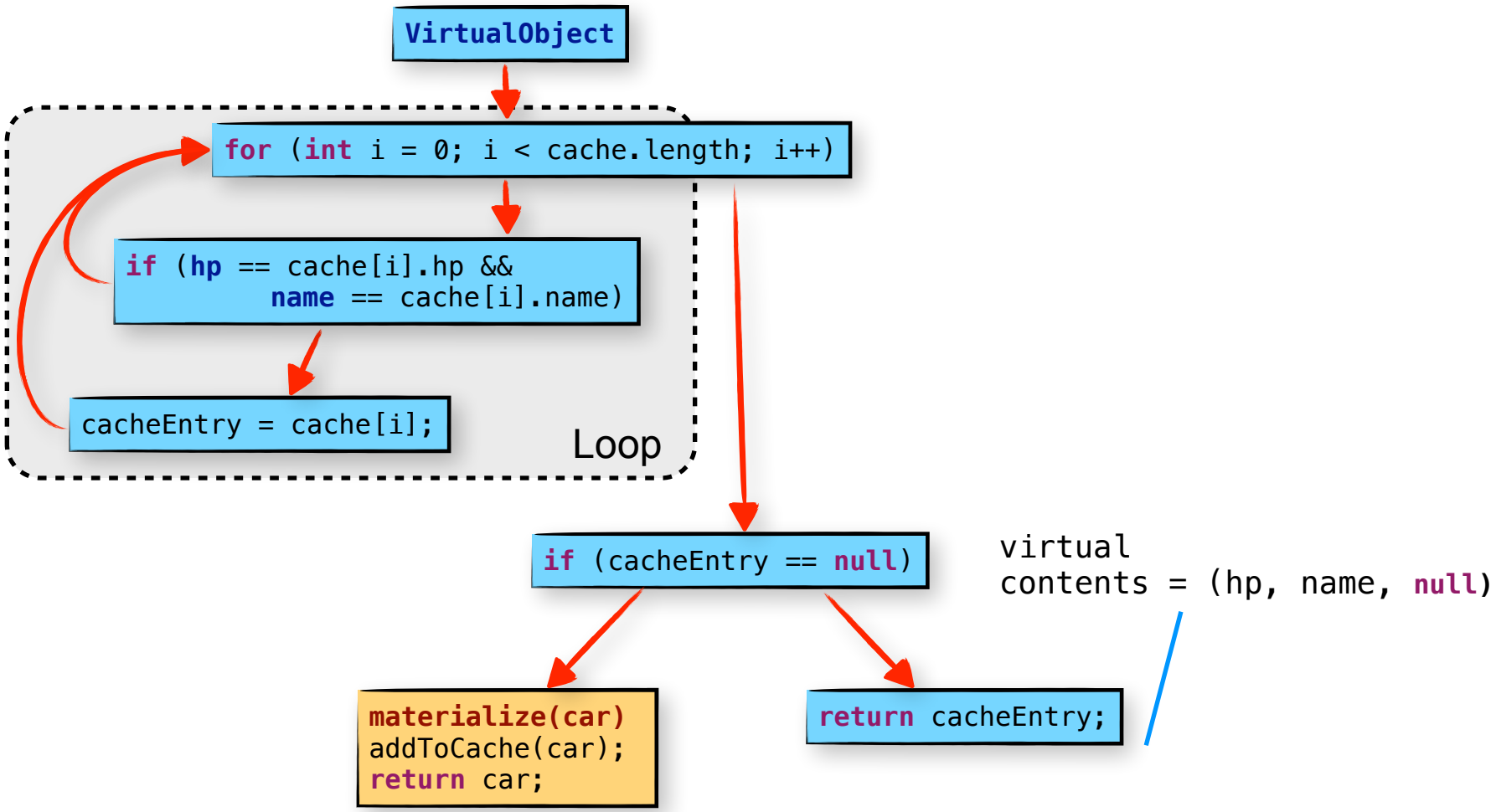
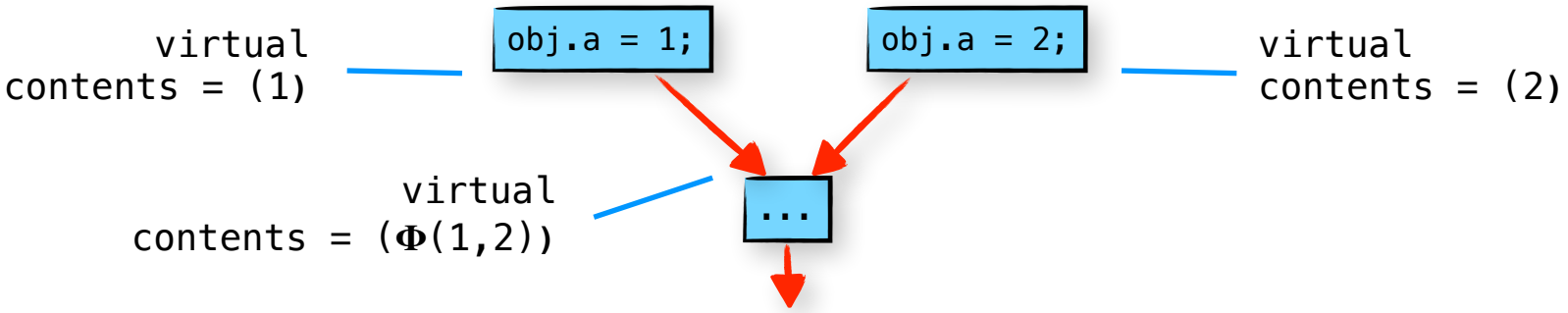


Partial Escape Analysis - Iteration

- Performs EA of all allocations in one iteration
  - Replaces IR nodes with virtualization effect
- Interfaces on IR node classes:
  - `interface VirtualizableAllocation`
    - Nodes that produce a virtualizable object (NewInstance, NewArray, ...)
  - `interface Virtualizable`
    - Nodes that have a virtualizable effect (StoreField, LoadIndexed, ...)

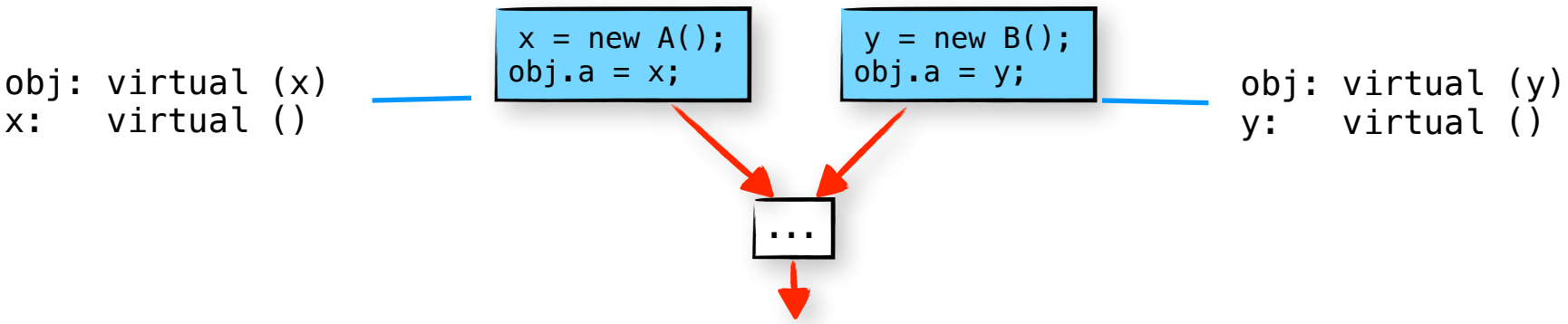
Partial Escape Analysis - Iteration

- Control Flow Merge
  - New Phi function



Partial Escape Analysis - Iteration

- Control Flow Merge
  - Merge of virtualized objects



Partial Escape Analysis - Iteration

- Control Flow Merge
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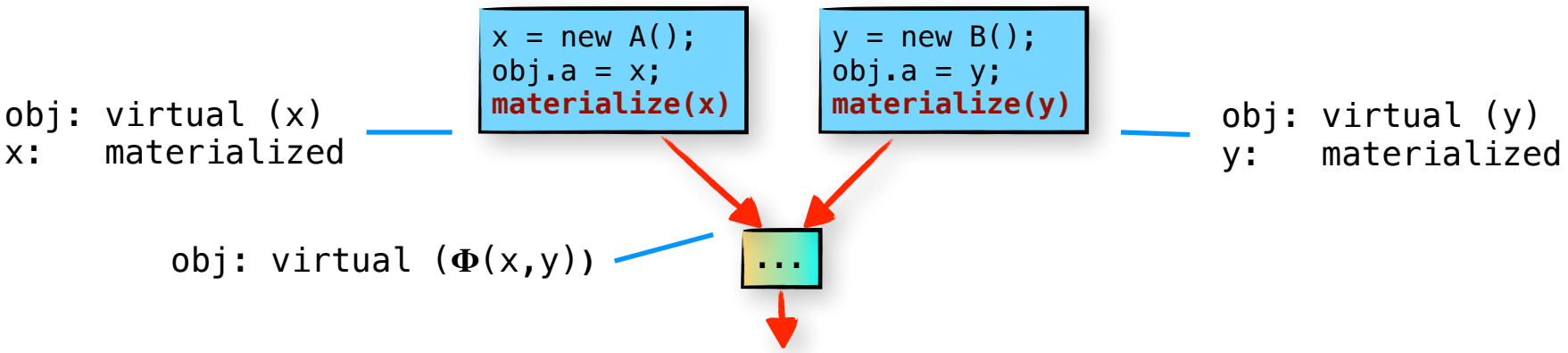
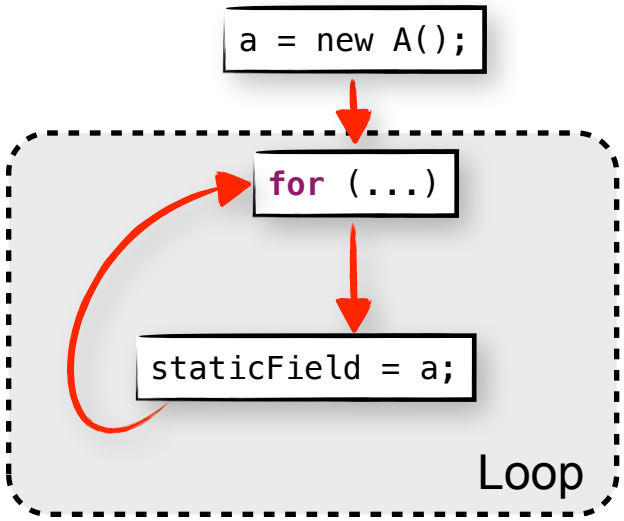


Partial Escape Analysis - Iteration

- Loops
  - Requires backtracking



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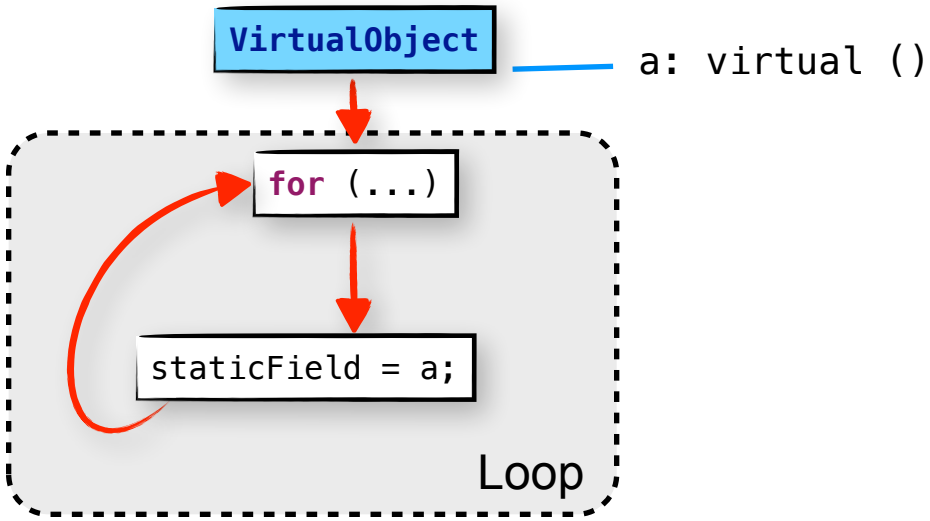

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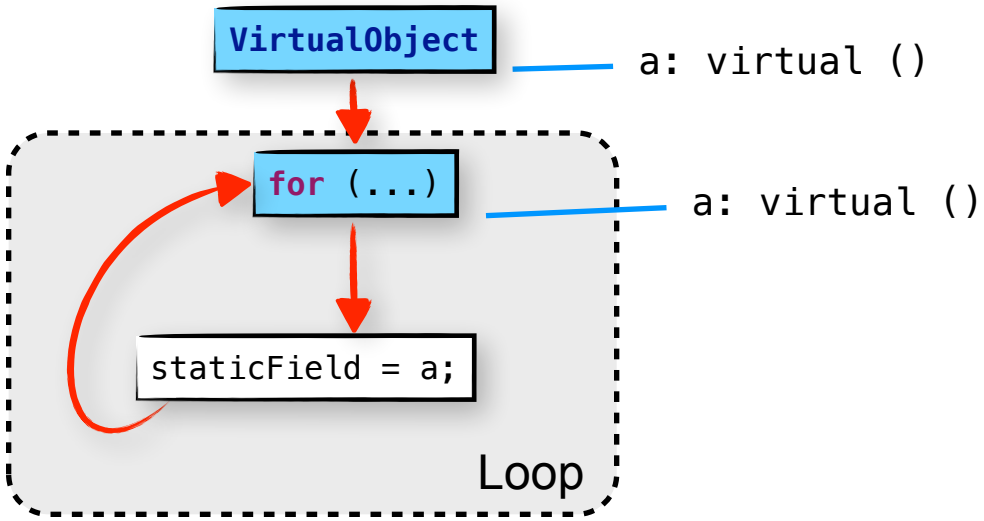

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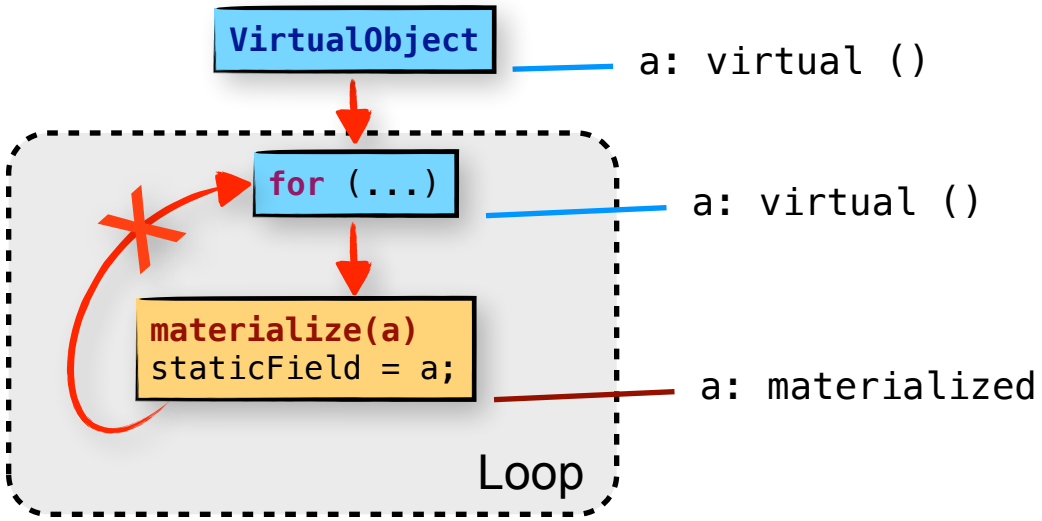

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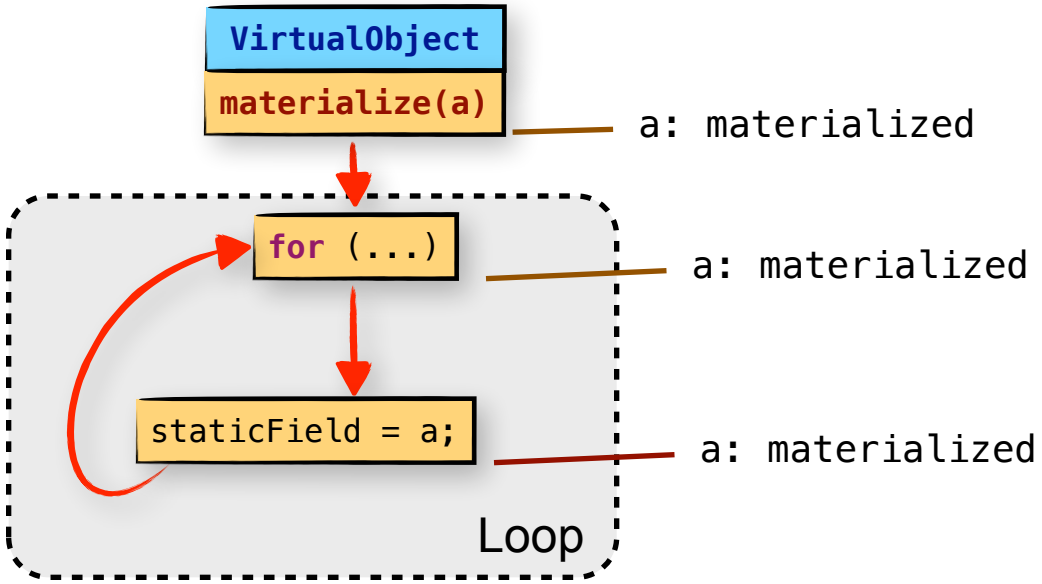


Evaluation

- Effects of Partial Escape Analysis:
  - Fewer allocations: less code
  - Fewer allocations: less GC work, less work for allocations
  - Fewer lock / unlock operations
  - Scalar Replacement: remove accesses
  - Coalescing allocations
  - Values not flowing through objects: easier for compiler
  - Clever handling of Boxing/Unboxing operations
- Impact on Compilation Time in Graal: 3.5 - 4%
  - Half of this is spent on scheduling
- Easy to implement PEA for new constructs:
  - Simply add `virtualize` method to new node type

Example - DaCapo sunflow

```
public Color getIrradiance(ShadingState state, Color diffRefl) {
  float b = (float) Math.PI * c / diffRefl.getMax();
  Color irr = Color.black();
  Point3 p = state.getPoint();
  Vector3 n = state.getNormal();
  int set = (int) (state.getRandom(0, 1, 1) * numSets);
  for (PointLight pl : virtualLights[set]) {
    Ray r = new Ray(p, pl.p);
    float dotNlD = -(r.dx * pl.n.x + r.dy * pl.n.y + r.dz * pl.n.z);
    float dotND = r.dx * n.x + r.dy * n.y + r.dz * n.z;
    if (dotNlD > 0 && dotND > 0) {
      float r2 = r.getMax() * r.getMax();
      Color opacity = state.traceShadow(r);
      Color power = Color.blend(pl.power, Color.BLACK, opacity);
      float g = (dotND * dotNlD) / r2;
      irr.madd(0.25f * Math.min(g, b), power);
    }
  }
  return irr;
}
```

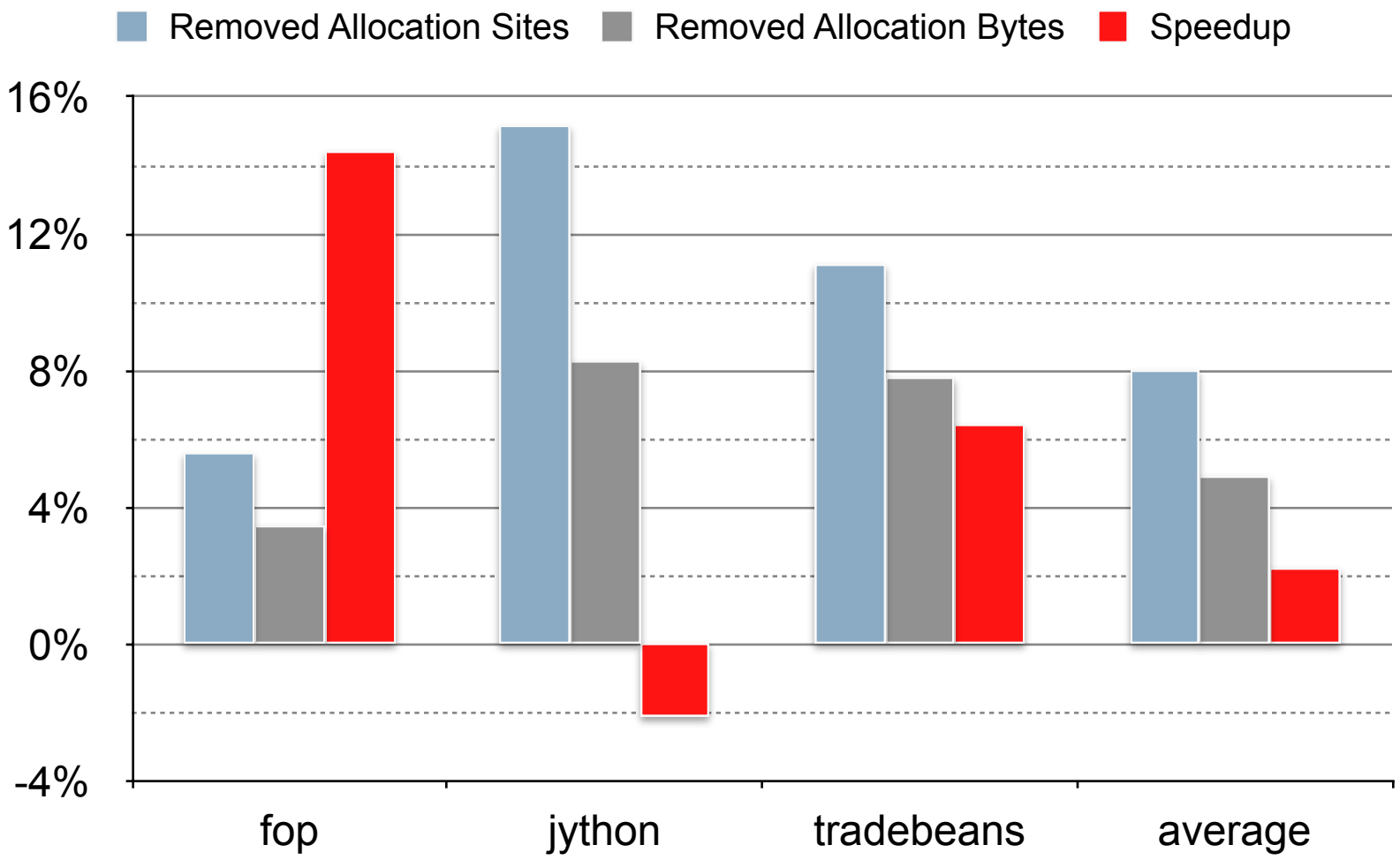
count: ~130

probability: 56%

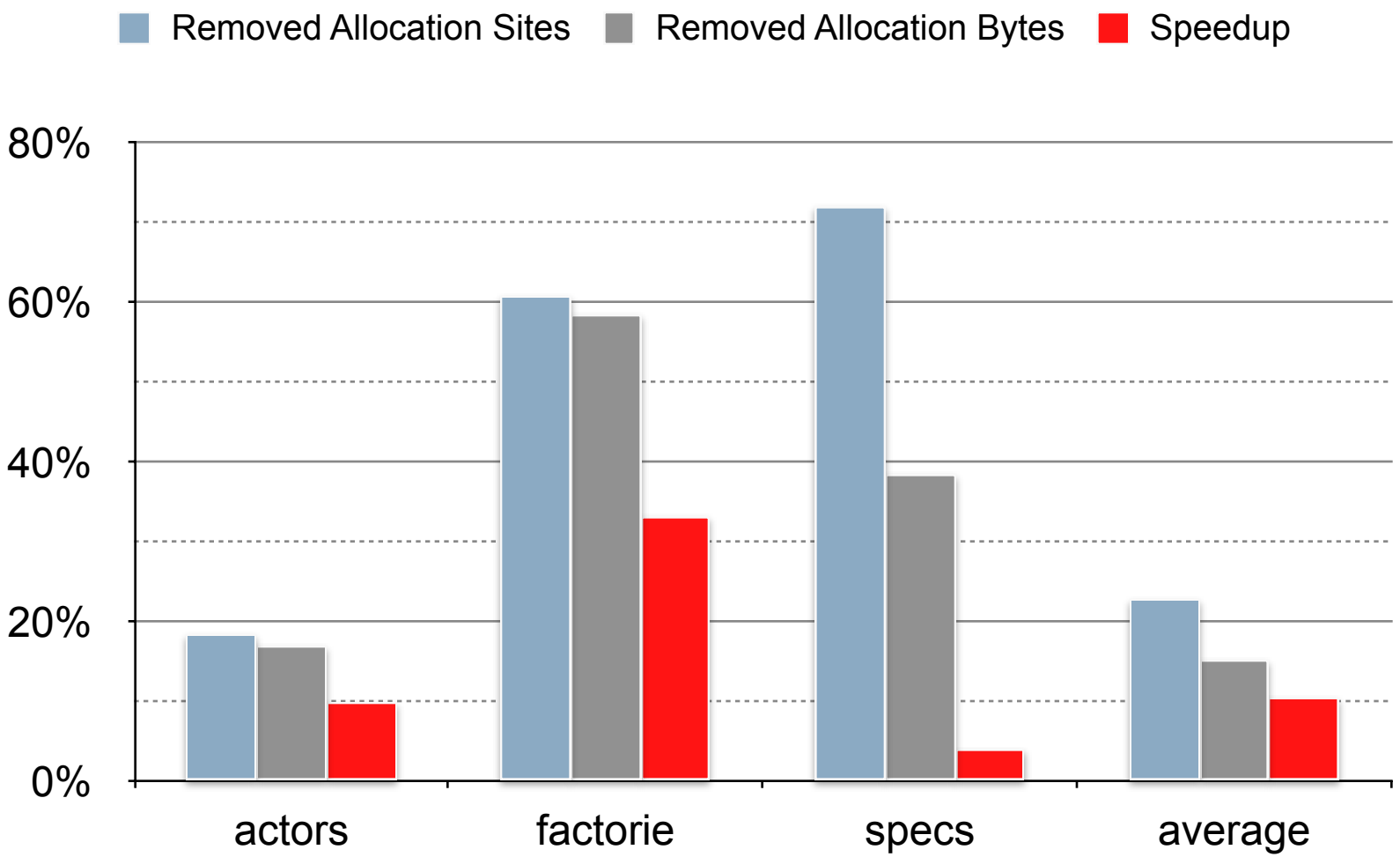
Partial Escape Analysis:
… removed 33% of allocation sites
… removed 64% of dynamic allocations (EA: 36%)
… reduced size of method by 18%

Evaluation - DaCapo

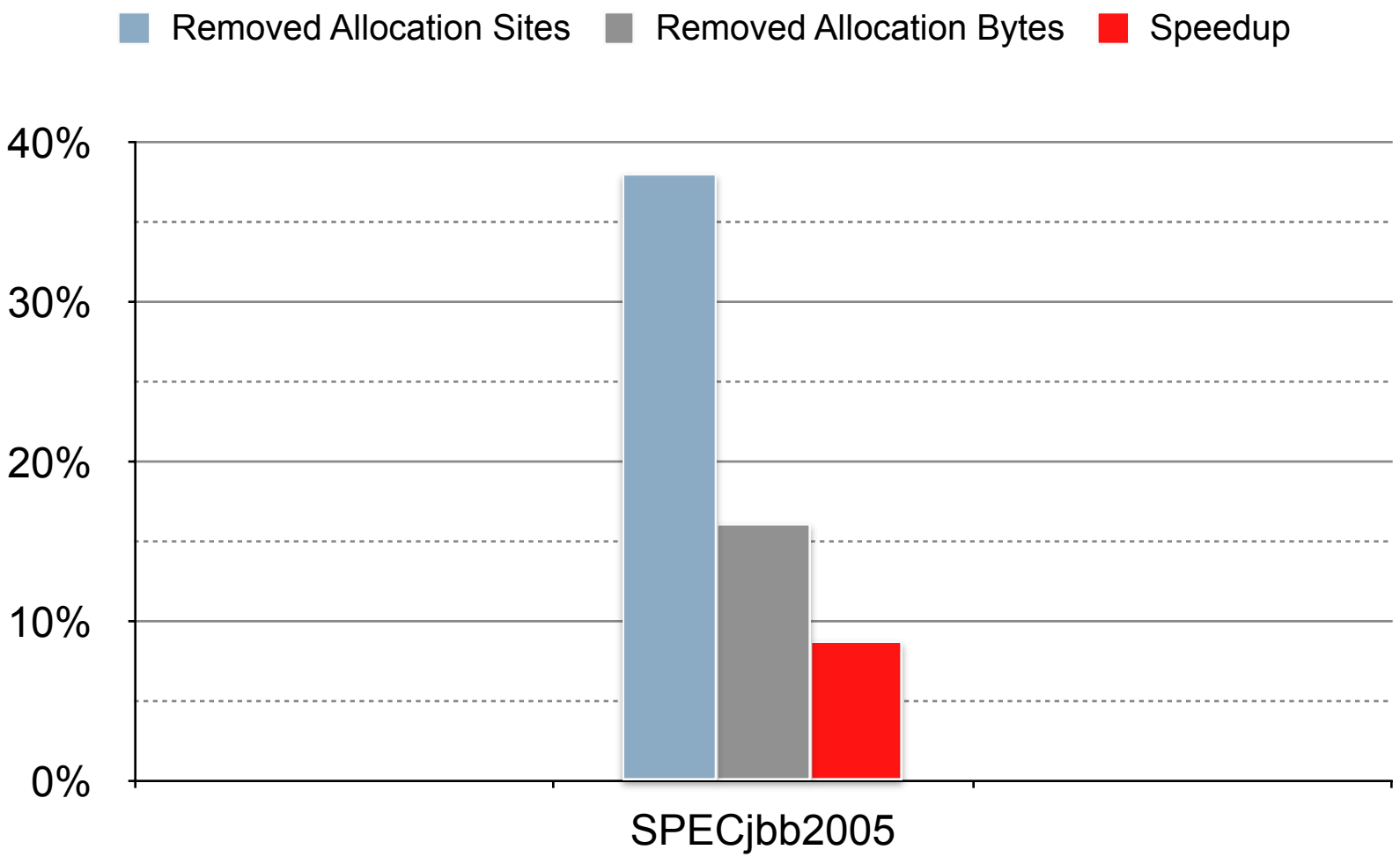
Xeon E5-2690, 2GB heap



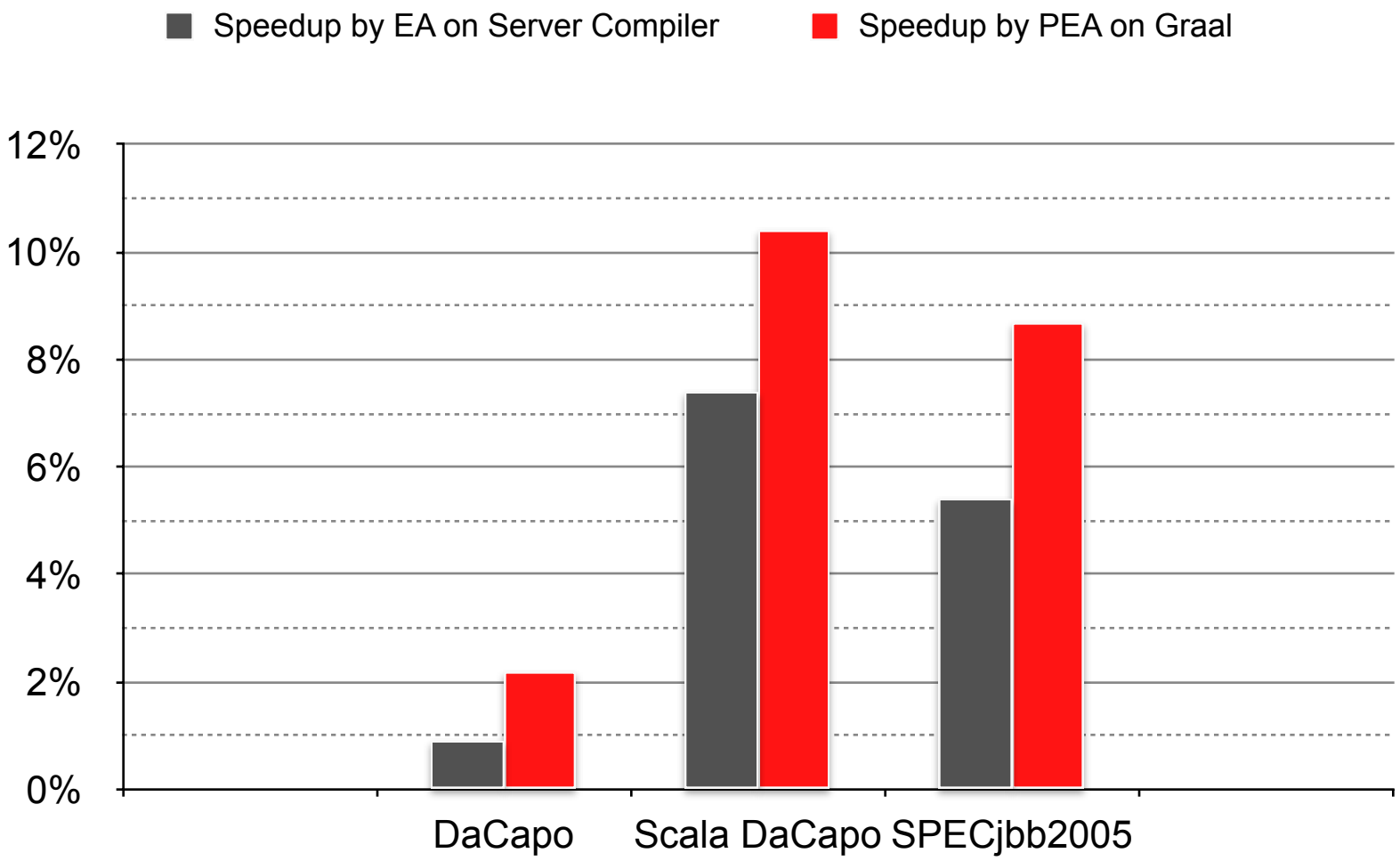
Evaluation - Scala DaCapo



Evaluation - SPECjbb2005



Evaluation - Comparison to Server Compiler



Conclusions

- Scheduling is costly
  - Non-scheduling version
  - Special scheduling that only places some nodes
- Efficient way to perform Escape Analysis
- Very important for Truffle framework
  - Can be applied multiple times during compilation

Acknowledgements

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Bernhard Urban (JKU)
Christian Wimmer (Oracle Labs)
Thomas Würthinger (Oracle Labs)

Q&A

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