Leak Pruning

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Deployed Software Fails

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  - 10,000 lines of C#

http://www.codeproject.com/KB/showcase/IfOnlyWedUsedANTSProfiler.aspx

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  "This problem was pernicious because it only showed up after 40 minutes to an hour of driving around and collecting obstacles."
- Quick "fix": restart after 40 minutes
- Environment sensitive
  - More obstacles in deployed setting
  - Unresponsive after 28 minutes

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- Environment sensitive
  - More obst g
  - Unrespons

Different environments & inputs → different behavior

Hard to fix before deployment

Uncertainty in deployed systems

Tolerating Memory Leaks

- Deployed systems have leaks
  - Critical systems need immediate help
- **Leak pruning** tolerates bad effects
  - Reclaims memory automatically
  - High precision & low overhead
  - Bounds resources
  - Preserves semantics

Outline

- Why tolerate leaks
- Why leaks are so bad
- How leak pruning works
- How leak pruning predicts leaked objects
- Evaluation

Memory Leaks in Deployed Systems

- Memory leaks are a real problem
  - Managed languages do not eliminate them

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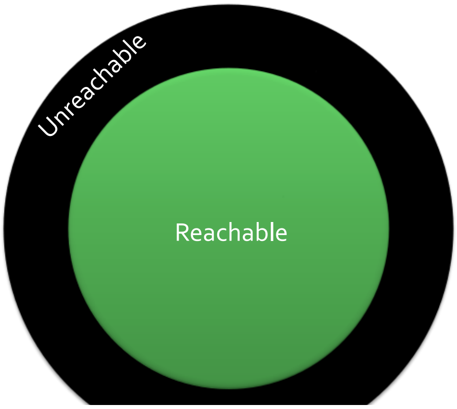

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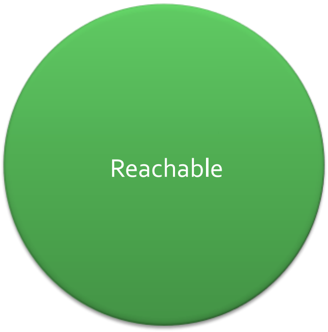

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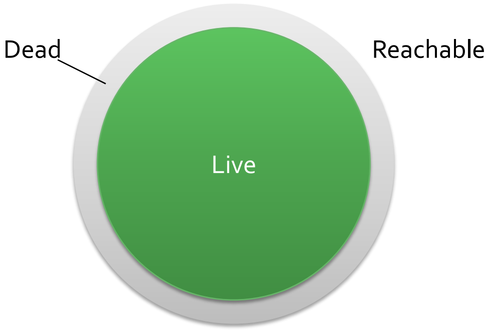

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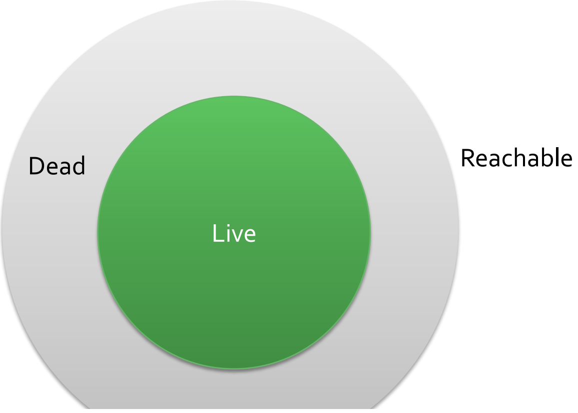

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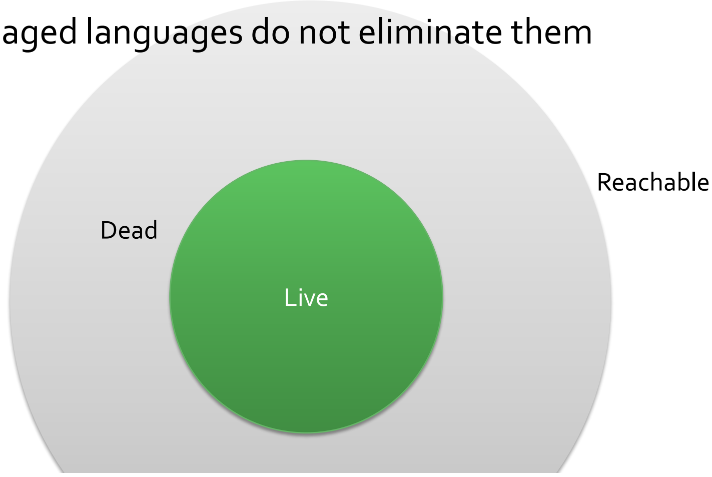

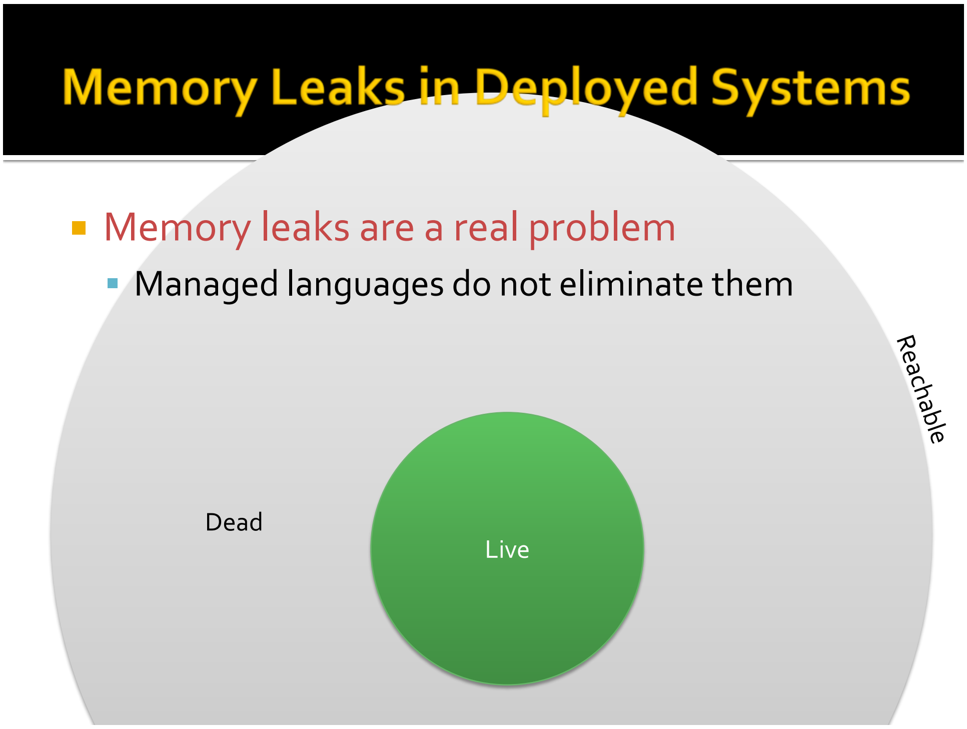

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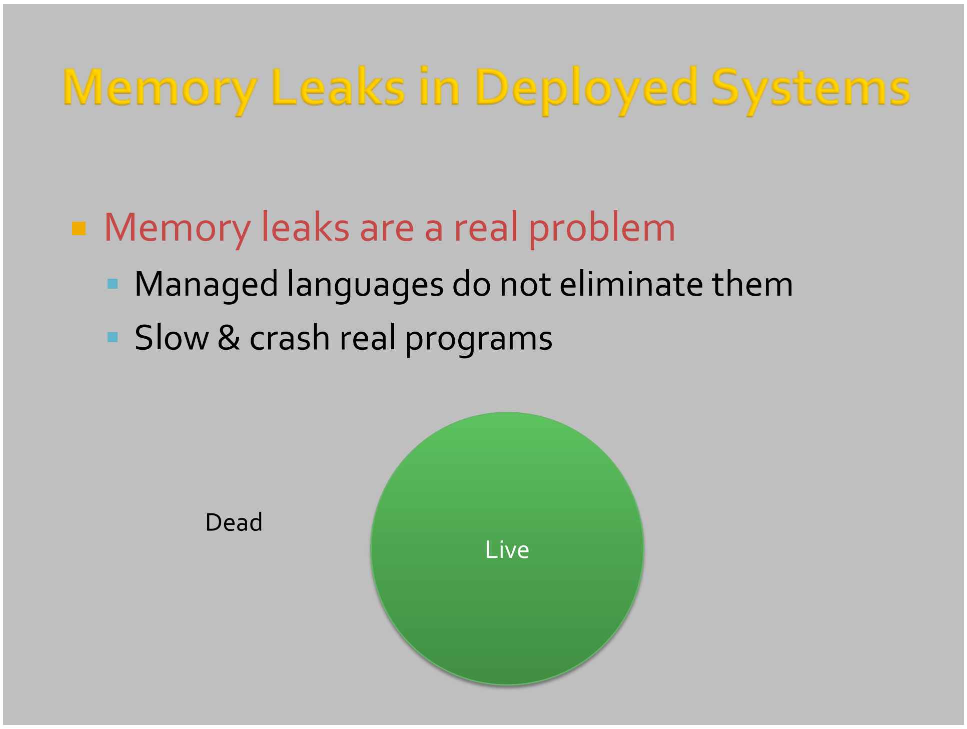
Reachable

Dead

Live



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  - Unacceptable for some applications

Memory Leaks in Deployed Systems

- Memory leaks are a real problem
  - Managed languages do not eliminate them
  - Slow & crash real programs
  - Unacceptable for some applications
- Fixing leaks is hard
  - Leaks take time to materialize
  - Failure far from cause

Outline

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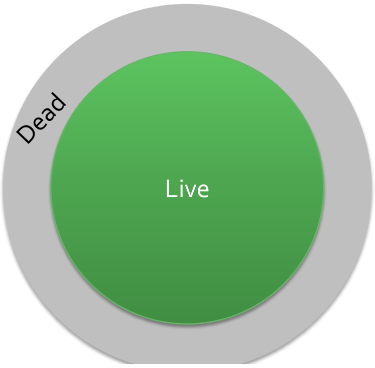
- Evaluation

Reclaiming Memory while Preserving Semantics

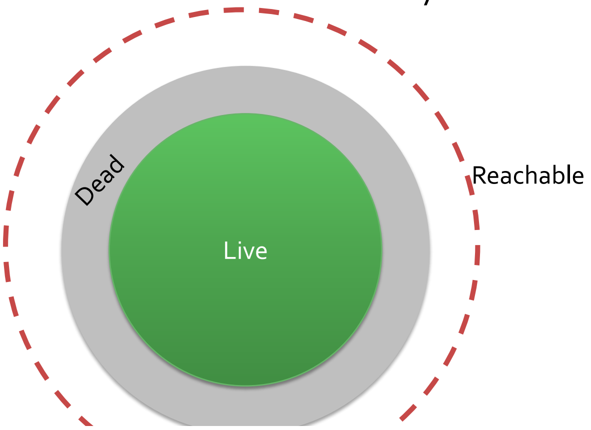
- Garbage collection based on liveness



Reachable

Reclaiming Memory while Preserving Semantics

- Garbage collection based on liveness
  - Take action when memory exhausted



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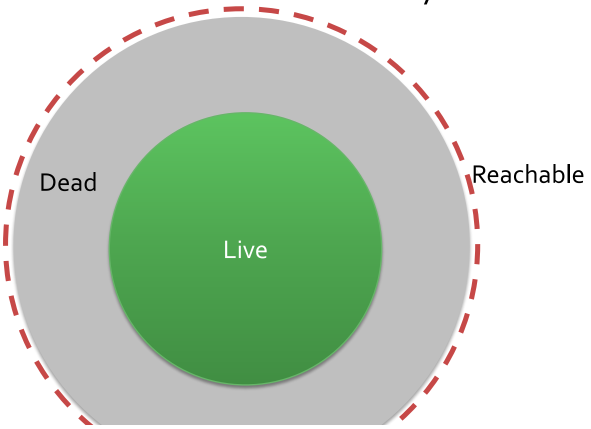

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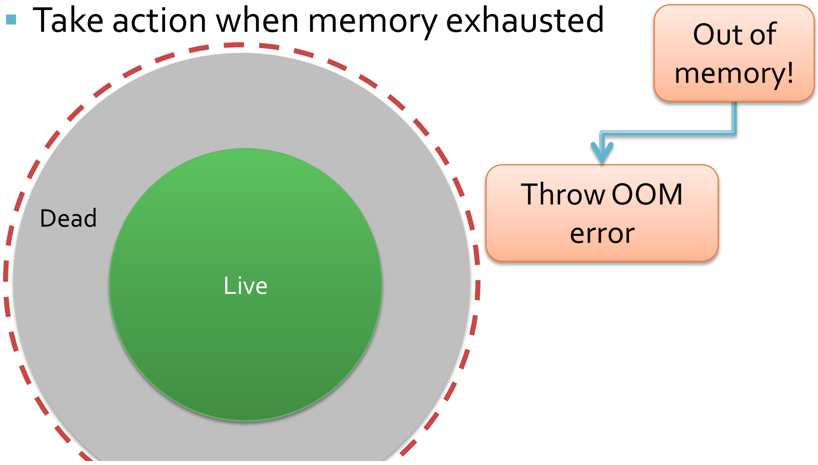

Dead

Live

Out of memory!

Throw OOM error

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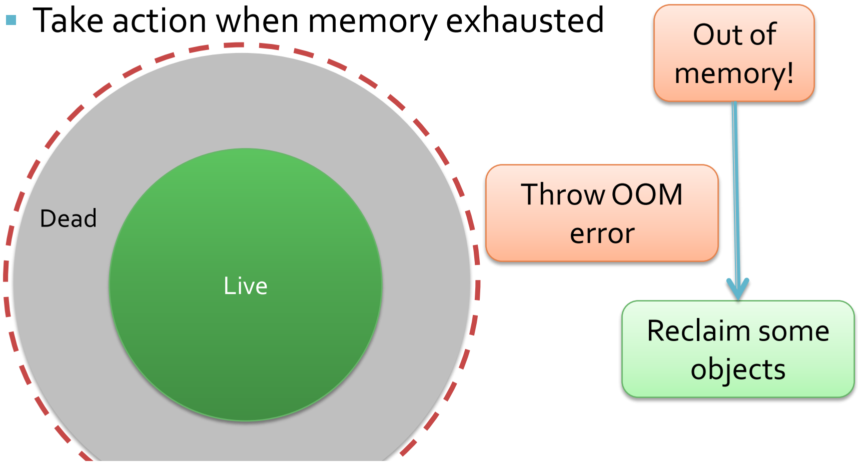

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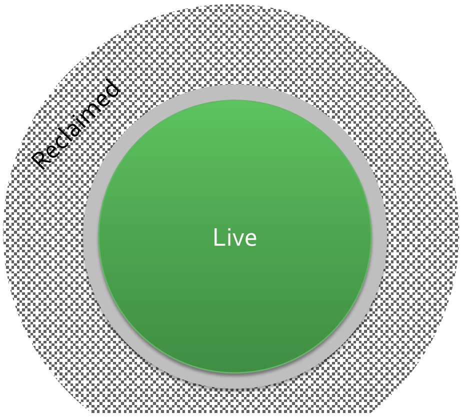
Reclaim some objects

Reclaiming Memory while Preserving Semantics

- Garbage collection based on liveness
  - Reclaim predicted dead objects



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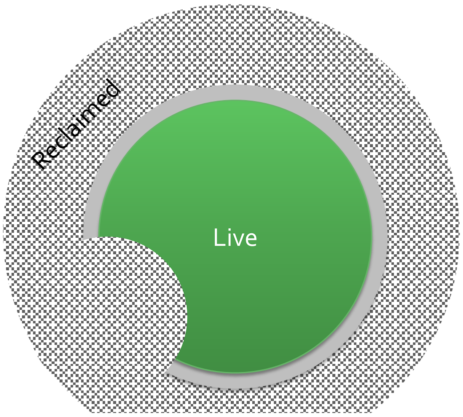

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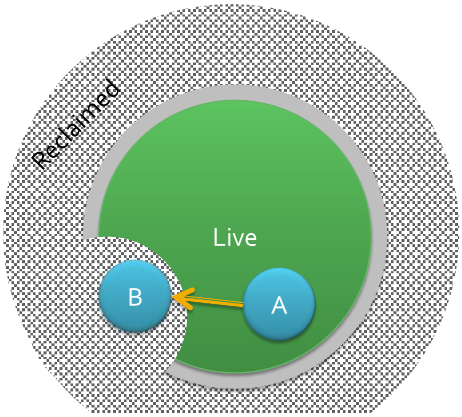

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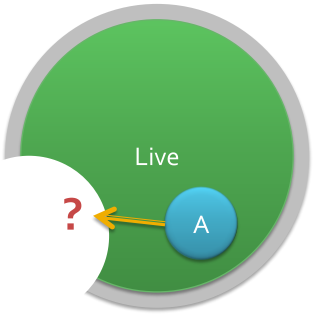
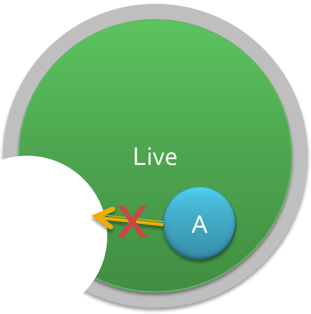


Reclaiming Memory while Preserving Semantics

- Garbage collection based on liveness
  - Reclaim predicted dead objects
  - *Poison* references to reclaimed objects



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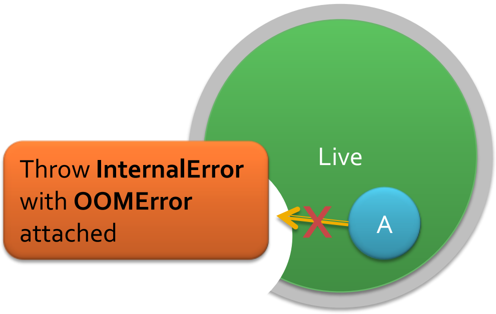

Throw **InternalError** with **OOMError** attached

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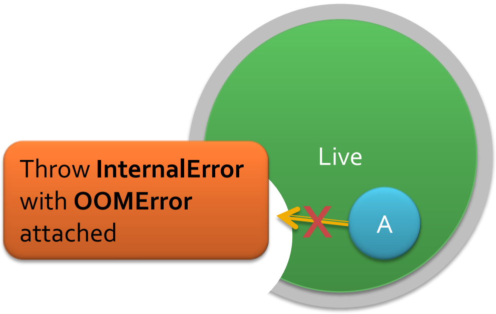

Throw **InternalError** with **OOMError** attached

Worst case: defers fatal errors

Best case: keeps leaky programs running much longer or indefinitely

Outline

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Predicting Dead Objects

- Predicting the future
  - Leaked objects → not used again
  - Highly *stale* objects → *likely* leaked

  [Chilimbi & Hauswirth ’04] [Qin et al. ’05] [Bond & McKinley ’06]

Predicting Dead Objects

- Predicting the future
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  - Highly *stale* objects → *likely* leaked
- Alternative: offload to disk

  [**Melt**, Bond & McKinley ’08]
  [**LeakSurvivor**, Tang et al. ’08]
  [**Panacea**, Goldstein et al. ’07, Breitgand et al. ’07]
  - Tolerates mispredictions
  - Eventually exhausts disk (if disk at all)

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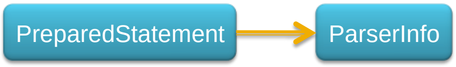
Need high precision

One misprediction: program terminates

Predicting Dead Data Structures

- Identify references to prune
  - Roots of leaked data structures
  - Categorize by *reference type*



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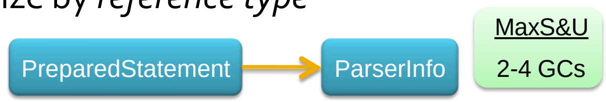

MaxS&U
2-4 GCs

  - Highly stale references
    - More stale than *most stale instance accessed previously*

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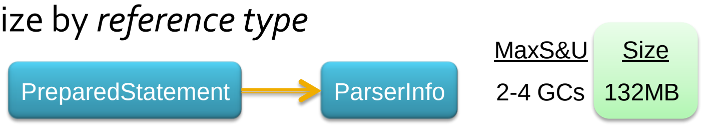

MaxS&U	Size
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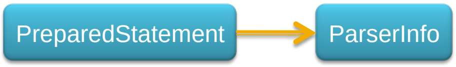

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- Criteria
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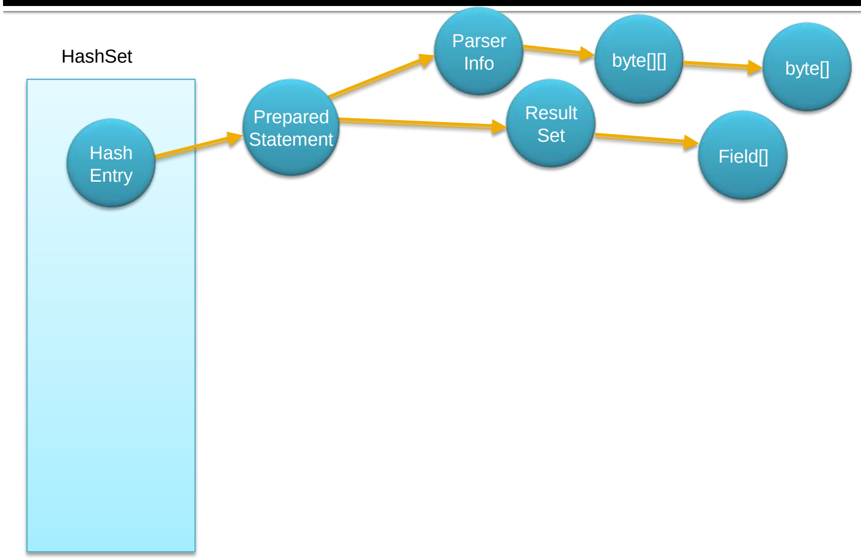
Piggyback on GC: two-phase transitive closure

MySQL Leak

- Based on colleague's JDBC application
- Leak: SQL statements remain in set

MySQL Leak



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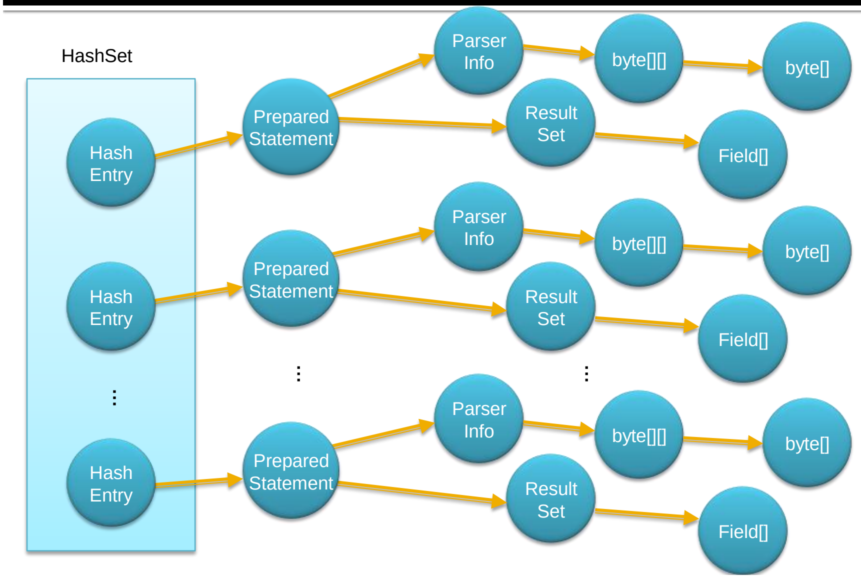
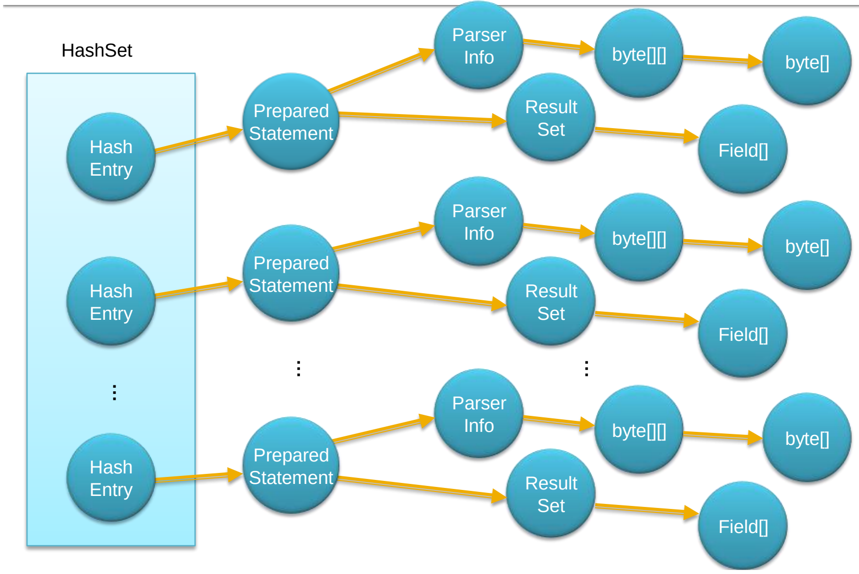
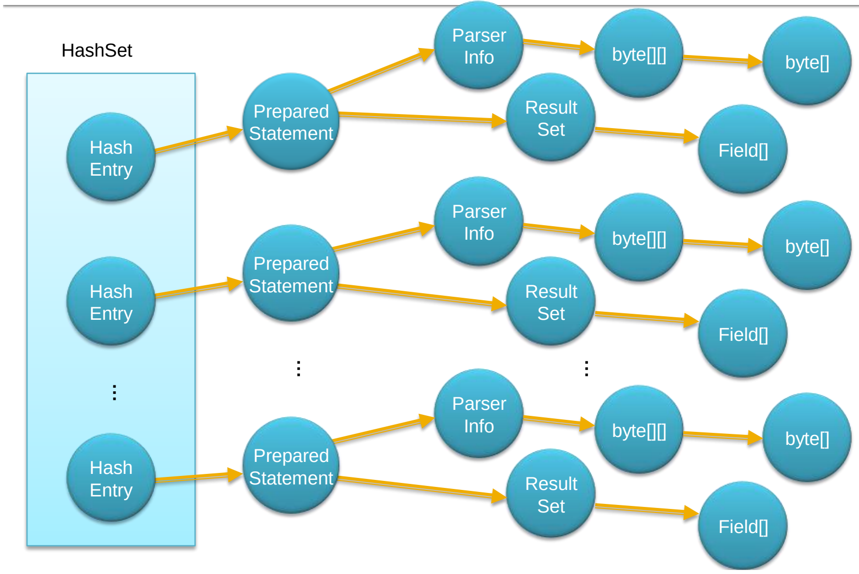


Transitive Closure: Phase One



Transitive Closure: Phase One

		MaxS&U
HashEntry →	PreparedStatement	16-32
PreparedStatement →	ParserInfo	0-1
PreparedStatement →	ResultSet	0-1



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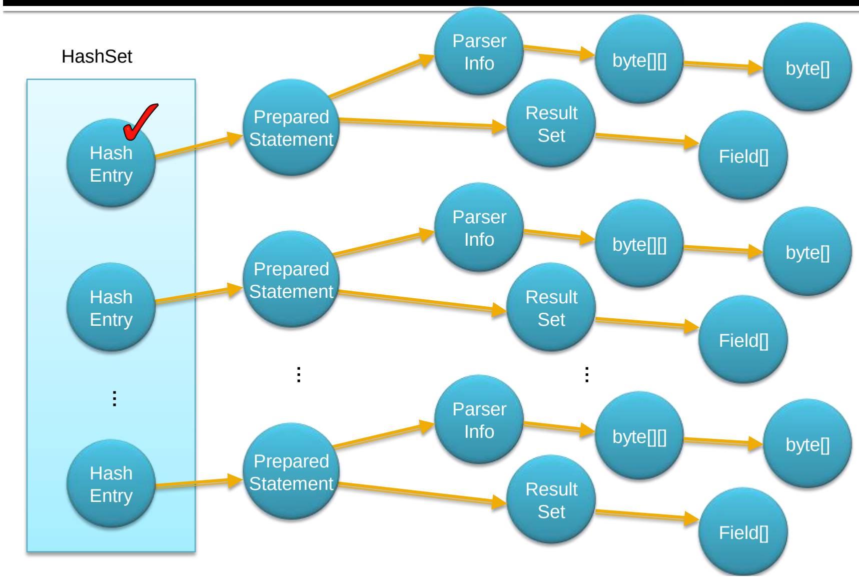

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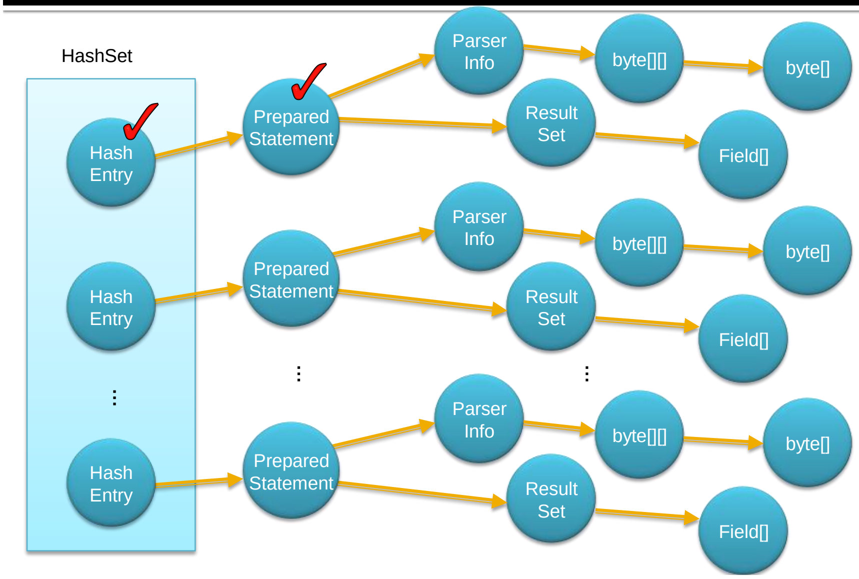

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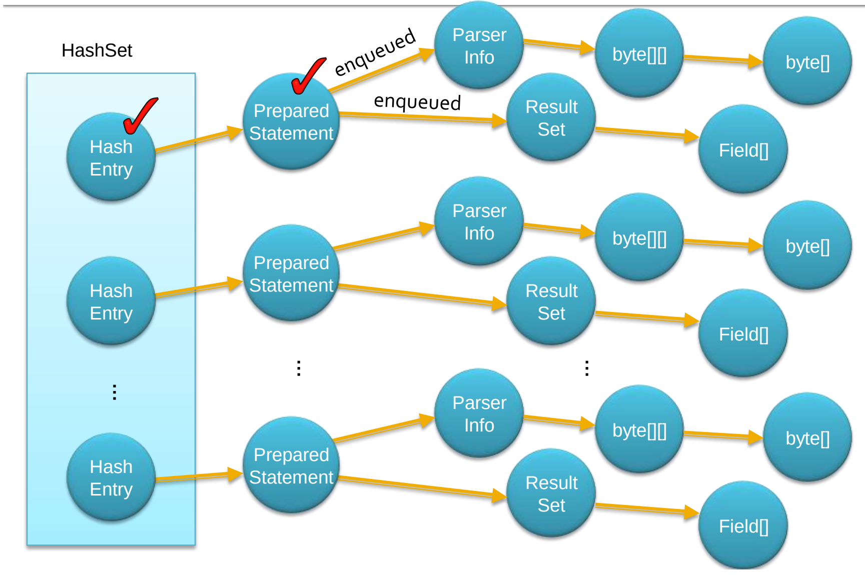

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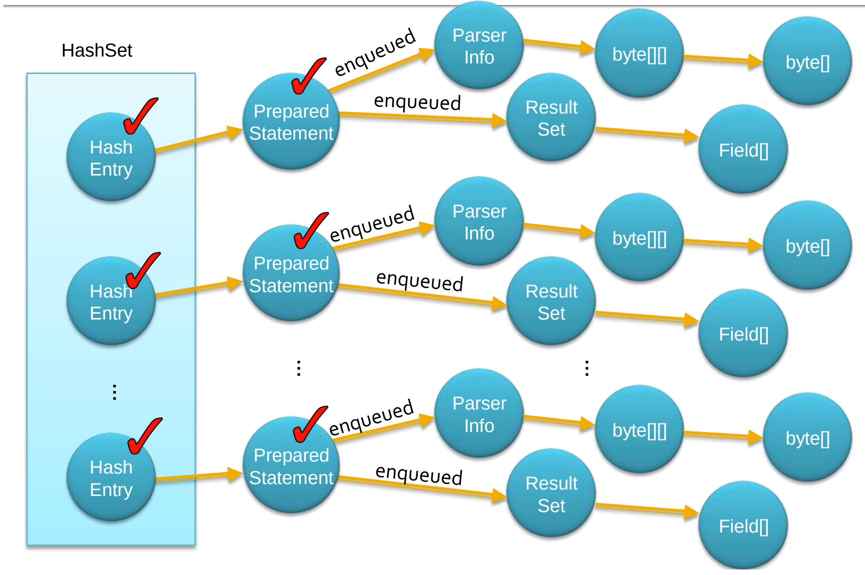
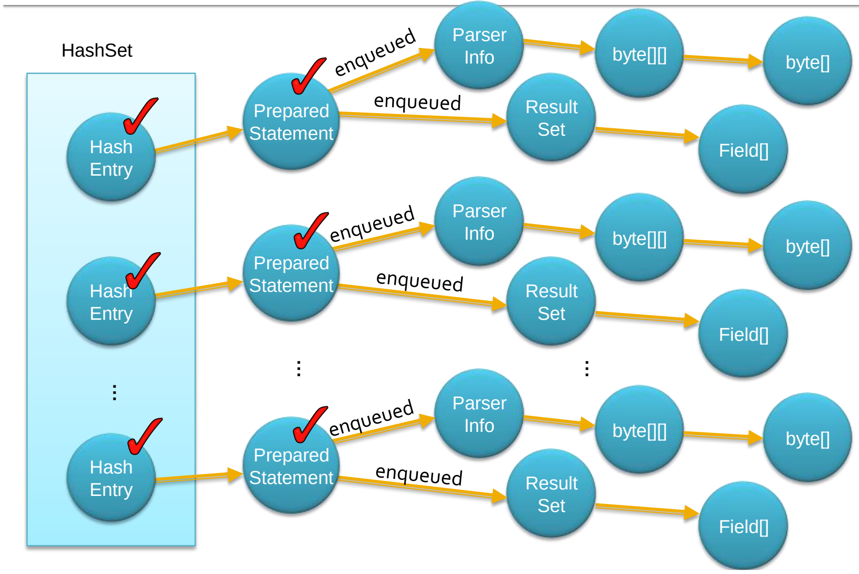


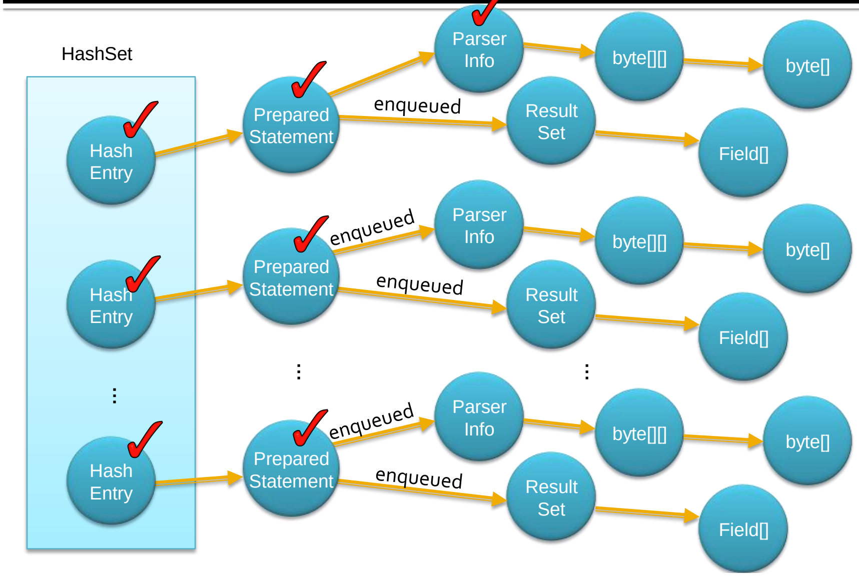
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	0
PreparedStatement → ResultSet	0-1	0



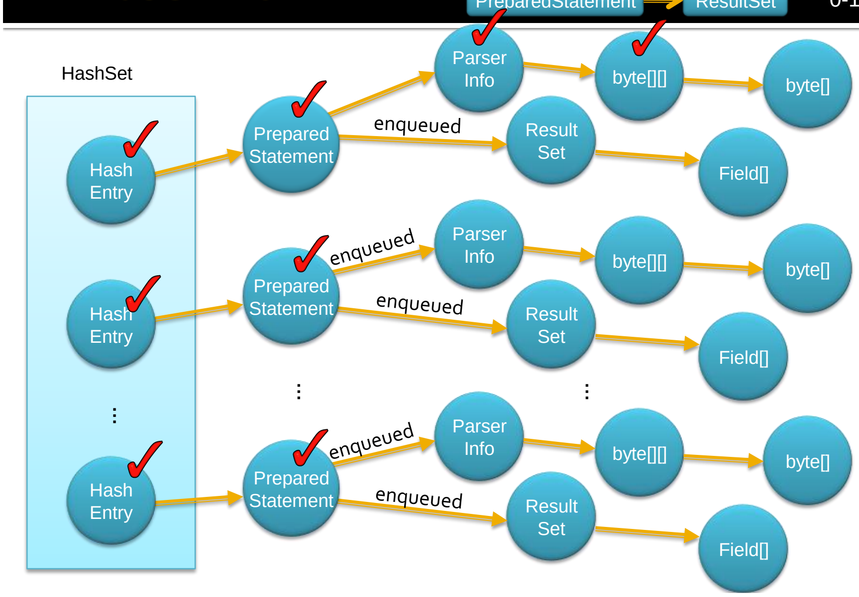
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	20
PreparedStatement → ResultSet	0-1	0



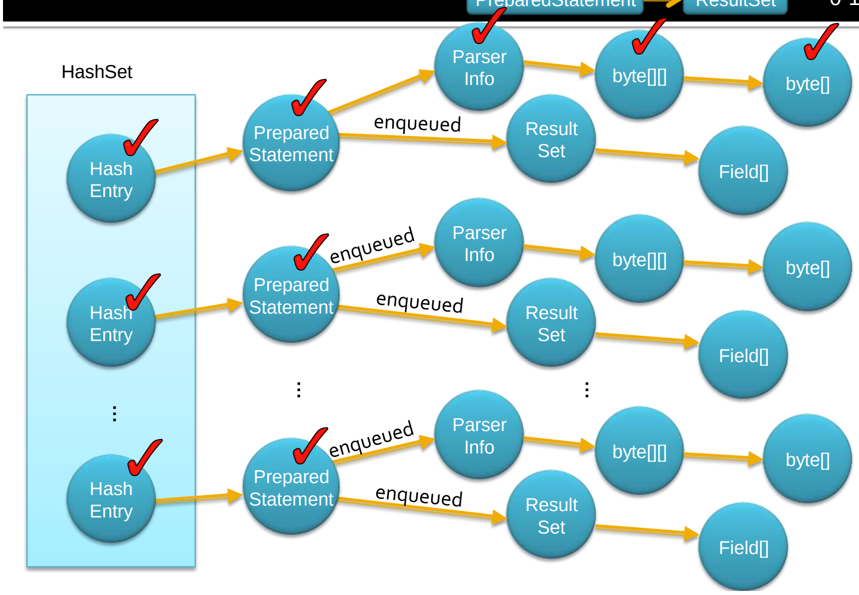
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	60
PreparedStatement → ResultSet	0-1	0



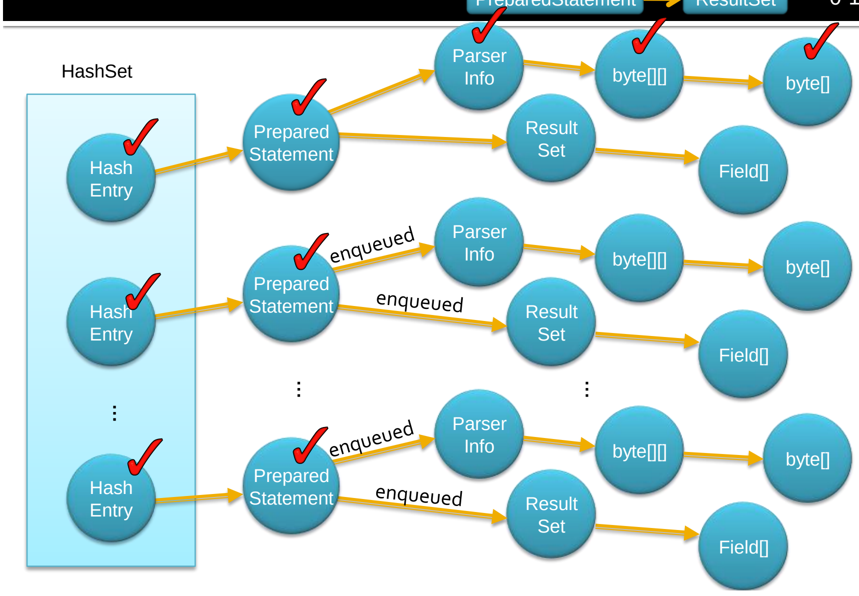
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	572
PreparedStatement → ResultSet	0-1	0



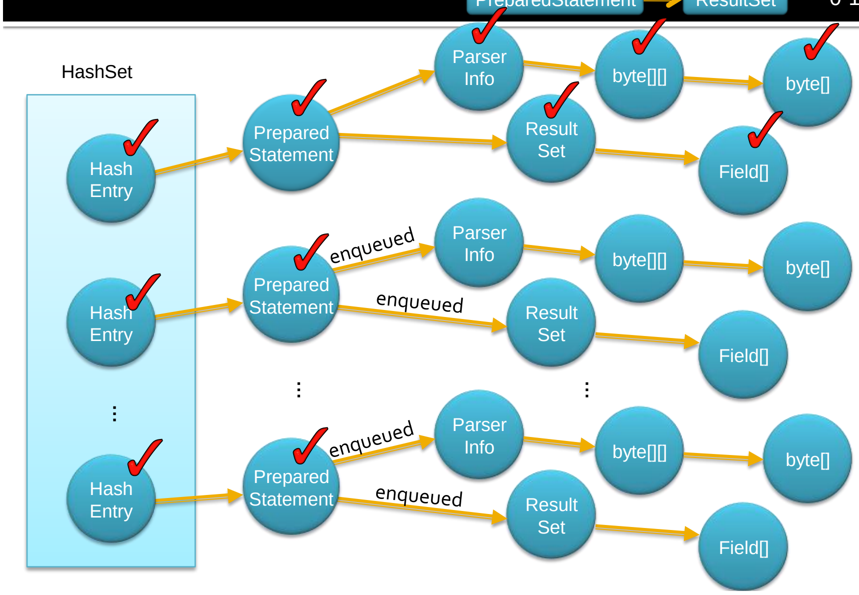
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	572
PreparedStatement → ResultSet	0-1	0



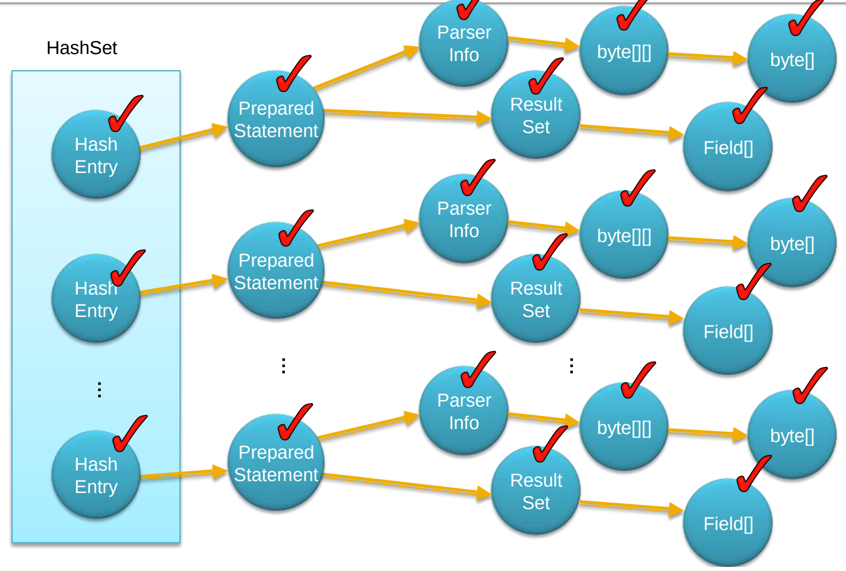
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	572
PreparedStatement → ResultSet	0-1	244



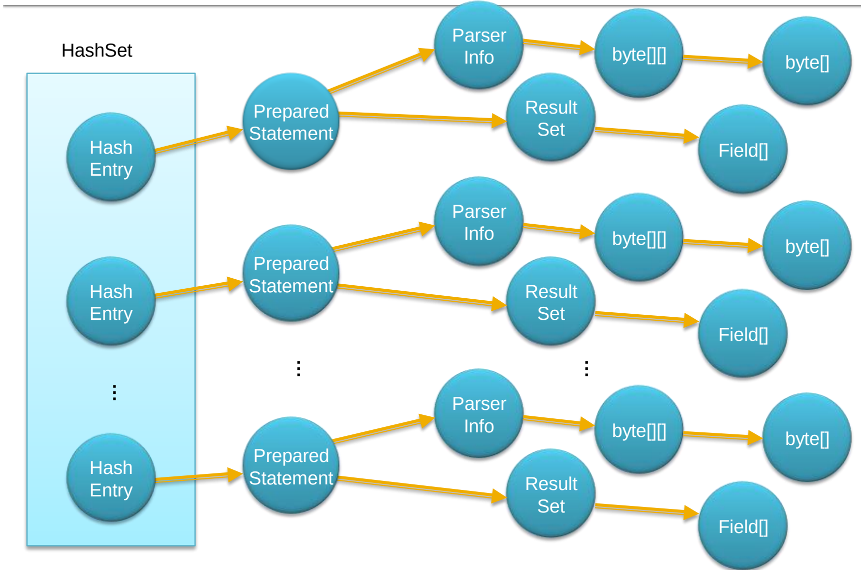
Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	420M
PreparedStatement → ResultSet	0-1	180M



Select Best Reference Type

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	420M
PreparedStatement → ResultSet	0-1	180M



Prune Selected Reference Type

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	420M
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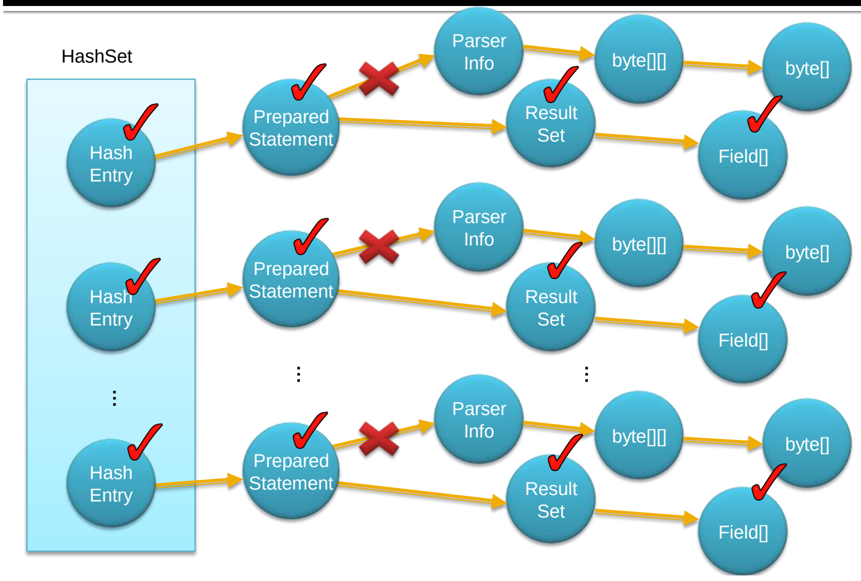

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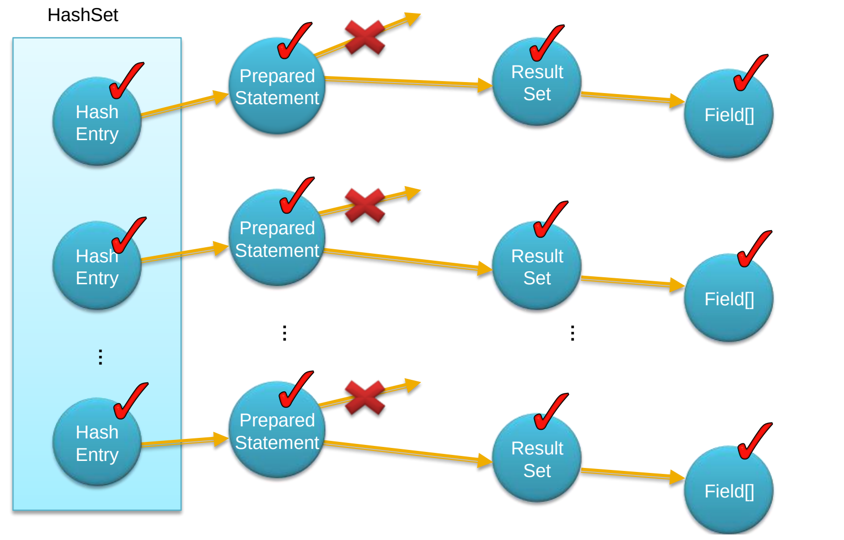
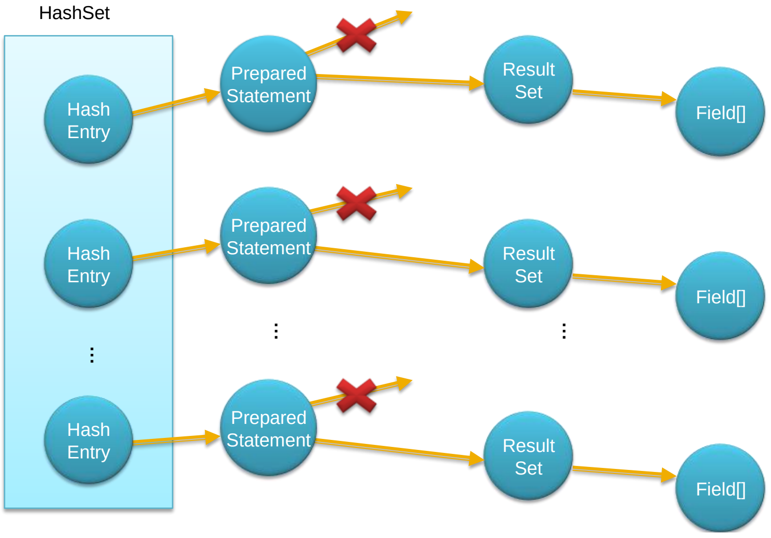


Leak Partially Eliminated

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	0
PreparedStatement → ResultSet	0-1	0



Transitive Closure: Phase One

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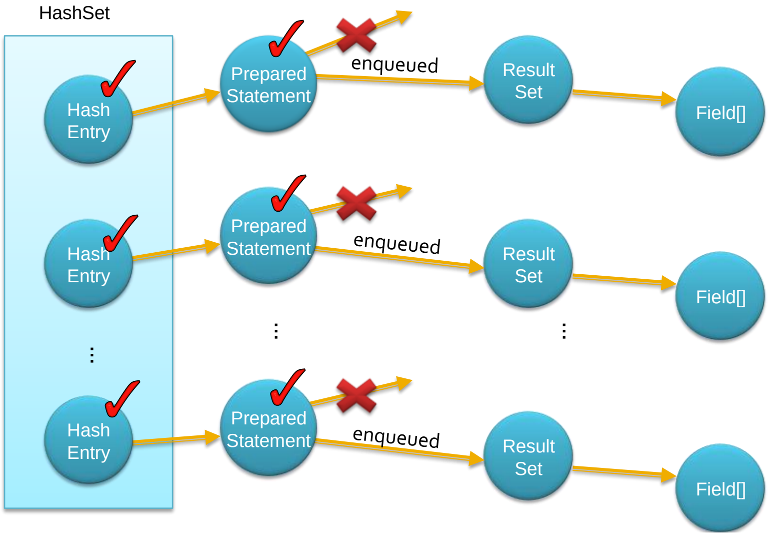
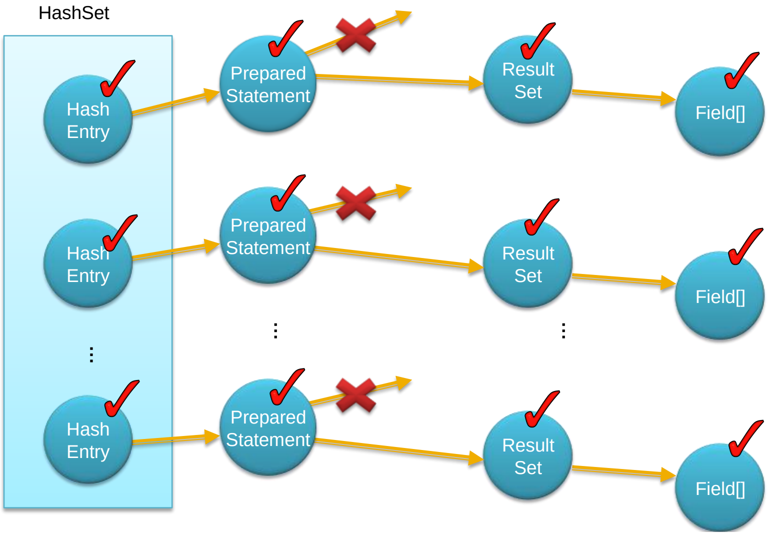
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	0
PreparedStatement → ResultSet	0-1	0



Transitive Closure: Phase Two

	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	50M
PreparedStatement → ResultSet	0-1	220M



Select Best Reference Type

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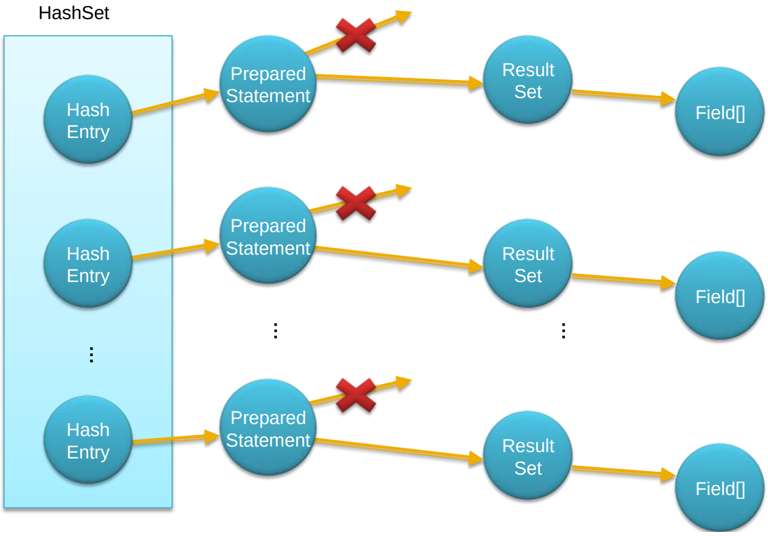
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	50M
PreparedStatement → ResultSet	0-1	220M



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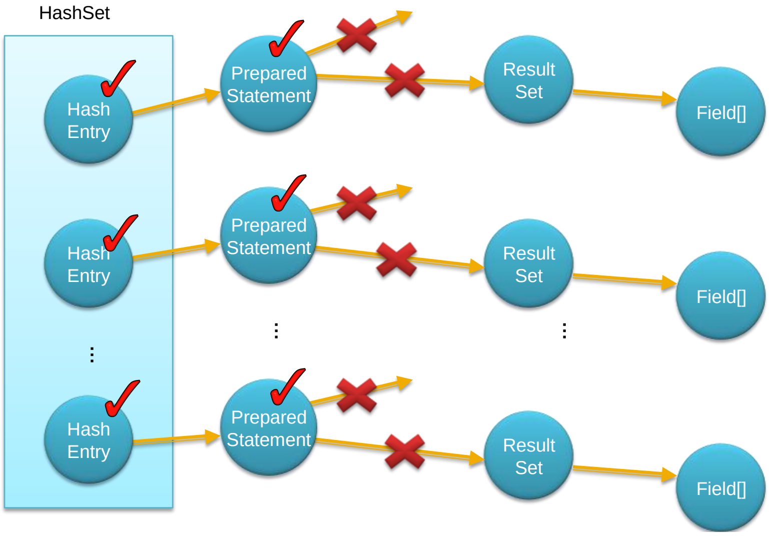
	MaxS&U	Bytes
HashEntry → PreparedStatement	16-32	0
PreparedStatement → ParserInfo	0-1	50M
PreparedStatement → ResultSet	0-1	220M



Prune Selected Reference Type

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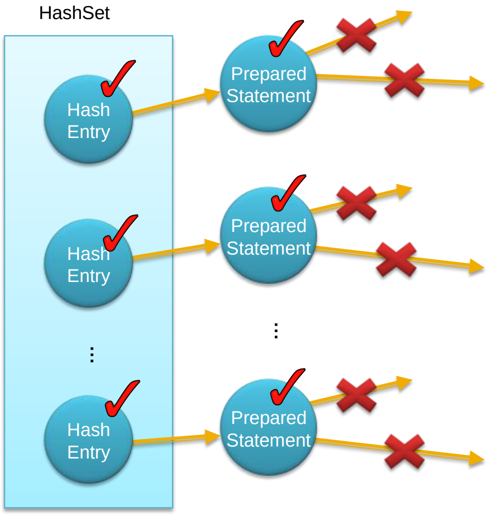
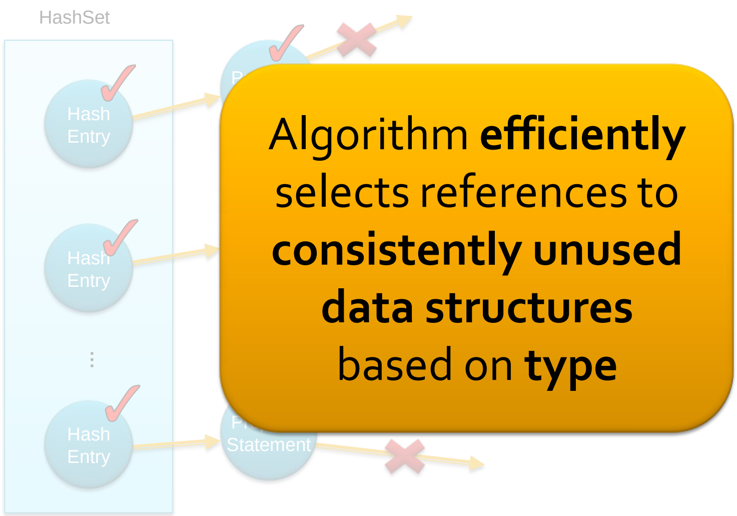


Prediction Summary



Algorithm **efficiently** selects references to **consistently unused data structures** based on **type**

Outline

- Why tolerate leaks
- Why leaks are so bad
- How leak pruning works
- How leak pruning predicts leaked objects
- Evaluation

Implementation

- Leak pruning added to Jikes RVM 2.9.2

  http://www.jikesrvm.org/Research+Archive

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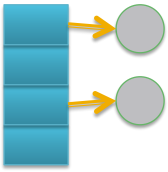
- Performance stress test
  - Non-leaking programs: DaCapo & SPEC benchmarks
  - Low overhead
    - 3% (Core 2) or 5% (Pentium 4)
    - Primarily read barriers

Tolerating Leaks

Leak	Leak pruning's effect
Eclipse "Diff"	Tolerates until 24-hr limit (>200X longer)
ListLeak	Tolerates until 24-hr limit (>25,000X longer)
SwapLeak	Tolerates until 24-hr limit (>2,200X longer)
Eclipse "Copy-Paste"	Most dead but some live (81X longer)
MySQL	Most dead but some live (35X longer)
JbbMod	All dead but pruning misses some (21X longer)
SPECjbb2000	Heap growth is mostly live (4.7X longer)
Mckoi Database	Thread leak: extra support needed (1.6X longer)
DualLeak	Heap growth is live (No help)

Tolerating Leaks



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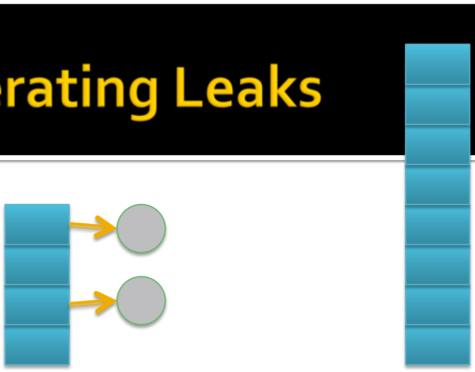

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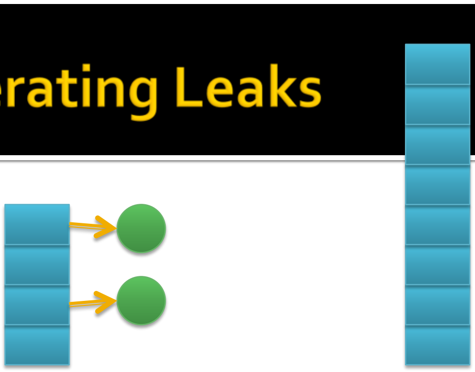

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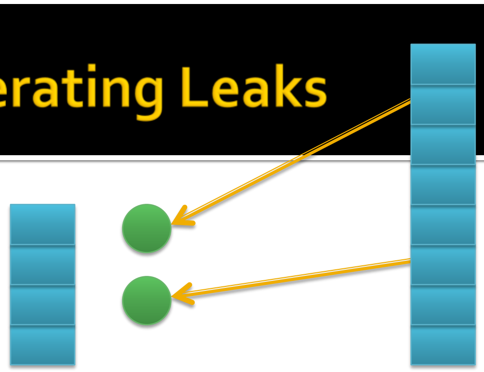

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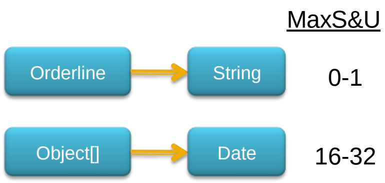

MaxS&U

Orderline → String 0-1

Object[] → Date 16-32

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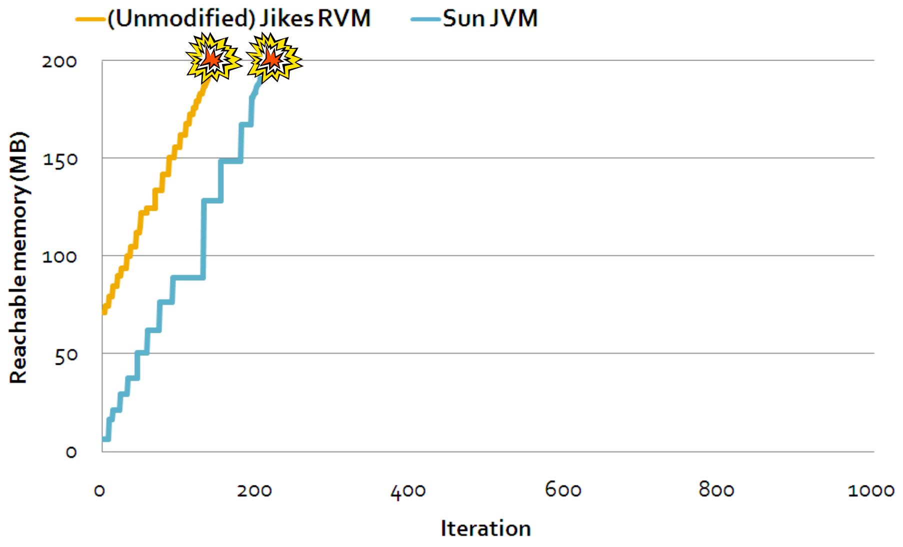
Tolerating Leaks

Eclipse “Diff”	Tolerates until 24-hr limit (>200X longer)

- Reported on Eclipse Bugzilla
- Leak: recursive difference
- Automated with Eclipse Plugin

Eclipse Diff: Reachable Memory



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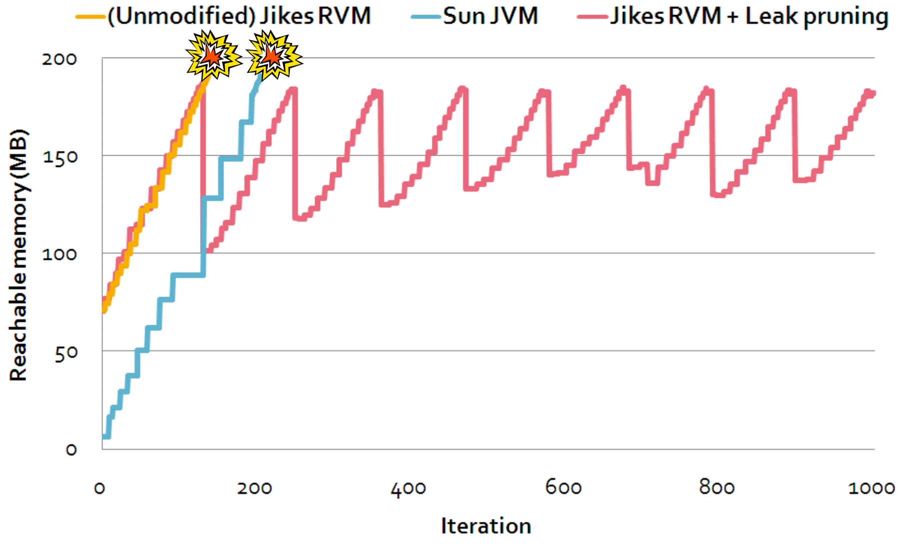

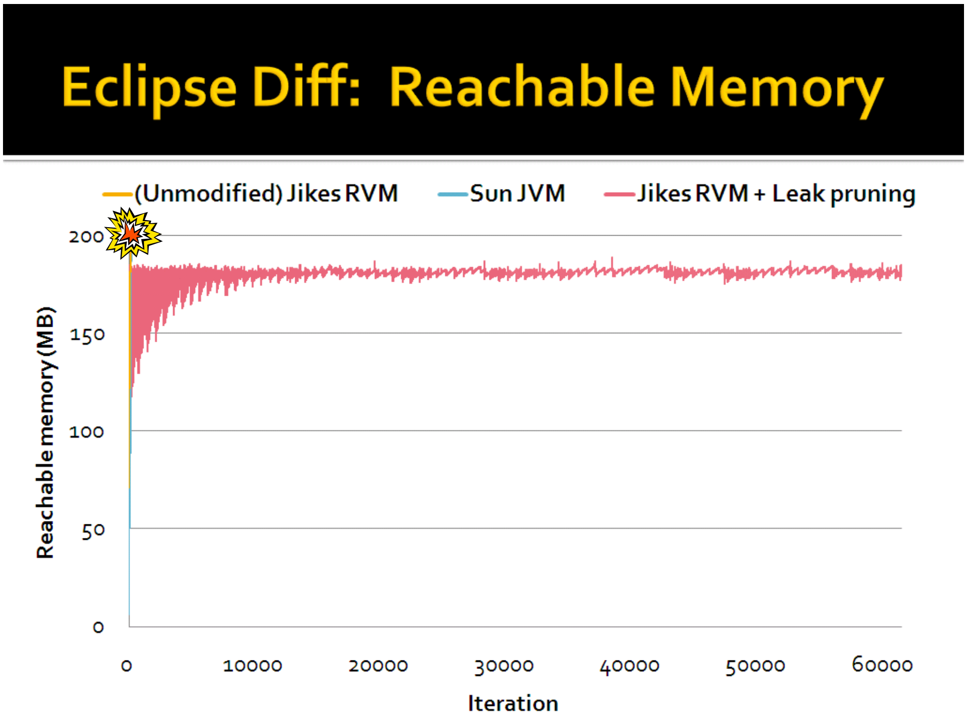

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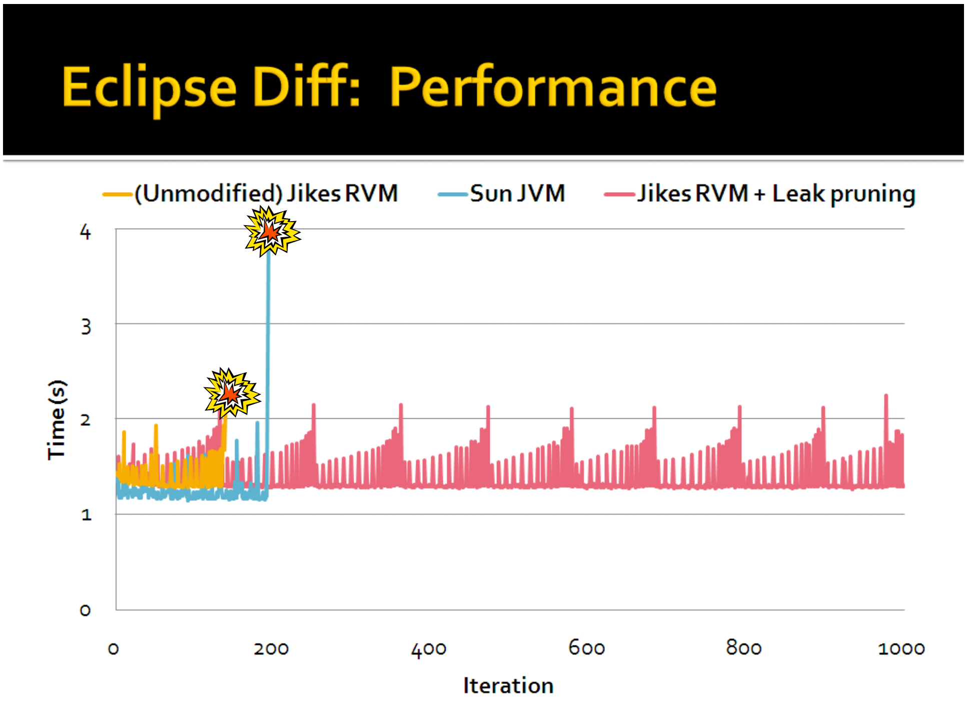
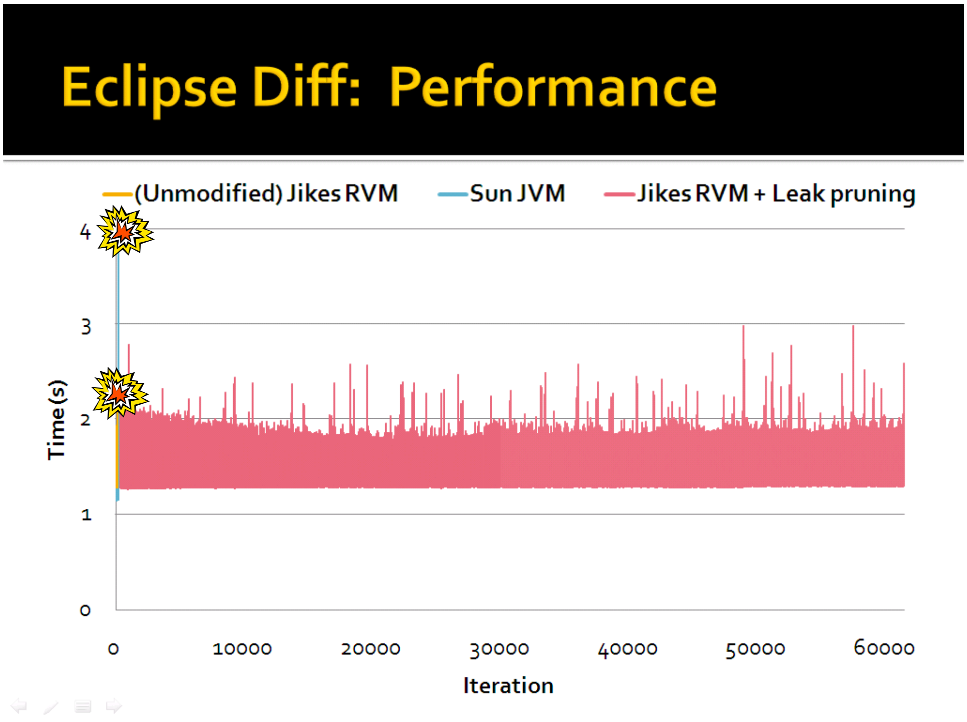
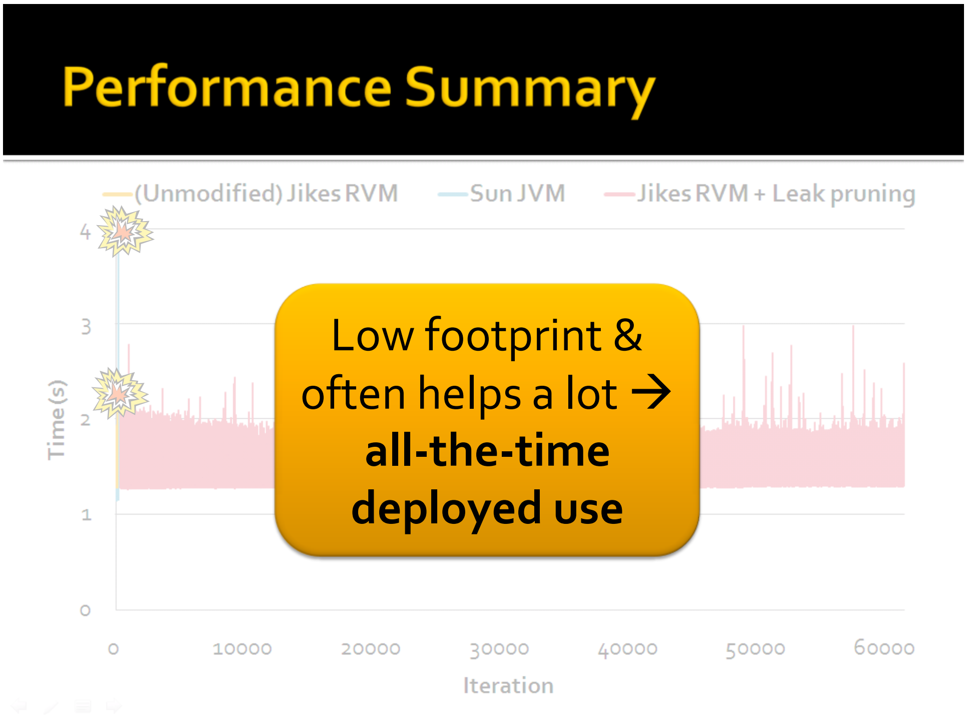


Eclipse Diff: Performance



Eclipse Diff: Performance



Performance Summary

Low footprint & often helps a lot → **all-the-time deployed use**

Related Work

- Memory corruption & concurrency bugs
  - Perturb layout & scheduling [**Rx**, Qin et al. '05] [**DieHard**, Berger & Zorn '06] [**Atom-Aid**, Lucia et al. '08] [**Grace**, Berger et al. '08]
- Fatal errors
  - Ignore errors [**Failure-oblivious computing**, Rinard et al. '04] [**Append**, Dobolyi & Weimer '08]

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- Memory leaks in unmanaged languages
  - Leak-friendly layout [**Plug**, Novark et al. '08]
  - Bound allocation sites [**Cyclic alloc**, Nguyen & Rinard '07]

Tolerating Memory Leaks in Managed Languages

- Finding leaks before deployment is hard
  - Deployed systems need immediate help
- Leak pruning: GC based on liveness
  - High precision & low overhead
  - Bounded resources
  - Preserves semantics

Tolerating Memory Leaks in Managed Languages

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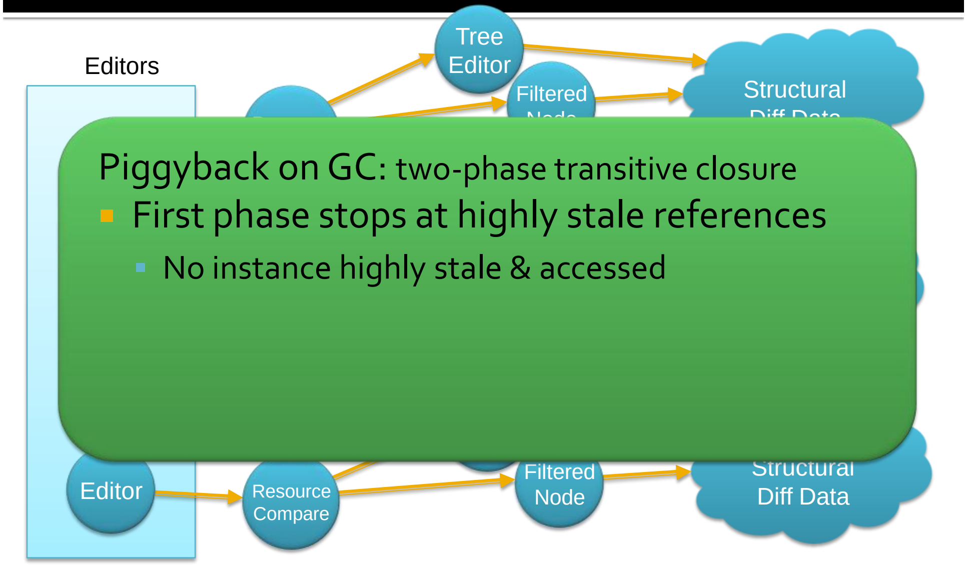
Thank you!

Backup

Eclipse "Diff" Leak

- Reported on Eclipse Bugzilla
- Recursive difference leaks memory

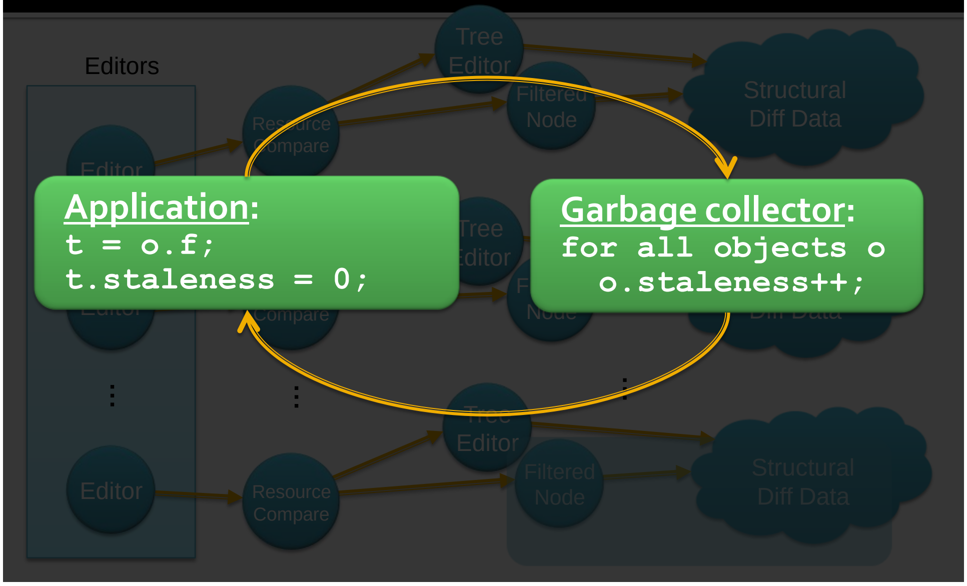
Eclipse "Diff" Leak



Piggyback on GC: two-phase transitive closure

- First phase stops at highly stale references
  - No instance highly stale & accessed

Fine-Grained Usage Tracking

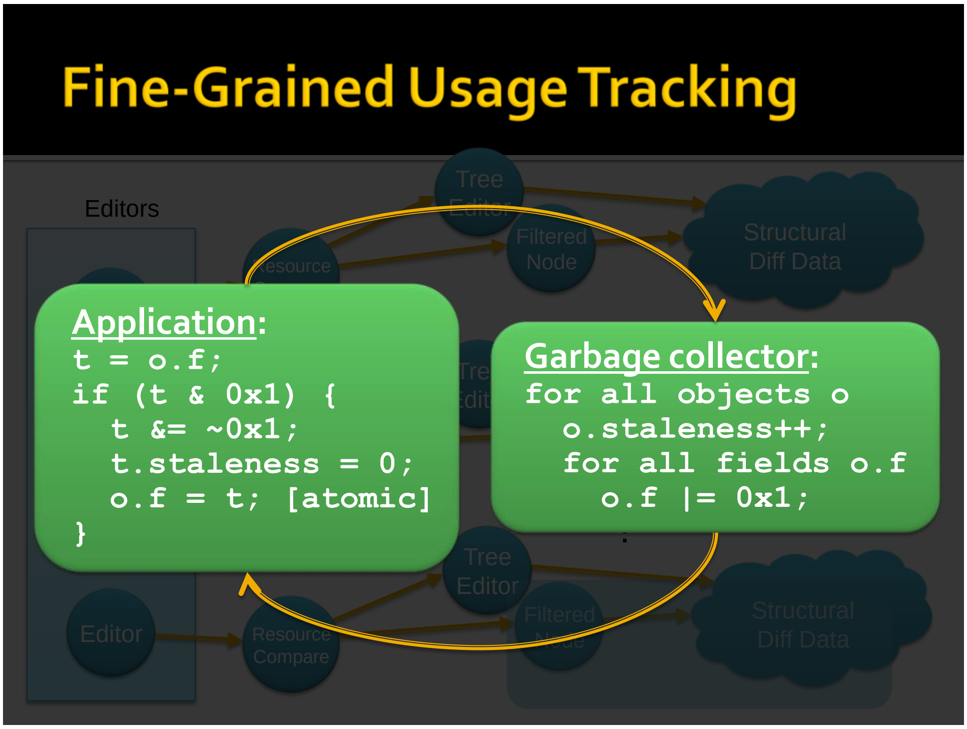


Application:

```
t = o.f;
t.staleness = 0;
```

Garbage collector:

```
for all objects o
  o.staleness++;
```



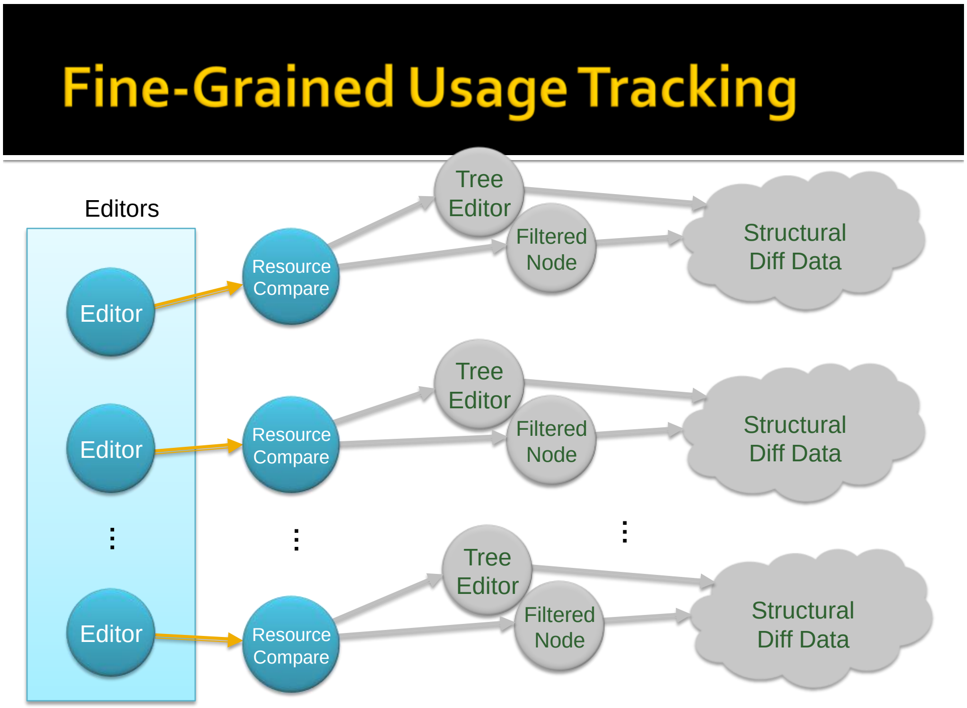
Fine-Grained Usage Tracking

Application:

```
t = o.f;
if (t & 0x1) {
  t &= ~0x1;
  t.staleness = 0;
  o.f = t; [atomic]
}
```

Garbage collector:

```
for all objects o
  o.staleness++;
  for all fields o.f
    o.f |= 0x1;
```



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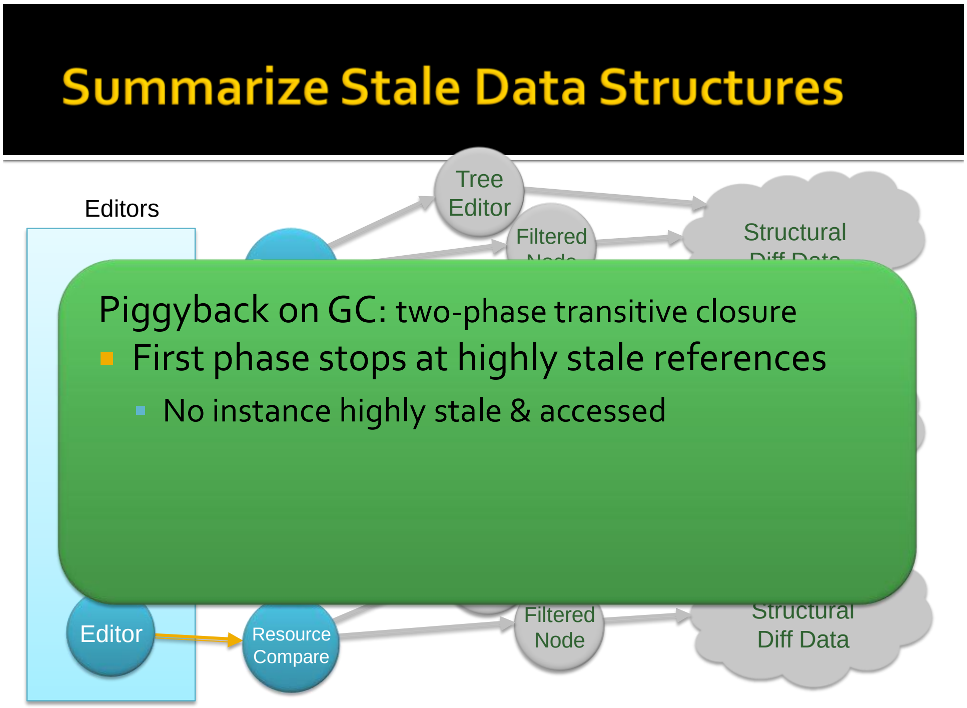
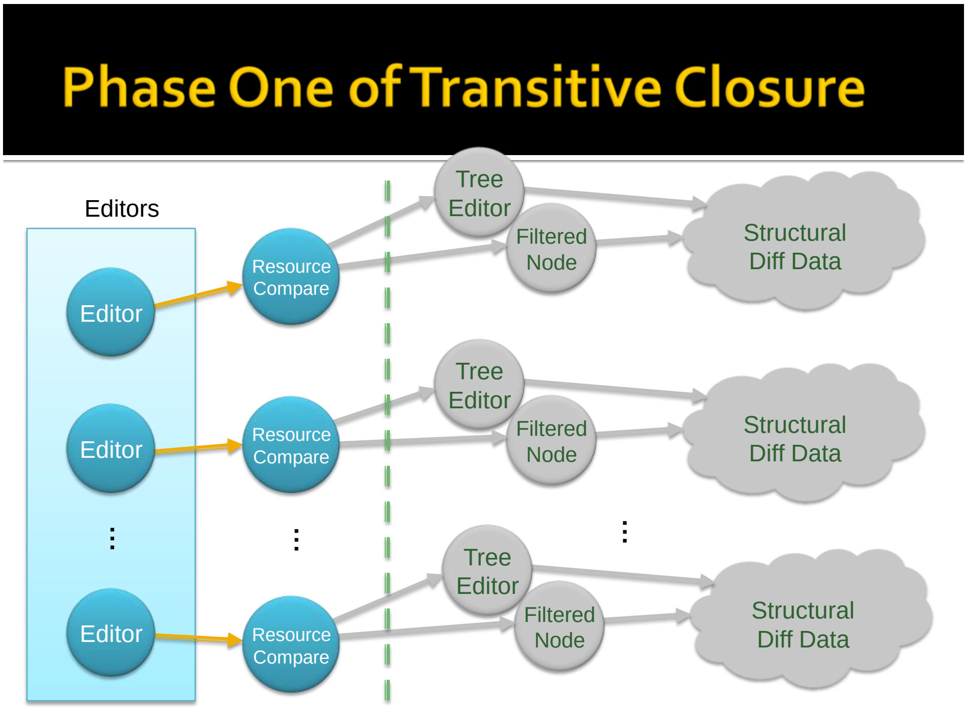


Summarize Stale Data Structures

Piggyback on GC: two-phase transitive closure

- First phase stops at highly stale references
  - No instance highly stale & accessed



Phase One of Transitive Closure

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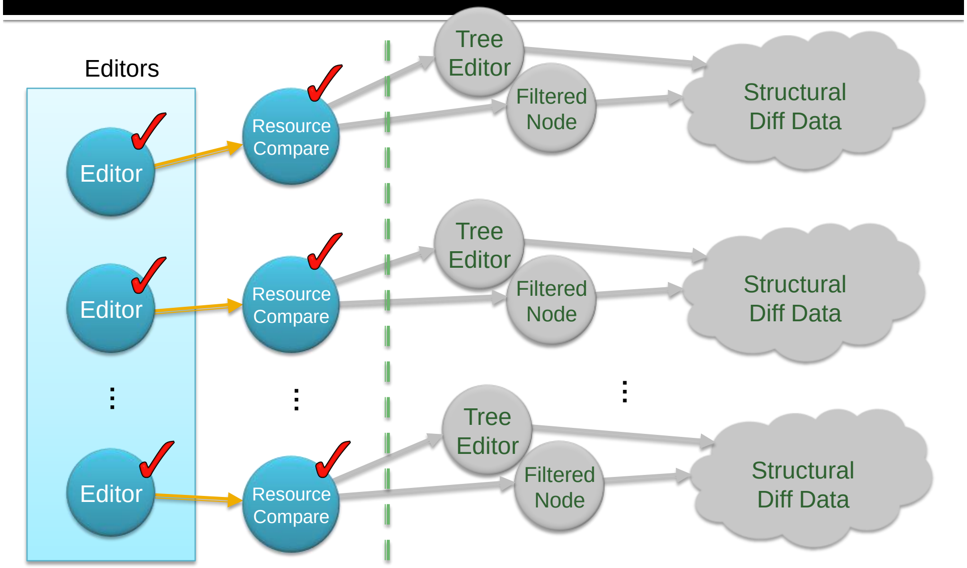
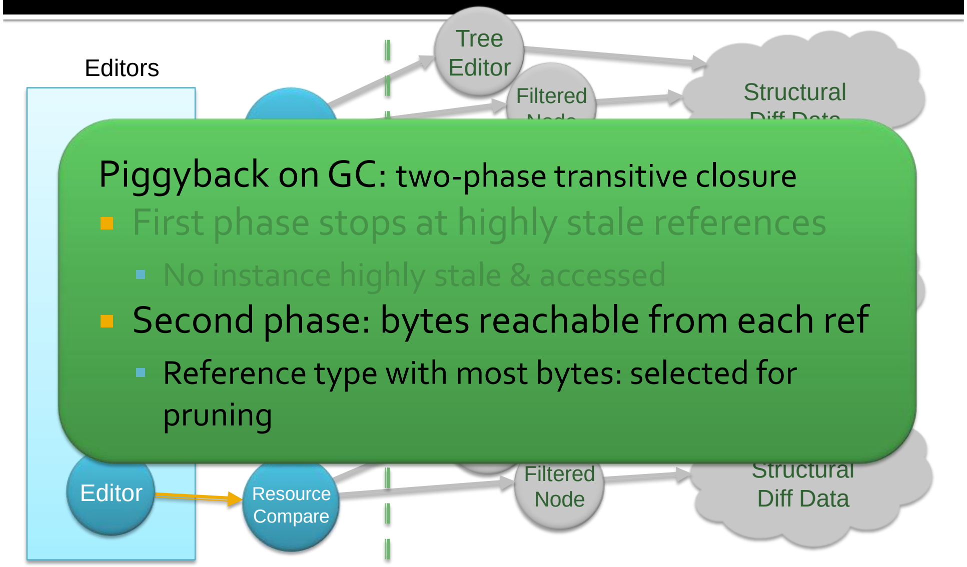


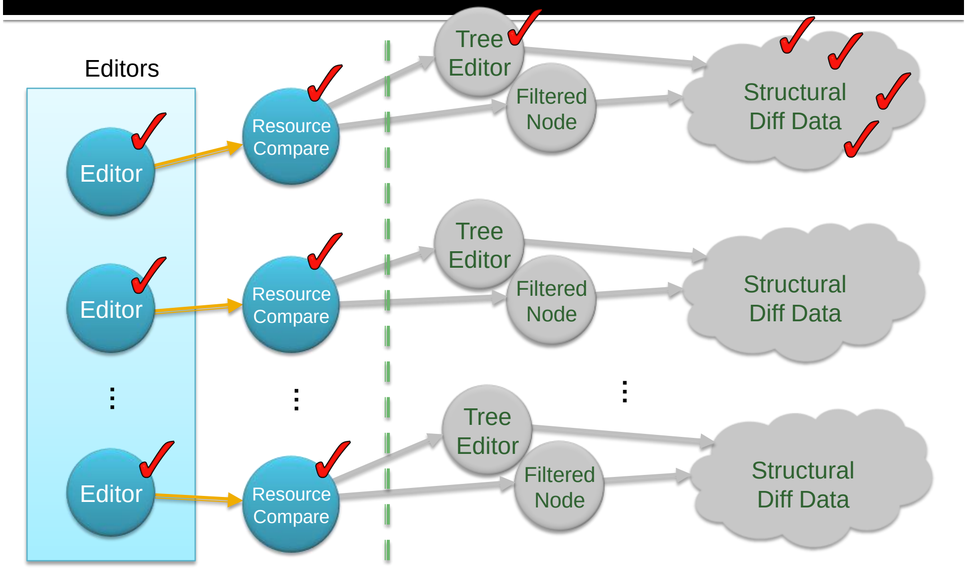
Phase Two of Transitive Closure



Piggyback on GC: two-phase transitive closure

- First phase stops at highly stale references
  - No instance highly stale & accessed
- Second phase: bytes reachable from each ref
  - Reference type with most bytes: selected for pruning

Phase Two of Transitive Closure



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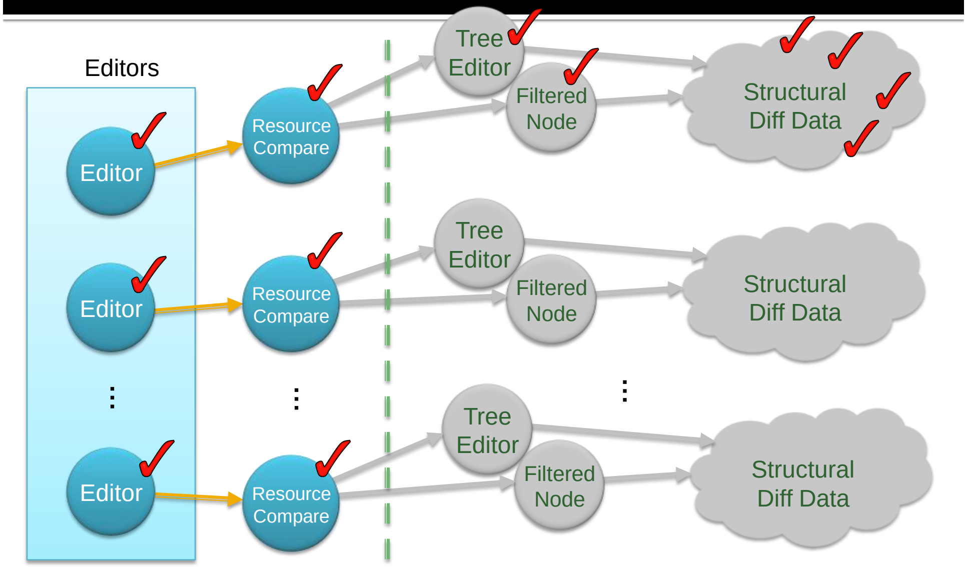

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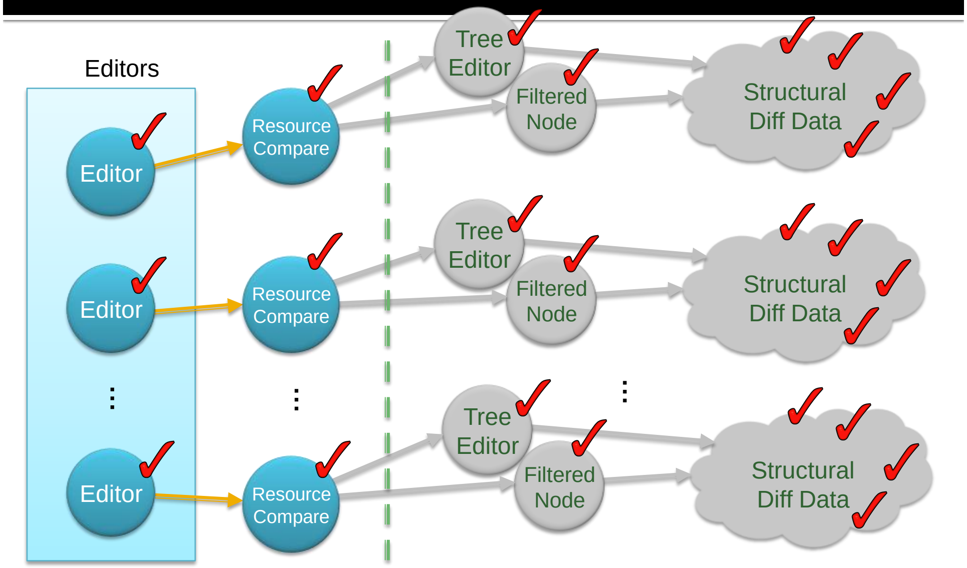
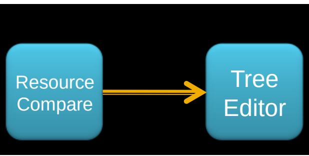
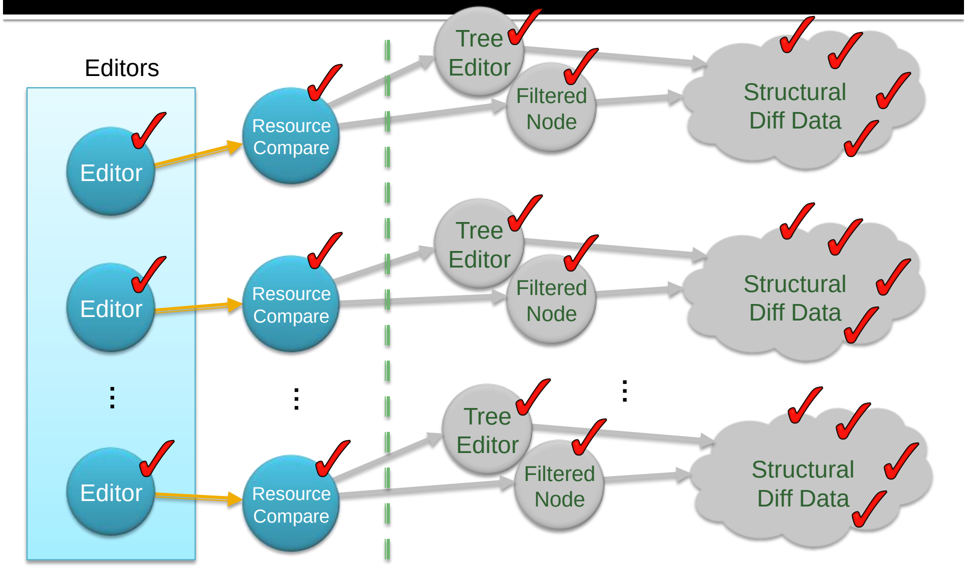
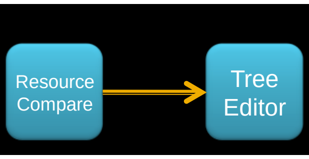


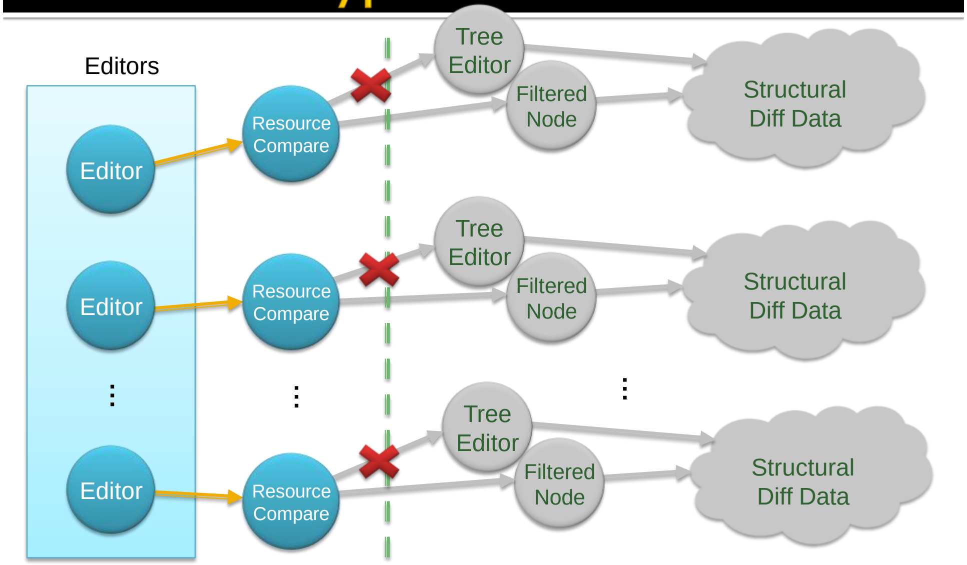
Select Reference Type





Prune Selected Reference Type





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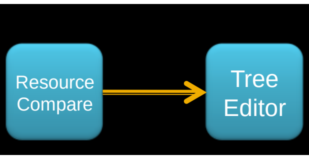

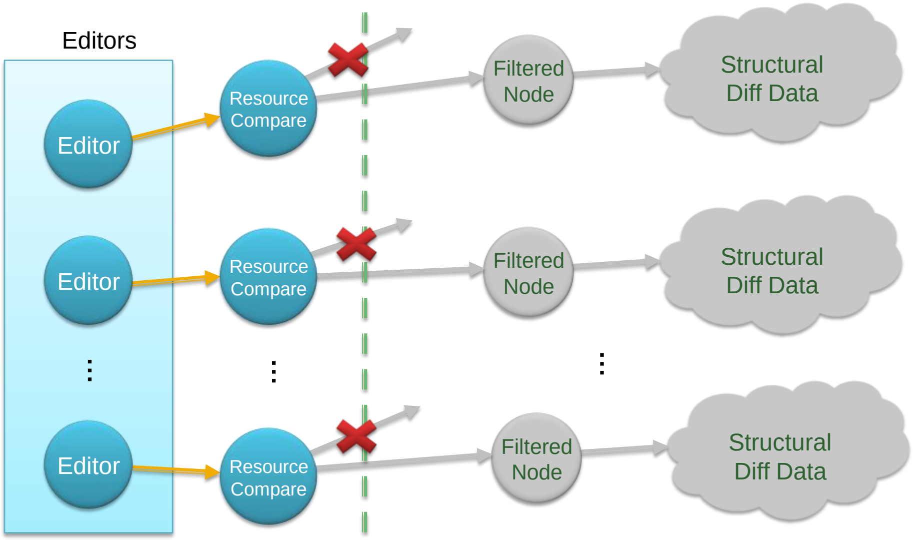

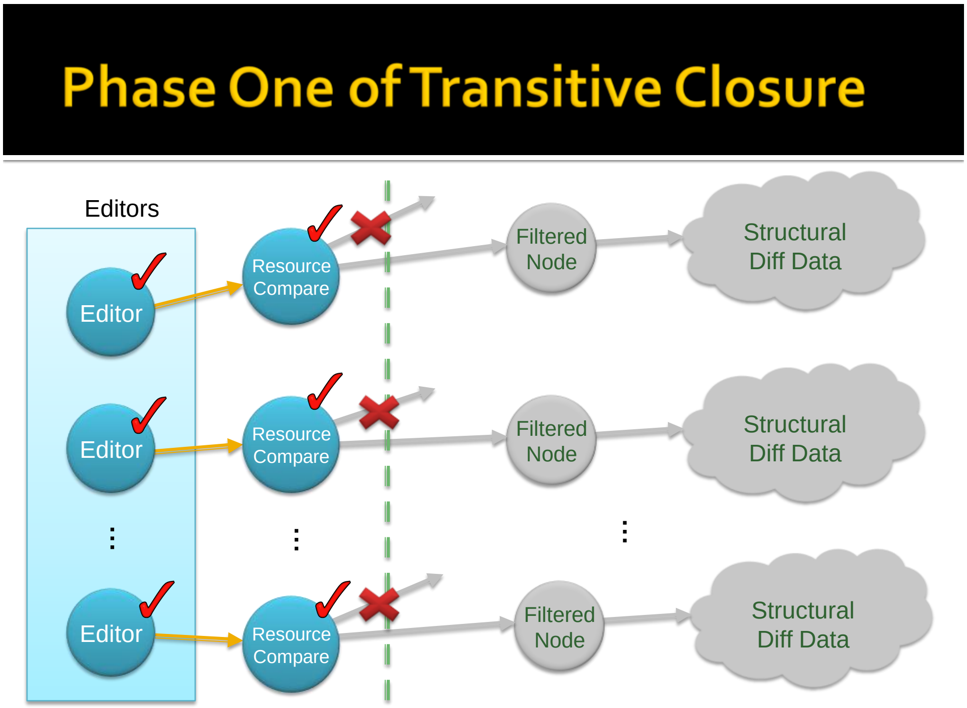

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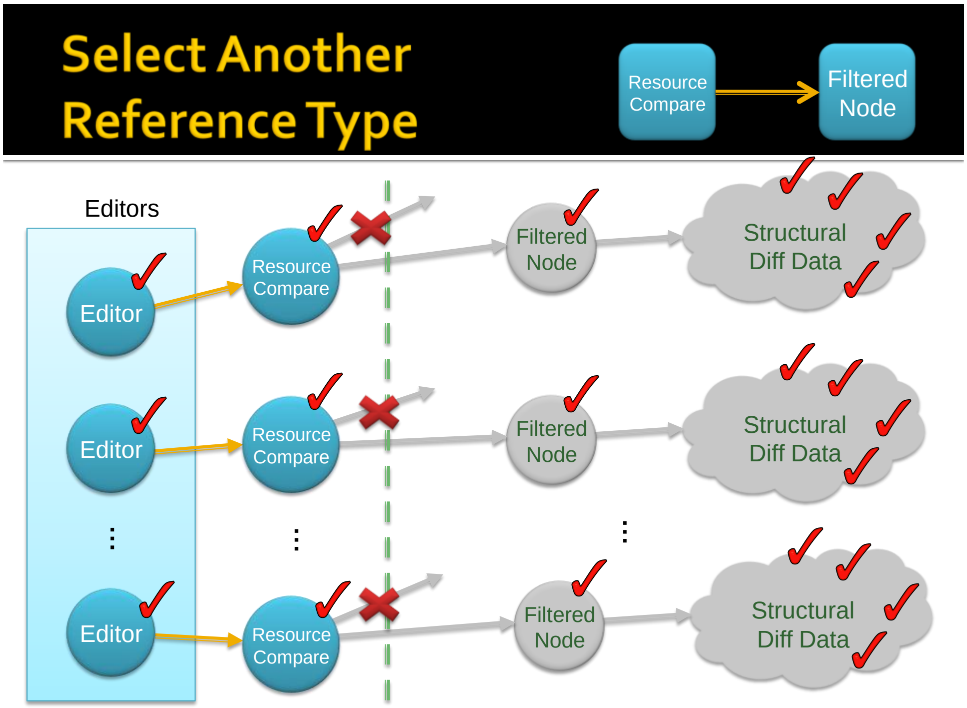
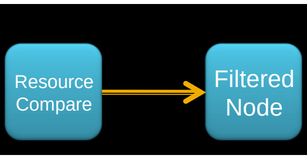
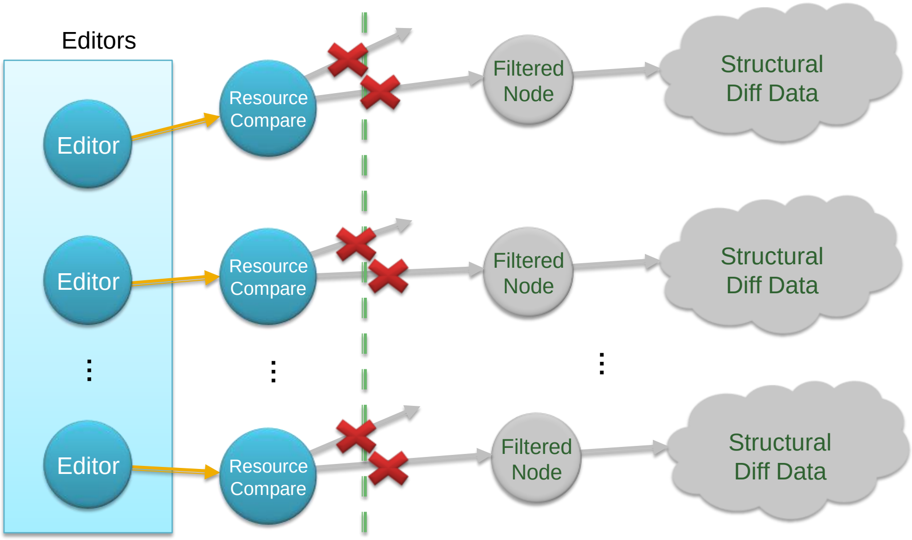


Select Another Reference Type

Prune Reference Type





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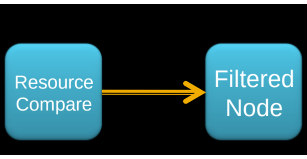
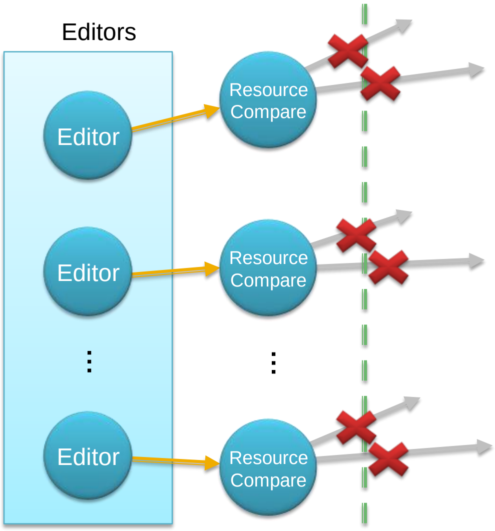

Resource Compare
Filtered Node


Editors
Editor
Editor
⋮
Editor
Resource Compare
Resource Compare
⋮
Resource Compare