Older-First Garbage Collection in Practice: Evaluation in a Java Virtual Machine

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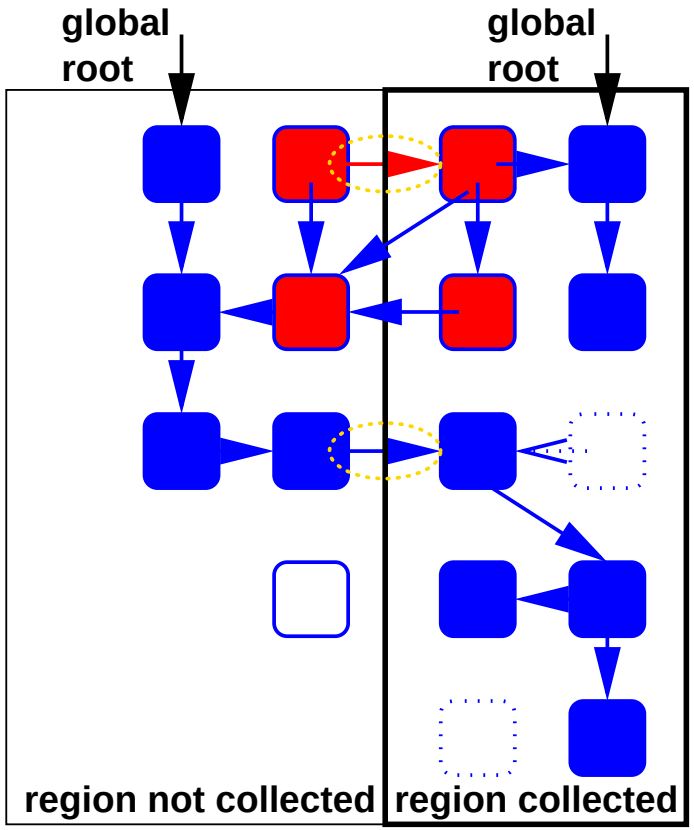
New findings in copying garbage collection

- established a trade-off between *copying cost* and *pointer-tracking cost*
- the trade-off can be exploited effectively
- generational collectors: very low pointer-tracking cost
- older-first collector: very low copying cost
- *total GC cost* lower for older-first collector
- pause times also lower for older-first collector

Region-based copying garbage collection

Compute reachability of heap objects in a *chosen region*:



remembered set for collected region

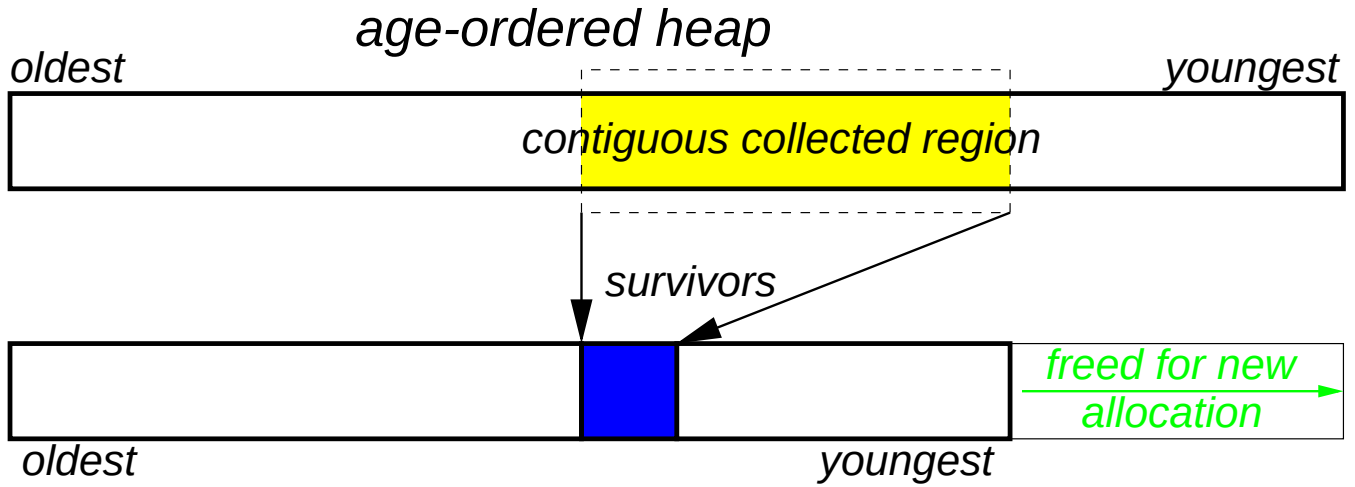
... then copy reachable objects over into a fresh *to-space*.

Actions in region-based copying garbage collection

- identifying global roots (stack scanning)
- identifying pointers across region boundaries
  - write barriers at pointer stores
  - recording pointers in remembered sets
  - processing remembered sets at GC time
- Cheney heap scanning — interleaves:
  - copying object bytes
  - identifying pointers in copied objects
  - transitively computing reachability

Age-based garbage collection

Choose regions according to *age*:

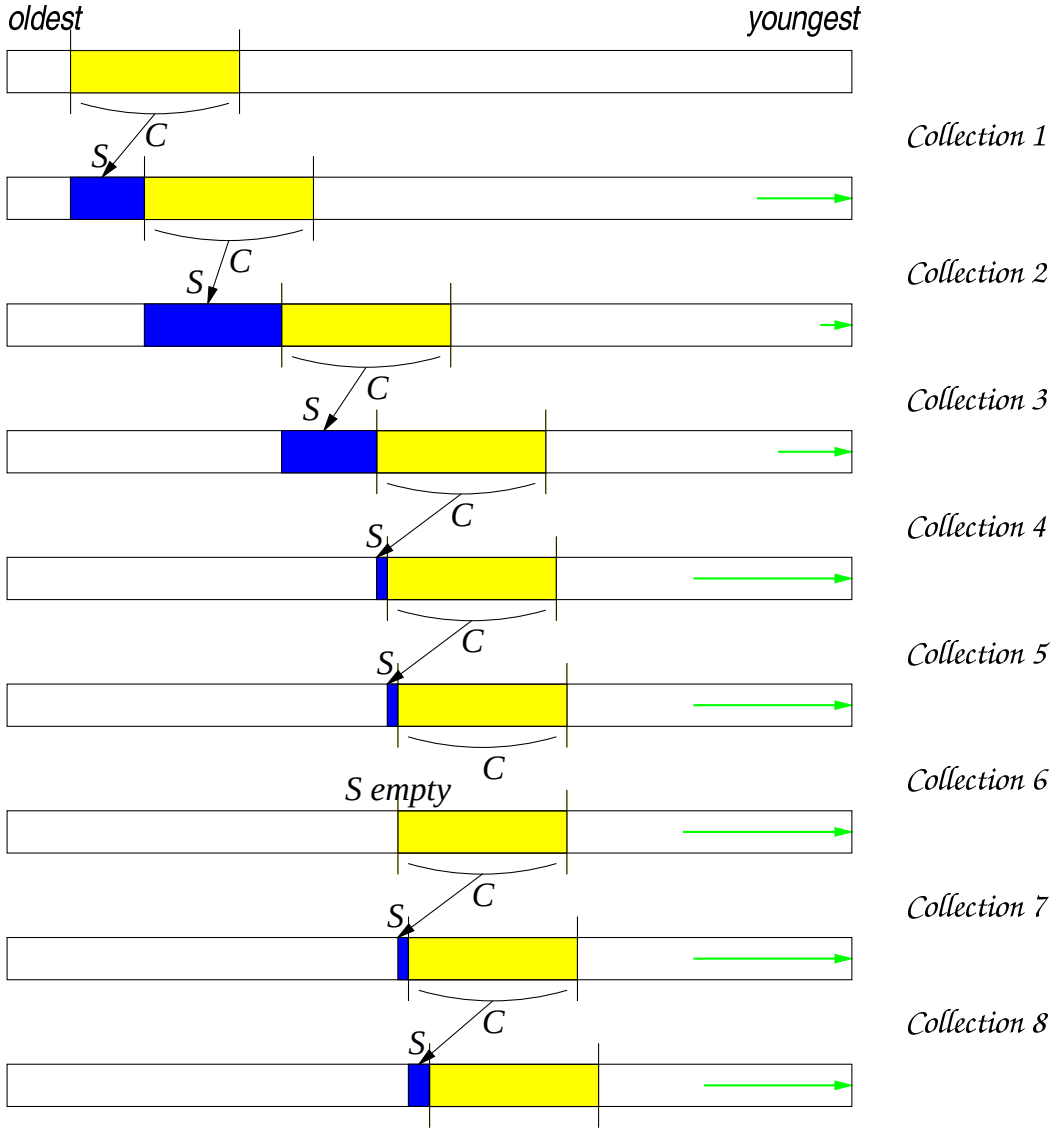


Generational collectors choose a *youngest* region.

Older-first collector chooses a *middle-aged* region, processing the heap from oldest to youngest end.

When should older-first policy work well?

When the collected region stays in the middle:



Experimental setup

- first implementation of older-first collector
- JikesRVM virtual machine for Java bytecode [IBM]
- highly optimizing compiler
- GC Toolkit for JikesRVM [UMass]
- SPEC benchmarks for Java (SPECjvm98, SPEC JBB)

Implementation details

- all collectors share the same GC Toolkit infrastructure, except for write barriers
- original design of older-first collector called for large address space to use fast write barrier
- JikesRVM runs on 32-bit PowerPC
- emulate effect of large address space by indirection through age table (slower)

Write barriers (Java pseudocode)

Direct write barrier:

```
if (source < ((target >>> 28) << 28))
   {
     ...remember pointer...
   }
```

Indirect write barrier:

```
s = (source >>> 26);
t = (target >>> 26);
if (s != t
     && t >= HeapBoundary
     && agetable [s] > agetable [t])
   {
     ...remember pointer...
   }
```

Direct write barrier, used in generational collector

```
;; clear low-order 28 bits of pointer source:
rlwinm Rtemp, Rsource, 0x0, 0x0, 0x3
;; compare with pointer target:
cmp cr1, Rtarget, Rtemp
;; if comparison is favorable, skip remembering:
bge 1 label:do-not-remember-pointer
;; fall-through: remember pointer
```

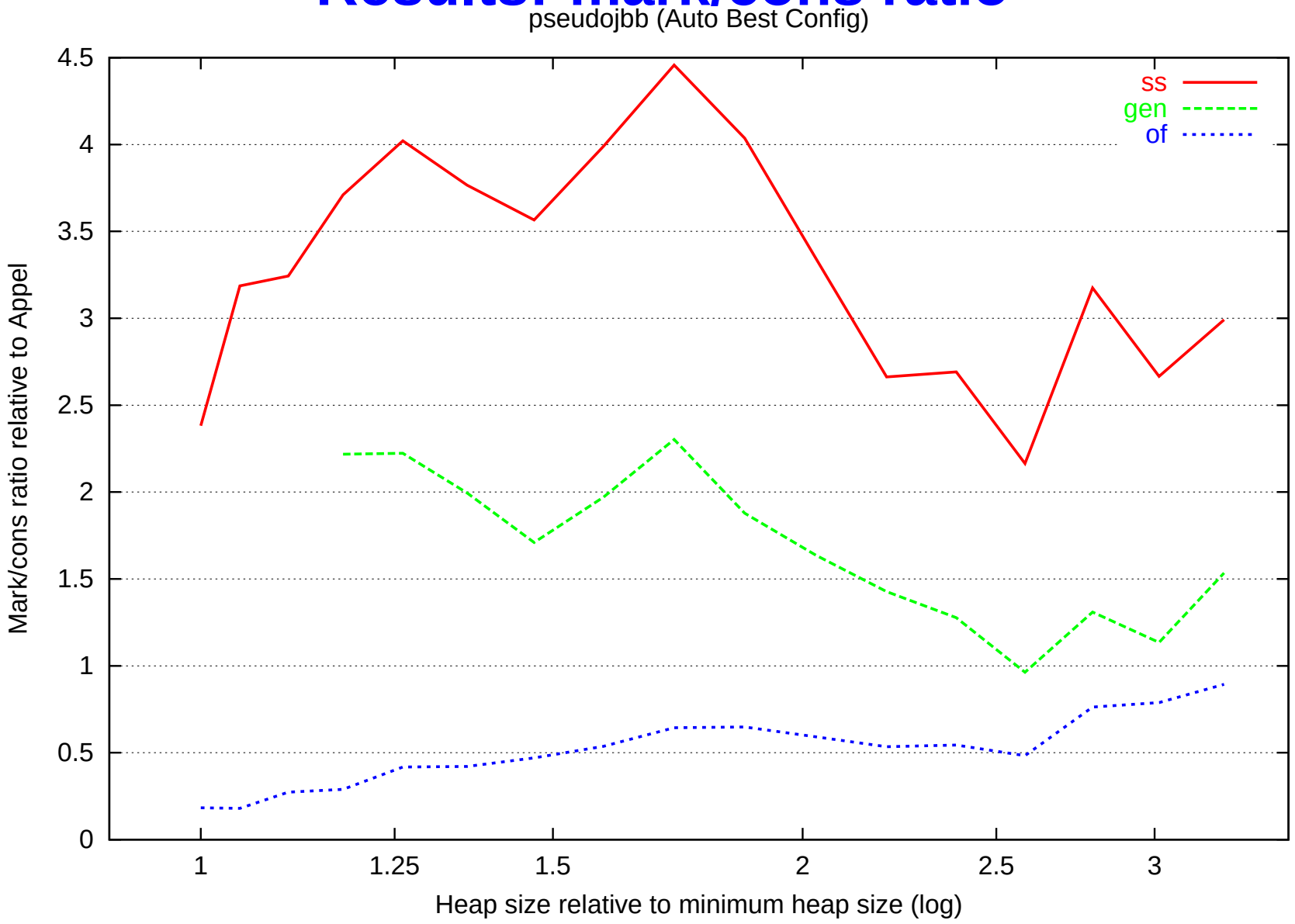
Indirect write barrier, used in older-first collector

```
;; calculate frame numbers for source and target:
rlwinm Rtemp1, Rsource, 0x6, 0x1a, 0x1f
extsb Rtemp1, Rtemp1
rlwinm Rtemp2, Rtarget, 0x6, 0x1a, 0x1f
extsb Rtemp2, Rtemp2
;; intraframe pointers test:
cmp cr1, Rtemp1, Rtemp2
beq 1 label:do-not-remember-pointer
;; heap boundary test:
cmpi cr1, Rtemp2, 0xf
blt 1 label:do-not-remember-pointer
```

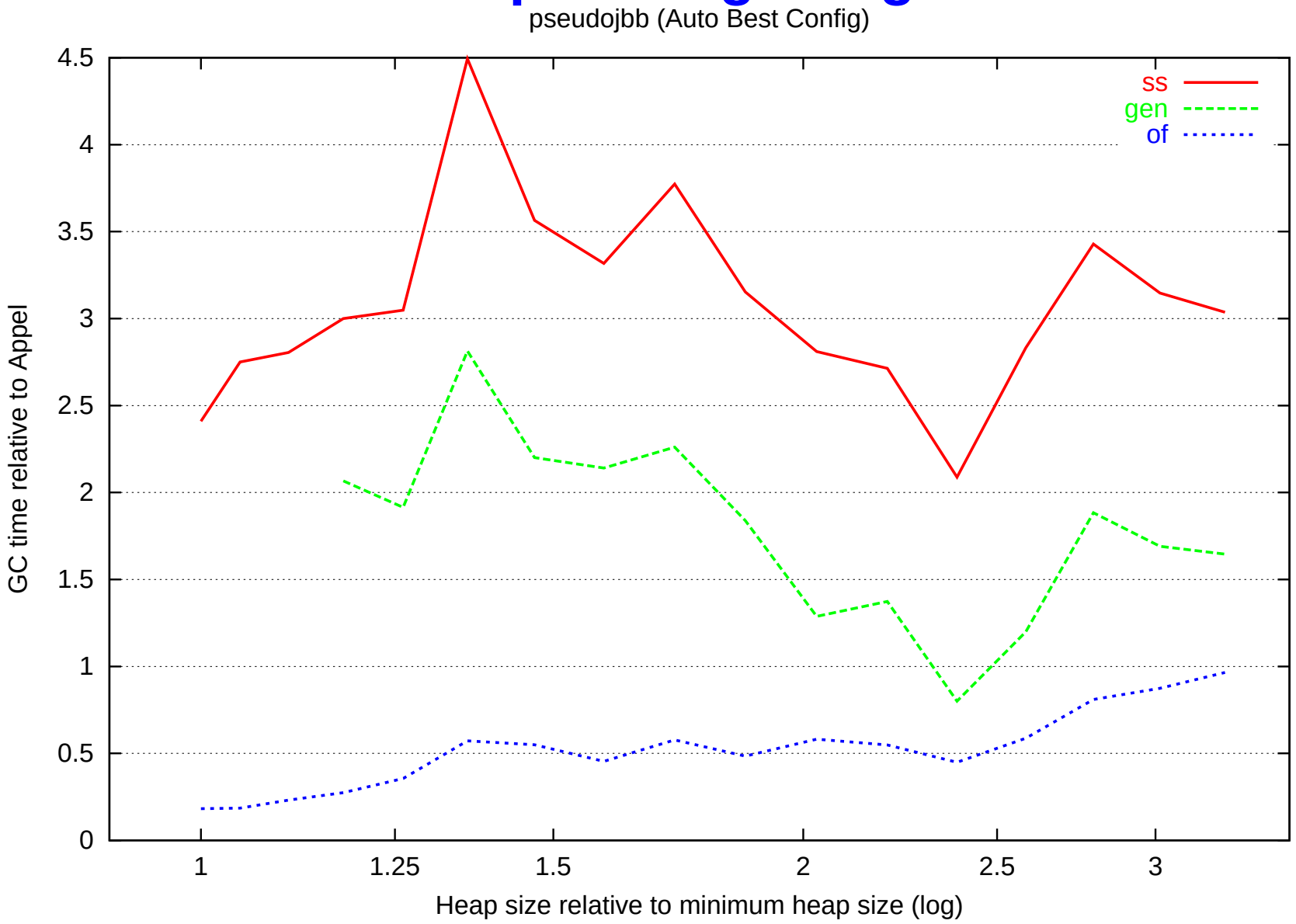
Indirect write barrier (cont'd)

```
;; load base of age table:
lwz Rtemp3, a-static-offset(JTOC)
;; look up age of source and target:
sli Rtemp1, Rtemp1, 0x2
lwzx Rtemp1, Rtemp3, Rtemp1
sli Rtemp2, Rtemp2, 0x2
lwzx Rtemp2, Rtemp3, Rtemp2
;; age comparison test:
cmp cr1, Rtemp1, Rtemp2
ble 1 label:do-not-remember-pointer
;; fall-through: remember pointer
```

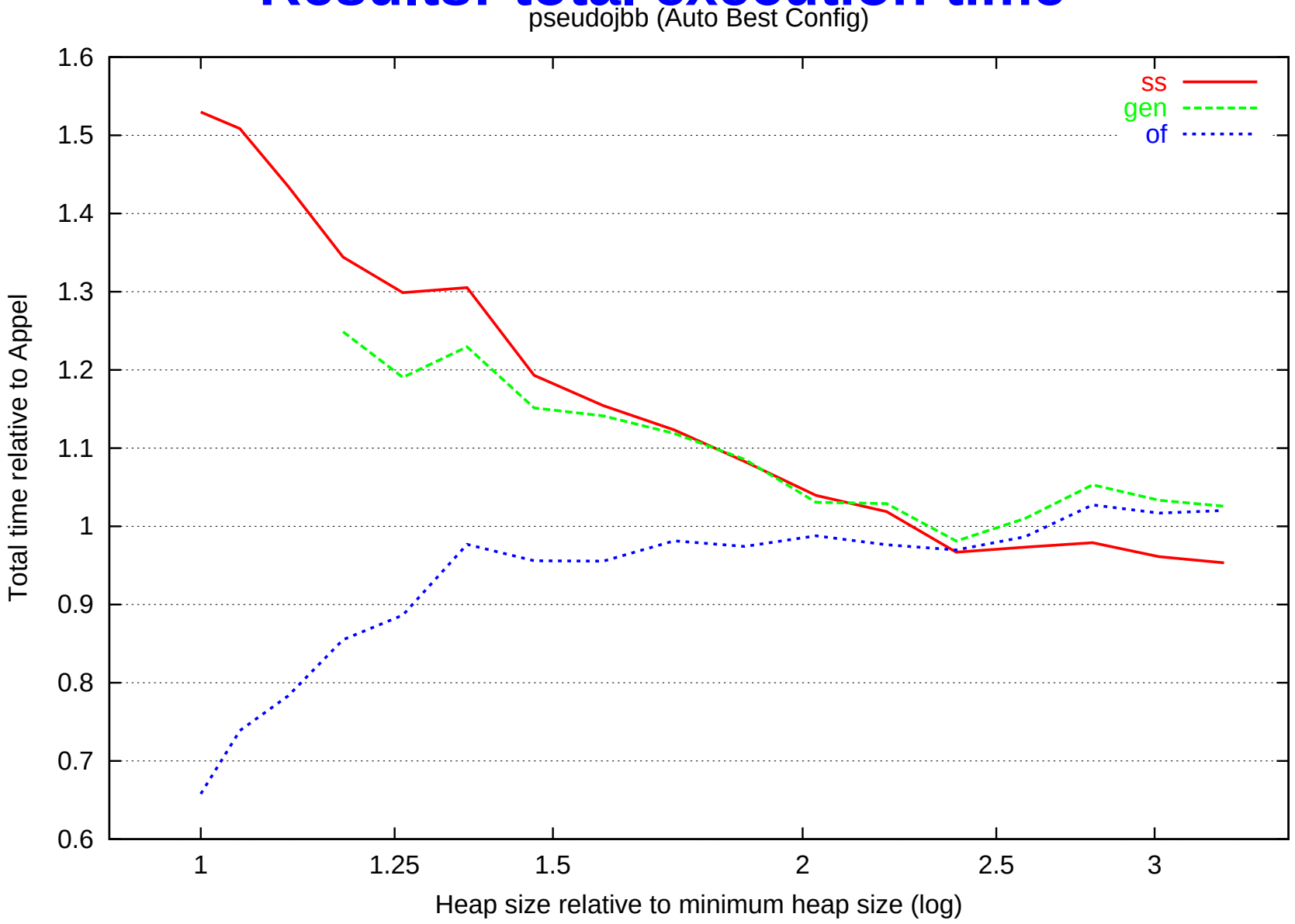
Results: mark/cons ratio



Results: time spent in garbage collection



Results: total execution time



Copying vs. pointer-tracking

Sample run — pseudojbb, heap size 1.25 times minimum

collector	Appel-style Gen.	Older-First 10%
bytes allocated	667 million	
bytes copied	221 million	117 million
mark/cons ratio	0.33	0.17
write barriers	98.2 million	
pointers remembered	2.59 million	6.24 million
pointers processed	2.59 million	10.32 million
GC time	9.38s	5.15s
total execution time	45.15s	42.04s

What we haven't done yet...

- write barrier (32-bit address space)
  - improve code sequence — estimate further 2-3% reduction possible in total execution time
  - need to inject code lower than compiler's HIR
- write barrier (64-bit address space)
  - porting JikesRVM to 64-bit PowerPC architecture

What we haven't done yet... (cont'd)

- properly investigate locality effects
  - building tools: robust JikesRVM - SimpleScalar - PowerPC simulator, must support dynamic code generation, signals, system calls
- flexible policies for collection region
  - Appel collector (flexible) better than fixed generational
  - flexible older-first: need good policies
  - Beltway collector provides mechanism [PLDI]

Achievements

- shown trade-off between copying and pointer-tracking
- fulfilled promise of older-first GC
- always improve over fixed generational GC
- often improve over Appel-style generational GC
- low end-to-end times *and* pause times