Quasi-Infinite Heaps

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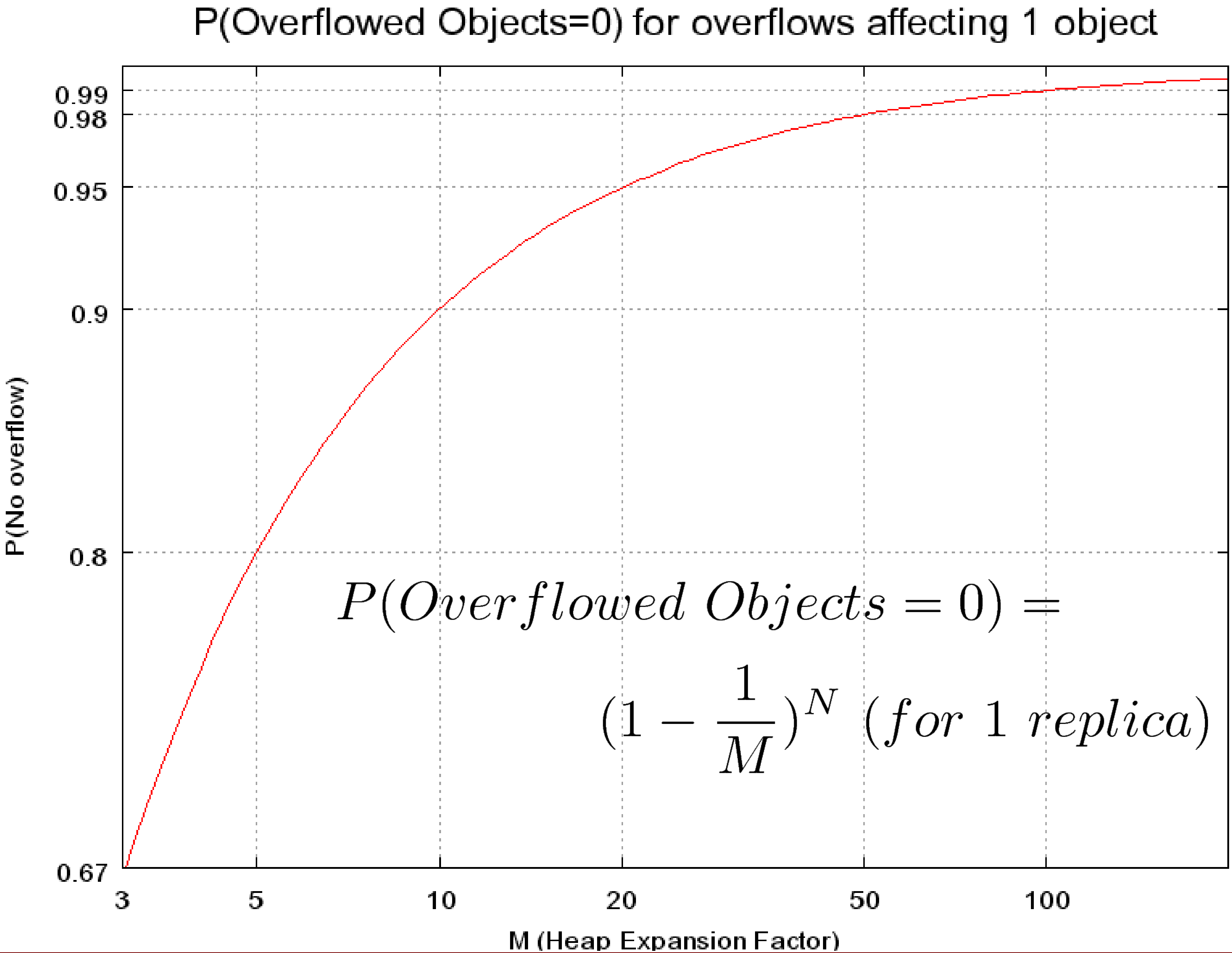
Infinite Heap Semantics

- Normally: memory errors $\Rightarrow \perp$
- Consider **infinite-heap** allocator:
  - All **news** *fresh*;
    ignore **delete**
    - No dangling pointers, invalid frees, double frees
  - Every object **infinitely large**
    - No buffer overflows, data overwrites
- Transparent to correct program
- "Erroneous" programs **sound**

Approximating Infinite Heaps

- **DieHard**:
  - Approximate ∞-heaps with M-heaps (e.g., 2)
  - Increases odds of **benign** errors
  - **Probabilistic** memory safety
    - **i.e., P(no error)** ≥ n
- **Protection increases as M increases**

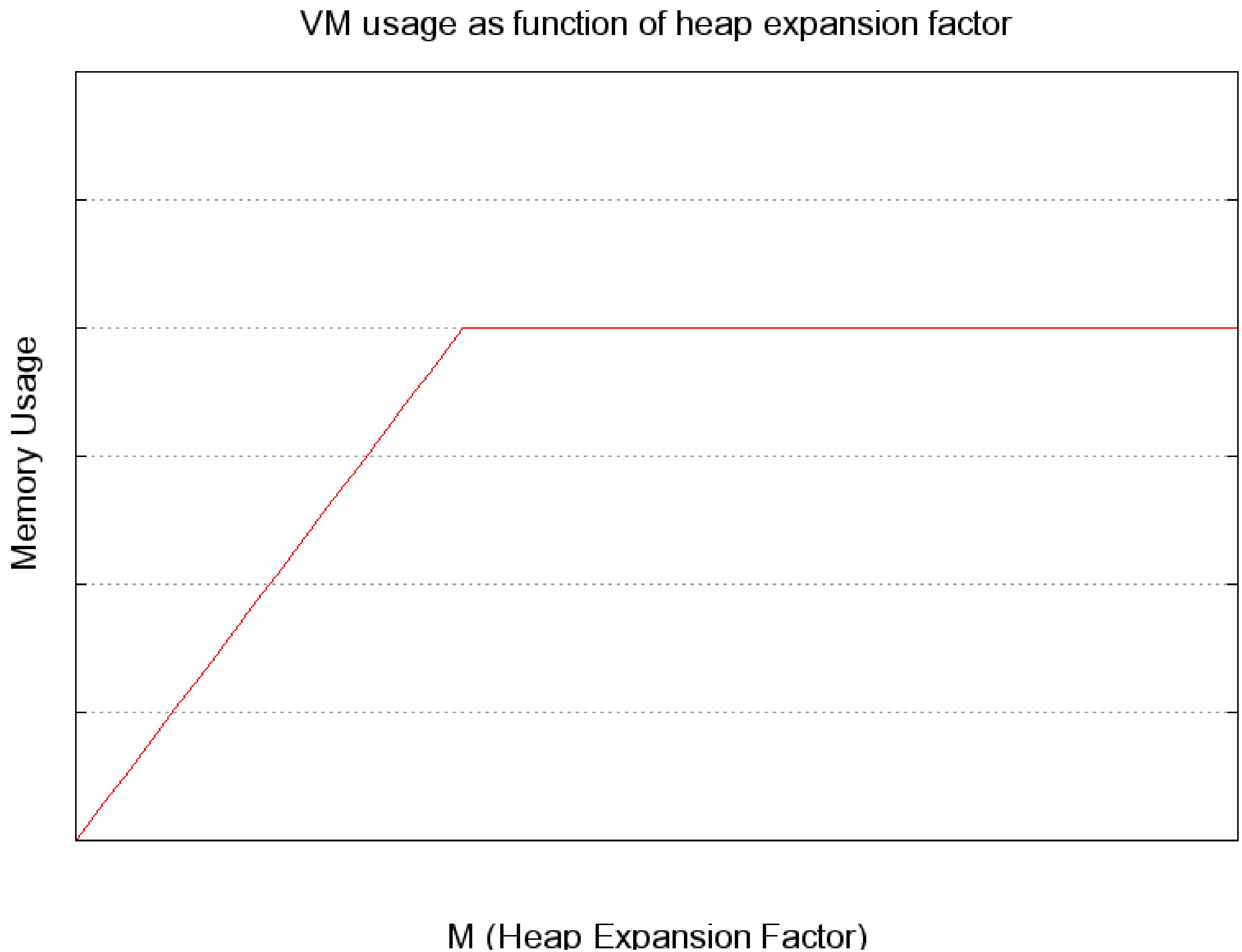
Probabilistic Memory Safety



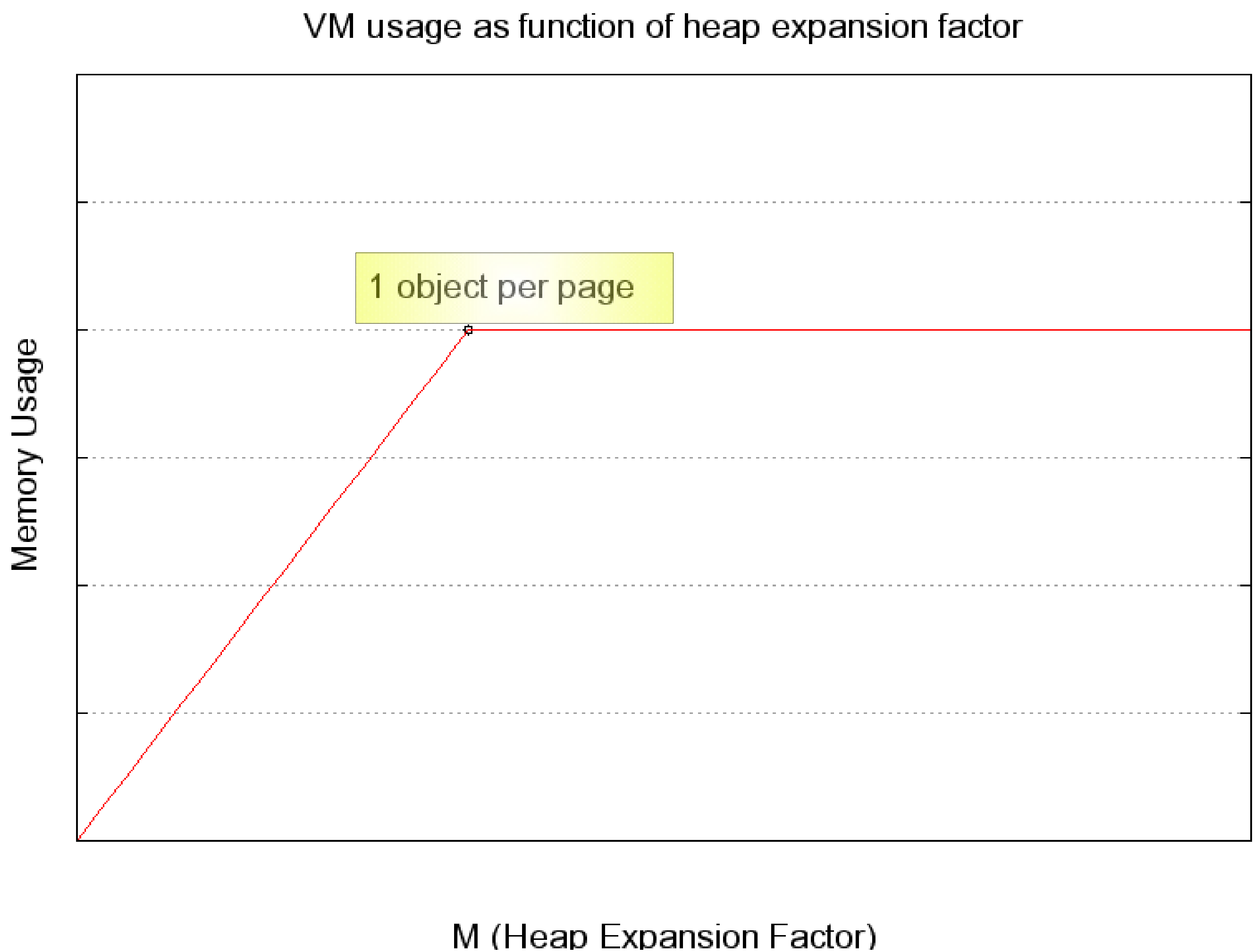
What if M = Huge?

- What if we make the heaps **huge**?
  - e.g., M=1000
- **Pros:**
  - *Dramatically* reduces risk of overflow
- **Cons:**
  - Increase memory consumption by 1000x(?)

Virtual Memory Usage



Virtual Memory Usage



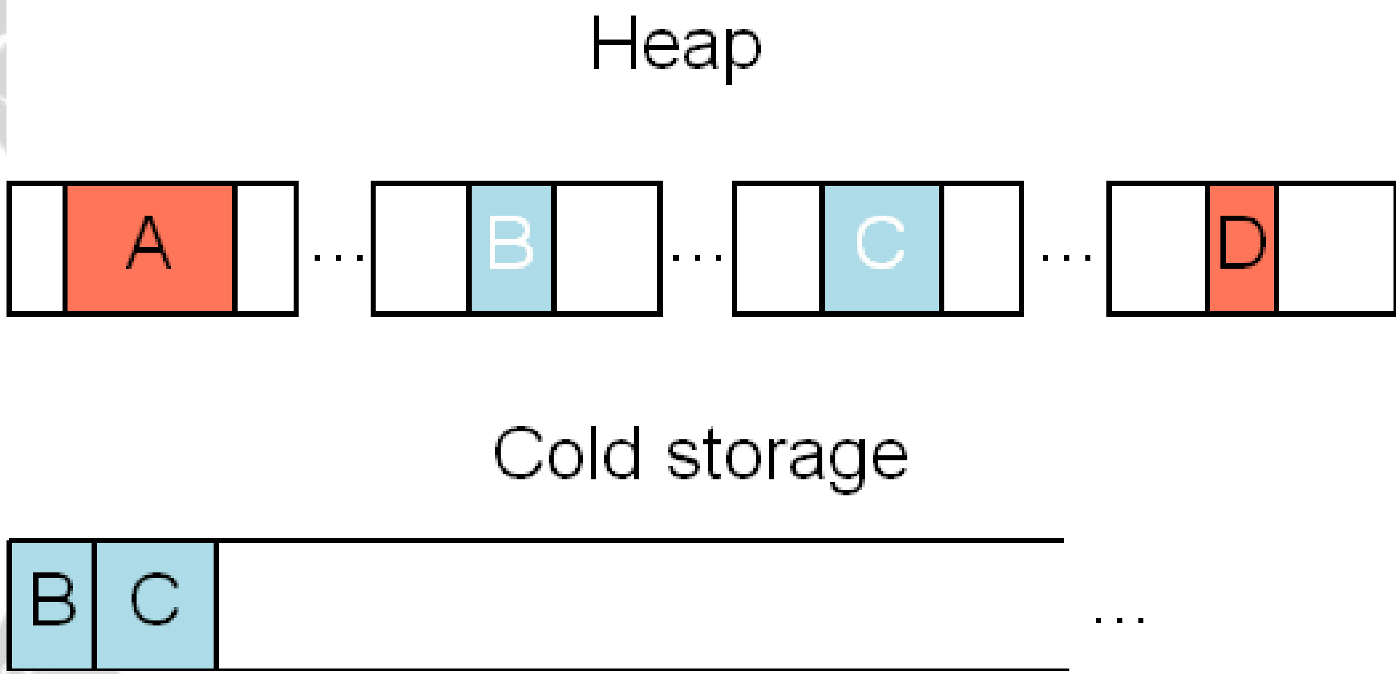
Quasi-Infinite Heaps

- **Idea:**
  one object per page – each *far* apart
  - Take advantage of large address spaces
    - Especially 64-bit
  - Closer to "infinite" heaps
- **Key challenge:**
  - Reducing physical memory consumption
  - Spend address space, not RAM
- Initial empirical results
  - Running time

Reducing memory consumption

- Assume locality of reference:
  - 90% time, access 10% data
- Use 2 different heaps
  - **Hot space** ("10%")
    - 1 object per page, empty pages in-between
    - Unrestricted access
  - **Cold space** ("90%")
    - Compacted or even compressed
    - No direct access
    - Copy into Hot space *on demand*

Heap regions



- A,D: **hot**
  - Directly accessible
- B,C: **cold**
  - Pages allocated, protected & evictable (*madvise*)
  - Contents in Cold Storage (ordinary heap)

Managing Hot-Cold Heap Spaces

- Evict objects from hot space
  - Currently using FIFO, fixed # of hot objects
- Page protection traps accesses to cold objects
  - Signal handler copies requested object back into place, unprotects page
- Note: manages pages, not whole objects
  - Allows eviction of cold parts of arrays, etc.

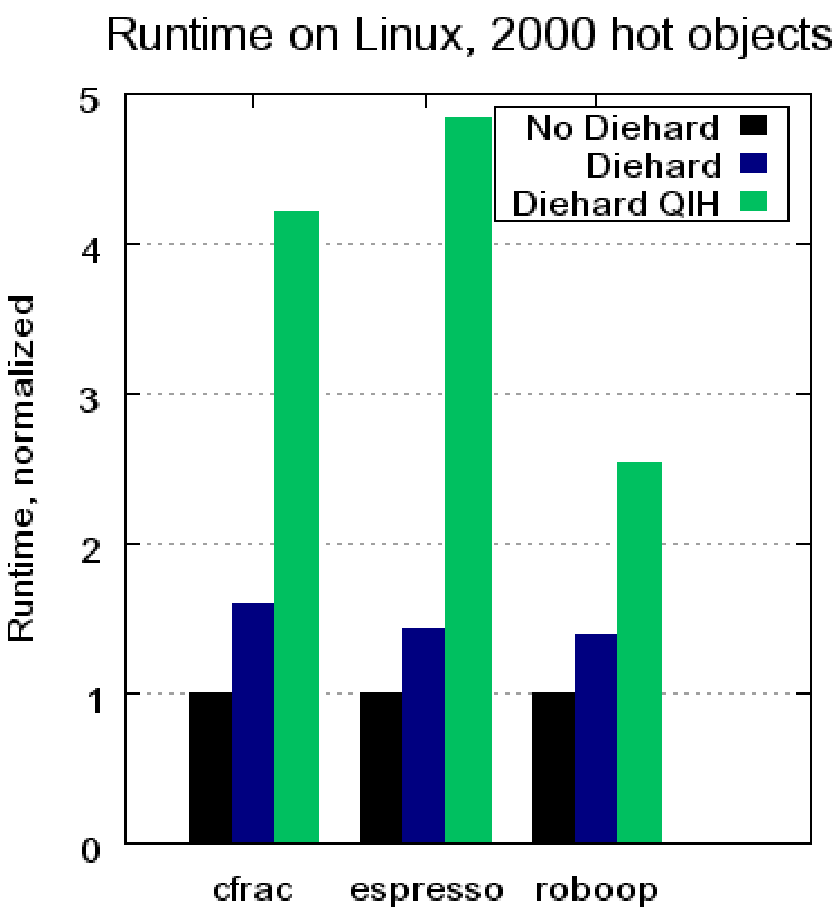
Maintaining soundness

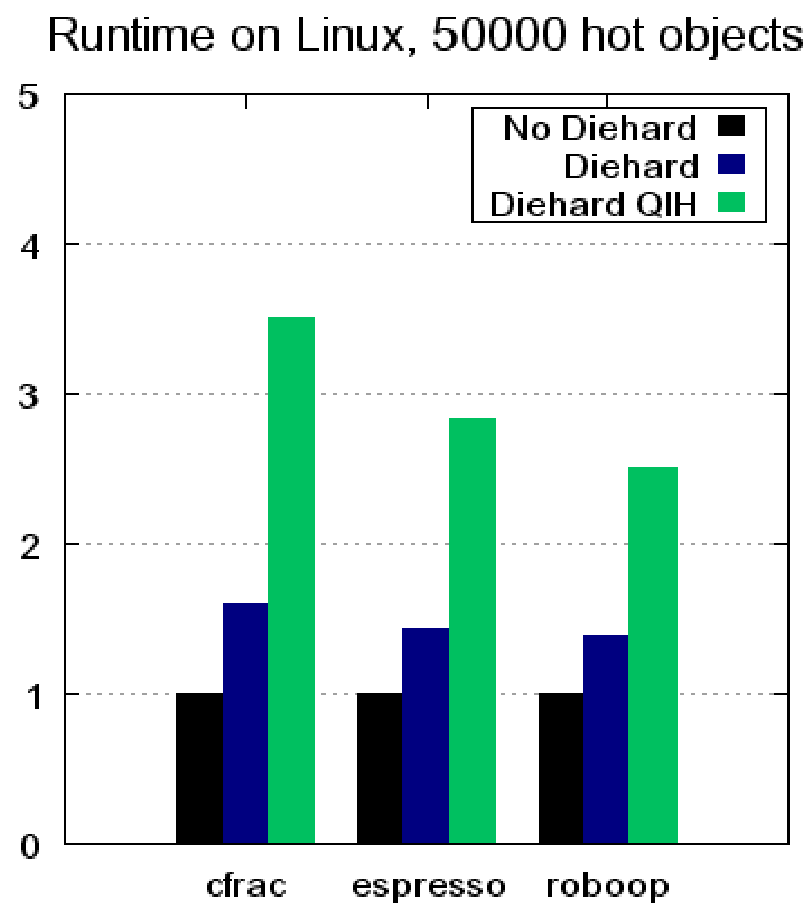
- Buffer overflows
  - Small overflows (within page)
    - Compaction preserves overflowed data across evictions
  - Large overflows (outside page)
    - Trigger signal handler
    - Can fail (now) or allow use of new page
- Dangling pointers
  - Defer frees
    - Evict freed objects to cold space to save space
    - Not yet implemented

Experimental Results

- Ran 3 allocation-intensive benchmarks
  - cfrac
  - espresso
  - roboop
- Compared GNU libc, Diehard and Diehard QIH
- Experimental platform
  - P4 3GHZ, 1 GB RAM, 512KB L2 Cache
  - Linux 2.6
- Measured execution time

Empirical Results: Runtime





Performance-limiting factors

- Increased cost of allocation/dealloc
- Reduces/Limits spatial locality
- Cache side-effects
  - Increased L2 miss rate
- VM side-effects
  - Increased TLB miss rate
  - Larger page tables

Future work

- Error-injection experiments
- Smarter eviction policies for Hot space
    - Clock with s/w referenced bits
    - Clock with h/w referenced bits (kernel mod)
- Concurrent evictions
    - Can be moved to a separate thread
- Automatic Hot space sizing
    - Adjust to application behavior
- Add object coloring to improve cache performance

Conclusion

- Our Goal:
  - Provide near-infinite heap guarantees against certain memory errors for unaltered C/C++ applications
  - Exploit VM and access locality to do it reasonably efficiently
- Work in progress

Questions?