Multiple-area collection, Regrouping strategies

Ideal strategy follows program execution behaviors

Multiple-area collection

- Problem:
  - CPU cost of scavenging depends in part on size of objects
    - Copying small objects no more expensive than marking with bitmap
    - Cost of copying large objects may be prohibitive
      - Typically contains bitmaps and strings (atomic)
- Solution:
  - Use large object space (separate memory region)
  - Assume objects have header and body
    - Keep header in semi-space
    - Keep body in large object space (use mark-sweep)

Multiple-area collection

- Problem:
  - Some objects may have some permanence
  - Repeatedly copying such objects is wasteful
- Solution:
  - Use separate static area
  - Do not garbage collect such region
  - Trace region for pointers to heap object outside static area
- Preview for generational garbage collection

Incrementally compacting collector

- Divide heap into multiple separately managed regions
  - Allows compacting of parts of the heap
  - Use mark-sweep or other approach on other regions
- Lang and Dupont:
  - Divide heap into n + 1 equally sized segments
  - At each GC cycle:
    - Choose 2 regions for copying GC
    - Mark-sweep other regions
    - Rotate regions used for copying GC
  - Collector chooses which transition to take next
    - Give preference to mark-sweep to limit growth of stack

Effects of incremental compactor

- Compact small fragments into single piece
- Compactor will pass through every segment of the heap in n collection cycle
- Small cost: extra segment used for a semi-space

How efficient is Cheney's alg.?

- Suppose:
  - M → size of each semi-space
  - R → number of reachable object
  - s → average size of each object
- Then:
  - # objects allocated between GC cycles: = M/s – R
  - If R = k, M/s – R = # objects reclaimed in each GC cycle

How efficient is Cheney's alg.?

- Suppose:
  - g → CPU cost of GC per object reclaimed
- Then:

$$g = \frac{c}{\frac{M}{sR} - 1}$$

  - g can be made arbitrary small by increasing M
    - Increasing heap size reduces GC time
    - See Jones and Lins, page 129

Garbage Collection locality issues

- Spatial locality: if a memory location is referenced at a particular time, then it is likely that its neighbors will be referenced in the near future
- Reasons for locality
  - Predictability:
    - one type of behavior in compute systems
  - Program structure:
    - related data stored in nearby locations.
    - Easy to access next item
  - Linear data structure:
    - code contains loops that tend to reference arrays or other data structures by indices

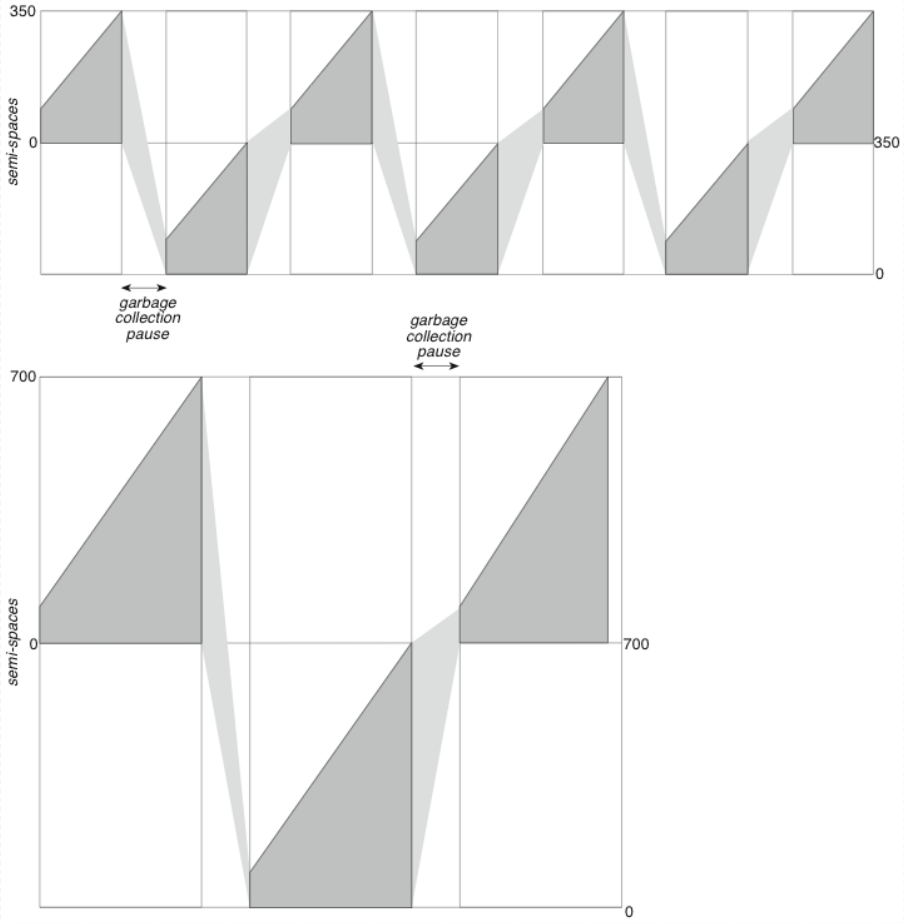
Garbage Collection locality issues

- On virtual memory systems:
  - Cost of page fault is expensive
    - Tens of thousands or
    - Millions of CPU cycles
  - Additional CPU cycles to minimize page faults are worthwhile

Garbage Collection locality issues

- Two spatial locality issues relevant here
  - MM system will touch every page in to-space
    - MM → allocator + garbage collector
    - Increasing heap size increases number of pages touched
  - Copying GC reorganizes the layout of objects in the heap
    - Will impact spatial locality of heap data structures
    - May compromise mutator's working set

Increase heap size reduces GC time



Paging behavior: MSGC vs Copying

- Sophisticated MS
  - Use stack or bitmap for mark-phase
  - Mark phase does not touch/dirty heap pages
  - Lazy sweeping does not affect paging behavior
    - Linked into free list and will soon be reallocated
- Copying GC
  - Next page to be allocated is likely the one LRU
  - LRU is a virtual memory page replacement policy
  - If set of pages in memory too small to hold both semi-spaces
    - To-space pages evicted before used for allocation

Paging behavior: MSGC vs Copying

- Zorn compared paging behavior of collectors
- Conclusions:
  - Virtual memory behavior of mark-sweep GC noticeably better than that of copying

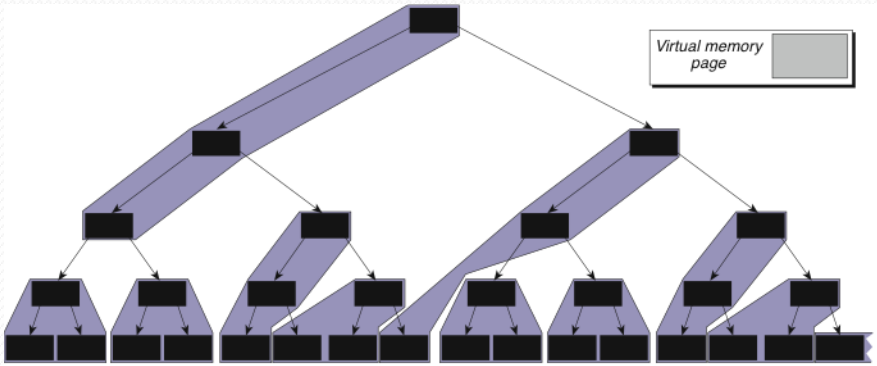
Regrouping strategies

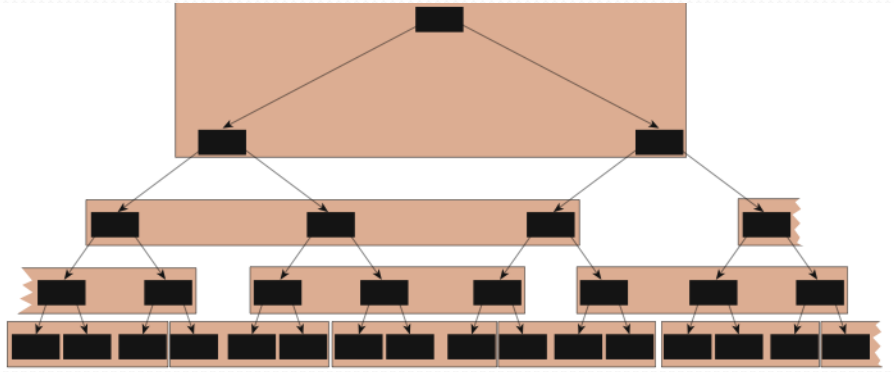
- Desire for relationship between data be reflected by their layout in heap
- More closely data are related the closer they should be placed in heap
- Relations may be
  - Structural: objects are part of same data structure
  - Temporal: objects accessed by mutator at similar times
- Placing related data on same page reduces page trafficking since bring data in memory also brings neighboring data

Regrouping strategies

- Objects typically created and destroyed in clusters
- Initial layout of objects in memory reflects future access patterns by user program
- Problem:
  - Copying objects may rearrange their order or layout in the heap
  - The way live objects are regrouped depends on the order that live graph is traversed.

Depth and breadth first copying





Regrouping strategies

- Can use regrouping strategies to improve locality
  - Static regrouping
    - Analyze topology of heap data at collection time.
    - Move structurally related objects more closely
  - Dynamic regrouping
    - Cluster objects based on mutator access pattern
    - Objects regrouped on-the-fly by incremental copying collector
- Depth first copying generally yields better locality than breadth-first copying

Copying vs Mark-sweep

Method/Cost	*Mark-sweep*	*Copying*
Initialisation	clear mark-bits	flip semi-space
Cost	negligible	negligible
Tracing	mark objects	copy objects
Cost	O(L)	O(L)
Sweeping	lazily: transferred to allocation	none
Cost		
Allocation	lazily: dominated by init	done directly
Cost	O(M - R)	O(M - R)

L = volume live data in heap

R = residency of user program

M = heap size

- Different constants of proportionality
- Object size is important, especially for copying
- Sophisticated copying collector easier to implement