Allocation

Schedule

	M	W
Sept 14	Intro/Background	Basics/ideas
Sept 21	Allocation/layout	GGGGC
Sept 28	Mark/Sweep	Mark/Sweep
Octo 5	Copying GC	Ref C
Octo 12	Thanksgiving	Mark/Compact
Octo 19	Partitioning/Gen	Generational
Octo 26	Other part	Runtime
Nove 2	Final/weak	Conservative
Nove 9	Ownership	Regions etc
Nove 16	Adv topics	Adv topics
Nove 23	Presentations	Presentations
Nove 30	Presentations	Presentations

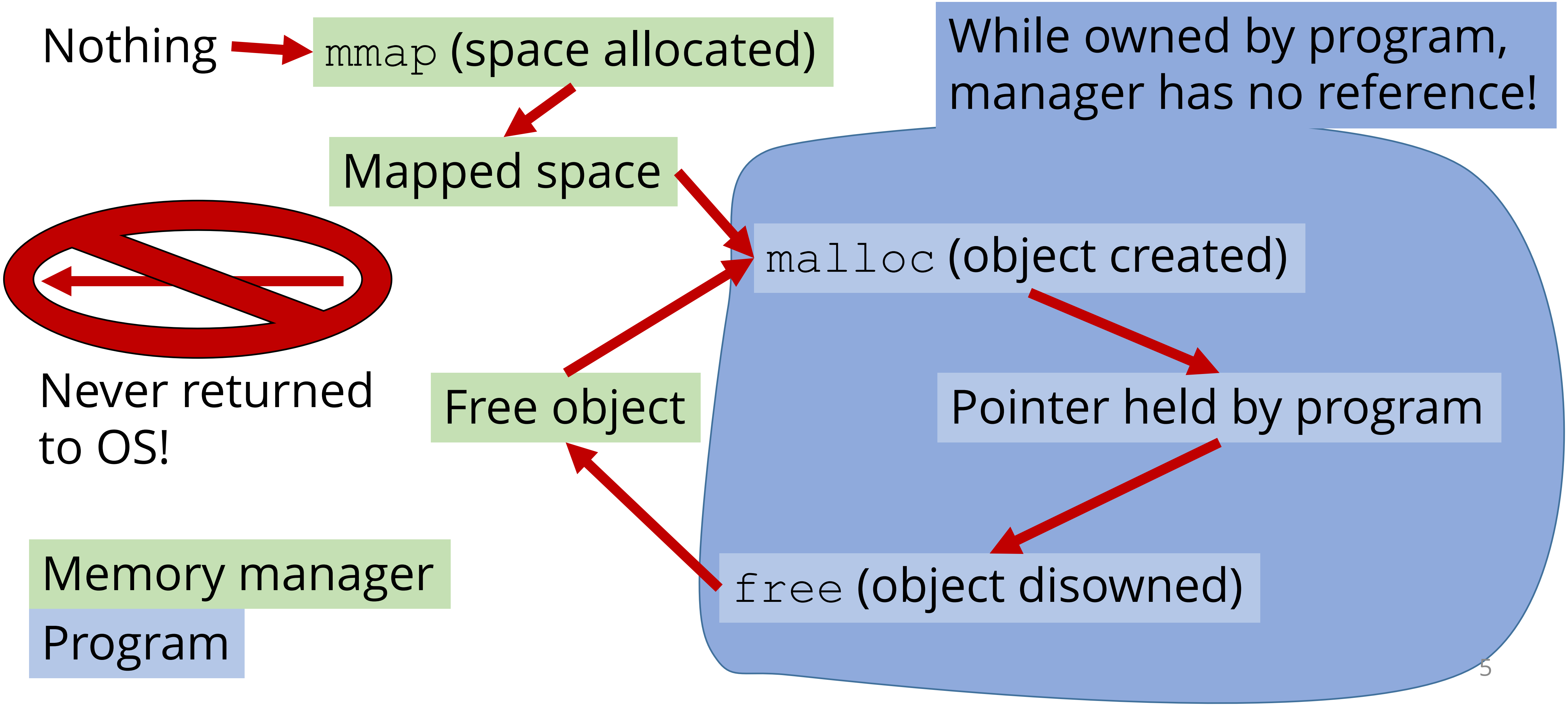
GC basics summary

- Compiler tells us roots
- Compiler tells us when we can collect
- Find reachable objects
- Discard unreachable objects

Allocation and revokation

- How you allocate depends on how you free
- Automatic memory management has more options than manual

Review


Nothing
mmap (space allocated)
Mapped space
While owned by program, manager has no reference!
malloc (object created)
Pointer held by program
free (object disowned)
Free object
Never returned to OS!
Memory manager
Program

Manual allocation review

- With free list:
  - First try to find a suitable object on the free list
  - If found, remove from free list and return
  - If not found, allocate new object from free space
  - If no free space, allocate new pool

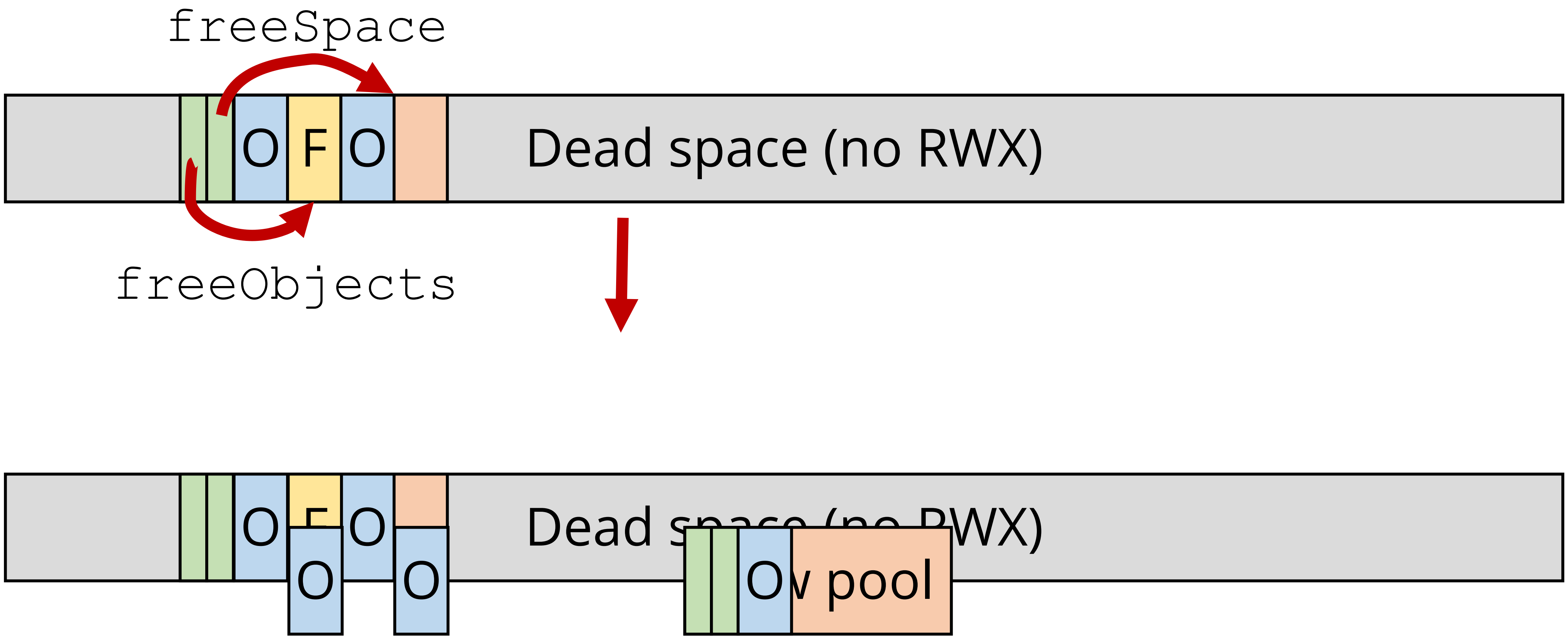
GC and allocation

- Style of GC will affect style of allocation
- Free-list still fundamental

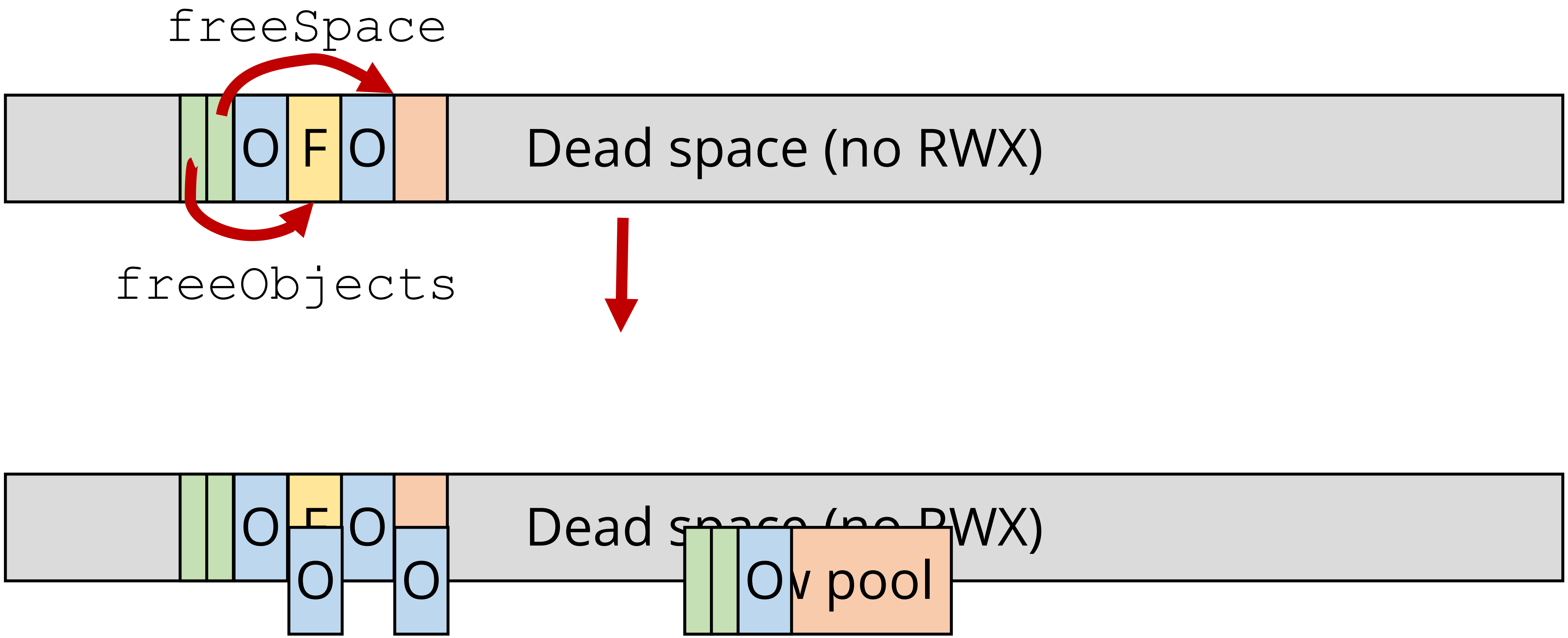
Alignment

- Will need to align allocation to make usable objects
- Most systems require (at least) word alignment
- Round all sizes up to *allocation granule*
- Some objects need larger alignment, but we ignore those in this course
- Minimum size may be larger than granule

Allocation options



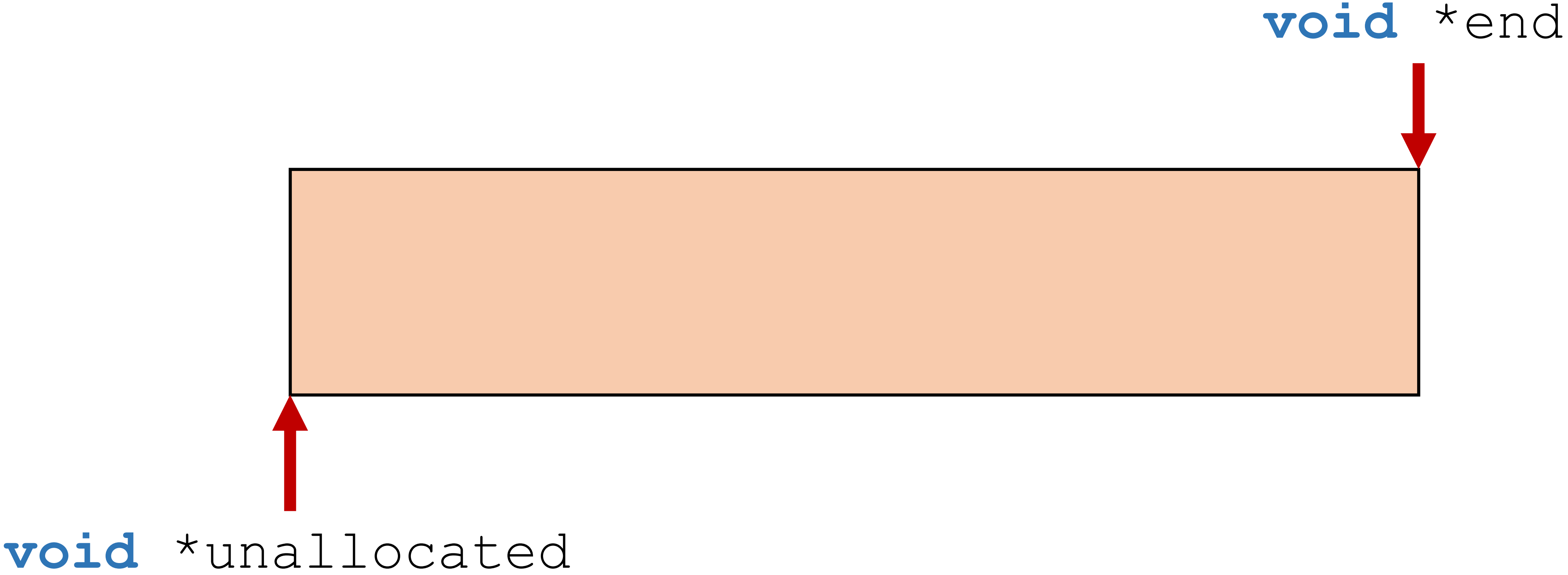
Allocation options



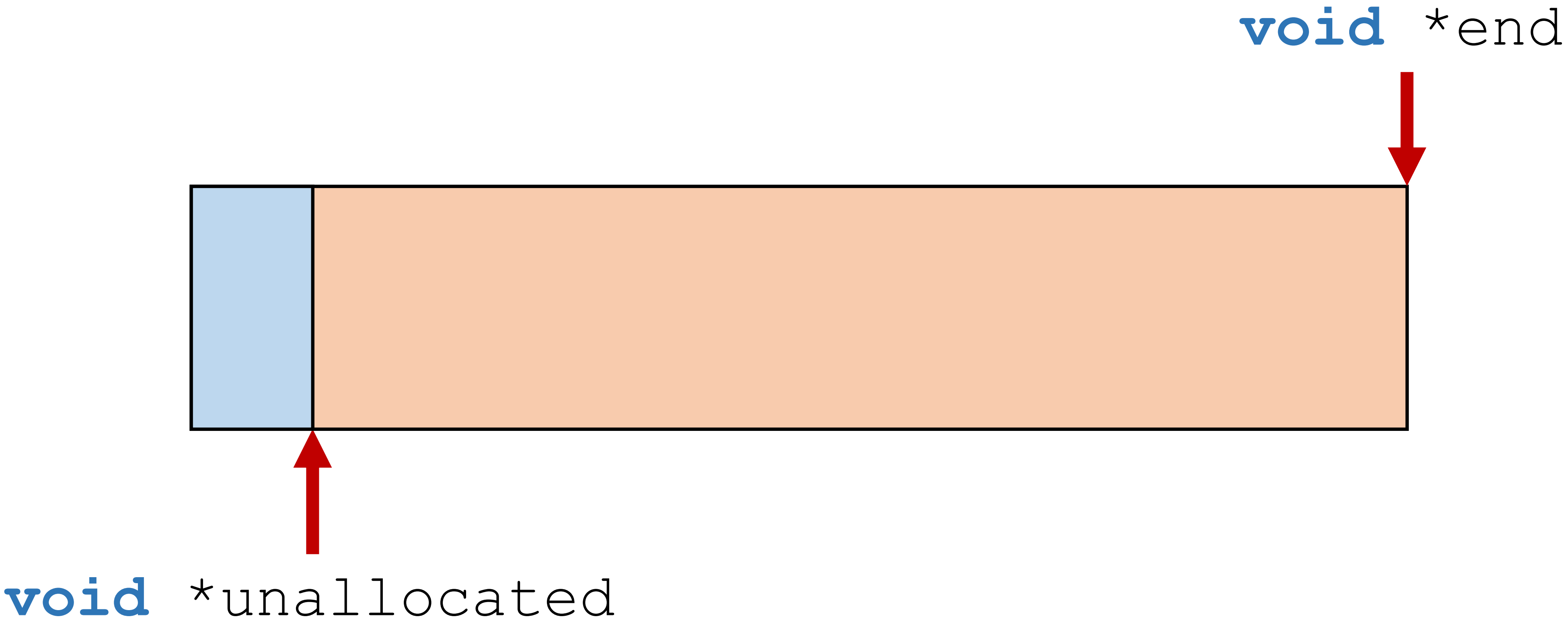
Big free regions

- Obvious option: Allocate from beginning towards end
- “Bump-pointer allocation” or “Sequential allocation”

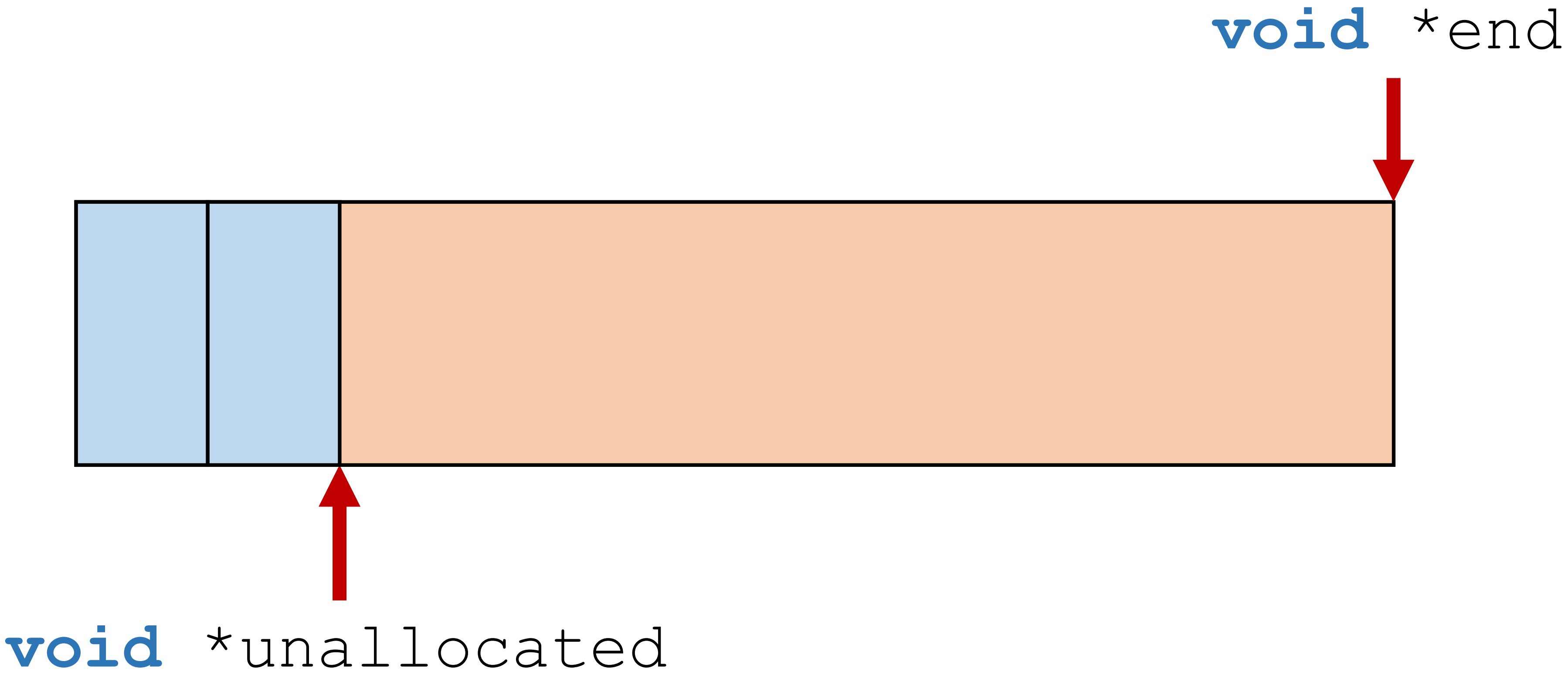
Bump-pointer allocation



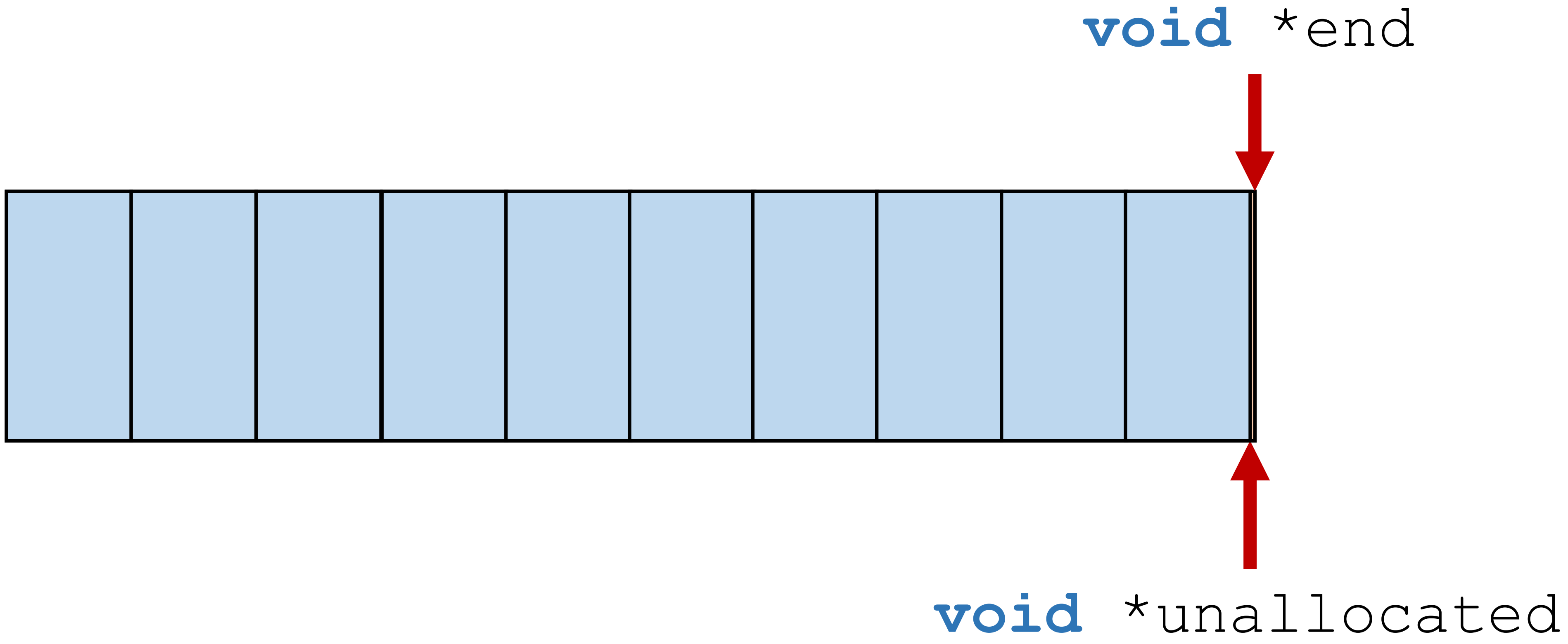
Bump-pointer allocation



Bump-pointer allocation



Bump-pointer allocation

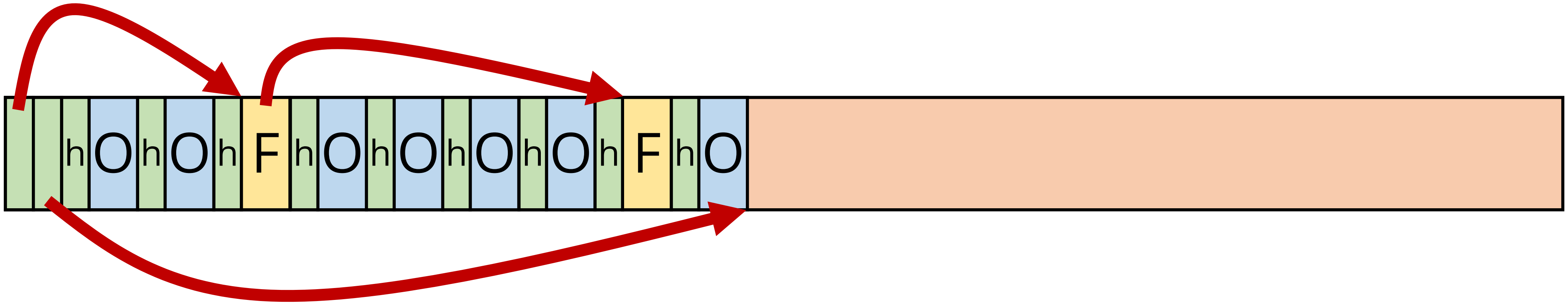


Why bump?

- Easy and fast
- No wasted space during allocation
- Only requires two pointers[1] per pool
- But: Only makes sense for big free regions

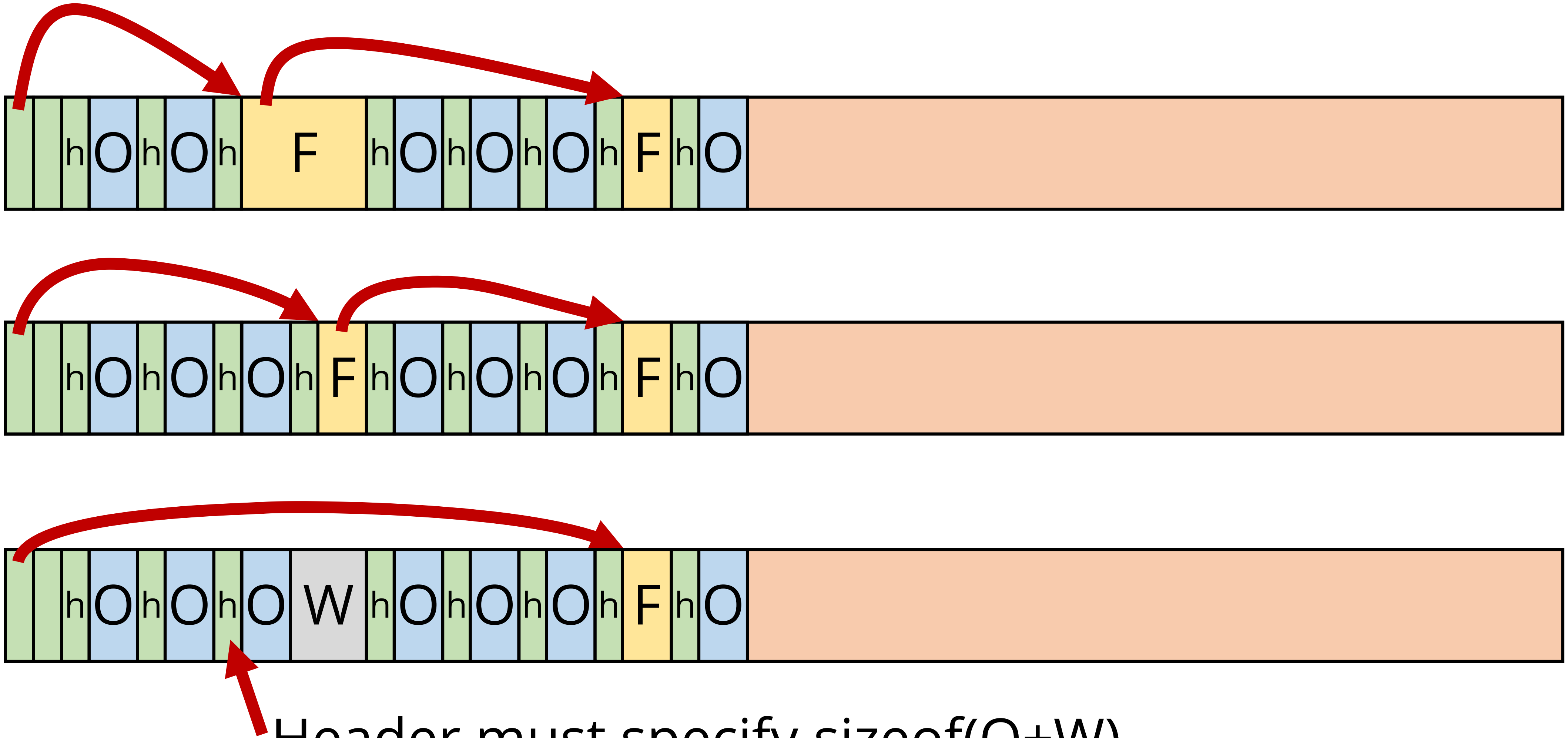
[1] The end pointer may be implicit

Free-list allocation



- Free objects kept on list
- Allocate by taking an object from the free list
- Object must be at least large enough

Splitting vs overallocation



Header must specify sizeof(O+W)

Fragmentation

- Unused space between used objects
- Cannot allocate objects larger than largest fragment!
- With unmoving objects, can only avoid fragmentation, not prevent

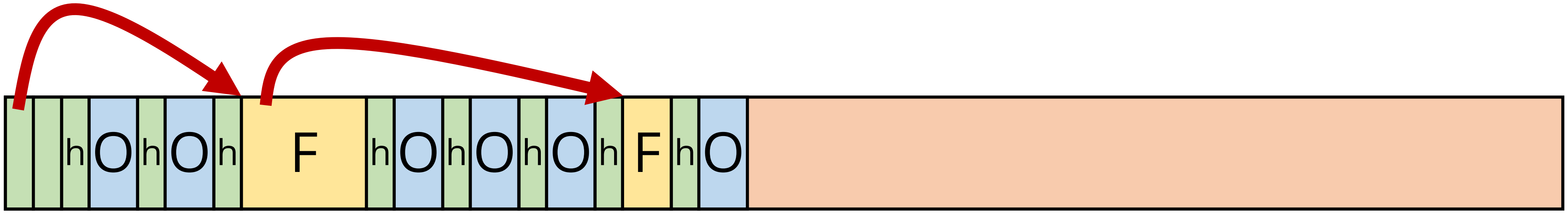
External vs internal fragments

- External fragmentation:
  - Unused space *between* objects (freeing and splitting)
- Internal fragmentation:
  - Unused space *within* objects (overallocation or padding/alignment issues)

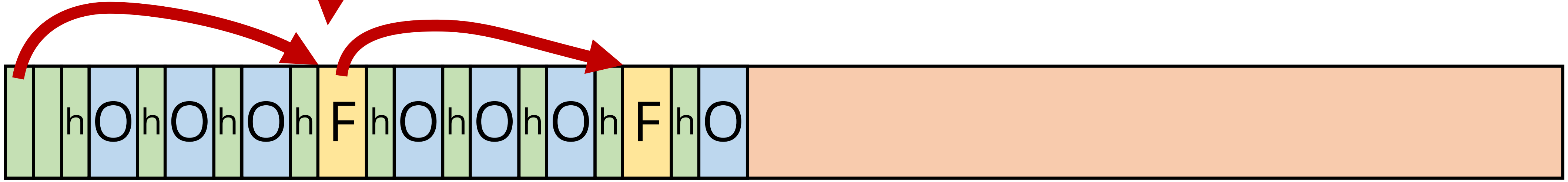
Choose wisely

- Free object of wrong size $\rightarrow$ splitting
- Alternatively, search through list for object of right size
- But searching through list takes time

First-fit



Always choose first, split if necessary



Aside: List order

- In manual memory management, list could be in any order
- In GC, list is created by sweep phase
- Typically ordered low memory to high memory

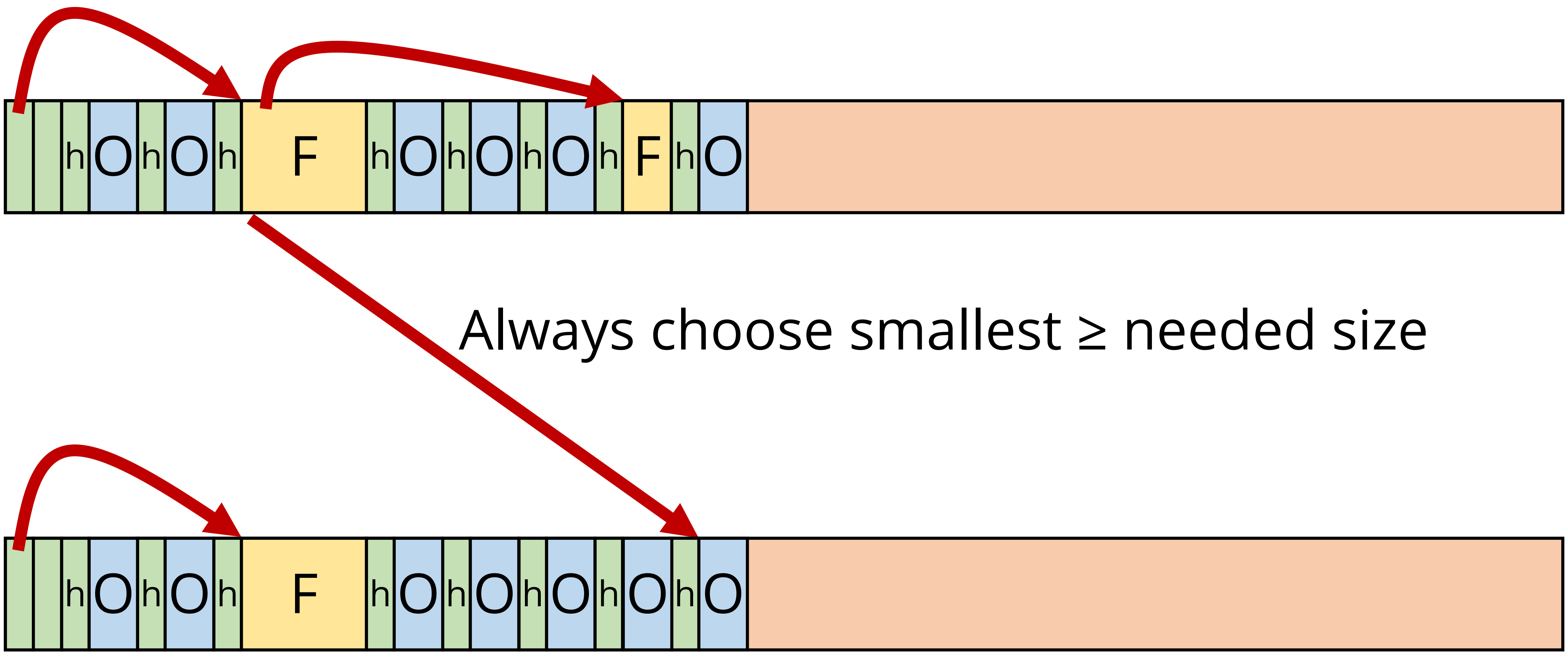
First-fit

- Fast to find objects (“expected” $O(1)$)
- Unusable fragments cluster at beginning
- Maximize memory reuse (cache!)

Next-fit

- Use a circular linked list
- Less skipping over fragments
- Less reuse

Best-fit



h O h O h F h O h O h O h F h O
Always choose smallest ≥ needed size
h O h O h F h O h O h O h O h O

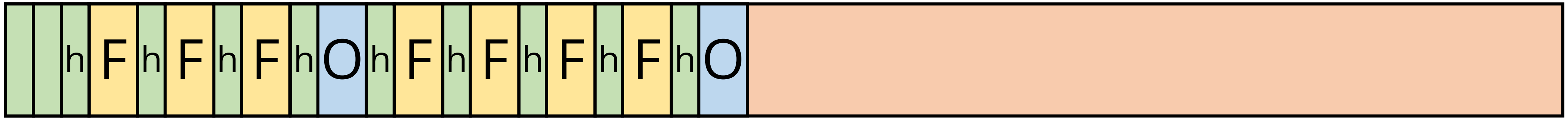
Best-fit

- Intuitive “best” fit
- Usual loads have perfect reuse
- On some loads, *worst* case: Unusable tiny fragments!
- Fragments don’t cluster

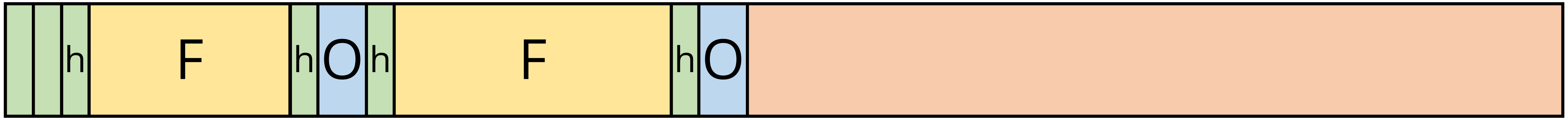
Which-fit?

- No fitting algorithm is always best
- With many similar-size objects, all the same!
- Cache locality is important

Coalescence



In free-list, all separate objects
In reality, two big blocks of space



To coalesce, must have sorted free-list
GC can do that!... but doesn't necessarily

Coalescence

- GC may provide unsorted free list
- To coalesce, must sort list
- When to sort/coalesce?
  - When fitting algo sucks too much, or
  - during GC

Breather

- Bump-pointer great when possible
- Free-list: First-, next-, best-fit
- Best not always the best
- Coalesce to avoid waste

Back to free-lists

- All this because lists suck!
- So, make a sorted tree of free objects
- Consequence: Free object definition changes

Free objects

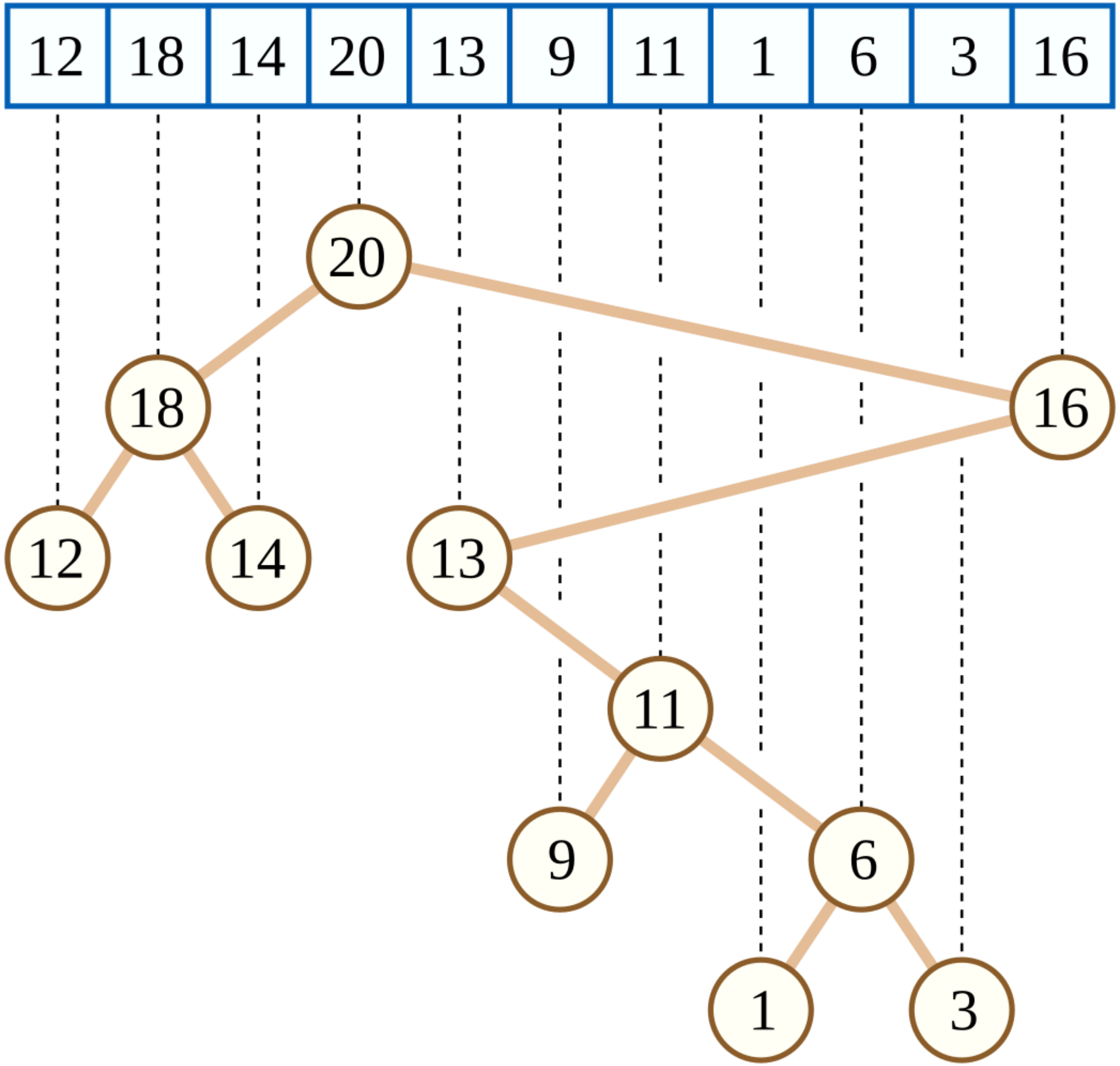
```
struct ObjectHeader {
  size_t objectSize;
};

struct FreeObject {
  struct FreeObject *left;
  struct FreeObject *right;
};

struct Pool {
  struct FreeObject *freeObjectsRoot;
  void *freeSpace;
};
```

How to sort

- Sort tree depending on fit algo:
  - First-fit/next-fit: Sorted by address
  - Best-fit: Sorted by size
- For best-fit, simple sorted tree OK
- For first-fit/next-fit, Cartesian tree

Cartesian tree

- Tree sorted by address
- Max-heap property on size
- Walk by address fast, walk by size fast enough



Segregated-fits

- We’ve assumed one free-list
- Why not multiple free-lists?
- Create size categories with free-lists per size

Segregated-fits

2 w	**4 w**	**8 w**	**16 w**	**32 w**	**64 w**	**big**

- Static (usually) number of size categories
- Last category is “big”, for bigger objects
- *Always* round up allocation to nearest size category!
- Creates internal fragmentation

Splitting in segregated-fits

- Allocation from “big” is usual
- Splitting necessary to move objects to lower category
- Must split into category-sized objects
- If such a split is impossible, must overallocate
- More internal fragmentation!

Worth it?

- Segregated-fit is much more complicated
- Creates internal fragmentation
- (Nearly) Eliminates external fragmentation
- Faster allocation

Segregated blocks

- Can get small objects by splitting big ones…
- Or, allocate objects of different sizes in different pools
- Eliminates external fragmentation
- Can remove size from object header

Bitmapped-fits

- Free objects must be coalesced
- Instead, put freeness info aside, at beginning of pool
- Need one bit per granule of pool
- Bit 0 = free, 1 = used

Bitmapped-fits

```
struct ObjectHeader {
  size_t objectSize;
};

struct Pool {
  unsigned char freeMap
    [POOL_SIZE/ALLOCATION_GRANULE/8];
  void *freeSpace;
};
```

Bitmapped-fits

- Some wasted space in pool
- Coalescence is automatic
- No explicit list/tree of free objects

Locality

- Locality matters!
- With no caches, best-fit always wins
- With cache, first-fit often wins
- Objects allocated at same time often used at same time