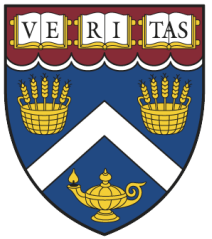
Tracing Garbage Collection



Mutators

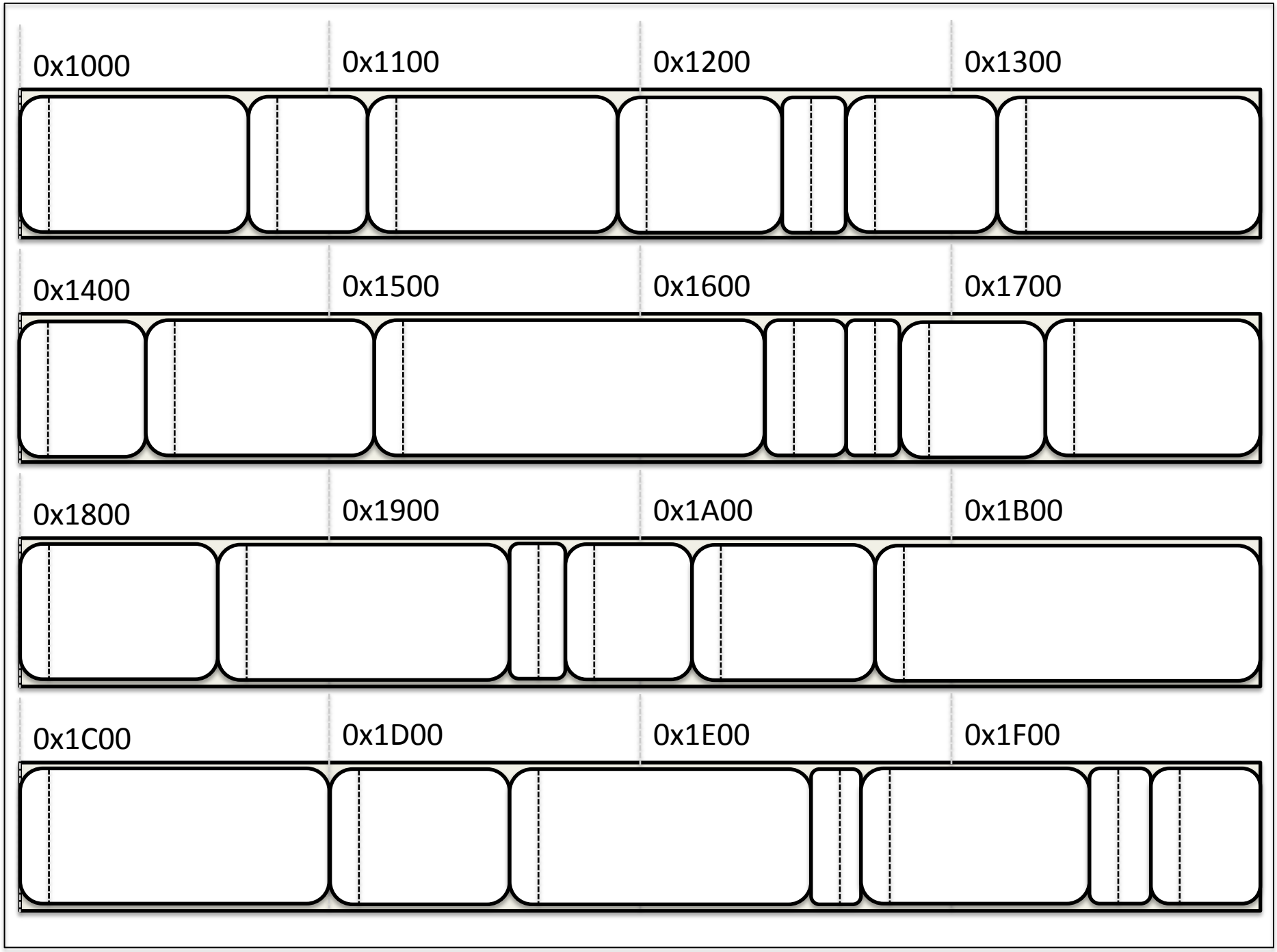
- Anything not doing memory management
  - Application threads
  - JIT compilation
  - Class loading
- Its only purpose is to change the object graph
- How we handle mutators is a major part of GC
  - Pause all non-GC activity
  - Work around a potentially changing graph

Stop the World Collection

- Look at garbage collection across the whole system
  - Not incremental like reference counting
- Simplest implementation strategy
  - Pause all mutator threads
  - Do garbage collection work in peace
  - Restart all mutator threads
- Useful way to think about algorithms
  - No longer state of the art
  - Pause times can become unbearable for large heaps

Tracing

- Tracing lets us find all live objects on the heap
  - Start with objects referred to from the system roots
  - Mark those objects as live
  - Scan those live objects for more references
  - Repeat until all reachable objects are marked
- Garbage cycles not an issue
  - Marked object terminates cycle
- Need perfect type information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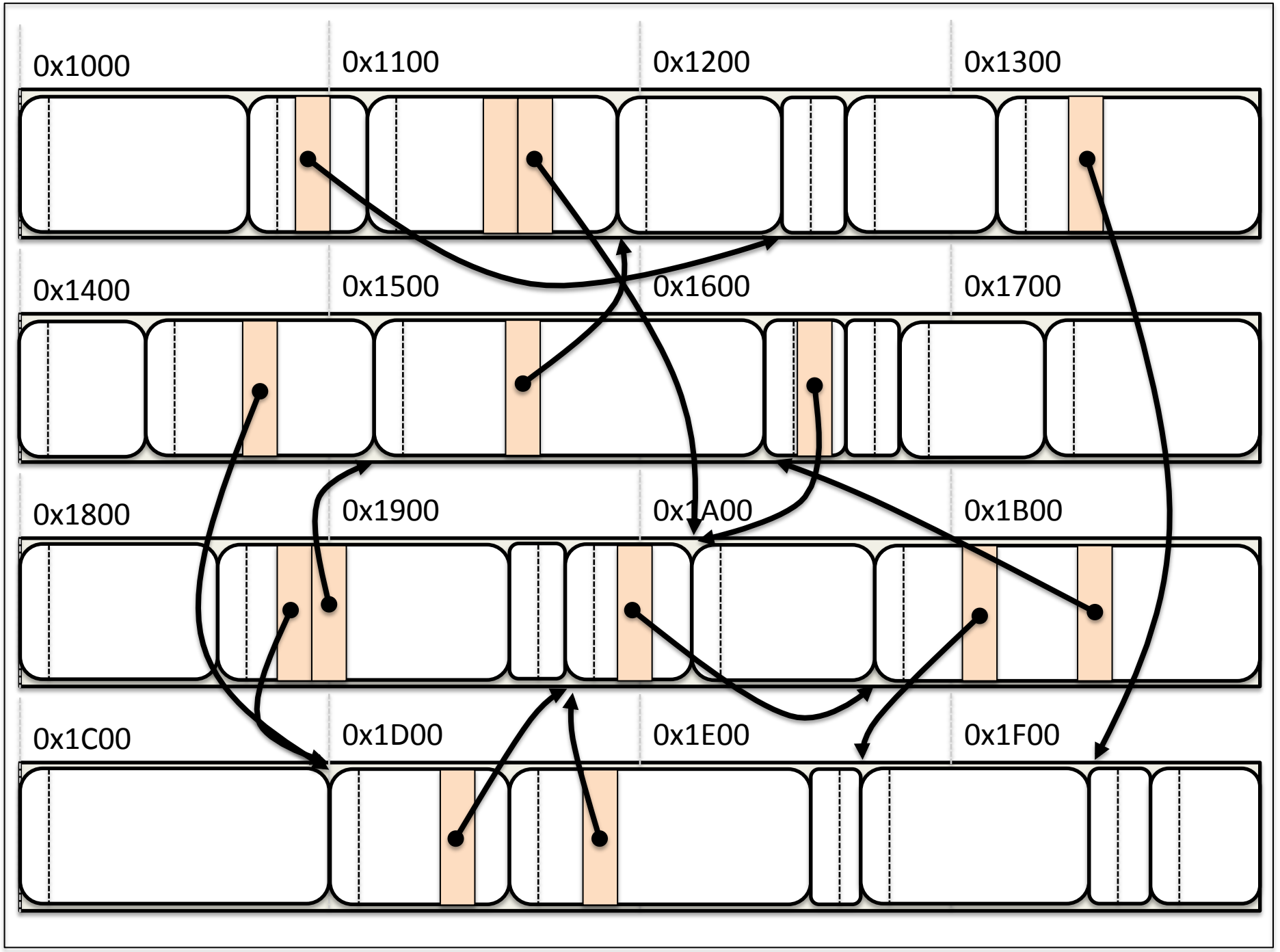
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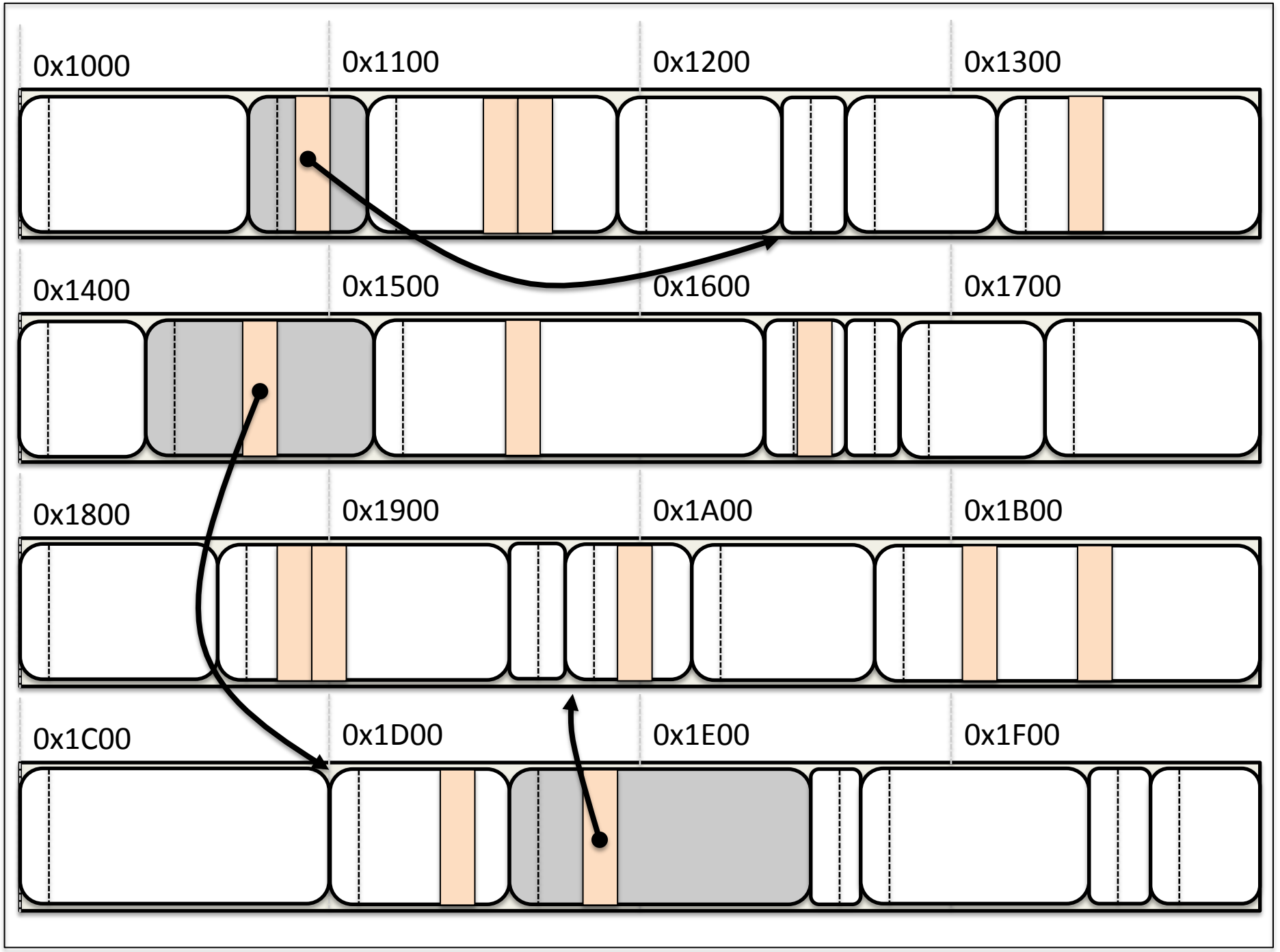
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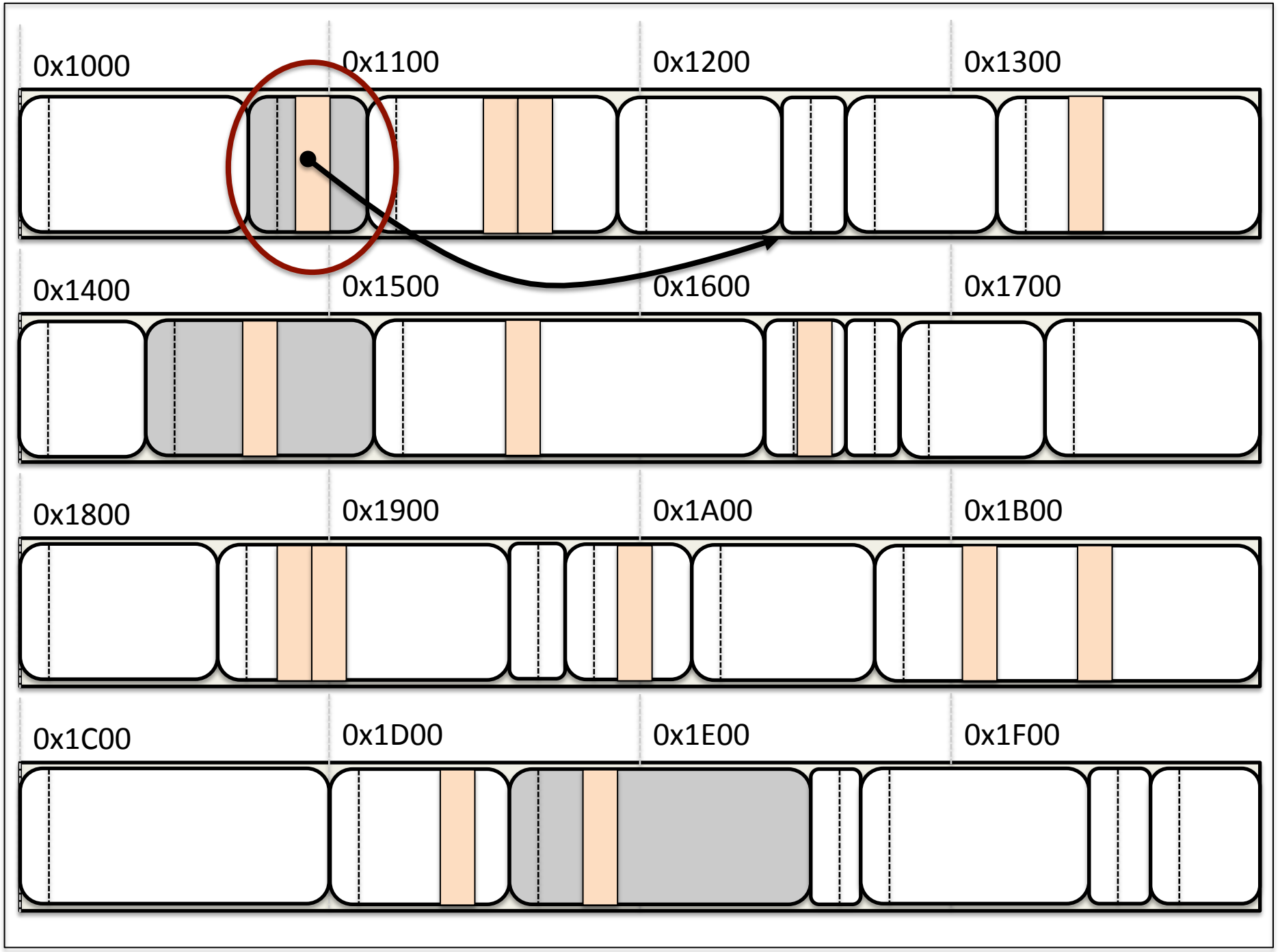
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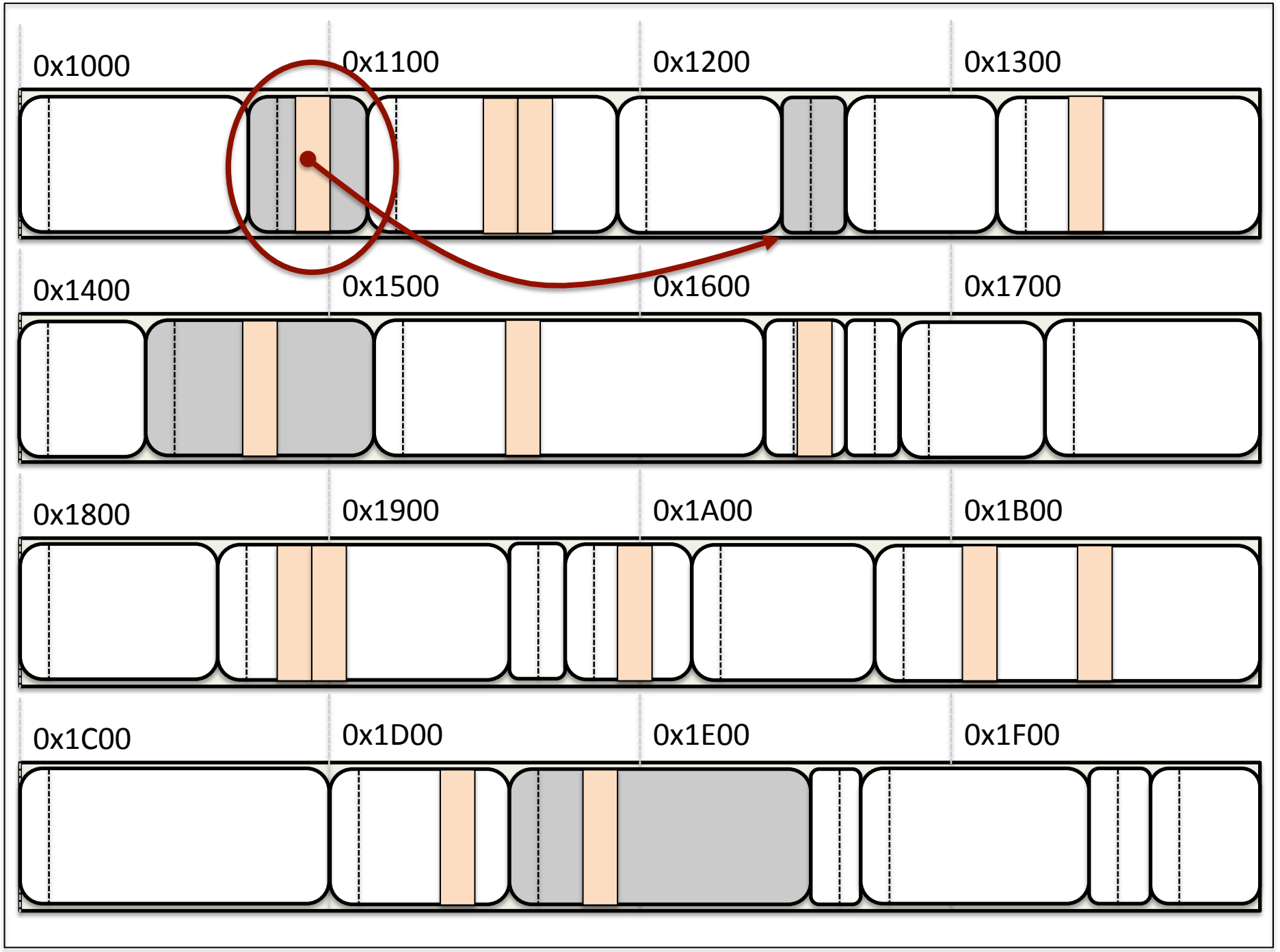
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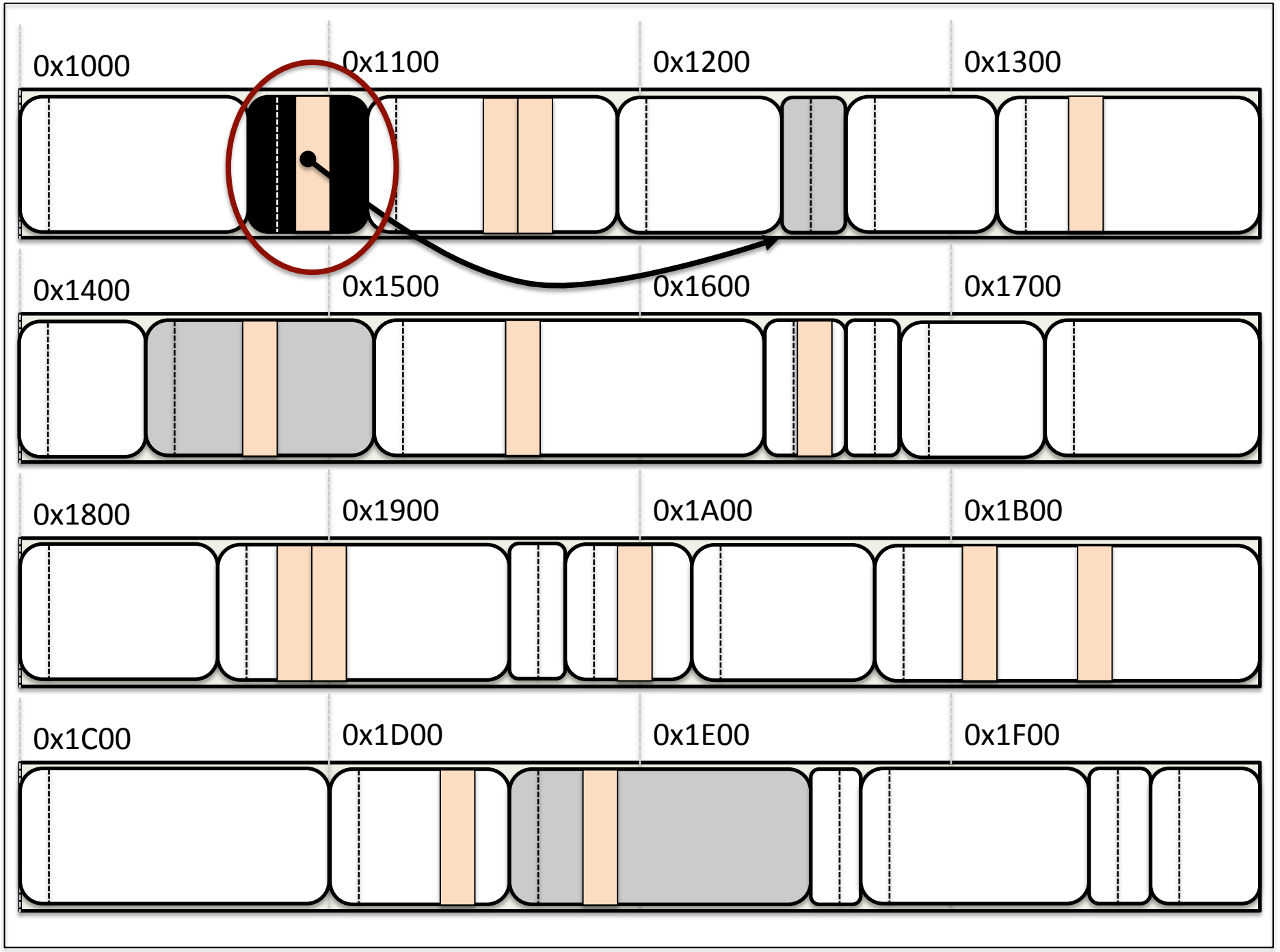
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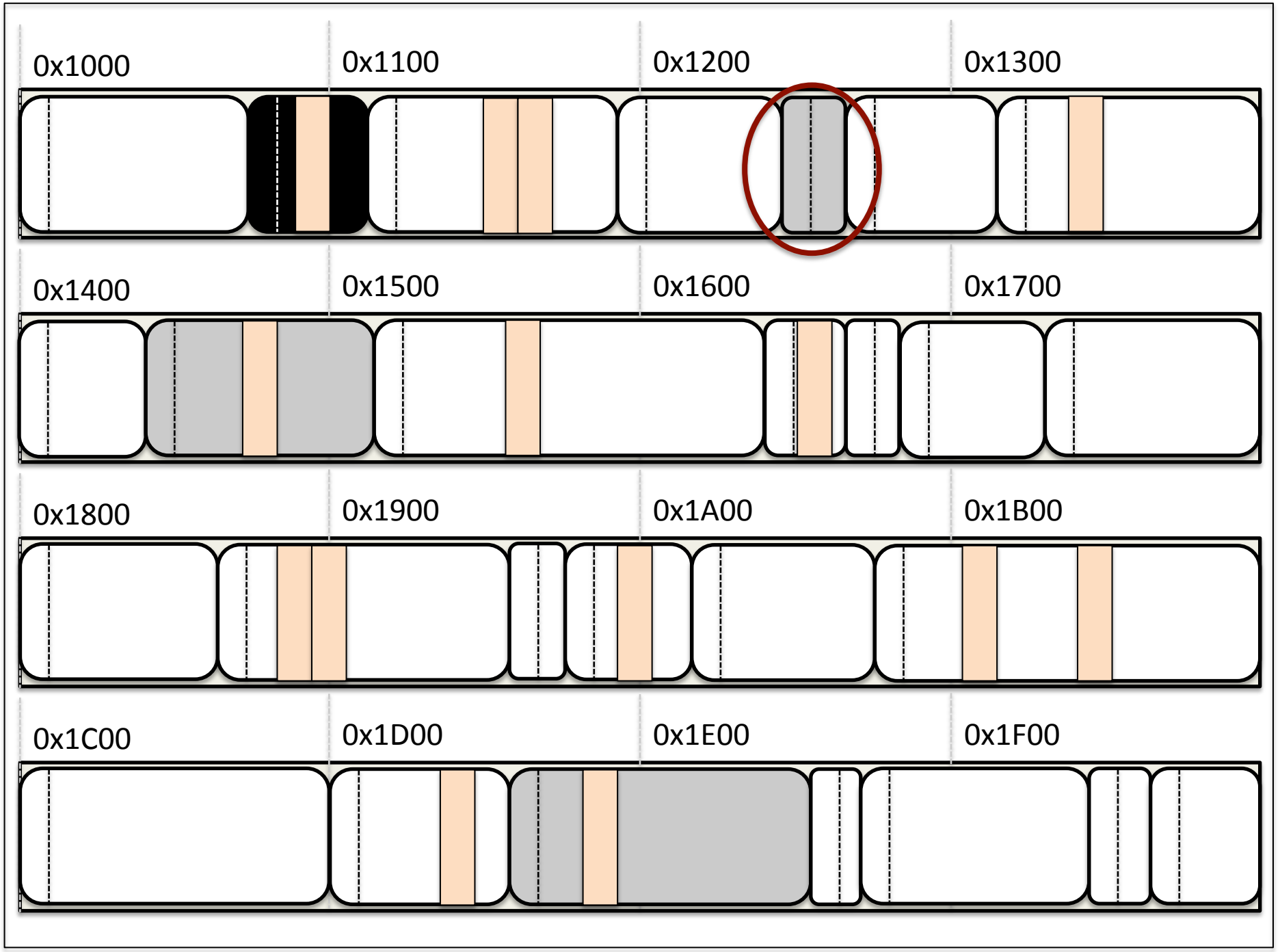
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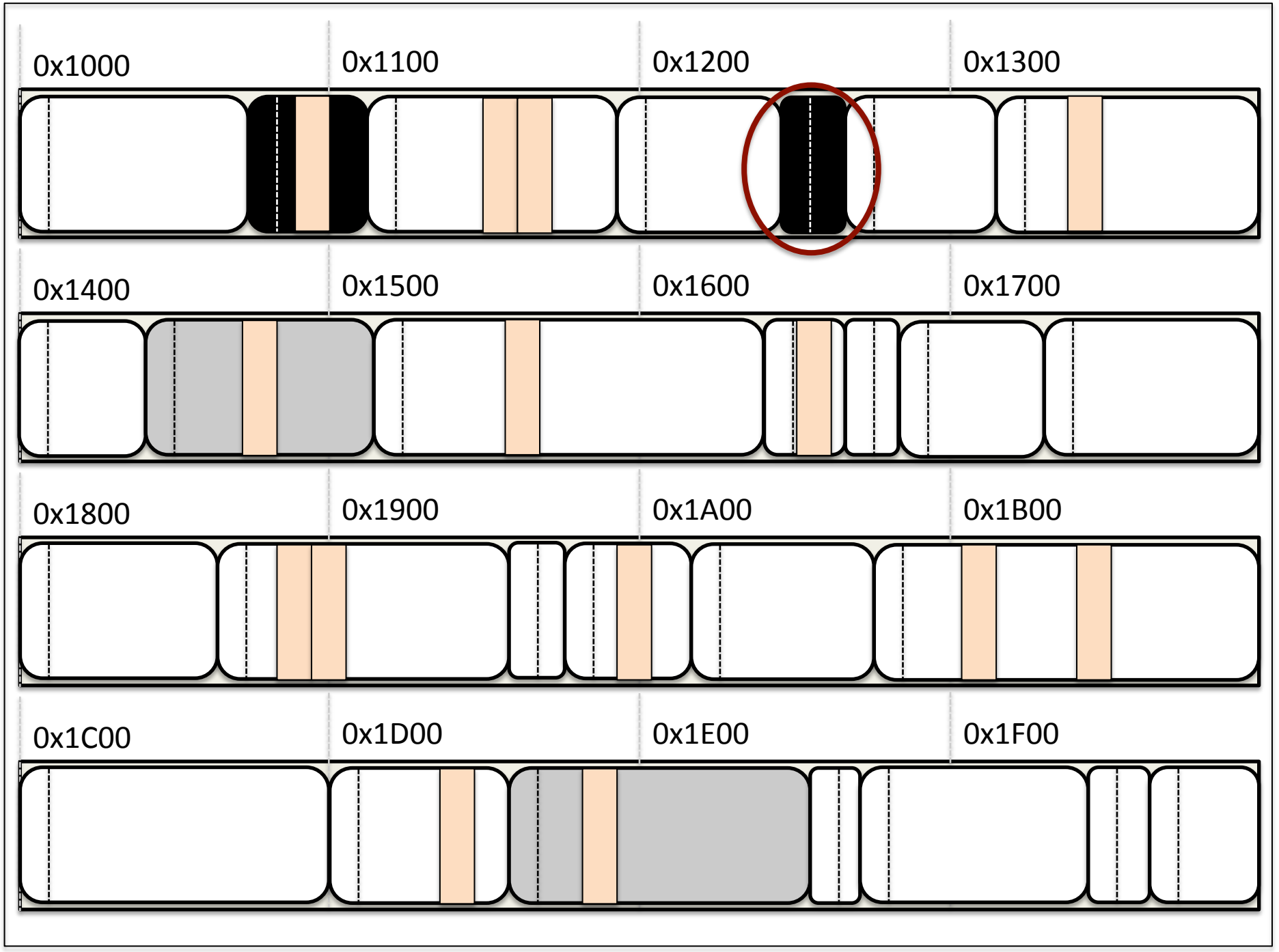
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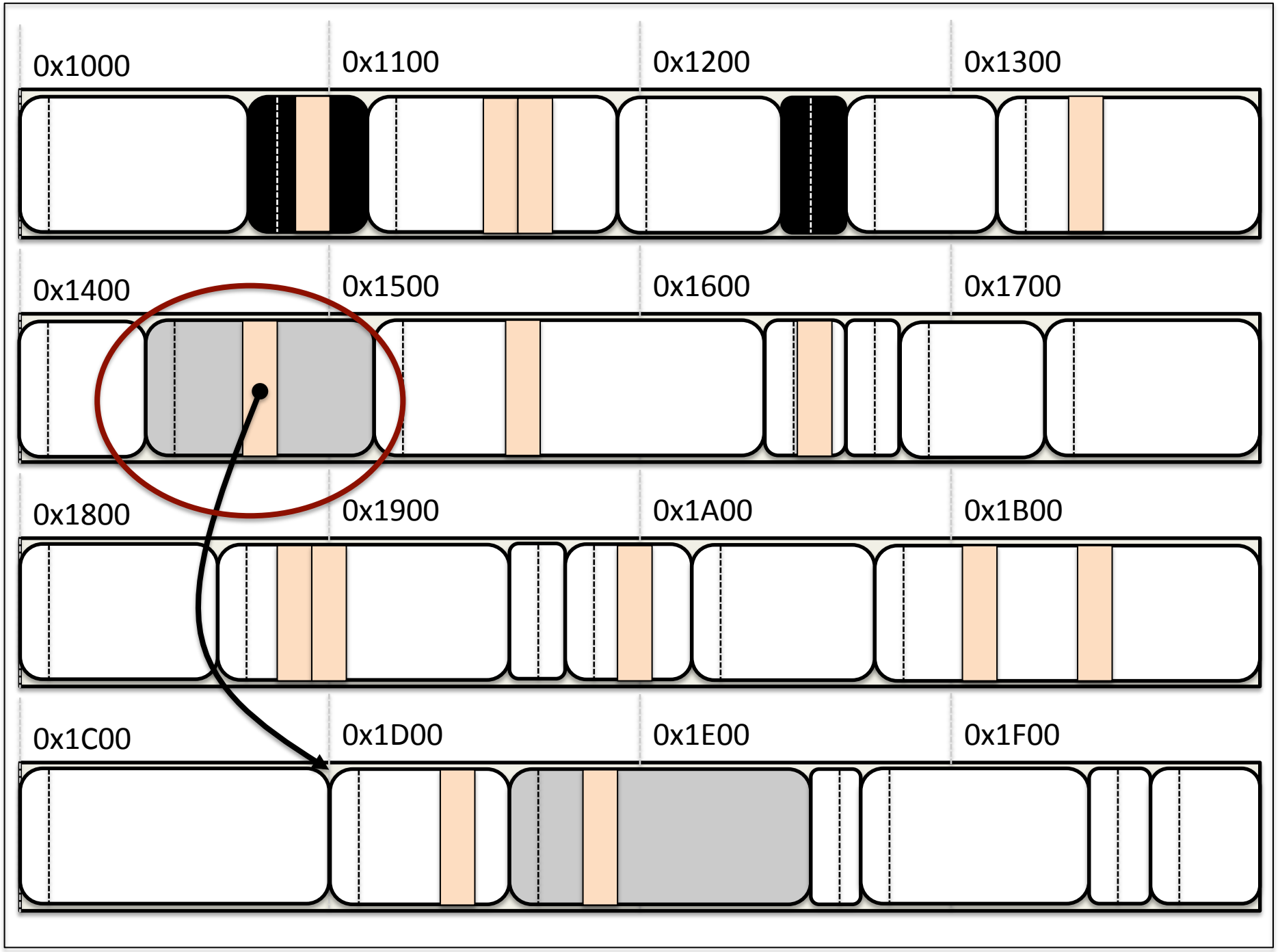
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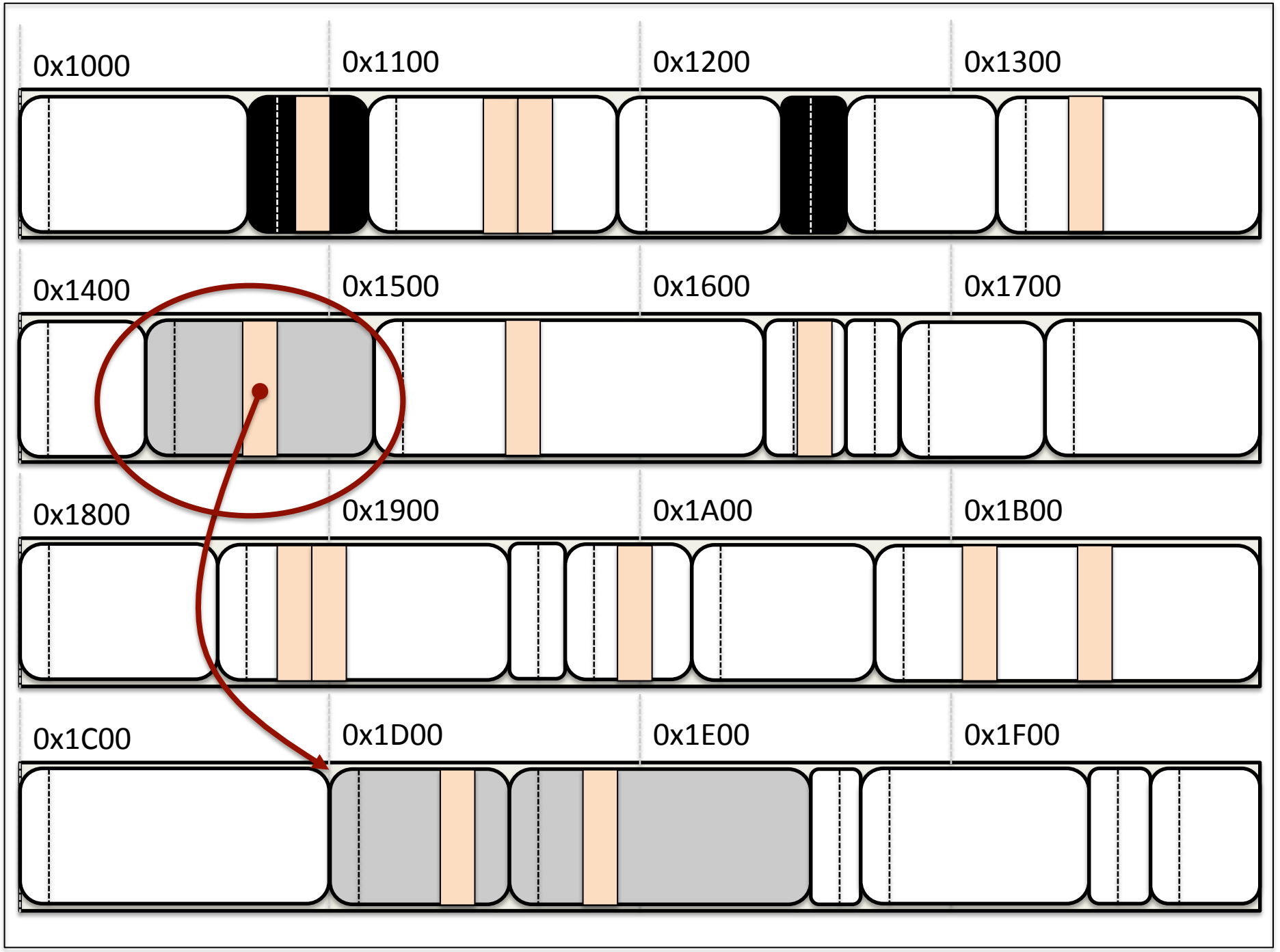
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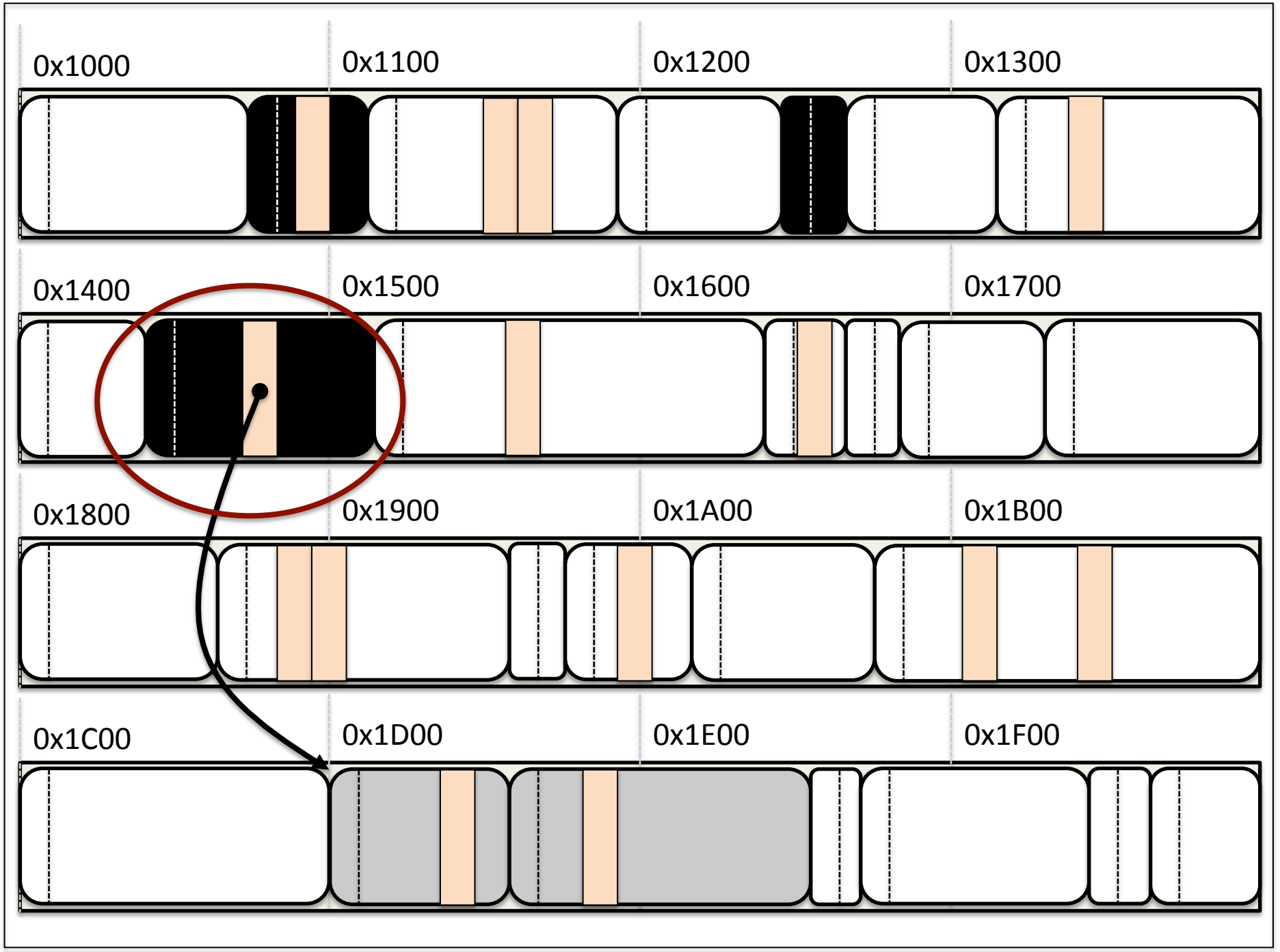
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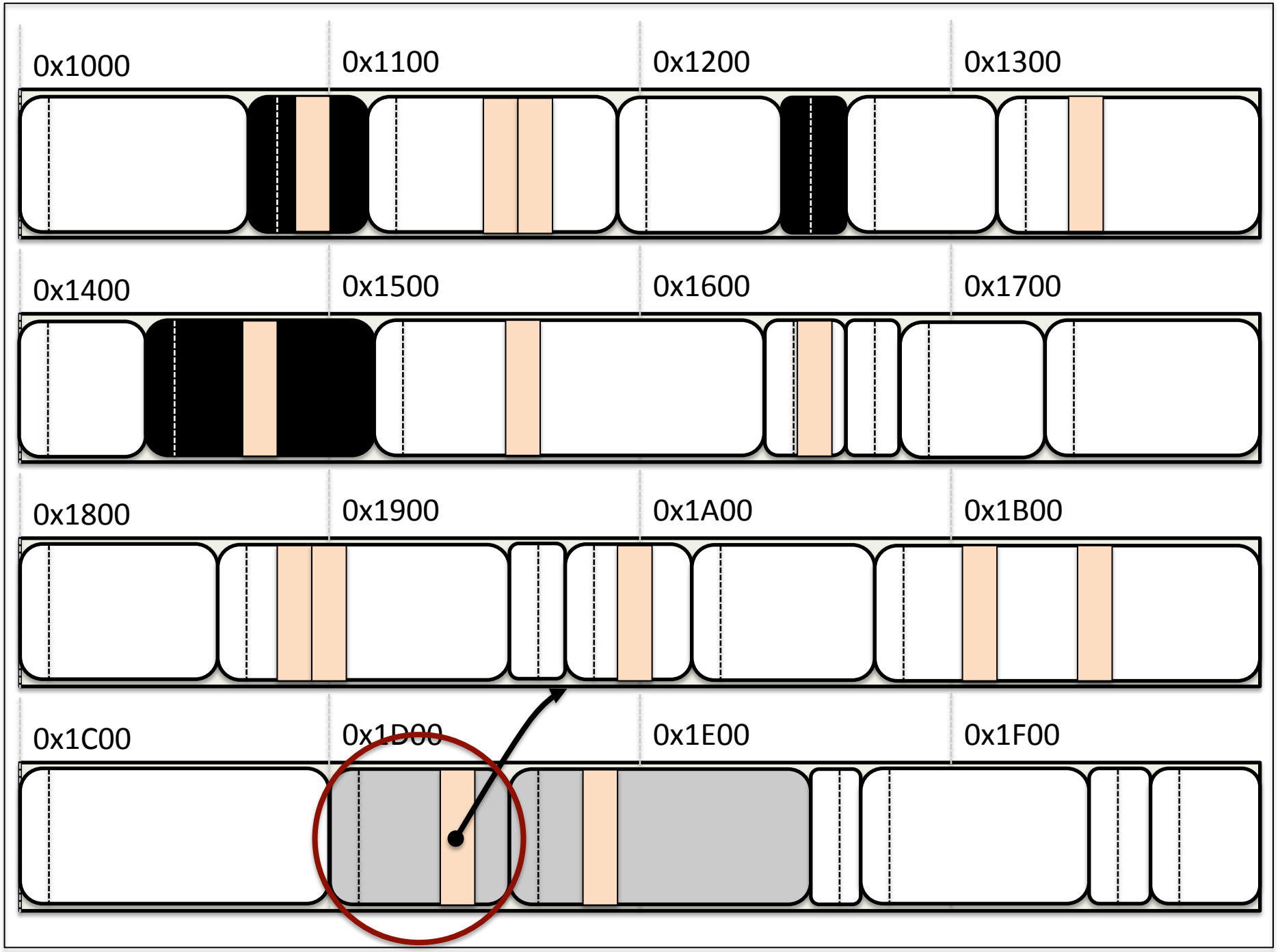
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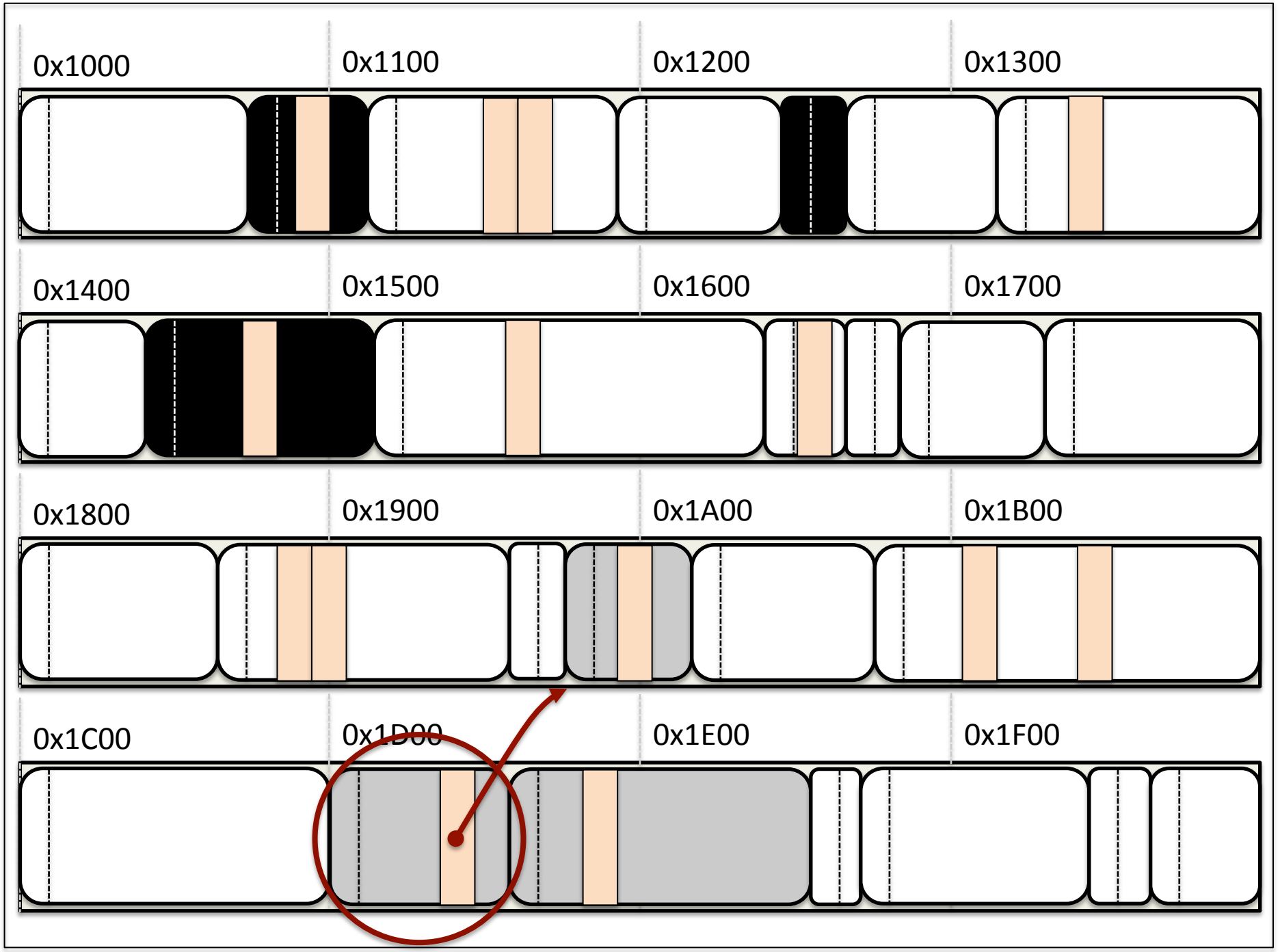
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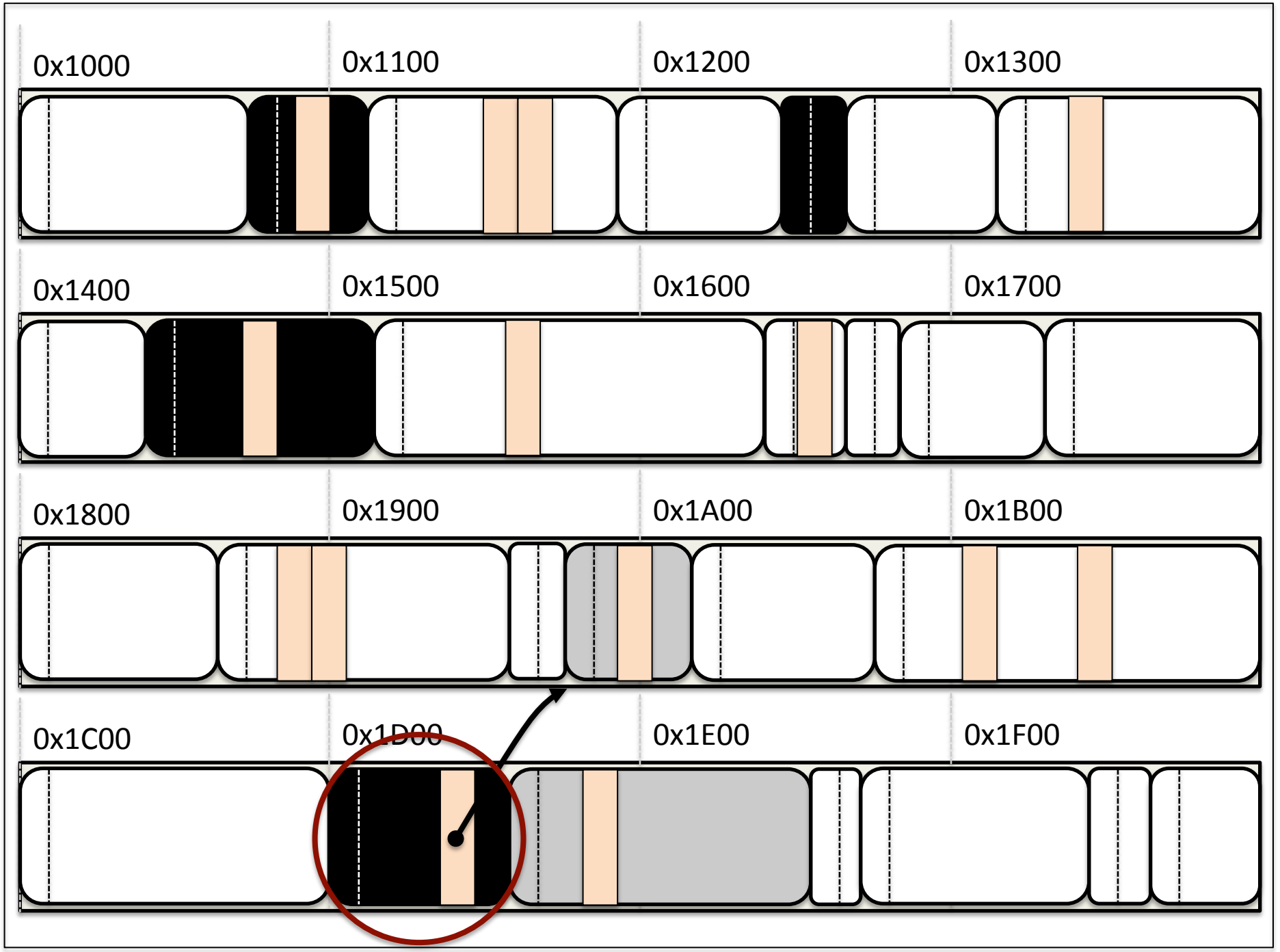
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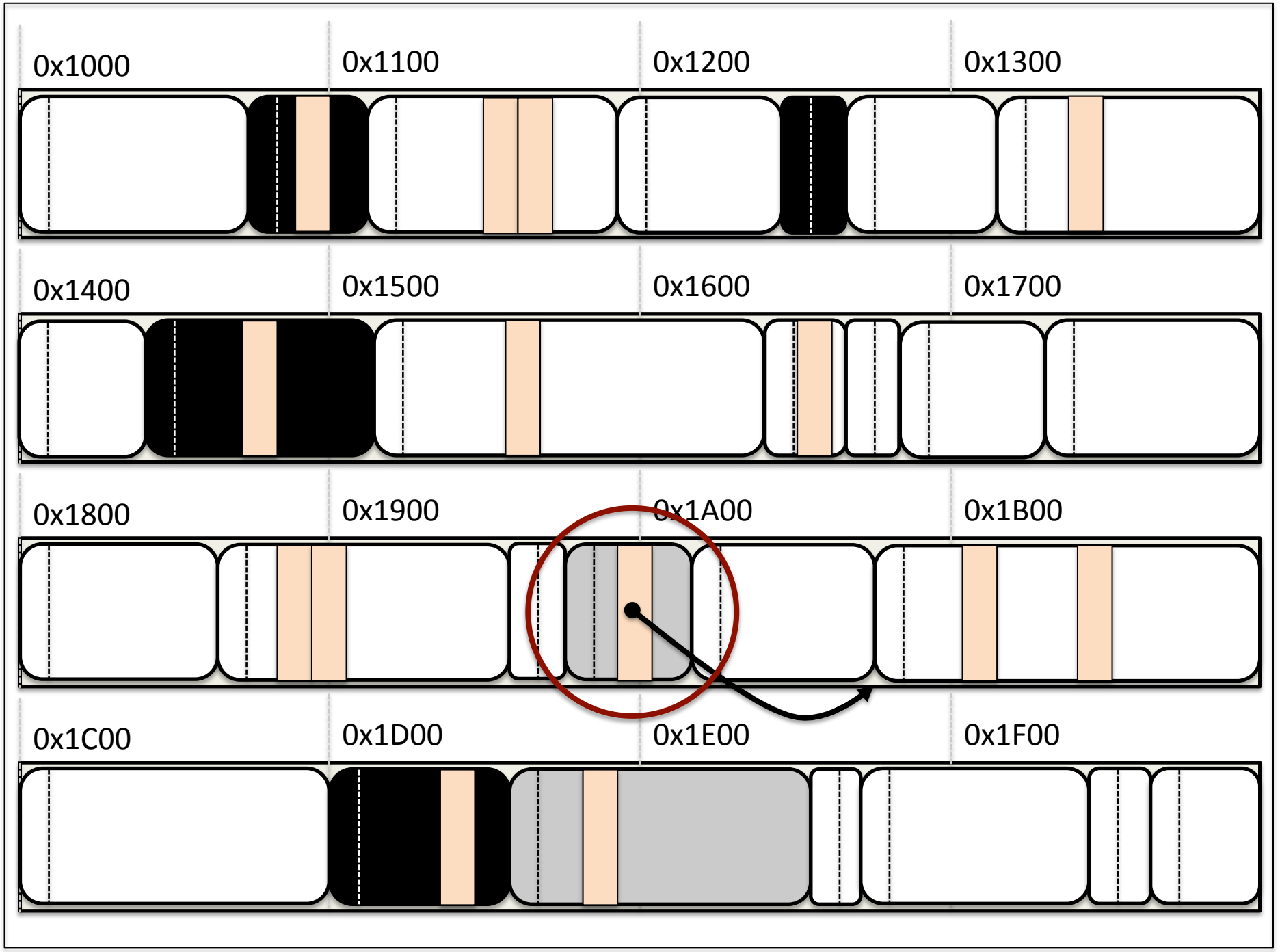
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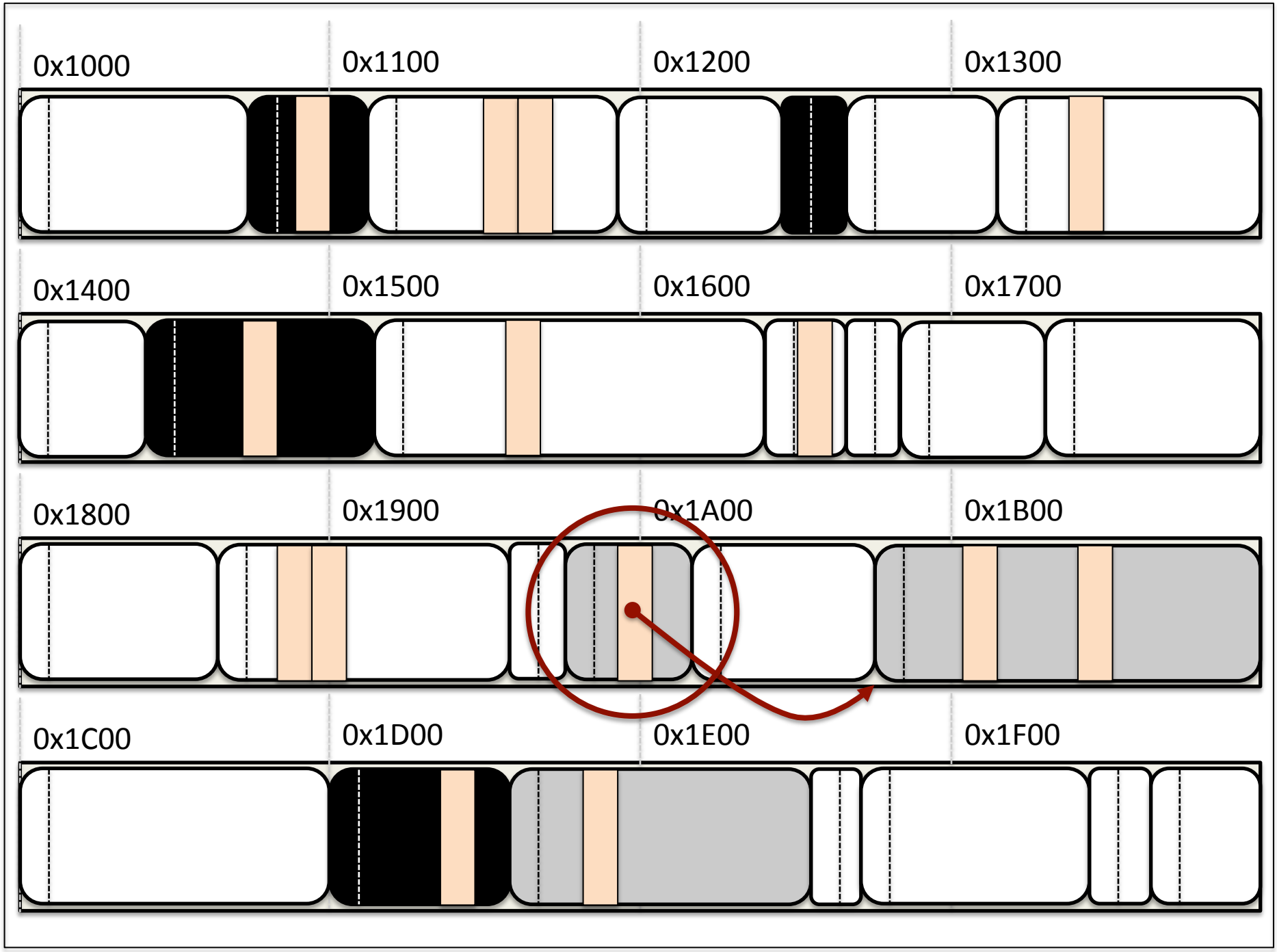
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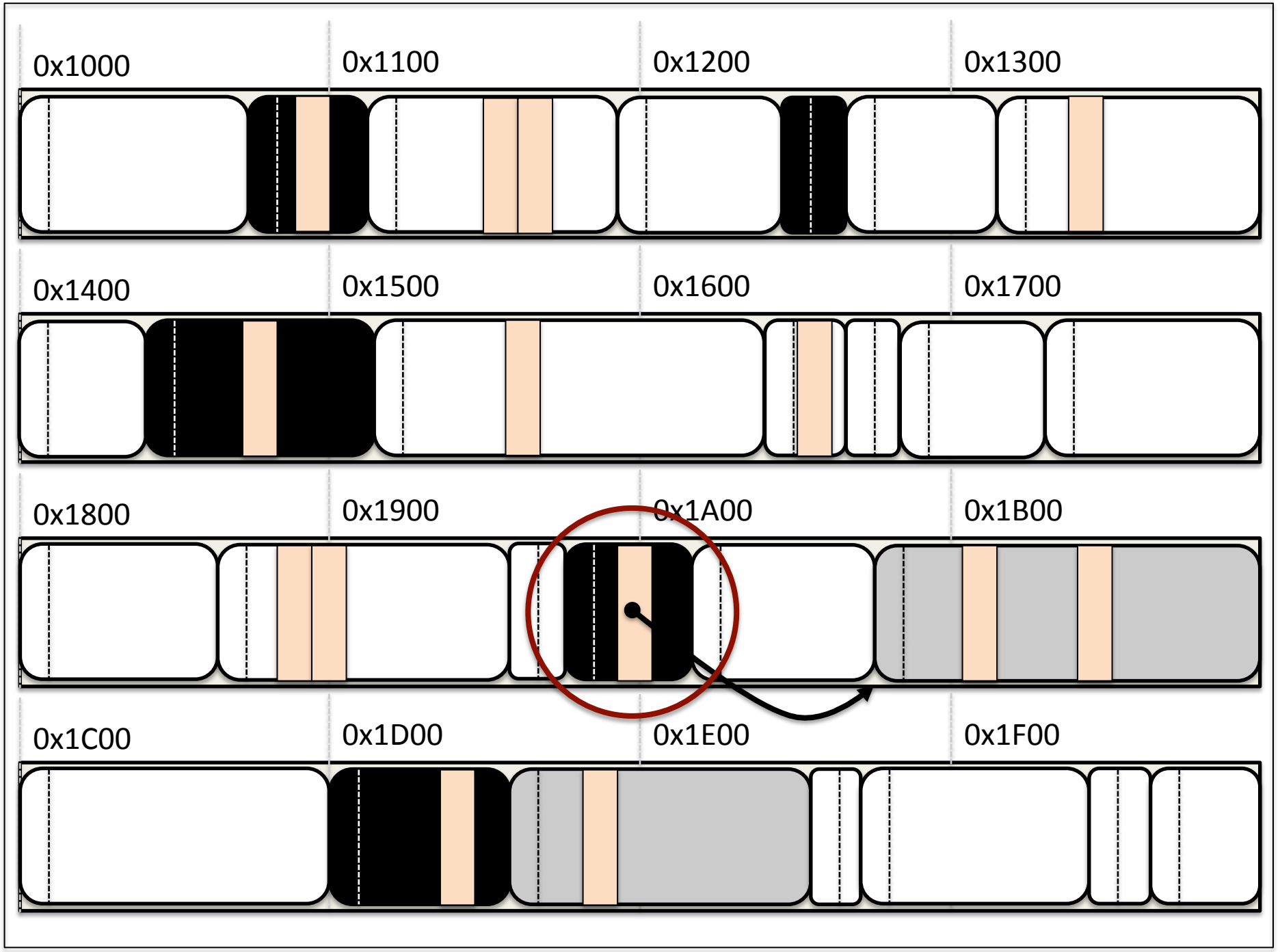
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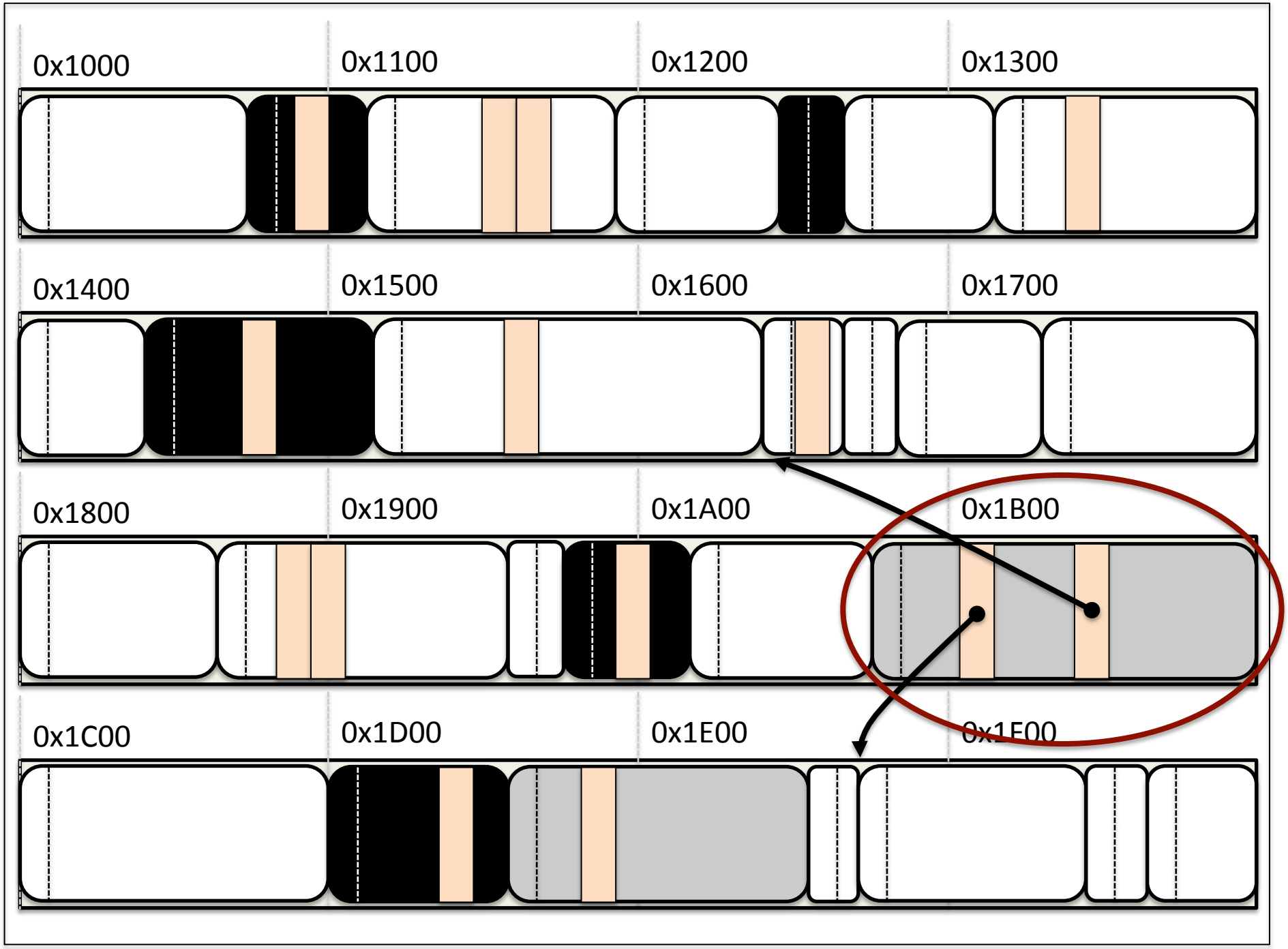
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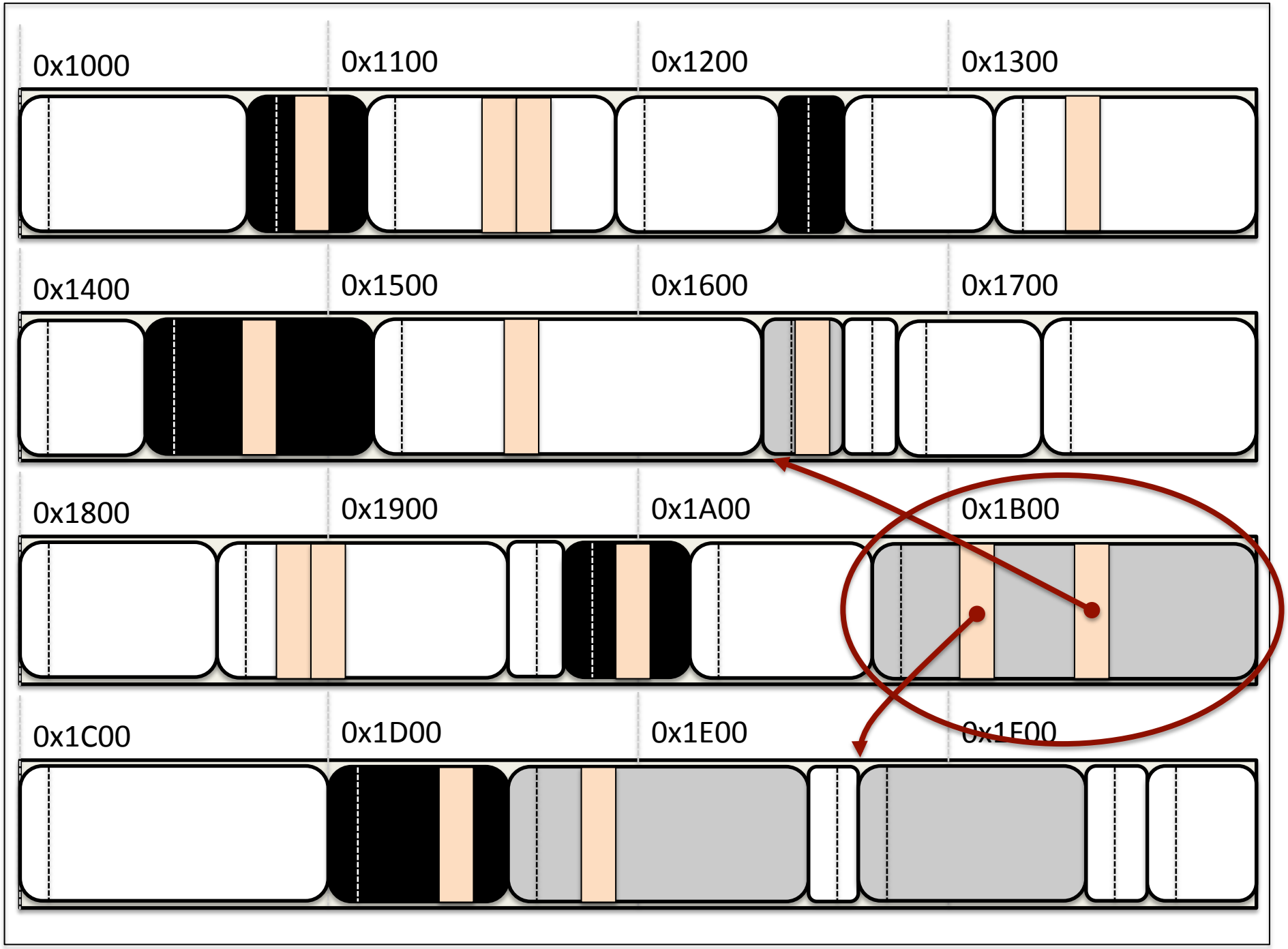
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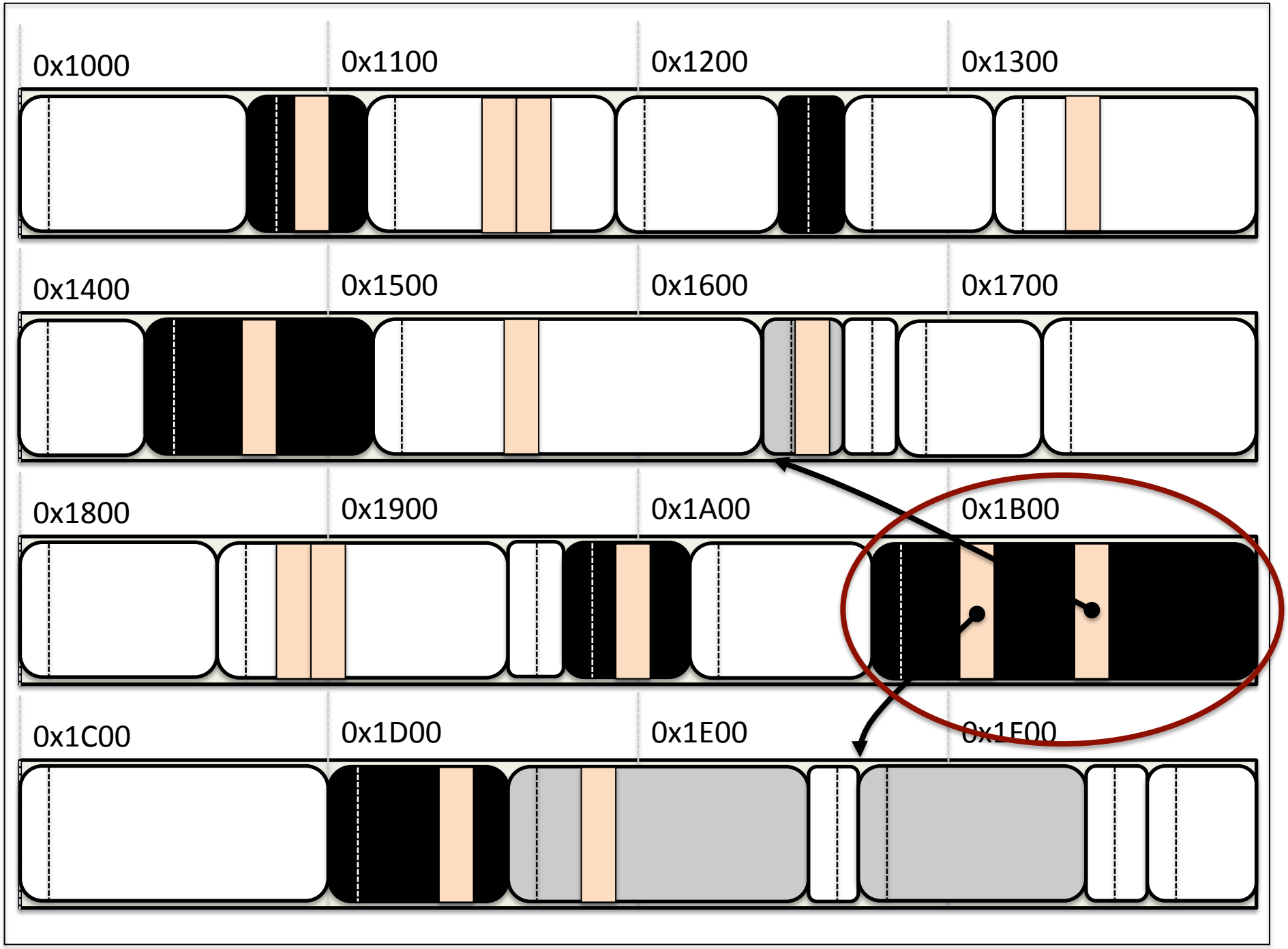
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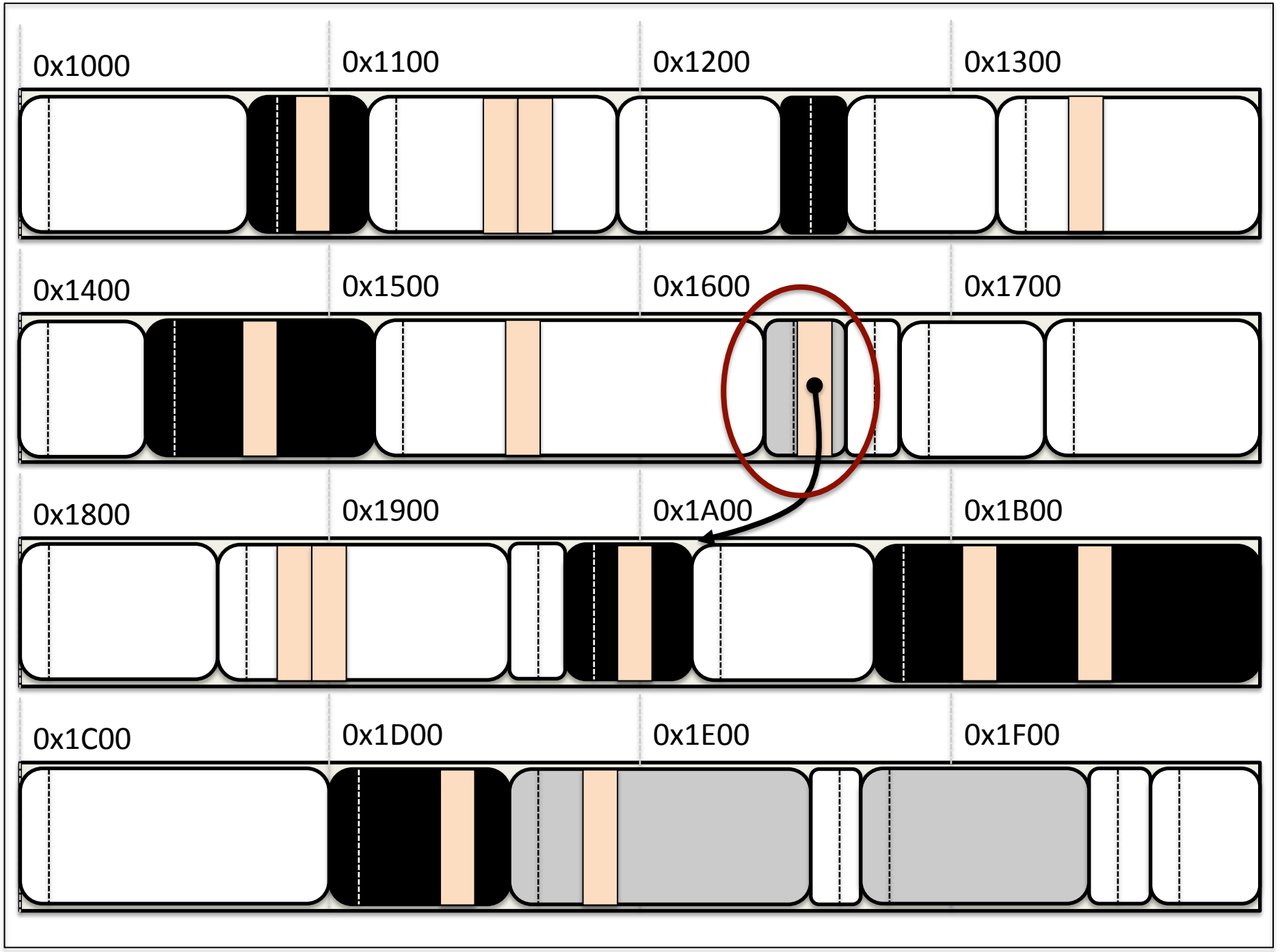
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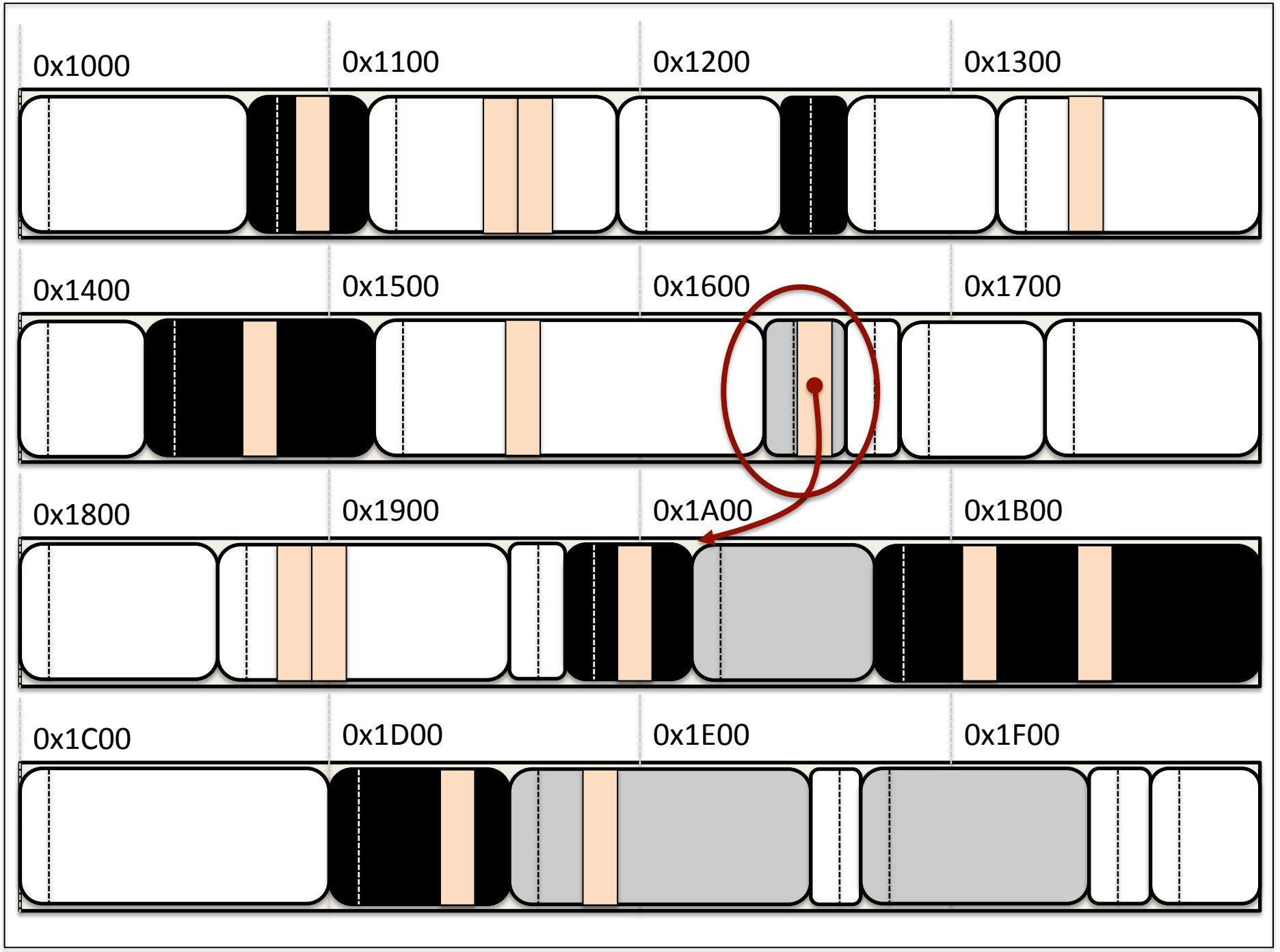
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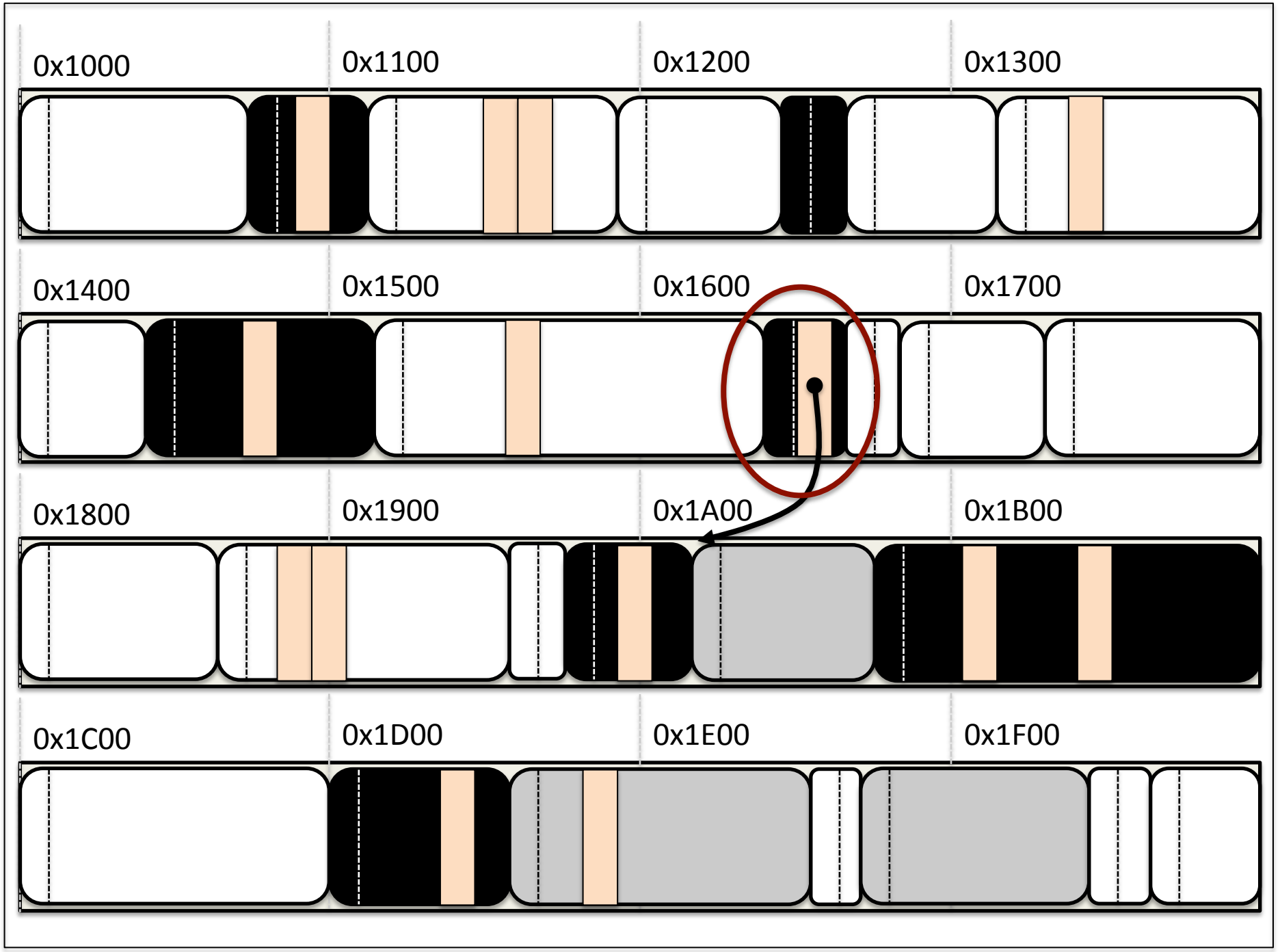
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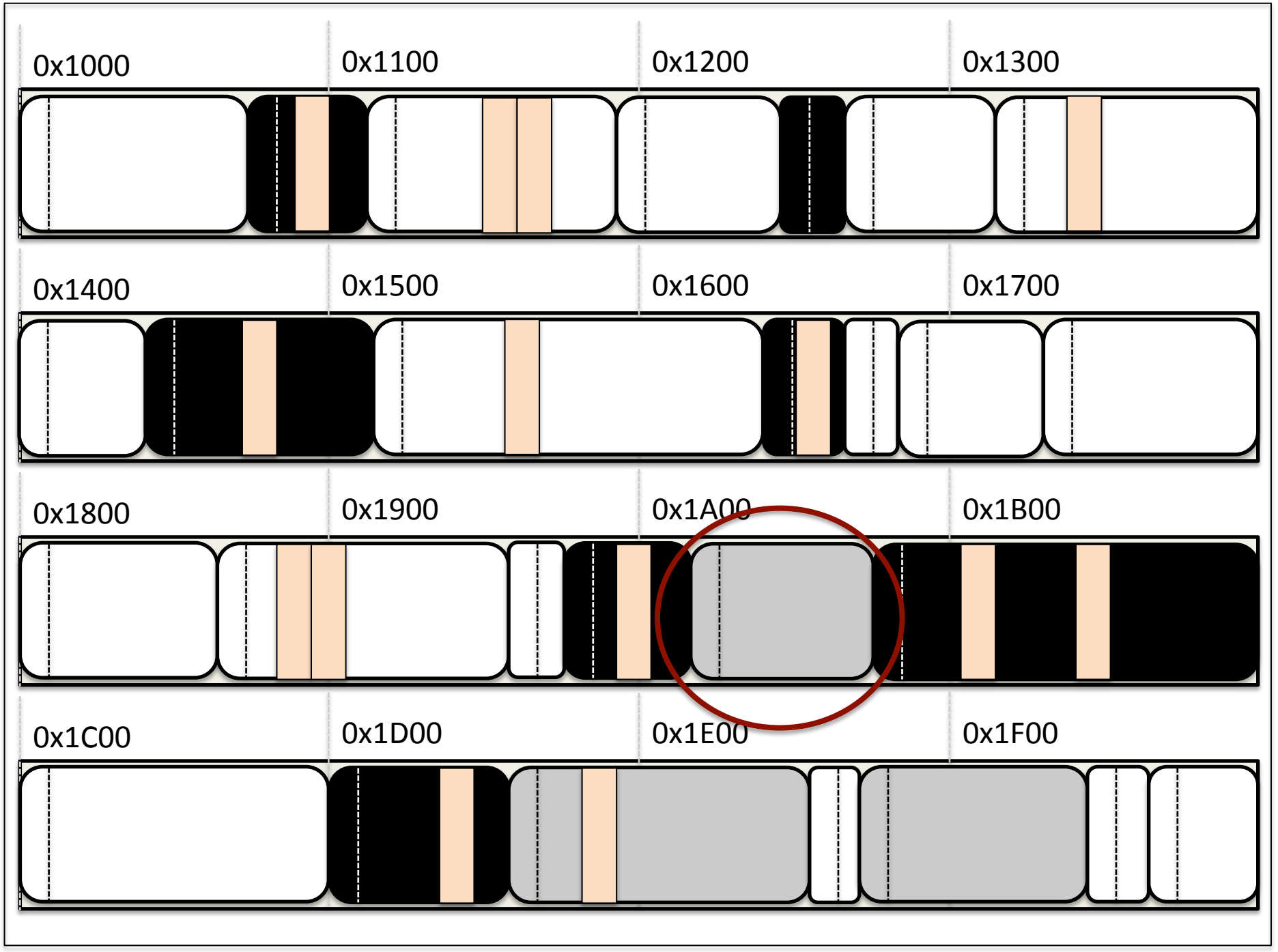
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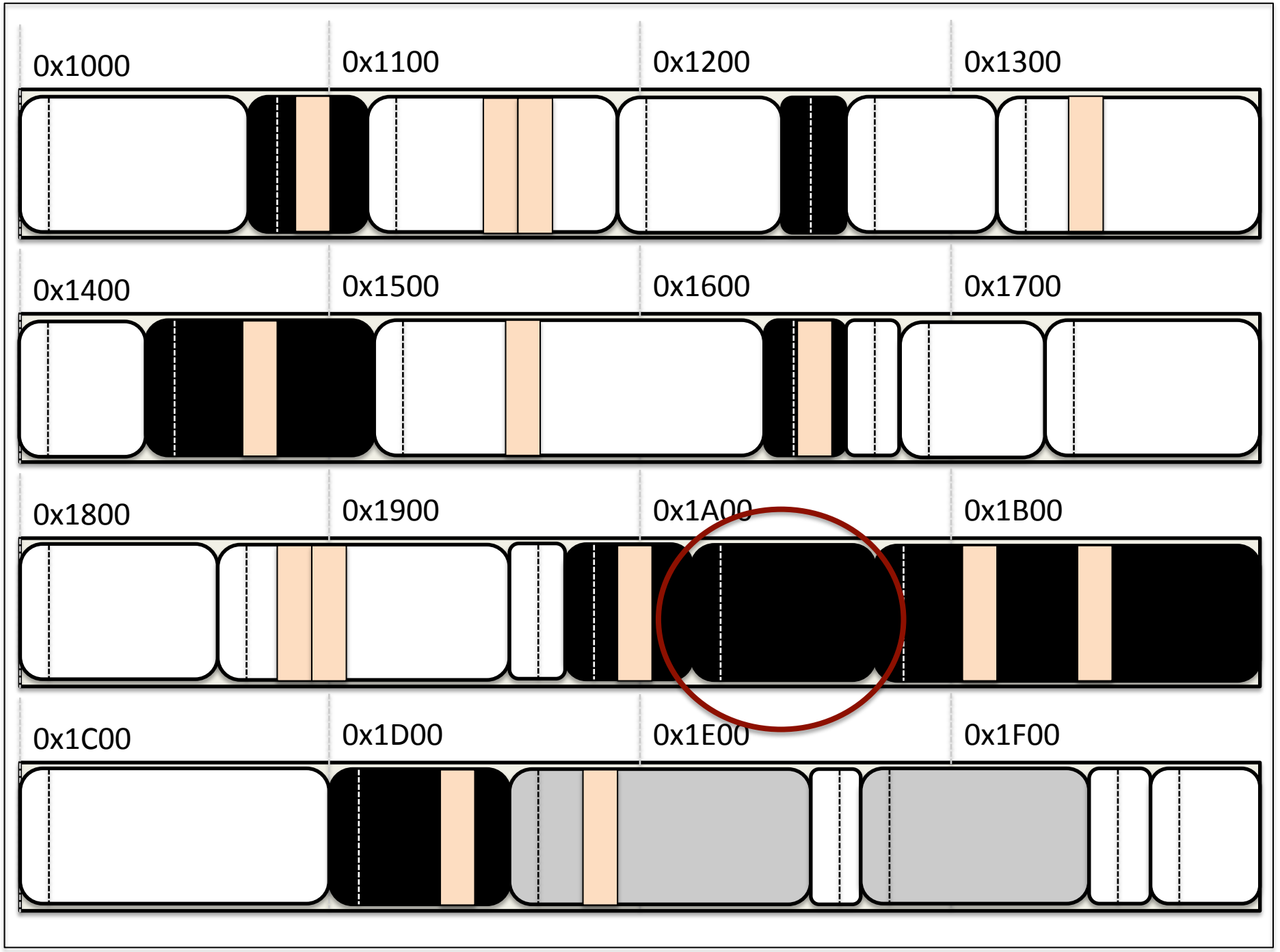
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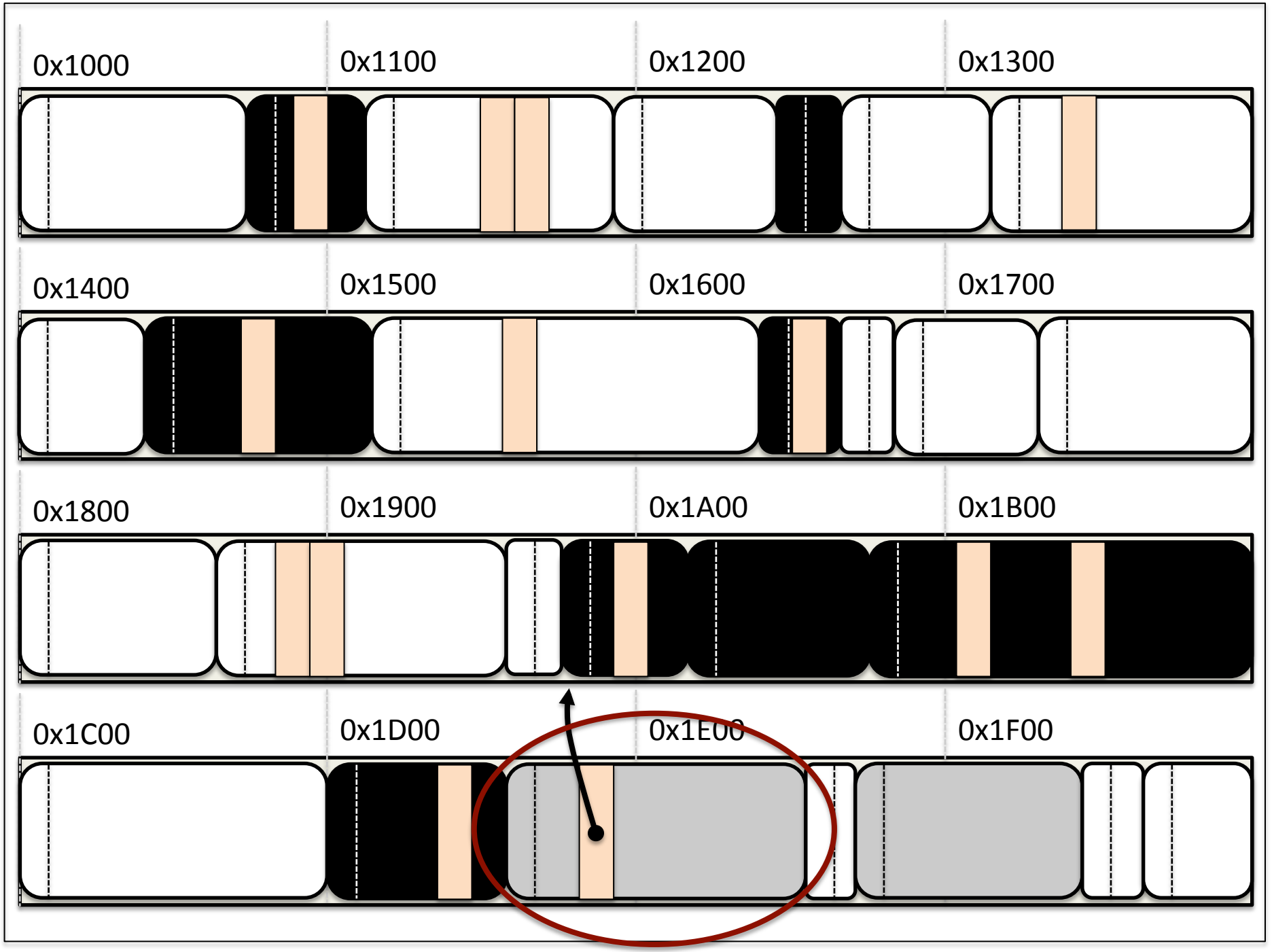
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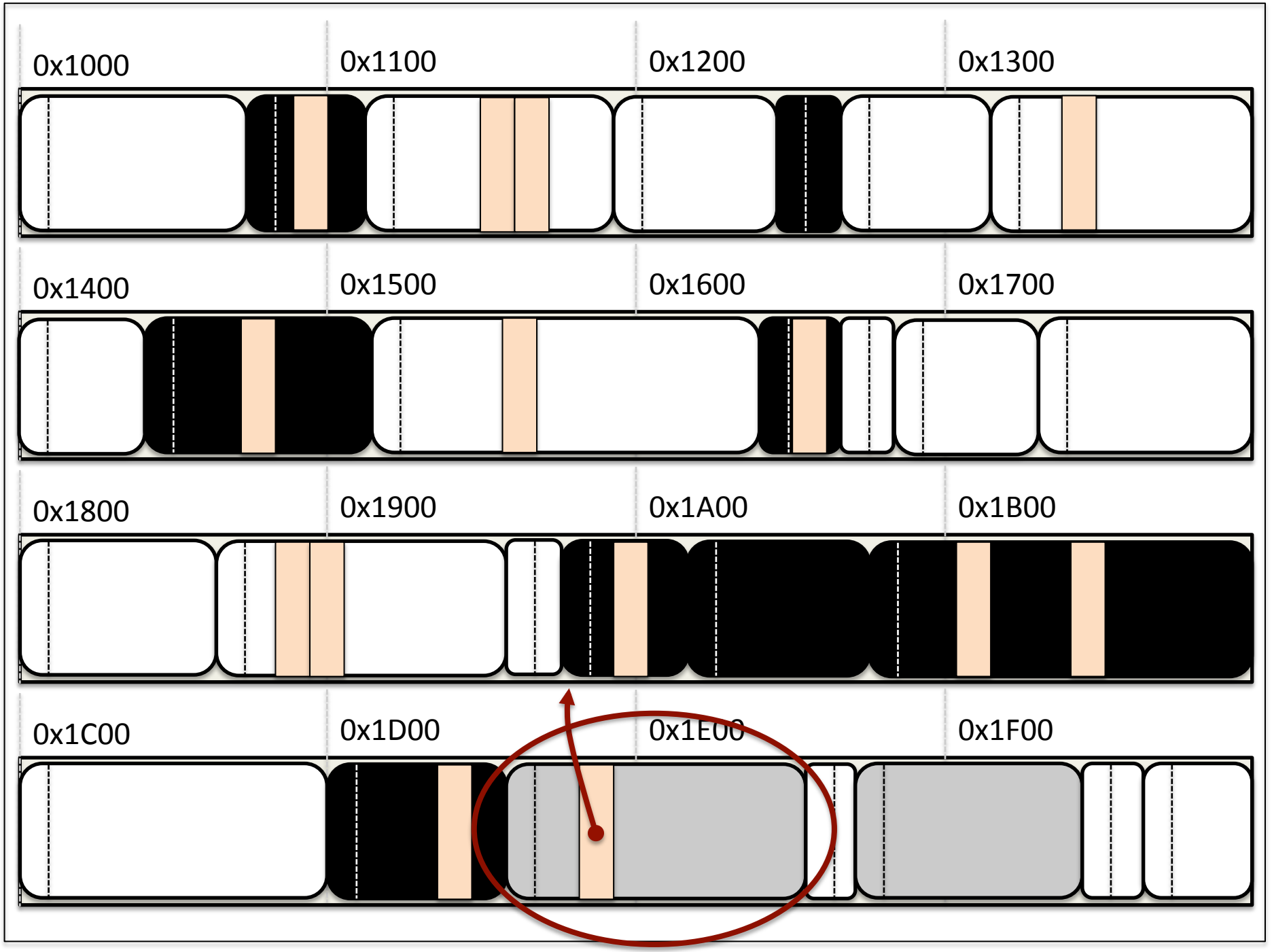
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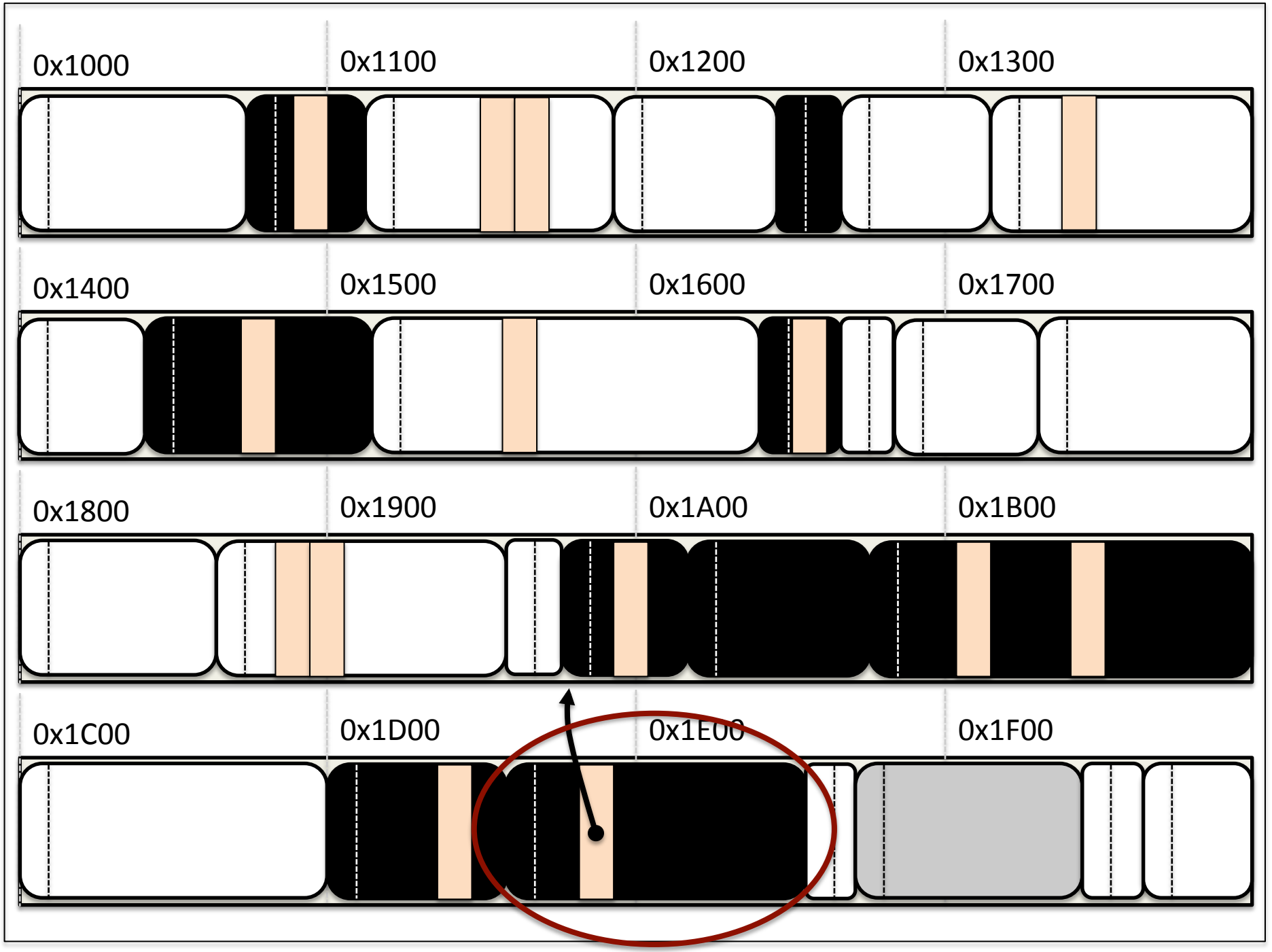
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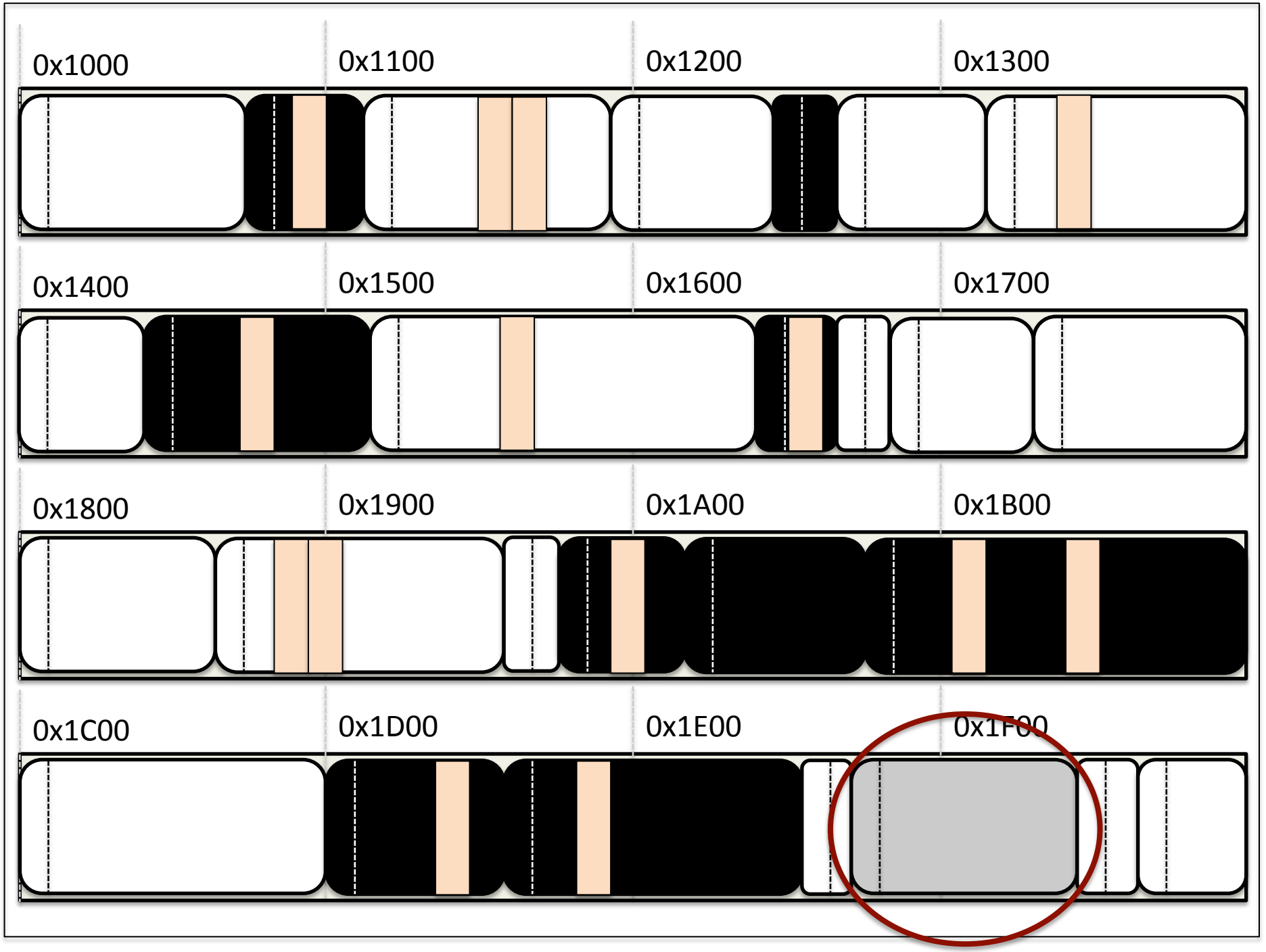
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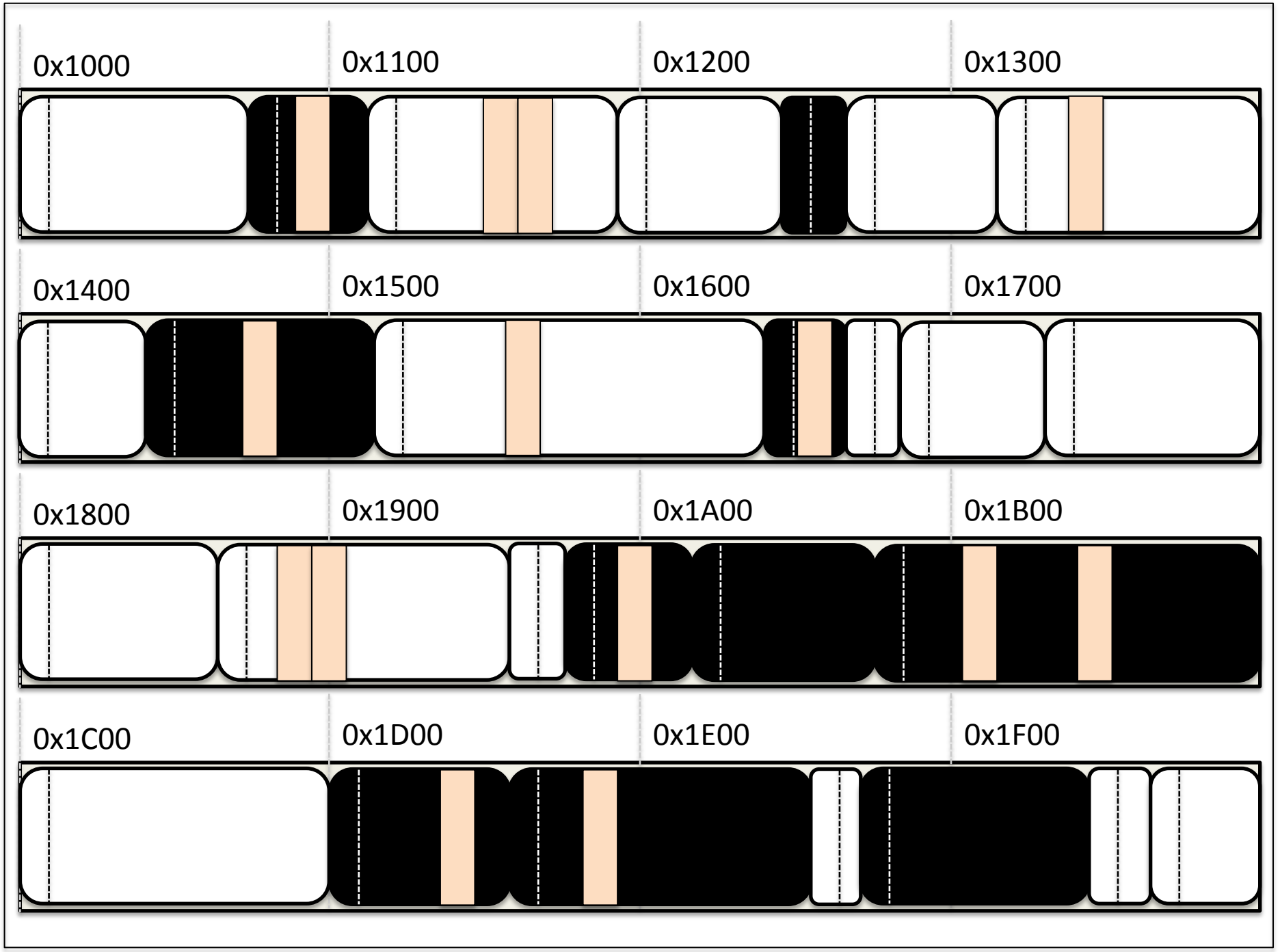
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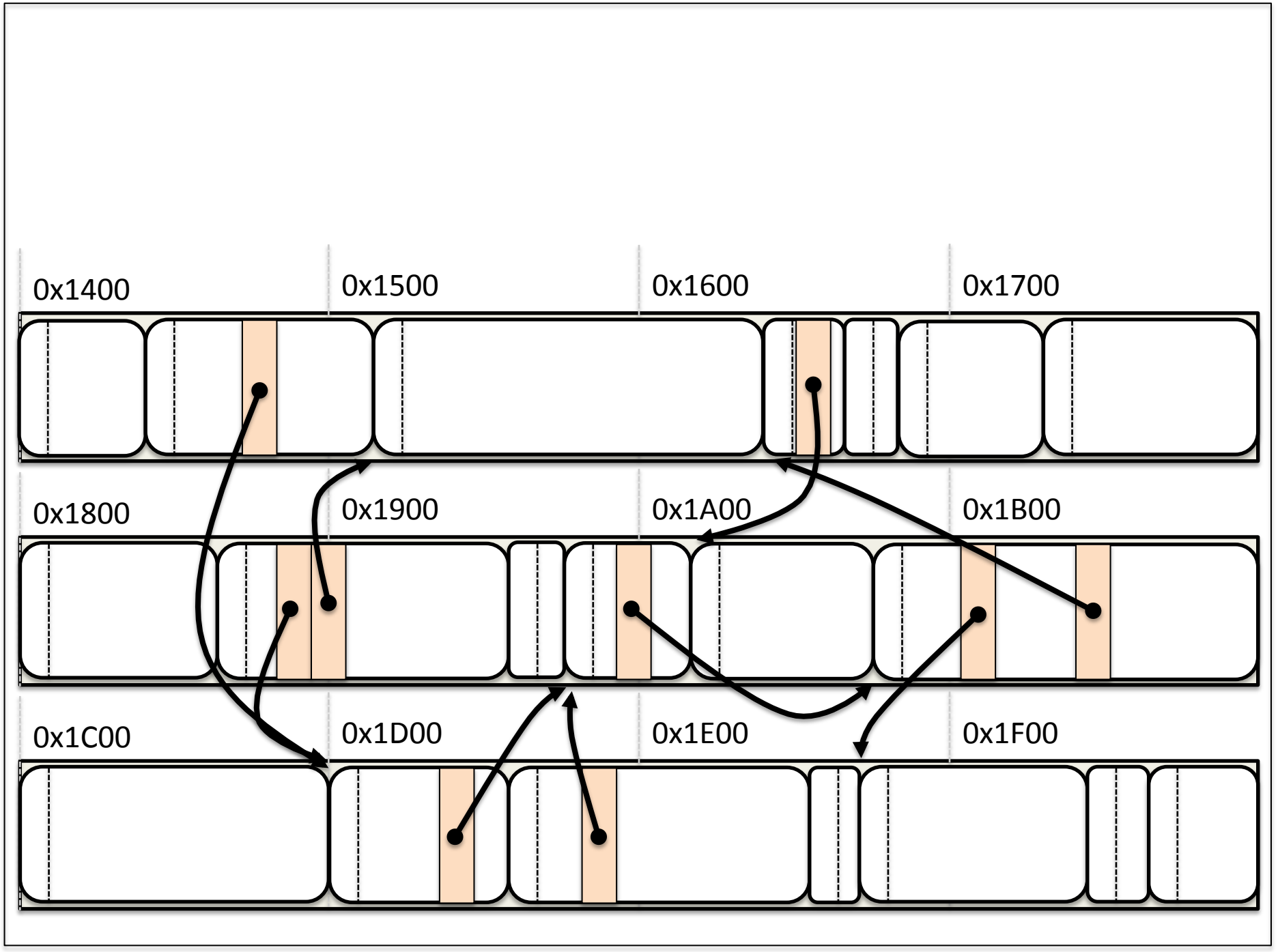
Tricolor Marking

- Convenient way to think about marking
- Objects exist in three possible states
  - White
  - Gray
  - Black
- Maintain invariants between colors
  - Black objects can't point to white
  - Objects cannot go from black or gray to white

Tracing Implementation

- How do you know the color of objects?
  - Can't look at the whole heap to check
- Track gray objects on a stack
  - Push when an object is set to gray
  - Pop when it is scanned
  - If an object is already marked, don't push it
  - Tracing done when the gray stack is empty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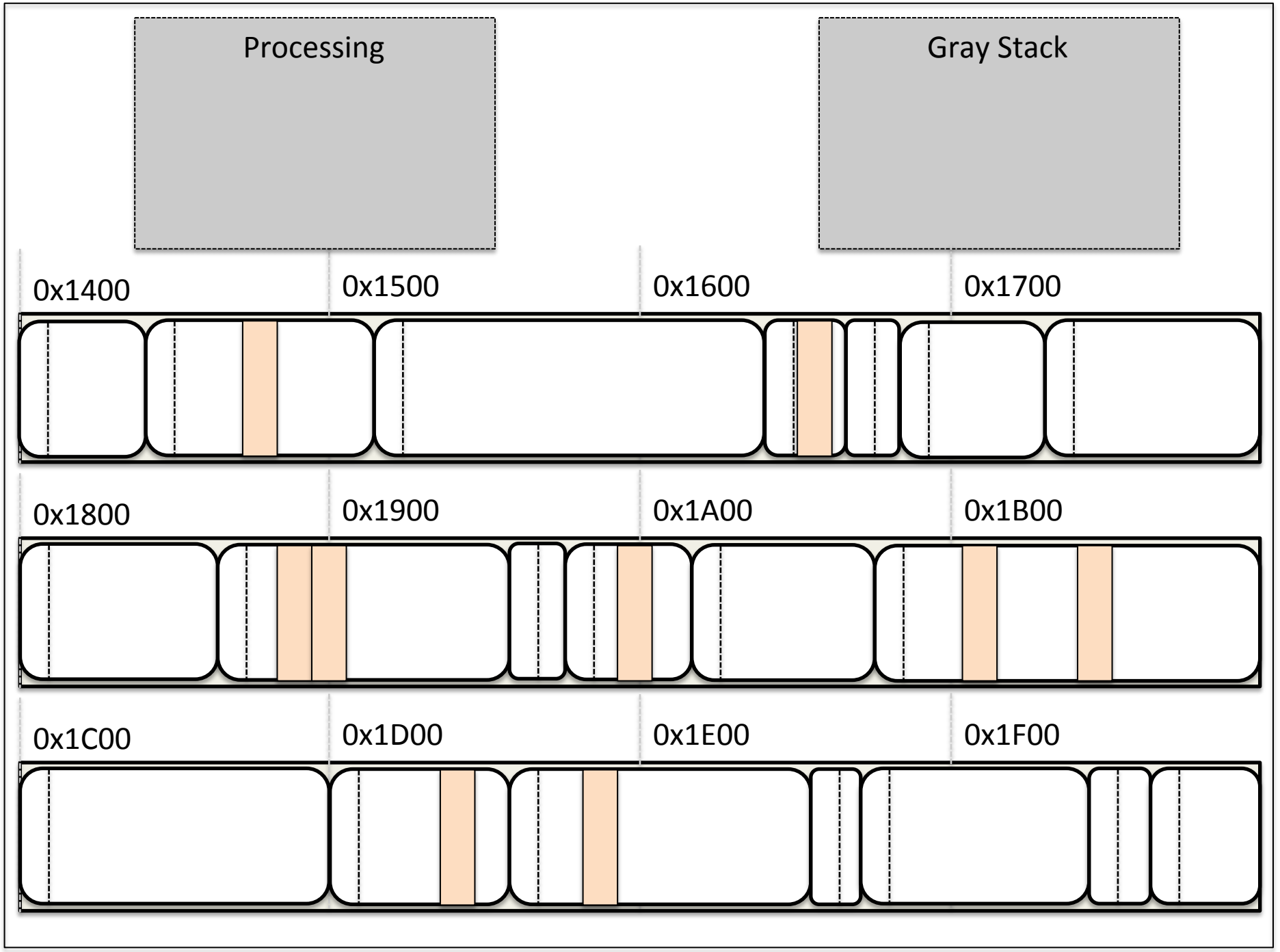
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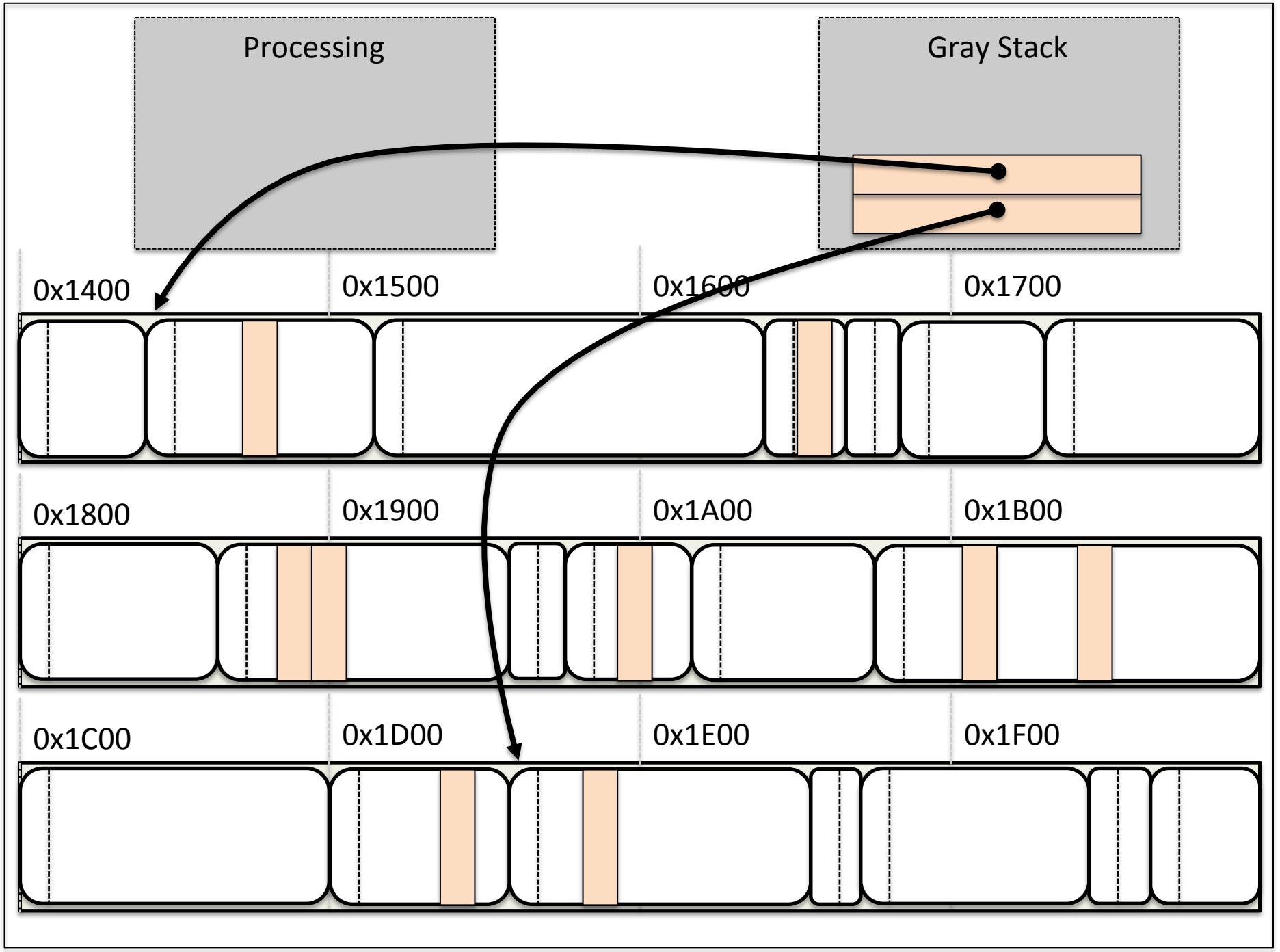
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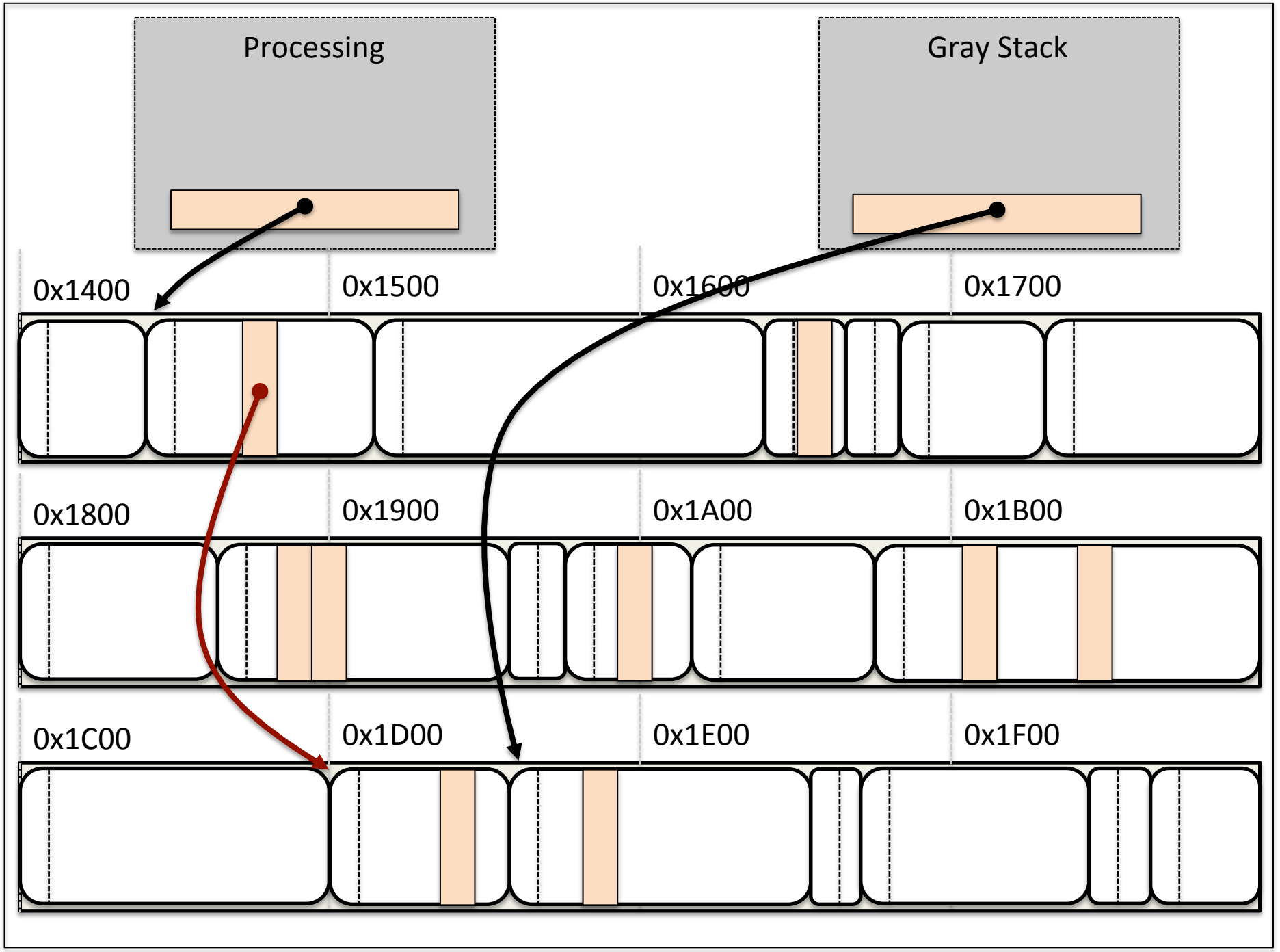
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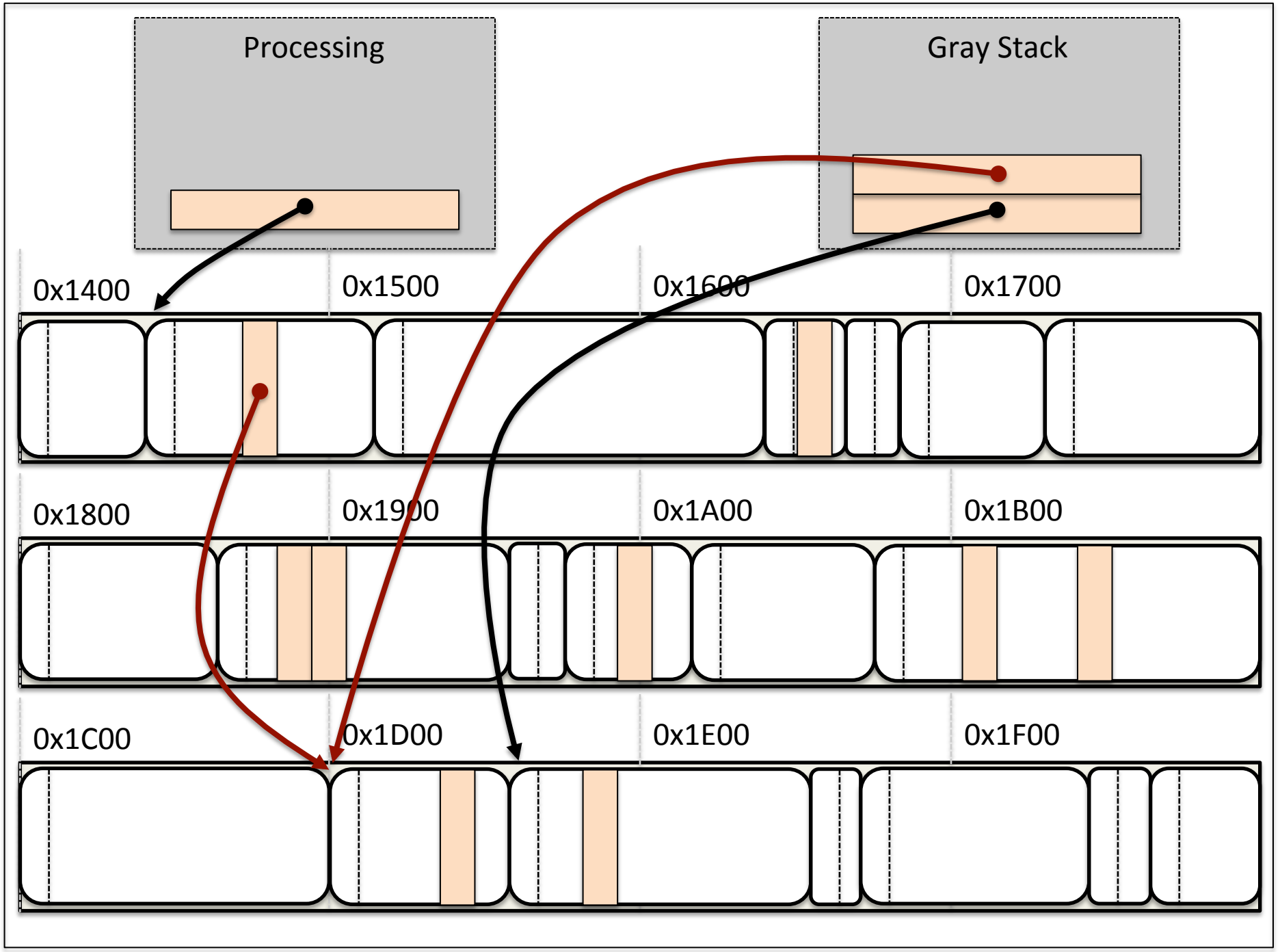
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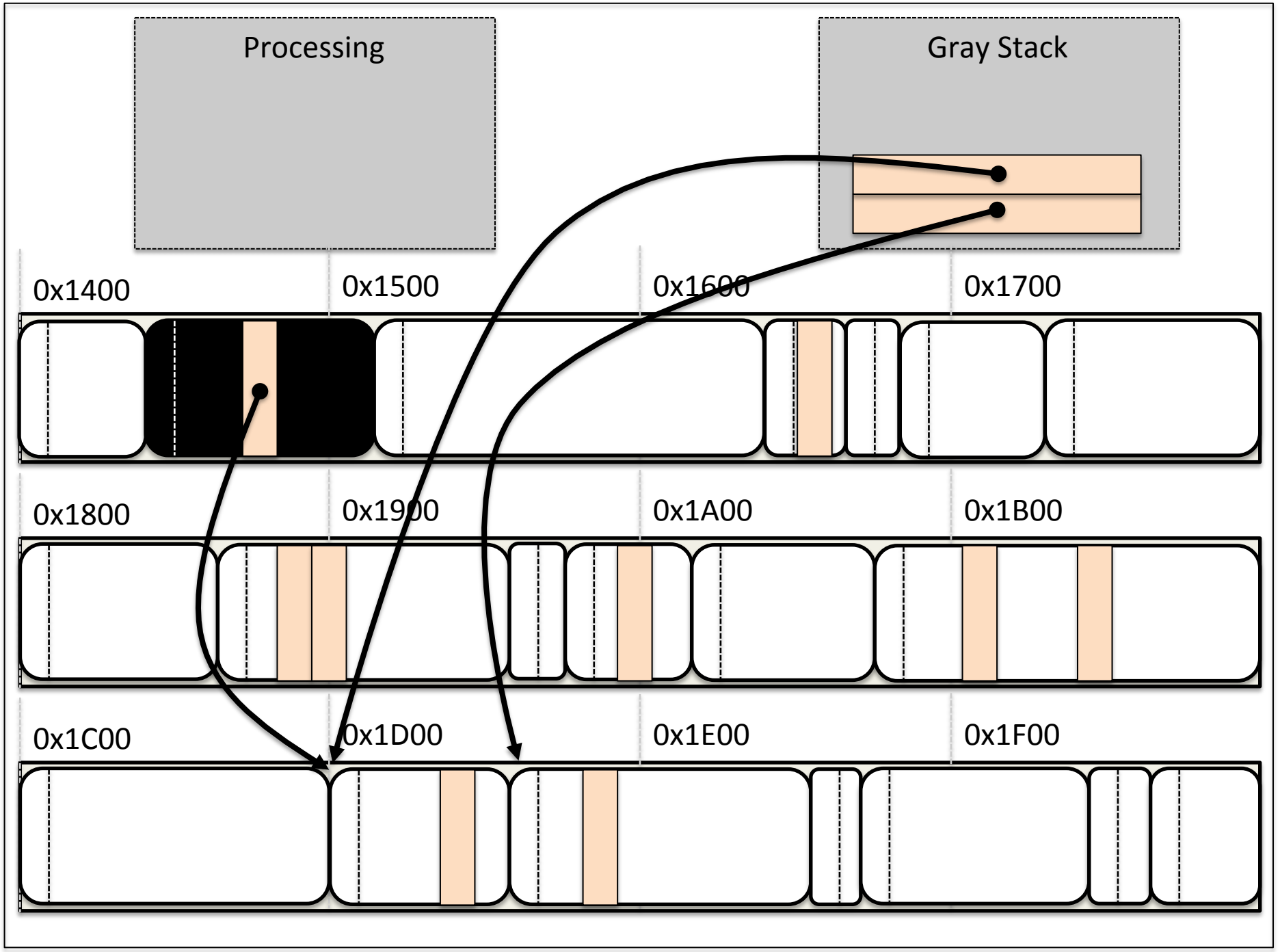
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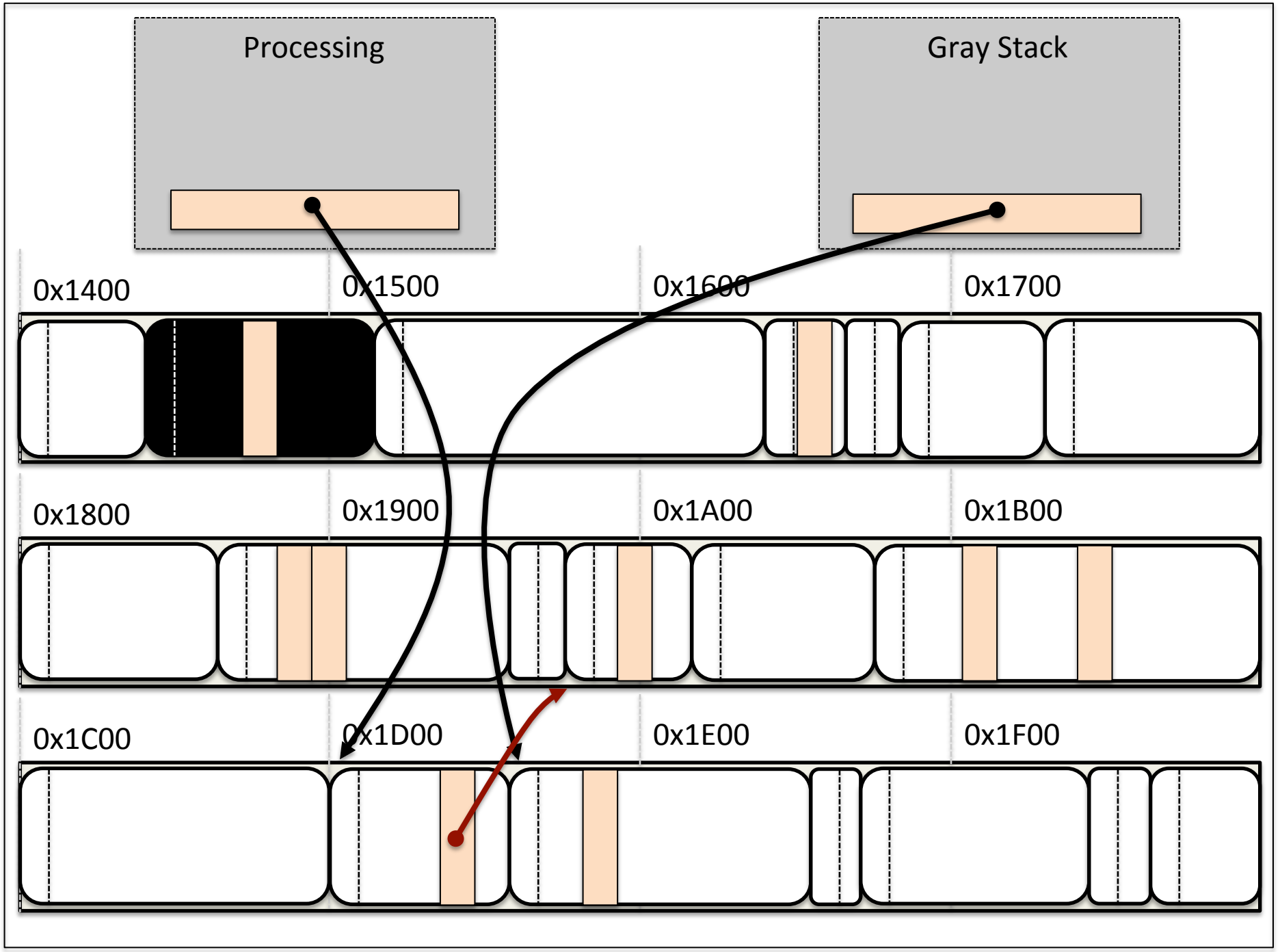
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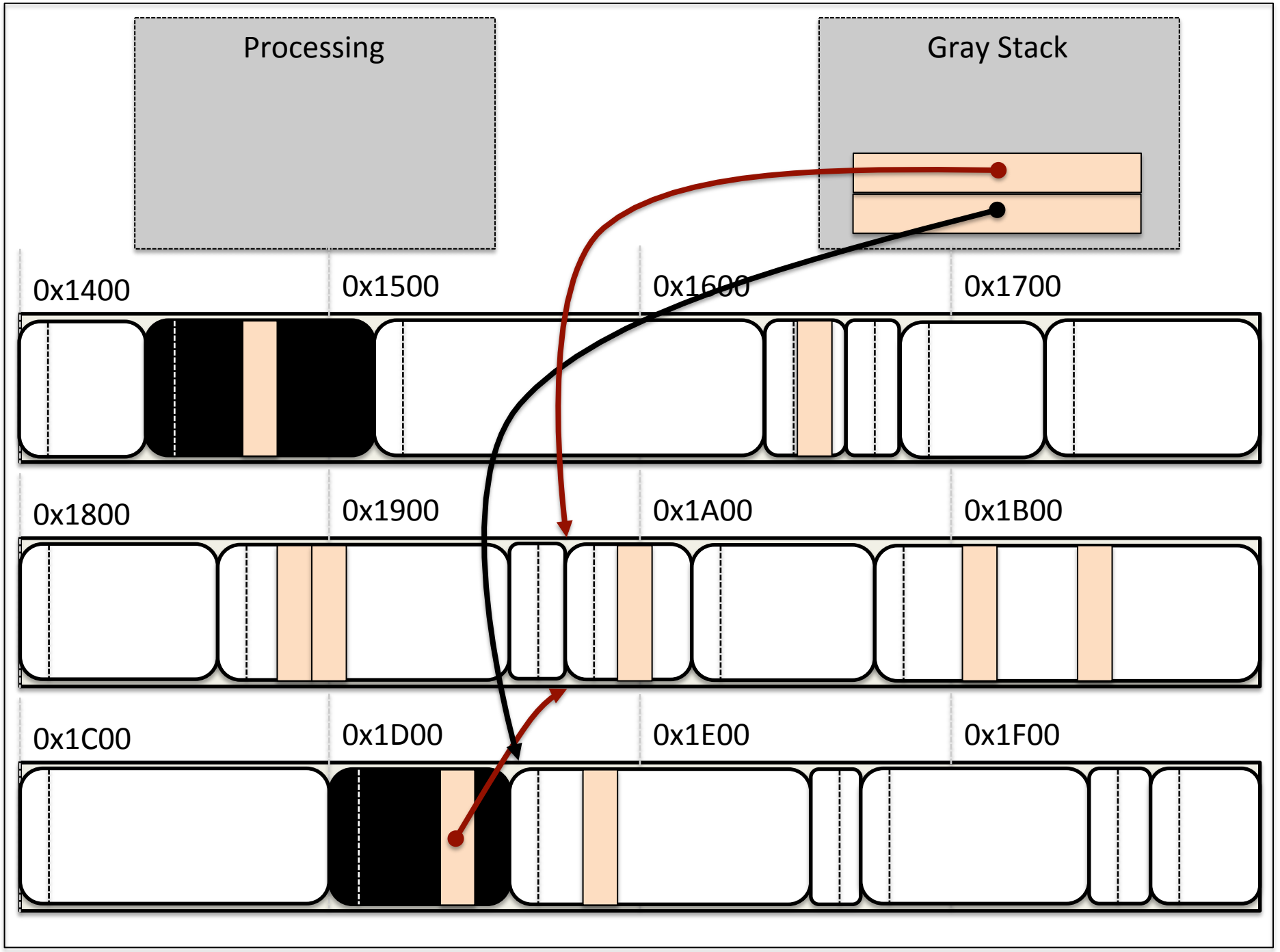
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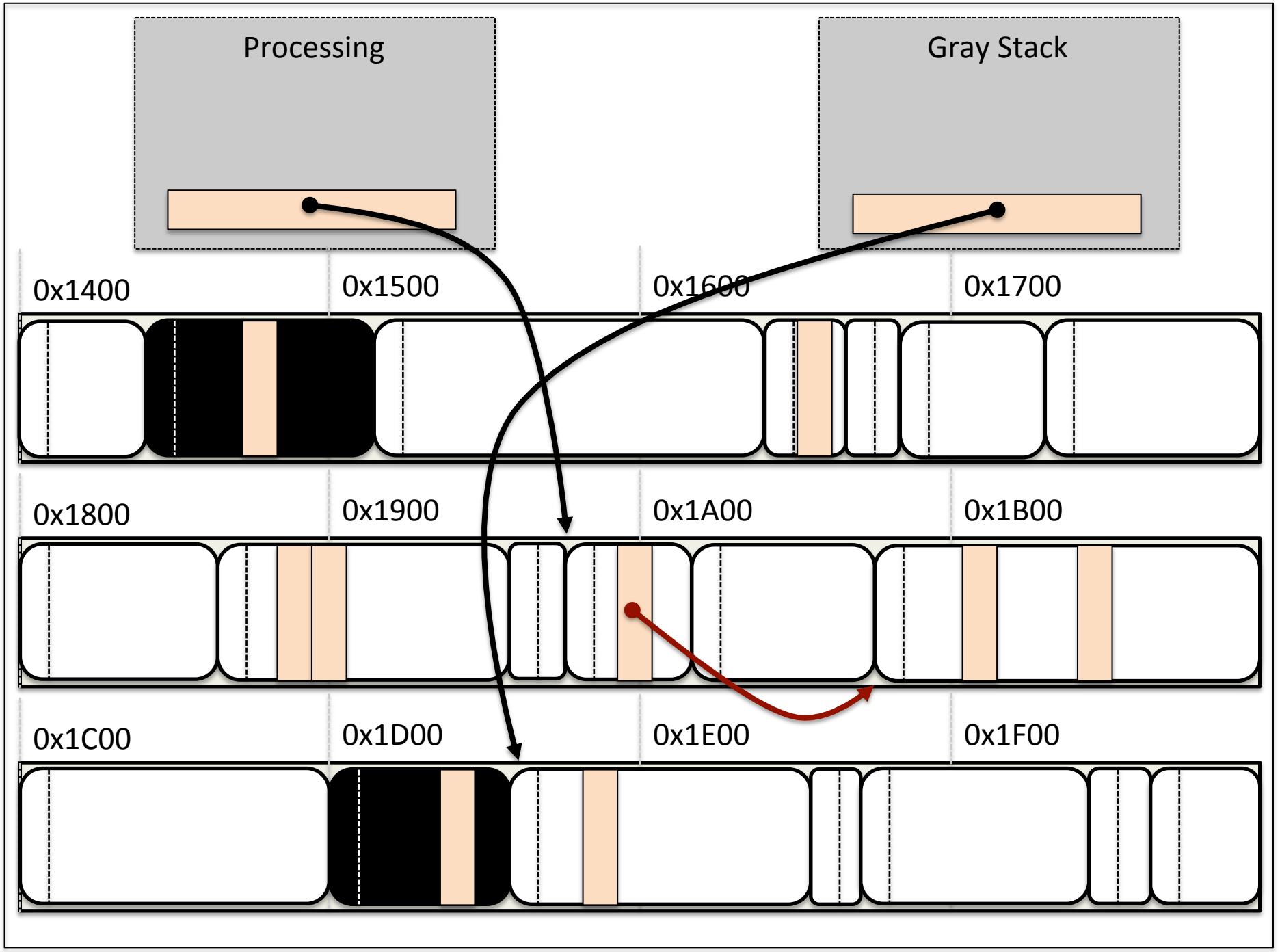
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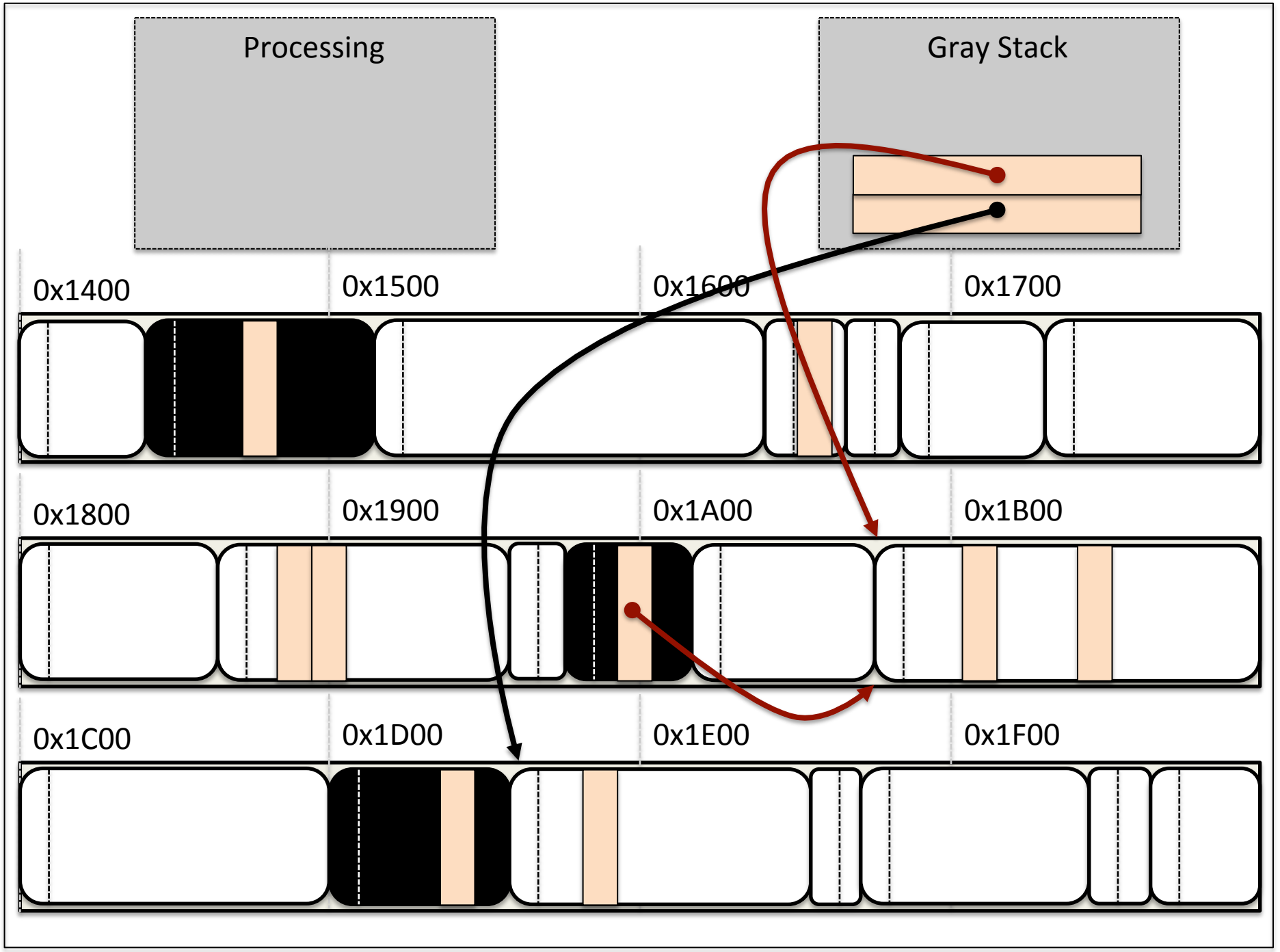
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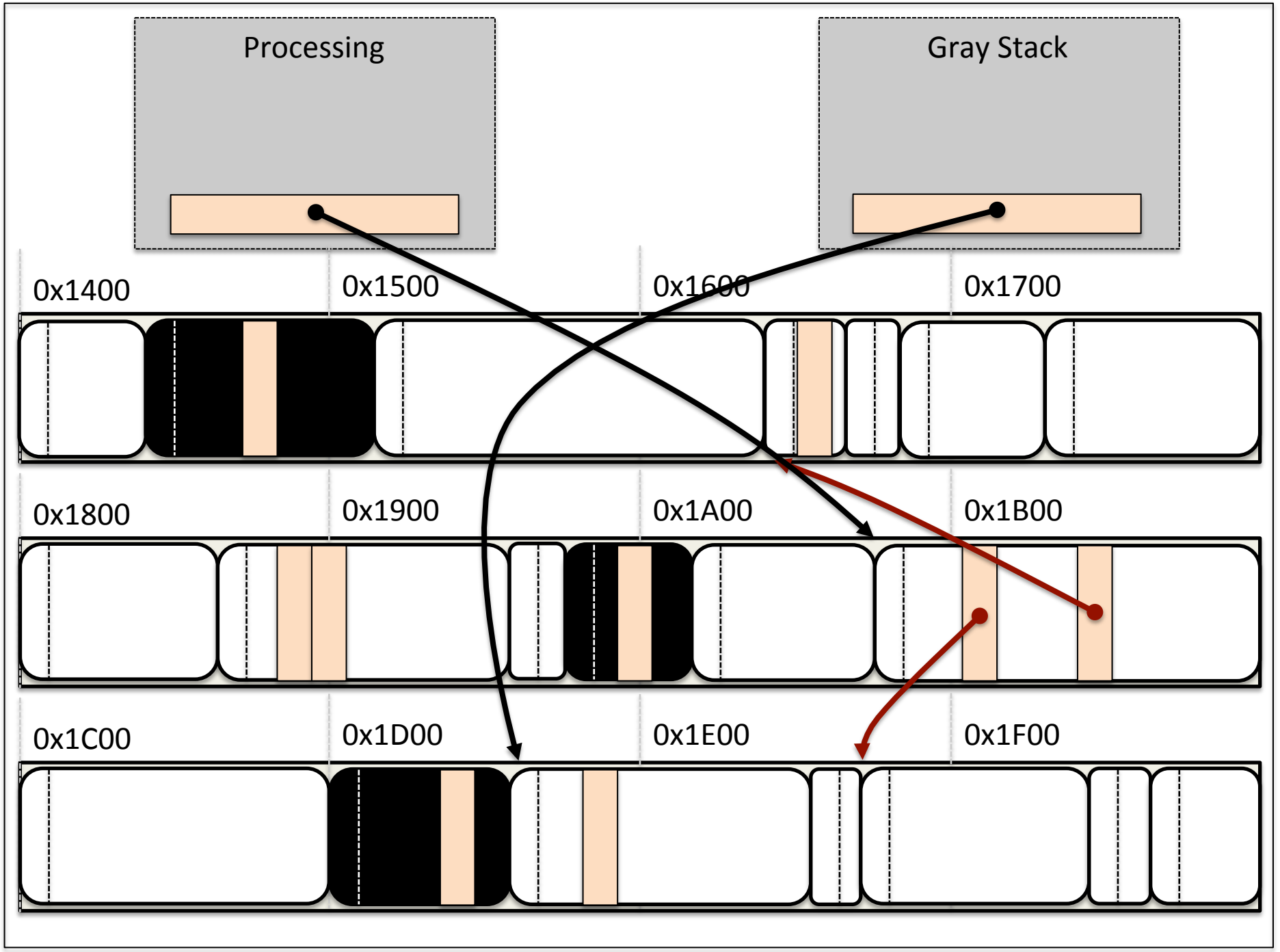
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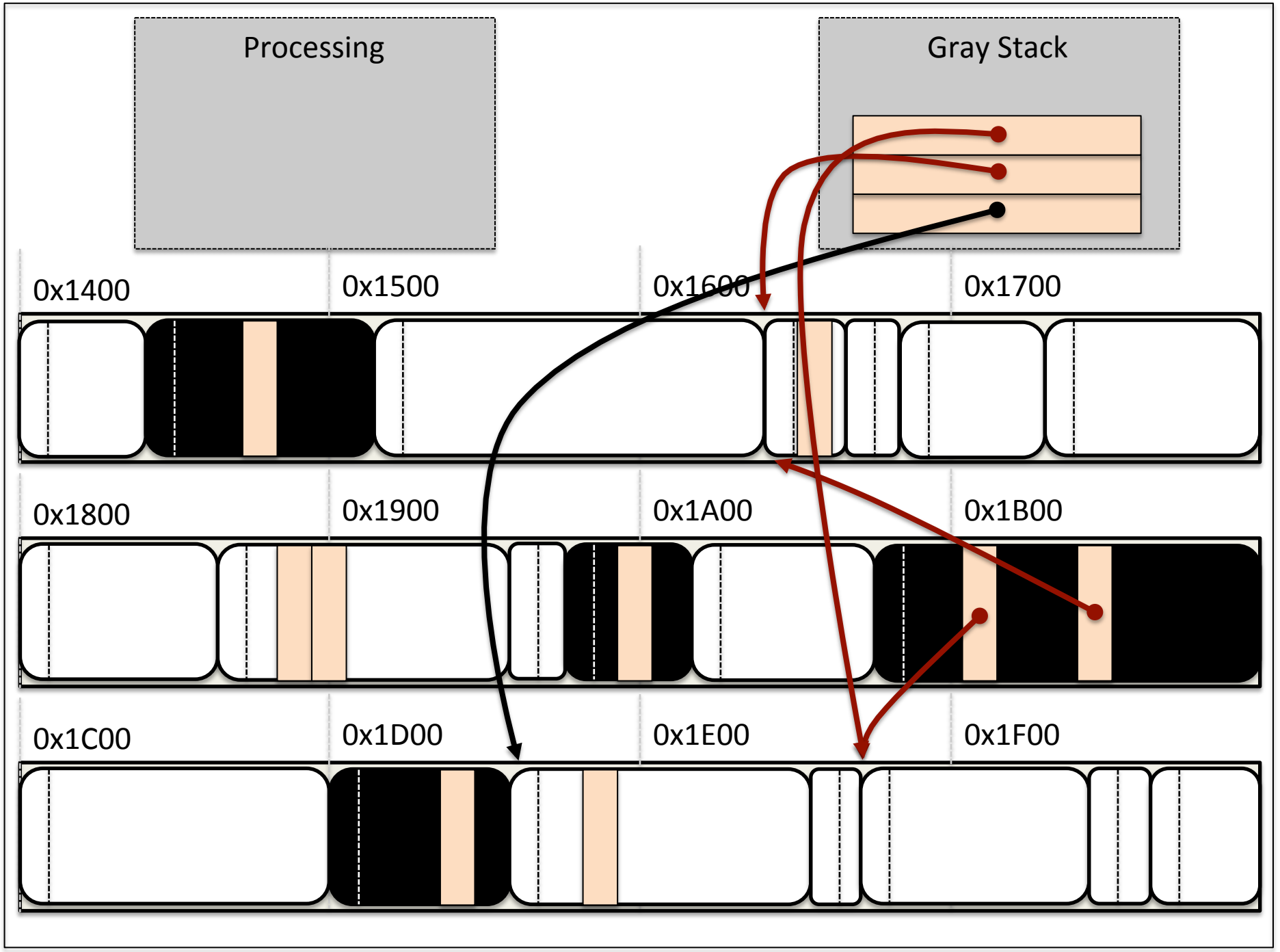
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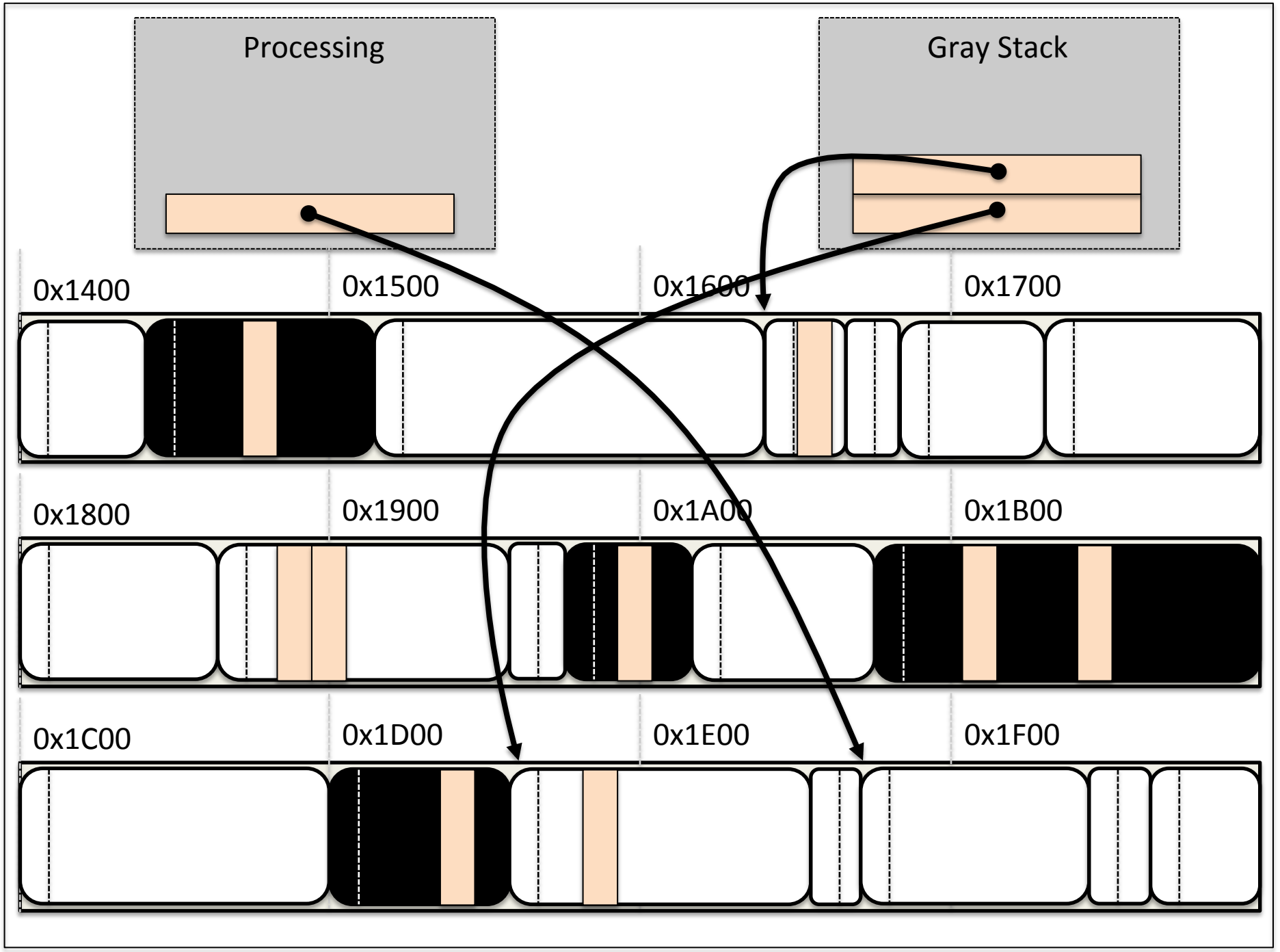
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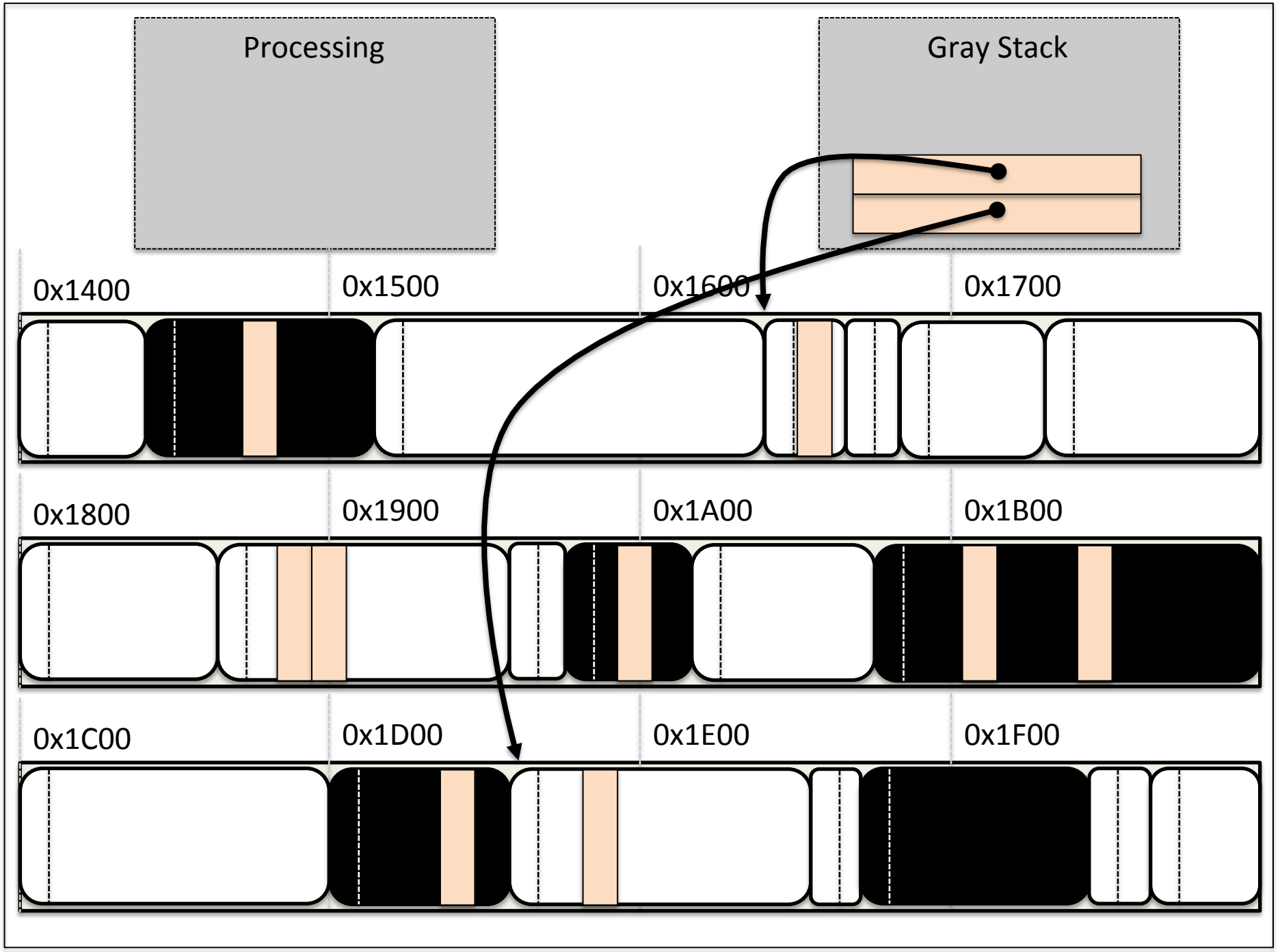
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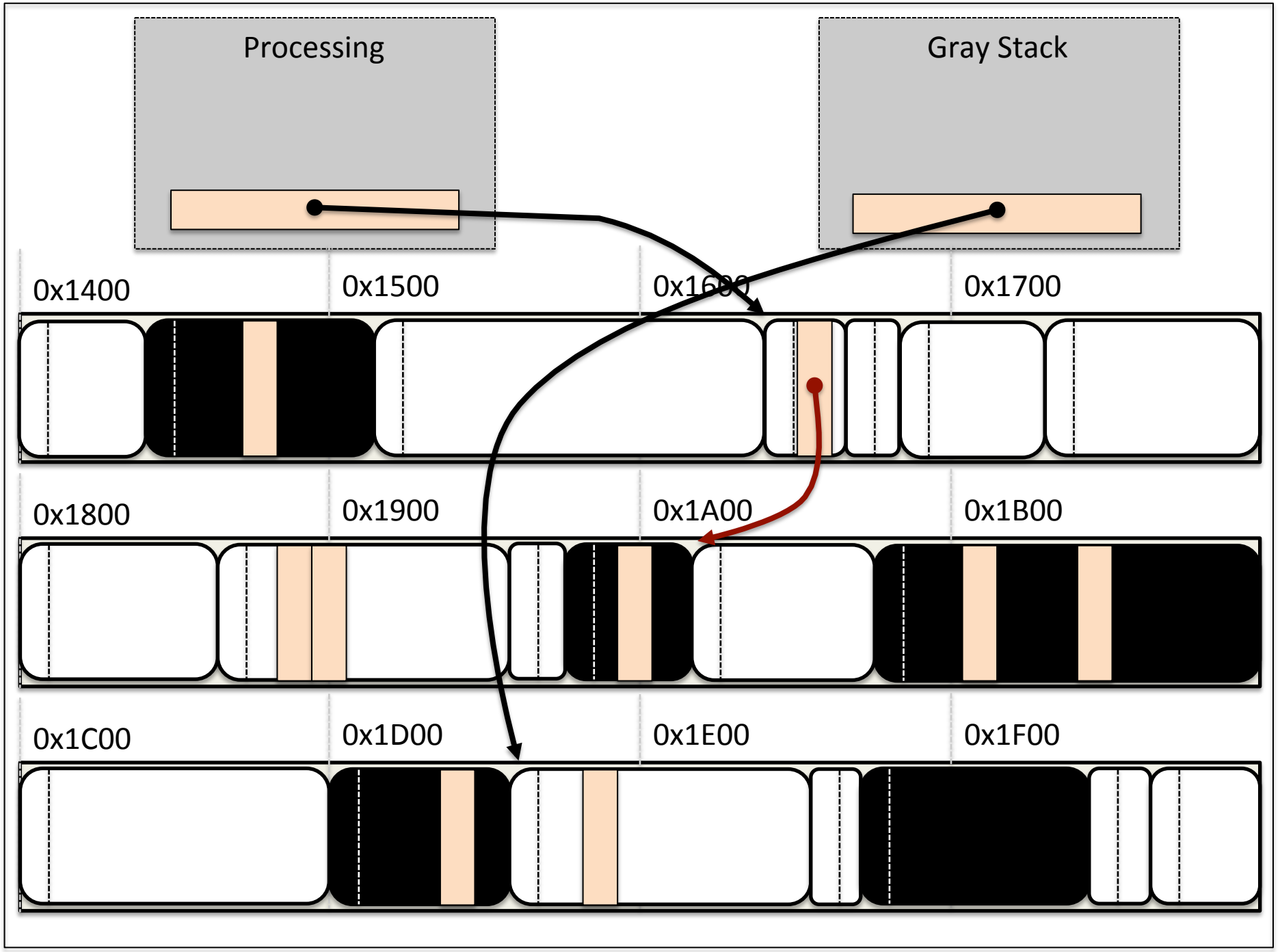
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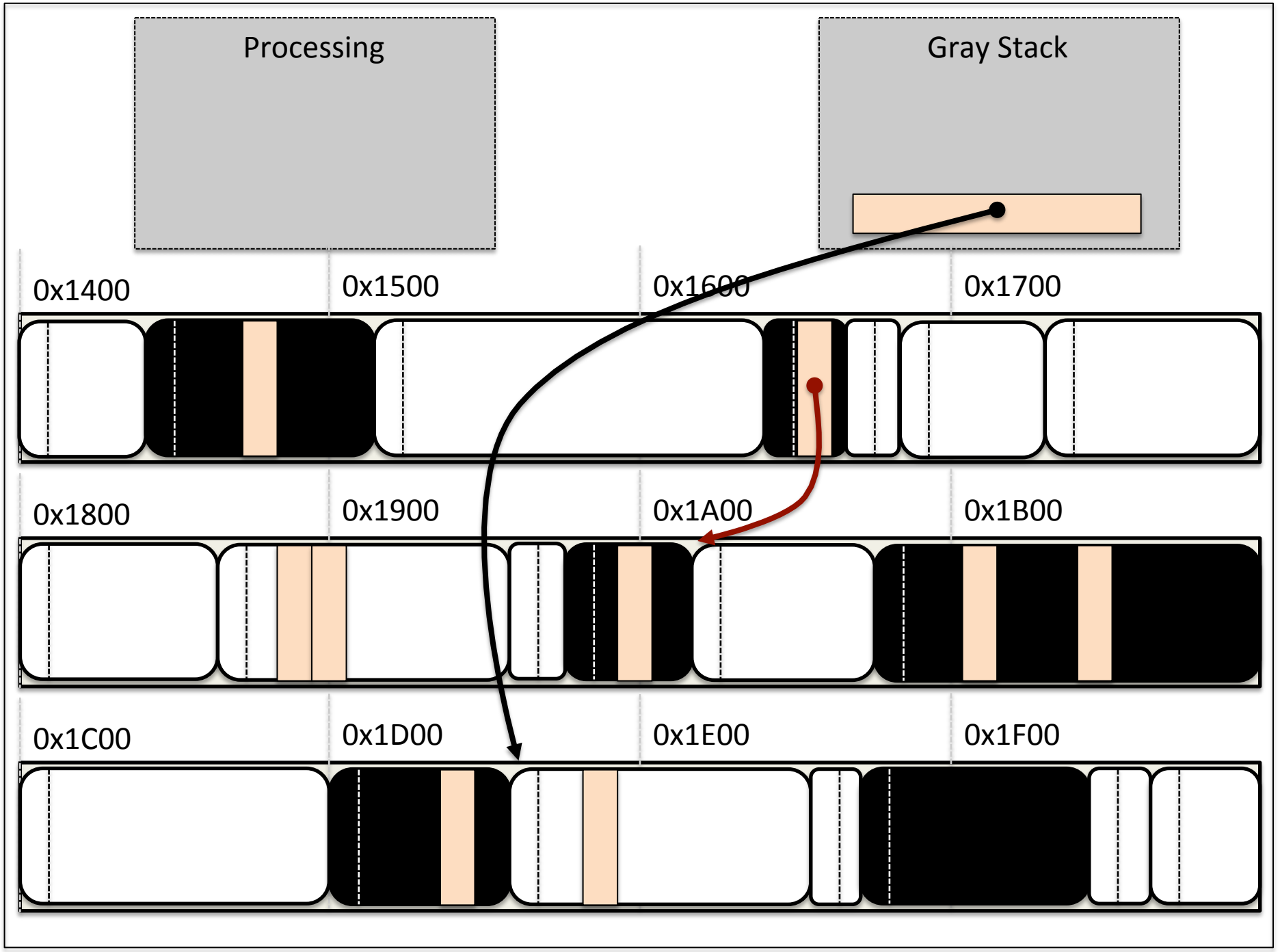
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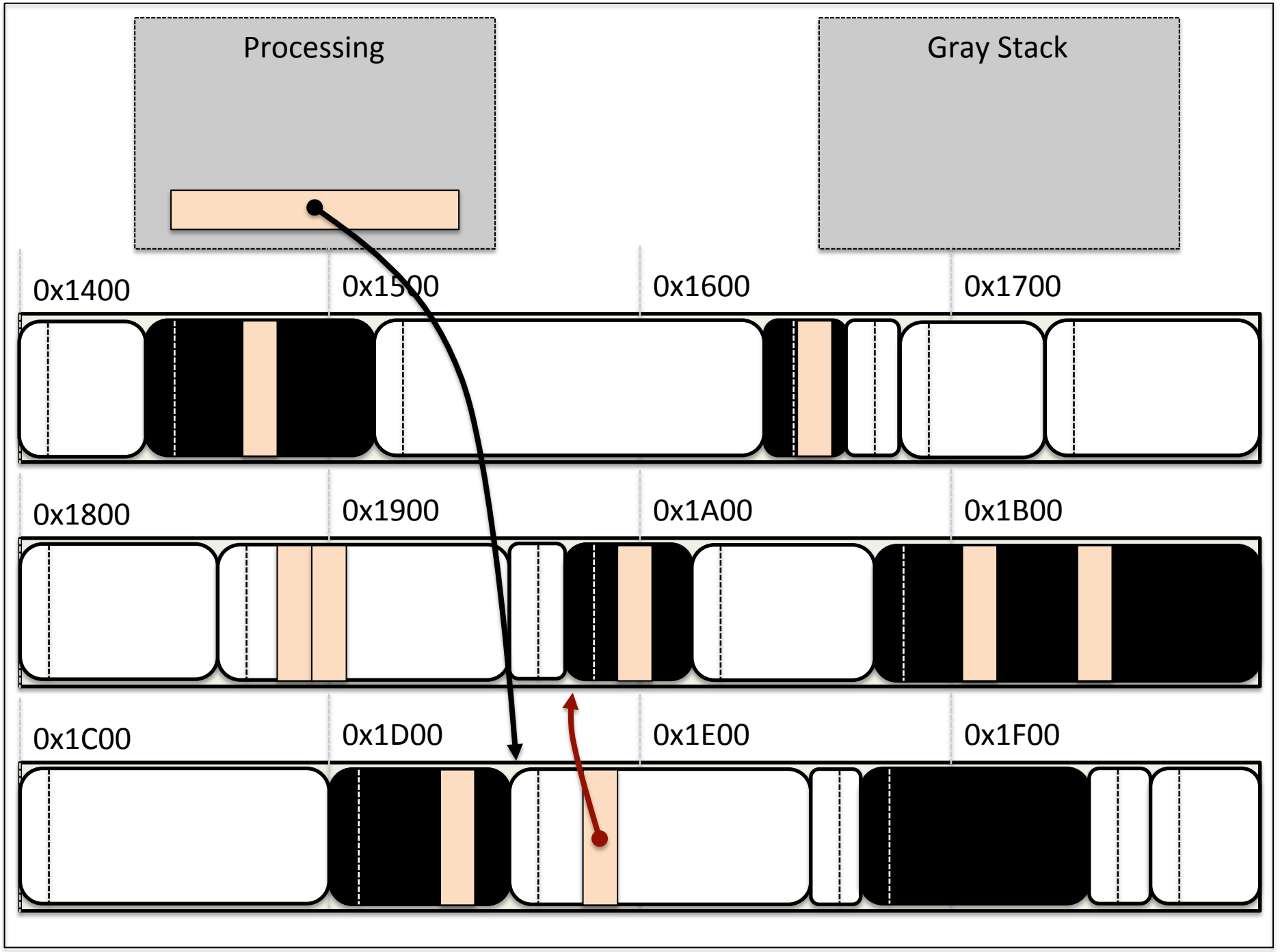
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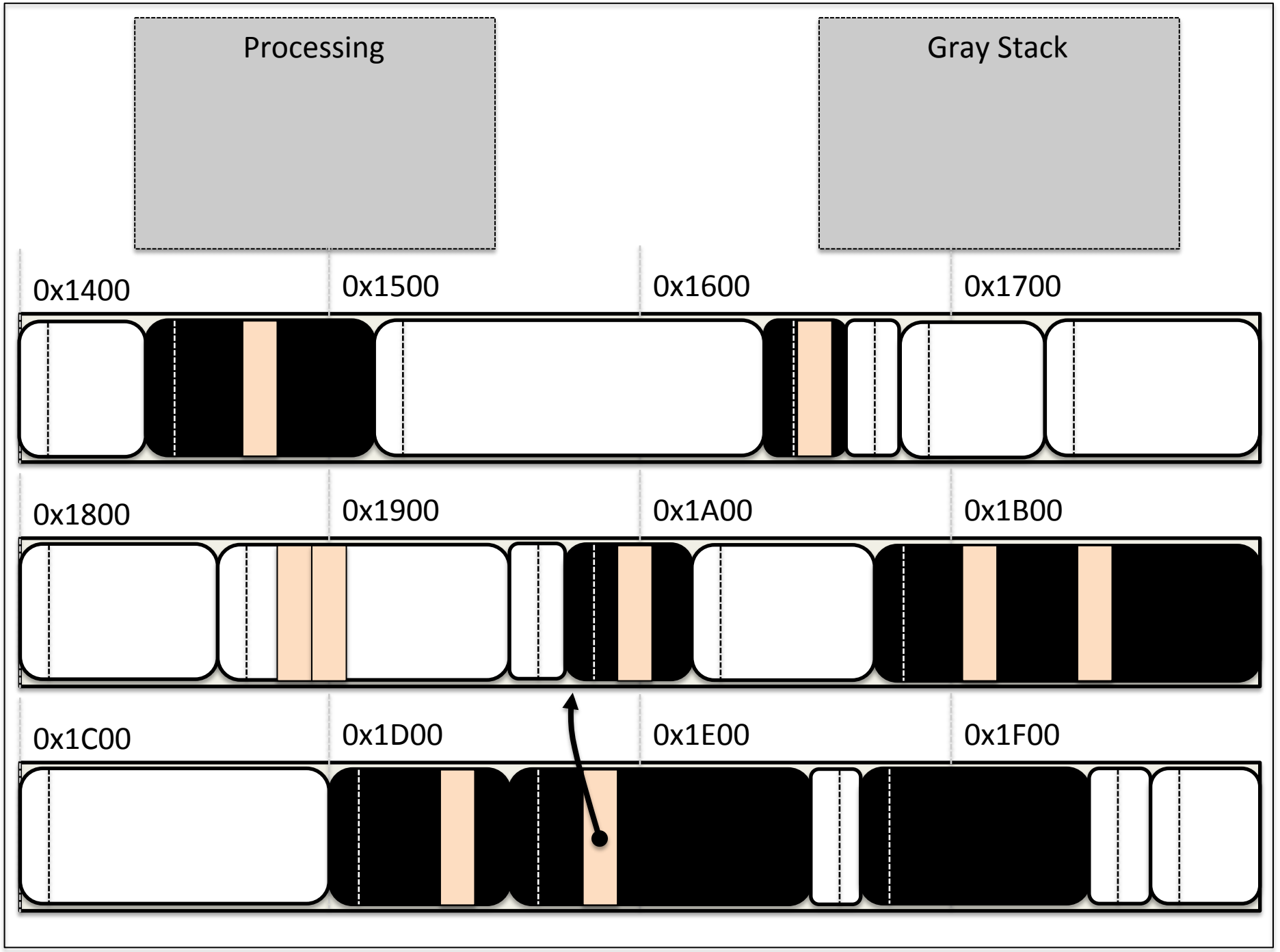
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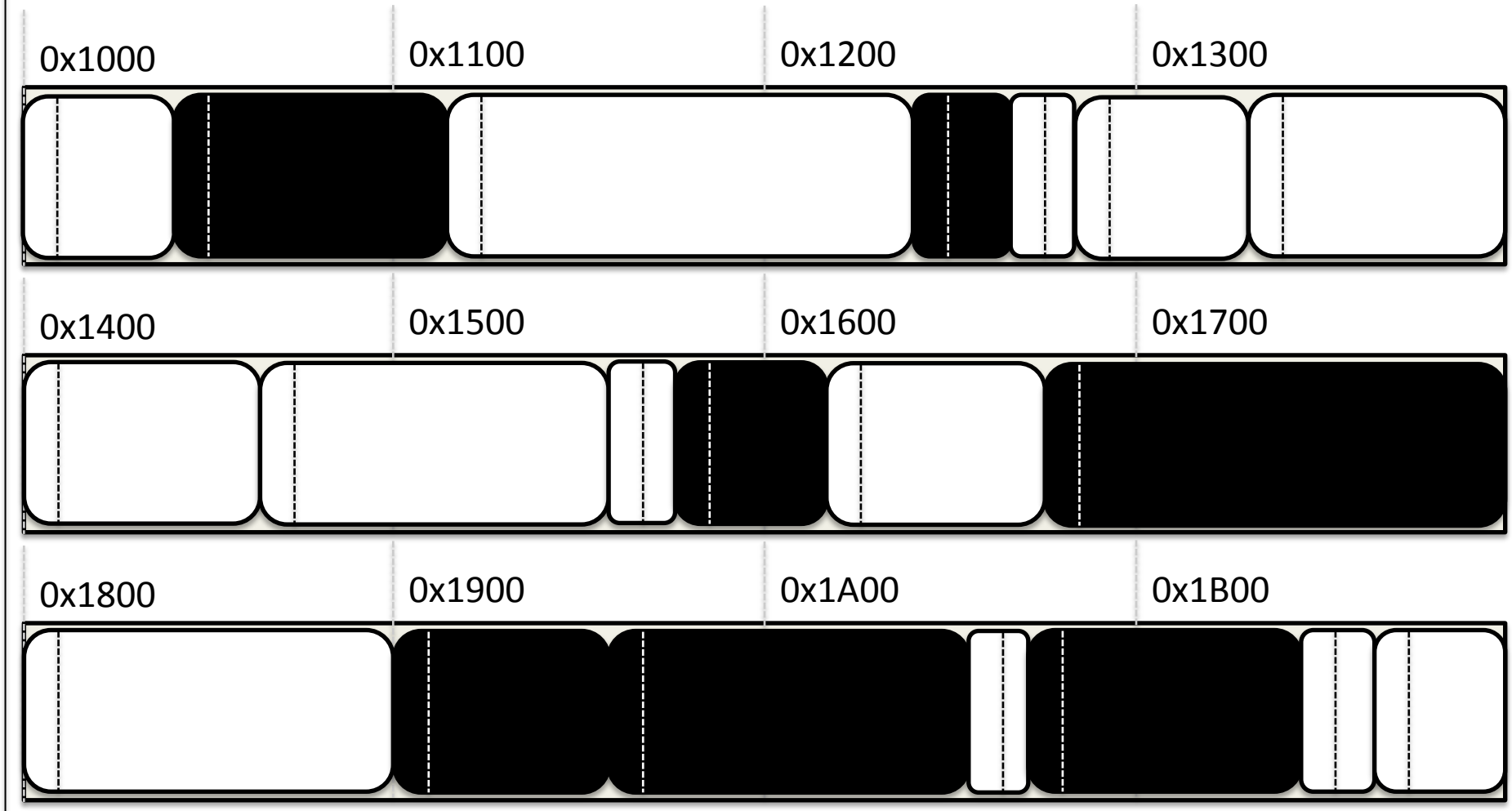
Mark Bits

- Tracing gives us black and white objects
  - Need to record what objects are black
- Requires at least one bit per object
  - Some algorithms may want more information
- We can use a bit in the object header
  - Recall the bit stealing technique
  - No overflow problem as in reference counting
- Can also store information on the side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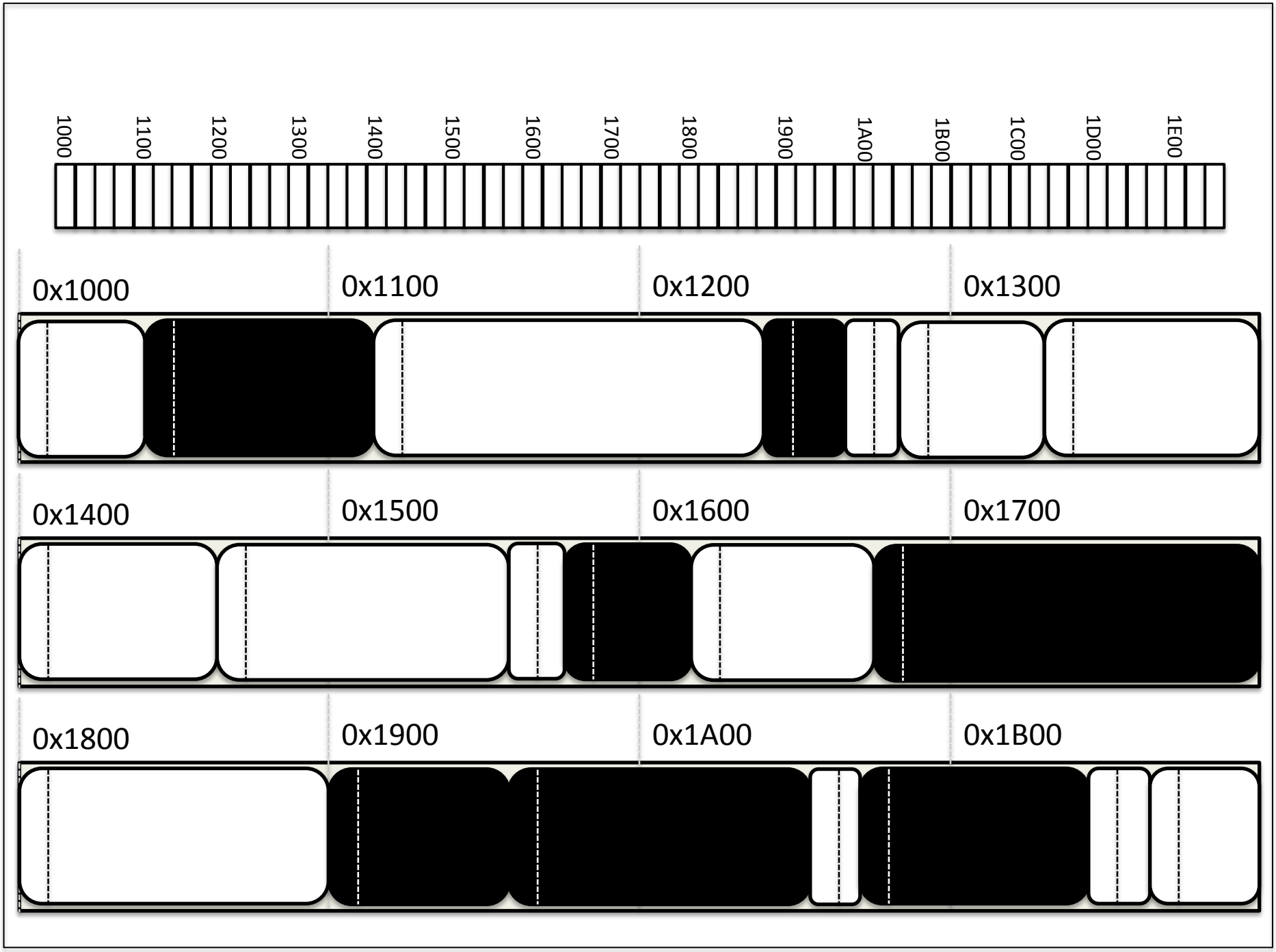
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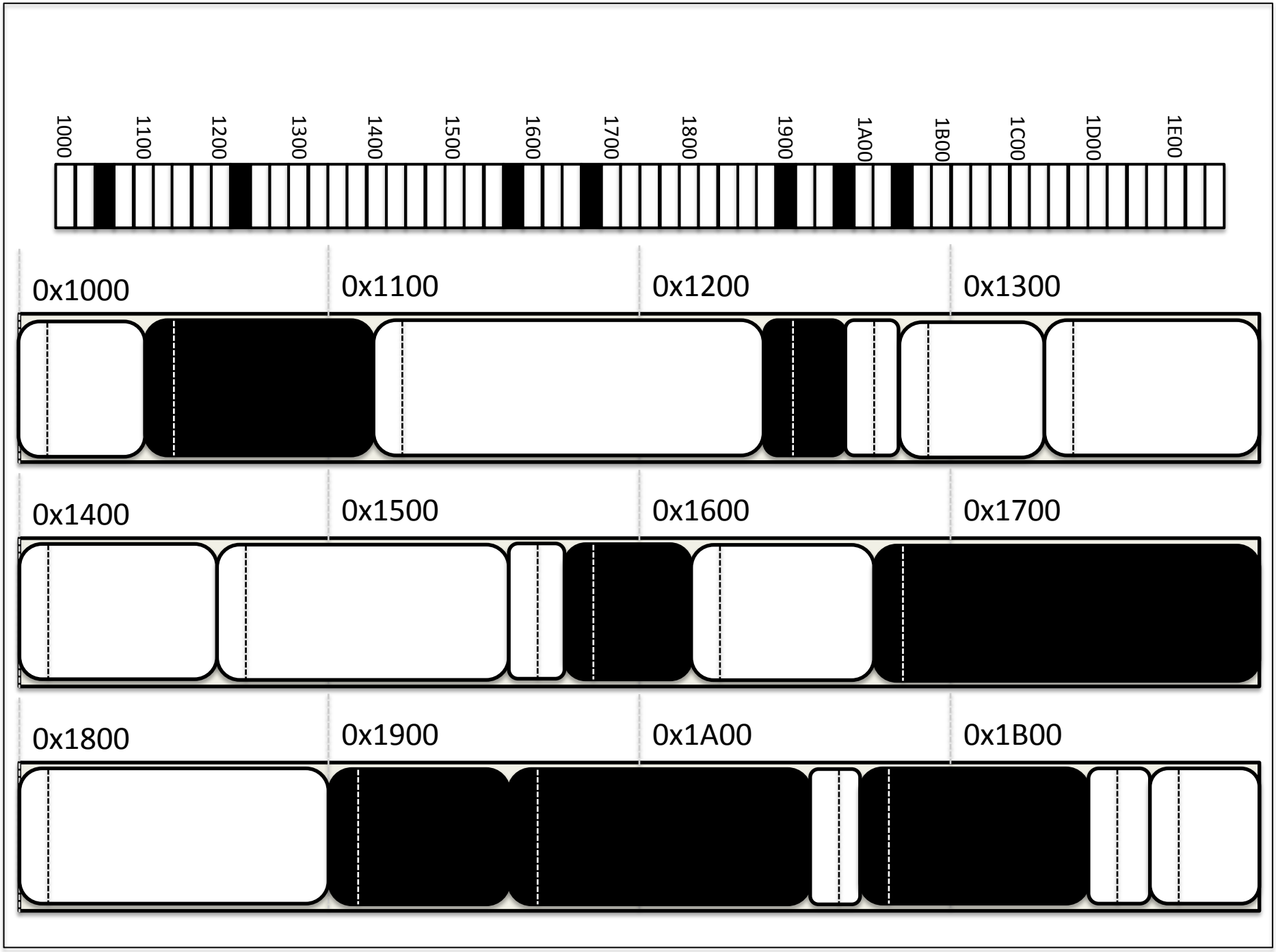
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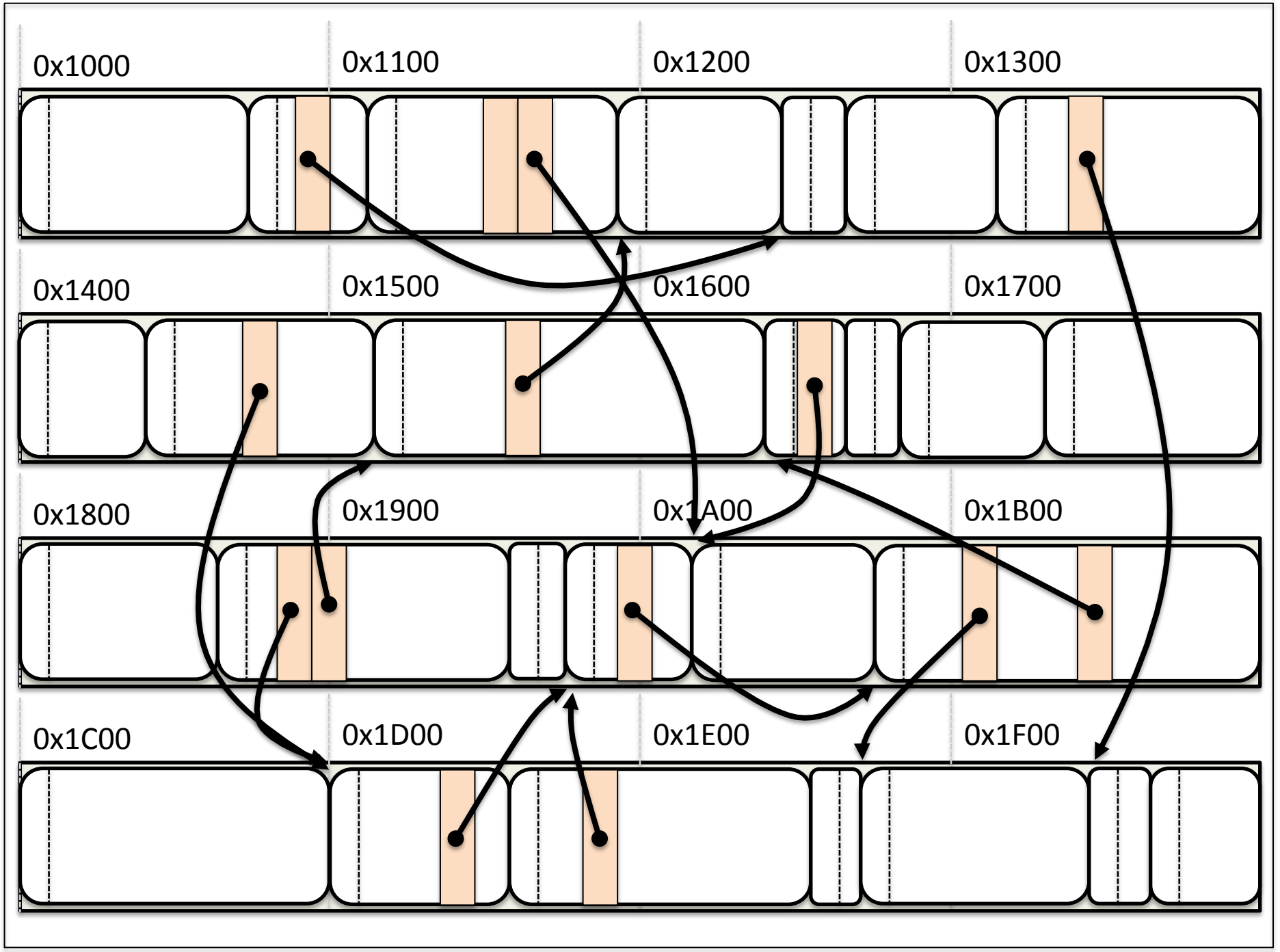
Mark Bitmaps

- Alternative to storing mark bits in headers
  - Metadata stored separate from data
  - One bit per fixed size memory range
- Some big advantages
  - Doesn't require masking of stolen bits
  - Good cache behavior
- Some problems
  - May be an extra load per read
  - Non-trivial memory overhead

Mark and Sweep Collectors

- Two-pass garbage collection algorithm
- Perform a trace across the heap
  - Mark all live objects
  - Everything else is garbage
- Follow up by sweeping over the heap
  - Free any unmarked objects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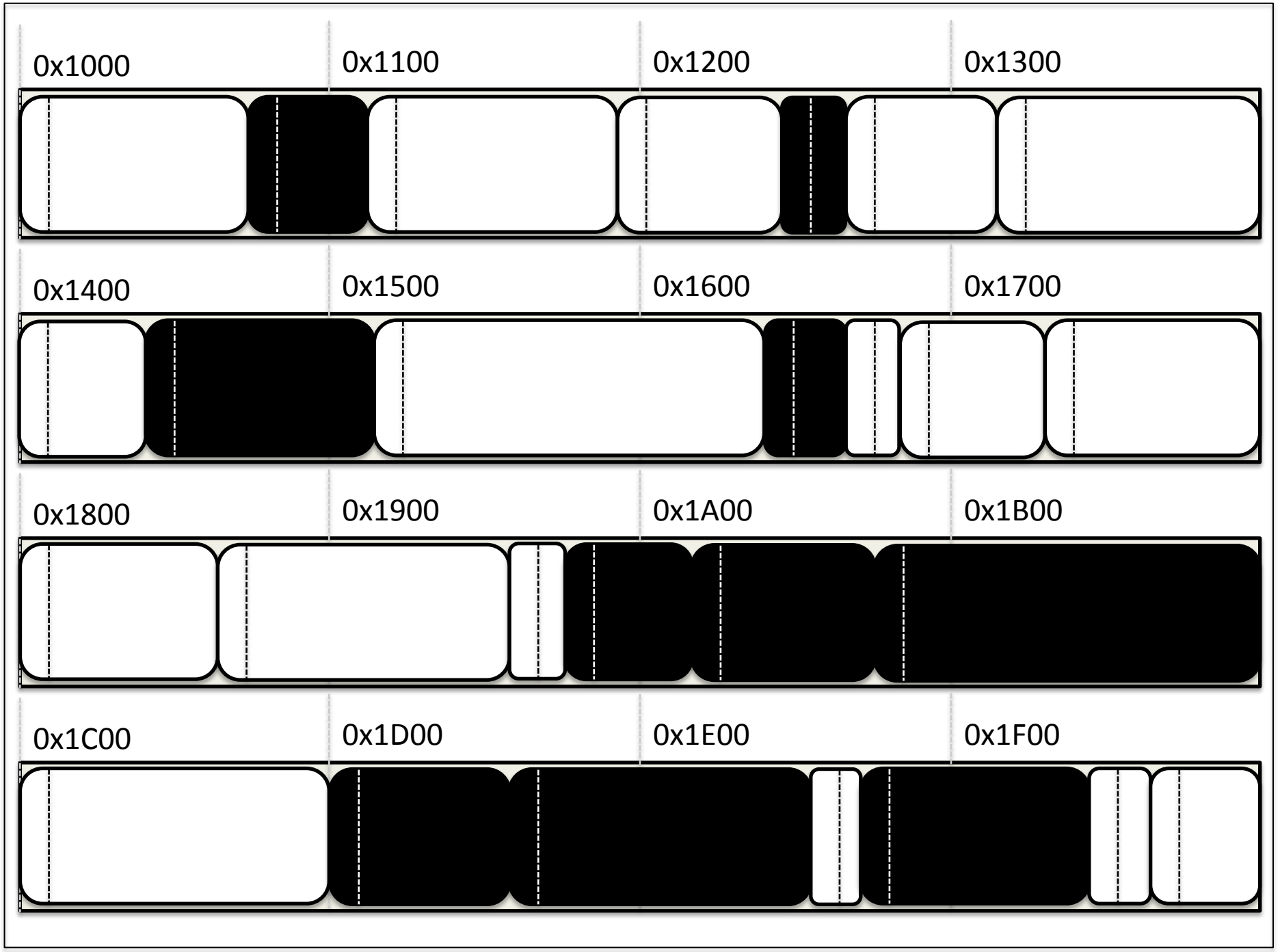
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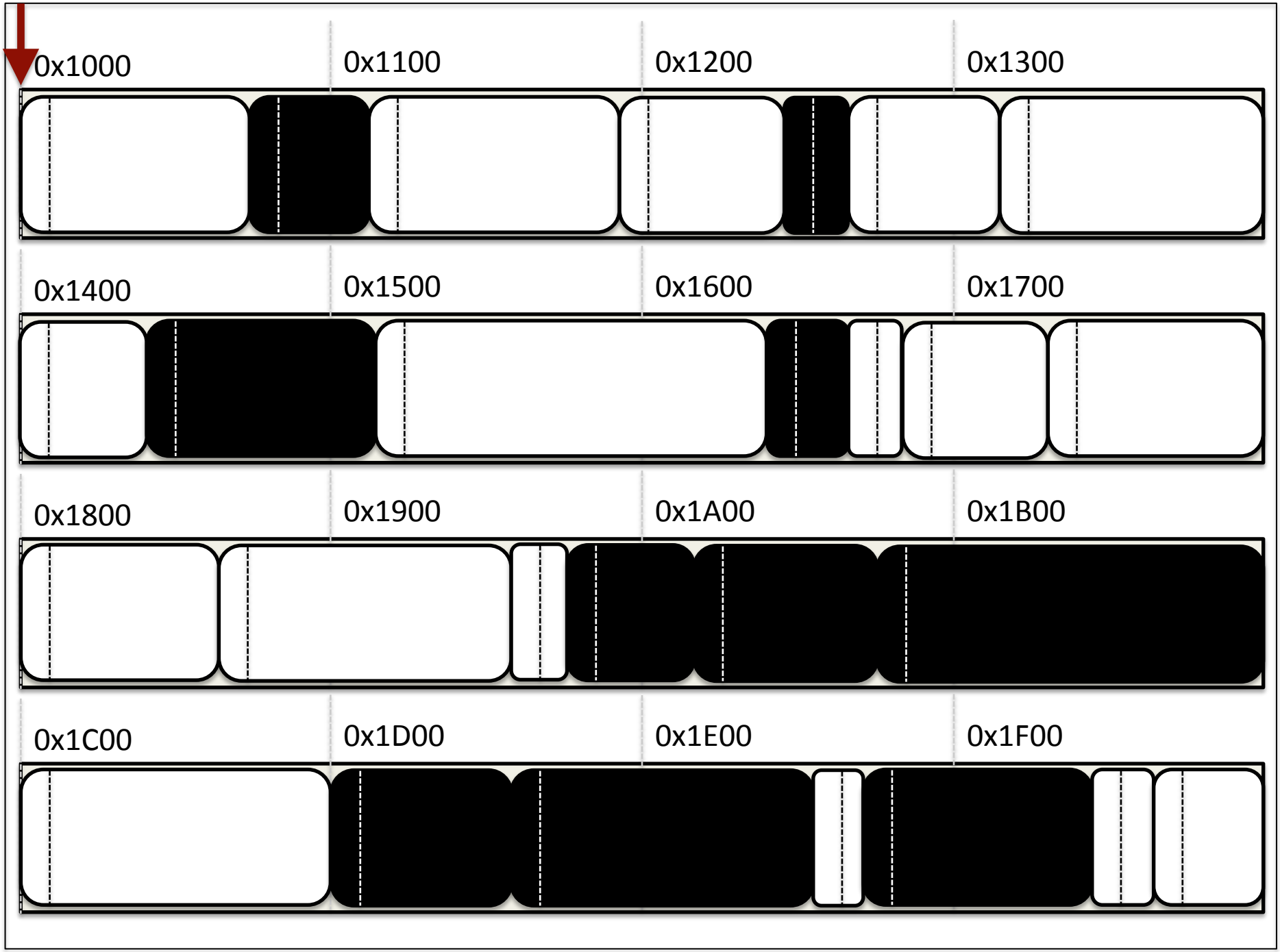
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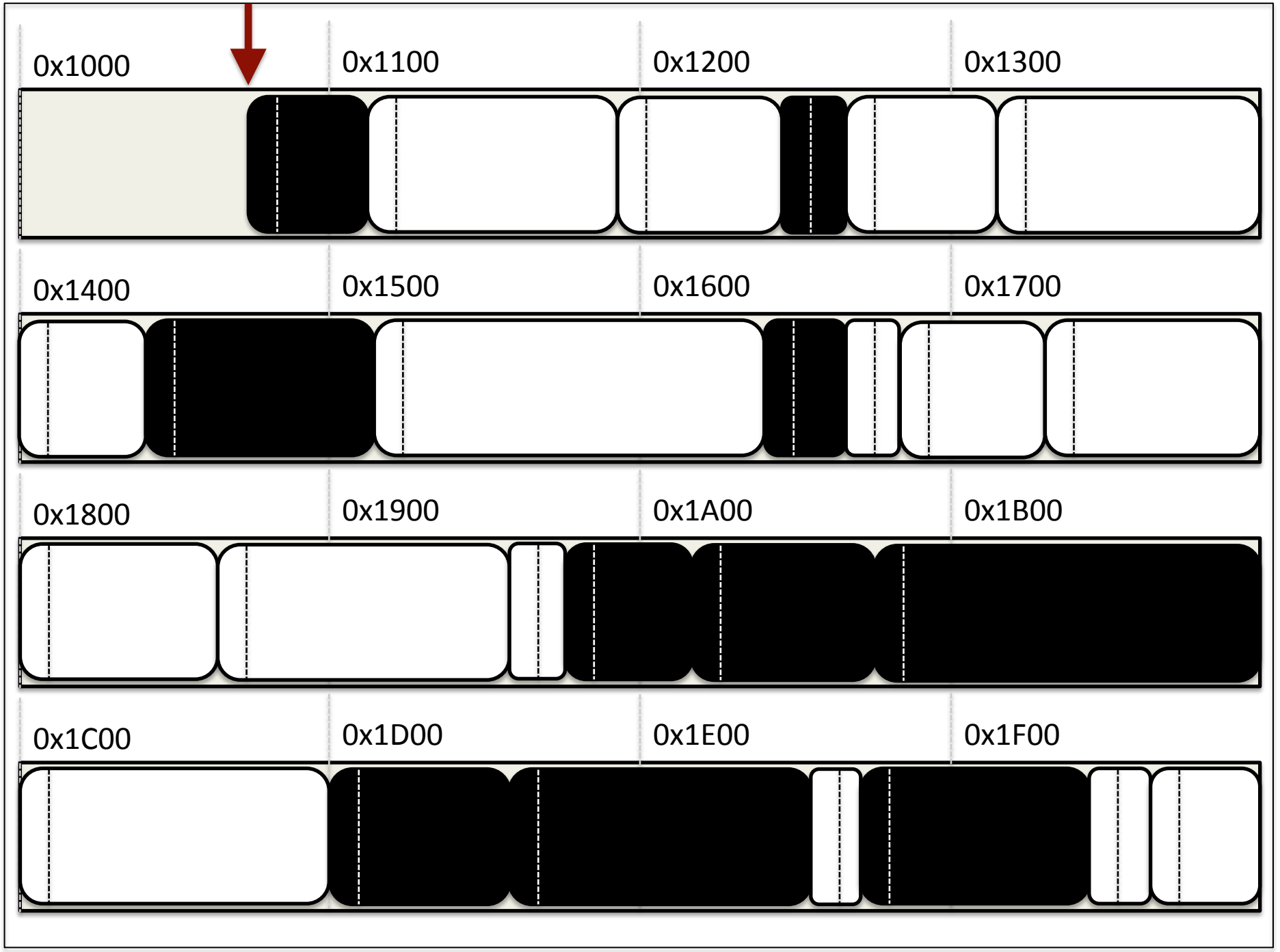
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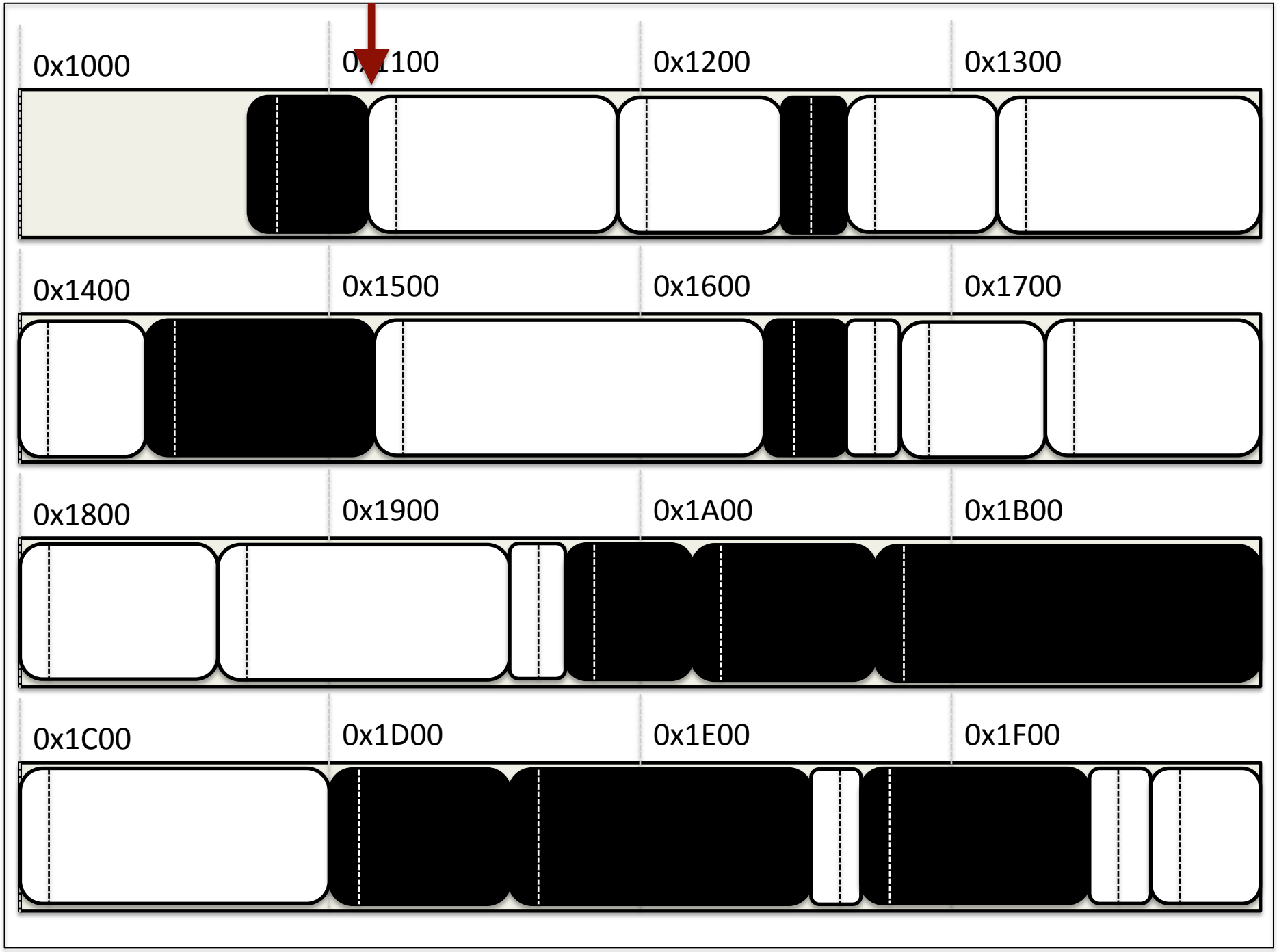
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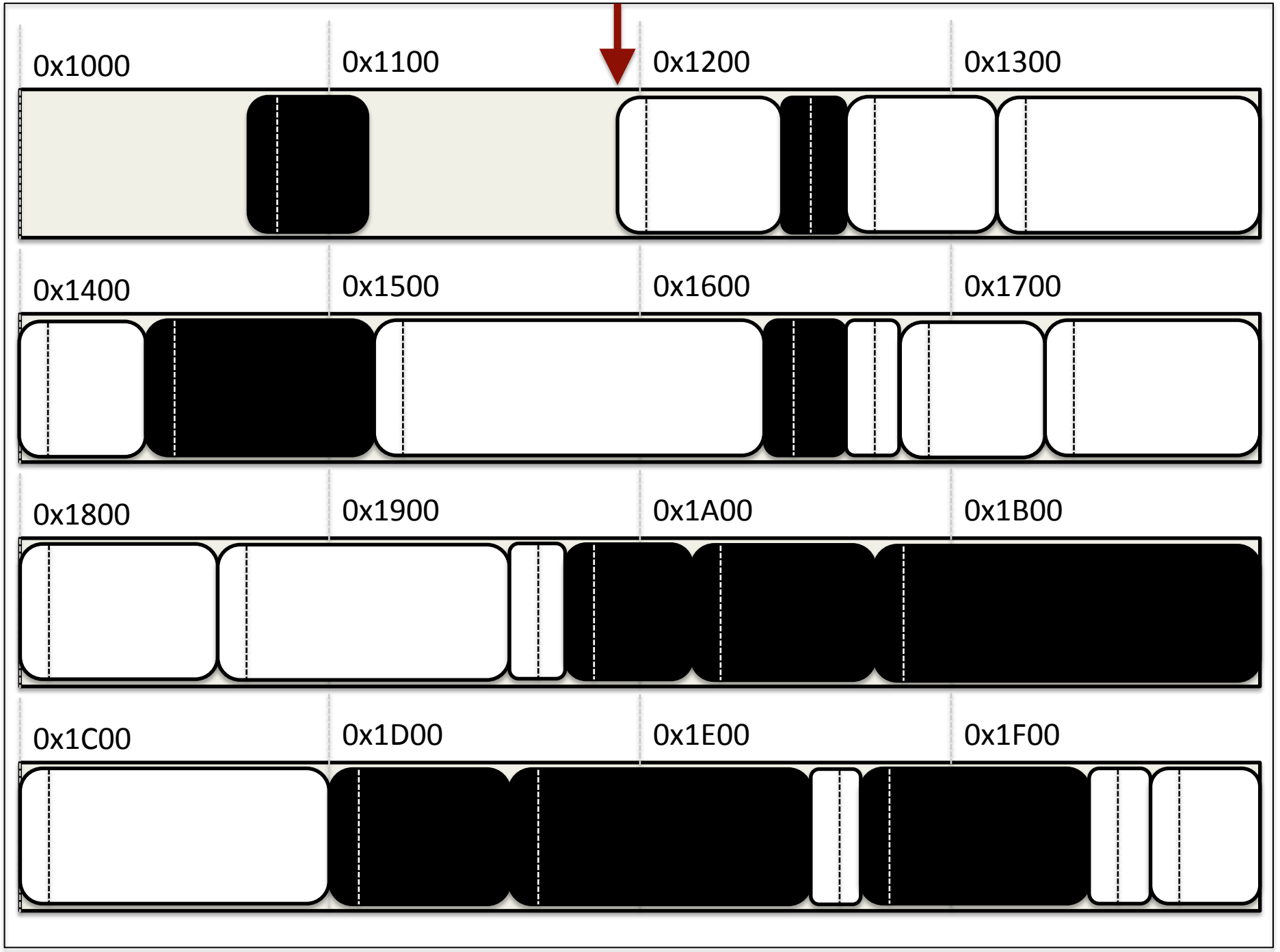
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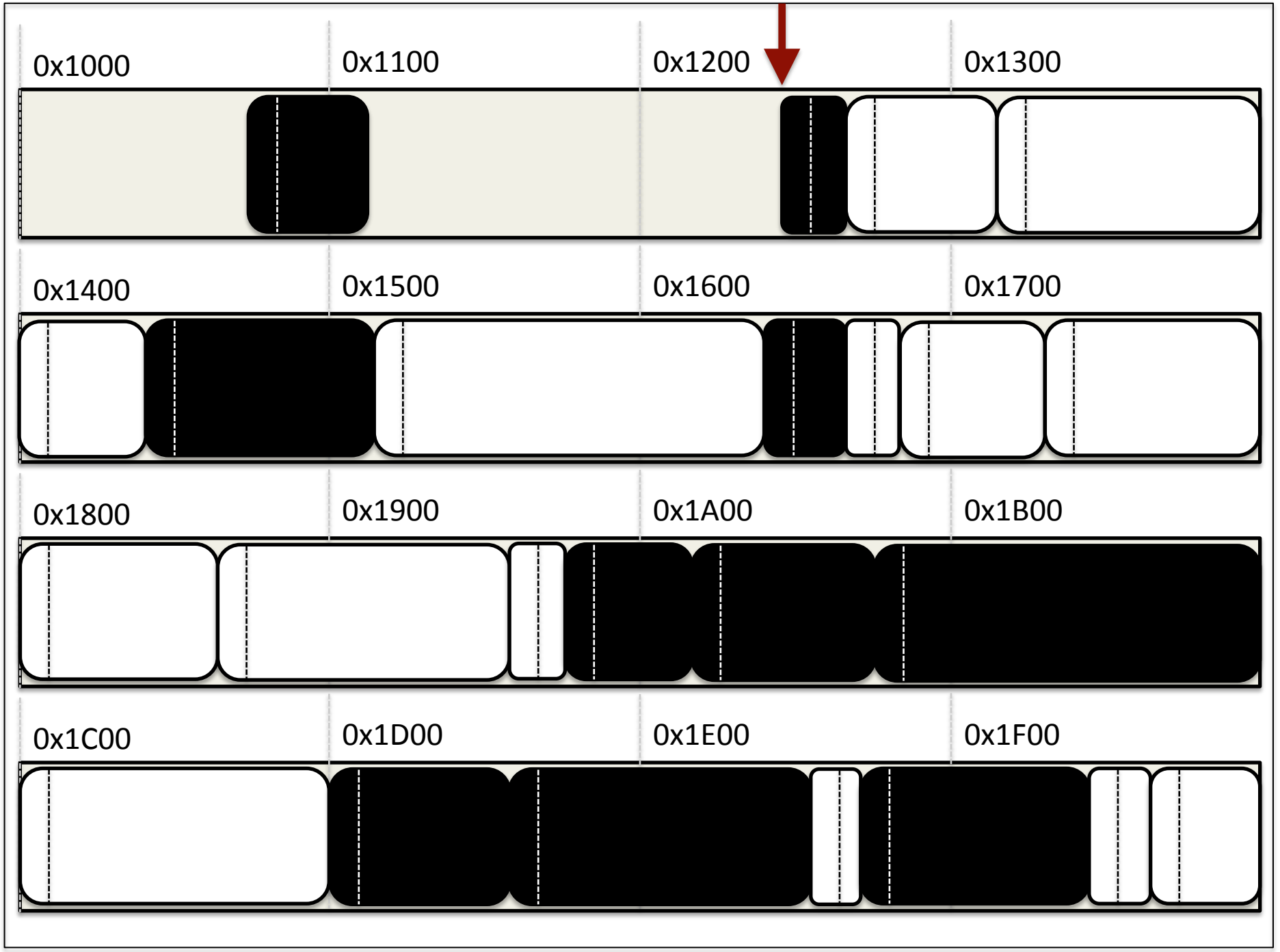
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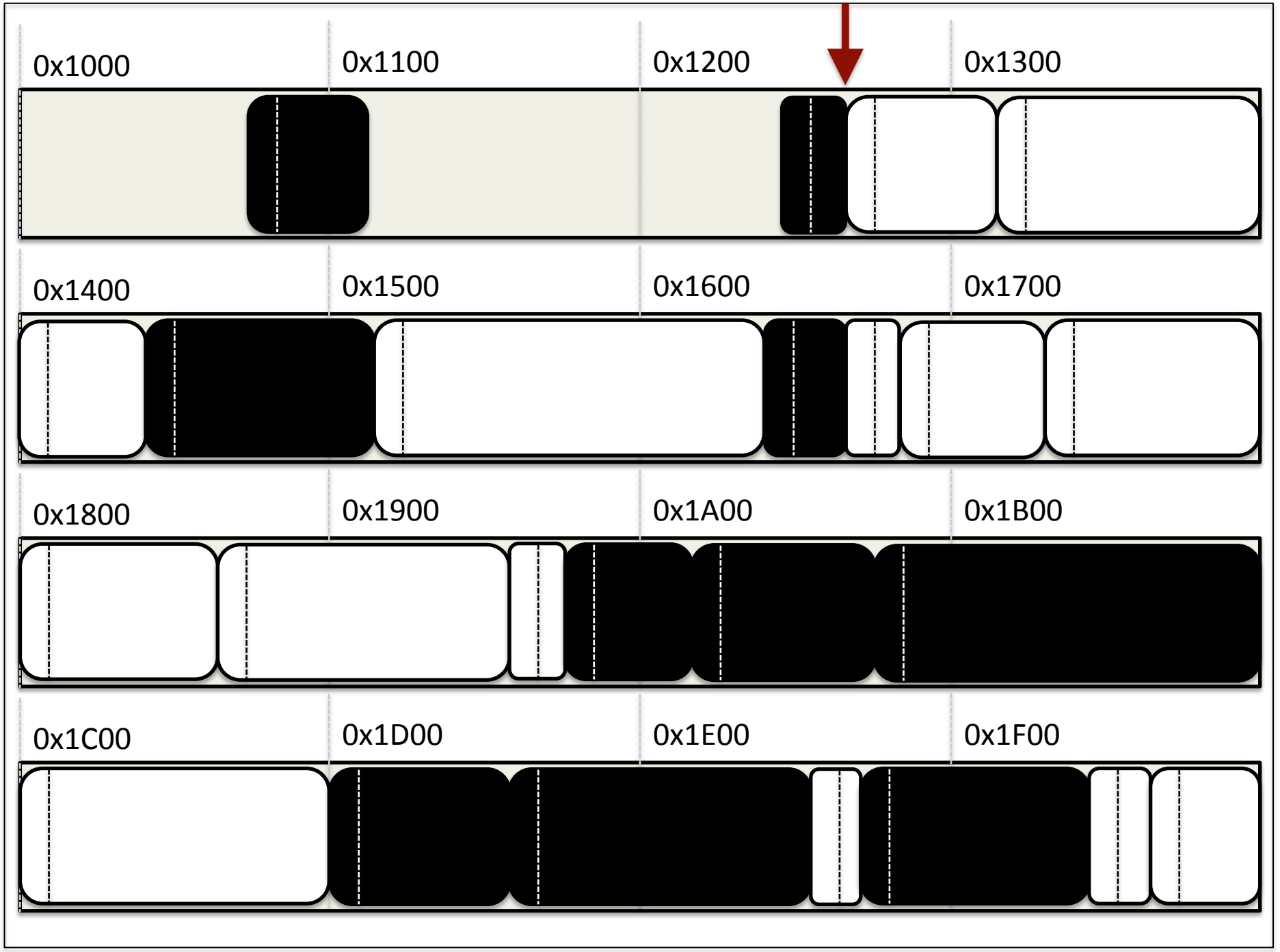
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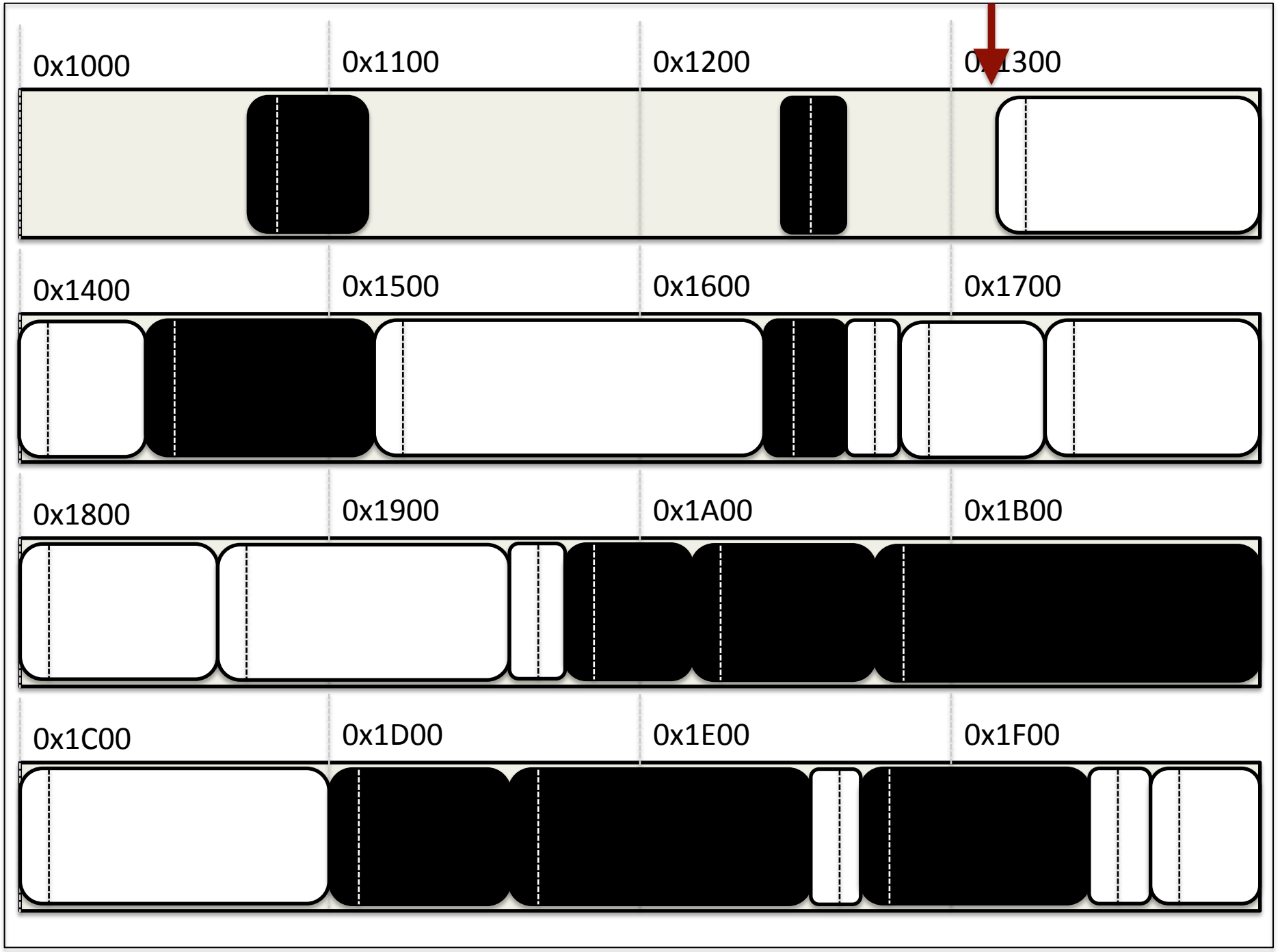
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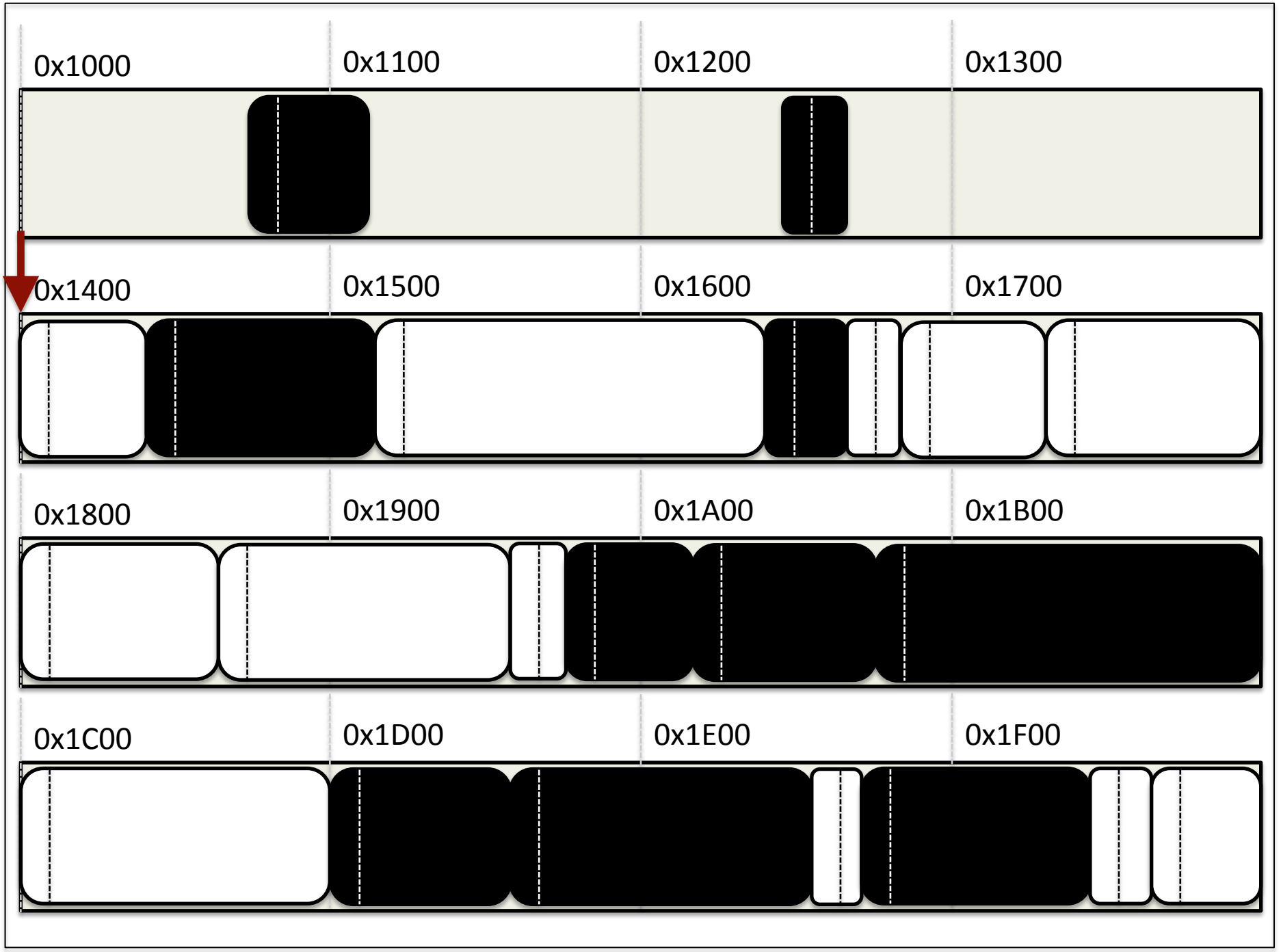
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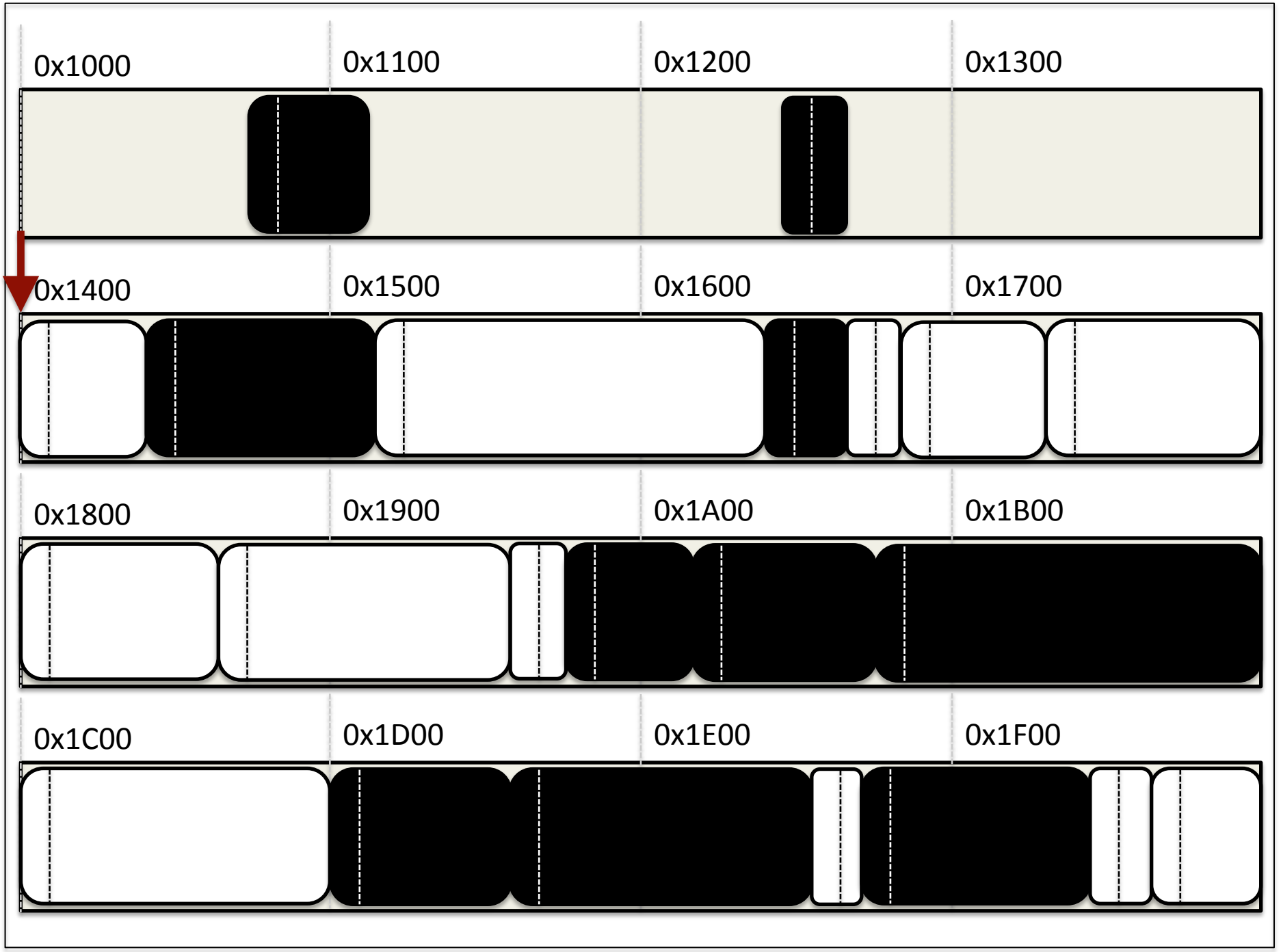
Sweep Phase

- Sweeping is a linear scan over the heap
  - Start at the first address
  - Calculate the offset of the next object
- Need to be able to scan over gaps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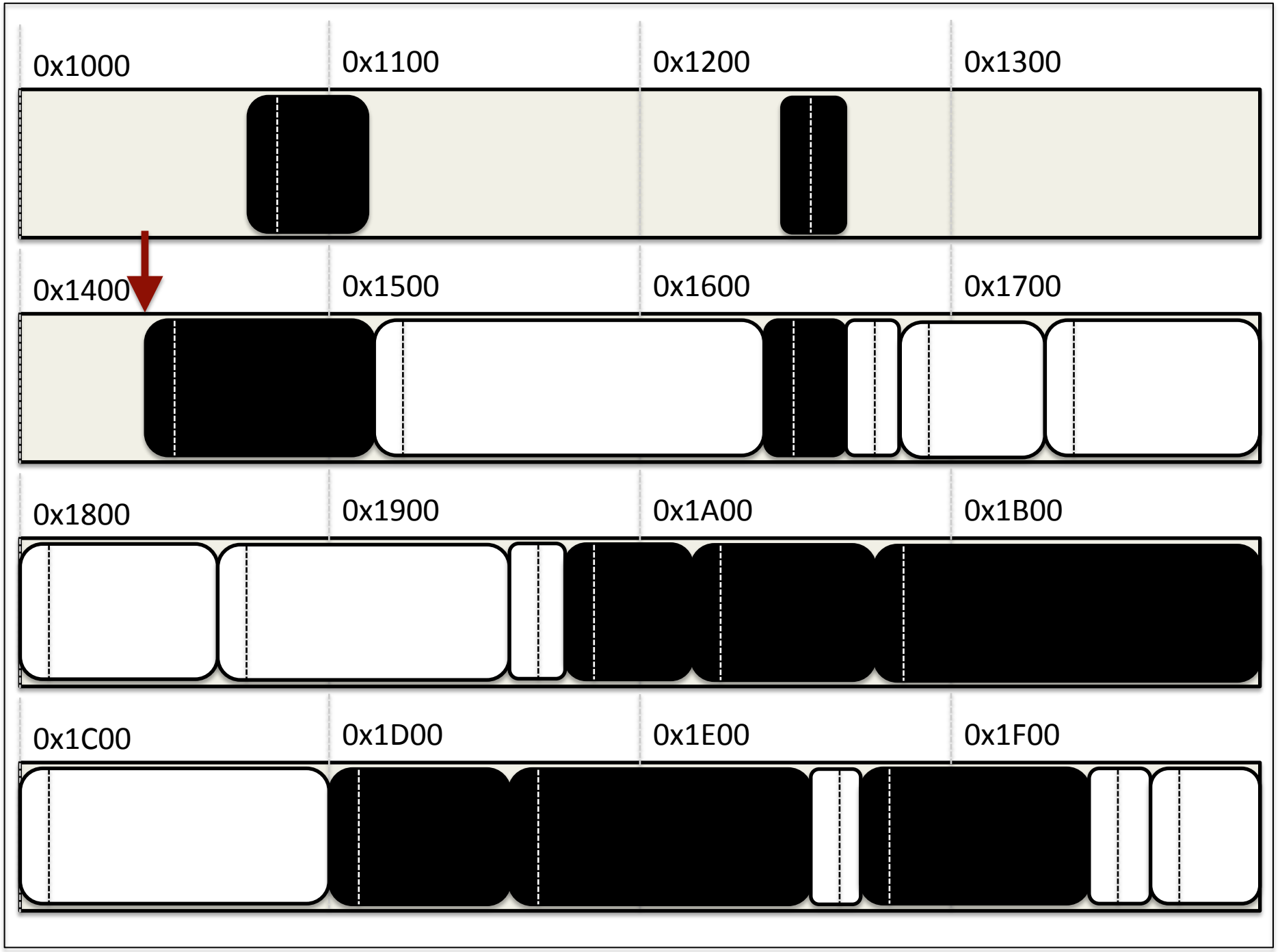
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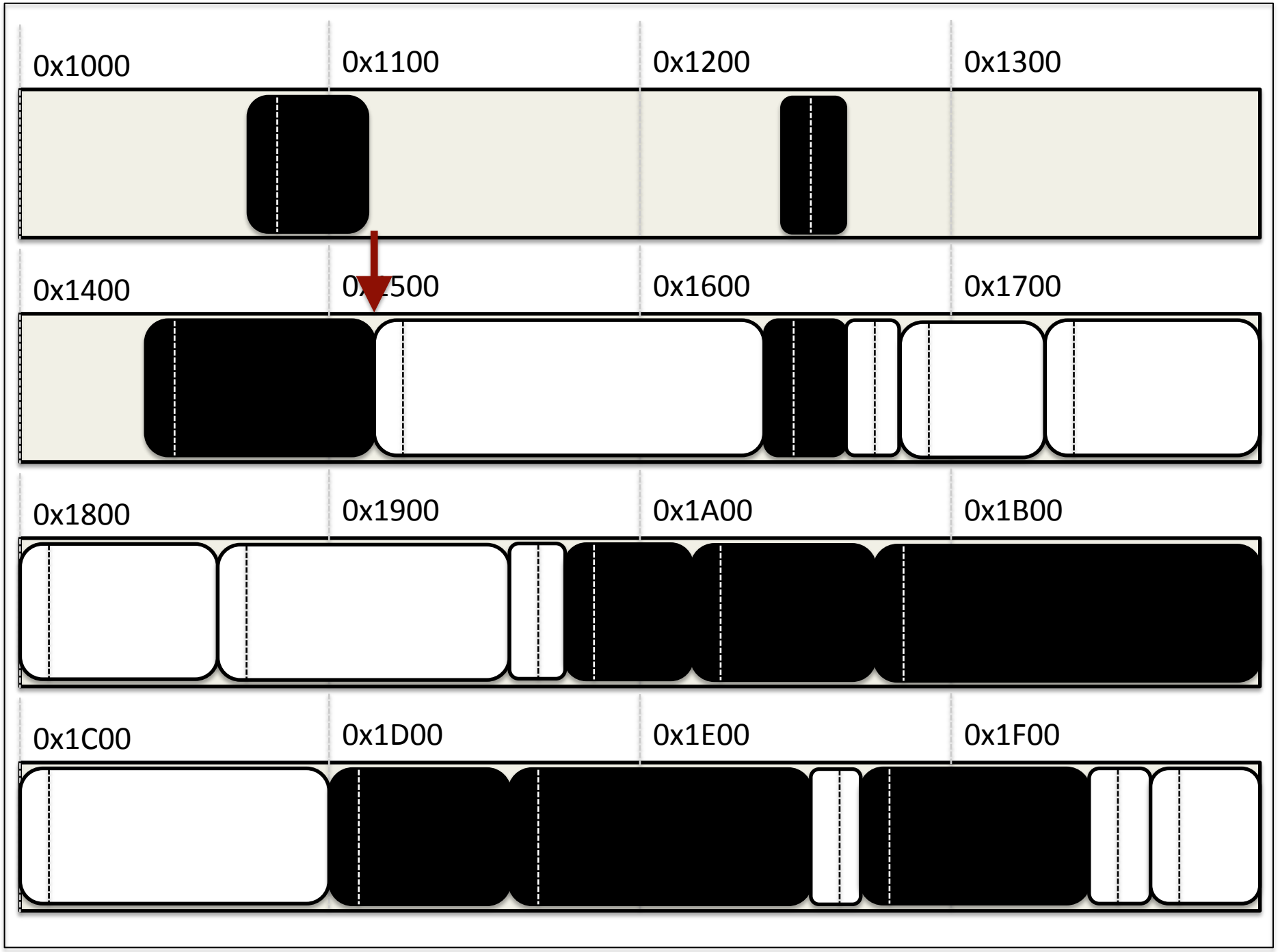
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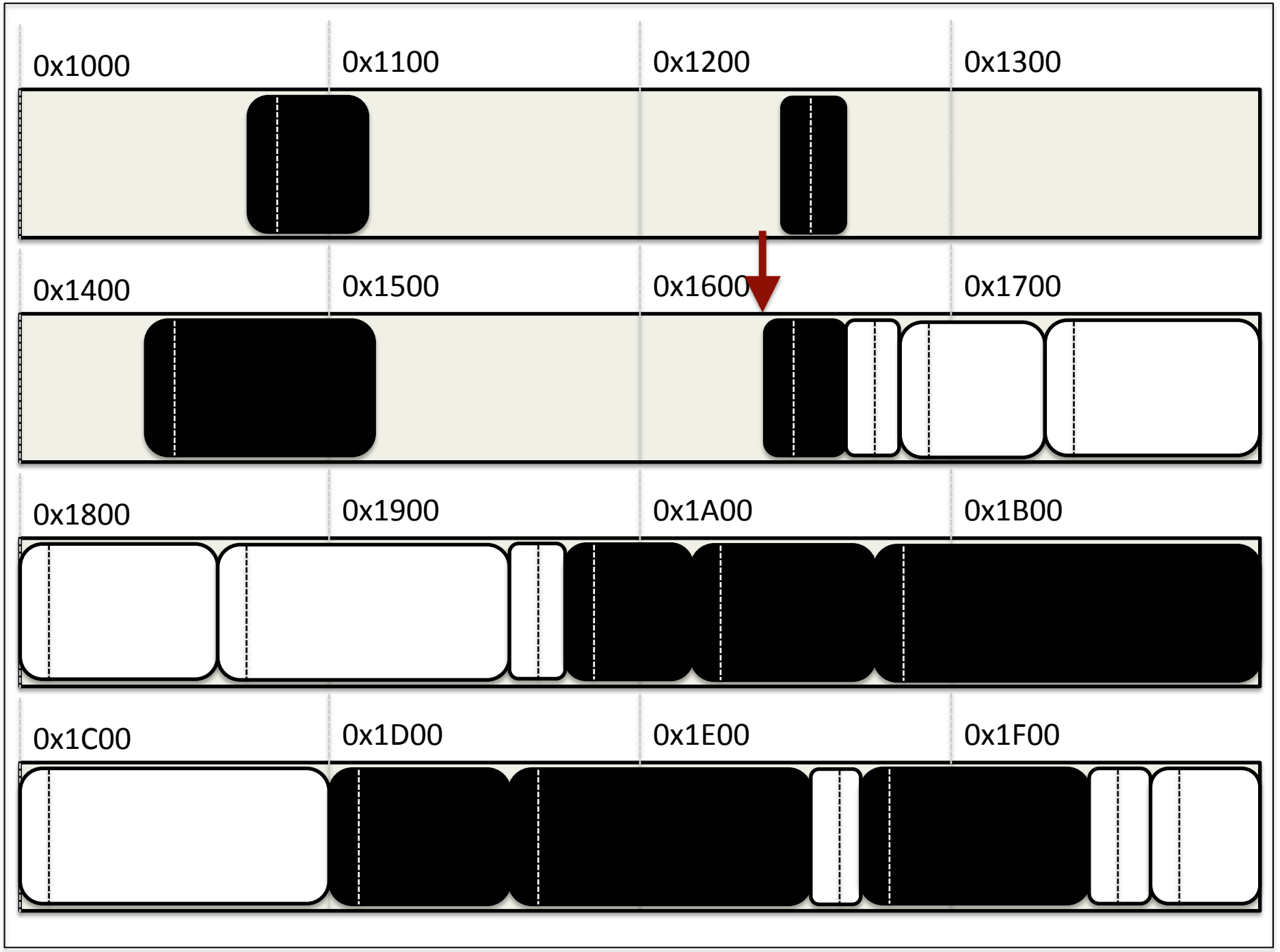
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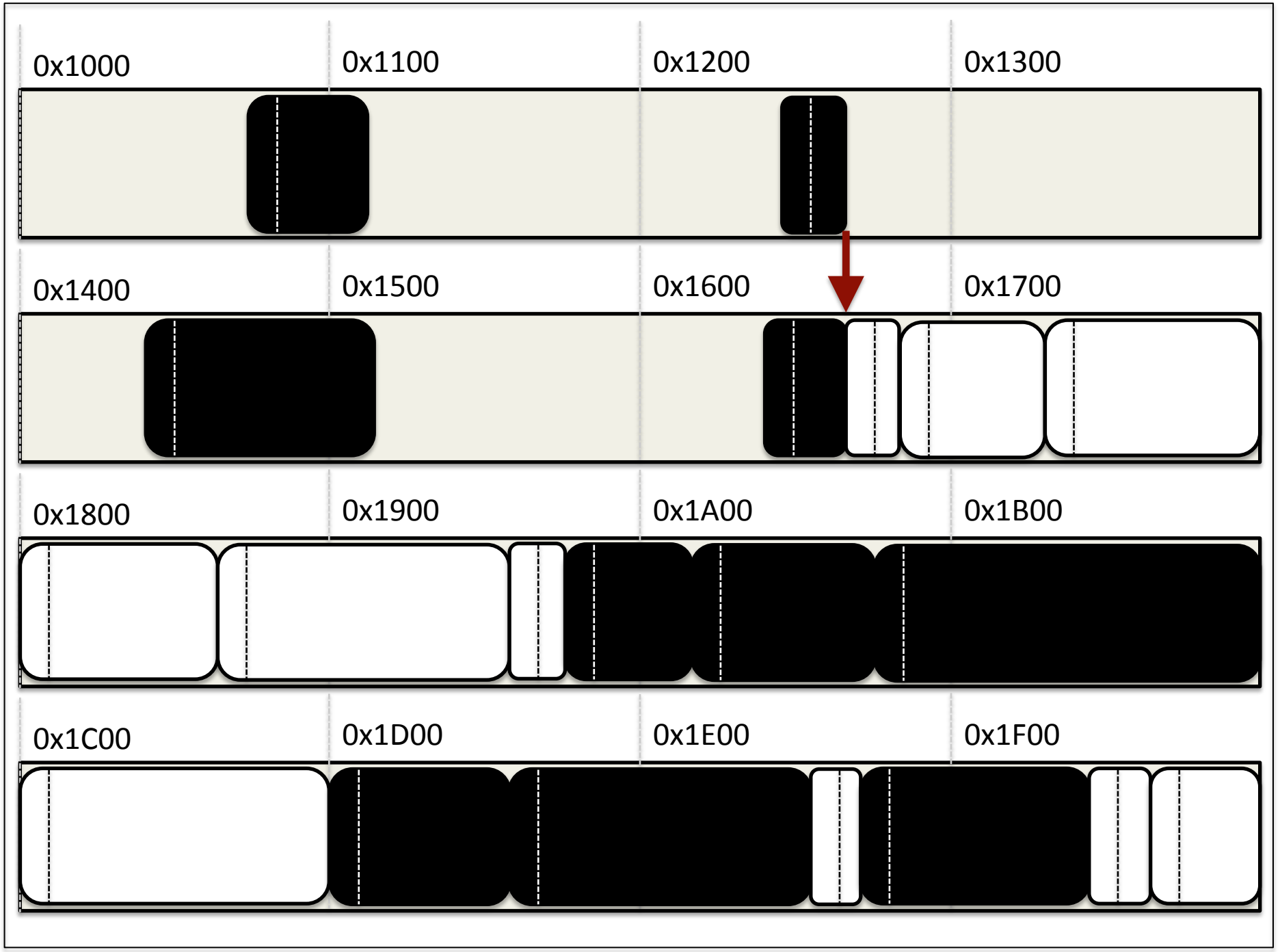
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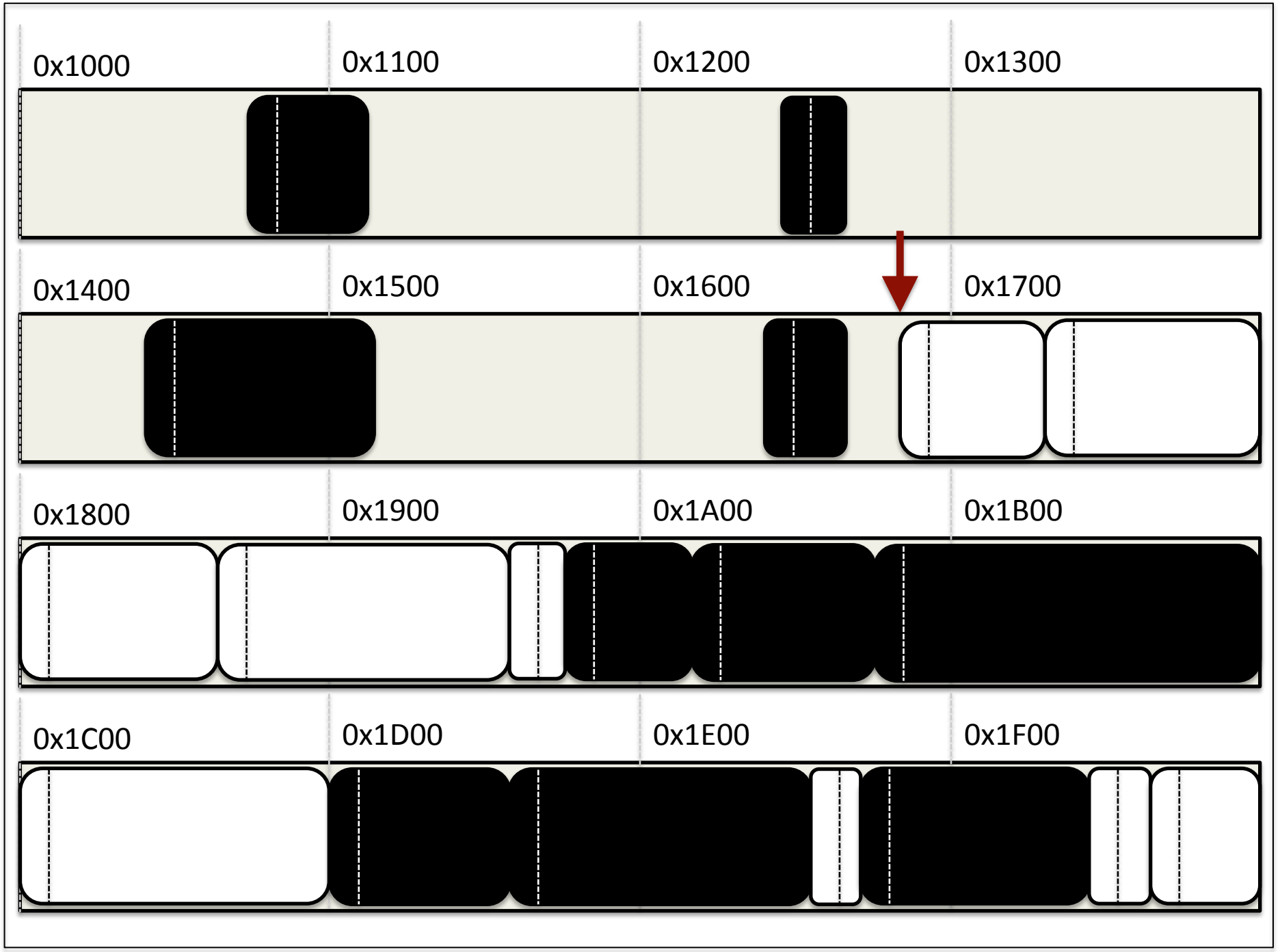
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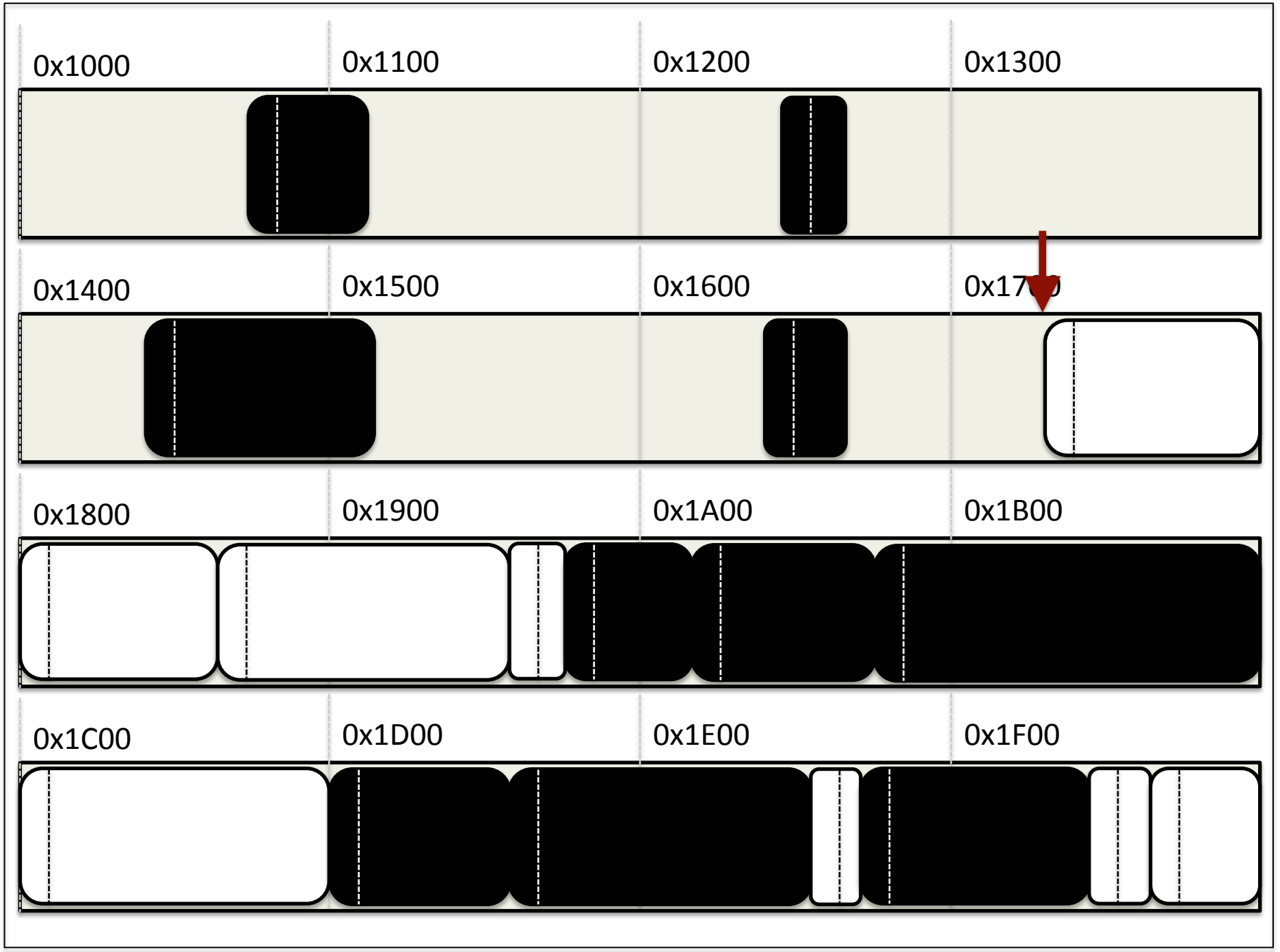
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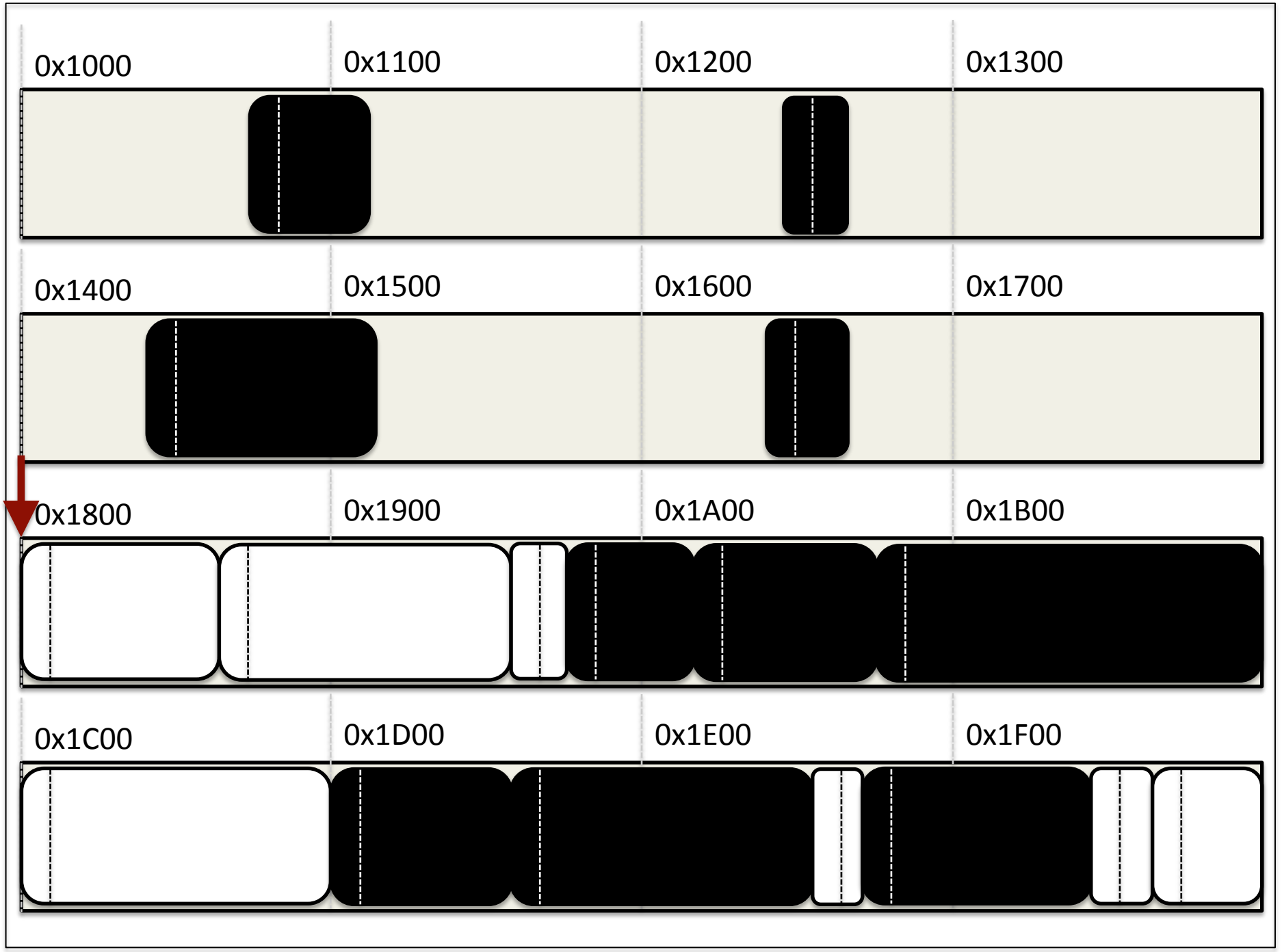
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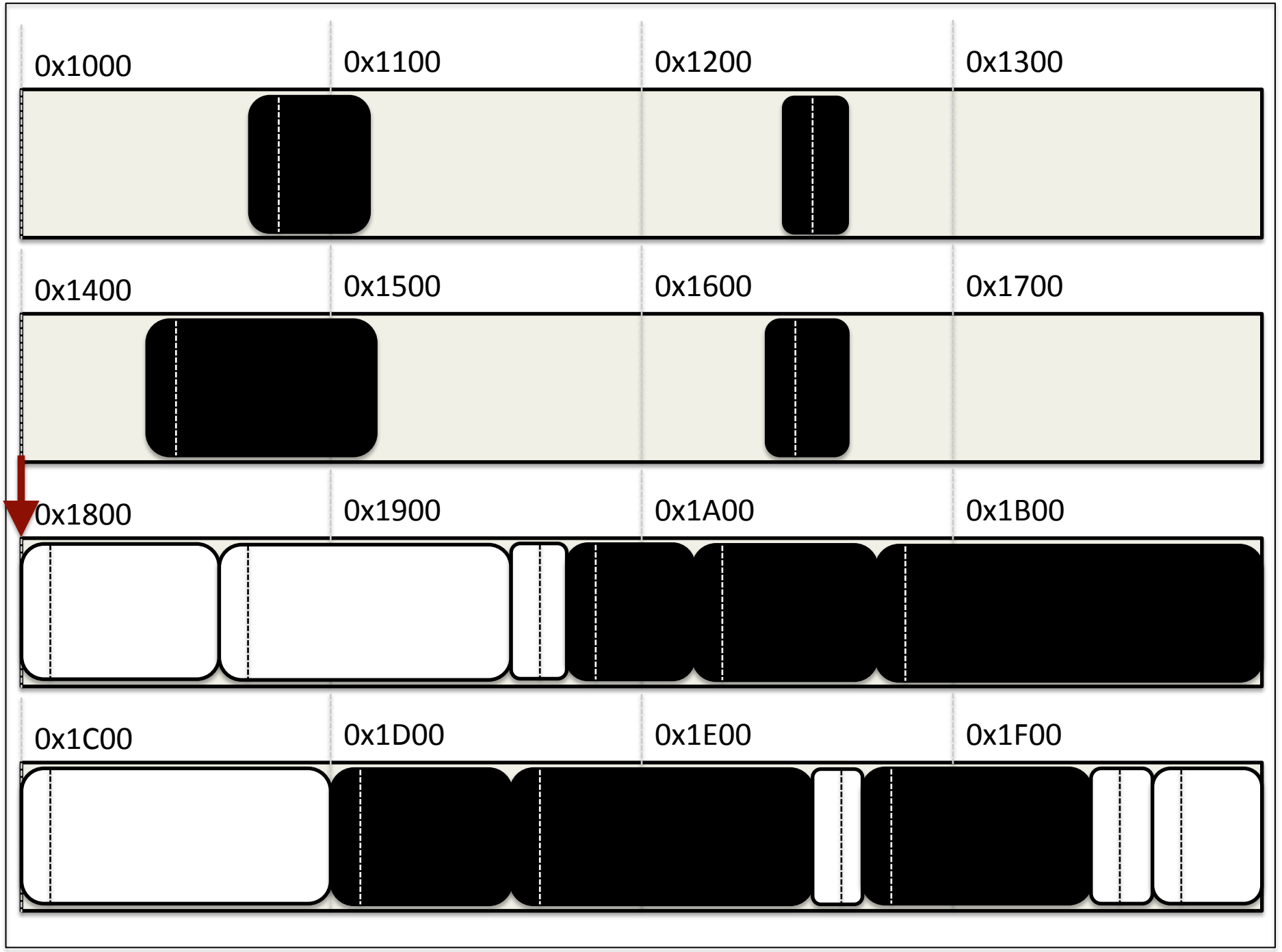
Sweep Phase

- Sweeping is a linear scan over the heap
  - Start at the first address
  - Calculate the offset of the next object
- Need to be able to scan over gaps
  - Fixed-size blocks
  - Block metadata as in malloc algorithm
  - Create dummy objects in empty spaces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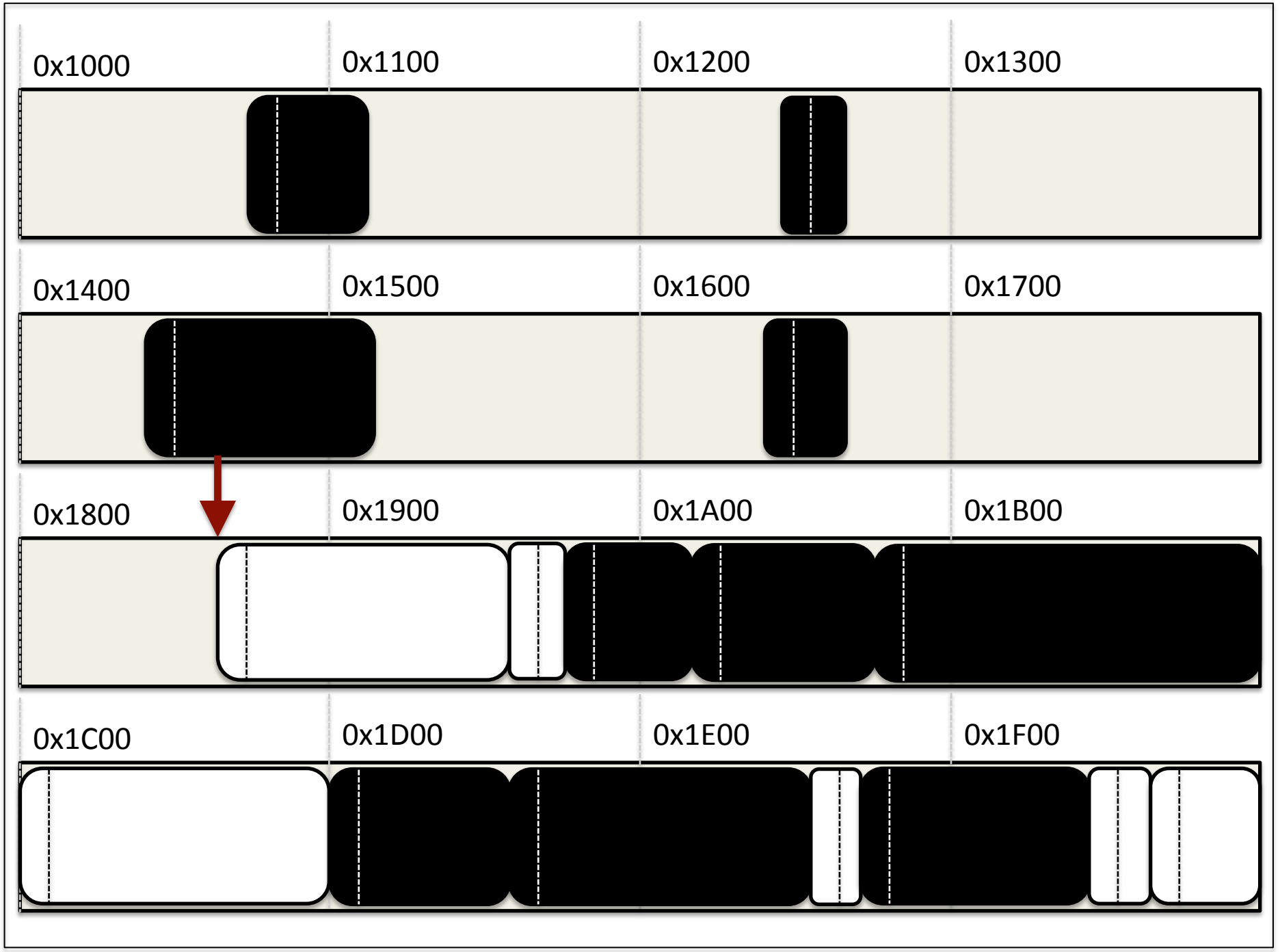
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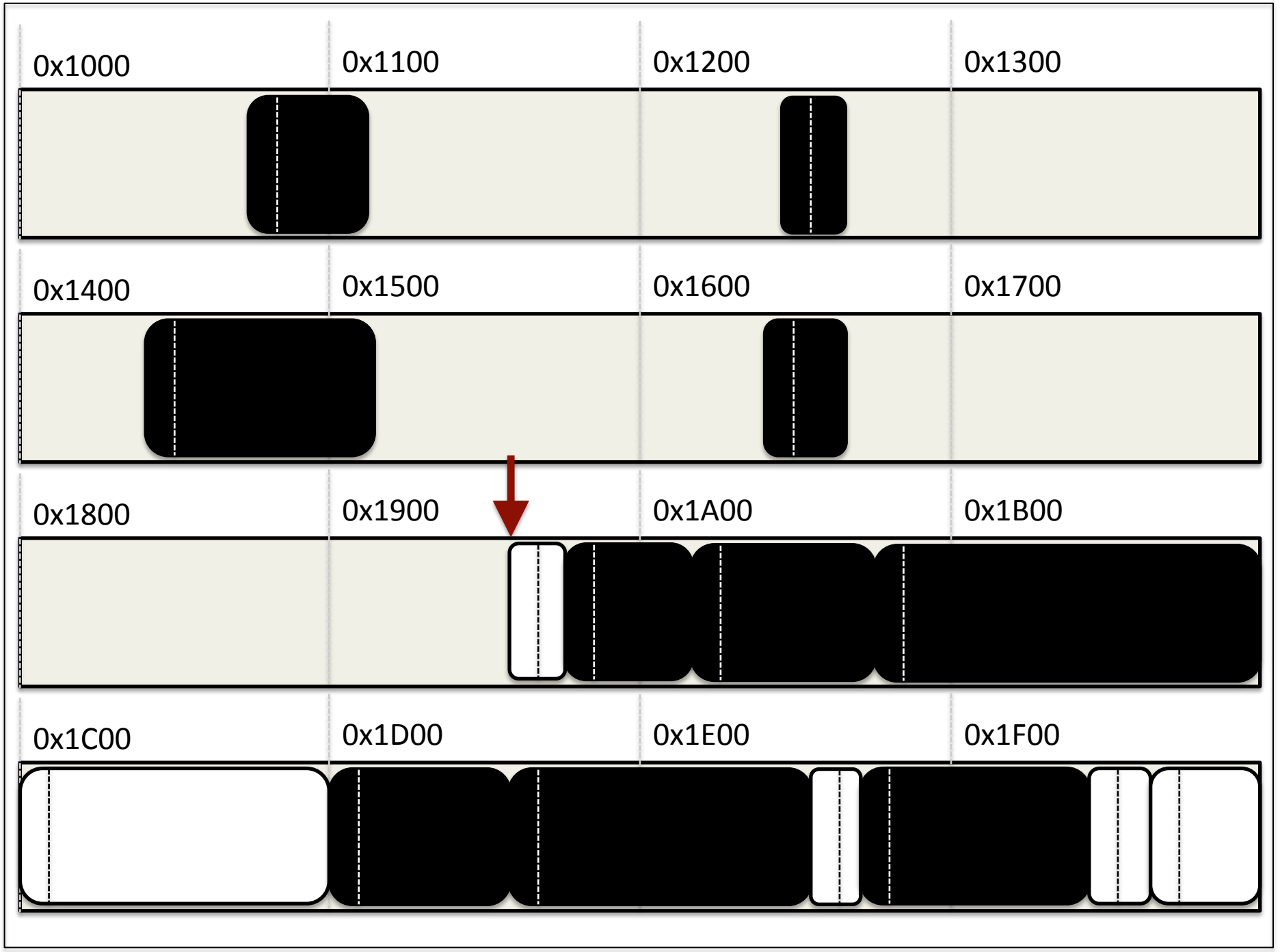
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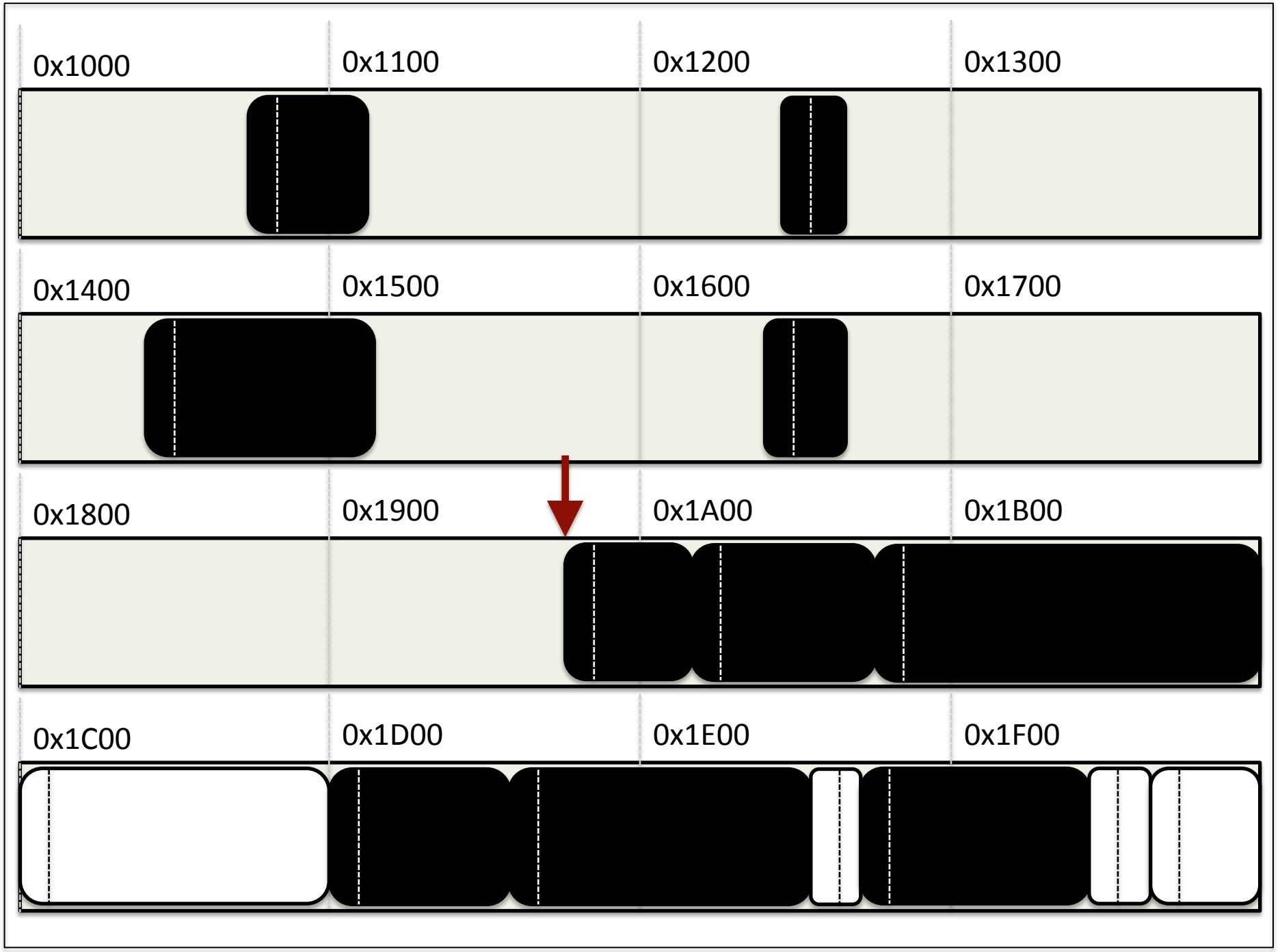
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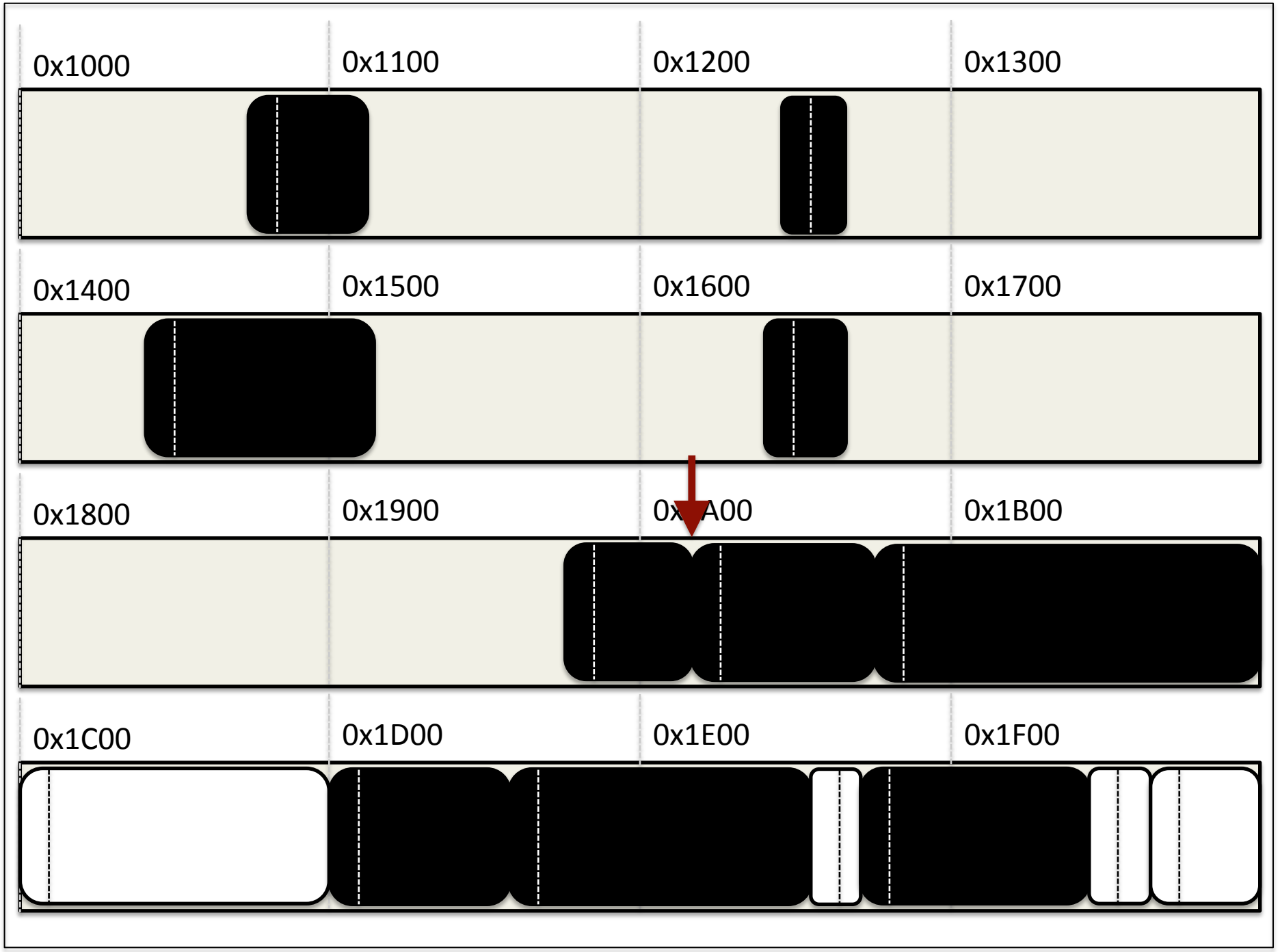
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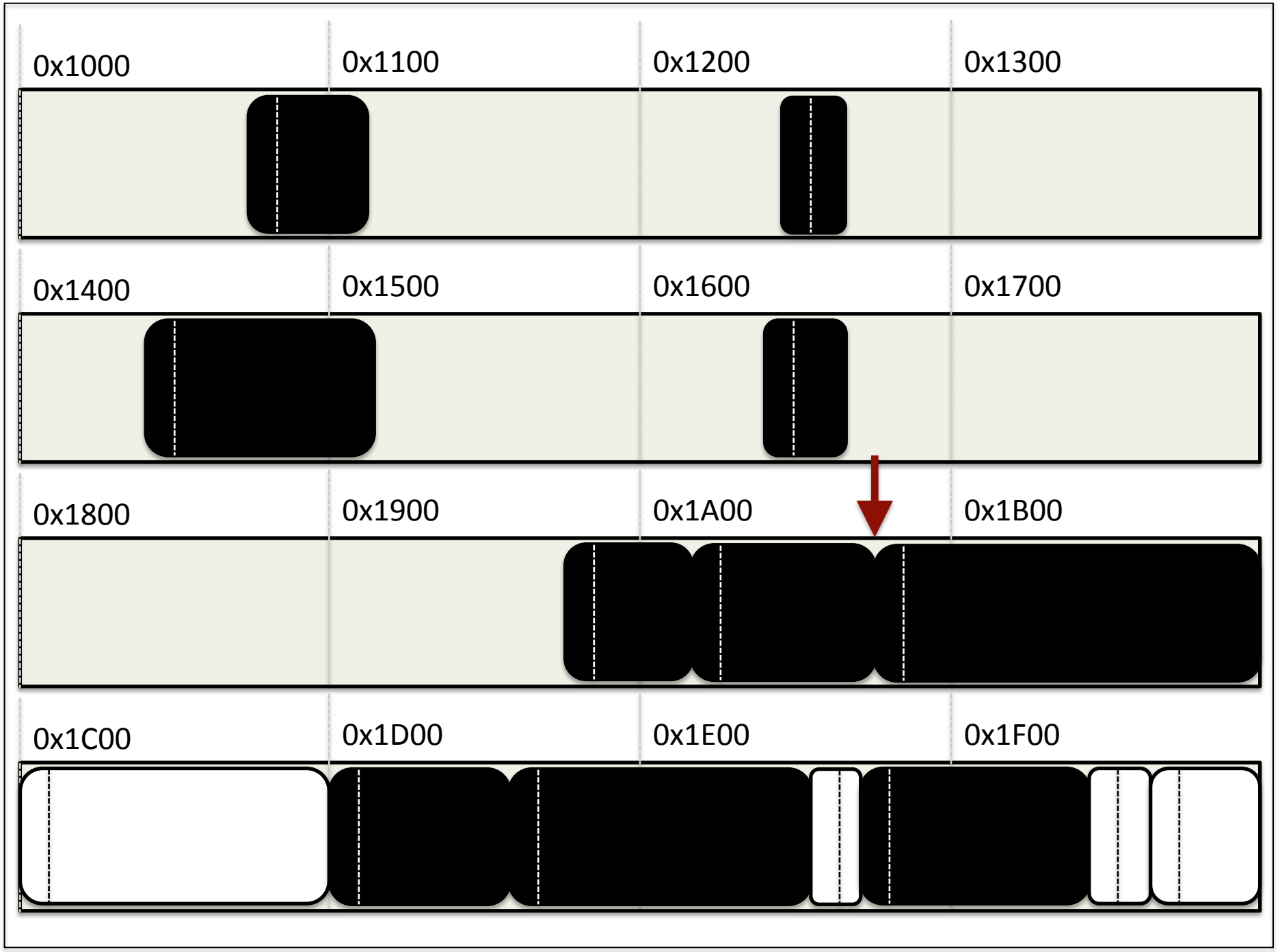
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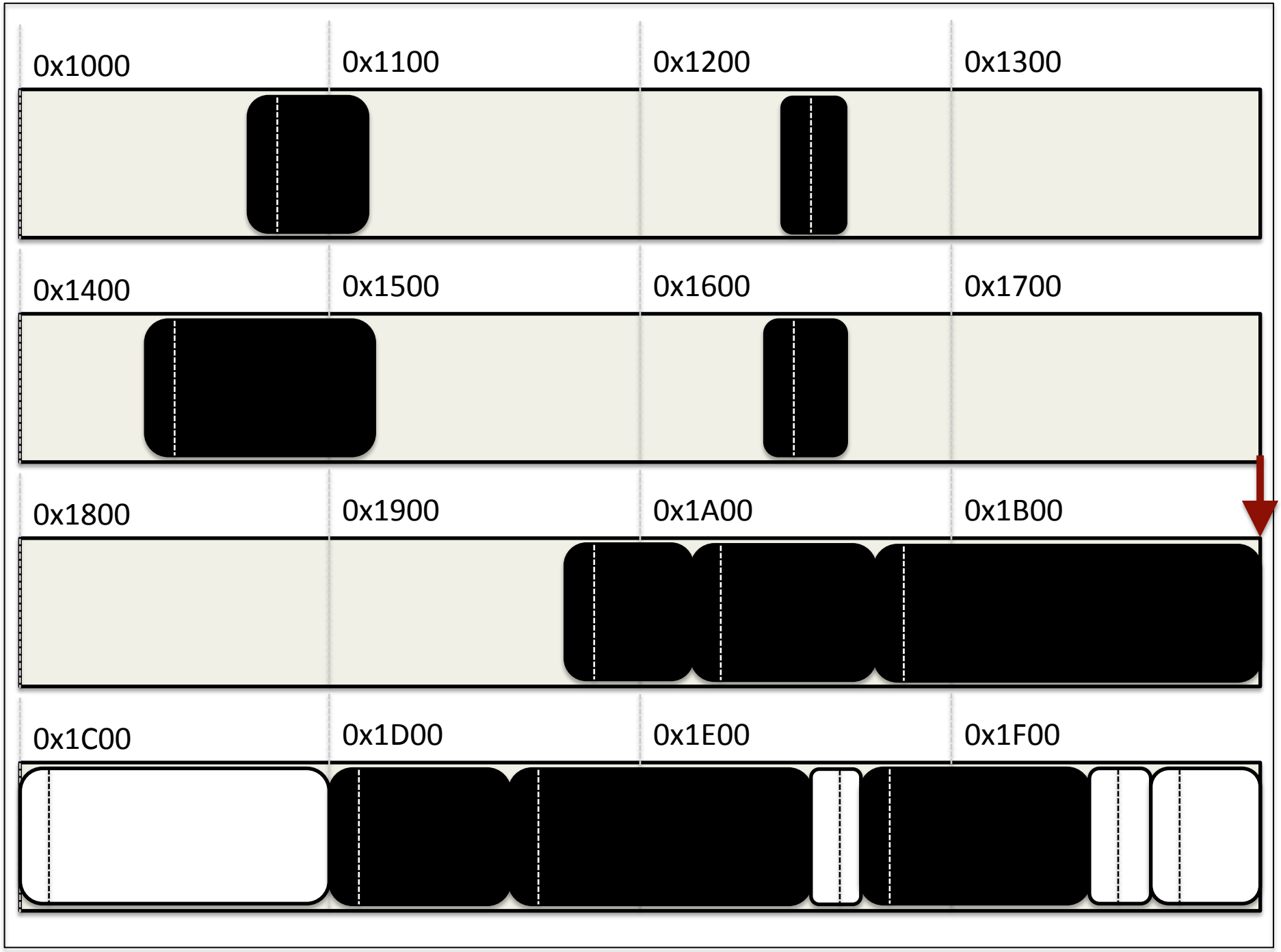
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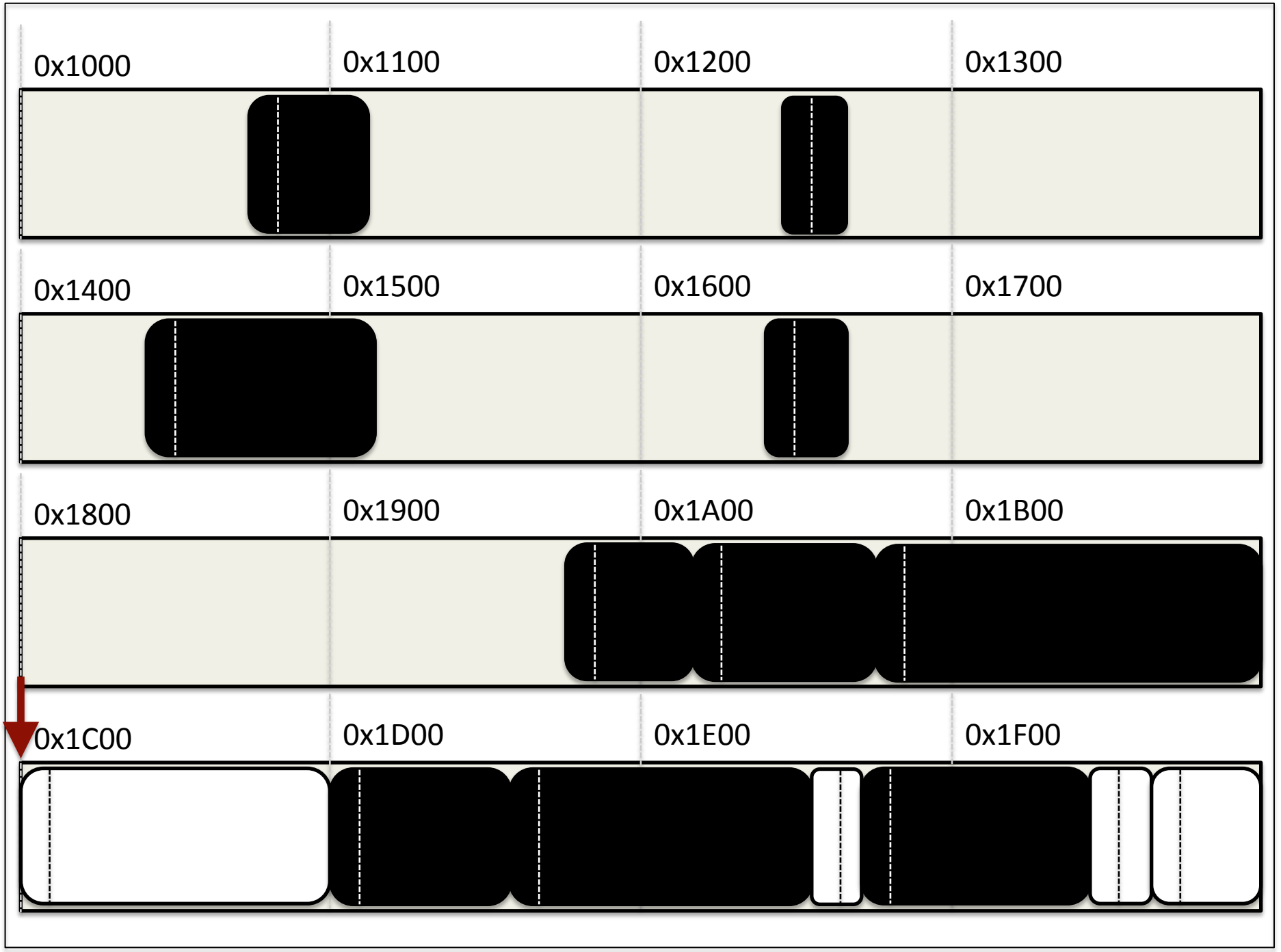
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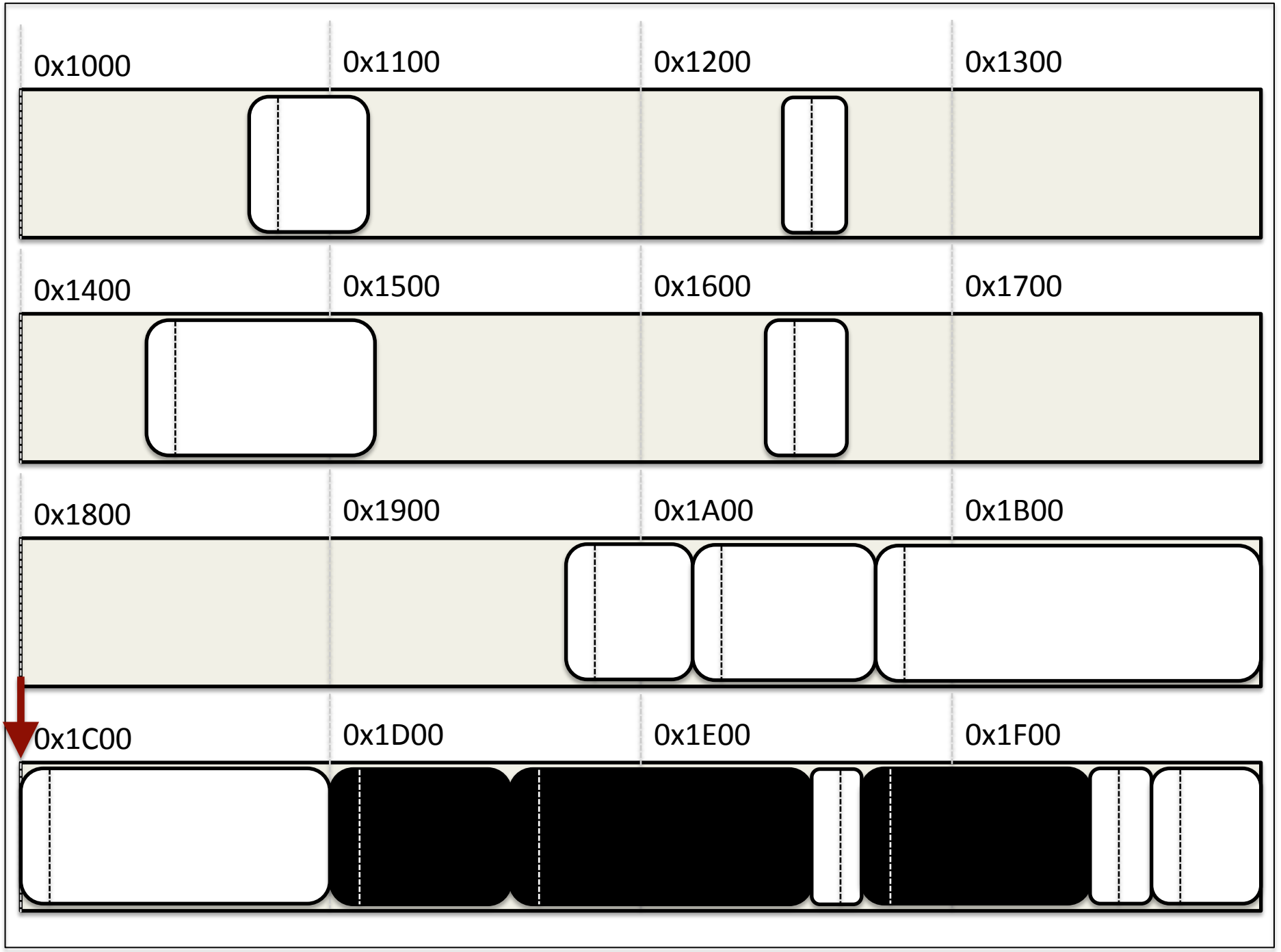
Finishing Up

- Clear all mark bits
  - Reset the heap ready for the next collection
- Can alternate the mark bit between GCs
  - Allocate objects with mark bit set
  - Introduces complexity if you are using bit stealing
- Can clear as you go with the sweep phase
  - Once the pointer passes an object it is done with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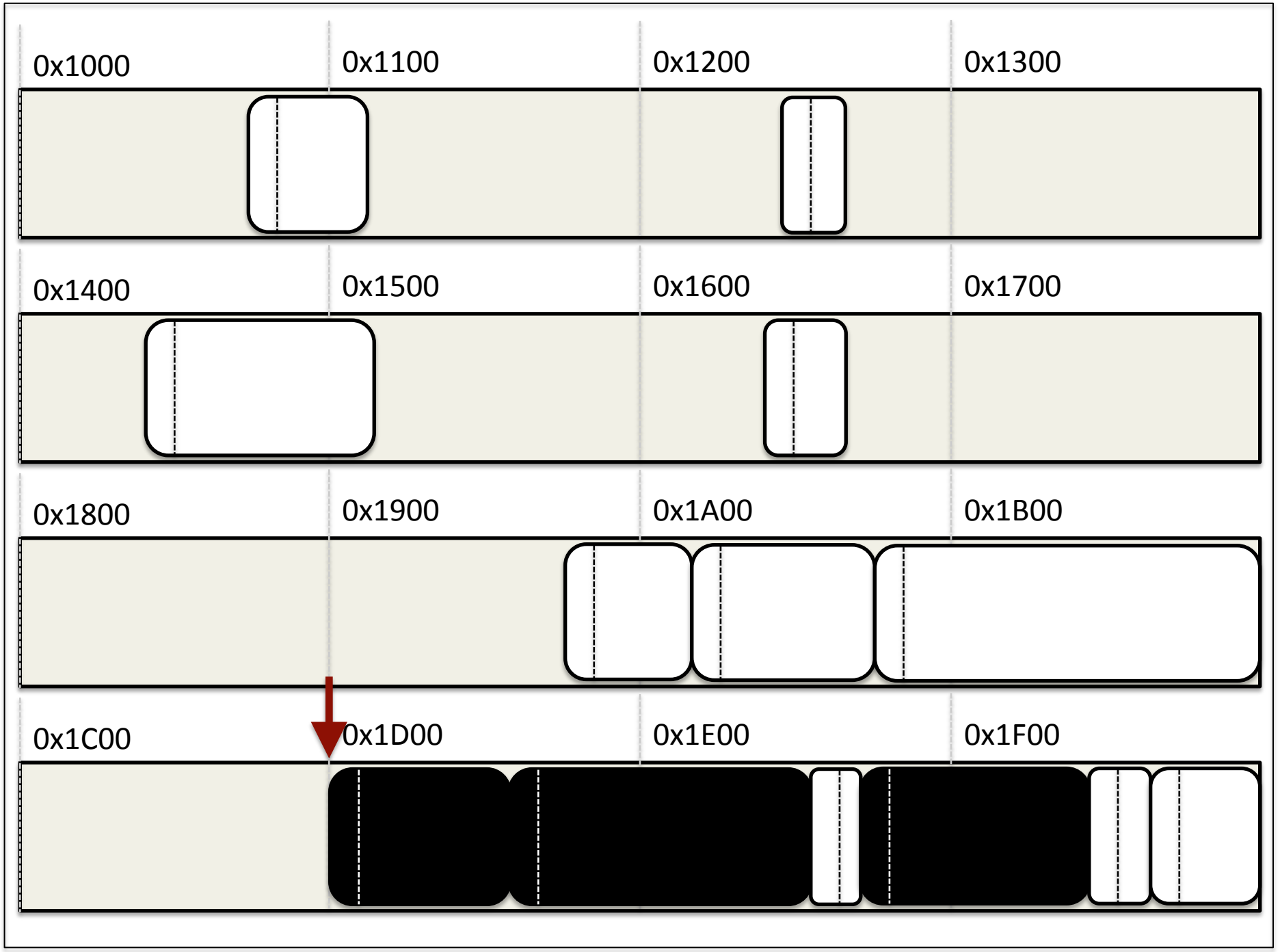
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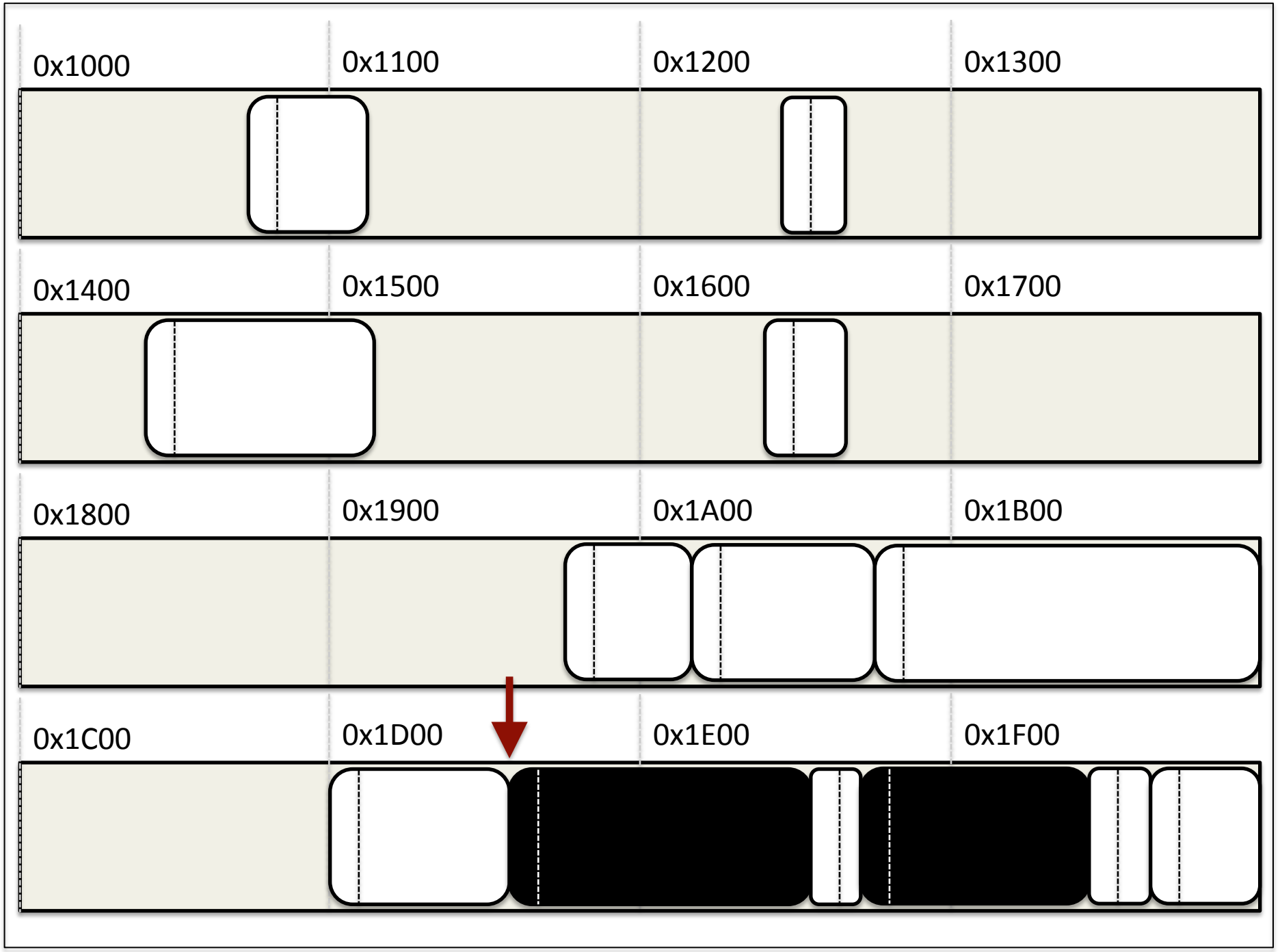
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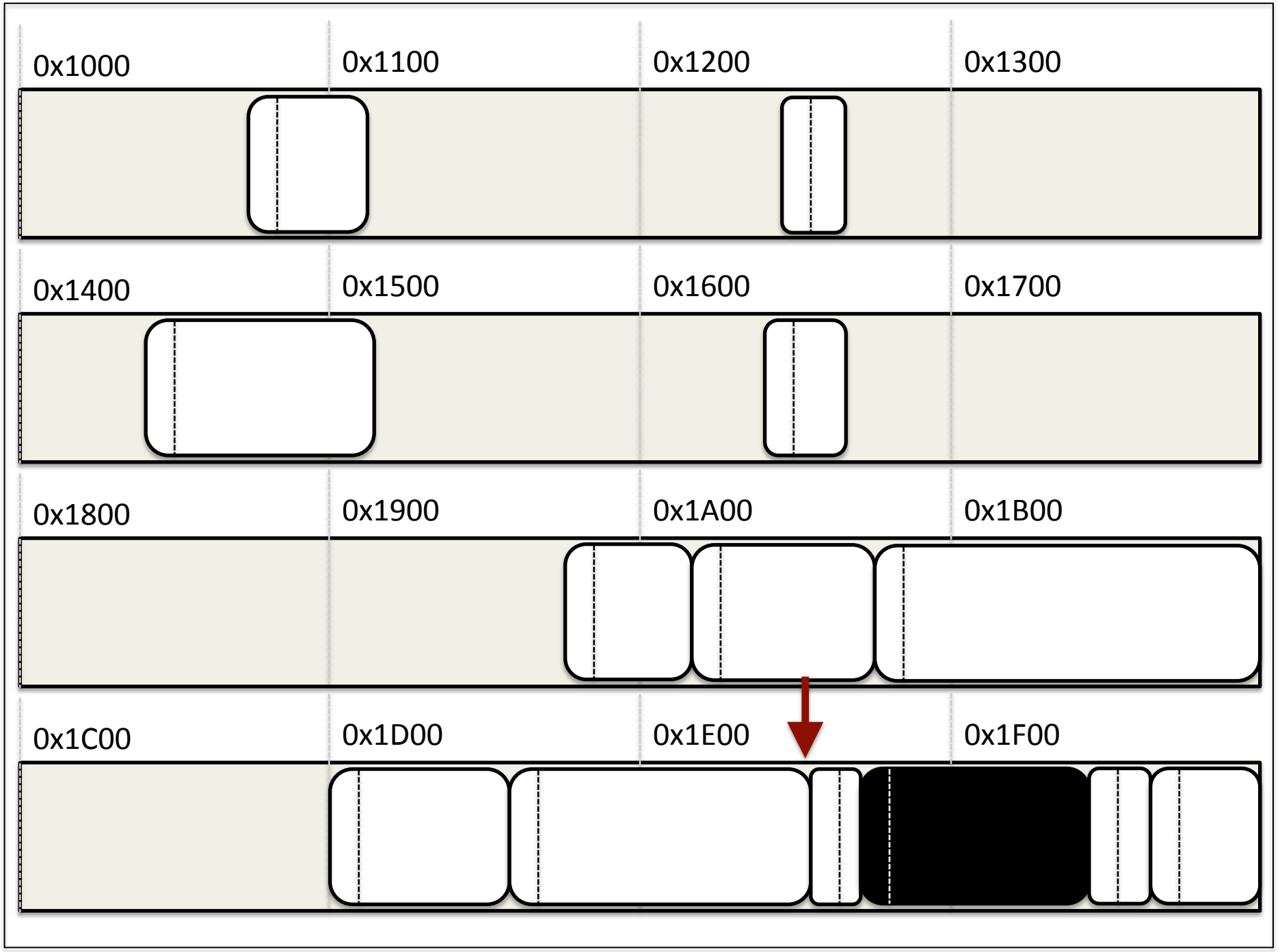
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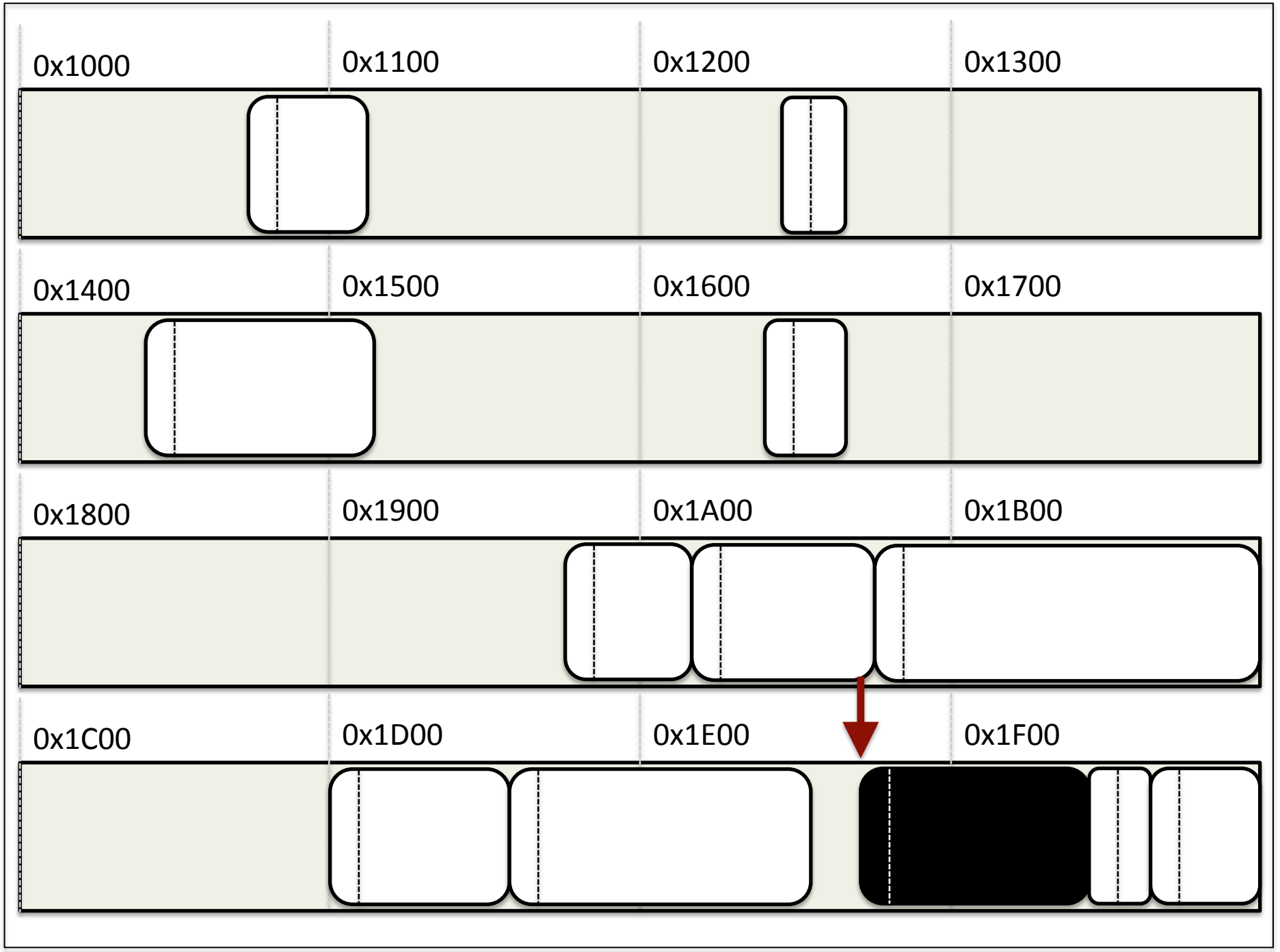
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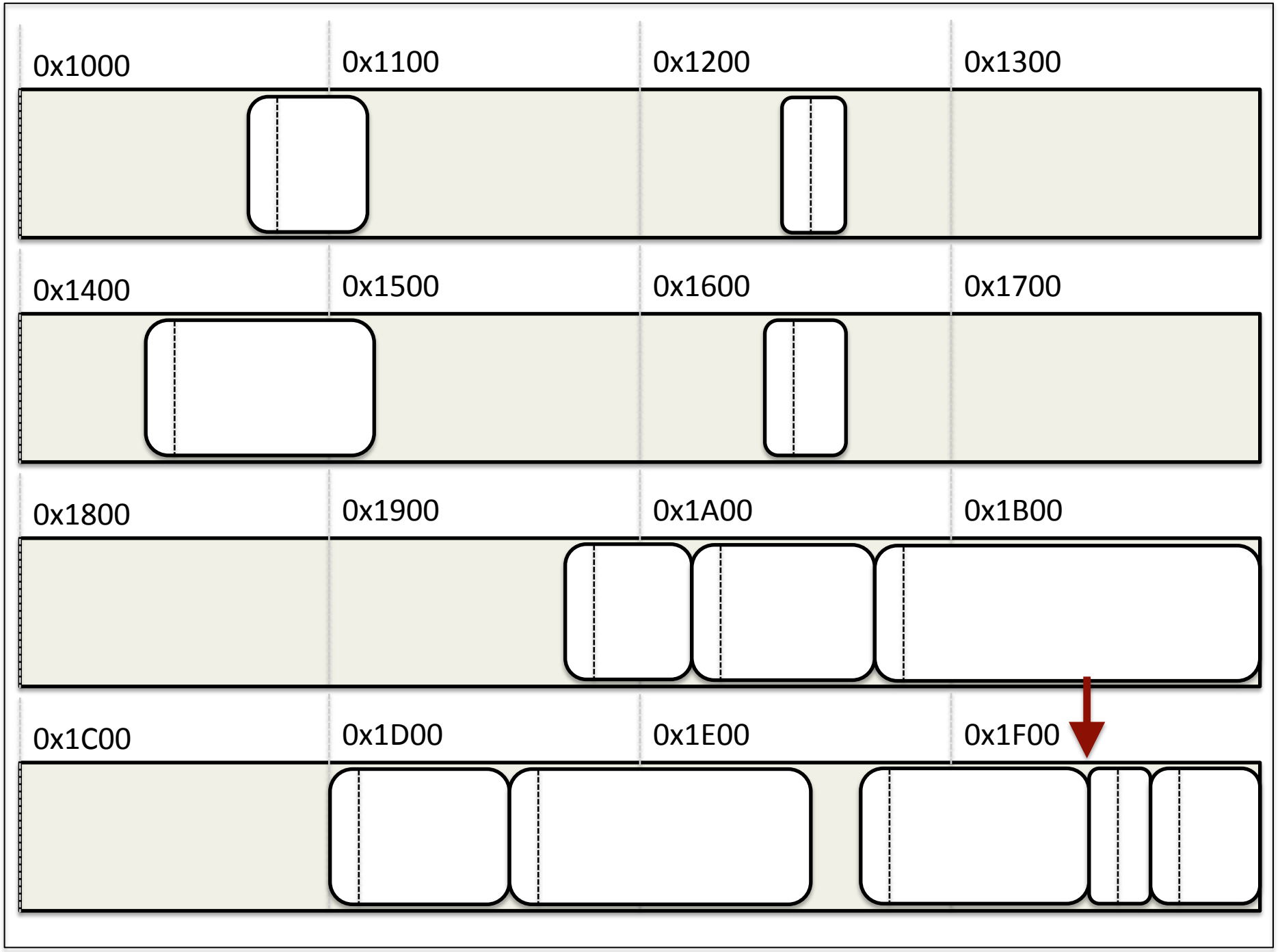
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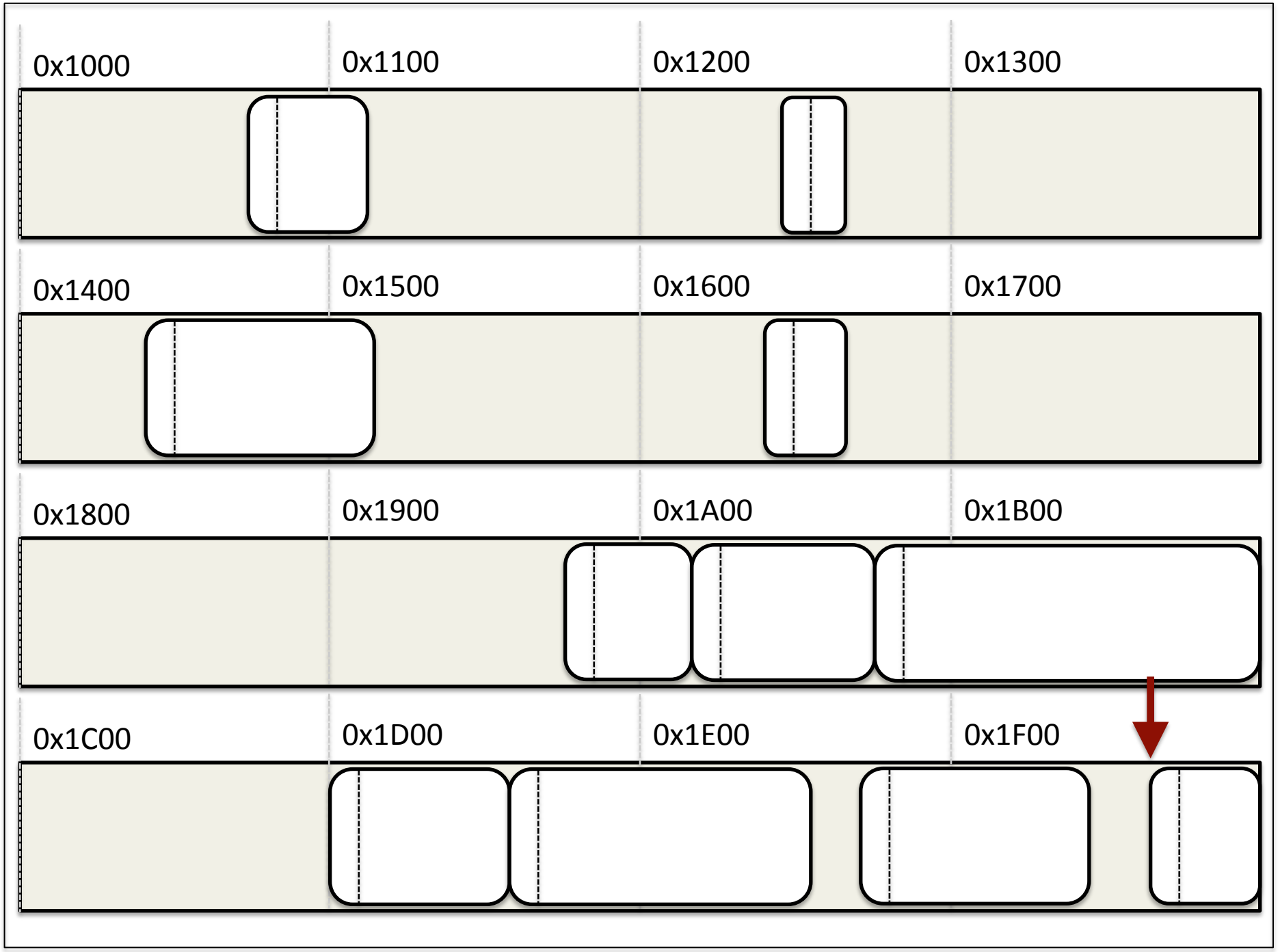
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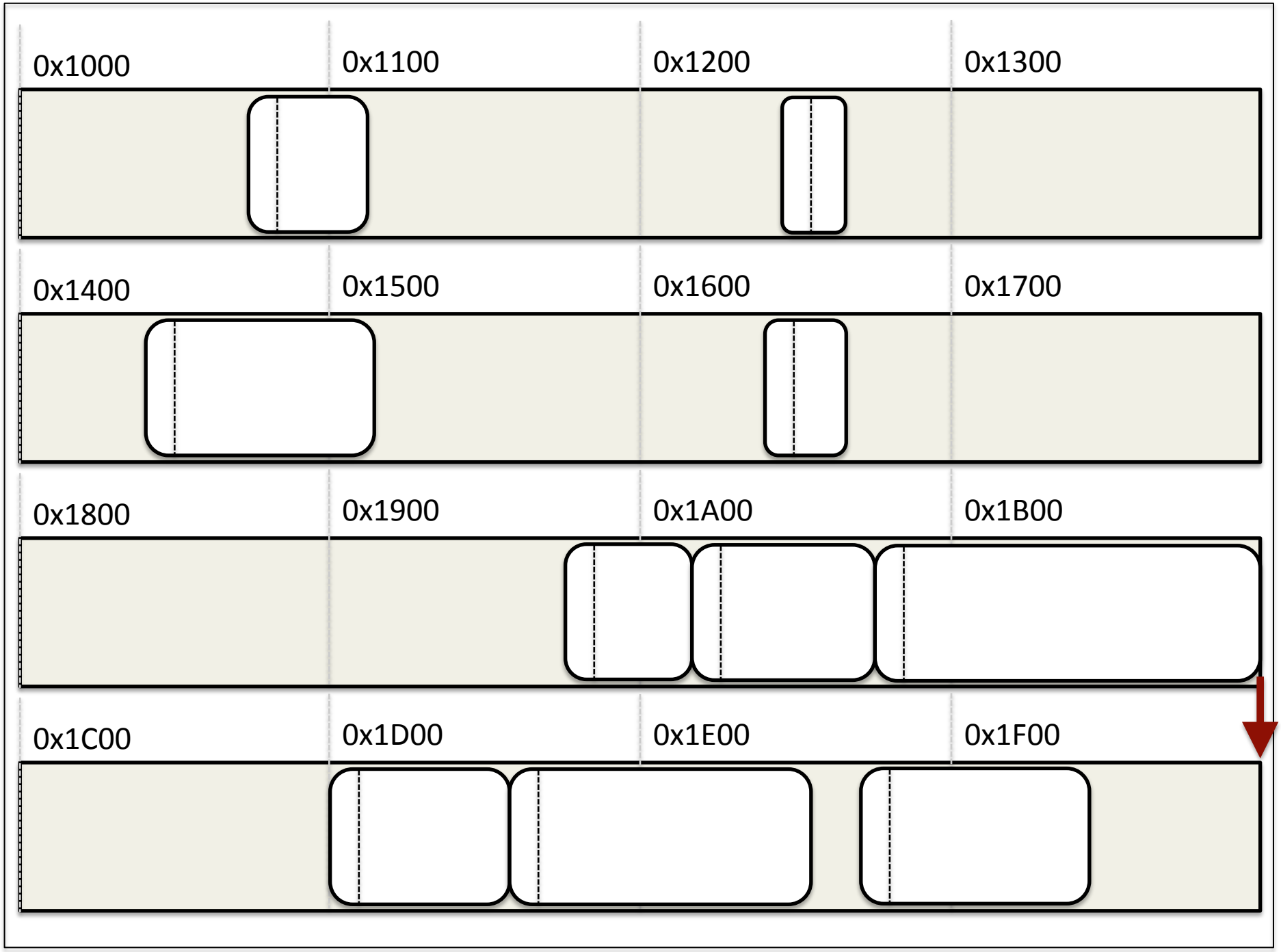
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Performance Characteristics

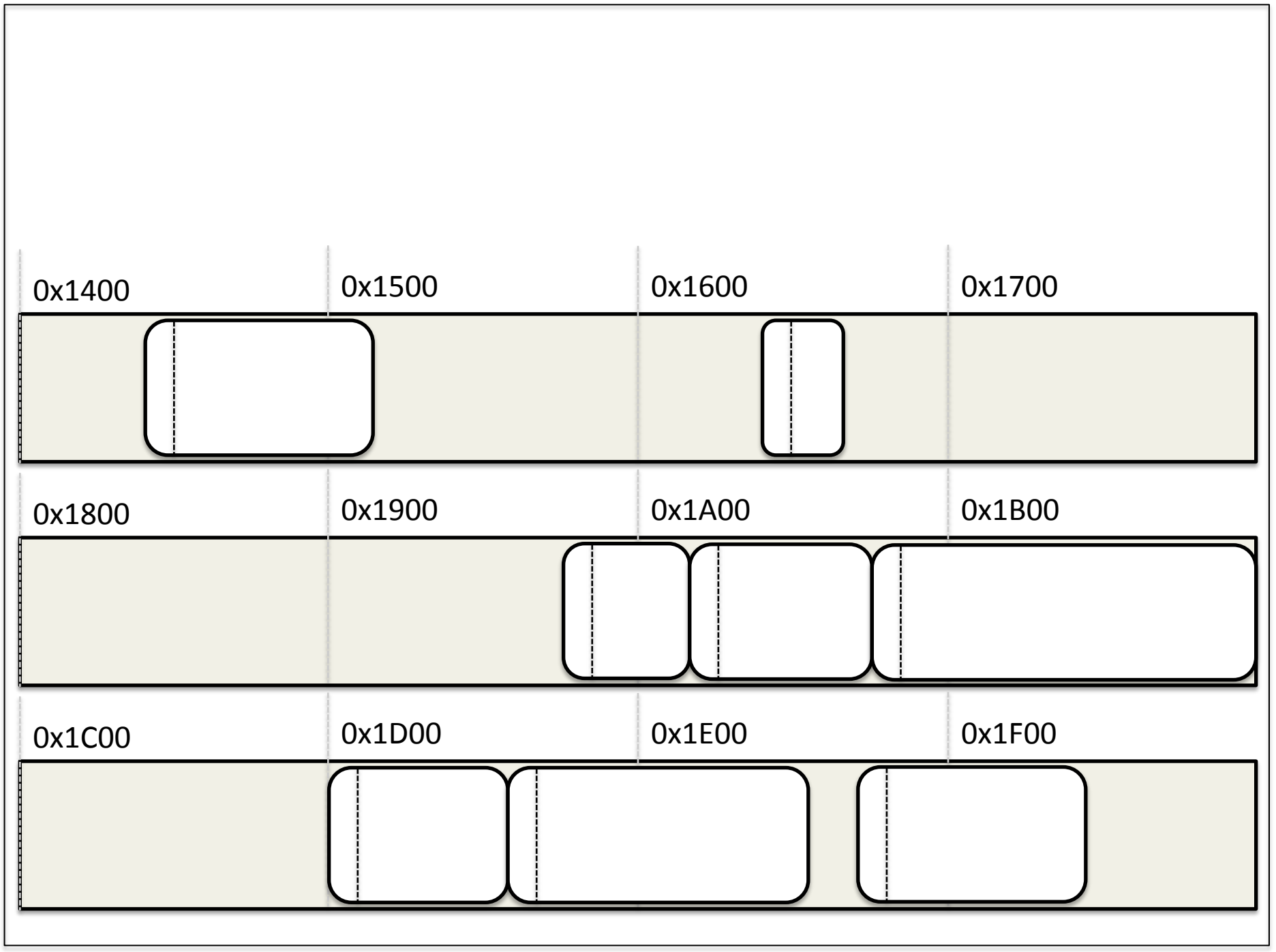
- Two passes over the heap
  - First phase random(ish) access
  - Second phase linear
- Not good for the cache
  - Second phase can be mitigated by prefetching
  - Mutator's cache completely blown

Mark and Sweep Allocation

- Sweep phase creates holes in the memory space
  - Known as fragmentation
- Allocator needs to fit objects to those holes
- Danger of wasting space if no object fits

Allocation Strategies

- First Fit
  - Put new object in the first hole that's large enough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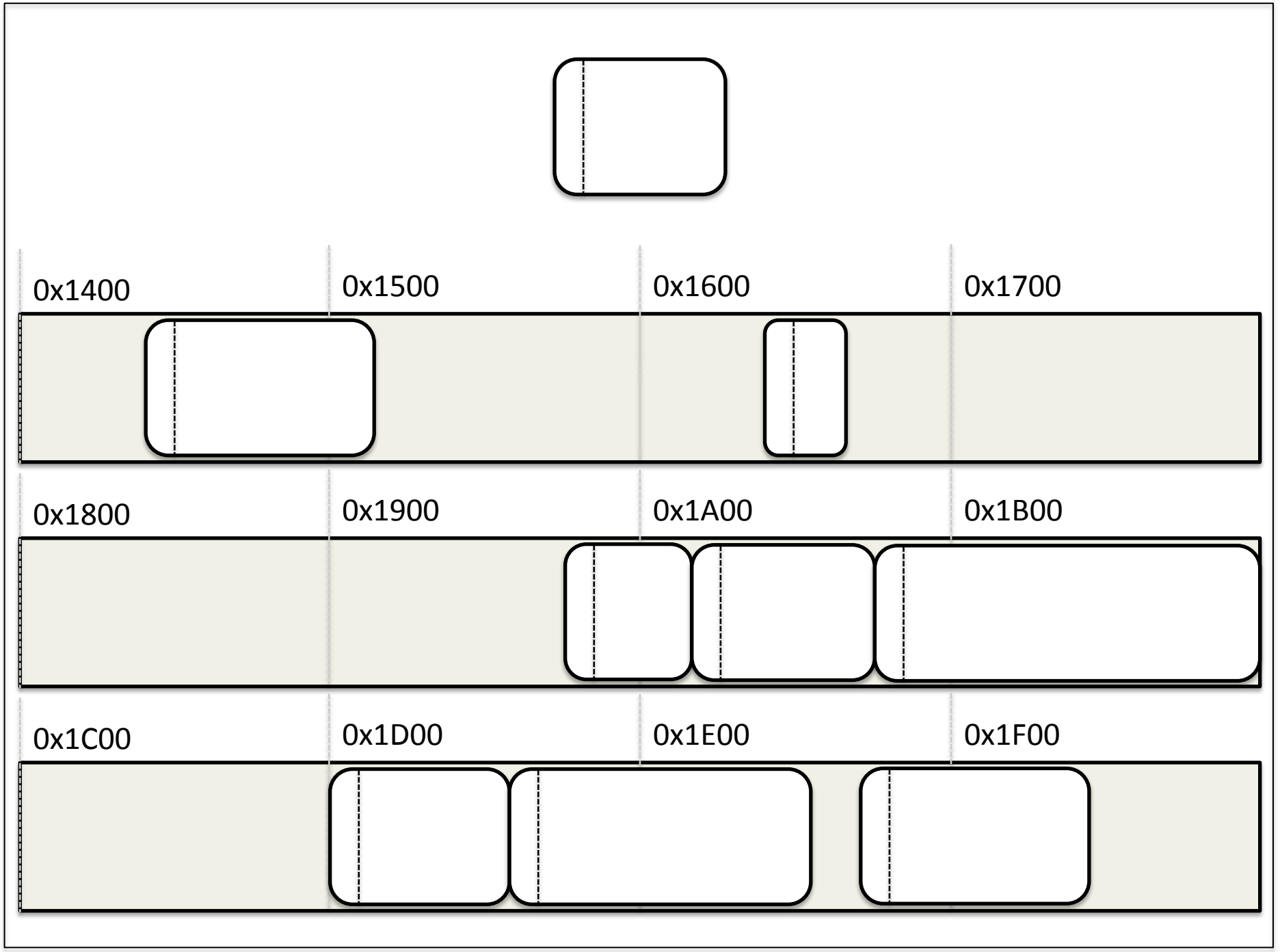
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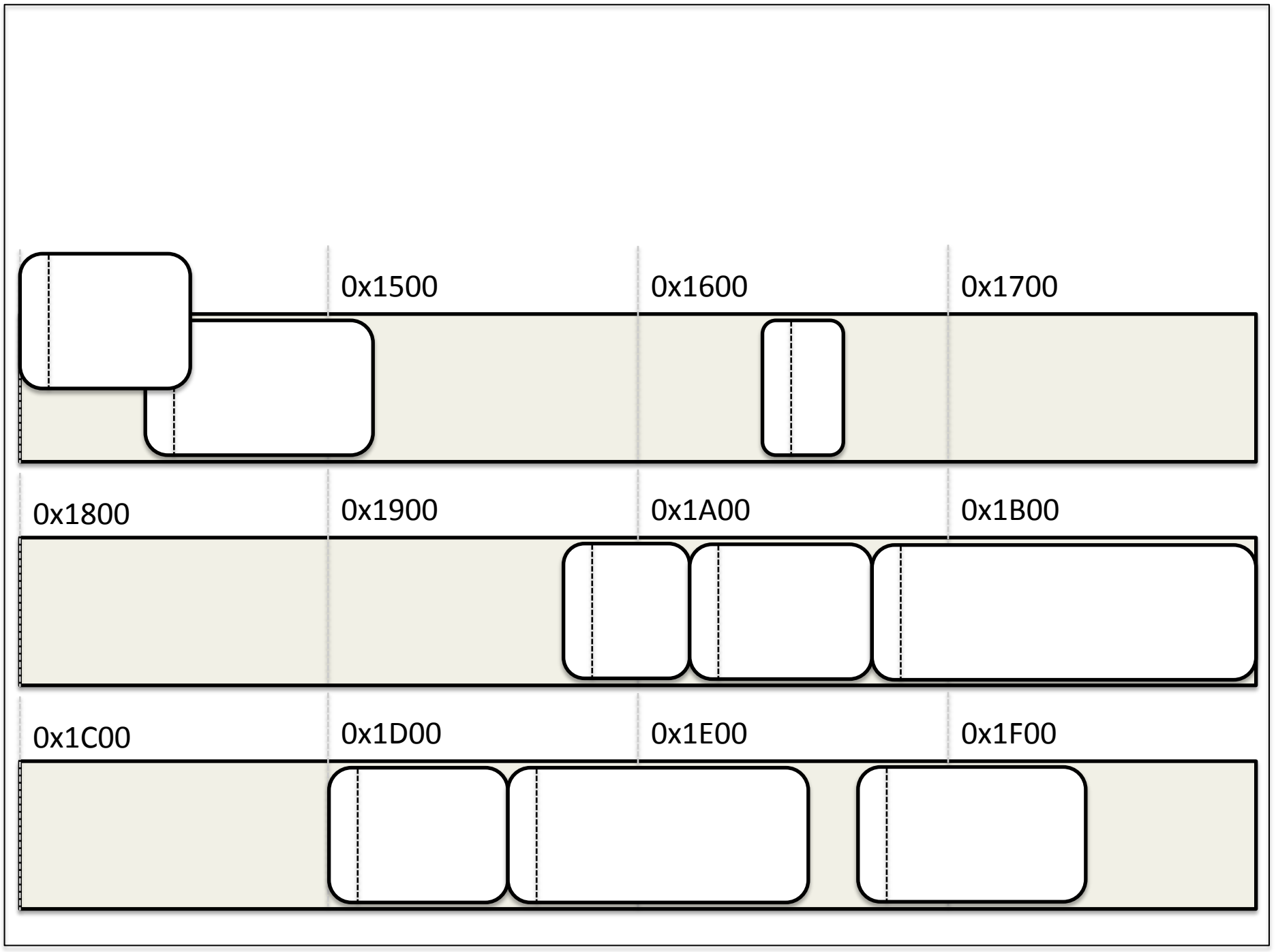
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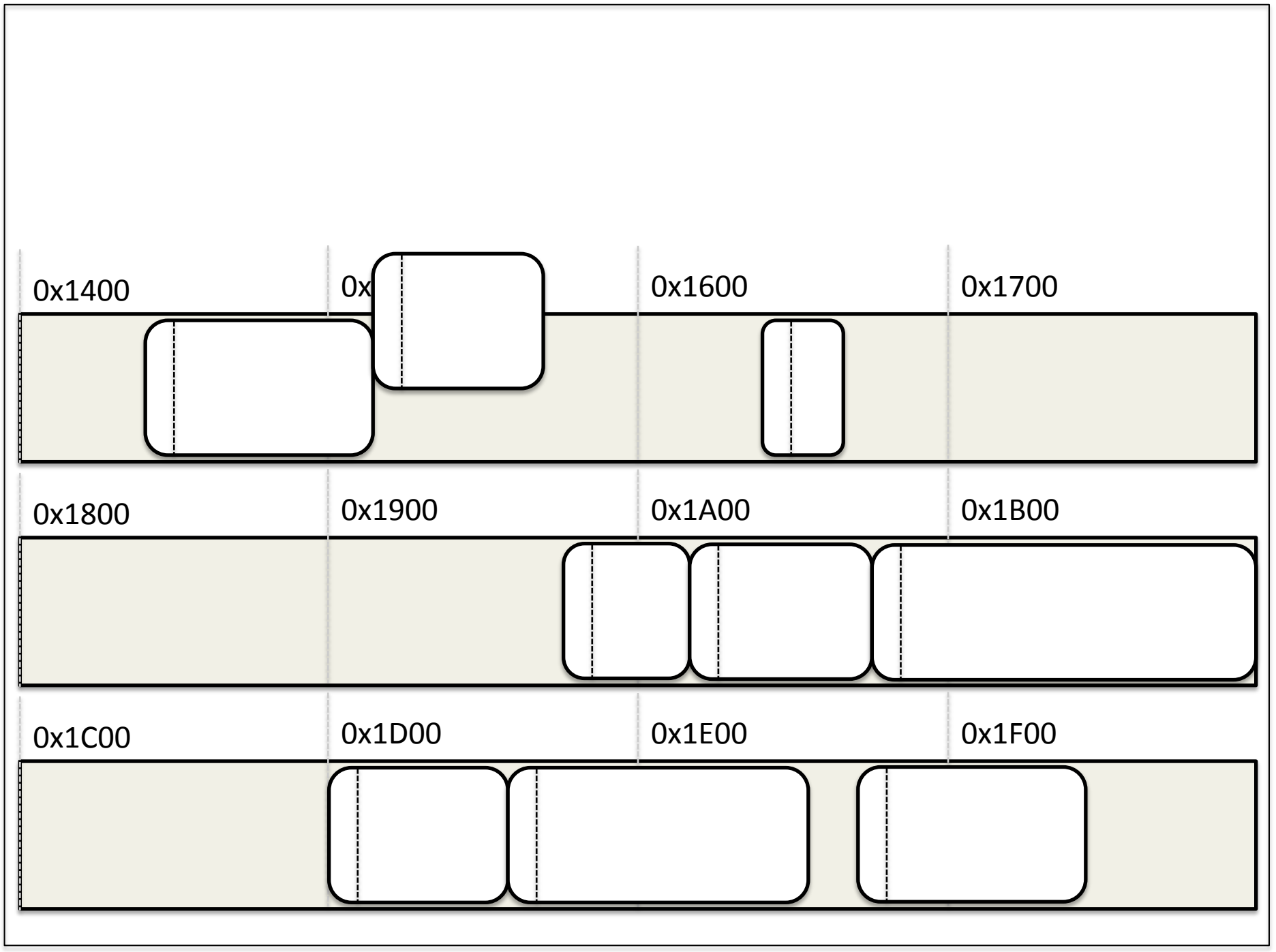
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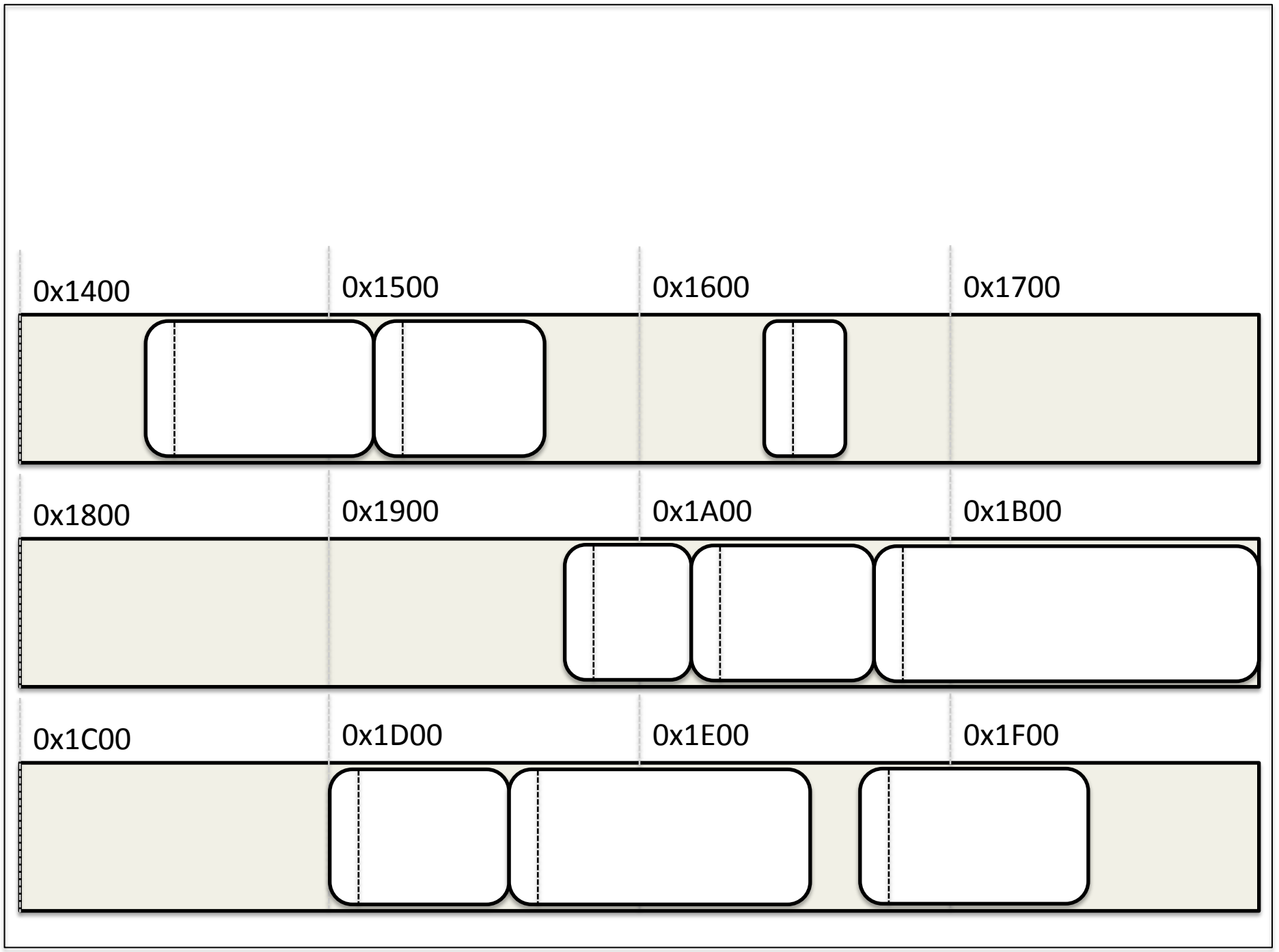
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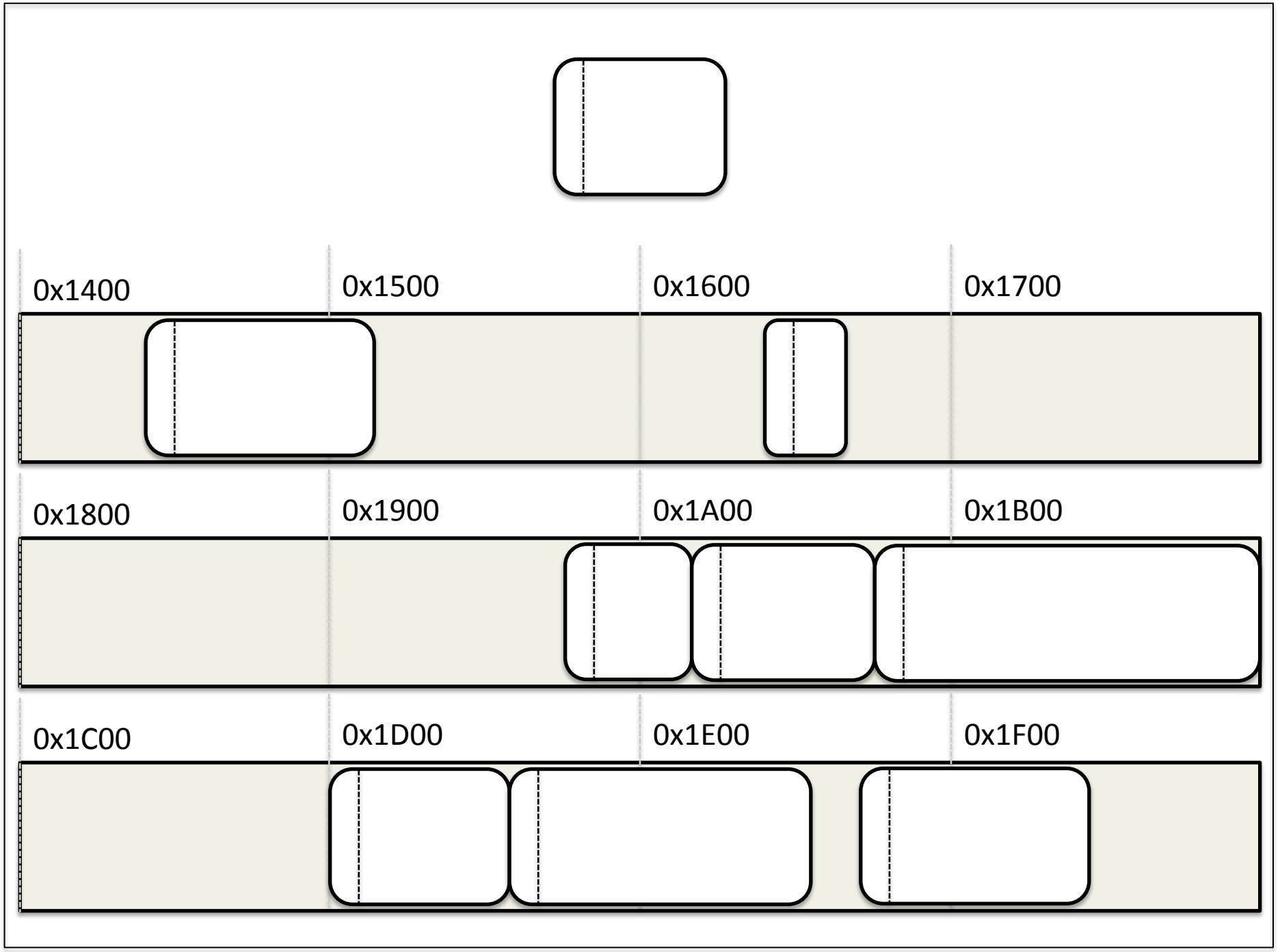
Allocation Strategies

- First Fit
  - Put new object in the first hole that's large enough
- Best Fit
  - Scan the heap to find the hole that fits best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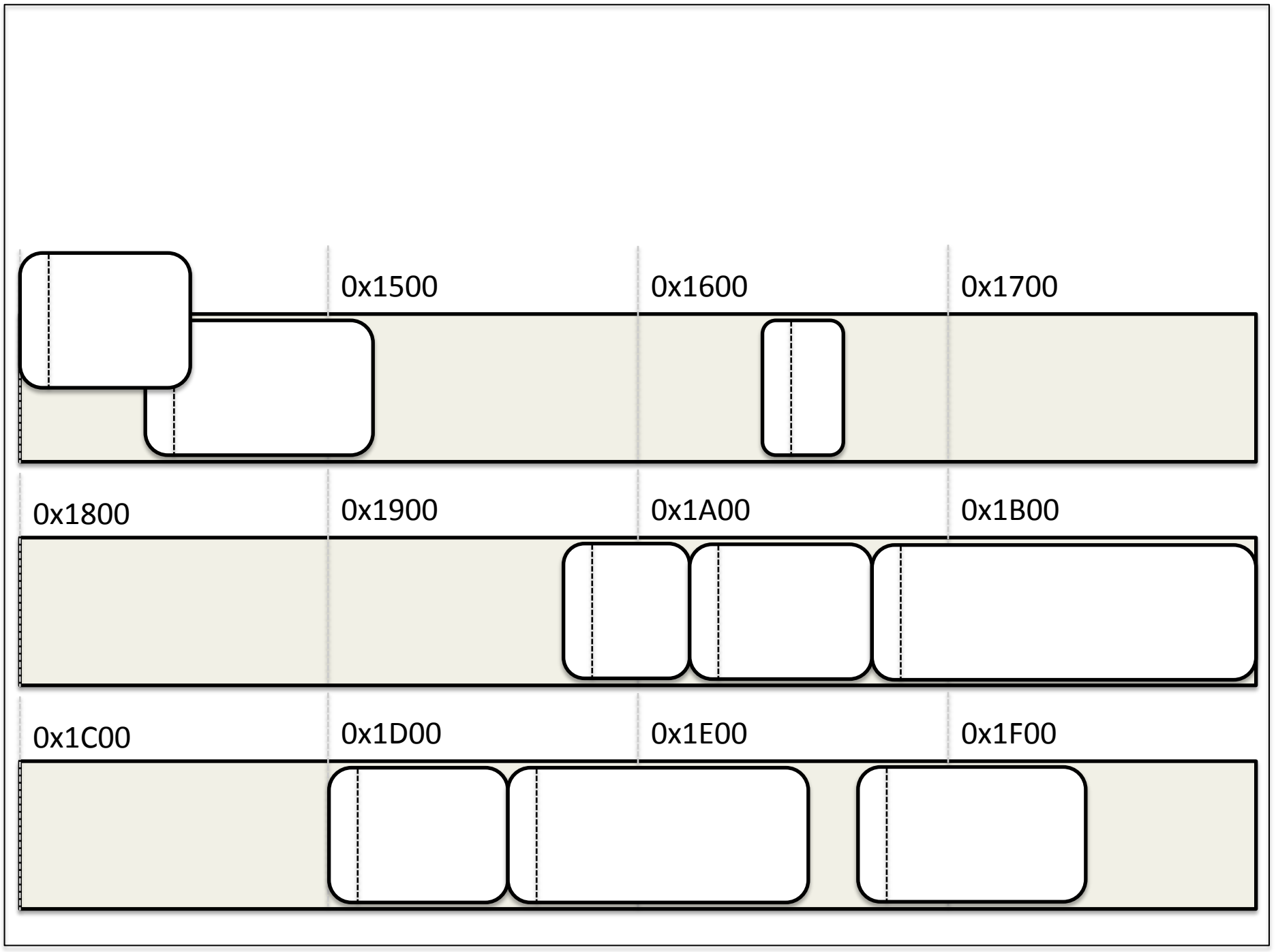
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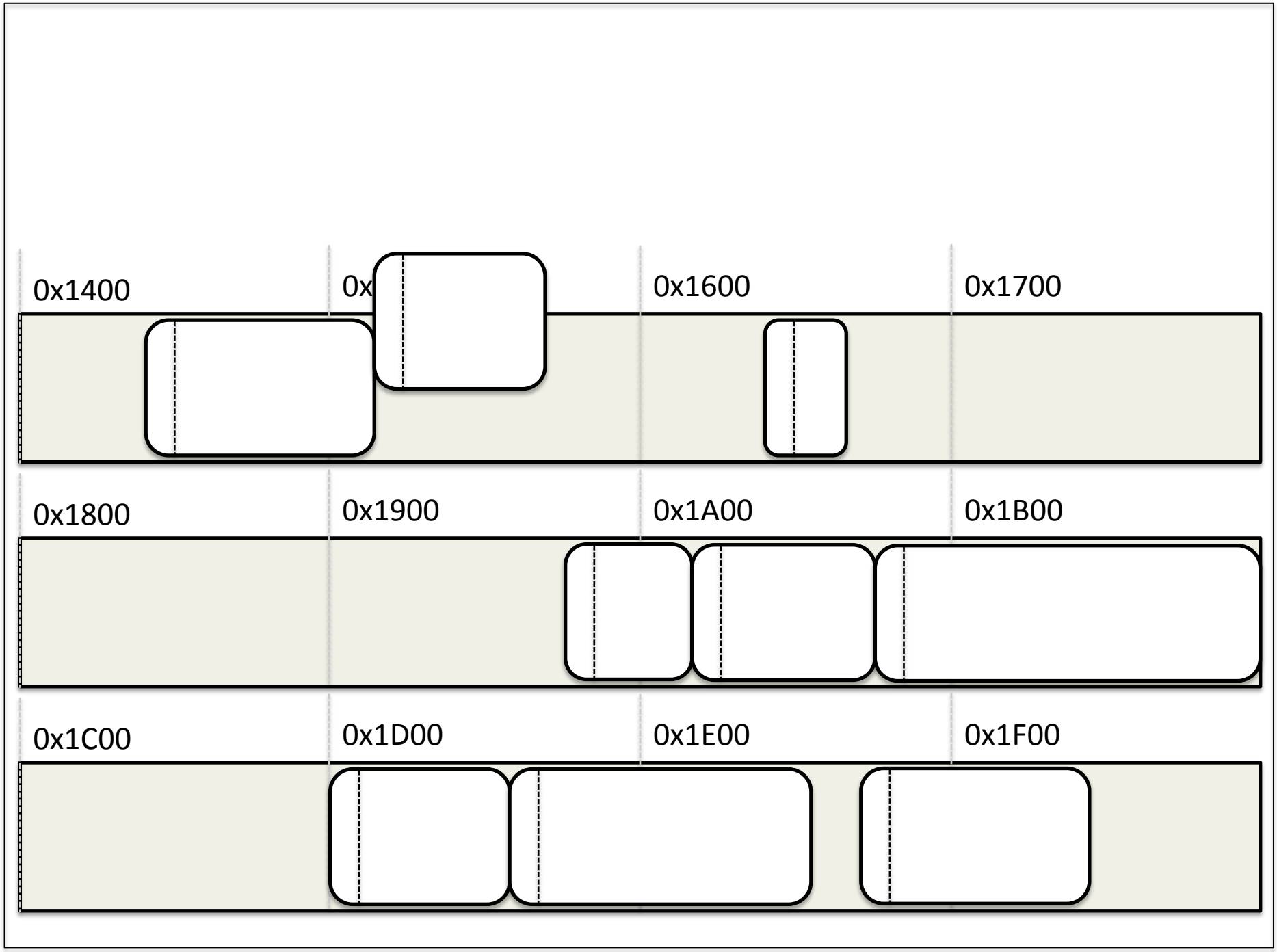
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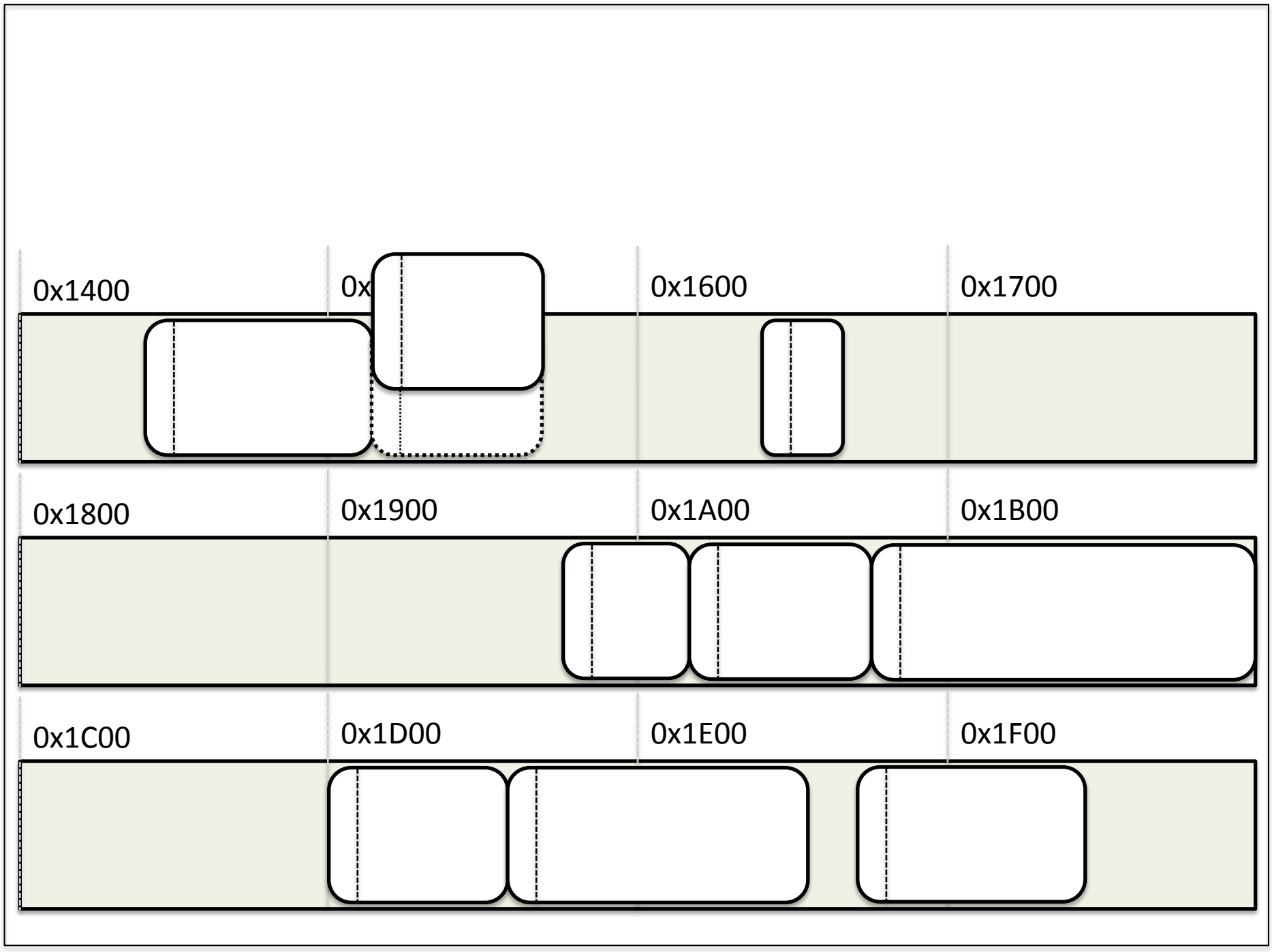
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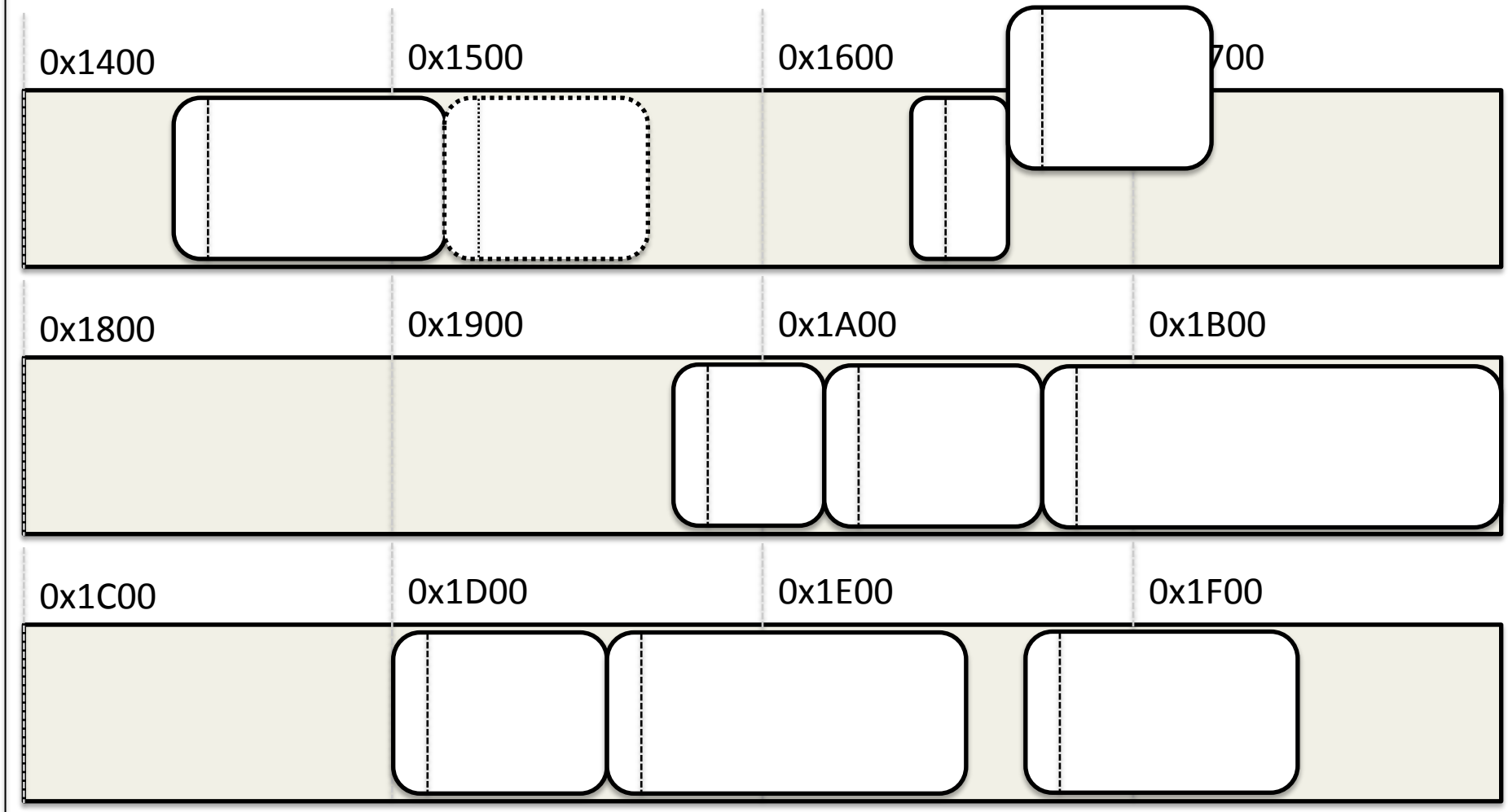
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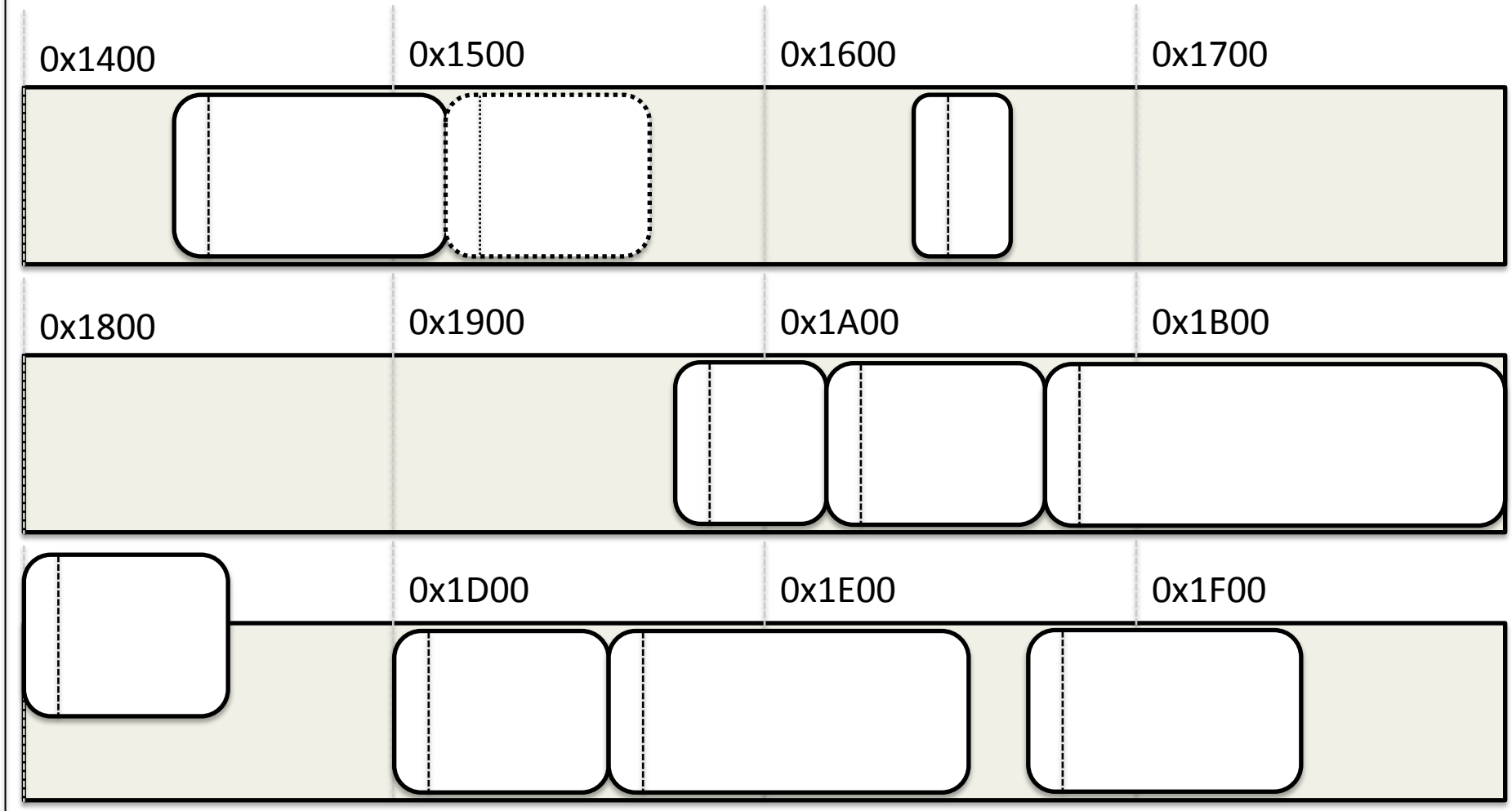
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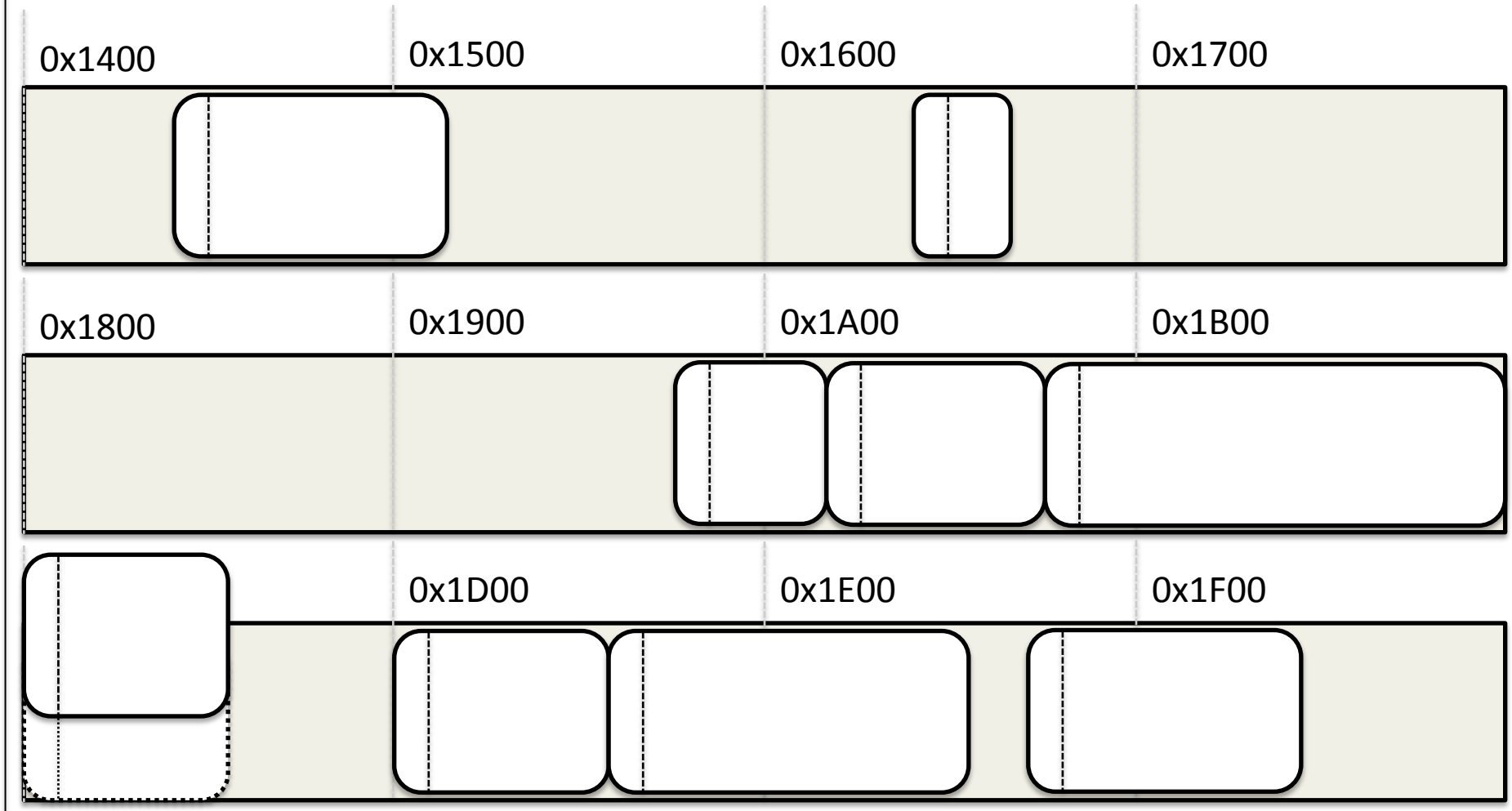
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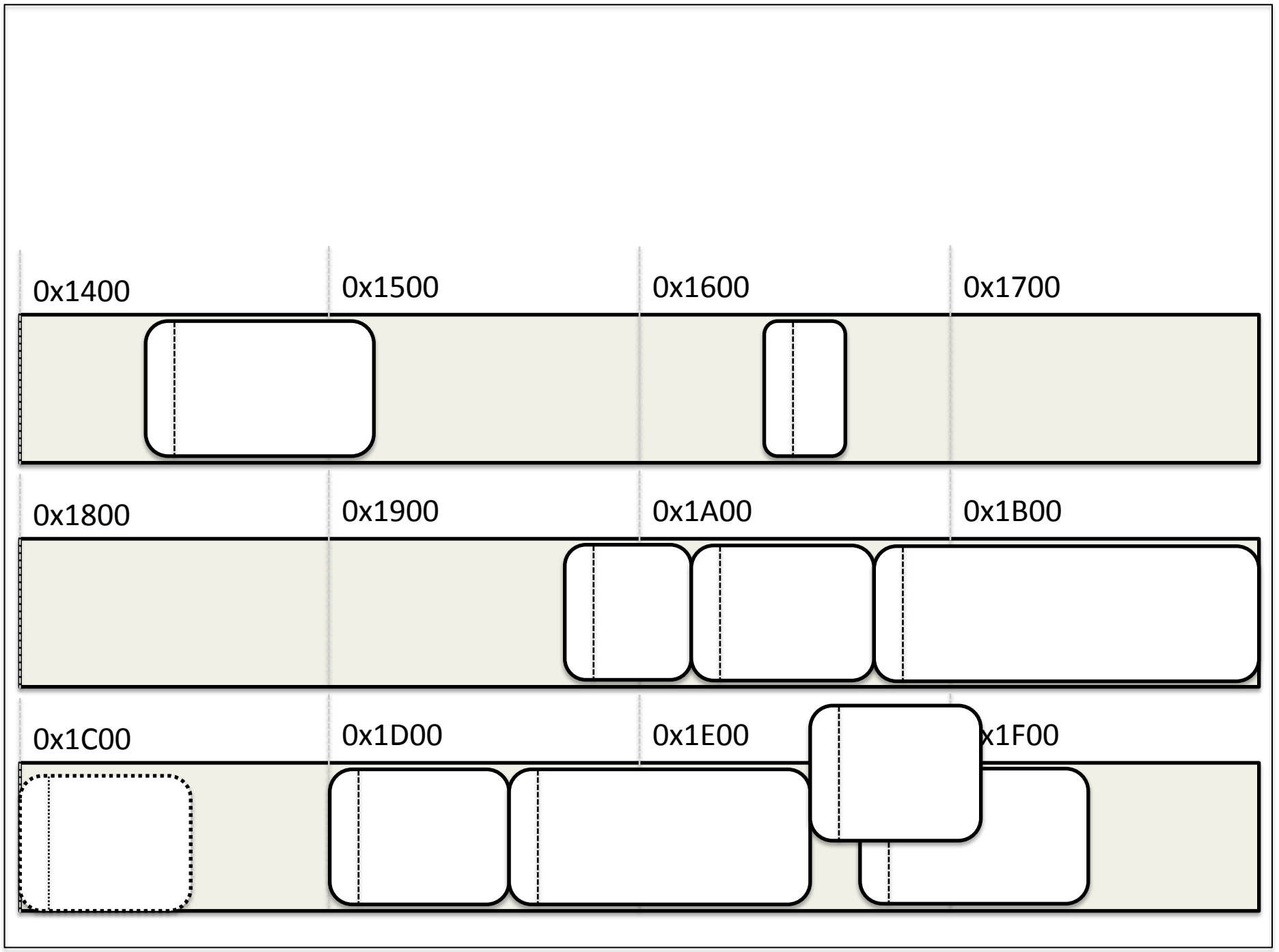
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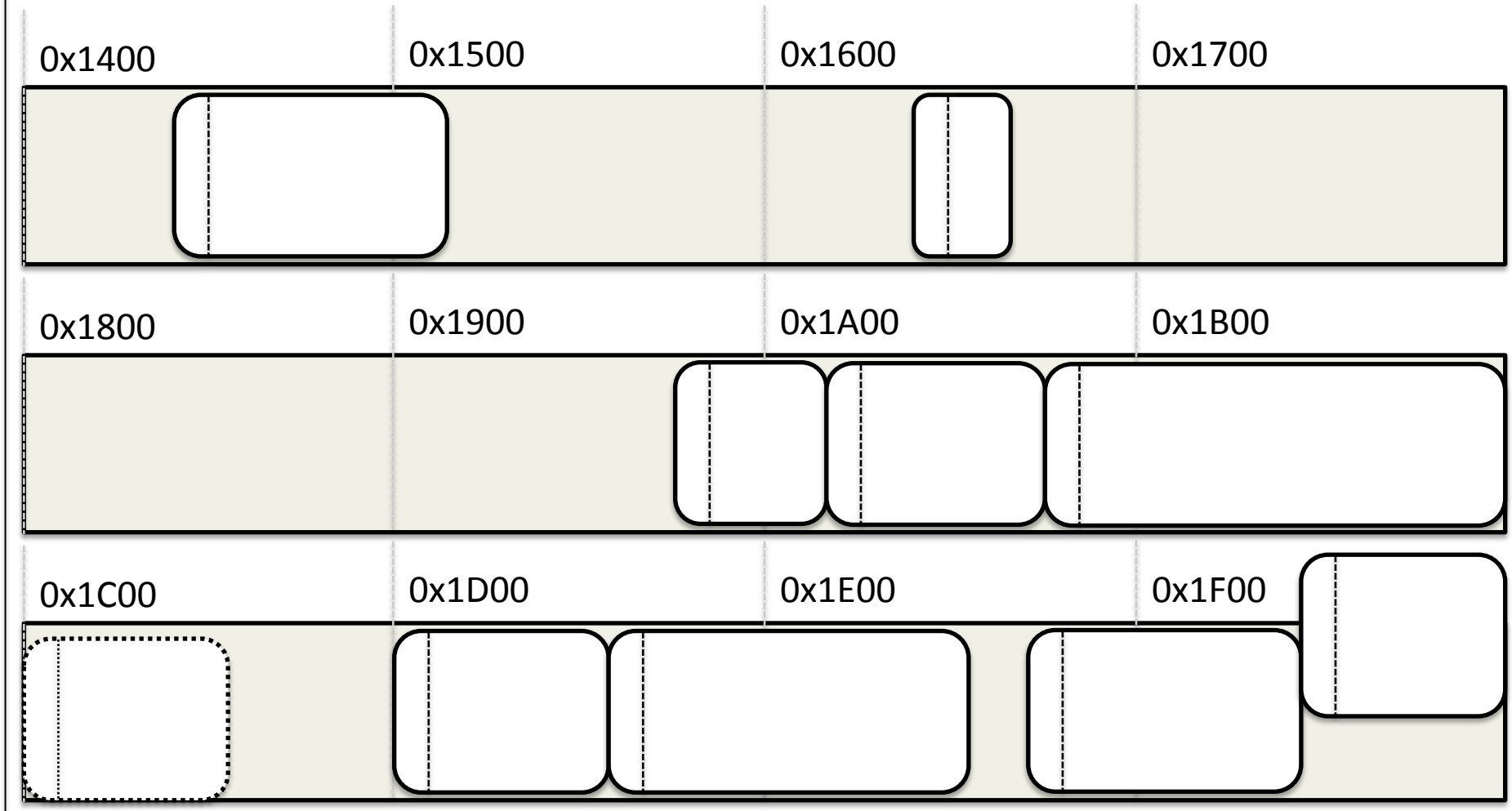
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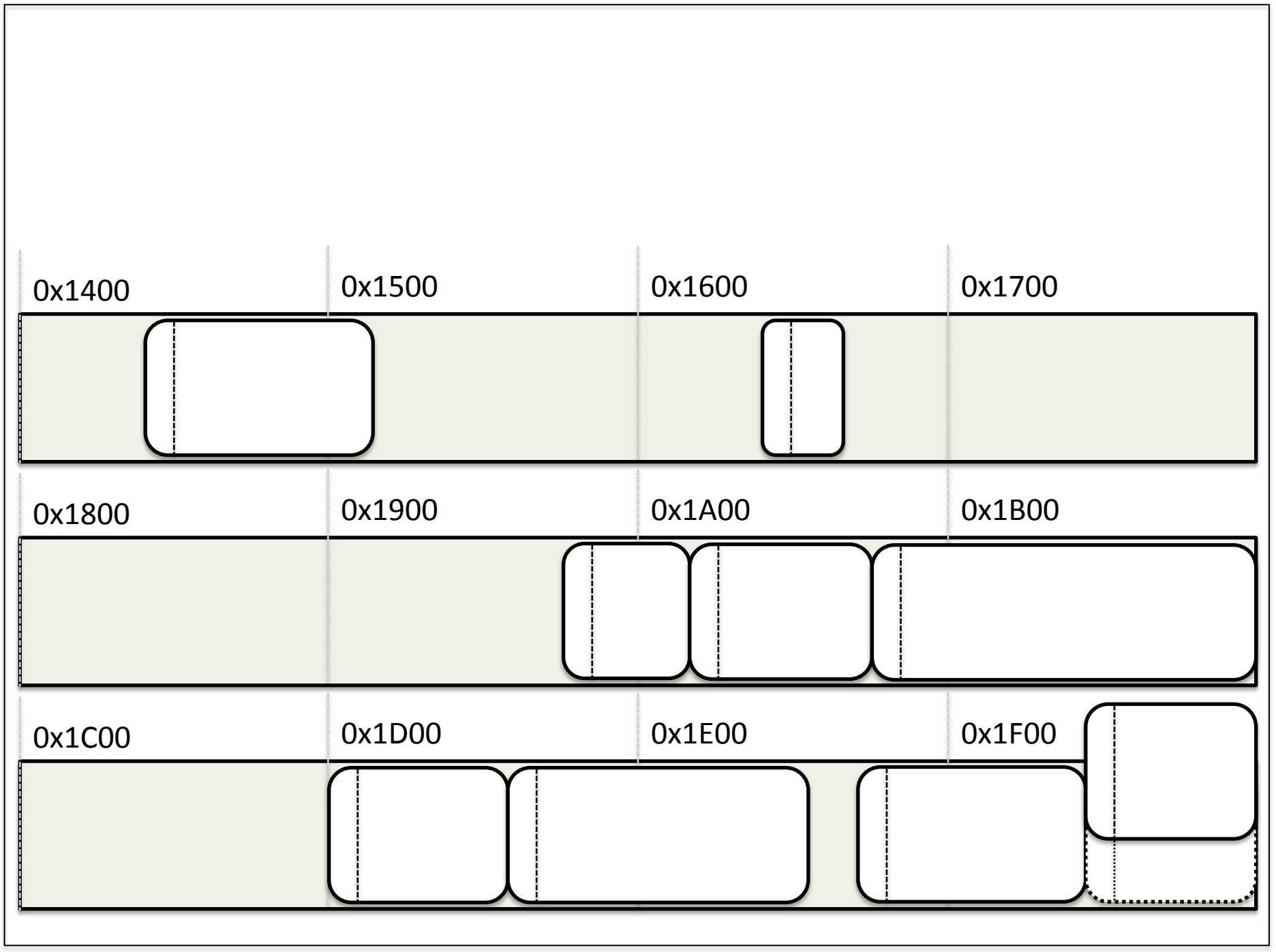
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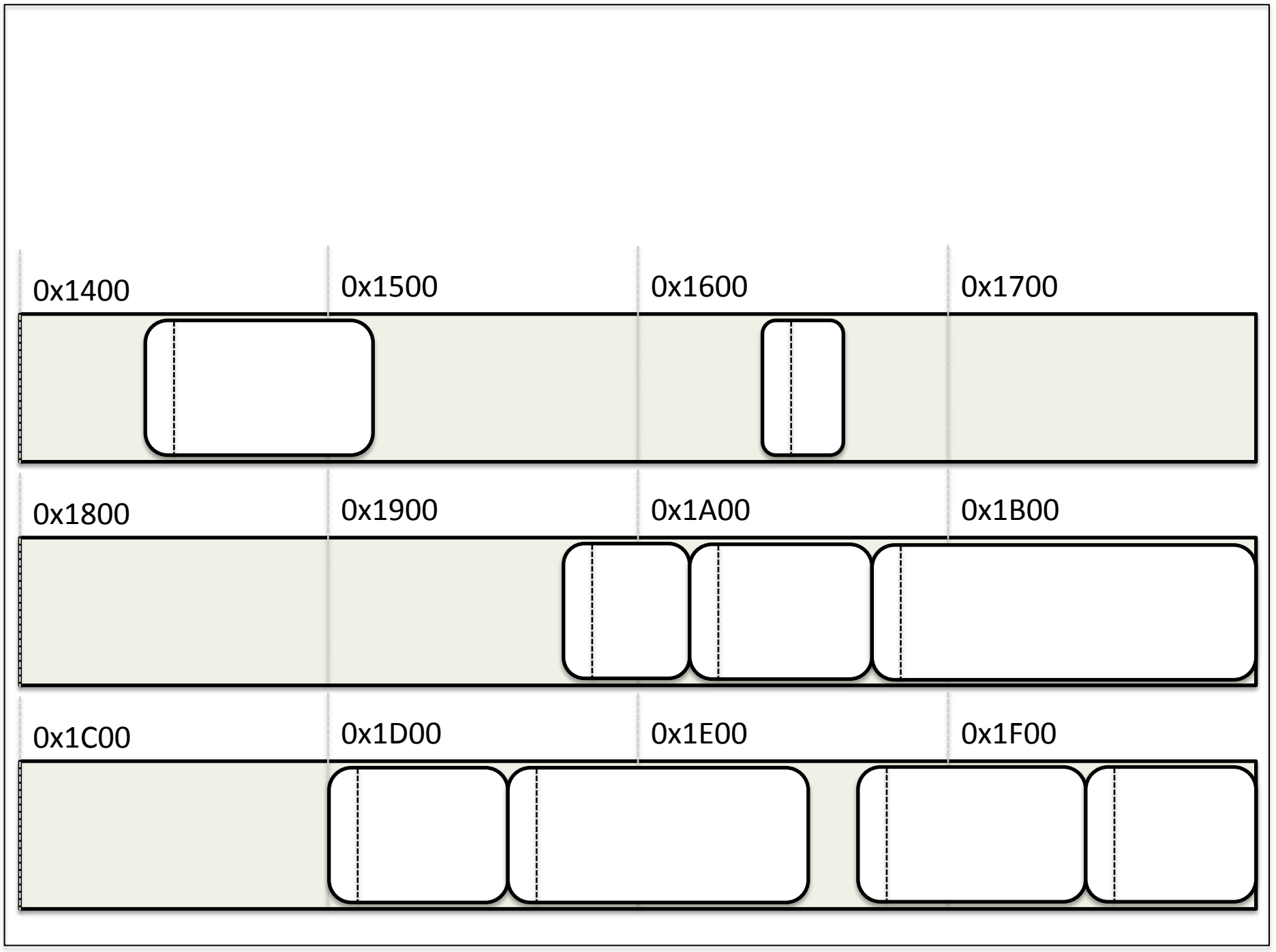
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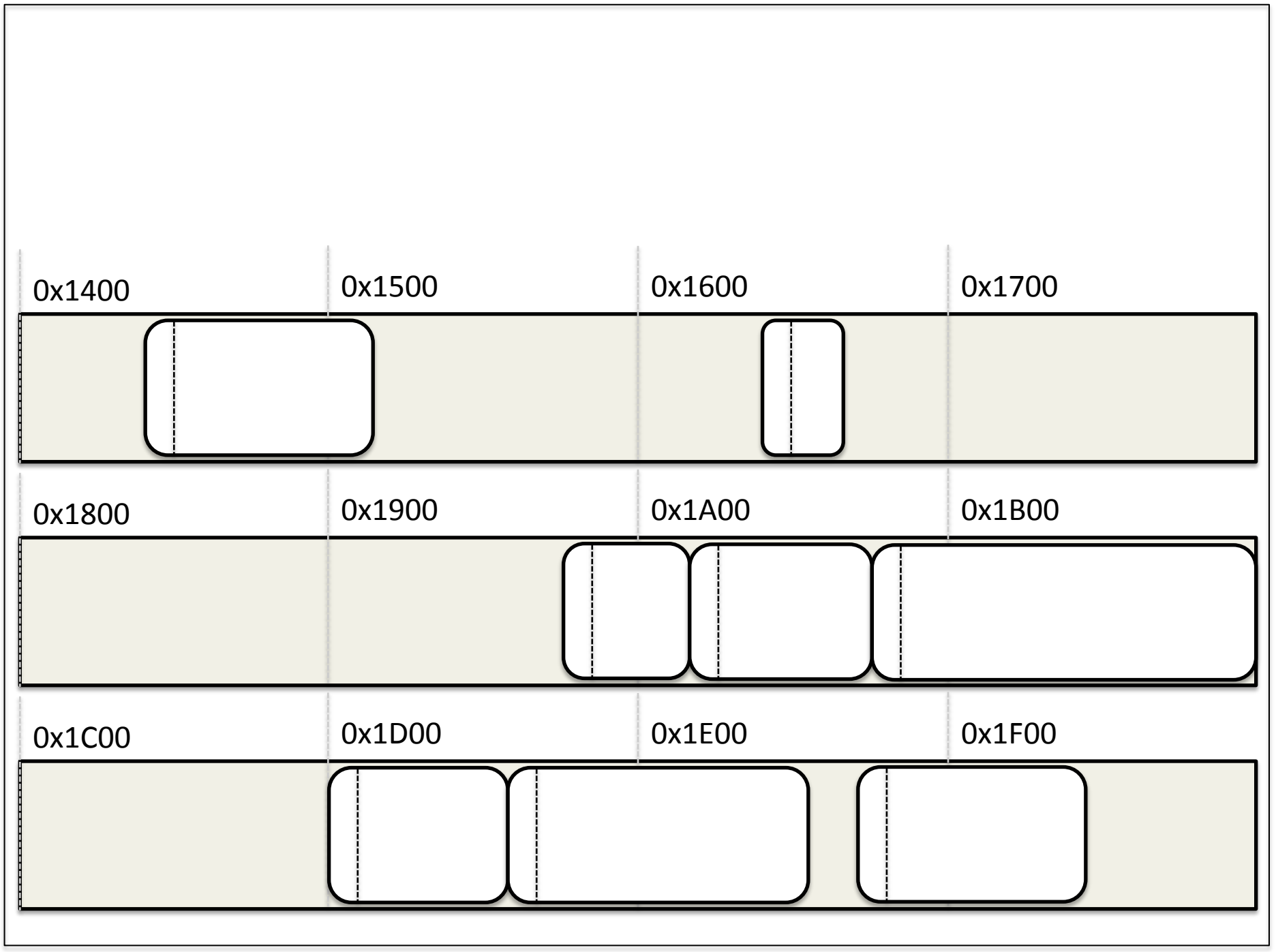
Allocation Strategies

- First Fit
  - Put new object in the first hole that's large enough
- Best Fit
  - Scan the heap to find the hole that fits best
- Free List
  - Maintain a sorted list of all holes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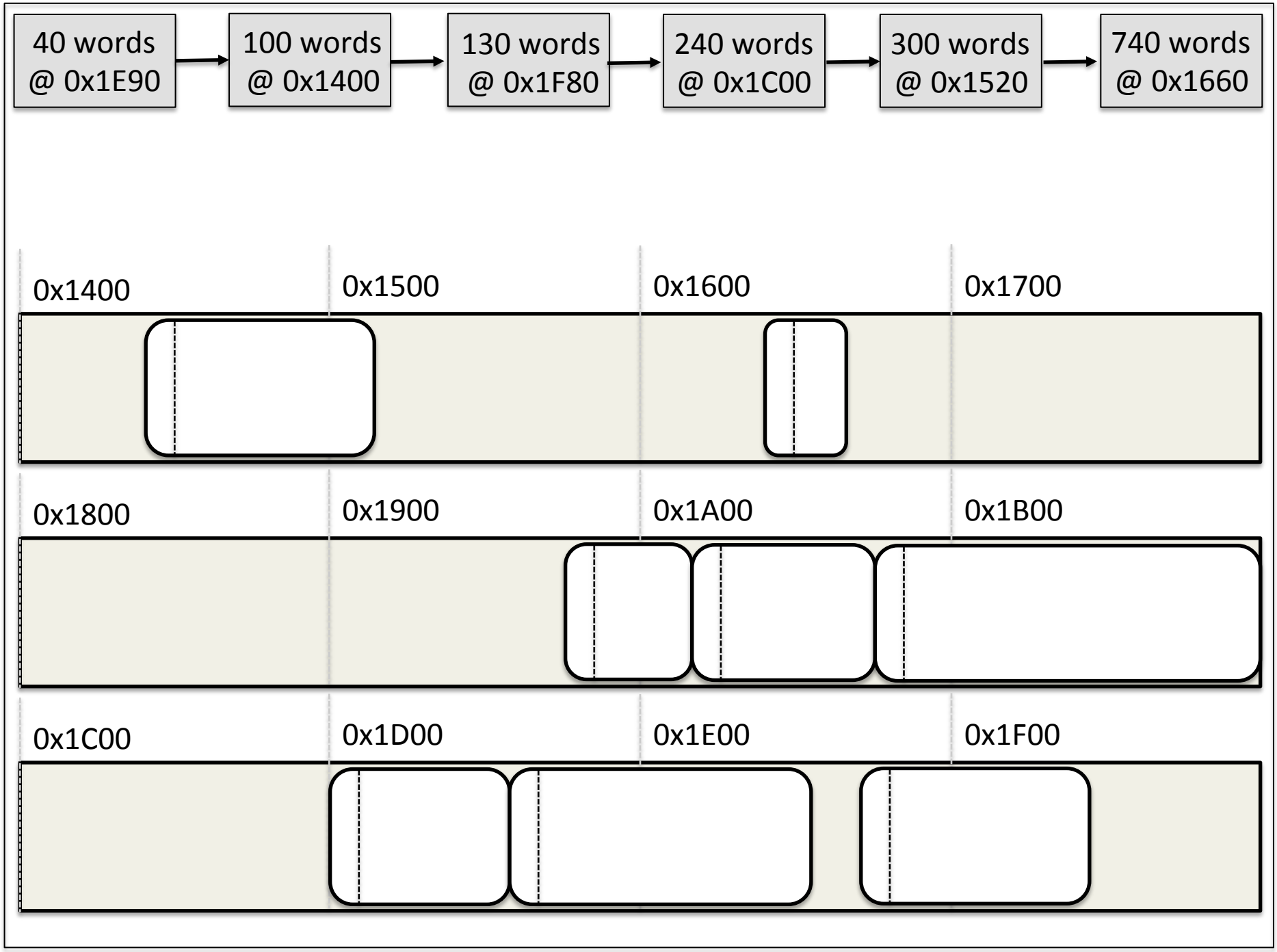
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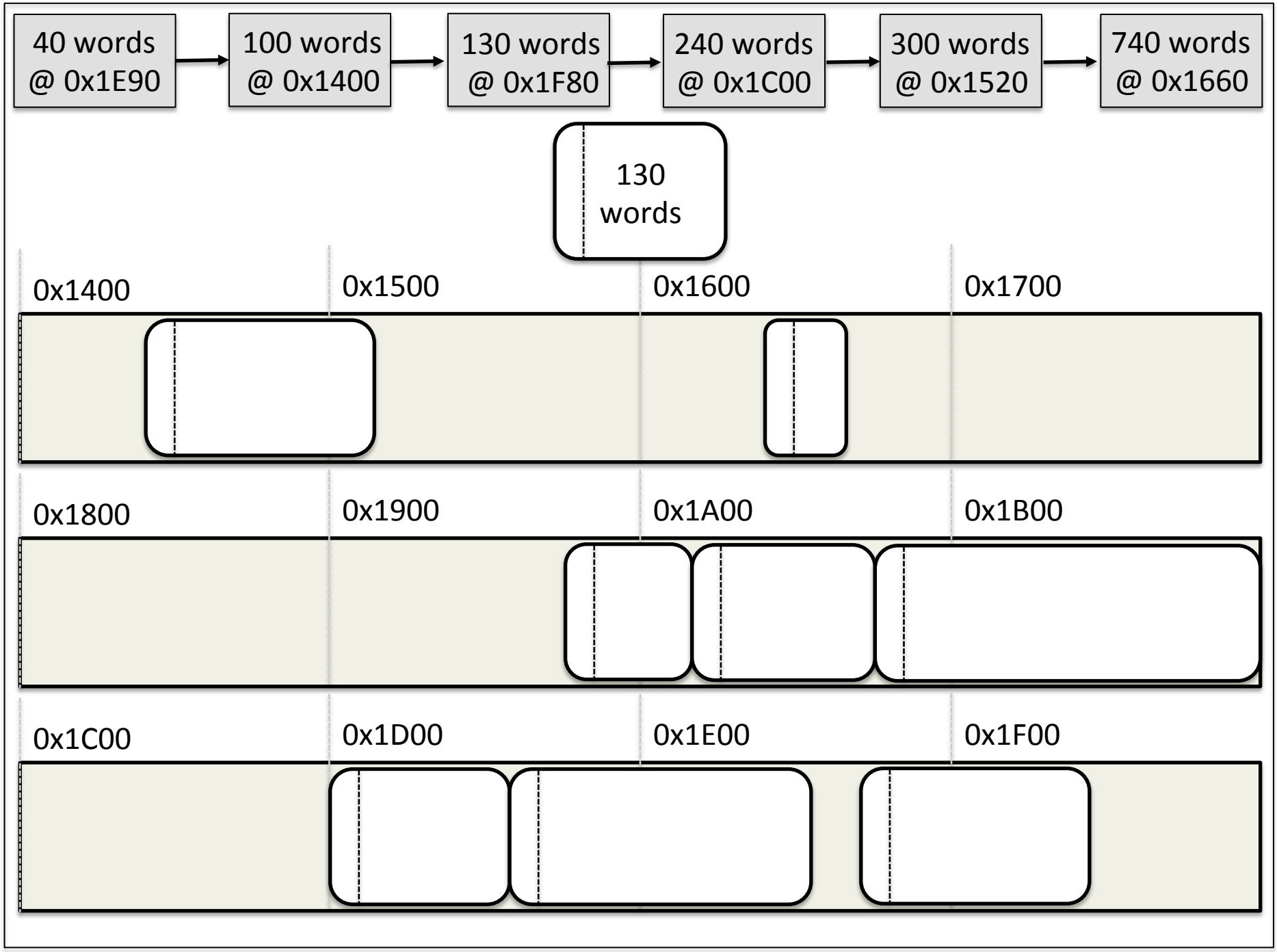
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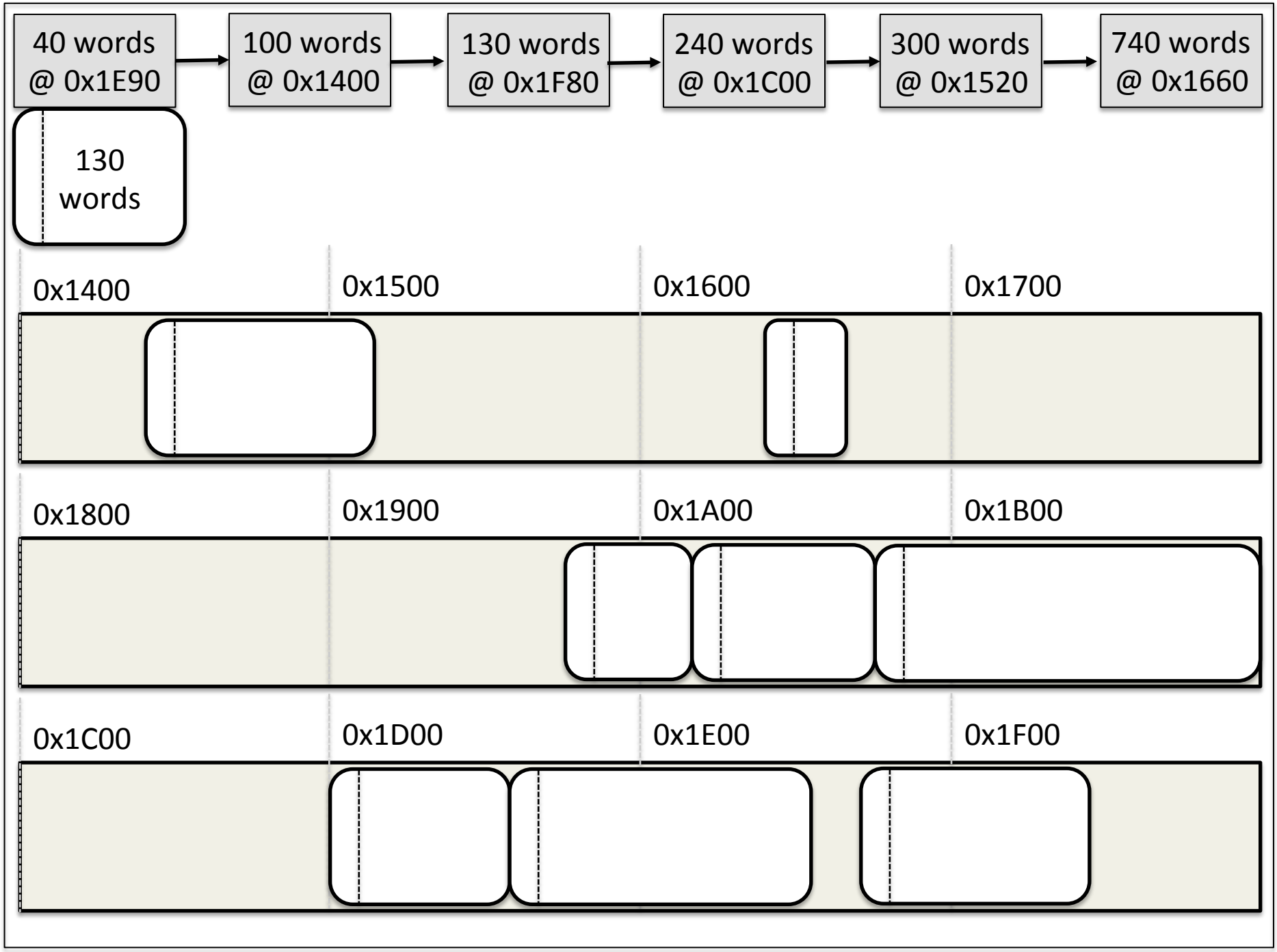
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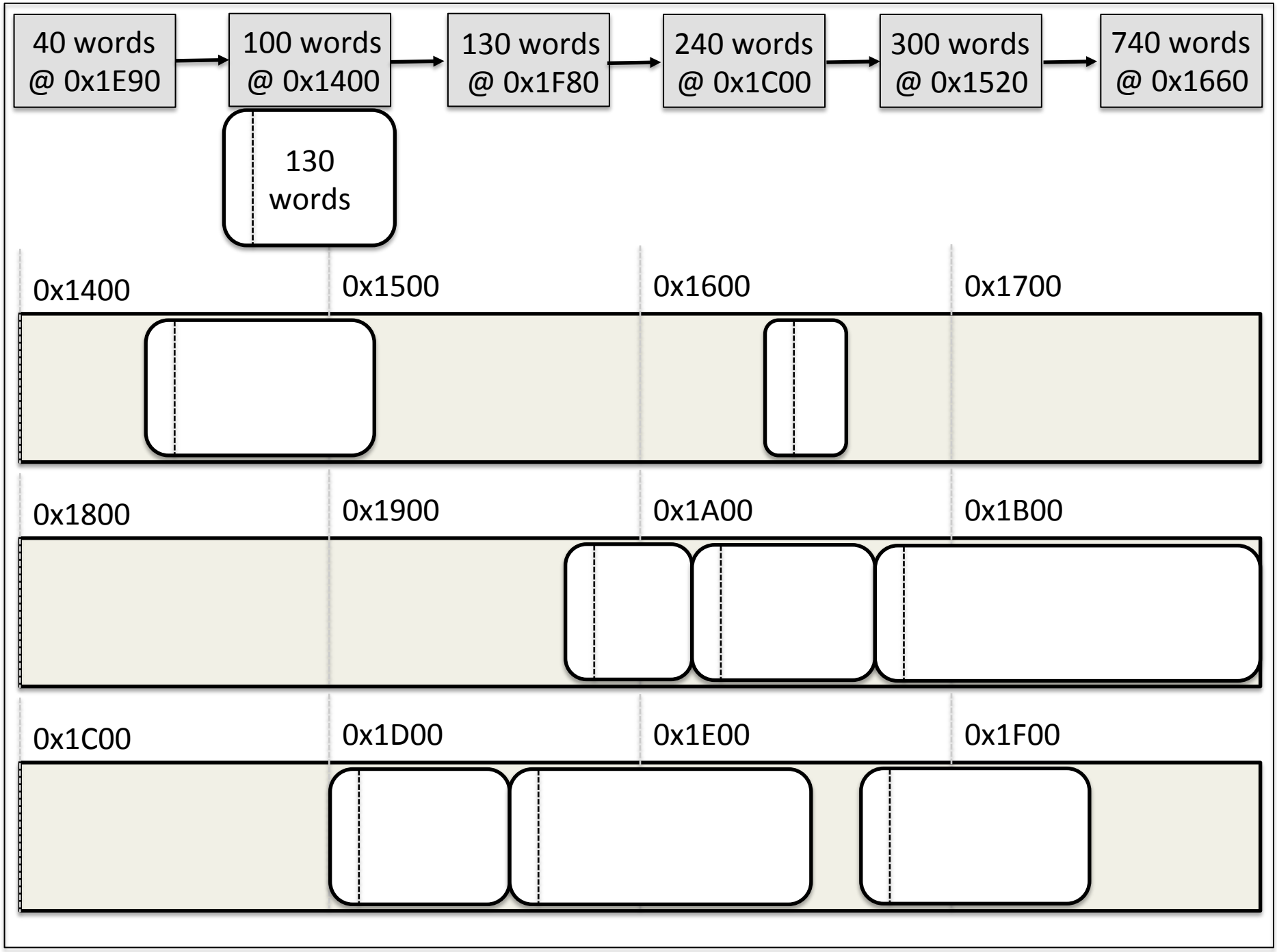
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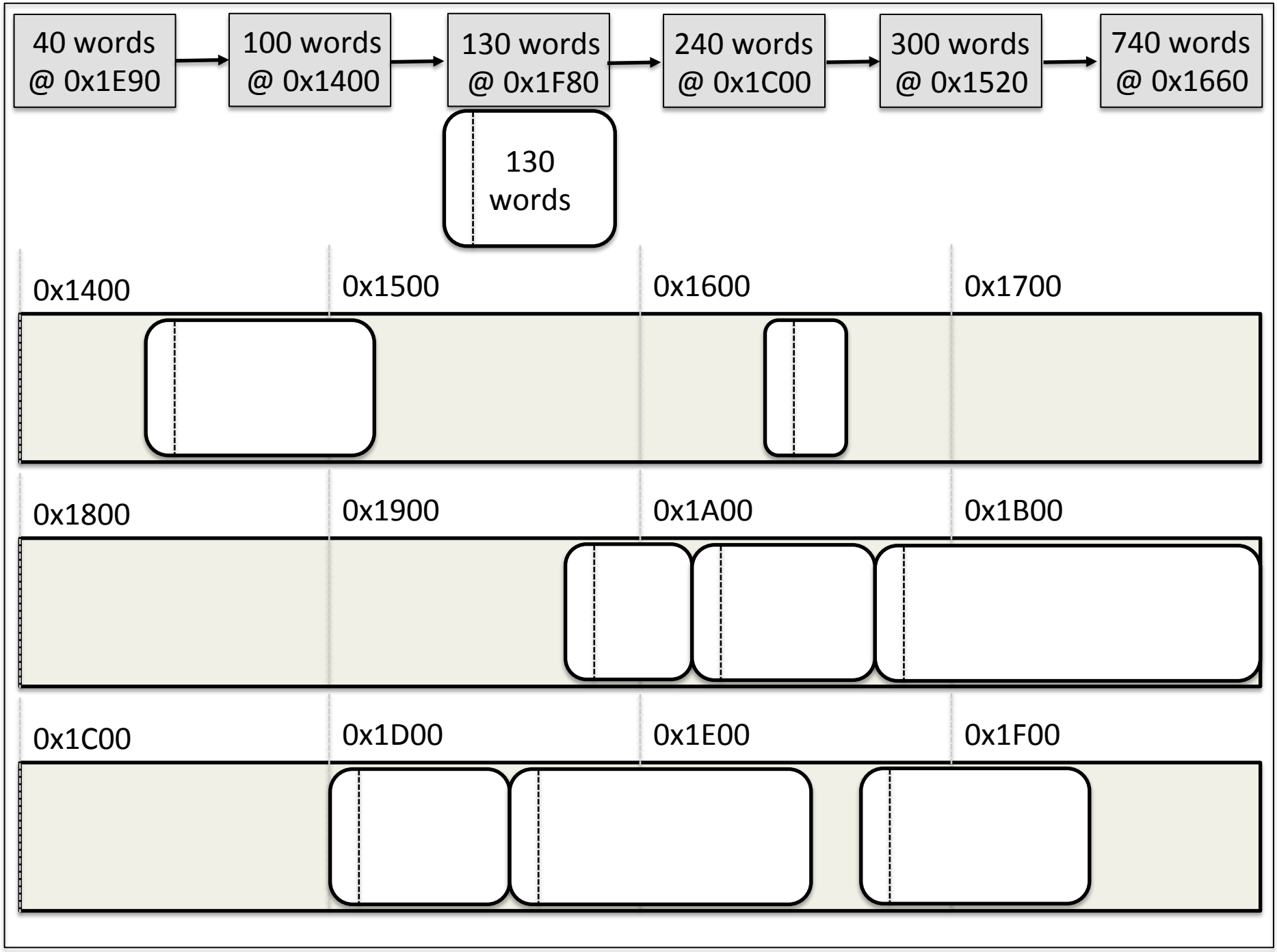
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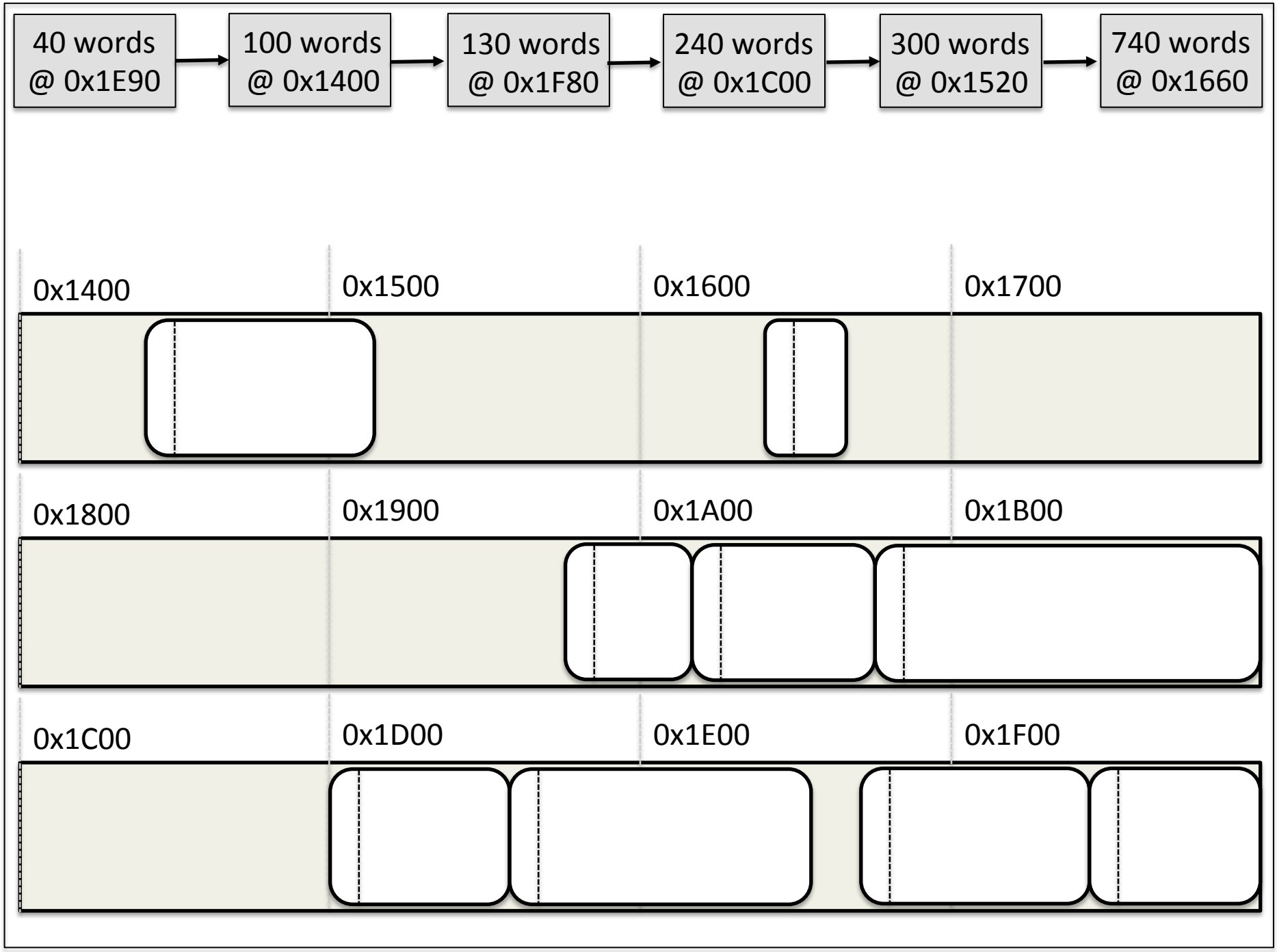
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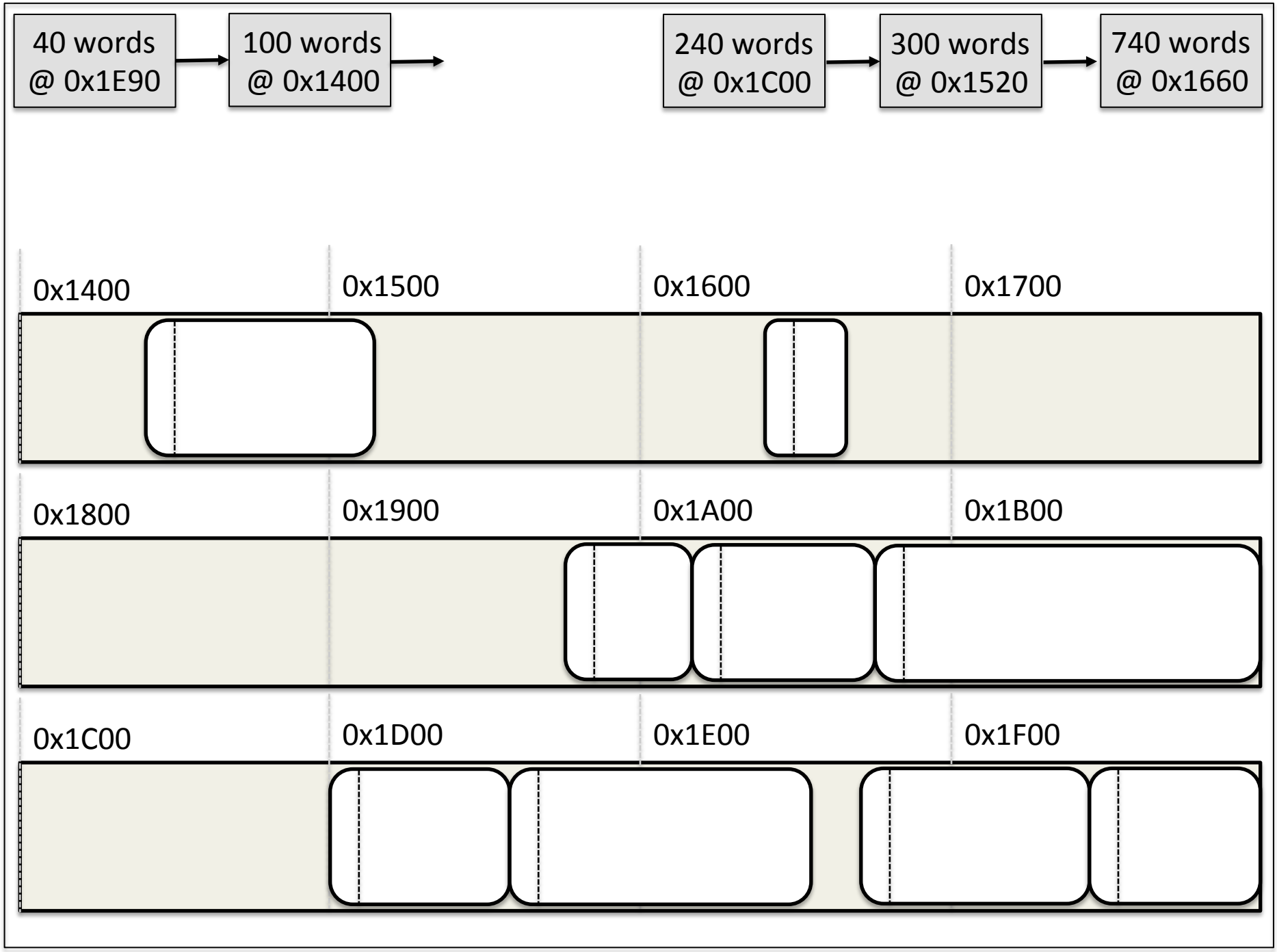
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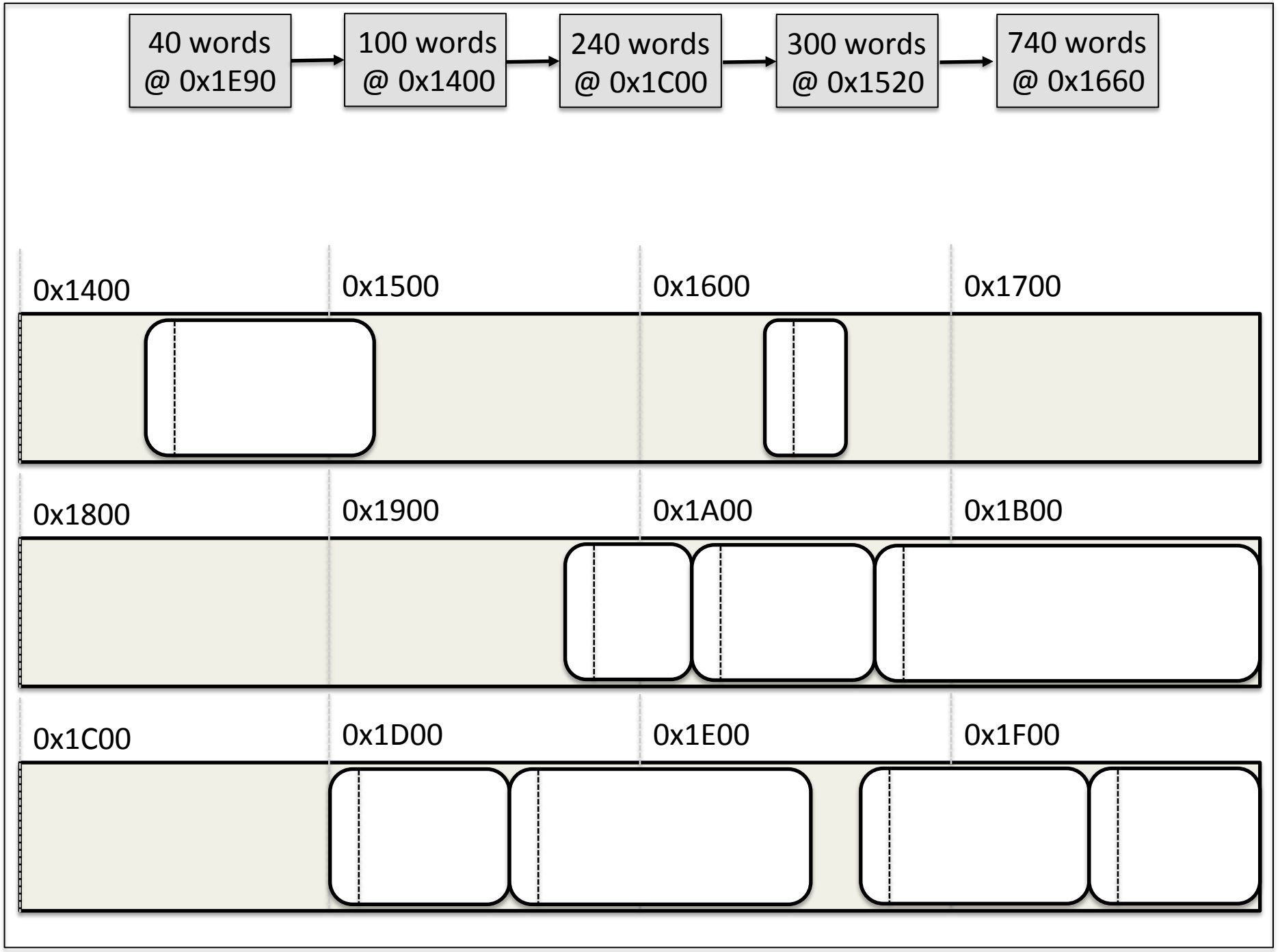
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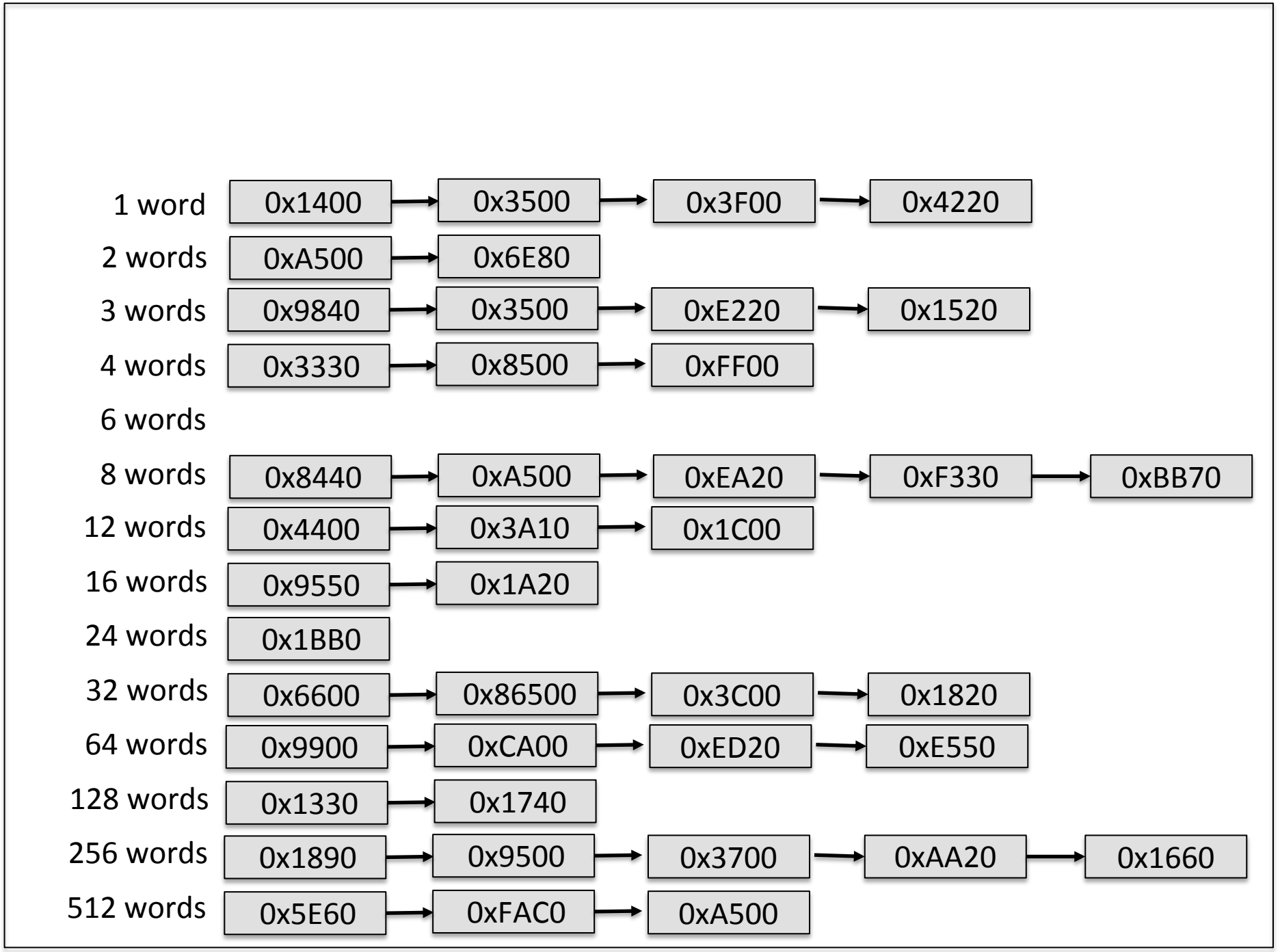
0x1C00
0x1D00
0x1E00
0x1F00

Allocation Strategies

- First Fit
  - Put new object in the first hole that's large enough
- Best Fit
  - Scan the heap to find the hole that fits best
- Free List
  - Maintain a sorted list of all holes
- Segregated Free List
  - Maintain multiple free lists for different sized holes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4 words
0x3330
0x8500
0xFF00
6 words
8 words
0x8440
0xA500
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0xF330
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12 words
0x4400
0x3A10
0x1C00
16 words
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24 words
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64 words
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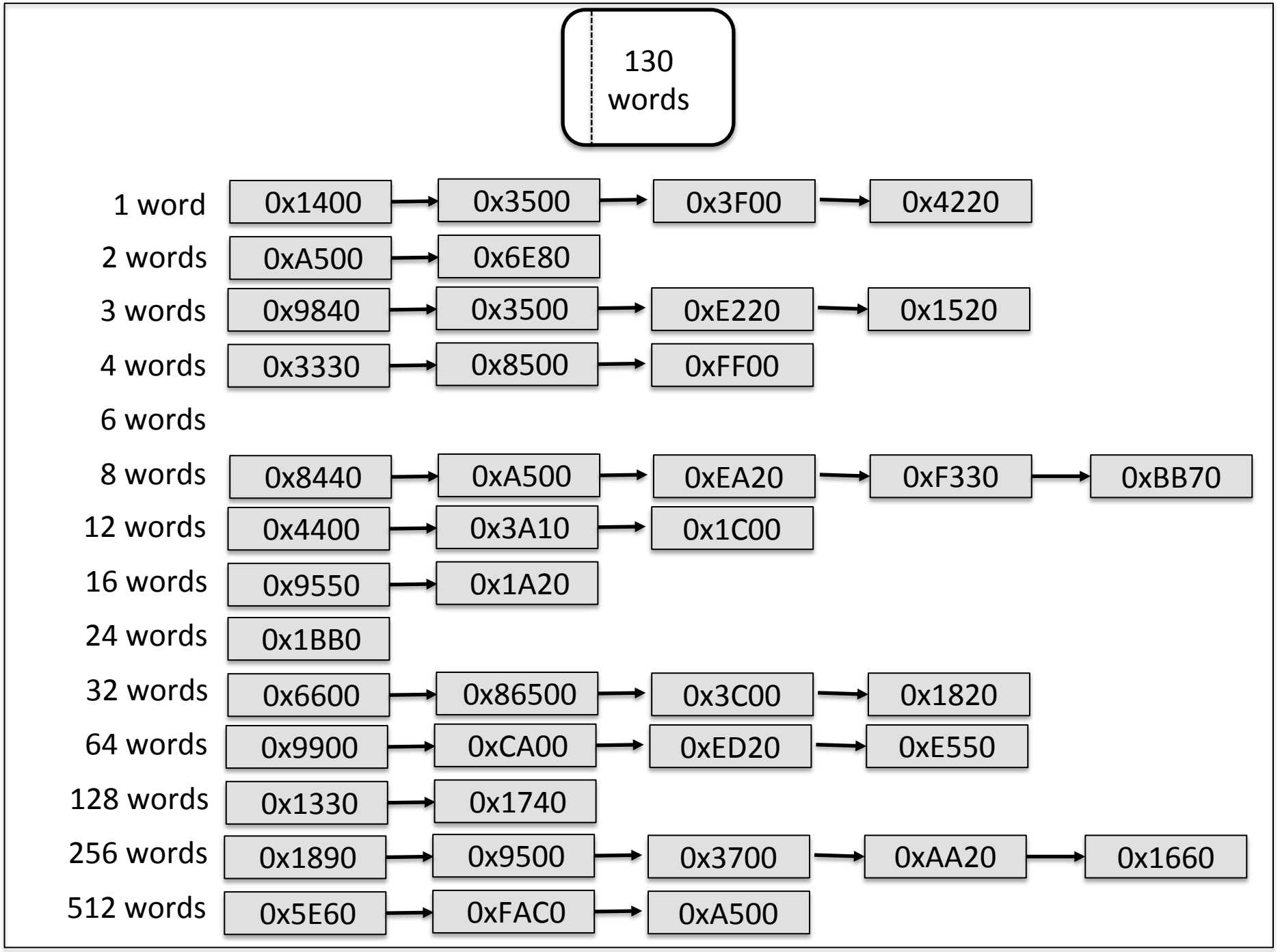
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4 words
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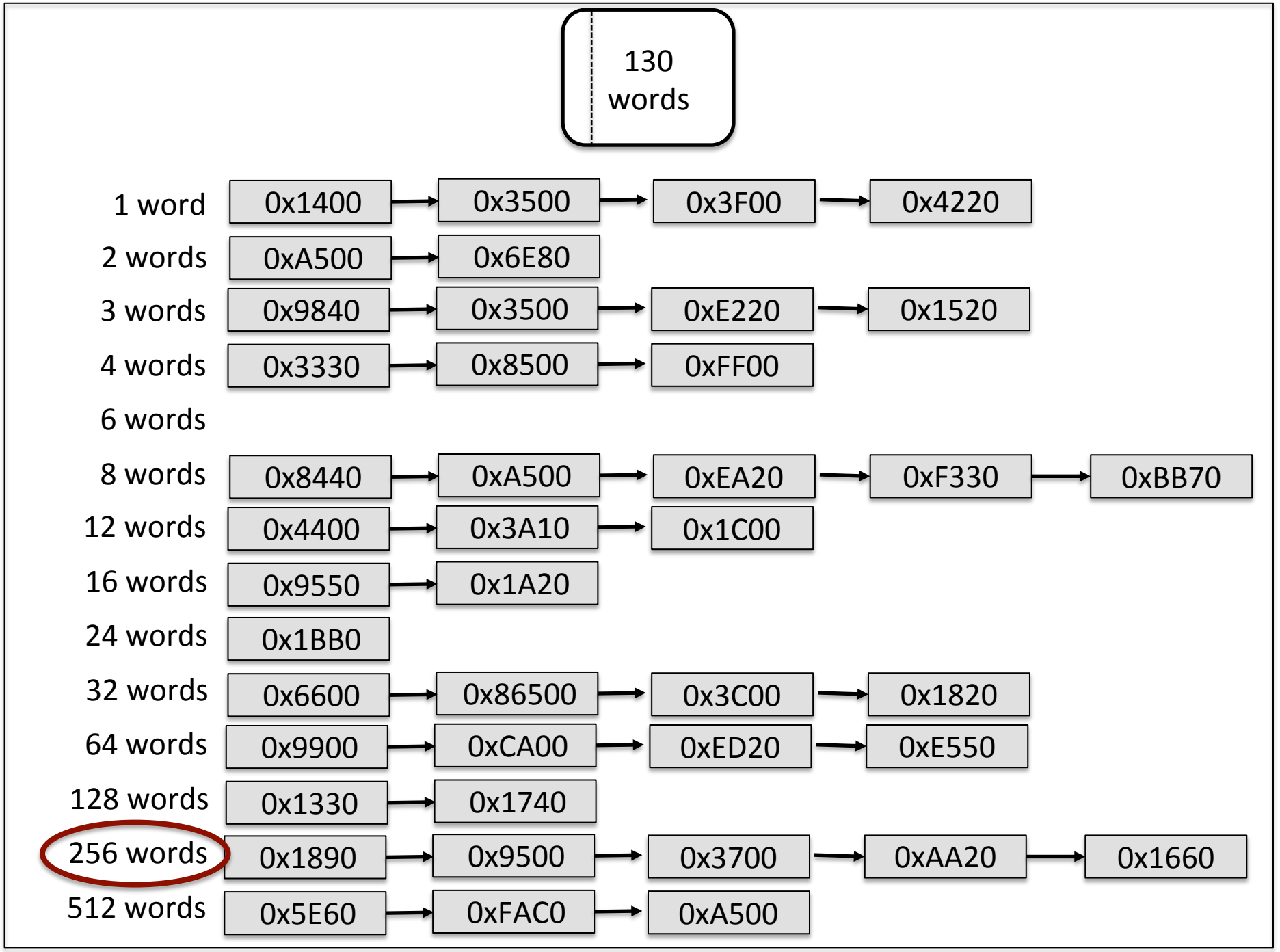
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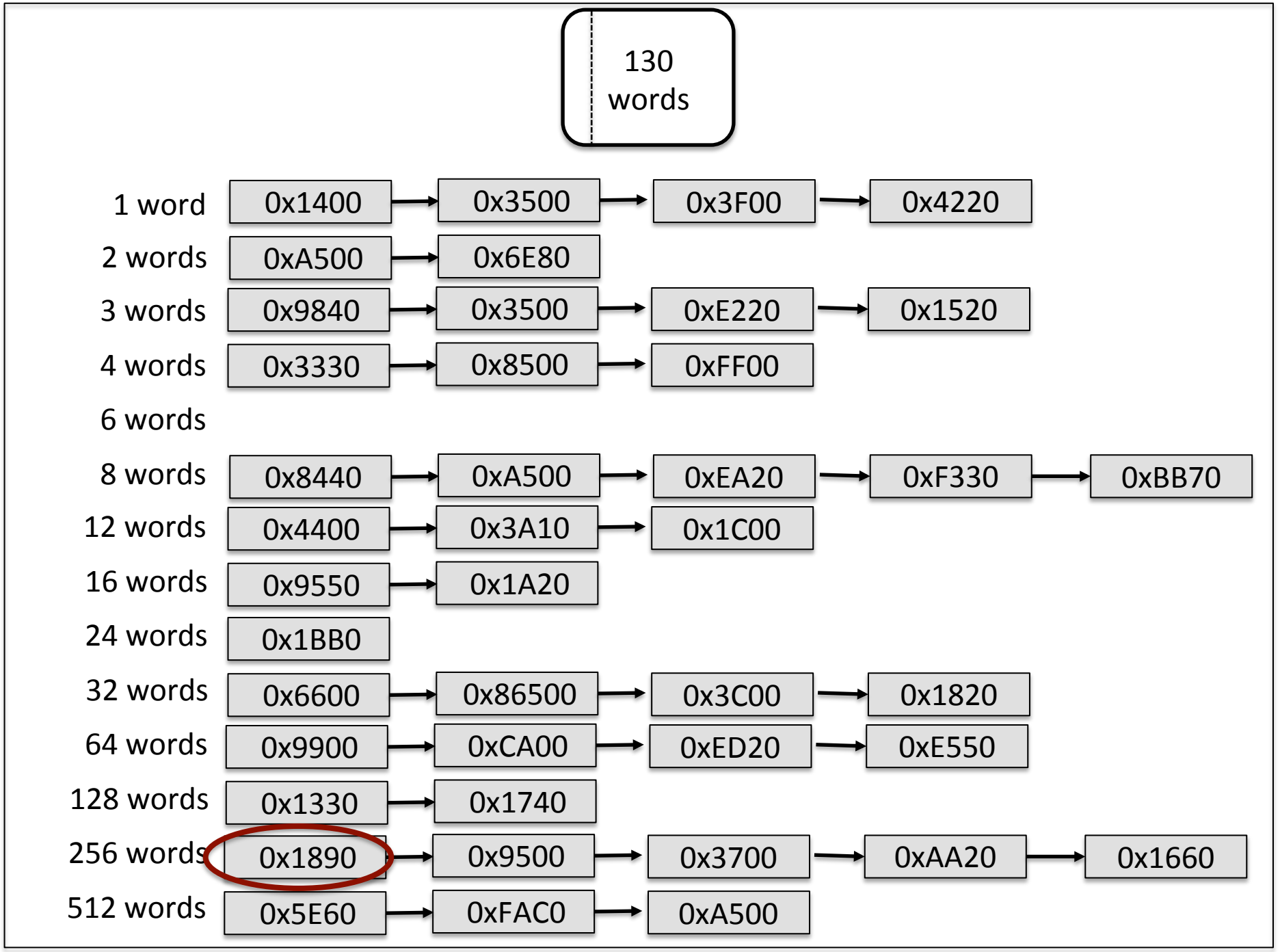
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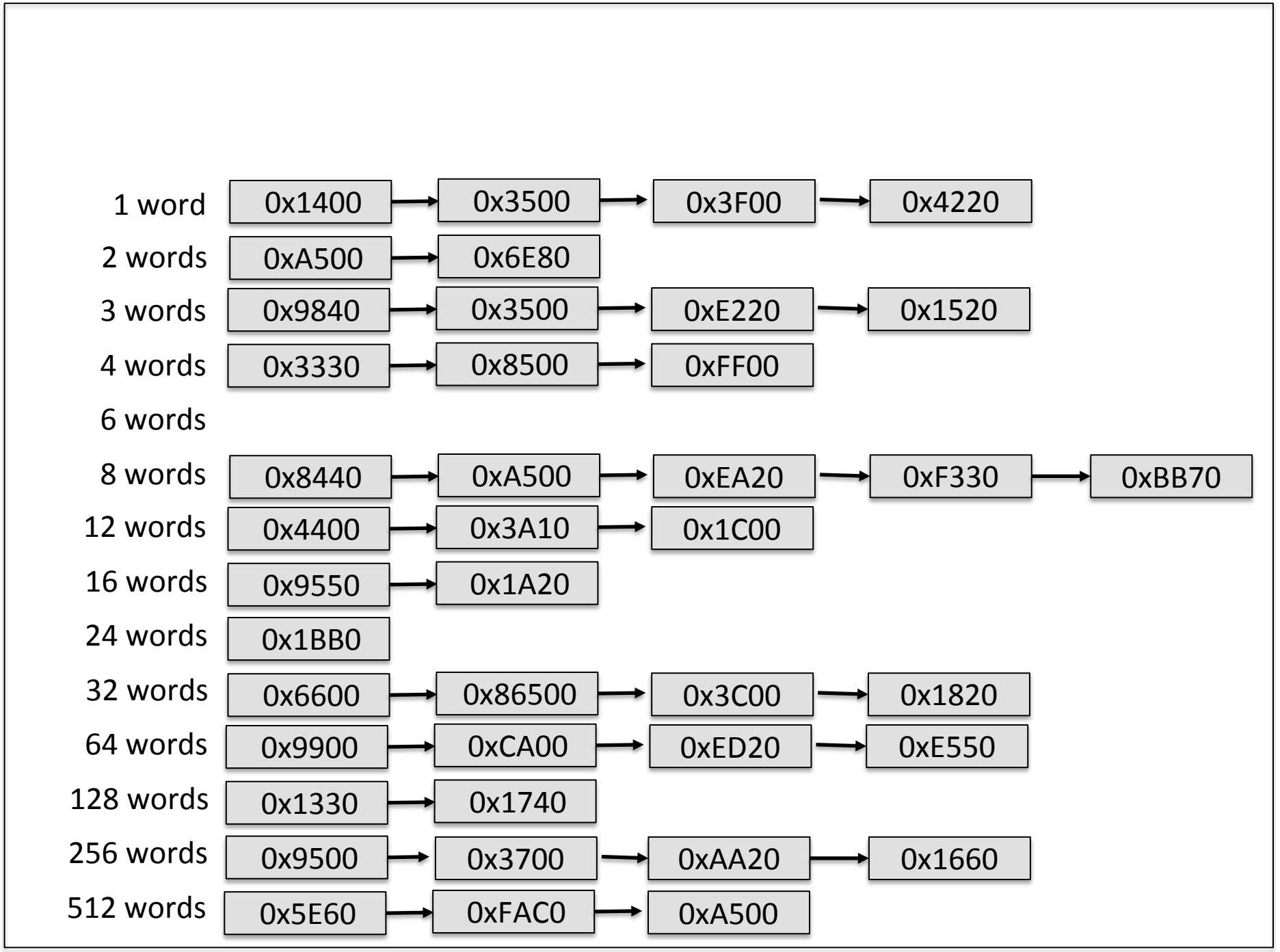
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Avoiding Fragmentation

- Segregated free lists help
  - Approximates best fit across the whole heap
  - Introduce some of wasted space
- Fragmentation a danger when objects are deleted
- Need to compact the heap to eliminate it