Explicit, Dynamic Memory Management with Temporal and Spatial Guarantees

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Artist Summer School 2009
Tsinghua University, Beijing, China

Memory Management

- Allocation:
  - `malloc`

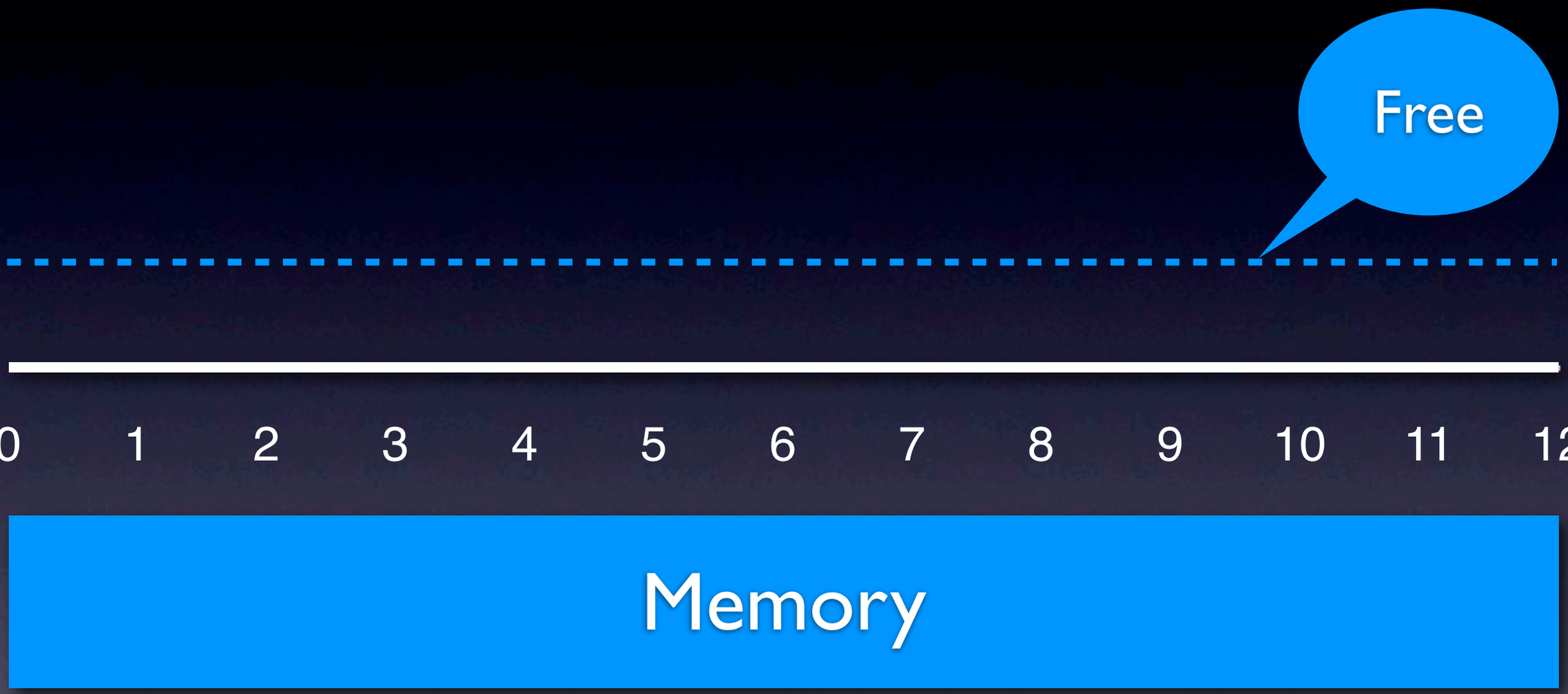
Memory Management

- Allocation:
  - `malloc`
- Deallocation:
  - `free`

Memory Management

- Allocation:
  - `malloc`
- Deallocation:
  - `free`
- Access:
  - `read` and `write`

Allocation



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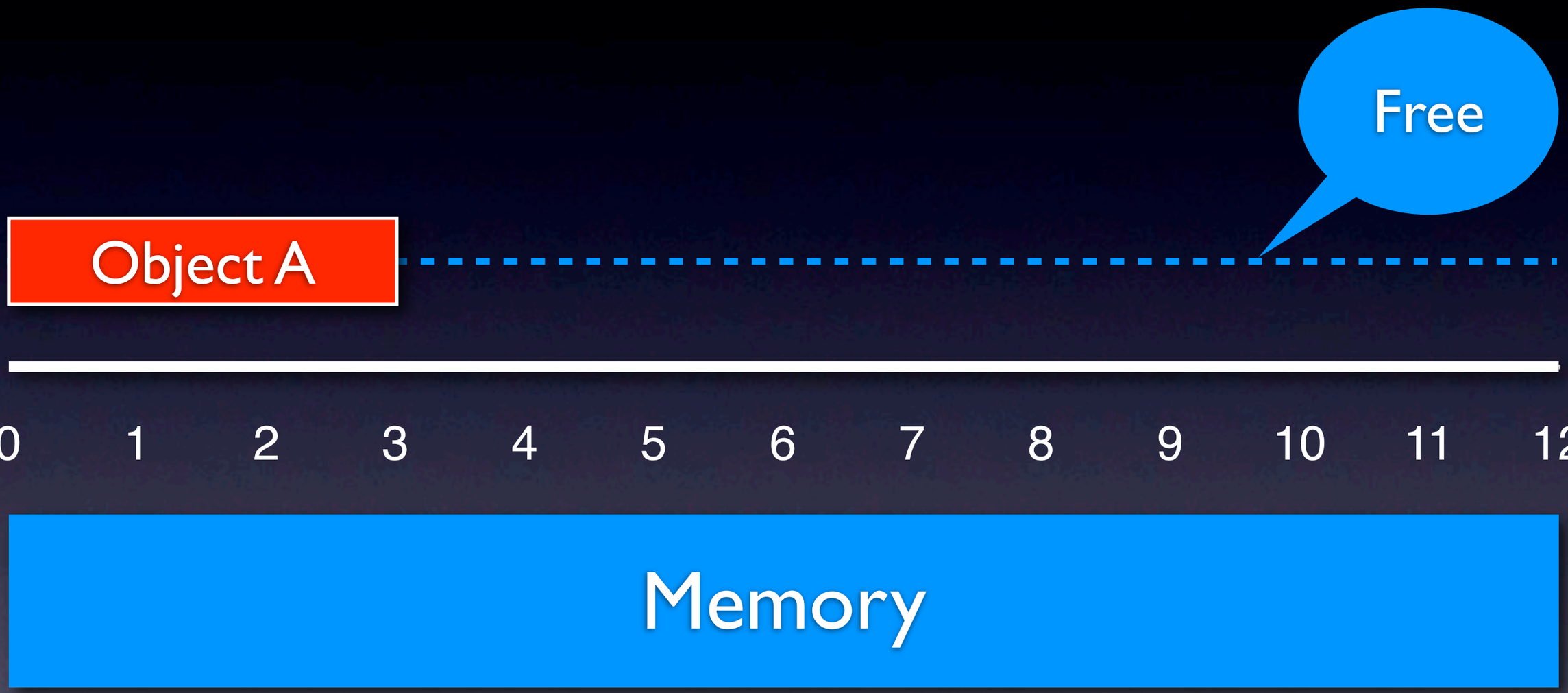

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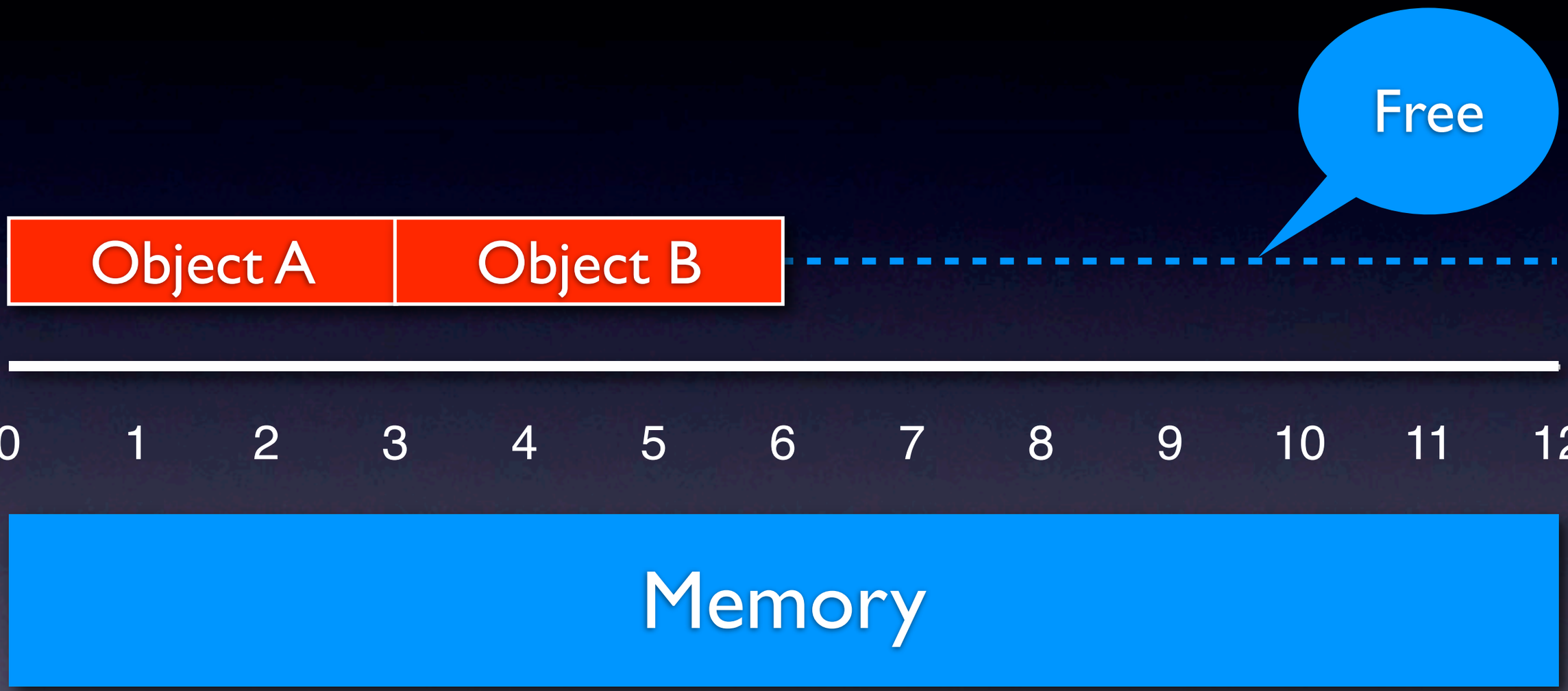

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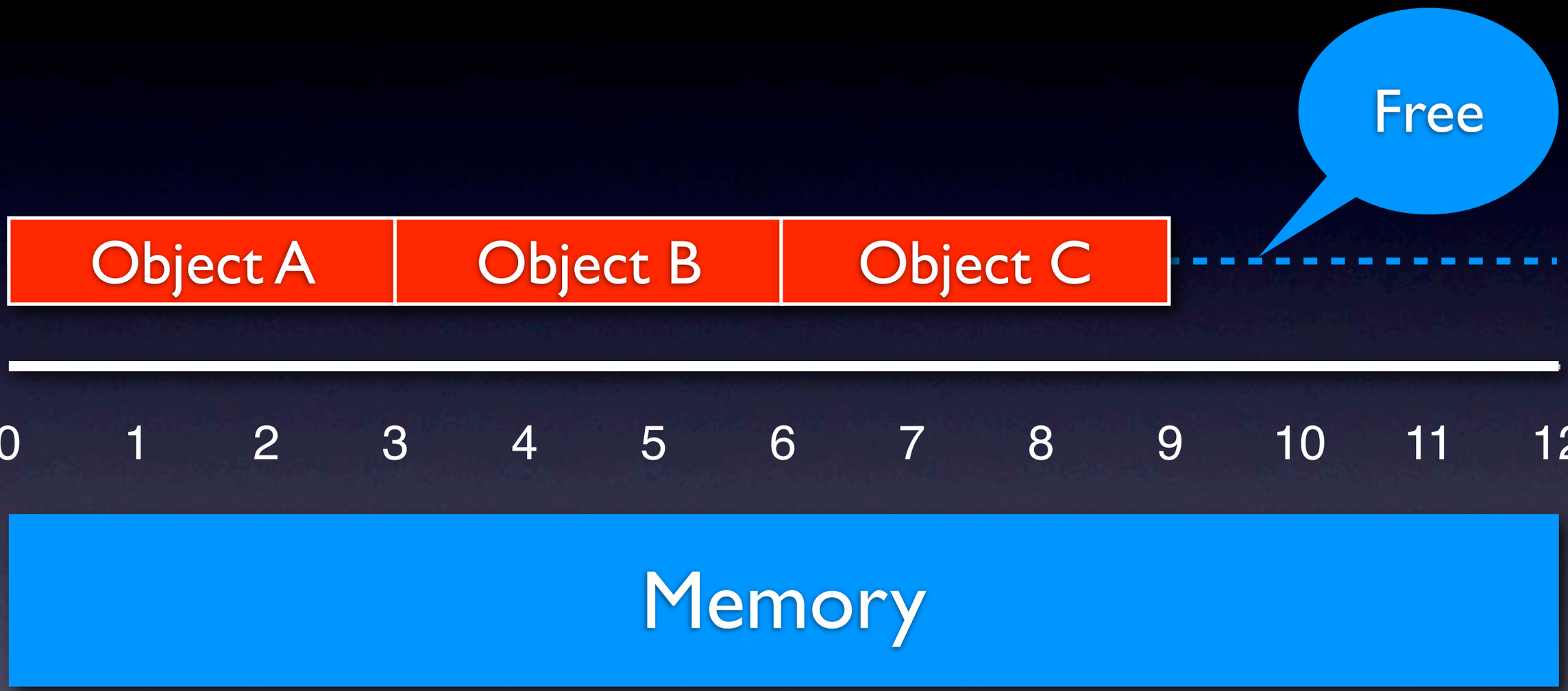

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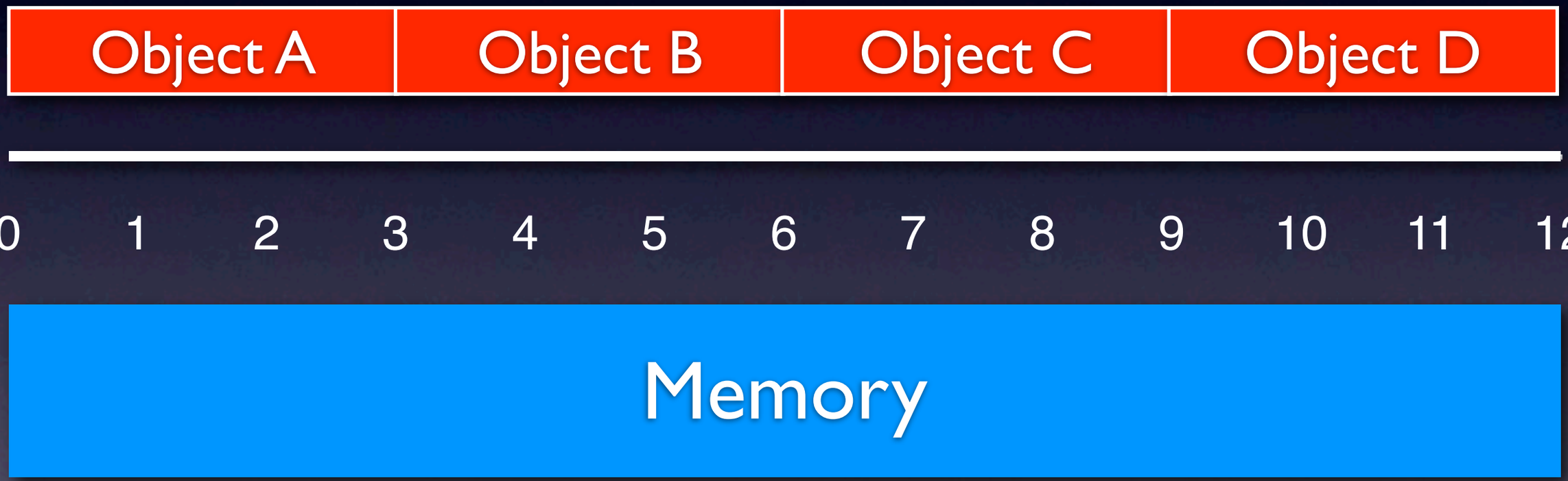
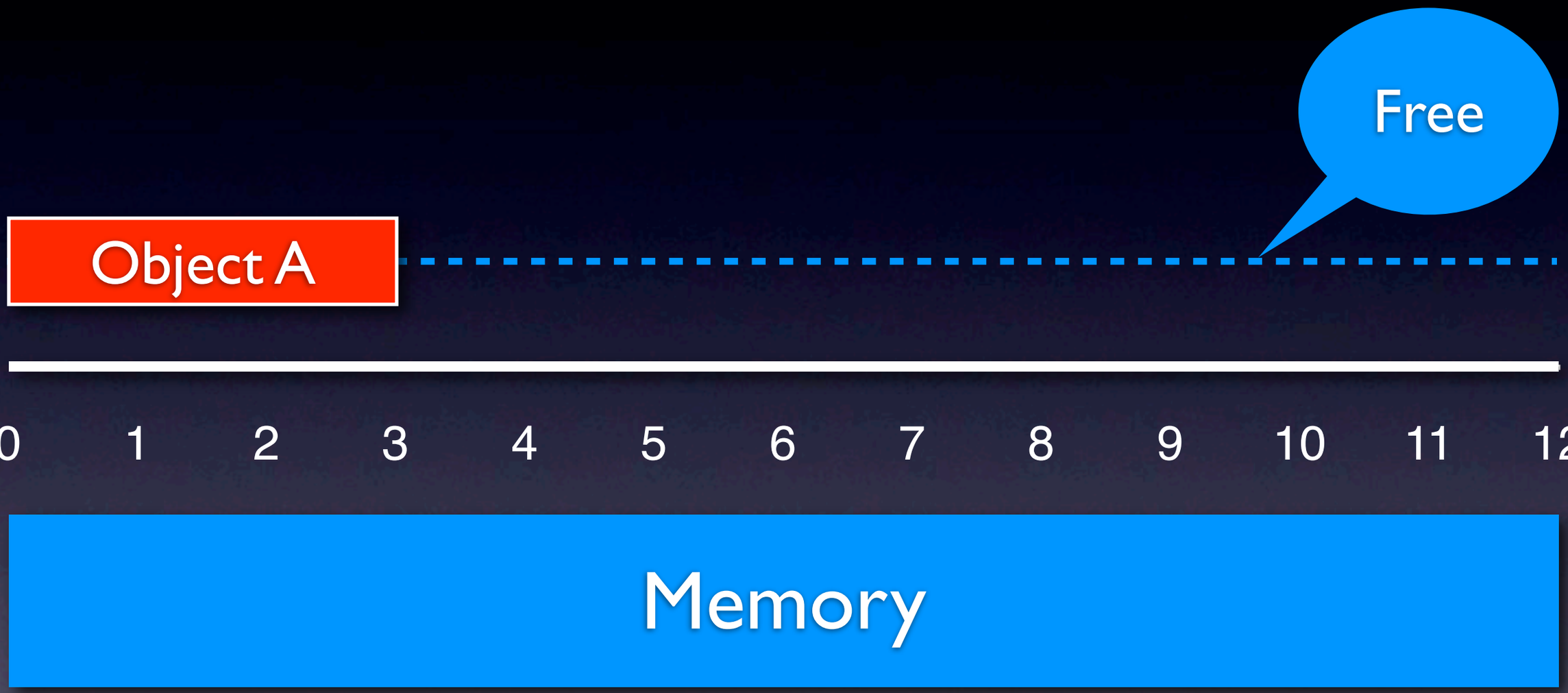


1. Assumption:

Objects may have different sizes

Allocation



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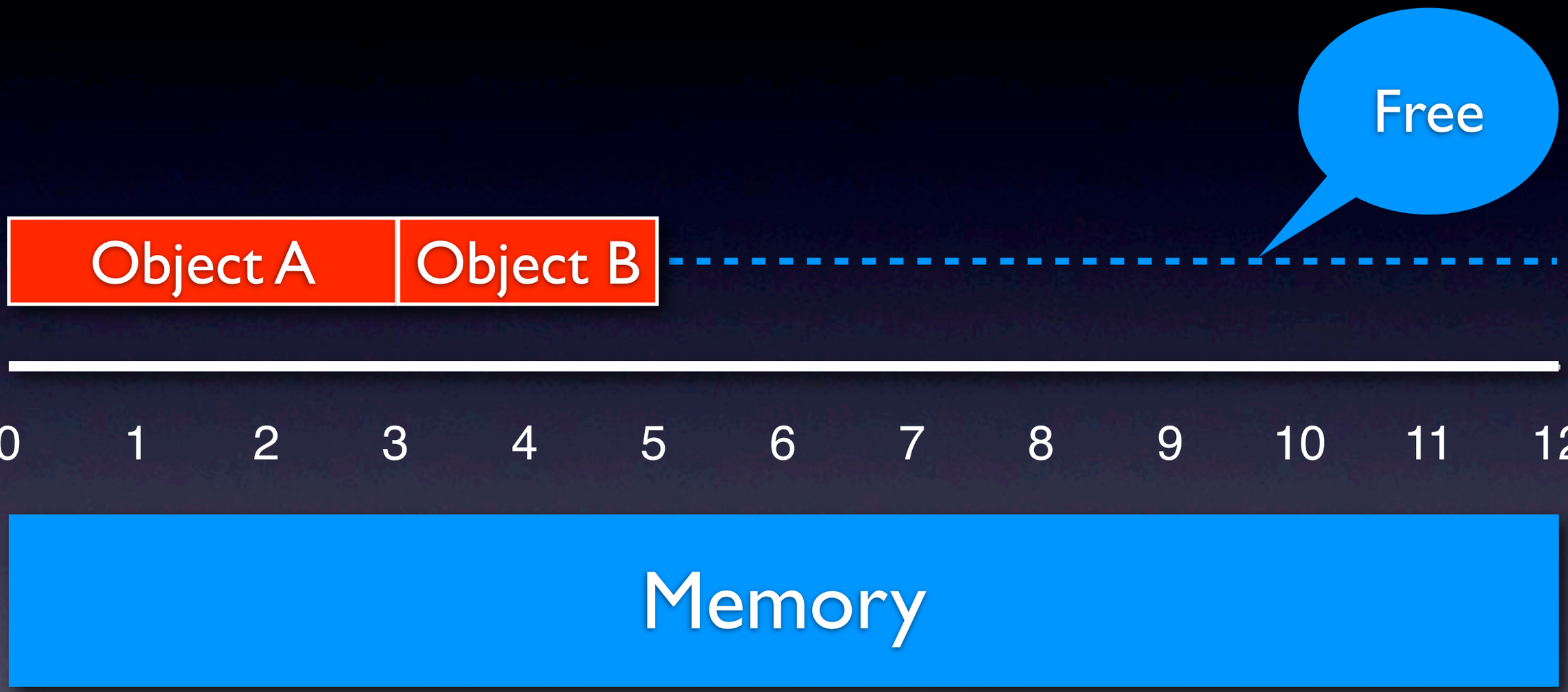

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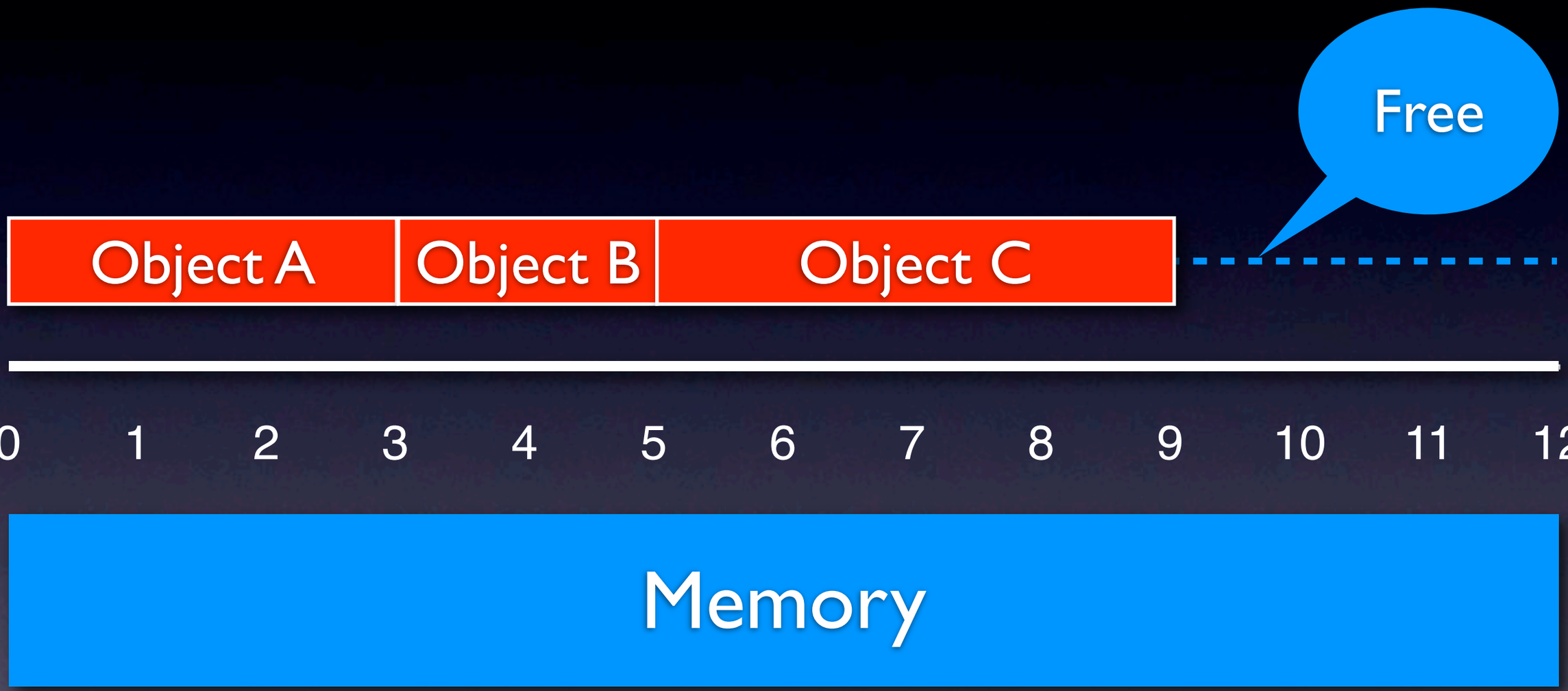

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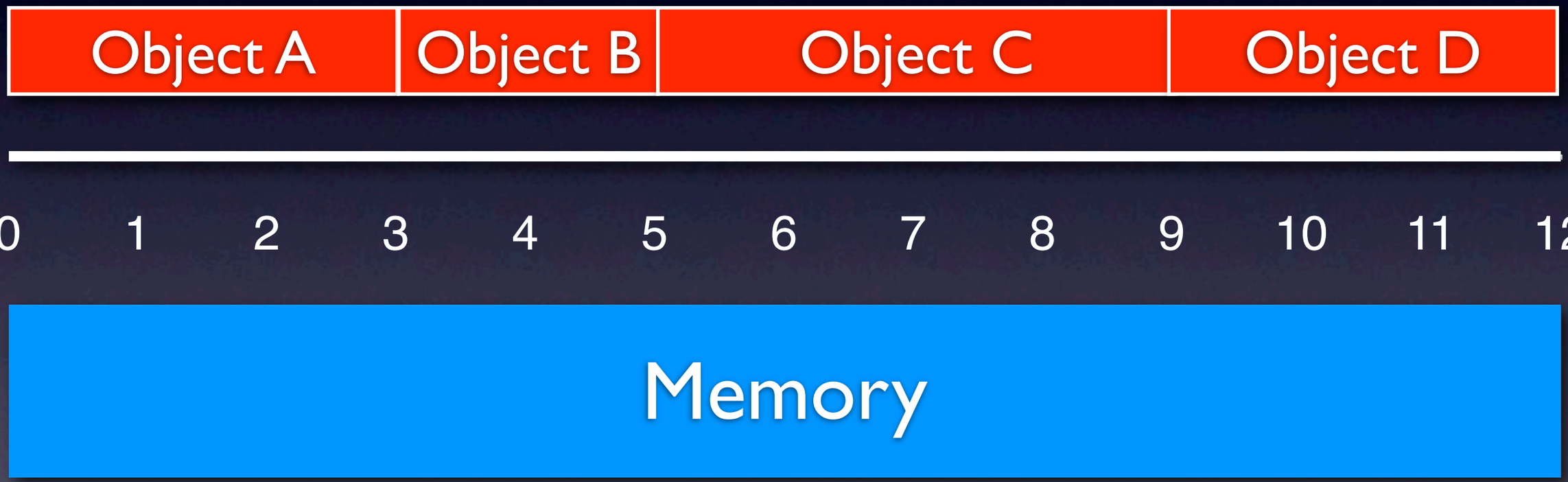
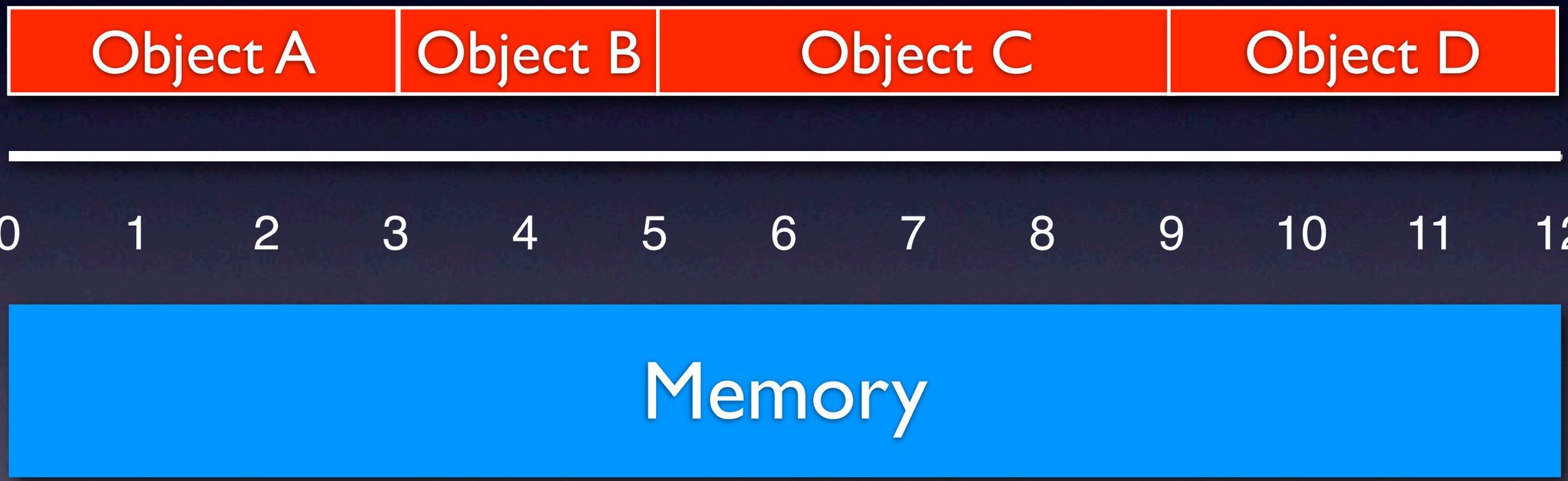


Deallocation



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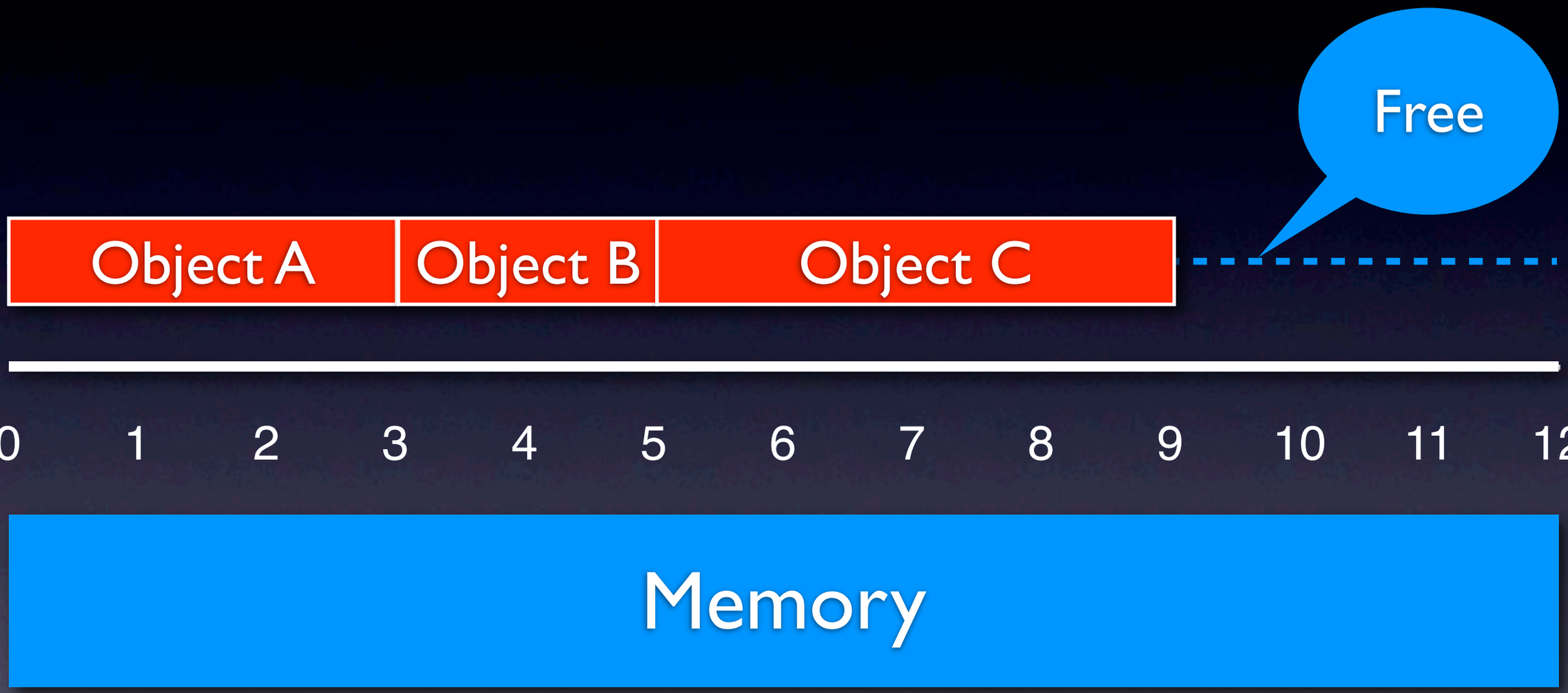

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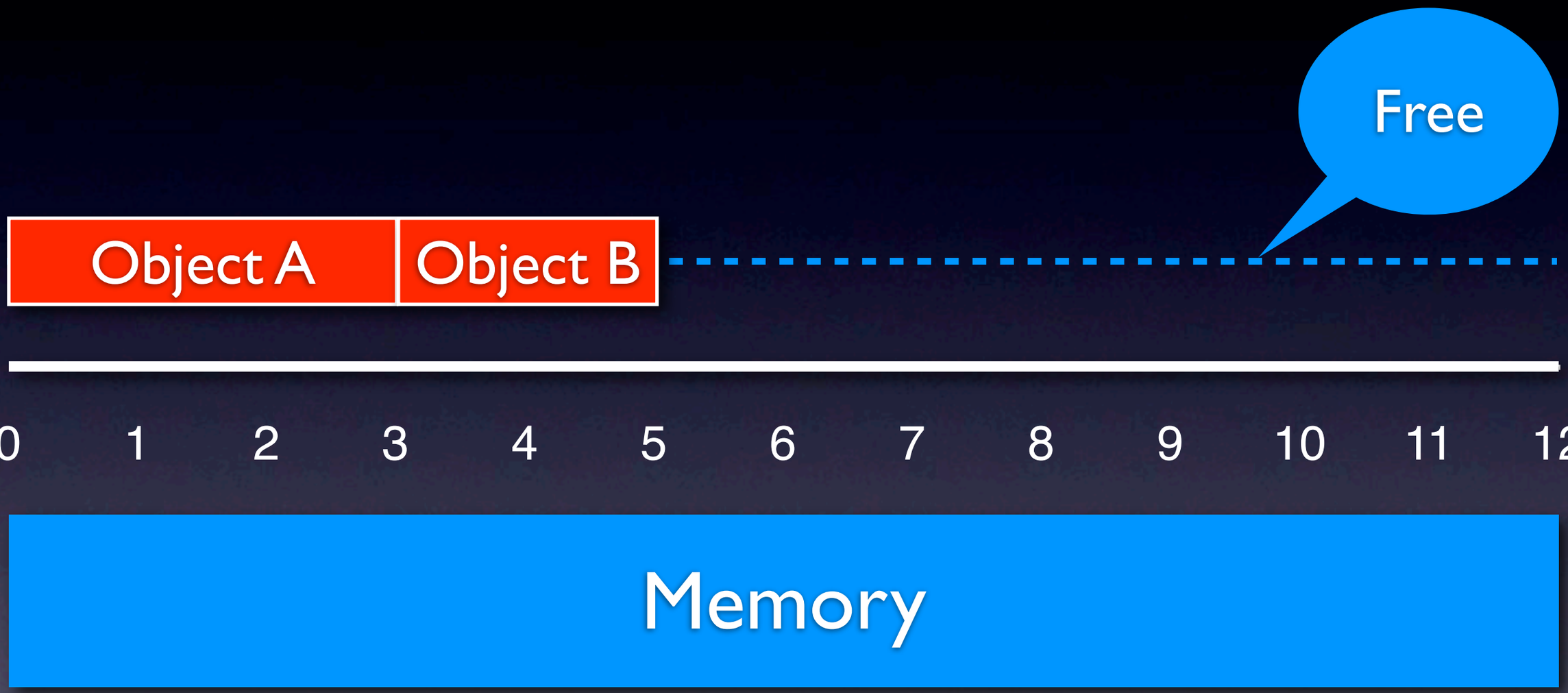

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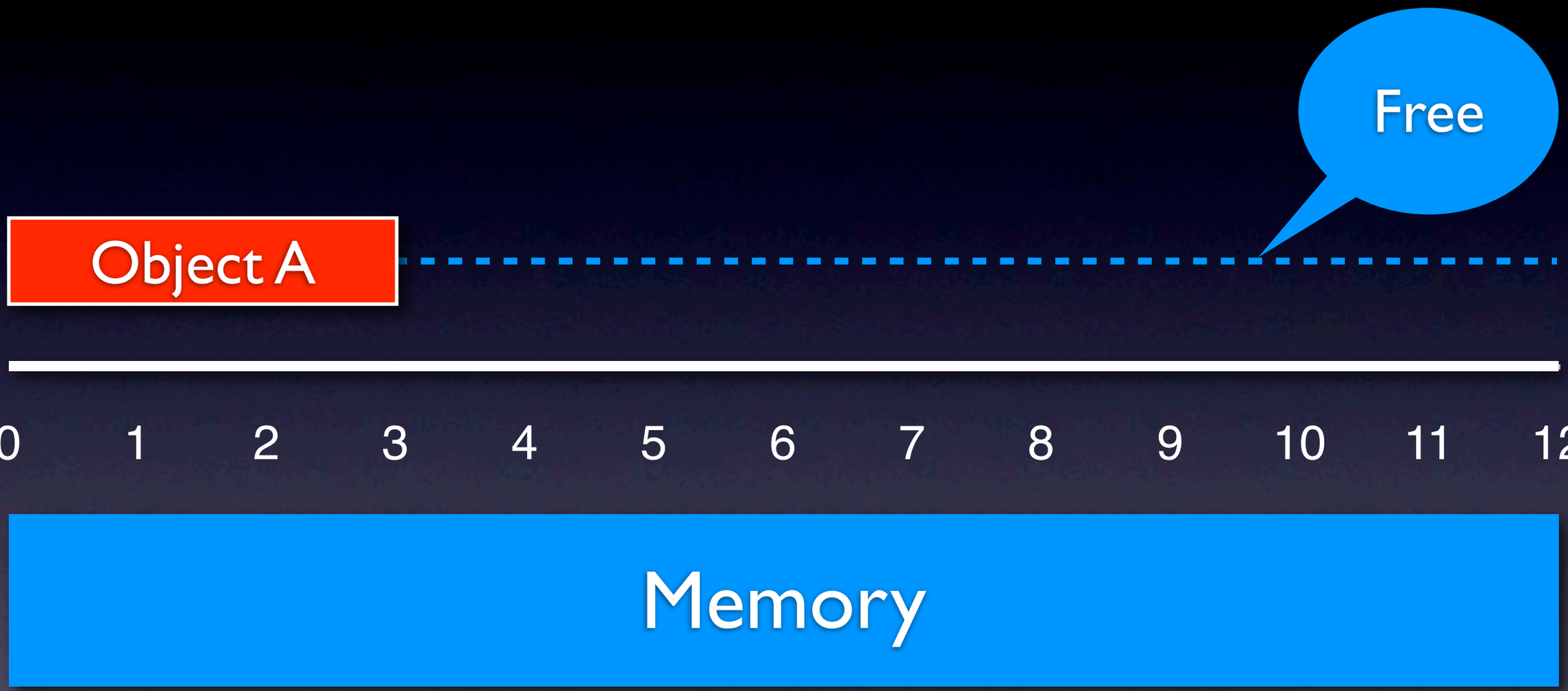

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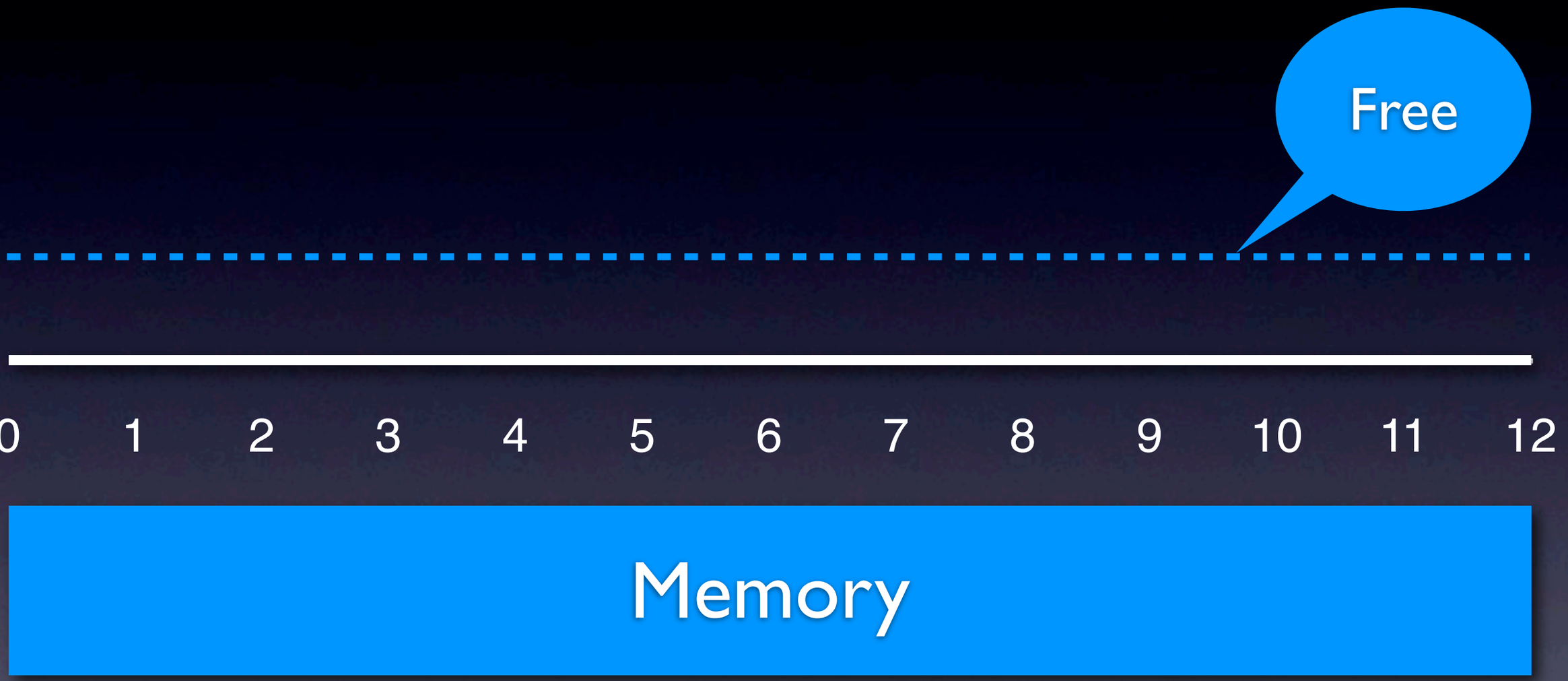
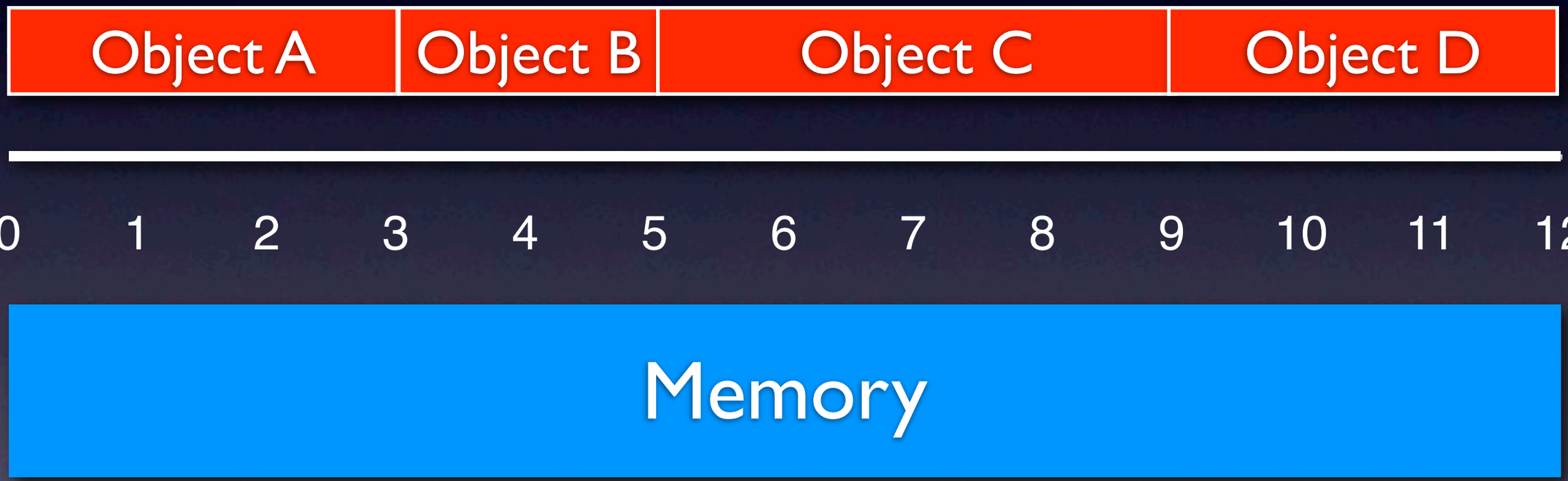


2. Assumption:

Objects may be allocated and deallocated in random order

Deallocation



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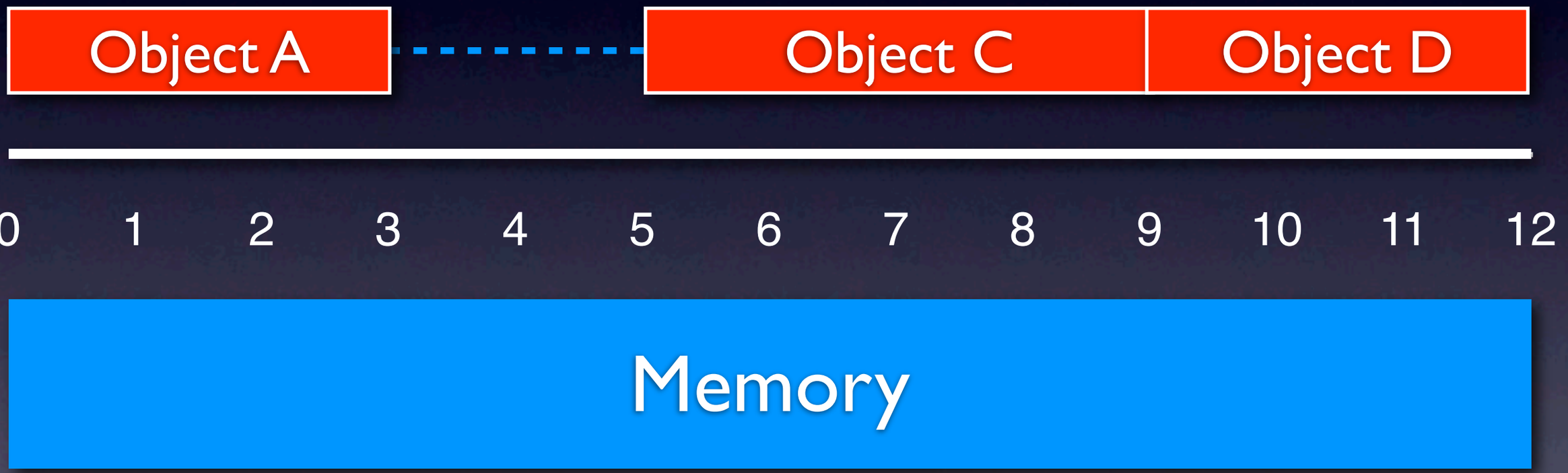
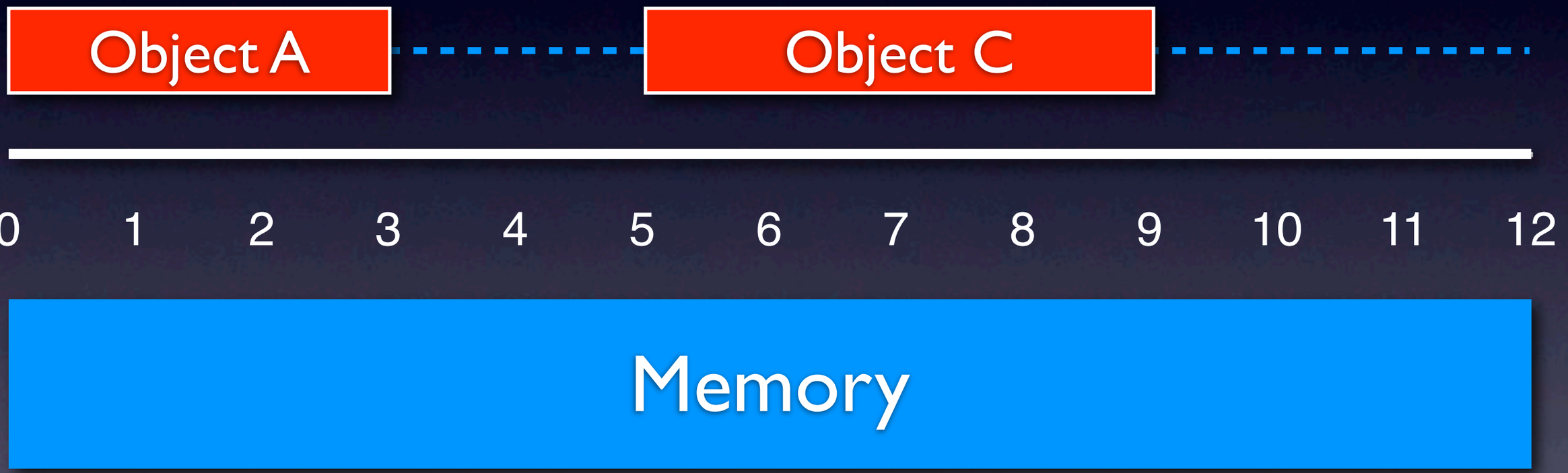
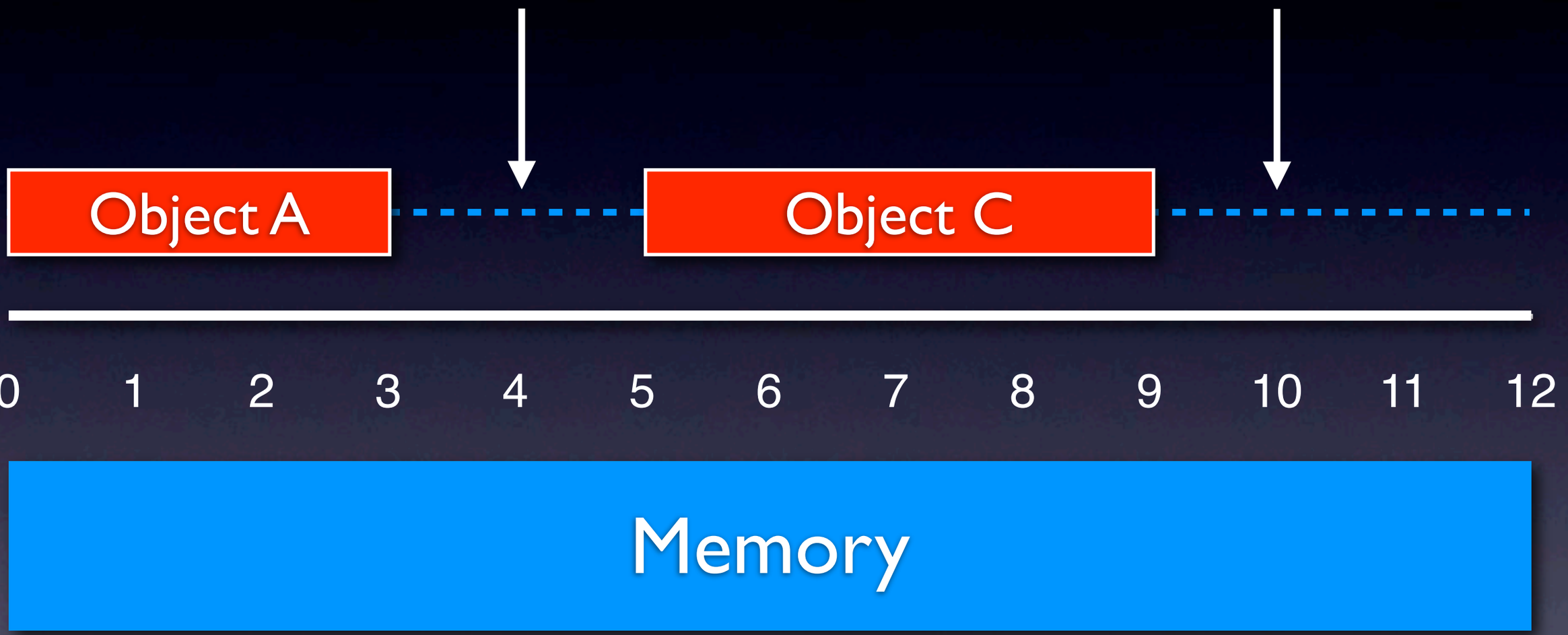


Deallocation



External Fragmentation



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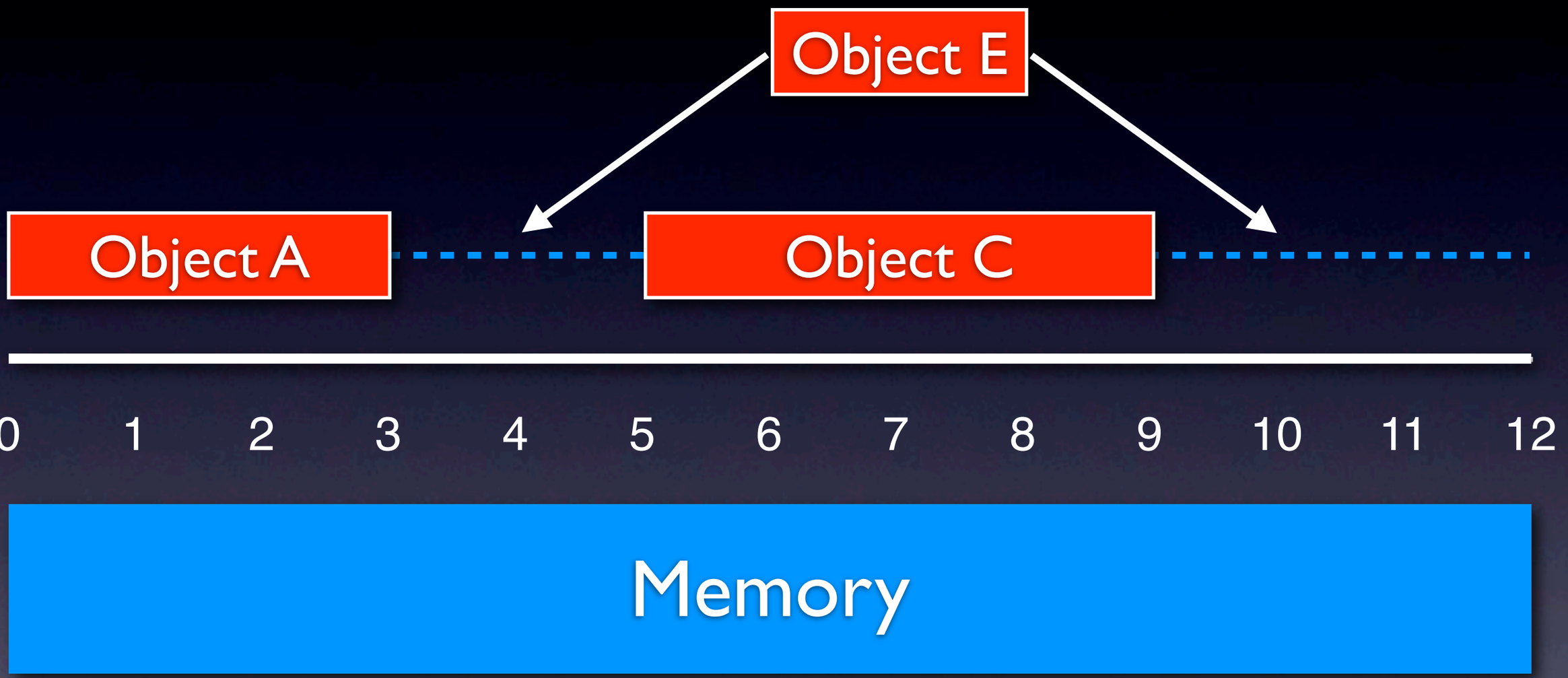

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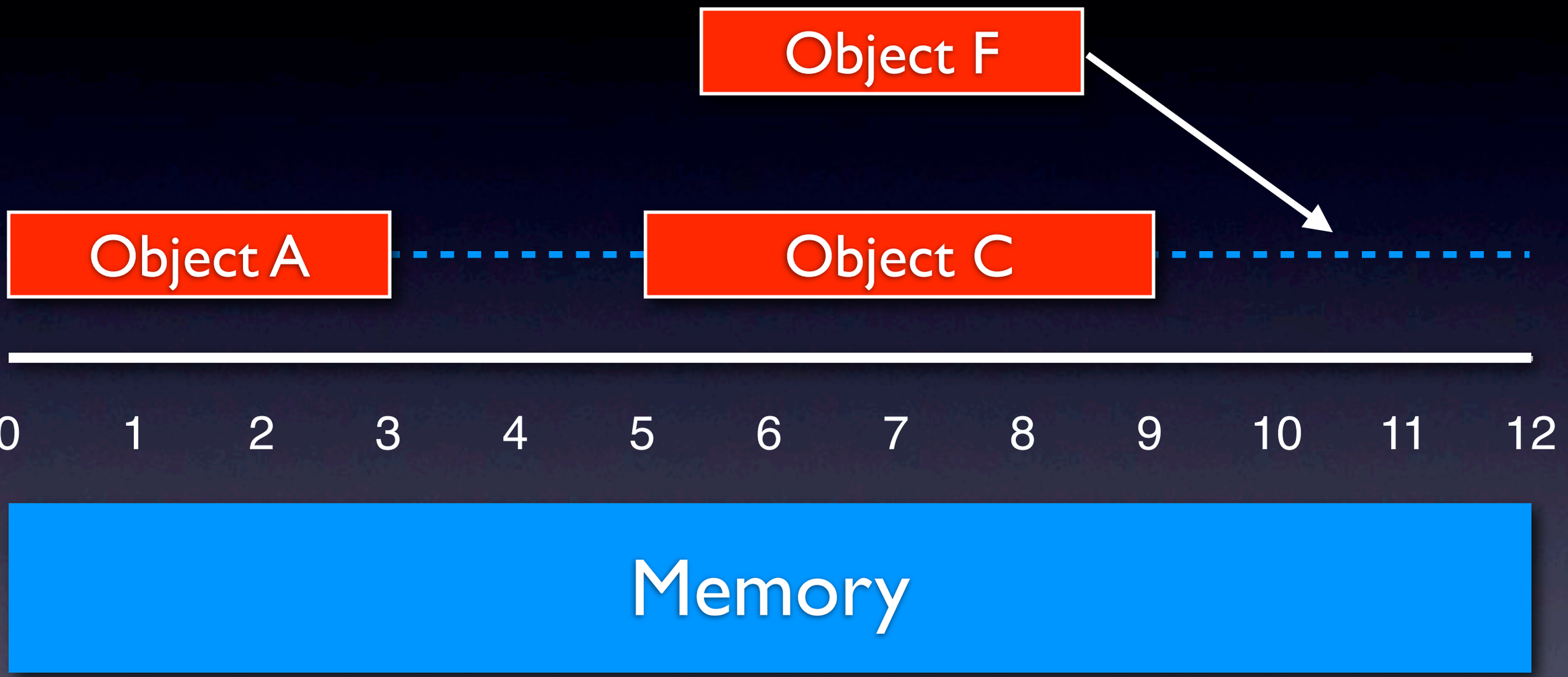

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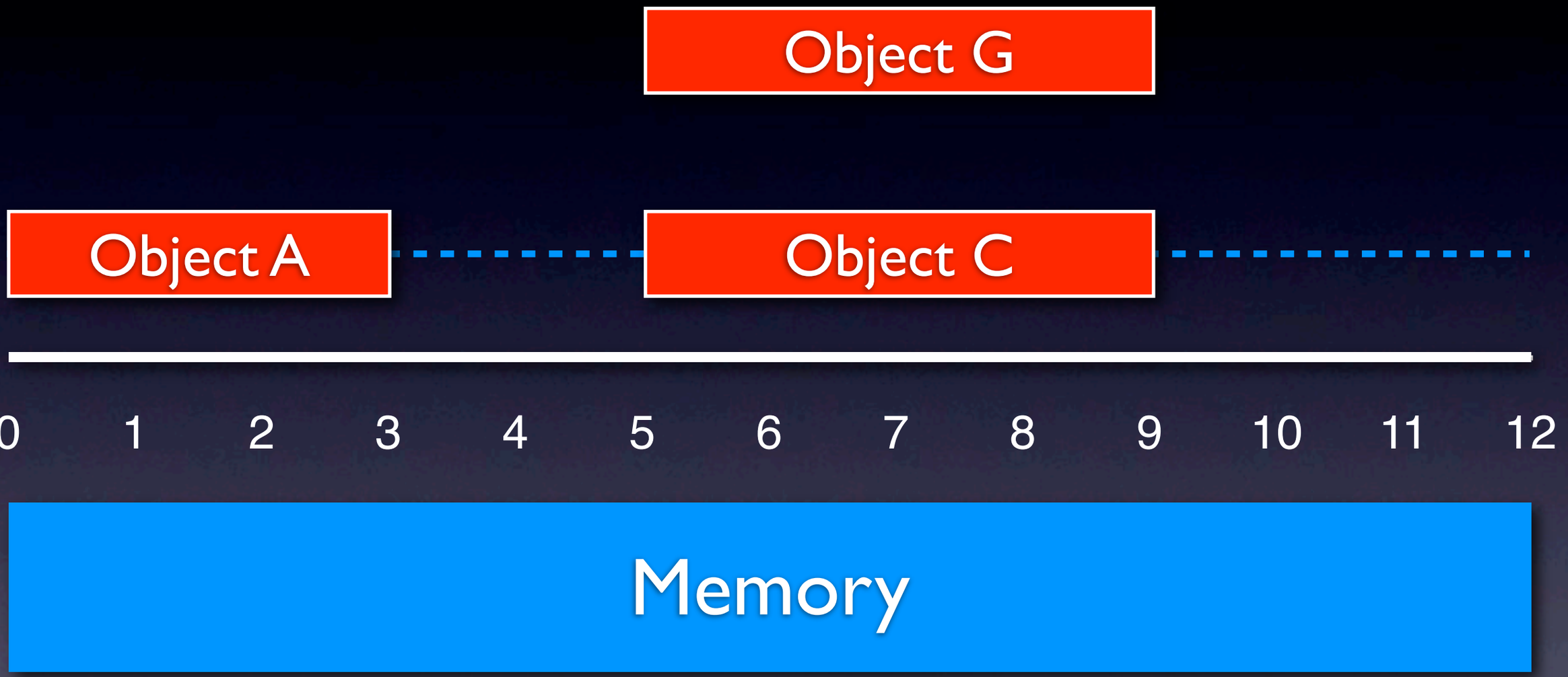

Memory is *fragmented* if the largest, contiguous piece of available space is smaller than the total available space

Fragmentation

- Memory objects may have different sizes
- Memory objects may be allocated and deallocated in random order
  - creates the problem of memory fragmentation!

Explicit, Dynamic Memory Management with Temporal and Spatial Guarantees

Static versus Dynamic

- Static memory management:
  - Preallocate all memory at compile time

Static versus Dynamic

- Static memory management:
  - Preallocate all memory at compile time
- Dynamic memory management:
  - Allocate and deallocate memory at run time

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Implicit versus Explicit

- Implicit, dynamic memory management:
  - Garbage collector (GC) deallocates objects, not programmer (implicit `free` calls by GC)

Implicit versus Explicit

- Implicit, dynamic memory management:
  - Garbage collector (GC) deallocates objects, not programmer (implicit `free` calls by GC)
- Explicit, dynamic memory management:
  - Objects are deallocated by programmer (explicit `free` calls)

Programming Abstraction

Runtime Overhead

Implicit, Dynamic Memory Management

Explicit, Dynamic Memory Management

Static Memory Management

Programming Abstraction

Runtime Overhead

Implicit

Web, Safety

Explicit

Server, Performance

Static

Embedded, Real Time

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Temporal Performance

- Throughput:
  - 10MB/s allocation rate
  - 10MB/s deallocation rate

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- Throughput:
  - 10MB/s allocation rate
  - 10MB/s deallocation rate
- Latency/Responsiveness:
  - 1ms execution time (malloc/free)
  - 0.1ms preemption time (malloc/free)

Spatial Performance

- Degree of fragmentation:
  - The number of contiguous pieces of memory of a given size that can still be allocated

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- Degree of fragmentation:
  - The number of contiguous pieces of memory of a given size that can still be allocated
- Administrative space:
  - meta data structures (used, free lists)

There is a trade-off
between
temporal and spatial
performance

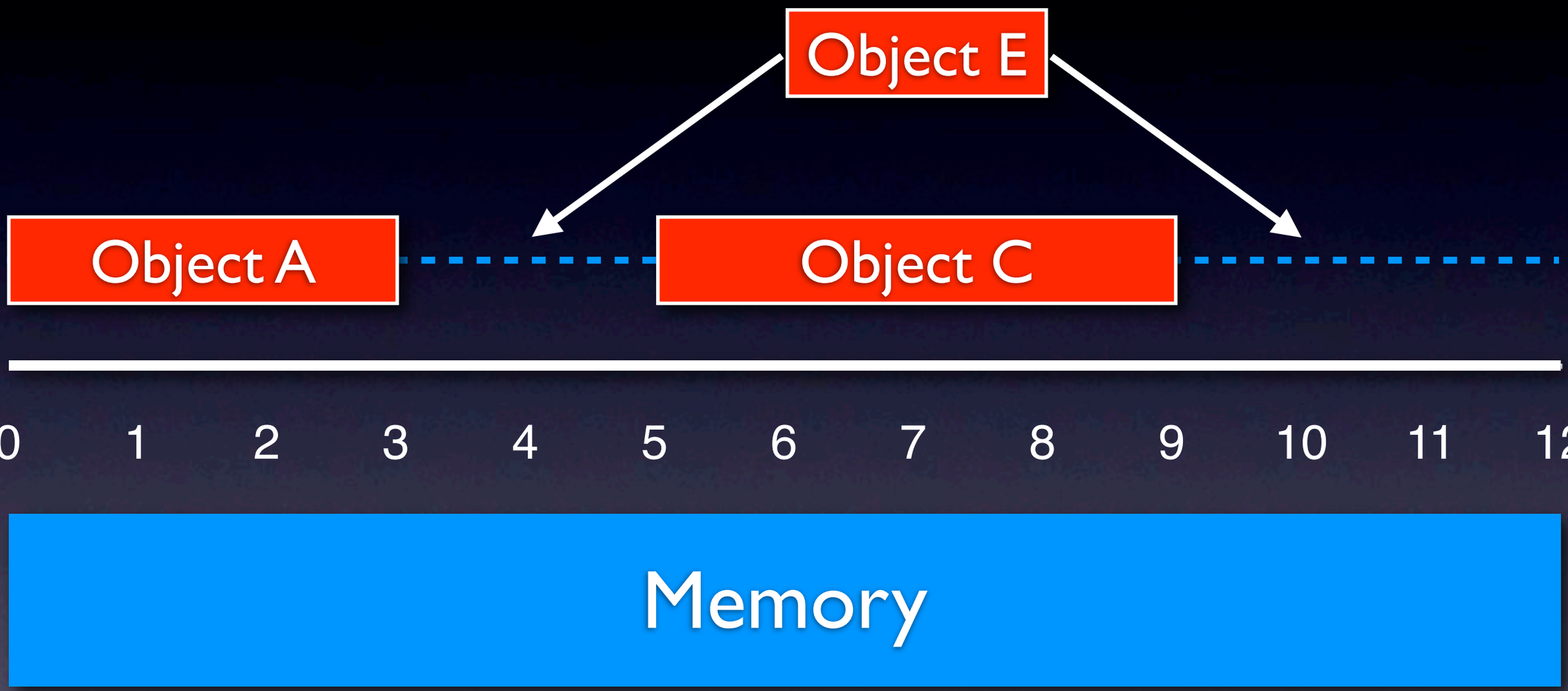
Temporal Predictability

- Unpredictable complexity (in terms of input):
  - allocation/deallocation may take time proportional to the total size of memory

Temporal Predictability

- Unpredictable complexity (in terms of input):
  - allocation/deallocation may take time proportional to the total size of memory
- Predictable complexity (in terms of input):
  - allocation/deallocation takes time at most proportional to the size of involved object
  - access takes time at most proportional to the size of involved object

Allocation Complexity



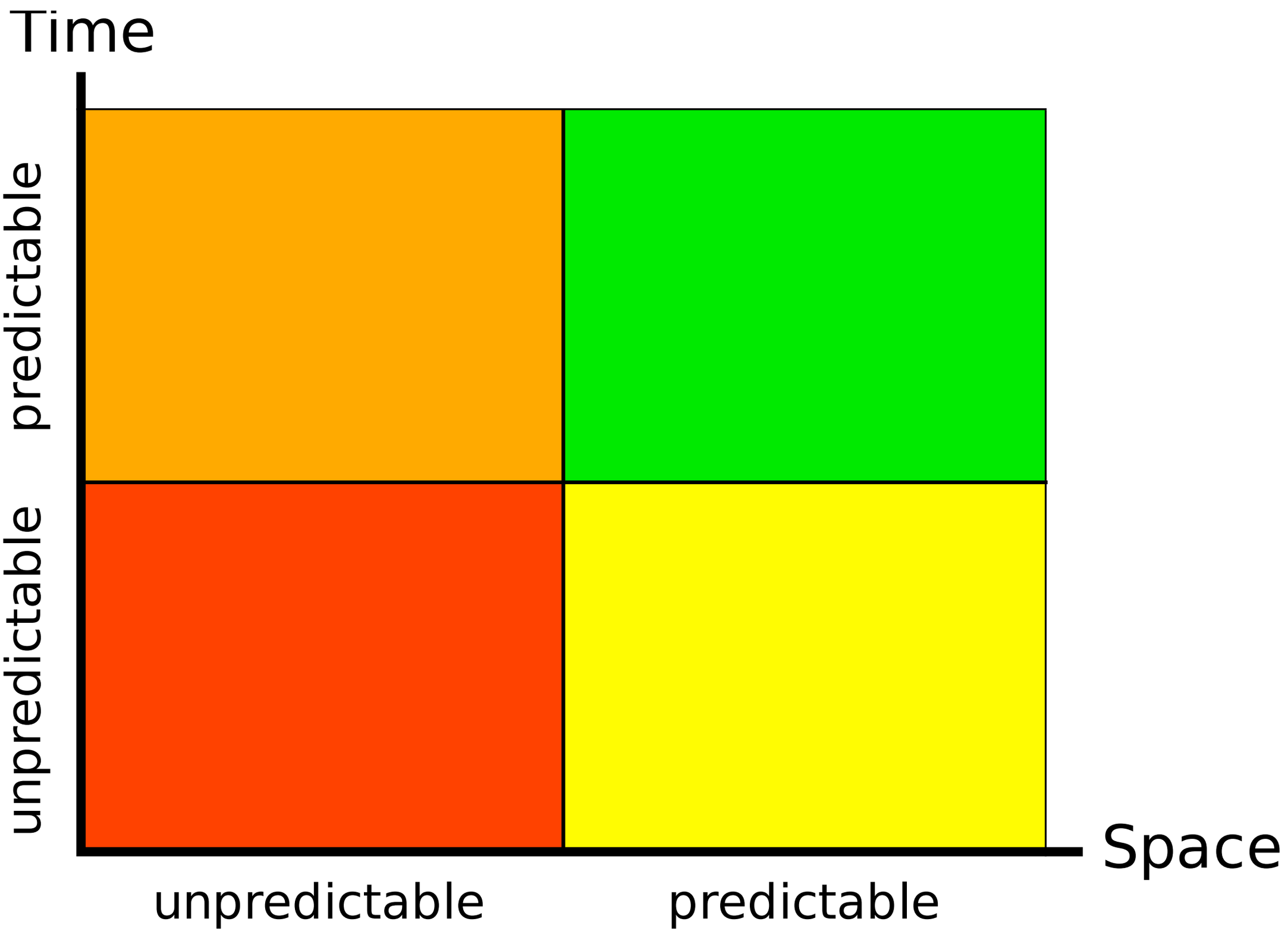
It may be difficult to
improve
average performance
but it may still be possible to
improve
predictability
without loosing too much
performance

Spatial Predictability

- Unpredictable fragmentation:
  - the degree of fragmentation may depend on the full allocation and deallocation history, i.e., the order of invocations

Spatial Predictability

- Unpredictable fragmentation:
  - the degree of fragmentation may depend on the full allocation and deallocation history, i.e., the order of invocations
- Predictable fragmentation:
  - the degree of fragmentation only depends on the number of allocations and deallocations, independently of the order of invocations



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- Silviu Craciunas[#] (Programming Model)
- Andreas Haas (Memory Management)
- Hannes Payer [#] (Memory Management)
- Harald Röck (VM, Scheduling)
- Ana Sokolova* (Theoretical Foundation)

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Tiptoe

- Tiptoe is a microkernel-based virtual machine and process monitor for embedded systems

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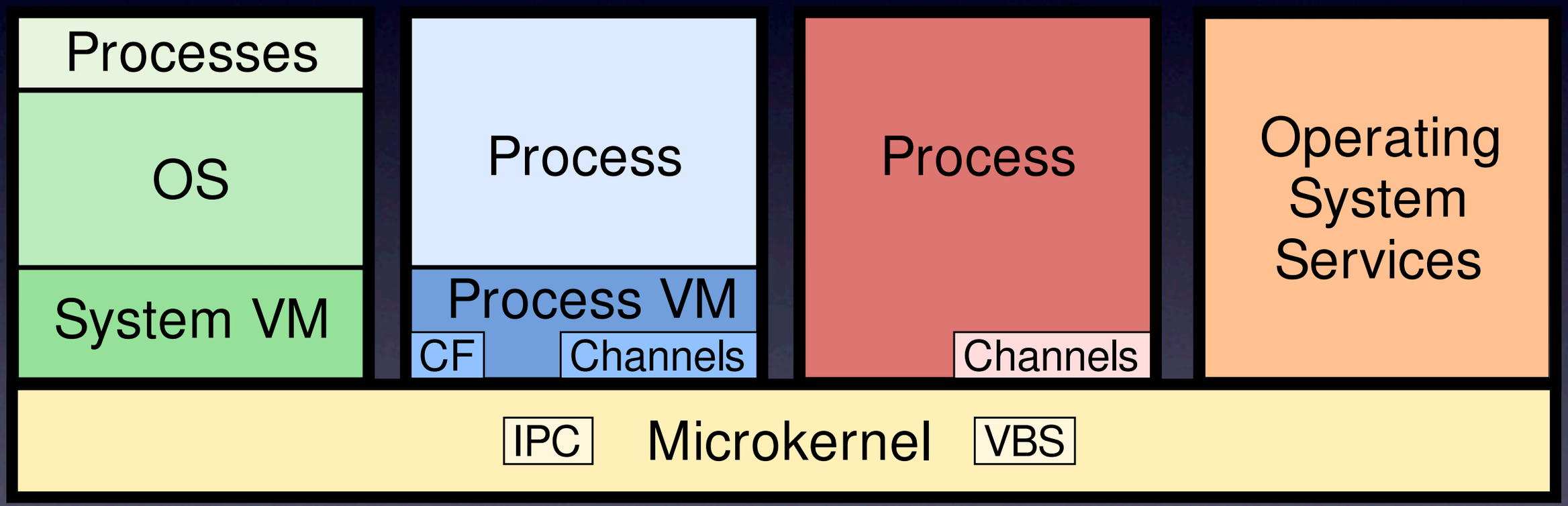
- Tiptoe virtualizes the host platform (system VM) and provides infrastructure to run process VMs and processes in real time
- Tiptoe controls throughput and latency of CPU, memory, and I/O
- I/O is multiplexed through IPC to a system VM running Linux

Tiptoe



The JAviator

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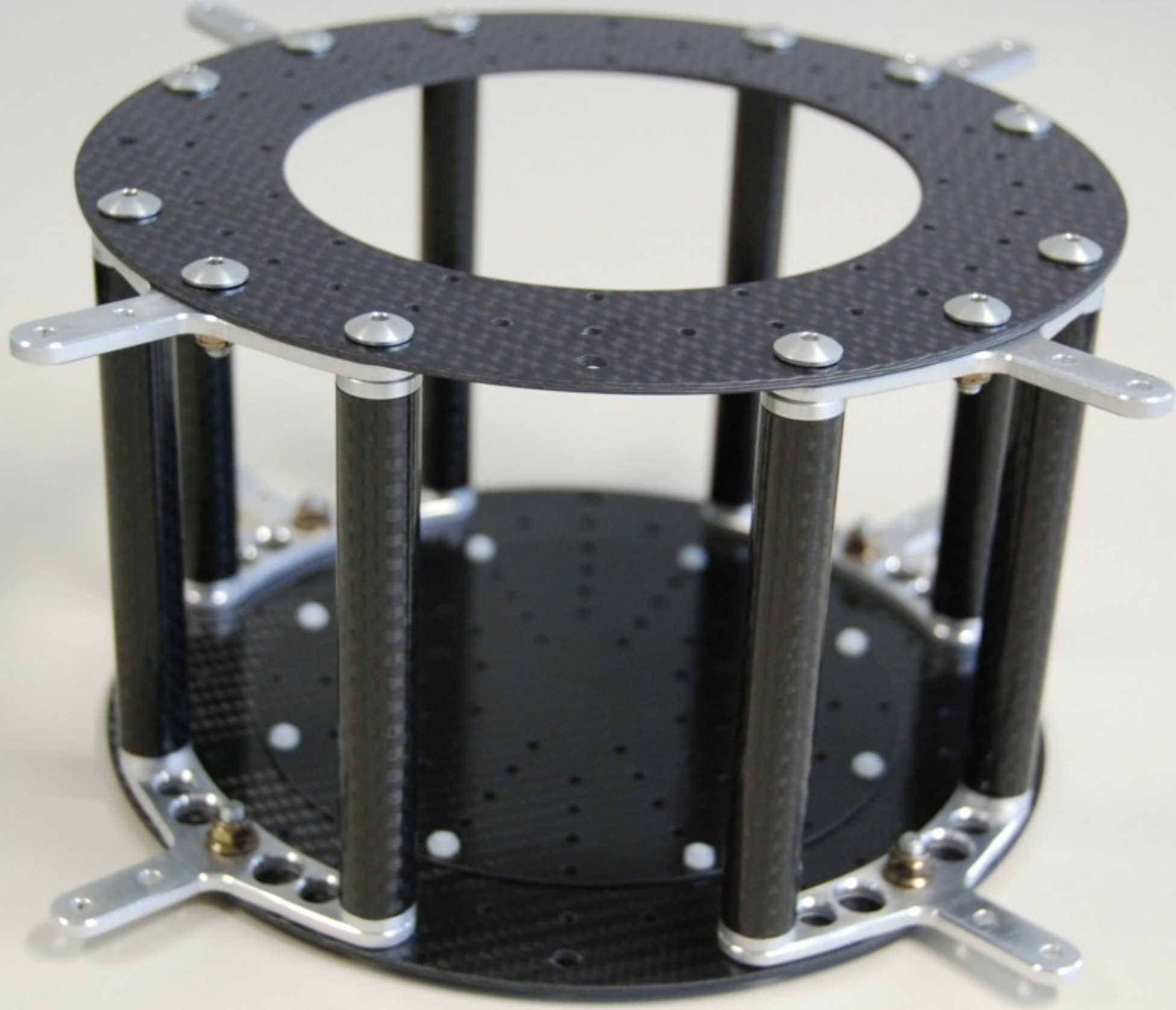
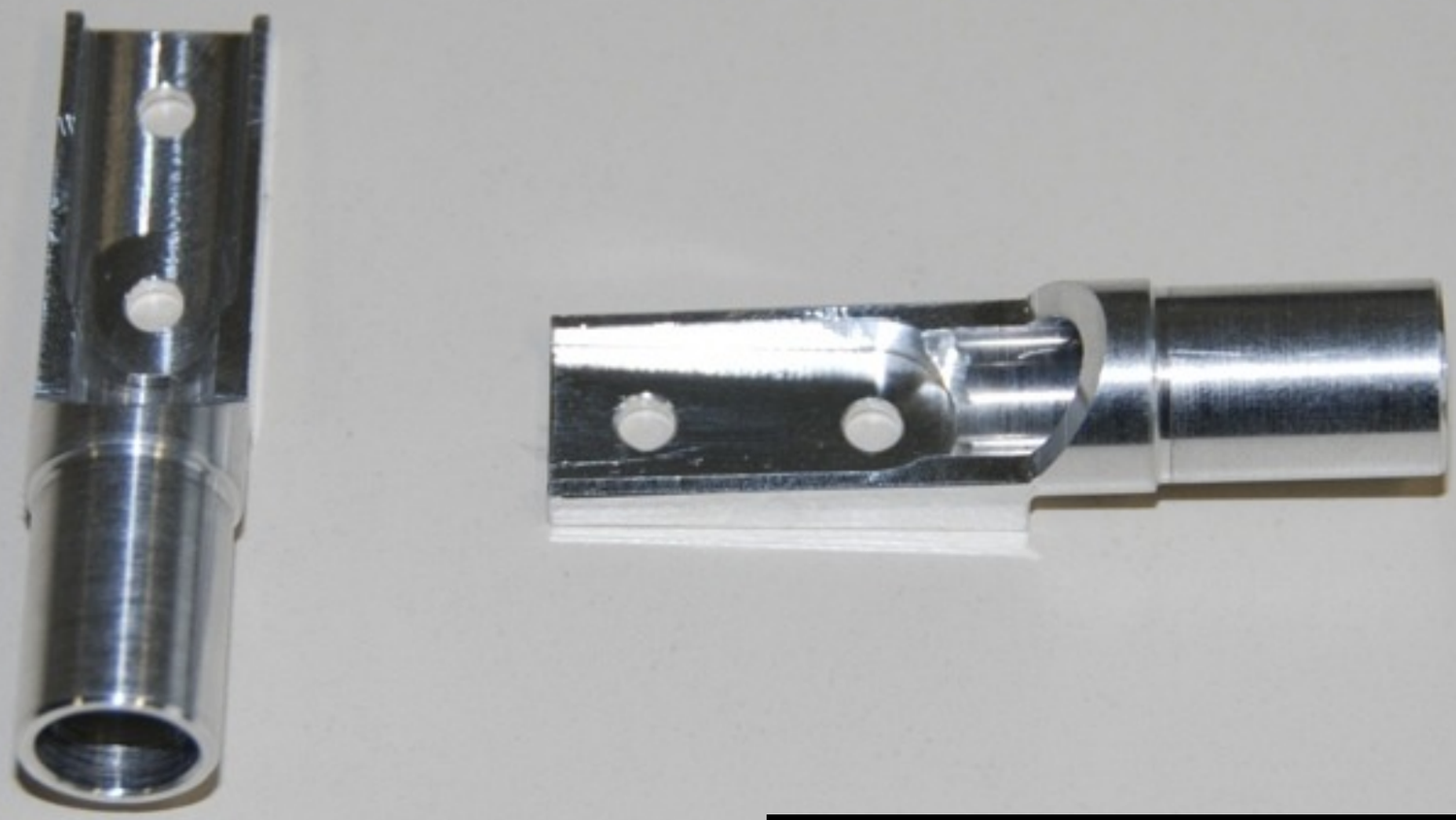
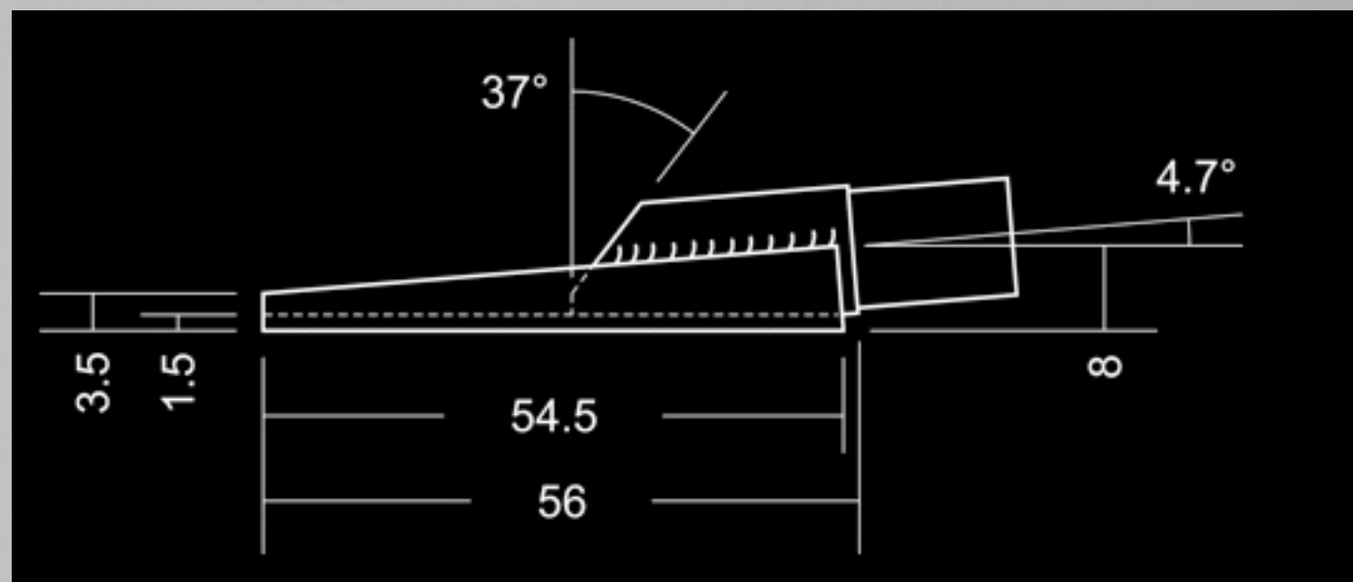
Quad-Rotor Helicopter



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4.7°
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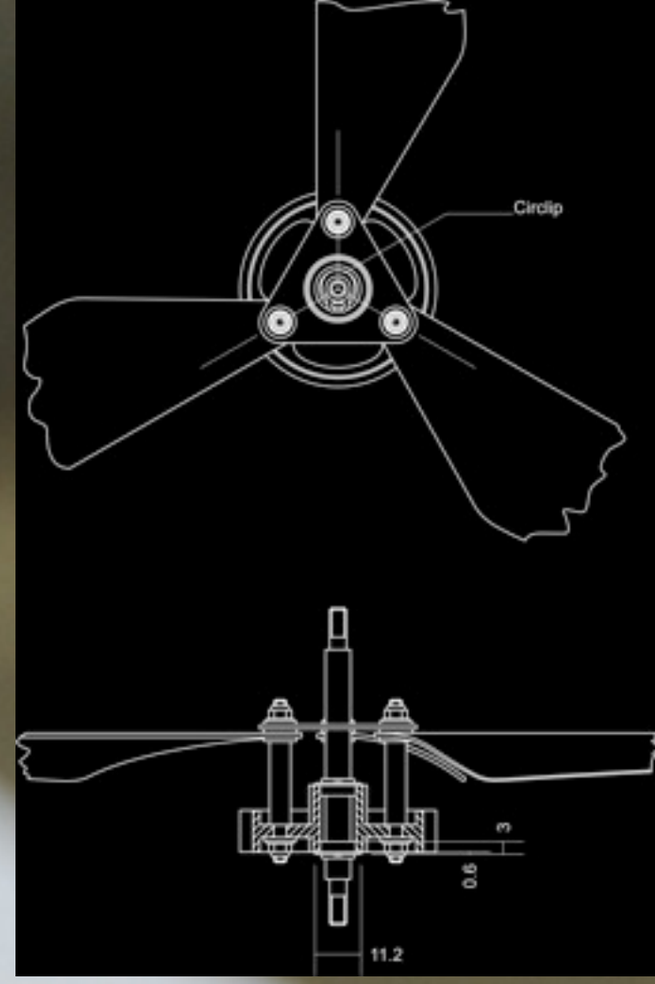
1.5
54.5
56
8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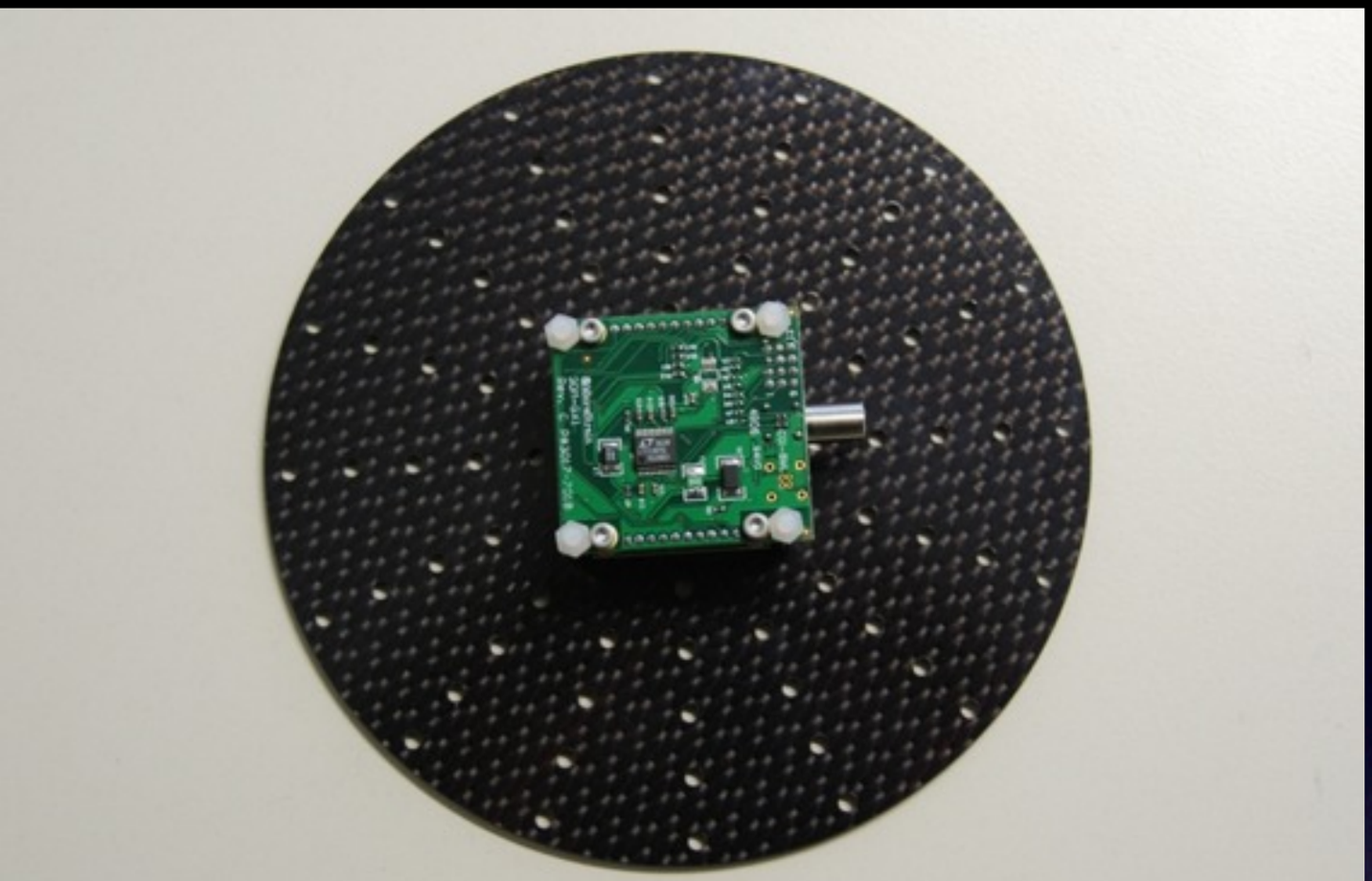
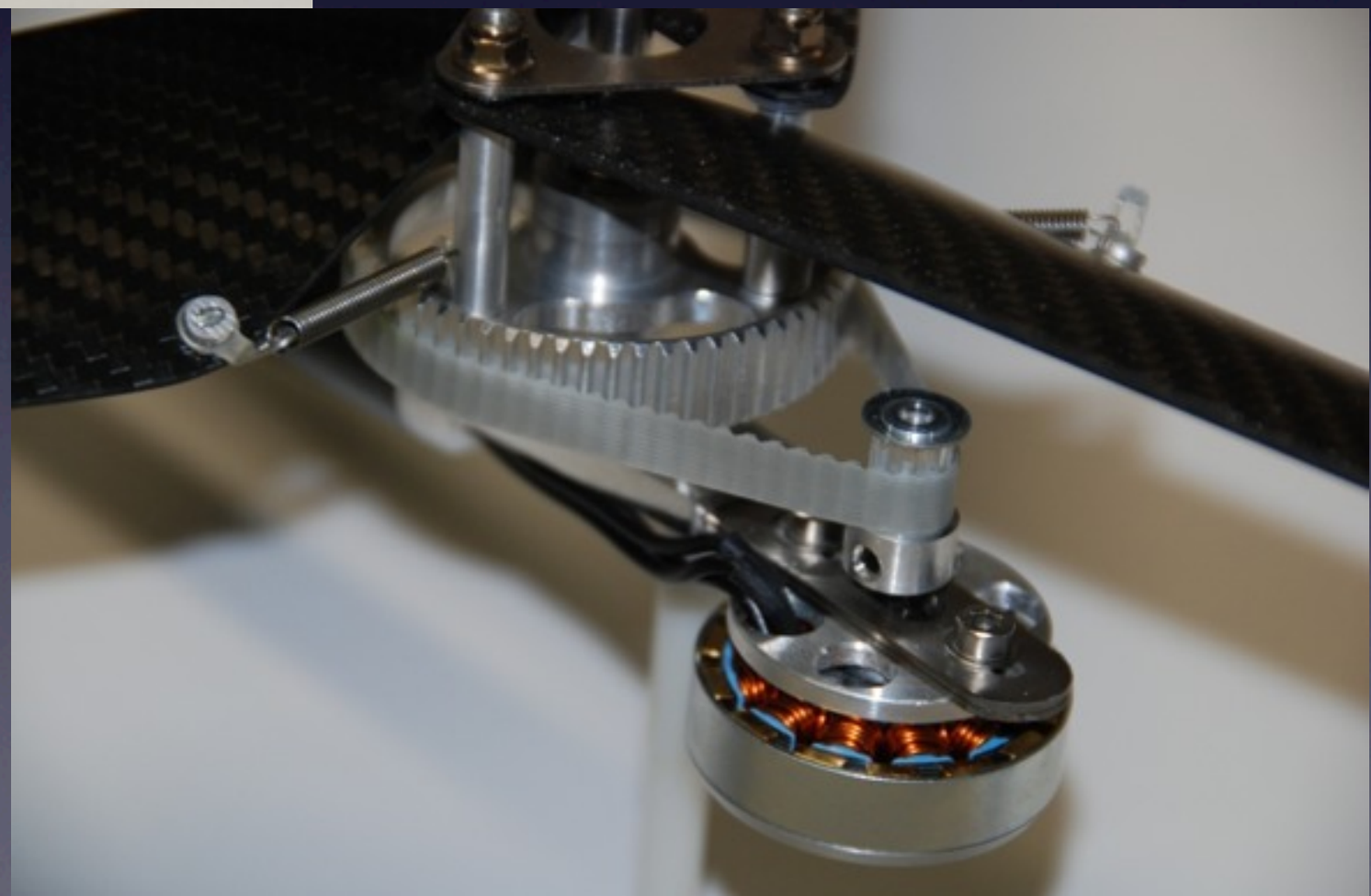
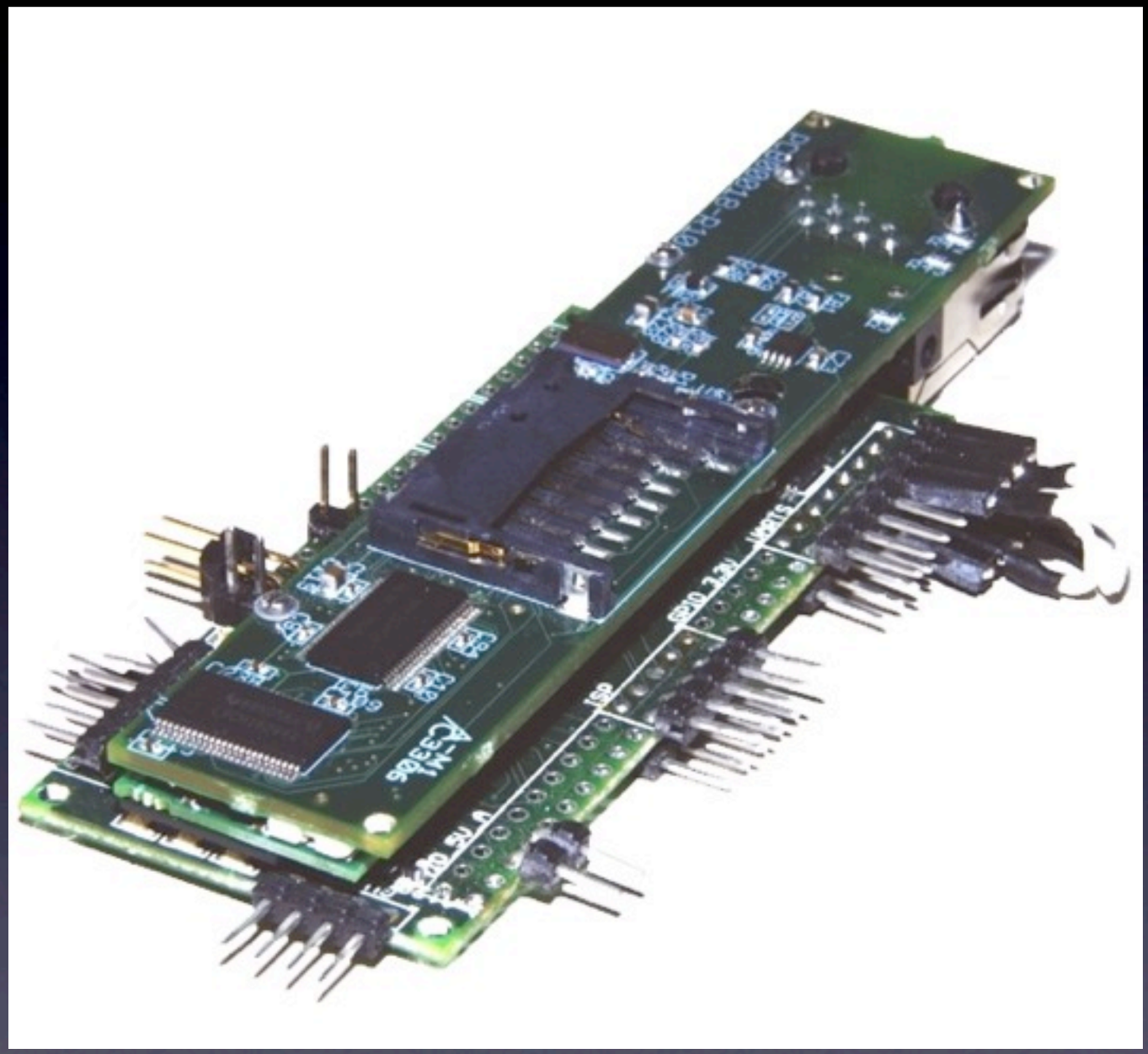


Gyro

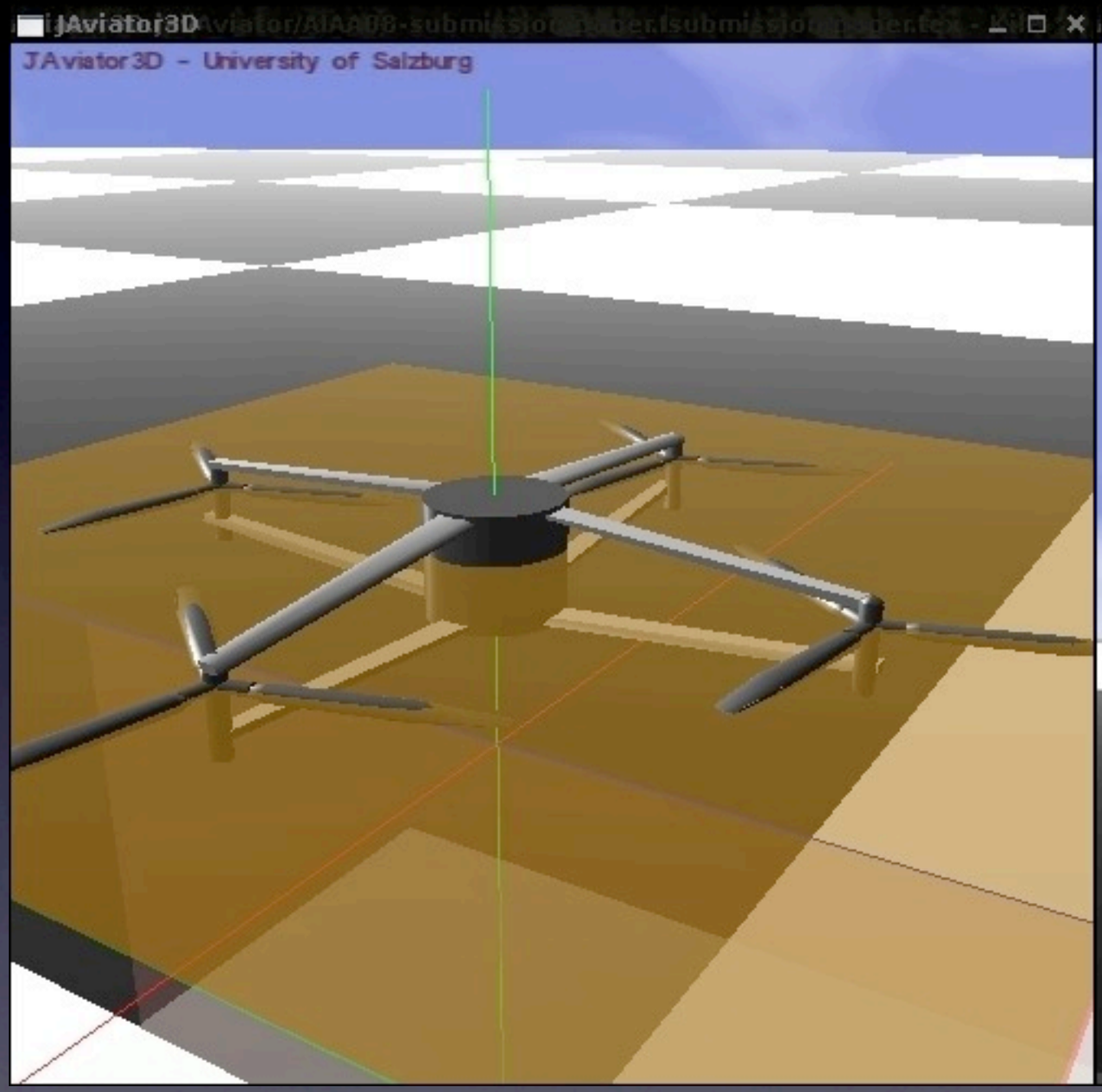
Propulsion

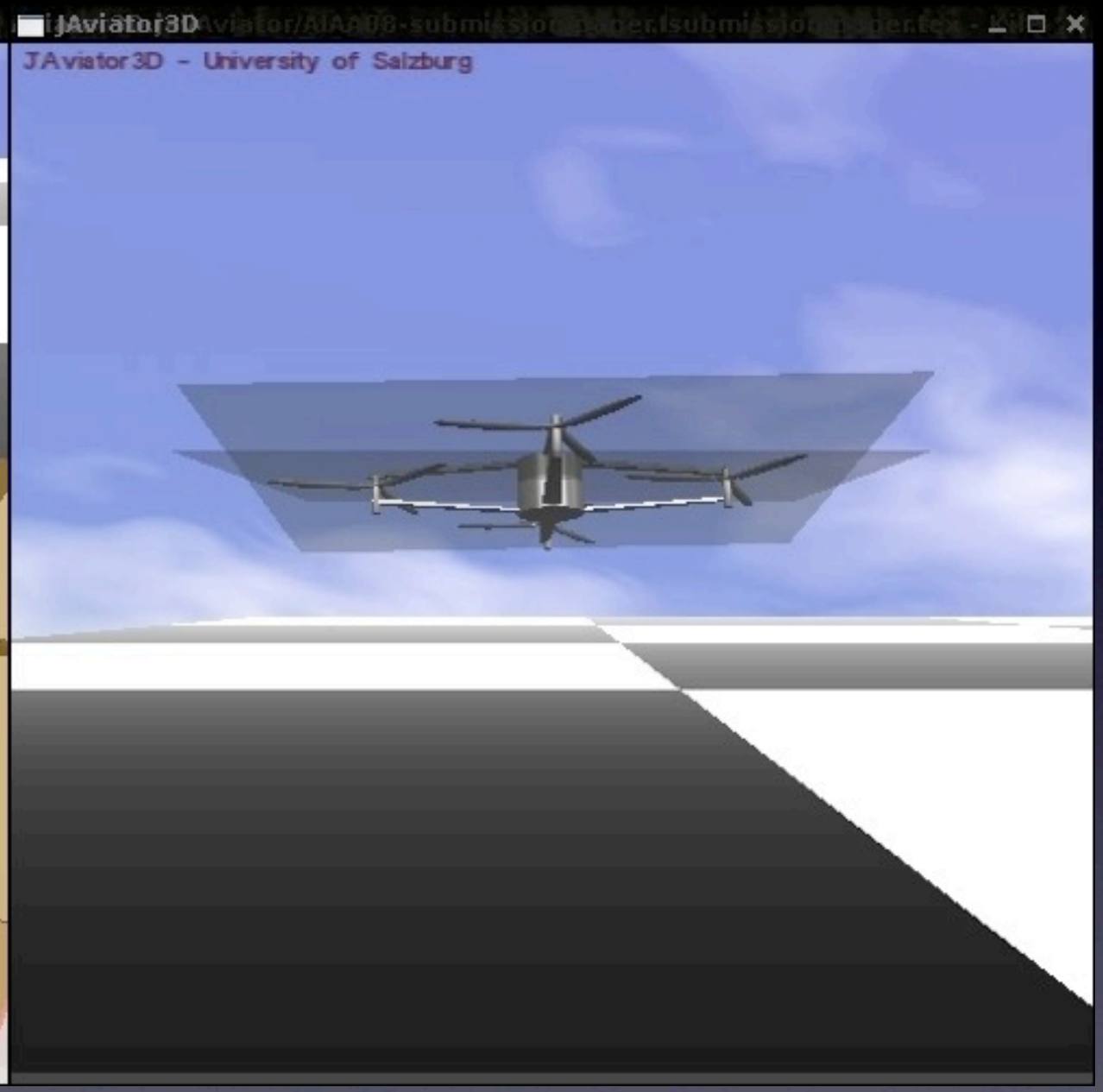


Gumstix



600MHz XScale, 128MB RAM, WLAN, Atmega uController





Indoor Flight
STARMAC Controller

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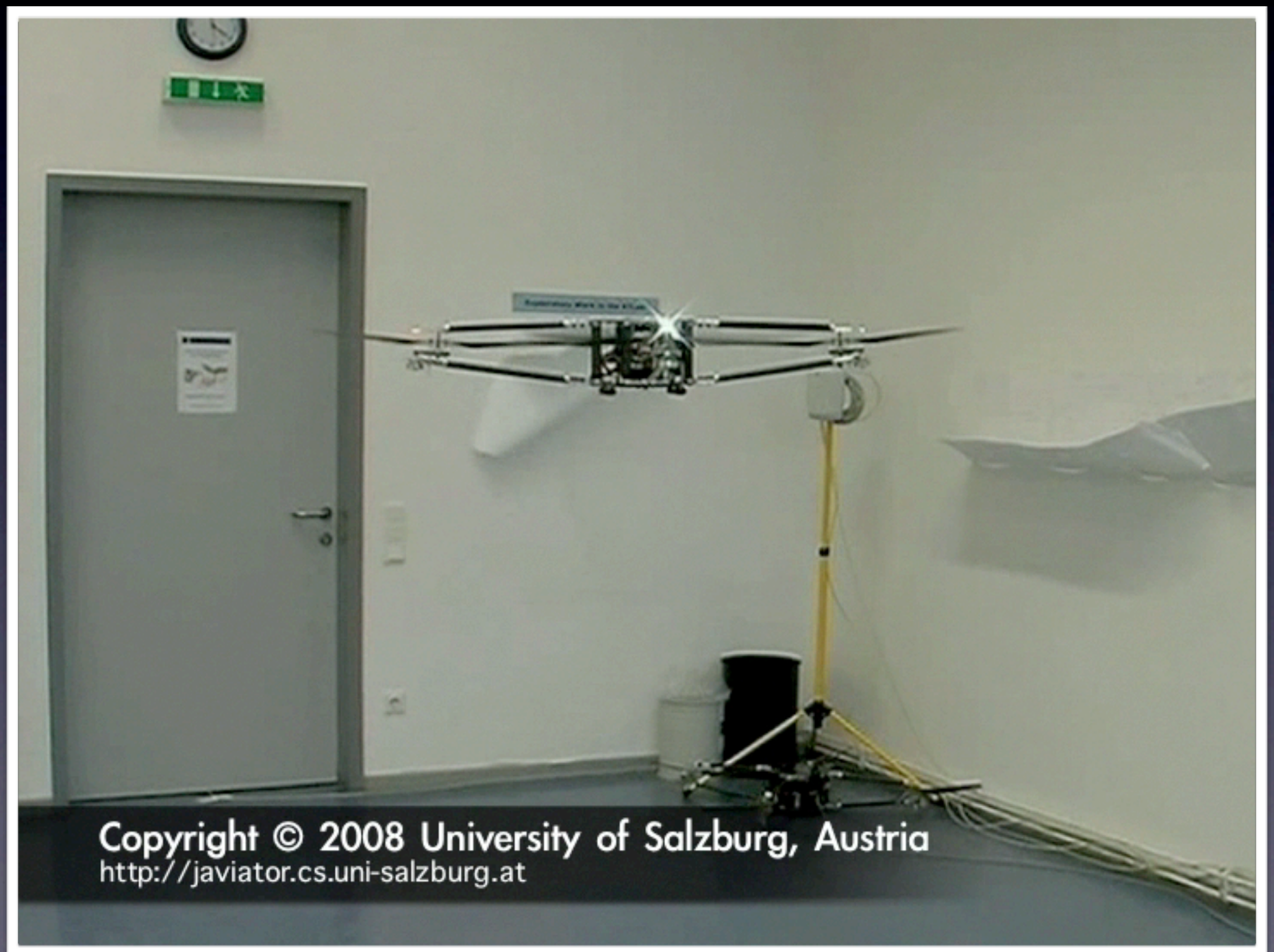

Outdoor Flight
STARMAC Controller

Outdoor Flight
STARMAC Controller

Outdoor Flight
Salzburg Controller

Outdoor Flight
Salzburg Controller

What's next?

- Autonomous single-vehicle flights
  - position controller
  - waypoint controller

What's next?

- Autonomous single-vehicle flights
  - position controller
  - waypoint controller
- Autonomous multi-vehicle flights
  - mission controller

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Salzburg Soft Walls Controller on JJ

Salzburg Soft Walls Controller on JJ