

# [544] Caching and PyArrow

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# Learning Objectives

- write cache-friendly code with Numpy and PyArrow
- use memory mappings via PyArrow to access data that is larger than physical memory
- enable swapping to alleviate memory pressure
- configure Docker memory limits on physical memory used

# Outline

CPU: L1-L3

Demos: PyTorch+PyArrow...

OS (Operating System): Page Cache

Demos: PyArrow+Docker

# Granularity

If a process reads 1 byte and misses, *how much data should the CPU bring into the cache?*

- **too little:** we'll have many more misses if we read nearby bytes soon
- **too much:** wasteful to load data to cache that might never be accessed

L1-L3 cache data in units called **cache lines**

- modern CPUs typically 64 bytes (for example, 8 int64 numbers)
- M1/M2 uses 128

# Cache Lines and Misses

cacheline

int64

int64

int64

int64

int64

int64

int64

cacheline

int64

int64

int64

int64

int64

int64

int64

how many  
misses?

cacheline

int64

int64

int64

int64

int64

int64

int64

cacheline

int64

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int64

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int64

int64

int64

int64

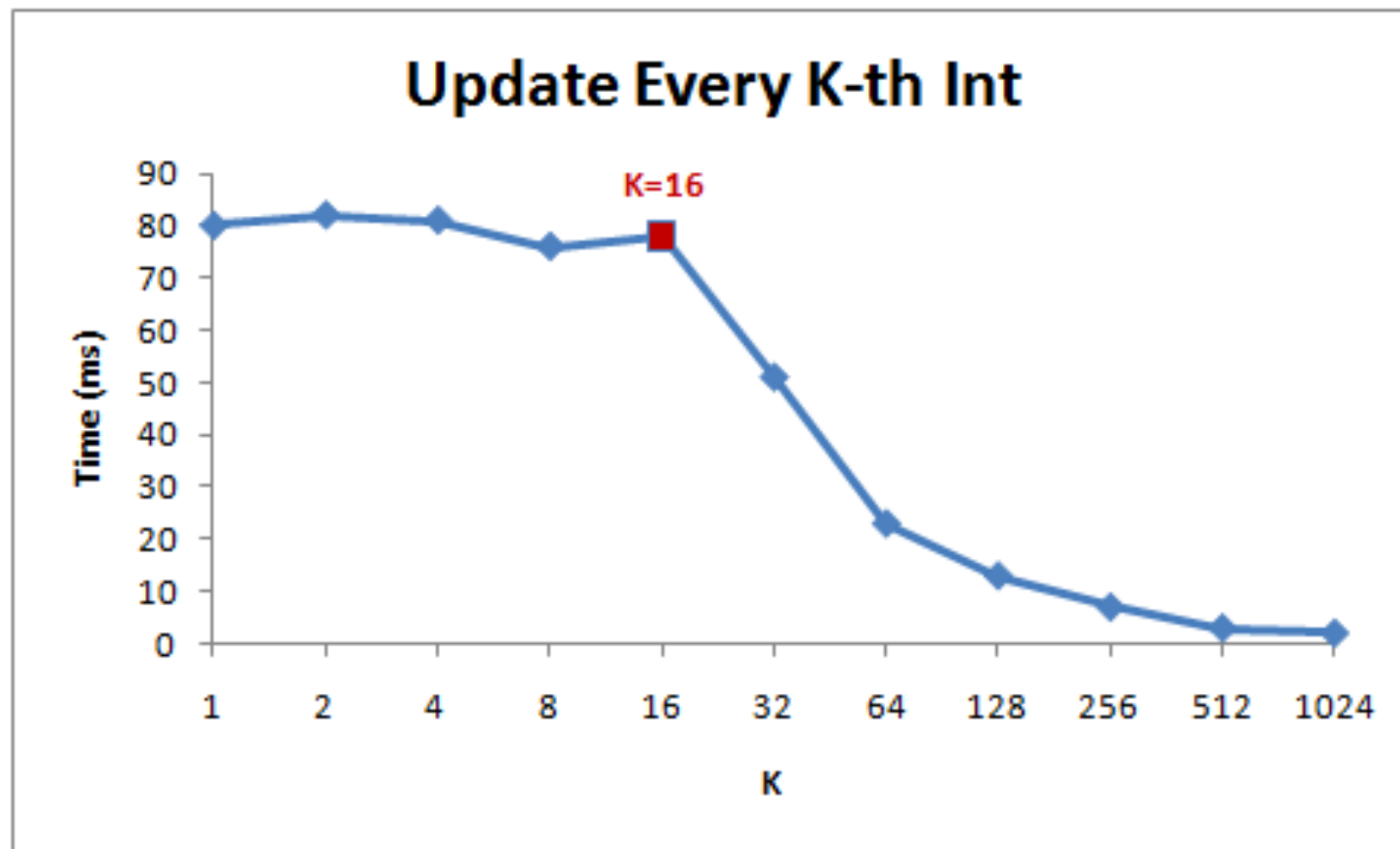
int64

how many  
misses?

# Example 1: Step and Multiply

as K gets bigger, we do fewer multiplications. But does it matter?

```
for (int i = 0; i < arr.Length; i += K) arr[i] *= 3;
```

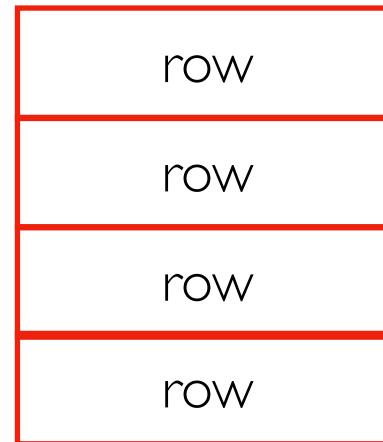


[Gallery of Processor Cache Effects](http://igoro.com/archive/gallery-of-processor-cache-effects/)

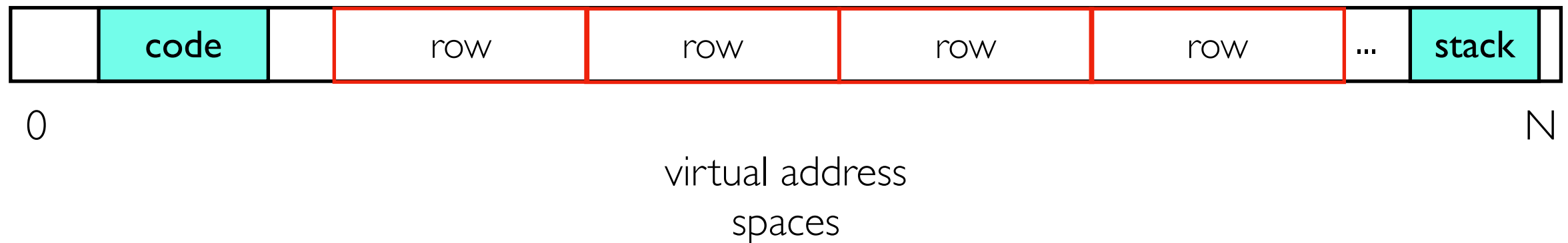
<http://igoro.com/archive/gallery-of-processor-cache-effects/>

# Example 2: Matrices

matrix of numbers  
**logically**, 2-dimensional

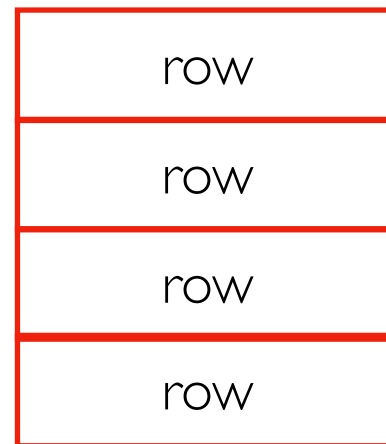


**physically**, those rows are arranged along  
1-dimension in the virtual address space

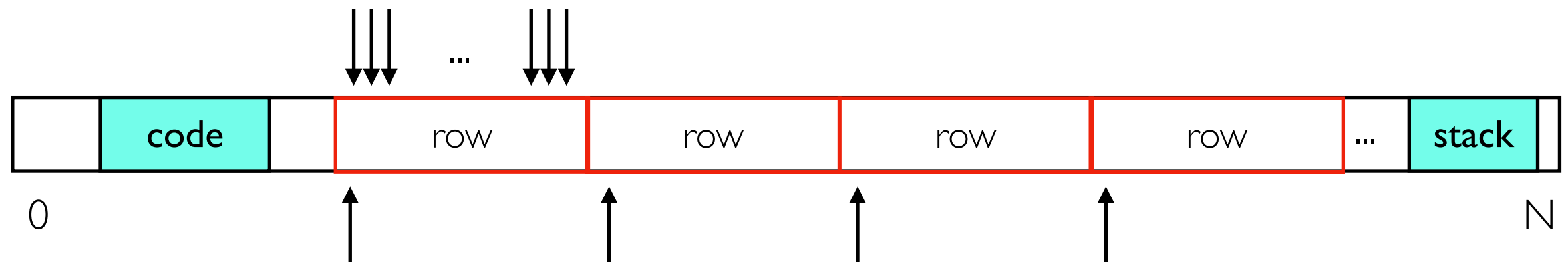


# Example 2: Matrices

matrix of numbers  
**logically**, 2-dimensional



summing over row:  
data consolidated over few cache lines



summing over column: each number is in its own cache line and triggers a cache miss

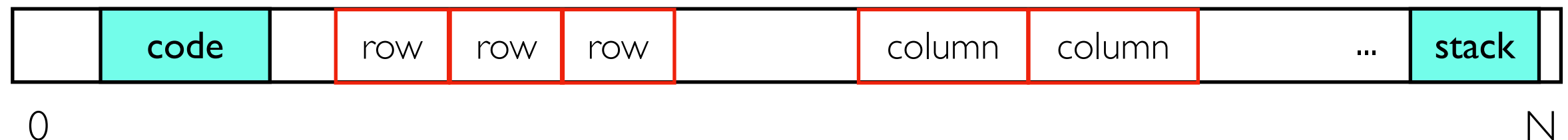


# Numpy: Controlling Layout with Transpose

for efficiency, transpose doesn't actually move/copy data,  
meaning we can get fast column sum by (a) putting  
column data in rows and (b) transposing

```
np.array([[1, 2],  
         [3, 4],  
         [5, 6]])
```

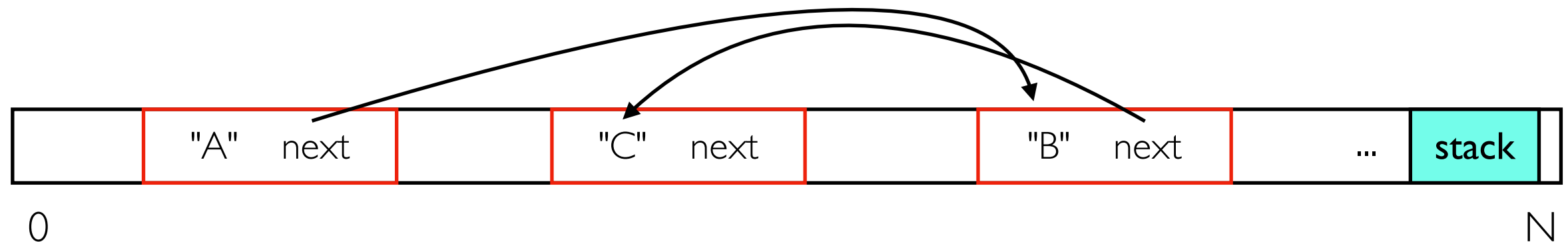
```
np.array([[1, 3, 5],  
         [2, 4, 6]]) .T
```



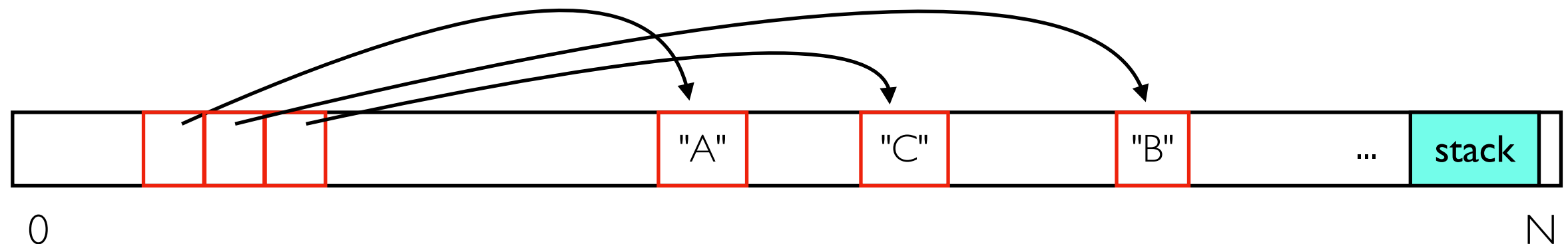
any calculations on the two tensors will produce the same results,  
but they'll each be faster for different access patterns!

# Example 3: Ordered Collections of Strings

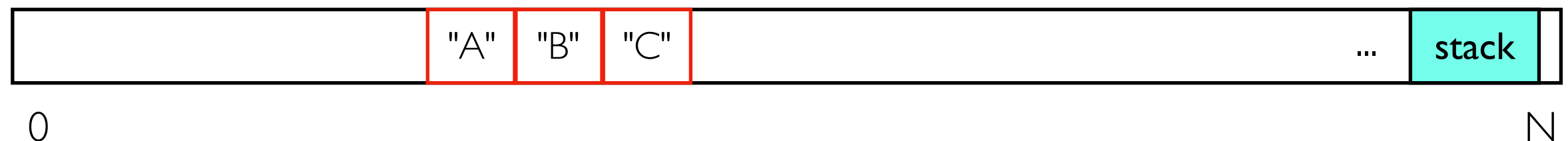
which layout is most cache friendly?



linked list



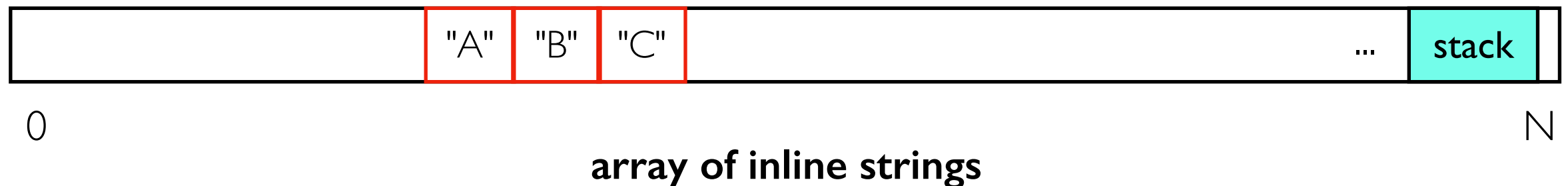
array of references to strings



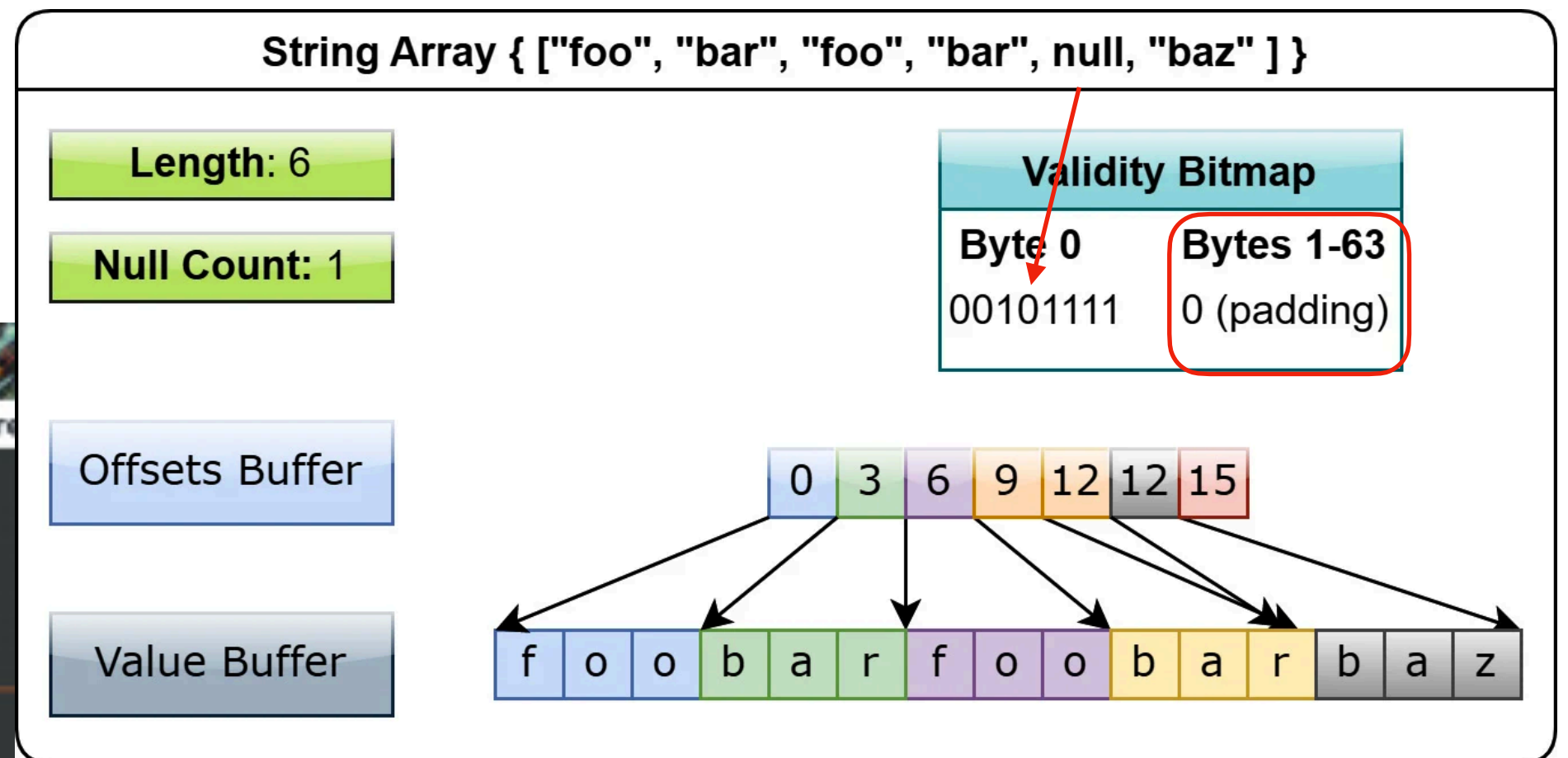
array of inline strings

# Example 3: Ordered Collections of Strings

how to tell the end of one string from the start of the next?  
how to jump immediately to string at index i?  
how support null/None?



# PyArrow String Array Data Structure



data is packed into fewest possible cache lines

- collection of named arrays is a Table
- arrays for different types, each cache friendly
- null support for types like int (not forced into floats)

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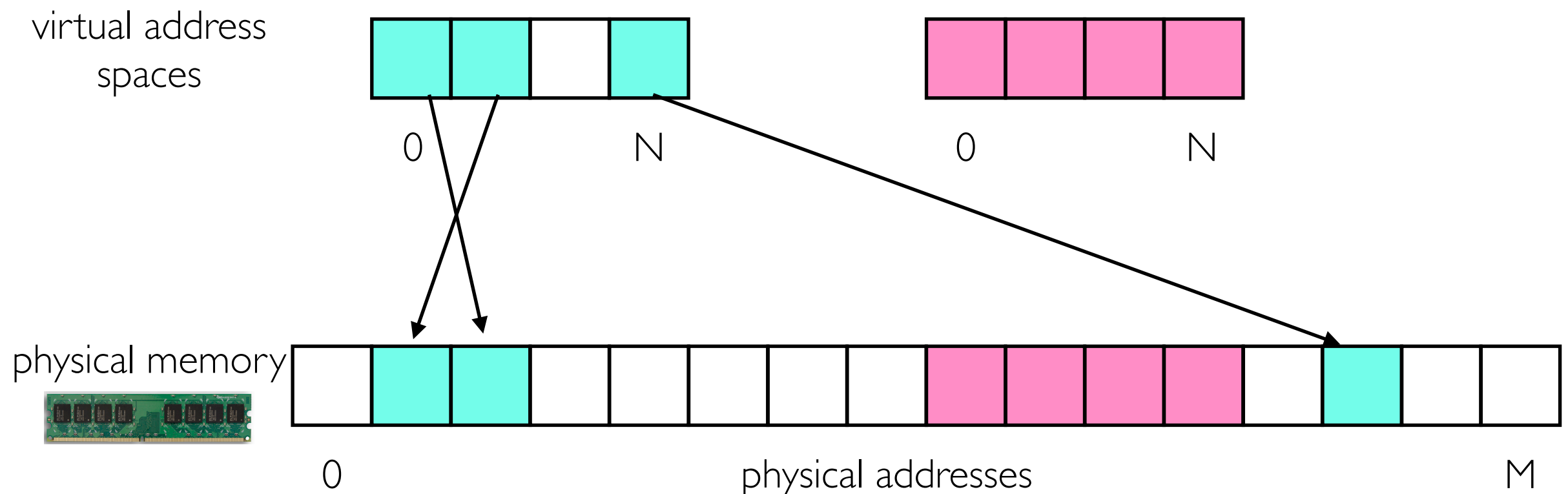
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# Review Processes and Address Spaces

Address spaces

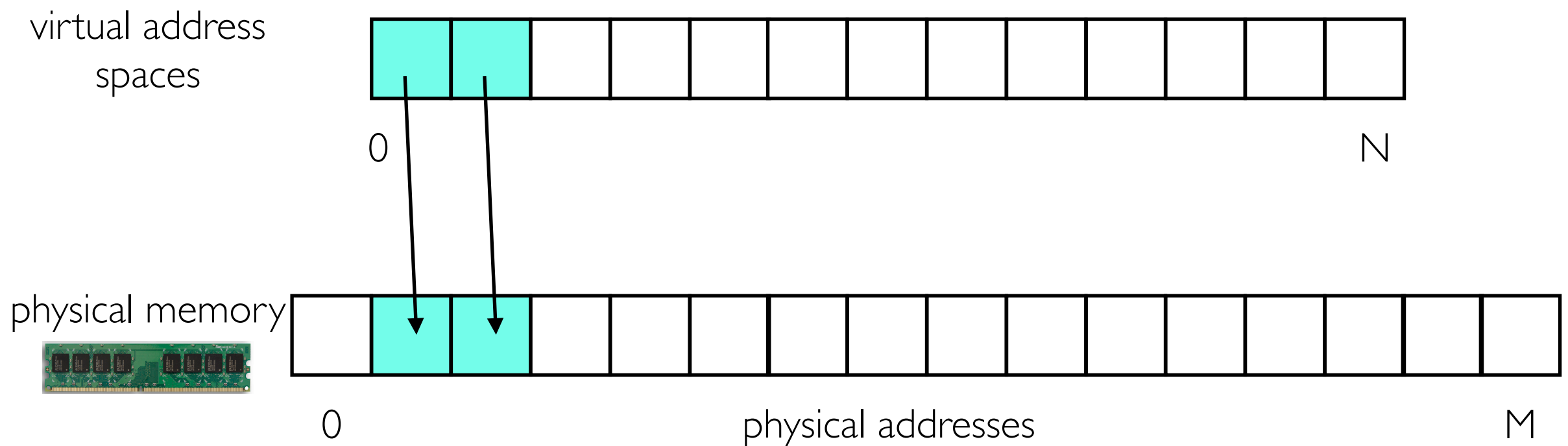
- Each process has its own **virtual address space**
- **pages** (usually 4 KB) of memory are mapped to physical memory



# mmap (Memory Map)

An mmap call can add new regions to a virtual address space. Two varieties:

- anonymous
- backed by a file





# Anonymous mmap

An mmap call can add new regions to a virtual address space. Two varieties:

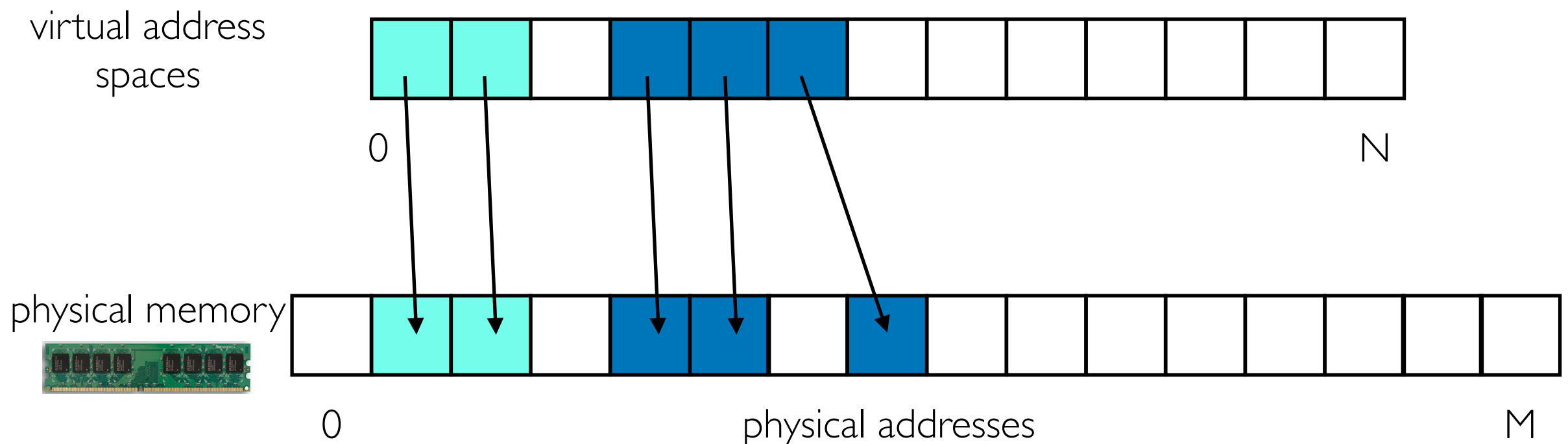
- **anonymous**
- backed by a file

```
import mmap
```

```
mm = mmap.mmap(-1, 4096*3)
```

anonymous

3 pages



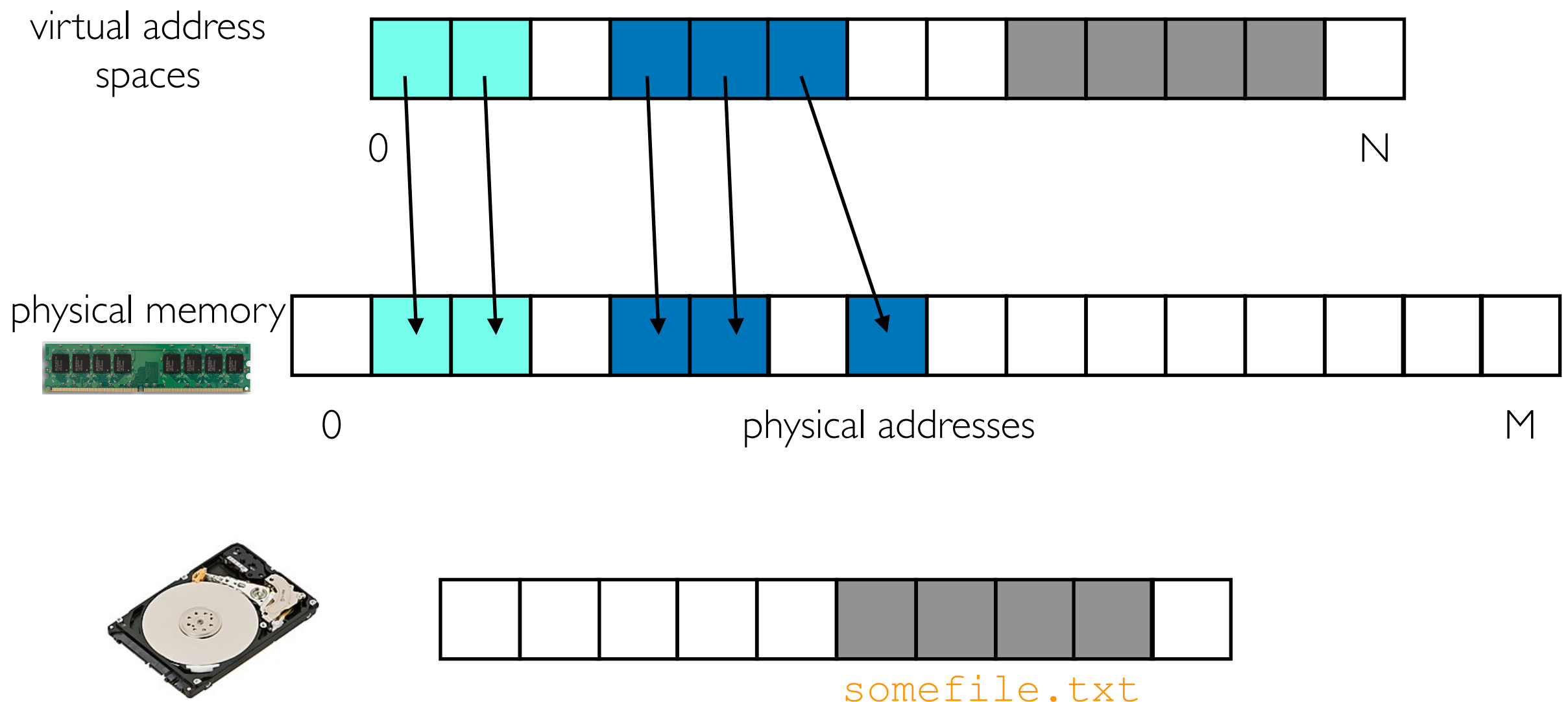
- Python (and other language runtimes) will mmap some anonymous memory when they need more heap space
- this will be used for Python objects (ints, lists, dicts, DataFrames, etc.)

# File-Backed mmap

An mmap call can add new regions to a virtual address space. Two varieties:

- anonymous
- backed by a file

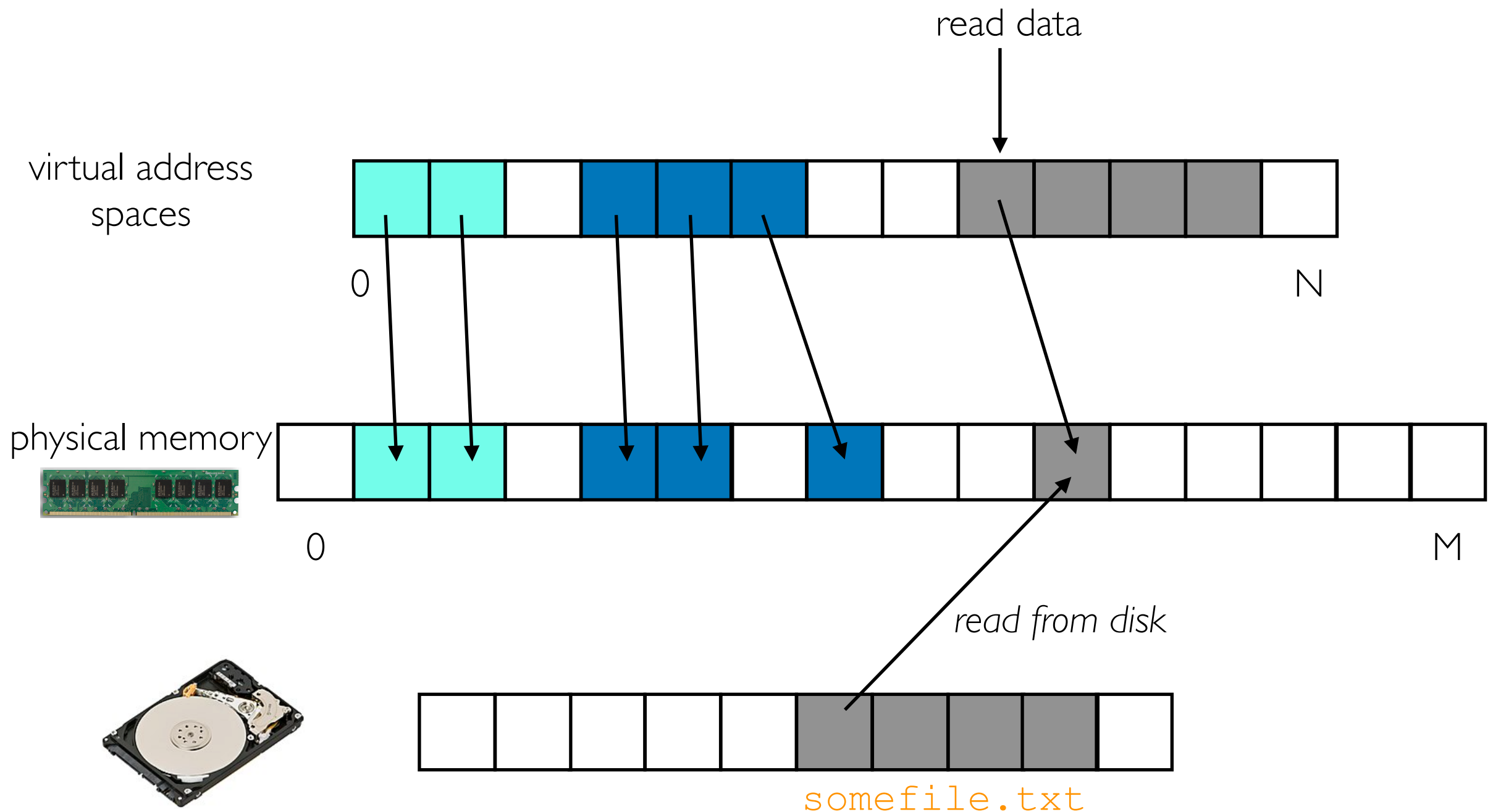
```
import mmap
f = open("somefile.txt", mode="rb")
mm = mmap.mmap(f.fileno(), 0, # 0 means all
               access=mmap.ACCESS_READ)
```



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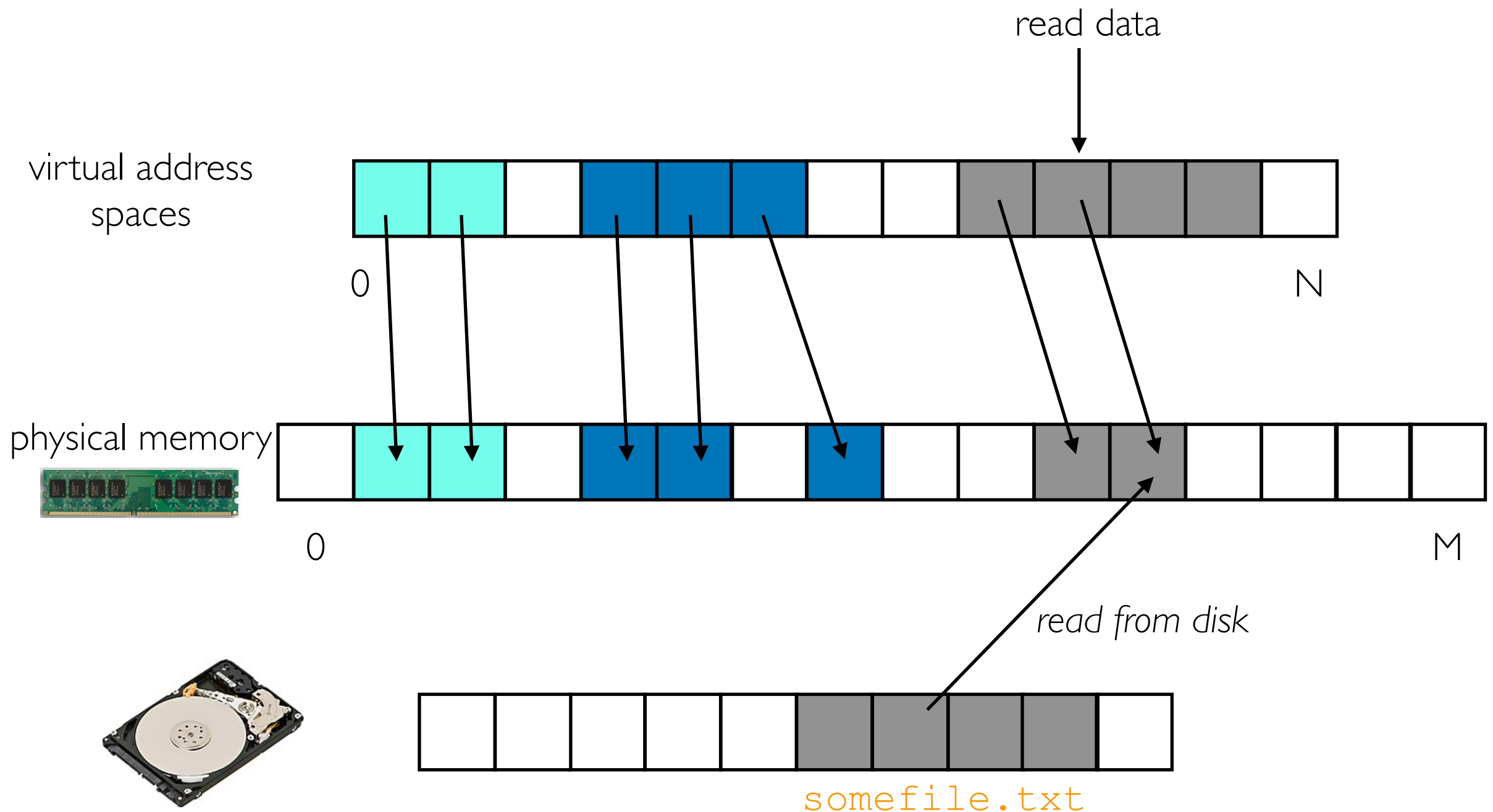
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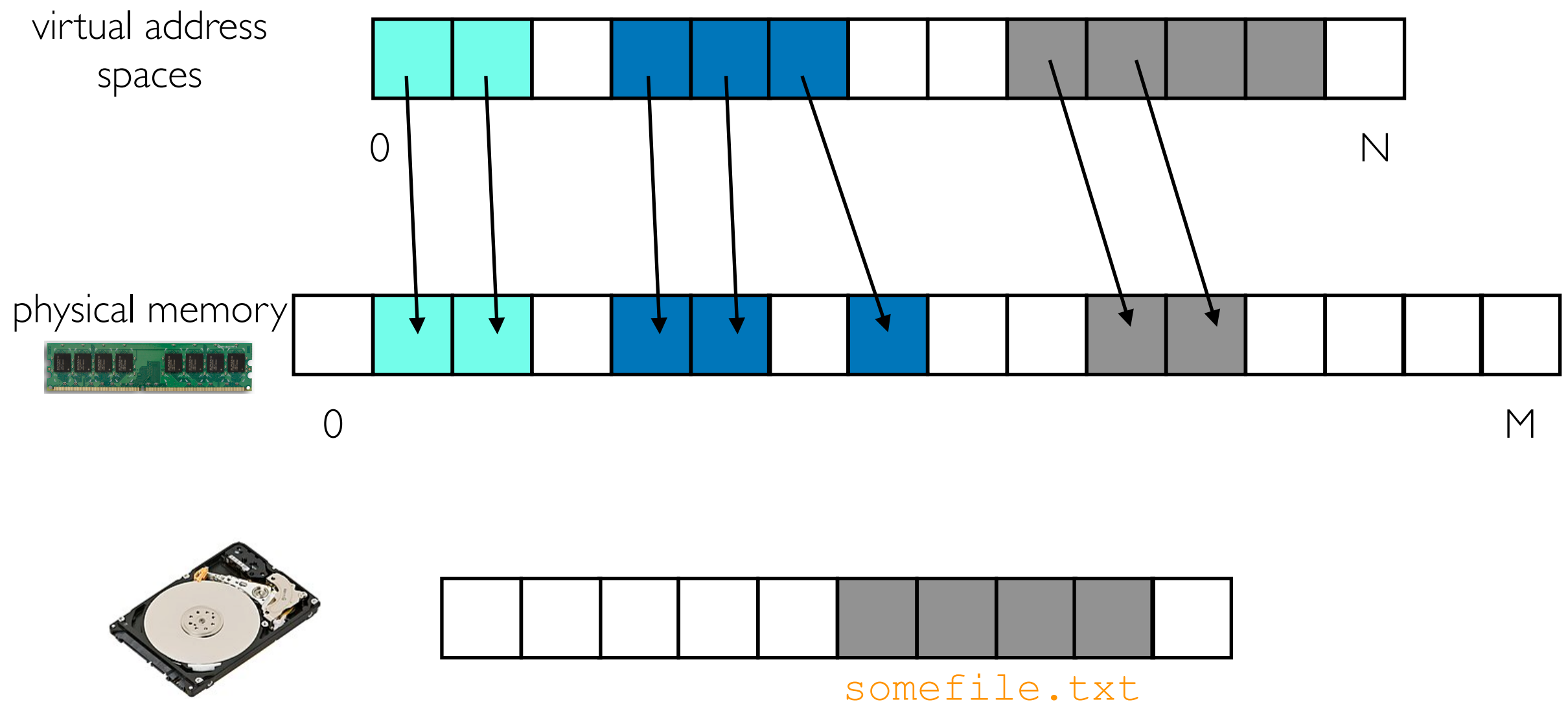
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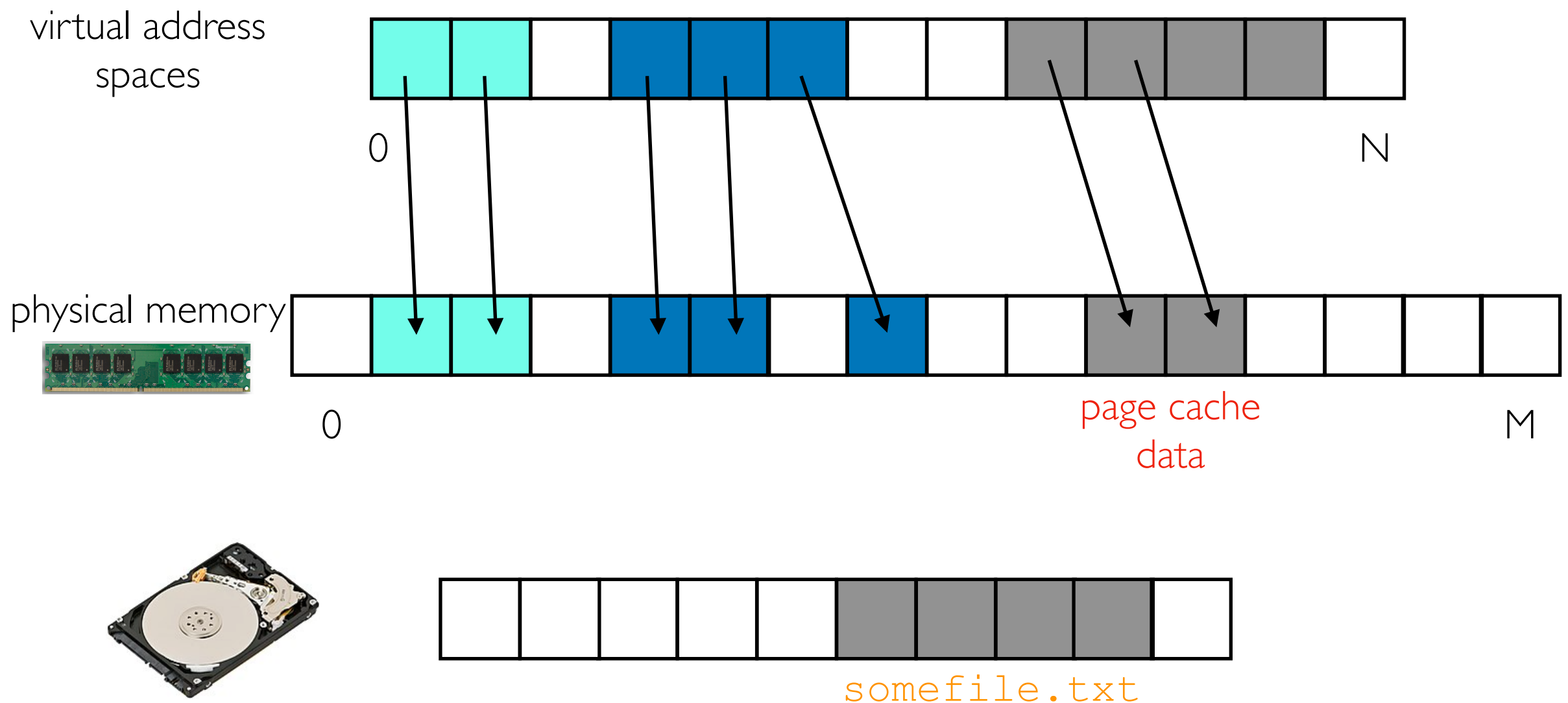
- anonymous
- backed by a file
- **virtual** memory used:  $9 * \text{pagesize} = 36 \text{ KB}$
- **physical** memory used:  $7 * \text{pagesize} = 28 \text{ KB}$



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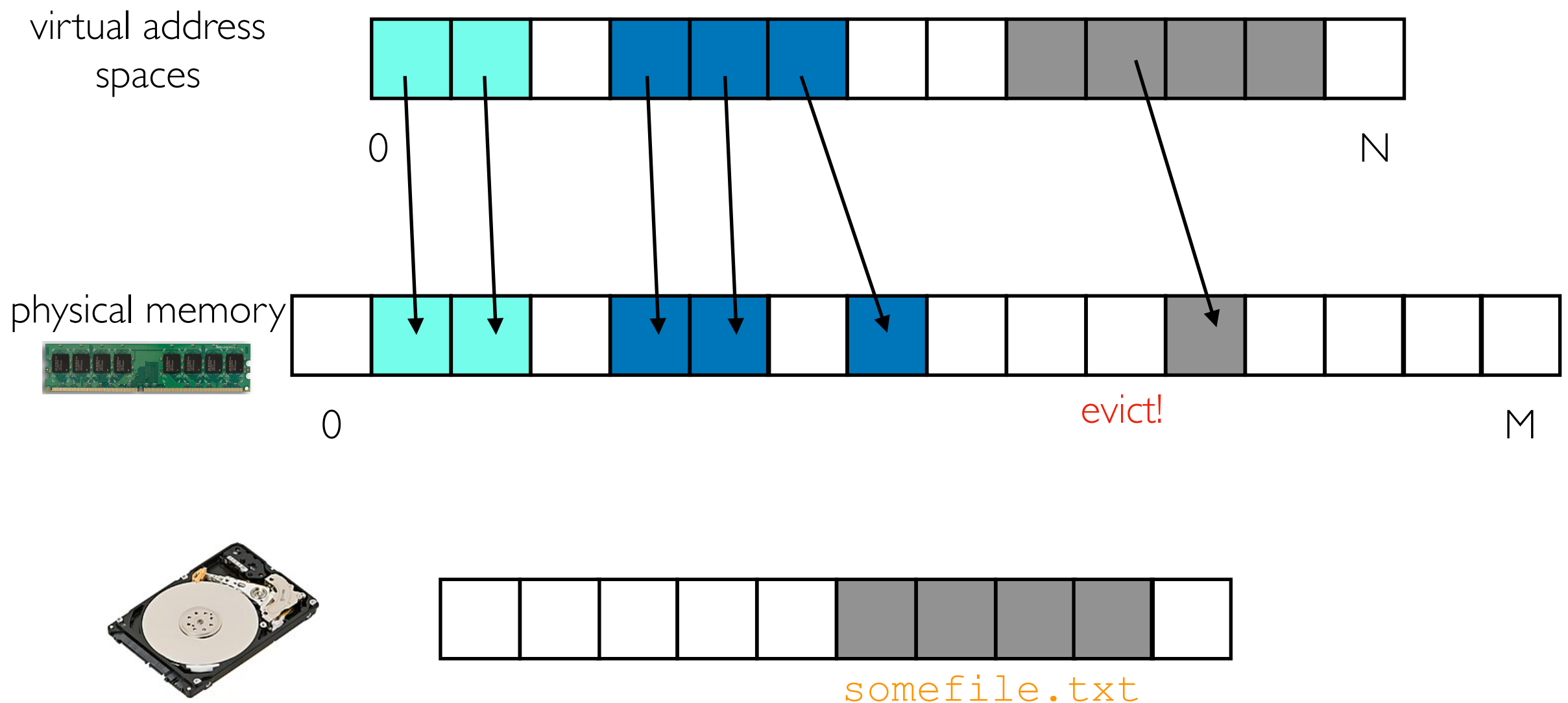
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- backed by a file
- data loaded for accesses to file-backed mmap regions are part of the "page cache"



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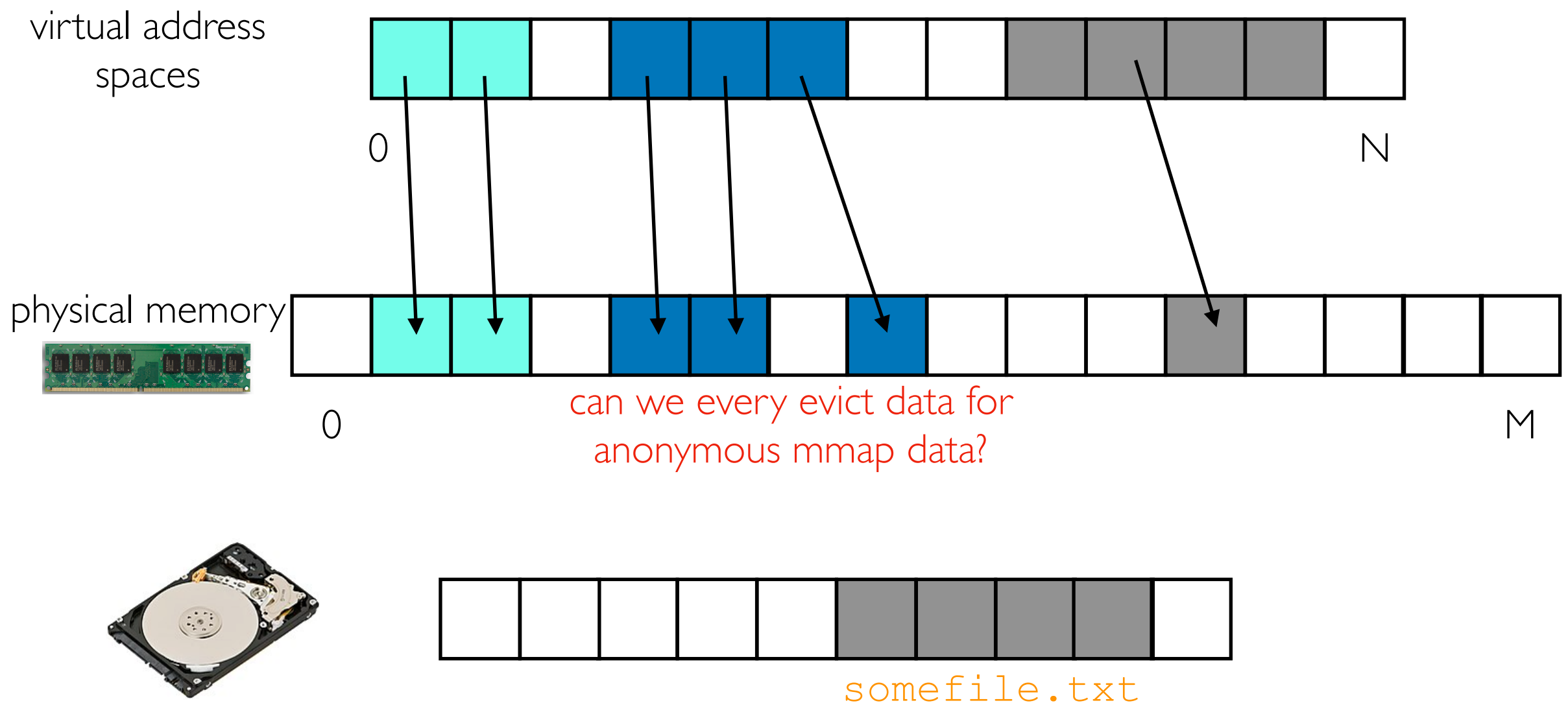
- anonymous
- backed by a file
- data loaded for accesses to file-backed mmap regions are part of the "page cache"
- it works like a cache because there is another copy on disk, so we can evict under memory pressure



# Swap Space

An mmap call can add new regions to a virtual address space. Two varieties:

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- backed by a file

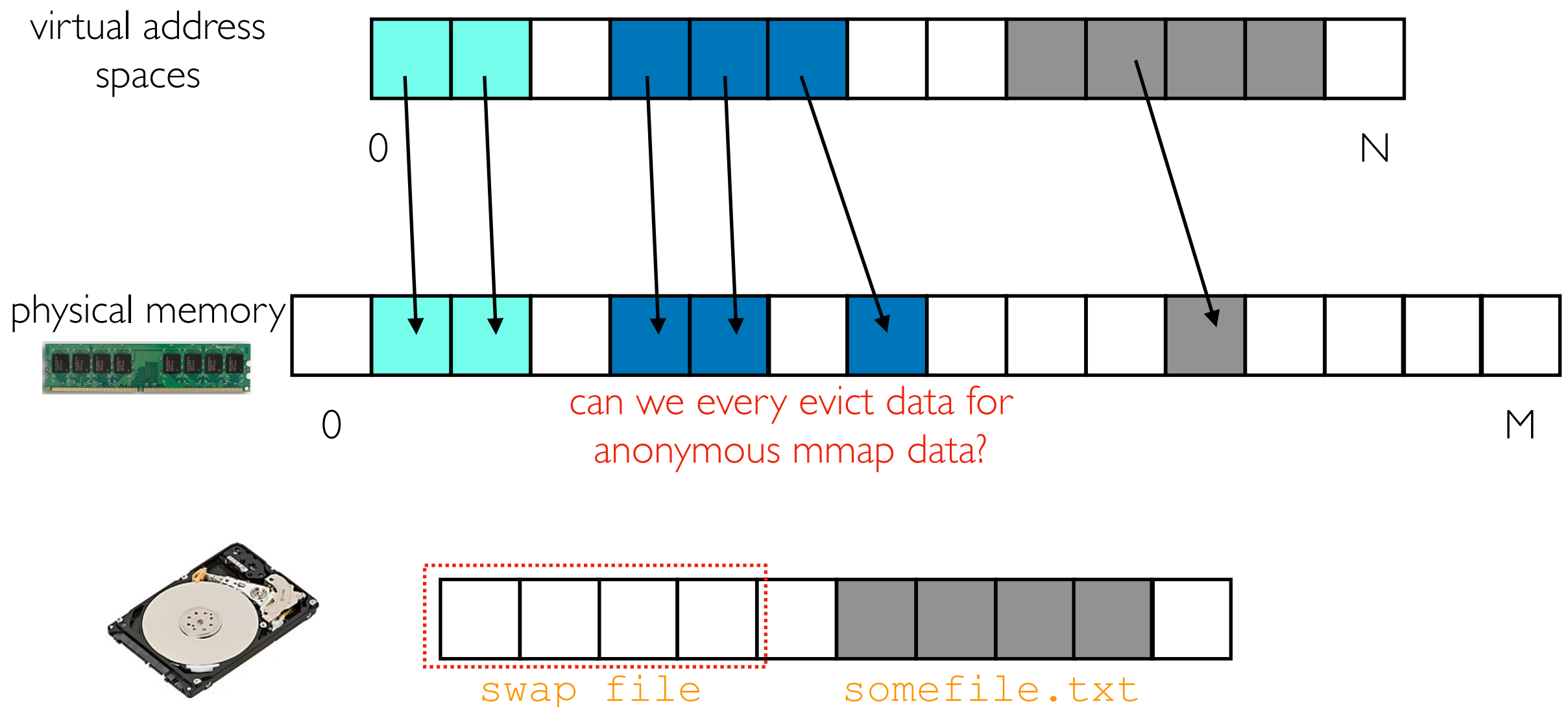




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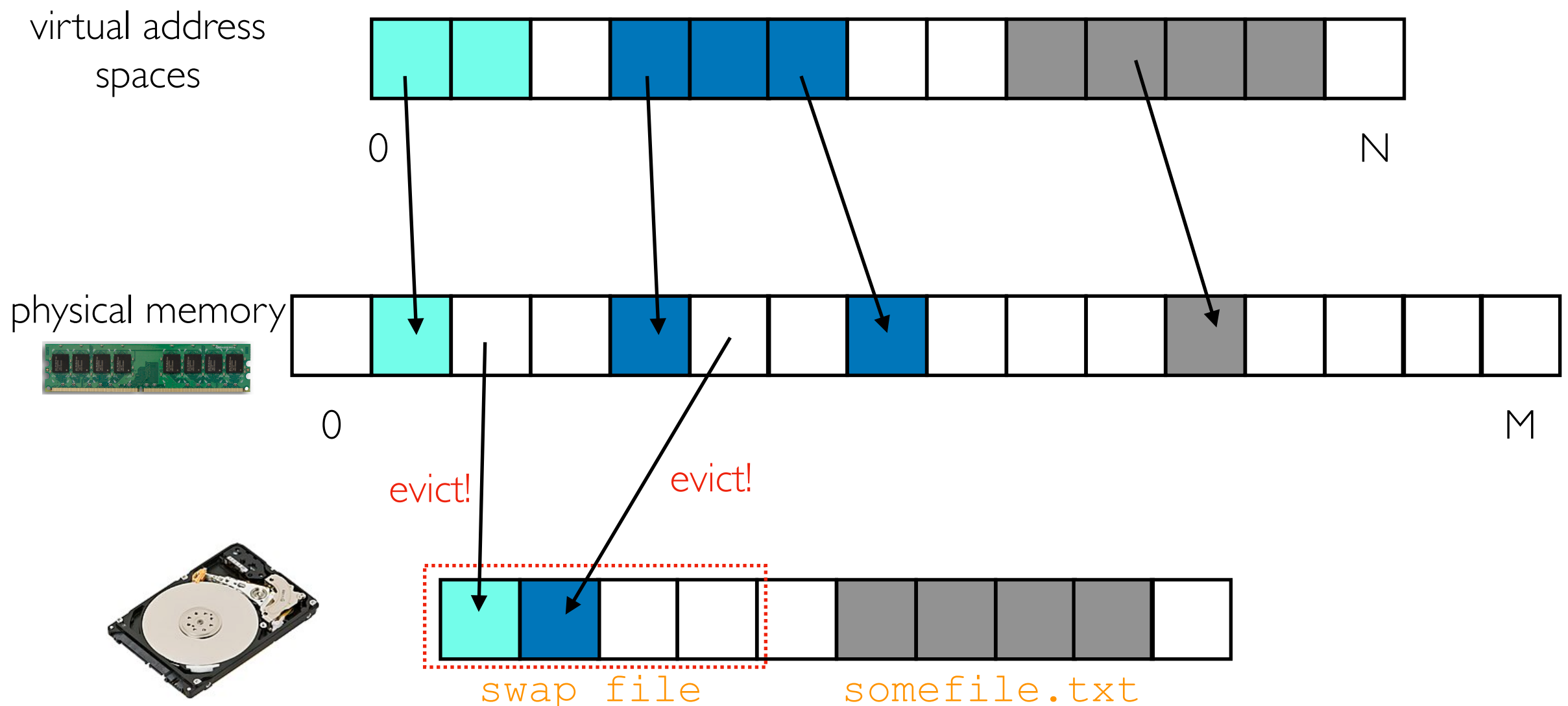
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- we can create same space (a swap file) to which the OS can evict data from anonymous mappings



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- **anonymous**
- backed by a file
  - we can create same space (a swap file) to which the OS can evict data from anonymous mappings
  - of course, if we access these virtual addresses again, it will be slow to bring the data back



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