Roadmap

C:

```
car *c = malloc(sizeof(car));
c->miles = 100;
c->gals = 17;
float mpg = get_mpg(c);
free(c);
```

Java:

```
Car c = new Car();
c.setMiles(100);
c.setGals(17);
float mpg =
    c.getMPG();
```

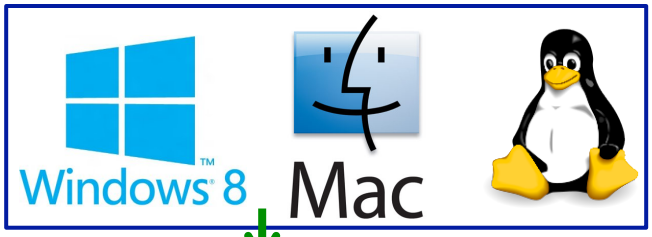
Assembly language:

```
get_mpg:
    pushq   %rbp
    movq    %rsp, %rbp
    ...
    popq    %rbp
    ret
```

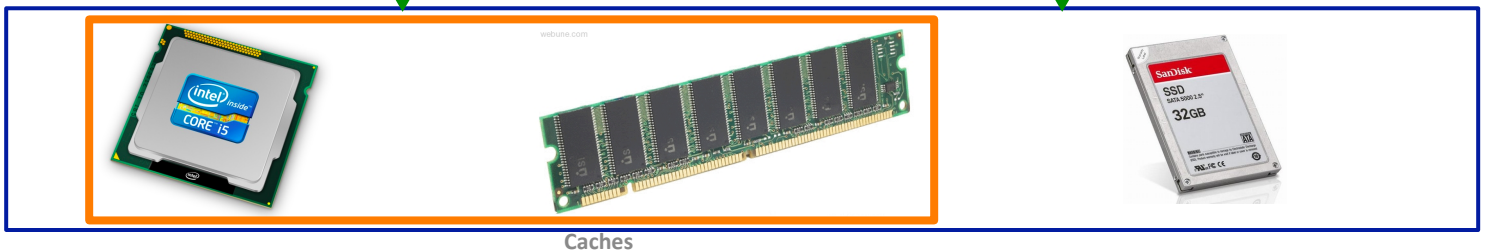
Machine code:

```
0111010000011000
100011010000010000000010
1000100111000010
11000001111110100011111
```

OS:



Computer system:



Caches

Memory & data
Integers & floats
Machine code & C
x86 assembly
Procedures & stacks
Arrays & structs
Memory & caches
Processes
Virtual memory
Memory allocation
Java vs. C

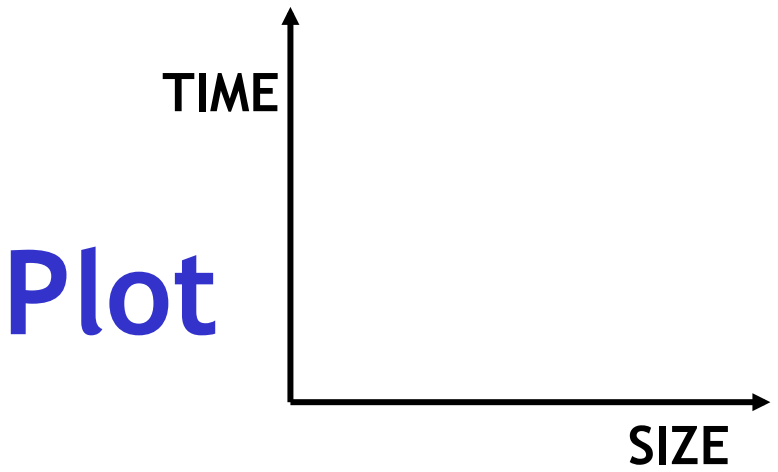
Section 7: Memory and Caches

- Cache basics
- Principle of locality
- Memory hierarchies
- Cache organization
- Program optimizations that consider caches

How does execution time grow with SIZE?

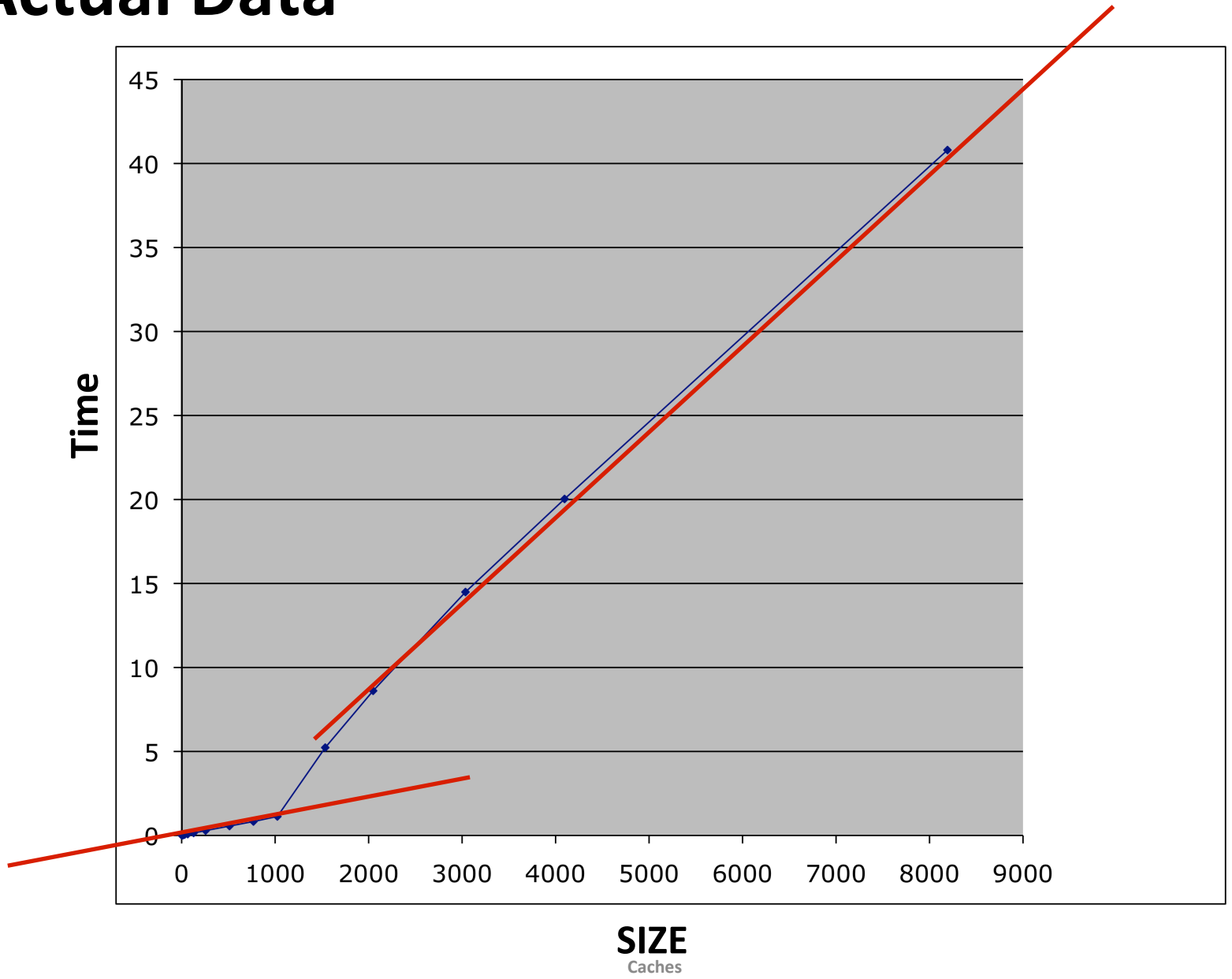
```
int array[SIZE];
int A = 0;

for (int i = 0 ; i < 200000 ; ++ i) {
  for (int j = 0 ; j < SIZE ; ++ j) {
     A += array[j];
  }
}
```

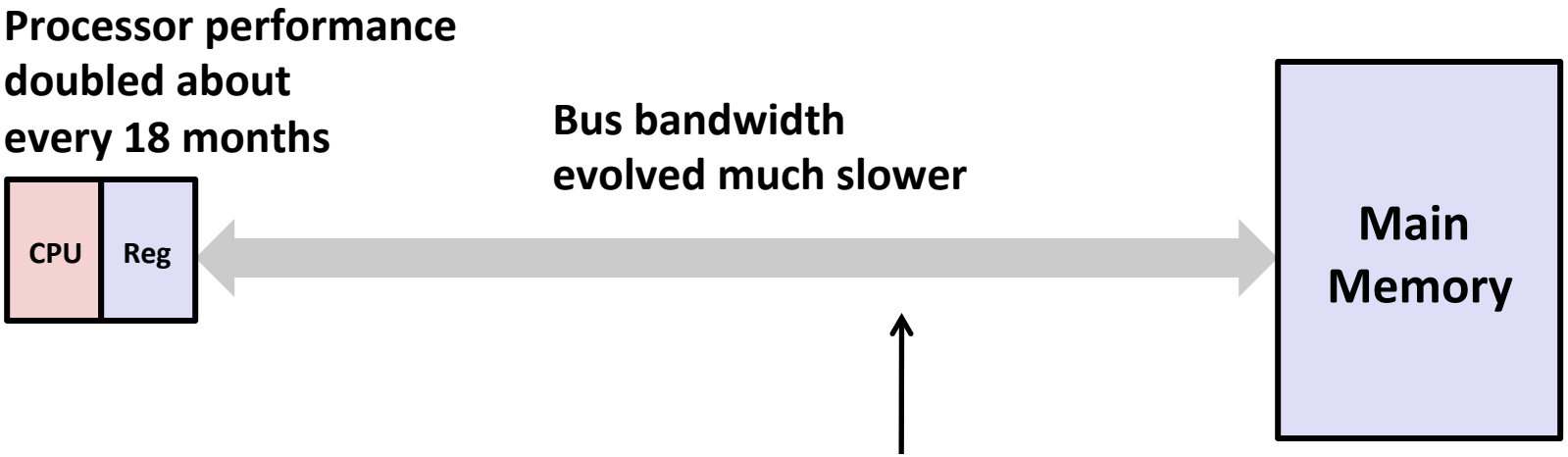


Plot

Actual Data


45
40
35
30
25
20
15
10
5
0
Time
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
SIZE
Caches

Problem: Processor-Memory Bottleneck

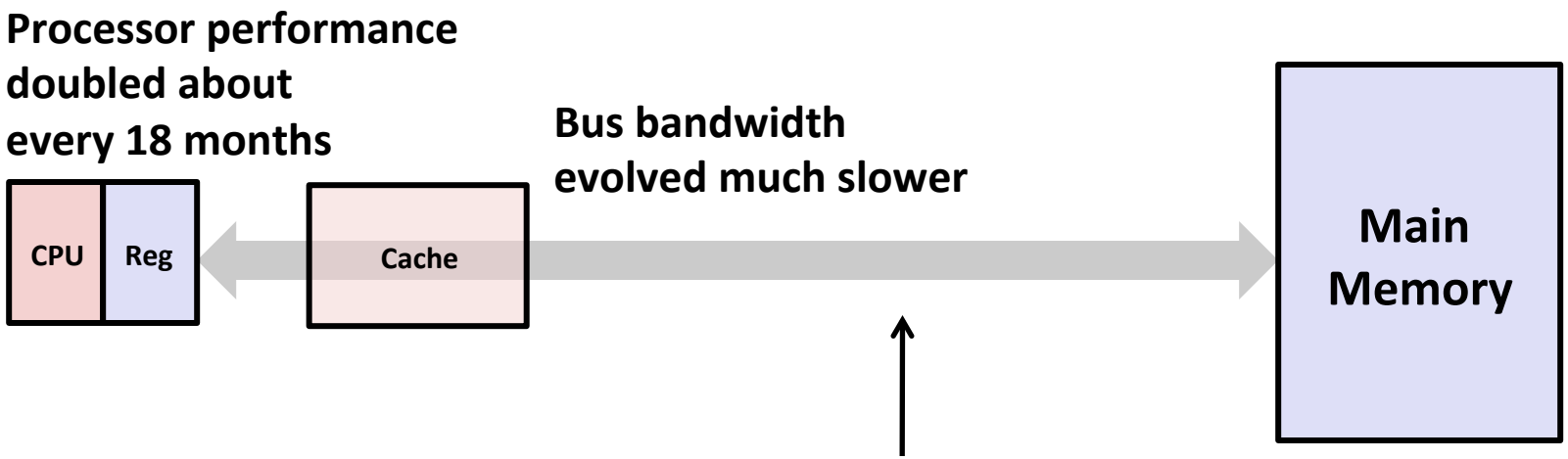


Core 2 Duo:
Can process at least
256 Bytes/cycle

Core 2 Duo:
Bandwidth
2 Bytes/cycle
Latency
100 cycles

Problem: lots of waiting on memory

Problem: Processor-Memory Bottleneck



Core 2 Duo:
Can process at least
256 Bytes/cycle

Core 2 Duo:
Bandwidth
2 Bytes/cycle
Latency
100 cycles

Solution: caches

Cache

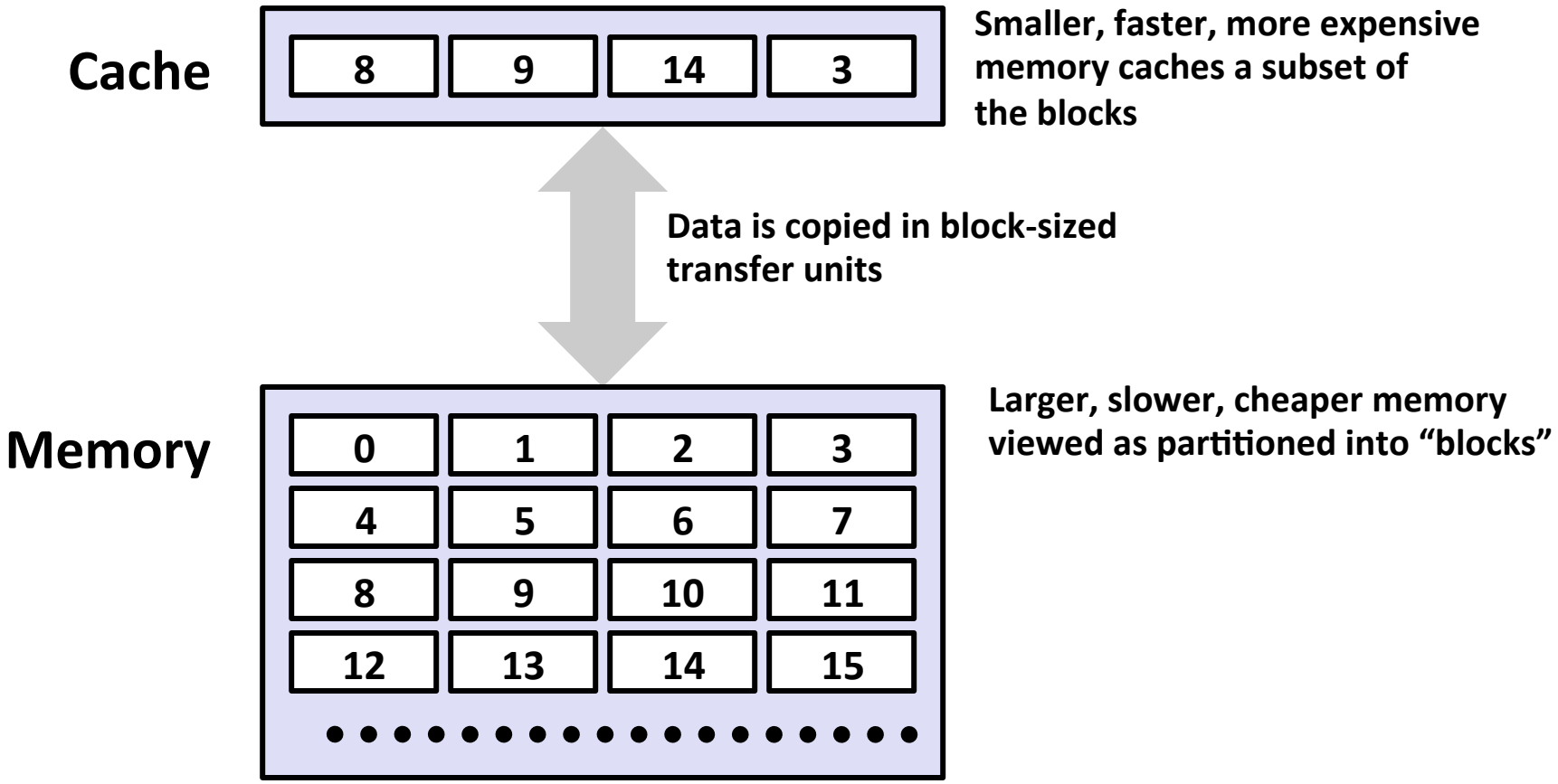
- **English definition:** a hidden storage space for provisions, weapons, and/or treasures

- **CSE definition:** computer memory with short access time used for the storage of frequently or recently used instructions or data (i-cache and d-cache)

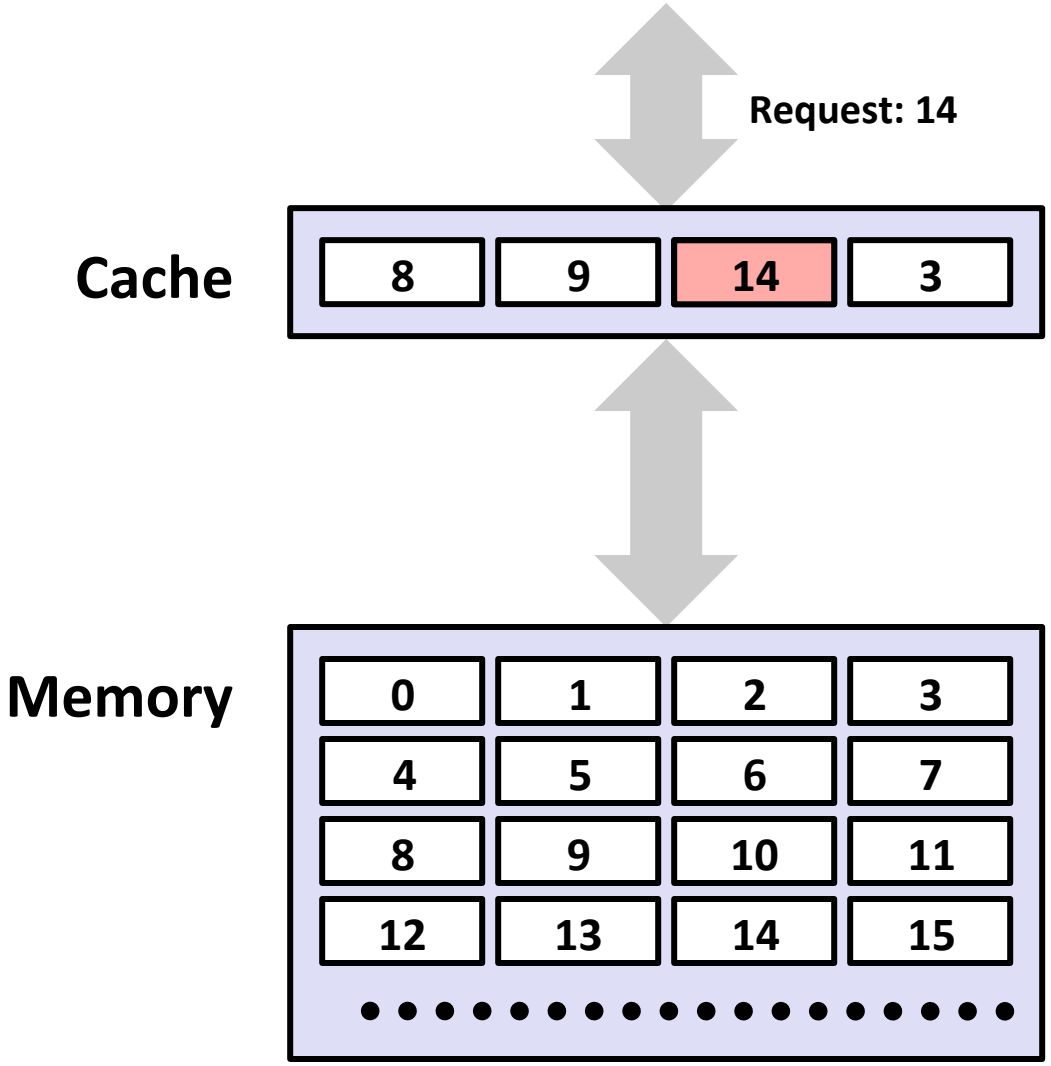
  more generally,

  used to optimize data transfers between system elements with different characteristics (network interface cache, I/O cache, etc.)

General Cache Mechanics



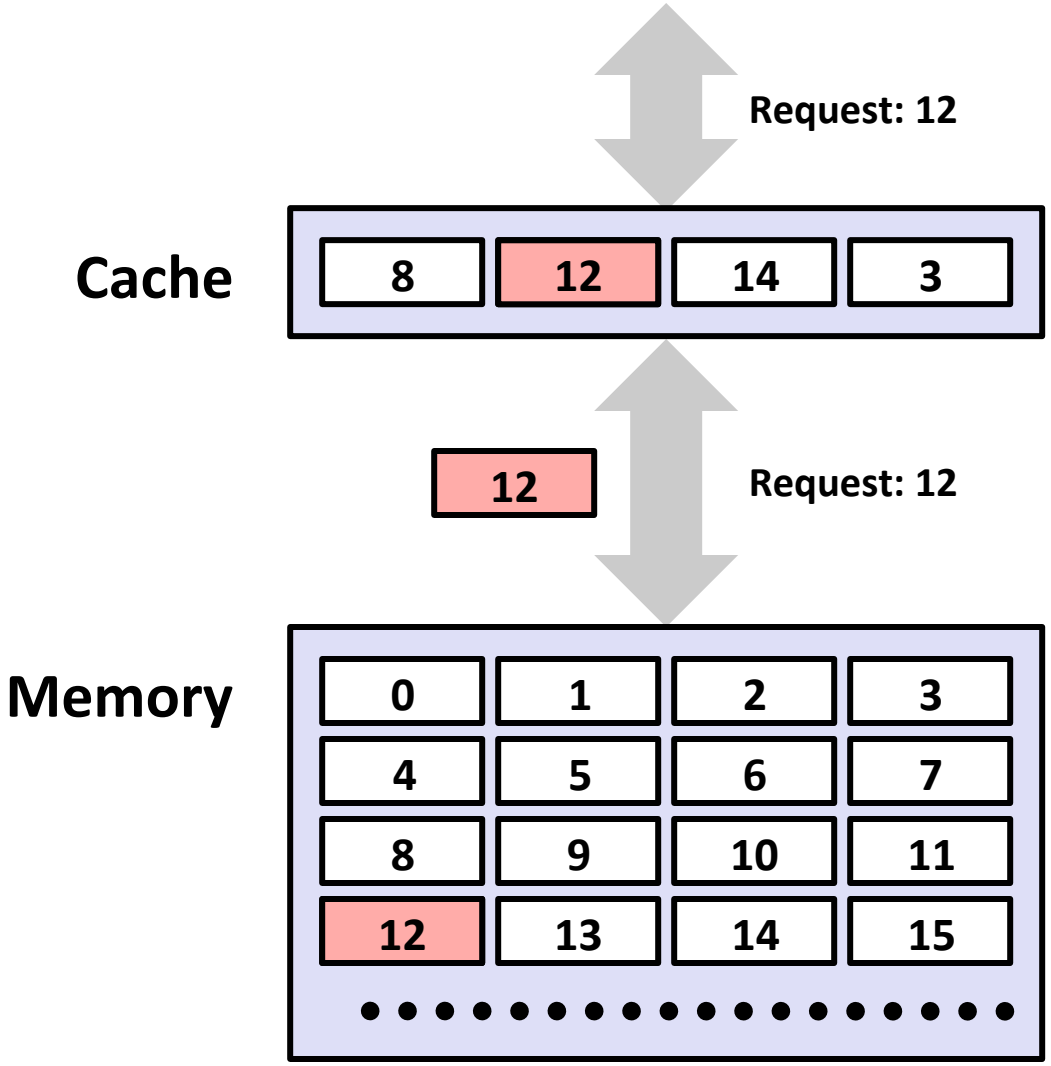
General Cache Concepts: Hit



Data in block b is needed

Block b is in cache:
Hit!

General Cache Concepts: Miss



Data in block b is needed

Block b is not in cache: Miss!

Block b is fetched from memory

Block b is stored in cache

- Placement policy: determines where b goes
- Replacement policy: determines which block gets evicted (victim)

Not to forget…