Memory Performance of Algorithms

CSE 373

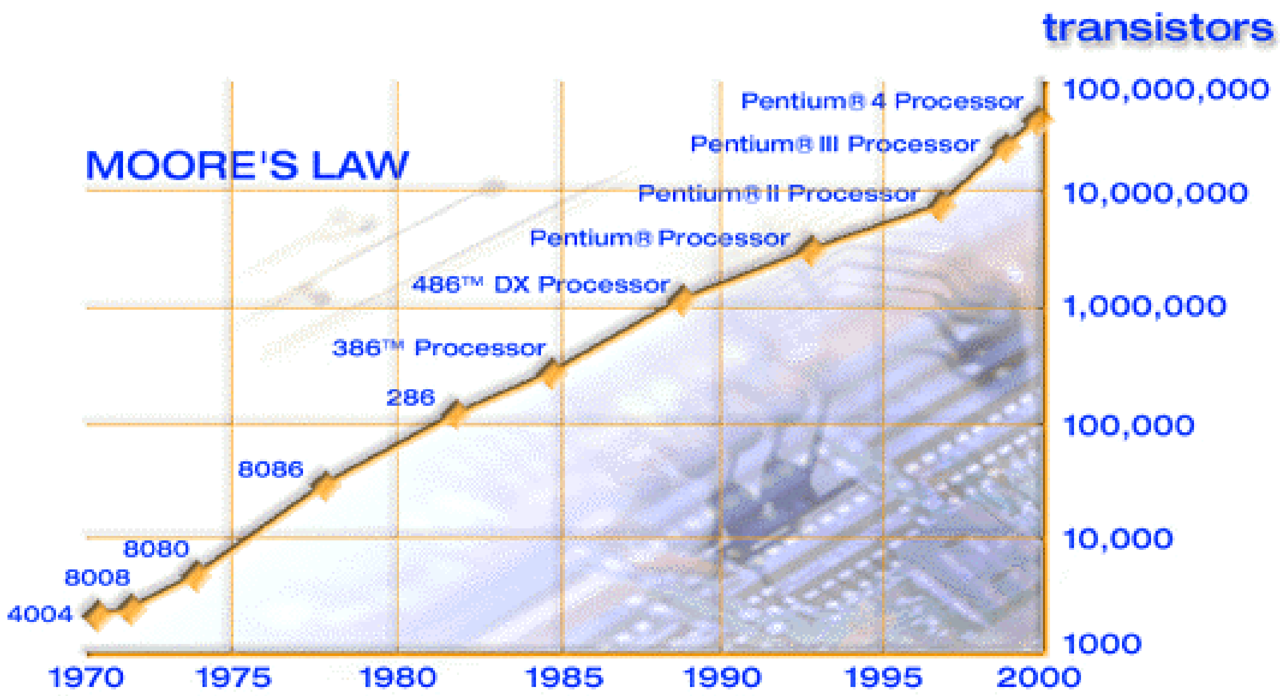
Data Structures

Lecture 16

Algorithm Performance Factors

- Algorithm choices (asymptotic running time)
  - › $O(n^2)$ or $O(n \log n)$ …
- Data structure choices
  - › Binary heap or linked list priority queue
- Language and Compiler
  - › C, C++, Java, Fortran
- Memory performance
  - › How near is the data to the processor

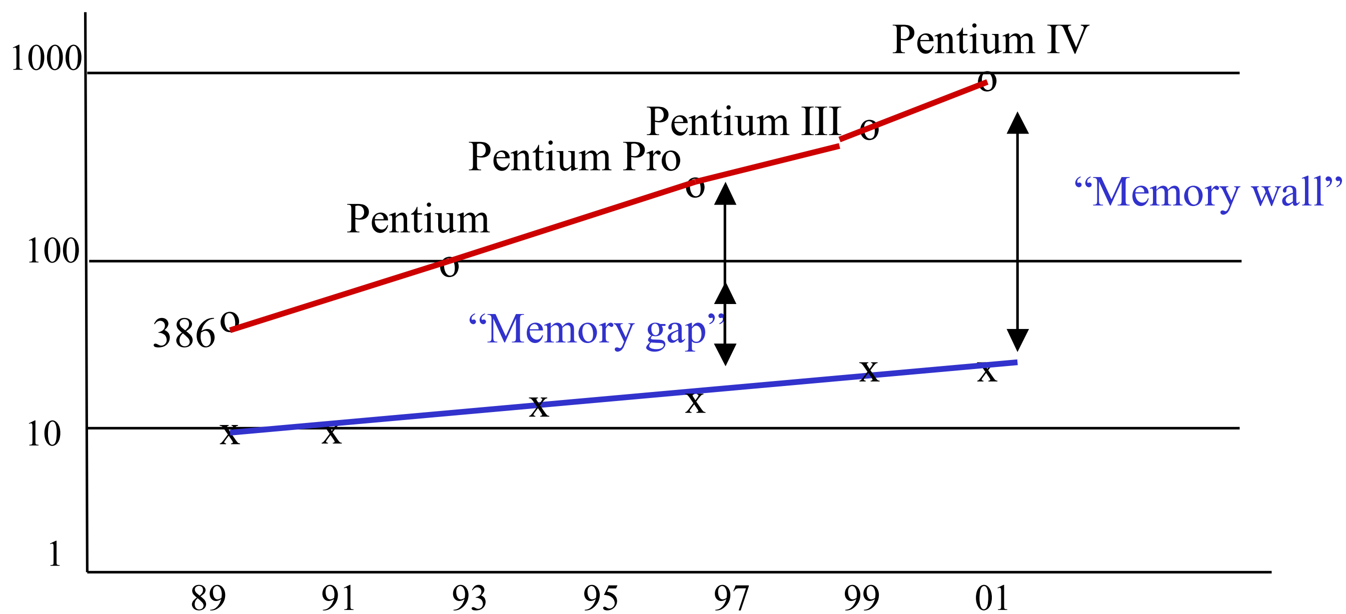
Moore's Law



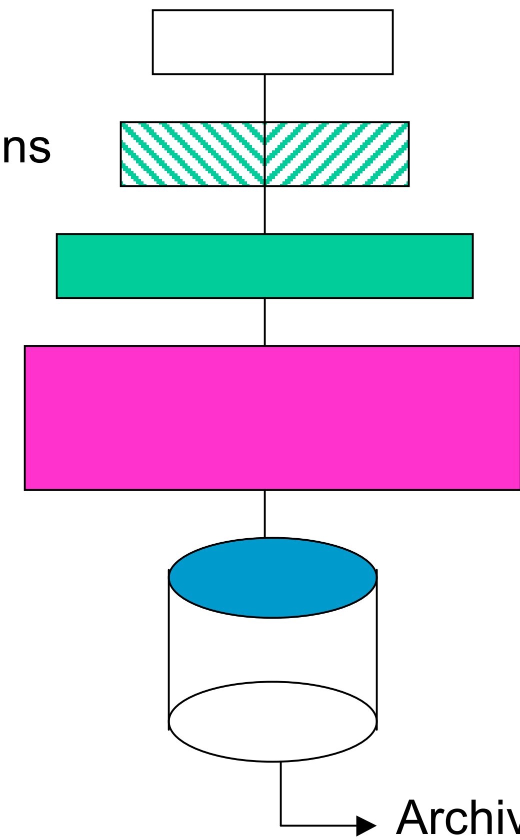
MOORE'S LAW
transistors
100,000,000
10,000,000
1,000,000
100,000
10,000
1000
Pentium® 4 Processor
Pentium® III Processor
Pentium® II Processor
Pentium® Processor
486™ DX Processor
386™ Processor
286
8086
8080
8008
4004
1970
1975
1980
1985
1990
1995
2000

Processor-Memory Performance Gap

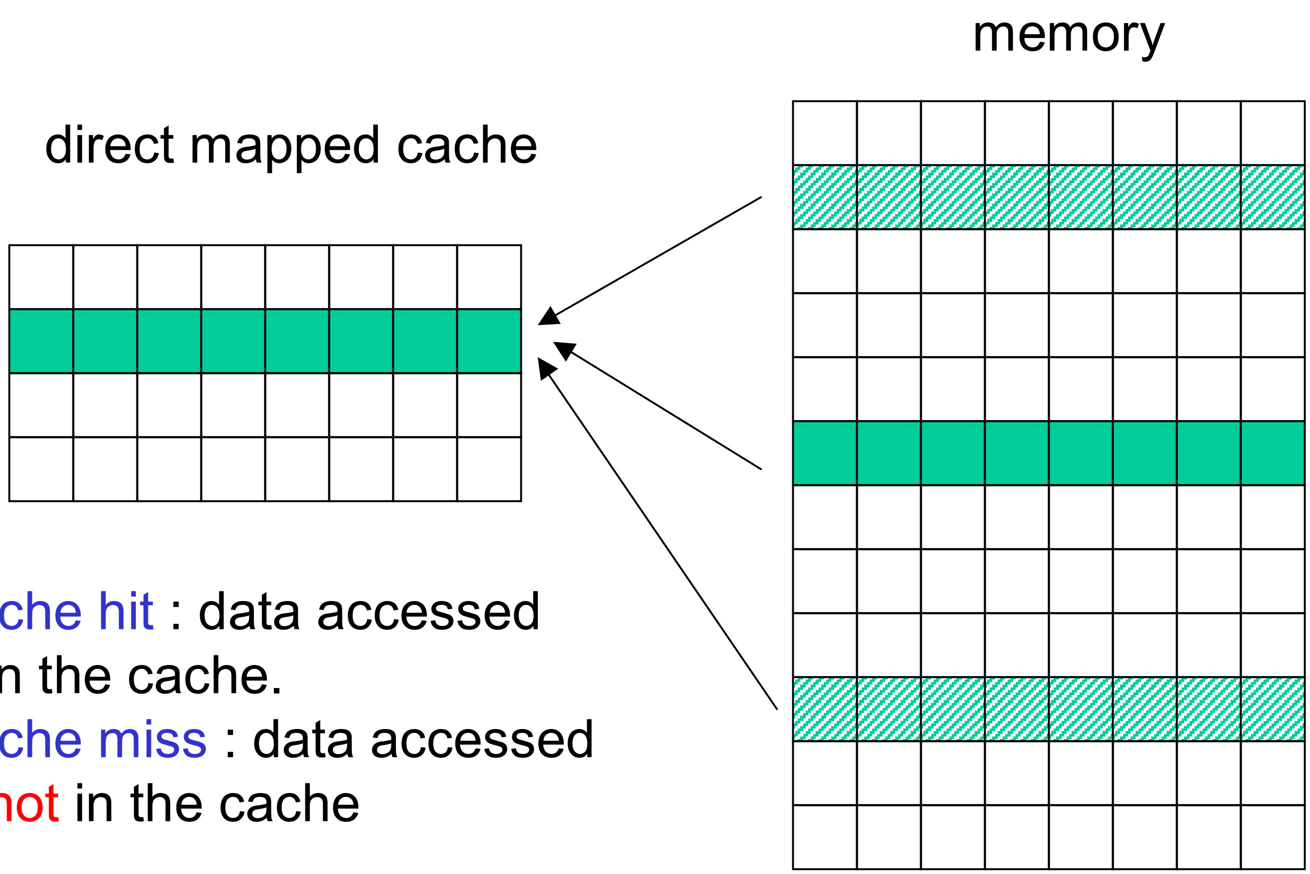
- x86 CPU speed (100x over 10 years)



Levels in the Memory Hierarchy

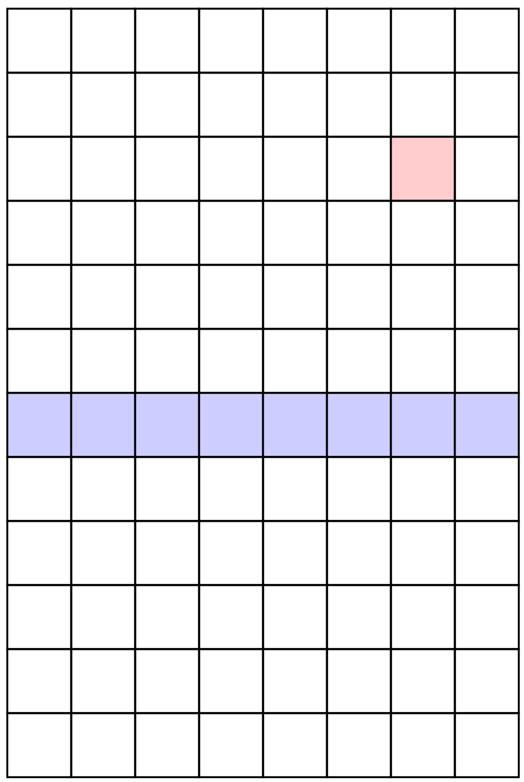


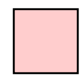
The Cache



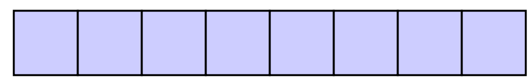
Cache hit : data accessed is in the cache.
Cache miss : data accessed Is not in the cache

Memory Blocks





Addressable unit, usually a byte



Memory block – unit of memory transferred as a whole from memory to cache. Sometimes called “cache line”. Usually, 32 64 bytes (but growing in size).

Why Memory Blocks

- Time to transfer x bytes is given by

  $T(x) = a + bx$. (a is latency, $b \sim 1/\text{bandwidth}$)

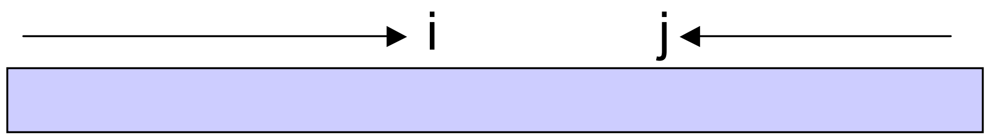
- Because a is large relative to b, it pays to transfer more than one byte at a time.
  - The hope is that bytes near the accessed byte will be accessed soon – good spatial locality.

Locality

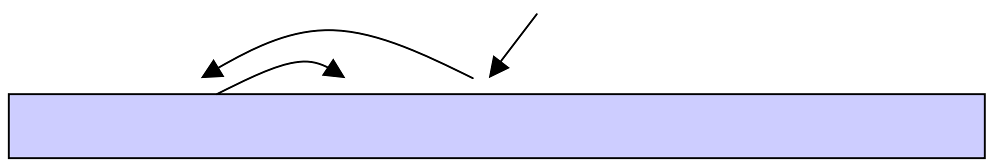
- Spatial locality : addresses near a recently accessed byte are accessed also.
- Temporal locality : the same address that was accessed recently is accessed again.

Examples of Locality

- Good spatial locality
  - › Quicksort – the array is scanned



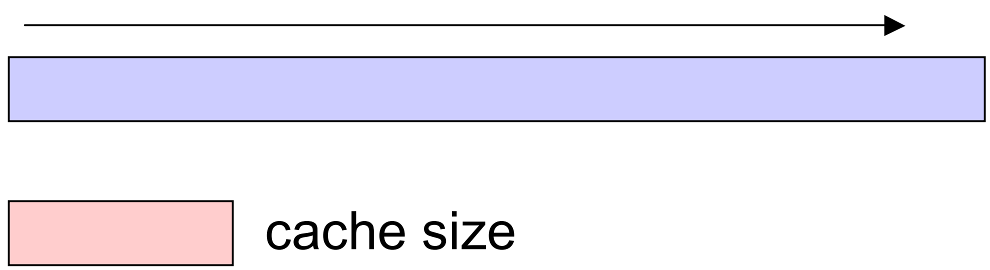
- Poor spatial locality
  - › Binary search – jump around the array



Examples of locality

- Good temporal locality
  - › For loop index i in a tight loop.

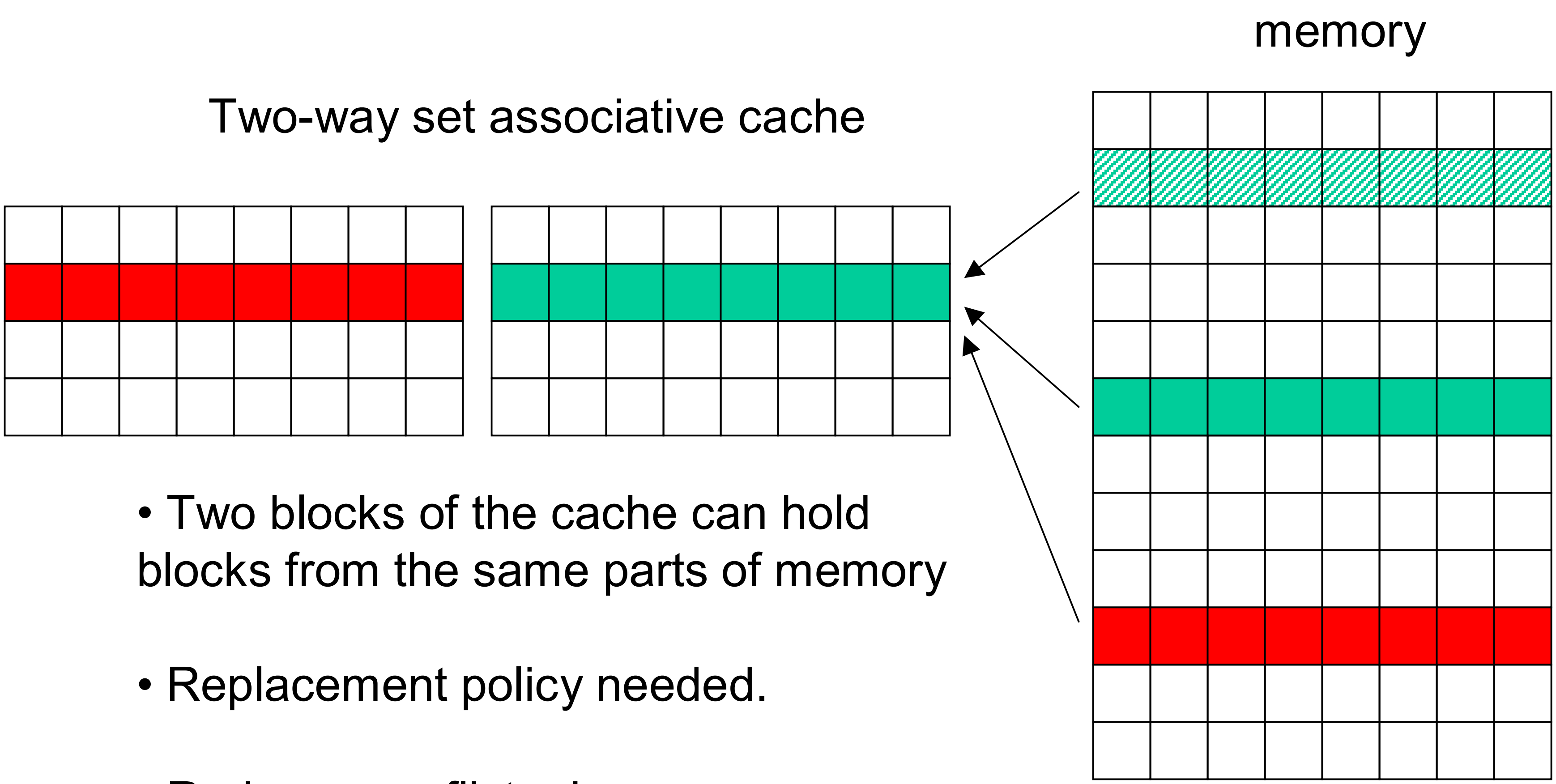
    for i = 1 to n do { …}
- Poor temporal locality
  - › Repeated long scans that exceeds the cache size, like in iterative merge sort.



Classifying Cache Misses

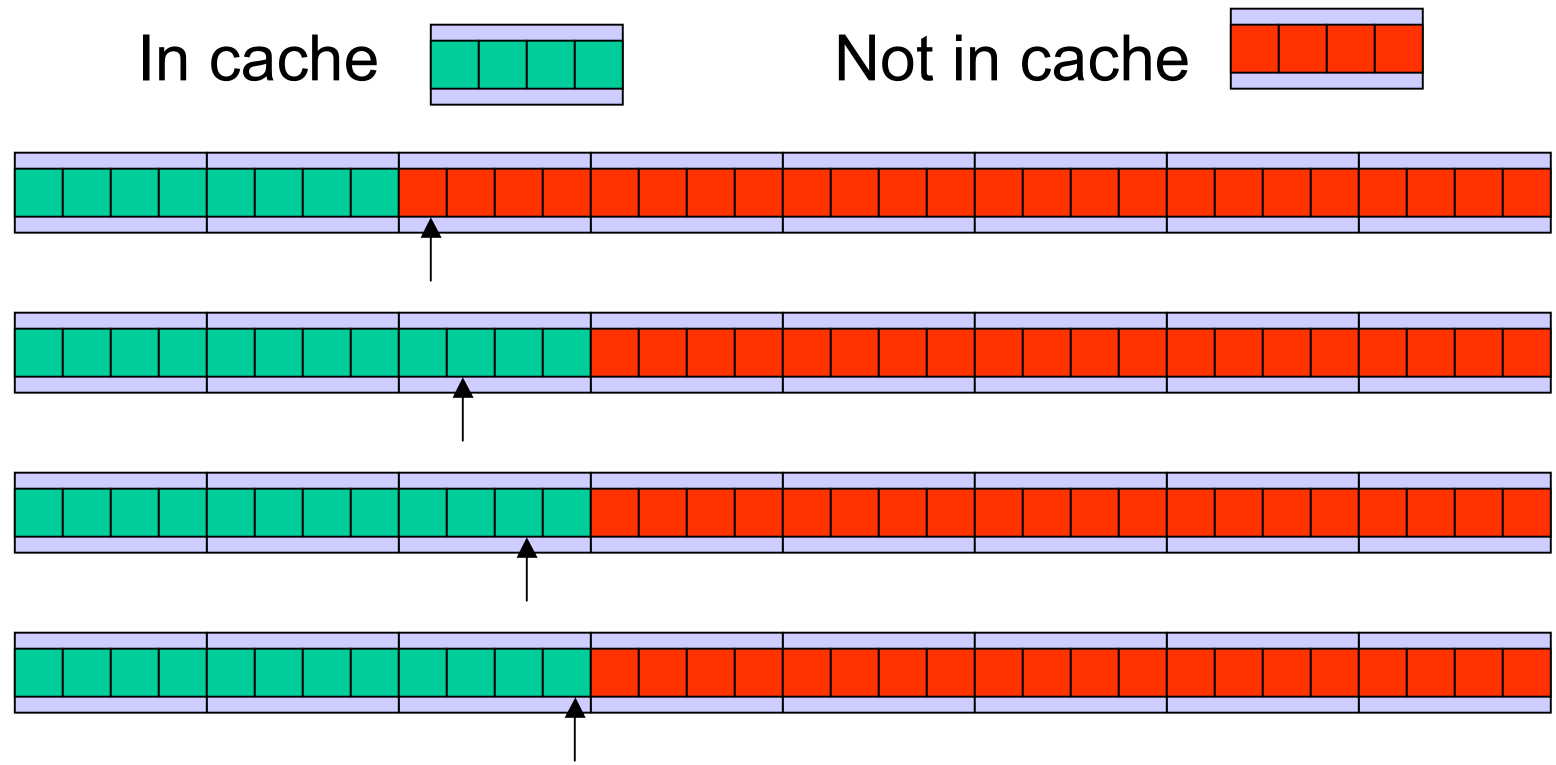
- Compulsory misses – first time a block is accessed
  - Can never be avoided
- Capacity misses – data structure does not fit in cache
  - Can be avoided by algorithmic design.
- Conflict misses – several accessed blocks map to the same location in cache
  - Conflict misses are not much of a problem because modern caches are set associative.

Set Associative Cache



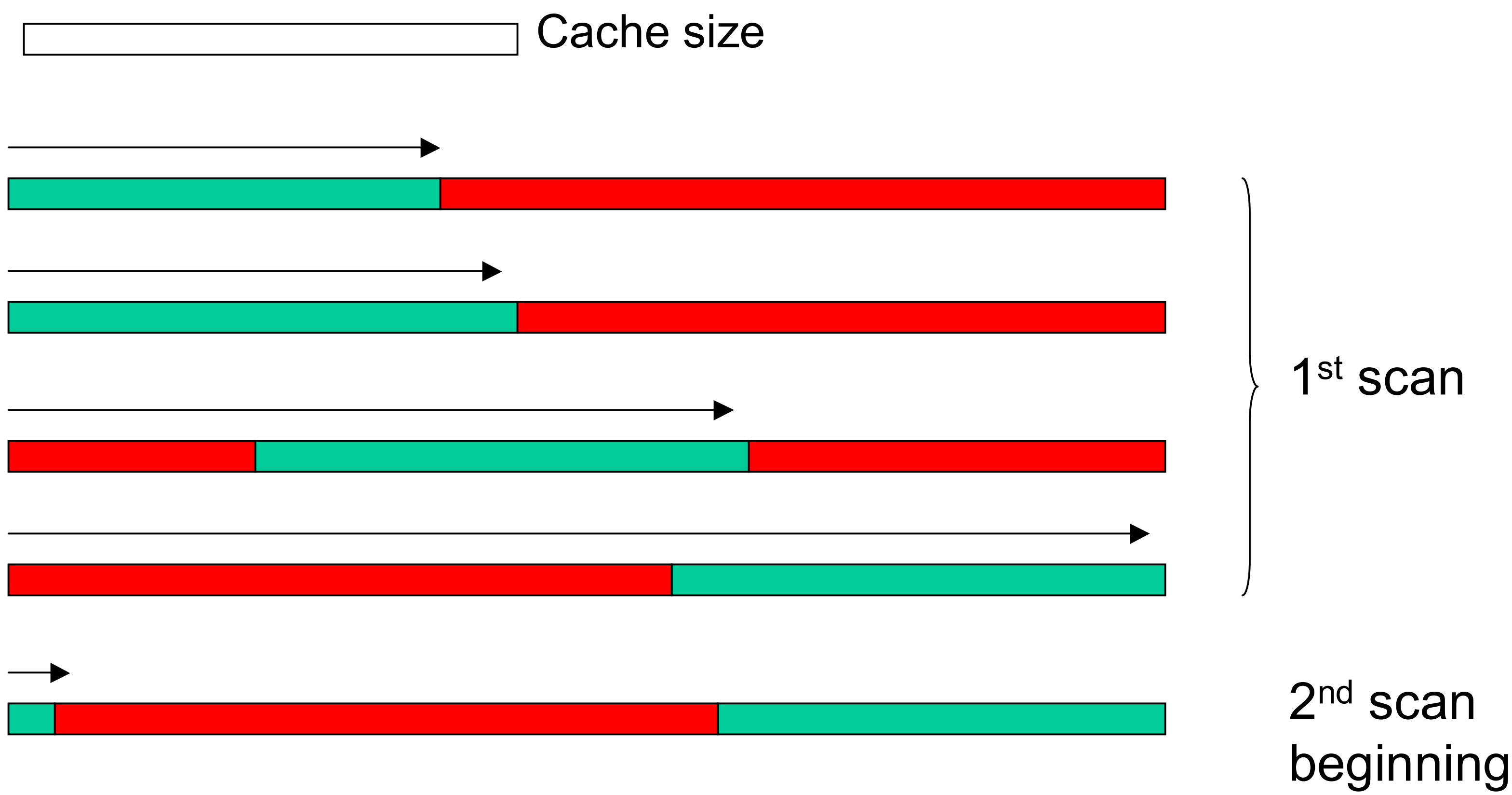
- Two blocks of the cache can hold blocks from the same parts of memory
- Replacement policy needed.
- Reduces conflict misses

Cache Misses for Scans



1/B misses per access where B is number of access per line

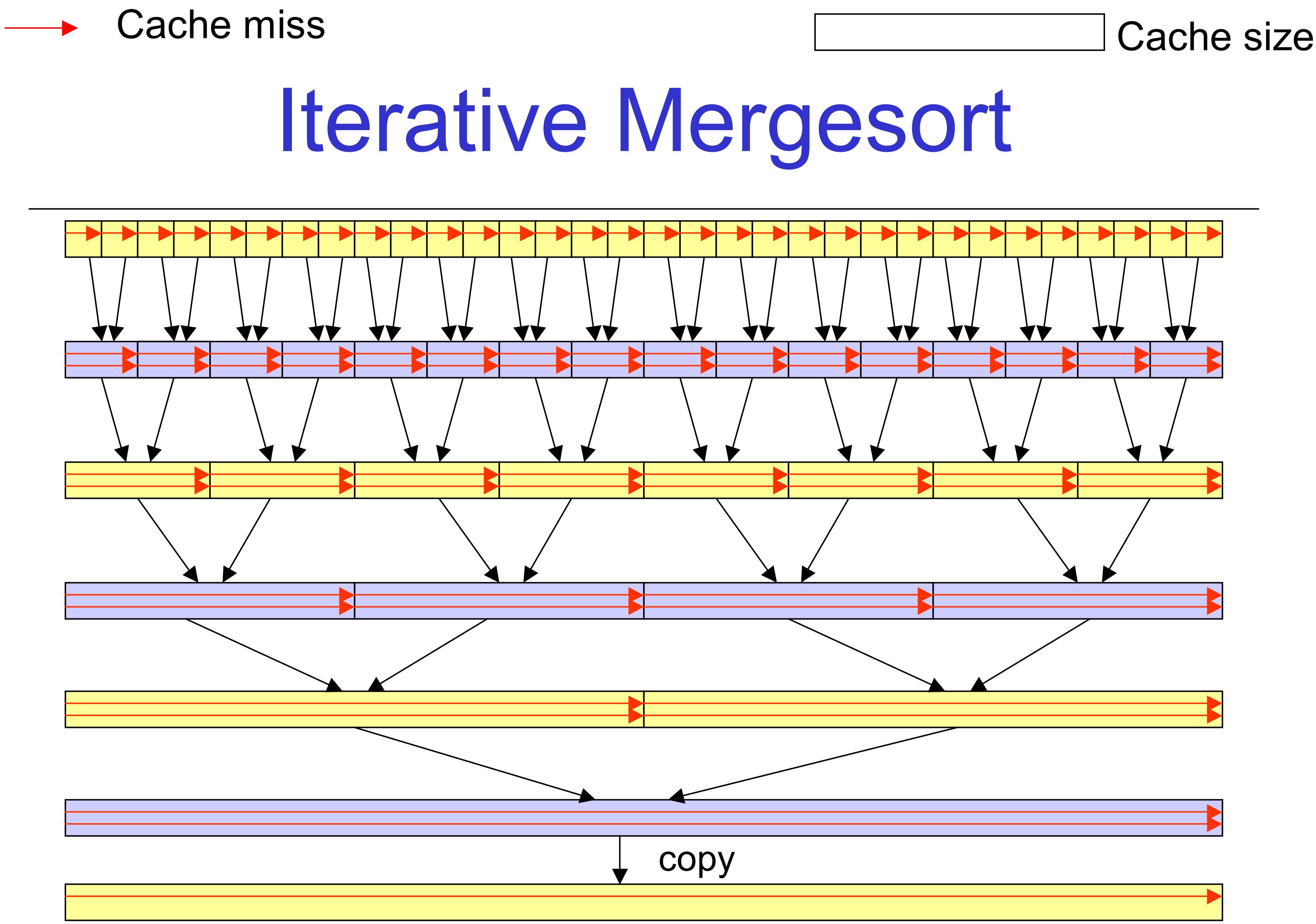
Repeated Long Scans



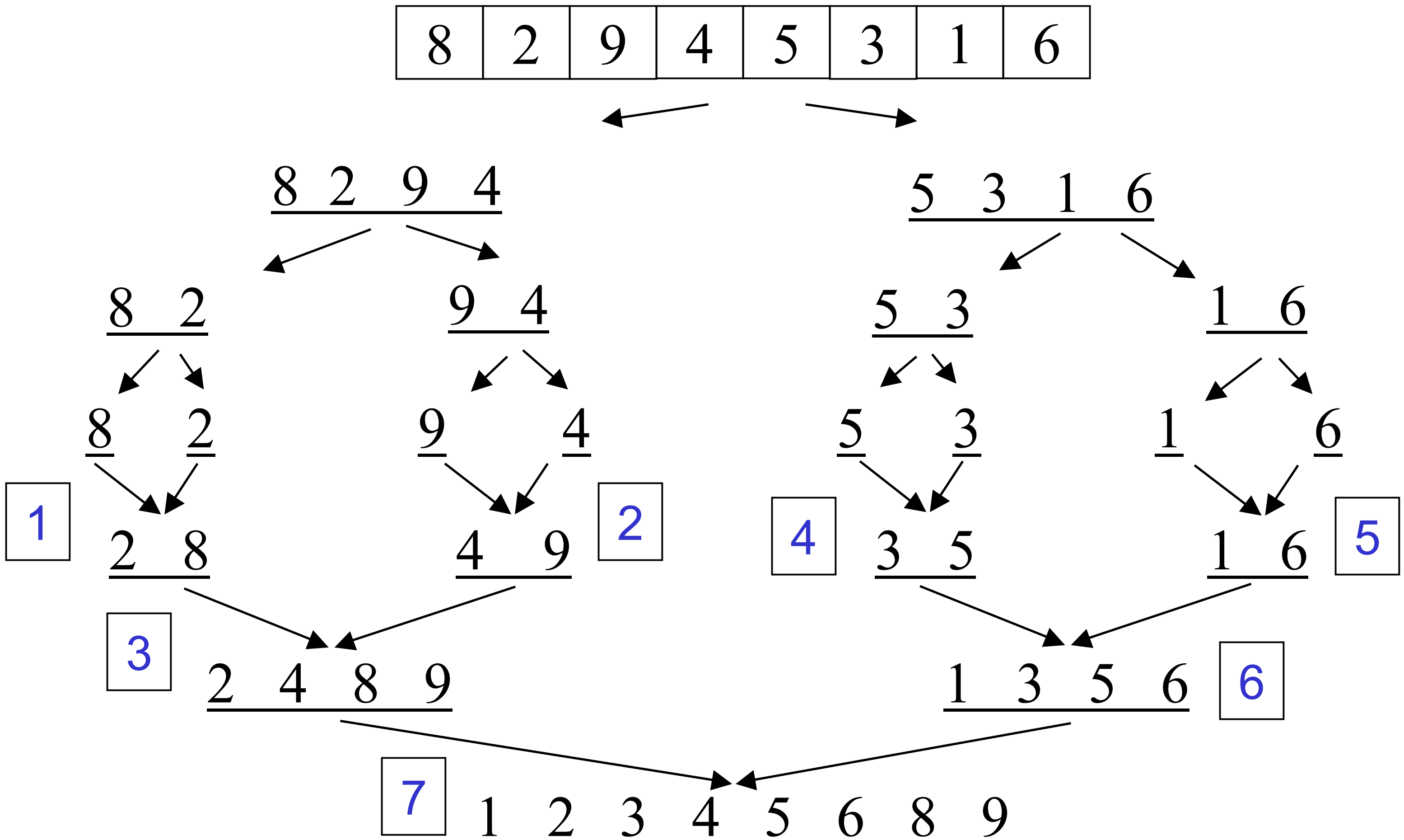
Repeated Long Scans

- Have good spatial locality
- Poor temporal locality
- If there are B accesses per memory block then 1/B of the accesses are cache misses.

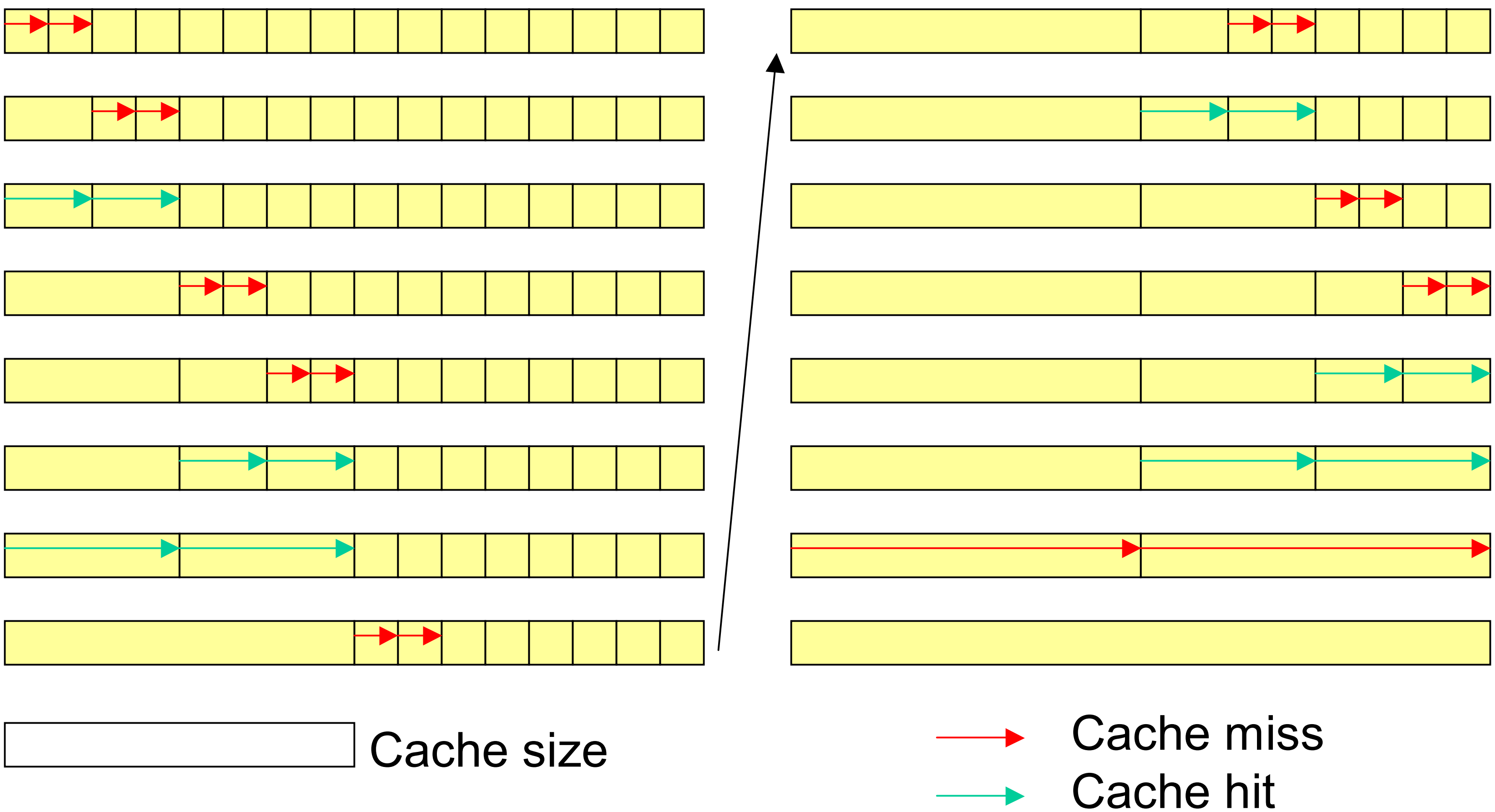
Iterative Mergesort



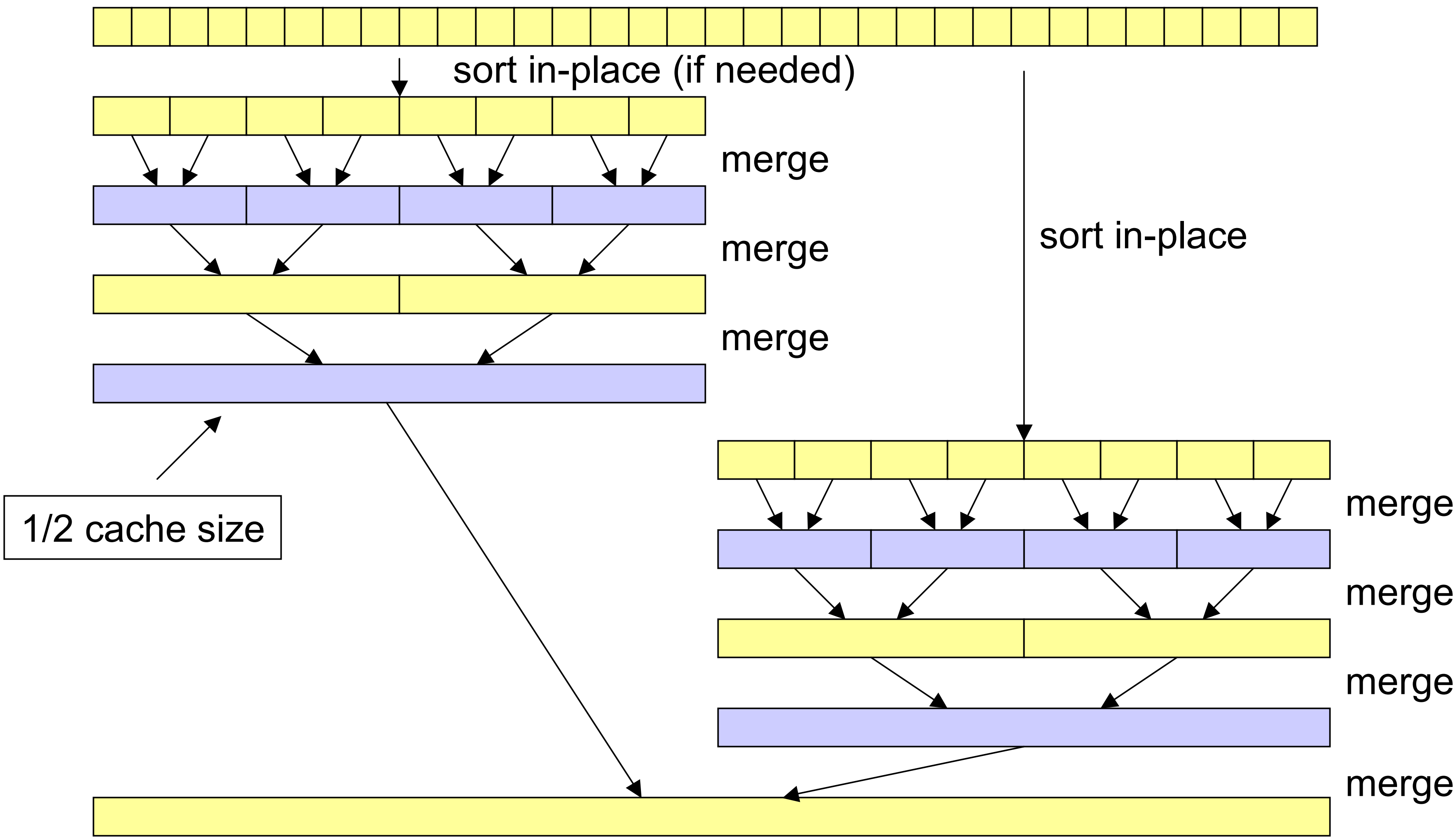
Recursive Mergesort



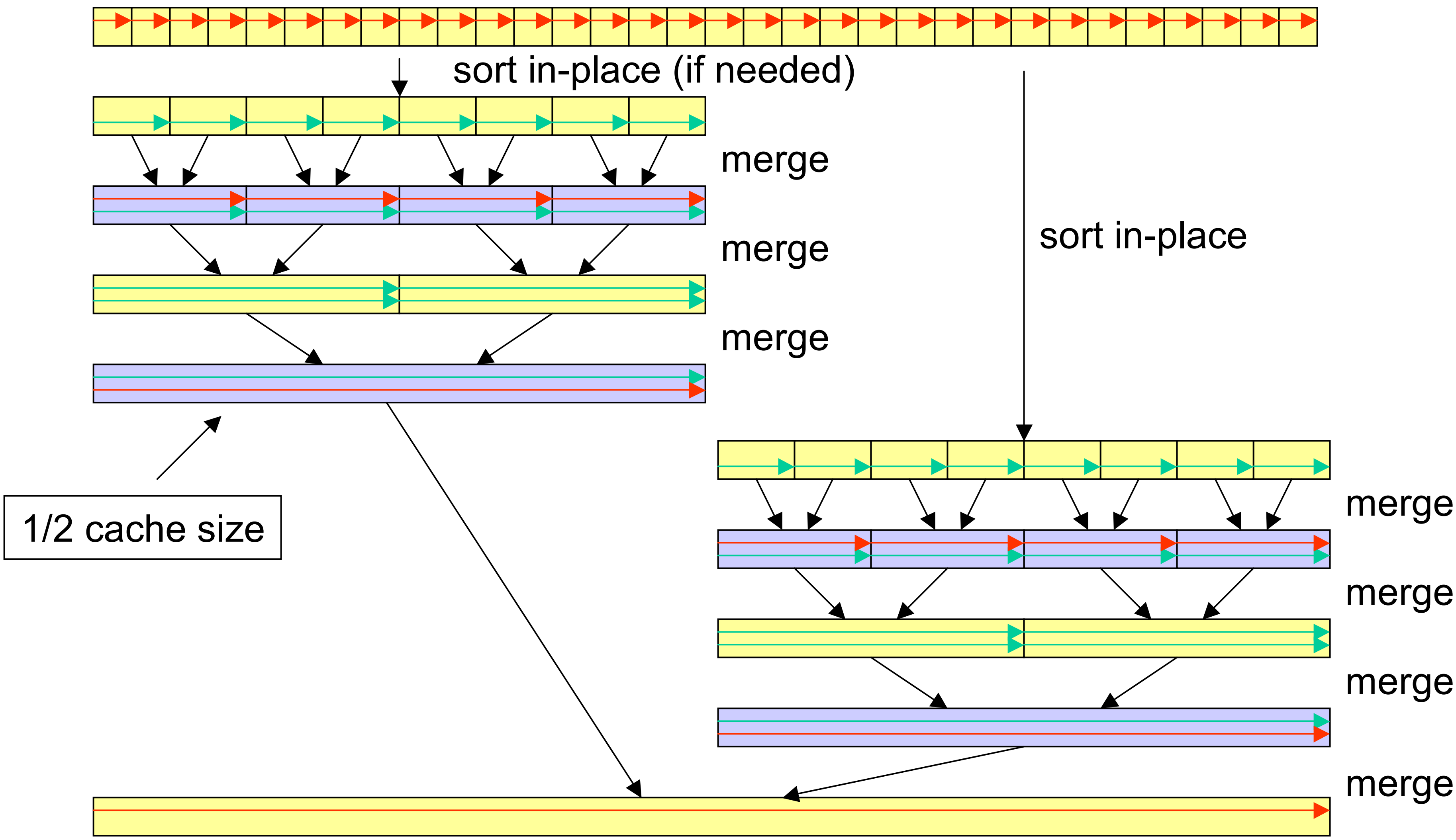
Recursive Mergesort



Multi-Mergesort



Multi-Mergesort Cache Behavior

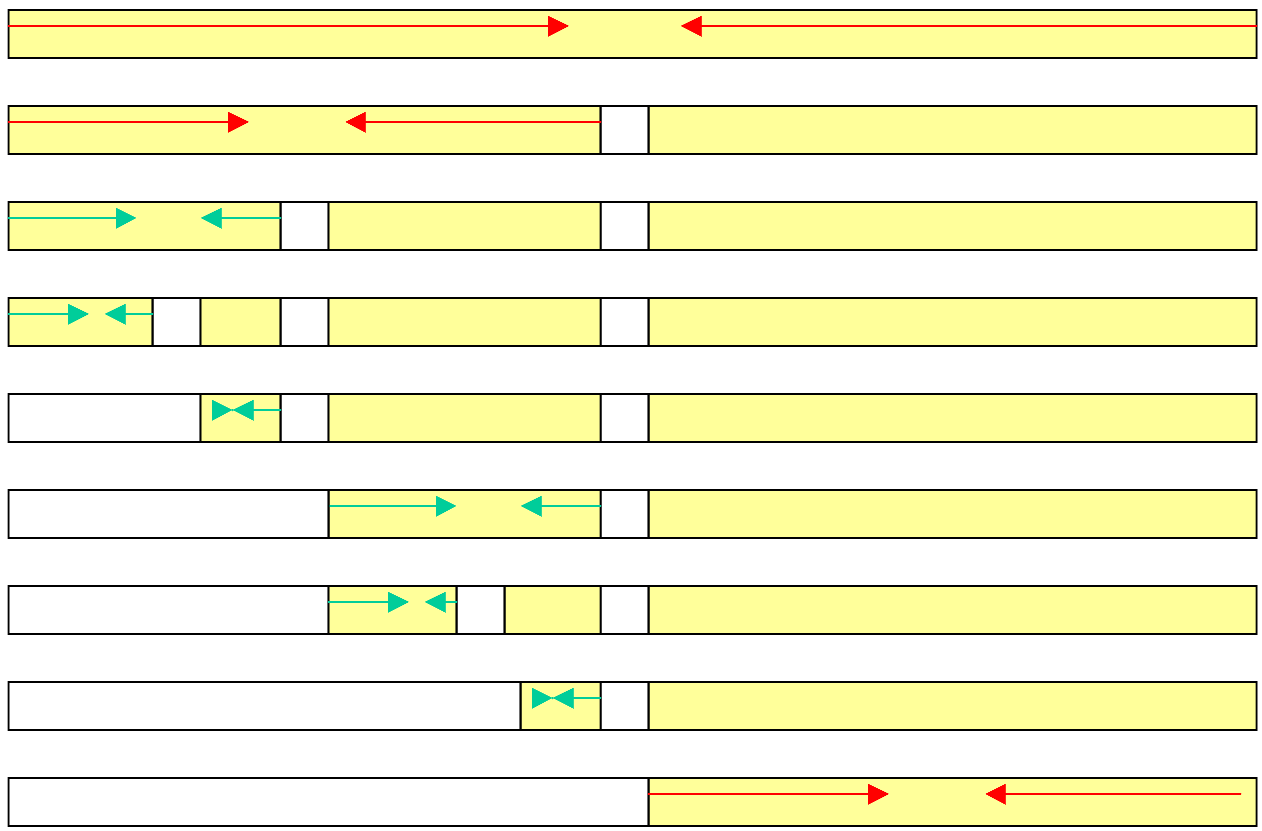


Quicksort

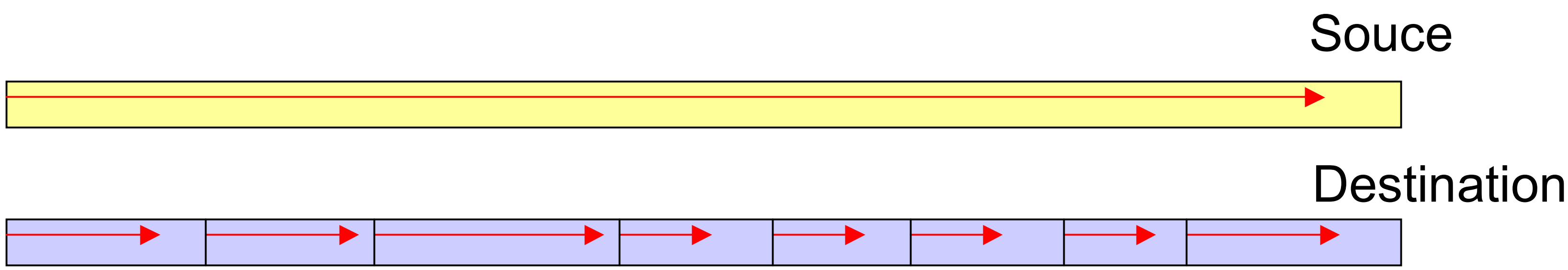
Cache size

Cache miss

Cache hit



Radix sort



Count array
Address array

Large memory foot print
Long scans

= poor memory performance

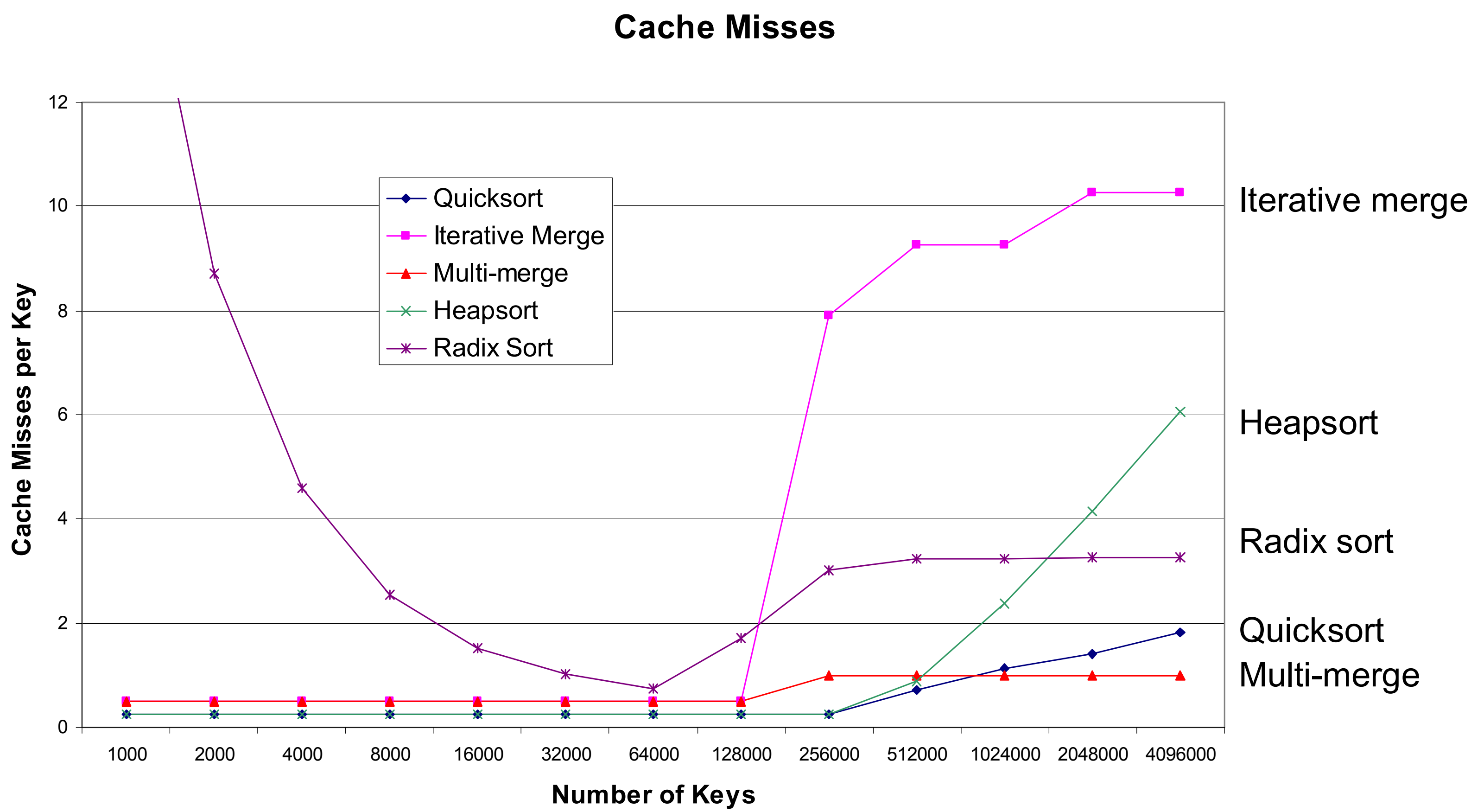
Sorting Study from 1996

- Compared sorting algorithms
  - Cache misses
  - Instruction count
  - Execution time
- The study is still valid today, because the gap between processor speed and memory speed is even larger.

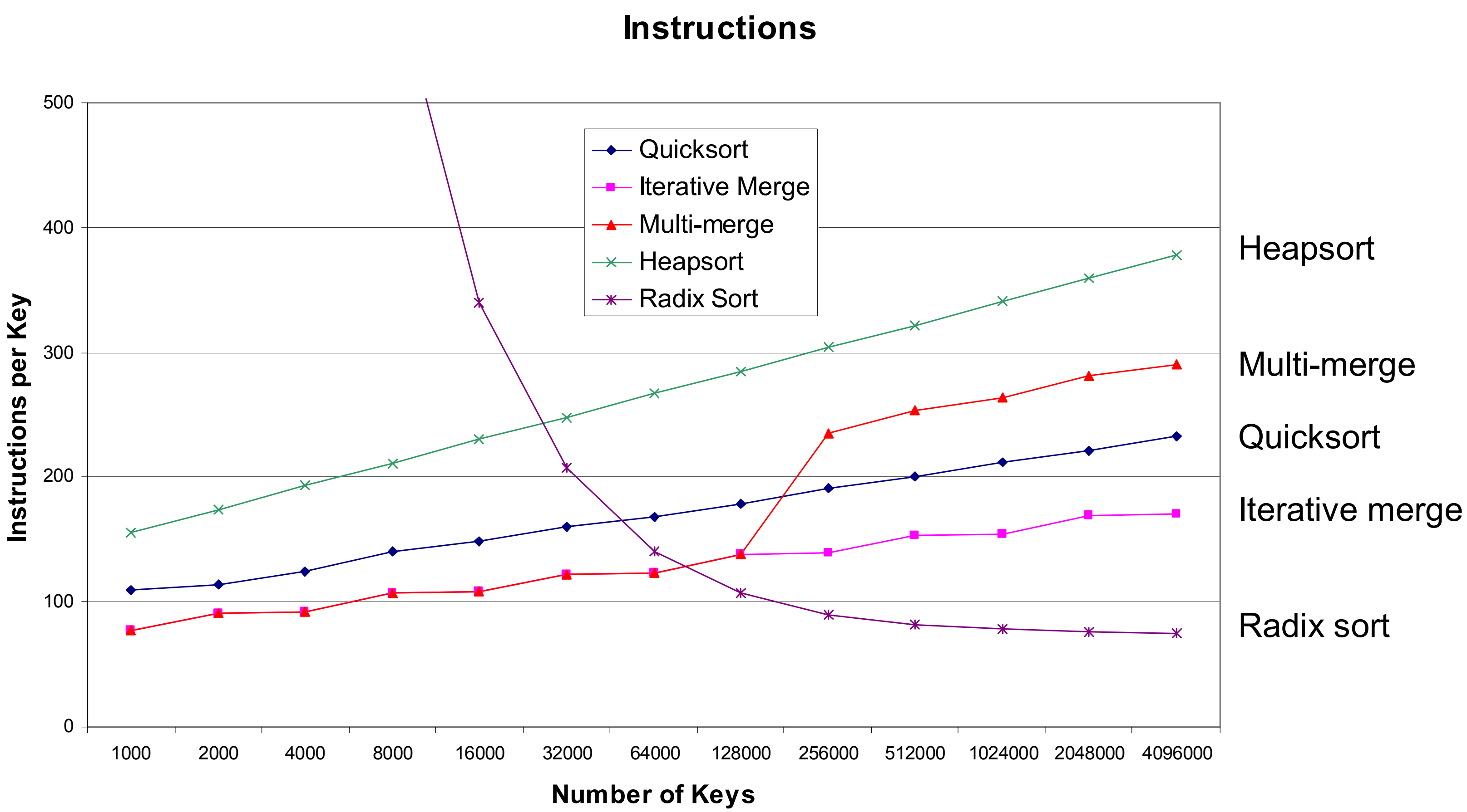
Algorithms

- Iterative mergesort
- Multi-mergesort
- Quicksort
- Heapsort
- Radix sort
  - › Parameters chosen for large data set.
  - › 4 passes for 64 bit integers.

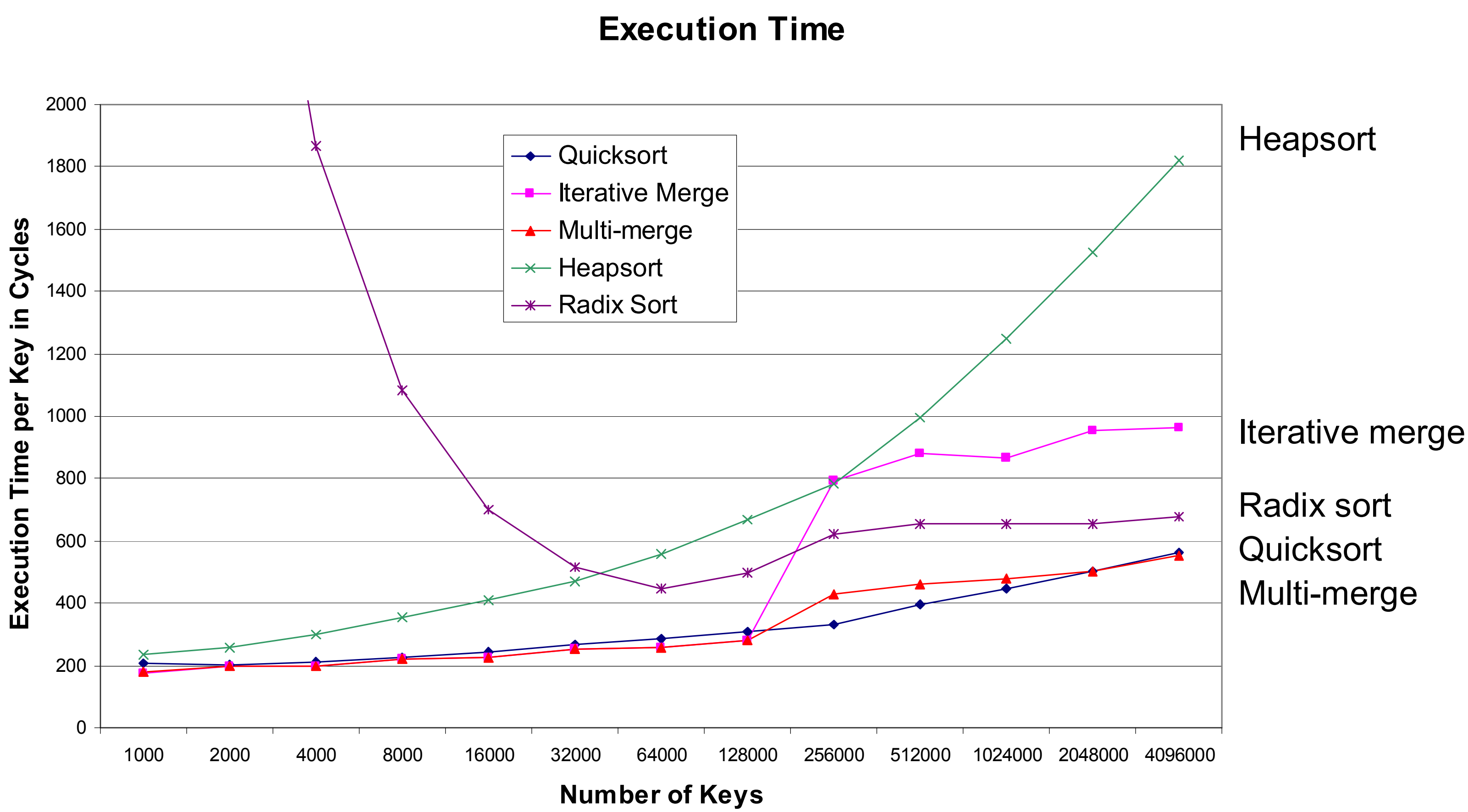
Cache Misses



Instructions



Execution Time



Notes on Memory Performance

- Memory performance may matter.
- Tips
  - › Sacrifice instructions to get better cache performance.
  - › Smaller memory footprint is good.
  - › Divide and conquer is good.
  - › Processing data into cache sized pieces is good.
  - › Fully utilize memory blocks if possible
    - Short scans are good.
    - Multiway trees are good.