How to Write Fast Code

18-645, spring 2008

26th Lecture, Apr. 21st

Instructor: Markus Püschel

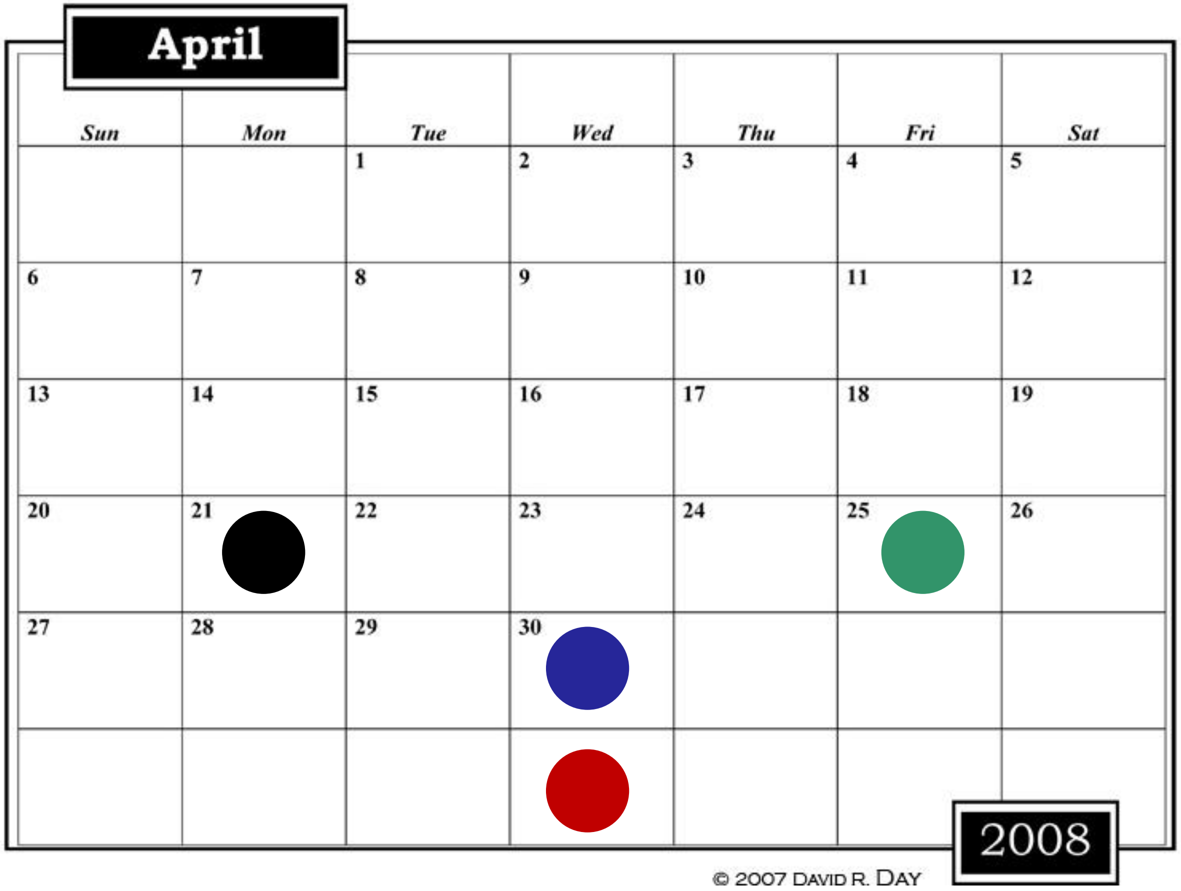
TAs: Srinivas Chellappa (Vas) and Frédéric de Mesmay (Fred)

Course Evaluations

- Are open now
- Please fill it out

Research Project

- Project expectations
- Paper templates and instructions on the website
- Poster template soon



April

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21 ⚫	22	23	24	25 🟢	26
27	28	29	30 🔵			
			🔴			

2008

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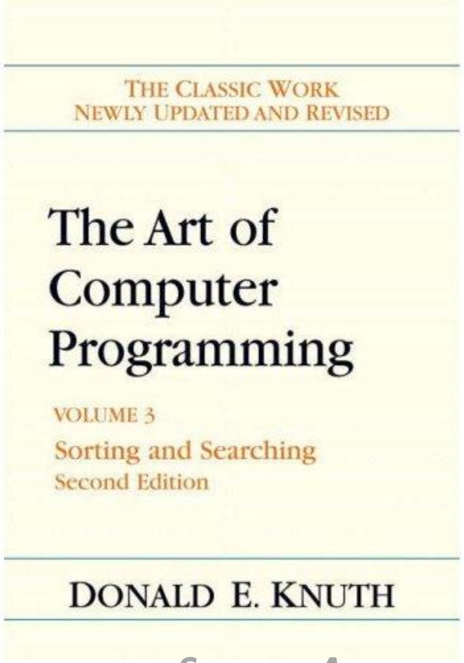
- ⚫ Today
- 🟢 Papers due (6 pm)
- 🔵 Last class:
  poster session
  Scaife Hall
  5:30 – 8:30 pm
- 🔴 Due:
  - Final papers
  - Final code

Today

- **Sorting**
  (Example of a non-numerical problem)

Sorting

- **Fundamental problem in computer science**
  - Extensively studied
  - Many different algorithms (Wikipedia)
- **Comparison based algorithms**
  - Complexity: $\Omega(n \log(n))$
  - Quicksort
  - Mergesort
  - Insertion sort
  - Sorting networks
- **Other algorithms**
  - Radix sort
- ***How to make sorting fast?***



THE CLASSIC WORK
NEWLY UPDATED AND REVISED

The Art of
Computer
Programming

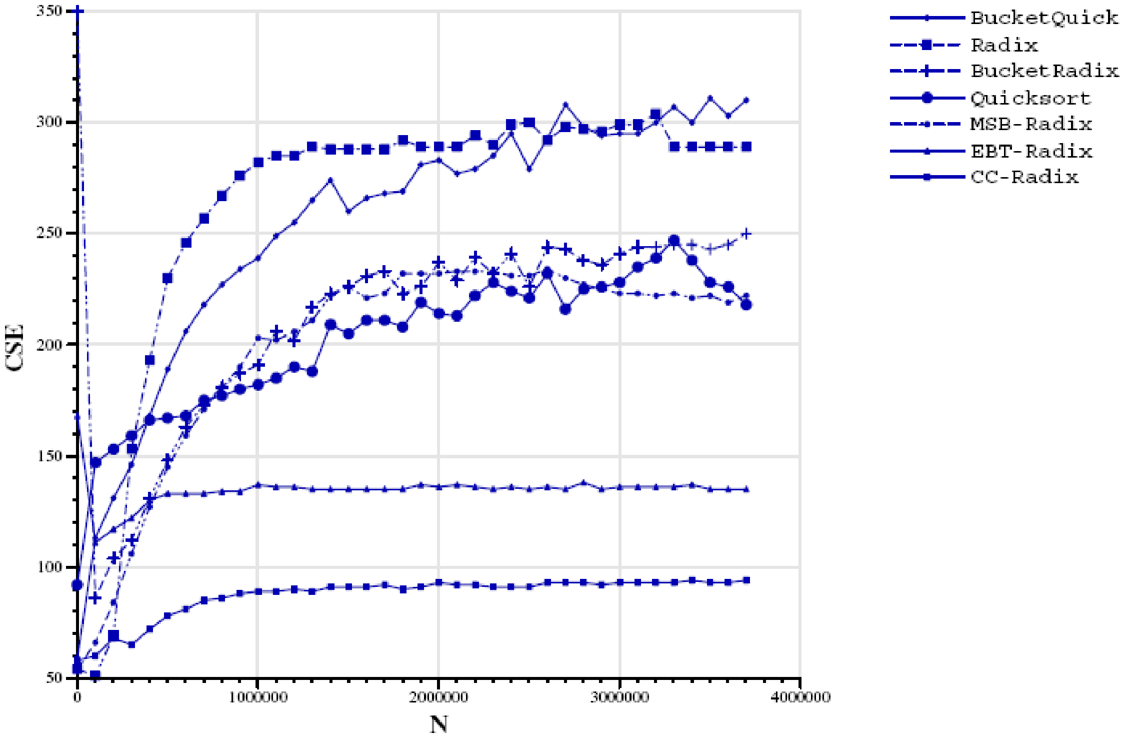
VOLUME 3
Sorting and Searching
Second Edition

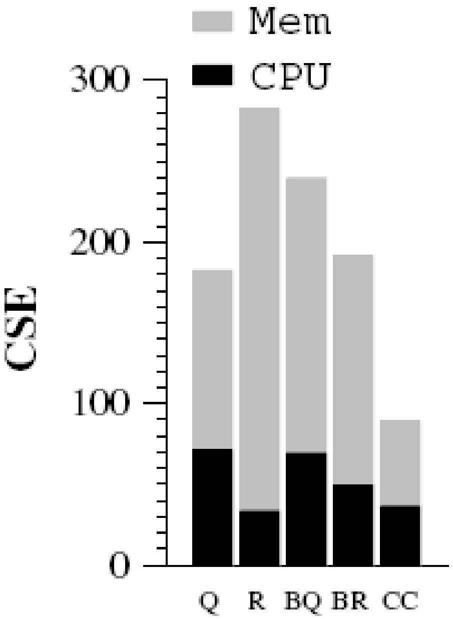
DONALD E. KNUTH

Source: Amazon

Performance Issues

- Many algorithms to choose from
- Usually not optimized for the memory hierarchy

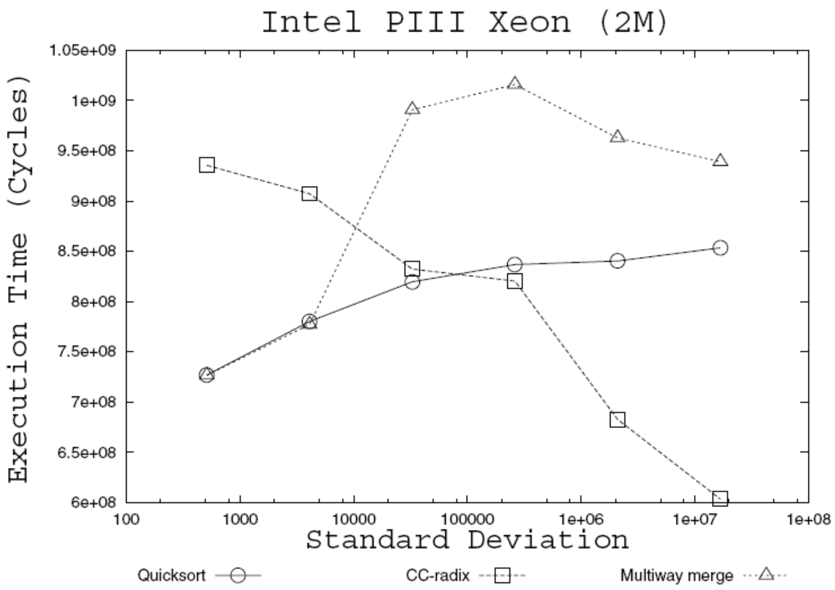


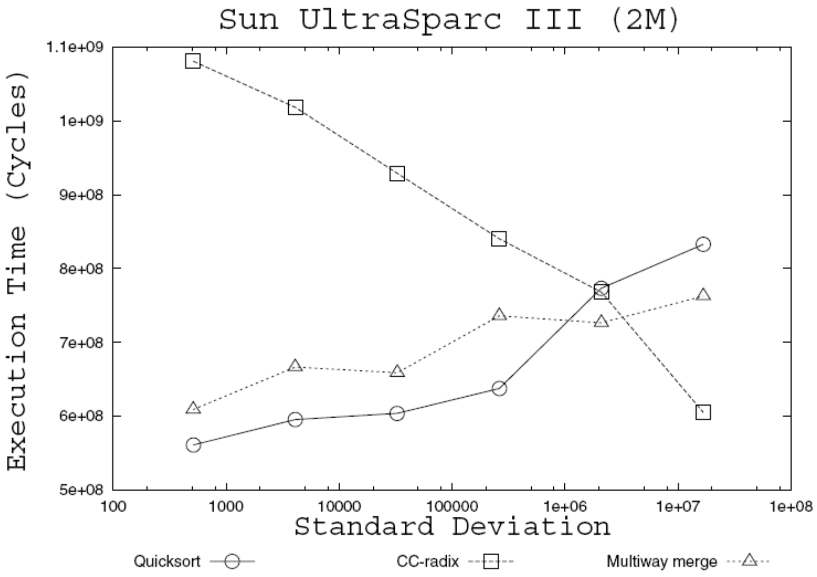


Plots: D. Jimenez-Gonzalez, J. Navarro, and J. Larriba-Pey. CC-Radix: A Cache Conscious Sorting Based on Radix Sort. In *Euromicro Conf. on Parallel Distributed and Network based Processing, pp.* 101–108, 2003

Performance Issues

- **Performance may depend on**
  - the distribution of input data
  - the computing platform





Plots: Xiaoming Li, María J. Garzarán and David Padua, A Dynamically Tuned Sorting Library, *Proc. International Symposium on Code Generation and Optimization (CGO),* pp. 111-124, 2004

Sorting Algorithms and Memory Hierarchy Optimizations

- Quicksort
- Mergesort
- Insertion sort
- Sorting networks
- Radix Sort

- Putting it together: adaptive sorting

Quicksort (Hoare 1961)

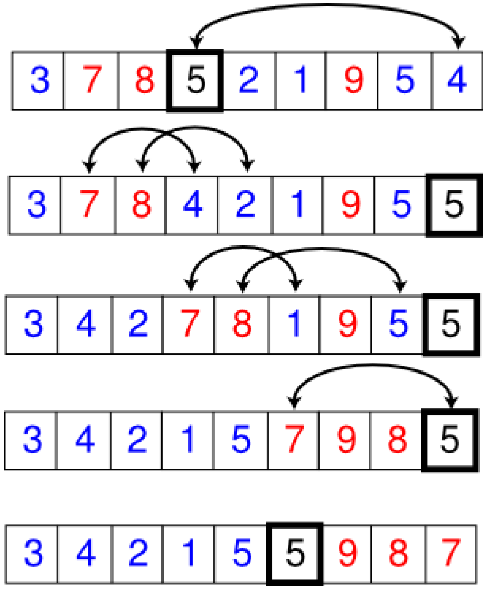
- **Start on blackboard**
- **One partitioning step (inplace version)**

```
function partition(array, left, right, pivotIndex)

    pivotValue := array[pivotIndex]
    swap array[pivotIndex] and array[right] // Move pivot to end
    storeIndex := left

    for i from left to right // left ≤ i < right
          if array[i] ≤ pivotValue
          swap array[i] and array[storeIndex]
          storeIndex := storeIndex + 1
          swap array[storeIndex] and array[right] // Move pivot to its final place

    return storeIndex
```



- **Discussion: blackboard**

Source: Wikipedia

Mergesort (von Neumann 1945)

- **Start on blackboard**
- **Merge function**

```
function merge(left,right)
    var list result
    while length(left) > 0 and length(right) > 0
        if first(left) ≤ first(right)
            append first(left) to result
            left = rest(left)
        else
            append first(right) to result
            right = rest(right)
    if length(left) > 0
        append rest(left) to result
    if length(right) > 0
        append rest(right) to result
    return result
```

- **Discussion: blackboard**

Source: Wikipedia

John von Neumann (1903-1957)

- **Hungarian (later American citizen) genius**
- **Among the first four selected for the Institute of Advanced Studies, Princeton (with Gödel and Einstein)**
- **Major contributions in:** set theory, functional analysis, quantum mechanics, ergodic theory, continuous geometry, economics and game theory, computer science, numerical analysis, hydrodynamics, statistics
  - Founded game theory and applied it to economics
  - Von Neumann computer architecture
  - Manhattan project

Insertion Sort

- **Pseudocode**

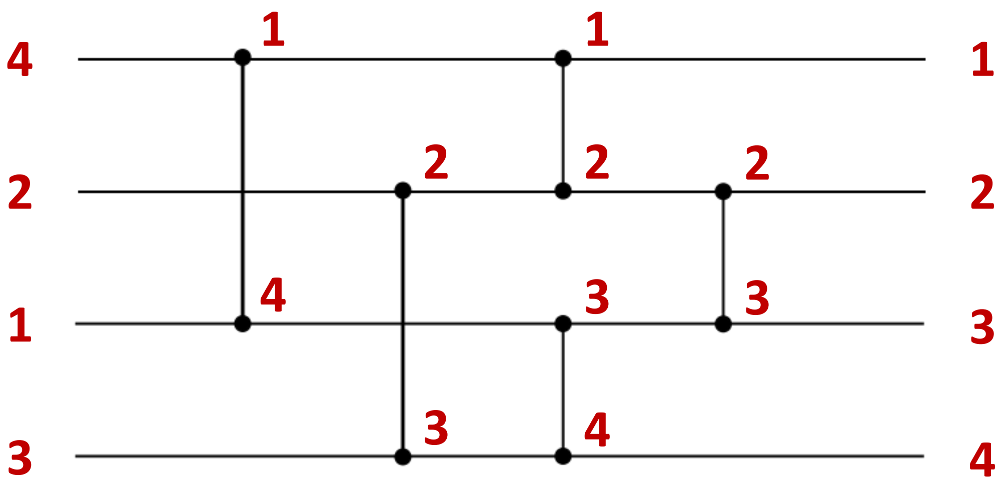
```
function insertionSort(array A)
    for i = 1 to length[A]-1 do
        value = A[i]
        j = i-1
        while j >= 0 and A[j] > value do
            A[j + 1] = A[j]
             j = j-1
        A[j+1] = value
```

- **Discussion: blackboard**

Source: Wikipedia

Sorting Networks

- Start on blackboard
- Example: N = 4, 5 comparators

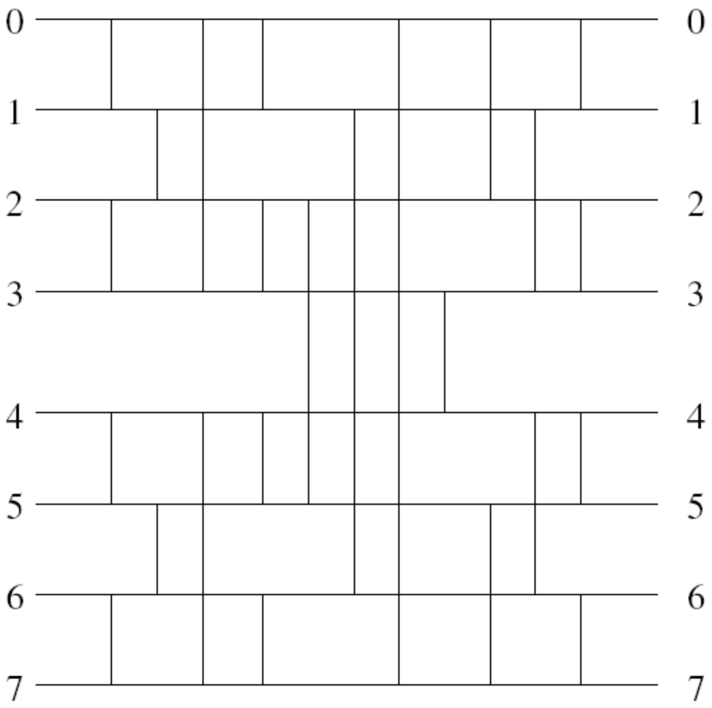


- Discussion: blackboard

Source: Wikipedia

Sorting Networks as Basic Blocks

- **Example**



network

```
cmp&swap (r0, r1)
cmp&swap (r2, r3)
cmp&swap (r4, r5)
cmp&swap (r0, r3)
cmp&swap (r6, r7)
      ⋮
cmp&swap (r2, r3)
cmp&swap (r4, r5)
cmp&swap (r6, r7)
```

unrolled code, scheduled for instruction level parallelism

Source: Xiaoming Li, María J. Garzarán and David Padua, A Dynamically Tuned Sorting Library, *Proc. International Symposium on Code Generation and Optimization (CGO),* pp. 111-124, 2004