CS61C : Machine Structures

Lecture #40
Writing Fast code

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http://economictimes.indiatimes.com/News/News_By_Industry/Telecom/Broadband_to_go_free_in_2_yrs/articleshow/msid-1955351,curpg-2.cms

Speed

- We like things to run fast
- But what determines speed?
    - Algorithmic Complexity
    - Number of instructions executed
    - Considering architecture
- We will focus on the last two – take cs170 for fast (low complexity) algorithms

Minimizing number of instructions

- **Know your input: If your input is constrained in some way, you can often optimize.**
  - **Many algorithms are ideal for large random data**
    - **Often you are dealing with smaller numbers, or less random ones**
    - **When taken into account, “worse” algorithms may perform better**
- **Preprocess if at all possible: If you know some function will be called often, you may wish to preprocess**
  - **The fixed costs (preprocessing) are high, but the lower variable costs (speed of a function often called) may make up for it.**

Example 1 – bit counting – Basic Idea

- Sometimes you may want to count the number of bits in a number:
  - This is used in encodings
  - Also used in interview questions
- Obviously, there is no (sequential) algorithm which has better complexity than O(n), with n being number of bits
- But we can optimize this in some ways

Example 1 – bit counting - Basic

- **The basic way of counting:**

```
int bitcount_std(uint32_t num){
  int cnt = 0;
  while (num){
     cnt+= (num & 1);
     num>>=1;
  }
  return cnt;
}
```

We simply test every bit until we are done!

Example 1 – bit counting – Optimized?

- The “optimized” way of counting:
- Linear in the number of 1’s present

```
int bitcount_op(uint32_t num){
    int cnt = 0;
    while (num){
        cnt++ ;
        num &= (num - 1) ;
    }
    return cnt;
}
```

This relies on the fact that

num = (num – 1) & num

changes rightmost 1 bit in num to a 0.

Try it out!

Example 1 – bit counting – Preprocess

- **Preprocessing!**

```
uint8_t tbl[256]; //tbl[i] has number of 1’s in i
inline int bitcount_preprocess(uint32_t num){
    int cnt =0;
    while (num){
        cnt+=tbl[num&0xff];
        num>>=8;
    }
    return cnt;
}
```

The table could be made smaller or larger; there is a trade-off between table size and speed.

Table can be built either A) initially or B) as it is accessed (like a cache)

Example 1 – Times

Test: Call bitcount on 20 million random numbers. Compiled with –O1, run on 2.4 Ghz Intel Core 2 Duo with 1 Gb RAM

Test	Totally Random number time	Random power of 2 time
Bitcount_std	830 ms	790 ms
Bitcount_op	860 ms	273 ms
Bitcount_ preprocess	720 ms	700 ms

Preprocessing improved (13% increase). Optimization was great for power of two numbers.

With random data, the linear in 1's optimization actually hurt speed (subtracting 1 may take more time than shifting on many x86 processors).

Inlining

- **A function in C:**

```
int foo(int v){
      //code
}
foo(9)
```

- **The same function in assembler:**

```
foo: #push back stack pointer
     #save regs
     #code
     #restore regs
     #push forward stack pointer
     jr $ra
#elsewhere
     jal foo
```

Inlining - Etc

- Function calling is quite expensive!
- C provides the inline command.
  - Functions that are marked inline (e.g. inline void f) will have their code inserted into the caller
  - Thus, inline functions are somewhat “macros with structure”.
- With inlining, bitcount-std took 830 ms.
- Without inling, bitcount-std took 1.2s!
- Bad things about inlining;
  - Inlined functions generally cannot be recursive.
  - Inlining large functions is actually a bad idea. It increases code size and may hurt cache performance.

Along the Same lines - Malloc

- Malloc is a function call – and a slow one at that.
- Often times, you will be allocating memory that is never freed
  - Or multiple blocks of memory that will be freed at once.
- Allocating a large block of memory a single time is much faster than multiple calls to malloc.

```
int *malloc_cur, *malloc_end;
//normal allocation:
malloc_cur = malloc(BLOCKCHUNK*sizeof(int*));
//block allocation – we allocate BLOCKSIZE at a time
malloc_cur += BLOCKSIZE;
  if (malloc_cur == malloc_end){
        malloc_cur = malloc(BLOCKSIZE*sizeof(int*));
        malloc_end = malloc_cur + BLOCKSIZE;
  }
Block allocation is 40% faster
  (BLOCKSIZE=256; BLOCKCHUNK=16)
```

Case Study - Hardware Dependence

- You have two integers arrays A and B.
- You want to make a third array C.
- C consists of all integers that are in both A and B.
- You can assume that no integer is repeated in either A or B.

A

6	4	8

B

8	3	4

C

8	4

Case Study - Hardware Dependence

- You have two integers arrays A and B.
- You want to make a third array C.
- C consists of all integers that are in both A and B.
- You can assume that no integer is repeated in either A or B.
- There are two reasonable ways to do this:
  - Method 1: Make a hash table.
    - Put all elements in A into the hash table.
    - Iterate through all elements n in B. If n is present in A, add it to C.
  - Method 2: Sort!
    - Quicksort A and B
    - Iterate through both as if to merge two sorted lists.
    - Whenever A[index_A] and B[index_B] are ever equal, add A[index_A] to C

Peer Instruction

Method 1: Make a hash table.

- Put all elements in A into the hash table.
- Iterate through all elements n in B. If n is in A, add it to C.

Method 2: Sort!

- Quicksort A and B
- Iterate through both as if to merge two sorted lists.
- Whenever A[index_A] and B[index_B] are ever equal, add A[index_A] to C

A. Method 1 is has lower average time complexity (Big O) than Method 2

B. Method 1 is faster for small arrays

C. Method 1 is faster for large arrays

	ABC
0:	FFF
1:	FFT
2:	FTF
3:	FTT
4:	TFF
5:	TFT
6:	TTF
7:	TTT

Peer Instruction

A. Hash Tables (assuming little collisions) are O(N). Quick sort averages O(N*log N). Both have worse case time complexity O(N^2).

For B and C, let's try it out:

Test data is random data injected into arrays equal to SIZE (duplicate entries filtered out).

Size	# matches	Hash Speed	Qsort speed
200	0	23 ms	10 ms
2 million	1,837	7.7 s	1 s
20 million	184,835	Started thrashing – gave up	11 s

So TFF!

Analysis

- The hash table performs worse and worse as N increases, even though it has better time complexity.
- The thrashing occurred when the table occupied more memory than physical RAM.
- But this doesn't explain the 2 million case: We will compare hashing to RADIX sort to analyze it.
- QUICKSORT – O(N*log(N)):

  Basically selects "pivot" in an array and rotates elements about the pivot

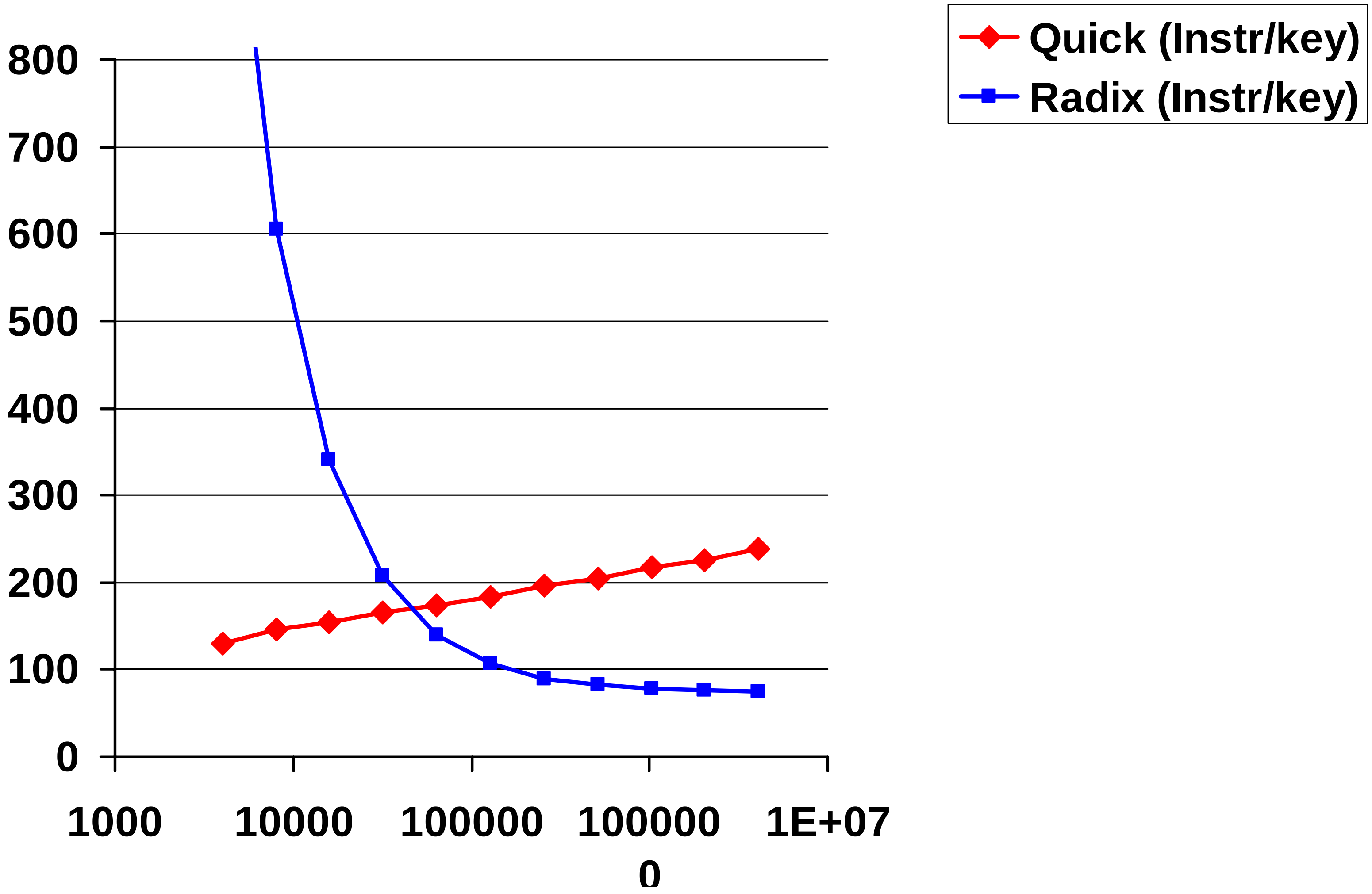
  Average Complexity: O(n*log(n))

RADIX SORT – O(n):

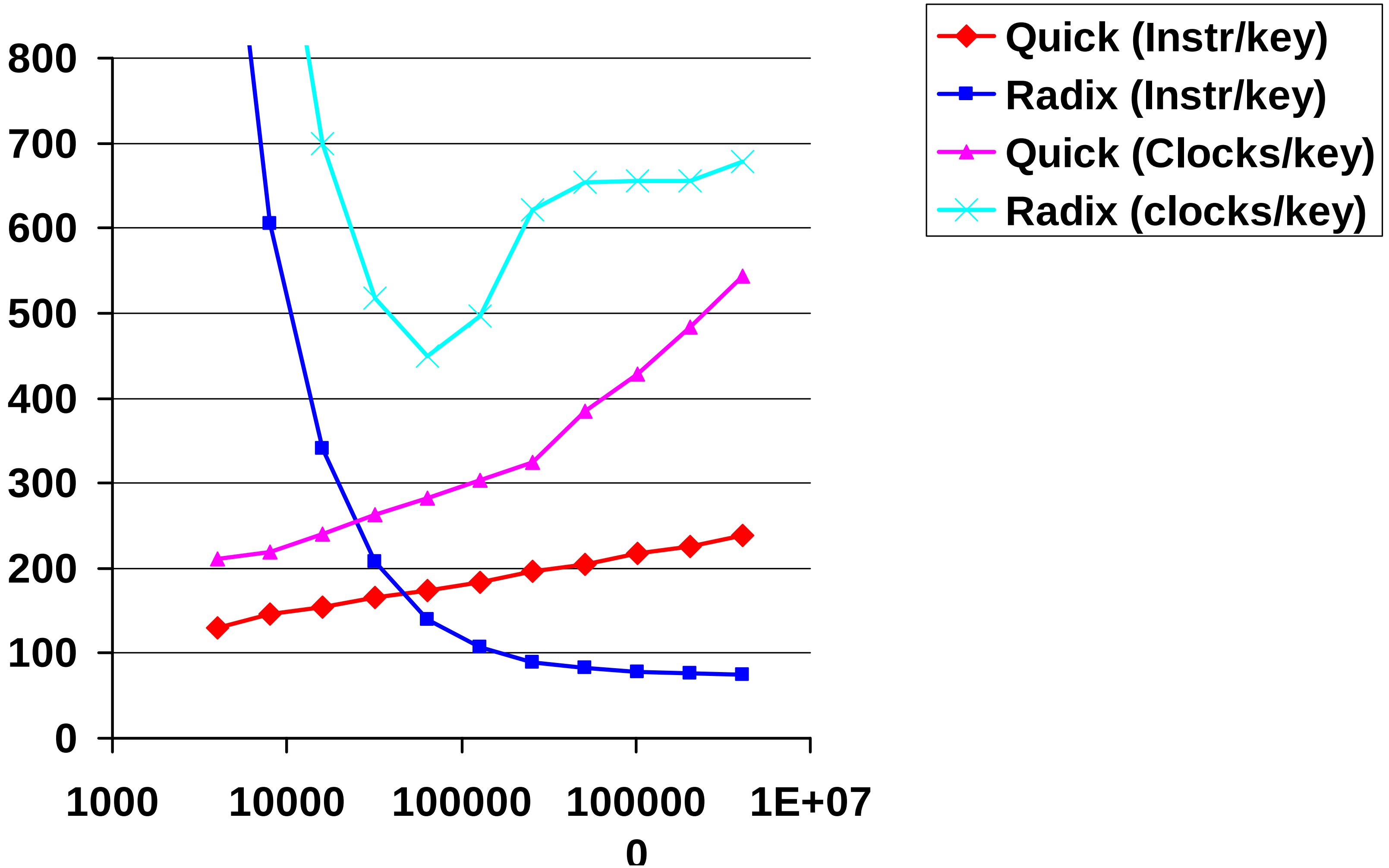
  Advanced bucket sort

  Basically "hashes" individual items.

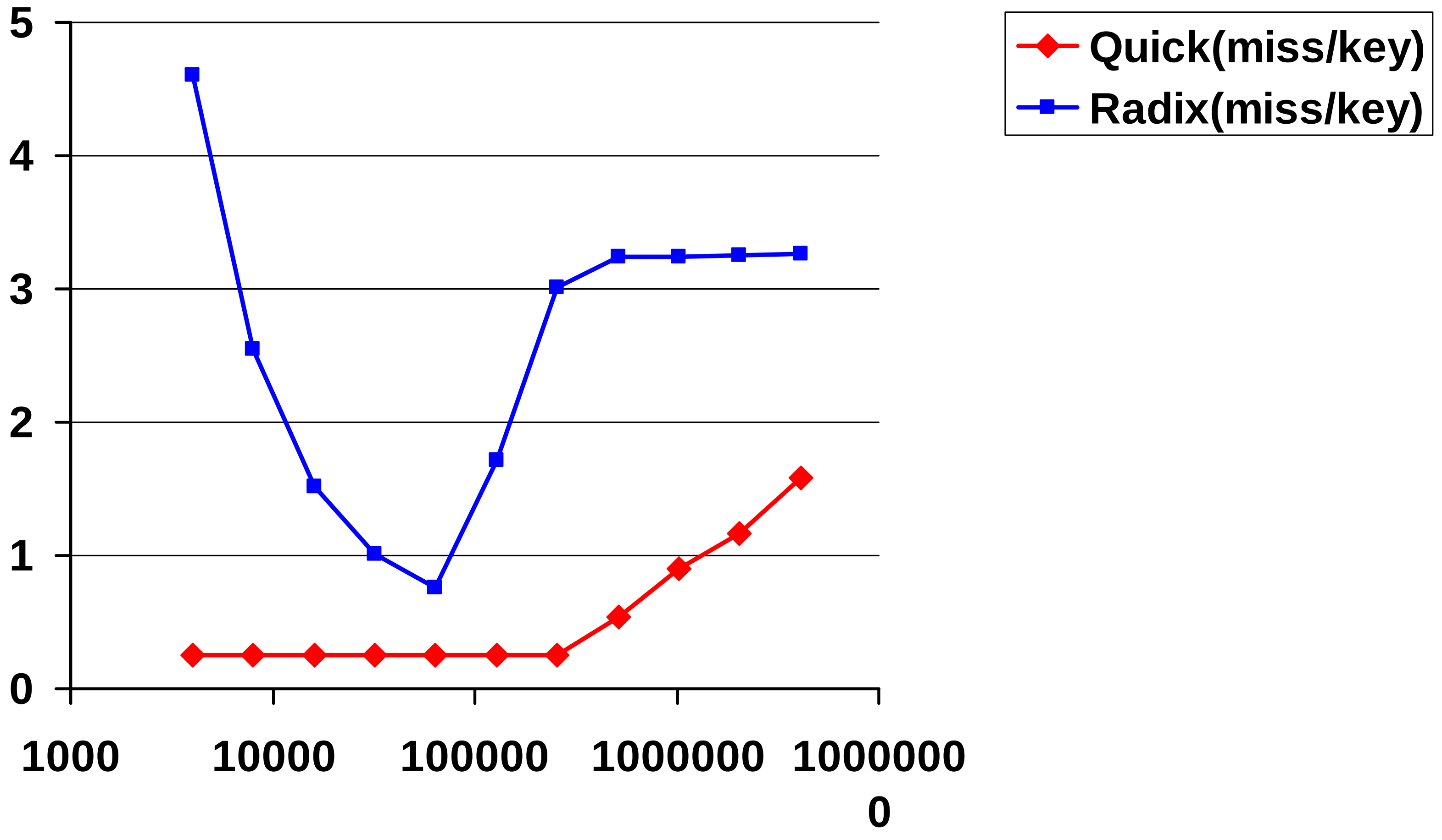
Complexity holds true for instruction count



Yet CPU time suggests otherwise…



Never forget Cache effects!



Other random tidbits

- **Approximation:** Often an approximation of a problem you are trying to solve is good enough – and will run much faster
  - For instance, cache and paging LRU algorithm uses an approximation

- **Parallelization:** Within a few years, all manufactured CPUs will have at least 4 cores. Use them!

- **Instruction Order Matters:** There is an instruction cache, so the common case should have high spatial locality
  - GCC's –O2 tries to do this for you

- **Test your optimizations.** You generally want to time your code and see if your latest optimization actually has improved anything.
  - Ideally, you want to know the *slowest* area of your code.

- **Don't over-optimize!** There is little reason to spend 3 additional months on a project to make it run 5% faster. CPU speeds increase faster than that.

“And in conclusion…”

- **CACHE, CACHE, CACHE.** Its effects can make seemingly fast algorithms run slower than expected. (For the record, there are specialized cache efficient hash tables).
- **Function Inlining:** For small, often called functions, this will help much.
- **Malloc:** Try to allocate larger blocks if at all possible,
- **Preprocessing and memoizing**: Very useful for often called functions.
- **There are other optimizations possible:** But be sure to test before using them!

Bonus slides

- Source code is provided beyond this point
- We don't have time to go over it in lecture.

Bonus

Method 1 Source – in C++

int I = 0, int j =0, int k=0;

int *array1, *array2, *result; //already allocated (array are set)

```
map<unsigned int, unsigned int> ht; //a hash table

for (int i=0; i<SIZE; i++) {  //add array1 to hash table
     ht[array1[i]] = 1;
}

for (int i=0; i<SIZE; i++) {
   if(ht.find(array2[i]) != ht.end()) { //is array2[i] in ht?
      result[k] = ht[array2[i]];  //add to result array
      k++;
   }
}
```

Method 2 Source

```
int I = 0, int j =0, int k=0;
int *array1, *array2, *result; //already allocated (array are set)
qsort(array1,SIZE,sizeof(int*),comparator);
qsort(array2,SIZE,sizeof(int*),comparator);
//once sort is done, we merge
while (i<SIZE && j<SIZE){
     if (array1[i] == array2[j]){ //if equal, add
          result[k++] = array1[i] ; //add to results
          i++;   j++; //increment pointers
     }
     else if (array1[i] < array2[j]) //move array1
          i++;
     else  //move array2
          j++;
}
```