Computer Programming: Skills & Concepts (CP1)
Sorting

2nd November 2010

Monday's lecture

- Arguing a program is correct
- Linear Search of an array.
- Binary search of an array
- (Theoretical) measurement of running time
- Timing your code on DICE
- *I never got to cover the slides on BubbleSort*

NOTE In the tests in `search.c`, I did NOT initialise the test array to be *sorted* (as required by `BinarySearch`)
... does not matter as the key -1 is not in the array at all

Today's lecture

- BubbleSort algorithm (from slides18.pdf).
- New sorting algorithm called MergeSort
- Analysis of running time.
- `calloc` for dynamically-sized arrays.

Merge

Idea:

Suppose we have two arrays `a, b` of length `n;` and `m` respectively, and that these arrays ARE ALREADY SORTED. Then the merge of `a` and `b` is the sorted array of length `n+m` we get by walking through both arrays jointly, taking the smallest item at each step.

example on board

merge

```
void merge(int a[], int b[], int c[], int m, int n) {
  int i=0, j=0, k=0;
  while (i < m && j < n) {
    if (a[i] <= b[j])
      c[k++] = a[i++];
    else
      c[k++] = b[j++];
  }
  while (i < m)          /* copying the 'rest' into c
    c[k++] = a[i++];      * (if b got finished first)  */
  while (j < n)          /* copying the 'rest' into c
    c[k++] = b[j++];      * (if a got finished first)  */
}
```

MergeSort - the idea

Given an array `a` of length `n`.

(i) Sort all subarrays of length 2: `a[0..1]`, `a[2...3]...`

(ii) Create sorted subarrays of length $2 * 2 = 4$ by *merging* pairs of the sorted length-2 subarrays ...

(iii) Create sorted subarrays of length $2 * 4 = 8$ by *merging* pairs of the sorted length-4 subarrays ...

...

Iterative approach - build from "the bottom up".

At each step we double the size of our "windows of interest"

mergesort

```
void mergesort(int key[], int n){
  int j, k, *w;
  w = calloc(n, sizeof(int));  /* Allocate space for the array */
  assert (w != NULL);          /* If not enough space, stop! */
  if ((n % 2) == 1)
    w[n-1] = key[n-1];
  for (k = 1; k < n; k *= 2) {
    for (j = 0; j < n - 2*k; j += 2*k)
      merge(key + j, key + j + k, w + j, k, k);
    if (n-j > k)            /* k, n-j-k different => more work. */
      merge(key + j, key + j + k, w + j, k, (n-j)-k);
    for (j = 0; j < n; ++j)    /* copy sorted array into 'key'  */
       key[j] = w[j];
  }
  free(w);                   /* Free-up memory pointed to by w */
}
```

checking output

```
* Function to write-out the contents of key[]. */
void wrt(int key[], int sz) {
  int i;
  for (i = 0; i < sz; ++i)
    printf("%4d%s", key[i], ((i < sz -1) ? "" : "\n"));
}
```

Trial run

```
int main(void) {
  int i, sz, key[] = {4, 3, 1, 67, 0, 4, -5, 37, 7, 2, -1, 199};
  sz = sizeof(key)/sizeof(int);
  printf("Before mergesort: \n");
  wrt(key, sz);
  mergesort(key, sz);
  printf("After mergesort:\n");
  wrt(key, sz);
  return EXIT_SUCCESS;
}
```

`calloc`

In previous applications we have always specified the length of the array as a fixed parameter defined in advance, directly in the program.

To define array size *dynamically*, use `calloc`:

- `calloc()` takes 2 arguments (of type `size_t`):

  `calloc(n,`*el_size*`)`
- This allocates (if available) space an array of length `n` of type *el* (each cell using *el_size* bytes).
- `calloc ()` returns a pointer to the address of the start of the array in memory.
- Space created is initialized to all-bits-0.
- `malloc()` similar.

Running-time of `mergesort`

(a) We double the "merge-size" `k` (starting from 1) at each pass.

(b) Can do this ONLY $2\log(n)$ times for `k < n`.

(c) Do a linear amount of "work" ($\Theta(n)$) across the array for each value of `k`.

$\Rightarrow$ Roughly $\Theta(n\log(n))$ overall running-time.

Not quite as obvious that (b) is true when the array-length is not a power-of-2 ... still true though!

Big difference in speed from BubbleSort. EXPERIMENT

A more dramatic example

Sometimes the gap between a good and bad algorithm can be dramatic. Consider the problem of testing whether an n-bit number is prime.

- The obvious brute force method requires $2^{n/2}$ integer divisions
  - why?
  - This is completely infeasible if $n = 200$ (say).
- On the other hand, a (non-obvious) algorithm for primality testing which take time *polynomial* in n was discovered in 2002 (Agrawal-Kayal-Saxena)

(Needed for RSA public-key cryptosystem.)

Homework

- Sections 6.8 and 6.9 of Kelley and Pohl!
- Experiment with the code.