Pointers to Functions

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CS246 Programming Paradigm

Pointers to Functions

- C doesn't require that pointers point only to *data;* it's also possible to have pointers to *functions*.
- Function pointers point to memory addresses where functions are stored.
  - `int (*fp) (void);`
  - A function pointer determines the prototype of a function, but not its implementation.
  - Any function of the identical prototype can be assigned to the function pointer.
  - A function without its argument lists becomes its own pointer
  - Function pointers do not need `&` or `*`

Function Pointer: Example

```
#include <stdio.h>

int main() {
  int i = 1;
  int (*fp) (const char *, ...) = printf;
  fp("i == %d\n", i);
  (*fp)("i == %d\n", i);
  return 0;
}
```

- Notice no need for `&printf` or `(*fp)`
- But I like to stick with `(*fp)`

Overriding Functions

- Also known as late-binding, this is emulated in C with function pointers.
- Together with generic pointers (`void *`), one can have typeless parameters and functions.

```
void fd (void *base, size_t n, size_t size){
  double *p = base;
  for (p = base; p < (double*) (base+(n*size)); p++) ;
}
int main() {
  double a[5] = {0, 1, 2, 3, 4};
  if (type == DOUBLE) {
    void (*f) (void *, size_t, size_t) = fd;
    (*f)(a, 5, sizeof(double));
  }
}
```

Printing of Generic Arrays

```
typedef struct {
  double x;
  double y;
} Point;
int main() {
  double a[5] = {0, 1, 2, 3, 4};
  int b[5] = {5, 6, 7, 8, 9};
  Point ps[2] = {{0.5, 0.5}, {1.5, 2.5}};

  gp(a, 5, sizeof(double));
  gp(b, 5, sizeof(int));
  gp(ps, 2, sizeof(Point));
}
```

Printing of Generic Arrays

```
void gp (void *b, size_t n, size_t size){
  char *p;
  for (p=b; p <(char*)(b+(n*size)); p+=size){
    switch (size) {
    case sizeof(double):
      printf("%.2f ", *(double*)p);
      break;
    case sizeof(int):
      printf("%d ", *(int*)p);
      break;
    case sizeof(Point):
      printf("x = %.2f ", ((Point *)p)->x);
      printf("y = %.2f ", ((Point *)p)->y);
      break;
    }}
  printf("\n"); }
```

The `qsort` Function

- Some of the most useful functions in the C library require a function pointer as an argument.
- One of these is `qsort`, which belongs to the `<stdlib.h>` header.
- `qsort` is a general-purpose sorting function that's capable of sorting any array.

The `qsort` Algorithm

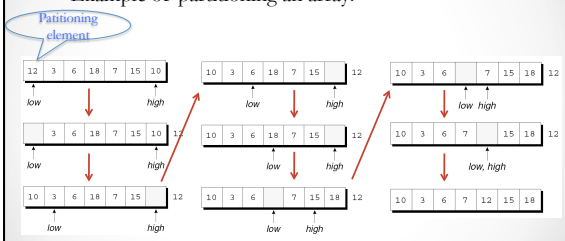
- Assume that the array to be sorted is indexed from 1 to *n*.

`qsort` algorithm

1. Choose an array element *e* (the "partitioning element"), then rearrange the array so that elements 1, …, *i* – 1 are less than or equal to *e*, element *i* contains e, and elements *i* + 1, …, *n* are greater than or equal to *e*.
2. Sort elements 1, …, *i* – 1 by using Quicksort recursively.
3. Sort elements *i* + 1, …, *n* by using Quicksort recursively.

The `qsort` Algorithm

- Example of partitioning an array:



The `qsort` Function

- `qsort` must be told how to determine which of two array elements is "smaller."
- This is done by passing `qsort` a pointer to a ***comparison function.***
- When given two pointers `p` and `q` to array elements, the comparison function must return an integer that is:
  - *Negative* if `*p` is "less than" `*q`
  - *Zero* if `*p` is "equal to" `*q`
  - *Positive* if `*p` is "greater than" `*q`

The `qsort` Function

- Prototype for `qsort`:

```
void qsort(void *base, size_t nmemb, size_t size,
  int (*compar)(const void *, const void *));
```

- `base` must point to the first element in the array (or the first element in the portion to be sorted).
- `nmemb` is the number of elements to be sorted.
- `size` is the size of each array element, measured in bytes.
- `compar` is a pointer to the comparison function.
- When `qsort` is called, it sorts the array into ascending order, calling the comparison function whenever it needs to compare array elements.

The `qsort` Example

```
int vs[] = {40, 10, 100, 90, 20, 25};
int comp ( const void *a,
           const void *b){
  return ( *(int*)a - *(int*)b );
}

int main () {
  qsort (vs, 6, sizeof(int), comp);
}
```

compar

```
int comp_nodes (const void *a, const void *b) {
  struct Node *n1 = a;  struct Node *n2 = b;

  if ( (n1->num < n2->num )  return -1;
  else if (n1->num > n2->num )  return 1;
  else return 0;
  /* or
  return ((struct Node *)n1)->num - ((struct Node
  *)n2)->num; */
}

qsort(nodes, 10, sizeof(struct Node), comp_nodes);
```

The qsort Example

- Recall in Chapter 16, we have the `inventory` array:

```
struct part {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} inventory[MAX_PARTS];
```

The qsort Example

- To sort the `inventory` array using qsort:

```
qsort(inventory, num_parts,
      sizeof(struct part), compare_parts);
```

- `compare_parts` is a function that compares two `part` structures.
- Writing the `compare_parts` function is tricky.
- `qsort` requires that its parameters have type `void *`, but we can't access the members of a `part` structure through a `void *` pointer.
- To solve the problem, `compare_parts` will assign its parameters, `p` and `q`, to variables of type `struct part *`.

The qsort Function

- A version of `compare_parts` that can be used to sort the `inventory` array into ascending order by part number:

```
int compare_parts(const void *p, const void *q)
{
  const struct part *p1 = p;
  const struct part *q1 = q;

  if (p1->number < q1->number)
    return -1;
  else if (p1->number == q1->number)
    return 0;
  else
    return 1;
}
```

The qsort Function

- Most C programmers would write the function more concisely:

```
int compare_parts(const void *p, const void *q)
{
  if (((struct part *) p)->number <
      ((struct part *) q)->number)
    return -1;
  else if (((struct part *) p)->number ==
           ((struct part *) q)->number)
    return 0;
  else
    return 1;
}
```

The qsort Function

- `compare_parts` can be made even shorter by removing the `if` statements:

```
int compare_parts(const void *p, const void *q)
{
  return ((struct part *) p)->number -
         ((struct part *) q)->number;
}
```

The `qsort` Function

- A version of `compare_parts` that can be used to sort the `inventory` array by part name instead of part number:

```
int compare_parts(const void *p, const void *q)
{
  return strcmp(((struct part *) p)->name,
                ((struct part *) q)->name);
}
```

Other Uses of Function Pointers

- Although function pointers are often used as arguments, that's not all they're good for.
- C treats pointers to functions just like pointers to data.
- They can be stored in variables or used as elements of an array or as members of a structure or union.
- It's even possible for functions to return function pointers.

Other Uses of Function Pointers

- A variable that can store a pointer to a function with an `int` parameter and a return type of `void`:

```
void (*pf)(int);
```

- If `f` is such a function, we can make `pf` point to `f` in the following way:

```
pf = f;
```

- We can now call `f` by writing either

```
(*pf)(i);
```

or

```
pf(i);
```

Other Uses of Function Pointers

- An array whose elements are function pointers:

```
void (*file_cmd[])(void) = {new_cmd,
                            open_cmd,
                            close_cmd,
                            close_all_cmd,
                            save_cmd,
                            save_as_cmd,
                            save_all_cmd,
                            print_cmd,
                            exit_cmd
                           };
```

Other Uses of Function Pointers

- A call of the function stored in position `n` of the `file_cmd` array:

```
(*file_cmd[n])();  /* or file_cmd[n](); */
```

- We could get a similar effect with a `switch` statement, but using an array of function pointers provides more flexibility.

Program: Tabulating the Trigonometric Functions

- The `tabulate.c` program prints tables showing the values of the `cos`, `sin`, and `tan` functions.
- The program is built around a function named `tabulate` that, when passed a function pointer `f`, prints a table showing the values of `f`.
- `tabulate` uses the `ceil` function.
- When given an argument `x` of `double` type, `ceil` returns the smallest integer that's greater than or equal to `x`.

Program: Tabulating the Trigonometric Functions

- A session with `tabulate.c`:

```
Enter initial value: 0
Enter final value: .5
Enter increment: .1

      x        cos(x)
-------     -------
0.00000     1.00000
0.10000     0.99500
0.20000     0.98007
0.30000     0.95534
0.40000     0.92106
0.50000     0.87758
```

Program: Tabulating the Trigonometric Functions

```
      x        sin(x)
-------     -------
0.00000     0.00000
0.10000     0.09983
0.20000     0.19867
0.30000     0.29552
0.40000     0.38942
0.50000     0.47943

      x        tan(x)
-------     -------
0.00000     0.00000
0.10000     0.10033
0.20000     0.20271
0.30000     0.30934
0.40000     0.42279
0.50000     0.54630
```

tabulate.c

```
/* Tabulates values of trigonometric functions */

#include <math.h>
#include <stdio.h>

void tabulate(double (*f)(double), double first,
              double last, double incr);

int main(void)
{
  double final, increment, initial;

  printf("Enter initial value: ");
  scanf("%lf", &initial);

  printf("Enter final value: ");
  scanf("%lf", &final);

  printf("Enter increment: ");
  scanf("%lf", &increment);

  printf("\n      x        cos(x)"
         "\n   -------     -------\n");
  tabulate(cos, initial, final, increment);

  printf("\n      x        sin(x)"
         "\n   -------     -------\n");
  tabulate(sin, initial, final, increment);

  printf("\n      x        tan(x)"
         "\n   -------     -------\n");
  tabulate(tan, initial, final, increment);

  return 0;
}

void tabulate(double (*f)(double), double first,
              double last, double incr)
{
  double x;
  int i, num_intervals;

  num_intervals = ceil((last - first) / incr);
  for (i = 0; i <= num_intervals; i++) {
    x = first + i * incr;
    printf("%10.5f %10.5f\n", x, (*f)(x));
  }
}
```