Introduction of
Data Structure and Algorithm
and C Programming

by

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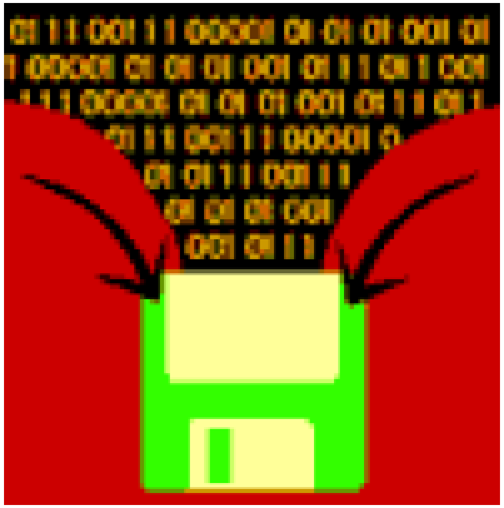
WHAT IS DATA STRUCTURE?



DATA STRUCTURE IS

- A data structure is an **arrangement of data** in a computer's memory or even disk storage.

- An example of several common data structures are
  - arrays,
  - linked lists,
  - queues,
  - stacks,
  - binary trees, and
  - hash tables.

WHAT IS ALGORITHMS?

ALGORITHMS ARE

- Algorithms are used to **manipulate the data** contained in the data structures as in
  - searching and
  - sorting

Data Structures

EXAMPLE OF DATA STRUCTURES

Name	Relationship
Alan	David's father
Alex	John's son
Betty	Alan's daughter
Candy	Nick's wife
David	Betty's brother
John	Alan's brother
Lisa	Alex's sister
Nick	Betty's grandfather
Ricky	Lisa's son
Susan	Betty's mother

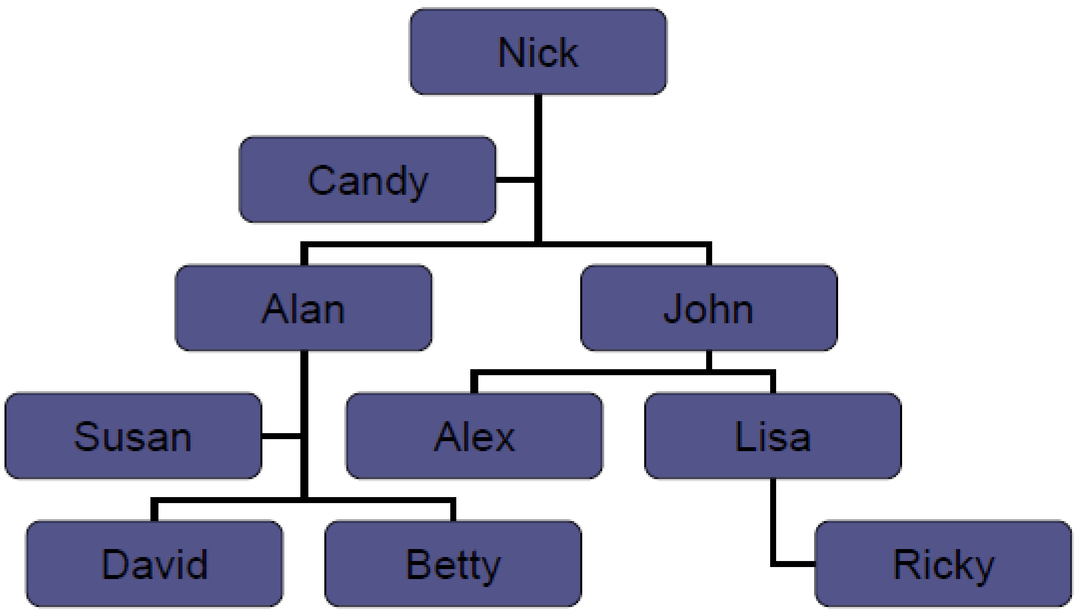
EXAMPLE OF DATA STRUCTURES

- From the table above
  - Do you know the relationship between Alex and Nick?
  - Can you find out the relationship between Candy and Ricky easily?

EXAMPLE OF DATA STRUCTURES

- In this example
  - You may think that the **tree diagram** is much **better** structure for showing the relationships

EXAMPLE OF DATA STRUCTURES



EXAMPLE OF DATA STRUCTURES

- The list and the diagrams are examples of the **different data structures**
  - The name can be stored in alphabetical order so that
    - We can locate the people very quickly
  - The tree structure is a much better suited for showing the relationships

Algorithm Analysis

ALGORITHM ANALYSIS

- What is an algorithm?

- Why do we want to analyze one?

ALGORITHM ANALYSIS

- An algorithm is a **step-by-step procedure** for accomplishing some end.

ALGORITHM ANALYSIS

- An algorithm can be given in many ways.
    - For example, it can be written down in English (or French, or any other "natural"' language).
    - However, we are interested in algorithms which have been precisely specified using an appropriate mathematical formalism - such as **a programming language**.

EXAMPLE OF ALGORITHM

- Searching a book in library
  - Say, you are searching the textbook
  - Input is?
  - Output is?
  - Procedures are?

EXAMPLE OF ALGORITHM

- Algorithm 1
  - Input: Title/Author/Keywords/Call number
  - Output: Get the book
  - Procedures:
    - 1. Go to the library
    - 2. Scan all books in the library from the leftmost bookshelf
    - 3. Compare the book information with the input
    - 4. If they are matched, get the book. Otherwise, compare with the next book

EXAMPLE OF ALGORITHM

- Algorithm 2
  - Input: Title/Author/Keywords/Call number
  - Output: Get the book
  - Procedures:
    - 1. Go to the library
    - 2. Use a computer to find the call number of the book
    - 3. Directly go to the bookshelf stated in the call number
    - 4. Compare the book information with the input
    - 5. If they are matched, get the book. Otherwise, compare with the next book

ALGORITHM ANALYSIS

- In order to learn more about an algorithm, we can "**analyze**" it.

- By this we mean to study the **specification** of the algorithm and to **draw conclusions** about how the implementation of that algorithm - the program - will perform in general.

WHAT CAN WE ANALYSIS

- Determine the **running time** of a program as a function of its inputs;
- Determine the **total or maximum memory space** needed for program data;
- Determine the **total size** of the program code;

WHAT CAN WE ANALYSIS

- Determine whether the program **correctly computes** the desired result;
- Determine the **complexity** of the program
  - e.g., how easy is it to read, understand, and modify;
- Determine the **robustness** of the program
  - e.g., how well does it deal with unexpected or erroneous inputs?

ALGORITHM ANALYSIS

- In this course,
  - We are concerned primarily with the **running time**.
  - We also consider the **memory space** needed to execute the program.

C Programming Crash Course

These were the basics of programming

- The ability to manipulate the computer to perform the required tasks

You saw data storage techniques: (Data Structure)

- Arrays, and
- Linked lists (collections were discussed)

You saw array accessing/manipulation techniques: (Algorithm)

- Searching, and
- Sorting

What is Pseudocode

Pseudocode uses a combination of programming terminology and plain English to describe algorithms in a form that is easier for people to understand than conventional programming language code.

Structured English

```
BEGIN
 READ name
 IF name EQUAL "Harry" THEN
  WRITE "Why don't you marry Pippa?"
 ELSE
  WRITE "Are you Royal enough?"
 END IF
END
```

Pseudo Code

```
BEGIN
 INPUT name
 IF name == "Harry" THEN
  OUTPUT "Why don't you marry Pippa?"
 ELSE
  OUTPUT "Are you Royal enough?"
 END IF
END
```

Executable Code

```
dim name as string
name = console.readline()
if name = "Harry" then
  console.writeline("Why don't you marry Pippa?")
else
  console.writeline("Are you Royal enough?")
End if
```

Pseudo Code Example: Add from 1 to 10

```
counter = 1
total = 0
while counter <= 10
{
   total = total + counter
   add 1 to counter
}
output total
```

helloworld.c

```
#include <stdio.h>

int main(int argc, char *argv[]) {
  printf(“hello world!\n”);

  return 0;
}
```

include

```
#include <stdio.h>
```

- Use the `#include` statement to include other C files
- Common includes are stdio.h, stdlib.h, math.h
- Generally include `.h` files to get function and variable declarations

```
#include <stdio.h>
```

vs.

```
#include "stdio.h"
```

- "" looks through current directory, while <> looks through system library folders

main

```
int main(int argc, char *argv[]) {
  /* Code */
}
```

- `main()` is a special function where execution of a C program starts.
- `argc` and `argv` are automatically passed as arguments
- `argc` is the number of arguments
- `argv` is an array containing the arguments

printf()

- `printf()` prints data to the screen
- Takes a variable number of arguments
- First argument is a **format string**
- Other arguments are optional, are inserted into the format string in the place of special sequences of characters

printf()

```
printf("hello world");
hello world
printf("5 == %d", 5);
5 == 5
printf("Char: %c, Double: %f", 'a', 1.2);
Char: a, Double: 1.2
printf("no newline");
printf("causes a run-on");
no newlinecauses a run-on
printf("line1\nline2");
line1
line2
```

Variables

- A variable is a named space in memory to store data
- In C, variables need to be **declared** before you can do anything with them
- After being declared, a variable is usually **initialized** to some initial value before being used
- A variable has a **type** and a **name**

```
int int1; // declares an integer named int1
double d; // declares a double
int1 = 5; // int1 is given the value 5
int int2 = 3; // int2 is declared and initialized
              // in one line
```

C Keywords

Variables/functions/structs may **not** be named after any keyword:

`auto`	`double`	`int`	`struct`
`break`	`else`	`long`	`switch`
`case`	`enum`	`register`	`typedef`
`char`	`extern`	`return`	`union`
`const`	`float`	`short`	`unsigned`
`continue`	`for`	`signed`	`void`
`default`	`goto`	`sizeof`	`volatile`
`do`	`if`	`static`	`while`

Arithmetic Operators

```
int x = 3, y = 4 + 4, z = 12 / 3;
printf("x: %d, y: %d, z: %d", x, y, z);
x: 3, y: 8, z: 4
z = x + y; // z is now 13
z = x + y * y; // z is now 67
double d;
d = x / y; // d is 0, C truncates integer division
d = ((double) x) / y; // now d is .375
```

Key points to keep in mind:

- Numbers in C have min/max values, unlike Scheme
- Remember to cast before dividing if you don't want integer truncation!

Bitwise Operators

```
& bitwise AND                  << left shift
| bitwise OR                   >> right shift
^ bitwise XOR                   ~ bitwise complement

 011010101                      00101101
&000000011                     |11110000
 000000001                      11111101

10000001 << 3 = 00001000
10000001 >> 3 = 00010000 or 11110000 (depending on
  whether 10000001 was a signed number or not)
```

Arrays

- An array is a contiguous segment of memory filled with values of the same type
- Arrays in C must be given a size when declared

```
int arr[10]; // declares an array of size 10
arr[0] = 3; // sets first element of arr to 3
```

Control Statements

```
if(pred) {
  /* code to run if pred is true */
} else {
  /* code to run if pred is false */
}

if(pred1) {
  /* code to run if pred1 is true */
} else if(pred2) {
  /* code to run if pred2 is true */
} else {
  /* code to run if neither is true */
}
```

Control Statements

```
char c;
switch(c) {
  case ‘a’:
    printf(“a\n”);
    break;
  case ‘b’:
    printf(“b\n”);
  case ‘c’:
  case ‘d’:
    printf(“after b\n”);
    break
  default:
    printf(“error\n”);
}
```

Control Statements

```
int i = 0;
while( i < 10 ) {
  printf("i: %d\n", i);
  i = i + 1;
}

int j;
for( j = 0; j < 10; j = j + 1) {
  printf("j: %d\n", j);
}
```

Control Statements

```
int i = 0;
while( 1 ) {
  if(i < 10) {
    continue;
  }
  printf("i reached 10!\n");
  i = i + 1;
  if(i > 10) {
    break;
  }
}
i reached 10!
```

Functions

- Use functions to break a large task into manageable small chunks
- Functions allow code to be reused (such as printf, atoi, etc.)
- Functions have a **name** and a **return type**
- Functions need to be declared and defined
- Generally happen at the same time, but not necessarily

Functions

```
int foo(); // declares a function foo

// definition of foo
int foo() {
  return 7; // returns something of type int
}

// declare and define a function at the same time
double caster(int x) {
  return (double) x;
}
```

Functions

- Arguments to functions are passed by value; this means that if we pass a variable as an argument to a function, the value of the variable is copied. Changing the copy does nothing to the original

```
void foo(int arg) { arg = 10; }

int main() {
  int x = 17;
  foo(x);
  printf("x:%d\n", x);
}
x:17
```

Pointers

- A pointer is a variable which points to data at a specific location in memory
- A pointer has a type; this is the type of data it is pointing to
- Key to doing many interesting things in C, such as functions that can change the value of a variable and dynamic memory management (more on memory in lecture)
- Can have a pointer to a pointer (to a pointer to a …)

Pointers

```
int x = 1, y = 2, z = 3;
int *p1, *p2; // declares two pointers to ints
p1 = &x; // p1 contains the address of x
y = *p1; // * dereferences p1, so y = 1
p2 = p1; // p2 points to the same thing as p1
*p2 = 4; // x is now 4
```

Pointers

```
void swap(int x, int y) {
  int tmp = x;
  x = y;
  x = tmp;
}

int a = 1, b = 2;
swap(a, b); // a and b did not get swapped
```

Pointers

```
void swap(int *x, int *y) {
  int tmp = *x;
  *x = *y;
  *x = tmp;
}

int a = 1, b = 2;
swap(&a, &b); // a and b did get swapped
```

Structures

- Used to define compound data types
- Can contain data of different types
- Useful for organizing and packing up related data. For example, in a 2D graphics program, might have structs to represent a point

Structures

```
struct point {
  int x;
  int y;
};

struct point p1, p2; // declares two variables
                     // of type struct point
p1.x = 3; // sets x of p1 to 3
p1.y = 5; // sets y of p1 to 5
```

Structures

- Can `typedef` to shorten the type name

```
typedef struct point point_t;
point_t p3; // equivalent to struct point p3;
```

- Can use user defined types inside a struct

```
struct rect {
  point_t ll; // lower left
  point_t ur; // upper right
}
```

Structures

- Functions can return structures

```
point_t makePoint(int x, int y) {
  point_t p;
  p.x = x;
  p.y = y;
  return p;
}
```

- Can use user defined types inside a struct

```
struct rect {
  point_t ll; // lower left
  point_t ur; // upper right
}
```

Memory Management

- You need to manage your own memory in C!
- Variables can be static, local, or malloc'ed
- Static variables live in special section of program, only 1 copy
- Local variables allocated automatically when a function is called, deallocated automatically when it returns
- Dynamic storage is managed through the function `malloc()`
- Malloc returns a pointer to a chunk of memory in the heap
- Use when we don't know how big an array needs to be, or we need a variable that doesn't disappear when a function returns

Memory Management

```
int main() {
  int x = 5; // x is on the stack
  // y is a pointer to a chunk of memory
  // big enough to hold one int
  int *y = (int *) malloc(sizeof(int));
  // double is a pointer to a chunk of memory
  // big enough to hold 10 doubles
  double *z = (double *) malloc(10 * sizeof(double));
  if(z == NULL) { exit(1);} // something went wrong...
  // we can access the memory z points to
  // as though z was an array
  z[5] = 1.1;
}
```

Memory Management

- What happens to memory given out by malloc when we're done with it?
- Answer: nothing, unless we do something about it!
- Need to say we're done with a chunk of memory when we don't need it anymore
- Use function `free()` to free memory. `free()` takes a pointer given out by malloc, and frees the memory given out so it can be used again
- Forgetting to call free is a cause of a significant percentage of memory leaks…

Memory Management

```
// arrays made without malloc are freed automatically
void ok() {
  int arr[10];
  return;
}

/* arr is never freed; since function returned, we lost
  the only pointer we had to the memory we malloc'ed! */
void leaky() {
  int *arr = (int *) malloc(10*sizeof(int));
  return;
}
```

Useful Data Structures

- Linked List

```
// example with a linked list of integers
struct node {
  int node_value;
  struct node *next; // pointer to next node
};
typedef struct node node_t; // optional
node_t *head = (node_t *) malloc(sizeof(node_t));
head->value = 0;
head->next = (node_t *) malloc(sizeof(node_t));
```

Useful Data Structures

- Binary Tree

```
// example with a linked list of integers
struct node {
  int node_value;
  struct node *left; // pointer to left child
  struct node *right; // pointer to right child
};
typedef struct node node_t; // optional
node_t *head = (node_t *) malloc(sizeof(node_t));
head->value = 0;
head->left = (node_t *) malloc(sizeof(node_t));
head->right = (node_t *) malloc(sizeof(node_t));
```

I/O

- `printf()` is your all-purpose output function to the console
- Reading from standard in:
  - `getchar()` – returns the next character typed in
  - `gets(char *buf)` – reads one line into the given buffer
- Opening a file:

```
FILE *f = fopen("foo.bar", "rw")
```

- Reading/writing from a file:

```
int next_char = getc(f);
putc('a', f);
```

- Remember to close your files when done

```
fclose(f);
```