COMSM1201 : Data Structures & Algorithms

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Table of Contents

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- Can sometimes lead to very simple and elegant programs.
- Let's look at some toy examples to begin with.

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

#define SWAP(A,B) {char temp; temp=A;A=B;B=temp;}

void strrev(char* s, int n);

int main(void)
{
   char str[] = "Hello World!";
   strrev(str, strlen(str));
   printf("%s\n", str);
   return 0;
}

/* Iterative Inplace String Reverse */
void strrev(char* s, int n)
{
   for(int i=0, j=n-1; i<j; i++, j--){
      SWAP(s[i], s[j]);
   }
}
```

Execution :

```
!dlroW olleH
```

Recursion for *strrev()*

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#include <stdio.h>
#include <string.h>

#define SWAP(A,B) {char temp; temp=A;A=B;B=temp;}

void strrev(char* s, int start, int end);

int main(void)
{
    char str[] = "Hello World!";
    strrev(str, 0, strlen(str)-1);
    printf("%s\n", str);
    return 0;
}

/* Recursive : Inplace String Reverse */
void strrev(char* s, int start, int end)
{
    if(start >= end){
        return;
    }
    SWAP(s[start], s[end]);
    strrev(s, start+1, end-1);
}
```

Execution :

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- We need to change the function prototype.

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/* Recursive : Inplace String Reverse */
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   if(start >= end){
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   SWAP(s[start], s[end]);
   strrev(s, start+1, end-1);
}
```

Execution :

```
!dlroW olleH
```

- We need to change the function prototype.
- This allows us to track both the start and the end of the string.

The Fibonacci Sequence

A well known example of a recursive function is the Fibonacci sequence. The first term is 1, the second term is 1 and each successive term is defined to be the sum of the two previous terms, i.e. :

fib(1) is 1
fib(2) is 1
fib(n) is fib(n-1)+fib(n-2)

1,1,2,3,5,8,13,21, ...

Iterative & Recursive Fibonacci

```c
#include <stdio.h>

#define MAXFIB 24

int fibonacci(int n);

int main(void)
{

    for(int i=1; i<=MAXFIB; i++){
        printf("%d = %d\n", i, fibonacci(i));
    }

    return 0;

}

int fibonacci(int n)
{
    if(n <= 2){
        return 1;
    }
    int a = 1;
    int b = 1;
    int next;
    for(int i=3; i<=n; i++){
        next = a + b;
        a = b;
        b = next;
    }
    return b;
}
```

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    for(int i=3; i<=n; i++){
        next = a + b;
        a = b;
        b = next;
    }
    return b;
}
```

Execution :

```
1 = 1
2 = 1
3 = 2
4 = 3
5 = 5
6 = 8
7 = 13
8 = 21
9 = 34
10 = 55
11 = 89
12 = 144
13 = 233
14 = 377
15 = 610
16 = 987
17 = 1597
18 = 2584
19 = 4181
20 = 6765
21 = 10946
22 = 17711
23 = 28657
24 = 46368
```

Iterative & Recursive Fibonacci

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int fibonacci(int n);

int main(void)
{

    for(int i=1; i<=MAXFIB; i++){
        printf("%d = %d\n", i, fibonacci(i));
    }

    return 0;

}

int fibonacci(int n)
{
    if(n == 1) return 1;
    if(n == 2) return 1;
    return( fibonacci(n-1)+fibonacci(n-2));
}
```

Iterative & Recursive Fibonacci

```c
#include <stdio.h>

#define MAXFIB 24

int fibonacci(int n);

int main(void)
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    return 0;

}

int fibonacci(int n)
{
    if(n == 1) return 1;
    if(n == 2) return 1;
    return( fibonacci(n-1)+fibonacci(n-2));
}
```
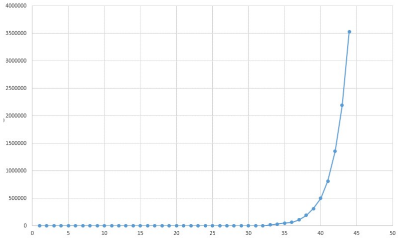
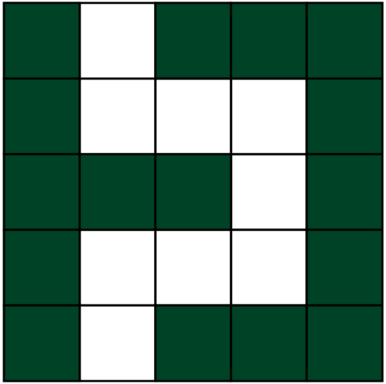

It's interesting to see how run-time increases as the length of the sequence is raised.



Maze Escape

The correct route through a maze can be obtained via recursive, rather than iterative, methods.



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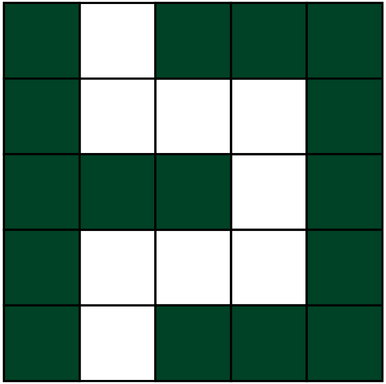

```
bool explore(int x, int y, char mz[YS][XS])
{
  if  mz[y][x] is exit return true;

  Mark mz[y][x] so we don't return here

  if we can go up :
    if(explore(x, y+1, mz)) return true

  if we can go right :
    if(explore(x+1, y, mz)) return true

  Do left & down in a similar manner

  return false; // Failed to find route
}
```

Permuting

- Here we consider the ways to permute a string (or more generally an array)

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- Permutations are all possible ways of rearranging the positions of the characters.

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CAB
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  Execution :

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  ACB
  BAC
  BCA
  CBA
  CAB

```c
// From e.g.  http://www.geeksforgeeks.org
#include <stdio.h>
#include <string.h>

#define SWAP(A,B) {char temp = *A; *A = *B; *B = temp;}

void permute(char* a, int s, int e);

int main()
{
    char str[] = "ABC";
    int n = strlen(str);
    permute(str, 0, n-1);
    return 0;
}

void permute(char* a, int s, int e)
{
   if (s == e){
     printf("%s\n", a);
     return;
   }
   for (int i = s; i <= e; i++){
      SWAP((a+s), (a+i)); // Bring one char to the front
      permute(a, s+1, e);
      SWAP((a+s), (a+i)); // Backtrack
   }
}
```

Self-test : Power

- Raising a number to a power `n = 2^5` is the same as multiple multiplications `n = 2*2*2*2*2`.

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- Or, thinking recursively, n = 2 * (2^4).

```c
/* Try to write power(a,b) to computer a^b
   without using any maths functions other than
   multiplication :
   Try (1) iterative then (2) recursive
   (3) Trick that for n%2==0, x^n = x^(n/2)*x^(n/2)

*/

#include <stdio.h>

int power(unsigned int a, unsigned int b);

int main(void)
{

   int x = 2;
   int y = 16;

   printf("%d^%d = %d\n", x, y, power(x,y));

}

int power(unsigned int a, unsigned int b)
{
}
```

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- Simply move through the array from beginning to end, stopping when you have found the value you require.

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- This is used to delete names from a mailing list, or upgrading the salary of an employee etc.
- The simplest method for searching is called the sequential search.
- Simply move through the array from beginning to end, stopping when you have found the value you require.

```c
#include <stdio.h>
#include <string.h>
#include <assert.h>

#define NOTFOUND -1
#define NUMPEOPLE 6
typedef struct person{
        char* name; int age;
} person;

int findAge(const char* name, const person* p, int n);

int main(void)
{
   person ppl[NUMPEOPLE] = { {"Ackerby", 21}, {"Bloggs", 25},
              {"Chumley", 26}, {"Dalton",  25},
              {"Eggson", 22}, {"Fulton",  41} };

   assert(findAge("Eggson",   ppl, NUMPEOPLE)==22);
   assert(findAge("Campbell", ppl, NUMPEOPLE)==NOTFOUND);
   return 0;
}

int findAge(const char* name, const person* p, int n)
{
   for(int j=0; j<n; j++){
      if(strcmp(name, p[j].name) == 0){
         return p[j].age;
      }
   }
   return NOTFOUND;
}
```

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   assert(findAge("Eggson",   ppl, NUMPEOPLE)==22);
   assert(findAge("Campbell", ppl, NUMPEOPLE)==NOTFOUND);
   return 0;
}

int findAge(const char* name, const person* p, int n)
{
   for(int j=0; j<n; j++){
      int m = strcmp(name, p[j].name);
      if(m == 0) // Braces!
         return p[j].age;
      if(m < 0)
         return NOTFOUND;
   }
   return NOTFOUND;
}
```

Binary Search for *101*

- Searching small lists doesn't require much computation time.

4	7	19	25	36	37	50	100	101	205	220	270	301	321
⇑						↑							⇑
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```c
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>
#include <time.h>
#define NMBRS 1000000

int bin_it(int k, const int* a, int l, int r);

int main(void)
{
   int a[NMBRS];
   srand(time(NULL));

   // Put even numbers into array
   for(int i=0; i<NMBRS; i++){
      a[i] = 2*i;
   }

   // Do many searches for a random number
   for(int i=0; i<10*NMBRS; i++){
      int n = rand()%NMBRS;
      if((n%2) == 0){
         assert(bin_it(n, a, 0, NMBRS-1) == n/2);
      }
      else{ // No odd numbers in this list
         assert(bin_it(n, a, 0, NMBRS-1) < 0);
      }
   }
   return 0;
}
```

Iterative v. Recursion Binary Search

```
int bin_it(int k, const int* a, int l, int r)
{
    while(l <= r){
        int m = (l+r)/2;
        if(k == a[m]){
            return m;
        }
        else{
            if (k > a[m]){
                l = m + 1;
            }
            else{
                r = m - 1;
            }
        }
    }
    return -1;
}
```

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            }
        }
    }
    return -1;
}
```

```c
int bin_rec(int k, const int* a, int l, int r)
{
    if(l > r) return -1;
    int m = (l+r)/2;
    if(k == a[m]){
        return m;
    }
    else{
        if (k > a[m]){
            return bin_rec(k, a, m+1, r);
        }
        else{
            return bin_rec(k, a, l, m-1);
        }
    }
}
```

Interpolation Search

- When we look for a word in a dictionary, we don't start in the middle. We make an educated guess as to where to start based on the 1st letter of the word being searched for.
- This idea led to the interpolation search.
- In binary searching, we simply used the middle of an ordered list as a best guess as to where to begin the search.
- Now we use an interpolation involving the key, the start of the list and the end.

$$i = (k - l[0])/(l[n-1] - l[0]) * n$$

- when searching for '15' :

$$\begin{array}{cccccccc} 0 & 4 & 5 & 9 & 10 & 12 & 15 & 20 \\ & & & & & & \Uparrow & \end{array}$$

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```
int interp(int k, const int* a, int l, int r)
{

    int m;
    double md;

    while(l <= r){
       md = ((double)(k-a[l])/
             (double)(a[r]-a[l])*
             (double)(r-l)
            )
            +(double)(l);
       m  = 0.5 + md;
       if((m > r) || (m < l)){
          return -1;
       }
       if(k == a[m])
          return m;
       else{
          if (k > a[m]){
             l = m + 1;
          }
          else{
             r = m- 1;
          }
       }
    }
```

Algorithmic Complexity

```c
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define CSEC (double)(CLOCKS_PER_SEC)
#define BIGLOOP 1000000000

int main(void)
{

    clock_t c1 = clock();
    for(int i=0; i<BIGLOOP; i++){
        int j = i * 2;
    }
    clock_t c2 = clock();
    printf("%f\n", (double)(c2-c1)/CSEC);
    return 0;

}
```

- This code on an old Dell laptop took:
  - 3.12 seconds using a non-optimzing compiler -O0
  - 0.00 seconds using an aggressive optimization -O3
- But "wall-clock" time is generally not the thing that excites Computer Scientists.

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- Searching and sorting algorithms have a complexity associated with them, called big-O.
- This complexity indicates how, for *n* numbers, performance deteriorates when *n* changes.
- Sequential Search : **O(n)**
- Binary Search : **O(log n)**
- Interpolation Search : **O(log log n)**
- We'll discuss the dream of a **O(1)** search later in "Hashing".

Binary vs. Interpolation Timing

```
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>
#include <time.h>

int bin_it(int k, const int *a, int l, int r);
int bin_rec(int k, const int *a, int l, int r);
int interp(int k, const int *a, int l, int r);
int* parse_args(int argc, char* argv[], int* n, int* srch);

int main(int argc, char* argv[])
{

   int i, n, srch;
   int* a;
   int (*p[3])(int k, const int*a, int l, int r) =
       {bin_it, bin_rec, interp};

   a = parse_args(argc, argv, &n, &srch);

   srand(time(NULL));
   for(i=0; i<n; i++){
      a[i] = 2*i;
   }
   for(i=0; i<5000000; i++){
      assert((*p[srch])(a[rand()%n], a, 0, n-1) >= 0);
   }

   free(a);
   return 0;

}
```

Binary vs. Interpolation Timing

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#include <stdlib.h>
#include <assert.h>
#include <time.h>

int bin_it(int k, const int *a, int l, int r);
int bin_rec(int k, const int *a, int l, int r);
int interp(int k, const int *a, int l, int r);
int* parse_args(int argc, char* argv[], int* n, int* srch);

int main(int argc, char* argv[])
{

    int i, n, srch;
    int* a;
    int (*p[3])(int k, const int*a, int l, int r) =
        {bin_it, bin_rec, interp};

    a = parse_args(argc, argv, &n, &srch);

    srand(time(NULL));
    for(i=0; i<n; i++){
        a[i] = 2*i;
    }
    for(i=0; i<5000000; i++){
        assert((*p[srch])(a[rand()%n], a, 0, n-1) >= 0);
    }

    free(a);
    return 0;

}
```

Execution :

```
Binary Search : Iterative
n =   100000 = 0.57
n =   800000 = 0.84
n =  6400000 = 2.20
n = 51200000 = 3.87
Binary Search : Recursive
n =   100000 = 1.23
n =   800000 = 1.79
n =  6400000 = 3.20
n = 51200000 = 4.85
Interpolation
n =   100000 = 0.20
n =   800000 = 0.28
n =  6400000 = 0.50
n = 51200000 = 0.70
```

Table of Contents

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- To create linked data representations we use pointers to connect separate blocks of storage together. If a given block contains a pointer to a second block, we can follow this pointer there.
- By following pointers one after another, we can travel right along the structure.

```c
#include <stdio.h>
#include <stdlib.h>
#include "general.h"

typedef struct data{
   int i;
   struct data* next;
} Data;

Data* allocateData(int i);
void printList(Data* l);

int main(void)
{
   int i;
   Data* start, *current;
   start = current = NULL;
   printf("Enter the first number: ");
   if(scanf("%i", &i) == 1){
      start = current = allocateData(i);
   }
   else{
      on_error("Couldn't read an int");
   }

   printf("Enter more numbers: ");
   while(scanf("%i", &i) == 1){
      current->next = allocateData(i);
      current = current->next;
   }
   printList(start);
   // Should Free List
   return 0;
}
```

Linked Lists

```c
Data* allocateData(int i)
{
   Data* p;
   p = (Data*) ncalloc(1, sizeof(Data));
   p->i = i;
   // Not really required
   p->next = NULL;
   return p;
}

void printList(Data* l)
{
   printf("\n");
   do{
      printf("Number : %i\n", l->i);
      l = l->next;
   }while(l != NULL);
   printf("END\n");
}
```

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   return p;
}

void printList(Data* l)
{
   printf("\n");
   do{
      printf("Number : %i\n", l->i);
      l = l->next;
   }while(l != NULL);
   printf("END\n");
}
```

Searching and Recursive printing:

```c
Data* inList(Data* n, int i)
{
   do{
      if(n->i==i){
         return n;
      }
      n = n->next;
   }while(n != NULL);
   return NULL;
}

void printList_r(Data* l)
{
   // Recursive Base-Case
   if(l == NULL) return;

   printf("Number: %i\n", l->i);
   printList_r(l->next);
}
```

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- The user of the ADT doesn't need to understand how the data is being stored (e.g. array vs. linked lists etc.)

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```c
#include "../General/general.h"

typedef int colltype;

typedef struct coll coll;

#include <stdio.h>
#include <stdlib.h>
#include <assert.h>

// Create an empty coll
coll* coll_init(void);
// Add element onto top
void coll_add(coll* c, colltype i);
// Take element out
bool coll_remove(coll* c, colltype d);
// Does this exist ?
bool coll_isin(coll* c, colltype i);
// Return size of coll
int coll_size(coll* c);
// Clears all space used
bool coll_free(coll* c);
```

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    - A dynamic array
    - A linked-list

Fixed/specific.h:

```c
#pragma once

#define COLLTYPE "Fixed"

#define FIXEDSIZE 5000
struct coll {
   // Underlying array
   colltype a[FIXEDSIZE];
   int size;
};
```

Collection ADT using a Fixed-size Array

Fixed/fixed.c:

```c
#include "../coll.h"
#include "specific.h"

coll* coll_init(void)
{
    coll* c = (coll*) ncalloc(sizeof(coll), 1);
   c->size = 0;
   return c;
}

int coll_size(coll* c)
{
   if(c==NULL){
      return 0;
   }
   return c->size;
}

bool coll_isin(coll* c, colltype d)
{
   for(int i=0; i<coll_size(c); i++){
      if(c->a[i] == d){
          return true;
      }
   }
   return false;
}
```

Fixed/fixed.c:

```c
#include "../coll.h"
#include "specific.h"

coll* coll_init(void)
{
    coll* c = (coll*) ncalloc(sizeof(coll), 1);
    c->size = 0;
    return c;
}

int coll_size(coll* c)
{
    if(c==NULL){
        return 0;
    }
    return c->size;
}

bool coll_isin(coll* c, colltype d)
{
    for(int i=0; i<coll_size(c); i++){
        if(c->a[i] == d){
            return true;
        }
    }
    return false;
}
```

```c
void coll_add(coll* c, colltype d)
{
    if(c){
        if(c->size >= FIXEDSIZE){
            on_error("Collection overflow");
        }
        c->a[c->size] = d;
        c->size = c->size + 1;
    }
}

bool coll_remove(coll* c, colltype d)
{
    for(int i=0; i<coll_size(c); i++){
        if(c->a[i] == d){
            // Shuffle end of array left one
            for(int j=i; j<coll_size(c); j++){
                c->a[j] = c->a[j+1];
            }
            c->size = c->size - 1;
            return true;
        }
    }
    return false;
}

bool coll_free(coll* c)
{
    free(c);
    return true;
}
```

Collection ADT via an Array (Realloc)

Realloc/specific.h:

```c
#pragma once

#define COLLTYPE "Realloc"

#define FIXEDSIZE 16
#define SCALEFACTOR 2
struct coll {
   // Underlying array
   colltype* a;
   int size;
   int capacity;
};
```

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```c
#pragma once

#define COLLTYPE "Realloc"

#define FIXEDSIZE 16
#define SCALEFACTOR 2
struct coll {
   // Underlying array
   colltype* a;
   int size;
   int capacity;
};
```

Realloc/realloc.c:

```c
#include "../coll.h"
#include "specific.h"

coll* coll_init(void)
{
   coll* c = (coll*) ncalloc(sizeof(coll), 1);
   c->a = (colltype*) ncalloc(sizeof(colltype), FIXEDSIZE);
   c->size = 0;
   c->capacity= FIXEDSIZE;
   return c;
}

void coll_add(coll* c, colltype d)
{
   if(c){
      if(c->size >= c->capacity){
         c->a = (colltype*) nremalloc(c->a,
                  sizeof(colltype)*c->capacity*SCALEFACTOR);
         c->capacity = c->capacity*SCALEFACTOR;
      }
      c->a[c->size] = d;
      c->size = c->size + 1;
   }
```

Collection ADT via a Linked List

Linked/specific.h:

```c
#pragma once

#define COLLTYPE "Linked"

struct dataframe {
   colltype i;
   struct dataframe* next;
};
typedef struct dataframe dataframe;

struct coll {
   // Underlying array
   dataframe* start;
   int size;
};
```

Collection ADT via a Linked List

Linked/specific.h:

```c
#pragma once

#define COLLTYPE "Linked"

struct dataframe {
   colltype i;
   struct dataframe* next;
};
typedef struct dataframe dataframe;

struct coll {
   // Underlying array
   dataframe* start;
   int size;
};
```

Linked/linked.c:

```c
#include "../coll.h"
#include "specific.h"

coll* coll_init(void)
{
   coll* c = (coll*) ncalloc(sizeof(coll), 1);
   return c;
}

int coll_size(coll* c)
{
   if(c==NULL){
      return 0;
   }
   return c->size;
}

bool coll_isin(coll* c, colltype d)
{
   if(c == NULL || c->start==NULL){
      return false;
   }
   dataframe* f = c->start;
   do{
      if(f->i == d){
         return true;
      }
      f = f->next;
   }while(f != NULL);
   return false;
}
```

Collection ADT via a Linked List II

```
void coll_add(coll* c, colltype d)
{
   if(c){
      dataframe* f = ncalloc(sizeof(dataframe), 1);
      f->i = d;
      f->next = c->start;
      c->start = f;
      c->size = c->size + 1;
   }

}

bool coll_free(coll* c)
{
   if(c){
      dataframe* tmp;
      dataframe* p = c->start;
      while(p!=NULL){
         tmp = p->next;
         free(p);
         p = tmp;
      }
      free(c);
   }
   return true;
}
```

Collection ADT via a Linked List II

```c
void coll_add(coll* c, colltype d)
{
   if(c){
      dataframe* f = ncalloc(sizeof(dataframe), 1);
      f->i = d;
      f->next = c->start;
      c->start = f;
      c->size = c->size + 1;
   }

}

bool coll_free(coll* c)
{
   if(c){
      dataframe* tmp;
      dataframe* p = c->start;
      while(p!=NULL){
         tmp = p->next;
         free(p);
         p = tmp;
      }
      free(c);
   }
   return true;
}
```

```c
bool coll_remove(coll* c, colltype d)
{
   dataframe* f1, *f2;
   if((c==NULL) || (c->start==NULL)){
      return false;
   }

   // If Front
   if(c->start->i == d){
      f1 = c->start->next;
      free(c->start);
      c->start = f1;
      c->size = c->size - 1;
      return true;
   }

   f1 = c->start;
   f2 = c->start->next;
   do{
      if(f2->i == d){
         f1->next = f2->next;
         free(f2);
         c->size = c->size - 1;
         return true;
      }
      f1 = f2;
      f2 = f1->next;
   }while(f2 != NULL);
   return false;
}
```

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Task	Fixed Array	Realloc Array	Linked List
Insert new element	O(1) at end *if space*	O(1) at end *but realloc()*	O(1) at front
Search for an element	O(n) *brute force*	O(n) *brute force*	O(n) *brute force*
Search + delete	O(n) + O(n) *move left*	O(n) + O(n) *move left*	O(n) + O(1) *delete 'free'*

- If we had ordered our ADT (ie. the elements were sorted), then the searches could be via a binary / interpolation search, leading to O(log `n`) or O(log log `n`) search times.

ADTs Making Coding Simpler

That Linked List code from the previous Chapter again:

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```c
#include "coll.h"
#include "Fixed/specific.h"

int main(void)
{
    coll* c;
    int i;

    printf("Please type some numbers :");
    c = coll_init();
    while(scanf("%i", &i) == 1){
       coll_add(c, i);
    }
    // Do print etc.
    coll_free(c);
    return 0;
}
```

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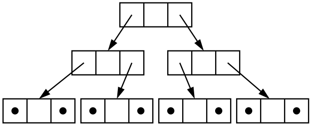
Binary Trees:



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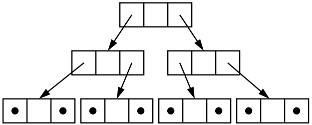
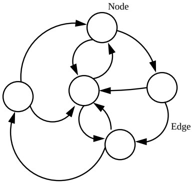
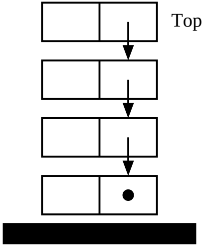


Unidirectional Graph:



Stacks

The push-down stack:



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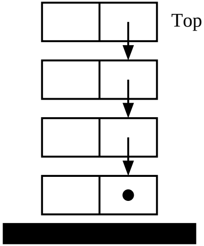
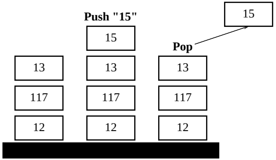


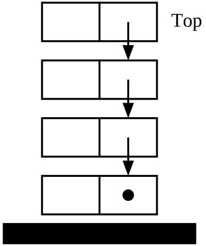
LIFO (Last in, First out):



- Operations include `push` and `pop`.

Stacks

The push-down stack:



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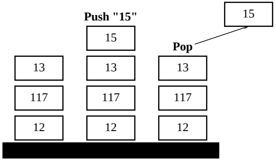

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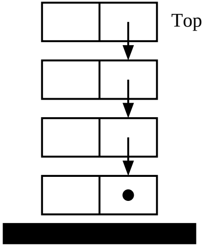
- In the C run-time system, function calls are implemented using stacks.

Stacks

The push-down stack:



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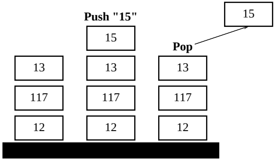
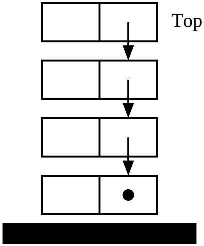


- Operations include `push` and `pop`.
- In the C run-time system, function calls are implemented using stacks.
- Most recursive algorithms can be re-written using stacks instead.

Stacks

The push-down stack:



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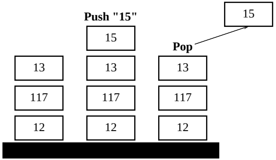


- Operations include `push` and `pop`.
- In the C run-time system, function calls are implemented using stacks.
- Most recursive algorithms can be re-written using stacks instead.
- But, once again, we are faced with the question : How best to implement such a data type ?

ADT:Stacks Arrays (Realloc) I

stack.h:

```
#pragma once

#include "../General/general.h"

typedef int stacktype;

typedef struct stack stack;

#include <stdio.h>
#include <stdlib.h>
#include <assert.h>
#include <string.h>

/* Create an empty stack */
stack* stack_init(void);
/* Add element to top */
void stack_push(stack* s, stacktype i);
/* Take element from top */
bool stack_pop(stack* s, stacktype* d);
/* Clears all space used */
bool stack_free(stack* s);

/* Optional? */

/* Copy top element into d (but don't pop it) */
bool stack_peek(stack*s,  stacktype* d);
/* Make a string version - keep .dot in mind */
void stack_tostring(stack*, char* str);
```

ADT:Stacks Arrays (Realloc) I

stack.h:

```c
#pragma once

#include "../General/general.h"

typedef int stacktype;

typedef struct stack stack;

#include <stdio.h>
#include <stdlib.h>
#include <assert.h>
#include <string.h>

/* Create an empty stack */
stack* stack_init(void);
/* Add element to top */
void stack_push(stack* s, stacktype i);
/* Take element from top */
bool stack_pop(stack* s, stacktype* d);
/* Clears all space used */
bool stack_free(stack* s);

/* Optional? */

/* Copy top element into d (but don't pop it) */
bool stack_peek(stack*s, stacktype* d);
/* Make a string version - keep .dot in mind */
void stack_tostring(stack*, char* str);
```

Realloc/specific.h:

```c
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20

#define STACKTYPE "Realloc"

#define FIXEDSIZE 16
#define SCALEFACTOR 2

struct stack {
   /* Underlying array */
   stacktype* a;
   int size;
   int capacity;
};
```

ADT:Stacks Arrays (Realloc) II

Realloc/realloc.c

```c
#include "../stack.h"
#include "specific.h"

#define DOTFILE 5000

stack* stack_init(void)
{
   stack *s = (stack*) ncalloc(sizeof(stack), 1);
   /* Some implementations would allow you to pass
      a hint about the initial size of the stack */
   s->a = (stacktype*) ncalloc(sizeof(stacktype), FIXEDSIZE);
   s->size = 0;
   s->capacity= FIXEDSIZE;
   return s;
}

void stack_push(stack* s, stacktype d)
{
   if(s==NULL){
       return;
   }
   if(s->size >= s->capacity){
      s->a = (stacktype*) nremalloc(s->a,
             sizeof(stacktype)*s->capacity*SCALEFACTOR);
      s->capacity = s->capacity*SCALEFACTOR;
   }
   s->a[s->size] = d;
   s->size = s->size + 1;
}
```

ADT:Stacks Arrays (Realloc) II

Realloc/realloc.c

```c
#include "../stack.h"
#include "specific.h"

#define DOTFILE 5000

stack* stack_init(void)
{
   stack *s = (stack*) ncalloc(sizeof(stack), 1);
   /* Some implementations would allow you to pass
      a hint about the initial size of the stack */
   s->a = (stacktype*) ncalloc(sizeof(stacktype), FIXEDSIZE);
   s->size = 0;
   s->capacity= FIXEDSIZE;
   return s;
}

void stack_push(stack* s, stacktype d)
{
   if(s==NULL){
       return;
   }
   if(s->size >= s->capacity){
      s->a = (stacktype*) nremalloc(s->a,
               sizeof(stacktype)*s->capacity*SCALEFACTOR);
      s->capacity = s->capacity*SCALEFACTOR;
   }
   s->a[s->size] = d;
   s->size = s->size + 1;
}
```

```c
bool stack_pop(stack* s, stacktype* d)
{
   if((s == NULL) || (s->size < 1)){
      return false;
   }
   s->size = s->size - 1;
   *d = s->a[s->size];
   return true;
}

bool stack_peek(stack* s, stacktype* d)
{
   if((s==NULL) || (s->size <= 0)){
      /* Stack is Empty */
      return false;
   }
   *d = s->a[s->size-1];
   return true;
}
```

ADT:Stacks Arrays (Realloc) III

Realloc/realloc.c

```c
void stack_tostring(stack* s, char* str)
{
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((s==NULL) || (s->size <1)){
      return;
   }
   for(int i=s->size-1; i>=0; i--){
      sprintf(tmp, FORMATSTR, s->a[i]);
      strcat(str, tmp);
      strcat(str, "|");
   }
   str[strlen(str)-1] = '\0';
}

bool stack_free(stack* s)
{
   if(s==NULL){
      return true;
   }
   free(s->a);
   free(s);
   return true;
}
```

ADT:Stacks Arrays (Realloc) III

Realloc/realloc.c

```c
void stack_tostring(stack* s, char* str)
{
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((s==NULL) || (s->size <1)){
      return;
   }
   for(int i=s->size-1; i>=0; i--){
      sprintf(tmp, FORMATSTR, s->a[i]);
      strcat(str, tmp);
      strcat(str, "|");
   }
   str[strlen(str)-1] = '\0';
}

bool stack_free(stack* s)
{
   if(s==NULL){
      return true;
   }
   free(s->a);
   free(s);
   return true;
}
```

- We need a thorough testing program teststack.c

ADT:Stacks Arrays (Realloc) III

Realloc/realloc.c

```
void stack_tostring(stack* s, char* str)
{
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((s==NULL) || (s->size <1)){
      return;
   }
   for(int i=s->size-1; i>=0; i--){
      sprintf(tmp, FORMATSTR, s->a[i]);
      strcat(str, tmp);
      strcat(str, "|");
   }
   str[strlen(str)-1] = '\0';
}

bool stack_free(stack* s)
{
   if(s==NULL){
      return true;
   }
   free(s->a);
   free(s);
   return true;
}
```

- We need a thorough testing program `teststack.c`
- See also `revstr.c` : a version of the string reverse code (for which we already seen an iterative (in-place) and a recursive solution).

ADT:Stacks Linked I

Linked/specific.h

```c
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20
#define STACKTYPE "Linked"

struct dataframe {
   stacktype i;
   struct dataframe* next;
};
typedef struct dataframe dataframe;

struct stack {
   /* Underlying array */
   dataframe* start;
   int size;
};
```

ADT:Stacks Linked I

Linked/specific.h

```c
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20
#define STACKTYPE "Linked"

struct dataframe {
   stacktype i;
   struct dataframe* next;
};
typedef struct dataframe dataframe;

struct stack {
   /* Underlying array */
   dataframe* start;
   int size;
};
```

Linked/linked.c

```c
#include "../stack.h"
#include "specific.h"

#define DOTFILE 5000

stack* stack_init(void)
{
   stack* s = (stack*) ncalloc(sizeof(stack), 1);
   return s;
}

void stack_push(stack* s, stacktype d)
{
   if(s){
      dataframe* f = ncalloc(sizeof(dataframe), 1);
      f->i = d;
      f->next = s->start;
      s->start = f;
      s->size = s->size + 1;
   }
}
```

ADT:Stacks Linked II

```c
bool stack_pop(stack* s, stacktype* d)
{
   if((s==NULL) || (s->start==NULL)){
      return false;
   }

   dataframe* f = s->start->next;
   *d = s->start->i;
   free(s->start);
   s->start = f;
   s->size = s->size - 1;
   return true;
}

bool stack_peek(stack* s, stacktype* d)
{
   if((s==NULL) || (s->start==NULL)){
      return false;
   }
   *d = s->start->i;
   return true;
}
```

ADT:Stacks Linked II

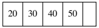
```c
bool stack_pop(stack* s, stacktype* d)
{
   if((s==NULL) || (s->start==NULL)){
      return false;
   }

   dataframe* f = s->start->next;
   *d = s->start->i;
   free(s->start);
   s->start = f;
   s->size = s->size - 1;
   return true;
}

bool stack_peek(stack* s, stacktype* d)
{
   if((s==NULL) || (s->start==NULL)){
      return false;
   }
   *d = s->start->i;
   return true;
}
```

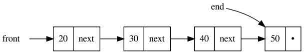
```c
void stack_tostring(stack* s, char* str)
{
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((s==NULL) || (s->size <1)){
      return;
   }
   dataframe* p = s->start;
   while(p){
      sprintf(tmp, FORMATSTR, p->i);
      strcat(str, tmp);
      strcat(str, "|");
      p = p->next;
   }
   str[strlen(str)-1] = '\0';
}

bool stack_free(stack* s)
{
   if(s){
      dataframe* p = s->start;
      while(p!=NULL){
         dataframe* tmp = p->next;
         free(p);
         p = tmp;
      }
      free(s);
   }
   return true;
}
```

Table of Contents

ADTs : Queues

FIFO (First in, First out):





- Intuitively more “useful” than a stack.

ADTs : Queues

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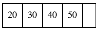

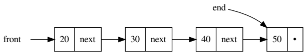

- Intuitively more “useful” than a stack.
- Think of implementing any kind of service (printer, web etc.)

ADTs : Queues

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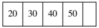

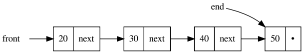

- Intuitively more "useful" than a stack.
- Think of implementing any kind of service (printer, web etc.)
- Operations include `enqueue`, `dequeue` and `size`.

ADTs : Queues

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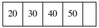

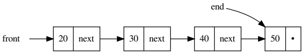

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ADTs : Queues

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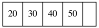
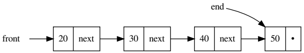




- Intuitively more "useful" than a stack.
- Think of implementing any kind of service (printer, web etc.)
- Operations include `enqueue`, `dequeue` and `size`.

queue.h

```c
#pragma once

#include "../General/general.h"

typedef int queuetype;

typedef struct queue queue;

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <assert.h>

/* Create an empty queue */
queue* queue_init(void);
/* Add element on end */
void queue_enqueue(queue* q, queuetype v);
/* Take element off front */
bool queue_dequeue(queue* q, queuetype* d);
/* Return size of queue */
int queue_size(queue* q);
/* Clears all space used */
bool queue_free(queue* q);

/* Helps with visualisation & testing */
void queue_tostring(queue* q, char* str);
```

ADTs : Queues (Fixed) I

specific.h

```
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20

#define QUEUETYPE "Fixed"

#define BOUNDED 5000

struct queue {
   /* Underlying array */
   queuetype a[BOUNDED];
   int front;
   int end;
};

#define DOTFILE 5000
```

ADTs : Queues (Fixed) I

specific.h

```c
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20

#define QUEUETYPE "Fixed"

#define BOUNDED 5000

struct queue {
   /* Underlying array */
   queuetype a[BOUNDED];
   int front;
   int end;
};

#define DOTFILE 5000
```

fixed.c

```c
#include "../queue.h"
#include "specific.h"

void _inc(queuetype* p);

queue* queue_init(void)
{
   queue* q = (queue*) ncalloc(sizeof(queue), 1);
   return q;
}


void queue_enqueue(queue* q, queuetype d)
{
   if(q){
      q->a[q->end] = d;
      _inc(&q->end);
      if(q->end == q->front){
         on_error("Queue too large");
      }
   }
}

bool queue_dequeue(queue* q, queuetype* d)
{
   if((q==NULL) || (q->front==q->end)){
      return false;
   }
   *d = q->a[q->front];
   _inc(&q->front);
   return true;
}
```

ADTs : Queues (Fixed) II

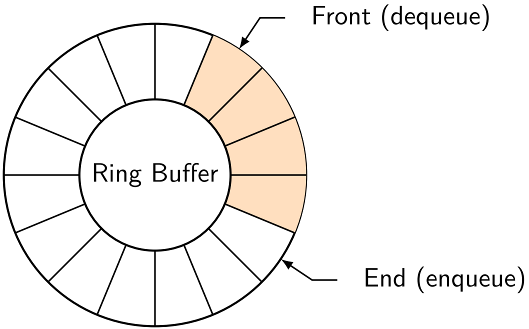
```c
void queue_tostring(queue* q, char* str)
{
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((q==NULL) || (queue_size(q)==0)){
      return;
   }
   for(int i=q->front; i != q->end;){
      sprintf(tmp, FORMATSTR, q->a[i]);
      strcat(str, tmp);
      strcat(str, "|");
      _inc(&i);
   }
   str[strlen(str)-1] = '\0';
}
```

ADTs : Queues (Fixed) II

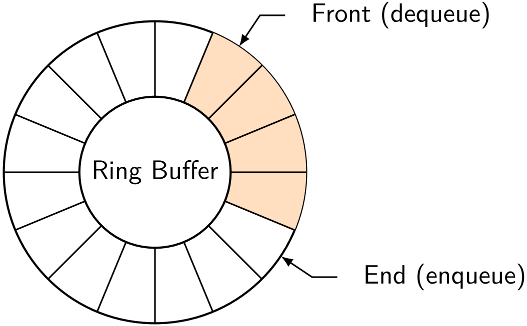
```c
void queue_tostring(queue* q, char* str)
{
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((q==NULL) || (queue_size(q)==0)){
      return;
   }
   for(int i=q->front; i != q->end;){
      sprintf(tmp, FORMATSTR, q->a[i]);
      strcat(str, tmp);
      strcat(str, "|");
      _inc(&i);
   }
   str[strlen(str)-1] = '\0';
}
```

```c
int queue_size(queue* q)
{
   if(q==NULL){
      return 0;
   }
   if(q->end >= q->front){
      return q->end-q->front;
   }
   return q->end + BOUNDED - q->front;
}

bool queue_free(queue* q)
{
   free(q);
   return true;
}

void _inc(queuetype* p)
{
   *p = (*p + 1) % BOUNDED;
}
```

Ring Buffers



Ring Buffers



- We need a thorough testing program
- We'll see queues again for traversing trees
- Simulating a (slow) printer

ADTs : Queues (Linked) I

specific.h

```
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20

#define QUEUETYPE "Linked"

struct dataframe {
   queuetype i;
   struct dataframe* next;
};
typedef struct dataframe dataframe;

struct queue {
   /* Underlying array */
   dataframe* front;
   dataframe* end;
   int size;
};











#define DOTFILE 5000
```

ADTs : Queues (Linked) I

specific.h

```c
#pragma once

#define FORMATSTR "%d"
#define ELEMSIZE 20

#define QUEUETYPE "Linked"

struct dataframe {
   queuetype i;
   struct dataframe* next;
};
typedef struct dataframe dataframe;

struct queue {
   /* Underlying array */
   dataframe* front;
   dataframe* end;
   int size;
};

#define DOTFILE 5000
```

linked.c

```c
#include "../queue.h"
#include "specific.h"

queue* queue_init(void)
{
   queue* q = (queue*) ncalloc(sizeof(queue), 1);
   return q;
}

void queue_enqueue(queue* q, queuetype d)
{
   dataframe* f;
   if(q==NULL){
      return;
   }

   /* Copy the data */
   f = ncalloc(sizeof(dataframe), 1);
   f->i = d;

   /* 1st one */
   if(q->front == NULL){
      q->front = f;
      q->end = f;
      q->size = q->size + 1;
      return;
   }
   /* Not 1st */
   q->end->next = f;
   q->end = f;
   q->size = q->size + 1;
}
```

ADTs : Queues (Linked) II

```c
bool queue_dequeue(queue* q, queuetype* d)
{
   dataframe* f;
   if((q==NULL) || (q->front==NULL) || (q->end==NULL)){
      return false;
   }
   f = q->front->next;
   *d = q->front->i;
   free(q->front);
   q->front = f;
   q->size = q->size - 1;
   return true;
}

bool queue_free(queue* q)
{
   if(q){
      dataframe* tmp;
      dataframe* p = q->front;
      while(p!=NULL){
         tmp = p->next;
         free(p);
         p = tmp;
      }
      free(q);
   }
   return true;
}
```

ADTs : Queues (Linked) II

```c
bool queue_dequeue(queue* q, queuetype* d)
{
   dataframe* f;
   if((q==NULL) || (q->front==NULL) || (q->end==NULL)){
      return false;
   }
   f = q->front->next;
   *d = q->front->i;
   free(q->front);
   q->front = f;
   q->size = q->size - 1;
   return true;
}

bool queue_free(queue* q)
{
   if(q){
      dataframe* tmp;
      dataframe* p = q->front;
      while(p!=NULL){
         tmp = p->next;
         free(p);
         p = tmp;
      }
      free(q);
   }
   return true;
}
```

```c
void queue_tostring(queue* q, char* str)
{
   dataframe *p;
   char tmp[ELEMSIZE];
   str[0] = '\0';
   if((q==NULL) || (q->front == NULL)){
      return;
   }
   p = q->front;
   while(p){
      sprintf(tmp, FORMATSTR, p->i);
      strcat(str, tmp);
      strcat(str, "|");
      p = p->next;
   }
   str[strlen(str)-1] = '\0';
}

int queue_size(queue* q)
{
   if((q==NULL) || (q->front==NULL)){

      return 0;
   }
   return q->size;
}
```

Detour : Graphviz

- There exists a nice package, called Graphviz:

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sudo apt install graphviz
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- This allows the visualisation of graphs/dynamic structures using the simple .dot language:

```
digraph {
   a -> b; b -> c; c -> a;
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- To create a .pdf:

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dot -Tpdf -o graphviz.pdf examp1.dot
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