(1-1) C Review: Pointers, Arrays, Strings, & Structs

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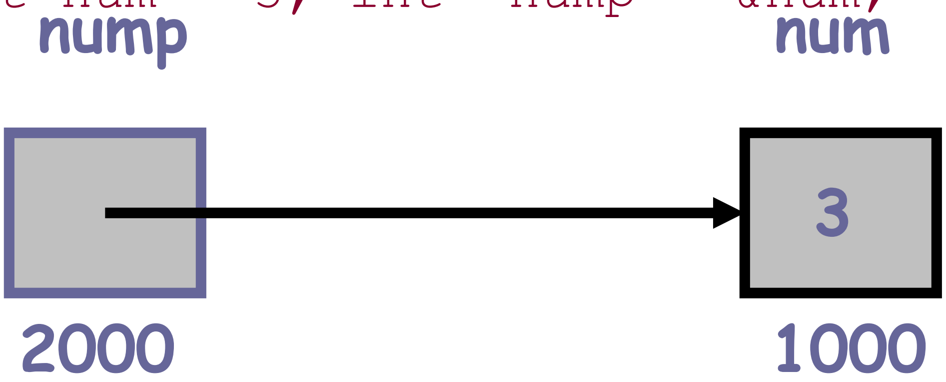
Crash Review on Critical C Topics

- Pointers
- Arrays
- Strings
- Structs

Pointers

Pointer Review (1)

- A pointer variable contains the address of another cell containing a data value
- Note that a pointer is "useless" unless we make sure that it points somewhere:
  - `int num = 3, int *nump = #`



- The *direct* value of *num* is 3, while the *direct* value of *nump* is the address (1000) of the memory cell which holds the 3

Pointer Review (2)

- The integer 3 is the *indirect* value of *nump*, this value can be accessed by following the pointer stored in *nump*
- If the indirection, dereferencing, or "pointer-following" operator is applied to a pointer variable, the indirect value of the pointer variable is accessed
- That is, if we apply **nump*, we are able to access the integer value 3
- The next slide summarizes…

Pointer Review (3)

Reference	Explanation	Value
num	Direct value of *num*	3
nump	Direct value of *nump*	1000
**nump*	Indirect value of *nump*	3
&*nump*	Address of *nump*	2000

Pointers as Function Parameters (1)

- Recall that we define an output parameter to a function by passing the address (&) of the variable to the function
- The output parameter is defined as a pointer in the formal parameter list
- Also, recall that output parameters allow us to return more than one value from a function
- The next slide shows a long division function which uses *quotientp* and *remainderp* as pointers

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Pointers as Function Parameters (2)

- Function with Pointers as Output Parameters

```
#include <stdio.h>

void long_division (int dividend, int divisor, int *quotientp, int *remainderp);

int main (void)
{
        int quot, rem;

        long_division (40, 3, &quot, &rem);
        printf ("40 divided by 3 yields quotient %d ", quot);
        printf ("and remainder %d\n", rem);

        return 0;
}

void long_division (int dividend, int divisor, int *quotientp, int *remainderp)
{
        *quotientp = dividend / divisor;
        *remainderp = dividend % divisor;
}
```


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Arrays

What is an array?

- A sequence of items that are contiguously allocated in memory
- All items in the array are of the same data type and of the same size
- All items are accessed by the same name, but a different index
- The length or size is fixed

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More About Arrays

- An array is a data structure
  - A data structure is a way of storing and organizing data in memory so that it may be accessed and manipulated efficiently

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Uses for Arrays?

- Store related information
  - Student ID numbers
  - Names of players on the Seattle Seahawks roster
  - Scores for each combination in Yahtzee
  - Many more…

The Many Dimensions of an Array

- A single dimensional array is logically viewed as a linear structure
- A two dimensional array is logically viewed as a table consisting of rows and columns
- What about three, four, etc., dimensions?

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Declaring a Single Dimensional Array (1)

- Arrays are declared in much the same way as variables:

```
int a[6];
```

declares an array `a` with 6 cells that hold integers:

a[0]	a[1]	a[2]	a[3]	a[4]	a[5]
10	12	0	89	1	91

Notice that array indexing begins at 0.

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Strings

String Fundamentals

- A string is a sequence of characters terminated by the null character (‘\0’)
  - “This is a string” is considered a string literal
  - A string may include letters, digits, and special characters
- A string may always be represented by a character array, but a character array is not always a string
- A string is accessed via a pointer to the first character in it

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String Basics (1)

- As with other data types, we can even initialize a string when we declare it:

```
char name[20] = “Bill Gates";
char *name = “Bill Gates";
char name[] = {‘B’, ‘i’, ‘l’, ‘l’, ‘ ‘, ‘G’, ‘a’, ‘t’, ‘e’,
               ‘s’, ‘\0’;}
// These are equivalent string declarations!
```

- Here's what the memory allocated to `name` looks like after either of the above is executed:

null character (terminates all strings)

name	B	i	l	l		G	a	t	e	s	\0	?	?	?	?	?	?	?	?	?
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

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String Basics (2)

- When a variable of type `char*` is initialized with a string literal, it may be placed in memory where the string can't be modified
- If you want to ensure modifiability of a string store it into a character array when initializing it

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String Basics (3)

- Arrays of Strings
  - Suppose we want to store a list of students in a class
  - We can do this by declaring an array of strings, one row for each student name:

```
#define NUM_STUDENTS 5
#define MAX_NAME_LENGTH 31
char student_names[NUM_STUDENTS][MAX_NAME_LENGTH];
```

  - We can initialize an array of strings "in line":

```
char student_names[NUM_STUDENTS][MAX_NAME_LENGTH] =
{"John Doe", "Jane Smith", "Sandra Connor", "Damien White",
 "Metilda Cougar"};
```

  - In most cases, however, we're probably going to want to read the names in from the keyboard or a file…

String Basics (4)

- Use `gets()` to read a complete line, including whitespace, from the keyboard until the <enter> key is pressed; the <enter> is not included as part of the string
  - Usage: `gets(my_array)`
  - If the user enters "Bill Gates" and presses <enter>, the entire string will be read into `my_array` excluding the <enter> or newline
- Use `puts()` to display a string followed by a newline
  - Usage: `puts(my_array)`

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String Manipulation in C (1)

- Standard operators applied to most numerical (including character) types cannot be applied to strings in C
  - The assignment operator (=) can't be applied except during declaration
  - The + operator doesn't have any true meaning (in some languages it means append)
  - The relational operators (==, <, >) don't perform string comparisons
  - Others?

String Manipulation in C (2)

- The string-handling library <string.h> provides many powerful functions which may be used in place of standard operators
  - strcpy ( ) or strncpy () replaces the assignment operator
  - strcat ( ) or strncat () replaces the + or append operator
  - strcmp ( ) replaces relational operators
  - Several others…i.e. strtok ( ), strlen ( )

Pointers Representing Arrays and Strings (1)

- Consider representing two arrays as follows:
  - `double list_of_nums[20];`
  - `char your_name[40];`
- When we pass either of these arrays to functions, we use the array name without a subscript
- The array name itself represents the address of the initial array element

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Pointers Representing Arrays and Strings (2)

- Hence, when we pass the array name, we are actually passing the entire array as a pointer
- So, the formal parameter for the string *name* may be declared in two ways:
  - `char name[]`
  - `char *name`
- Note that, in general, it is a good idea to pass the maximum size of the array to the function, e.g.:
  - `void func (char *name, int size);`

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Structs

`struct` Type (1)

- C supports another kind of user-defined type: the `struct`
- `struct`s are a way to combine multiple variables into a single "package" (this is called "encapsulation")
- Sometimes referred to as an *aggregate*, where all variables are under one name
- Suppose, for example, that we want to create a database of students in a course. We could define a student `struct` as follows:

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struct Type (2)

```
typedef enum {freshman, sophomore, junior, senior}
        class_t; /* class standing */
typedef enum {anthropology, biology, chemistry,
              english, compsci, polisci,
psychology,
              physics, engineering, sociology}
        major_t; /* representative majors */
typedef struct
  {
     int id_number;
     class_t class_standing; /* see above */
     major_t major; /* see above */
     double gpa;
    int credits_taken;
  } student_t;
```

`struct` Type (3)

- We can then define some students:

```
student_t student1, student2;
student1.id_num = 123456789;
student1.class_standing = freshman;
student1.major = anthropology;
student1.gpa = 3.5;
student1.credits_taken = 15;
student2.id_num = 321123456;
student2.class_standing = senior;
student2.major = biology;
studnet2.gpa = 3.2;
student2.credits_taken = 100;
```

Notice how we use the "." (selection) operator to access the "fields" of the `struct`

More About Structs

- Recall structs are used to represent real world objects
- They contain attributes that describe these objects
  - Such as a car, where the attributes of the struct car could include steering wheel, seats, engine, etc.
  - Such as a student, where the attributes of the struct student could include ID#, name, standing, etc.
- In many cases, we need a list or array of these objects
  - A list of cars representing a car lot
  - A list of students representing an attendance sheet

Arrays of Structs (1)

- Let's first define a struct student

```
typedef struct student
{
    int ID;
    char name[100];
    int present; // Attended class or not
} Student;
```

- Next we will build up an attendance sheet

Arrays of Structs (2)

```
int main (void)
{
    Student attendance_sheet[100]; // 100 students in the class

    return 0;
}
```

- Let's look at a logical view of this attendance sheet on the next slide

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Arrays of Structs (3)

- Attendance sheet, which consists of multiple struct student types

0	1	2	…	99
{ID, name, present}	{ID, name, present}	{ID, name, present}	…	{ID, name, present}
1000	1108	1216		10692

Arrays of Structs (4)

- To initialize one item in the array, try:

```
attendance_sheet[index].ID = 1111;
strcpy (attendance_sheet[index].name, “Bill Gates”);
Attendance_sheet[index].present = 1;
   // 1 means in attendance, 0 means not in present
```


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Pointers to Structures

- Recall that when we have a pointer to a structure, we can use the indirect component selection operator -> to access components within the structure

```
typedef struct
{
        double x;
        double y;
} Point;

int main (void)
{
        Point p1, *struct_ptr;
        p1.x = 12.3;
        p1.y = 2.5;

        struct_ptr = &p1;

        struct_ptr->x; /* Access the x component in Point, i.e. 12.3 */
        .
        .
        .
}
```


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Keep Reviewing C Material!

References

- J.R. Hanly & E.B. Koffman, *Problem Solving and Program Design in C (8th Ed.)*, Addison-Wesley, 2016.
- P.J. Deitel & H.M. Deitel, *C How to Program (7th Ed.)*, Pearson Education , Inc., 2013.

Collaborators

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(2-1) Data Structures & The Basics of a Linked List I

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How do we Select a Data Structure? (1)

- Select a data structure as follows:
  - Analyze the problem and requirements to determine the resource constraints for the solution
  - Determine basic operations that must be supported
    - Quantify resource constraints for each operation
  - Select the data structure that best fits these requirements/constraints

- Courtesy of Will Thacker, Winthrop University

How do we Select a Data Structure? (2)

- Questions that must be considered:
  - Is the data inserted into the structure at the beginning or the end? Or are insertions interspersed with other operations?
  - Can data be deleted?
  - Is the data processed in some well-defined order, or is random access allowed?

- Courtesy of Will Thacker, Winthrop University

Other Considerations for Data Structures? (1)

- Each data structure has costs and benefits
- Rarely is one data structure better than another in all situations
- A data structure requires:
  - Space for each data item it stores,
  - Time to perform each basic operation,
  - Programming effort

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Other Considerations for Data Structures? (2)

- Each problem has constraints on available time and space
- Only after a careful analysis of problem characteristics can we know the best data structure for the task

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Definition of Linked List

- A finite sequence of nodes, where each node may be only accessed sequentially (through links or pointers), starting from the first node
- It is also defined as a linear collection of self-referential structures connected by pointers

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Conventions

- An uppercase first character of a function name indicates that we are referencing the List ADT operation
- A lowercase first character of a function indicates our implementation

Struct Node

- For these examples, we'll use the following definition for `Node`:

```
typedef struct node
{
    char data;
    // self-referential
    struct node *pNext;
} Node;
```


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Initializing a List (1)

- **InitList (L)** Procedure to initialize the list L to empty
- Our implementation:

```
void initList (Node **pList)
{
    // Recall: we must dereference a
    // pointer to retain changes
    *pList = NULL;
}
```


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Initializing a List (2)

- The `initList()` function is elementary and is not always implemented
- We may instead initialize the pointer to the start of the list with `NULL` within `main()`

```
int main (void)
{
    Node *pList = NULL;
    …
}
```


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Checking for Empty List (1)

- **ListIsEmpty (L) -> b:** Boolean function to return TRUE if L is empty
- Our implementation:

```
int isEmpty (Node *pList)
{
	int status = 0; // False initially

	if (pList == NULL) // The list is empty
	{
		status = 1; // True
	}

	return status;
}
```


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Checking for Empty List (2)

- Note: we could substitute the `int` return type with an enumerated type such as Boolean

```
typedef enum boolean
{
    FALSE, TRUE
} Boolean;
```


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Checking for Empty List (3)

- Our implementation with `Boolean` defined:

```
Boolean isEmpty (Node *pList)
{
     Boolean status = FALSE;

     if (pList == NULL)
     {
          status = TRUE;
     }

     return status;
}
```


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Printing Data in List (1)

- Our implementation:

```
void printListIterative (Node *pList)
{
    printf ("X -> ");
    while (pList != NULL)
    {
          printf ("%c -> ", pList -> data);
          // Get to the next item
          pList = pList -> pNext;
    }
    printf ("NULL\n");
}
```

Printing Data in List (2)

- Another possible implementation using `isEmpty()`:

```
void printListIterative (Node *pList)
{
    printf ("X -> ");
    while (!isEmpty (pList))
    {
        printf ("%c -> ", pList -> data);
        // Get to the next item
        pList = pList -> pNext;
    }
    printf ("NULL\n");
}
```

Printing Data in List (3)

- We can determine the end of the list by searching for the `NULL` pointer
- If the list is initially empty, no problem, the `while()` loop will not execute

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Inserting Data at Front of List

- **InsertFront (L,e):** Procedure to insert a node with information e into L as the first node in the List; in case L is empty, make a node containing e the only node in L and the current node

Inserting Data at Front of List w/o Error Checking (1)

- Our implementation:

```
void insertFront (Node **pList, char newData)
{
     Node *pMem = NULL;

     pMem = (Node *) malloc (sizeof (Node));
     // Initialize the dynamic memory
     pMem -> data = newData;
     pMem -> pNext = NULL;

     // Insert the new node into front of list
     pMem -> pNext = *pList;
     *pList = pMem;

}
```


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Inserting Data at Front of List w/o Error Checking (2)

- Let's define a new function which handles the dynamic allocation and initialization of a node:

```
Node * makeNode (char newData)
{
     Node *pMem = NULL;

     pMem = (Node *) malloc (sizeof (Node));
     // Initialize the dynamic memory
     pMem -> data = newData;
     pMem -> pNext = NULL;

     return pMem;
}
```


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Inserting Data at Front of List w/o Error Checking (3)

- Now we can reorganize our code and take advantage of the new function:

```
void insertFront (Node **pList, char newData)
{
     Node *pMem = NULL;

     pMem = makeNode (newData);

     // Insert the new node into front of list
     pMem -> pNext = *pList;
     *pList = pMem;

}
```


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Inserting Data at Front of List w/ Error Checking (1)

- Let’s modify our code so that we can check for dynamic memory allocation errors
- We’ll start with `makeNode()`:

```
Node * makeNode (char newData)
{
      Node *pMem = NULL;

      pMem = (Node *) malloc (sizeof (Node));
      if (pMem != NULL)
      {
              // Initialize the dynamic memory
              pMem -> data = newData;
              pMem -> pNext = NULL;
      }
      // Otherwise no memory is available; could use else, but
      // it’s not necessary

      return pMem;
}
```

Inserting Data at Front of List w/ Error Checking (2)

- Now let's add some error checking to `insertFront()`:

```
void insertFront (Node **pList, char newData)
{
      Node *pMem = NULL;

      pMem = makeNode (newData);

      if (pMem != NULL) // Memory was available
      {
                // Insert the new node into front of list
                pMem -> pNext = *pList;
                *pList = pMem;
      }
      else // Can't allocate anymore dynamic memory
      {
          printf ("WARNING: No memory is available for data insertion!\n")
      }

}
```


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Closing Thoughts

- Can you build a driver program to test these functions?
- Is it possible to return a `Boolean` for `insertFront()` to indicate a memory allocation error, where TRUE means error and FALSE means no error?
- `insertFront()` will be seen again with a Stack data structure…

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Next Lecture…

- Continue our discussion and implementation of linked lists

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References

- P.J. Deitel & H.M. Deitel, *C: How to Program* (8th ed.), Prentice Hall, 2017
- J.R. Hanly & E.B. Koffman, *Problem Solving and Program Design in C (7th Ed.)*, Addison-Wesley, 2013

Collaborators

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(1 - 2) Introduction to C Data Structures & Abstract Data Types

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What is a Data Structure?

- A software construct describing the organization and storage of information
  - Designed to be accessed efficiently
  - Composite of related items
- An implementation of an abstract data type (ADTs) to be defined later
- Defined and applied for particular applications and/or tasks

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Data Structures Exposed

- You've already seen a few fixed-sized data structures
  - Arrays
  - Structures or structs in C

Review of Basic C Data Structures (1)

- Recall an *array* is a collection of related data items
  - Accessed by the same variable name and an index
  - Data is of the same type
  - Items are contiguous in memory
  - Subscripts or indices must be integral and 0 or positive only
- Our visual representation of an array of chars, where first row is index and second is contents

index	0	…	n-2	n-1
contents	‘b’	…	‘3’	‘\0’

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Review of Basic C Data Structures (2)

- Recall a *structure* or *struct* is a collection of related fields or variables under one name
  - Represent real world objects
  - Each field may be of a different data type
  - The fields are contiguous in memory
- Example struct describing a dog

```
typedef struct dog
{
    char *breed; // need to allocate memory for
                 // string separately
    char name[100]; // memory is included for string
    double weight;
} Dog;
```

How Can We Expand on Our Data Structure Knowledge?

- In this course we will focus on dynamic data structures
  - These grow and shrink at runtime
- The major dynamic data structures include:
  - Lists
  - Stacks
  - Queues
  - Binary Trees
  - Binary Search Trees (BSTs)

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Basic Applications of Dynamic Data Structures (1)

- Lists are collections of data items lined up in a row
  - Insertions and deletions may be made anywhere
  - May represent movie & music collections, grocery store lists, & many more…
- Stacks are restricted lists
  - Insertions and deletions may be made at one end only
    - These are Last In, First Out (LIFO) structures
  - May be used with compilers & operating systems, & many more applications…

Basic Applications of Dynamic Data Structures (2)

- Queues are also restricted lists
  - Insertions are made at the back of the queue and deletions are made from the front
    - These are First In, First Out (FIFO) structures
  - May represent waiting lines, etc.
- BSTs require linked data items
  - Efficient for searching and sorting of data
  - May represent directories on a file system, etc.
- This course will focus on these dynamic data structures and corresponding implementations in both C and C++

What do these C Dynamic Structures have in Common?

- Of course dynamic growing and shrinking properties…
- Implemented with pointers
  - Recall a *pointer* is a variable that stores as its contents the address of another variable
    - Operators applied to pointers include
      - Pointer declaration – i.e. char *ptr
      - Dereference or indirection – i.e. *ptr
      - Address of – i.e. &ptr
      - Assignment – i.e. ptr1 = ptr2
      - Others?
- Require the use of structs
  - Actually self-referential structures for linked implementations

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What is a Self-Referential Structure?

- A struct which contains a pointer field that represents an address of a struct of the same type
- Example

```
typedef struct node
{
     char data;
     // self-referential
     struct node *pNext;
} Node;
```


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Dynamic Memory Allocation / De-allocation in C (1)

- The growing and shrinking properties may be achieved through functions located in <stdlib.h> including:
  - `malloc()` for allocating/growing memory
  - `free()` for de-allocating/shrinking memory
  - `realloc()` for resizing memory
  - Also consider `calloc()`

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Dynamic Memory Allocation / De-allocation in C (2)

- Assume the following:

```
Node *pItem = NULL;
```

- How to use `malloc()`

```
pItem = (Node *) malloc (sizeof (Node));
// Recall malloc ( ) returns a void *,
// which should be typecasted
```

- How to use `free()`

```
free (pItem);
// Requires the pointer to the memory to be
// de-allocated
```

- How to use `realloc()`

```
pItem = realloc (pItem, sizeof (Node) * 2);
// Allocates space for two Nodes and
// returns pointer to beginning of resized
// memory
```


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How Do We Know Which Values and Operations are Supported?

- Each data structure has a corresponding model represented by the abstract data type (ADT)
  - The model defines the behavior of operations, but not how they should be implemented

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Abstract Data Types

- Abstract Data Types or ADTs according to National Institute of Standards and Technology (NIST)
  – Definition: *A set of data values and associated operations that are precisely specified independent of any particular implementation.*

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Data Structure

- Data Structures according to NIST
  - Definition: *An organization of information, usually in memory, for better algorithm efficiency, such as queue, stack, linked list, heap, dictionary, and tree, or conceptual unity, such as the name and address of a person. It may include redundant information, such as length of the list or number of nodes in a subtree.*

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ADTs versus Data Structures

- Many people think that ADTs and Data Structures are interchangeable in meaning
  - ADTs are logical descriptions or specifications of data and operations
    - To abstract is to leave out concrete details
  - Data structures are the actual representations of data and operations, i.e. implementation
- Semantic versus syntactic

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Specification of ADT

- Consists of at least 5 items
  - Types/Data
  - Functions/Methods/Operations
  - Axioms
  - Preconditions
  - Postconditions
  - Others?

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Example Specification of List ADT (1)

- Description: A list is a finite sequence of nodes, where each node may be only accessed sequentially, starting from the first node
- Types/Data
  - e is the element type
  - L is the list type

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Example Specification of List ADT (2)

- Functions/Methods/Operations
  - **InitList (L):** Procedure to initialize the list L to empty
  - **DestroyList (L):** Procedure to make an existing list L empty
  - **ListIsEmpty (L) -> b:** Boolean function to return TRUE if L is empty
  - **ListIsFull (L) -> b:** Boolean function to return TRUE if L is full
  - **CurIsEmpty (L) -> b:** Boolean function to return TRUE if the current position in L is empty

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Example Specification of List ADT (3)

- Functions/Methods/Operations Continued
  - **ToFirst (L):** Procedure to make the current node the first node in L; if the list is empty, the current position remains empty
  - **AtFirst (L) -> b:** Boolean function to return TRUE if the current node is the first node in the list or if the list and the current position are both empty
  - **AtEnd (L) -> b:** Boolean function to return TRUE if the current node is the last node in the list or if the list and the current position are both empty
  - **Advance (L):** Procedure to make the current position indicate the next node in L; if the current node is the last node the current position becomes empty

Example Specification of List ADT (4)

- Functions/Methods/Operations Continued Again
  - **Insert (L,e):** Procedure to insert a node with information e before the current position or, in case L was empty, as the only node in L; the new node becomes the current node
  - **InsertAfter (L,e):** Procedure to insert a node with information e into L after the current node without changing the current position; in case L is empty, make a node containing e the only node in L and the current node
  - **InsertFront (L,e):** Procedure to insert a node with information e into L as the first node in the List; in case L is empty, make a node containing e the only node in L and the current node
  - **InsertInOrder (L,e):** Procedure to insert a node with information e into L as node in the List, order of the elements is preserved; in case L is empty, make a node containing e the only node in L and the current node

Example Specification of List ADT (5)

- Functions/Methods/Operations Continued One Last Time
  - **Delete (L):** Procedure to delete the current node in L and to have the current position indicate the next node; if the current node is the last node the current position becomes empty
  - **StoreInfo (L,e):** Procedure to update the information portion of the current node to contain e; assume the current position is nonempty
  - **RetrieveInfo (L) -> e:** Function to return the information in the current node; assume the current position is nonempty

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Example Specification of List ADT (6)

- Axioms
  - Empty ()?
  - Not empty ()?
  - Others?
- Preconditions
  - Delete () requires that the list is not empty ()
- Postconditions
  - After Insert () is executed the list is not empty ()
- Others?

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Visual of List ADT

- View diagrams on the board
  - Nodes?
  - List?

Next Lecture…

- Introduction to implementation of a dynamically linked list

References

- P.J. Deitel & H.M. Deitel, *C++: How to Program* (10th ed.), Pearson Education Inc, 2017
- J.R. Hanly & E.B. Koffman, *Problem Solving and Program Design in C (7th Ed.)*, Addison-Wesley, 2013

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