

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

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CptS 122 (January 11, 2019)
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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



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'



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)



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



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;
```



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()`



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
```



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



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.*



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.*



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



Specification of ADT

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



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



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



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



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?



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



Collaborators

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