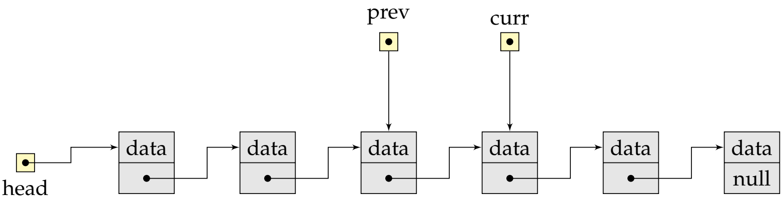
CSCI 2270: Data Structures

Lecture 07: Implementing "Lists" Using Arrays

Ashutosh Trivedi



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- Procedural Abstraction *lets us think about a series of computational steps as an abstract unit (procedure)*.
- Data Abstraction *lets us think about collections of data as abstract entities (abstract data types)*.

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- Early programming languages had fixed data types (`int`, `char`) and operations over these types (`+, -, *, /`).
- *Abstract data types* (Dahl, Hoare, Liskov among others) marked a major advance in *programming languages*: it allowed a programmer to define their own data types (along with operations over these types).

Data Abstraction

What are some typical operations on data?

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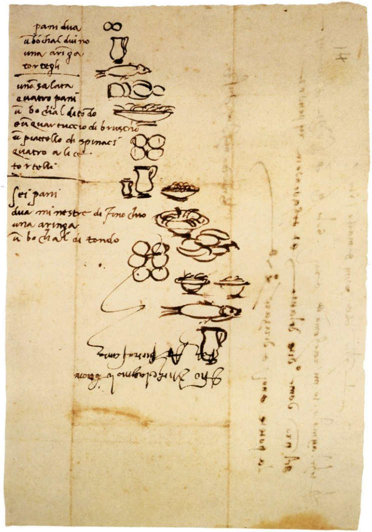
Data abstraction:

1. requires you to think about <u>what</u> (interface) you would like to do with your data, and not focus on <u>how</u> (implementation) you will do it.
2. allows "separation of concerns" by letting you develop different components of your software in isolation

Abstract Data Type: List

Abstract Data Type: Lists

A List by Michelangelo



Abstract Data Types: Lists

1. A list is an ordered sequence of items (with potential duplication), e.g.

$$\langle \text{Denver, Boulder, Erie, Louisville, Denver, Erie} \rangle$$

2. Lists are everywhere:
   - lists of students/addresses/patients/appointments,
   - list of processes/files/interrupts
3. Operations required on a list data type:
   - *construct* an empty list
   - *destruct* a list (return the space to the free store.)
   - *size()*: return size of the list.
   - *insert* an element at a given index on the list.
   - *remove* an element at a given index on the list.
   - *search* for an element in the list.
   - *retrieve* the element at a given index on the list.
   - *capacity()*: return size of allocated storage capacity.
   - *is_empty()*: check if the list is empty.
4. Let's implement such a list in C++.

Lists: Implementation using Fixed-Size Arrays

```
#define MAX_LIST_SIZE 100
/* Class Declaration */
class List {
private:
  std::string m_list[MAX_LIST_SIZE]; //List of items
  int m_size; // number of items in the list
  int m_capacity; // total capacity of the list

public:
  List();   // Default Constructor
  ~List();  // Default Destructor

  int getSize();  // returns number of items in the list
  int getCapacity(); // returns the capacity of the list
  bool isEmpty(); // return true if the list is empty; false otherwise
  bool isFull(); // return true if the list is full; false otherwise

  void insert(std::string data); // insert at item to the end of the list
  void insert(std::string data, int index); // insert an item at a given index
  void remove(int index); // remove the item at a given index
  int search(std::string data); // return the index of the first occurence of the given data, -1 otherwise.
  std::string retrieve(int index); //retrieve an item at a given index
  void print(); // print the list
};
```

- Access level: public, private (default), and protected.
- Public members can be accessed out of the class (the interface).
- Private members can only be accessed from within the class (data-hiding).

Insert operation (Destructive)

Operation. Insert element 99 at index 3:

list $\longrightarrow$

1	1	3	5	6	8	$\perp$	$\perp$

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Insert operation (Non-destructive: Shuffling-Up)

Operation. Insert element 99 at index 3 (while item at the original index must be moved up, and all the items after that index must be shuffled up):

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void List::insert(std::string data, int index) {
  if ((index < 0) ||  (index > m_size))  throw "Index out of bounds";
  if (m_size < m_capacity) {
    for (int i = m_size; i > index; i--) {
      m_list[i] = m_list[i-1];
    }
    m_list[index] = data;
    m_size = m_size + 1;
  }
  else {
    throw "List capacity reached";
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Remove operation (Keep array gap-free)

Operation. Remove the element at the index 3 (all the items after the removed item's index must be shuffled down):

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list $\longrightarrow$ | 1 | 1 | 3 | 5 | 6 | 8 | $\perp$ | $\perp$ |

```
void List::remove(int index) {
  if ((index < 0) ||  (index > m_size))  throw "Index out of bounds";
  for (int i = index; i < m_size - 1; i++) {
    m_list[i] = m_list[i+1];
  }
  m_list[m_size-1] = "";
  m_size = m_size - 1;
}
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  m_list[m_size-1] = "";
  m_size = m_size - 1;
}
```

Fixed-Array List Implementation

```
void List::insert(std::string data, int index) {
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  if (m_size < m_capacity) {
    for (int i = m_size; i > index; i--) {
      m_list[i] = m_list[i-1];
    }
    m_list[index] = data;
    m_size = m_size + 1;
  }
  else {
    throw "List capacity reached";
  }
}
```

Pros:

- Fast access of the elements of the list
- Extremely memory efficient as very little memory is required other than that needed to store the contents

Cons:

- Slow deletion and insertion of elements
- Size must be known when the array is created and is fixed

Solution: Dynamic Arrays

```
class List {
private:
  std::string* m_list;
  int m_size;
  int m_capacity;
  int m_resize;
public:
  List();   // Default Constructor
  ~List();  // Default Destructor
  int getSize();  // returns number of items in the list
  bool isEmpty(); // return true if the list is empty; false otherwise
  void insert(std::string data); // insert at item to the end of the list
  void insert(std::string data, int index); // insert an item at a given index
  void remove(int index); // remove the item at a given index
  int search(std::string data); // return the index of the first occurence of the given data, -1 otherwise.
  std::string retrieve(int index); //retrieve an item at a given index
  void print(); // print the list
private:
  void resize(); // Dynamically resize by doubling
};
```

Dynamic Arrays: Insert

```
void List::insert(std::string data, int index) {

  if ((index < 0) ||  (index > m_size))  throw "Index out of bounds";

  if (m_size == m_capacity) resize();

  for (int i = m_size; i > index; i--) {
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```

Operation. Insert element 99 at index 3:

list →	1	1	3	5	6	8	11	5

Dynamic Arrays: Insert

```
void List::resize() {
  m_resize = m_resize + 1;
  std::cout << "Resizing " << m_resize << " times and no of elements: " << m_size << std::endl;


  if (m_capacity == 0) {
    m_list = new std::string [1];
    m_capacity = 1;
  }
  else {
    std::string *n_list = new std::string [m_capacity*2];

    for (int i=0; i< m_capacity; i++) {
      n_list[i] = m_list[i];
    }
    delete[] m_list;

    m_list = n_list;
    m_capacity = m_capacity * 2;
  }
}
```

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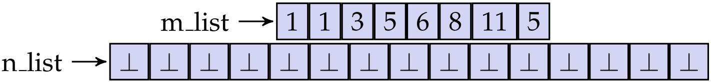

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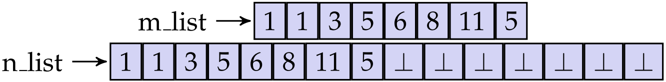

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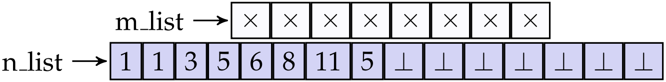

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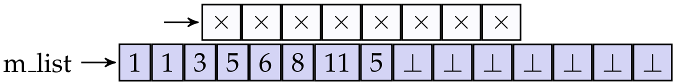

Dynamic Arrays: Remove

```
void List::remove(int index) {
  if ((index < 0) ||  (index > m_size))  throw "Index out of bounds";
  for (int i = index; i < m_size - 1; i++) {
    m_list[i] = m_list[i+1];
  }
  m_list[m_size-1] = "";
  m_size = m_size - 1;
}
```

Dynamic Arrays: Summary

- Before every insertion, check to see if the array needs to resize (grow)
- Growing by doubling works well in practice: to insert n items you need to $\log_2(n)$ resize operations!
- When resizing happens, it is time-consuming!
- Deleting and inserting is the middle still remain efficient (Amortized Cost)!

Abstract Data Types

Abstract data types are an instance of a general principle in software engineering, that combines the following ideas:

1. *Abstraction*. Hiding low-level details with a simpler higher-level idea.
2. *Modularity*. Dividing a system into modules where each module can be separately designed, implemented, and tested.
3. *Encapsulation*. Building walls around the functionality of a module such that bugs in other parts can not damage its integrity, and correctness of the module is its own responsibility.
4. *Information hiding*. Hiding implementation details of a module from the rest of the system, so that those details can be changed without requiring to change the rest of the system.
5. *Separation of concerns*. Making each module responsible for a specific feature (or "concern") rather than distributing responsibilities across multiple modules.