Topic 7: Lists and Vectors

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revision: 2019-09-30-09-01

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Sections marked with a star (★) are not covered in lecture but are instead covered in the online lecture notes. Students are responsible for all material covered in lecture and in the online lecture notes. Material from the online lecture notes will definitely be assessed in the prelim and final exam.

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• An **algorithm** is a clear set of steps to solve any problem in a particular problem class

```python
1  def fib( n ):
2     if ( n == 0 ): return 0
3     if ( n == 1 ): return 1
4     return fib( n-1 ) + fib( n-2 )
```

• A **data structure** is a structured way of storing data and the operations that can be applied to the data
  – **chain** of nodes each storing one integer
  – **array** of elements each storing one integer

• The `fib` algorithms do not involve a data structure
• The chain and array data structures do not involve an algorithm
• Most interesting programs involve a combination of algorithms and data structures

• Think of algorithms as **verbs** and data structures as **nouns**
• Most interesting stories involve a combination of verbs and nouns
## Algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>mul</td>
<td>iter, single step</td>
</tr>
<tr>
<td>sqrt</td>
<td>iter, recur</td>
</tr>
<tr>
<td>pow</td>
<td>iter, recur</td>
</tr>
<tr>
<td>search</td>
<td>linear, binary</td>
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<tr>
<td>sort</td>
<td>insertion, selection, merge, quick, hybrid, digit</td>
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<td></td>
<td>set intersection, set union</td>
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<tr>
<td>shortest path</td>
<td>Dijkstra</td>
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## Data Structures

<table>
<thead>
<tr>
<th>Data Structure</th>
</tr>
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<tbody>
<tr>
<td>chain of nodes</td>
</tr>
<tr>
<td>array of elements</td>
</tr>
<tr>
<td>list, vector</td>
</tr>
<tr>
<td>stack, queue, set, map</td>
</tr>
<tr>
<td>tree, table, graph</td>
</tr>
</tbody>
</table>

- Simple algorithms do not use a non-trivial data structure
- Simple data structures do not provide non-trivial operations
- Many algorithms operate on a simple data structure
- Many data structures provide operations which are implemented using an algorithm that operates on a simple data structure
- Sometimes our programs are more algorithm centric, sometimes they are more data-structure centric, but they almost always use both algorithms and data structures

Algorithm + Data Structure = Program

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**Topic 7: Lists and Vectors**
• A data structure includes both an interface and an implementation
  – The interface specifies the “what”
  – The implementation specifies the “how”

• Separating interface from implementation is called data encapsulation or information hiding
1. Lists

- Recall our example of a chain of dynamically allocated nodes
- Let’s combine this data structure with a few simple algorithms to create a new concrete data type called a **singly linked list**

### 1.1. Singly Linked List Interface

```c
typedef struct {
    // implementation specific
} slist_int_t;

void slist_int_construct ( slist_int_t* this );
void slist_int_destruct ( slist_int_t* this );
void slist_int_push_front ( slist_int_t* this, int v );
void slist_int_reverse ( slist_int_t* this );
```

- **void slist_int_construct** ( slist_int_t* this );
  Construct the slist initializing all fields in this slist_int_t.

- **void slist_int_destruct** ( slist_int_t* this );
  Destruct the slist by freeing any dynamically allocated memory used by this slist_int_t.

- **void slist_int_push_front** ( slist_int_t* this, int v );
  Push a new value (v) at the front of this slist_int_t.

- **void slist_int_reverse** ( slist_int_t* this );
  Reverse all values in this slist_int_t.
1. Lists

1.2. Singly Linked List Implementation

Example of using list interface

```c
int main( void )
{
    slist_int_t lst;
    slist_int_construct( &lst );
    slist_int_push_front( &lst, 12 );
    slist_int_push_front( &lst, 11 );
    slist_int_push_front( &lst, 10 );
    slist_int_reverse( &lst );
    slist_int_destruct( &lst );
    return 0;
}
```

1.2. Singly Linked List Implementation

```c
typedef struct _slist_int_node_t
{
    int value;
    struct _slist_int_node_t* next_p;
} slist_int_node_t;

typedef struct
{
    slist_int_node_t* head_p;
} slist_int_t;
```
Approach for implementing functions

1. Draw figure to explore high-level approach
2. Develop pseudo-code to capture high-level approach
3. Translate the pseudo-code to actual C code

**Pseudo-code for slist_int_construct**

1. void slist_int_construct( slist_int_t* this )
2. set head ptr to NULL

**Pseudo-code for slist_int_push_front**

After push front of value 12

After push front of value 11
After push front of value 10

```c
void slist_int_push_front( slist_int_t* this, int v )
allocate new node
set new node’s value to v
set new node’s next ptr to head ptr
set head ptr to point to new node
```

**Pseudo-code for** `slist_int_destruct`

Dellocate head node?

Dellocate head node’s next pointer?
Need temporary pointer to point to next node!

```c
void slist_int_destruct( slist_int_t* this )
  while head ptr is not NULL
    set temp ptr to head node’s next ptr
    free head node
    set head node ptr to temp ptr
```
1. Lists

1.2. Singly Linked List Implementation

```c
// Construct slist
void slist_int_construct(
    slist_int_t* this )
{
    this->head_p = NULL;
}

// Push value on front of slist
void slist_int_push_front(
    slist_int_t* this,
    int v )
{
    slist_int_node_t* new_node_p
        = malloc( sizeof(slist_int_node_t) );
    new_node_p->value = v;
    new_node_p->next_p = this->head_p;
    this->head_p = new_node_p;
}

// Destruct slist
void slist_int_destruct(
    slist_int_t* this )
{
    while ( this->head_p != NULL ) {
        slist_int_node_t* temp_p
            = this->head_p->next_p;
        free( this->head_p );
        this->head_p = temp_p;
    }
}

// Main function
int main( void )
{
    slist_int_t lst;
    slist_int_construct ( &lst );
    slist_int_push_front( &lst, 12 );
    slist_int_push_front( &lst, 11 );
    slist_int_push_front( &lst, 10 );
    slist_int_destruct ( &lst );
    return 0;
}
```

https://repl.it/@cbatten/ece2400-T07-ex1
Interface vs. Implementation

- Implementation details are exposed in slist_int_t
- A user can freely manipulate fields in slist_int_t
- C does not provide any mechanism to enforce encapsulation

Develop an algorithm for slist_int_reverse
1.3. Singly Linked Lists vs. Doubly Linked Lists
2. Vectors

- Recall the constraints on allocating arrays on the stack, and the need to explicitly pass the array size
- Let’s transform a dynamically allocated array along with its maximum size and actual size into a data structure

2.1. Bounded Vector Interface

```c
typedef struct {
    // implementation specific
} bvector_int_t;

void bvector_int_construct ( bvector_int_t* this, size_t maxsize );
void bvector_int_destruct ( bvector_int_t* this );
void bvector_int_push_front ( bvector_int_t* this, int v );
void bvector_int_reverse ( bvector_int_t* this );
```

- `void bvector_int_construct( bvector_int_t* this, size_t maxsize );`
  Construct the `bvector` initializing all fields in this `bvector_int_t`.

- `void bvector_int_destruct( bvector_int_t* this );`
  Destruct the `bvector` by freeing any dynamically allocated memory used by this `bvector_int_t`.

- `void bvector_int_push_front( bvector_int_t* this, int v );`
  Push a new value (v) at the front of this `bvector_int_t`. Undefined to push more than `maxsize` values.

- `void bvector_int_reverse( bvector_int_t* this );`
  Reverse all values in this `bvector_int_t`.
Example of using vector interface

```c
int main( void )
{
    bvector_int_t vec;
    bvector_int_construct( &vec, 4 );
    bvector_int_push_front( &vec, 12 );
    bvector_int_push_front( &vec, 11 );
    bvector_int_push_front( &vec, 10 );
    bvector_int_reverse( &vec );
    bvector_int_destruct( &vec );
    return 0;
}
```

2.2. Bounded Vector Implementation

```c
typedef struct
{
    int*   data;
    size_t maxsize;
    size_t size;
} bvector_int_t;
```

- data is pointer to dynamically allocated array of maxsize elements
- maxsize is max number of elements we can store in bvector
- size is how many elements currently stored in bvector
Approach for implementing functions

1. Draw figure to explore high-level approach
2. Develop pseudo-code to capture high-level approach
3. Translate the pseudo-code to actual C code

**Pseudo-code for `bvector_int_construct`**

```c
void vector_construct( bvector_int_t* this, size_t maxsize )
allocate new array with maxsize elements
set bvector’s data to point to new array
set bvector’s maxsize to maxsize
set bvector’s size to zero
```

**Pseudo-code for `bvector_int_push_front`**

Initial state of `bvector`

After push front of value 9
2. Vectors

2.2. Bounded Vector Implementation

After push front of value 8

Implement moving down all of the elements

1. void vector_push_front( bvector_int_t* this, int v )
   2. set prev value to v
   3. for i in 0 to bvector’s size (inclusive)
      4. set temp value to bvector’s data[i]
      5. set bvector’s data[i] to prev value
      6. set prev value to temp value
      7. set bvector’s size to size + 1

Pseudo-code for bvector_int_destruct

1. void vector_destruct( bvector_int_t* this )
   2. free bvector’s data
2. Vectors

2.2. Bounded Vector Implementation

```c
// Construct bvector
void bvector_int_construct(
    bvector_int_t* this,
    size_t maxsize )
{
    this->data = malloc( maxsize * sizeof(int) );
    this->maxsize = 8;
    this->size = 0;
}

// Push value on front of bvector
void bvector_int_push_front(
    bvector_int_t* this, int v )
{
    int prev_value = v;
    for ( size_t i=0; i<=this->size; i++ ) {
        int temp_value = this->data[i];
        this->data[i] = prev_value;
        prev_value = temp_value;
    }
    this->size += 1;
}

// Destruct bvector
void bvector_int_destruct(
    bvector_int_t* this )
{
    free( this->data );
}

// Main function
int main( void )
{
    bvector_int_t vec;
    bvector_int_construct ( &vec, 4 );
    bvector_int_push_front( &vec, 12 );
    bvector_int_push_front( &vec, 11 );
    bvector_int_push_front( &vec, 10 );
    bvector_int_destruct ( &vec );
    return 0;
}
```

https://repl.it/@cbatten/ece2400-T07-ex2
Interface vs. Implementation

- Implementation details are exposed in `bvector_int_t`
- A user can freely manipulate fields in `bvector_int_t`
- C does not provide any mechanism to enforce encapsulation

**Develop an algorithm for** `bvector_int_reverse`
2.3. Bounded Vectors vs. Resizable Vectors
3. Comparing Lists and Vectors

- The list and vector data structures ...
  - ... have similar interfaces, but
  - ... very different execution times, and
  - ... very different space usage.

- Compare the execution time and space usage of the algorithms?

<table>
<thead>
<tr>
<th>Operation</th>
<th>Execution Time</th>
<th>Space Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>slist</td>
<td>bvector</td>
</tr>
<tr>
<td>push_front</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reverse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at</td>
<td></td>
<td></td>
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<tr>
<td>push_back</td>
<td></td>
<td></td>
</tr>
<tr>
<td>find</td>
<td></td>
<td></td>
</tr>
<tr>
<td>insert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>remove</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- What about comparing a doubly linked list or a resizable vector?
- Compare the space usage of the data structure itself?