1 Lists
1.1. Singly Linked List Interface ........................................... 5
1.2. Singly Linked List Implementation .................................. 6
1.3. Singly Linked Lists vs. Doubly Linked Lists ....................... 12

2 Vectors
2.1. Bounded Vector Interface ............................................... 13
2.2. Bounded Vector Implementation ..................................... 14
2.3. Bounded Vectors vs. Resizable Vectors ............................ 19

3 Comparing Lists and Vectors

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

```python
def fib( n ):

    if ( n == 0 ): return 0
    if ( n == 1 ): return 1

    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
<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Data Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>mul: iter, single step</td>
<td>chain of nodes</td>
</tr>
<tr>
<td>sqrt: iter, recur</td>
<td>array of elements</td>
</tr>
<tr>
<td>search: linear, binary</td>
<td>list, vector</td>
</tr>
<tr>
<td>sort: insertion, selection, merge, quick, hybrid, bucket</td>
<td>stack, queue, set, map</td>
</tr>
<tr>
<td>set intersection, set union</td>
<td>tree, table, graph</td>
</tr>
<tr>
<td>find path: DFS, BFS, Dijkstra</td>
<td></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

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**

**Brainstorm other non-programming examples of interfaces and implementations. What are some reasons to separate the interface from the implementation?**
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 data structure called a **singly linked list**

1.1. Singly Linked List Interface

```c
typedef struct
{
    // implementation defined
}
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 slist initializing all fields in this slist_int_t.
  Undefined if this is NULL, or if call more than once on same slist.

- **void slist_int_destruct(slist_int_t* this);**
  Destruct slist by freeing any dynamically allocated memory used by this slist_int_t. Undefined if this is NULL, or if call more than once on same slist.

- **void slist_int_push_front(slist_int_t* this, int v);**
  Push a new value (v) at the front of this slist_int_t. Undefined if this is NULL, or if call before construct or after destruct.

- **void slist_int_reverse(slist_int_t* this);**
  Reverse all values in this slist_int_t. Undefined if this is NULL, or if call before construct or after destruct.
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`

```c
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
1. Lists

1.2. Singly Linked List Implementation

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?
1. Lists

1.2. Singly Linked List Implementation

Need temporary pointer to point to next node!

```
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

1.1. 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

• When programmers say “list” they usually mean a doubly linked list
• We will use `slist` for singly linked list, and just `list` for a doubly linked list
• We will try and be explicit in the course about the kind of list
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 defined
}
bvector_int_t;

void bvector_int_construct ( bvector_int_t* this, int 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, int maxsize );`
  Construct the bvector initializing all fields in this bvector_int_t.
  Undefined if this is NULL, or if call more than once on same bvector.

- `void bvector_int_destruct ( bvector_int_t* this );`
  Destruct the bvector by freeing any dynamically allocated memory used by this bvector_int_t. Undefined if this is NULL, or if call more than once on same bvector.

- `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. Undefined if this is NULL, or if call before construct or after destruct.
2. Vectors

2.2. Bounded Vector Implementation

- \texttt{void bvector\_int\_reverse( bvector\_int\_t* this );}
  
  Reverse all values in this \texttt{bvector\_int\_t}. Undefined if this is \texttt{NULL}, or if call before construct or after destruct.

Example of using vector interface

\begin{verbatim}
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;
}
\end{verbatim}

2.2. Bounded Vector Implementation

\begin{verbatim}
typedef struct
{
    int* data;
    int maxsize;
    int size;
}
    bvector_int_t;
\end{verbatim}

- data is pointer to dynamically allocated array of \texttt{maxsize} elements
- maxsize is max number of elements we can store in \texttt{bvector}
- size is how many elements currently stored in \texttt{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 bvector_int_construct( bvector_int_t* this, int 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

After push front of value 8

Implement moving down all of the elements

```c
void bvector_int_push_front( bvector_int_t* this, int v )
{
    set prev value to v
    for i in 0 to bvector’s size (inclusive)
        set temp value to bvector’s data[i]
        set bvector’s data[i] to prev value
        set prev value to temp value
    set bvector’s size to size + 1
}
```

**Pseudo-code for** `bvector_int_destruct`

```c
void bvector_int_destruct( bvector_int_t* this )
{
    free bvector’s data
}
```
2. Vectors  

### 2.2. Bounded Vector Implementation

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

- When programmers say “vector” they usually mean a resizable vector.
- We will use `bvector` for bounded vector, and `just vector` for a resizable vector.
- We will try and be explicit in the course about the kind of vector.
3. Comparing Lists and Vectors

- Many more functions are possible for both lists and vectors

```c
void ds_int_construct ( ds_int_t* this );
void ds_int_destruct ( ds_int_t* this );
void ds_int_push_front ( ds_int_t* this, int v );
void ds_int_reverse ( ds_int_t* this );
void ds_int_push_back ( ds_int_t* this, int v );
int ds_int_size ( ds_int_t* this );
int ds_int_at ( ds_int_t* this, int idx );
int ds_int_contains ( ds_int_t* this, int v );
void ds_int_print ( ds_int_t* this );
void ds_int_insert ( ds_int_t* this, int idx, int v );
void ds_int_remove ( ds_int_t* this, int idx );
void ds_int_insert ( ds_int_t* this, ptr_t* ptr, int v );
void ds_int_remove ( ds_int_t* this, ptr_t* ptr );
```

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

- 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>bvctor</td>
</tr>
<tr>
<td>push_front</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reverse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>push_back</td>
<td></td>
<td></td>
</tr>
<tr>
<td>size</td>
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<td>at</td>
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<tr>
<td>contains</td>
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<tr>
<td>print</td>
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<tr>
<td>insert w/ idx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>remove w/ idx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>insert w/ ptr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>remove w/ ptr</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?