ECE 2400 Computer Systems Programming
Fall 2021

Topic 7: Lists and Vectors

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zyBooks The zyBooks logo is used to indicate additional material included in the course zyBook which will not be discussed in detail in lecture. Students are responsible for all material covered in lecture and in the course zyBook.

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

```
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

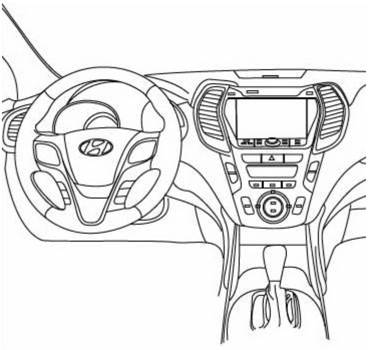
Algorithms	**Data Structures**
mul: iter, single step sqrt: iter, recur	chain of nodes array of elements
search: linear, binary sort: insertion, selection, merge, quick, hybrid, bucket set intersection, set union find path: DFS, BFS, Dijkstra	list, vector stack, queue, set, map tree, table, graph

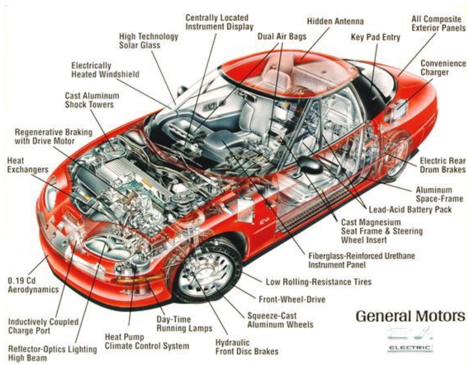
- Simple algorithms do not use a non-trivial data structure
- Simple data structures do not provide non-trivial operations
- Many algorithms operate on a simple data structure
- Many data structures provide operations which are implemented using an algorithm that operates on a simple data structure

- 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

- 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

```
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

```
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

```
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`

```
void slist_int_construct( slist_int_t* this )
  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

```
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!

```
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
```

```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;
}
```

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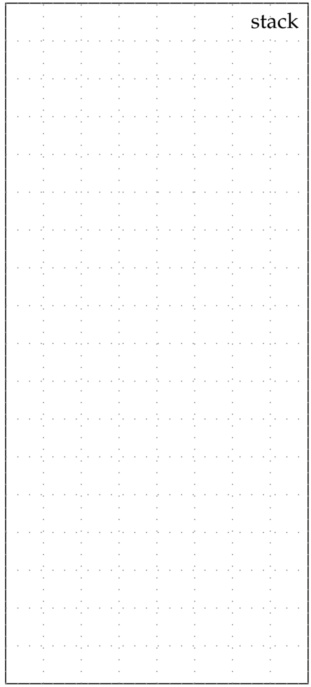

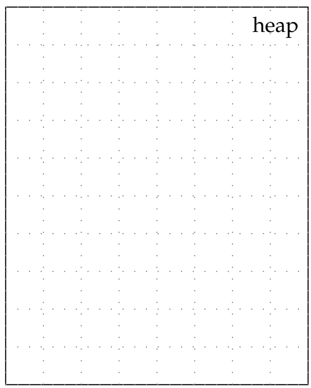

Interface vs. Implementation

- 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

```
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`.

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

Example of using vector interface

```
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

```
typedef struct
{
  int* data;
  int  maxsize;
  int  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`

```
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

```
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`

```
void bvector_int_destruct( bvector_int_t* this )
  free bvector's data
```

```
// 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;
}
```

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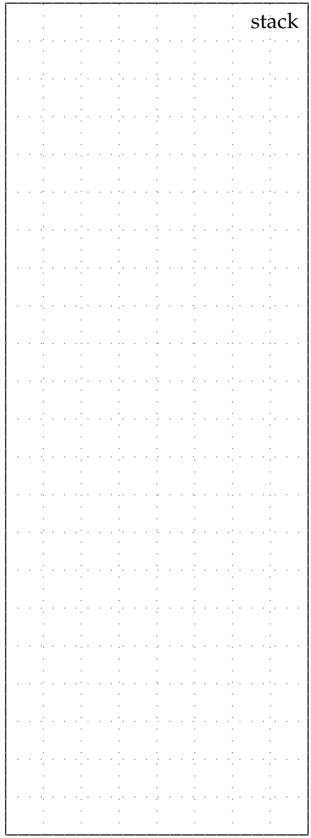

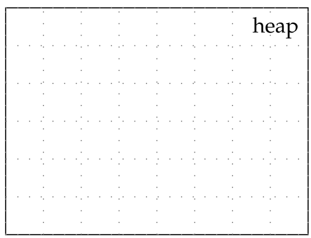

Interface vs. Implementation

- 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

```
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.

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

	Execution Time		Space Usage	
Operation	`slist`	`bvector`	`slist`	`bvector`
`push_front`				
`reverse`				
`push_back`				
`size`				
`at`				
`contains`				
`print`				
`insert` w/ idx				
`remove` w/ idx				
`insert` w/ ptr				
`remove` w/ ptr				

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