CSCI 104
List ADT & Array-based Implementations
Queues and Stacks

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Lists

- Ordered collection of items, which may contain duplicate values, usually accessed based on their position (index)
  - Ordered = Each item has an index and there is a front and back (start and end)
  - Duplicates allowed (i.e. in a list of integers, the value 0 could appear multiple times)
  - Accessed based on their position (list[0], list[1], etc.)
- What are some operations you perform on a list?

List Operations

Operation	Description	Input(s)	Output(s)
insert	Add a new value at a particular location shifting others back	Index : int Value	
remove	Remove value at the given location	Index : int	Value at location
get / at	Get value at given location	Index : int	Value at location
set	Changes the value at a given location	Index : int Value	
empty	Returns true if there are no values in the list		bool
size	Returns the number of values in the list		int
push_back / append	Add a new value to the end of the list	Value	
find	Return the location of a given value	Value	Int : Index

IMPLEMENTATIONS

Implementation Strategies

- Linked List
  - Can grow with user needs
- Bounded Dynamic Array
  - Let user choose initial size but is then fixed
- Unbounded Dynamic Array
  - Can grow with user needs

Linked List Runtime Analysis

- What is worst-case runtime of set(i, value)?
- What is worst-case runtime of get(i)?
- What is worst-case runtime of pushback(value) [assume tail pointer is used]?
- What is worst-case runtime of insert(i, value)?
- What is worst-case runtime of remove(i)?

BOUNDED DYNAMIC ARRAY STRATEGY

A Bounded Dynamic Array Strategy

- Allocate an array of some user-provided size
- What data members do I need?
- Together, think through the implications of each operation when using a bounded array (what issues could be caused due to it being bounded)?

```
#ifndef BALISTINT_H
#define BALISTINT_H

class BAListInt {
 public:
  BAListInt(unsigned int cap);

  bool empty() const;
  unsigned int  size() const;
  void insert(int pos,
              const int& val);
  bool remove(int pos);
  int& const  get(int loc) const;
  int& get(int loc);
  void set(int loc, const int& val);
  void push_back(const int& val);
 private:




};
#endif
```

balistint.h

A Bounded Dynamic Array Strategy

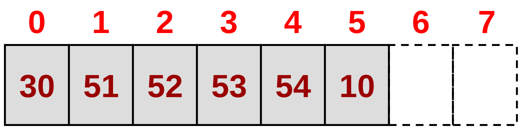
- What data members do I need?
  - Pointer to Array
  - Current size
  - Capacity
- Together, think through the implications of each operation when using a static (bounded) array
  - Push_back: Run out of room?
  - Insert: Run out of room, invalid location

```
#ifndef BALISTINT_H
#define BALISTINT_H

class BAListInt {
 public:
  BAListInt(unsigned int cap);

  bool empty() const;
  unsigned int  size() const;
  void insert(int pos,
              const int& val);
  void remove(int pos);
  int const & get(int loc) const;
  int& get(int loc);
  void set(int loc, const int& val);
  void push_back(const int& val);
 private:
  int* data_;
  unsigned int size_;
  unsigned int cap_;

};
#endif
```

balistint.h

Implementation

- Implement the following member functions
  - A picture to help write the code




```
BAListInt::BAListInt (unsigned int cap)
{


}

void BAListInt::push_back(const int& val)
{






}

void BAListInt::insert(int loc, const int& val)
{






}
```

balistint.cpp

Implementation (cont.)

- Implement the following member functions
  - A picture to help write the code

0	1	2	3	4	5	6	7
30	51	52	53	54	10		

```
void BAListInt::remove(int loc)
{




}
```

balistint.cpp

Array List Runtime Analysis

- What is worst-case runtime of set(i, value)?
- What is worst-case runtime of get(i)?
- What is worst-case runtime of pushback(value)?
- What is worst-case runtime of insert(i, value)?
- What is worst-case runtime of remove(i)?

Const-ness

- Notice the get() functions?
- Why do we need two versions of get?

```
#ifndef BALISTINT_H
#define BALISTINT_H

class BAListInt {
 public:
  BAListInt(unsigned int cap);

  bool empty() const;
  unsigned int  size() const;
  void insert(int pos, const int& val);
  bool remove(int pos);

  int& const  get(int loc) const;
  int& get(int loc);

  void set(int loc, const int& val);
  void push_back(const int& val);
 private:


};
#endif
```

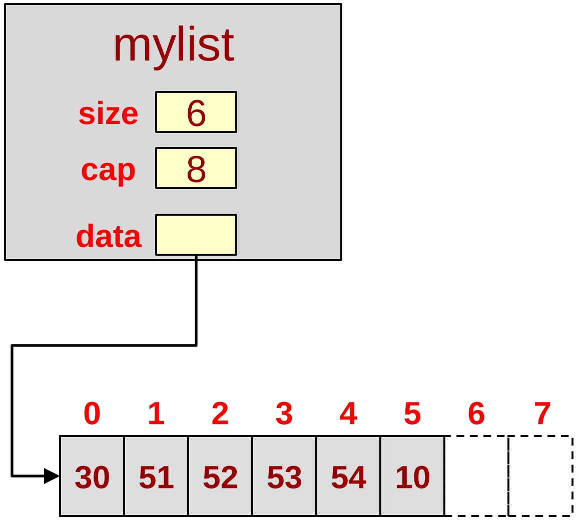
Const-ness

- Notice the get() functions?
- Why do we need two versions of get?
- Because we have two use cases…
  - 1. Just read a value in the array w/o changes
  - 2. Get a value w/ intention of changing it

```
#ifndef BALISTINT_H
#define BALISTINT_H

class BAListInt {
 public:
  BAListInt(unsigned int cap);

  bool empty() const;
  unsigned int  size() const;
  void insert(int pos, const int& val);
  bool remove(int pos);

  int& const  get(int loc) const;
  int& get(int loc);

  void set(int loc, const int& val);
  void push_back(const int& val);
 private:


};
#endif
```

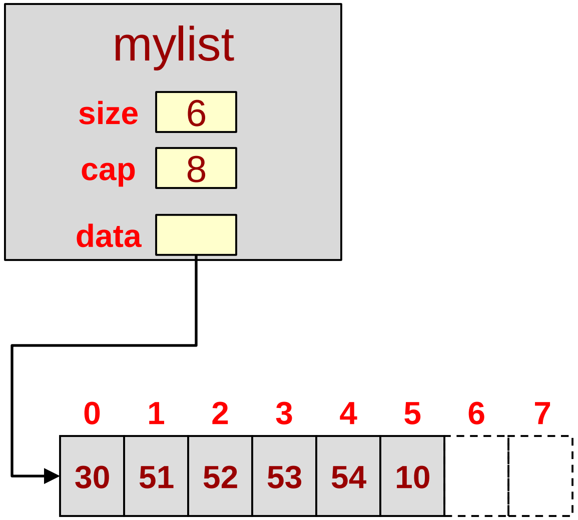
Constness

```
// ---- Recall List Member functions ------
// const version
int& const  BAListInt::get(int loc) const
{ return data_[i]; }

// non-const version
int& BAListInt::get(int loc)
{ return data_[i]; }

void BAListInt::insert(int pos, const int& val);


// ---- Now consider this code ------
void f1(const BAListInt& mylist)
{
  // This calls the const version of get.
  // W/o the const-version this would not compile
  //  since mylist was passed as a const parameter
  cout << mylist.get(0) << endl;
  mylist.insert(0, 57); // won't compile..insert is non-const

}

int main()
{
  BAListInt mylist;
  f1(mylist);

}
```



Returning References

```
// ---- Recall List Member functions ------
// const version
int& const  BAListInt::get(int loc) const
{ return data_[i]; }

// non-const version
int& BAListInt::get(int loc)
{ return data_[i]; }

void BAListInt::insert(int pos, const int& val);

// ---- Now consider this code ------
void f1(BAListInt& mylist)
{
  // This calls the non-const version of get
  // if you only had the const-version this would not compile
  //  since we are trying to modify what the
  //  return value is referencing
  mylist.get(0) += 1;  // equiv. mylist.set(mylist.get(0)+1);
  mylist.insert(0, 57);
  // will compile since mylist is non-const
}
int main()
{ BAListInt mylist;
  f1(mylist);
}
```

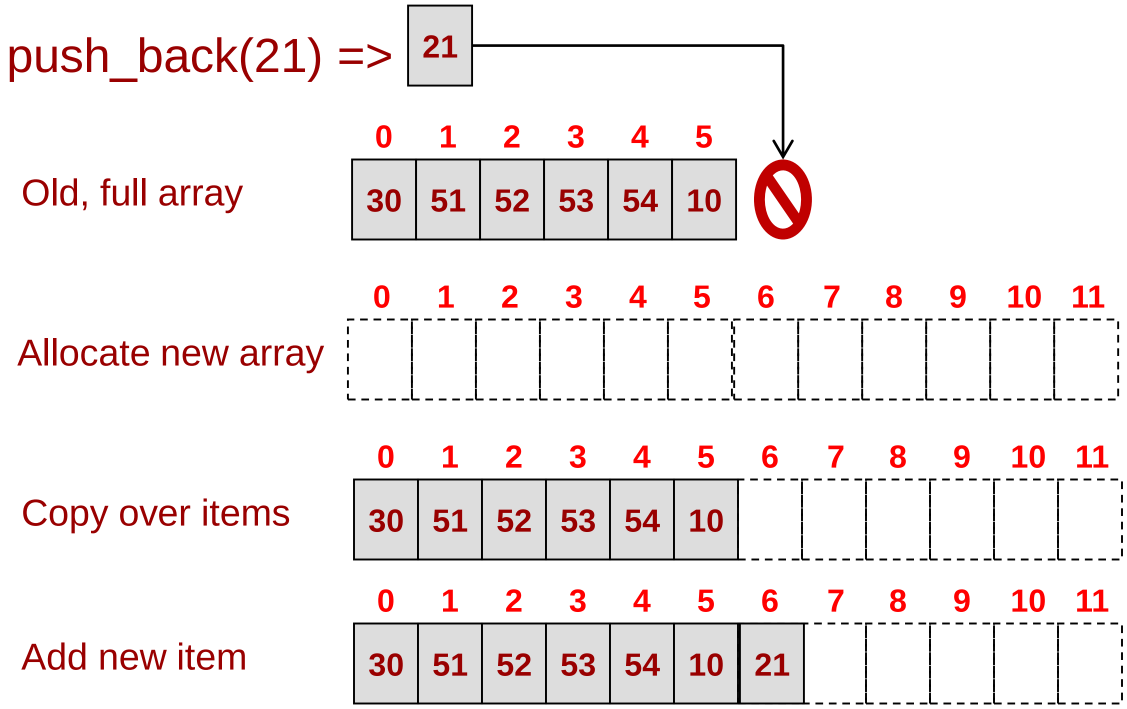


Moral of the Story: We need both versions of get()

UNBOUNDED DYNAMIC ARRAY STRATEGY

Unbounded Array

- Any bounded array solution runs the risk of running out of room when we insert() or push_back()
- We can create an unbounded array solution where we allocate a whole new, larger array when we try to add a new item to a full array



We can use the strategy of allocating a new array ***twice*** the size of the old array

Activity

- What function implementations need to change if any?

```
#ifndef ALISTINT_H
#define ALISTINT_H

class AListInt  {
 public:
  bool empty() const;
  unsigned int  size() const;
  void insert(int loc, const int& val);
  void remove(int loc);
  int& const   get(int loc) const;
  int& get(int loc);
  void set(int loc, const int& val);
  void push_back(const T& new_val);
 private:


  int* _data;
  unsigned int _size;
  unsigned int _capacity;
};

// implementations here
#endif
```

Activity

- What function implementations need to change if any?

```
#ifndef ALISTINT_H
#define ALISTINT_H

class AListInt  {
 public:
  bool empty() const;
  unsigned int  size() const;
  void insert(int loc, const int& val);
  void remove(int loc);
  int& const   get(int loc) const;
  int& get(int loc);
  void set(int loc, const int& val);
  void push_back(const T& new_val);
 private:
  void resize(); // increases array size
  int* _data;
  unsigned int _size;
  unsigned int _capacity;
};

// implementations here
#endif
```

A Unbounded Dynamic Array Strategy

- Implement the push_back method for an unbounded dynamic array

```
#include "alistint.h"

void AListInt::push_back(const int& val)
{











}
```

alistint.cpp

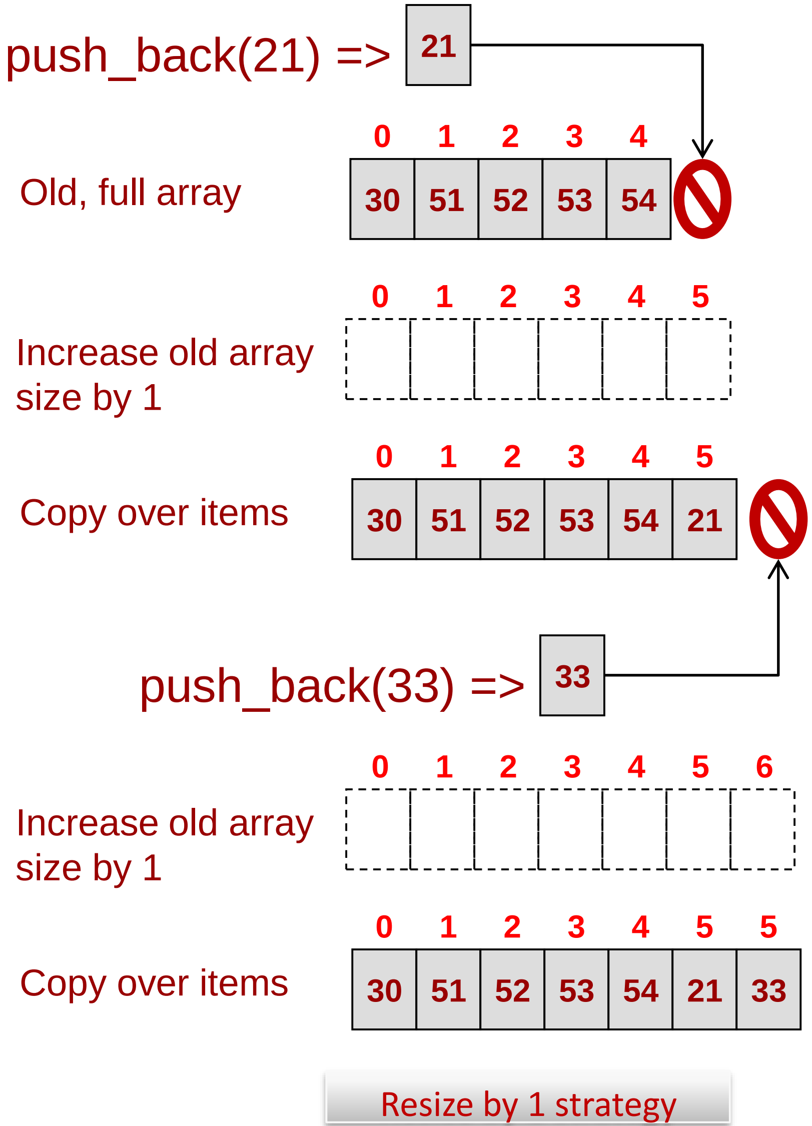
AMORTIZED RUNTIME

Example

- You love going to Disneyland. You purchase an annual pass for $240. You visit Disneyland once a month for a year. Each time you go you spend $20 on food, etc.
  - What is the cost of a visit?
- Your annual pass cost is spread or "**amortized**" (or averaged) over the duration of its usefulness
- Often times an operation on a data structure will have similar "irregular" (i.e. if we can prove the worst case can't happen each call) costs that we can then amortize over future calls

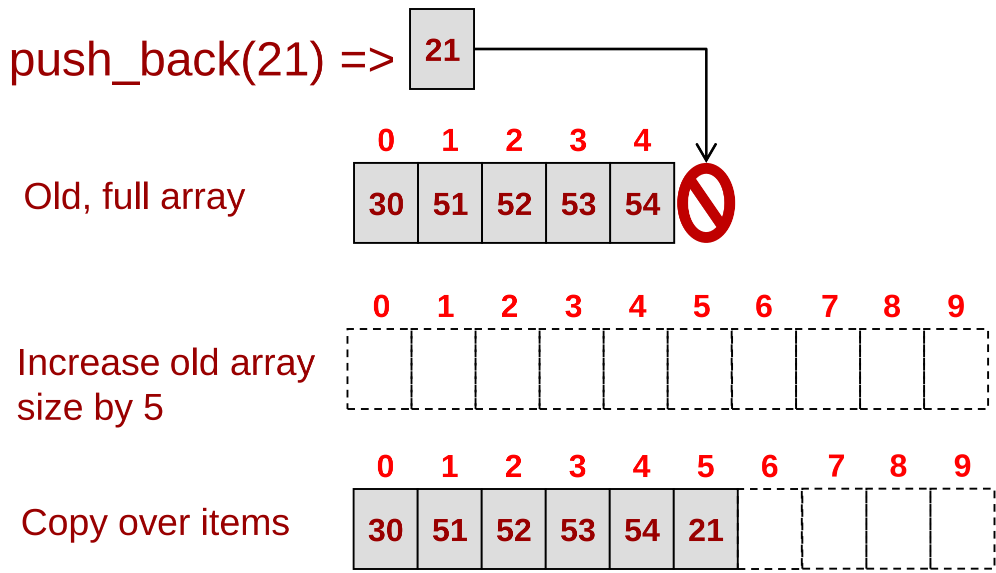
Amortized Array Resize Run-time

- What is the run-time of insert or push_back:
  - If we have to resize?
  - O(n)
  - If we don't have to resize?
  - O(1)
- Now compute the total cost of a series of insertions using resize by 1 at a time
- Each insert now costs O(n)… not good



Amortized Array Resize Run-time

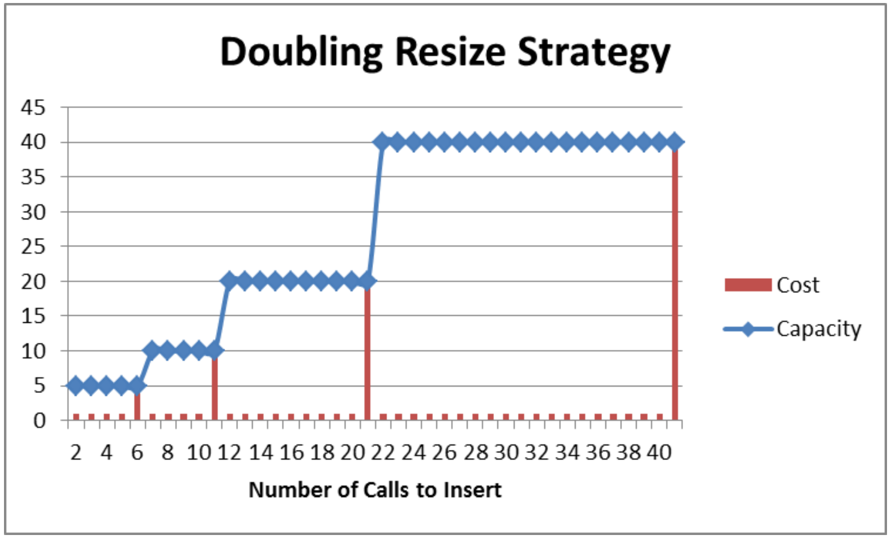
- What if we resize by adding 5 new locations each time
- Start analyzing when the list is full…
  - 1 call to insert will cost: 5
  - What can I guarantee about the next 4 calls to insert?
    - They will cost 1 each because I have room
  - After those 4 calls the next insert will cost: 10
  - Then 4 more at cost=1
- If the list is size n and full
  - Next insert cost = n
  - 4 inserts after than = 1 each
  - Cost for 5 inserts = n+5
  - Runtime = cost / insert = (n+5)/5 = O(n)



Resize by 5 strategy

Consider a Doubling Size Strategy

- Start when the list is full and at size n
- Next insertion will cost?
  - O(n+1)
- How many future insertions will be guaranteed to be cost = 1?
  - n-1 insertions
  - At a cost of 1 each, I get n-1 total cost
- So for the n insertions my total cost was
  - n+1 + n-1 = 2*n
- Amortized runtime is then:
  - Cost / insertions
  - O(2*n / n) = O(2) = O(1) = constant!!!



When To Use Amortized Runtime

- When should I use amortized runtime?
  - When it is impossible for the worst case of an operation to happen on each call (i.e. we can prove after paying a high cost that we will not have to pay that cost again for some number of future operations)
- Over how many calls should I average the runtime?
  - Determine how many times you can guarantee a cheaper cost after paying the higher cost
  - Average the cost over the that number of calls

Another Example

- Let's say you are writing an algorithm to take a n-bit binary combination (3-bit and 4-bit combinations are to the right) and produce the next binary combination
- Assume all the cost in the algorithm is spent changing a bit (define that as 1 unit of work)
- I could give you any combination, what is the worst case run-time? Best-case?
  - O(n) => 011 to 100
  - O(1) => 000 to 001

3-bit Binary
000
001
010
011
100
101
110
111

4-bit Binary
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111

Another Example

- Now let's consider the program that generates all the combinations sequentially (in order)
  - Starting at 000 => 001 : cost = 1
  - Starting at 001 => 010 : cost = 2
  - Starting at 010 => 011 : cost = 1
  - Starting at 011 => 100 : cost = 3
  - Starting at 100 => 101 : cost = 1
  - Starting at 101 => 110 : cost = 2
  - Starting at 101 => 111 : cost = 1
  - Starting at 111 => 000 : cost = 3
  - Total = 14 / 8 calls = 1.75
- Repeat for the 4-bit
  - 1 + 2 + 1 + 3 + 1 + 2 + 1 + 4 + …
  - Total = 30 / 16 = 1.875
- As n gets larger…Amortized cost per call = 2

3-bit Binary
000
001
010
011
100
101
110
111

4-bit Binary
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111