COS30008
Data Structures and Patterns

Basic Collection Types

Container Types, Stacks, and Queues

Overview

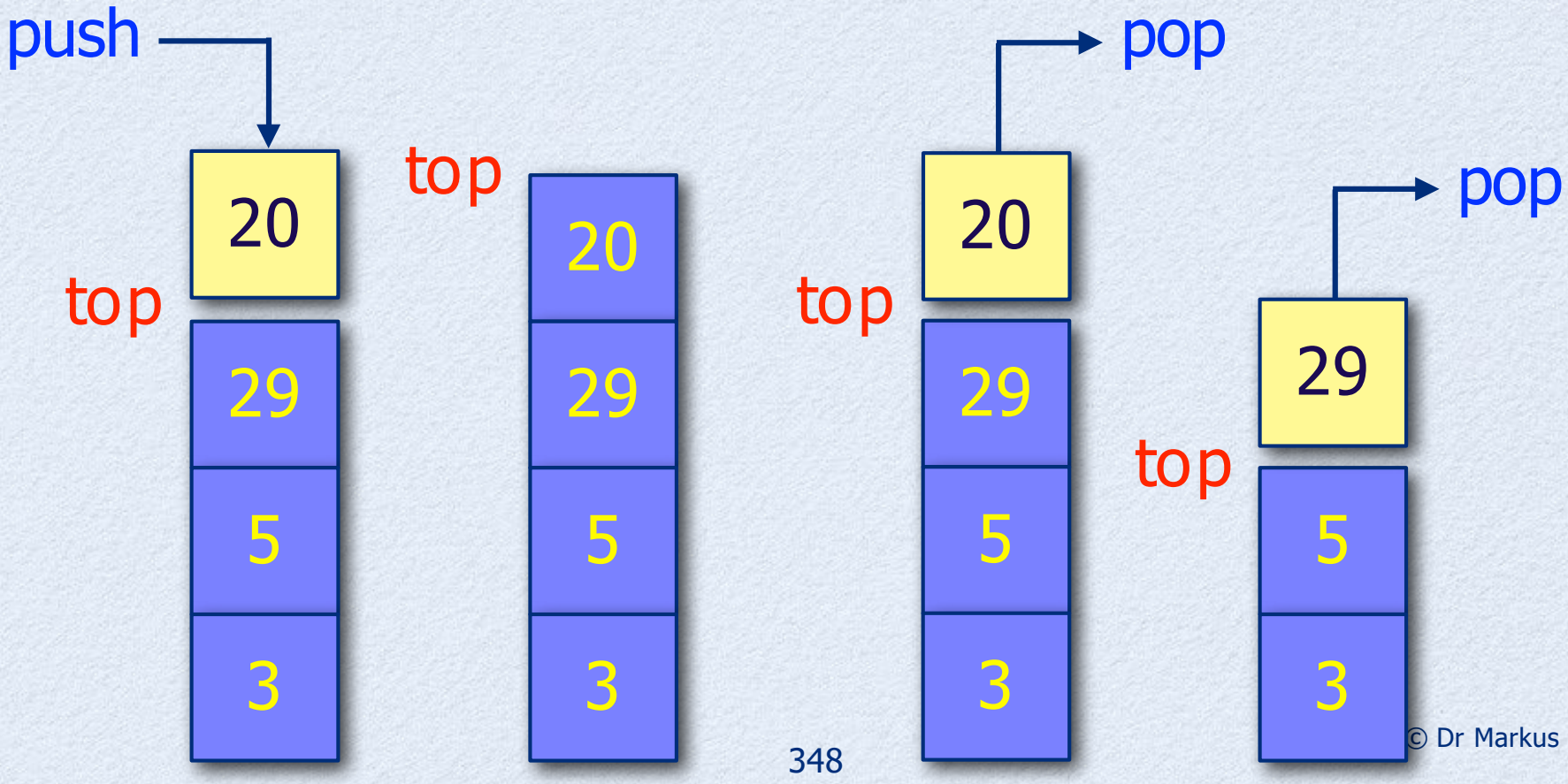
- Stacks
- Container types and references

References

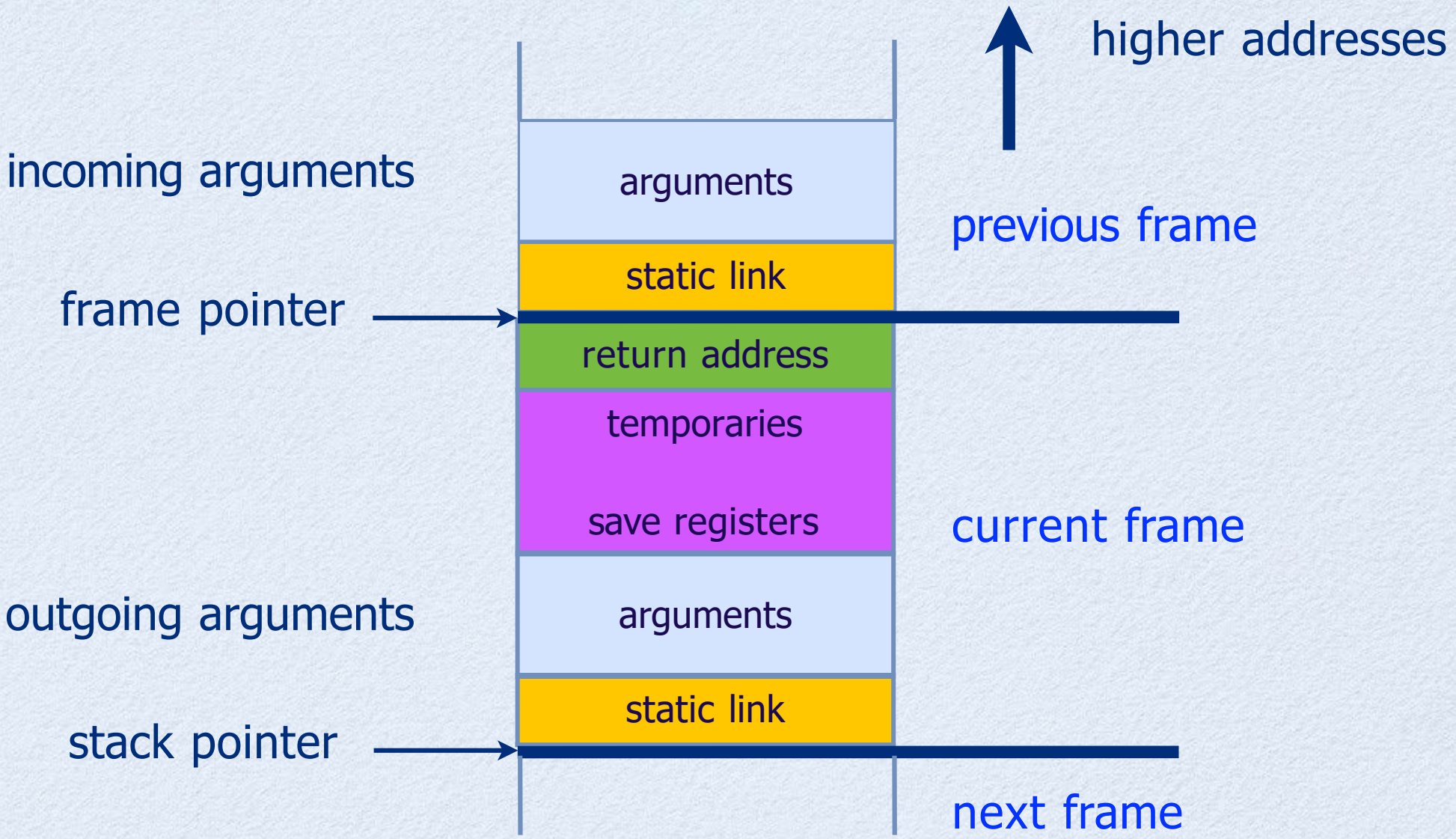
- Bruno R. Preiss: Data Structures and Algorithms with Object-Oriented Design Patterns in C++. John Wiley & Sons, Inc. (1999)
- Richard F. Gilberg and Behrouz A. Forouzan: Data Structures - A Pseudocode Approach with C. 2nd Edition. Thomson (2005)
- Nicolai M. Josuttis: The C++ Standard Library - A Tutorial and Reference. Addison-Wesley (1999)
- Stanley B. Lippman, Josée Lajoie, and Barbara E. Moo: C++ Primer. 5th Edition. Addison-Wesley (2013)

Stacks

- A stack is a special version of a linear list where items are added and deleted at only one end called the top.



Stack Frames (PASCAL)



Stack Behavior

- Stacks manage elements in last-in, first-out (LIFO) manner.
- A stack underflow happens when one tries to pop on an empty stack.
- A stack overflow happens when one tries to push onto a full stack.

Applications of Stacks

- Reversal of input (like push_front for List<T>)
- Checking for matching parentheses (e.g., stack automata in compiler implementations)
- Backtracking (e.g., Prolog or graph analysis)
- State of program execution (e.g., storage for parameters and local variables of functions)
- Tree traversal

Reverse Polish Notation

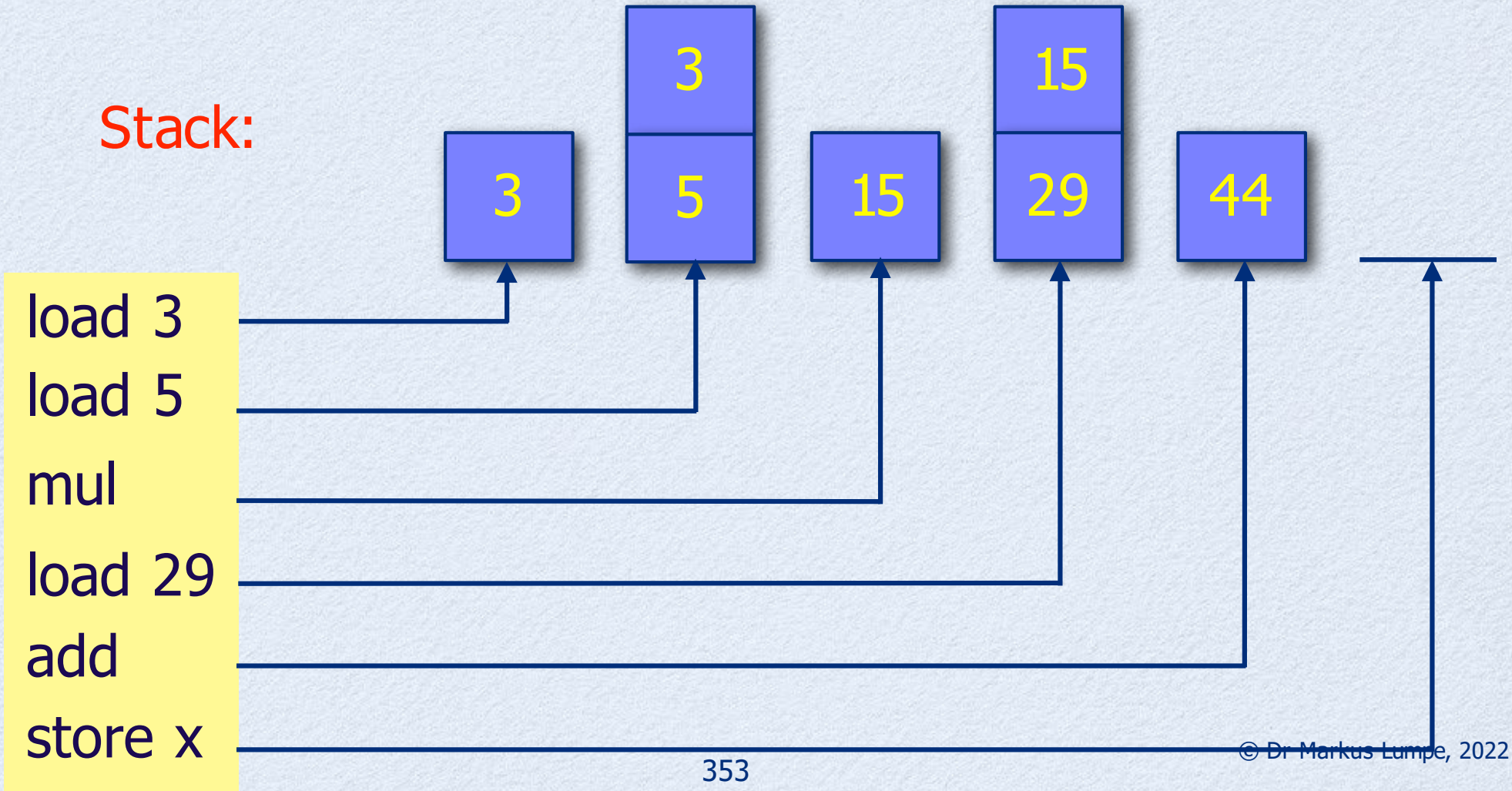
- Reverse Polish Notation (RPN) is a prefix notation wherein operands come before operators.

RPN: a b * c +

Infix: a * b + c

RPN Calculation

- x = 3 * 5 + 29



Stack Interface

Stack SPEC A.h

```
6   class Stack
7   {
8   public:
9       Stack( size_t aSize );
10      ~Stack();
11
12      bool isEmpty() const;
13      size_t size() const;
14      void push( const T& aItem );
15      void push( T&& aItem );
16      void pop();
17      const T& top() const;
18  };
```

Line: 2 Column: 12 C++ Tab Size: 4

- When defining a container type we wish to minimize the number of value copies required for the objects stored in the container. In order to achieve this, we use references.

Container Types

- Stacks belong to a special group of data types called container types.
- The de facto standard approach for the definition of container types in C++ is to use value-based semantics.
- Other examples of container types are Lists, Queues, Hash Tables, Maps, Arrays, or Trees.

The Stack's Private Interface

Stack SPEC B.h

```
6   template<class T>
7   class Stack
8   {
9   private:
10      T* fElements;
11      size_t fStackPointer;
12      size_t fStackSize;
13
14  public:
15
16      ...
17  };
```

Line: 3 Column: 1 C++ Tab Size: 4

- Inside Stack we need to be able to store objects of type T. Hence we need to dynamically allocate memory (i.e, an array of type T) and store the address of the first element in a matching pointer variable.

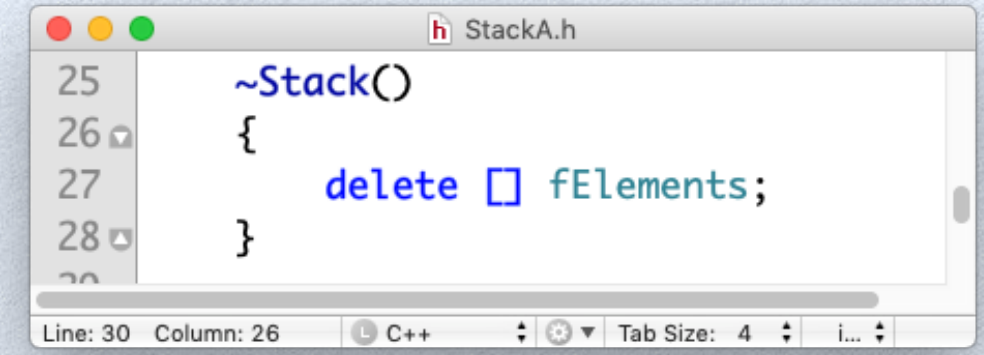
Stack Constructor

StackA.h

```
18      Stack( size_t aSize )
19      {
20          fStackSize = aSize;
21          fElements = new T[fStackSize];
22          fStackPointer = 0;
23      }
```

Line: 5 Column: 1 C++ Tab Size: 4

Stack Destructor



- There are two forms of delete:
  - delete ptr - release the memory associated with pointer ptr.
  - delete [] ptr - release the memory associated with all elements of array ptr and the array ptr itself.
- Whenever you allocate memory for an array of elements of a generic type, say T* arr = new T[10], you must use the array form of delete, delete [], to guarantee that all array cells are released before the array itself is freed.

Stack Auxiliaries

StackA.h

```
30      bool isEmpty() const
31      {
32          return fStackPointer == 0;
33      }
34
35      size_t size() const
36      {
37          return fStackPointer;
38      }
```

Line: 1 Column: 1 C++ Tab Size: 4

- isEmpty(): Boolean predicate to indicate whether there are elements on the stack.
- size(): returns the actual stack size.

Push

StackA.h

```
41      void push( const T& aItem )
42      {
43          if ( fStackPointer < fStackSize )
44          {
45              fElements[fStackPointer++] = aItem;
46          }
47          else
48          {
49              throw std::overflow_error( "Stack full." );
50          }
51      }
52
53      void push( T&& aItem )
54      {
55          if ( fStackPointer < fStackSize )
56          {
57              fElements[fStackPointer++] = std::move(aItem);
58          }
59          else
60          {
61              throw std::overflow_error( "Stack full." );
62          }
63      }
64
```

Line: 1 Column: 1 C++ Tab Size: 4

- The push method stores a item at the next free slot in the stack, if there is room.

Pop

StackA.h

```
64
65      void pop()
66      {
67          if ( !isEmpty() )
68          {
69              fStackPointer--;
70          }
71          else
72          {
73              throw std::underflow_error( "Stack empty." );
74          }
75      }
76
```

Line: 78 Column: 1 C++ Tab Size: 4 top

- The pop method shifts the stack pointer to the previous slot in the stack, if there is such a slot. Note, the element in the current slot itself is not yet destroyed.

Top

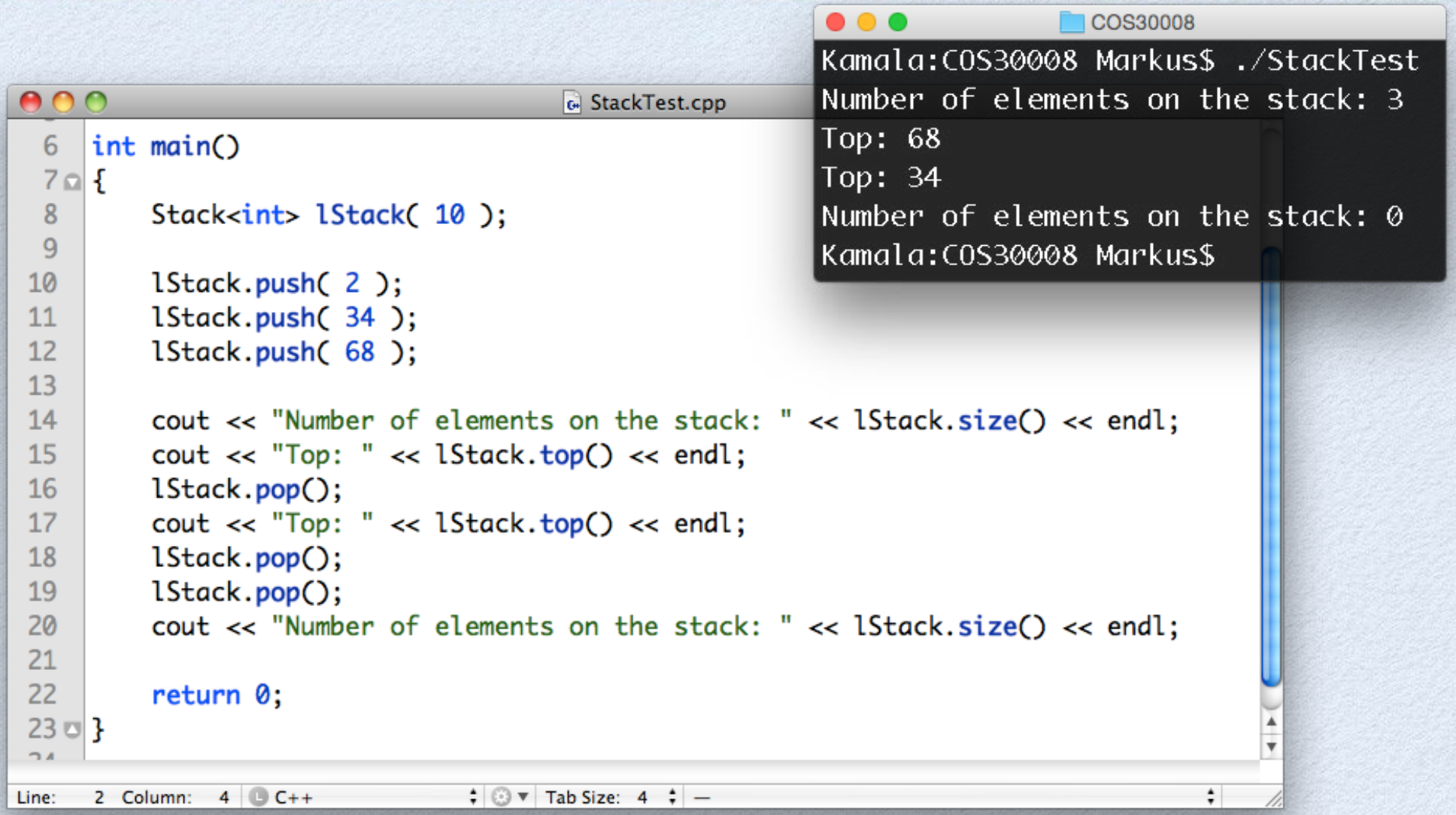
StackA.h

```
77      const T& top() const
78      {
79          if ( !isEmpty() )
80          {
81              return fElements[fStackPointer - 1];
82          }
83          else
84          {
85              throw std::underflow_error( "Stack empty." );
86          }
87      }
```

Line: 1 Column: 1 C++ Tab Size: 4

- The top method returns a const reference to the item in the current slot in the stack, if there is such a slot.

Stack Sample



Dynamic Stack

- We can define a dynamic stack that uses a list as underlying data type to host an arbitrary number of elements:

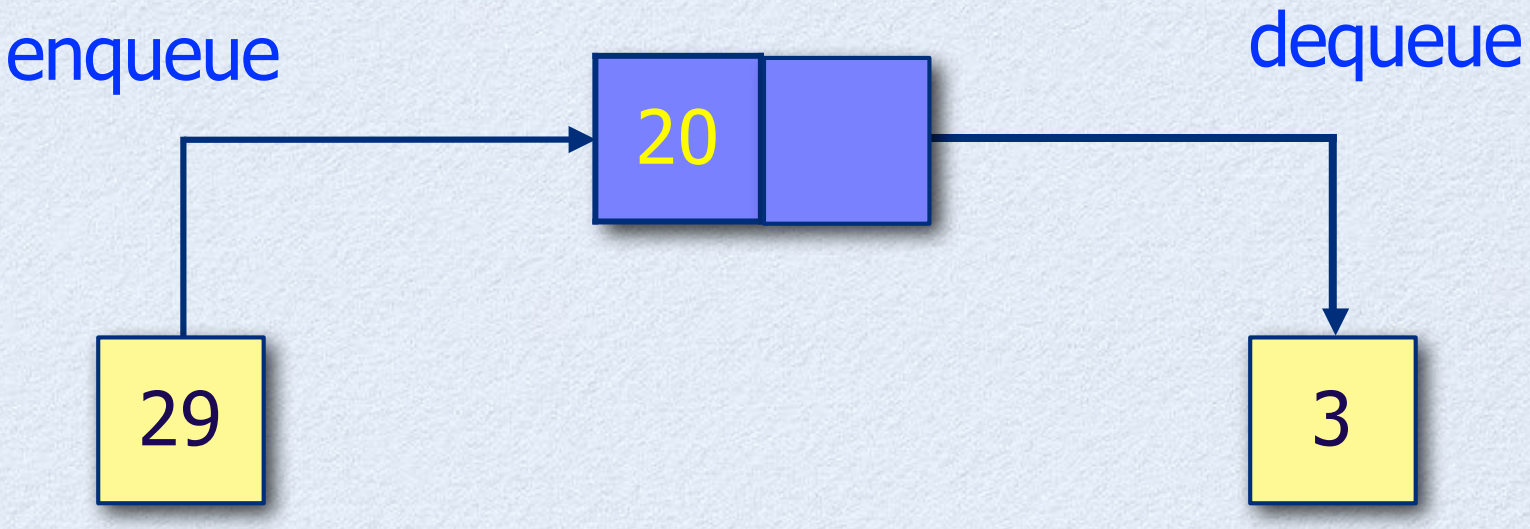
Stack SPEC.h

```
10  template<class T>
11  class Stack
12  {
13  private:
14      List<T> fElements;
15
16  public:
17
18      bool isEmpty() const;
19      int size() const;
20      void push( const T& aItem );
21      void push( T&& aItem );
22      void pop();
23      const T& top() const;
24  };
```

Line: 6 Column: 13 C++ Tab Size: 4

Queues

- A queue is a special version of a linear list where access to items is only possible at its front and end.

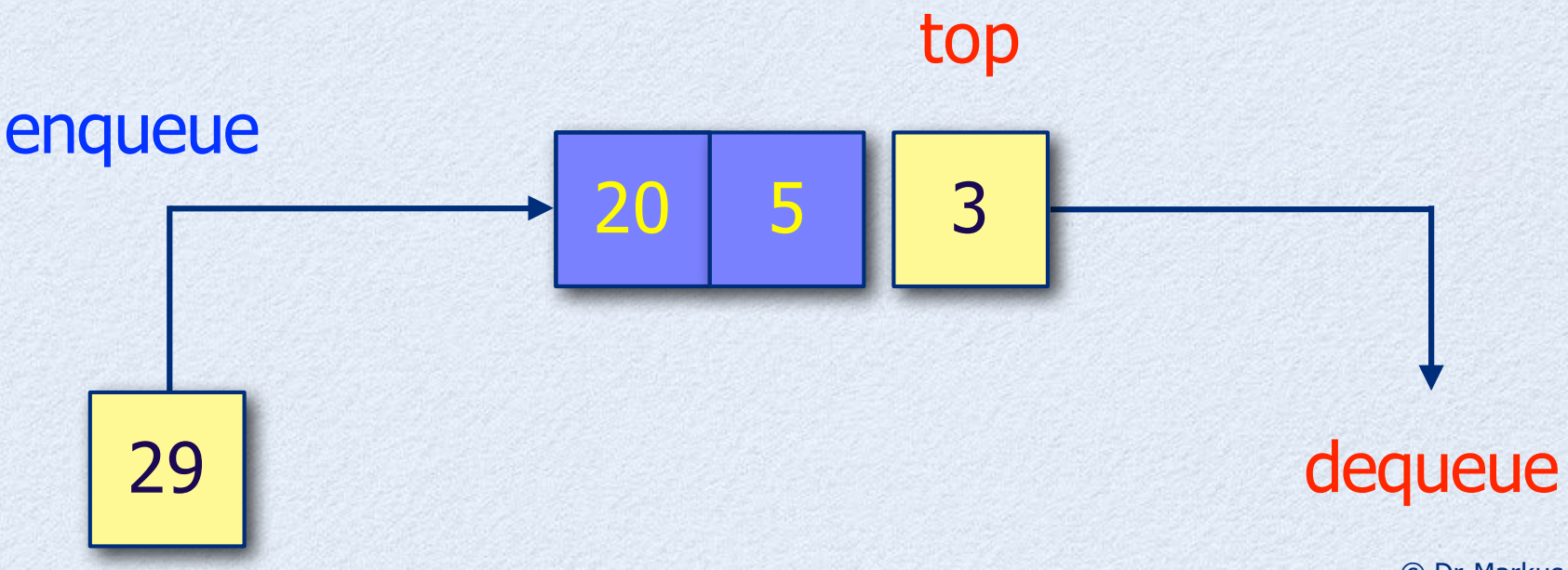


Queue Behavior

- Queues manage elements in first-in, first-out (FIFO) manner.
- A queue underflow happens when one tries to dequeue on an empty queue.
- A queue overflow happens when one tries to enqueue on a full queue.

Implementation of Queues

- A concrete queue implementation requires us to split the dequeue operation into two steps: access to the first element (via top) and removal of first element (the actual dequeue).
- If we were to perform both steps as one (just dequeue), we would create a memory leak in C++ (i.e., we would create a reference to released memory). Hence, we need:



A Queue Interface

Queue SPEC.h

```
4  #include "List.h"
5
6  template<class T>
7  class Queue
8  {
9  private:
10     List<T> fElements;
11
12 public:
13
14     bool isEmpty() const;                  // empty queue predicate
15     size_t size() const;                   // get number of elements
16     void enqueue( const T& aElement );     // insert element at end
17     void enqueue( T&& aElement );          // insert element at end
18     void dequeue();                        // remove element at end
19     const T& top() const;                  // access element at front
20 };
```

Line: 2 Column: 12 C++ Tab Size: 4

Queue Service Members

Queue.h

```
34      bool isEmpty() const
35      {
36          return fElements.isEmpty();
37      }
38
39      int size() const
40      {
41          return fElements.size();
42      }
43
```

Line: 20 Column: 1 C++ Tab Size: 4

Queue Semantics

Queue.h

```
60  void enqueue( const T& aElement )
61  {
62      fElements.push_back( aElement );
63  }
64
65  void dequeue()
66  {
67      if ( isEmpty() )
68          throw std::underflow_error( "Queue empty." );
69
70      fElements.remove( fElements[0]);
71  }
72
73  const T& top() const
74  {
75      if ( isEmpty() )
76          throw std::underflow_error( "Queue empty." );
77
78      return fElements[0];
79  }
80
```

Line: 57 Column: 1 C++ Tab Size: 4 T

Queue Test

QueueTest.cpp

```
1  #include <iostream>
2
3  #include "Queue.h"
4
5  using namespace std;
6
7  int main()
8  {
9      Queue<int> lQueue;
10
11     lQueue.enqueue( 20 );
12     lQueue.enqueue( 3 );
13     lQueue.enqueue( 37 );
14
15     cout << "Number of elements in the queue: " << lQueue.size() << endl;
16
17     cout << "value: " << lQueue.top() << endl; lQueue.dequeue();
18     cout << "value: " << lQueue.top() << endl; lQueue.dequeue();
19     cout << "value: " << lQueue.top() << endl; lQueue.dequeue();
20
21     cout << "Number of elements in the queue: " << lQueue.size() << endl;
22
23     return 0;
24 }
```

Line: 26 Column: 1 C++ Tab Size: 4 main

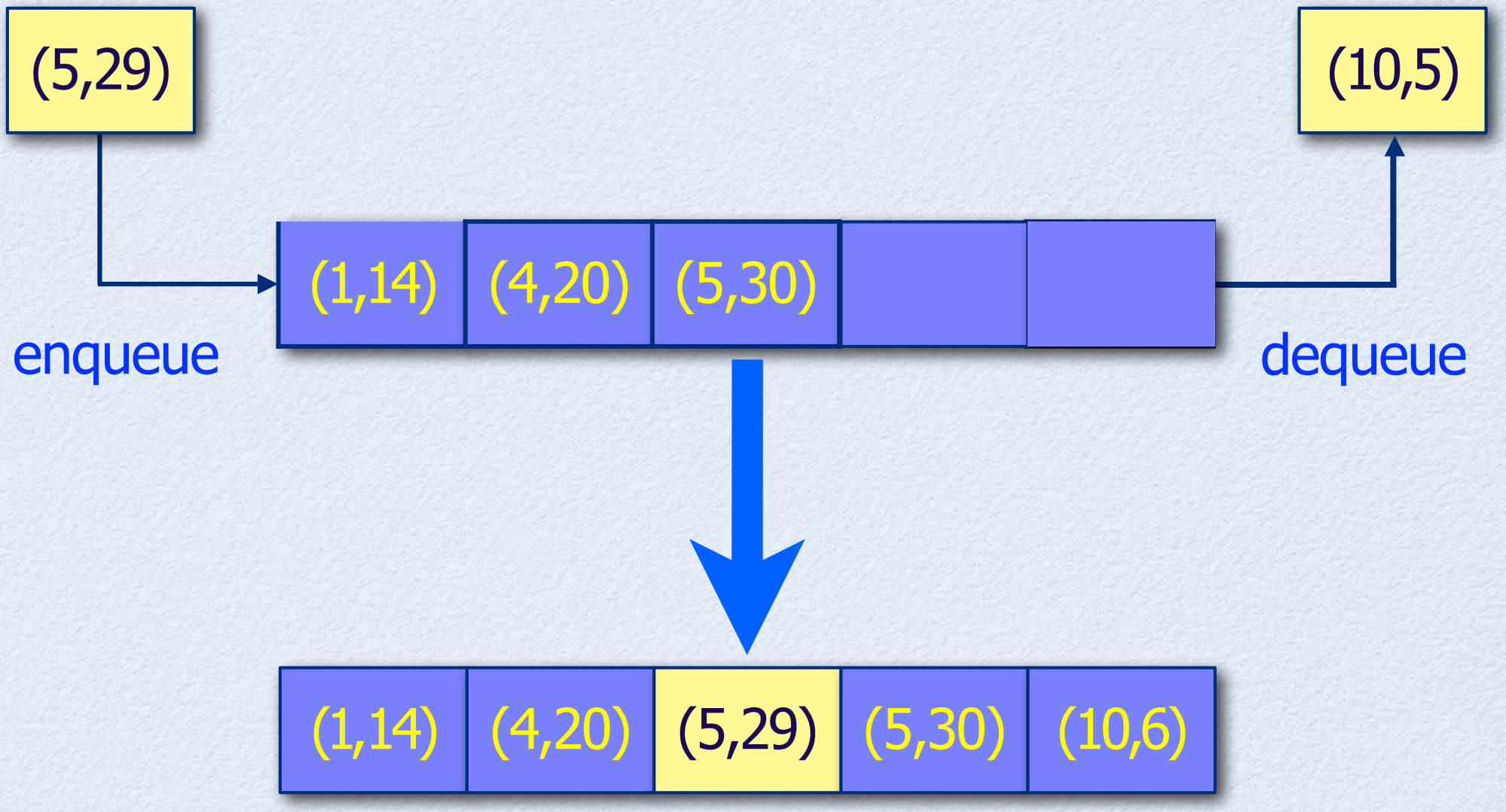
COS30008

```
Kamala:COS30008 Markus$ ./QueueTest
Number of elements in the queue: 3
value: 20
value: 3
value: 37
Number of elements in the queue: 0
Kamala:COS30008 Markus$
```

Requirements for a Priority Queue

- The underlying data structure for a priority queue must be sorted (e.g., SortedList<T>).
- Elements are queued using an integer to specify priority. We use a Pair<Key, T> to store elements with their associated priority.
- We need to provide a matching operator< on key values to sort elements in the priority queue.

Priority Queue



SortedList SPEC.h

```
#include "DoublyLinkedList.h"
#include "DoublyLinkedListIterator.h"

#include <stdexcept>

template<class T>
class SortedList
{
private:
    // auxiliary definition to simplify node usage
    using Node = DoublyLinkedList<T>;

    Node* fRoot;    // the first element in the list
    int fCount;     // number of elements in the list

public:
    // auxiliary definition to simplify iterator usage
    using Iterator = DoublyLinkedListIterator<T>;

    SortedList();                                       // default constructor - creates empty list
    SortedList( const SortedList& aOtherList );         // copy constructor
    SortedList( SortedList&& aOtherList );              // move constructor
    SortedList& operator=( const SortedList& aOtherList ); // assignment operator
    SortedList& operator=( SortedList&& aOtherList );   // move assignment operator
    ~SortedList();                                      // destructor - frees all nodes

    bool isEmpty() const;                               // Is list empty?
    int size() const;                                   // list size

    void insert( const T& aElement );                   // adds aElement at proper position
    void insert( T&& aElement );                        // adds aElement at proper position
    void remove( const T& aElement );                   // remove first match from list

    const T& operator[]( size_t aIndex ) const;         // list indexer

    Iterator begin() const;                             // return a forward iterator
    Iterator end() const;                               // return a forward end iterator
    Iterator rbegin() const;                            // return a backwards iterator
    Iterator rend() const;                              // return a backwards end iterator
};
```

Line: 3 Column: 1 C++ Tab Size: 4

The Pair Class

Pair.h

```
4  template<class K,class V>
5  struct Pair
6  {
7      K key;
8      V value;
9
10     Pair( const K& aKey, const V& aValue ) : key(aKey), value(aValue)
11     {}
12
13     bool operator<( const Pair<K,V>& aOther ) const
14     {
15         return key < aOther.key;
16     }
17
18     bool operator==( const Pair<K,V>& aOther ) const
19     {
20         return key == aOther.key && value == aOther.value;
21     }
22 };
```

Line: 2 Column: 13 C++ Tab Size: 4

SortedList uses an increasing order.

A Priority Queue

PriorityQueue SPEC.h

```
4  #include "SortedList.h"
5
6  template<class T>
7  class PriorityQueue
8  {
9  private:
10     SortedList<T> fElements;
11
12 public:
13
14     bool isEmpty() const;                  // empty queue predicate
15     size_t size() const;                   // get number of elements
16     void enqueue( const T& aElement );     // insert element
17     void enqueue( T&& aElement );          // insert element
18     void dequeue();                        // remove element at front
19     const T& top() const;                  // access element at front
20 };
21
```

Line: 2 Column: 13 C++ Tab Size: 4

Priority Queue Semantics

PriorityQueue.h

```
27      void enqueue( const T& aElement )   // insert element
28      {
29          fElements.insert( aElement );
30      }
31
32      void enqueue( T&& aElement )        // insert element
33      {
34          fElements.insert( aElement );
35      }
36
37      void dequeue()                      // remove element at end
38      {
39          if ( isEmpty() )
40          {
41              throw std::underflow_error( "Queue empty." );
42          }
43
44          fElements.remove( fElements[size() - 1] );
45      }
46
47      const T& top() const                // access element at front
48      {
49          if ( isEmpty() )
50          {
51              throw std::underflow_error( "Queue empty." );
52          }
53
54          return fElements[size() - 1];
55      }
```

Line: 19 Column: 27 C++ Tab Size: 4 isEmpty

A PriorityQueue Test

PriorityQueueTest.cpp

```
7  int main()
8  {
9      PriorityQueue< Pair<int,int> > lQueue;
10
11     Pair<int,int> p1( 4, 20 );
12     Pair<int,int> p2( 5, 30 );
13     Pair<int,int> p3( 5, 29 );
14
15     lQueue.enqueue( p1 );
16     lQueue.enqueue( p2 );
17     lQueue.enqueue( p3 );
18
19     cout << "Number of elements in the queue: " << lQueue.size() << endl;
20
21     cout << "value: " << lQueue.top().value << endl; lQueue.dequeue();
22     cout << "value: " << lQueue.top().value << endl; lQueue.dequeue();
23     cout << "value: " << lQueue.top().value << endl; lQueue.dequeue();
24
25     cout << "Number of elements in the queue: " << lQueue.size() << endl;
26
27     return 0;
28 }
```

Line: 2 Column: 18 C++ Tab Size: 4

COS30008

```
Kamala:COS30008 Markus$ ./PriorityQueueTest
Number of elements in the queue: 3
value: 30
value: 29
value: 20
Number of elements in the queue: 0
Kamala:COS30008 Markus$
```