Intermediate Programming

Day 23

Outline

- Templates and the STL
- `std::vector`
- Iterators
- Review questions

Templates (overview)

Q: What is a *template*?

A: Consider an example:

- What needs to change if I want to make the payload member a float/string/etc. instead of an int?

```
…
using std::cout;
using std::endl;


struct Node
{
	int payload;
	Node *next;
};


void print( const Node *n )
{
	cout << n->payload << " ";
	if( n->next ) print( n->next );
	else		cout << endl;
}

int main( void )
{
	Node *node;
	…
	print( node );
}
```

Templates (overview)

Q: What is a *template*?

A: Consider an example:

- What needs to change if I want to make the `payload` member a `float`/`string`/etc. instead of an `int`?

Note:

In C++ we can declare a `struct` directly, without having to `typedef`.

```
…
using std::cout;
using std::endl;


struct Node
{
        int payload;
        Node *next;
};


void print( const Node *n )
{
        cout << n->payload << " ";
        if( n->next ) print( n->next );
        else          cout << endl;
}

int main( void )
{
        Node *node;
        …
        print( node );
}
```

Templates (overview)

Q: What is a *template*?

A: Templates are a way of describing a generic class (Node) or function (print) and allowing it to work with a parameterized family of types*

⇒ Instead of defining a single class / function, we provide the compiler with a recipe for generating the class / function for whichever type we need, as we need it

*More on this later

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
	PType payload;
	Node* next;
};

template< class T >
void print( const Node< T > *n )
{
	cout << n->payload << " ";
	if( n->next ) print( n->next );
	else		cout << endl;
}

int main( void )
{
	Node< int > *node;
	…
	print( node );
}
```

Templates (overview)

In this example:

- Node is now a *template* class, parameterized by a type referred to as PType

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
	PType payload;
	Node* next;
};

template< class T >
void print( const Node< T > *n )
{
	cout << n->payload << " ";
	if( n->next ) print( n->next );
	else		cout << endl;
}

int main( void )
{
	Node< int > *node;
	…
	print( node );
}
```

Templates (overview)

In this example:

- Node is now a *template* class, parameterized by a type referred to as PType
  - We declare payload to be of generic type PType

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
      PType payload;
      Node* next;
};

template< class T >
void print( const Node< T > *n )
{
      cout << n->payload << " ";
      if( n->next ) print( n->next );
      else          cout << endl;
}

int main( void )
{
      Node< int > *node;
      …
      print( node );
}
```

Templates (overview)

In this example:

- Node is now a *template* class, parameterized by a type referred to as PType
- When declaring a variable of type Node, we specify the payload type, in angle brackets

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
	PType payload;
	Node* next;
};

template< class T >
void print( const Node< T > *n )
{
	cout << n->payload << " ";
	if( n->next ) print( n->next );
	else		cout << endl;
}

int main( void )
{
	Node< int > *node;
	…
	print( node );
}
```

Templates (overview)

In this example:

- Node is now a *template* class, parameterized by a type referred to as PType
- When declaring a variable of type Node, we specify the payload type, in angle brackets
- When defining a function with a generic Node argument, the function is templated by Node's parameter
  - We are creating a recipe for the function
  - Note:
    We do not need to use the same parameter name
    T ≠ PType

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
      PType payload;
      Node* next;
};

template< class T >
void print( const Node< T > *n )
{
      cout << n->payload << " ";
      if( n->next ) print( n->next );
      else          cout << endl;
}

int main( void )
{
      Node< int > *node;
      …
      print( node );
}
```

Templates (overview)

In this example:

- Node is now a *template* class, parameterized by a type referred to as PType
- When declaring a variable of type Node, we specify the payload type, in angle brackets
- When defining a function with a generic Node argument, the function is templated by Node's parameter
  - We specify Node's parameter to be the generic type T

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
      PType payload;
      Node* next;
};

template< class T >
void print( const Node< T > *n )
{
      cout << n->payload << " ";
      if( n->next ) print( n->next );
      else          cout << endl;
}

int main( void )
{
      Node< int > *node;
      …
      print( node );
}
```

Templates (overview)

In this example:

- Node is now a *template* class, parameterized by a type referred to as PType
- When declaring a variable of type Node, we specify the payload type, in angle brackets
- When defining a function with a generic Node argument, the function is templated by Node's parameter
  - We specify Node's parameter to be the generic type T
  - When invoking the function, we do not need to specify the parameter type if it can be deduced from the arguments (in this case node is of type Node< int >).

```
…
using std::cout;
using std::endl;

template< class PType >
struct Node
{
      PType payload;
      Node* next;
};

template< class T >
void print( const Node< T > *n )
{
      cout << n->payload << " ";
      if( n->next ) print( n->next );
      else          cout << endl;
}

int main( void )
{
      Node< int > *node;

      …
      print( node );
}
```

The Standard Template Library

- The Standard Template Library (STL) is C++'s compendium of useful data structures and algorithms
  - `pair` – pair of values (possibly of different types)
  - `tuple` – a tuple of values (possibly of different types and arbitrary long)
  - `list` – linked list!
  - `vector` – dynamically-sized array
  - `array` – fixed-length array (not as useful as vector)
  - `map` – associative list, i.e. dictionary
  - `stack` – last-in first-out (LIFO)
  - `deque` – double-ended queue, flexible combo of LIFO/FIFO
  - and many more

Outline

- Templates and the STL
- `std::vector`
- Iterators
- Review questions

std::vector

A dynamically sized array of elements:

- The template parameter specifies the element type

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cin;
using std::cout;
int main( void )
{
        vector< float > grades;
        float grade;
        while( cin >> grade ) grades.push_back( grade );
        grades.insert( grades.begin() , 100 );
        cout << "First grade was " << grades[1] << endl;
        cout << "Last grade was " << grades[ grades.size()-1 ] << endl;
        return 0;
}
```

std::vector

- push_back:
  - inserts an element at the end
- insert
  - Insert an element before the prescribed position
- [ ] operator:
  - gives access to an element at a prescribed index
- size:
  - returns the number of elements in the vector

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cin;
using std::cout;
int main( void )
{
	vector< float > grades;
	float grade;
	while( cin >> grade ) grades.push_back( grade );
	grades.insert( grades.begin() , 100 );
	cout << "First grade was " << grades[1] << endl;
	cout << "Last grade was " << grades[ grades.size()-1 ] << endl;
	return 0;
}
```

std::vector

- back:
  - returns the last element
- pop_back:
  - removes the last element
- resize:
  - resizes the vector to be able to store a specified number of elements
- erase
- clear
- at
- empty

See:
http://www.cplusplus.com/reference/vector/vector/
for more std::vector functionality

std::vector

Using the [ ] operator and the **size** method, we can iterate over the entries of a **vector**

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cout;
using std::endl;
int main( void )
{
	vector< int > values;
	values.push_back( 1 );
	values.push_back( 3 );
	values.push_back( 2 );
	for( int i=0 ; i<values.size() ; ++i )
		cout << values[i] << " ";
	cout << endl;
	return 0;
}
```

```
>> ./a.out
1 3 2
>>
```

std::vector

Using the [ ] operator and the **size** method, we can iterate over the entries of a **vector**

Or we can use **iterators**

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cout;
using std::endl;
int main( void )
{
	vector< int > values;
	values.push_back( 1 );
	values.push_back( 3 );
	values.push_back( 2 );
	for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it )
		cout << *it << " ";
	cout << endl;
	return 0;
}
```

```
>> ./a.out
1 3 2
>>
```

std::vector

Using the [ ] operator and the **size** method, we can iterate over the entries of a **vector**

Or we can use **iterators**:

- The container defines its own **iterator** sub-class

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cout;
using std::endl;
int main( void )
{
	vector< int > values;
	values.push_back( 1 );
	values.push_back( 3 );
	values.push_back( 2 );
	for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it )
		cout << *it << " ";
	cout << endl;
	return 0;
}
```

```
>> ./a.out
1 3 2
>>
```

std::vector

Using the [ ] operator and the **size** method, we can iterate over the entries of a **vector**

Or we can use **iterators**:

- The container defines its own **iterator** sub-class
- Iterators are "clever pointers" that know how to move over elements of a container
  - Container could be simple (e.g. array) or more complicated (e.g. linked list) or very complicated (e.g. tree)

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cout;
using std::endl;
int main( void )
{
	vector< int > values;
	values.push_back( 1 );
	values.push_back( 3 );
	values.push_back( 2 );
	for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it )
		cout << *it << " ";
	cout << endl;
	return 0;
}
```

```
>> ./a.out
1 3 2
>>
```

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- Templates and the STL
- `std::vector`
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Forward iterators

```
vector< int > values;
…
for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it ) cout << *it << " ";
```

For an STL container of type *C* (in this example , *C*=vector< int >):

- The forward iterator has type *C*::iterator

Forward iterators

```
vector< int > values;
…
for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it ) cout << *it << " ";
```

For an STL container of type *C* (in this example , *C*=vector< int >):

- The forward iterator has type *C*::iterator
- The container defines a *C*::begin method
  - Returns an iterator to the first element in the container

Forward iterators

```
vector< int > values;
…
for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it ) cout << *it << " ";
```

For an STL container of type *C* (in this example , *C*=vector< int >):

- The forward iterator has type *C*::iterator
- The container defines a *C*::begin method
- The container defines a *C*::end method
  - Returns an iterator to the element just past the last element in the container

Forward iterators

```
vector< int > values;
…
for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it ) cout << *it << " ";
```

For an STL container of type **C** (in this example , **C=vector< int >**):

- The forward iterator has type **C::iterator**
- The container defines a **C::begin** method
- The container defines a **C::end** method
- **C::iterator** overloads the pre-increment operator **++**
  - Advances the iterator to the next element

Forward iterators

```
vector< int > values;
…
for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it ) cout << *it << " ";
```

For an STL container of type C (in this example , C=vector< int >):

- The forward iterator has type C::iterator
- The container defines a C::begin method
- The container defines a C::end method
- C::iterator overloads the pre-increment operator ++
- C::iterator overloads the inequality operator !=
  - Checks if two iterators are different

Forward iterators

```
vector< int > values;
…
for( vector< int >::iterator it=values.begin() ; it!=values.end() ; ++it ) cout << *it << " ";
```

For an STL container of type C (in this example , C=vector< int >):

- The forward iterator has type C::iterator
- The container defines a C::begin method
- The container defines a C::end method
- C::iterator overloads the pre-increment operator ++
- C::iterator overloads the inequality operator !=
- C::iterator overloads the dereference operator *
  - Returns the contents of what the iterator is “pointing to”

Reverse iterators

```
vector< int > values;
…
for( vector< int >::reverse_iterator it=values.rbegin() ; it!=values.rend() ; ++it ) cout << *it << " ";
```

For an STL container of type **C** (in this example , **C=vector< int >**):

- The reverse iterator has type **C::reverse_iterator**
- The container defines a **C::rbegin** method
- The container defines a **C::rend** method

Reverse iterators

```
vector< int > values;
…
for( vector< int >::reverse_
```

For an STL contain

- The reverse iter
- The container d
- The container d

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cout;
using std::endl;
int main( void )
{
	vector< int > values;
	values.push_back( 1 );
	values.push_back( 3 );
	values.push_back( 2 );
	for( vector< int >::reverse_iterator it=values.rbegin() ; it!=values.rend() ; ++it )
		cout << *it << " ";
	cout << endl;
	return 0;
}
```

```
>> ./a.out
2 3 1
>>
```

Constant iterators

```
vector< int > values;
…
for( vector< int >::const_iterator it=values.cbegin() ; it!=values.cend() ; ++it ) cout << *it << " ";
```

For an STL container of type *C* (in this example , *C*=vector< int >):

- The constant iterator has type *C*::const_iterator
  - The contents of the container cannot be modified
- The container defines a *C*::cbegin method
- The container defines a *C*::cend method

Constant iterators

```
vector< int > values;
...
for( vector< int >::const_it
```

For an STL contain

- The constant ite
  - The contents c
- The container d
- The container d

main.cpp

```
#include <iostream>
#include <vector>
using std::vector;
using std::cout;
using std::endl;
int main( void )
{
	vector< int > values;
	values.push_back( 1 );
	values.push_back( 3 );
	values.push_back( 2 );
	for( vector< int >::const_iterator it=values.cbegin() ; it!=values.cend() ; ++it )
		cout << *it << " ";
	cout << endl;
	return 0;
}
```

```
>> ./a.out
1 3 2
>>
```

Iterators

In general, iterators act like “smart” pointers, allowing us to iterate through the contents of a container and get its values.

For iterators `iter1` and `iter2`, supported operations include:

- Increment: `iter1++` or `++iter1`
- Dereference: `*iter`
- Assignment: `iter1=iter2`
- Comparison: `iter1!=iter2` or `iter1==iter2`

Random access iterators

Like pointers, some iterators also support arithmetic (random access).

For iterators `iter1` and `iter2` and integer `n` supported operations include:

- Arithmetic: `iter1=iter2+n` or `iter1=iter2-n`
- Compound arithmetic: `iter1+=n` or `iter1-=n`
- Comparison: `iter1<=iter2`, `iter1>iter2`, etc.
- Differencing: `n=iter2-iter1`

Note:

Not all iterators support random access:

✓ `std::vector::iterator` does

× `std::list::iterator` does not

Outline

- Templates and the STL
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Review questions

1. What is a template in C++?

A way of writing an object (generalization of a struct) so that they can work with any type

Review questions

2. What is the standard template library?

A collection of standardly used, templated objects and functions

Review questions

3. How do you iterate a `std::vector` and print out its elements?

```
for( int i=0 ; i<v.size() ; i++ )
        std::cout << v[i] << std::endl;
```

or

```
for( vector<type>::iterator it=v.begin() ; it!=v.end ; it++ )
        std::cout << *it << std::endl;
```

Review questions

4. What is an iterator in C++?

Clever pointers, defined as a subclass of the container, that know how to move over the components of the container (e.g. support increment and dereferencing)

Review questions

5. How do you add an element to an existing `std::vector`?

Use the `push_back` or `insert` method.

Review questions

6. (Bonus) What is the output of this program?

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

v = {}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=1

v = {0.5}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=2

v = {0.5, 4.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=3

v = {1.5, 0.5, 4.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=4

v = {1.5, 0.5, 4., 8.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=5

v = {2.5, 1.5, 0.5, 4., 8.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=6

v = {2.5, 1.5, 0.5, 4., 8., 12.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=7

v = {3.5, 2.5, 1.5, 0.5, 4., 8., 12.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=8

v = {3.5, 2.5, 1.5, 0.5, 4., 8., 12., 16.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

i=9

v = {4.5, 3.5, 2.5, 1.5, 0.5, 4., 8., 12., 16.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?

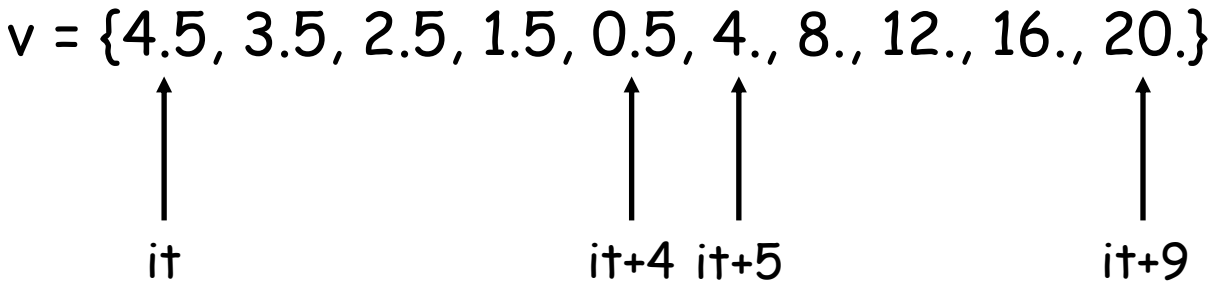
i=10

v = {4.5, 3.5, 2.5, 1.5, 0.5, 4., 8., 12., 16., 20.}

```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Review questions

6. (Bonus) What is the output of this program?




```
#include <iostream>
#include <vector>
using std::cin;
using std::cout;
using std::endl;
using std::vector;
int main( void )
{
	vector< double > v;
	for( int i=1 ; i<=10 ; i++ )
	{
		if( i%2==1 ) v.insert( v.begin() , i/2.0 );
		else v.push_back( i*2.0 );
	}
	vector< double >::iterator it = v.begin();
	cout << "first == " << *it << endl;
	cout << "middle1 == " << *(it + 4) << endl;
	cout << "middle2 == " << *(it + 5) << endl;
	cout << "last == " << *(it + 9) << endl;
}
```

Exercise 23

- Website -> Course Materials -> Exercise 23