Looping

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Reference material

The following slides are a high-level introduction;
for details see: chapter Textbook, section 6 upto Textbook, section 6.4

For loops

1. 'For' statement

Sometimes you need to repeat a statement a number of times. That's where the loop comes in. A loop has a counter, called a loop variable, which (usually) ranges from a lower bound to an upper bound.

Here is the syntax in the simplest case:

```
1 // loop/sumsquares.cpp
2 int sum_of_squares{0};
3 for (int var=low; var<upper; ++var) {
4   sum_of_squares += var*var;
5 }
6 cout << "The sum of squares from "
7      << low << " to " << upper
8      << " is " << sum_of_squares << '\n';
```

2. Loop variable

Old-style loop declaration:

```
1 int i;
2 for ( i=0; i<N; i++ )
3   // stuff
```

- Variable should be local to a loop (legal syntax since C99)
- Trouble later with OpenMP

3. Loop syntax: variable

The loop variable is usually an integer:

```
1 for ( int index=0; index<max_index; index=index+1) {
2   ...
3 }
```

But other types are allowed too:

```
1 for ( float x=0.0; x<10.0; x+=delta ) {
2   ...
3 }
```

Beware the stopping test for non-integral variables!

4. Loop syntax: test

- If this boolean expression is true, do the next iteration.
- Done before the first iteration too!
- Test can be empty. This means no test is applied.

```
1 for ( int i=0; i<N; i++) {...}
2 for ( int i=0; ; i++ ) {...}
```

5. Loop syntax: increment

Increment performed after each iteration. Most common:

- `i++` for a loop that counts forward;
- `i--` for a loop that counts backward;

Others:

- `i+=2` to cover only odd or even numbers, depending on where you started;
- `i*=10` to cover powers of ten.

Even optional:

```
1 for (int i=0; i<N; ) {
2   // stuff
3   if ( something ) i+=1; else i+=2;
4 }
```

Quiz 1

For each of the following loop headers, how many times is the body executed? (You can assume that the body does not change the loop variable.)

```
1 for (int i=0; i<7; i++)
```

```
1 for (int i=0; i<=7; i++)
```

```
1 for (int i=0; i<0; i++)
```

Quiz 2

What is the last iteration executed?

```
1 for (int i=1; i<=2; i=i+2)
```

```
1 for (int i=1; i<=5; i*=2)
```

```
1 for (int i=0; i<0; i--)
```

```
1 for (int i=5; i>=0; i--)
```

```
1 for (int i=5; i>0; i--)
```

Exercise 1

Take this code:

```
1 // loop/sumsquares.cpp
2 int sum_of_squares{0};
3 for (int var=low; var<upper; ++var) {
4   sum_of_squares += var*var;
5 }
6 cout << "The sum of squares from "
7      << low << " to " << upper
8      << " is " << sum_of_squares << '\n';
```

and modify it to sum only the squares of every other number, starting at *low*.

Can you find a way to sum the squares of the even numbers $\geq$*low*?

Programming Project Exercise 2

Read an integer and set a boolean variable to determine whether it is prime by testing for the smaller numbers if they divide that number.

Print a final message

```
Your number is prime
```

or

```
Your number is not prime: it is divisible by ....
```

where you report just one found factor.

6. Nested loops

Traversing a matrix
(we will discuss actual matrix data structures later):

```
1 for (int row=0; row<m; row++)
2   for (int col=0; col<n; col++)
3     ...
```

This is called 'loop nest', with

`row`: outer loop

`col`: inner loop.

7. Indefinite looping

Sometimes you want to iterate some statements not a predetermined number of times, but until a certain condition is met. There are two ways to do this.

First of all, you can use a 'for' loop and leave the upper bound unspecified:

```
1 for (int var=low; ; var=var+1) { ... }
```

8. Break out of a loop

This loop would run forever, so you need a different way to end it. For this, use the `break` statement:

```
1 for (int var=low; ; var=var+1) {
2   statement;
3   if (some_test) break;
4   statement;
5 }
```

Exercise 3

The integer sequence

$$u_{n+1} = \begin{cases} u_n/2 & \text{if } u_n \text{ is even} \\ 3u_n + 1 & \text{if } u_n \text{ is odd} \end{cases}$$

leads to the Collatz conjecture: no matter the starting guess u_1, the sequence $n \mapsto u_n$ will always terminate at 1.

$$5 \to 16 \to 8 \to 4 \to 2 \to 1$$

$$7 \to 22 \to 11 \to 34 \to 17 \to 52 \to 26 \to 13 \to 40 \to 20 \to 10 \to 5 \cdots$$

(What happens if you keep iterating after reaching 1?)

Try all starting values $u_1 = 1, \ldots, 1000$ to find the values that lead to the longest sequence: every time you find a sequence that is longer than the previous maximum, print out the starting number.

Breaking out of a loop

Reference material

The following slides are a high-level introduction;
for details see: section Textbook, section 6.3

9. Where did the break happen?

Suppose you want to know what the loop variable was when the break happened. You need the loop variable to be global:

```
1 int var;
2 ... code that sets var ...
3 for ( ; var<upper; var++) {
4   ... statements ...
5   if (some condition) break
6   ... more statements ...
7 }
8 ... code that uses the breaking value of var ...
```

In other cases: define the loop variable in the header!

10. Test in the loop header

If the test comes at the start or end of an iteration, you can move it to the loop header:

```
1 bool need_to_stop{false};
2 for (int var=low; !need_to_stop ; var++) {
3   ... some code ...
4   if ( some condition )
5     need_to_stop = true;
6 }
```

Exercise 4

Write an i, j loop nest that prints out all pairs with

$$1 \leq i, j \leq 10, \quad j \leq i.$$

Output one line for each `i` value.

Now write an i, j loop that prints all pairs with

$$1 \leq i, j \leq 10, \quad |i - j| < 2,$$

again printing one line per `i` value. Food for thought: this exercise is definitely easiest with a conditional in the inner loop, but can you do it without?

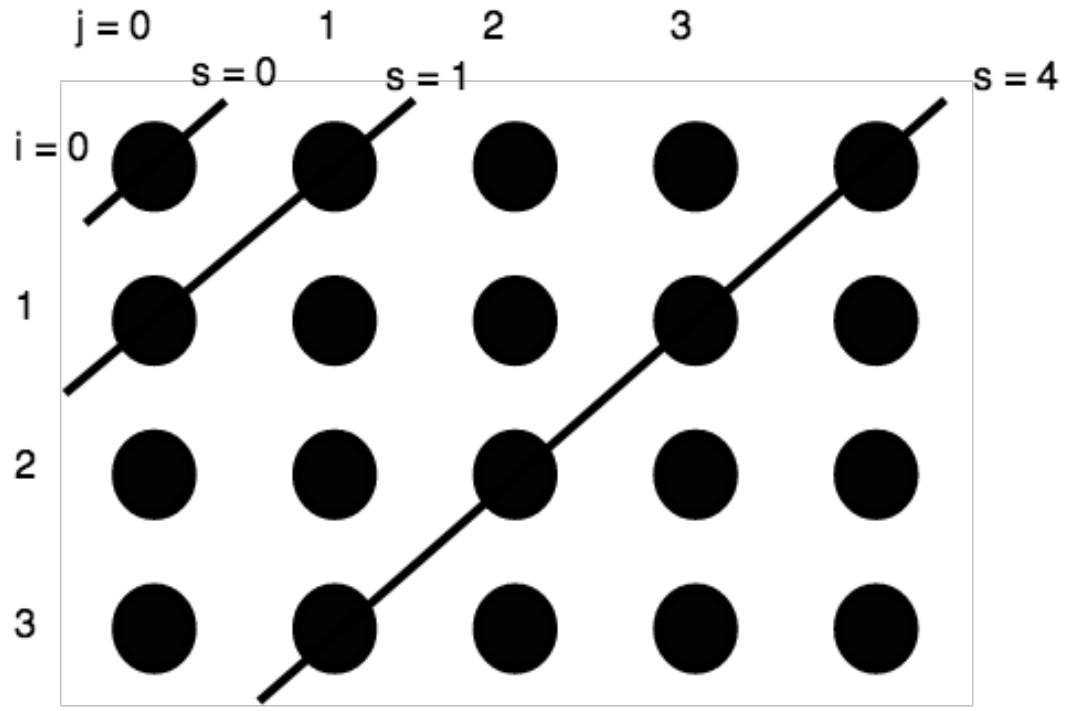
Exercise 5

Write a double loop over $0 \leq i, j < 10$ that prints the first pair where the product of indices satisfies $i \cdot j > N$, where N is a number your read in. A good test case is $N = 40$.

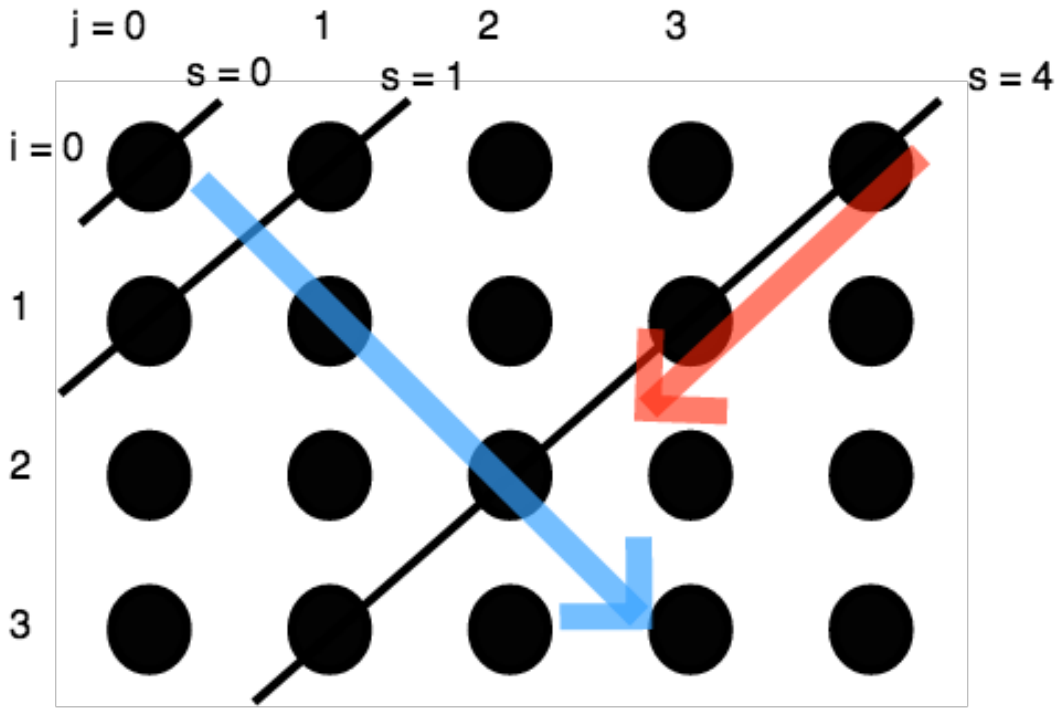
Secondly, find a pair with $i \cdot j > N$, but with the smallest value for $i + j$. (If there is more than one pair, report the one with lower i value.) Can you traverse the i, j indices such that they first enumerate all pairs $i + j = 1$, then $i + j = 2$, then $i + j = 3$ et cetera? Hint: write a loop over the sum value $1, 2, 3, \ldots$, then find i, j.

You program should print out both pairs, each on a separate line, with the numbers separated with a comma, for instance `8,5`.

Suggestive picture 1



Suggestive picture 2



Turn it in!

- If you have compiled your program, do:

  `coe_ij yourprogram.cc`

  where '`yourprogram.cc`' stands for the name of your source file.
- Is it reporting that your program is correct? If so, do:

  `coe_ij -s yourprogram.cc`

  where the `-s` flag stands for 'submit'.

11. Skip iteration

```
1 for (int var=low; var<N; var++) {
2   statement;
3   if (some_test) {
4     statement;
5     statement;
6   }
7 }
```

Alternative:

```
1 for (int var=low; var<N; var++) {
2   statement;
3   if (!some_test) continue;
4   statement;
5   statement;
6 }
```

The only difference is in layout.

While loops

Reference material

The following slides are a high-level introduction;
for details see: section Textbook, section 6.3.1

12. While loop

Syntax:

```
while ( condition ) {
  statements;
}
```

or

```
do {
  statements;
} while ( condition );
```

13. Pre-test while loop

```
1 float money = inheritance();
2 while ( money < 1.e+6 )
3   money += on_year_savings();
```

14. While syntax 1

Code:

```
1 // basic/whiledo.cpp
2 cout << "Enter a positive number: "
      ;
3 cin >> invar; cout << '\n';
4 cout << "You said: " << invar << '\n
      ';
5 while (invar<=0) {
6   cout << "Enter a positive number:
      " ;
7   cin >> invar; cout << '\n';
8   cout << "You said: " << invar <<
      '\n';
9 }
10 cout << "Your positive number was "
11      << invar << '\n';
```

Output:

```
1 Enter a positive
      ↪number:
2 You said: -3
3 Enter a positive
      ↪number:
4 You said: 0
5 Enter a positive
      ↪number:
6 You said: 2
7 Your positive number
      ↪was 2
```

Problem: code duplication.

15. While syntax 2

Code:

```
1 // basic/dowhile.cpp
2 int invar;
3 do {
4   cout << "Enter a positive number:
      " ;
5   cin >> invar; cout << '\n';
6   cout << "You said: " << invar <<
      '\n';
7 } while (invar<=0);
8 cout << "Your positive number was: "
9      << invar << '\n';
```

Output:

```
1 Enter a positive
      ↪number:
2 You said: -3
3 Enter a positive
      ↪number:
4 You said: 0
5 Enter a positive
      ↪number:
6 You said: 2
7 Your positive number
      ↪was: 2
```

The post-test syntax leads to more elegant code.

Optional exercise 6

A horse is tied to a post with a 1 meter elastic band. A spider that was sitting on the post starts walking to the horse over the band, at 1cm/sec. This startles the horse, which runs away at 1m/sec. Assuming that the elastic band is infinitely stretchable, will the spider ever reach the horse?