Loops

Loops will allow our programs to repeat the same action over and over. The most general version of a loop is a while loop, but there are other specialized loops such as for, which is used when we know how many times the loop should run, and do-while, which is used when we know the loop must run at least once. Like conditionals, loops are controlled with boolean values; the statements in a loop are run repeatedly as long as the loops condition is true, and stop when it is false. The two most common types of loop errors are infinite loops, which never stop, and no-loops, which never start.

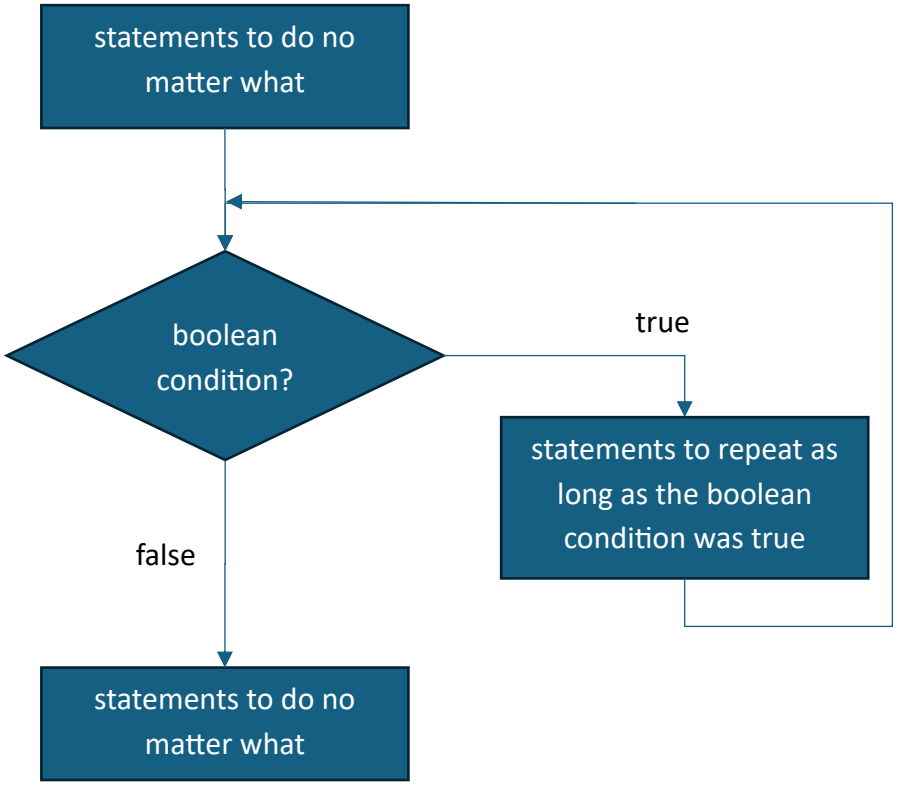
While

The simplest version of a loop is a while loop. The keyword `while` is followed by a boolean condition in parentheses, which must have been set up before the loop. Inside the while structure we put the sequence of statements that we want to repeat for as long as the while's condition remains true. The structure ends with the keyword `endwhile`.

```
statements to do no matter what – need to set up the loop
     condition
while (boolean_condition)
     statements to do as long as the condition is true –
     need to have the opportunity to eventually change the
     condition
endwhile
statements to do no matter what
```

When we reach the while in the execution of code, the condition is evaluated. If it is true, we run through all the statements inside the while structure, but if it is false, we skip them and go on with the rest of the program. If it was true and we ran the statements, we then jump back and re-evaluate the condition to see whether it is still true, and we keep doing this until it is false, and which point we jump to after the while structure and go on with the rest of the program.

To picture this:



Here is a sequence of statements

```
int x = 0
print x
x = x + 1 // x is 1
print x
x = x + 1 // x is 2
print x
x = x + 1 // x is 3
print x
x = x + 1 // x is 4
print x
x = x + 1 // x is 5
```

We could describe this as "x starts as 0 and we want to print x and add 1 to it, as long as x is under 5. This is tedious enough if we only go from 0 to 4. If instead we wanted to go from 0 to 499, it would be horrendous!

Here is the loop version of the code above.

```
int x = 0
while (x < 5)
```

```
        print x
        x = x + 1 // x is 1 bigger than it was
    endwhile
```

x goes through the same values and gets printed each time. Notice that if we want to change this loop so that we count from 0 to 499, the code doesn't get any longer, we just write x < 500 instead of x < 5.

Notice also that computer scientists usually count from 0. It is not uncommon to translate "computer scientist numbers" to "human numbers" when printing, in which case we would just print x+1 each time.

It is important that the code inside the while structure can change the value of the boolean condition and eventually make it false. In this case, we were checking for x < 5, so we had code inside the loop to move x towards 5 by adding one to it each time.

For this first example we were simply doing something a certain number of times; actually we have a specialized loop, the for, that we usually use for such situations. We often think of the code inside a while loop as either something we want to keep doing, but can only do as long as the condition is true, or else something we have to do as long as the condition is true, until we fix it. Either way, a while is generally used when we do not know how many times we will have to run the loop before it stops, called an *indefinite loop*. Any time our program is interacting with a user, or other source of unpredictable input, we probably want a while loop.

In many cases, we would create a *loop control variable*, to keep track of whether the loop should continue or not. We could think of the x above as a loop control variable, but for while loops it is common for these variables to be booleans. For instance, suppose we are having the user guess our secret number:

```
int sekrit = 47
int user = 0
// loop control variable
boolean done = false
// as long as we are not done
while ( NOT done)
     user = prompt "guess?"
     // decide if we are done based on user input
     if (user == sekrit) then
          done = true
     endif
endwhile
print "you guessed it!"
```

The boolean done keeps track of whether the user guessed or not. If they did we are done, but until then we are not done.

Notice that we put a conditional inside the loop; we can always nest like this.

Notice also: while always checks its condition for true, not false – it is a *while* loop not an *until* loop. If it is easier to describe the condition under which we want to stop, we just put a NOT in front of it. We can use any boolean expression, including relational and logical operators, as our loop condition.

In the case that there are various things that might happen to cause the loop to end, having a single boolean like done is usually the right approach.

However, in a simple situation like this, where the value of done is always the same as the result of checking whether the user guessed the secret number, we could put that check directly into the while (remembering we want the loop to continue as long as we are NOT done)…

```
int sekrit = 47
int user = 0
while (user != sekrit)
     user = prompt "guess?"
endwhile
print "you guessed it!"
```

Notice that this loop depends on setting the user variable to a starting value, 0, before the loop starts. This starting value, sometimes called a *dummy value*, can be anything but the one value (in this case 47) that would make the loop not start. It does not matter what other value we use for the dummy value, because the first thing we're going to do in the loop is replace the dummy value with something we read in from the user.

Infinite Loops and No-Loops

An *infinite loop* is one that can start, but which then runs the statements inside the loop forever and never continues with the rest of the program.

One way an infinite loop could happen is that we simply wrote a condition that can never be false:

```
while (x < 3 || x > 3 || x == 3)
          x = x + 1
endwhile
```

In this code, no matter what value x has, the condition will be true, because every number is either less than, greater than, or equal to three. This example is (hopefully) easy to spot as a *tautology* – an expression that is always true. In your real programs you might end up having to work your way through a truth table for your boolean expression to check whether it can ever come out false.

Another way an infinite loop could happen is that the condition never gets the chance to change inside the loop. In general, this will mean that the loop control variable never has the chance to change.

```
int x = prompt "guess"
while (x != 47)
          print “guess again!”
endwhile
```

In this code we got a value for x before the loop started, but inside the loop, while we printed the words “guess again” we never actually prompted the user for a new value of x. If there is no code inside the loop that assigns the loop variable, that is a good sign that we are having this problem. But the problem could be more complicated, for example we might have a statement that can change the variable, but that change is inside a conditional, and the boolean for that conditional was written incorrectly so that it can never be true.

Finally, we could change the condition, but do so in a way that does not end the loop. For instance we could change the value of the condition variable, but then change it back, or we could change it in the wrong way

```
int x = 100
while (x > 0)
     x = x + 1
endwhile
```

This code does change x, but x started at 100 and is going to continue until it gets down to 0 or lower, so for the loop to end, x would have to be decreased. Instead we are increasing it. For another example

```
int x = 100
int y = 101
while (x < y)
     x = x + 1
     y = y + 1
endwhile
```

In this example, known as *moving the goalposts*, we are changing both variables in the condition, so that although we update x to move towards y, we keep moving y farther up at the same pace.

If the boolean condition of a while is false the first time we check it, we will simply skip the statements inside the loop entirely and go on with the rest of the program. This is not a problem. However, if the way we wrote the condition means that it is never, under any circumstances, true, then the loop might as well not be in the program, and this problem is called a *no loop*.

```
while (x > 3 && x < 3)
          x = x + 1
endwhile
```

This code is a no-loop because there are no numbers that are greater than and less than 3 at the same time. Since the problem with a no-loop is that it never runs the code inside the loop structure, the cause of the no-loop can only be the condition, not the code inside the loop (obviously, this does not mean that the code inside the loop is correct, just that it isn't causing the no-loop).

Do-While Loops

A *do-while* loop is designed for the case where we must always do the code in the loop at least once, even if we don't repeat it again after that. This is also called a post-test loop, because it checks its boolean condition at the end of the loop instead of the start.

A do-while begins with the keyword do, then has the code we want to repeat, and ends with the keyword while and, in parentheses, the boolean condition that is true as long as we want to repeat the do-while code.

```
statements to do no matter what – need to set up the loop
     condition
do
     statements to do at least once and repeat as long as
     the condition is true – need to have the opportunity
     to eventually change the condition
while (boolean_condition)
statements to do no matter what
```

do-while loops are often used for input validation. *Defensive programming* is the practice of writing programs that proactively assume that input values may be invalid; one good basic tool is to include *validation loops* every time we get user input. Since we have to get the input once anyway, but then may have to repeat if the input is bad, this is a good use for a do-while.

```
double income
do
      income = prompt "income? (value cannot be negative)"
while (income < 0)
```

This code reads in the user's income, but if they give a negative value, makes them keep trying. Notice that in a do-while, they see the same prompt every time, even after giving an invalid answer. If we want to give a different prompt to tell them their previous answer was wrong, we'd have to nest a conditional inside the do-while. A validation loop with a normal while would allow us to add this alternative prompt more naturally:

```
double income = prompt "income? (value cannot be negative)"
while (income < 0)
     print income + " is negative, please try again"
     income = prompt "income?"
endwhile
```

So it depends on how important it is to add extra clarifications when the user gives us a bad response.

For Loops

A *for* loop is designed for the very common case where we need to do the code inside the loop a certain number of times, a *definite loop*, also known as a *counter controlled loop*.

Suppose we try to use a while loop to do a counted task:

```
int count = 0 // initialize counter
while (count < 10) // check counter
     print "#" + count
     count = count + 1 // update counter
endwhile
```

Other than the actual task for the loop-- printing-- the things we had to do to make this loop work were: to initialize the counter, check the counter in the condition, and update the counter so that the loop can eventually end.

A for loop collects these three standard parts of counting in a loop and puts them all on one line at the top of the loop. This makes it easy at a glance to see where the loop starts, how long it keeps going, and how the counter changes. Here's the same code in a for, but with the three parts on different lines:

```
for (int count = 0; // initialize counter
     count < 10; // check counter
     count = count + 1) // update counter
```

```
     print "#" + count
endfor
```

But the head of a for loop is almost always written on a single line:

```
for (int count = 0; count < 10; count = count + 1)
          print "#" + count
endfor
```

The keyword for has parentheses containing: a statement that initializes the loop variable, then a boolean condition, then a statement that changes the loop variable, with semicolons as separators. The structure ends with endfor, and in between in the body of the loop we have the statements to be repeated as long as the condition is true.

When for is evaluated, the initialization statement runs once, before the loop starts, then the boolean condition is evaluated. If the condition is false, we skip the loop and go on to the rest of the program, but if it is true we run the statements inside the loop structure. When we reach the endfor, we come back and evaluate the update statement, and then check the boolean condition again, and if it is still true, repeat the loop code.

```
code to do no matter what
for (initialize counter; boolean_condition; update counter)
     statements to repeat as long as condition is true – it
     makes sense to use the counter in this code, but we
     should not change the counter inside the loop
endfor
code to do no matter what
```

A for loop can actually put any statement in the initialization and update positions, and any boolean as its condition, so we can do anything with a for loop that we could do with a while loop, but most of the time for loops have the same parts – set a counter to an initial value, check the counter against a bound, update the counter by an increment:

```
// initial value 0, upper bound 10, increment 1
for (int count = 0;      count < 10; count = count + 1)
     // things to do while counting from 0 to 9
endfor
```

Most of the time we start at 0 and count up by incrementing the counter, but the math could be different:

```
// initial value 100, lower bound 10, decrement 5
for (int count = 0;      count > 10; count = count - 5)
     // things to do while counting down from 100 by 5's
endfor
```

Code inside a for loop often makes use of the value of the counter, but it is usually a bad idea to *change* the value of the counter inside the loop. Programmers are used to being able to look at the top of the for loop and know how long the loop runs; if something inside the loop can change that, the for loop is much less readable.

But what if we are writing a loop for a situation that is mostly definite, depending on the value of a counter, but somewhat indefinite, because under some situations it could end early? What if we need to go through 1000 values, but if we find what we were looking for we can stop? We want to end early if we can! It is tempting to have a conditional inside the loop that just jumps the counter ahead to the end, but this makes the code hard to follow. Instead, we can simply change the boolean conditional: although most for loops just compare the counter to some bound, we can actually put any boolean expression in a for, so we can use logical operators like AND and OR to describe in more detail how long the loop should repeat.

```
// loop happens 1000 times but could end early
for (int i = 0; i < 10000 && !doneEarly; i = i + 1)
     // things to do 1000 times
     // add in a conditional to check if we are done early
endfor
```

Nested Loops

We can put structures inside other structures to create more complex code. Earlier we put a conditional inside a loop. This is a very frequent construction. A while with an if inside means that we are repeatedly making a decision. A for loop with an if inside means we are making a decision a certain number of times. We can also put an if outside a loop in order to choose whether or not to do the loop at all.

We can also nest a loop inside another loop. We would talk about the “outer loop” and “inner loop” or “big” and “little” loop. Tracing through nested for loops should help understand how nesting works for loops:

```
for (int i = 0; i < 3; i = i + 1)
     print "i is " + i
     for (int j = 0; j < 4; j = j + 1)
         print "(" + i + " " + j + ")"
     endfor
endfor
```

This prints (shown in 3 columns just for readability, read down each column, then across):

```
i is 0
(0,0)
(0,1)
(0,2)
(0,3)
 continued…
```

```
i is 1
(1,0)
(1,1)
(1,2)
(1,3)
       continued…
```

```
i is 2
(2,0)
(2,1)
(2,2)
(2,3)
```

First thing to notice: after `(0,0)` the next pair is `(0,1)` not (1,1) because j is still less than 4. We have to finish going all the way through the inner (j) loop before we will get back to the outer (i) loop and be able to get to i.

Second thing to notice: After `(0,3)` we have finally finished the inner (j) loop so we finally update i and get `i is 1`, and after that `(1,0)`, not (1,4) because when we re-started the code in the body of the outer (i) loop, this included creating a new j variable starting at 0. Remember that variables only exist in the scope where they were created, so the previous j was thrown away when we completed the inner (j) loop for the first time.

So, when we nest a loop inside another loop, each trip through the outer loop restarts the inner loop from scratch, and then we have to finish the inner loop entirely before we finish that iteration of the outer loop.

If the outer loop is a while loop and the inner loop is a for loop, that means we don't know how many times we will do something, but each time it will involve a known number of repeats. If the outer loop is a for loop and the inner loop is a while loop, that means we are doing something a certain number of times, and each time there is a step we don't know how many times we have to repeat.

Sentinel Values

Suppose we are getting values from a user, each of which we have to do some processing on, but we don't know how many there will be. One option is to ask the user how many; then we could use a for loop… but what if the user doesn't know either?

One approach is to have two inputs, one for data, and one for whether the loop should continue. Here is an example that does an average:

```
int sum = 0 // adding up the entered numbers
int count = 0 // how many numbers
int current // will hold user's current number
String ans = prompt "Is there another number (y/n)?"
```

```
while (ans == "y")
     current = prompt "What number?"
     count = count + 1
     sum  = sum + current
     ans = prompt "Is there another number (y/n)?"
endwhile
// could check for count == 0 if that is a problem
print "average: " + sum/count
```

To use this code, the user has to alternate between entering “y” and the data. Most people find using a program with this kind of input frustrating because it feels like doubling the length of the task, and also it is easy to get off-rhythm and accidentally enter a “y” when it should have been a number or a number when it should have been “y”.

We can instead let the user just enter data, but use a special value to indicate that we need to stop. This is called a *sentinel value*. Here is the average code with a sentinel:

```
int sum = 0 // adding up the entered numbers
int count = 0 // how many numbers
const int STOP = -989
print "Enter " + STOP + " to quit"

int current = 0 // anything but STOP

while (current != STOP)
     current = prompt "What number?"
     if (current != STOP) then
          count = count + 1
          sum  = sum + current
     endif
endwhile

print "average: " + sum/count
```

With this code, the user only has to type data, and when they are done, type the sentinel value, -989 and the loop will stop. Note that in this version, we read the value in at the top of the loop and then we needed to use a conditional to make sure that we did not tread the sentinel value as if it were part of the date. To support reading at the top of the loop, we also started off by giving current a dummy value to start the loop, and then replaced it when we got into the loop.

Here is a version that avoids the extra if, but it reads input twice, once before the loop and once at the bottom, so each time through the loop we process data, and then read in a value, which some people find hard to read.

```
int sum = 0 // adding up the entered numbers
int count = 0 // how many numbers
const int STOP = -989
print "Enter " + STOP + " to quit"

int current = prompt "What number?" // first number

while (current != STOP)
       count = count + 1
       sum  = sum + current
       current = prompt "What number?" // for next time
endwhile

print "average: " + sum/count
```

Whichever way around we get the data, we have made sure we never included -989 in the calculation of our average. But what if -989 is one of the numbers the user wanted to use? The major limitation of the sentinel method is that we can only work with a sentinel value if there is at least one possible value that is not valid data for the task we are doing.

If what we want is to accept all possible ints, we could take in our data as doubles and tell the user to enter a number with a decimal place to stop. If what we want are doubles, we could enter the data as strings, and tell the user to enter a non-number to stop. This would work, but the time spent converting from double to int is a little inefficient, and the time to convert from string to double could slow things down considerably. So these solutions may be too inefficient to be practical. And, if we want to accept any string, we are back to the limitation: there has to be at least one string we don't accept as valid to be able to use a sentinel value.

Menus and Submenus

Historically, most programs were menu-driven. The user was given a list of options called a menu, and entered a number or letter to choose which option to do, which often led to another submenu of options contingent on the user's choice, and so on. Each menu would repeat until the user chose to quit, and then they would be back at the previous menu, until they quit out of the first menu and ended the whole program.

Modern programs are much less likely to be menu driven; we tend to now give the user access to everything the program can do all at once, and they can use the tools in any order. However you have probably used a menu-driven system when buying gas at the pump, or using an ATM, and many programs have portions that are menu-driven when we need the user to go through a certain list of steps with options in the right order, to do some task within the program.

Menus also are an excellent way to practice writing loops because they are so interactive for testing. Here is a basic menu:

```
double balance = bankBalance()
// loop control variable used for user input
// starts with a dummy value
int menuOp = -1
print "Welcome to the bank"
// they will enter 0 to indicate print
while (menuOp != 0)
     // print their options
     print "0 Quit"
     print "1 Show Balance"
     print "2 Deposit"
     print "3 Withdraw"
     // get input for their choice
     menuOp = prompt "Enter your choice:"

     // do what they asked
     if (menuOp == 1) then
          print "$" + balance"
     else if (menuOp == 2) then
          balance = balance + 5
     else if (menuOp == 3) then
          balance = balance - 5
     endif
endwhile
print "Thank you for banking with us!  Goodbye"
```

Since we don't know how long the user will spend in the menu, we almost always use while for menu loops. menuOp was our loop control variable, and we set it to a dummy value so that the loop could start; the only value we could not set it to was 0, since that was the value we used so the user could signal they wanted to quit.

We printed the options inside the loop, because it usually helps the user to show them what their choices are every time. Then we got the user's actual choice by prompting. An if-else-if structure allows us to do the appropriate behaviors based on user choice. Since we are looking at individual possible values of a single variable, a case/switch statement would also be a good choice, in fact, the main use of case/switch was to handle menus.

Notice that there is no check in the if-else-if for 0. While we could put in a check for the quit value inside the loop if we wanted to check if the user is sure they want to quit, we don't need

that if we are just going to let them quit. Anything that happens after they choose to quit can just go after the end of the loop.

Notice also that there is no check for invalid values. We could add one, if it is important to scold the user for mis-typing, but as written, since we have no final else, if they give a bad value we will just do nothing and loop back around to show them the menu again, which is probably enough to remind them what the valid entries are.

Here is an example with a submenu, this time using case instead if if-else-if:

```
double balance = bankBalance()
double savingsBalance = savingsAccountBalance()
// main menu
string menuOp = -1
while (menuOp != 0)
     print "0 Quit"
     print "1 Show Balance"
     print "2 Deposit"
     print "3 Withdraw"
     print "4 Transfer Menu"
     menuOp = prompt "Choice?"

     // case to handle user choices
     case menuOp
     1:
          print "$" + balance"
     2:
          balance = balance + 5
     3:
          balance = balance – 5
     4: // this choice takes us to submenu
          // new loop control for submenu
          int tMenuOp = -1
          // submenu's loop
          while (tMenuOp != 0)
               print "0 Return to main menu"
               print "1 Transfer from Savings"
               print "2 Transfer to Savings"
               tMenuOp = prompt "Choice?"
               case tMenuOp
               1:
                    balance = balance + 5
                    savings = savings – 5
               2:
```

```
                    balance = balance - 5
                    savings = savings + 5
                endcase
            endwhile // end of submenu
            // when submenu ends, we are still in main loop
        endcase
    endwhile
```

The submenu gets its own while loop and its own loop control variable, tMenuOp. It is important that this variable gets set back to a dummy value before the submenu starts. Otherwise, once we have quit the submenu once, we can't return to it because the variable would still have the quit value from the last time the user quit. For this reason, we generally just create and initialize each submenu's control variable right above the submenu.

The code inside the submenu is very much like what was in the main menu. Notice that again we don't need a special option for the quit value. When the user enters 0 to return to main menu, we will end the submenu's while loop, which means we will be back in the big loop for the main menu, which will just loop around again and show the main menu options.

We can have as many levels of submenu as we want. You can see how this sort of code would get very long, especially if the options are actions more complex than one or two lines. We really need a good way to break up our code into named subtasks to keep it readable – we need methods.

Break and Continue (are bad)

Most high level programming languages also provide the keywords break and continue. These allow the program to act in a way that does not respect the loop structure.

Break ends the loop early, ignoring the value of the boolean condition that is supposed to control the loop. Continue skips statements inside the loop and jumps back up to re-evaluate the condition immediately.

The same results as break could almost always be achieved by making the expression for the boolean condition more complex. The same results as continue could almost always be achieved by adding a conditional inside the loop. Like goto, break and continue in loops generally provide a short-term convenience at the cost of code that is harder to read, debug, maintain, and update.