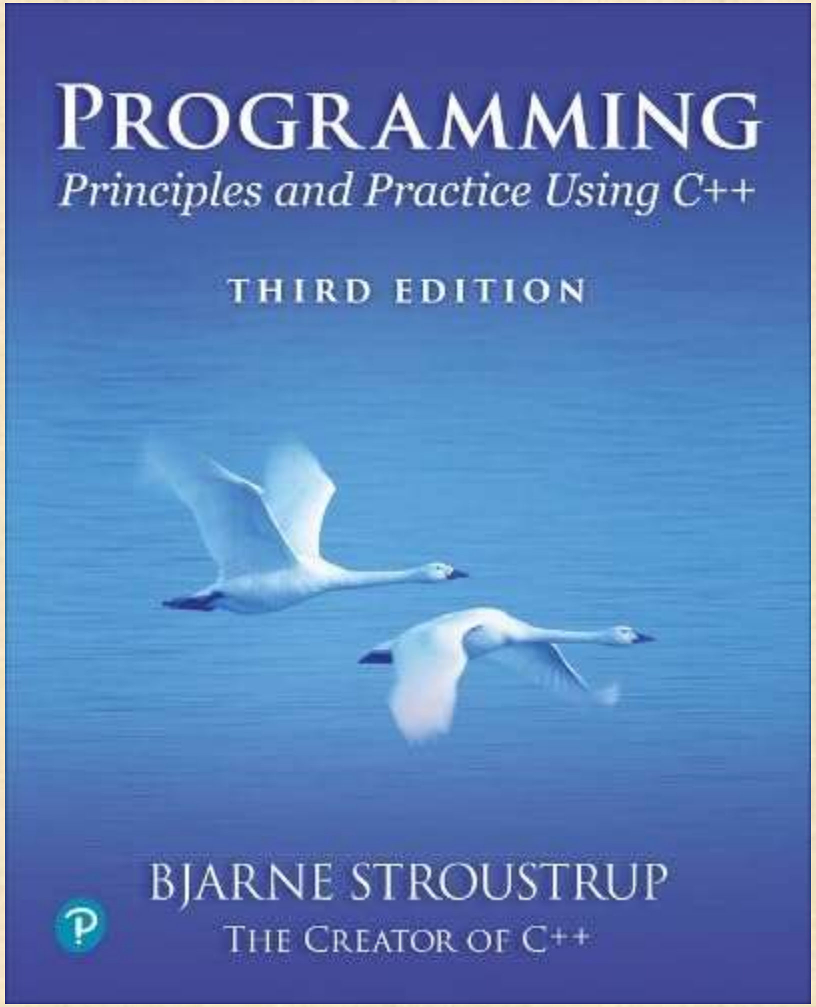
Chapter 5 – Writing a Program



Programming is understanding.
– Kristen Nygaard

Overview

- Some thoughts on software development
- The idea of a calculator
- Using a grammar
- Expression evaluation
- Program organization

Building a program

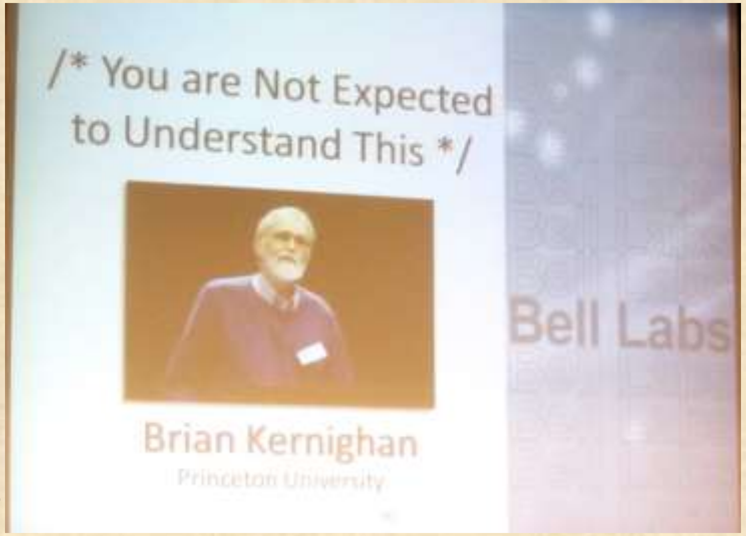
- Analysis
  - Refine our understanding of the problem
    - Think of the final use of our program
- Design
  - Create an overall structure for the program
- Implementation
  - Write code
  - Debug
  - Test
- Go through these stages repeatedly

Writing a program: Strategy

- What is the problem to be solved?
  - Is the problem statement clear?
  - Is the problem manageable, given the time, skills, and tools available?
- Try breaking it into manageable parts
  - Do we know of any tools, libraries, etc. string, that might help?
    - Yes, even this early: **iostreams**, **vector**, etc.
- Build a small, limited version solving a key part of the problem
  - To bring out problems in our understanding, ideas, or tools
  - Possibly change the details of the problem statement to make it manageable
- If that doesn't work
  - Throw away the first version and make another limited version
  - Keep doing that until we find a version that we' re happy with
- Build a full-scale solution
  - Ideally by using part of your initial version

Programming is also a practical still

- We learn by example
  - Not by just seeing explanations of principles
  - Not just by understanding programming language rules
- The more and the more varied examples the better
  - You won't get it right the first time
  - "You can't learn to ride a bike from a correspondence course"
- You can't learn it all at once



Writing a program: Example

- I’ll build a program in stages, making lot of “typical mistakes” along the way
  - Even experienced programmers make mistakes
    - Lots of mistakes; it’s a necessary part of learning
  - Designing a good program is genuinely difficult
  - It’s often faster to let the compiler detect gross mistakes than to try to get every detail right the first time
    - Concentrate on the important design choices
  - Building a simple, incomplete version allows us to experiment and get feedback
    - Good programs are “grown”

A simple calculator

- Given expressions as input from the keyboard, evaluate them and write out the resulting value
  - For example:
    - Expression: **2+2**
    - Result: **4**
    - Expression: **2+2*3**
    - Result: **8**
    - Expression: **2+3-25/5**
    - Result: **0**

- Let's refine this a bit more …

Pseudo Code

- A first idea:

```
int main()
{
   variables
   while (get a line) {                    // what's a line?
         analyze the expression            // what does that mean?
         evaluate the expression
         print the result
   }
}
```

- How do we represent **45+5/7** as data?
- How do we find **45 + 5 / and 7** in an input string?
- How do we make sure that **45+5/7** means **45+(5/7)** rather than **(45+5)/7**?
- Should we allow floating-point numbers (sure!)
- Can we have variables? **v=7; m=9; v*m** (later)

A simple calculator

- Wait!
  - We are just about to reinvent the wheel!
  - Read Chapter 5 for more examples of dead-end approaches
- What would the experts do?
  - Computers have been evaluating expressions for 50+ years
  - There *has* to be a solution!
  - What *did* the experts do?
    - Reading is good for you
    - Asking more experienced friends/colleagues can be far more effective, pleasant, and time-effective than slogging along on your own
    - “Don’t re-invent the wheel”

experts usually write a grammar

Expression :
  Term
  Expression '+' Term   *e.g.*, 1+2, (1-2)+3, 2*3+1
  Expression '-' Term
Term :
  Primary
  Term '*' Primary   *e.g.*, 1*2, (1-2)*3.5
  Term '/' Primary
  Term '%' Primary
Primary :
  Number   *e.g.*, 1, 3.5
  '(' Expression ')'   *e.g.*, (1+2*3)
Number :
  floating-point literal   *e.g.*, 3.14, 0.274e1, or 42 – as defined for C++

A program is built out of Tokens (*e.g.*, numbers and operators).

A side trip: Grammars

- What's a *grammar*?
  - A set of (syntax) rules for expressions.
    - The rules say how to analyze ("parse") an expression.
  - Some rules seem hard-wired into our brains
  - Example, you know what this means:
    - **2*3+4/2**
    - **birds fly but fish swim**
  - You know that this is wrong:
    - **2 * + 3 4/2**
    - **fly birds fish but swim**
  - How can we teach what we know to a computer?
    - Why is it right/wrong?
    - How do we know?

Grammars – "English"

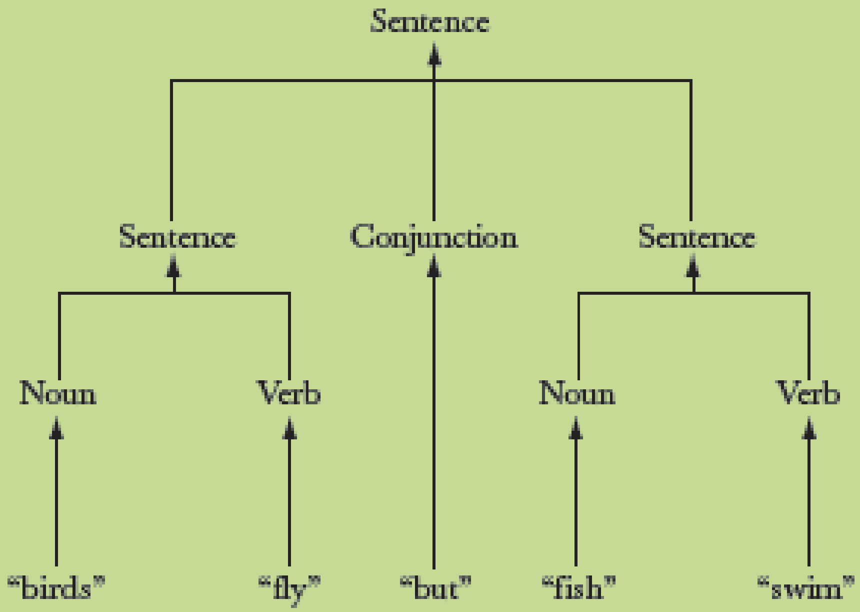
Parsing a simple English sentence

Sentence :
  Noun Verb
  Sentence Conjunction Sentence

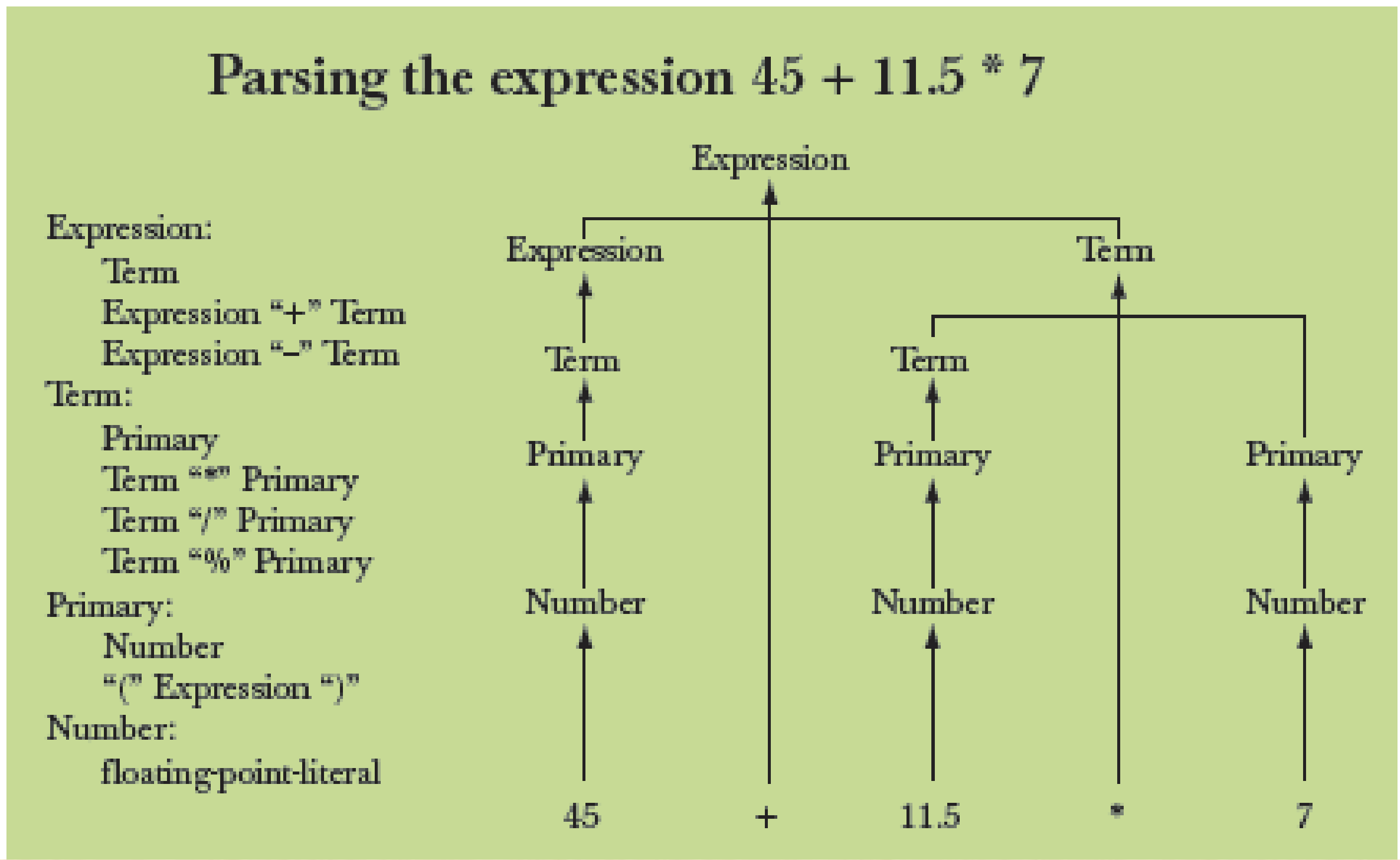
Conjunction :
  "and"
  "or"
  "but"

Noun :
  "birds"
  "fish"
  "C++"

Verb :
  "rules"
  "fly"
  "swim"



Grammars – expression



Functions for parsing

We need functions to match the grammar rules

get() *// read characters and compose tokens; calls **cin** for input*

expression() *// deal with + and -; calls **term()** and **get()***

term() *// deal with *, /, and %; calls **primary()** and **get()***

primary() *// deal with numbers and parentheses; calls **expression()** and **get()***

Note: each function deals with a specific part of an expression and leaves everything else to other functions – this radically simplifies each function.

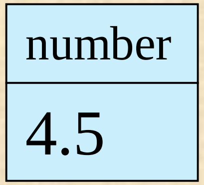
Analogy: a group of people can deal with a complex problem by each person handling only problems in his/her own specialty, leaving the rest for colleagues.

Function Return Types

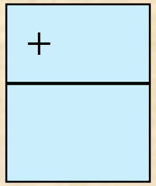
- What should the parser functions return?
  - How about the result?

```
Token get_token();      // read characters and compose tokens;   return a Token
double expression();    // deal with + and -;                    return the sum (or difference)
double term();          // deal with *, /, and %;                return the product (or …)
double primary();       // deal with numbers and parentheses;    return the value
```

- What is a **Token**?



What is a token?



- We want to see input as a stream of tokens
  - We read characters **1 + 4*(4.5-6)** (That’s 13 characters incl. 2 spaces)
  - 9 tokens in that expression: **1 + 4 * (4.5 - 6)**
  - 6 kinds of tokens in that expression: number **+ * (-)**
- We want each token to have two parts
  - A “kind”; e.g., number
  - A value; e.g., **4**
- We need a type to represent this “Token” idea
  - We’ll build that in the next lecture, but for now:
    - **get_token()** gives us the next token from input
    - **t.kind** gives us the kind of the token
    - **t.value** gives us the value of the token

Dealing with + and -

Expression:
Term
Expression '+' Term
Expression '-' Term

```
double expression()       // read and evaluate: 1   1+2.5   1+2+3.14 etc.
{
  double left = term();                  // get the Term; every Expression starts with a Term

  while (true) {
      Token t = get_token();             // get the next token…
      switch (t.kind) {                  // … and do the right thing with it
      case '+':       left += term(); break;
      case '-':       left -= term(); break;
      default:        return left;            // return the value of the expression
```

Dealing with *, /, and %

```
Term :
    Primary
    Term '*' Primary
    Term '/' Primary
    Term '%' Primary
```

```
double term()      // exactly like expression(), but for *, /, and %
{
  double left = primary();              // get the Primary
  while (true) {
        Token t = get_token();          // get the next Token…
        switch (t.kind) {
        case '*':       left *= primary(); break;
        case '/':       left /= primary(); break;
        case '%':    left %= primary(); break;     // Oops: doesn't compile
                                        // % isn't defined for floating-point numbers
        default:        return left;           // return the value
        }
  }
}
```

Dealing with * and /

Term :
Primary
Term '*' Primary
Term '/' Primary

```
double term()     // exactly like expression(), but for *, and /
{
  double left = primary();              // get the Primary
  while (true) {
      Token t = get_token();            // get the next Token
      switch (t.kind) {
      case '*':       left *= primary(); break;
      case '/':       left /= primary(); break;
      default:        return left;            // return the value
      }
  }
}
```

Dealing with divide by 0

Term :
  Primary
  Term '*' Primary
  Term '/' Primary

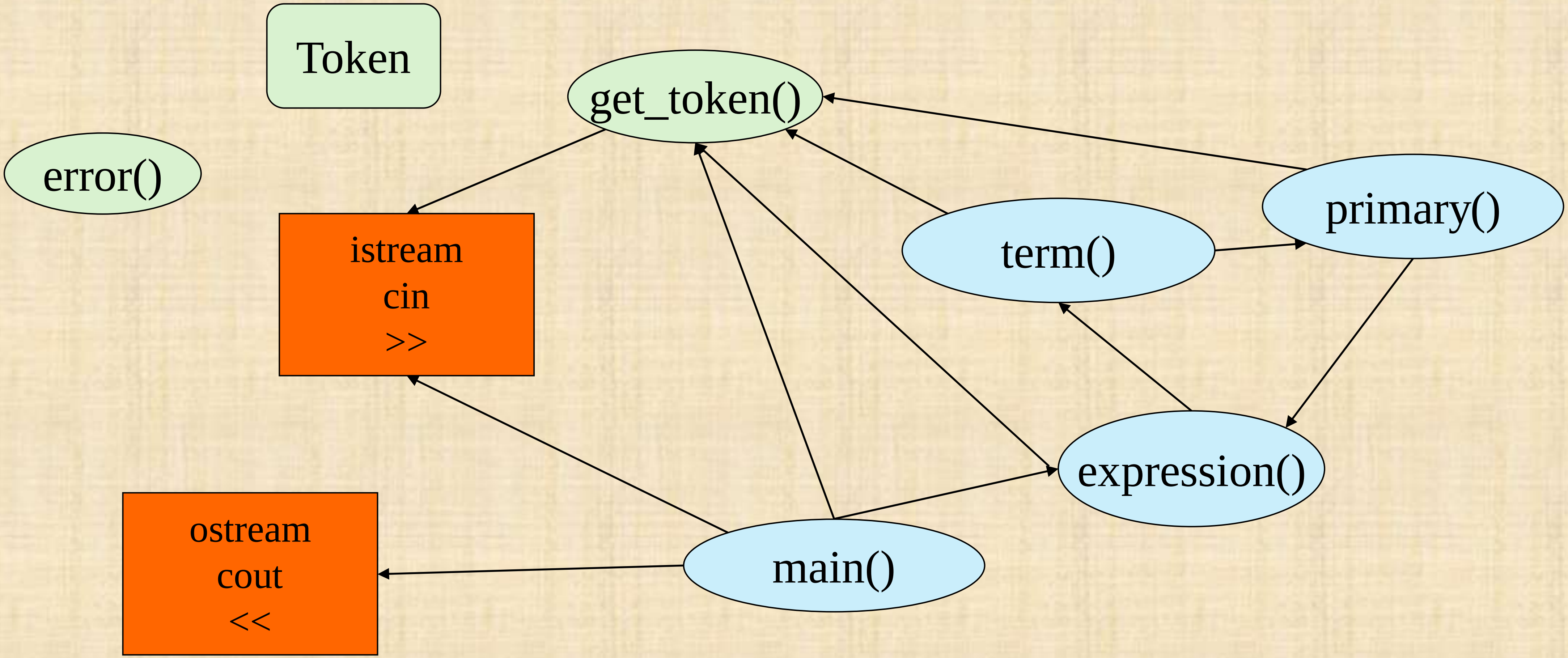
```
double term() // exactly like expression(), but for * and  /
{
        // …
        case '/':
         {      double d = primary();
                if   (d==0)
                        error("divide by zero");
                left /= d;
                break;
          }
        // …
}
```

Note: when you want to define a value in a case, you need to use a block

Dealing with numbers and parentheses

```
double primary()  // Number or '(' Expression ')'
{
  Token t = get_token();
  switch (t.kind) {
  case '(':                          // handle '('expression ')'
   {   double d = expression();
       t = get_token();
       if (t.kind != ')') error("')' expected");
       return d;
   }
  case '8':            // we use '8' to represent the "kind" of a number
       return t.value;     // return the number's value
  default:
       error("primary expected");
  }
}
```

Program organization



- Who calls whom? (note the loop)

The program

```
#include “PPP.h"

// Token stuff (explained in the next lecture)

double expression();              // declaration so that primary() can
  call expression()

double primary() { /* … */ }  // deal with numbers and parentheses
double term() { /* … */ }             // deal with * and / (pity
  about %)
double expression() { /* … */ }      // deal with + and –

int main() { /* … */ }          // on next slide
```

The program – main()

```
int main()
try {
  while (cin)
        cout << expression() << '\n';
}
catch (runtime_error& e) {
  cerr << e.what() << '\n';
  return 1;
}
catch (…) {
  cerr << "exception \n";
  return 2;
}
```

A mystery

- 2
-
- 3
- 4
- 2   an answer
- 5+6
- 5   an answer
- X
- Bad token   an answer (finally, an expected answer)

A mystery

- Expect "mysteries"
- Your first try rarely works as expected
  - That's normal and to be expected
    - Even for experienced programmers
  - If it looks as if it works be suspicious
    - And test a bit more
  - Now comes the debugging
    - Finding out why the program misbehaves
  - And don't expect your second try to work either

A mystery

- 1 2 3 4+5 6+7 8+9 10 11 12
- 1 an answer
- 4 an answer
- 6 an answer
- 8 an answer
- 10 an answer

- Aha! Our program "eats" two out of three input tokens
  - How come?
  - Let's have a look at expression()

Dealing with + and –

Expression:
Term
Expression '+' Term
Expression '–' Term

```
double expression()      // read and evaluate: 1   1+2.5
  1+2+3.14  etc.
{
  double left = term();                // get the Term
  while (true) {
      Token t = get_token();           // get the next token…
      switch (t.kind) {                // … and do the right thing
  with it
      case '+':   left += term(); break;
      case '-':         left -= term(); break;
      default:          return left;             // <<< doesn't
  use "next token"
      }
  }
}
```

Dealing with + and -

- So, we need a way to “put back” a token!
  - Put back into what?
  - “the input,” of course: we need an input stream of tokens, a “token stream”

```
double expression()      // deal with + and -
{
  double left = term();
  while (true) {
       Token t = ts.get();              // get the next token from a
  "token stream"
       switch (t.kind) {
       case '+':    left += term(); break;
       case '-':          left -= term(); break;
       default:           ts.putback(t);    // put the unused token
  back
                    return left;
       }
```

Dealing with * and /

- Now make the same change to **term()**

```
double term()      // deal with * and  /
{
  double left = primary();
  while (true) {
       Token t = ts.get();      // get the next Token from input
       switch (t.kind) {
       case '*':   // deal with *
       case '/':           // deal with /
       default:
              ts.putback(t);     // put unused token back into
  input stream
              return left;
       }
  }
```

The program

- It “sort of works”
  - That’s not bad for a first try
    - Well, second try
    - Well, really, the fourth try; see the book
  - But “sort of works” is not good enough
  - When the program “sort of works” is when the work (and fun) really start
- Now we can get feedback!

Another mystery

- 2 3 4 2+3 2*3
- 2 an answer
- 3 an answer
- 4 an answer
- 5 an answer

- What! No "6" ?
  - The program looks ahead one token
    - It's waiting for the user
  - So, we introduce a "print result" command
  - While we're at it, we also introduce a "quit" command

The main() program

```
int main()
{
  double val = 0;
  while (cin) {
        Token t = ts.get();                 // rather than get_token()
        if (t.kind == 'q’)                        // ‘q’ for “quit”
              break;
        if (t.kind == ';')                        // ‘;’ for “print now”
              cout <<  val << '\n';   // print result
        else
              ts. putback(t);               // put a token back into
  the input stream
        val = expression();                 // evaluate
  }
}
// … exception handling …
```

Now the calculator is minimally useful

- 2;
- 2 an answer
- 2+3;
- 5 an answer
- 3+4*5;
- 23 an answer
- q

Next lecture

- Completing a program
  - Tokens
  - Recovering from errors
  - Cleaning up the code
  - Code review
  - Testing