问题求解与实践
——实现一个计算器

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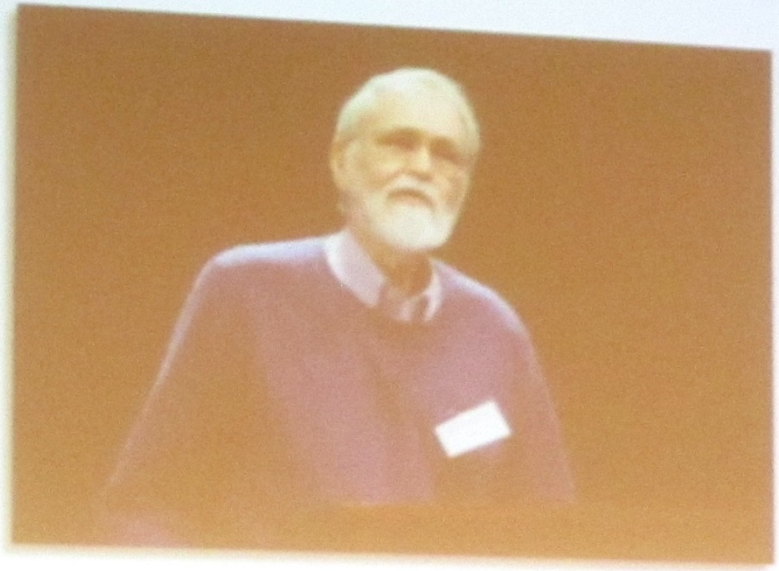
Overview

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

/* You are Not Expected to Understand This */



Brian Kernighan

Princeton University

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Bell Labs

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

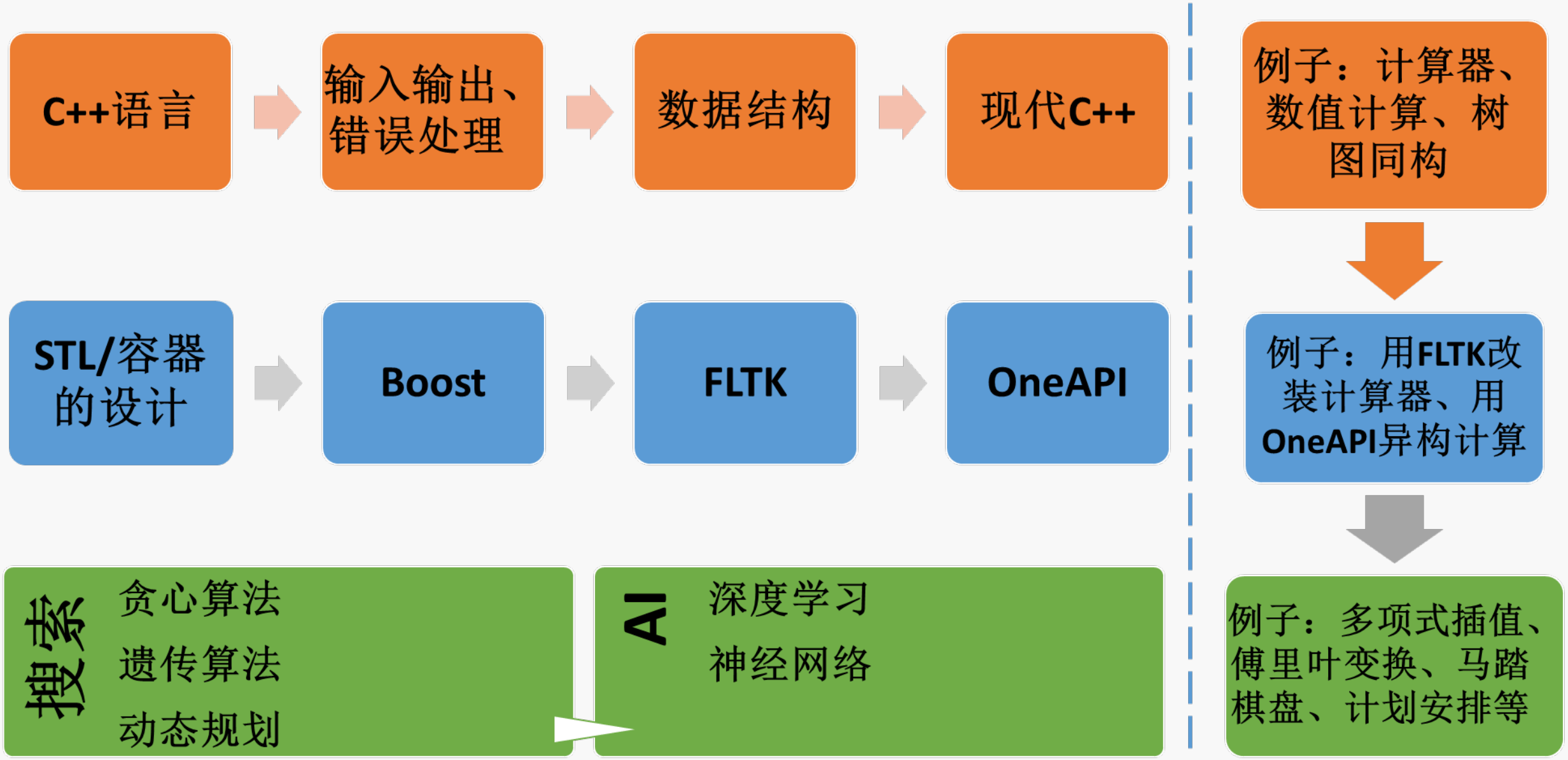
Writing a program: Strategy

- 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. that might help?
    - Yes, even this early: **iostream**s, **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”

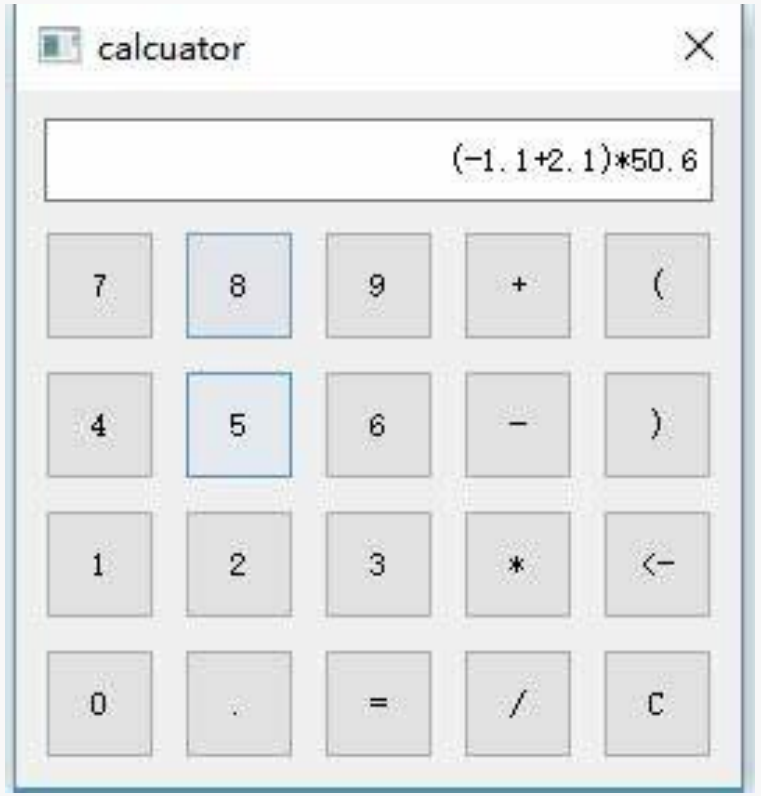

C++语言
输入输出、错误处理
数据结构
现代C++
STL/容器的设计
Boost
FLTK
OneAPI
贪心算法
遗传算法
动态规划
AI
深度学习
神经网络
例子：计算器、数值计算、树图同构
例子：用FLTK改装计算器、用OneAPI异构计算
例子：多项式插值、傅里叶变换、马踏棋盘、计划安排等

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

- **H**ow do we represent **45+5/7** as data?
- **H**ow 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!)
- **C**an we have variables? **v=7; m=9; v*m** (later)

A simple calculator

- Wait!
  - We are just about to reinvent the wheel!
  - Read Chapter 6 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”

Expression Grammar

- This is what the experts usually do – 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”

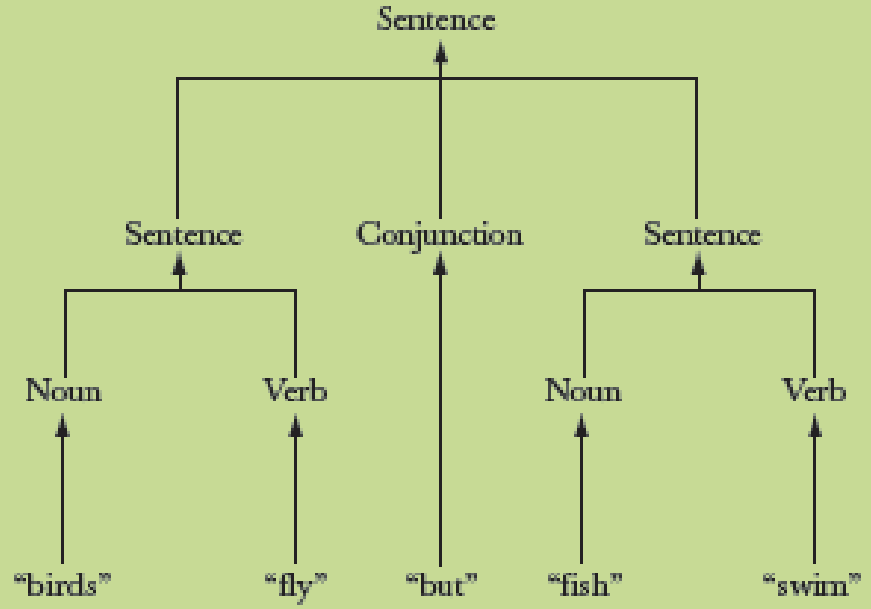
Parsing a simple English sentence

Sentence :
- Noun Verb
- Sentence Conjunction Sentence

Conjunction :
- “and”
- “or”
- “but”

Noun :
- “birds”
- “fish”
- “C++”

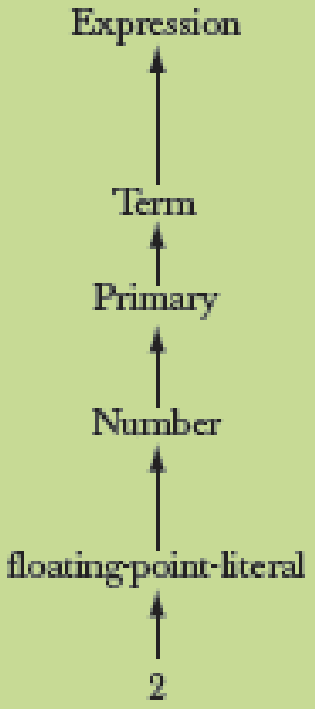
Verb :
- “rules”
- “fly”
- “swim”



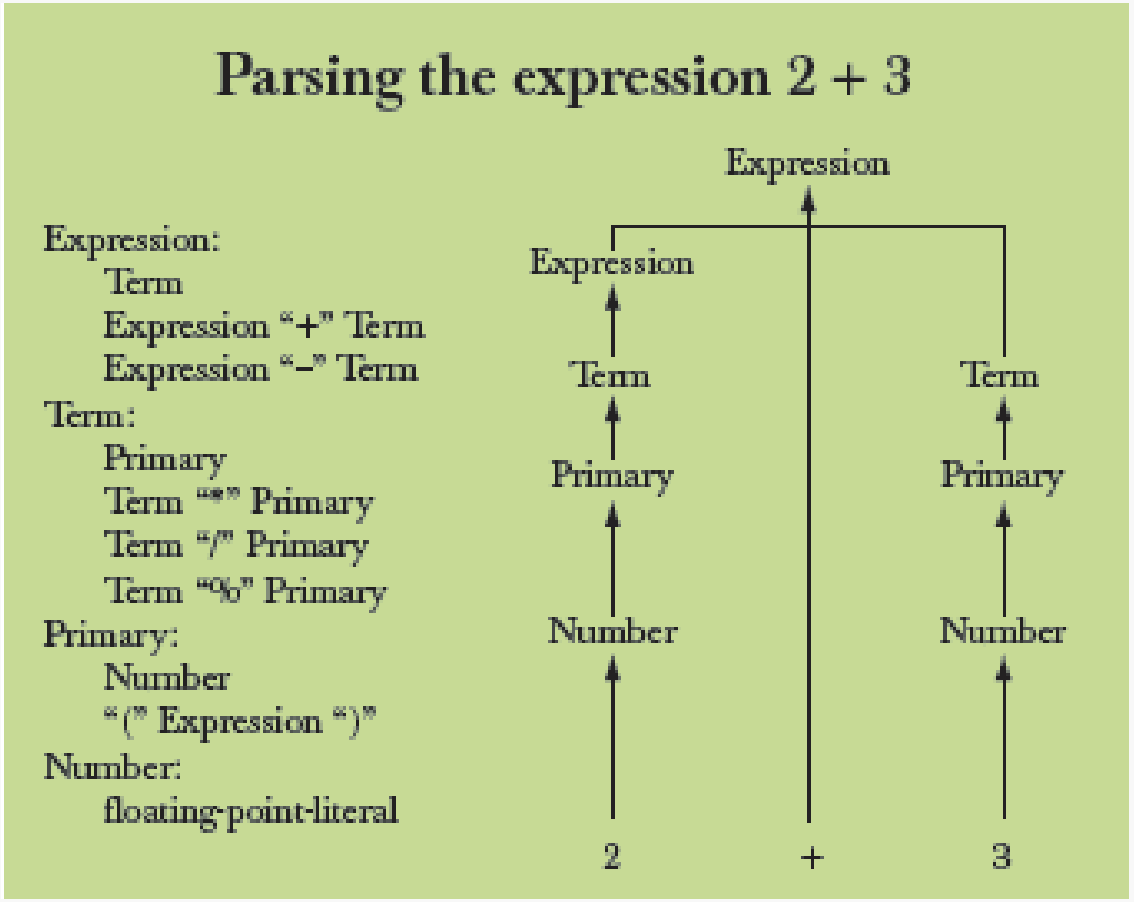
Grammars - expression

Parsing the number 2

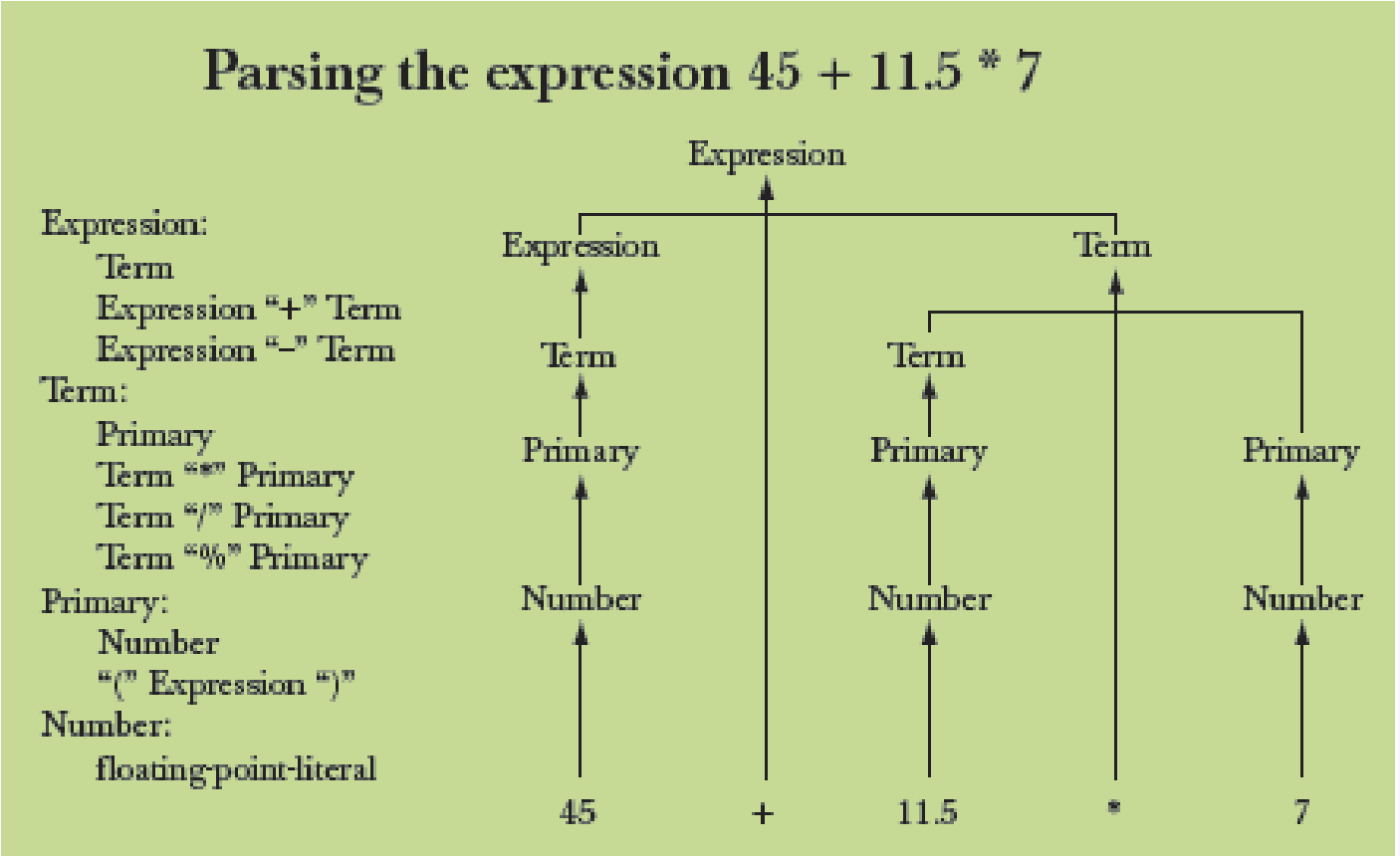
Expression:
    Term
    Expression "+" Term
    Expression "–" Term
Term:
    Primary
    Term "*" Primary
    Term "/" Primary
    Term "%" Primary
Primary:
    Number
    "(" Expression ")"
Number:
    floating-point-literal



Grammars - expression

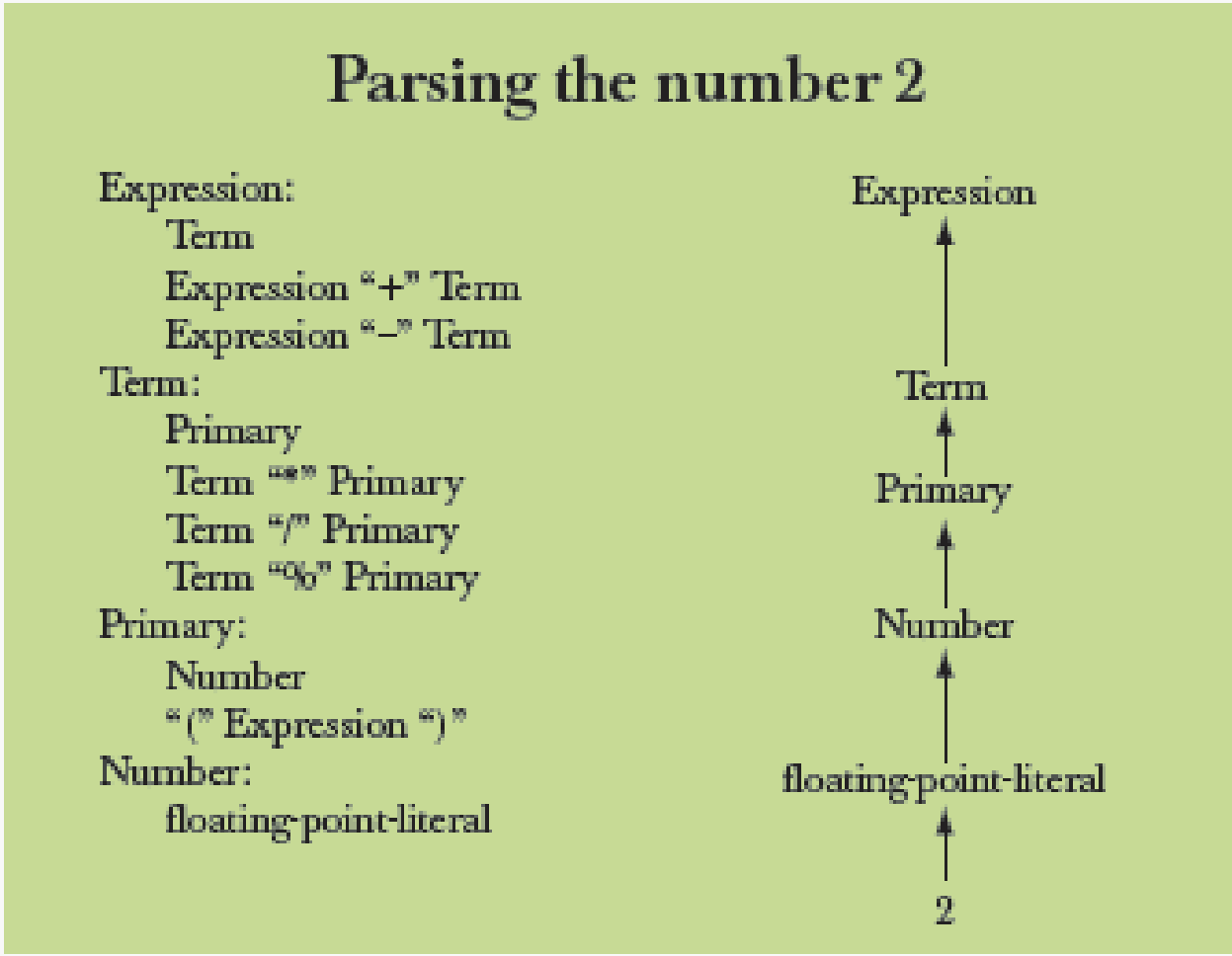


Grammars - expression



QUIZ

- 请设计一元多项式的语法
  - 设计不存在负指数次数的情形
  - 修改语法，设计存在负指数次数的情形（你是不是需要引入括号？）
- 请设计线性方程组的语法（作业）



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
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
```

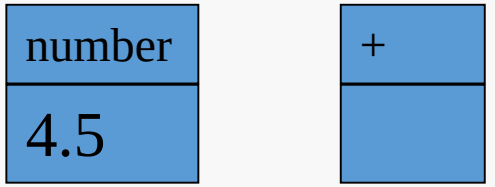
- What is a **Token**?

The program – main()

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

输入： 2 2+3 3+4*5
输出：
2
5
23

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 -

输入： 2 2+3 3+4*5
输出：
2
5
23

Expression:
    Term
    Expression '+' Term   // *Note: every Expression starts with a 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;        // return the value of the expression
            }
    }
}
```

Dealing with *, /, and %

输入：2 2+3 3+4*5
输出：
2
5
23

```
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;
            default:        return left;                 // return the value
            }
    }
}
```

- Oops: doesn't compile
  - % isn't defined for floating-point numbers

Dealing with * and /

Term :
    Primary
    Term ‘*’ Primary   *// Note: every Term starts with a 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

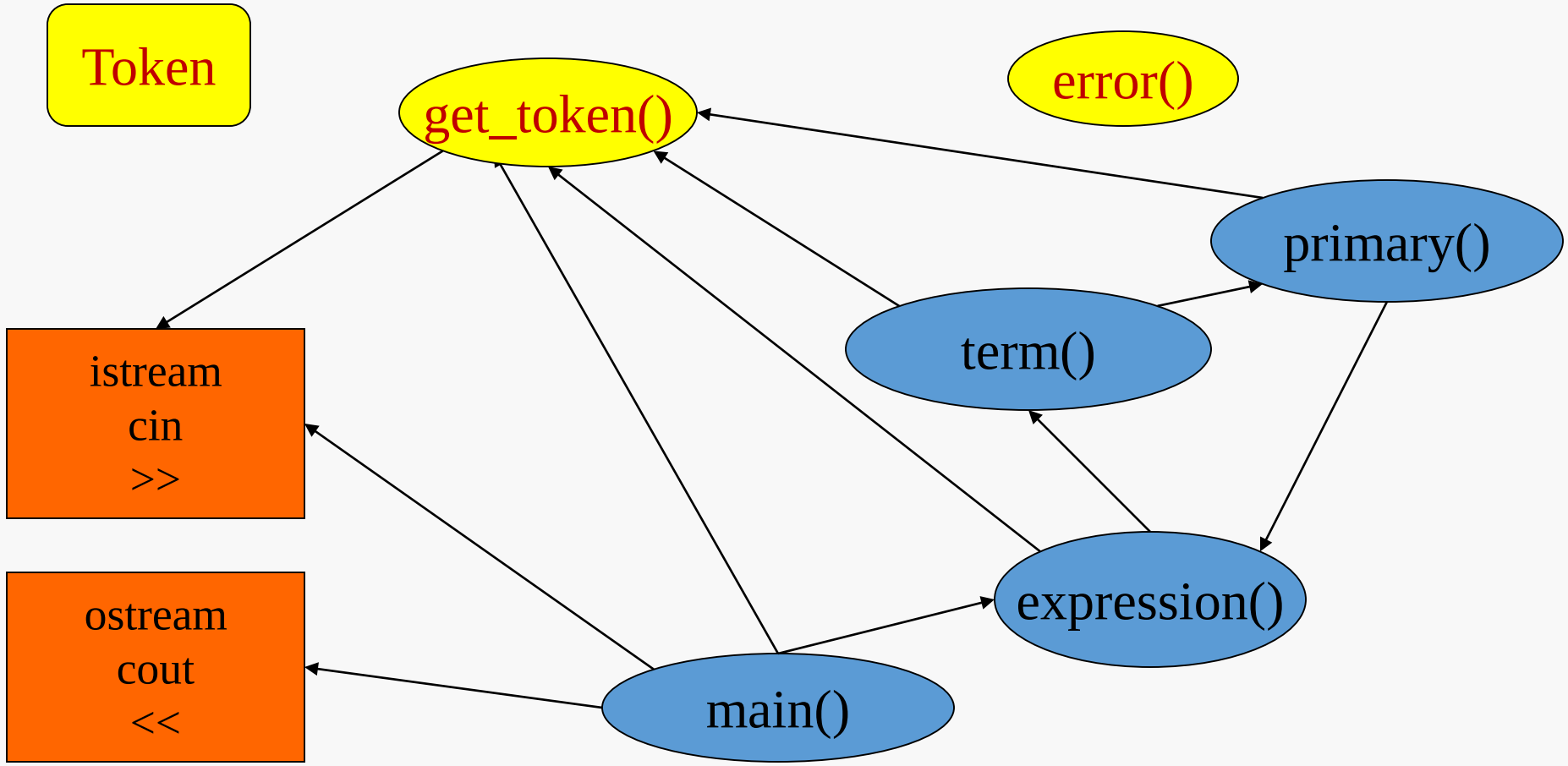
```
double term()           // exactly like expression(), but for * and  /
{
    double left = primary();                    // get the Primary
    while (true) {
            Token t = get_token();  // get the next Token
            switch (t.kind) {
            case '*':
                        left *= primary();
                        break;
            case '/':
                {       double d = primary();
                        if  (d==0) error("divide by zero");
                        left /= d;
                        break;
                }
            default:
                        return left; // return the value
            }
    }
}
```

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");
    }
}
```

输入：2 2+3 3+4*（5）
输出：
2
5
23

Program organization



- Who calls whom? (note the loop)

The program

```
#include "std_lib_facilities.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';
    keep_window_open();                    // for some Windows versions
}
catch (runtime_error& e) {
    cerr << e.what() << endl;
    keep_window_open ();
    return 1;
}
catch (…) {
    cerr << "exception \n";
    keep_window_open ();
    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 inputs
  - How come?
  - Let’s have a look at expression()

Dealing with + and -

```
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
```

Expression:
  Term
  Expression ‘+’ Term *// Note: every Expression starts with a 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 /

```
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
```

- 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') break;                    // ‘q’ for “quit”
        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
    }
    keep_window_open();
}
// … 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

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