Programming and Program Style

The material for this lecture is drawn, in part, from The Practice of Programming (Kernighan & Pike) Chapter 1

Goals of this Lecture

• Help you learn about:
  • Good programming (verb) style
  • Good program (noun) style

• Why?
  • A well-styled program is easier to maintain and more likely to be correct than a poorly-styled program
  • A power programmer knows the qualities of a well-styled program, and how to develop one
Lecture Overview

- Programming style: how to create a good program
  - Top-down design
  - Successive refinement
  - Example: left and right justifying text

- Program style: qualities of a good program
  - Well structured
  - Uses common idioms
  - Uses descriptive names
  - Contains proper comments
  - Modular

Part 1: Programming Style
Bottom-Up Design is Bad

• **Bottom-up design** 😞
  • Design one part in detail
  • Design another part in detail
  • Repeat until finished

• **Bottom-up design in painting**
  • Paint upper left part of painting in complete detail
  • Paint next part of painting in complete detail
  • Repeat until finished
  • *Unlikely to produce a good painting*

• **Bottom-up design in programming**
  • Write first part of program in complete detail
  • Write next part of program in complete detail
  • Repeat until finished
  • *Unlikely to produce a good program*

Top-Down Design is Good

• **Top-down design** 😊
  • Design entire product with minimal detail
  • Successively refine until finished

• **Top-down design in painting**
  • Sketch the entire painting with minimal detail
  • Successively refine the entire painting

• **Top-down design in programming**
  • Define main() function in pseudocode with minimal detail
  • Refine each pseudocode statement
    • Small job => replace with real code
    • Large job => replace with function call
  • Recurse in (mostly) breadth-first order
  • Bonus: Product is naturally modular
Top-Down Design in Reality

- Top-down design in programming in reality
  - Define main() function in pseudocode
  - Refine each pseudocode statement
    - Oops! Details reveal design error, so...
    - Backtrack to refine existing (pseudo)code, and proceed
  - Recurse in (mostly) breadth-first order, until all functions are defined

Example: Text Formatting

- Goals of the example
  - Illustrate good programming style
    - Especially function-level modularity and top-down design
  - Illustrate how to go from problem statement to code
    - Review and illustrate C constructs

- Text formatting (derived from King Section 15.3)
  - Input: ASCII text, with arbitrary spaces and newlines
  - Output: the same text, left and right justified
    - Fit as many words as possible on each 50-character line
    - Add even spacing between words to right justify the text
    - No need to right justify the very last line
  - Simplifying assumptions
    - Word ends at white space or end-of-file
    - No word is longer than 20 characters
Tune every heart and every voice.
Bid every bank withdrawal.
Let’s all with our accounts rejoice.
In funding Old Nassau.
In funding Old Nassau we spend more money every year.
Our banks shall give, while we shall live.
We’re funding Old Nassau.

### Example Input and Output

**Input**

| Tune every heart and every voice. |
| Bid every bank withdrawal. |
| Let’s all with our accounts rejoice. |
| In funding Old Nassau. |
| In funding Old Nassau we spend more money every year. |
| Our banks shall give, while we shall live. |
| We’re funding Old Nassau. |

**Output**

| Tune every heart and every voice. Bid every bank withdrawal. Let’s all with our accounts rejoice. In funding Old Nassau. In funding Old Nassau we spend more money every year. Our banks shall give, while we shall live. We’re funding Old Nassau. |

### Thinking About the Problem

- **I need a notion of “word”**
  - Sequence of characters with no white space
  - All characters in a word must be printed on the same line

- **I need to be able to read and print words**
  - Read characters from `stdin` till white space or `EOF`
  - Print characters to `stdout` followed by space(s) or newline

- **I need to deal with poorly-formatted input**
  - I need to remove extra white space in input

- **Unfortunately, I can’t print the words as they are read**
  - I don’t know # of spaces needed till I read the future words
  - Need to buffer the words until I can safely print an entire line

- **But, how much space should I add between words?**
  - Need at least one space between adjacent words on a line
  - Can add extra spaces evenly to fill up an entire line
Writing the Program

• Key constructs
  • Word
  • Line

• Next steps
  • Write pseudocode for `main()`
  • Successively refine

• Caveats concerning the following presentation
  • Function comments and some blank lines are omitted because of space constraints
    • Don’t do that!!!
  • Design sequence is idealized
    • In reality, much backtracking would occur

The Top Level

• First, let’s sketch `main()`...

```c
int main(void) {
  <Clear line>
  for (;;) {
    <Read a word>
    if (<No more words>) {
      <Print line with no justification>
      return 0;
    } else if (<Word doesn’t fit on this line>) {
      <Print line with justification>
      <Clear line>
    }
    <Add word to line>
  }
  return 0;
}
```
Reading a Word

Now let's successively refine. What does <Read a word> mean? The job seems complicated enough that it should be delegated to a distinct function...

```
enum {MAX_WORD_LEN = 20};
int main(void) {
    char word[MAX_WORD_LEN + 1];
    int wordLen;
    <Clear line>
    for (;;) {
        wordLen = ReadWord(word);
        if (<No more words>) { }
            <Print line with no justification>
            return 0;
        } if (<Word doesn’t fit on this line>) { }
            <Print line with justification>
            <Clear line>
    } <Add word to line>
    return 0;
}
```

int ReadWord(char *word) {
    <Skip over whitespace>
    <Store chars up to MAX_WORD_LEN in word>
    <Return length of word>
}

Reading a Word (cont.)

• ReadWord() seems easy enough to design. So let's flesh it out...

```
int ReadWord(char *word) {
    int ch, pos = 0;
    /* Skip over white space. */
    ch = getchar();
    while ((ch != EOF) && isspace(ch))
        ch = getchar();
    /* Store chars up to MAX_WORD_LEN in word. */
    while ((ch != EOF) && (! isspace(ch))) {
        if (pos < MAX_WORD_LEN) {
            word[pos] = (char)ch;
            pos++;
        }
        ch = getchar();
    }
    word[pos] = '\0';
    /* Return length of word. */
    return pos;
}
```
Now, back to `main()`. What does `<Add word to line>` mean? The job seems complicated enough to demand a distinct function...

```c
enum {MAX_WORD_LEN = 20};
enum {MAX_LINE_LEN = 50};
int main(void) {
    char word[MAX_WORD_LEN + 1];
    int wordLen;
    char line[MAX_LINE_LEN + 1];
    int lineLen = 0;
    <Clear line>
    for (;;) {
        wordLen = ReadWord(word);
        if (<No more words>) {
            <Print line with no justification>
            return 0;
        }
        if (<Word doesn’t fit on this line>) {
            <Print line with justification>
            <Clear line>
        }
        AddWord(word, line, &lineLen);
    }
    return 0;
}
```

`AddWord()` is almost complete already, so let’s get that out of the way...

```c
void AddWord(const char *word, char *line, int *lineLen) {
    /* If line already contains some words, append a space. */
    if (*lineLen > 0) {
        line[*lineLen] = ' ';  
        line[*lineLen + 1] = '\0';
        (*lineLen)++;
    }
    strcat(line, word);
    (*lineLen) += strlen(word);
}
```
Printing the Last Line

Again, back to main(). What do <No more words> and <Print line with no justification> mean? Those jobs seem easy enough that we need not define additional functions...

```c
int main(void) {
    char word[MAX_WORD_LEN + 1];
    int wordLen;
    char line[MAX_LINE_LEN + 1];
    int lineLen = 0;
    <Clear line buffer>
    for (;;) {
        wordLen = ReadWord(word);
        /* If no more words, print line with no justification. */
        if ((wordLen == 0) && (lineLen > 0)) {
            puts(line);
            return 0;
        }
        if (<Word doesn’t fit on this line>) {
            <Print line with justification>
            <Clear line buffer>
        } else {
            AddWord(word, line, &lineLen);
        }
        return 0;
    }
}
```

Deciding When to Print

What does <Word doesn’t fit on this line> mean? That’s somewhat tricky, but involves little code...

```c
int main(void) {
    char word[MAX_WORD_LEN + 1];
    int wordLen;
    char line[MAX_LINE_LEN + 1];
    int lineLen = 0;
    <Clear line buffer>
    for (;;) {
        wordLen = ReadWord(word);
        /* If no more words, print line with no justification. */
        if ((wordLen == 0) && (lineLen > 0)) {
            puts(line);
            return 0;
        }
        /* If word doesn’t fit on this line, then... */
        if ((wordLen + wordLen) > MAX_LINE_LEN) {
            <Print line with justification>
            <Clear line buffer>
        } else {
            AddWord(word, line, &lineLen);
        }
        return 0;
    }
}```
Now, to the heart of the program. What does <Print line with justification> mean? Certainly that job demands a distinct function. Moreover, it’s clear that the function must know how many words are in the given line. So let’s change main() accordingly...

```c
int main(void) {
    ... int numWords = 0;
    <Clear line>
    for (;;) {
        /* If word doesn’t fit on this line, then... */
        if ((wordLen + 1 + lineLen) > MAX_LINE_LEN) {
            WriteLine(line, lineLen, numWords);
            <Clear line>
        }
        AddWord(word, line, &lineLen);
        numWords++;
    }
    return 0;
}
```

And write pseudocode for WriteLine()...

```c
void WriteLine(const char *line, int lineLen, int numWords) {
    <Compute number of excess spaces for line>
    for (i = 0; i < lineLen; i++) {
        if (<line[i] is not a space>)
            <Print the character>
        else {
            <Compute additional spaces to insert>
            <Print a space, plus additional spaces>
            <Decrease extra spaces and word count>
        }
    }
}
```
Printing with Justification (cont.)

```c
void WriteLine(const char *line, int lineLen, int numWords) {
    int extraSpaces, spacesToInsert, i, j;
    /* Compute number of excess spaces for line. */
    extraSpaces = MAX_LINE_LEN - lineLen;
    for (i = 0; i < lineLen; i++) {
        if (line[i] != ' ')
            putchar(line[i]);
        else {
            /* Compute additional spaces to insert. */
            spacesToInsert = extraSpaces / (numWords - 1);
            /* Print a space, plus additional spaces. */
            for (j = 1; j <= spacesToInsert + 1; j++)
                putchar(' ');
            /* Decrease extra spaces and word count. */
            extraSpaces -= spacesToInsert;
            numWords--;
        }
    }
    putchar('
');
}
```

Let's go ahead and complete `WriteLine()`...

The number of gaps

Example: If extraSpaces is 10 and numWords is 5, then gaps will contain 2, 2, 3, and 3 extra spaces respectively.

Clearing the Line

• One step remains. What does `<Clear line>` mean? It's an easy job, but it's done in two places. So we probably should delegate the work to a distinct function, and call the function in the two places...

```c
int main(void) {
    int numWords = 0;
    ClearLine(line, &lineLen, &numWords);
    for (;;) {
        /* If word doesn't fit on this line, then… */
        if ((wordLen + 1 + lineLen) > MAX_LINE_LEN) {
            WriteLine(line, lineLen, numWords);
            ClearLine(line, &lineLen, &numWords);
        }
        addWord(word, line, &lineLen);
        numWords++;
    }
    return 0;
}
```

```c
void ClearLine(char *line, int *lineLen, int *numWords) {
    line[0] = '\0';
    *lineLen = 0;
    *numWords = 0;
}
```
Modularity: Summary of Example

- To the user of the program
  - Input: Text in messy format
  - Output: Same text left and right justified, looking mighty pretty

- Between parts of the program
  - Word-handling functions
  - Line-handling functions
  - `main()` function

- The many benefits of modularity
  - Reading the code: In small, separable pieces
  - Testing the code: Test each function separately
  - Speeding up the code: Focus only on the slow parts
  - Extending the code: Change only the relevant parts

Part 2: Program Style
**Program Style**

- **Who reads your code?**
  - The compiler
  - Other programmers

```
typedef struct{double x,y,z}vec;
struct sphere{vec cen,color;double rad,kd,ks,kt,kl,ir};
sphere* intersect(P,D){
  best=0; tmin=1e30;
  s=sph+5; while(s--)
    b=vdot(D,U=vcomb(-1.,P,s-cen)),
    u=b*b-vdot(U,U)+s-rad;
    if(u>0)
      u0=sqrt(u),
      u=b-u1e-7?
        b-u:
        b+u,
    tmin=
      u
      ?
      best=
        s,
      u
      :
      tmin; return
}
```

This is a working ray tracer! (courtesy of Paul Heckbert)

**Program Style**

- **Why does program style matter?**
  - Bugs often caused by programmer’s misunderstanding
  - What does this variable do?
  - How is this function called?
  - Good code = human readable code

**How can code become easier for humans to read?**
- Convey program structure
- Use common idioms
- Be consistent!
- Choose descriptive names
- Compose proper comments
- Use modularity
But Ultimately...

- You only have a certain amount of brainpower
- Where do you want to spend it:
  - Doing new and interesting stuff
  - Finding bugs in old stuff
  - Deciphering things that could have been written clearly
  - Finding something that appears wrong and then double-guessing yourself or the person who wrote it
- There is nothing fun about debugging cryptic code
  - if (a & (a-1))
  - a &= a-1
  - Exceptions: crypto code, other high-performance bit-twiddling, but has to be properly documented

C Idioms

- Use C idioms
  - Example: Set each array element to 1.0.
  - Bad code (complex for no obvious gain)

```c
i = 0;
while (i <= n-1)
    array[i++] = 1.0;
```

- Good code

```c
for (i=0; i<n; i++)
    array[i] = 1.0;
```

- We’ll see many C idioms throughout the course
- Don’t feel obliged to use C idioms that decrease clarity
Naming

- Use descriptive names for globals and functions
  - E.g., display, CONTROL, CAPACITY
- Use concise names for local variables
  - E.g., i (not arrayIndex) for loop variable
- Use case judiciously
  - E.g., Buffer_insert (Module_function)
    - CAPACITY (constant)
    - buf (local variable)
- Use a consistent style for compound names
  - E.g., frontsize, frontSize, front_size
- Use active names for functions
  - E.g., getchar(), putchar(), Check_octal(), etc.

Modularity

- Big programs are harder to write than small ones
  - “A dog house can be built without any particular design, using whatever materials are at hand. A house for humans, on the other hand, is too complex to just throw together.” – K. N. King
- Abstraction is the key to managing complexity
  - Abstraction allows programmer to know what something does without knowing how
- Examples of function-level abstraction
  - Function to sort an array of integers
  - Character I/O functions such as getchar() and putchar()
  - Mathematical functions such as lcm() and gcd()
- Examples of file-level abstraction
  - (Described in a later lecture)
Structure: Expressions

• Use natural form of expressions
  • Example: Check if integer \( n \) satisfies \( j < n < k \)
  • Bad code

\[
\text{if } (! (n >= k) \&\& ! (n <= j))
\]

• Good code

\[
\text{if } ((j < n) \&\& (n < k))
\]

• Conditions should read as you’d say them aloud
  • Not “Conditions shouldn’t read as you’d never say them aloud”!

Structure: Expressions (cont.)

• Parenthesize to resolve ambiguity
  • Example: Check if integer \( n \) satisfies \( j < n < k \)

• Common code

\[
\text{if } (j < n \&\& n < k)
\]

• Clearer code

\[
\text{if } ((j < n) \&\& (n < k))
\]

Does this code work?
Structure: Expressions (cont.)

- Parenthesize to resolve ambiguity (cont.)
  - Example: read and print character until end-of-file

- Bad code

```c
while (c = getchar() != EOF) 
  putchar(c);
```

- Good code

```c
while ((c = getchar()) != EOF) 
  putchar(c);
```

Structure: Expressions (cont.)

- Break up complex expressions
  - Example: Identify chars corresponding to months of year

- Bad code

```c
if ((c == 'J') || (c == 'F') || (c == 'M') || (c == 'A') || (c == 'S') || (c == 'O') || (c == 'N') || (c == 'D'))
```

- Good code – lining up things helps

```c
if ((c == 'J') || (c == 'F') || (c == 'M') || (c == 'A') || (c == 'S') || (c == 'O') || (c == 'N') || (c == 'D'))
```

- Very common, though, to elide parentheses

```c
if (c == 'J' || c == 'F' || c == 'M' || c == 'A' || c == 'S' || c == 'O' || c == 'N' || c == 'D')
```
Structure: Expressions (cont.)

• Sometimes, clarity can save you
  • Example: you know that \(i \% 2^n\) is the same as \(i \& 2^n - 1\)
  • So what happens when you replace

```
for (i = 0; i < 16; i++) {
    if (i % 4 == 0)
        printf("%d mod 4\n", i);
}
```

• With the following?

```
for (i = 0; i < 16; i++) {
    if (i & 3 == 0)
        printf("%d and 3\n", i);
}
```

Structure: Spacing

• Use readable/consistent spacing
  • Example: Assign each array element \(a[j]\) to the value \(j\).
  • Bad code

```
for (j=0;j<100;j++) a[j]=j;
```

• Good code

```
for (j = 0; j < 100; j++)
    a[j] = j;
```

• Often can rely on auto-indenting feature in editor
Structure: Indentation (cont.)

• Use readable/consistent/correct indentation
  • Example: Checking for leap year (does Feb 29 exist?)

```plaintext
legal = TRUE;
if (month == FEB) {
  if ((year % 4) == 0) {
    if (day > 29)
      legal = FALSE;
    else
      if (day > 28)
        legal = FALSE;
  }
}

legal = TRUE;
if (month == FEB) {
  if ((year % 4) == 0) {
    if (day > 29)
      legal = FALSE;
  } else {
    if (day > 28)
      legal = FALSE;
  }
}
```

Does this code work?

Structure: Indentation (cont.)

• Use “else-if” for multi-way decision structures
  • Example: Comparison step in a binary search.
  • Bad code

```plaintext
if (x < v[mid])
  high = mid - 1;
else
  if (x > v[mid])
    low = mid + 1;
else
  return mid;
```

• Good code

```plaintext
if (x < v[mid])
  high = mid - 1;
else if (x > v[mid])
  low = mid + 1;
else
  return mid;
```

v
low=0
mid=3
high=6

x
10
2
4
5
7
8
10
17
```c
#include <stdio.h>
#include <stdlib.h>

int main(void)
/* Read a circle's radius from stdin, and compute and write its
diameter and circumference to stdout. Return 0 if successful. */
{
    const double PI = 3.14159;
    int radius;
    int diam;
    double circum;

    printf("Enter the circle's radius:
");
    if (scanf("%d", &radius) != 1)
    {
        fprintf(stderr, "Error: Not a number\n");
        exit(EXIT_FAILURE); /* or: return EXIT_FAILURE; */
    }
    ...
    diam = 2 * radius;
    circum = PI * (double)diam;

    printf("A circle with radius %d has diameter %d\n",
            radius, diam);
    printf("and circumference %f.\n", circum);
    return 0;
}
```
Comments

- Master the language and its idioms
  - Let the code speak for itself
  - And then...

- Compose comments that add new information
  i++; /* add one to i */

- Comment sections ("paragraphs") of code, not lines of code
  - E.g., “Sort array in ascending order”

- Comment global data
  - Global variables, structure type definitions, field definitions, etc.

- Compose comments that agree with the code!!!
  - And change as the code itself changes. 😊

Comments (cont.)

- Comment sections ("paragraphs") of code, not lines of code

```c
#include <stdio.h>
#include <stdlib.h>

int main(void)
/* Read a circle’s radius from stdin, and compute and write its
diameter and circumference to stdout. Return 0 if successful. */
{
  const double PI = 3.14159;
  int radius;
  int diam;
  double circum;

  /* Read the circle’s radius. */
  printf("Enter the circle’s radius:\n");
  if (scanf("%d", &radius) != 1)  
    
    } /* or: return EXIT_FAILURE; */
...
/* Compute the diameter and circumference. */
diam = 2 * radius;
circum = PI * (double)diam;

/* Print the results. */
printf("A circle with radius %d has diameter %d\n", radius, diam);
printf("and circumference %.1f\n", circum);

return 0;

Function Comments

- Describe what a caller needs to know to call the function properly
- Describe what the function does, not how it works
- Code itself should clearly reveal how it works...
- If not, compose “paragraph” comments within definition

- Describe input
  - Parameters, files read, global variables used

- Describe output
  - Return value, parameters, files written, global variables affected

- Refer to parameters by name
Function Comments (cont.)

• Bad function comment

/* decomment.c */
int main(void) {
  /* Read a character. Based upon the character and the current DFA state, call the appropriate state-handling function. Repeat until end-of-file. */
  ... 
}

• Describes how the function works

Function Comments (cont.)

• Good function comment

/* decomment.c */
int main(void) {
  /* Read a C program from stdin. Write it to stdout with each comment replaced by a single space. Preserve line numbers. Return 0 if successful, EXIT_FAILURE if not. */
  ... 
}

• Describes what the function does
Summary

• Programming style
  • Think about the problem
  • Use top-down design and successive refinement
  • But know that backtracking inevitably will occur

Summary (cont.)

• Program style
  • Convey program structure
    • Spacing, indentation, parentheses
  • Use common C idioms
    • But not at the expense of clarity
  • Choose consistent and descriptive names
    • For variables, functions, etc.
  • Compose proper comments
    • Especially for functions
  • Divide code into modules
    • Functions and files
# include <stdio.h>
# include <ctype.h>
# include <string.h>

enum { MAX_WORD_LEN = 20};
enum { MAX_LINE_LEN = 50};

Continued on next slide

Appendix: The “justify” Program

```c
int ReadWord(char *word) {
    /* Read a word from stdin. Assign it to word. Return the length
       of the word, or 0 if no word could be read. */
    int ch, pos = 0;
    /* skip over white space. */
    ch = getchar();
    while ((ch != EOF) && isspace(ch))
        ch = getchar();
    /* store chars up to MAX_WORD_LEN in word. */
    while ((ch != EOF) && (! isspace(ch))) {
        if (pos < MAX_WORD_LEN) {
            word[pos] = (char)ch;
            pos++;
        }
        ch = getchar();
    }
    word[pos] = '\0';
    /* return length of word. */
    return pos;
}
```

Continued on next slide
Appendix: The “justify” Program

void ClearLine(char *line, int *lineLen, int *numWords) {
    /* Clear the given line. That is, clear line, and set *lineLen
     and *numWords to 0. */
    line[0] = '\0';
    *lineLen = 0;
    *numWords = 0;
}

void AddWord(const char *word, char *line, int *lineLen) {
    /* Append word to line, making sure that the words within line are
     separated with spaces. Update *lineLen to indicate the
     new line length. */
    if (*lineLen > 0) {
        line[*lineLen] = ' ';  
        line[*lineLen + 1] = '\0';
        (*lineLen)++;
    }
    strcat(line, word);
    (*lineLen) += strlen(word);
}

void WriteLine(const char *line, int lineLen, int numWords) {
    /* Write line to stdout, in right justified form. lineLen
     indicates the number of characters in line. numWords indicates
     the number of words in line. */
    int extraSpaces, spacesToInsert, i, j;
    /* Compute number of excess spaces for line. */
    extraSpaces = MAX_LINE_LEN - lineLen;
    for (i = 0; i < lineLen; i++) {
        if (line[i] != ' ')
            putchar(line[i]);
        else {
            /* Compute additional spaces to insert. */
            spacesToInsert = extraSpaces / (numWords - 1);
            /* Print a space, plus additional spaces. */
            for (j = 1; j <= spacesToInsert + 1; j++)
                putchar(' ');
            /* Decrease extra spaces and word count. */
            extraSpaces -= spacesToInsert;
            numWords--;
        }
    }
    putchar('
');
}

Continued on next slide
int main(void) {
    /* Read words from stdin, and write the words in justified format
to stdout. */
    /* Simplifying assumptions:
    Each word ends with a space, tab, newline, or end-of-file.
    No word is longer than MAX_WORD_LEN characters. */
    char word[MAX_WORD_LEN + 1];
    int wordLen;
    char line[MAX_LINE_LEN + 1];
    int lineLen = 0;
    int numWords = 0;
    ClearLine(line, &lineLen, &numWords);
    ...
    for (;;) {
        wordLen = ReadWord(word);
        /* If no more words, print line
        with no justification. */
        if ((wordLen == 0) && (lineLen > 0)) {
            puts(line);
            break;
        }
        /* If word doesn’t fit on this line, then... */
        if ((wordLen + 1 + lineLen) > MAX_LINE_LEN) {
            WriteLine(line, lineLen, numWords);
            ClearLine(line, &lineLen, &numWords);
            AddWord(word, line, &lineLen);
            numWords++;
        }
        return 0;
    }
    Continued on next slide