Programming and Program Style

Jennifer Rexford

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**
  - A well-styled program is **more likely to be correct**

Lecture Overview

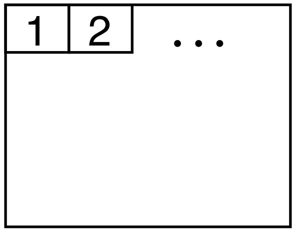
- **Programming style**: creating a good program
  - Top-down design
  - Successive refinement
  - Example: left and right justifying text
- **Program style**: qualities of a good program
  - Well structured
  - Uses common idioms
  - Uses descriptive names
  - Contains proper comments
  - Modular

Part 1: Programming Style

Bottom-Up Design is Bad

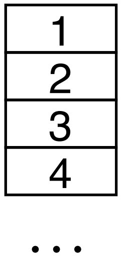
- Bottom-up design ☹
  - Design one part in detail
  - Design another part in detail
  - Repeat until finished

- Bottom-up design in **painting**
  - Paint upper left part, paint next part, …
  - *Unlikely to produce a good painting*



1 2 …

- Bottom-up design in **programming**
  - Write first part, write next part of program, ….
  - *Unlikely to produce a good program*

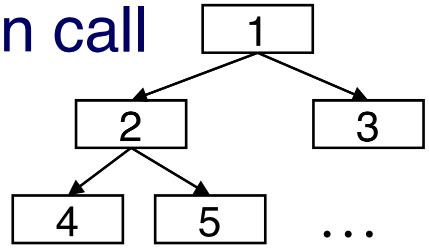


1
2
3
4
…

Top-Down Design is Good

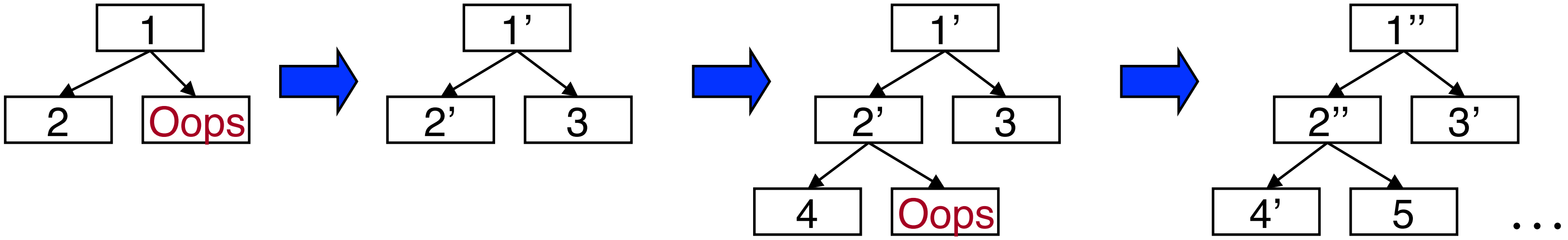
- Top-down design ☺
  - Design entire product with minimal detail
  - Successively refine until finished
- Top-down design in **painting**
  - Sketch the entire painting with minimal detail
  - Successively refine the entire painting

- Top-down design in **programming**
  - Define main() function in pseudocode
  - Refine each statement with code or 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
  - Recurse in (mostly) breadth-first order
    - Until all functions are defined



Illustrative Example

- Illustrate good programming style
  - Especially function-level modularity and top-down design
- Illustrate going from problem statement to code
  - Review and illustrate C constructs
- Example: text formatting
  - Derived from King Section 15.3

Example: Text Formatting

- Input: ASCII text
  - Text with arbitrary spaces & 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

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 in practice!!!
  - Design sequence is idealized
    - In reality, much backtracking would occur

The Top Level

- First, let’s sketch **`main()`**…

```
int main(void) {
   <Clear line>
   for (;;) {
      <Read a 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;
}
```

Reading a Word

```
…
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>
}
```

- 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…

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;
}
```

Saving a Word

```
…
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
         return
      }
      if (<Word
         <Print
         <Clear
      }
      AddWord(word, line, &lineLen);
   }
   return 0;
}
```

- Now, back to **`main()`**. What does <Add word to line> mean? The job seems complicated enough to demand a distinct function…

```
void AddWord(const char *word, char *line, int *lineLen) {
   <if line already contains some words, append a space>
   strcat(line, word);
   (*lineLen) += strlen(word);
}
```

Saving a Word (cont.)

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

```
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

```
…
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>
      }
      AddWord(word, line, &lineLen);
   }
   return 0;
}
```

- 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…

Deciding When to Print

```
…
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 + 1 + lineLen) > MAX_LINE_LEN) {
         <Print line with justification>
         <Clear line buffer>
      }
      AddWord(word, line, &lineLen);
   }
   return 0;
}
```

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

Printing with Justification

- 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…

```
…
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;
}
```

Printing with Justification (cont.)

- And write pseudocode for **`WriteLine()`**…

```
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.)

```
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('\n');
}
```

- 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…

```
…
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(wo
      numWords++
   }
   return 0;
}
```

```
void ClearLine(char *line, int *lineLen, int *numWords) {
   line[0] = '\0';
   *lineLen = 0;
   *numWords = 0;
}
```

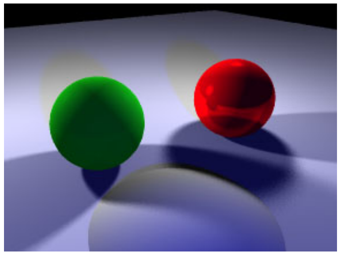
Modularity: Summary of Example

- To the user of the program
  - Input: Text in messy format
  - Output: Same text left and right justified
- 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;vec U,black,amb={.02,.02,.02};struct sphere{ vec
cen,color;double rad,kd,ks,kt,kl,ir}*s,*best,sph[]={0.,6.,.5,1.,1.,1.,.9, .
05,.2,.85,0.,1.7,-1.,8.,-.5,1.,.5,.2,1.,.7,.3,0.,.05,1.2,1.,8.,-.5,.1,.8,.8,
1.,.3,.7,0.,0.,1.2,3.,-6.,15.,1.,.8,1.,7.,0.,0.,0.,.6,1.5,-3.,-3.,12.,.8,1.,
1.,5.,0.,0.,0.,.5,1.5,};yx;double u,b,tmin,sqrt(),tan();double vdot(A,B)vec A ,B;{return
A.x*B.x+A.y*B.y+A.z*B.z;}vec vcomb(a,A,B)double a;vec A,B;{B.x+=a* A.x;B.y+=a*A.y;B.z
+=a*A.z;return B;}vec vunit(A)vec A;{return vcomb(1./sqrt( vdot(A,A)),A,black);}struct
sphere*intersect(P,D)vec P,D;{best=0;tmin=1e30;s= sph+5;while(s--sph)b=vdot(D,U=vcomb(-1.,P,s-
cen)),u=b*b-vdot(U,U)+s-rad*s -rad,u=u0?sqrt(u):1e31,u=b-u1e-7?b-u:b+u,tmin=u=1e-7&&u<tmin?
best=s,u: tmin;return best;}vec trace(level,P,D)vec P,D;{double d,eta,e;vec N,color; struct
sphere*s,*l;if(!level--)return black;if(s=intersect(P,D));else return amb;color=amb;eta=s-ir;d=
-vdot(D,N=vunit(vcomb(-1.,P=vcomb(tmin,D,P),s-cen )));if(d<0)N=vcomb(-1.,N,black),eta=1/eta,d=
-d;l=sph+5;while(l--sph)if((e=l -kl*vdot(N,U=vunit(vcomb(-1.,P,l-cen))))0&&intersect(P,U)==l)
color=vcomb(e ,l-color,color);U=s-color;color.x*=U.x;color.y*=U.y;color.z*=U.z;e=1-eta* eta*(1-
d*d);return vcomb(s-kt,e0?trace(level,P,vcomb(eta,D,vcomb(eta*d-sqrt (e),N,black))):black,vcomb
(s-ks,trace(level,P,vcomb(2*d,N,D)),vcomb(s-kd, color,vcomb(s-kl,U,black))));}main(){printf("%d
%d\n",32,32);while(yx<32*32) U.x=yx%32-32/2,U.z=32/2-yx++/32,U.y=32/2/tan
(25/114.5915590261),U=vcomb(255., trace(3,black,vunit(U)),black),printf("%.0f %.0f %.0f\n",U);}
```

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
    - Choose descriptive names
    - Compose proper comments
    - Use modularity

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?)

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

Does this code work?

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

Does this code work?

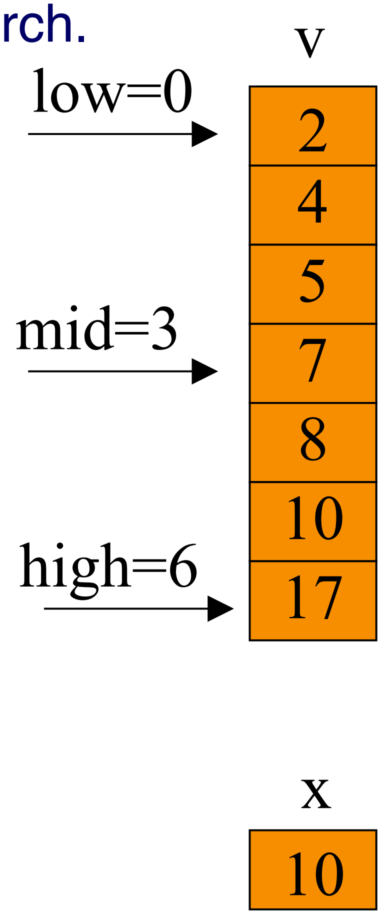
Structure: Indentation (cont.)

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

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

  - Good code

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



Structure: “Paragraphs”

- Use blank lines to divide the code into key parts

```
#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:\n");
   if (scanf("%d", &radius) != 1)
   {
      fprintf(stderr, "Error: Not a number\n");
      exit(EXIT_FAILURE);  /* or:  return EXIT_FAILURE; */
   }
…
```

Structure: “Paragraphs”

- Use blank lines to divide the code into key parts

```
   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;
}
```

Structure: Expressions

- Use natural form of expressions
  - Example: Check if integer `n` satisfies `j < n < k`
  - Bad code

```
if (!(n >= k) && !(n <= j))
```

  - Good code

```
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`**
  - Bad code

```
if (j < n && n < k)
```

Does this code work?

  - Good code

```
if ((j < n) && (n < k))
```

Structure: Expressions (cont.)

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

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

Does this code work?

  - Good code

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

Structure: Expressions (cont.)

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

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

  - Good code

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

  - Lining up the parallel structures is helpful, too!

C Idioms

- Use C idioms
  - Example: Set each array element to 1.0.
  - Bad code (or, perhaps just “so-so” code)

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

  - Good code

```
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.

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

```
#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)
   {
      fprintf(stderr, "Error: Not a number\n");
      exit(EXIT_FAILURE);  /* or:  return EXIT_FAILURE; */
   }
…
```

Comments (cont.)

```
   /* 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 %f.\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**

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)

Summary

- Programming style
  - Think about the problem
  - Use top-down design and successive refinement
  - But know that backtracking inevitably will occur
- Program style
  - Convey structure (spacing, indentation, parentheses)
  - Use common C idioms
  - Choose descriptive names for variables, functions
  - Compose proper comments, especially for functions
  - Divide code into modules (functions and files)

Appendix: The “justify” Program

```
#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

```
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 line already contains some words, append a space. */
   if (*lineLen > 0) {
      line[*lineLen] = ' ';
      line[*lineLen + 1] = '\0';
      (*lineLen)++;
   }
   strcat(line, word);
   (*lineLen) += strlen(word);
}
```

Continued on next slide

Appendix: The “justify” Program

```
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('\n');
}
```

Continued on next slide

Appendix: The “justify” Program

```
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);

   …
```

Continued on next slide

Appendix: The “justify” Program

```
   …

   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;
}
```