Princeton University
Computer Science 217: Introduction to Programming Systems

Program and Programming Style

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

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For Your Amusement

Any fool can write code that a computer can understand. Good programmers write code that humans can understand.
-- Martin Fowler

Good code is its own best documentation. As you're about to add a comment, ask yourself, "How can I improve the code so that this comment isn't needed?"
-- Steve McConnell

Programs must be written for people to read, and only incidentally for machines to execute.
-- Abelson / Sussman

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Goals of this Lecture

Help you learn about:
- Good **program** style
- Good **programming** style

Why?
- A well-styled program is more likely to **be correct** than a poorly-styled program
- A well-styled program is more likely to **stay correct** (i.e. is more maintainable) than a poorly-styled program
- A power programmer knows the qualities of a well-styled program, and how to compose one quickly

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Agenda

Program style
- **Qualities of a good program**

Programming style
- How to write a good program quickly

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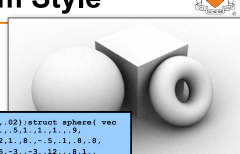
Motivation for Program Style

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)

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Motivation for Program Style

Why does program style matter?
- Correctness
  - The clearer a program is, the more likely it is to be correct
- Maintainability
  - The clearer a program is, the more likely it is to **stay** correct over time

Good program ≈ clear program

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Choosing Names

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

Length of name ≈ proportional to scope of variable

Use case judiciously

- E.g., Stack_push (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 that do something

- E.g., `getchar()`, `putchar()`, `Check_octal()`, etc.

Not necessarily for functions that are something: sin(), sqrt()

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Using C Idioms

Use C idioms

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

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

- Good code (not because it's vastly simpler—it isn't!—but because it uses a standard idiom that programmers can grasp at a glance)

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

- Don't feel obliged to use C idioms that decrease clarity

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Revealing Structure: Expressions

Parenthesize for correctness and to resolve ambiguity

- Example: read and print character until end-of-file
- Broken code

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

- Working, idiomatic code

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

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iClicker Question

Q: Does the following code work to check if integer `n` satisfies `j < n < k`?

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

A. No, needs to be `if ((j < n) && (n < k))`

B. Correct, but I'd parenthesize anyway

C. Correct, and I'd leave it alone

Revealing Structure: Expressions

Parenthesize for correctness and to resolve ambiguity

- Example: Check if integer `n` satisfies `j < n < k`
- Common code

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

- Clearer code (maybe)

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

It's clearer *depending* on whether your audience can be trusted to know the precedence of all the C operators. Use your judgment on this!

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iClicker Question

Q: Does the following code work to check if integer `n` satisfies `j < n < k`?

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

A. No, incorrect

B. Not sure – I can't be expected to apply DeMorgan's laws during a 10 AM lecture

C. Correct, but I'd never write such a monstrosity

Revealing 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 in other than a purely internal dialog!"

Revealing Structure: Expressions

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 – lining up things helps

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

- Very common, though, to elide parentheses

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


Revealing Structure

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

Perhaps better in this case: a switch statement

```
switch (c) {
  case 'J': case 'F': case 'M':
  case 'A': case 'S': case 'O':
  case 'N': case 'D':
    do_this();
    break;
  default:
    do_that();
}
```


Revealing 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

Revealing Structure: Indentation

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?

Revealing Structure: Indentation

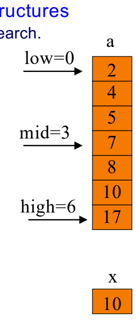
Use "else-if" for multi-way decision structures

- Example: Comparison step in a binary search.
- Bad code

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

- Good code

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



Revealing Structure: "Paragraphs"

Use blank lines to divide the code into key parts

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

/* Read a circle's radius from stdin, and compute and write its
   diameter and circumference to stdout.  Return 0 if successful. */

int main(void)
{  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; */
   }
…
```

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Revealing 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;
}
```

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Composing 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 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!!!

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Composing Comments

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

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

/* Read a circle's radius from stdin, and compute and write its
   diameter and circumference to stdout.  Return 0 if successful. */

int main(void)
{  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; */
   }
…
```

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Composing Comments

```
   /* 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;
}
```

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Composing 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**

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Composing Function Comments

Bad function comment

```
/* decomment.c */

/* Read a character.  Based upon the character and
   the current DFA state, call the appropriate
   state-handling function.  Repeat until
   end-of-file. */

int main(void)
{
   …
}
```

Describes **how the function works**

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Composing Function Comments

Good function comment

```
/* decomment.c */

/* 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. */

int main(void)
{
   …
}
```

- Describes **what the function does**

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Using Modularity

Abstraction is the key to managing complexity
- Abstraction is a tool (the only one?) that people use to understand complex systems
- Abstraction allows people to know *what* a (sub)system does without knowing *how*

Proper modularity is the manifestation of abstraction
- Proper modularity makes a program's abstractions explicit
- Proper modularity can dramatically increase clarity
  - ⇒ Programs should be modular

However
- *Excessive* modularity can *decrease* clarity!
- *Improper* modularity can *dramatically* decrease clarity!!!
  - ⇒ Programming is an art

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Modularity Examples

Examples of **function**-level modularity
- Character I/O functions such as `getchar()` and `putchar()`
- Mathematical functions such as `sin()` and `gcd()`
- Function to sort an array of integers

Examples of **file**-level modularity
- Assignment 3.
- And all the other assignments.

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Program Style Summary

Good program ≈ clear program

Qualities of a clear program
- Uses appropriate names
- Uses common idioms
- Reveals program structure
- Contains proper comments
- Is modular

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Agenda

Program style
- Qualities of a good program

Programming style
- **How to write a good program quickly**

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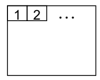
Bottom-Up Design

Bottom-up design ☹
- Design one part of the system in detail
- Design another part of the system in detail
- Combine
- Repeat until finished

Bottom-up design in **painting**
- Paint part of painting in complete detail
- Paint another part of painting in complete detail
- Combine
- Repeat until finished
- *Unlikely to produce a good painting*
  (except sometimes: see the movie "Tim's Vermeer")



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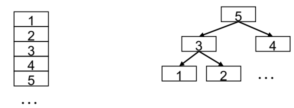
Bottom-Up Design

Bottom-up design in **programming**
- Compose part of program in complete detail
- Compose another part of program in complete detail
- Combine
- Repeat until finished
- *Unlikely to produce a good program*



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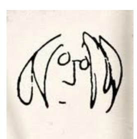
Top-Down Design

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 until finished



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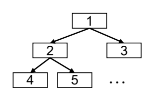
Top-Down Design

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
- Repeat in (mostly) breadth-first order until finished
- Bonus: Product is naturally **modular**



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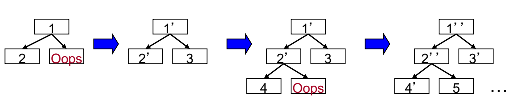
Top-Down Design in Reality

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
- Repeat in (mostly) breadth-first order until finished



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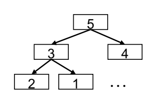
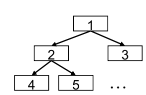
Aside: Least-Risk Design

Design process should minimize risk

Bottom-up design
- Compose each child module before its parent
- **Risk level**: high
  - May compose modules that are never used



Top-down design
- Compose each parent module before its children
- **Risk level**: low
  - Compose only those modules that are required



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Aside: Least-Risk Design

Recommendation

- Work mostly top-down
- But give high priority to risky modules (that may result in major rewrites)
- Create scaffolds and stubs as required

Example: Text Formatting

Functionality (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 last line
- **Assumptions**
  - "Word" is a sequence of non-white-space chars followed by a white-space char or end-of-file
  - No word is longer than 20 chars

Example Input and Output

Input

```
"C is quirky,    flawed, and an    enormous success.
   While    accidents of        history
surely helped,
it    evidently satisfied a    need for a
system implementation     language   efficient enough
 to displace assembly language,
yet sufficiently abstract  and fluent to       describe
algorithms     and interactions in a
wide variety of environments." -- Dennis Ritchie
```

Output

```
"C is quirky, flawed,  and  an  enormous  success.
While  accidents  of  history  surely  helped,  it
evidently  satisfied  a  need  for  a  system
implementation  language  efficient  enough  to
displace  assembly  language,  yet  sufficiently
abstract and fluent  to  describe  algorithms  and
interactions in a wide variety  of  environments."
-- Dennis Ritchie
```


Caveats

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, typically much backtracking would occur

The main() Function

```
int main(void)
{  <clear line>
   <read a word>
   while (<there is a word>)
   {  if (<word doesn't fit on line>)
      {  <write justified line>
         <clear line>
      }
      <add word to line>
      <read a word>
   }
   if (<line isn't empty>)
      <write line>
   return 0;
}
```


The main() Function

```
enum {MAX_WORD_LEN = 20};
int main(void)
{  char word[MAX_WORD_LEN+1];
   int wordLen;
   <clear line>
   wordLen = readWord(word);
   while (<there is a word>)
   {  if (<word doesn't fit on line>)
      {  <write justified line>
         <clear line>
      }
      <add word to line>
      wordLen = readWord(word);
   }
   if (<line isn't empty>)
      <write line>
   return 0;
}
```

The main() Function

```
enum {MAX_WORD_LEN = 20};
int main(void)
{  char word[MAX_WORD_LEN+1];
   int wordLen;
   <clear line>
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if (<word doesn't fit on line>)
      {  <write justified line>
         <clear line>
      }
      <add word to line>
      wordLen = readWord(word);
   }
   if (<line isn't empty>)
      <write line>
   return 0;
}
```

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The main() Function

```
enum {MAX_WORD_LEN = 20};
int main(void)
{  char word[MAX_WORD_LEN+1];
   int wordLen;
   int lineLen;
   <clear line>
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if (<word doesn't fit on line>)
      {  <write justified line>
         <clear line>
      }
      <add word to line>
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      <write line>
   return 0;
}
```

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The main() Function

```
enum {MAX_WORD_LEN = 20};
enum {MAX_LINE_LEN = 50};
int main(void)
{  char word[MAX_WORD_LEN+1];
   char line[MAX_LINE_LEN+1];
   int wordLen;
   int lineLen;
   <clear line>
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if (<word doesn't fit on line>)
      {  <write justified line>
         <clear line>
      }
      lineLen = addWord(word, line, lineLen);
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      <write line>
   return 0;
}
```

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The main() Function

```
enum {MAX_WORD_LEN = 20};
enum {MAX_LINE_LEN = 50};
int main(void)
{  char word[MAX_WORD_LEN+1];
   char line[MAX_LINE_LEN+1];
   int wordLen;
   int lineLen;
   <clear line>
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if (<word doesn't fit on line>)
      {  <write justified line>
         <clear line>
      }
      lineLen = addWord(word, line, lineLen);
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      puts(line);
   return 0;
}
```

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The main() Function

```
enum {MAX_WORD_LEN = 20};
enum {MAX_LINE_LEN = 50};
int main(void)
{  char word[MAX_WORD_LEN+1];
   char line[MAX_LINE_LEN+1];
   int wordLen;
   int lineLen = 0;
   int wordCount = 0;
   <clear line>
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if (<word doesn't fit on line>)
      {  writeLine(line, lineLen, wordCount);
         <clear line>
      }
      lineLen = addWord(word, line, lineLen);
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      puts(line);
   return 0;
}
```

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The main() Function

```
enum {MAX_WORD_LEN = 20};
enum {MAX_LINE_LEN = 50};
int main(void)
{  char word[MAX_WORD_LEN+1];
   char line[MAX_LINE_LEN+1];
   int wordLen;
   int lineLen = 0;
   int wordCount = 0'
   <clear line>
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if ((wordLen + 1 + lineLen) > MAX_LINE_LEN)
      {  writeLine(line, lineLen, wordCount);
         <clear line>
      }
      lineLen = addWord(word, line, lineLen);
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      puts(line);
   return 0;
}
```

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The main() Function

```
enum {MAX_WORD_LEN = 20};
enum {MAX_LINE_LEN = 50};
int main(void)
{  char word[MAX_WORD_LEN+1];
   char line[MAX_LINE_LEN+1];
   int wordLen;
   int lineLen = 0;
   int wordCount = 0;
   line[0] = '\0'; lineLen = 0; wordCount = 0;
   wordLen = readWord(word);
   while (wordLen != 0)
   {  if ((wordLen + 1 + lineLen) > MAX_LINE_LEN)
      {  writeLine(line, lineLen, wordCount);
         line[0] = '\0'; lineLen = 0; wordCount = 0;
      }
      lineLen = addWord(word, line, lineLen);
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      puts(line);
   return 0;
}
```

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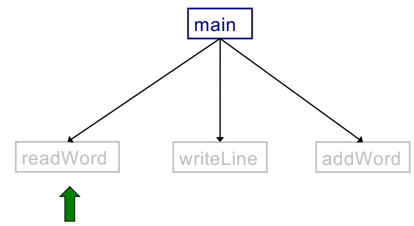
Status



50

The readWord() Function

```
int readWord(char *word)
{
   <skip over white space>

   <read chars, storing up to MAX_WORD_LEN in word>

   <return length of word>
}
```

51

The readWord() Function

```
int readWord(char *word)
{
   int ch;

   /* Skip over white space. */
   ch = getchar();
   while ((ch != EOF) && isspace(ch))
      ch = getchar();

   <read up to MAX_WORD_LEN chars into word>

   <return length of word>
}
```

Note the use of a function from the standard library. Very appropriate for your top-down design to target things that are already built.

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The readWord() Function

```
int readWord(char *word)
{
   int ch;
   int pos = 0;

   /* Skip over white space. */
   ch = getchar();
   while ((ch != EOF) && isspace(ch))
      ch = getchar();

   /* Read up to MAX_WORD_LEN chars into 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>
}
```

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The readWord() Function

```
int readWord(char *word)
{
   int ch;
   int pos = 0;
   ch = getchar();

   /* Skip over white space. */
   while ((ch != EOF) && isspace(ch))
      ch = getchar();

   /* Read up to MAX_WORD_LEN chars into word. */
   while ((ch != EOF) && (! isspace(ch)))
   {  if (pos < MAX_WORD_LEN)
      {  word[pos] = (char)ch;
         pos++;
      }
      ch = getchar();
   }
   word[pos] = '\0';

   return pos;
}
```

readWord() gets away with murder here, consuming/discarding one character past the end of the word.

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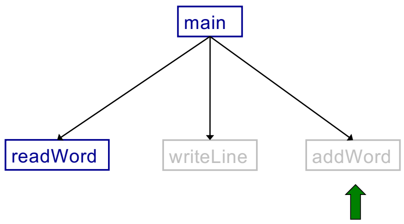
Status



The addWord() Function

```
int addWord(const char *word, char *line, int lineLen)
{
   <if line already contains words, then append a space>

   <append word to line>

   <return the new line length>
}
```


The addWord() Function

```
int addWord(const char *word, char *line, int lineLen)
{
   int newLineLen = lineLen;

   /* if line already contains words, then append a space. */
   if (newLineLen > 0)
   {  strcat(line, " ");
      newLineLen++;
   }

   <append word to line>

   <return the new line length>
}
```


The addWord() Function

```
int addWord(const char *word, char *line, int lineLen)
{
   int newLineLen = lineLen;

   /* if line already contains words, then append a space. */
   if (newLineLen > 0)
   {  strcat(line, " ");
      newLineLen++;
   }

   strcat(line, word);

   <return the new line length>
}
```


The addWord() Function

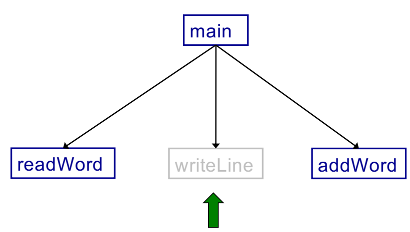
```
int addWord(const char *word, char *line, int lineLen)
{
   int newLineLen = lineLen;

   /* If line already contains some words, then append a space. */
   if (newLineLen > 0)
   {  strcat(line, " ");
      newLineLen++;
   }

   strcat(line, word);

   newLineLen += strlen(word);
   return newLineLen;
}
```


Status



The writeLine() Function

```
void writeLine(const char *line, int lineLen, int wordCount)
{  int i;

   <compute number of excess spaces for line>

   for (i = 0; i < lineLen; i++)
   {  if (line[i] != ' ')
         putchar(line[i])
      else
      {
         <compute additional spaces to insert>

         <print a space, plus additional spaces>

         <decrease extra spaces and word count>
      }
   }
   putchar('\n');
}
```

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The writeLine() Function

```
void writeLine(const char *line, int lineLen, int wordCount)
{  int i, extraSpaces;

   /* 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>

         <print a space, plus additional spaces>

         <decrease extra spaces and word count>
      }
   }
   putchar('\n');
}
```

62

The writeLine() Function

```
void writeLine(const char *line, int lineLen, int wordCount)
{  int i, extraSpaces, spacesToInsert;

   /* 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 / (wordCount - 1);

         <print a space, plus additional spaces>

         <decrease extra spaces and word count>
      }
   }
   putchar('\n');
}
```

The number of gaps

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The writeLine() Function

```
void writeLine(const char *line, int lineLen, int wordCount)
{  int i, extraSpaces, spacesToInsert, 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 / (wordCount - 1);

         /* Print a space, plus additional spaces. */
         for (j = 1; j <= spacesToInsert + 1; j++)
            putchar(' ');

         <decrease extra spaces and word count>
      }
   }
   putchar('\n');
}
```

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

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The writeLine() Function

```
void writeLine(const char *line, int lineLen, int wordCount)
{  int i, extraSpaces, spacesToInsert, 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 / (wordCount - 1);

         /* Print a space, plus additional spaces. */
         for (j = 1; j <= spacesToInsert + 1; j++)
            putchar(' ');

         /* Decrease extra spaces and word count. */
         extraSpaces -= spacesToInsert;
         wordCount--;
      }
   }
   putchar('\n');
}
```

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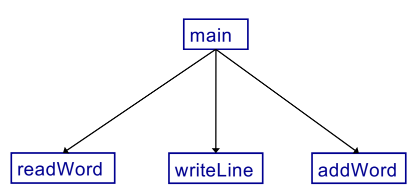
Status



Complete! And modular!

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Summary

Program style
- Choose appropriate names (for variables, functions, …)
- Use common idioms (but not at the expense of clarity)
- Reveal program structure (spacing, indentation, parentheses, …)
- Compose proper comments (especially for functions)
- Use modularity (because modularity reveals abstractions)

Programming style
- Use top-down design and successive refinement
- But know that backtracking inevitably will occur
- And give high priority to risky modules

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Are we there yet?

Now that the top-down design is done, and the program "works," does that mean we're done?

No. There are almost always things to improve, perhaps by a bottom-up pass that better uses existing libraries.

The second time you write the same program, it turns out better.

What's wrong with this output?

Input

```
"C is quirky,    flawed, and an    enormous success.
   While     accidents of        history
surely helped,
it    evidently satisfied a    need for a
system implementation    language   efficient enough
 to displace assembly language,
yet sufficiently abstract  and fluent to        describe
algorithms     and interactions in a
wide variety of environments." -- Dennis Ritchie
```

Output

```
"C is quirky, flawed,  and  an  enormous  success.
While  accidents  of  history  surely  helped,  it
evidently  satisfied  a   need  for  a   system
implementation  language  efficient  enough  to
displace  assembly  language,  yet  sufficiently
abstract and fluent  to  describe  algorithms  and
interactions in a wide variety  of  environments."
-- Dennis Ritchie
```

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What's better with this output?

Adequate

```
"C is quirky, flawed,  and  an  enormous  success.
While  accidents  of  history  surely  helped,  it
evidently  satisfied  a   need  for  a   system
implementation  language  efficient  enough  to
displace  assembly  language,  yet  sufficiently
abstract and fluent  to  describe  algorithms  and
interactions in a wide variety  of  environments."
-- Dennis Ritchie
```

Better

```
"C is  quirky, flawed,  and  an enormous  success.
While  accidents  of  history  surely  helped,  it
evidently  satisfied  a   need  for  a   system
implementation  language efficient  enough  to
displace  assembly  language,  yet  sufficiently
abstract  and  fluent  to  describe algorithms  and
interactions  in  a wide variety of  environments."
-- Dennis Ritchie
```

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Challenge problem

Design a function `int spacesHere(int i, int k, int n)`

that calculates how many marbles to put into the *i*th jar, assuming that there are *n* marbles to distribute over *k* jars.

(1) the jars should add up to *n*, that is,

```
{s=0; for(i=0;i<k;i++) s+=spacesHere(i,k,n); assert (s==n);}
```

or in math notation, $\sum_{i=0}^{k-1}$ spacesHere(i,k,n) = n

(2) marbles should be distributed evenly—the "extra" marbles should not bunch up in nearby jars.

HINT: You should be able to write this in one or two lines, without any loops.

One solution uses floating-point division and rounding; do "man round" and pay attention to where that man page says "include <math.h>".

"Programming in the Large" Steps

Design & Implement
- Program & programming style
- Common data structures and algorithms
- Modularity
- Building techniques & tools

Debug
- Debugging techniques & tools

Test
- Testing techniques & tools

Maintain
- Performance improvement techniques & tools

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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

```
/* Read a word from stdin.  Assign it to word.  Return the length
   of the word, or 0 if no word could be read. */

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;
}
```

Continued on next slide

Appendix: The “justify” Program

```
/* Append word to line, making sure that the words within line are
   separated with spaces.  lineLen is the current line length.
   Return the new line length. */

int addWord(const char *word, char *line, int lineLen)
{
   int newLineLen = lineLen;

   /* If line already contains some words, then append a space. */
   if (newLineLen > 0)
   {  strcat(line, " ");
      newLineLen++;
   }

   strcat(line, word);
   newLineLen += strlen(word);
   return newLineLen;
}
```

Continued on next slide

Appendix: The “justify” Program

```
/* Write line to stdout, in right justified form.  lineLen
   indicates the number of characters in line.  wordCount indicates
   the number of words in line. */

void writeLine(const char *line, int lineLen, int wordCount)
{  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 / (wordCount - 1);

         /* Print a space, plus additional spaces. */
         for (j = 1; j <= spacesToInsert + 1; j++)
            putchar(' ');

         /* Decrease extra spaces and word count. */
         extraSpaces -= spacesToInsert;
         wordCount--;
      }
   }
   putchar('\n');
}
```

Continued on next slide

Appendix: The “justify” Program

```
/* Read words from stdin, and write the words in justified format
   to stdout. Return 0. */

int main(void)
{
   /* 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];
   char line[MAX_LINE_LEN + 1];
   int wordLen;
   int lineLen = 0;
   int wordCount = 0;

   line[0] = '\0'; lineLen = 0; wordCount = 0;
…
```

Continued on next slide

Appendix: The “justify” Program

```
   …

   wordLen = readWord(word);
   while ((wordLen != 0)
   {
      /* If word doesn't fit on this line, then write this line. */
      if ((wordLen + 1 + lineLen) > MAX_LINE_LEN)
      {  writeLine(line, lineLen, wordCount);
         line[0] = '\0'; lineLen = 0; wordCount = 0;
      }
      lineLen = addWord(word, line, lineLen);
      wordCount++;
      wordLen = readWord(word);
   }
   if (lineLen > 0)
      puts(line);
   return 0;
}
```