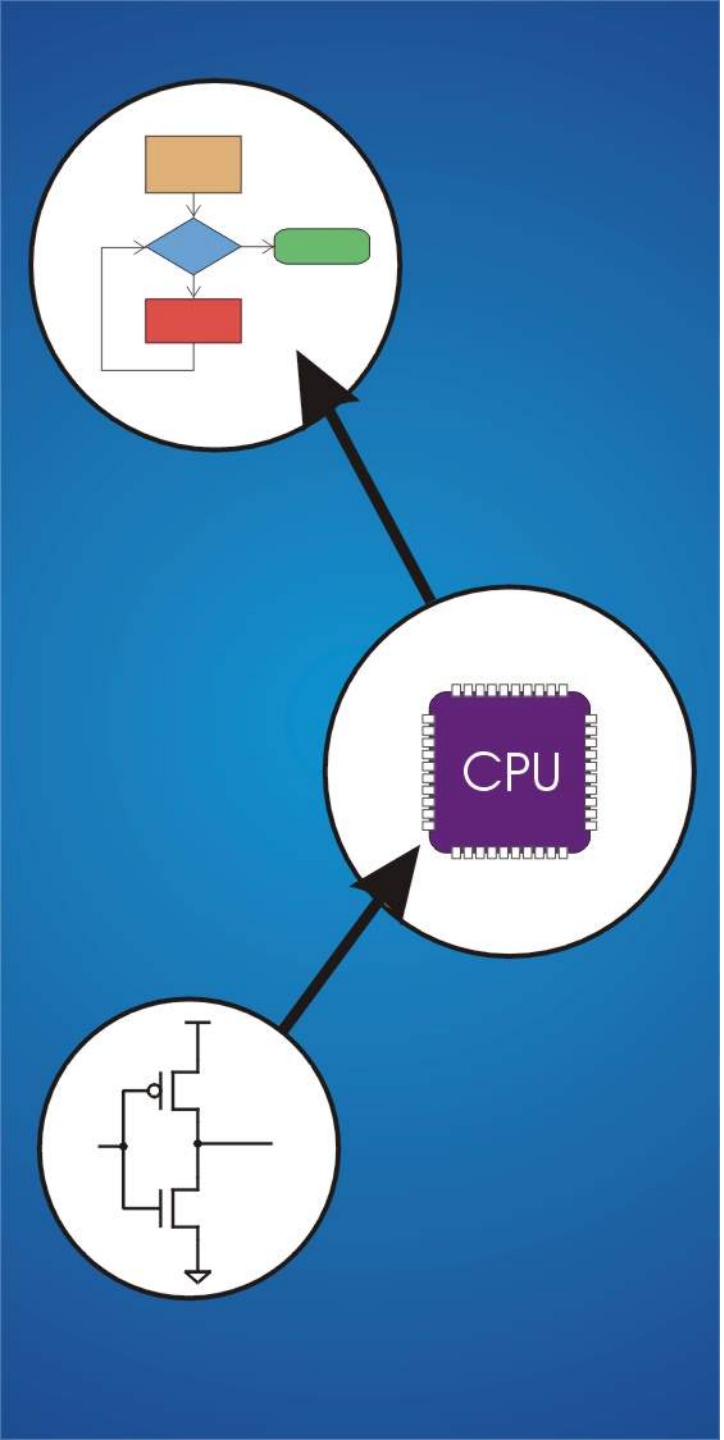


z = x + + - - y

Chapter 13
Control Structures

Control Structures

Conditional

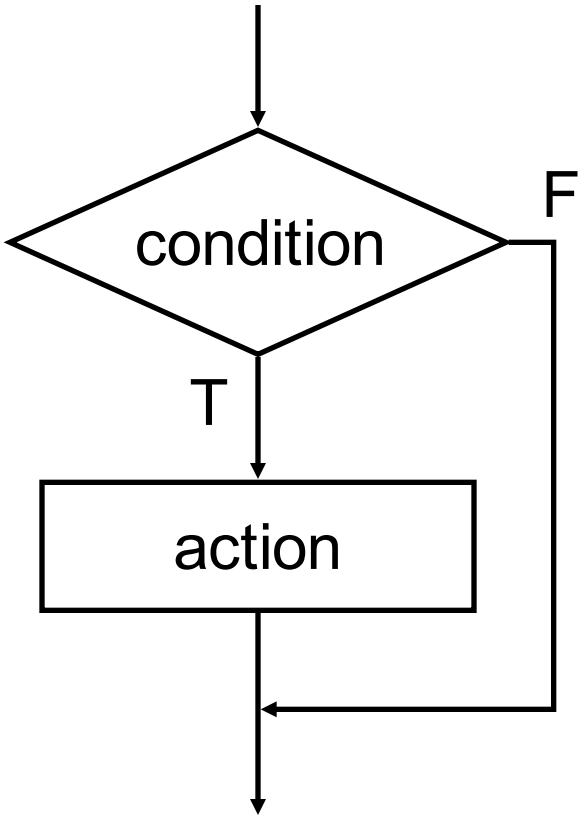
- making a decision about which code to execute, based on evaluated expression
- `if`
- `if-else`
- `switch`

Iteration

- executing code multiple times, ending based on evaluated expression
- `while`
- `for`
- `do-while`

If

```
if (condition)
  action;
```



Condition is a C expression,
which evaluates to TRUE (non-zero) or FALSE (zero).
Action is a C statement,
which may be simple or compound (a block).

Example If Statements

```
if (x <= 10)
   y = x * x + 5;
```

```
if (x <= 10) {
   y = x * x + 5;
   z = (2 * y) / 3;
}
```

compound statement; both executed if x <= 10

```
if (x <= 10)
   y = x * x + 5;
   z = (2 * y) / 3;
```

only first statement is conditional; second statement is ***always*** executed

More If Examples

```
if (0 <= age && age <= 11)
  kids += 1;
```

```
if (month == 4 || month == 6 ||
    month == 9 || month == 11)
  printf("The month has 30 days.\n");
```

```
if (x = 2)
  y = 5;
```

always true,
so action is ***always*** executed!

This is a common programming error (= instead of ==), not caught by compiler because it's syntactically correct.

If's Can Be Nested

```
if (x == 3)
  if (y != 6) {
    z = z + 1;
    w = w + 2;
  }
```

is the same as...

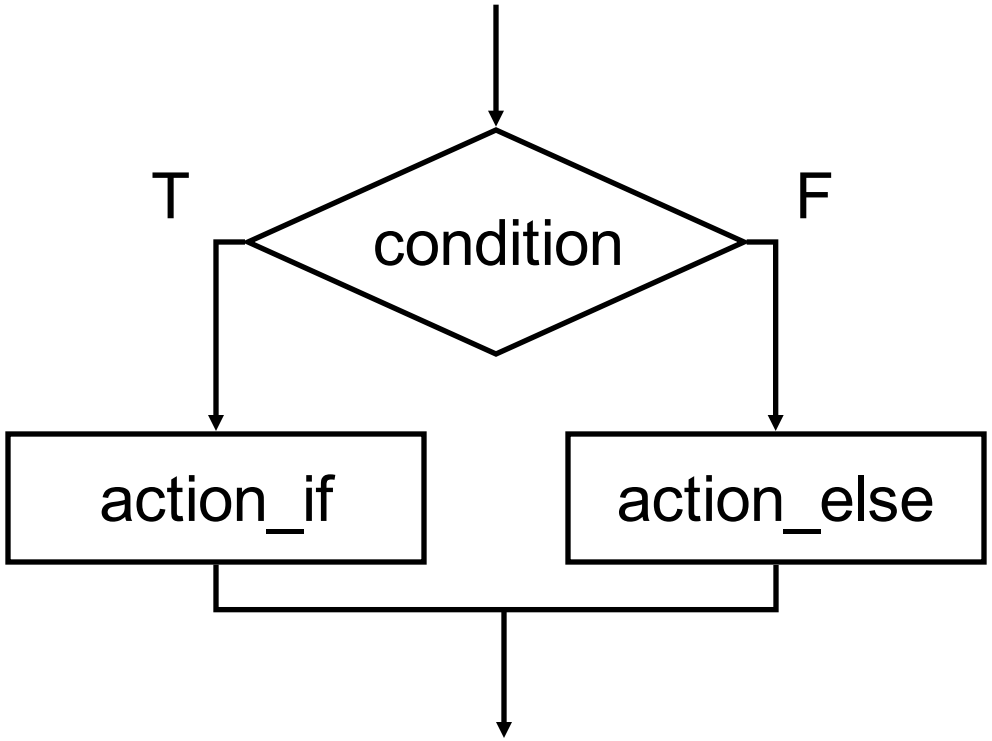
```
if ((x == 3) && (y != 6)) {
  z = z + 1;
  w = w + 2;
}
```

Generating Code for If Statement

```
; if (x == 2) y = 5;
        LDR   R0, R5, #0    ; load x into R0
        ADD   R0, R0, #-2   ; subtract 2
        BRnp  NOT_TRUE      ; if non-zero, x is not 2

        AND   R1, R1, #0    ; store 5 to y
        ADD   R1, R1, #5
        STR   R1, R5, #-1

NOT_TRUE  ...               ; next statement
```

If-else

```
if (condition)
  action_if;
else
  action_else;
```



Else allows choice between two mutually exclusive actions without re-testing condition.

Generating Code for If-Else

```
if (x) {
   y++;
   z--;
}
else {
   y--;
   z++;
}
```

```
        LDR   R0, R5, #0
        BRz   ELSE
        ; x is not zero
        LDR   R1, R5, #-1   ; incr y
        ADD   R1, R1, #1
        STR   R1, R5, #-1
        LDR   R1, R5, #-2   ; decr z
        ADD   R1, R1, #-1
        STR   R1, R5, #-2
        BR    DONE          ; skip else code
        ; x is zero
ELSE    LDR   R1, R5, #-1   ; decr y
        ADD   R1, R1, #-1
        STR   R1, R5, #-1
        LDR   R1, R5, #-2   ; incr z
        ADD   R1, R1, #1
        STR   R1, R5, #-2
DONE    ...   ; next statement
```

Matching Else with If

Else is always associated with *closest* unassociated if.

```
if (x != 10)
  if (y > 3)
    z = z / 2;
  else
    z = z * 2;
```

is the same as...

```
if (x != 10) {
  if (y > 3)
    z = z / 2;
  else
    z = z * 2;
}
```

is NOT the same as...

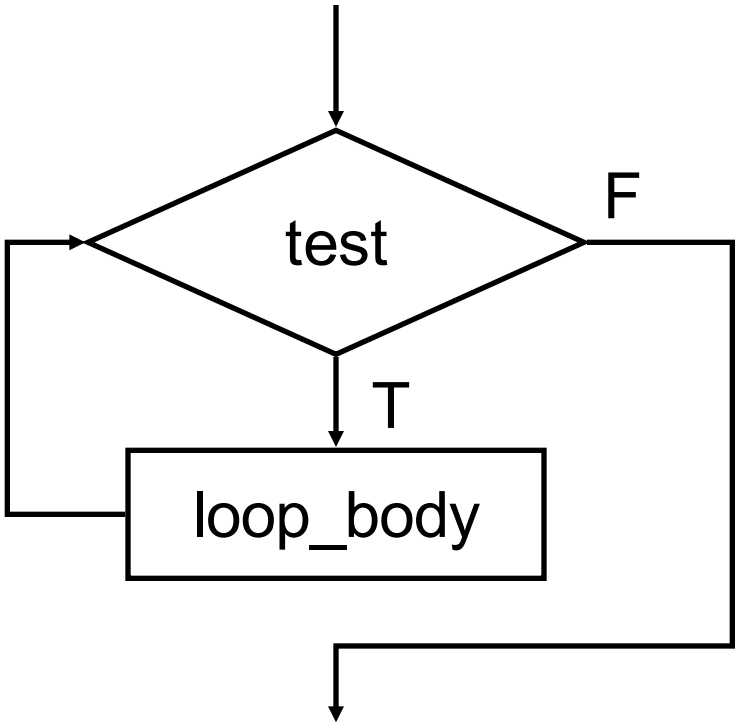
```
if (x != 10) {
  if (y > 3)
    z = z / 2;
}
else
    z = z * 2;
```

Chaining If's and Else's

```
if (month == 4 || month == 6 || month == 9 ||
    month == 11)
  printf("Month has 30 days.\n");
else if (month == 1 || month == 3 ||
         month == 5 || month == 7 ||
         month == 8 || month == 10 ||
         month == 12)
  printf("Month has 31 days.\n");
else if (month == 2)
  printf("Month has 28 or 29 days.\n");
else
  printf("Don't know that month.\n");
```

While

```
while (test)
  loop_body;
```



Executes loop body as long as test evaluates to TRUE (non-zero).

*Note: Test is evaluated **before** executing loop body.*

Generating Code for While

```
x = 0;
while (x < 10) {
  printf("%d ", x);
  x = x + 1;
}
```

```
        AND  R0, R0, #0
        STR  R0, R5, #0  ; x = 0
        ; test
LOOP    LDR  R0, R5, #0  ; load x
        ADD  R0, R0, #-10
        BRzp DONE
        ; loop body
        LDR  R0, R5, #0  ; load x
        ...
        <printf>
        ...
        ADD  R0, R0, #1  ; incr x
        STR  R0, R5, #0
        JMP  LOOP        ; test again

DONE    ; next statement
```

Infinite Loops

The following loop will never terminate:

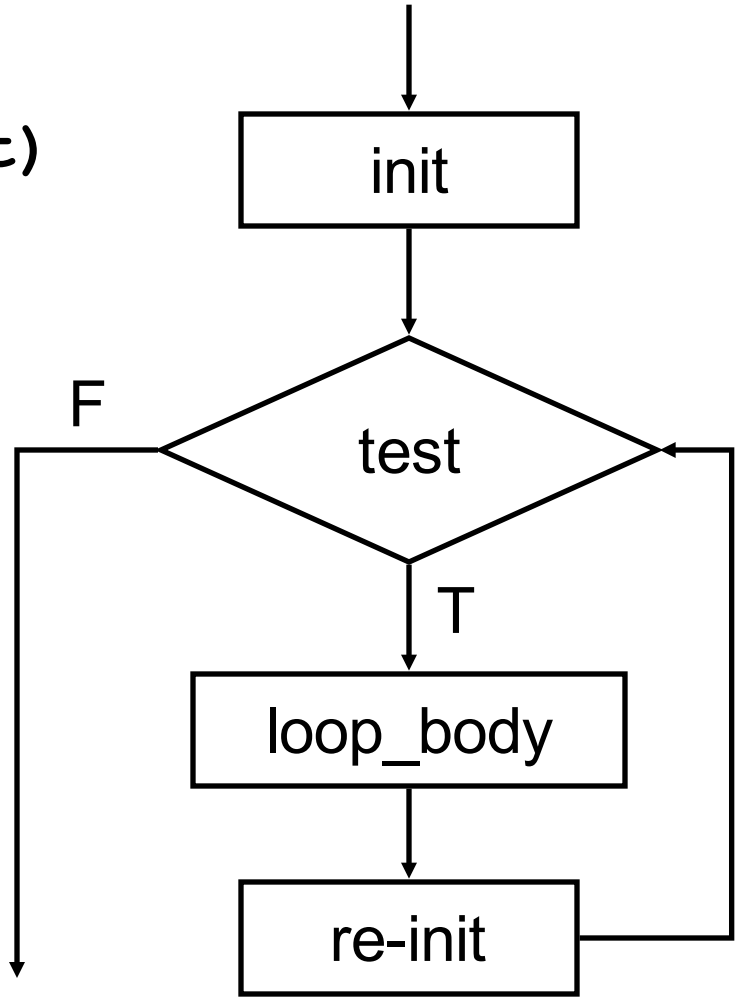
```
x = 0;
while (x < 10)
  printf("%d ", x);
```

Loop body does not change condition, so test never fails.

This is a common programming error that can be difficult to find.

For

```
for (init; end-test; re-init)
  statement
```



Executes loop body as long as test evaluates to TRUE (non-zero). Initialization and re-initialization code includedin loop statement.

*Note: Test is evaluated **before** executing loop body.*

Generating Code for For

```
for (i = 0; i < 10; i++)
  printf("%d ", i);
```

This is the same as the while example!

```
        ; init
        AND  R0, R0, #0
        STR  R0, R5, #0  ; i = 0
        ; test
LOOP    LDR  R0, R5, #0  ; load i
        ADD  R0, R0, #-10
        BRzp DONE
        ; loop body
        LDR  R0, R5, #0  ; load i
        ...
        <printf>
        ...
        ; re-init
        ADD  R0, R0, #1  ; incr i
        STR  R0, R5, #0
        JMP  LOOP        ; test again

DONE    ; next statement
```

Example For Loops

```
/* -- what is the output of this loop? -- */
for (i = 0; i <= 10; i ++)
  printf("%d ", i);

/* -- what does this one output? -- */
letter = 'a';
for (c = 0; c < 26; c++)
  printf("%c ", letter+c);

/* -- what does this loop do? -- */
numberOfOnes = 0;
for (bitNum = 0; bitNum < 16; bitNum++) {
  if (inputValue & (1 << bitNum))
    numberOfOnes++;
}
```

Nested Loops

Loop body can (of course) be another loop.

```
/* print a multiplication table */
for (mp1 = 0; mp1 < 10; mp1++) {
  for (mp2 = 0; mp2 < 10; mp2++) {
    printf("%d\t", mp1*mp2);
  }
  printf("\n");
}
```

Braces aren't necessary,
but they make the code easier to read.

Another Nested Loop

The test for the inner loop depends on the counter variable of the outer loop.

```
for (outer = 1; outer <= input; outer++) {
   for (inner = 0; inner < outer; inner++) {
      sum += inner;
   }
}
```

For vs. While

In general:

For loop is preferred for counter-based loops.

- **Explicit counter variable**
- **Easy to see how counter is modified each loop**

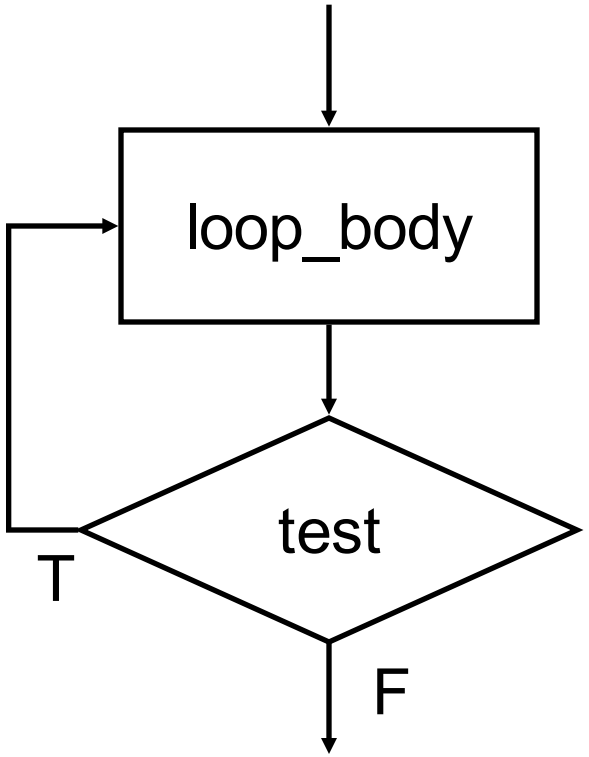
While loop is preferred for sentinel-based loops.

- **Test checks for sentinel value.**

Either kind of loop can be expressed as the other, so it's really a matter of style and readability.

Do-While

```
do
   loop_body;
while (test);
```



Executes loop body as long as test evaluates to TRUE (non-zero).

*Note: Test is evaluated **after** executing loop body.*

Problem Solving in C

Stepwise Refinement

- as covered in Chapter 6

...but can stop refining at a higher level of abstraction.

Same basic constructs

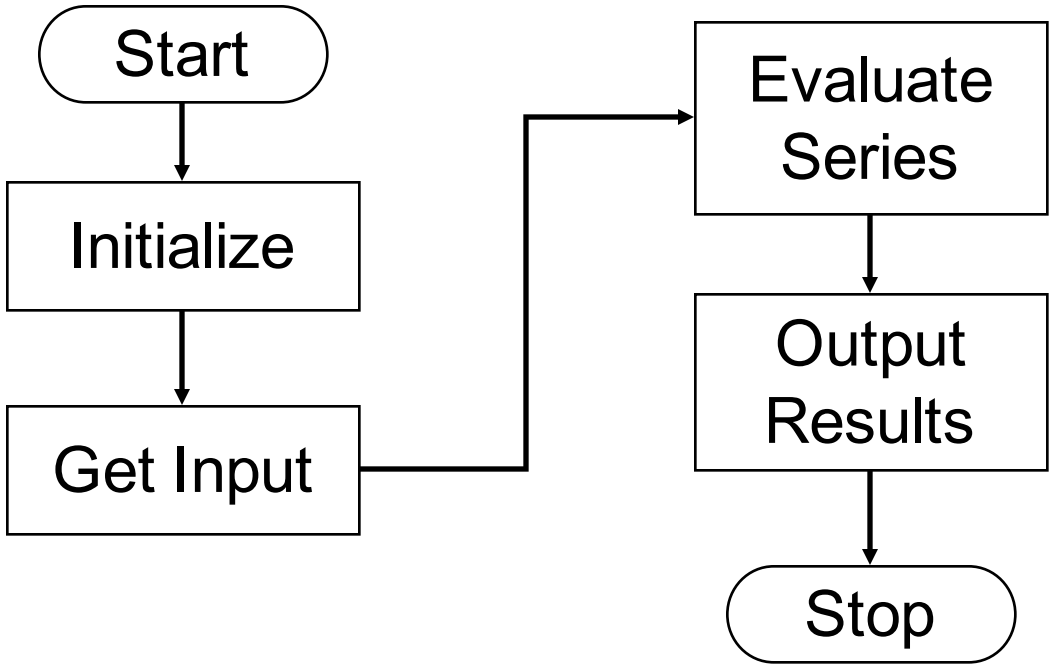
- Sequential -- C statements
- Conditional -- if-else, switch
- Iterative -- while, for, do-while

Problem 1: Calculating Pi

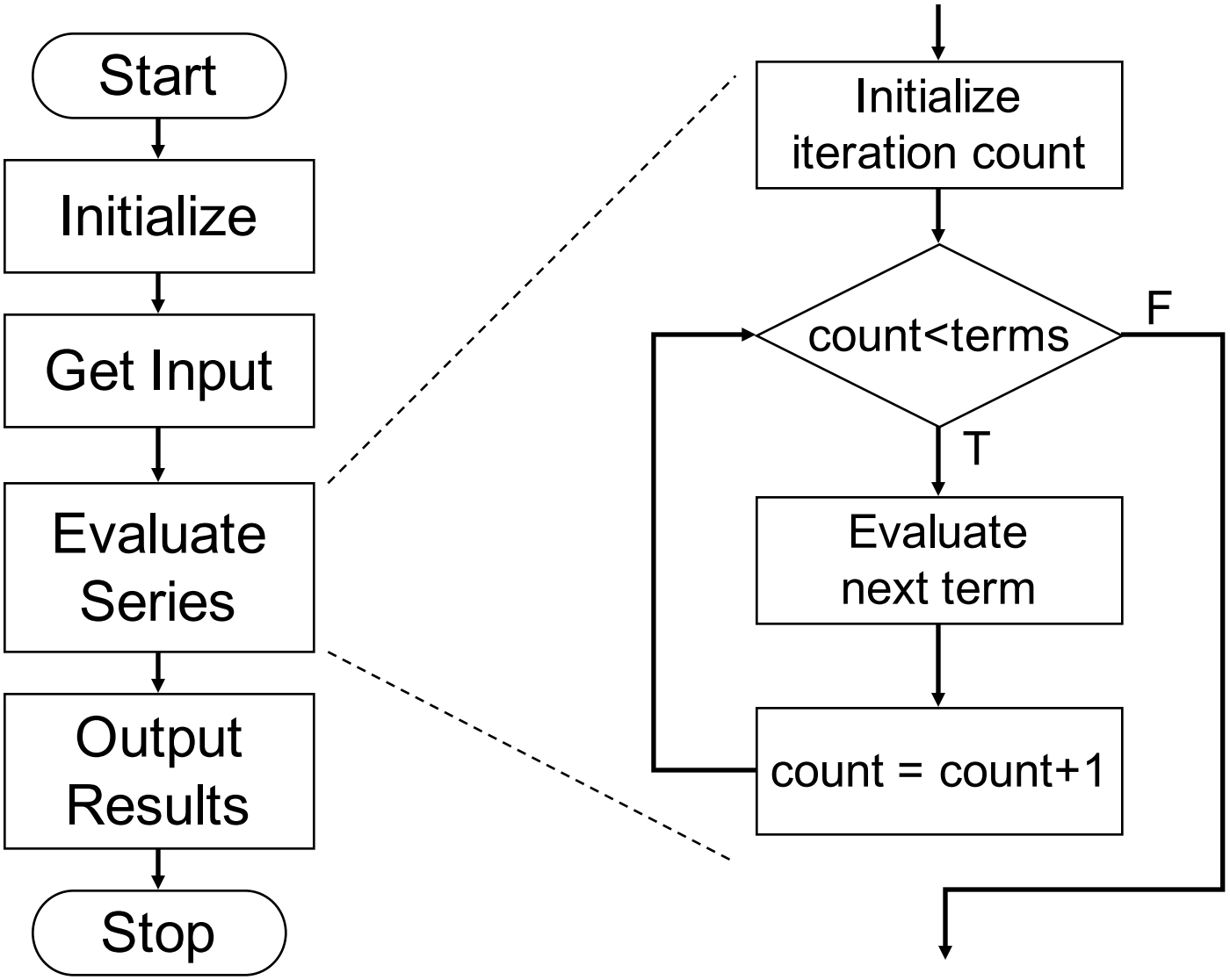
Calculate π using its series expansion.

User inputs number of terms.

$$\pi = 4 - \frac{4}{3} + \frac{4}{5} - \frac{4}{7} + \cdots + (-1)^{n-1}\frac{4}{2n+1} + \cdots$$

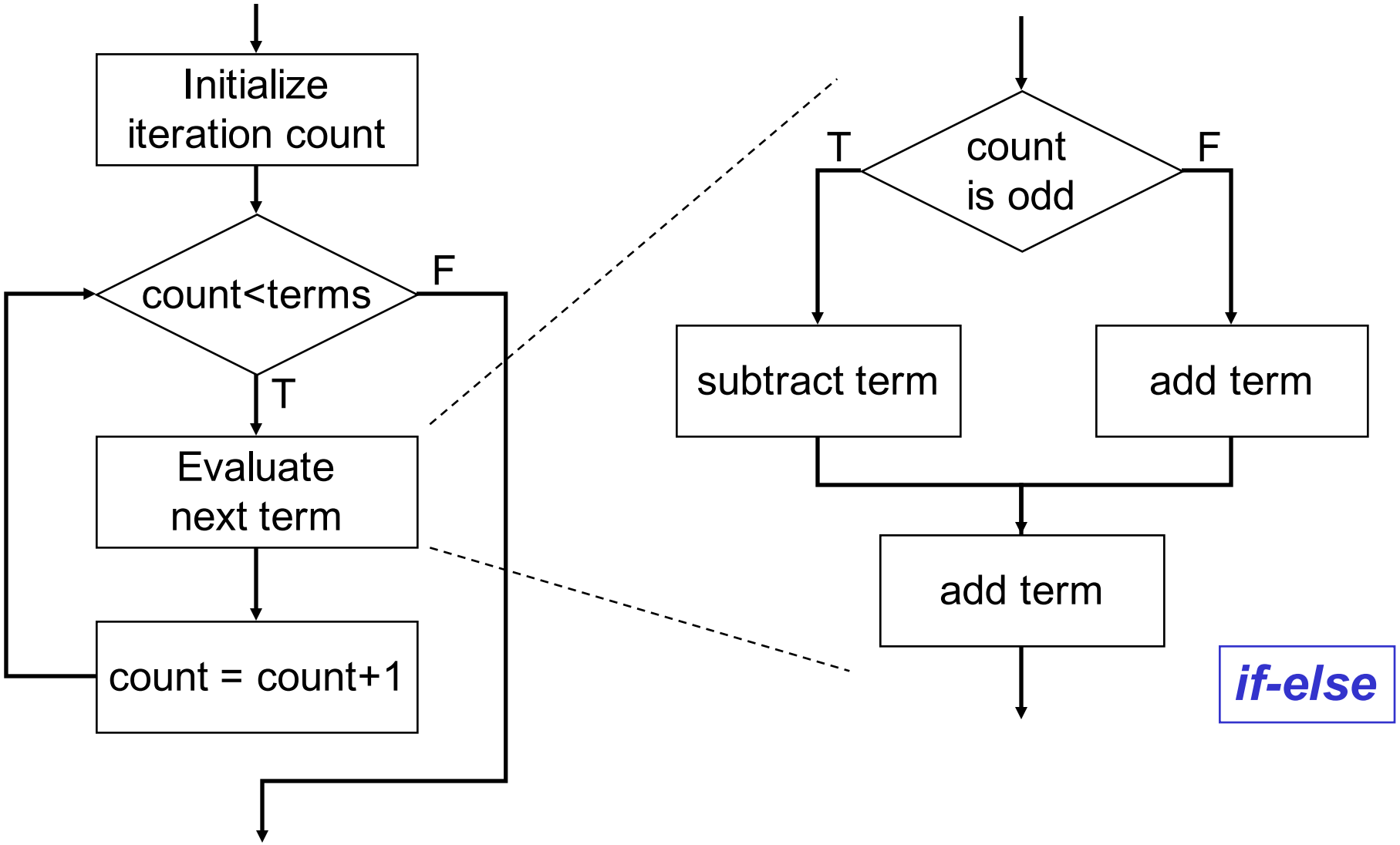


Pi: 1st refinement



for loop

Pi: 2nd refinement



Pi: Code for Evaluate Terms

```
for (count=0; count < numOfTerms; count++) {
  if (count % 2) {
    /* odd term -- subtract */
    pi -= 4.0 / (2 * count + 1);
  }
  else {
    /* even term -- add */
    pi += 4.0 / (2 * count + 1);
}
```

Note: Code in text is slightly different,
but this code corresponds to equation.

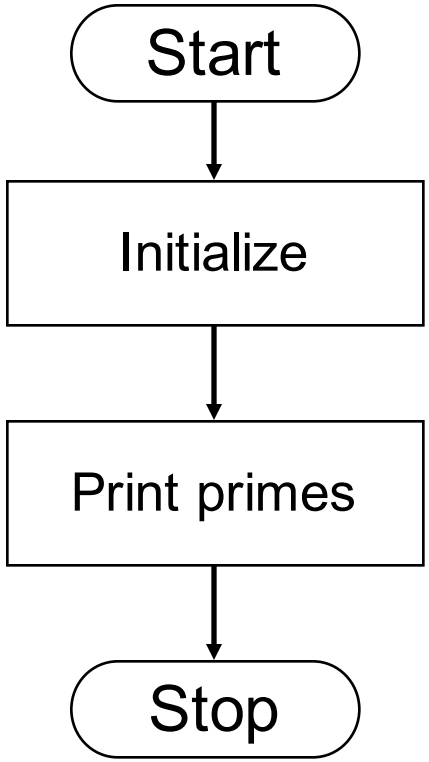
Pi: Complete Code

```
#include <stdio.h>


main() {
  double pi = 0.0;
  int numOfTerms, count;

  printf("Number of terms (must be 1 or larger) : ");
  scanf("%d", &numOfTerms);

  for (count=0; count < numOfTerms; count++) {
  if (count % 2) {
    pi -= 4.0 / (2 * count + 1); /* odd term -- subtract */
  }
  else {
    pi += 4.0 / (2 * count + 1); /* even term -- add */
  }
  printf("The approximate value of pi is %f\n", pi);
}
```

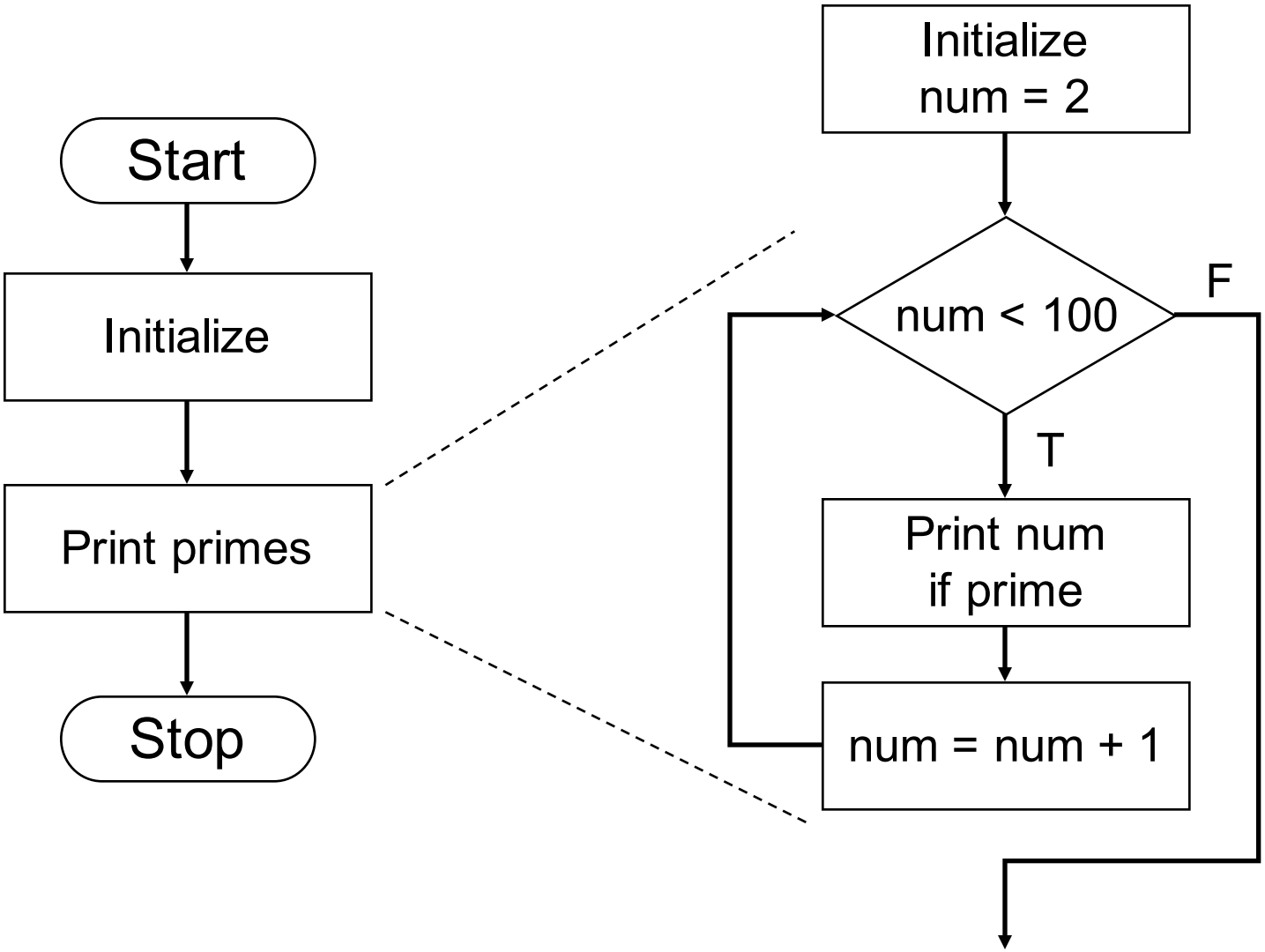
Problem 2: Finding Prime Numbers

Print all prime numbers less than 100.

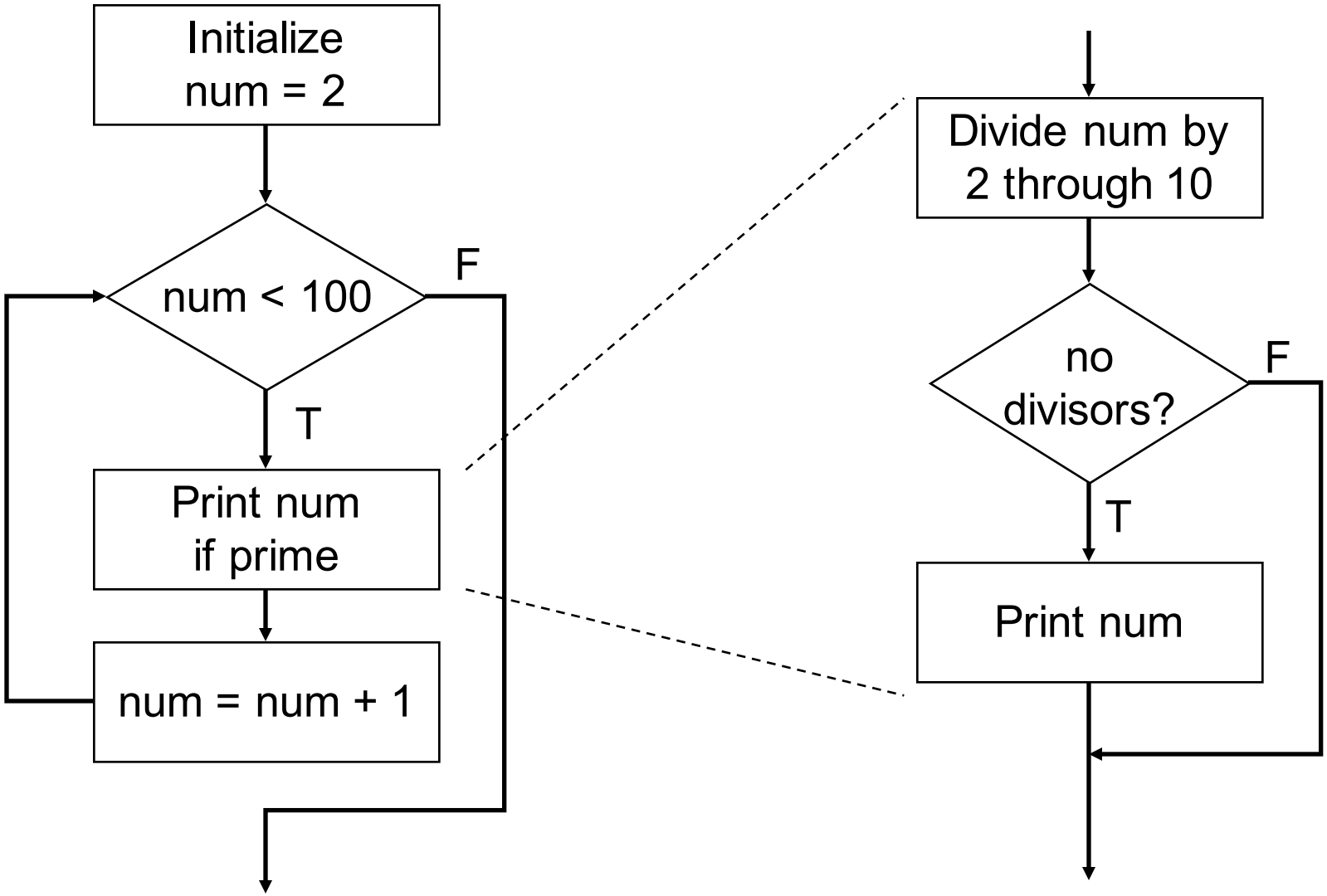
- **A number is prime if its only divisors are 1 and itself.**
- **All non-prime numbers less than 100 will have a divisor between 2 and 10.**



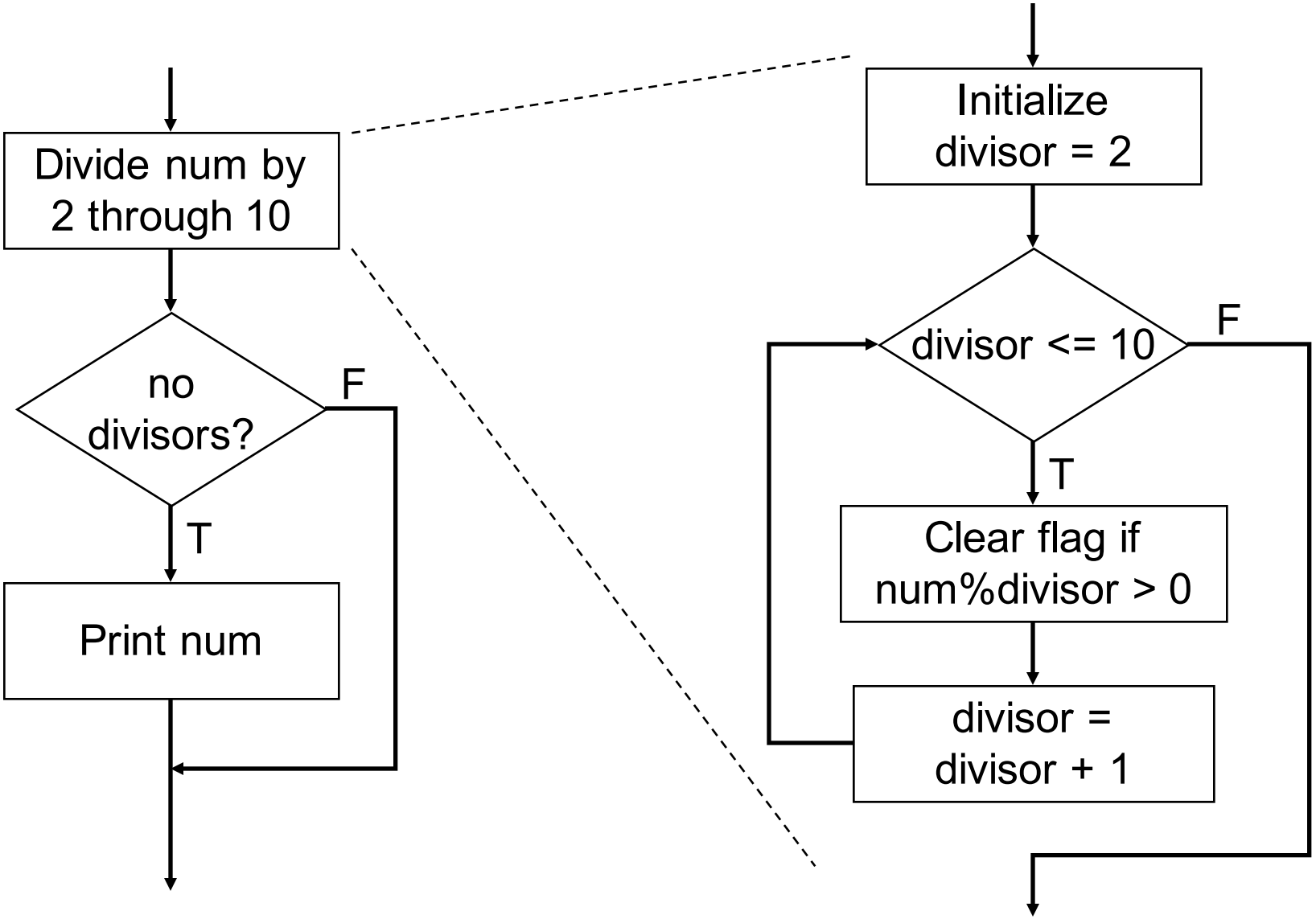
Primes: 1st refinement



Primes: 2nd refinement



Primes: 3rd refinement



Primes: Using a Flag Variable

To keep track of whether number was divisible, we use a "flag" variable.

- **Set prime = TRUE, assuming that this number is prime.**
- **If any divisor divides number evenly, set prime = FALSE.**
  - **Once it is set to FALSE, it stays FALSE.**
- **After all divisors are checked, number is prime if the flag variable is still TRUE.**

Use macros to help readability.

```
#define TRUE  1
#define FALSE 0
```

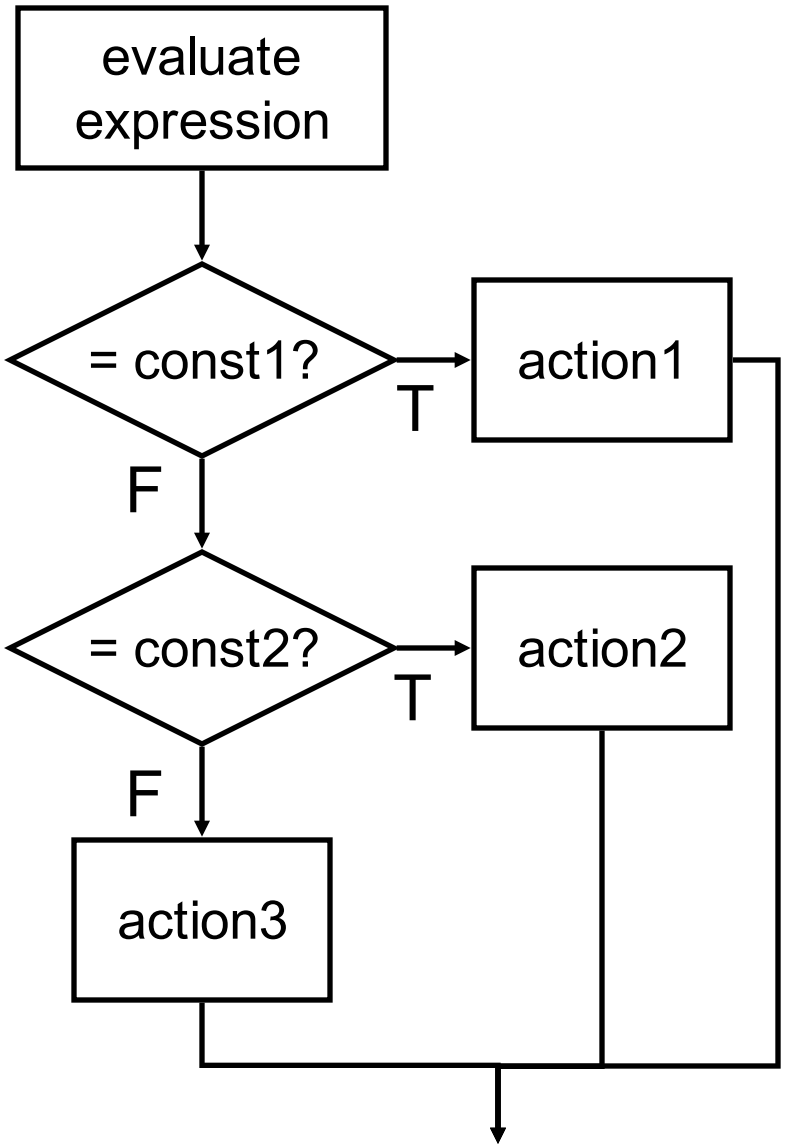
Primes: Complete Code

```
#include <stdio.h>
#define TRUE  1
#define FALSE 0

main () {
  int num, divisor, prime;

  /* start with 2 and go up to 100 */
  for (num = 2; num < 100; num ++ ) {

    prime = TRUE;  /* assume num is prime */
    /* test whether divisible by 2 through 10 */
    for (divisor = 2; divisor <= 10; divisor++)
      if (((num % divisor) == 0) && (num != divisor))
        prime = FALSE;  /* not prime */

    if (prime)  /* if prime, print it */
      printf("The number %d is prime\n", num);
  }
}
```

Optimization: Could put a break here to avoid some work. (Section 13.5.2)

Switch

```
switch (expression) {
case const1:
  action1; break;
case const2:
  action2; break;
default:
  action3;
}
```



Alternative to long if-else chain.
If break is not used, then case "falls through" to the next.

Switch Example

```
/* same as month example for if-else */
switch (month) {
  case 4:
  case 6:
  case 9:
  case 11:
    printf("Month has 30 days.\n");
    break;
  case 1:
  case 3:
  /* some cases omitted for brevity...*/
    printf("Month has 31 days.\n");
    break;
  case 2:
    printf("Month has 28 or 29 days.\n");
    break;
  default:
    printf("Don't know that month.\n");
}
```

More About Switch

Case expressions must be constant.

```
case i:   /* illegal if i is a variable */
```

If no break, then next case is also executed.

```
switch (a) {
  case 1:
    printf("A");
  case 2:
    printf("B");
  default:
    printf("C");
}
```

If a is 1, prints "ABC".
If a is 2, prints "BC".
Otherwise, prints "C".

Problem 3: Searching for Substring

Have user type in a line of text (ending with linefeed) and print the number of occurrences of "the".

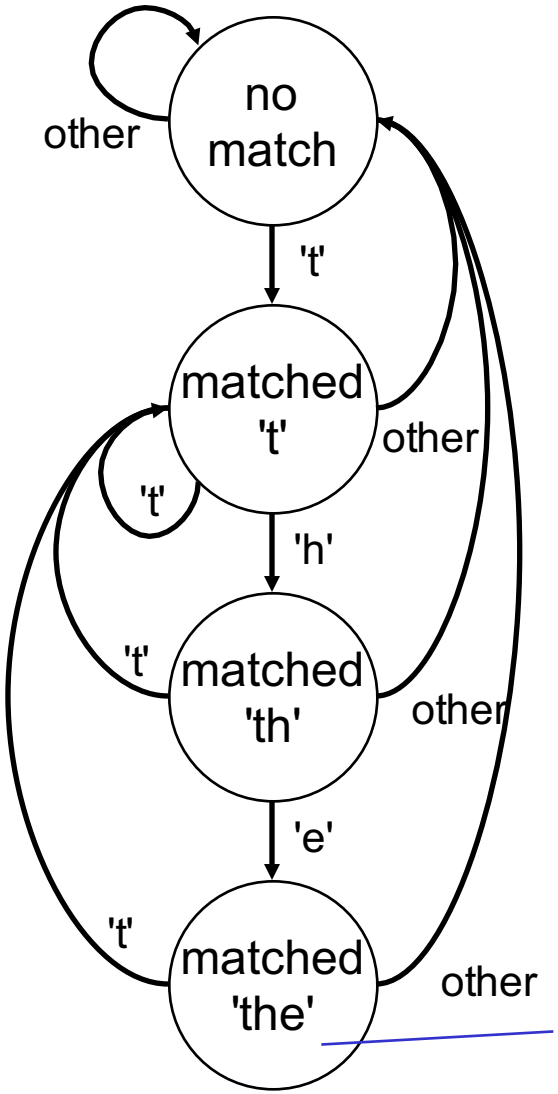
Reading characters one at a time

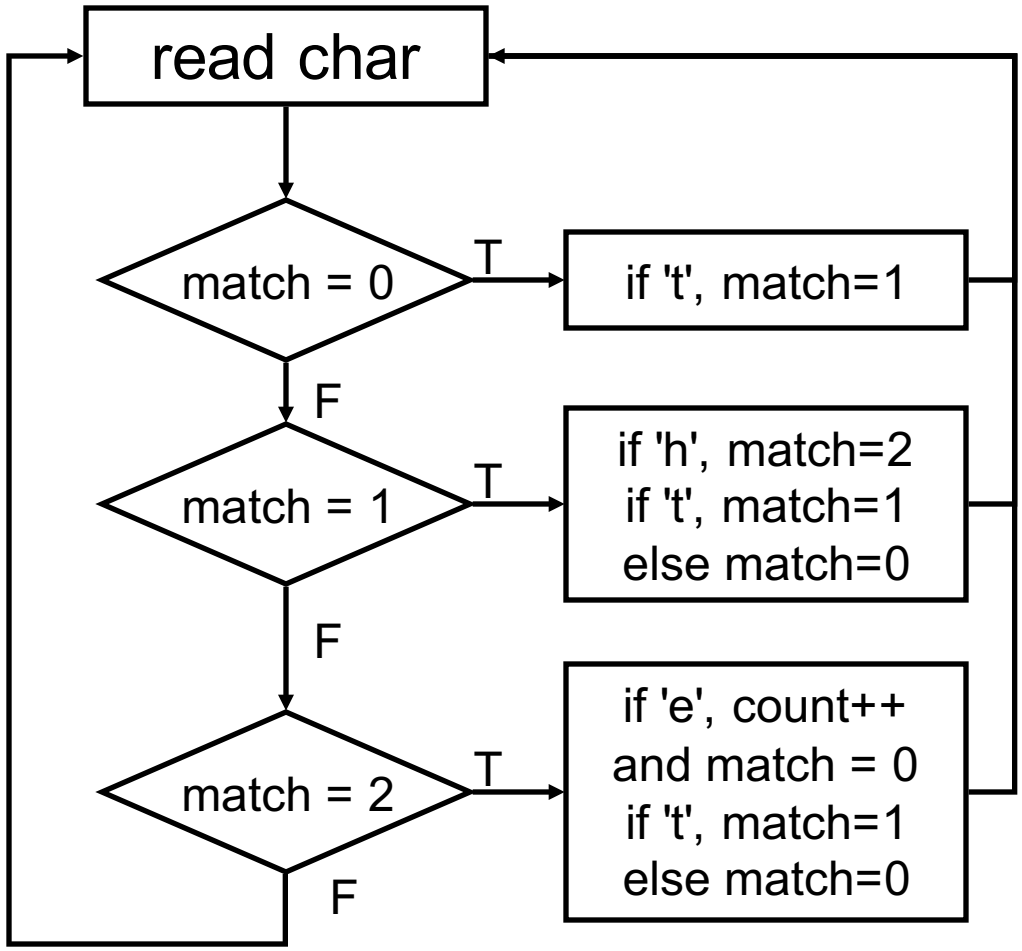
- **Use the `getchar()` function -- returns a single character.**

Don't need to store input string;
look for substring as characters are being typed.

- **Similar to state machine:**
  based on characters seen, move toward success state or move back to start state.
- **Switch statement is a good match to state machine.**

Substring: State machine to flow chart





Substring: Code (Part 1)

```
#include <stdio.h>


main() {
  char key;       /* input character from user */
  int match = 0; /* keep track of characters matched */
  int count = 0; /* number of substring matches */

  /* Read character until newline is typed */
  while ((key = getchar()) != '\n') {

    /* Action depends on number of matches so far */
    switch (match) {


      case 0:  /* starting - no matches yet */
        if (key == 't')
          match = 1;
        break;
```

Substring: Code (Part 2)

```
case 1:  /* 't' has been matched */
  if (key == 'h')
    match = 2;
  else if (key == 't')
    match = 1;
  else
    match = 0;
  break;
```

Substring: Code (Part 3)

```
      case 2:  /* 'th' has been matched */
        if (key == 'e') {
          count++;   /* increment count */
          match = 0; /* go to starting point */
        }
        else if (key == 't') {
          match = 1;
        else
          match = 0;
        break;
    }
  }
  printf("Number of matches = %d\n", count);
}
```

Break and Continue

`break;`

- used *only* in switch statement or iteration statement
- passes control out of the "smallest" (loop or switch) statement containing it to the statement immediately following
- usually used to exit a loop before terminating condition occurs (or to exit switch statement when case is done)

`continue;`

- used only in iteration statement
- terminates the execution of the loop body for this iteration
- loop expression is evaluated to see whether another iteration should be performed
- if `for` loop, also executes the re-initializer

Example

What does the following loop do?

```
for (i = 0; i <= 20; i++) {
  if (i%2 == 0) continue;
  printf("%d ", i);
}
```

What would be an easier way to write this?

What happens if `break` instead of `continue`?