C data types and declarations

(Reek, Ch. 3)

Four basic data types

- Integer: `char`, `short int`, `int`, `long int`, `enum`
- Floating-point: `float`, `double`, `long double`
- Pointer
- Aggregate: `struct`, `union`
  - Reek categorizes arrays as “aggregate” types – fair enough, but as we’ve seen, arrays also have a lot in common with pointers
- Integer and floating-point types are atomic, but pointers and aggregate types combine with other types, to form a virtually limitless variety of types

Characters are of integer type

- From a C perspective, a character is indistinguishable from its numeric ASCII value – the only difference is in how it's displayed

- Ex: converting a character digit to its numeric value
  - The value of `'2'` is not `2` – it's `50`
  - To convert, subtract the ASCII value of `'0'` (which is `48`)

```
char digit, digit_num_value;
...
digit_num_value = digit - '0';
```

Behaviorally, this is identical to `digit - 48`
Why is `digit - '0'` preferable?

Integer values play the role of "Booleans"

- There is no "Boolean" type
  - Relational operators (`==`, `<`, etc.) return either `0` or `1`
  - Boolean operators (`&&`, `||`, etc.) return either `0` or `1`, and take *any* `int` values as operands
- How to interpret an arbitrary `int` as a Boolean value:
  - `0` → `false`
  - Any other value → `true`

The infamous = blunder

- Easy to confuse equality with assignment
  - In C, the test expression of an `if` statement can be any `int` expression — including an assignment expression

```
if (y = 0)
  printf("Sorry, can't divide by zero.\n");
else
  result = x / y;
```

Assignment performed; y set to 0 (oops)

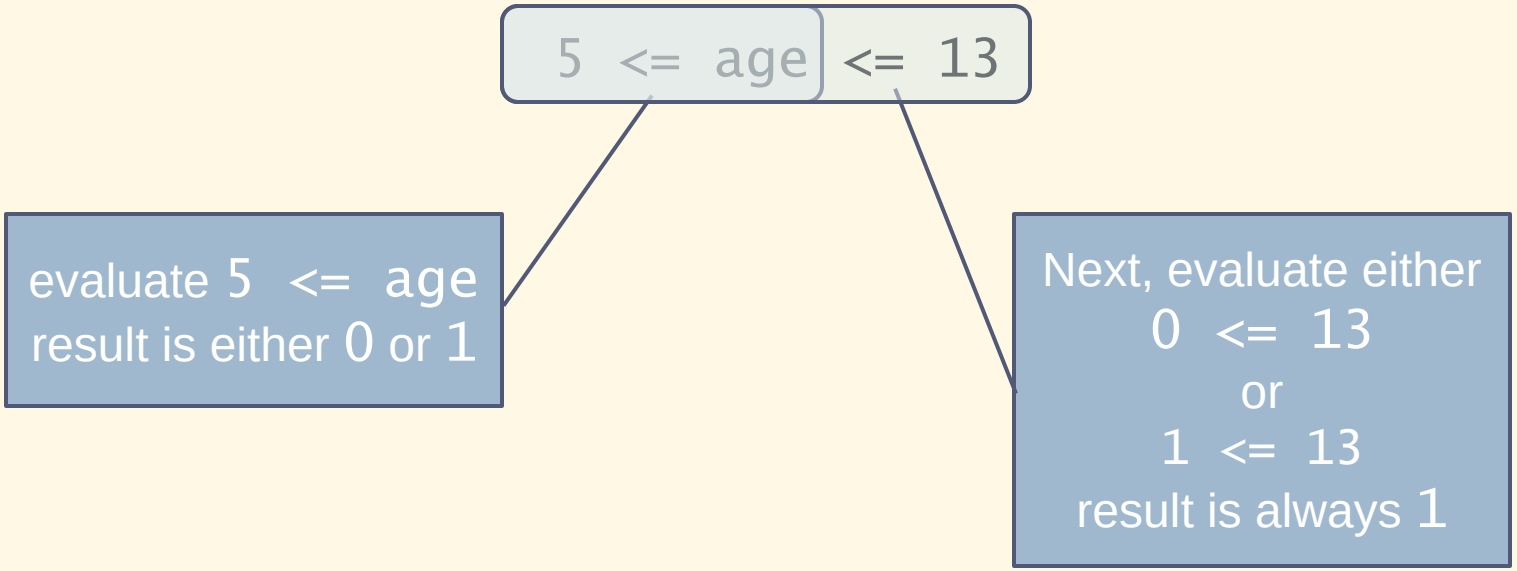
Expression returns result of assignment: 0, or "false"

`else` clause executed: divide by 0!

- The compiler will not catch this bug!

The less infamous “relational chain” blunder

- Using relational operators in a “chain” doesn't work
- Ex: “age is between 5 and 13”



- A correct solution: `5 <= age && age <= 13`

Enumerated types

- Values are programmer-defined names
- Enumerated types are declared:

```
enum Jar_Type { CUP=8, PINT=16, QUART=32,
                HALF_GALLON=64, GALLON=128 };
```

  - The name of the type is `enum Jar_Type`, not simply `Jar_Type`.
  - If the programmer does not supply literal values for the names, the default is `0` for the first name, `1` for the second, and so on.
- The ugly truth: `enum` types are just `int`s in disguise!
  - Any `int` value can be assigned to a variable of `enum` type
  - So, don't rely on such variables to remain within the enumerated values

Ranges of integer types

Type	Min value	Max value
`char`	0	`UCHAR_MAX` (≥ 127)
`signed char`	`SCHAR_MIN` (≤ -127)	`SCHAR_MAX` (≥ 127)
`unsigned char`	0	`UCHAR_MAX` (≥ 255)
`short int`	`SHRT_MIN` (≤ -32767)	`SHRT_MAX` (≥ 32767)
`unsigned short int`	0	`USHRT_MAX` (≥ 65535)
`int`	`INT_MIN` (≤ -32767)	`INT_MAX` (≥ 32767)
`unsigned int`	0	`INT_MAX` (≥ 65535)
`long int`	`LONG_MIN` (≤ -2147483647)	`LONG_MAX` (≥ 2147483647)
`unsigned long int`	0	`ULONG_MAX` (≥ 4294967295)

Ranges of integer types

- Ranges for a given platform can be found at `/usr/include/limits.h`
- `char` can be used for very small integer values
- Plain `char` may be implemented as signed or unsigned on a given platform – safest to "assume nothing" and just use the range `0...127`
- `short int` "supposed" to be smaller than `int` — but it depends on the underlying platform

Ranges of floating-point types

Type	Min value	Max value
`float`	`FLT_MIN` ($\leq -10^{37}$)	`FLT_MAX` ($\leq -10^{37}$)
`double`	`DBL_MIN` ($\leq$ `-FLT_MIN`)	`DBL_MAX`($\geq$ `FLT_MAX`)
`long double`	`LDBL_MIN` ($\leq$ `-DBL_MIN`)	`LDBL_MAX` ($\geq$ `DBL_MAX`)

Floating-point literals must contain a decimal point, an exponent, or both.

```
3.14159          25.          6.023e23
```

Danger: precision of floating-point values

- Remember the Patriot story –
  - How much error can your software tolerate?
- Testing for equality between two floating-point values: almost always a bad idea
  - One idea: instead of simply using ==, call an “equality routine” to check whether the two values are within some margin of error.
  - In general, use of floating-point values in safety-critical software should be avoided

Casting: converting one type to another

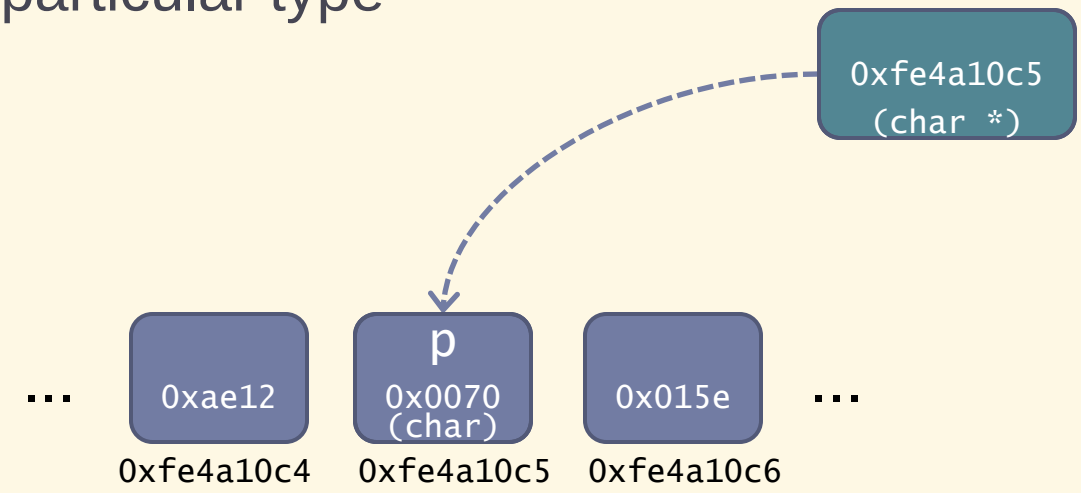
- The compiler will do a certain amount of type conversion for you:

```
int a = 'A';    /* char literal converted to int */
```

- In some circumstances, you need to explicitly cast an expression as a different type – by putting the desired type name in parentheses before the expression
- e.g. `(int) 3.14159` will return the `int` value `3`

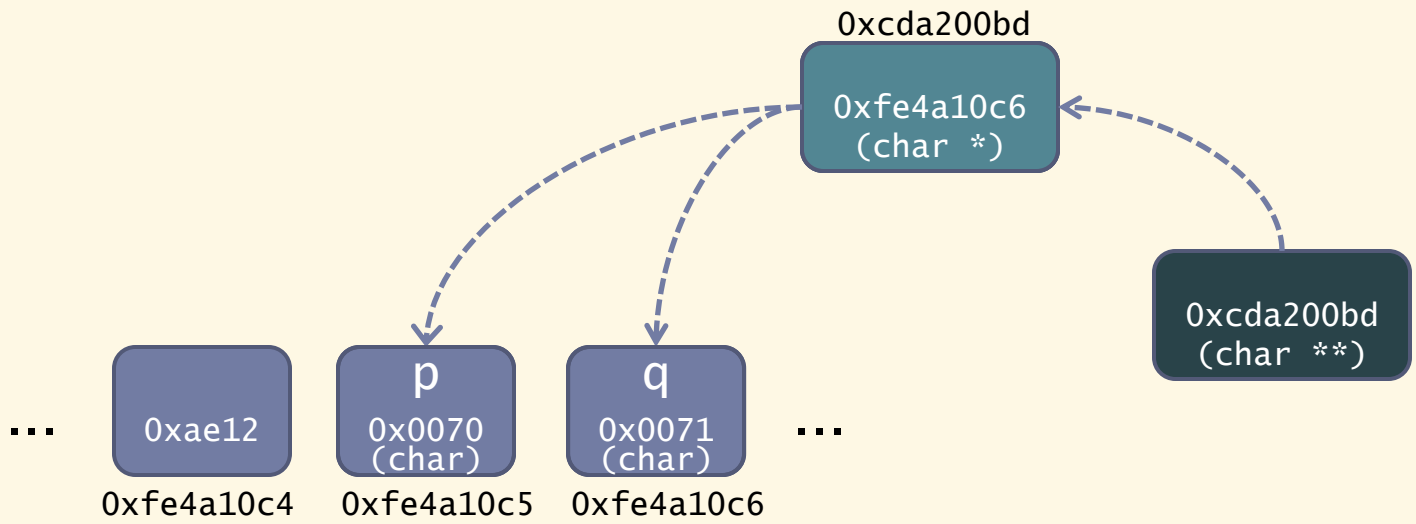
Pointers

- A pointer is nothing more than a memory location.
  - In reality, it's simply an integer value, that just happens to be interpreted as an address in memory
  - It may help to visualize it as an arrow "pointing" to a data item
  - It may help further to think of it as pointing to a data item of a particular type



Pointer variables

- A pointer variable is just like any other variable
  - It contains a value – in this case, a value interpreted as a memory location.
  - Since it's a variable, its value can change...
  - ... and since it occupies some address in memory, there's no reason why another pointer can't point to it



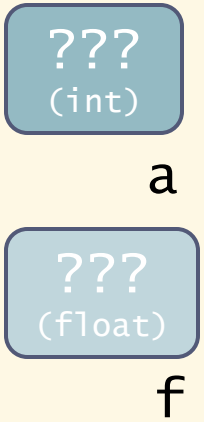
Pointers

- Reek uses the metaphor of “street address” vs. “house” to distinguish a pointer (address) from the data it points to
  - OK, but don’t forget that the data at an address may change, possibly quite rapidly
- Maybe a better metaphor: Imagine a parking lot with numbered spaces. Over time, space #135 may have a Ford in it, then a Porsche, then a Yugo,...
  - Here the “pointer” is the space number, and the data is the make of car.

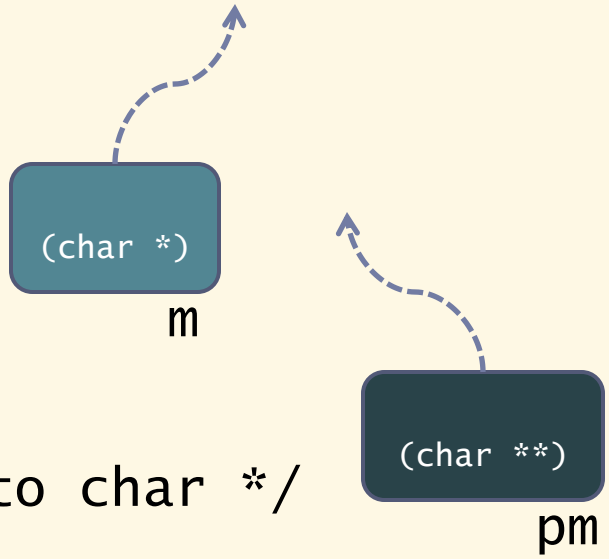
Variable declarations

- A variable without an initializing expression contains "garbage" until it is assigned a value.

```
int a;
float f;
```

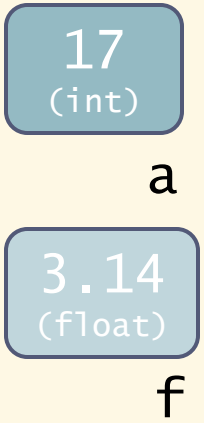


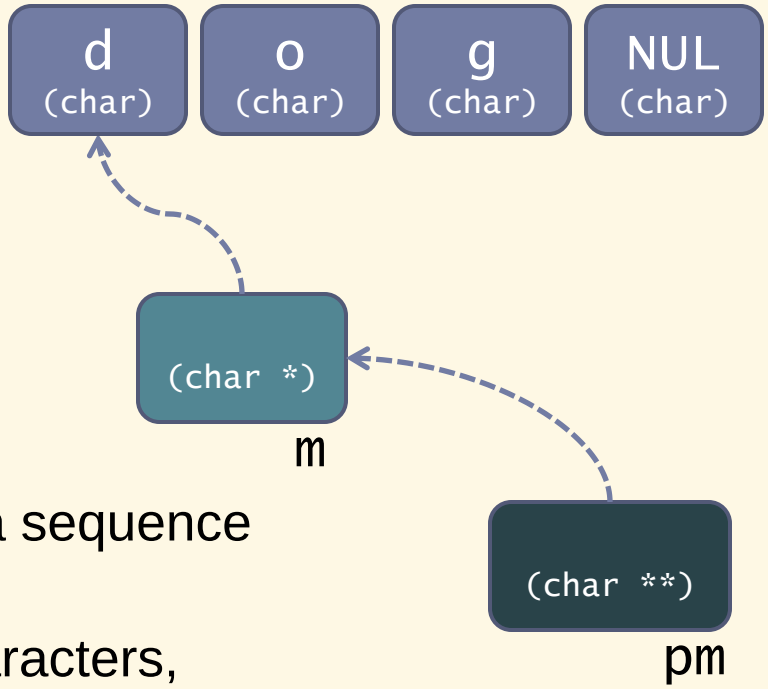

```
char  *m, **pm;
/* m is a pointer to char */
/* pm is a pointer to a pointer to char */
```



Variable initialization

```
int a = 17;
float 3.14;
```





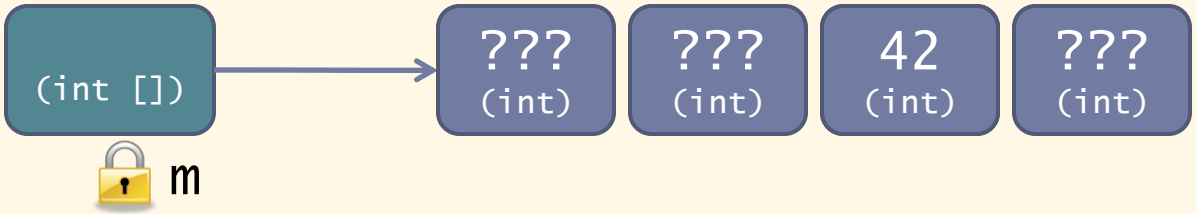

```
char  *m = "dog",
      **pm = &m;
```

- The string literal `"dog"` generates a sequence of four characters in memory.
- `m` then points to the first of these characters,
- and `mp` points to `&m`, the address of `m`.

Array declaration

- Subtle but important point: There are no “array variables” in C. Why not?

```
int m[4];
```



- The declaration creates a sequence of four spaces for `char`s.
- The array name m refers to a *constant* pointer – *not* a variable
  - Of course, the contents of the four char spaces may vary
    `m[2] = 42;`

typedef

- A convenient way of abbreviating type names
- Usage: keyword `typedef`, followed by type definition, followed by new type name

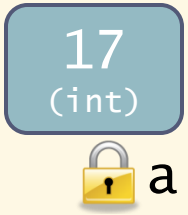
```
typedef char *ptr_to_char;
ptr_to_char p;    /* p is of type (char *) */
```

Constant declarations

- The keyword `const` makes the declared entity a constant rather than a variable:

  It is given an initial value and then cannot be changed

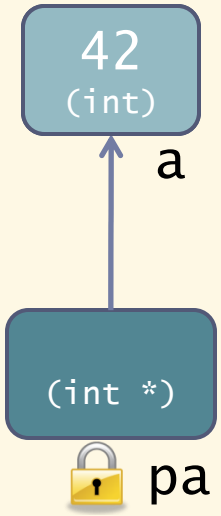
- `int const a = 17;`



Constant declarations

```
int a = 17;
```

```
int * const pa = &a;
```



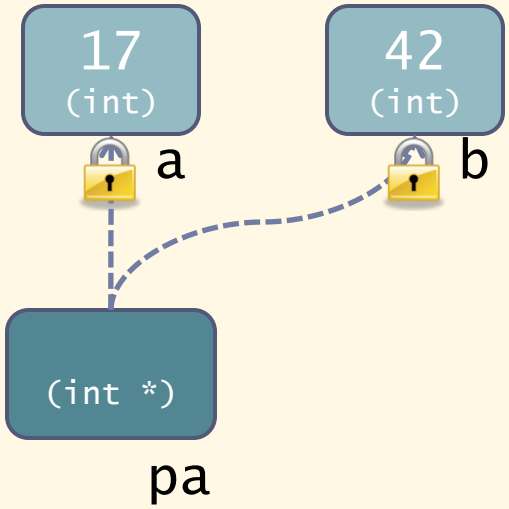
- The pointer pa will always point to the same address, but the data content at that address can be changed:

  `*pa = 42;`

Constant declarations

```
int a = 17;
int b = 42;


int const * pa = &a;
```

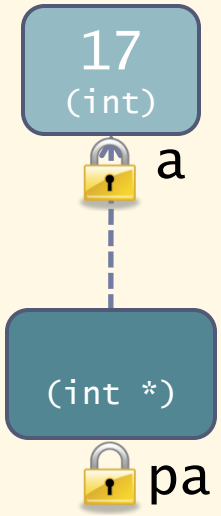


- The pointer pa can be changed, but the data content that it's pointing to cannot be changed:

  `pa = &b;`

Constant declarations

```
int a = 17;
```




```
int const * const pa = &a;
```

- Neither the pointer `pa` nor the data that it's pointing to can be changed

Linkage

- *If a variable is declared multiple times in a program, how many distinct variables are created?*
- Local variable declared within a function: a fresh instance of the variable is created – even if there's a local variable in another function with exactly the same name.
- There is *no* linkage here.

file1.c

```
int f ( void ) {

  int a;

}
```

Two distinct variables

file2.c

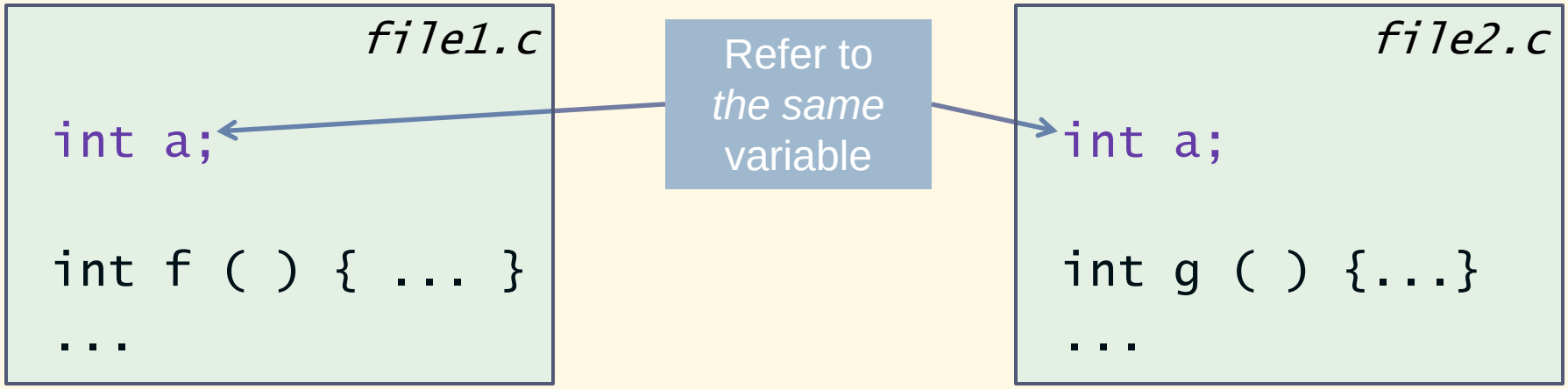
```
int g ( void ) {

  int a;

}
```

Linkage

- *If a variable is declared multiple times in a program, how many distinct variables are created?*
- Variables declared outside of any function: Only one instance of the variable is created (even if it's declared in multiple files).
- This is external linkage.



Forcing external linkage

- A local variable declared as `extern` has external linkage.

file1.c

```
int a;

int f ( void ) {

  extern int a;

}
```

Refer to *the same* variable

file2.c

```
int g ( void ) {

  extern int a;

}
```

Declaring `a` here is not strictly necessary, since `f()` is within the scope of the first `a` declaration

Dangers of external linkage

- It's a way to avoid the trouble (both for the programmer and the machine) of passing parameters).
- But... it can lead to trouble, especially in large multi-file programs constructed by many people
  - Where exactly is the variable `a` declared?
  - What is all that other code (possibly in different files) doing with `a`?
  - If I modify `a` in a certain way, is it going to mess up code elsewhere that uses `a`?
  - It's harder to reuse `g()` if it depends on a variable declared elsewhere

Restricting external linkage

- Q: What if you have a "global" variable, but you only want internal linkage (i.e. just within the file)?
- A: Declare it `static`:

file1.c

```
static int a;

int f ( void ) {

  extern int a;

}
```

Two *distinct* variables

file2.c

```
static int a;

int g ( void ) {

  extern int a;

}
```

Storage class: automatic

- *If a variable declaration is executed multiple times, is new memory for the variable allocated each time?*
- For automatic variables (what we're accustomed to), the answer is "yes".

```
int f ( void ) { int temporary; ... }
```

- Each time `f()` is called, new memory is allocated for `temporary`. And every time a call to `f()` terminates, the memory is deallocated – that instance of `temporary` "vanishes".
- All that "housekeeping" takes time and effort

Storage class: static

- *If a variable declaration is executed multiple times, is new memory for the variable allocated each time?*
- For static variables the answer is “no”. Memory is allocated once – at the first use of the variable – and then reused.

```
int f ( void ) { static int persistent; ... }
```

- The first time `f()` is called, new memory is allocated for `persistent`.
- And every subsequent call to `f()` reuses that memory – potentially using values that earlier calls to `f()` left behind.

Why use static storage?

- Avoid overhead of allocating, initializing, deallocating memory with each function call
- Maintain some state information over multiple calls to the function

```
int f( void ) {

  /* count number of times f has been called */
  static int num_calls = 0;
  ...
  num_calls++;
  return;
}
```

Confused about `static`?

- Yes, that's right – `static` means two different things:
  - For "global" variables, declared outside of any function, static means "restrict the linkage of this variable to internal linkage".
  - For "local" variables, declared inside a function, static means "allocate static memory for this variable".