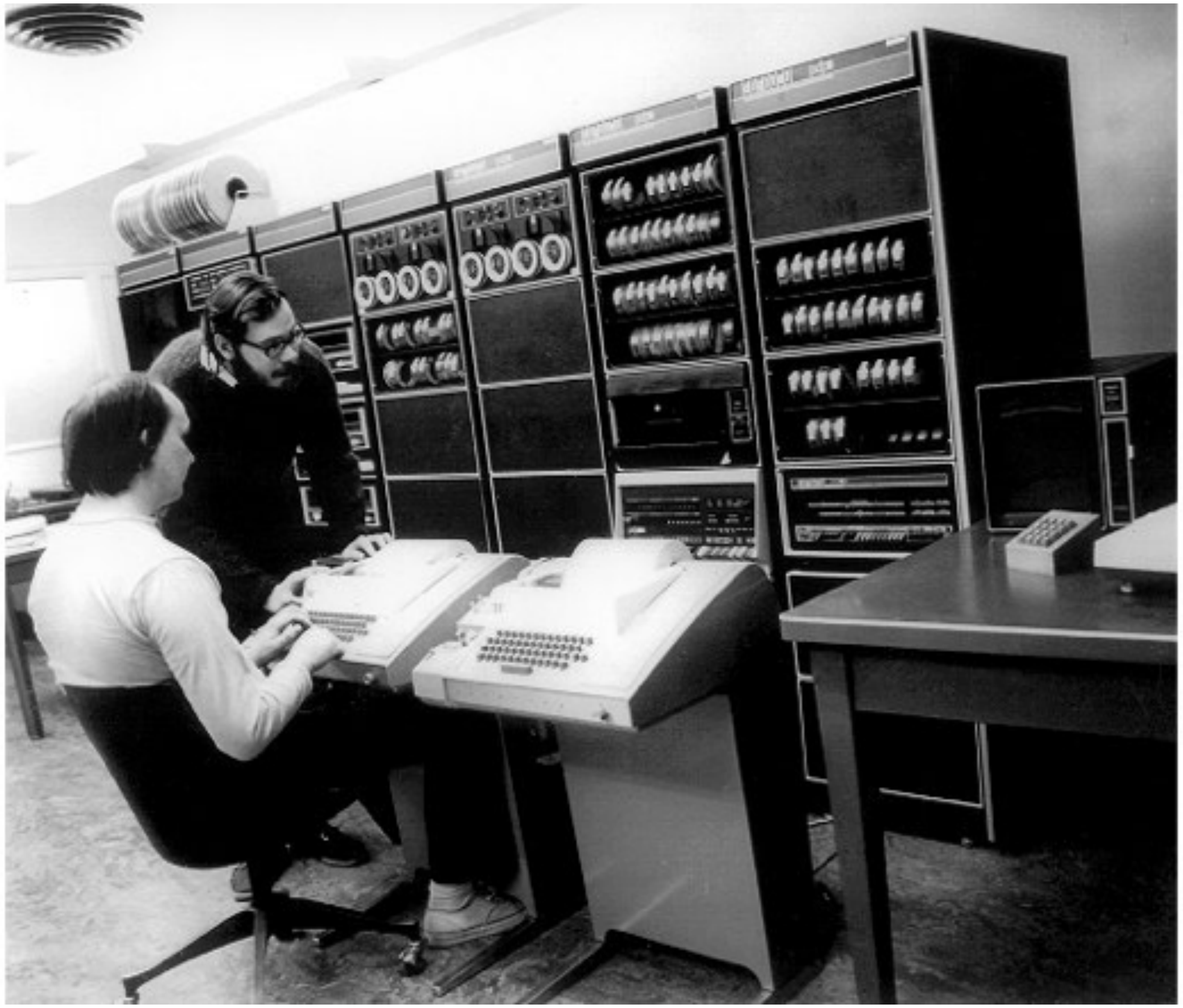
Program Structure

“to get a deeper understanding of the language”



Deep C - a 3 day course

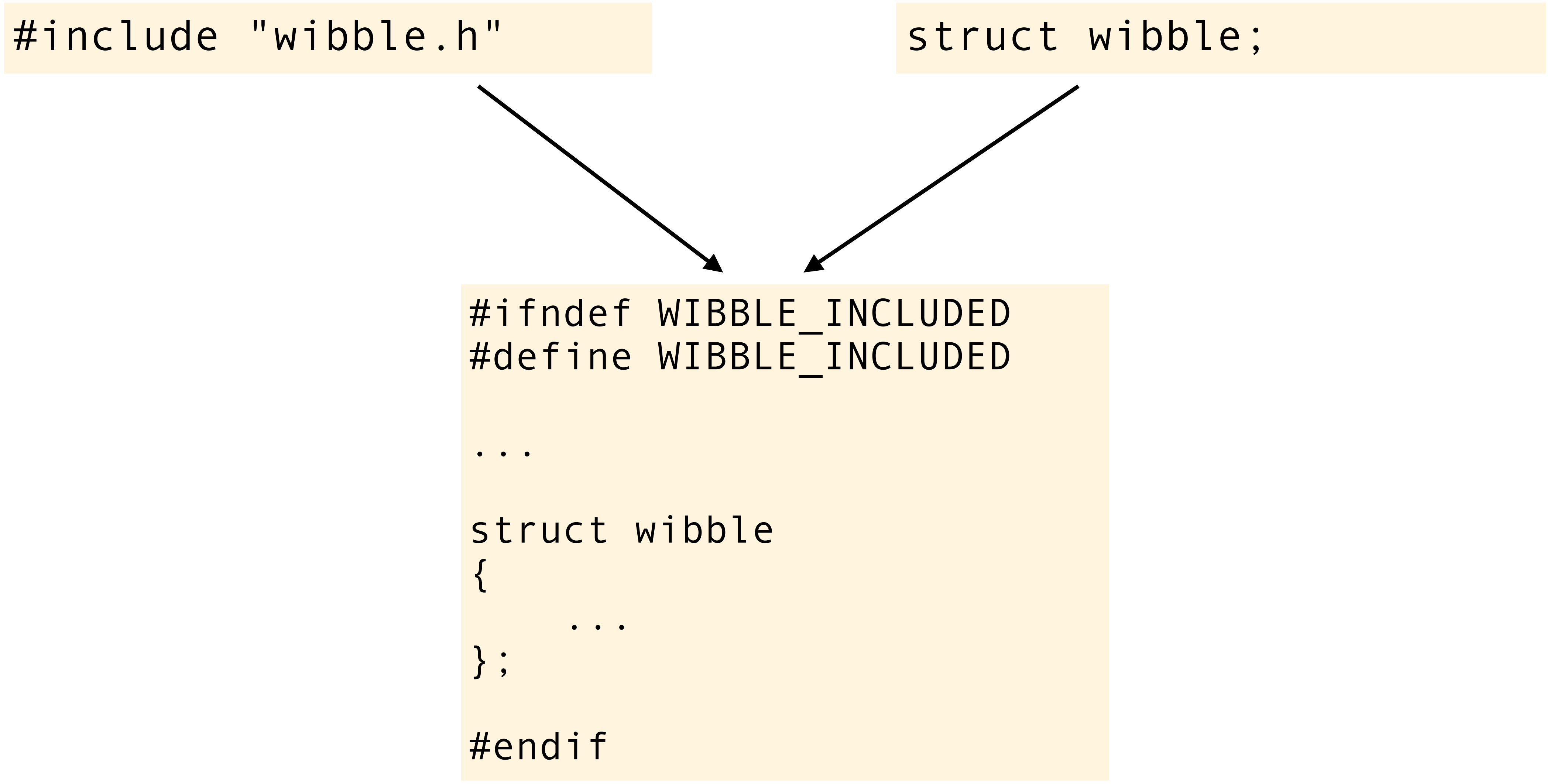
Jon Jagger & Olve Maudal

forward declaration

- #include is the most obvious code reflection of coupling

when is a #include required?

when is a #include *not* required?



```
#include "wibble.h"
```

```
struct wibble;
```

```
#ifndef WIBBLE_INCLUDED
#define WIBBLE_INCLUDED

...

struct wibble
{
    ...
};

#endif
```

forward declaration

- which of 1,2,3,4,5,6 *won't* compile?

```
struct wibble;

struct data_member
{
   struct wibble   value;    // 1
   struct wibble * pointer;  // 2
};

struct wibble   global_value;   // 3
struct wibble * global_pointer; // 4

extern struct wibble   ext_global_value;   // 5
extern struct wibble * ext_global_pointer; // 6
```

data declarations/definitions

forward declaration

- 1 and 3 won't compile

```
struct wibble;

struct data_member
{
   struct wibble   value;    // 1
   struct wibble * pointer;  // 2
};

struct wibble   global_value;   // 3
struct wibble * global_pointer; // 4

extern struct wibble   ext_global_value;   // 5
extern struct wibble * ext_global_pointer; // 6
```

data declarations/definitions

forward declaration

- which of 7,8,9,10 *won't* compile?

```
struct wibble;

struct wibble   return_value(void);         //  7
struct wibble * return_pointer(void);       //  8

void parameter_value(struct wibble w);      //  9
void parameter_pointer(struct wibble * p); // 10
```

function declarations

forward declaration

- they all compile!

```
struct wibble;

struct wibble   return_value(void);        //  7    ✓
struct wibble * return_pointer(void);      //  8    ✓

void parameter_value(struct wibble w);     //  9    ✓
void parameter_pointer(struct wibble * p); // 10    ✓
```

function declarations

forward declaration

- which of 11,12,13,14 *won't* compile?

```
struct wibble;

struct wibble return_value(void)          // 11
{ ... }

void parameter_value(struct wibble w)     // 12
{ ... }

struct wibble * return_pointer(void)      // 13
{ ... }

void parameter_pointer(struct wibble * p) // 14
{ ... }
```

function definition '*signatures*'

forward declaration

- 11,12 won't compile

```
struct wibble;

struct wibble return_value(void)          // 11
{ ... }

void parameter_value(struct wibble w)     // 12
{ ... }

struct wibble * return_pointer(void)      // 13
{ ... }

void parameter_pointer(struct wibble * p) // 14
{ ... }
```

function definition '*signatures*'

forward declaration

- which of 15,16,17 *won't* compile*

```
struct wibble;

void pass_pointer(struct wibble * p) // 15
{
    pass(p);
}

void arrow_pointer(struct wibble * p) // 16
{
    arrow(p->member);
}

void deref_pointer(struct wibble * p) // 17
{
    deref(*p);
}
```

function definition *bodies*

* ignore pass(),arrow(),deref() not being prototyped

forward declaration

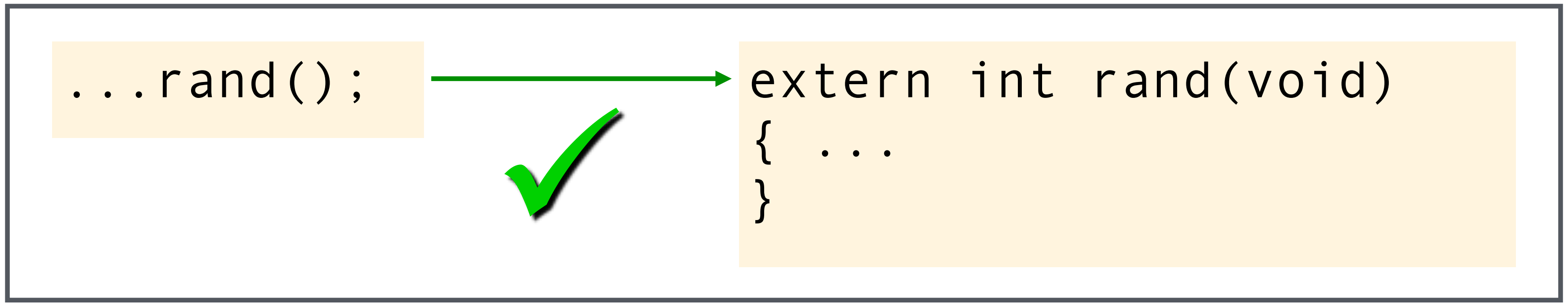
- 16 and 17 ***won't*** compile

```
struct wibble;

void pass_pointer(struct wibble * p) // 15
{
    pass(p);
}

void arrow_pointer(struct wibble * p) // 16
{
    arrow(p->member);
}

void deref_pointer(struct wibble * p) // 17
{
    deref(*p);
}
```

function definition ***bodies***

linking

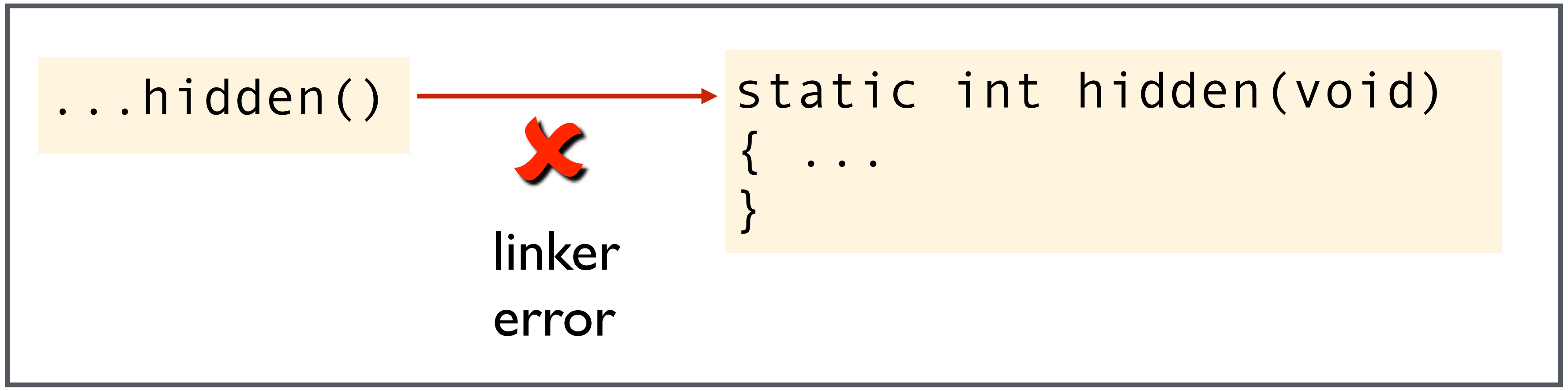
- a linker links the use of an identifier in one file with its definition in another file
- an identifier is made available to the linker by giving it external linkage (the default) or using the `extern` keyword
- an identifier is hidden from the linker by giving it internal linkage using the `static` keyword



```
...rand();
```

✓

```
extern int rand(void)
{ ...
}
```



```
...hidden()
```

✗

linker error

```
static int hidden(void)
{ ...
}
```

external linkage pattern

- if a function definition has external linkage it ***<u>should</u>*** have been previously prototyped (in a header file)

eg.h

```
...
int eg(const char * s);
...
```

function prototype

eg.c

```
#include "eg.h"

int eg(const char * s)
{   ...
}
```

✓

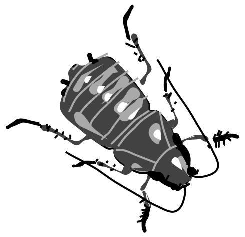
Using -Wmissing-prototypes detects
function definitions with external linkage
but *no* prior function prototype

```
...
```

eg.h

```
#include "eg.h"

int eg(const char * s)   ✘
{    ...
}
```

eg.c



```
$ gcc ... -Werror -Wmissing-prototypes eg.c
error: no previous prototype for 'eg'
$
```

If the function should have external linkage then add a function prototype to the header...

eg.h

```
...
int eg(const char * s);    ✓
...
```

eg.c

```
#include "eg.h"

int eg(const char * s)
{    ...
}
```

```
$ gcc ... -Werror -Wmissing-prototypes eg.c
$
```

If the function should have internal linkage then make it so!

```
...
```

eg.h

```
#include "eg.h"

static int eg(const char * s)
{   ...
}
```

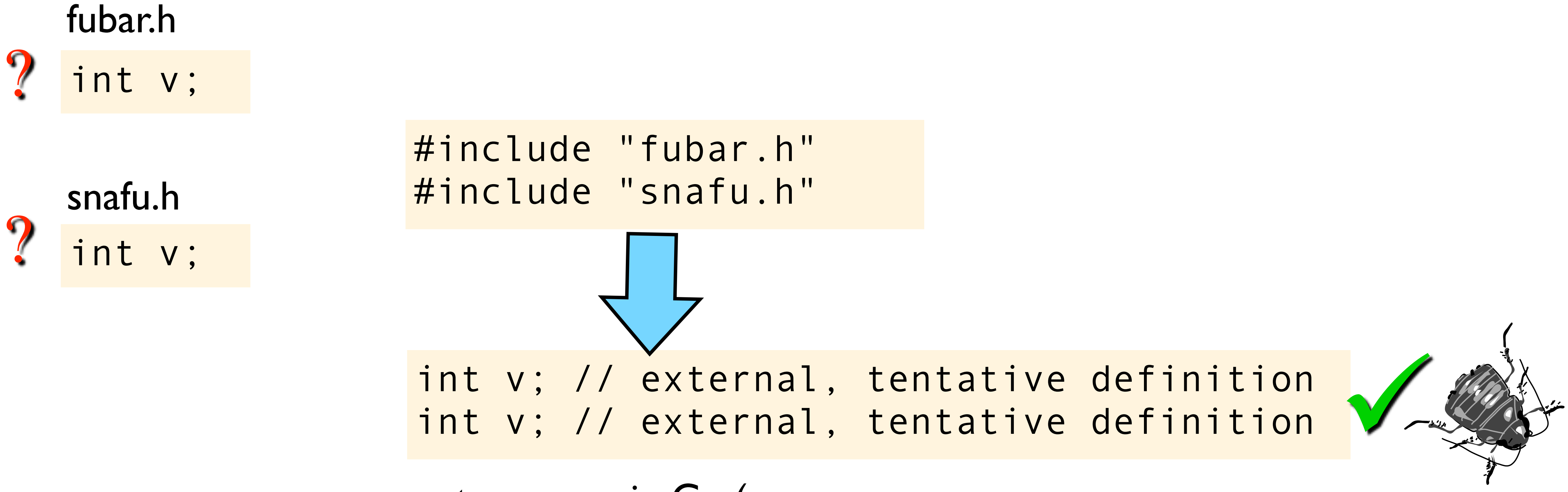
✓

eg.c

```
$ gcc ... -Werror -Wmissing-prototypes eg.c
$
```

data linkage

- without a storage class specifier or an initializer a data definition is tentative (external) – and can be repeated!
- at link time the duplicates collapse into one!
- this is confusing and *not* compatible with C++



fubar.h

?
```
int v;
```

snafu.h

?
```
int v;
```

```
#include "fubar.h"
#include "snafu.h"
```

```
int v; // external, tentative definition
int v; // external, tentative definition
```

✓

not an error in C :-(
duplicate definition error in C++ :-)

data linkage recommendation

- extern data *declarations:* use extern keyword, do *<u>not</u>* initialize

multiple declarations

```
extern int v;

extern int v;
```

✓

- extern data *definitions:* do *<u>not</u>* use extern keyword, *<u>do</u>* initialize

multiple definitions

```
int v = 42;

int v = 42;
```

✗

spot the problem

snafu.h

```
#ifndef SNAFU_INCLUDED
#define SNAFU_INCLUDED

#include <stddef.h>

int snafu(size_t);

#endif
```

wibble.h

```
#ifndef WIBBLE_INCLUDED
#define WIBBLE_INCLUDED

int wibble(const char *);
void wobble(size_t);

#endif
```

snafu.c

```
#include "snafu.h"
...
```

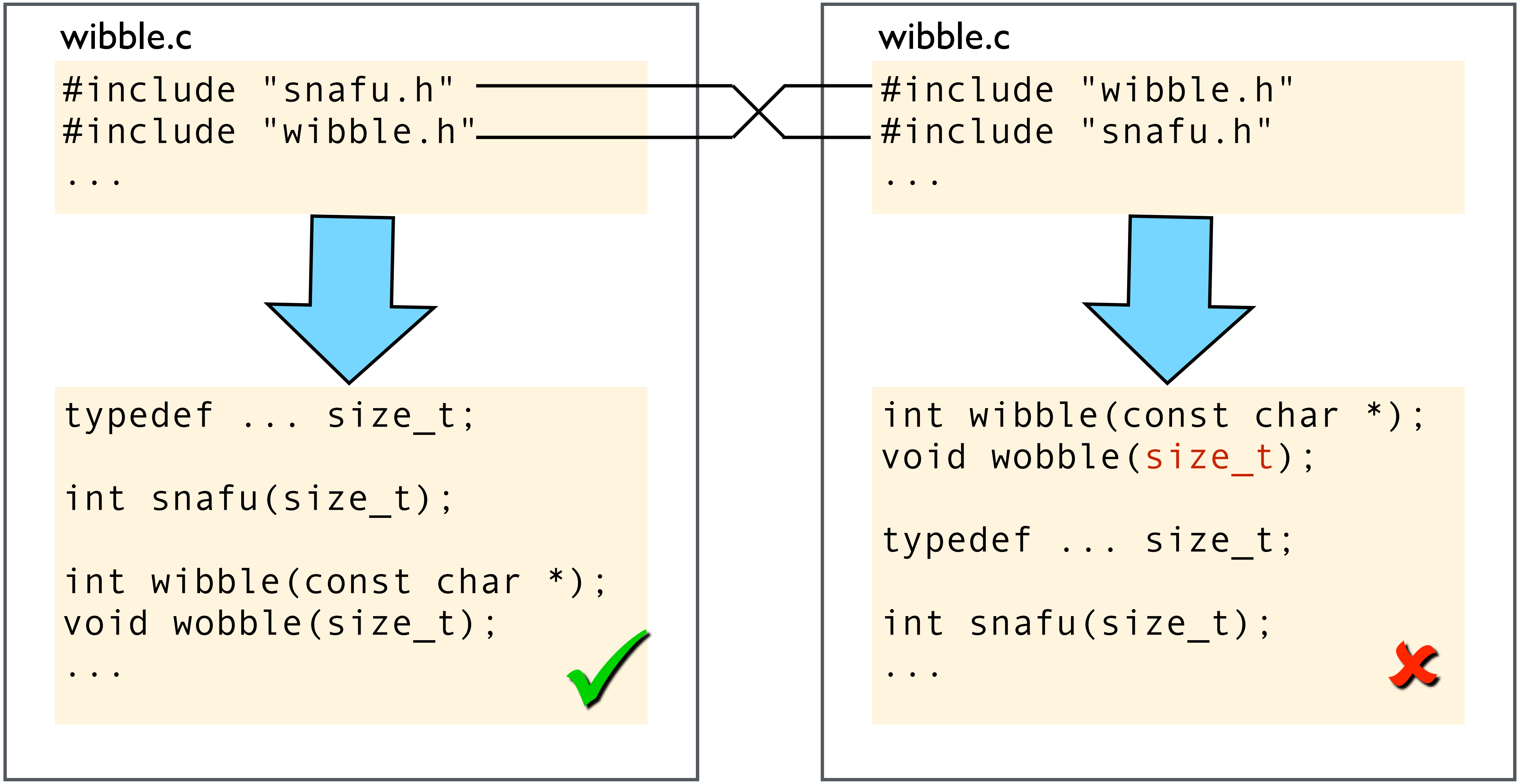
wibble.c

```
#include "snafu.h"
#include "wibble.h"
...
```

<stddef.h> contains a typedef for size_t

spot the problem

- wibble.c depends on the order of its #includes



wibble.c

```
#include "snafu.h"
#include "wibble.h"
...
```

```
typedef ... size_t;

int snafu(size_t);

int wibble(const char *);
void wobble(size_t);
...
```

✓

wibble.c

```
#include "wibble.h"
#include "snafu.h"
...
```

```
int wibble(const char *);
void wobble(size_t);

typedef ... size_t;

int snafu(size_t);
...
```

✗

recommendation

- each source file should could #include it's *own* header first
  - easy to automate a test for this
- consider checking each individual header file compiles! (-x c)
  - as part of the build

wibble.h

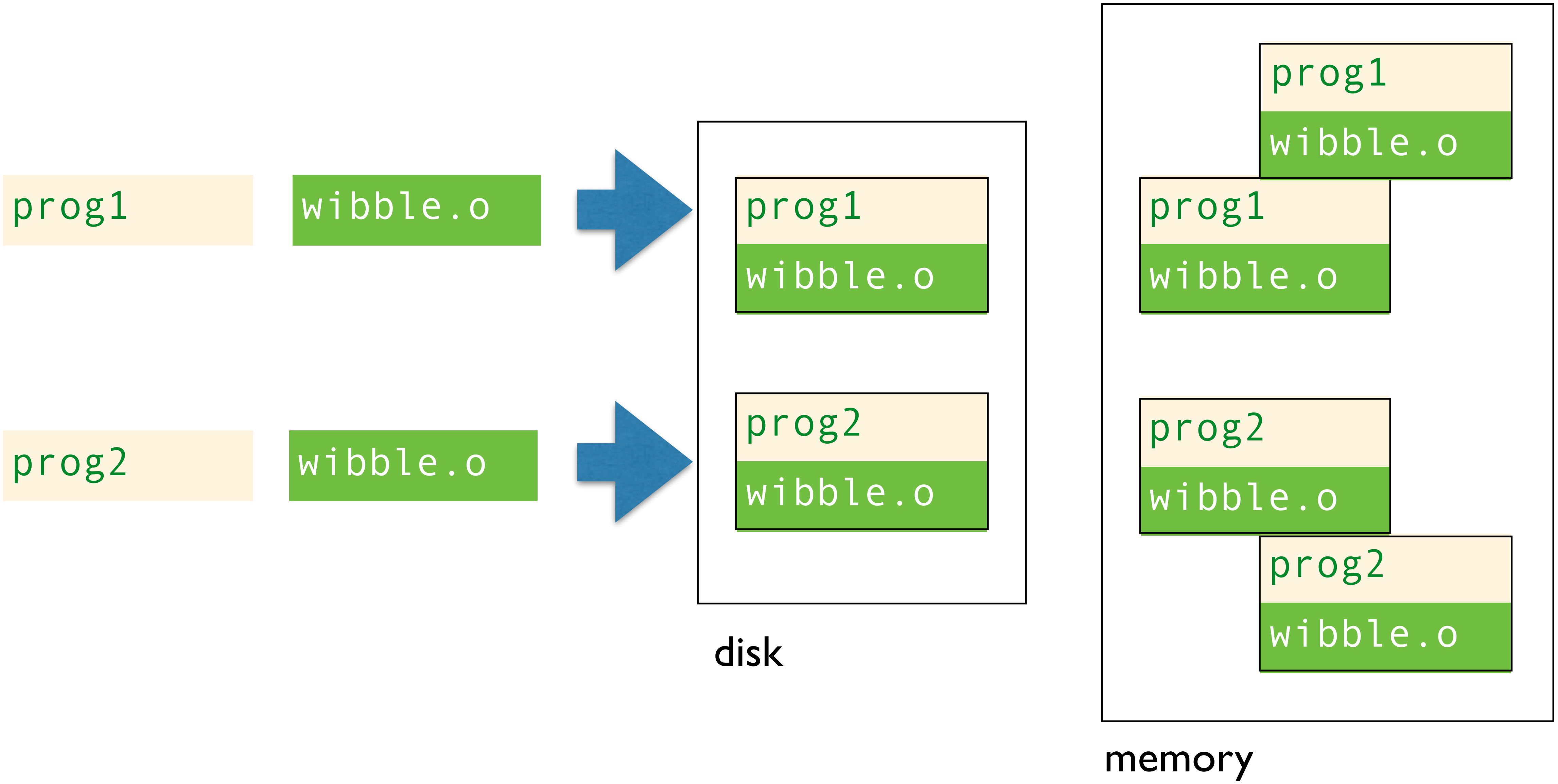
```
#ifndef WIBBLE_INCLUDED
#define WIBBLE_INCLUDED

#include <stddef.h> // size_t

int wibble(const char *);
void wobble(size_t);

#endif
```

wibble.c

```
#include "wibble.h"
#include "snafu.h"
...
```

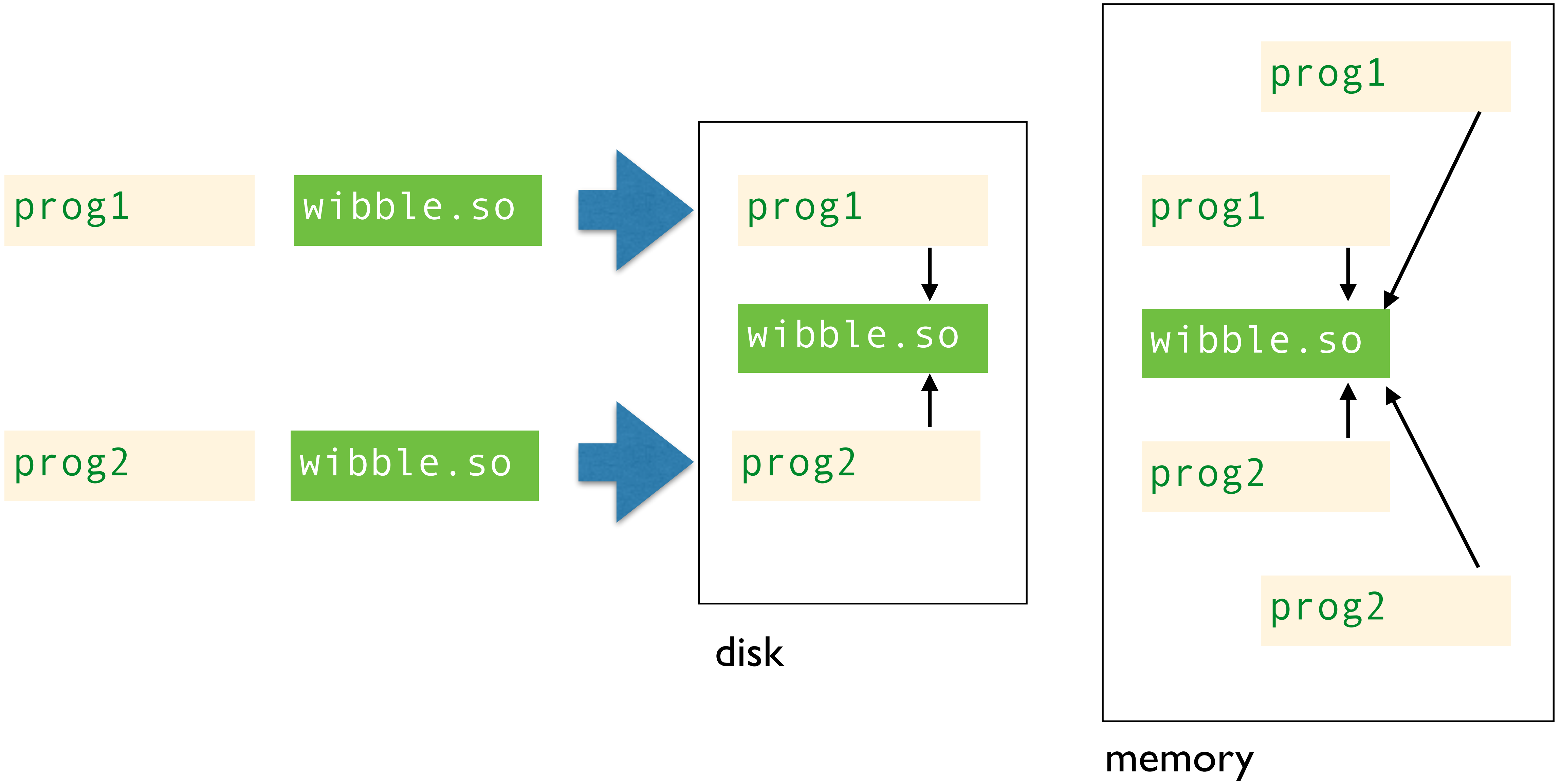
static linking

- static libraries have their code embedded directly
- static libraries are *not* shared
- don't need static library anymore
- simplest option when you need to distribute the executable
- to fix a bug you have to relink every executable



dynamic linking

- dynamic libraries do *not* have their code embedded directly
- dynamic libraries is shared and loaded at load-time
- dynamic library has to exist
- reduce disk & memory footprint
- to fix a bug you only have to replace the .so file



dynamic linking

- compile .c files with -fPIC option (Position Independent Code)

```
gcc $(CFLAGS) -fPIC wibble.c
```

- convert .o files into .so files using -shared option

```
gcc -shared wibble.o -o libwibble.so
```

- build executable telling gcc where shared libraries live

```
gcc -L/sandbox ... -o test -lwibble
```

- run the executable telling the os where to look for new .so files

```
$ export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/sandbox
$ ./test
All tests passed
```

optimization

-O, -O0

no optimization; make debugging produce expected results; the default

-O1

moderate optimization; tries to reduce code and size and execution time without increasing compilation time significantly;

-O2

full optimization minus space-time optimizations; increases compilation time

-O3

-O2 plus aggressive inlining of subprograms - may increase program size
attempts to vectorize loops

-Os

optimize to reduce size (code and data)

-Og

enable optimizations that do not interfere with debugging

https://gcc.gnu.org/onlinedocs/gcc/Optimize-Options.html

optimization

Requesting greater optimization forces the compiler to increase its 'span of attention'.
This helps it detect more warnings.
You should compile with optimisation _on_.

```
    int n;
    scanf("%d", &n);
```

```
$ gcc -Wall -Wextra -O0 ...
$
```

```
$ gcc -Wall -Wextra -O2 ...
'scanf' ... [-Werror=unused-result]
```

summary

- forward declarations help reduce coupling
- -Wmissing-prototypes for sensible linkage patterns
- avoid tentative data declarations
- every header file should compile in its own right
- static linking and dynamic linking
- switch optimization on by default