

CM3 - C Language

Representations, programs, and builds

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Course Shape

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The rule for this deck

Horizontal movement continues the lecture path.

Vertical movement opens details, examples, or exercises on the current topic.

In printable formats, the same vertical detail slides become normal pages.

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Today as a C course

- ▶ C programs are data plus representation choices.

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- ▶ Source files are translated, linked, and executed.

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- ▶ C programs are data plus representation choices.
- ▶ Source files are translated, linked, and executed.
- ▶ Tools matter: compiler warnings, make, debugger, memory checker.

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Today as a C course

- ▶ C programs are data plus representation choices.
- ▶ Source files are translated, linked, and executed.
- ▶ Tools matter: compiler warnings, make, debugger, memory checker.
- ▶ The deck itself is a testbed for teaching code well.

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What this version demonstrates

Feature	RevealJS	Beamer PDF	Typst handout
Vertical detail slides	interactive	printed as pages	printed as sections
Progressive line highlights	stepped	static fallback	static fallback
Code annotations	hover/selectable	below code	below code
Scrollable long code	live only	avoid for final	avoid for final
Executed C example	executed at render	executed at render	executed at render

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Sources and adaptation

This version combines:

- ▶ your imported CM3 material on files, compilation, make, tools, and style;
- ▶ the Berkeley CS61C lecture you added, especially number representations, C vs Java, printf, and undefined behavior;
- ▶ Quarto/RevealJS features that are useful for teaching code.

The Berkeley material is used as inspiration for topic order and examples, not as a slide import.

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Values And Bits

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Representation is a contract

A bit pattern has no meaning by itself.

0b11111111 can mean:

- ▶ unsigned integer: 255
- ▶ signed 8-bit integer: -1
- ▶ character byte: implementation dependent
- ▶ raw mask: all bits set

The program works only if writer and reader agree on the representation.

Listing 1 read_byte.c

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

int main(void) {
    uint8_t byte = 0xff;
    printf("%u\n", byte);
}
```

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Fixed-width integers

When the size matters, say it.

Listing 2 types.c

```
1 #include <stdint.h>
2 #include <stdio.h>
3
4 int main(void) {
5     uint8_t byte = 0xff;
6     int32_t temp = -12;
7
8     printf("byte=%u temp=%d\n", byte, temp);
9     return 0;
10 }
```

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Unsigned arithmetic wraps

Listing 3 wrap.c

```
1 #include <stdint.h>
2 #include <stdio.h>
3
4 int main(void) {
5     uint8_t x = 255;
6     x = x + 1;
7     printf("%u\n", x);
8 }
```

The result is 0 because unsigned arithmetic is modulo 2^N .

Quick check

What does this program print?

```
#include <stdint.h>
```

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Signed overflow is different

Listing 4 overflow.c

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

int main(void) {
    int x = INT_MAX;
    printf("%d\n", x + 1);
}
```

This is not the same story as unsigned wraparound. Signed overflow is undefined behavior in C.

Warning

For teaching: this is a good moment to separate "what my machine did today" from "what C promises".

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First Program

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Anatomy of main

Listing 5 hello.c

```
#include <stdio.h> ①
int main(int argc, char *argv[]) { ②
    printf("hello, CM3\n"); ③
    return 0; ④
}
```

- ① Declaration of the standard I/O interface.
- ② Entry point; argc and argv describe command-line arguments.
- ③ Formatted output.
- ④ Exit status returned to the shell.

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argv is just data from the shell

Listing 6 session.sh

```
$ ./show_args 1 hi
argv[0] = ./show_args
argv[1] = 1
argv[2] = hi
```

Listing 7 show_args.c

```
1 #include <stdio.h>
2
3 int main(int argc, char *argv[]) {
4     for (int i = 0; i < argc; i++) {
5         printf("argv[%d] = %s\n", i, argv[i]);
6     }
7     return 0;
8 }
```

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printf: integer first

Listing 8 printf.c

```
int n = 42;
printf("value = %d\n", n);
```

%d asks printf to read the next argument as a signed decimal integer.

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printf: then floating point

Listing 9 printf.c

```
double x = 42.0;
printf("value = %f\n", x);
```

%f asks printf to read the next argument as a floating-point value.

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Format strings are contracts

Listing 10 wrong-format.c

```
1 #include <stdio.h>
2
3 int main(void) {
4     double x = 42.0;
5     printf("as int: %d\n", x);
6     printf("as double: %f\n", x);
7 }
```

The compiler may warn, but printf itself trusts the format string.

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Common printf specifiers

Specifier	Meaning	Typical argument
%d	signed decimal integer	int
%u	unsigned decimal integer	unsigned int
%x, %X	hexadecimal integer	unsigned int
%f	floating point	double
%s	string	char *
%p	address	void *
%%	literal percent sign	none

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Compilation

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C is compiled for a target machine

C:

- ▶ source is translated before execution;
- ▶ output depends on architecture and system ABI;
- ▶ compiler warnings are part of the feedback loop.

Java/Python comparison:

- ▶ Java source becomes bytecode, then JIT/runtime work happens;
- ▶ Python usually compiles to bytecode at runtime;
- ▶ portability is paid for by a runtime.

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The build pipeline

Listing 11 build.sh

```
1 $ gcc -E hello.c -o hello.i
2 $ gcc -S hello.i -o hello.s
3 $ gcc -c hello.s -o hello.o
4 $ gcc hello.o -o hello
```

- ▶ Preprocess: expand directives like #include.

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The build pipeline

Listing 12 build.sh

```
1 $ gcc -E hello.c -o hello.i
2 $ gcc -S hello.i -o hello.s
3 $ gcc -c hello.s -o hello.o
4 $ gcc hello.o -o hello
```

- ▶ Preprocess: expand directives like #include.
- ▶ Compile: turn C into assembly.

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The build pipeline

Listing 13 build.sh

```
1 $ gcc -E hello.c -o hello.i
2 $ gcc -S hello.i -o hello.s
3 $ gcc -c hello.s -o hello.o
4 $ gcc hello.o -o hello
```

- ▶ Preprocess: expand directives like #include.
- ▶ Compile: turn C into assembly.
- ▶ Assemble: turn assembly into an object file.

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The build pipeline

Listing 14 build.sh

```
1 $ gcc -E hello.c -o hello.i
2 $ gcc -S hello.i -o hello.s
3 $ gcc -c hello.s -o hello.o
4 $ gcc hello.o -o hello
```

- ▶ Preprocess: expand directives like #include.
- ▶ Compile: turn C into assembly.
- ▶ Assemble: turn assembly into an object file.
- ▶ Link: combine objects and libraries into an executable.

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Quarto can execute a C build at render time

The generated RevealJS/Beamer/Typst output is static, but this cell compiles and runs C while the document is rendered.

```
$ gcc -Wall -Wextra hello.c -o hello
$ ./hello
hello from compiled C
```

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Static trace is still useful

Use a plain bash code block when the goal is a readable transcript rather than live execution.

Listing 15 session.sh

```
$ gcc -Wall -Wextra hello.c -o hello
$ ./hello
hello from compiled C
```

This is deterministic, portable, and easy to print.

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Multi-File Projects

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A header is the public contract

Listing 16 counter.h

```
#ifndef COUNTER_H
#define COUNTER_H

extern int counter;
int next_value(void);

#endif
```

Listing 17 counter.c

```
#include "counter.h"

int counter = 0;

int next_value(void) {
    return ++counter;
}
```

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Include declarations, not duplicate definitions

Listing 18 main.c

```
1 #include "counter.h"
2 #include <stdio.h>
3
4 int main(void) {
5     printf("%d\n", next_value());
6     return 0;
7 }
```

The header lets each .c file compile independently while agreeing on shared declarations.

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Longer example with scrolling

In printable exports, prefer splitting this example into several shorter slides or keeping it as an appendix.

Listing 19 counter.h

```
#ifndef COUNTER_H
#define COUNTER_H

extern int counter;
int next_value(void);

#endif
```

Listing 20 counter.c

```
#include "counter.h"

int counter = 0;
```

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Build Automation

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Separate compilation

Listing 23 build.sh

```
1 $ gcc -Wall -Wextra -c main.c -o main.o
2 $ gcc -Wall -Wextra -c counter.c -o counter.o
3 $ gcc -Wall -Wextra -c report.c -o report.o
4 $ gcc main.o counter.o report.o -o demo
5 $ ./demo
```

Object files let us rebuild only what changed.

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A Makefile records dependencies

Listing 24 Makefile

```
1 CC = gcc
2 CFLAGS = -Wall -Wextra -g
3 OBJ = main.o counter.o report.o
4 EXEC = demo
5
6 all: $(EXEC)
7
8 $(EXEC): $(OBJ)
9     $(CC) $(OBJ) -o $@
10
11 main.o: main.c counter.h
12     $(CC) $(CFLAGS) -c $< -o $@
13
14 counter.o: counter.c counter.h
15     $(CC) $(CFLAGS) -c $< -o $@
```

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Full Makefile with tests

For printable exports, keep the long Makefile in a handout or repository file. The slide deck should show the dependency pattern, not every target.

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The tab matters

Listing 25 Makefile

```
clean:
    rm -f *.o demo
```

The command line under a target starts with a real tab character.

Tip

For class, make the invisible tab visible once, then stop talking about it and let make enforce the rule.

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What make changes

Listing 26 session.sh

```
$ make
gcc -Wall -Wextra -g -c main.c -o main.o
gcc -Wall -Wextra -g -c counter.c -o counter.o
gcc -Wall -Wextra -g -c report.c -o report.o
gcc main.o counter.o report.o -o demo

$ touch report.c
$ make
gcc -Wall -Wextra -g -c report.c -o report.o
gcc main.o counter.o report.o -o demo
```

Only the affected object and the final executable are rebuilt.

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Undefined Behavior

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Quiz: uninitialized local variable

Listing 27 ub.c

```
1 #include <stdio.h>
2
3 int main(void) {
4     int x;
5     printf("%d\n", x);
6     return 0;
7 }
```

What should students answer?

- ▶ Not "0".

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Quiz: uninitialized local variable

Listing 28 ub.c

```
1 #include <stdio.h>
2
3 int main(void) {
4     int x;
5     printf("%d\n", x);
6     return 0;
7 }
```

What should students answer?

- ▶ Not "0".
- ▶ Not "a random number" as a language guarantee.

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Quiz: uninitialized local variable

Listing 29 ub.c

```
1 #include <stdio.h>
2
3 int main(void) {
4     int x;
5     printf("%d\n", x);
6     return 0;
7 }
```

What should students answer?

- ▶ Not "0".
- ▶ Not "a random number" as a language guarantee.
- ▶ The correct C answer is: the program has undefined behavior.

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Undefined behavior breaks reasoning

Undefined behavior can:

- ▶ appear stable on one machine;

The teaching rule: compile with warnings, remove undefined behavior first, then debug logic.

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Undefined behavior breaks reasoning

Undefined behavior can:

- ▶ appear stable on one machine;
- ▶ change after optimization;

The teaching rule: compile with warnings, remove undefined behavior first, then debug logic.

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Undefined behavior breaks reasoning

Undefined behavior can:

- ▶ appear stable on one machine;
- ▶ change after optimization;
- ▶ change when a debugger is attached;

The teaching rule: compile with warnings, remove undefined behavior first, then debug logic.

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Undefined behavior breaks reasoning

Undefined behavior can:

- ▶ appear stable on one machine;
- ▶ change after optimization;
- ▶ change when a debugger is attached;
- ▶ disappear when a print is added;

The teaching rule: compile with warnings, remove undefined behavior first, then debug logic.

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Undefined behavior breaks reasoning

Undefined behavior can:

- ▶ appear stable on one machine;
- ▶ change after optimization;
- ▶ change when a debugger is attached;
- ▶ disappear when a print is added;
- ▶ survive tests and fail later.

The teaching rule: compile with warnings, remove undefined behavior first, then debug logic.

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Use braces

Listing 30 braces.c

```
1 if (ready)
2     start();
3
4 if (ready) {
5     start();
6 }
7 cleanup();
```

The second form makes scope visible and prevents future edits from changing control flow by accident.

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C truthiness

Listing 31 truth.c

```
if (0) {
    puts("false");
}

if (42) {
    puts("true");
}

if ("hello") {
    puts("also true");
}
```

In C17, include `<stdbool.h>` if you want `bool`, `true`, and `false`.

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Tools

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Warnings are part of the course

Listing 32 session.sh

```
$ gcc -Wall -Wextra -Wpedantic -g ub.c -o ub
ub.c: In function 'main':
ub.c:5:5: warning: 'x' is used uninitialized [-Wuninitialized]
```

Do not treat warnings as decoration. In this course, students should read them from the top.

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Scrollable diagnostics trace

Printable exports should use a shorter diagnostic excerpt and discuss the full trace in the handout.

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Debugger workflow

Listing 33 gdb-session.sh

```
$ gcc -Wall -Wextra -g main.c counter.c report.c -o demo
$ gdb ./demo
(gdb) break main
(gdb) run
(gdb) next
(gdb) print counter
(gdb) backtrace
```

Good debugger slides are usually command traces plus a small code fragment, not screenshots.

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Memory checker workflow

Listing 34 valgrind-session.sh

```
$ valgrind --tool=memcheck ./demo
==12345== HEAP SUMMARY:
==12345==    in use at exit: 16 bytes in 1 blocks
==12345== total heap usage: 1 allocs, 0 frees
==12345==
==12345== LEAK SUMMARY:
==12345==    definitely lost: 16 bytes in 1 blocks
```

The tool is useful after the program compiles and the failure is runtime behavior.

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Export Strategy

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One source, three outputs

Listing 35 render.sh

```
$ PATH="$PWD/venv/bin:$PATH" quarto render cm3.qmd --to revealjs
$ PATH="$PWD/venv/bin:$PATH" quarto render cm3.qmd --to beamer
$ PATH="$PWD/venv/bin:$PATH" quarto render cm3.qmd --to typst
```

Output	File	Use
RevealJS	cm3.html	live lecture with navigation, fragments, scroll, animation
Beamer	cm3-beamer.pdf	slide PDF close to the classroom deck
Typst	cm3-handout.pdf	printable reading handout from the same source

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Print handouts

RevealJS can still be printed from the browser using `?print-pdf`, but the student n-up PDFs use the Beamer export as their source. That keeps the printed versions clean, centered, and free of the web background.

Listing 36 handouts.sh

```
$ chromium --headless --no-sandbox \
  --print-to-pdf=cm3-reveal-print.pdf \
  "file://$PWD/cm3.html?print-pdf"

$ pdftjam cm3-beamer.pdf --nup 1x2 --paper a4paper \
  --frame true --delta "0cm 0.25cm" --scale 0.96 \
  --outfile cm3-2up.pdf
$ pdftjam cm3-beamer.pdf --nup 2x2 --landscape --paper a4paper \
  --frame true --delta "0.20cm 0.20cm" --scale 0.96 \
  --outfile cm3-4up.pdf
$ pdftjam cm3-beamer.pdf --nup 2x3 --paper a4paper \
  --frame true --delta "0.18cm 0.18cm" --scale 0.96 \
```

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What to keep in the final course

Keep:

- ▶ code filenames and line highlights;

Avoid:

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What to keep in the final course

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- ▶ vertical detail slides for optional explanations;

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- ▶ one executed example per topic when it proves something;

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What to keep in the final course

Keep:

- ▶ code filenames and line highlights;
- ▶ vertical detail slides for optional explanations;
- ▶ one executed example per topic when it proves something;
- ▶ short command traces for terminal stories;

Avoid:

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What to keep in the final course

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Avoid:

- ▶ long scrollable slides as the only source of information;

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- ▶ terminal styling that competes with syntax highlighting;

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What to keep in the final course

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Avoid:

- ▶ long scrollable slides as the only source of information;
- ▶ terminal styling that competes with syntax highlighting;
- ▶ animations that carry essential meaning with no PDF fallback.