COS 217: Introduction to Programming Systems

A Taste of C

PRINCETON UNIVERSITY

Agenda

Simple C Programs

- charcount (loops, standard input)
  - 4-stage build process
- upper (character data, ctype library)
  - portability concerns

Source code control with `git`

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Simple C Programs

- charcount (loops, standard input)
  - 4-stage build process
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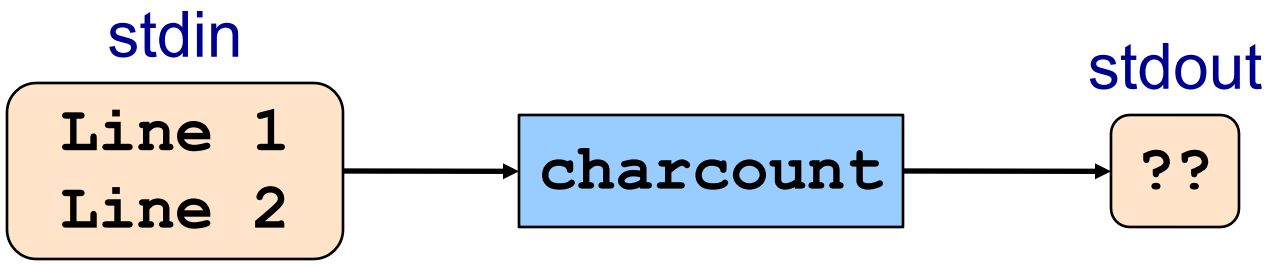
Source code control with `git`

The “charcount” Program

Functionality:

- Read all characters from standard input stream
- Write to standard output stream the number of characters read



The "charcount" Program

The program:

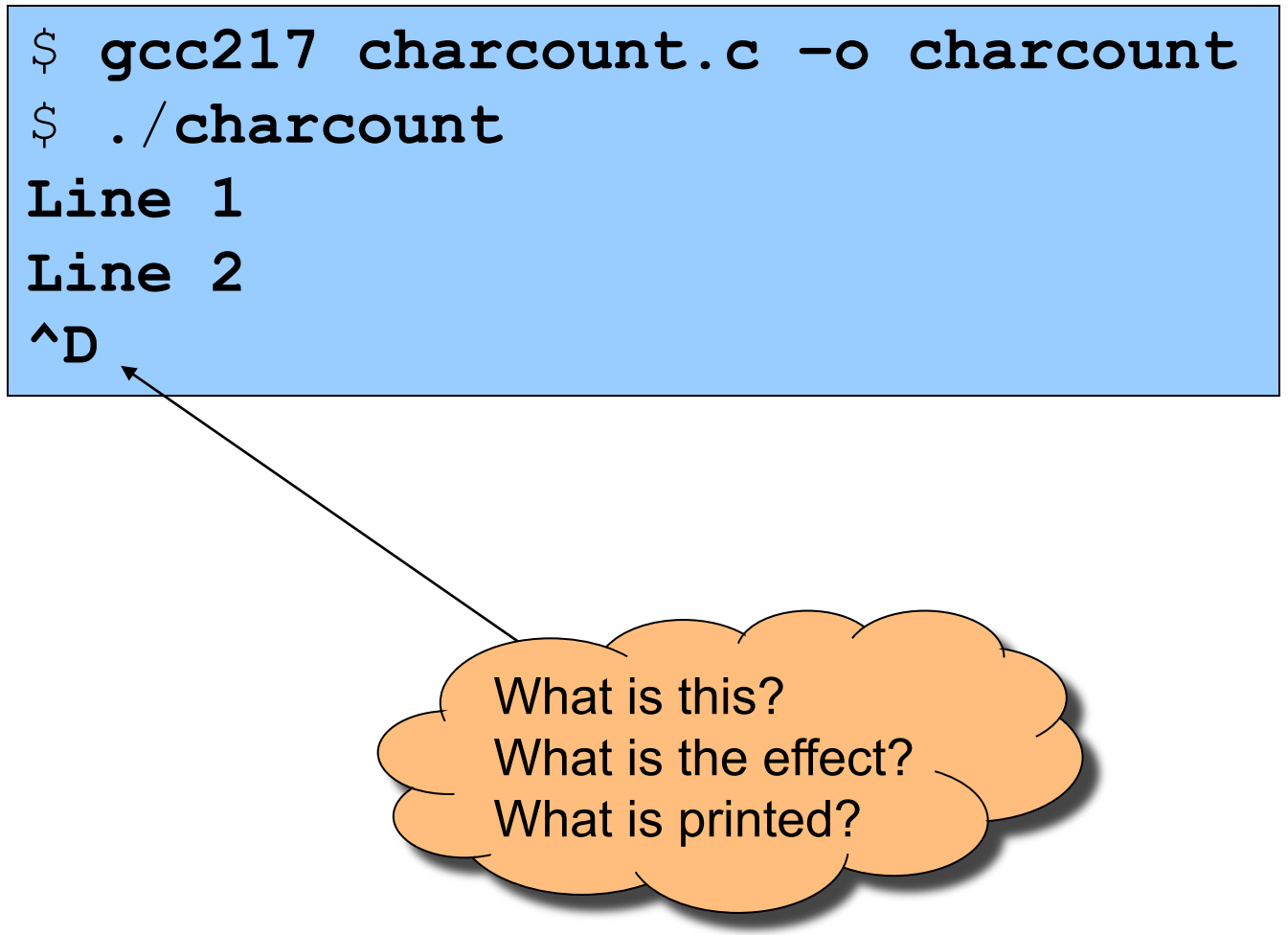
charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

“charcount” Building and Running

```
$ gcc217 charcount.c
$ ls
.     ..    a.out
$ gcc217 charcount.c -o charcount
$ ls
.     ..    a.out      charcount
$
```

“charcount” Building and Running



“charcount” Building and Running

```
$ gcc217 charcount.c -o charcount
$ ./charcount
Line 1
Line 2
^D
14
$
```

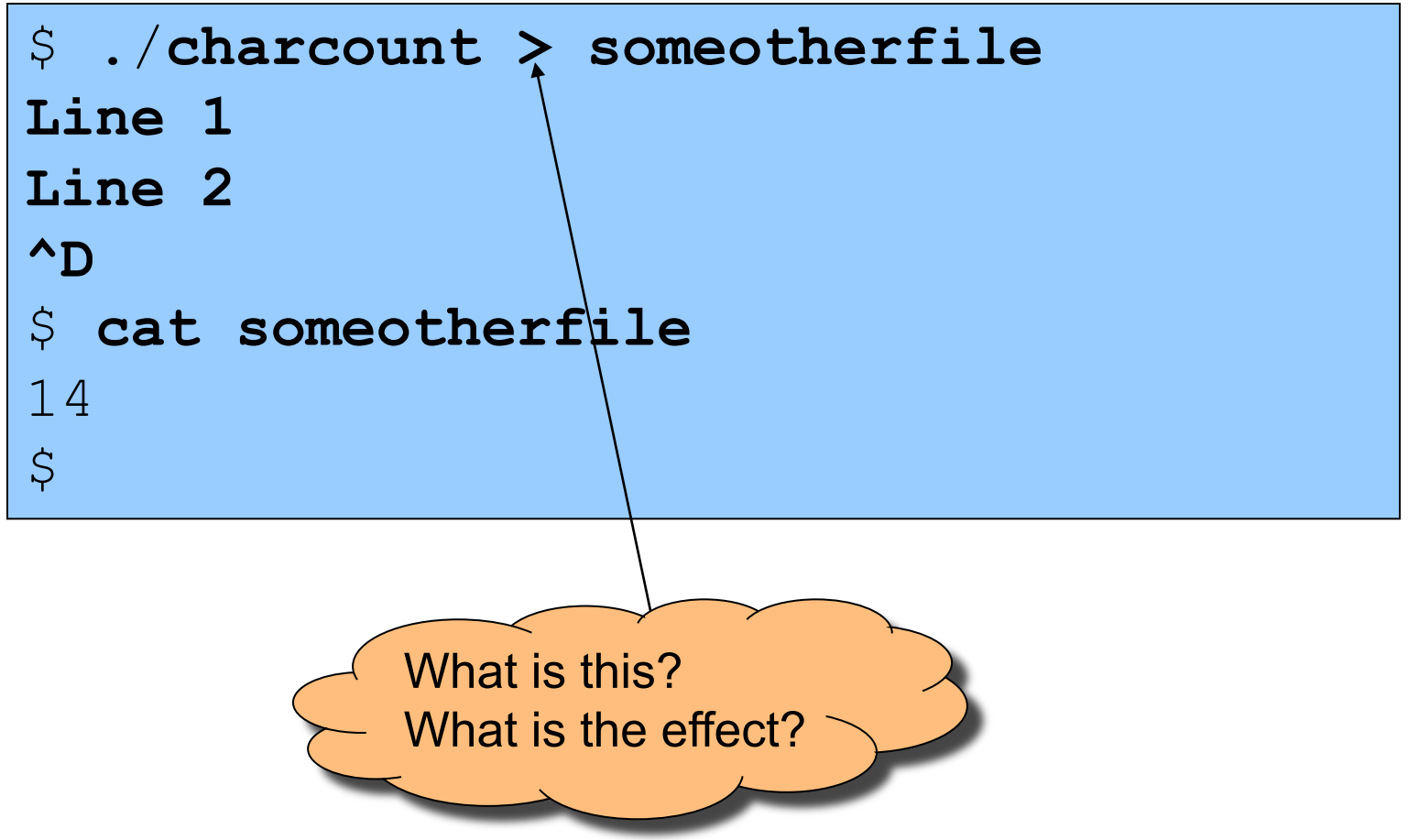
Includes visible characters plus two newlines

“charcount” Building and Running

```
$ cat somefile
Line 1
Line 2
$ ./charcount < somefile
14
$
```

What is this?
What is the effect?

“charcount” Building and Running



Running "charcount"

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

Execution begins at **`main()`** function

- No classes in the C language.

Running "charcount"

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

We allocate space for c and charCount in the stack section of memory

Why **int** instead of **char**?

Running "charcount"

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

EOF is a special value, distinct from all possible chars

getchar() tries to read char from stdin

- Success ⇒ returns that char value (within an int)
- Failure ⇒ returns **EOF**

Running "charcount"

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

Assuming c ≠ EOF, we increment charCount

Running “charcount”

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

We call getchar() again and recheck loop condition

Running “charcount”

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- Eventually getchar() returns EOF
- Loop condition fails
- We call printf() to write final charCount

Running "charcount"

Run-time trace, referencing the original C code…

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- return statement returns to calling function
- return from main() terminates program

Normal execution ⇒ 0 or **EXIT_SUCCESS**
Abnormal execution ⇒ **EXIT_FAILURE**

“charcount” Build Process in Detail

Question:

- Exactly what happens when you issue the command
  `gcc217 charcount.c -o charcount`

Answer: Four steps

- Preprocess
- Compile
- Assemble
- Link

"charcount" Build Process in Detail

The starting point

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- C language
- Missing declarations of getchar() and printf()
- Missing definitions of getchar() and printf()

Preprocessing “charcount”

Command to preprocess:

- `gcc217 -E charcount.c > charcount.i`

Preprocessor functionality

- Removes comments
- Handles preprocessor directives

Preprocessing “charcount”

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

Preprocessor removes comment (this is A1!)

Preprocessing "charcount"

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

Preprocessor replaces
#include <stdio.h>
with contents of
/usr/include/stdio.h

Preprocessor replaces
EOF with -1

Preprocessing "charcount"

The result

charcount.i

```
...
int getchar();
int printf(char *fmt, ...);
...


int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != -1)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- C language
- Missing comments
- Missing preprocessor directives
- Contains code from stdio.h: **declarations** of getchar() and printf()
- Missing **definitions** of getchar() and printf()
- Contains value for EOF

Compiling “charcount”

Command to compile:

- `gcc217 -S charcount.i`

Compiler functionality

- Translate from C to assembly language
- Use function declarations to check calls of getchar() and printf()

Compiling “charcount”

charcount.i

```
...
int getchar();
int printf(char *fmt, ...);
...
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != -1)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- Compiler sees function declarations
- So compiler has enough information to check subsequent calls of getchar() and printf()

Compiling "charcount"

charcount.i

```
...
int getchar();
int printf(char *fmt, ...);
...
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != -1)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- Definition of main() function
- Compiler checks calls of getchar() and printf() when encountered
- Compiler translates to assembly language

Compiling “charcount”

The result:
charcount.s

```
        .section        .rodata
.LC0:
        .string "%d\n"

        .section        .text
        .global main
main:
        stp     x29, x30, [sp, -32]!
        add     x29, sp, 0
        str     wzr, [x29,24]
        bl      getchar
        str     w0, [x29,28]
        b       .L2
.L3:
        ldr     w0, [x29,24]
        add     w0, w0, 1
        str     w0, [x29,24]
        bl      getchar
        str     w0, [x29,28]
.L2:
        ldr     w0, [x29,28]
        cmn     w0, #1
        bne     .L3
        adrp    x0, .LC0
        add     x0, x0, :lo12:.LC0
        ldr     w1, [x29,24]
        bl      printf
        mov     w0, 0
        ldp     x29, x30, [sp], 32
        ret
```

- Assembly language
- Missing definitions of getchar() and printf()

Assembling “charcount”

Command to assemble:

- `gcc217 -c charcount.s`

Assembler functionality

- Translate from assembly language to machine language

Assembling "charcount"

The result:

charcount.o

```
Machine language
version of the
program

No longer human
readable
```

- Machine language
- Missing definitions of getchar() and printf()

Linking “charcount”

Command to link:

- `gcc217 charcount.o -o charcount`

Linker functionality

- Resolve references within the code
- Fetch machine language code from the standard C library (/usr/lib/libc.a) to make the program complete

Linking “charcount”

The result:

charcount

```
Machine language
version of the
program

No longer human
readable
```

- Machine language
- Contains definitions of getchar() and printf()

Complete! Executable!

iClicker Question

Q: There are other ways to **`charcount`** – which is best?

A.
```
for (c=getchar(); c!=EOF; c=getchar())
    charCount++;
```

B.
```
while ((c=getchar()) != EOF)
    charCount++;
```

C.
```
for (;;)
{   c = getchar();
    if (c == EOF)
        break;
    charCount++;
}
```

D.
```
c = getchar();
while (c!=EOF)
{   charCount++;
    c =
    getchar();
}
```

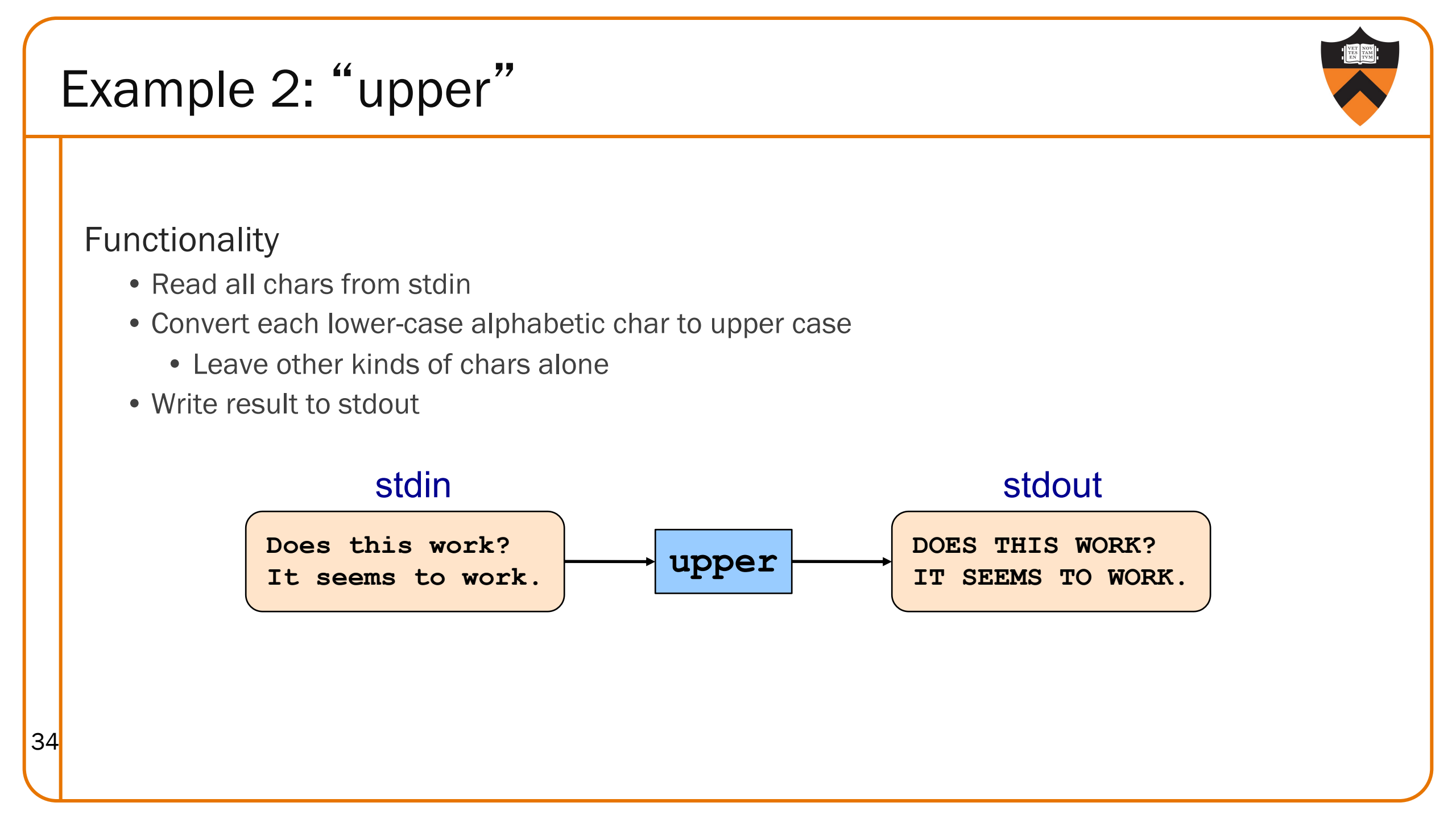
Agenda

Simple C Programs

- charcount (loops, standard input)
  - 4-stage build process
- upper (character data, ctype library)
  - portability concerns

Source code control with `git`

Example 2: “upper”



Functionality

- Read all chars from stdin
- Convert each lower-case alphabetic char to upper case
  - Leave other kinds of chars alone
- Write result to stdout

ASCII

American Standard Code for Information Interchange

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	NUL									HT	LF					
16																
32	SP	!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
48	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
64	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
80	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
96	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
112	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	

Partial map

Note: Lower-case and
upper-case letters are 32 apart

“upper” Version 1

```
#include <stdio.h>
int main(void)
{   int c;
    while ((c = getchar()) != EOF)
    {   if ((c >= 97) && (c <= 122))
            c -= 32;
        putchar(c);
    }
    return 0;
}
```

What’s wrong?

Character Literals

Examples

```
'a'         the a character
                    97 on ASCII systems

'\n'        newline
                    10 on ASCII systems

'\t'        horizontal tab
                    9 on ASCII systems

'\\'        backslash
                    92 on ASCII systems

'\''        single quote
                    39 on ASCII systems

'\0'        the null character (alias NUL)
                    0 on all systems
```

“upper” Version 2

```
#include <stdio.h>
int main(void)
{   int c;
    while ((c = getchar()) != EOF)
    {   if ((c >= 'a') && (c <= 'z'))
            c += 'A' - 'a';
        putchar(c);
    }
    return 0;
}
```

Arithmetic on chars?

What’s wrong now?

ctype.h Functions

```
$ man islower
NAME
       isalnum, isalpha, isascii, isblank, iscntrl, isdigit, isgraph,
       islower, isprint, ispunct, isspace, isupper, isxdigit -
       character classification routines

SYNOPSIS
       #include <ctype.h>
       int isalnum(int c);
       int isalpha(int c);
       int isascii(int c);
       int isblank(int c);
       int iscntrl(int c);
       int isdigit(int c);
       int isgraph(int c);
       int islower(int c);
       int isprint(int c);
       int ispunct(int c);
       int isspace(int c);
       int isupper(int c);
       int isxdigit(int c);
```

These functions check whether c falls into various character classes

ctype.h Functions

```
$ man toupper
NAME
      toupper, tolower - convert letter to upper or lower case

SYNOPSIS
      #include <ctype.h>
      int toupper(int c);
      int tolower(int c);

DESCRIPTION
      toupper() converts the letter c to upper case, if possible.
      tolower() converts the letter c to lower case, if possible.

      If c is not an unsigned char value, or EOF, the behavior of
      these functions is undefined.

RETURN VALUE
      The value returned is that of the converted letter,
      or c if the conversion was not possible.
```

“upper” Version 3

```
#include <stdio.h>
#include <ctype.h>
int main(void)
{   int c;
    while ((c = getchar()) != EOF)
    {   if (islower(c))
            c = toupper(c);
        putchar(c);
    }
    return 0;
}
```

iClicker Question

Q: Is the **if** statement really necessary?

A. Gee, I don't know.
Let me check
the man page
(again)!

```
#include <stdio.h>
#include <ctype.h>
int main(void)
{   int c;
    while ((c = getchar()) != EOF)
    {   if (islower(c))
            c = toupper(c);
        putchar(c);
    }
    return 0;
}
```

ctype.h Functions

```
$ man toupper
NAME
      toupper, tolower - convert letter to upper or lower case

SYNOPSIS
      #include <ctype.h>
      int toupper(int c);
      int tolower(int c);

DESCRIPTION
      toupper() converts the letter c to upper case, if possible.
      tolower() converts the letter c to lower case, if possible.

      If c is not an unsigned char value, or EOF, the behavior of
      these functions is undefined.

RETURN VALUE
      The value returned is that of the converted letter,
      or c if the conversion was not possible.
```

iClicker Question

Q: Is the **if** statement really necessary?

A. Yes, necessary for correctness.

B. Not necessary, but I'd leave it in.

C. Not necessary, and I'd get rid of it.

```
#include <stdio.h>
#include <ctype.h>
int main(void)
{   int c;
    while ((c = getchar()) != EOF)
    {   if (islower(c))
            c = toupper(c);
        putchar(c);
    }
    return 0;
}
```

Agenda

Simple C Programs

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- upper (character data, ctype library)
  - portability concerns

Source code control with `git`

Revision Control Systems

Problems often faced by programmers:

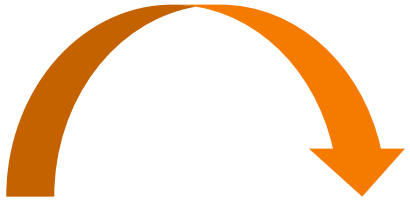
- How do I work with source code on multiple computers?
- How do I work with others (e.g. a COS 217 partner) on the same program?
- What changes did my partner just make?
- If my partner and I make changes to different parts of a program, how do we merge those changes?
- How can I try out one way of writing this function, and go back if it doesn't work?
- Help! I've deleted my code! How do I get it back?
- Help! I've introduced a subtle bug that I can't find. How can I see what I've changed since the last working version?

All of these problems solved by specialized tools, such as `git`

Repository vs. Working Copy

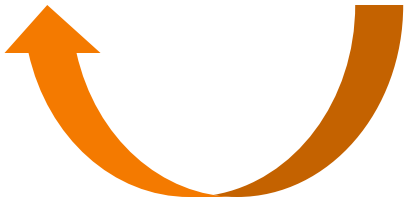
WORKING COPY

- Represents single version of the code
- Plain files (e.g, .c)
- Make a coherent set of modifications, then *commit* this version of code to the repository
- Best practice: write a meaningful *commit message*



git commit

git checkout



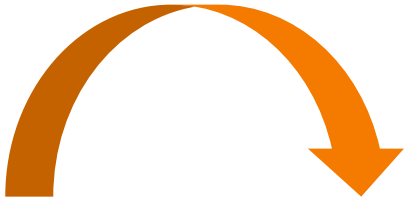
REPOSITORY

- Contains all checked-in versions of the code
- Specialized format, located in .git directory
- Can view commit history
- Can diff any versions
- Can *check out* any version, by default the most recent (known as HEAD)

Local vs. Remote Repositories

LOCAL REPO

- Located in .git directory
- Only accessible from the current computer
- Commit early, commit often – you can only go back to versions you've committed
- Can *push* current state (i.e., complete checked-in history) to a remote repository



git push

git clone
git pull

REMOTE REPO

- Located in the cloud, e.g. github.com
- Can *clone* to multiple machines
- Any clone can *pull* the current state

COS 217 ❤ github

We distribute assignment code through a github.com repo

- But you can't push to our repo!

Need to create your own (private!) repo for each assignment

- Two methods in git primer handout
- One clone on armlab, to test and submit
- If developing on your own machine, another clone there: be sure to commit and push to github, then pull on armlab