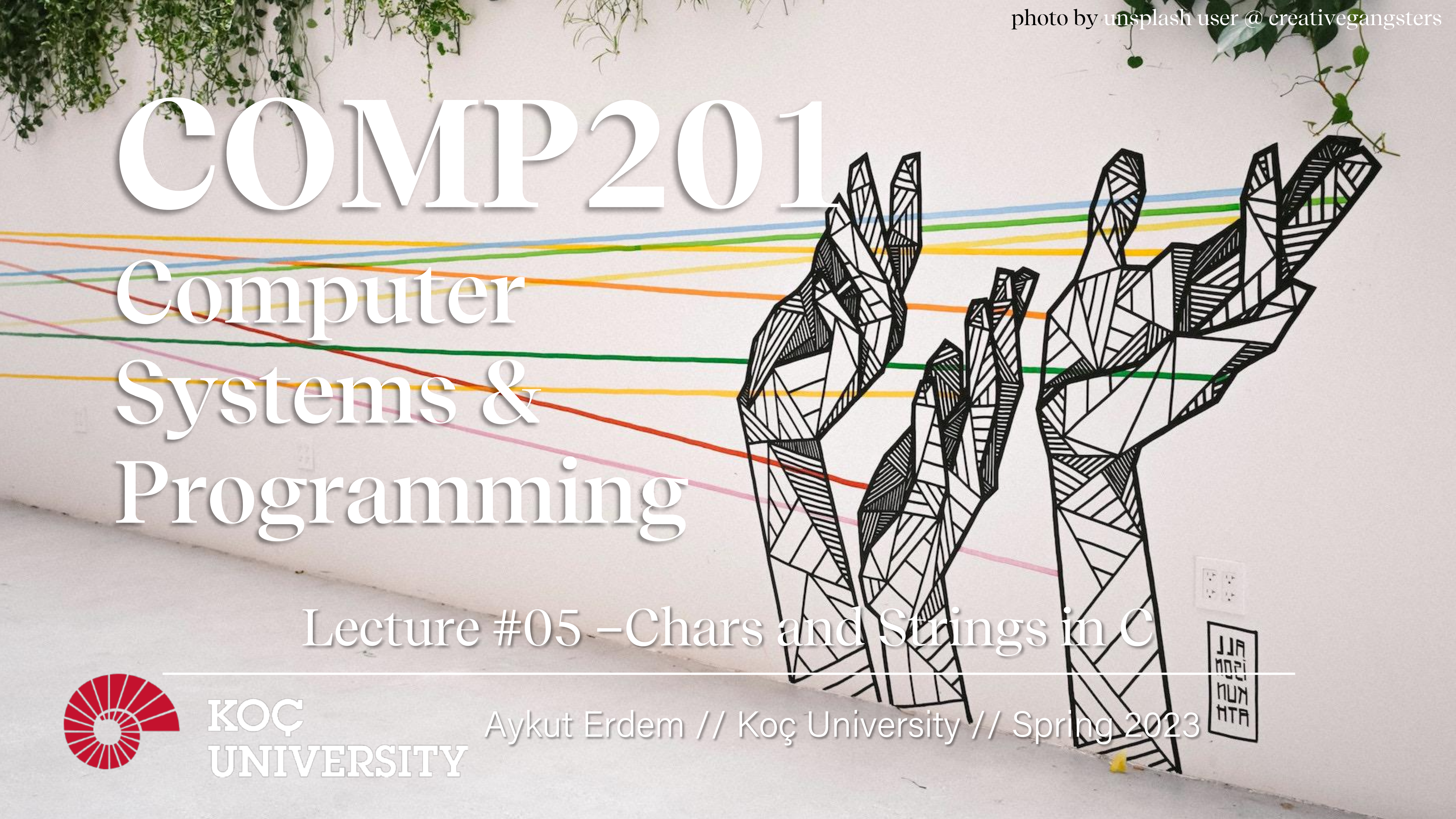


photo by unsplash user @ creativegangsters

COMP201

Computer Systems & Programming

Lecture #05 –Chars and Strings in C

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Spring 2023

Good news, everyone!

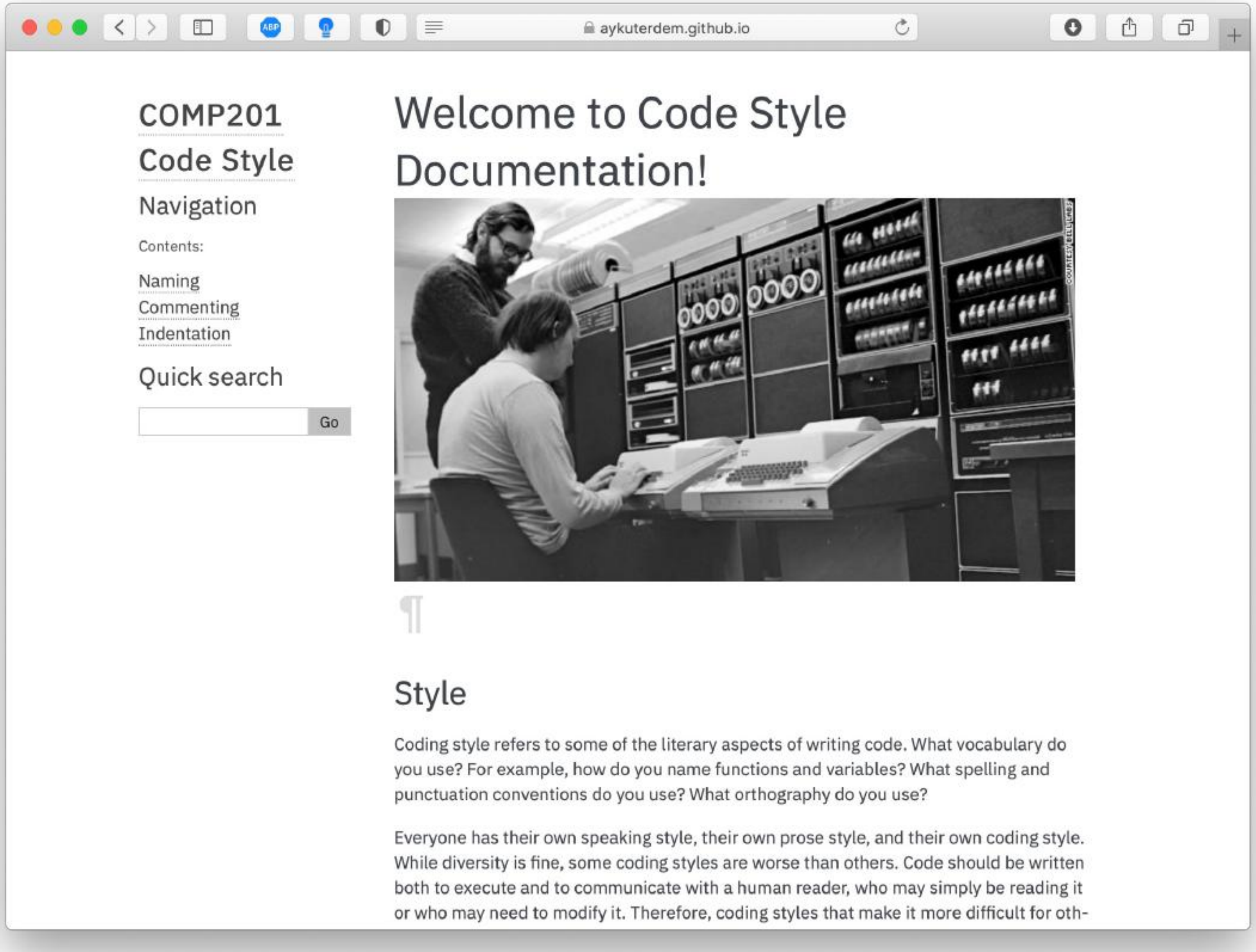
Office Hour	Time
Aykut	Wed 10:00-11:00
Batur	Wed 15:00-16:00
Mert	Thu 17:30-18:30
Nafiseh	Mon 09.00-10.00
Beyza	Tue 13:30-14:30
Eda	Thu 14:30-15.30
Emir	Mon 10:00-11:00
Sinan	Fri 10:00-11:00

* Place and Zoom links available on Blackboard

Image: Professor Farnsworth (Futurama)

COMP201 Coding Style Guide for C Programming

- Our guide serves as a brief introduction to C coding style.
- Following a formal style is very important to write a clean and easy to read code.
- There are many standards out there!



COMP201 Code Style

Navigation

Contents:

- Naming
- Commenting
- Indentation

Quick search

Welcome to Code Style Documentation!

¶

Style

Coding style refers to some of the literary aspects of writing code. What vocabulary do you use? For example, how do you name functions and variables? What spelling and punctuation conventions do you use? What orthography do you use?

Everyone has their own speaking style, their own prose style, and their own coding style. While diversity is fine, some coding styles are worse than others. Code should be written both to execute and to communicate with a human reader, who may simply be reading it or who may need to modify it. Therefore, coding styles that make it more difficult for oth-

https://aykuterdem.github.io/classes/comp201/code-style/html/index.html

Recap: Real Numbers

Problem: unlike with the integer number line, where there are a finite number of values between two numbers, there are an *infinite* number of real number values between two numbers!

Integers between 0 and 2: 1

Real Numbers Between 0 and 2: 0.1, 0.01, 0.001, 0.0001, 0.00001,…

We need a fixed-width representation for real numbers. Therefore, by definition, *we will not be able to represent all numbers*.

Recap: Fixed Point

- **Idea:** Like in base 10, let’s add binary decimal places to our existing number representation.

1	0	1	1	.	0	1	1
8s	4s	2s	1s		1/2s	1/4s	1/8s

- **Pros:** arithmetic is easy! And we know exactly how much precision we have.

Recap: Fixed Point

- **Problem:** we have to fix where the decimal point is in our representation. What should we pick? This also fixes us to 1 place per bit.

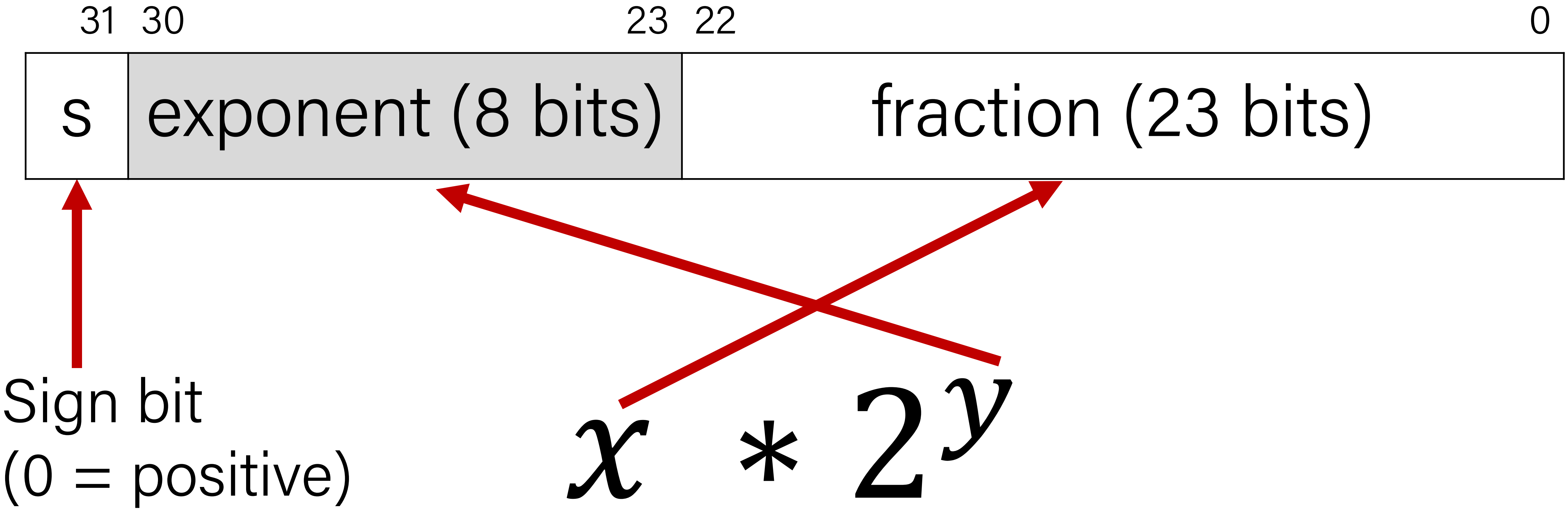
Base 10 Base 2

$$5.07E30 = 10\underbrace{\cdot\cdot\cdot\cdot\cdot}_{\text{100 zeros}}0.1$$

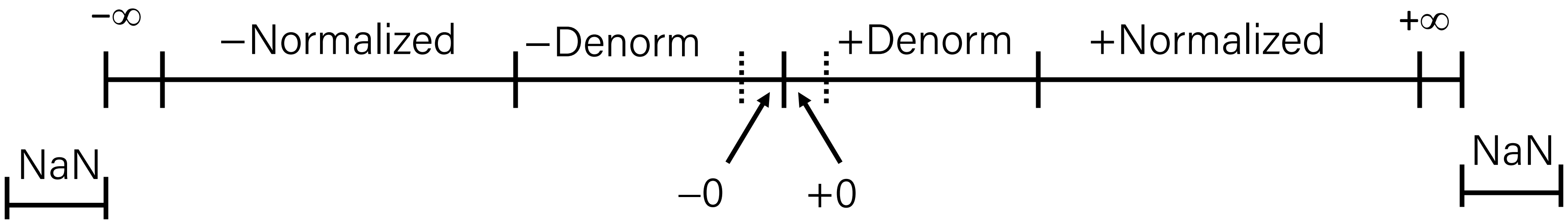
$$9.86E\text{-}32 = 0.0\underbrace{\cdot\cdot\cdot\cdot\cdot}_{\text{100 zeros}}01$$

To be able to store both these numbers using the same fixed point representation, the bitwidth of the type would need to be at least 207 bits wide!

Recap: IEEE Single Precision Floating Point



Recap: Floating Point Encodings



Recap: Floating Point Arithmetic

Is this just overflowing? It turns out it's more subtle.

```
float a = 3.14;
float b = 1e20;
printf("(3.14 + 1e20) - 1e20 = %g\n", (a + b) - b);  // prints 0
printf("3.14 + (1e20 - 1e20) = %g\n", a + (b - b));  // prints
3.14
```

Let's look at the binary representations for 3.14 and 1e20:

	31	30 23	22 0
3.14:	0	10000000	10010001111010111000011

	31	30 23	22 0
1e20:	0	11000001	01011010111100011101100

Recap: Floating Point Equality Comparisons

Equality comparison operations are often unwise!

```
double a = 0.1;
double b = 0.2;
double c = 0.3;
double d = a + b;
printf("0.1 + 0.2 == 0.3 ? %s\n", a + b == c ? "true" : "false");
printf("d: %.10lf\n", d);
```

- Output:

```
0.1 + 0.2 == 0.3 ? false
d: 0.30000000000000004441
```

COMP201 Topic 3: How can a computer represent and manipulate more complex data like text?

Plan for Today

- Characters
- Strings
- Common String Operations
- Practice: Diamonds

Disclaimer: Slides for this lecture were borrowed from

—Nick Troccoli and Lisa Yan's Stanford CS107 class

—Swami Iyer’s Umass Boston CS110 class

Lecture Plan

- Characters
- Strings
- Common String Operations
- Practice: Diamonds

Char

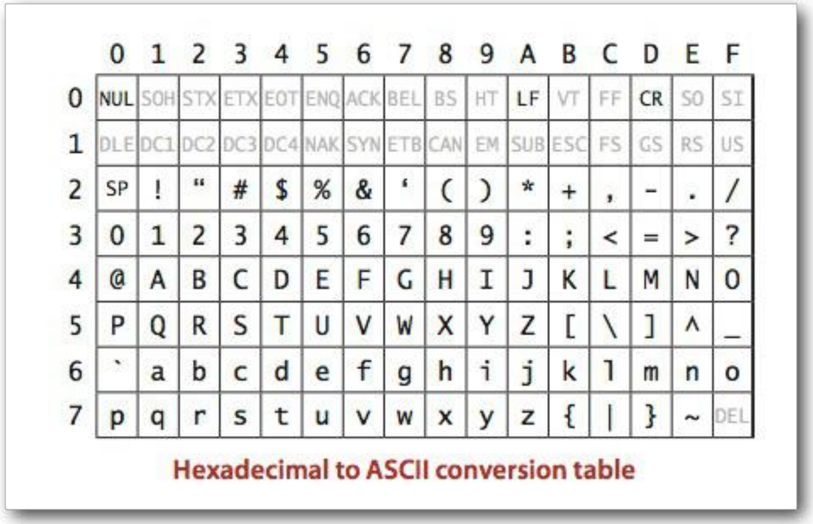
A **char** is a variable type that represents a single character or “glyph”.

```
char letterA = 'A';
char plus = '+';
char zero = '0';
char space = ' ';
char newLine = '\n';
char tab = '\t';
char singleQuote = '\'';
char backSlash = '\\';
```

ASCII

Under the hood, C represents each **char** as an 8-bit *integer* (its “ASCII value”).

- Uppercase letters are sequentially numbered
- Lowercase letters are sequentially numbered
- Digits are sequentially numbered
- Lowercase letters are 32 more than their uppercase equivalents (bit flip!)



	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
1	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EM	SUB	ESC	FS	GS	RS	US
2	SP	!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
3	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
6	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
7	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	DEL

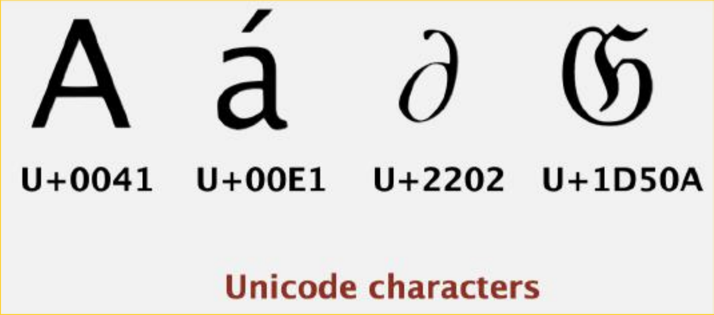
Hexadecimal to ASCII conversion table

```
char uppercaseA = 'A';         // Actually 65
char lowercaseA = 'a';         // Actually 97
char zeroDigit = '0’;              // Actually 48
```

Unicode Transformation Formats

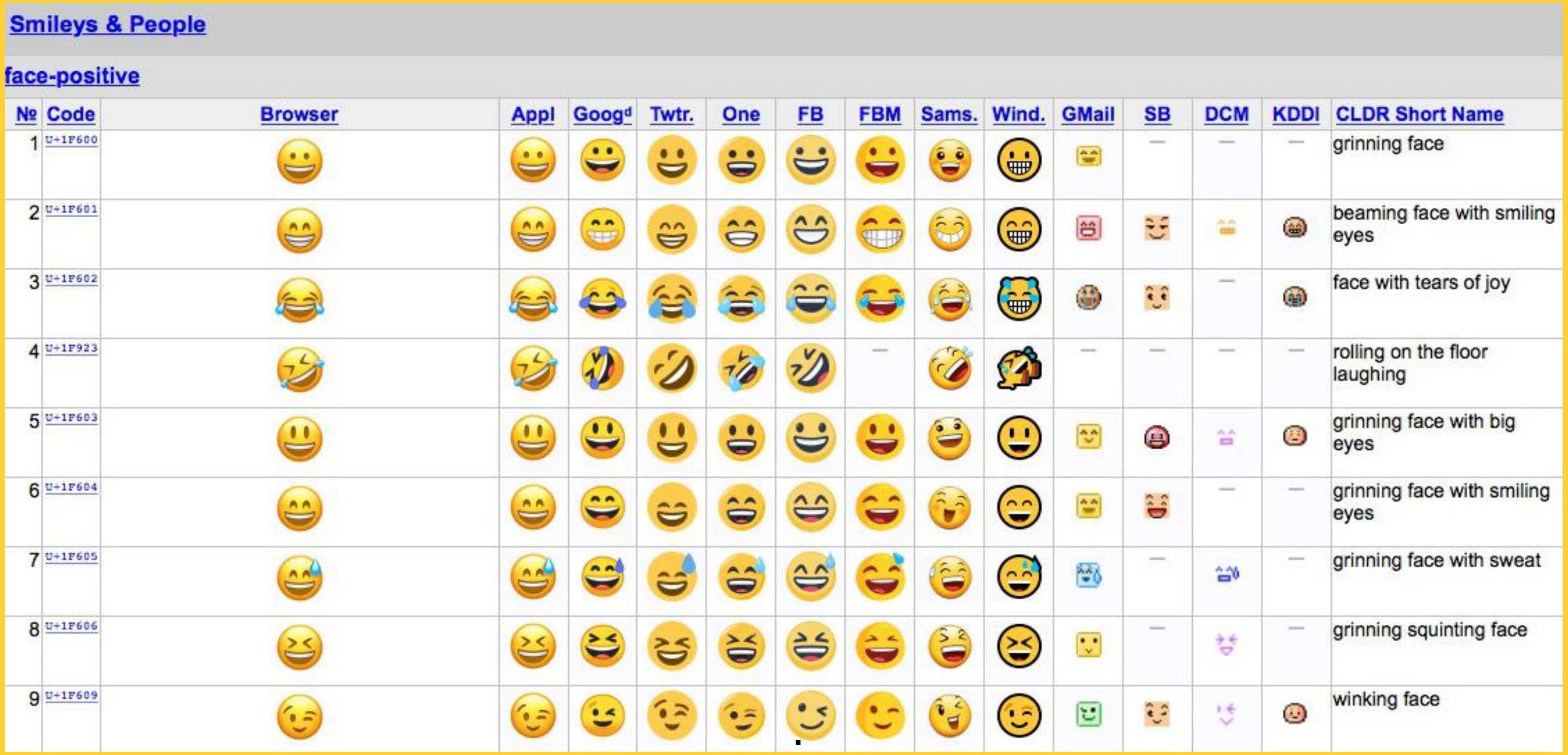
- The International Standards Organization’s (ISO) 16-bit Unicode system can represent every character in every known language, with room for more

- Unicode being somewhat wasteful of space for English documents, ISO also defined several “Unicode Transformation Formats” (UTF), the most popular being UTF-8



Emojis

- Emojis are just like characters, and they have a standard, too



Smileys & People

face-positive

№	Code	Browser	Appl	Goog^{d}	Twtr.	One	FB	FBM	Sams.	Wind.	GMail	SB	DCM	KDDI	CLDR Short Name
1	U+1F600	😀	😀	😀	😀	😀	😀	😀	😀	😀	😀	—	—	—	grinning face
2	U+1F601	😁	😁	😁	😁	😁	😁	😁	😁	😁	😁	😁	😁	😁	beaming face with smiling eyes
3	U+1F602	😂	😂	😂	😂	😂	😂	😂	😂	😂	😂	😂	—	😂	face with tears of joy
4	U+1F923	🤣	🤣	🤣	🤣	🤣	🤣	—	🤣	🤣	—	—	—	—	rolling on the floor laughing
5	U+1F603	😃	😃	😃	😃	😃	😃	😃	😃	😃	😃	😃	😃	😃	grinning face with big eyes
6	U+1F604	😄	😄	😄	😄	😄	😄	😄	😄	😄	😄	😄	—	—	grinning face with smiling eyes
7	U+1F605	😅	😅	😅	😅	😅	😅	😅	😅	😅	😅	—	😅	—	grinning face with sweat
8	U+1F606	😆	😆	😆	😆	😆	😆	😆	😆	😆	😆	—	😆	—	grinning squinting face
9	U+1F609	😉	😉	😉	😉	😉	😉	😉	😉	😉	😉	😉	😉	😉	winking face

⋮

- Full Emoji List, v15.0
  https://unicode.org/emoji/charts/full-emoji-list.html

ASCII

We can take advantage of C representing each **char** as an *integer:*

```
bool areEqual = 'A' == 'A';      // true
bool earlierLetter = 'f' < 'c';  // false
char uppercaseB = 'A' + 1;
int diff = 'c' - 'a';                // 2
int numLettersInAlphabet = 'z' - 'a' + 1;
// or
int numLettersInAlphabet = 'Z' - 'A' + 1;
```

ASCII

We can take advantage of C representing each **char** as an *integer:*

```
// prints out every lowercase character
for (char ch = 'a'; ch <= 'z'; ch++) {
    printf("%c", ch);
}
```

Common `ctype.h` Functions

Function	Description
`isalpha(`***`ch`***`)`	true if *ch* is `'a'` through `'z'` or `'A'` through `'Z'`
`islower(`***`ch`***`)`	true if *ch* is `'a'` through `'z'`
`isupper(`***`ch`***`)`	true if *ch* is `'A'` through `'Z'`
`isspace(`***`ch`***`)`	true if *ch* is a space, tab, new line, etc.
`isdigit(`***`ch`***`)`	true if *ch* is `'0'` through `'9'`
`toupper(`***`ch`***`)`	returns uppercase equivalent of a letter
`tolower(`***`ch`***`)`	returns lowercase equivalent of a letter

Remember: these **return** a char; they cannot modify an existing char!

More documentation with `man isalpha`, `man tolower`

Common `ctype.h` Functions

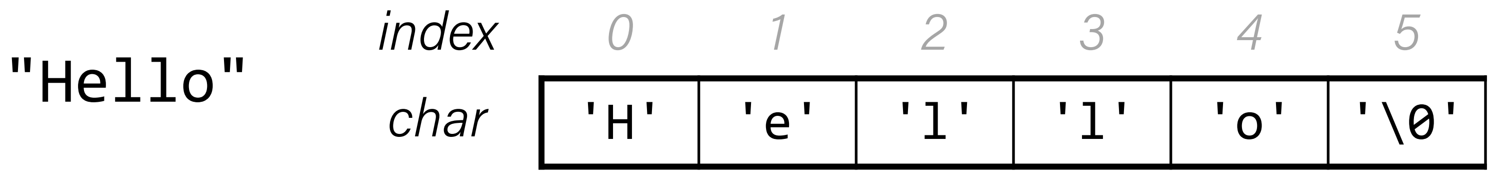
```
bool isLetter = isalpha('A');         // true
bool capital = isupper('f');         // false
char uppercaseB = toupper('b');
bool isADigit = isdigit('4');        // true
```

Lecture Plan

- Characters
- Strings
- Common String Operations
- Practice: Diamonds

C Strings

C has no dedicated variable type for strings. Instead, a string is represented as an **array of characters** with a special ending sentinel value.



"Hello"

index	*0*	*1*	*2*	*3*	*4*	*5*
char	`'H'`	`'e'`	`'l'`	`'l'`	`'o'`	`'\0'`

`'\0'` is the **null-terminating character**; you always need to allocate one extra space in an array for it.

String Length

Strings are **not** objects. They do not embed additional information (e.g., string length). We must calculate this!

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13
value	'H'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

We can use the provided **`strlen`** function to calculate string length. The null-terminating character does *not* count towards the length.

```
int length = strlen(myStr);        // e.g. 13
```

Caution: `strlen` is `O(N)` because it must scan the entire string! We should save the value if we plan to refer to the length later.

C Strings As Parameters

When we pass a string as a parameter, it is passed as a **`char *`**. C passes the location of the first character rather than a copy of the whole array.

```
int doSomething(char *str) {
     ...
}


char myString[6];
...
doSomething(myString);
```

C Strings As Parameters

When we pass a string as a parameter, it is passed as a **char ***. C passes the location of the first character rather than a copy of the whole array.

```
int doSomething(char *str) {
    ...
    str[0] = 'c'; // modifies original string!
    printf("%s\n", str);    // prints cello
}

char myString[6];
... // e.g. this string is “Hello”
doSomething(myString);
```

We can still use a **char *** the same way as a **char[]**.

Lecture Plan

- Characters
- Strings
- Common String Operations
  - Comparing
  - Copying
  - Concatenating
  - Substrings
- Practice: Diamonds

Common string.h Functions

Function	Description
strlen(***str***)	returns the # of chars in a C string (before null-terminating character).
strcmp(***str1, str2***), strncmp(***str1, str2, n***)	compares two strings; returns 0 if identical, <0 if ***str1*** comes before ***str2*** in alphabet, >0 if ***str1*** comes after ***str2*** in alphabet. ***strncmp*** stops comparing after at most ***n*** characters.

strchr(***str, ch***)
strrchr(***str, ch***)
	character search: returns a pointer to the first occurrence of ***ch*** in ***str***, or ***NULL*** if ***ch*** was not found in ***str***. strrchr find the last occurrence.

strstr(***haystack, needle***)	string search: returns a pointer to the start of the first occurrence of ***needle*** in ***haystack***, or ***NULL*** if ***needle*** was not found in ***haystack***.
strcpy(***dst, src***), strncpy(***dst, src, n***)	copies characters in ***src*** to ***dst***, including null-terminating character. Assumes enough space in ***dst***. Strings must not overlap. **strncpy** stops after at most ***n*** chars, and does not add null-terminating char.
strcat(***dst, src***), strncat(***dst, src, n***)	concatenate ***src*** onto the end of ***dst***. **strncat** stops concatenating after at most ***n*** characters. Always adds a null-terminating character.
strspn(***str, accept***), strcspn(***str, reject***)	**strspn** returns the length of the initial part of ***str*** which contains only characters in ***accept***. **strcspn** returns the length of the initial part of ***str*** which does not contain any characters in ***reject***.

Common string.h Functions

Function	Description
strlen(***str***)	returns the # of chars in a C string (before null-terminating character).
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strstr(***haystack, n***	he first occurrence of ot found in ***haystack***.
strcpy(***dst, src***), strncpy(***dst, src, n***)	-terminating character. Assumes enough space in ***dst***. Strings must not overlap. **strncpy** stops after at most ***n*** chars, and does not add null-terminating char.
strcat(***dst, src***), strncat(***dst, src, n***)	concatenate ***src*** onto the end of ***dst***. **strncat** stops concatenating after at most ***n*** characters. Always adds a null-terminating character.
strspn(***str, accept***), strcspn(***str, reject***)	**strspn** returns the length of the initial part of ***str*** which contains only characters in ***accept***. **strcspn** returns the length of the initial part of ***str*** which does not contain any characters in ***reject***.

Many string functions assume **valid string** input; i.e., ends in a null terminator.

Comparing Strings

We cannot compare C strings using comparison operators like ==, < or >. This compares addresses!

```
// e.g. str1 = 0x7f42, str2 = 0x654d
void doSomething(char *str1, char *str2) {
     if (str1 > str2) { …    // compares 0x7f42 > 0x654d!
```

Instead, use **`strcmp`.**

The string library: `strcmp`

`strcmp(str1, str2)`: compares two strings.

- returns 0 if identical
- <0 if ***`str1`*** comes before ***`str2`*** in alphabet
- >0 if ***`str1`*** comes after ***`str2`*** in alphabet.

```
int compResult = strcmp(str1, str2);
if (compResult == 0) {
     // equal
} else if (compResult < 0) {
     // str1 comes before str2
} else {
     // str1 comes after str2
}
```

Copying Strings

We cannot copy C strings using =. This copies addresses!

```
// e.g. param1 = 0x7f42, param2 = 0x654d
void doSomething(char *param1, char *param2) {
     param1 = param2;   // copies 0x654d.  Points to same string!
     param2[0] = 'H';   // modifies the one original string!
```

Instead, use **strcpy**.

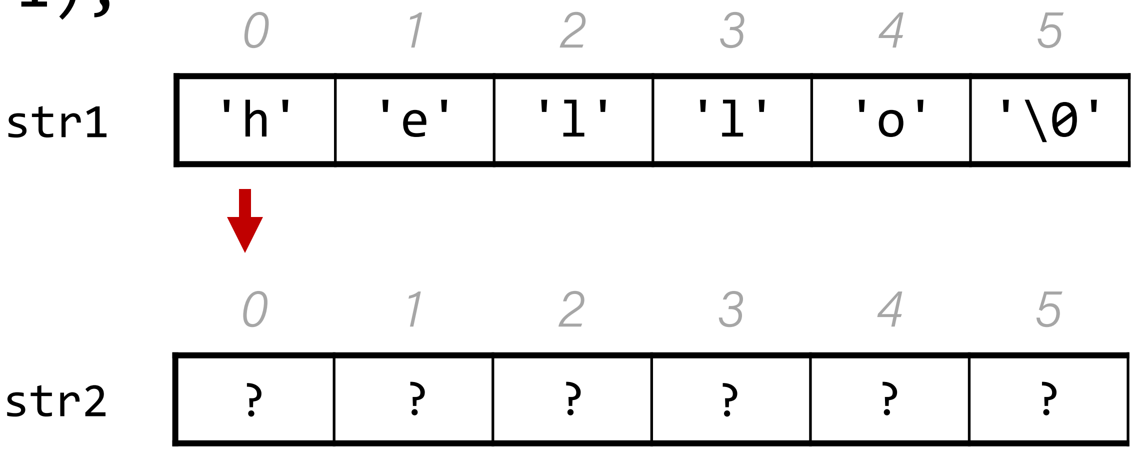
The string library: `strcpy`

`strcpy(dst, src)`: copies the contents of **`src`** into the string **`dst`**, including the null terminator.

```
char str1[6];
strcpy(str1, "hello");

char str2[6];
strcpy(str2, str1);
str2[0] = 'c';

printf("%s", str1);        // hello
printf("%s", str2);        // cello
```

Copying Strings – strcpy

```c
char str1[6];
strcpy(str1, "hello");

char str2[6];
strcpy(str2, str1);
```



	0	1	2	3	4	5
str1	'h'	'e'	'l'	'l'	'o'	'\0'

	0	1	2	3	4	5
str2	?	?	?	?	?	?

Copying Strings – `strcpy`

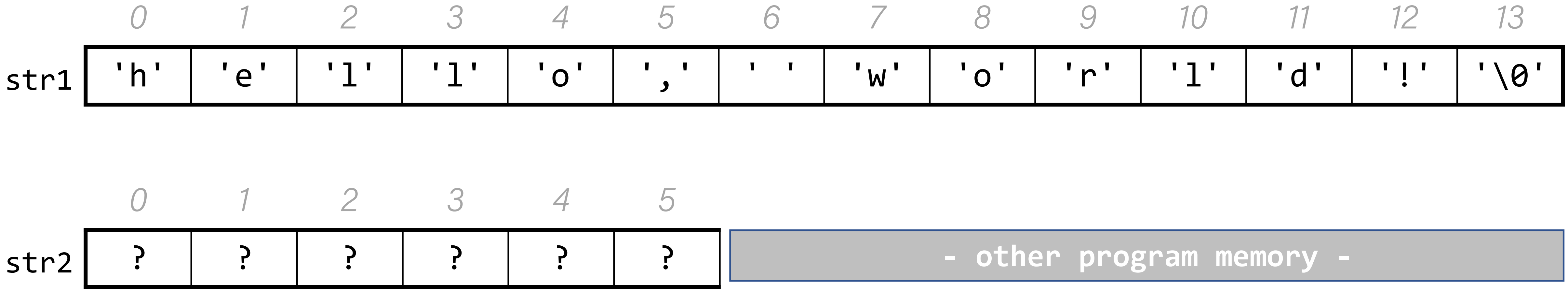
We must make sure there is enough space in the destination to hold the entire copy, *including the null-terminating character*.

```
char str2[6];                     // not enough space!
strcpy(str2, "hello, world!");   // overwrites other memory!
```

Writing past memory bounds is called a “buffer overflow”. It can allow for security vulnerabilities!

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other
memory!
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5
str2	?	?	?	?	?	?

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
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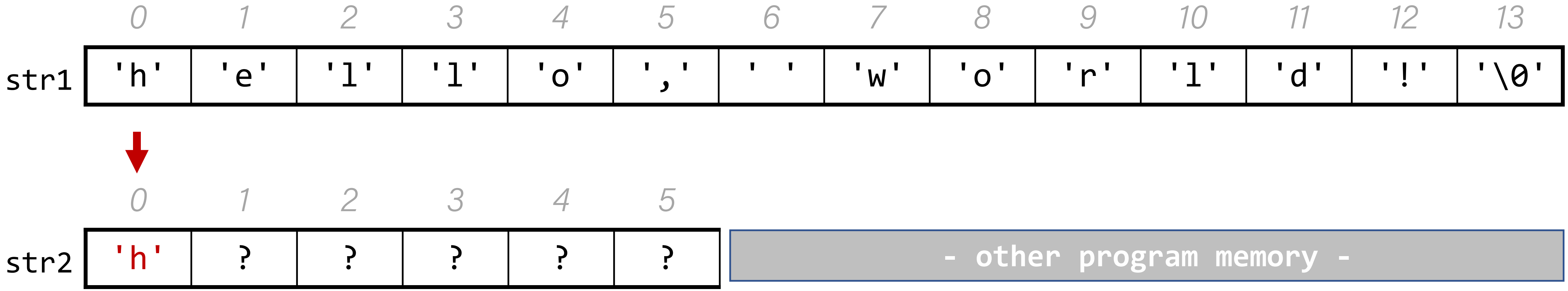

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	?	?	?	?	?	- other program memory -

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
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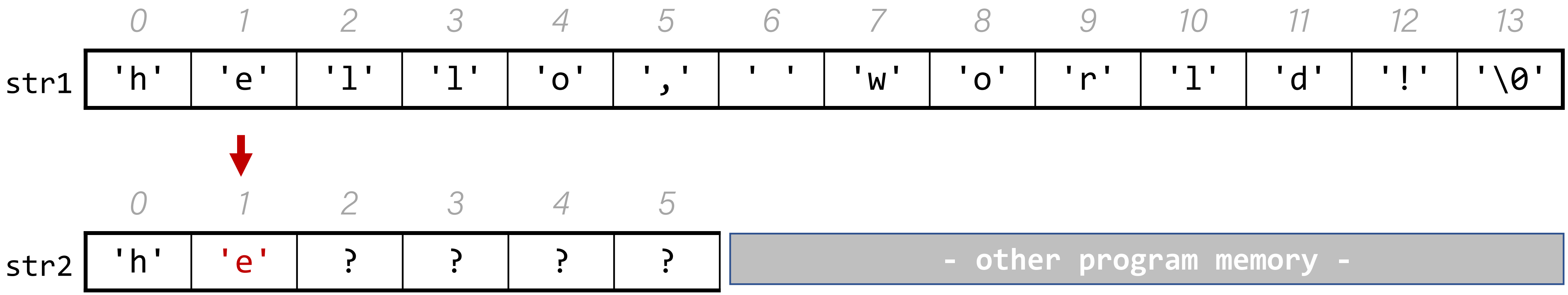

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	?	?	?	?	- other program memory -

Copying Strings – Buffer Overflows

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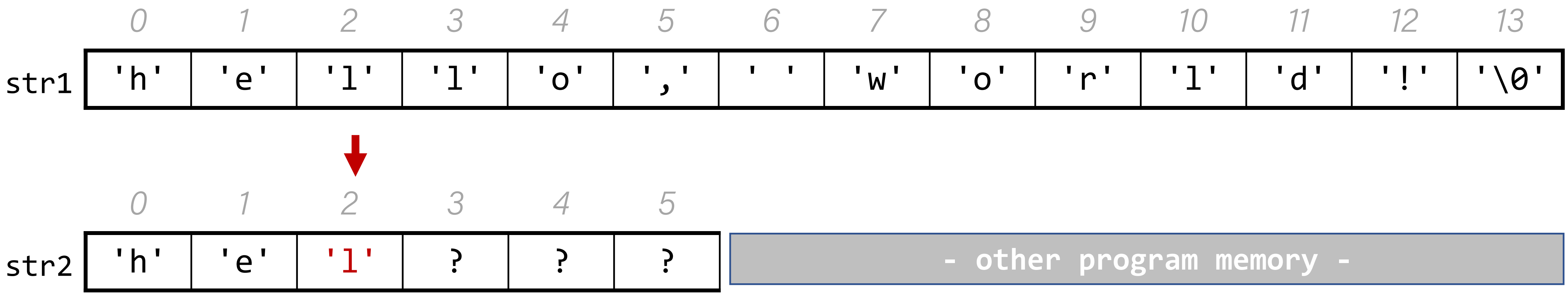

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	?	?	?	- other program memory -

Copying Strings – Buffer Overflows

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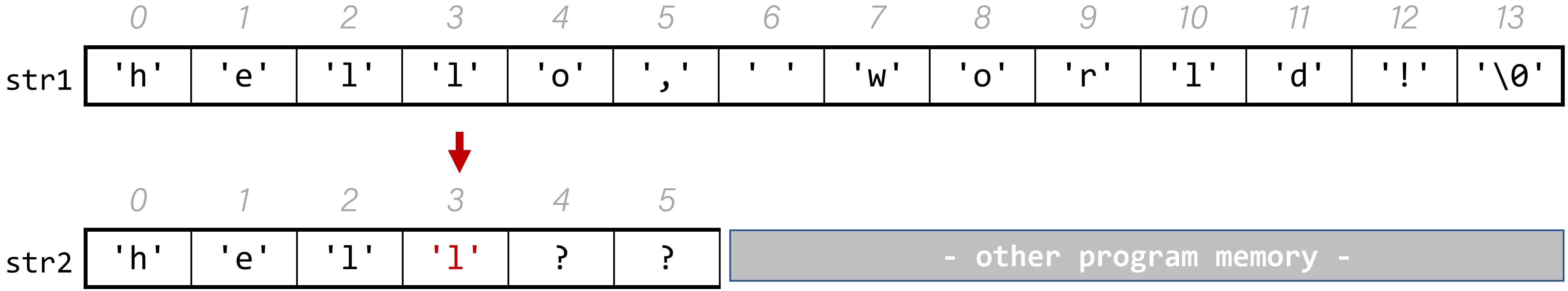

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	'l'	?	?	- other program memory -

Copying Strings – Buffer Overflows

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char str1[14];
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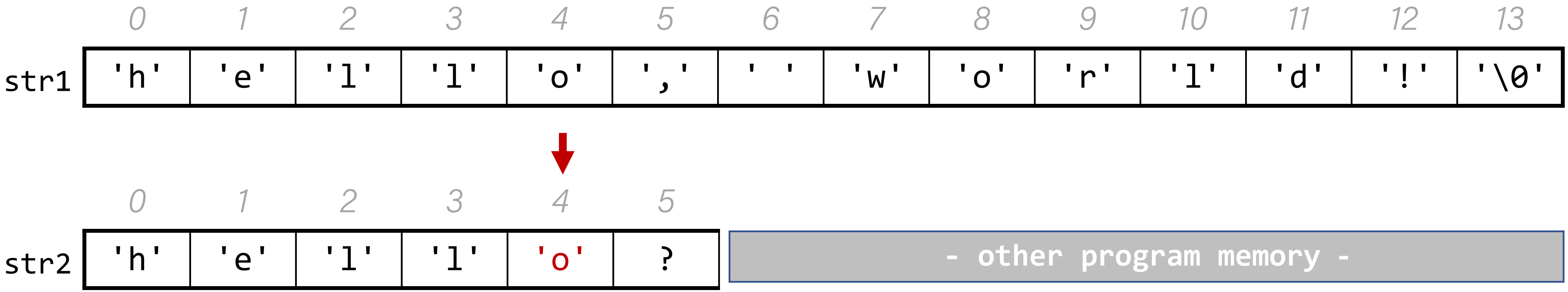
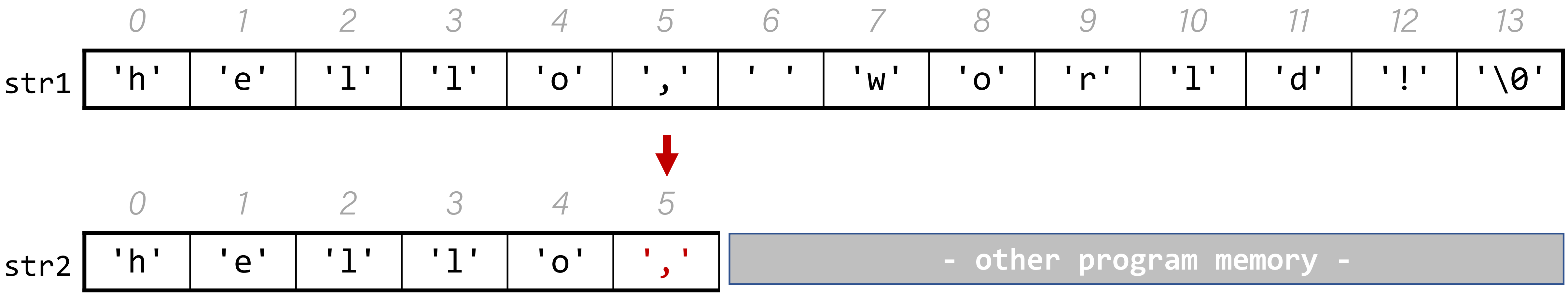


	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	'l'	'o'	?	- other program memory -

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other memory!
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	'l'	'o'	','	- other program memory -

Copying Strings – Buffer Overflows

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strcpy(str1, "hello, world!");
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strcpy(str2, str1);   // not enough space - overwrites other memory!
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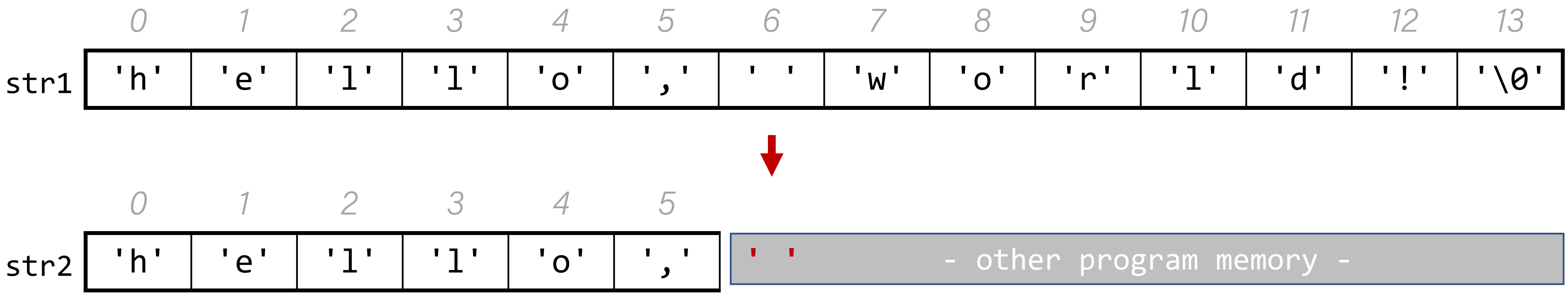

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	'l'	'o'	','	' ' - other program memory -

Copying Strings – Buffer Overflows

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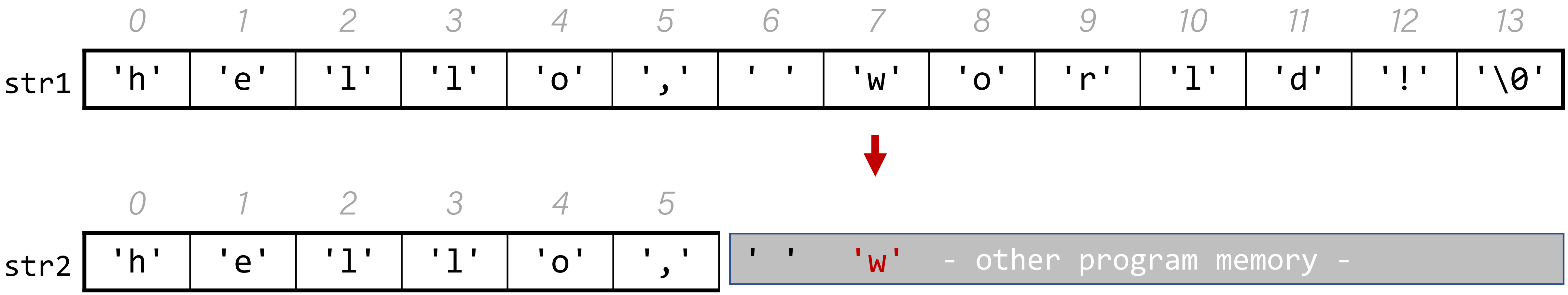

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	'l'	'o'	','	' ' 'w' - other program memory -

Copying Strings – Buffer Overflows

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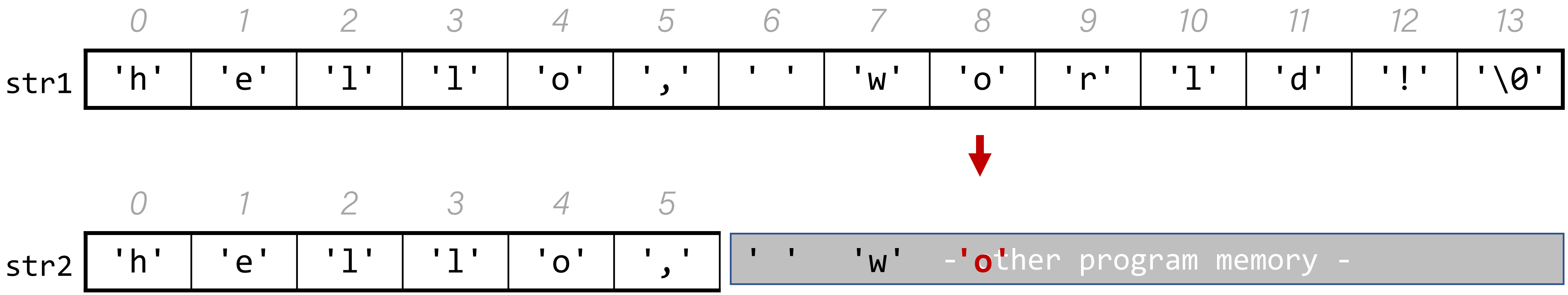

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5
str2	'h'	'e'	'l'	'l'	'o'	','

' '   'w'   -'o'ther program memory -

Copying Strings – Buffer Overflows

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char str1[14];
strcpy(str1, "hello, world!");
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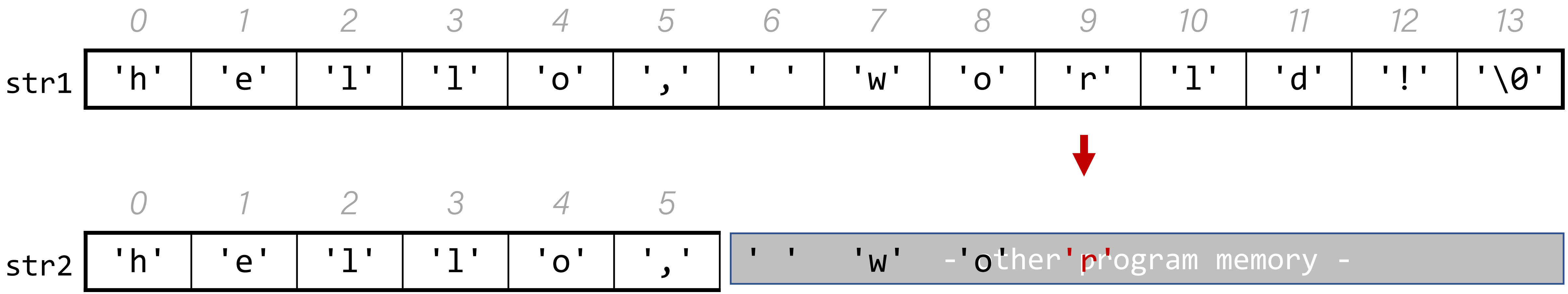

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	
str2	'h'	'e'	'l'	'l'	'o'	','	' ' 'w' 'o' 'r' - other program memory -

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other memory!
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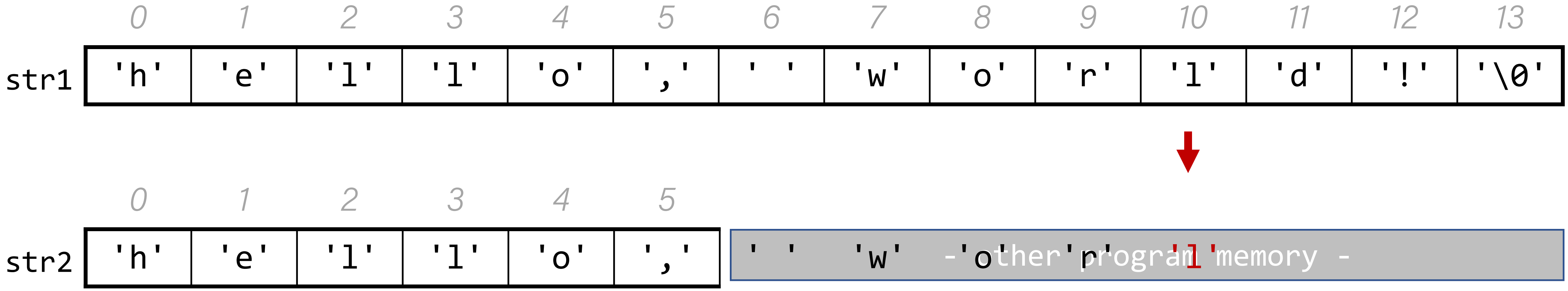

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5
str2	'h'	'e'	'l'	'l'	'o'	','

' ' 'w' 'o' 'r' 'l'

- other program memory -

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);    // not enough space - overwrites other memory!
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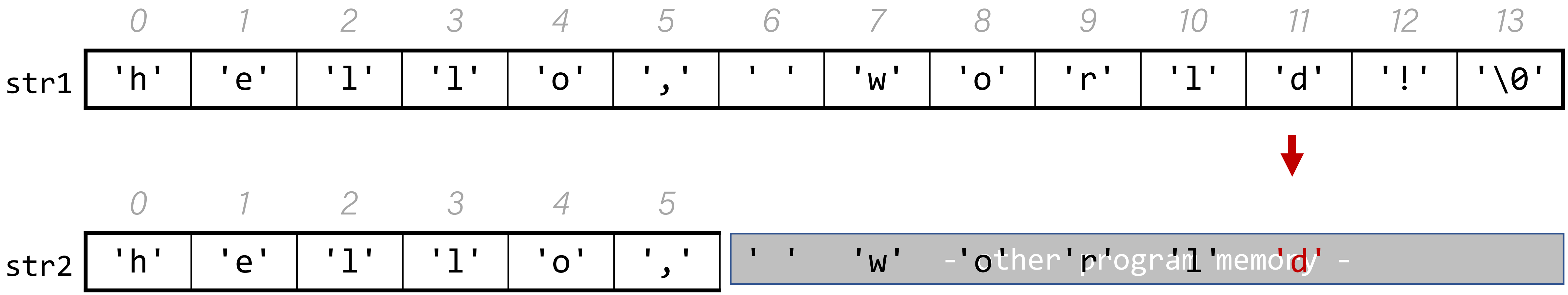
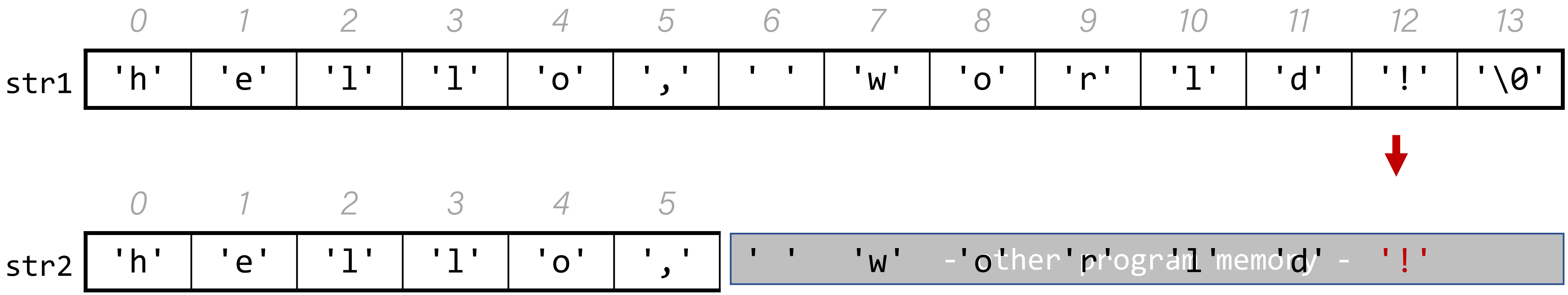


	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5						
str2	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other memory!
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

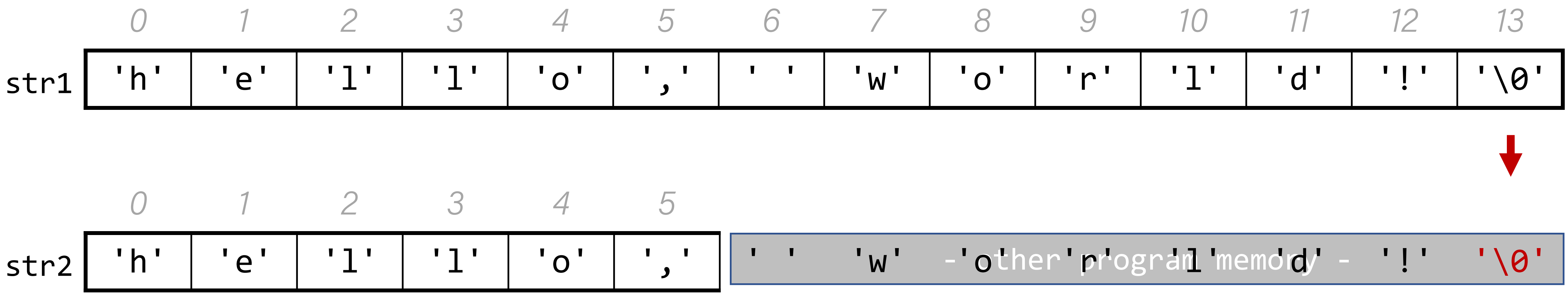
	0	1	2	3	4	5
str2	'h'	'e'	'l'	'l'	'o'	','

' ' 'w' 'o' 'r' 'l' 'd' '!'

- other program memory -

Copying Strings – Buffer Overflows

```c
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other memory!
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5								
str2	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Copying Strings – Buffer Overflows

```
char str1[14];
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other memory!
```

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5								
str2	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

- other program memory -

String Copying Exercise

What value should go in the blank at right?

A. 4

B. 5

C. 6

D. 12

E. `strlen("hello")`

F. Something else

```
char str[______];
strcpy(str, "hello");
```

String Exercise

What is printed out by the following program?

```c
int main(int argc, char *argv[]) {
    char str[9];
    strcpy(str, "Hi earth");
    str[2] = '\0';
    printf("str = %s, len = %lu\n",
           str, strlen(str));
    return 0;
}
```

A. `str = Hi, len = 8`
B. `str = Hi, len = 2`
C. `str = Hi earth, len = 8`
D. `str = Hi earth, len = 2`
E. None/other

Copying Strings – `strncpy`

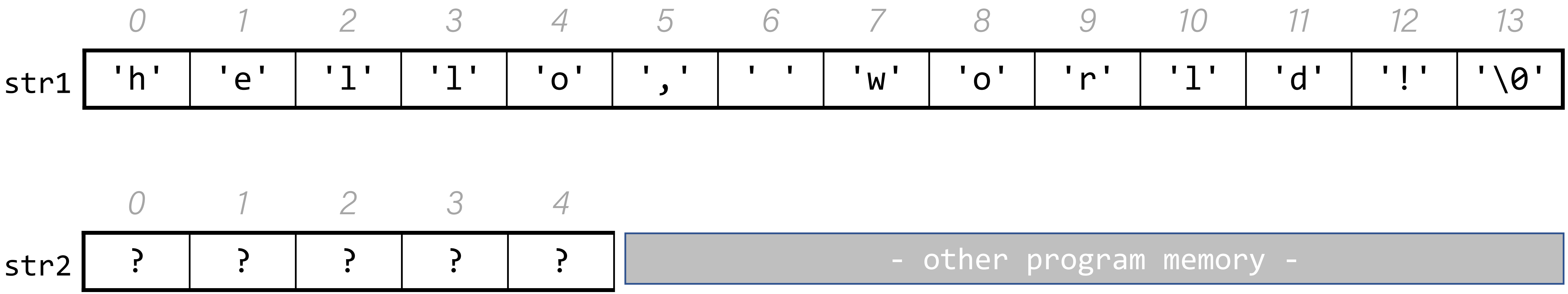
`strncpy(dst, src, n)`: copies at most the first n bytes from **src** into the string **dst**. If there is no null-terminating character in these bytes, then **`dst`** will *not be null terminated*!

```
// copying "hello"
char str2[5];
strncpy(str2, "hello, world!", 5);    // doesn’t copy '\0'!
```

If there is no null-terminating character, we may not be able to tell where the end of the string is anymore. E.g. `strlen` may continue reading into some other memory in search of `'\0'`!

Copying Strings – strncpy

```
char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
```

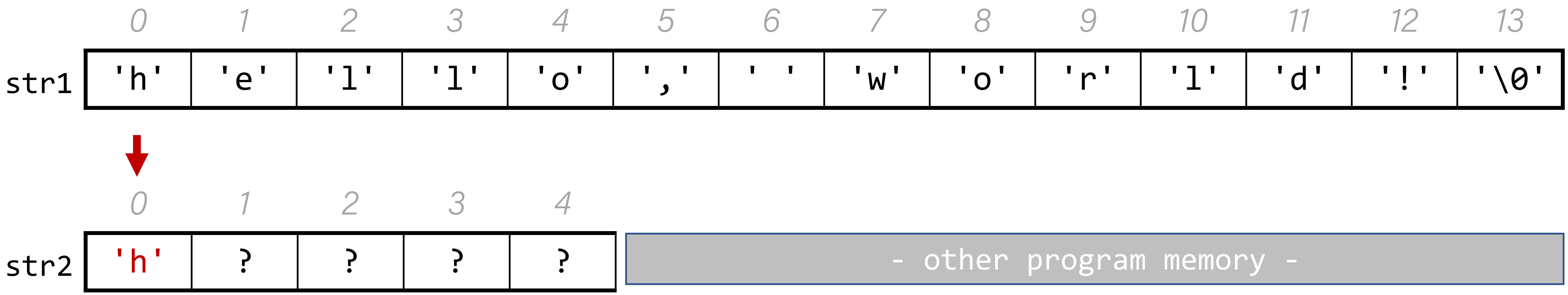


	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	?	?	?	?	?	- other program memory -

Copying Strings – strncpy

```
char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
```

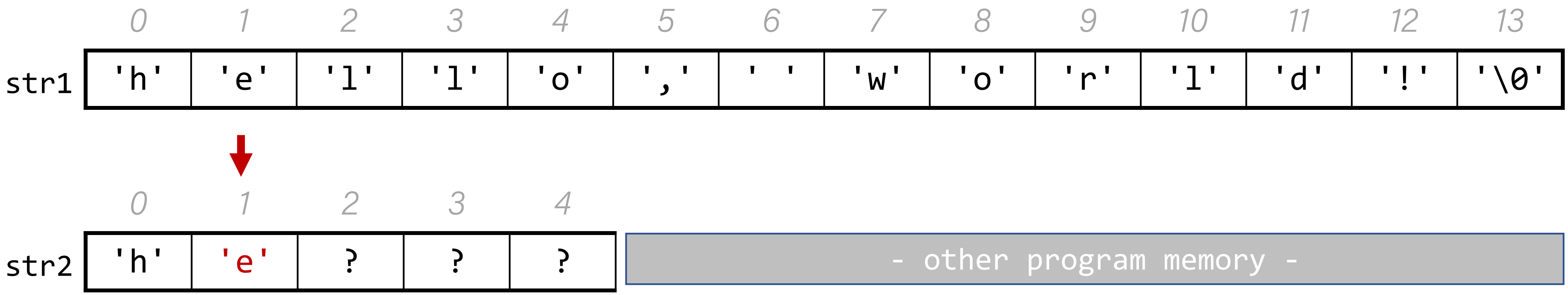


	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	?	?	?	?	- other program memory -

Copying Strings – strncpy

```
char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
```

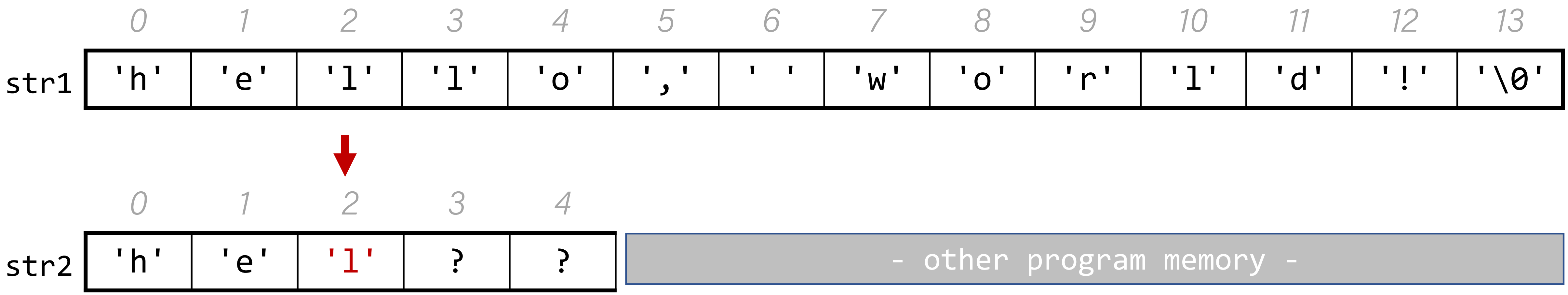


	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	?	?	?	- other program memory -

Copying Strings – strncpy

```
char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4
str2	'h'	'e'	'l'	?	?

Copying Strings – strncpy

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char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
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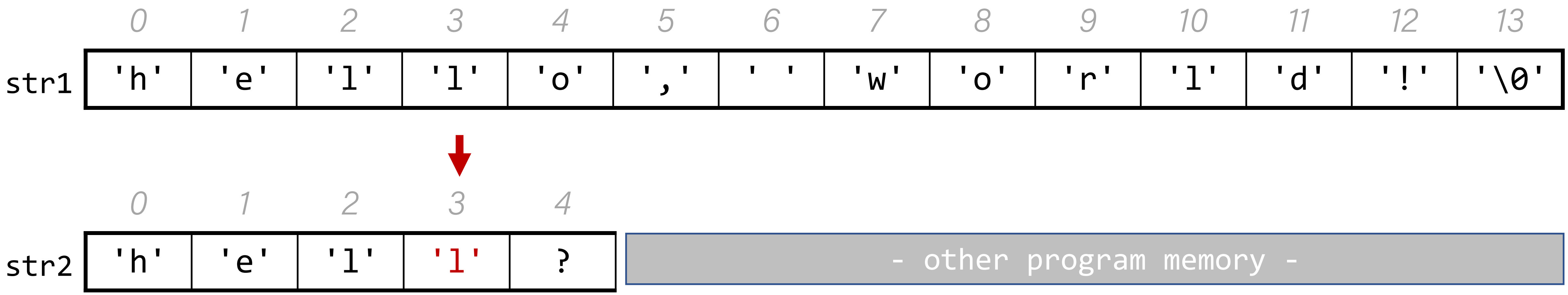

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	?	- other program memory -

Copying Strings – strncpy

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char str2[5];
strncpy(str2, "hello, world!", 5);
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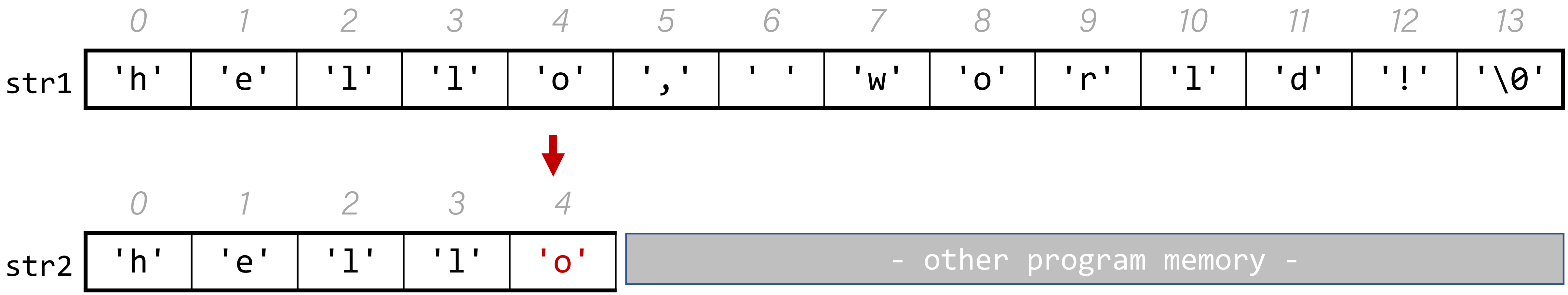

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

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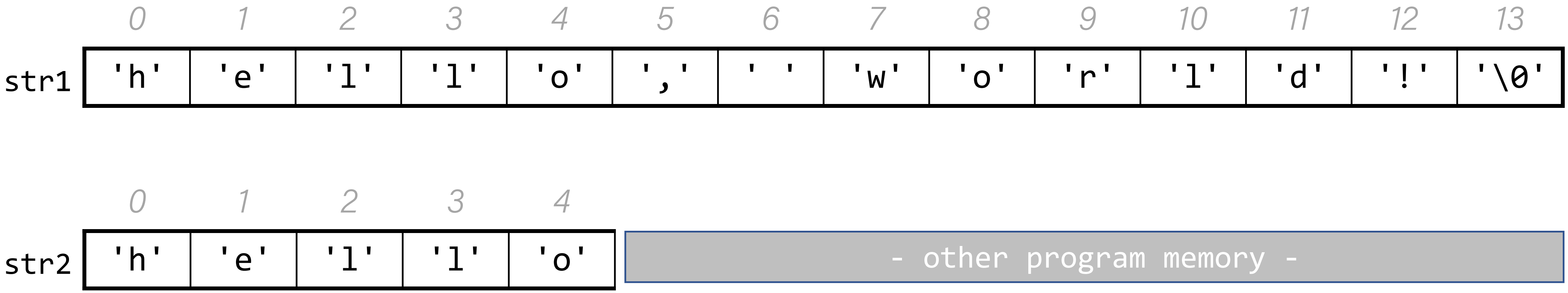

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

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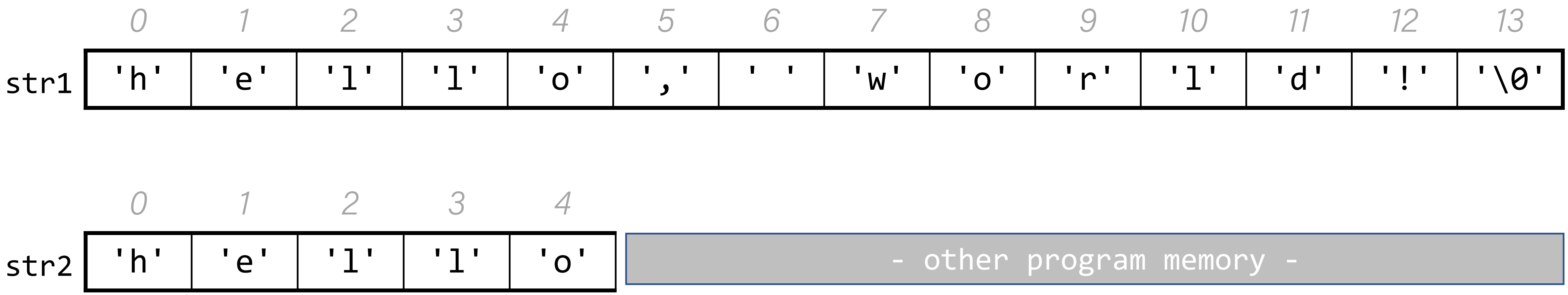

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
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Copying Strings – strncpy

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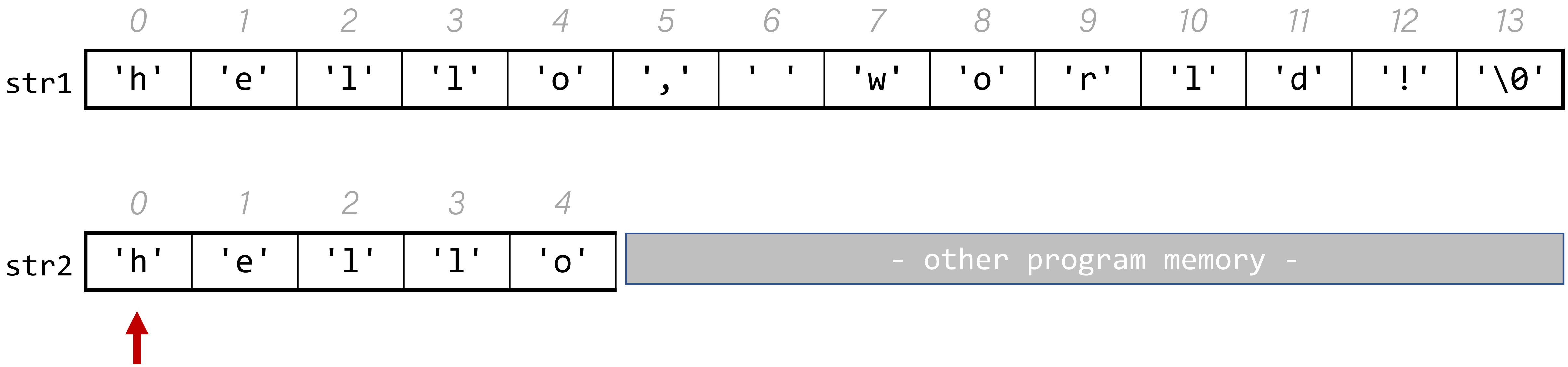

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

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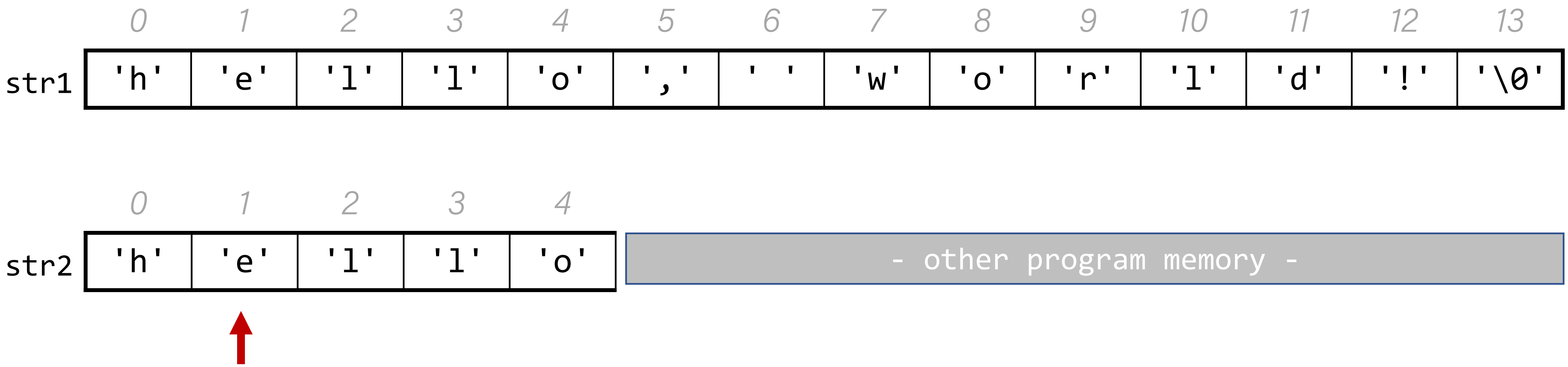

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

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str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

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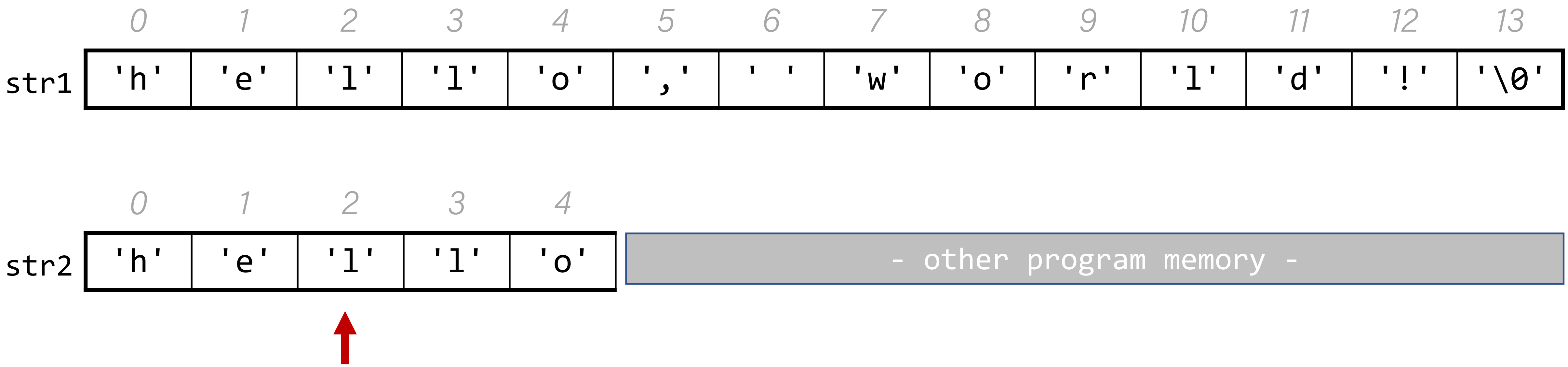

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

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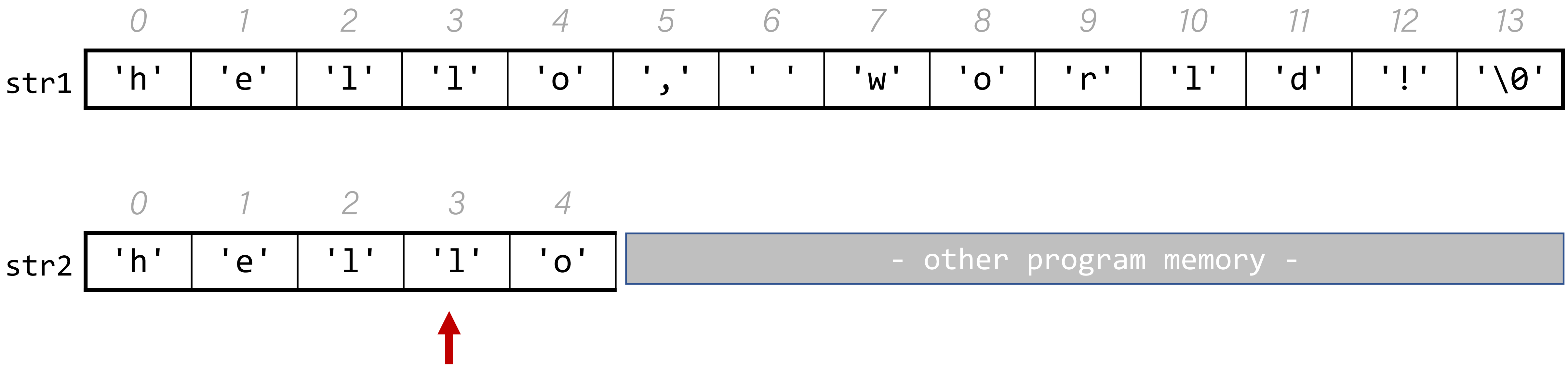

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str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4
str2	'h'	'e'	'l'	'l'	'o'

- other program memory -

Copying Strings – strncpy

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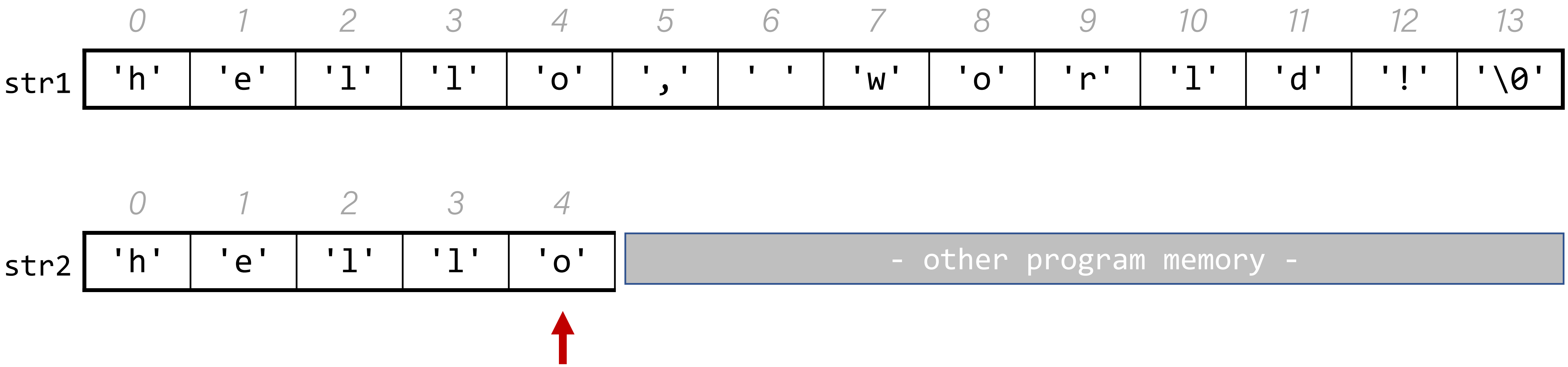

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

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str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

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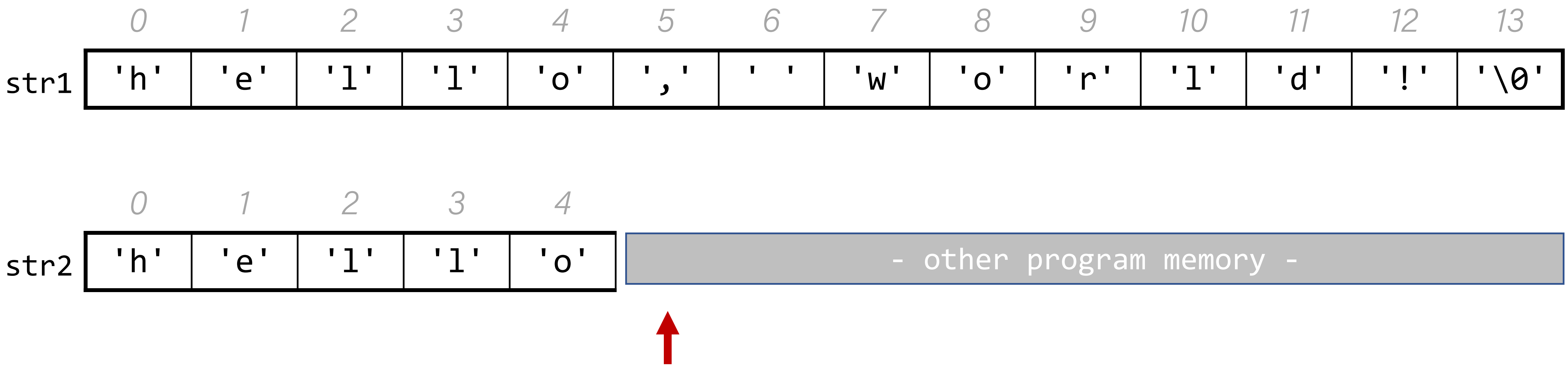
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

```
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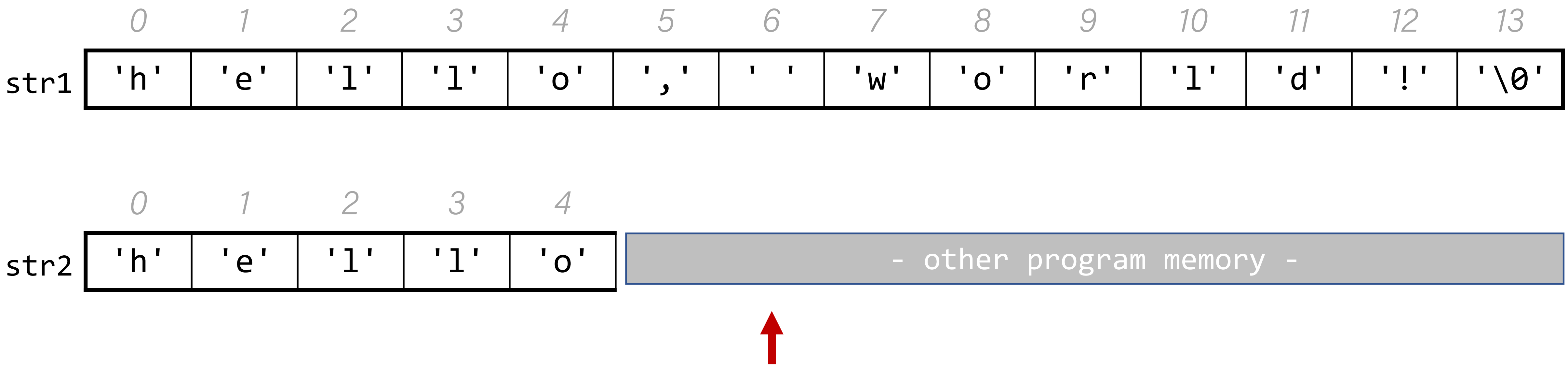

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4
str2	'h'	'e'	'l'	'l'	'o'

- other program memory -

Copying Strings – strncpy

```
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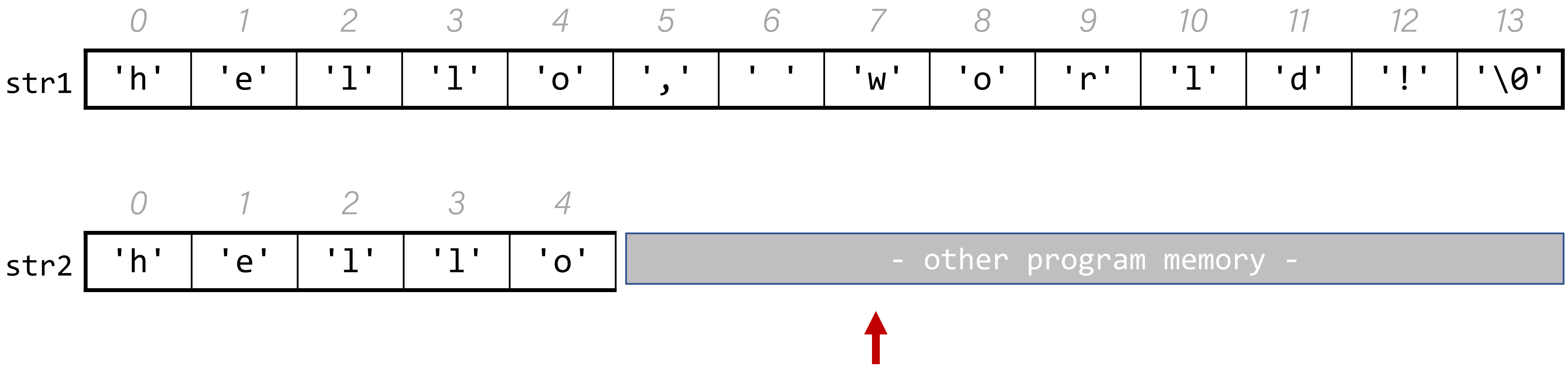
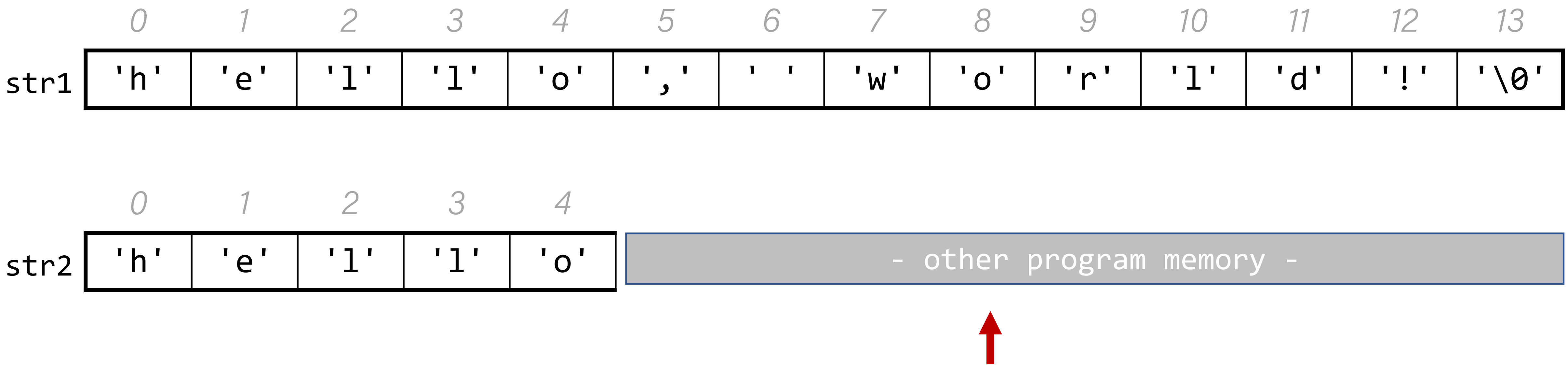


	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

Copying Strings – strncpy

```
char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	','	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	
str2	'h'	'e'	'l'	'l'	'o'	- other program memory -

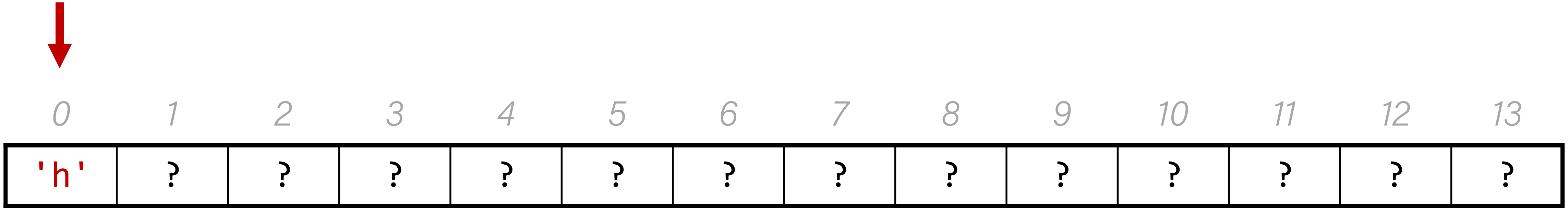
Copying Strings – strncpy

```
char str1[14];
strncpy(str1, "hello there", 5);
```

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	?	?	?	?	?	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

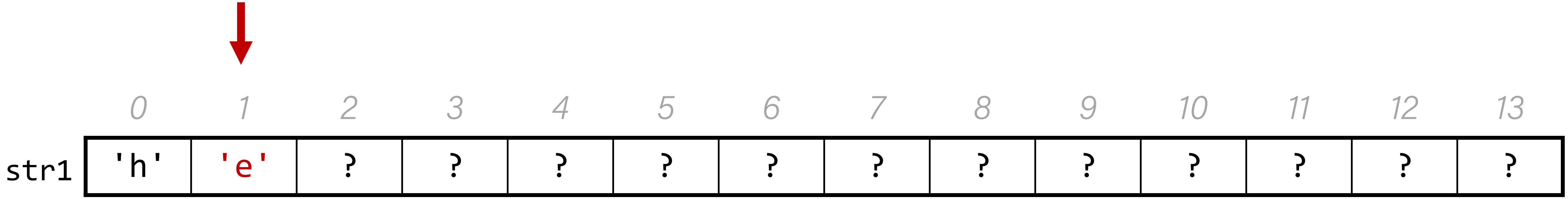
```
char str1[14];
strncpy(str1, "hello there", 5);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	?	?	?	?	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

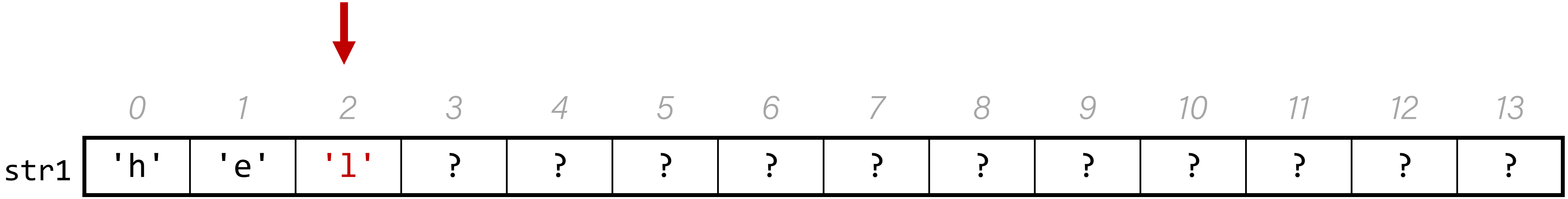
```
char str1[14];
strncpy(str1, "hello there", 5);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	?	?	?	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

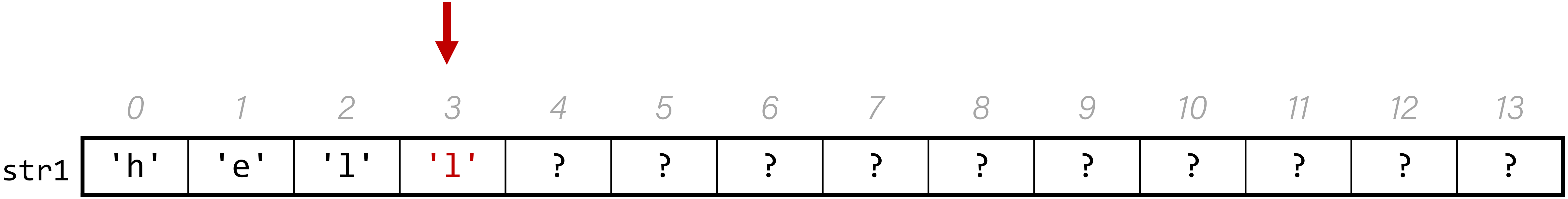
```
char str1[14];
strncpy(str1, "hello there", 5);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	?	?	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

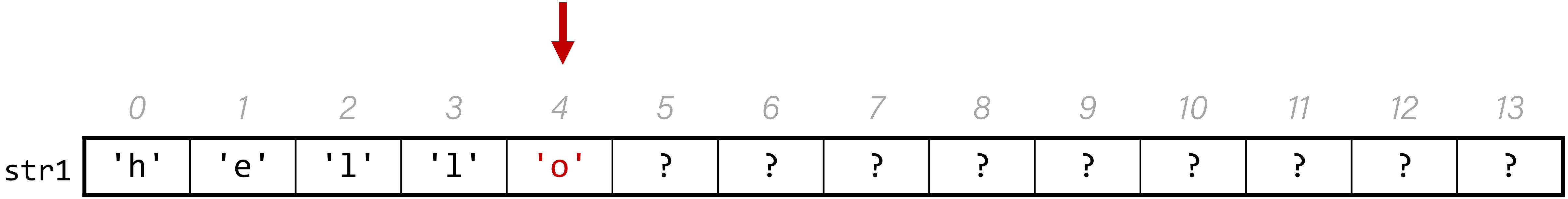
```
char str1[14];
strncpy(str1, "hello there", 5);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	?	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

```
char str1[14];
strncpy(str1, "hello there", 5);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

```
char str1[14];
strncpy(str1, "hello there", 5);
```

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

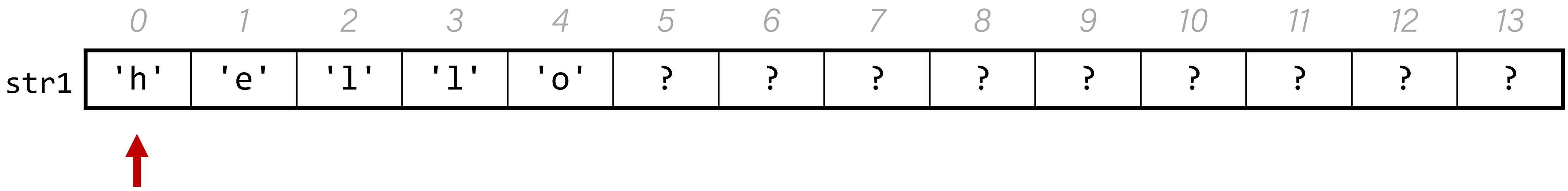
Copying Strings – strncpy

```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

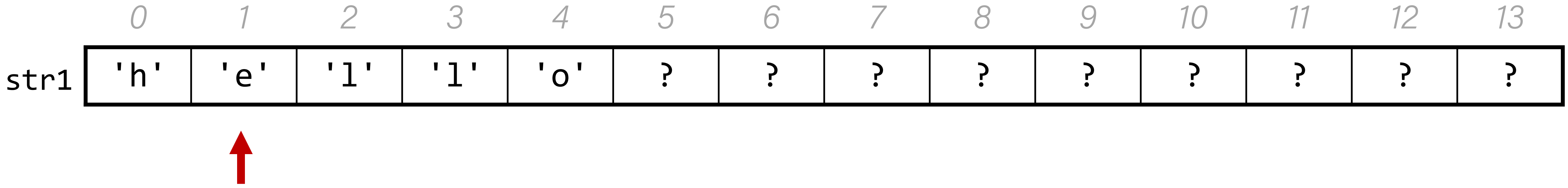
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

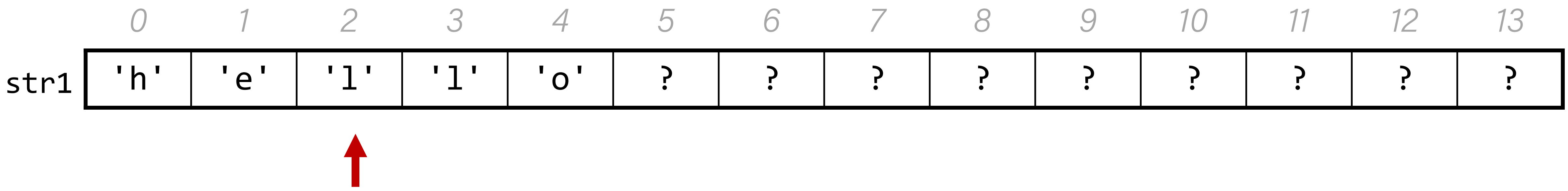
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

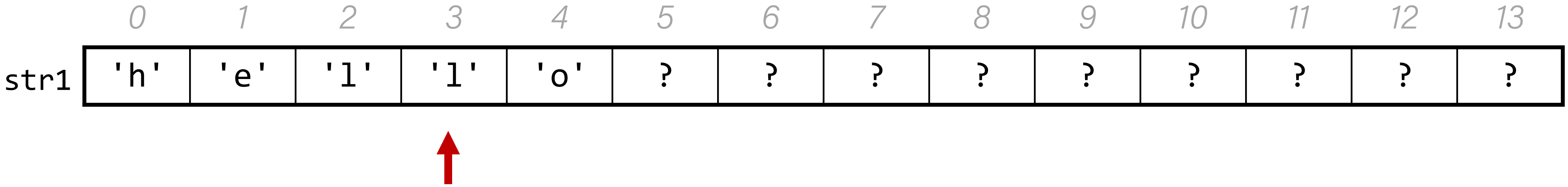
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

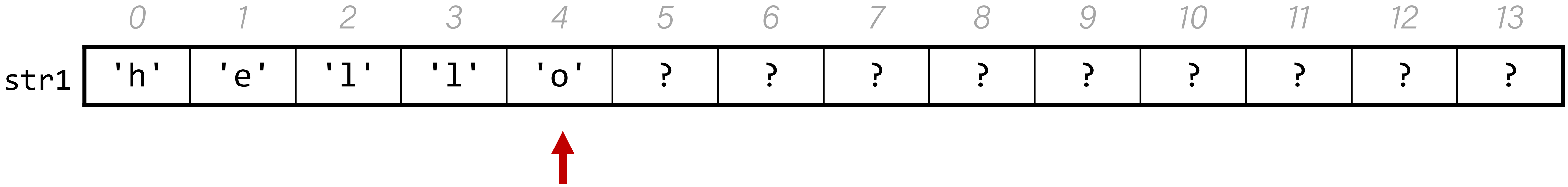
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

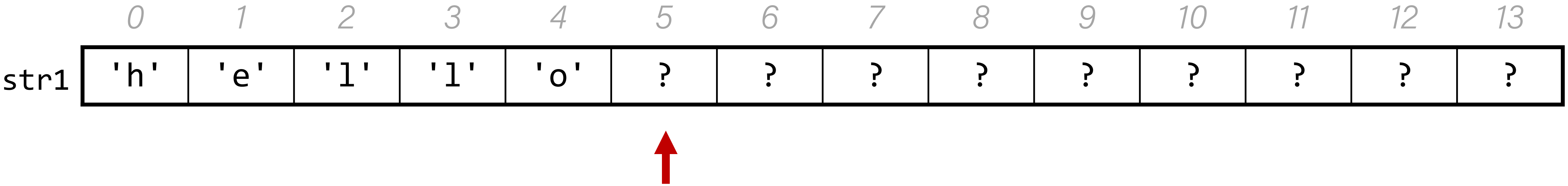
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

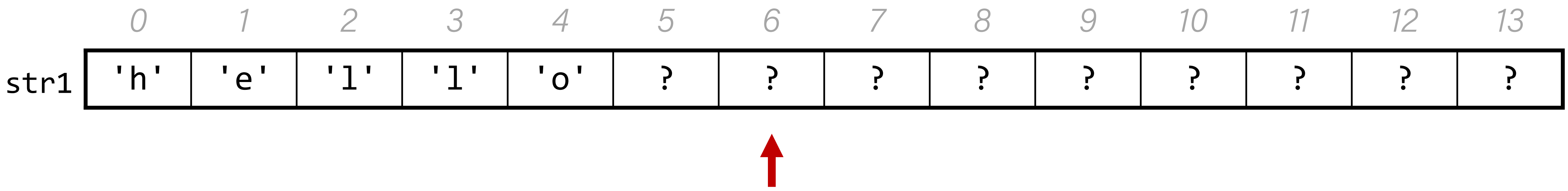
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

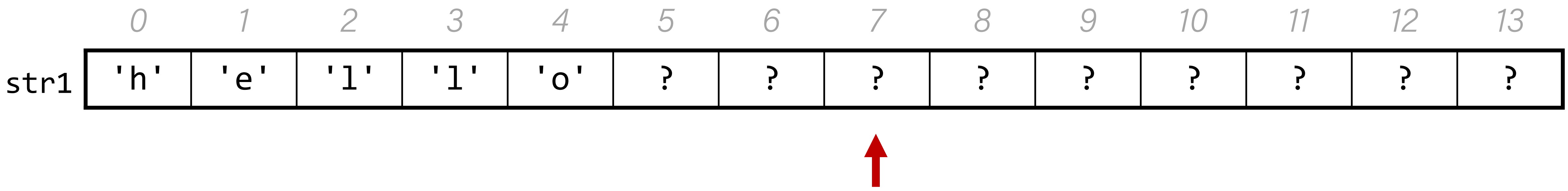
```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

Copying Strings – strncpy

```
char str1[14];
strncpy(str1, "hello there", 5);
printf("%s\n", str1);
```

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
str1	'h'	'e'	'l'	'l'	'o'	?	?	?	?	?	?	?	?	?

```
hello⍰⍰J⍰⍰⍰
```

Copying Strings – strncpy

If necessary, we can add a null-terminating character ourselves.

```
// copying "hello"
char str2[6];                     // room for string and '\0'
strncpy(str2, "hello, world!", 5);    // doesn’t copy '\0'!
str2[5] = '\0';                   // add null-terminating char
```

Concatenating Strings

We cannot concatenate C strings using **+**. This adds addresses!

```
// e.g. param1 = 0x7f, param2 = 0x65
void doSomething(char *param1, char *param2) {
    printf("%s", param1 + param2);   // adds 0x7f and 0x65!
```

Instead, use **strcat**.

The string library: `str(n)cat`

`strcat(dst, src)`: concatenates the contents of **src** into the string **dst**.

`strncat(dst, src, n)`: same, but concats at most **n** bytes from **src**.

```
char str1[13];                  // enough space for strings + '\0'
strcpy(str1, "hello ");
strcat(str1, "world!");         // removes old '\0', adds new '\0' at end
printf("%s", str1);             // hello world!
```

Both **`strcat`** and **`strncat`** remove the old `'\0'` and add a new one at the end.

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```

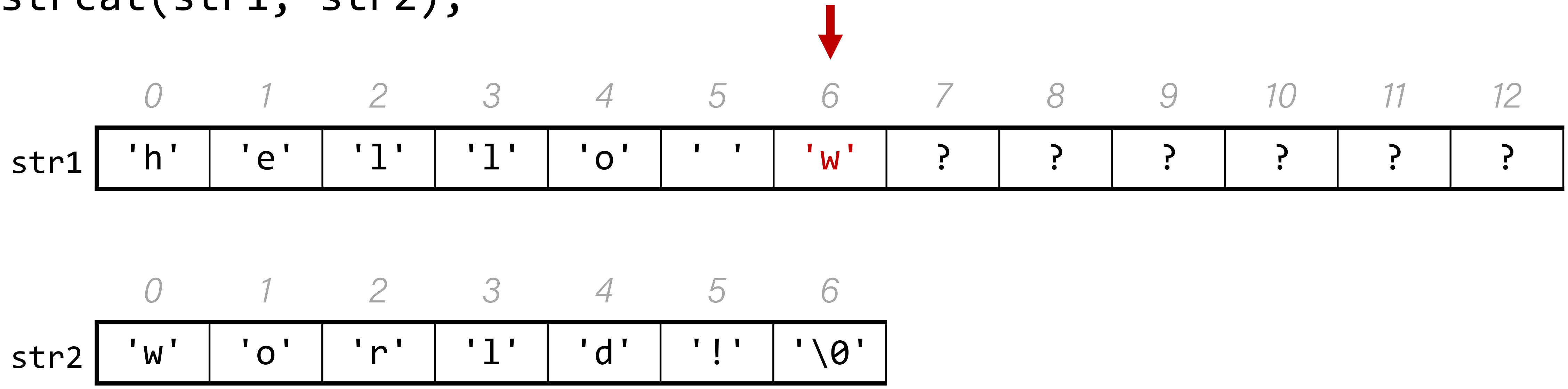
	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'\0'	?	?	?	?	?	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```



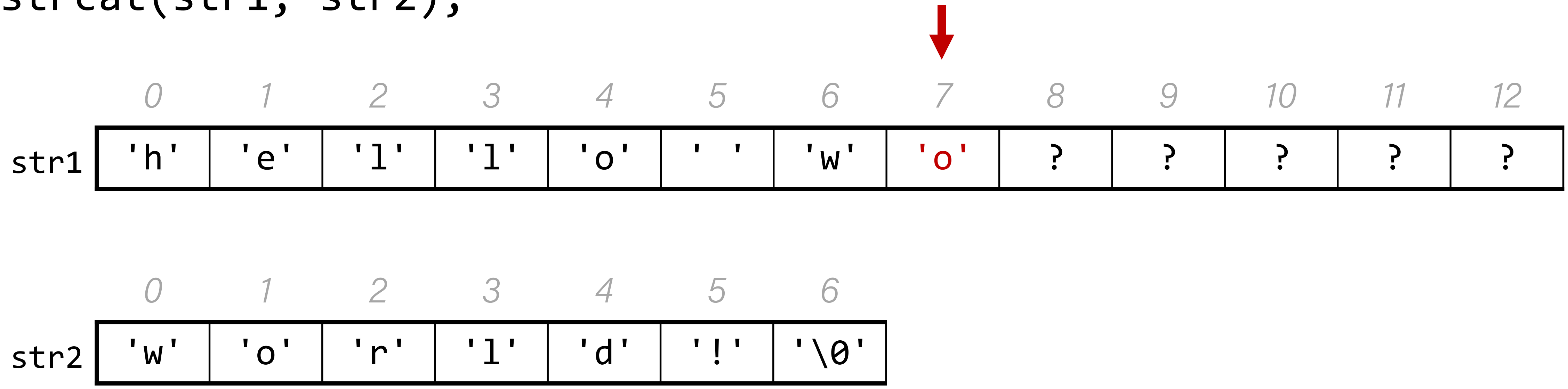
	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	?	?	?	?	?	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```



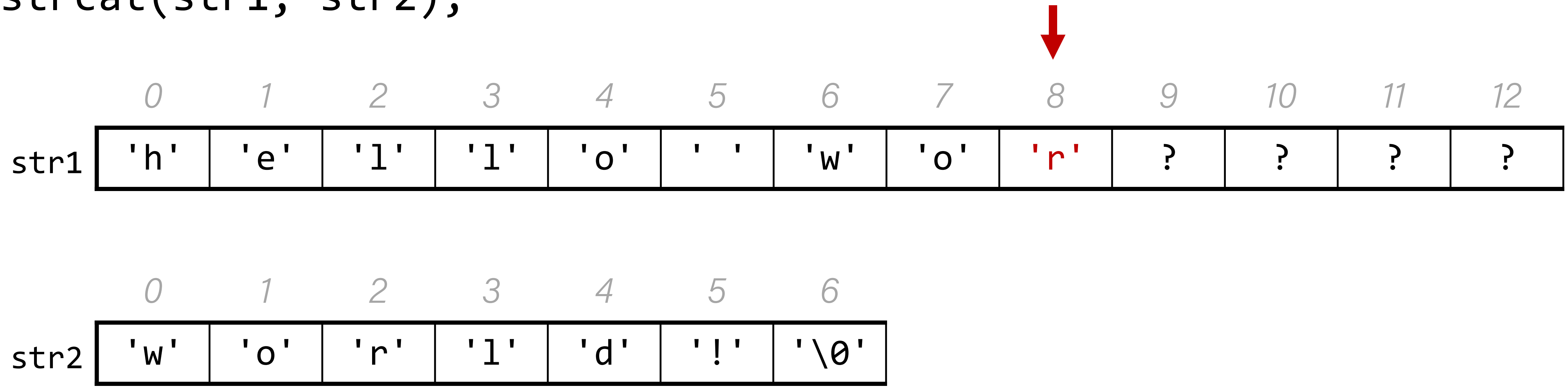
	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	?	?	?	?	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```



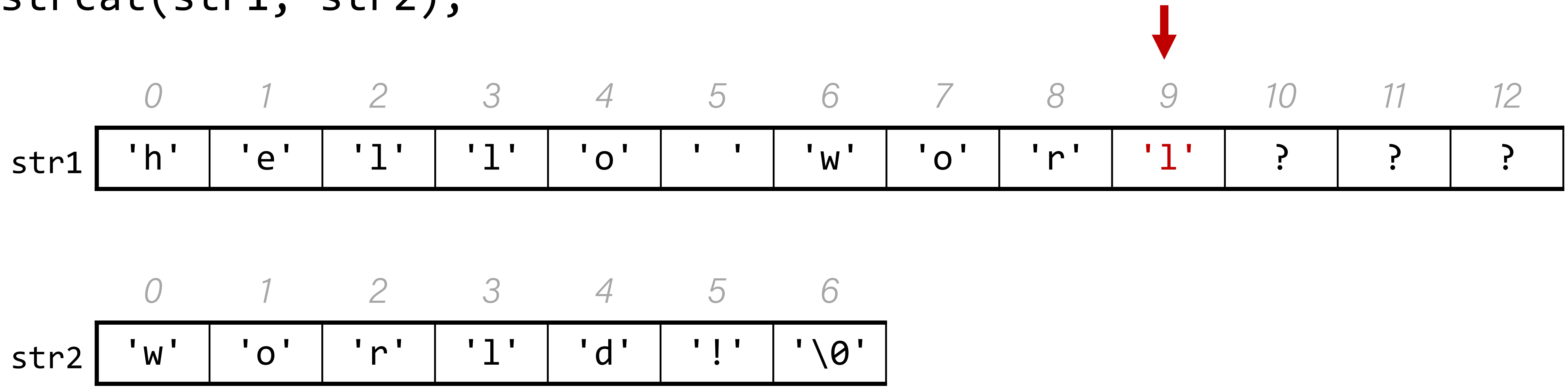
	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	?	?	?	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	'l'	?	?	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```

	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	'l'	'd'	?	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```

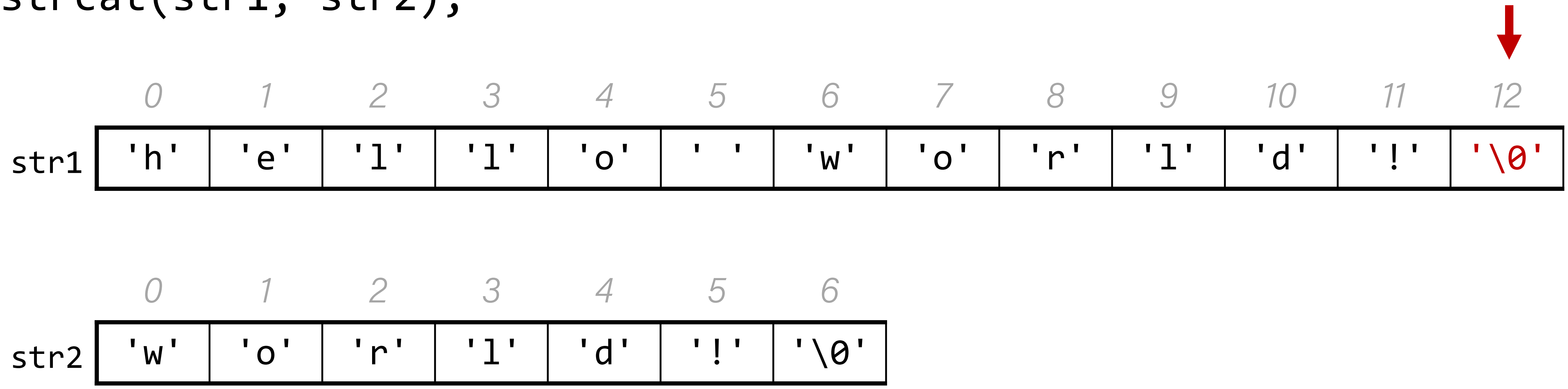
	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	'l'	'd'	'!'	?

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```



	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Concatenating Strings

```
char str1[13];
strcpy(str1, "hello ");
char str2[7];
strcpy(str2, "world!");

strcat(str1, str2);
```

	0	1	2	3	4	5	6	7	8	9	10	11	12
str1	'h'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

	0	1	2	3	4	5	6
str2	'w'	'o'	'r'	'l'	'd'	'!'	'\0'

Substrings and char *

You can also create a char * variable yourself that points to an address within in an existing string.

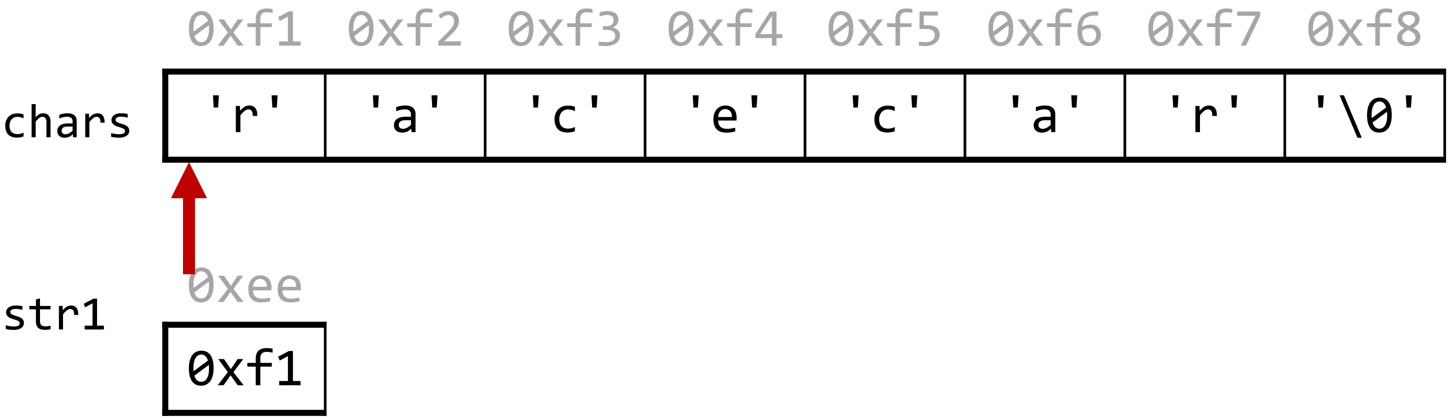
```
char myString[3];
myString[0] = 'H';
myString[1] = 'i';
myString[2] = '\0';

char *otherStr = myString;  // points to 'H'
```

Substrings

**char ***s are pointers to characters. We can use them to create substrings of larger strings.

```
// Want just "car"
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
```



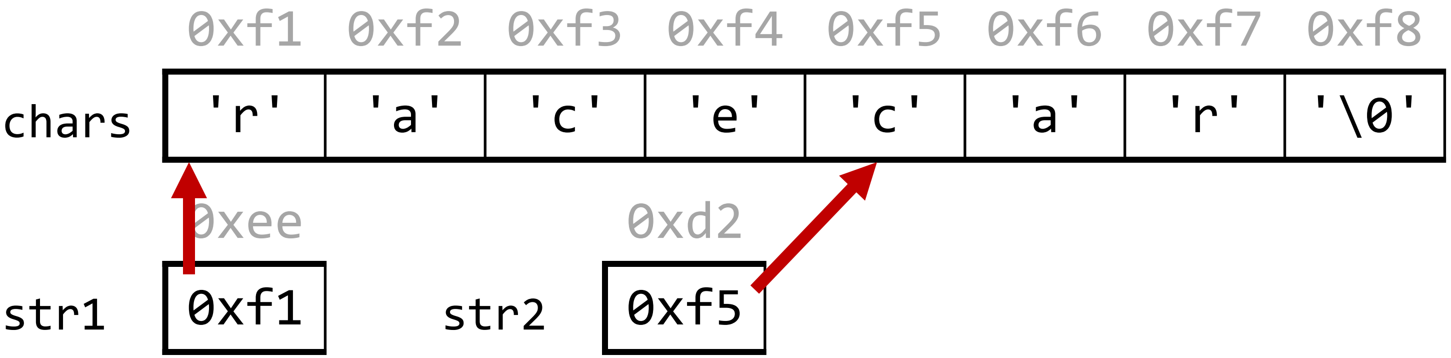
	0xf1	0xf2	0xf3	0xf4	0xf5	0xf6	0xf7	0xf8
chars	'r'	'a'	'c'	'e'	'c'	'a'	'r'	'\0'

	0xee
str1	0xf1

Substrings

Since C strings are pointers to characters, we can adjust the pointer to omit characters at the beginning.

```
// Want just "car"
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
```



	0xf1	0xf2	0xf3	0xf4	0xf5	0xf6	0xf7	0xf8
chars	'r'	'a'	'c'	'e'	'c'	'a'	'r'	'\0'

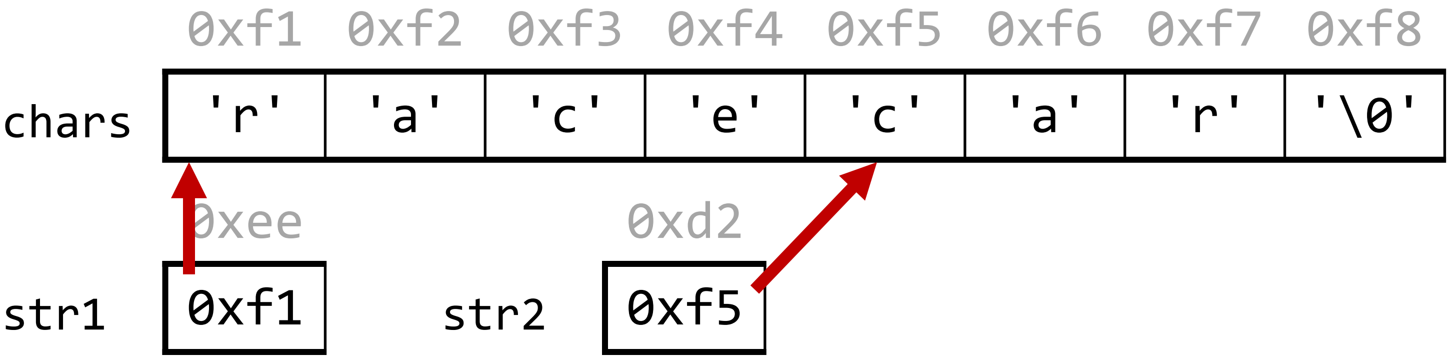
0xee
str1 0xf1

0xd2
str2 0xf5

Substrings

Since C strings are pointers to characters, we can adjust the pointer to omit characters at the beginning.

```
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
printf("%s\n", str1);                // racecar
printf("%s\n", str2);                // car
```



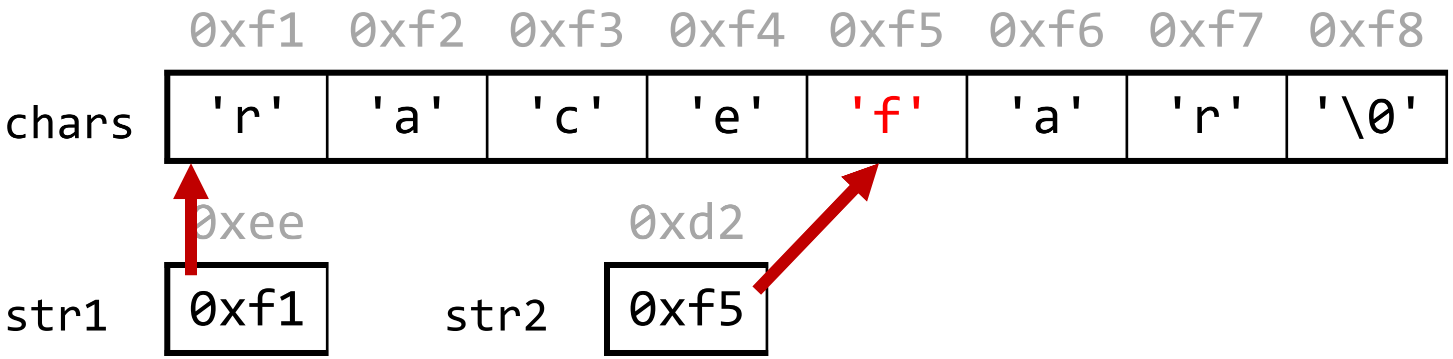
	0xf1	0xf2	0xf3	0xf4	0xf5	0xf6	0xf7	0xf8
chars	'r'	'a'	'c'	'e'	'c'	'a'	'r'	'\0'

	0xee		0xd2
str1	0xf1	str2	0xf5

Substrings

Since C strings are pointers to characters, we can adjust the pointer to omit characters at the beginning. **NOTE:** the pointer still refers to the same characters!

```
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
str2[0] = 'f';
printf("%s %s\n", chars, str1);
printf("%s\n", str2);
```



	0xf1	0xf2	0xf3	0xf4	0xf5	0xf6	0xf7	0xf8
chars	'r'	'a'	'c'	'e'	'f'	'a'	'r'	'\0'

0xee

str1 0xf1

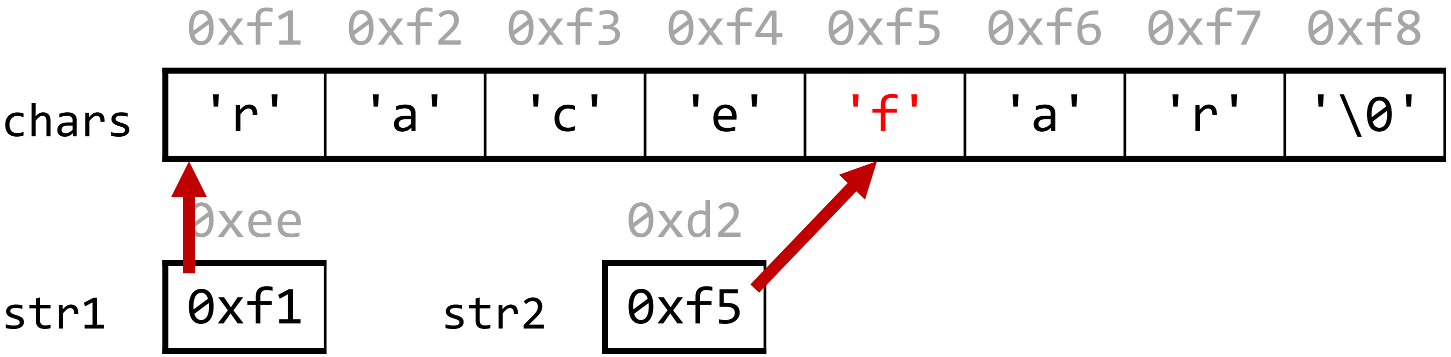
0xd2

str2 0xf5

Substrings

Since C strings are pointers to characters, we can adjust the pointer to omit characters at the beginning. **NOTE:** the pointer still refers to the same characters!

```
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
str2[0] = 'f';
printf("%s %s\n", chars, str1);      // racefar racefar
printf("%s\n", str2);                // far
```



	0xf1	0xf2	0xf3	0xf4	0xf5	0xf6	0xf7	0xf8
chars	'r'	'a'	'c'	'e'	'f'	'a'	'r'	'\0'

0xee	0xd2
str1: 0xf1	str2: 0xf5

String copying exercise

```
1  char buf[____ ];
2  strcpy(buf, "Potatoes");
3  printf("%s\n", buf);
4  char *word = buf + 2;
5  strncpy(word, "mat", 3);
6  printf("%s\n", buf);
```

Line 1: What value should go in the blank?

A. `7`
B. `8`
C. `9`
D. `12`
E. `strlen("Potatoes")`

Line 6: What is printed?

A. `matoes`
B. `mattoes`
C. `Pomat`
D. `Pomatoes`
E. Something else
F. Compile error

🤔

char * vs. char[]

`char myString[]`

vs

`char *myString`

You can create **char *** pointers to point to any character in an existing string and reassign them since they are just pointer variables. You **cannot** reassign an array.

```
char myString[6];
strcpy(myString, "Hello");
~~myString = "Another string";~~                  // not allowed!
---
char *myOtherString = myString;
myOtherString = somethingElse;                    // ok
```

Substrings

To omit characters at the end, make a new string that is a partial copy of the original.

```
// Want just "race"
char str1[8];
strcpy(str1, "racecar");

char str2[5];
strncpy(str2, str1, 4);
str2[4] = '\0';
printf("%s\n", str1);          // racecar
printf("%s\n", str2);          // race
```

Substrings

We can combine pointer arithmetic and copying to make any substrings we'd like.

```c
// Want just "ace"
char str1[8];
strcpy(str1, "racecar");

char str2[4];
strncpy(str2, str1 + 1, 3);
str2[3] = '\0';
printf("%s\n", str1);       // racecar
printf("%s\n", str2);       // ace
```

Lecture Plan

- Characters
- Strings
- Common String Operations
- Practice: Diamonds

String Diamond

- Write a function **`diamond`** that accepts a string parameter and prints its letters in a "diamond" format as shown below.
  - For example, `diamond("COMP201")` should print:

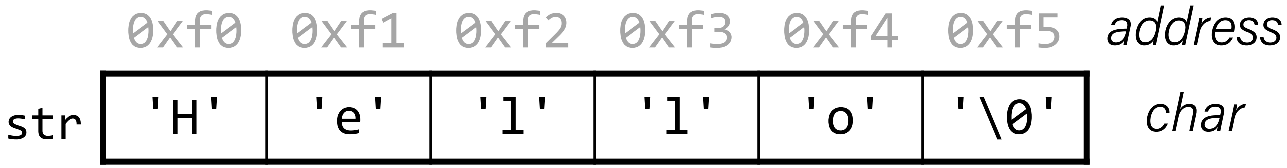
```
C
CO
COM
COMP
COMP2
COMP20
COMP201
 OMP201
  MP201
   P201
    201
     01
      1
```

Practice: Diamond

`diamond.c`

Key takeaways

1. Valid strings are null-terminated.

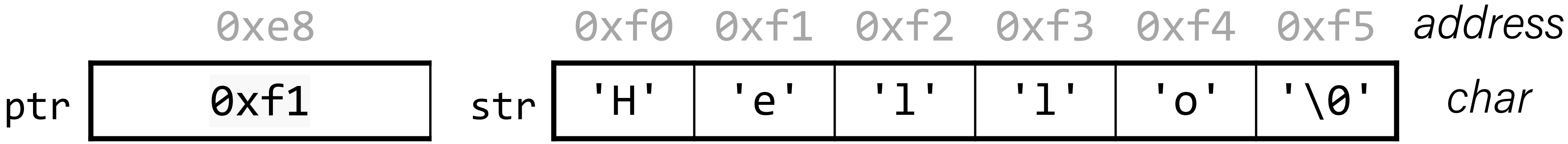


	0xf0	0xf1	0xf2	0xf3	0xf4	0xf5	*address*
str	'H'	'e'	'l'	'l'	'o'	'\0'	*char*

```
char str[6];
strcpy(str, "Hello");
int length = strlen(str);   // 5
```

Key takeaways from this time

1. Valid strings are null-terminated.
2. An array name (and a string name, by extension) is the address of the first element.



```
char str[6];
strcpy(str, "Hello");
int length = strlen(str);   // 5
char *ptr = str + 1;        // 0xf1
printf("%s\n", ptr);        // ello
```

Key takeaways from this time

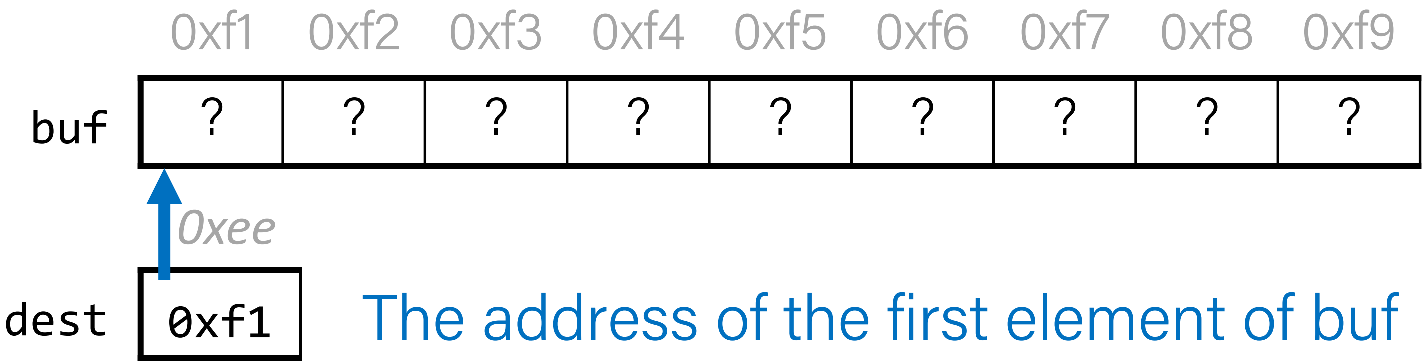
1. Valid strings are null-terminated.
2. An array name (and a string name, by extension) is the address of the first element.
3. When you pass a `char[]` as a parameter, it is automatically passed as a `char *` (pointer to its first character)

Why did C bother with this representation?

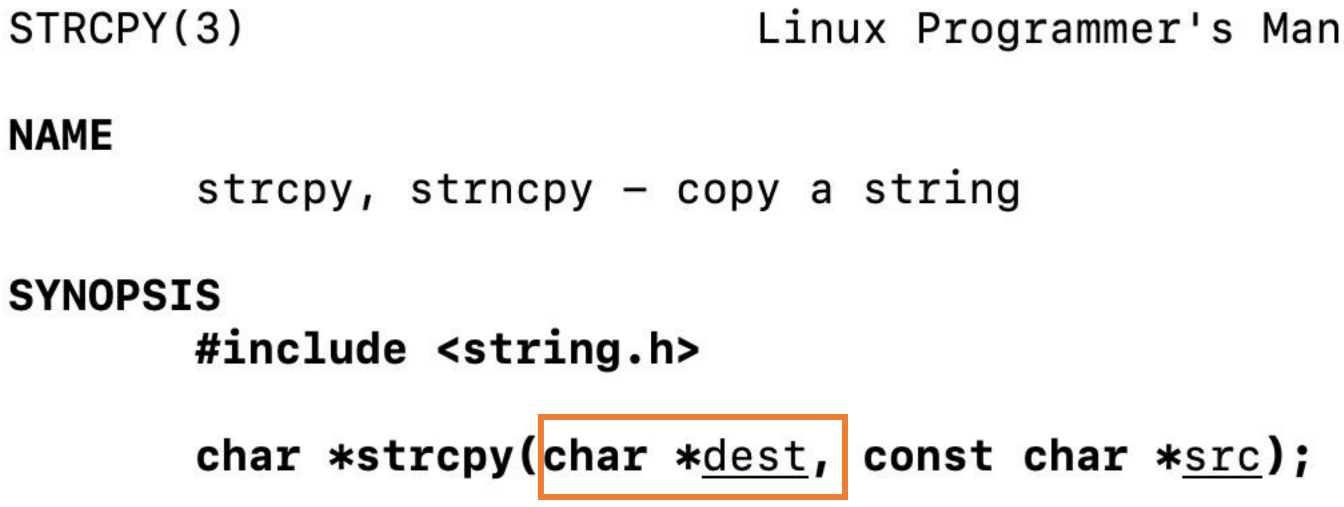
- C is a powerful, **efficient** language that requires a solid understanding of computer memory.
- We'll hone this understanding over these next two weeks!

Takeaway #3: `man strcpy`

```
char buf[6];
strcpy(buf, "Hello");
printf("%s\n", buf);
...
```



The address of the first element of buf



```
STRCPY(3)                    Linux Programmer's Manual

NAME
       strcpy, strncpy - copy a string

SYNOPSIS
       #include <string.h>

       char *strcpy(char *dest, const char *src);
```

- Lecture 6: where string constants like `"hello"` are stored.
- Lecture 12: what `const` means

Recap

- Characters
- Strings
- Common String Operations
- Practice: Diamonds

Next time: *More strings, pointers*