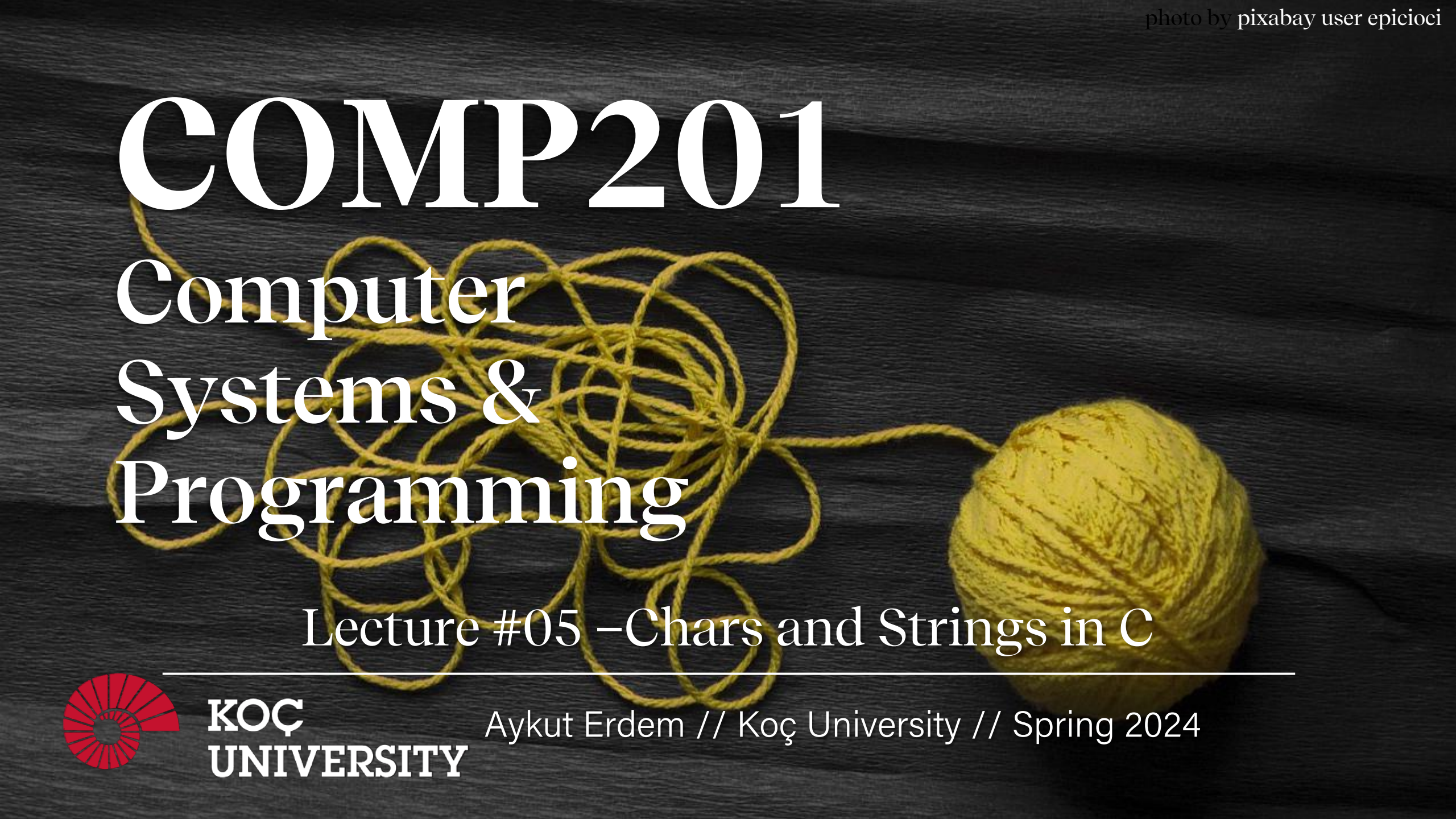


COMP201

Computer Systems & Programming

Lecture #05 –Chars and Strings in C

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Spring 2024

Good news, everyone!

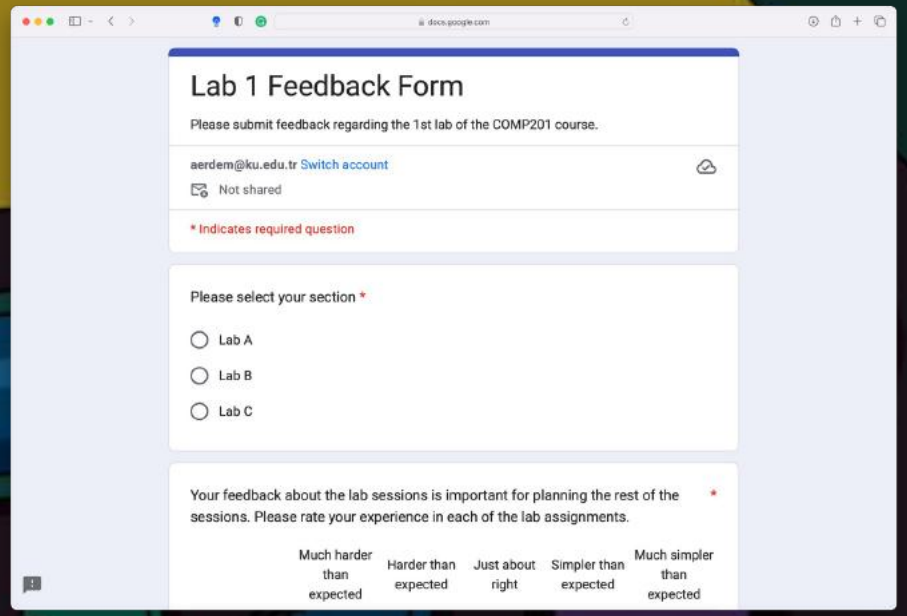
Office Hour	Time
Aykut	Mon 17:30-18:30
Batur	Tue 17:30-18:30
Doga	Wed 17:30-18:30
Burak	
Yusuf	Thu 18:00-19:00
Eda	Mon 14.30 - 15.40
Atalay	Wed 16.00 - 17.00
Idil	Tue 13:15-14:15
Mehmet	Mon 16.00 -17.00
Kivanc	Mon 10.00 - 11.00

* Place or Zoom links available on Blackboard

Image: Professor Farnsworth (Futurama)

Good news, everyone!

Image: Professor Farnsworth (Futurama)



Lab 1 Feedback Form

Please submit feedback regarding the 1st lab of the COMP201 course.

aerdem@ku.edu.tr Switch account

Not shared

* Indicates required question

Please select your section *

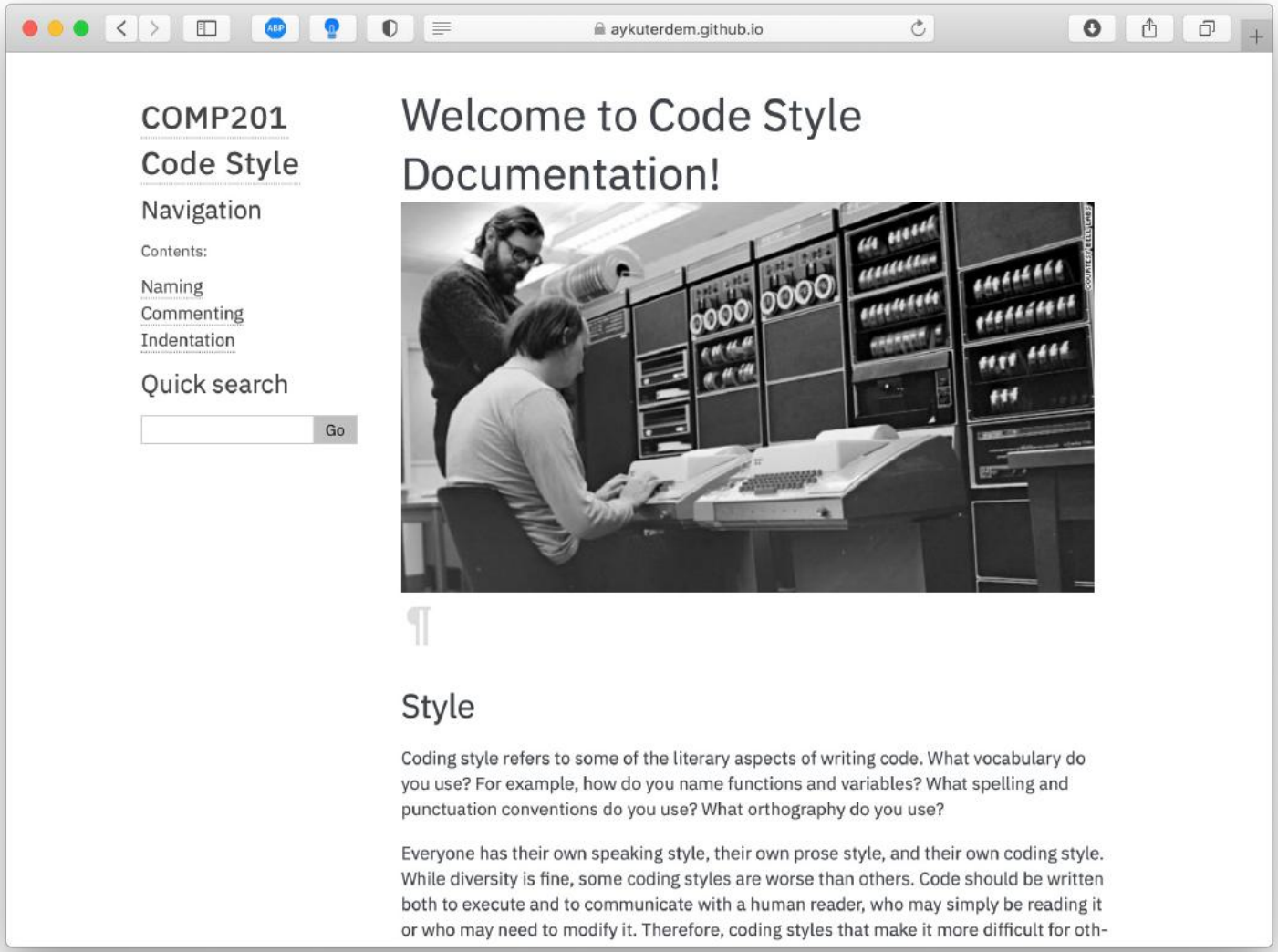
- Lab A
- Lab B
- Lab C

Your feedback about the lab sessions is important for planning the rest of the sessions. Please rate your experience in each of the lab assignments. *

	Much harder than expected	Harder than expected	Just about right	Simpler than expected	Much simpler than expected

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!



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.

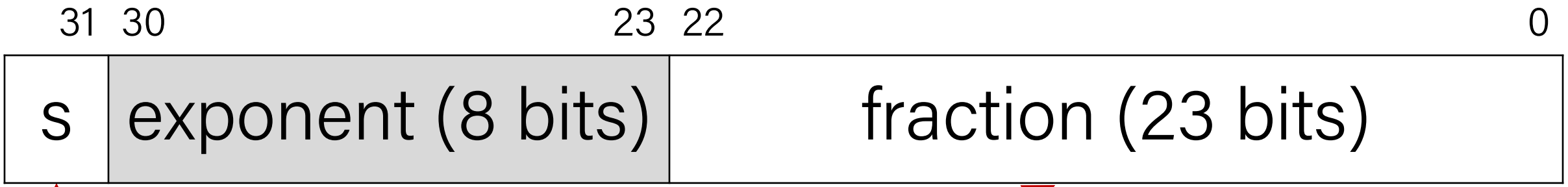
Base 10 Base 2

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

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

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!

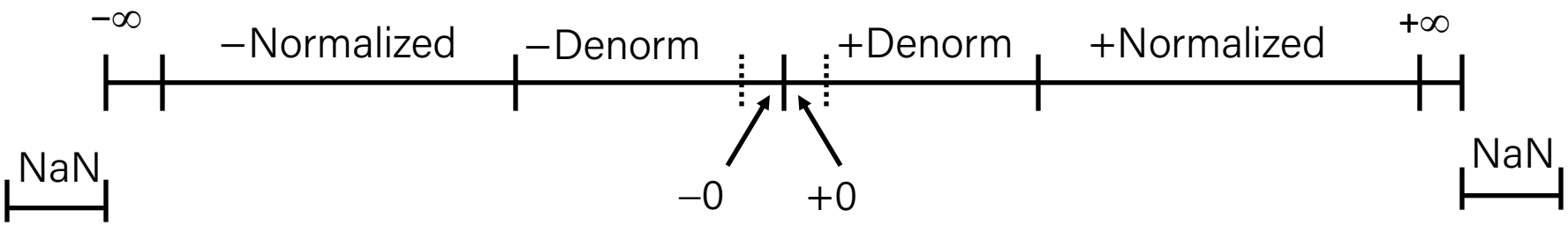
Recap: IEEE Single Precision Floating Point



Sign bit
(0 = positive)

$$x * 2^y$$

Recap: Floating Point Encodings

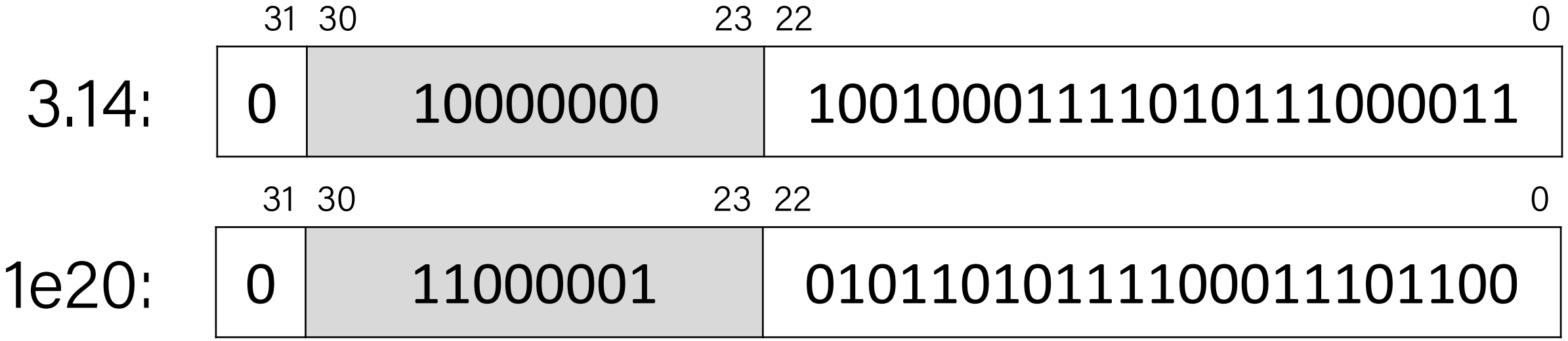


Recap: Floating Point Arithmetic

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:



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: 0.3000000000000004441
```

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

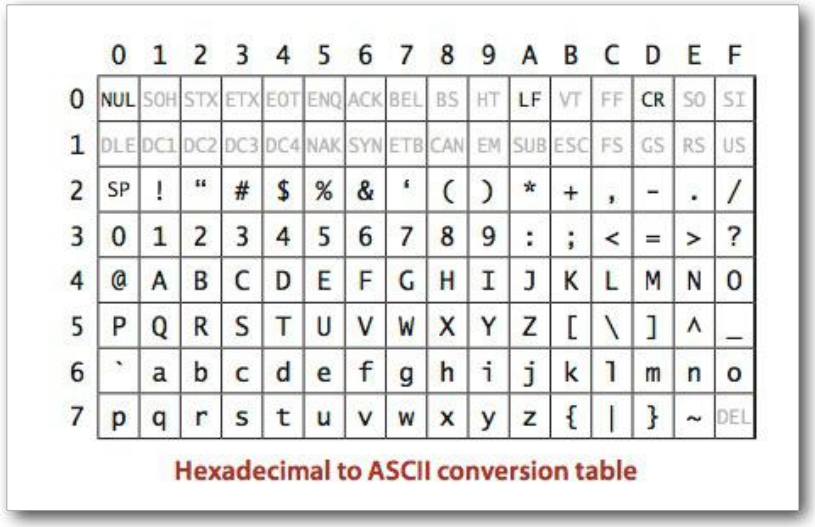
Char

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").



	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

- 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!)

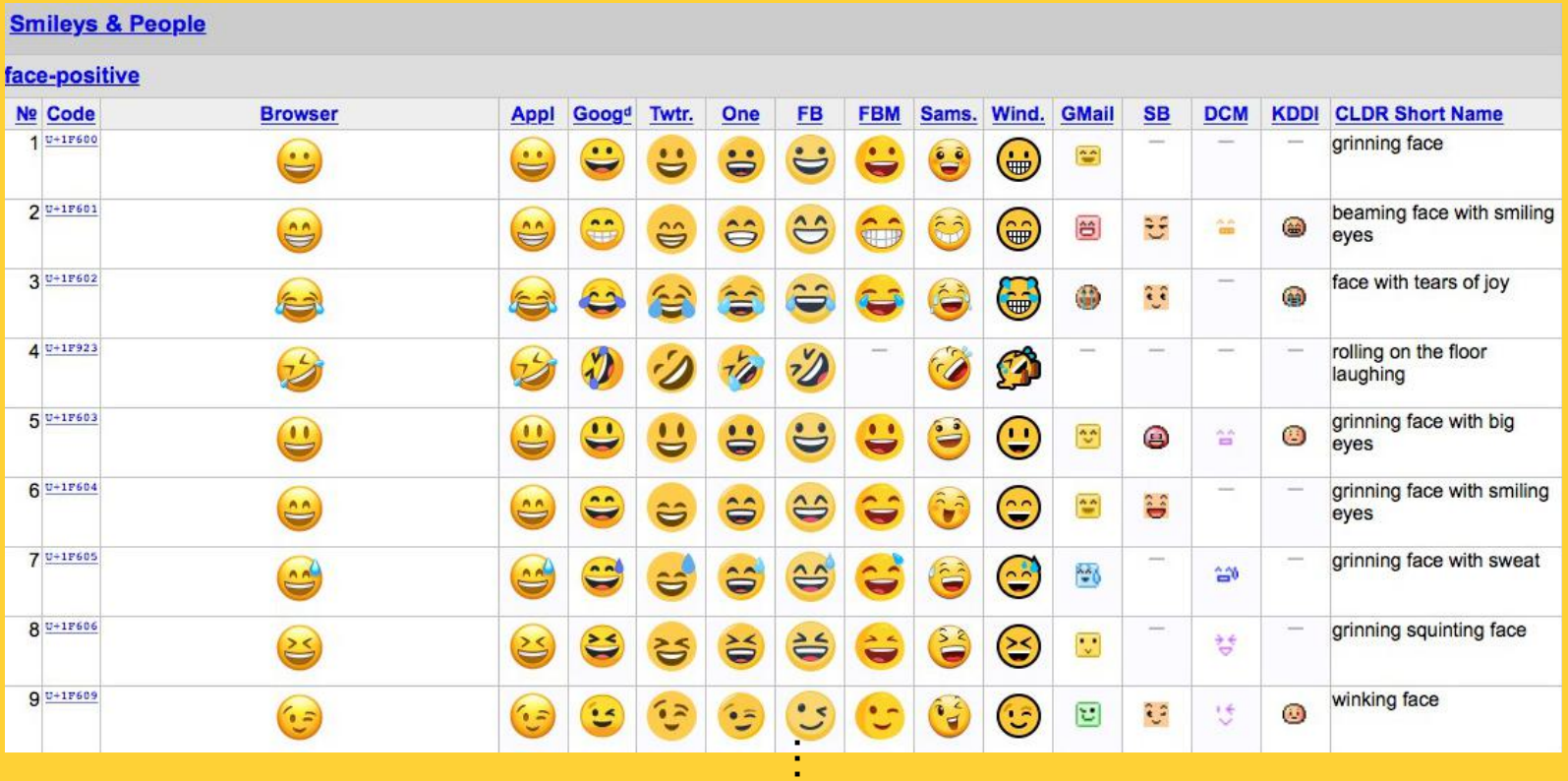
```
char uppercaseA = 'A';        // Actually 65
char lowercaseA = 'a';        // Actually 97
char zeroDigit = '0';            // Actually 48
```

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	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, v15.1
  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
```

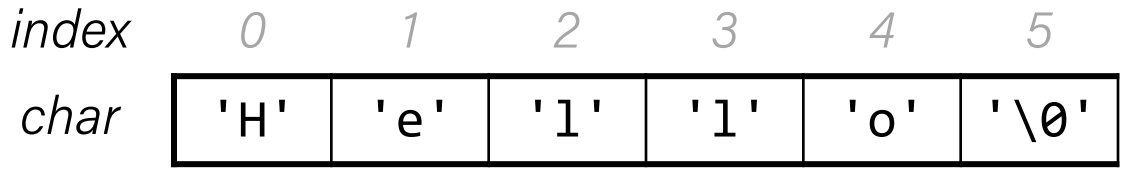
Lecture Plan

- 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.

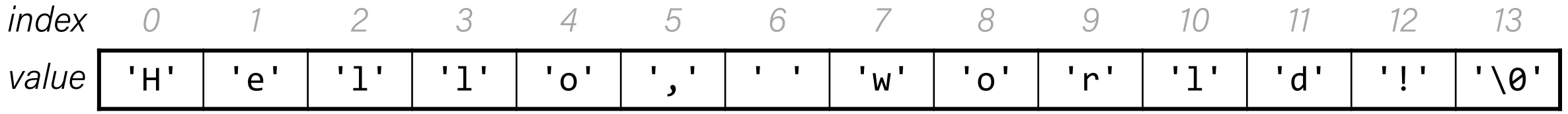
`"Hello"`



`'\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!



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 <u>does not</u> 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. <u>Always</u> adds a null-terminating character.
`strspn(`***`str, accept`***`),` `strcspn(`***`str, reject`***`)`	**`strspn`** returns the length of the initial part of ***`str`*** which contains <u>only</u> characters in ***`accept`***. **`strcspn`** returns the length of the initial part of ***`str`*** which does <u>not</u> contain any characters in ***`reject`***.

Common `string.h` Functions

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`strlen(`***`str`***`)`	returns the # of chars in a C string (before null-terminating character).
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`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.
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`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");

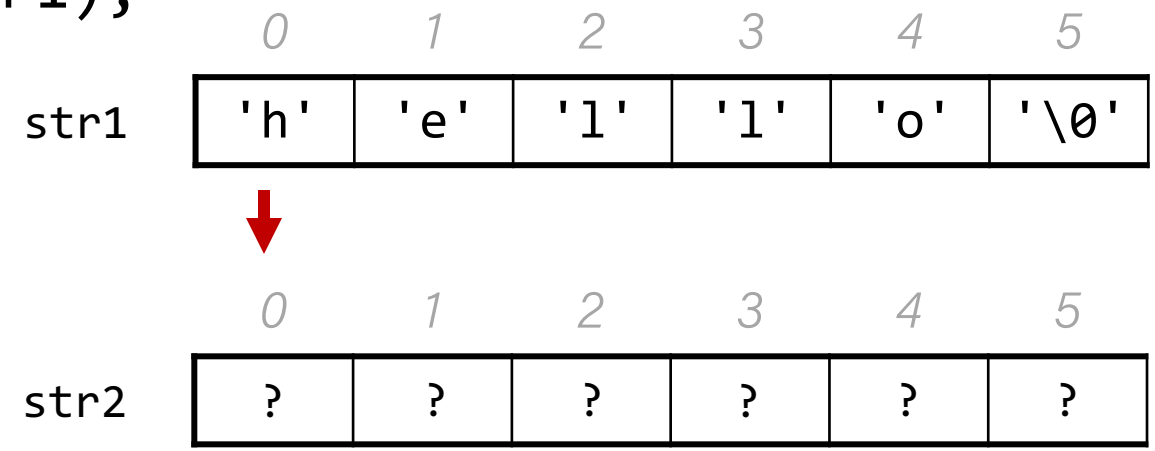
char str2[6];
strcpy(str2, str1);
str2[0] = 'c';

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

Copying Strings – `strcpy`

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

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



Copying Strings – `strcpy`

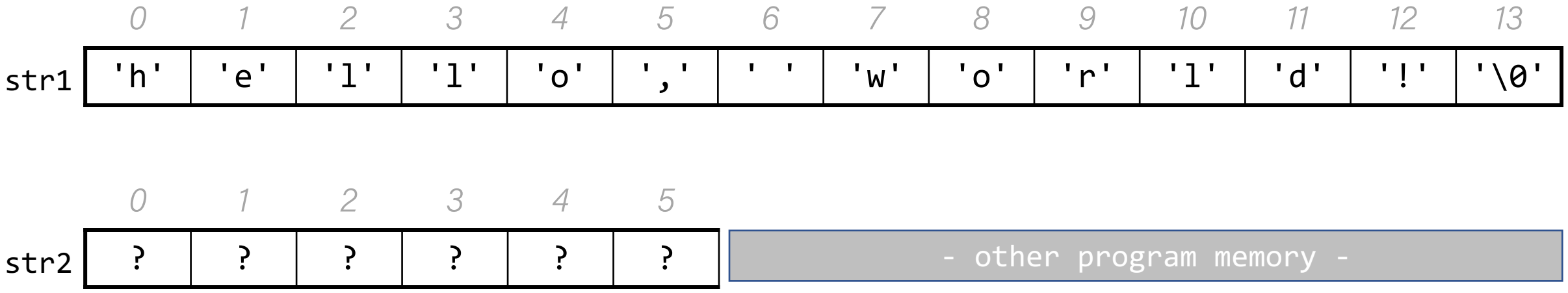
We must make sure there is enough space in the destination to hold the entire copy, *including the null-terminating character*.

```
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!
```



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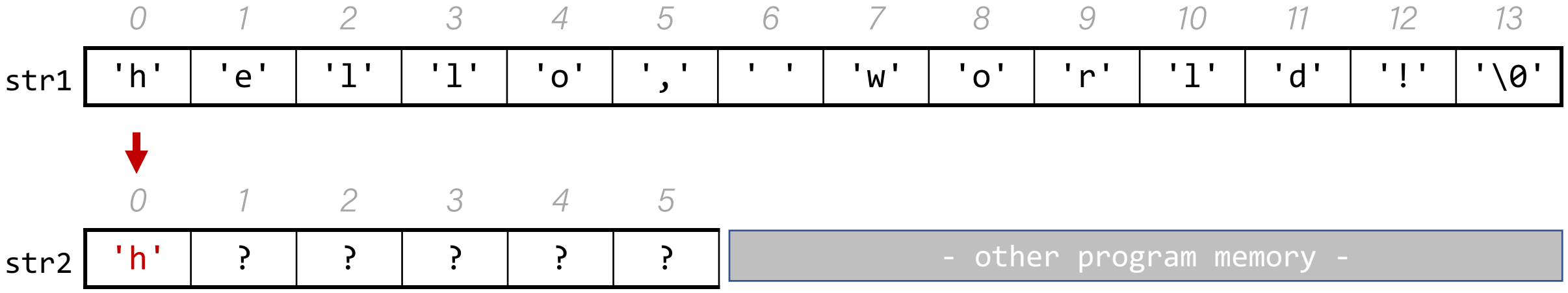

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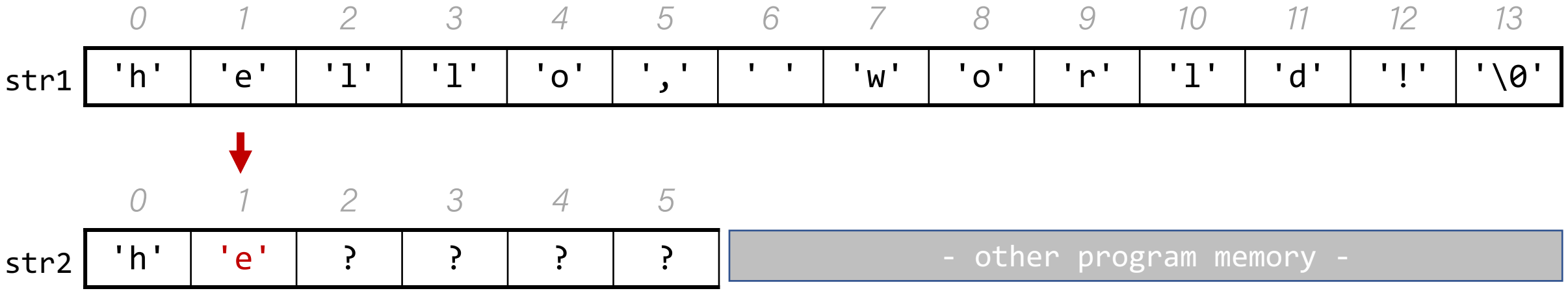

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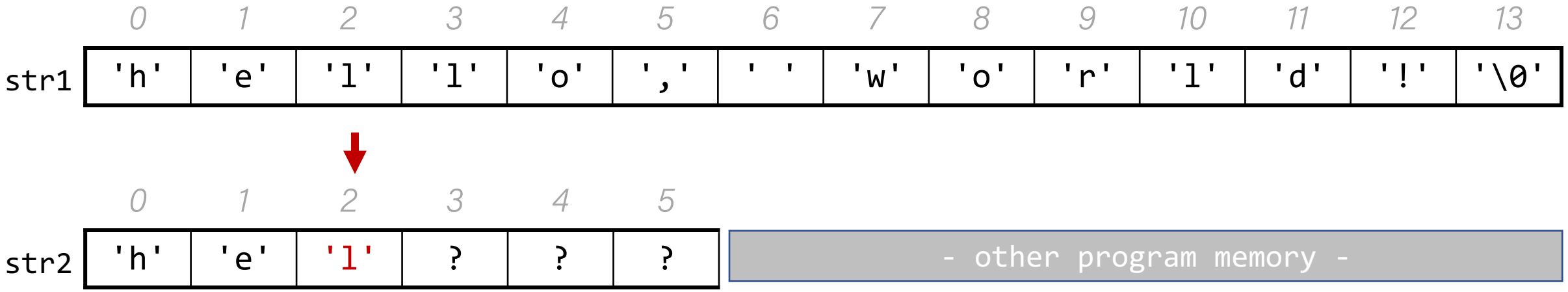

Copying Strings – Buffer Overflows

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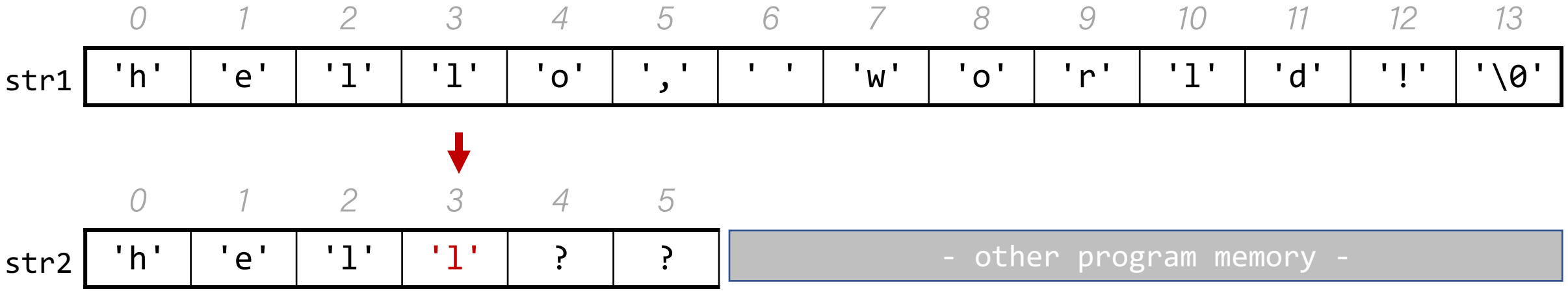

Copying Strings – Buffer Overflows

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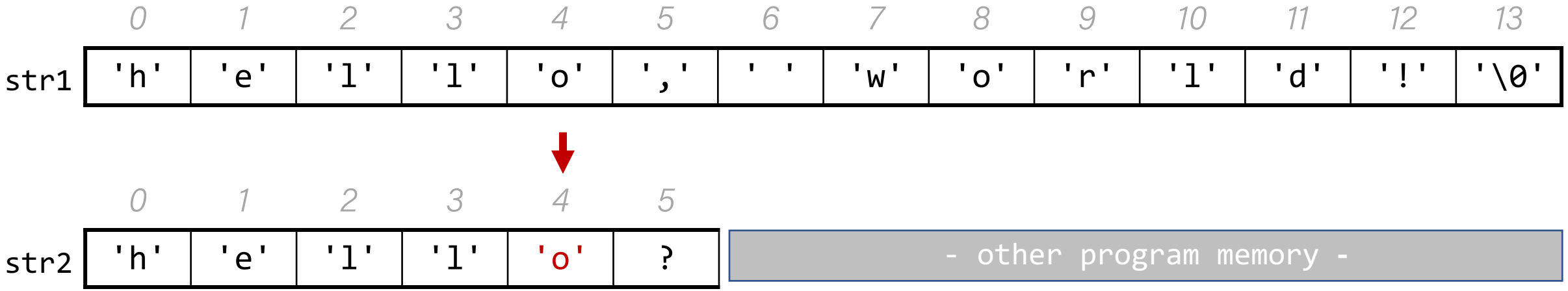

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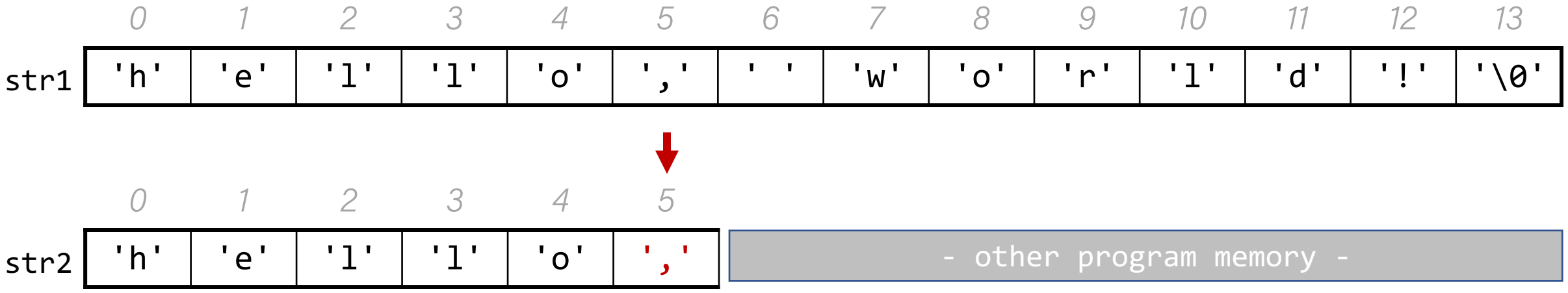

Copying Strings – Buffer Overflows

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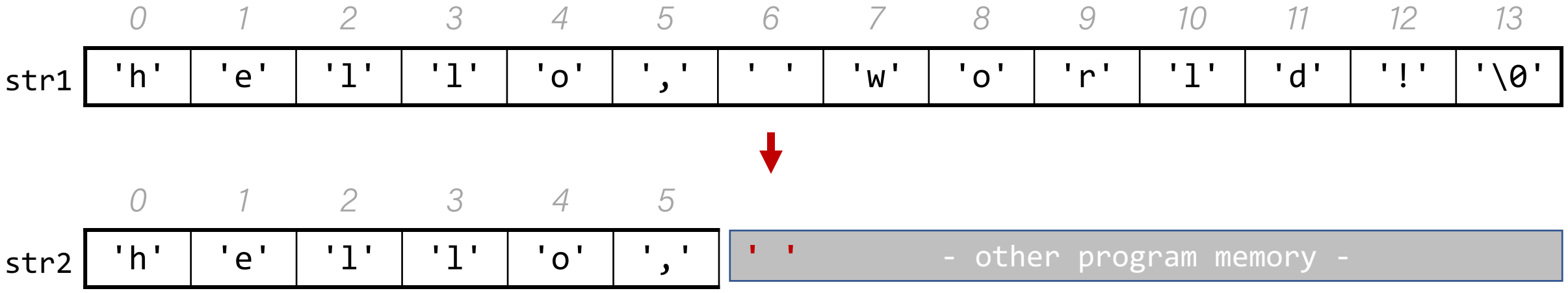

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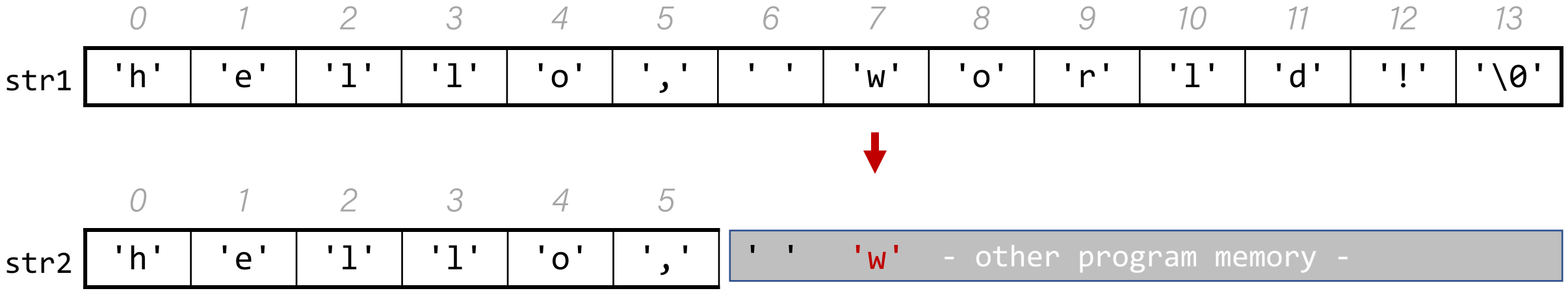

Copying Strings – Buffer Overflows

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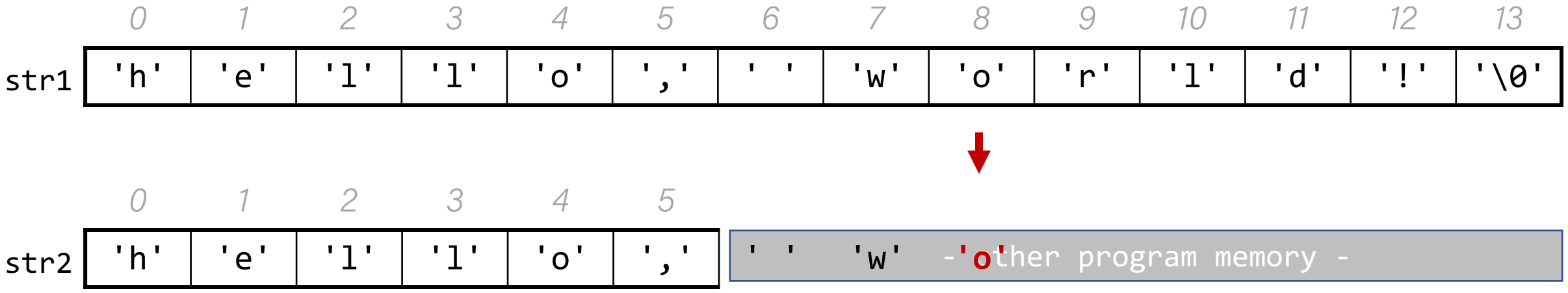

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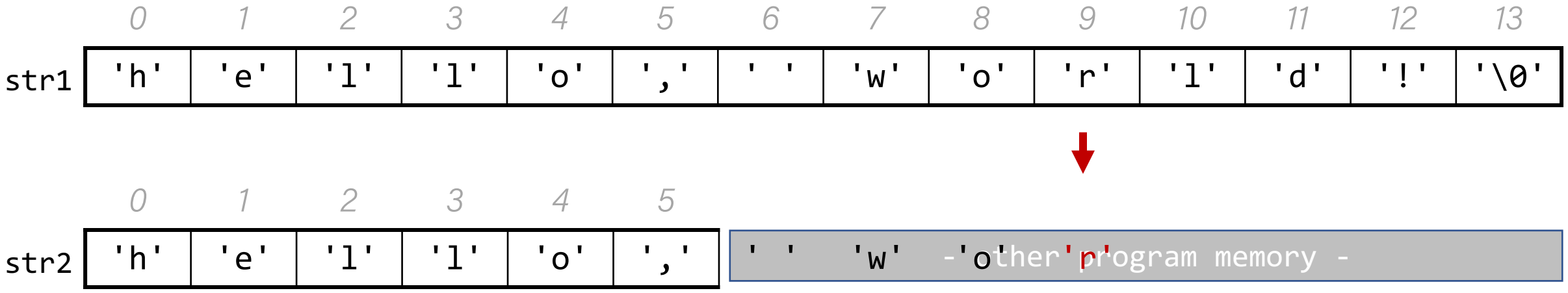

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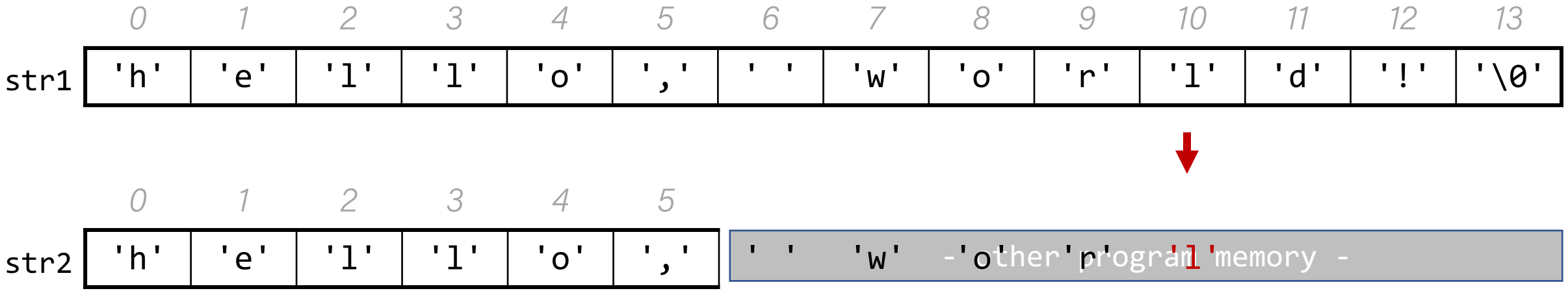

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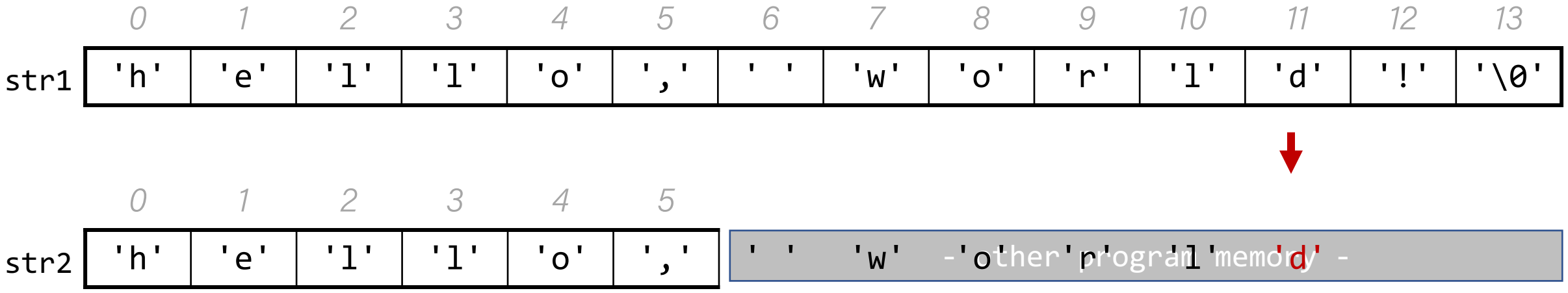

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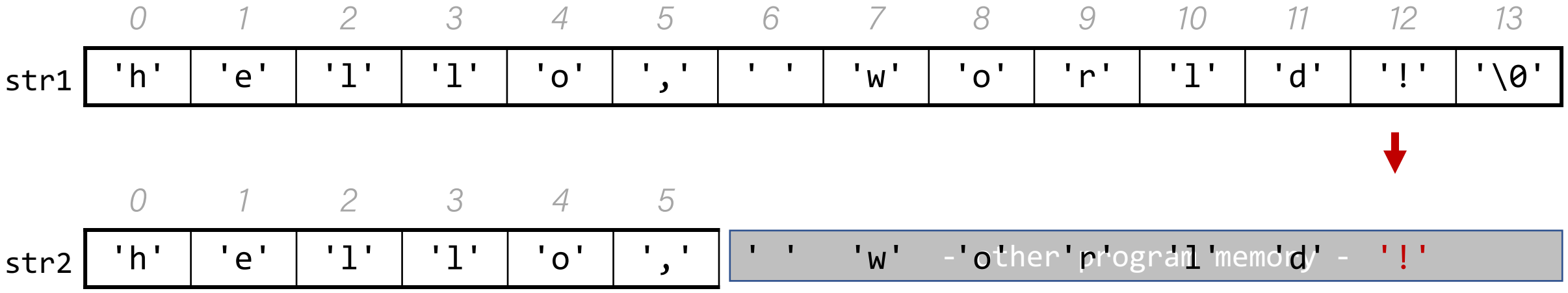

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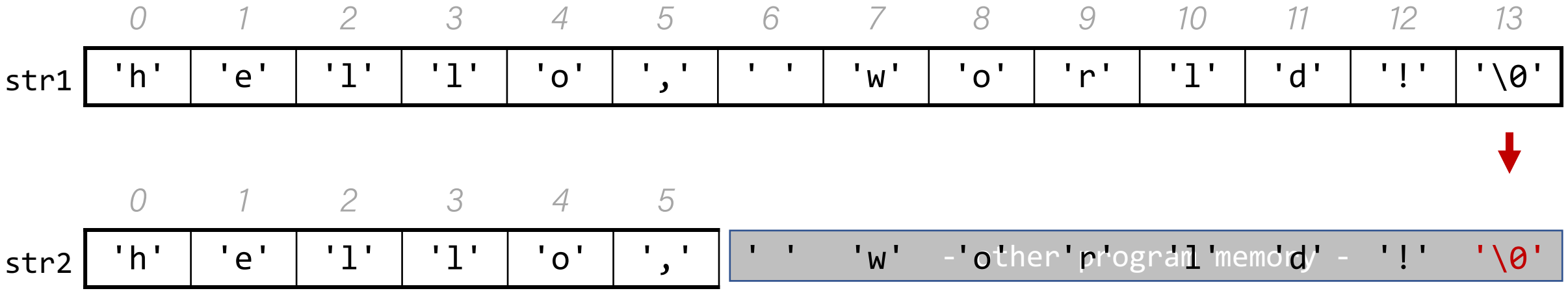

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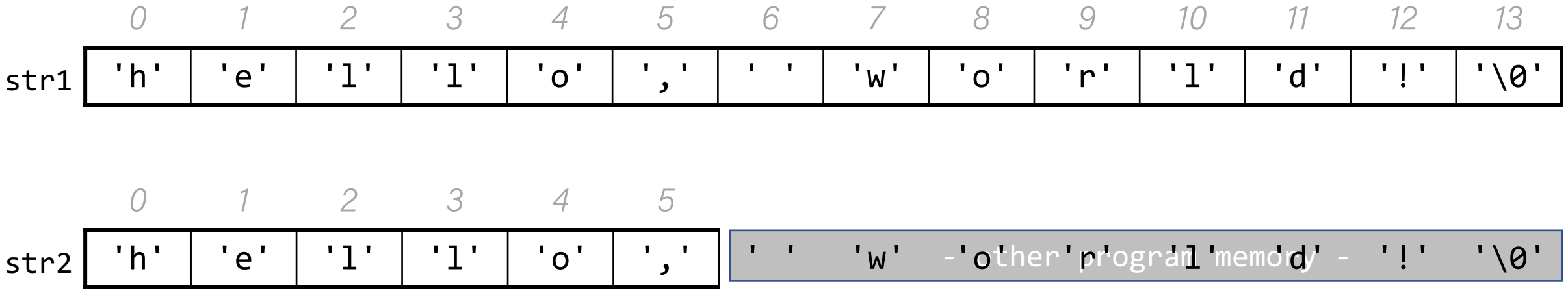

String Copying Exercise

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?

```
1  int main(int argc, char *argv[]) {
2      char str[9];
3      strcpy(str, "Hi earth");
4      str[2] = '\0';
5      printf("str = %s, len = %lu\n",
6             str, strlen(str));
7      return 0;
8  }
```

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

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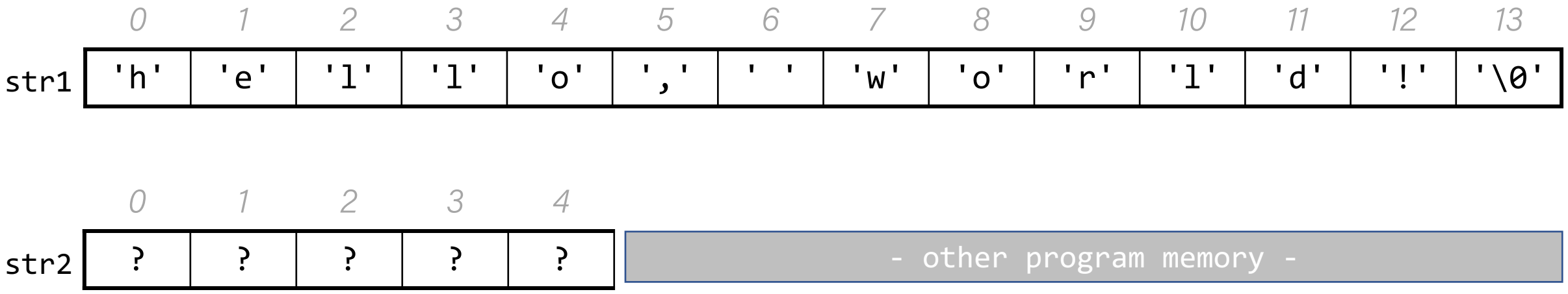
char str2[5];
strncpy(str2, "hello, world!", 5);
int length = strlen(str2);
```



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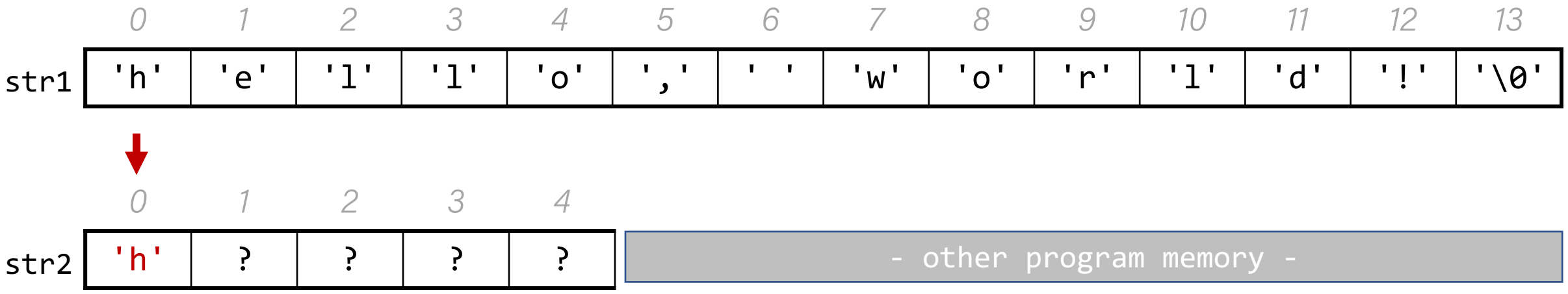

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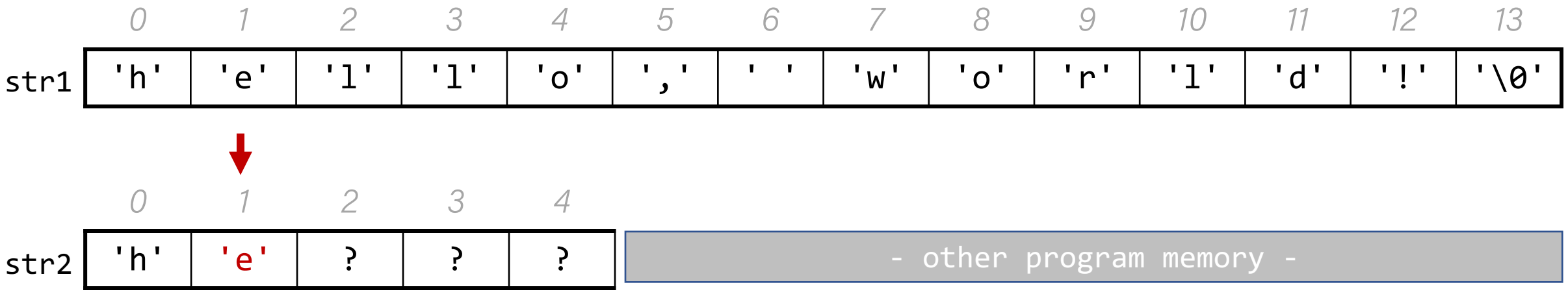

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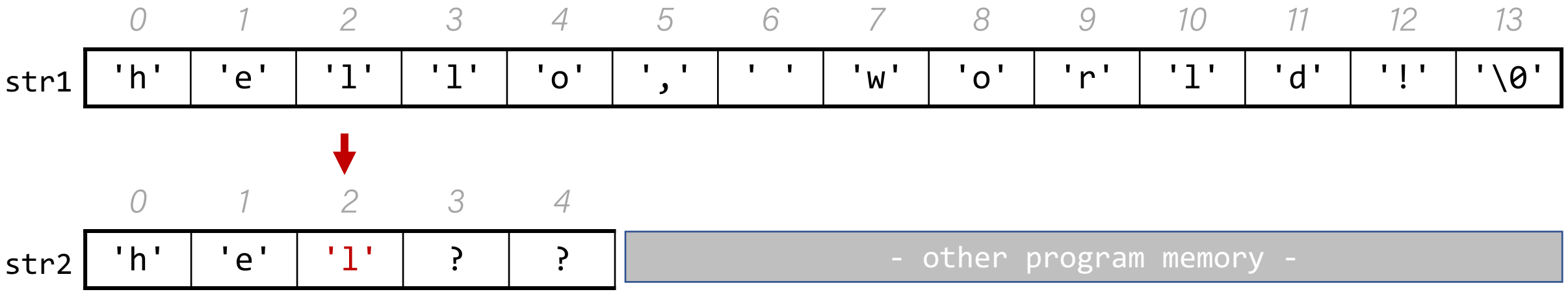

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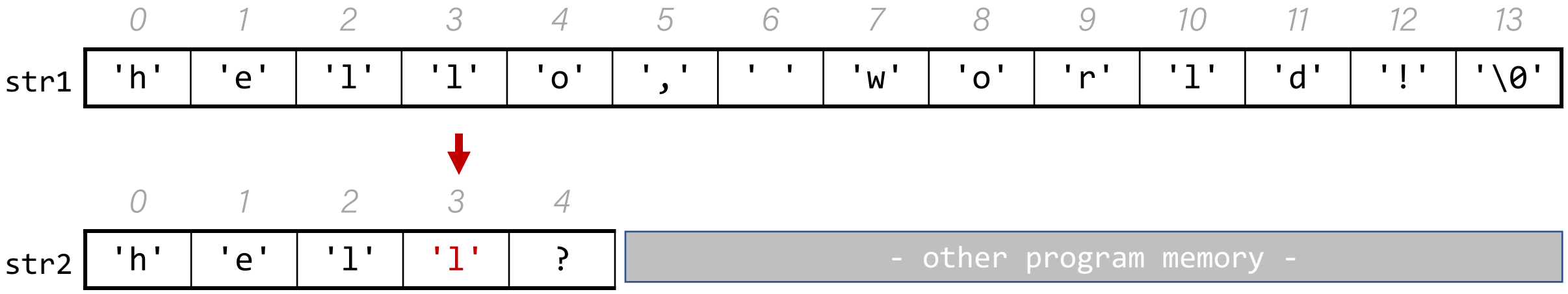

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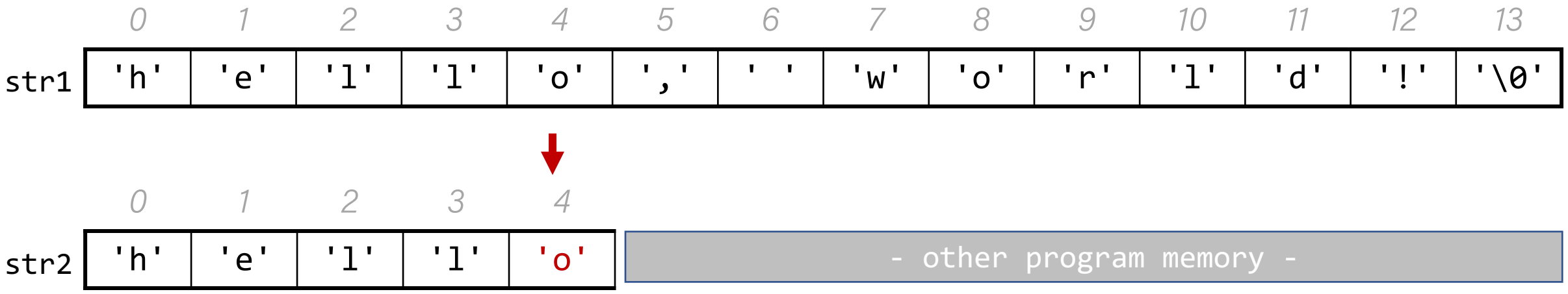

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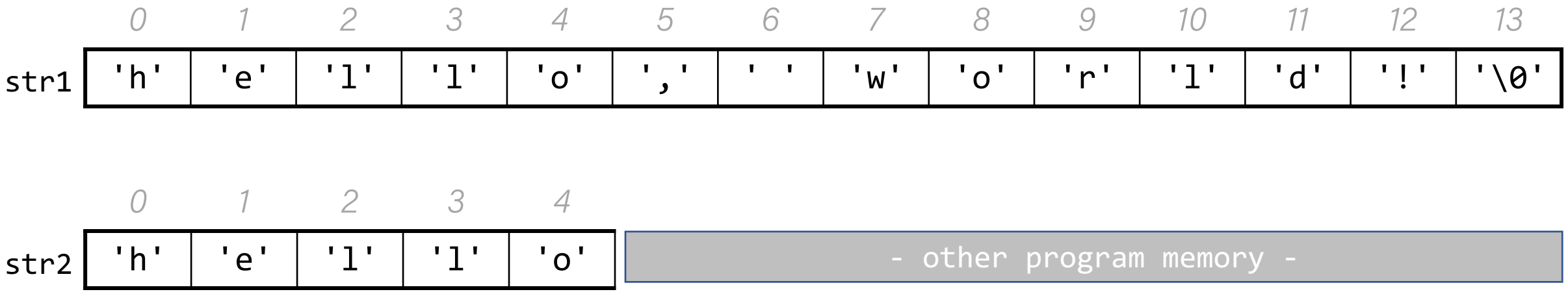

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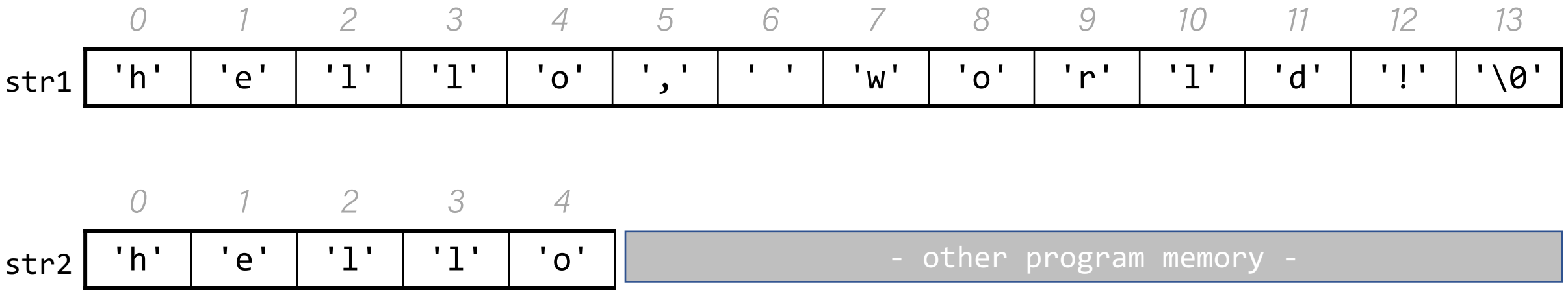

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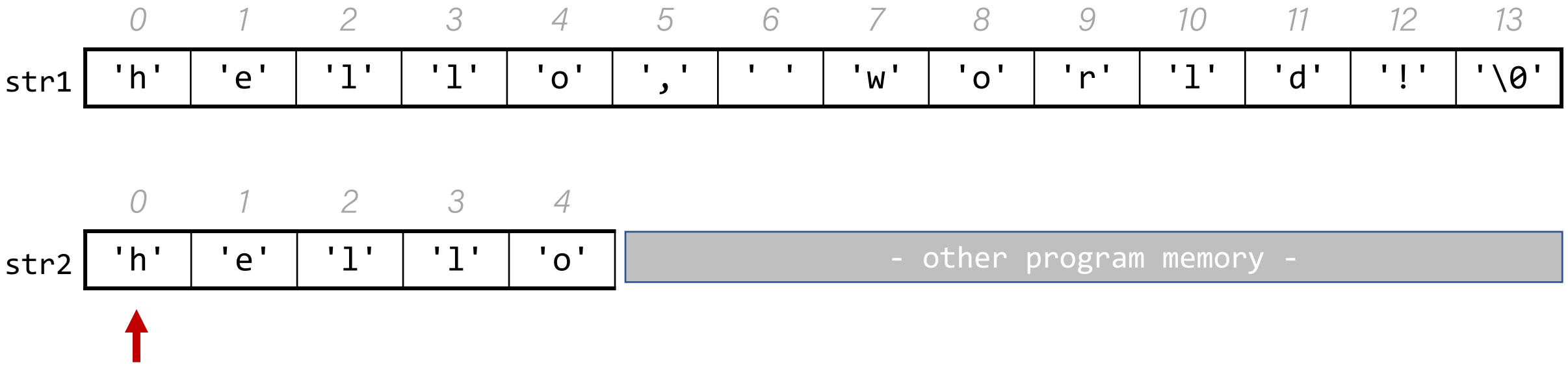

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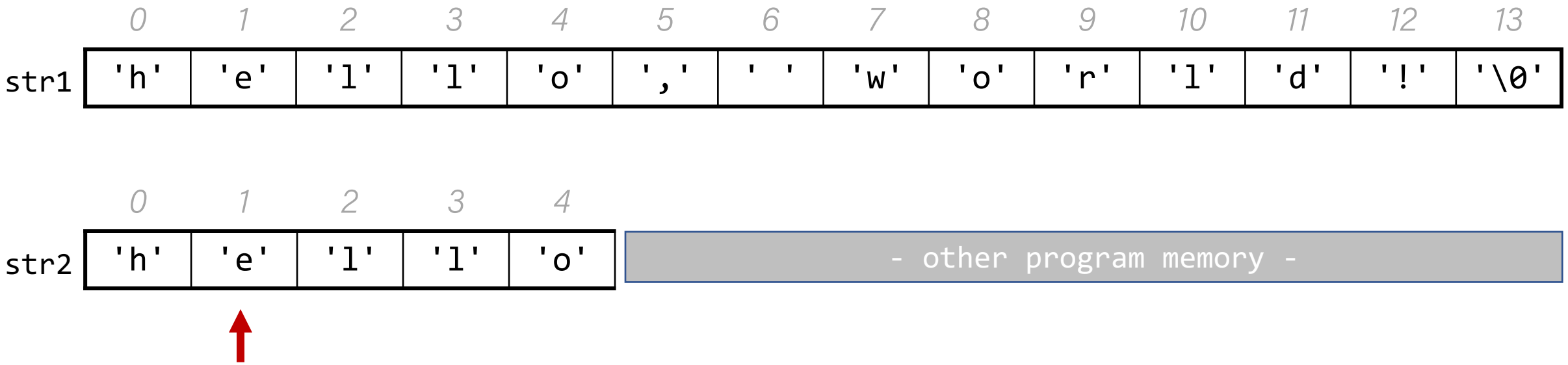

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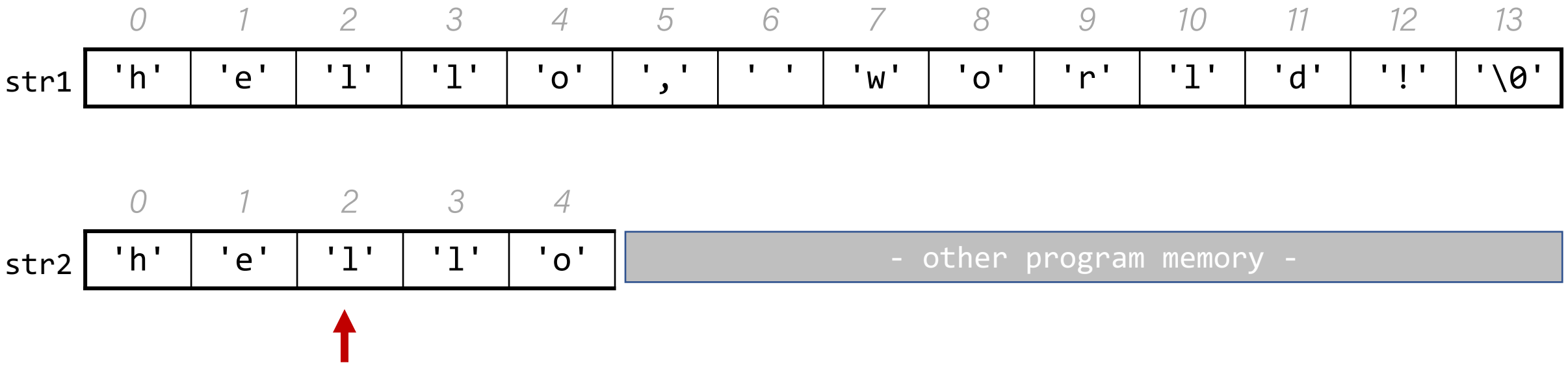

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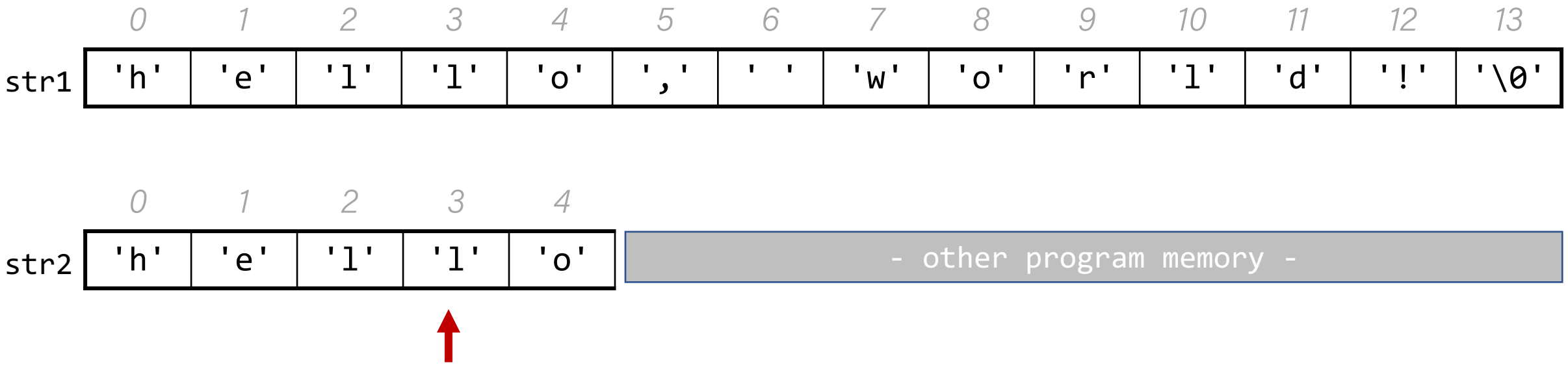

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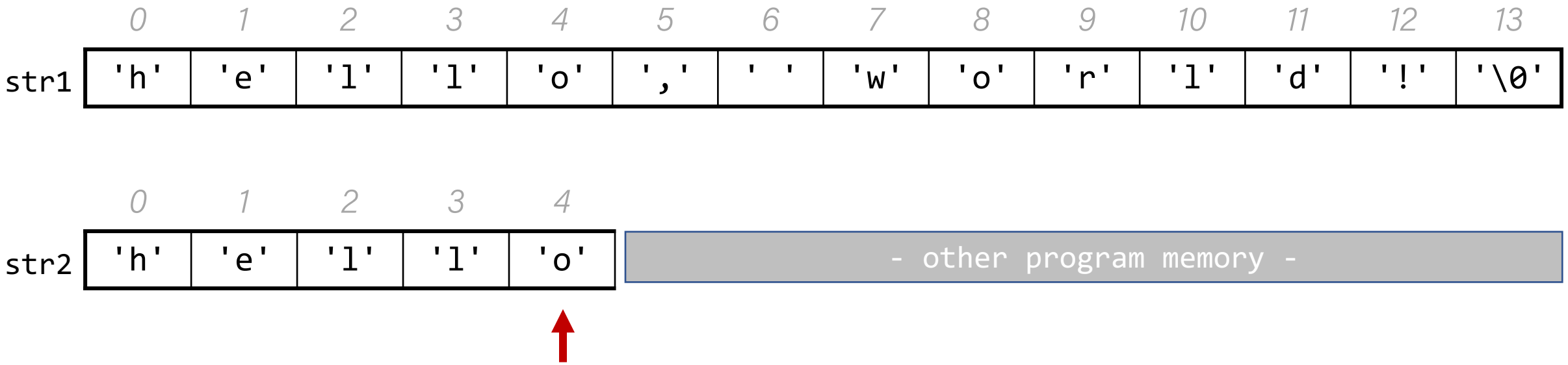

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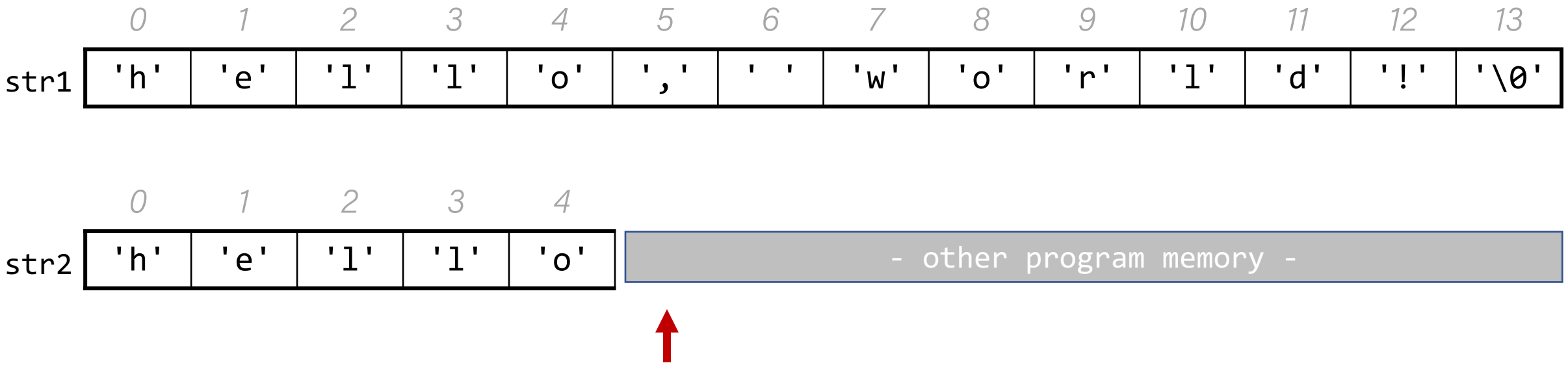

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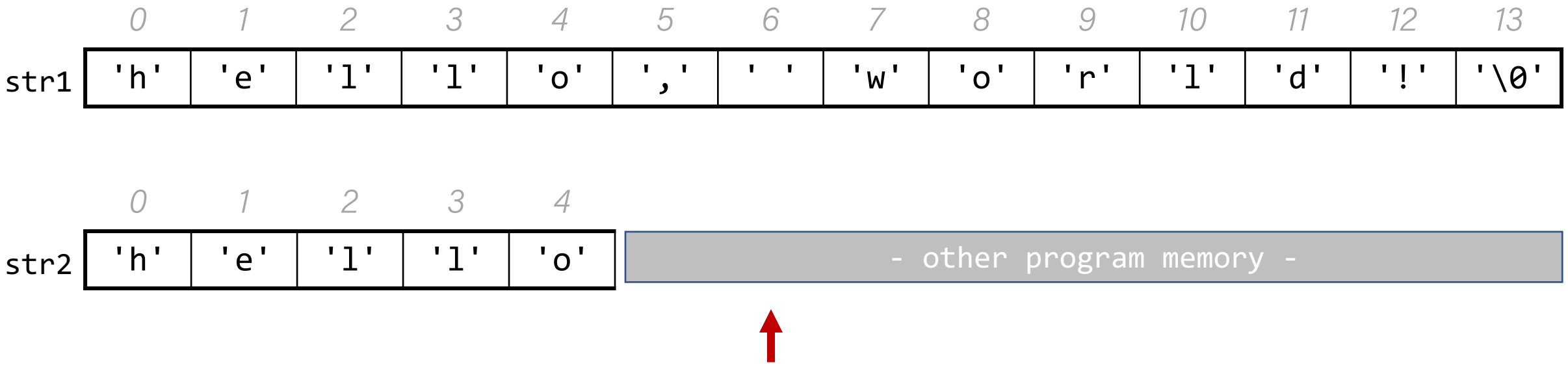

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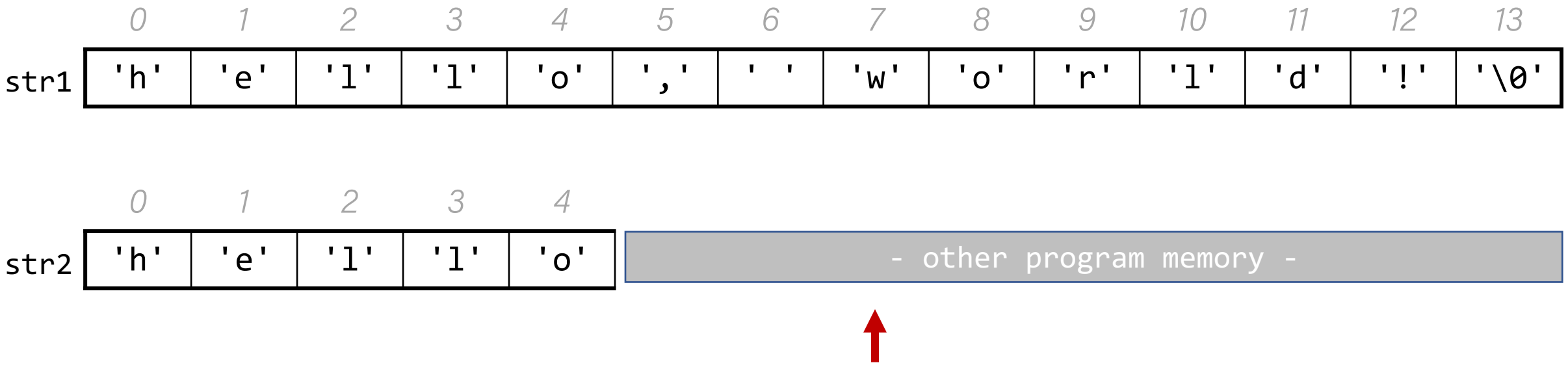

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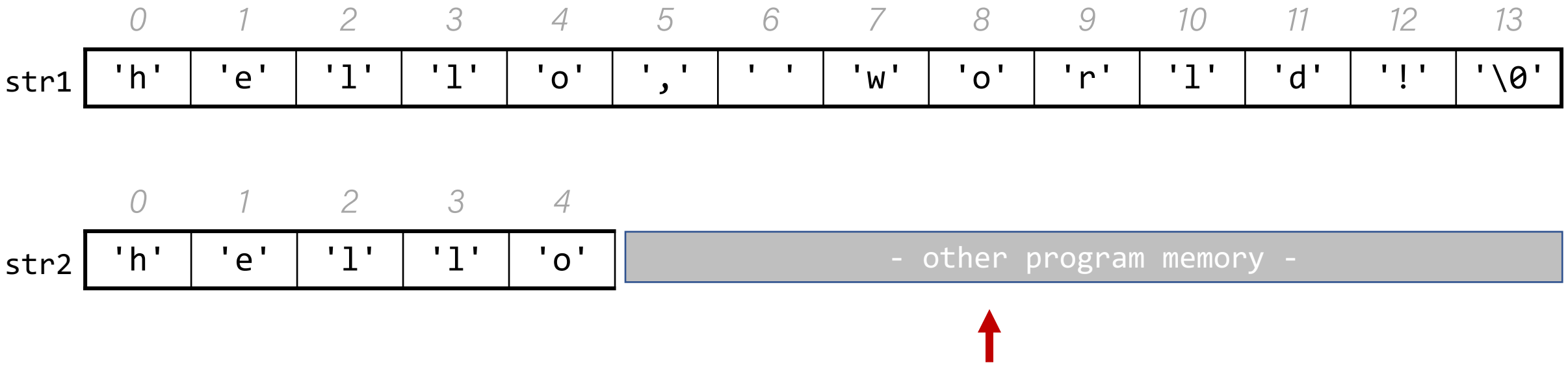

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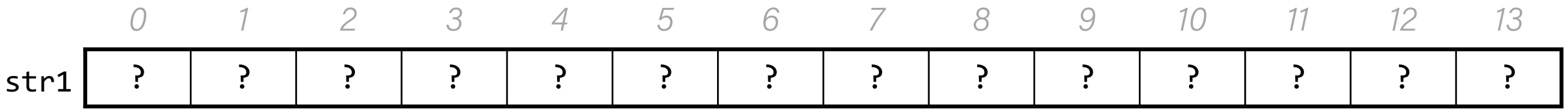

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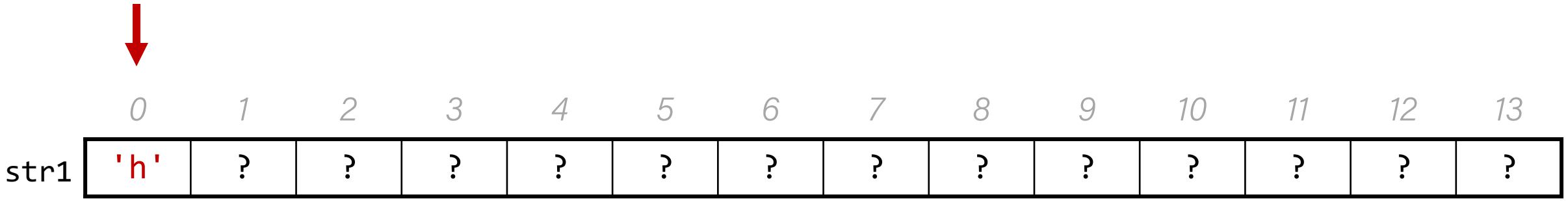

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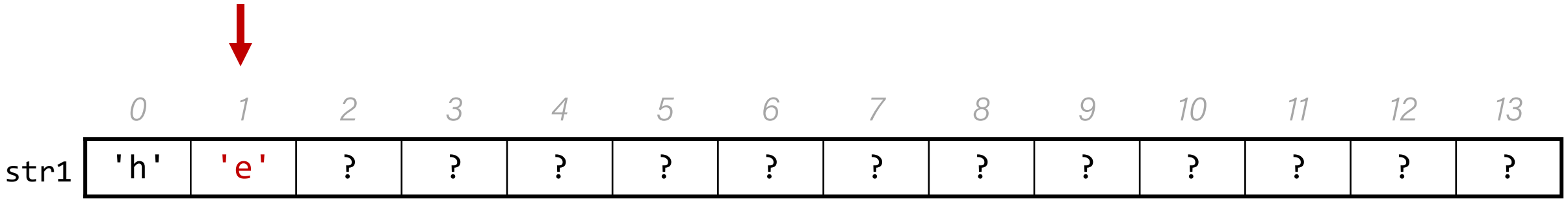

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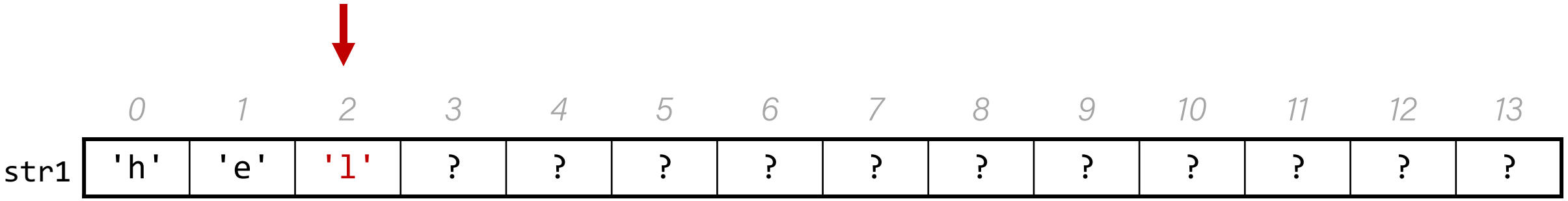

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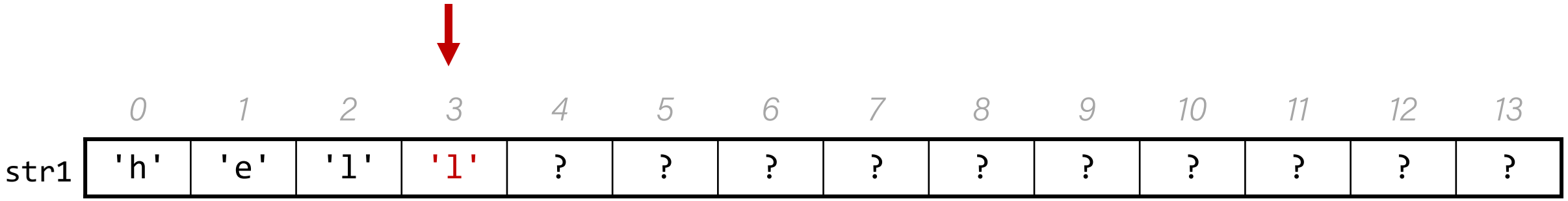

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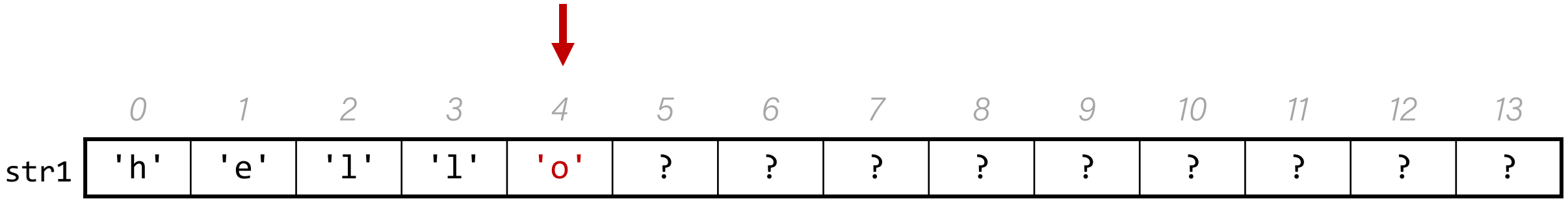

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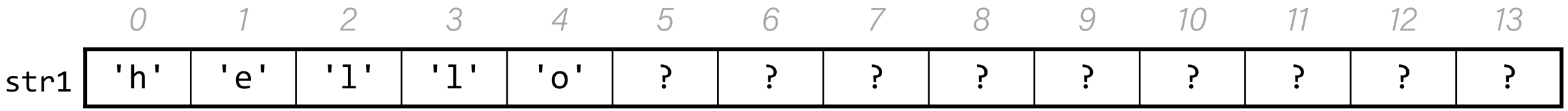

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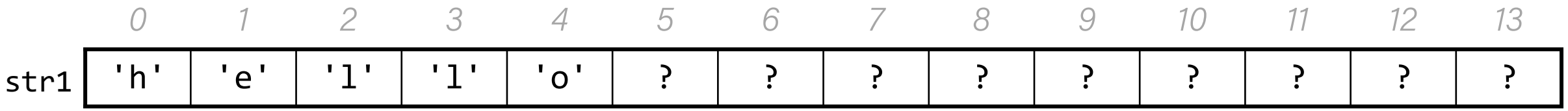

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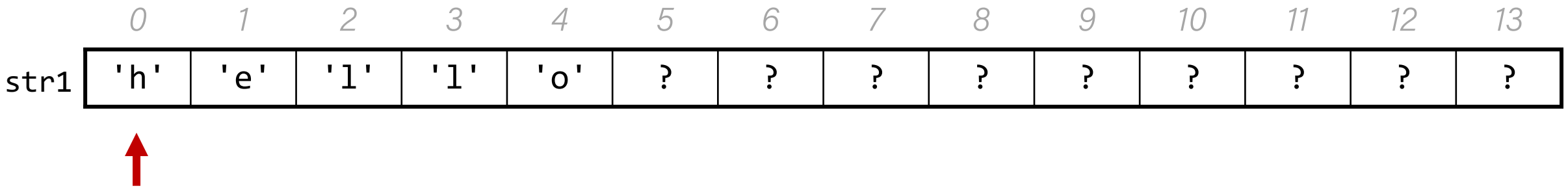

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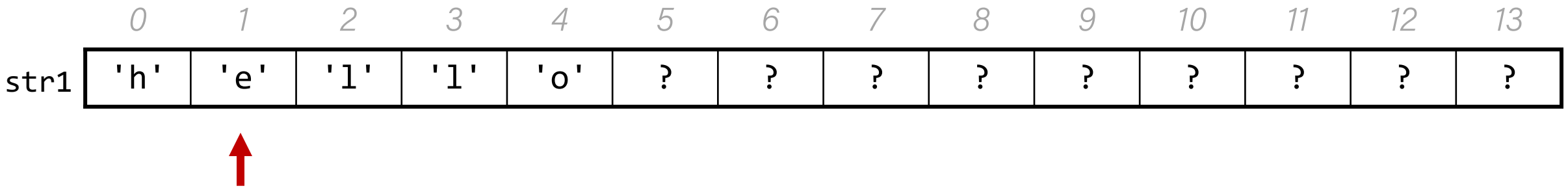

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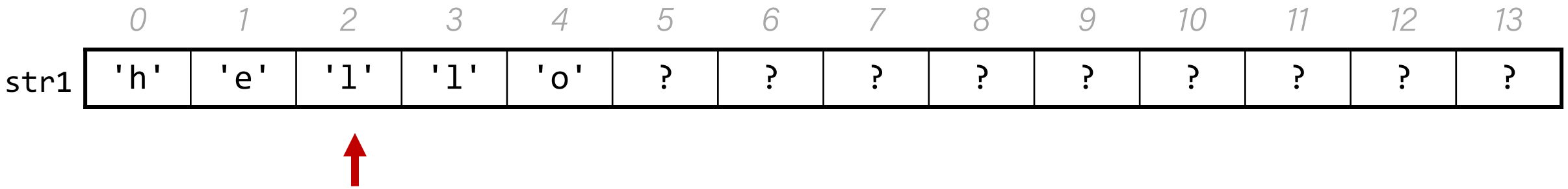

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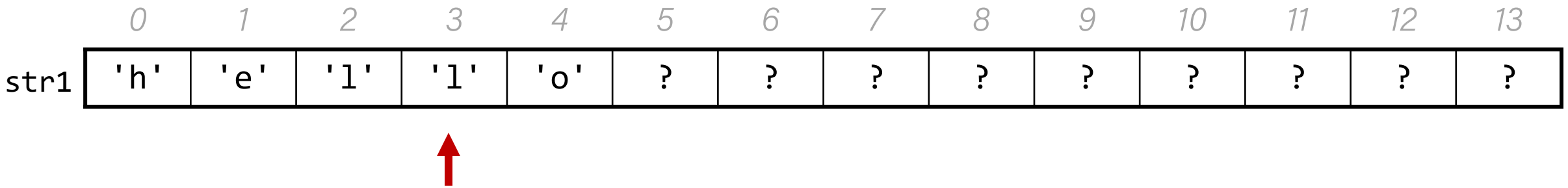

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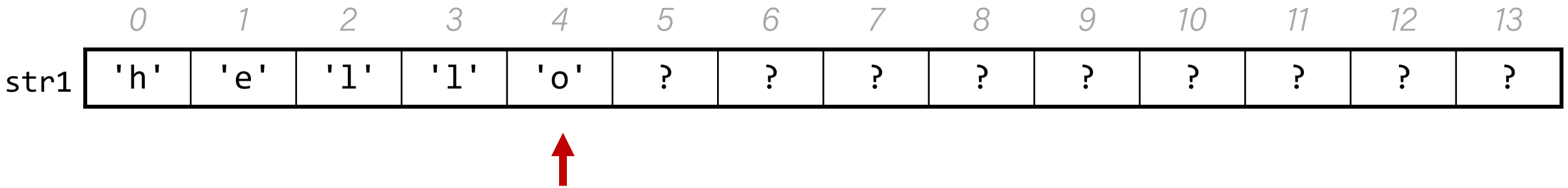

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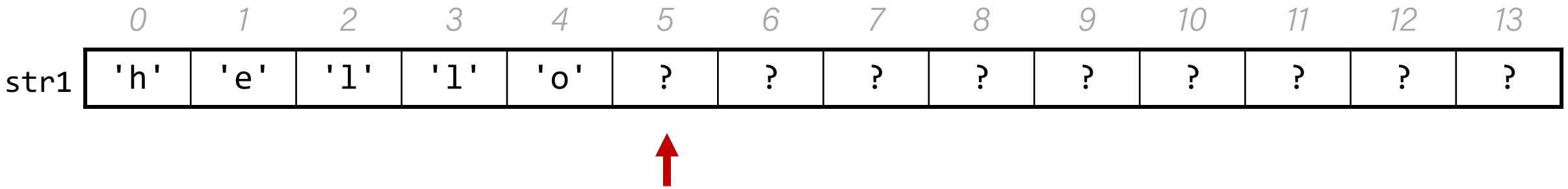

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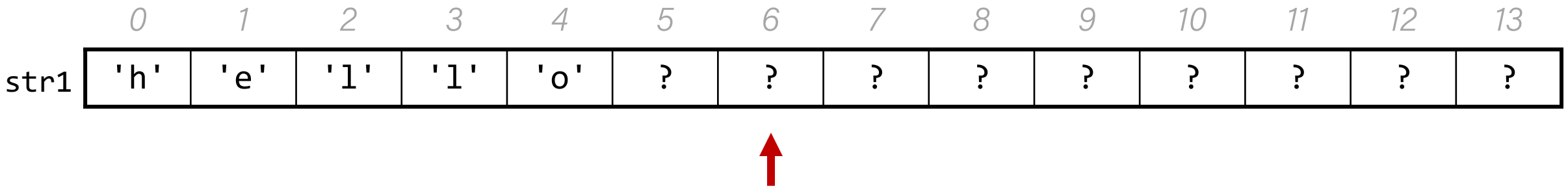

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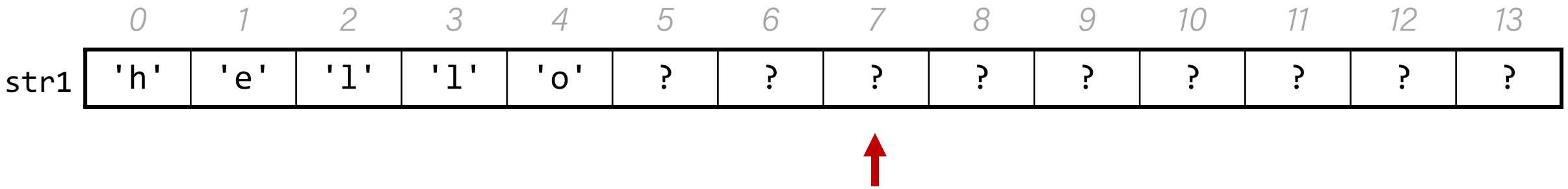

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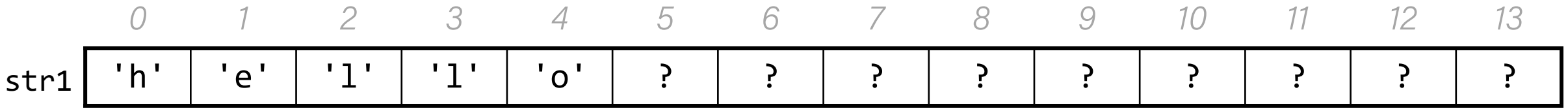



```
hello?J???
```

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**.

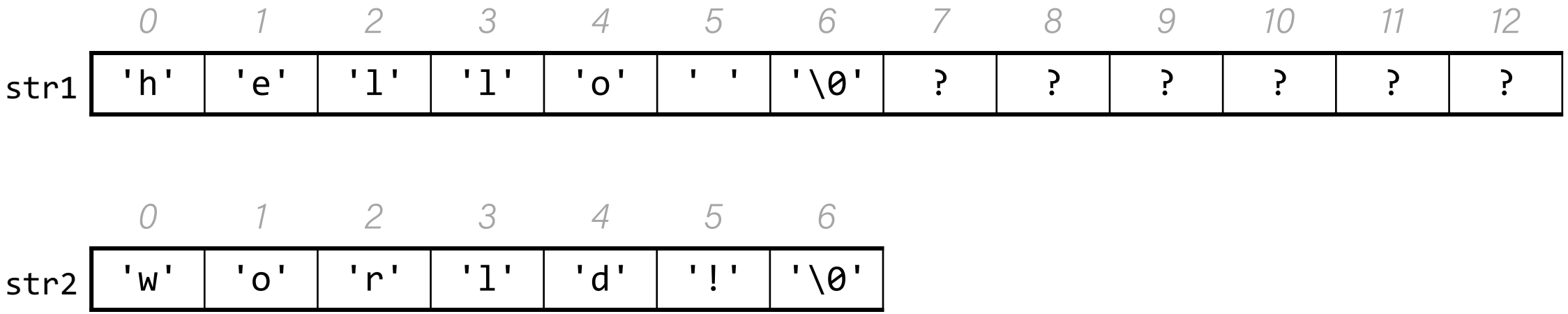
```
char str1[13];                  // enough space for strings + '\0'
strcpy(str1, "hello ");
strcat(str1, "world!");         // removes old '\0', adds new '\0' at end
printf("%s", str1);             // hello world!
```

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);
```



Concatenating Strings

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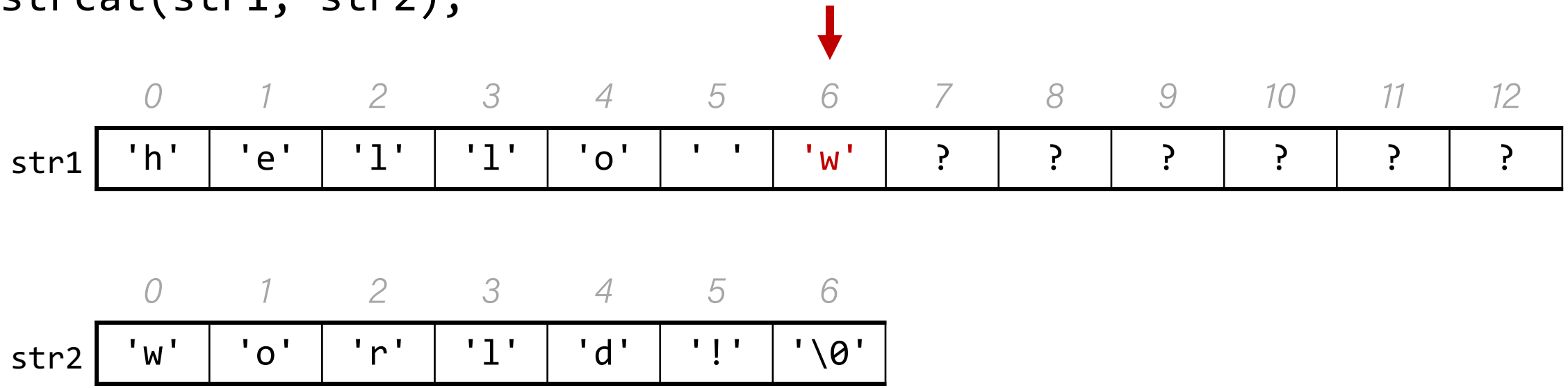

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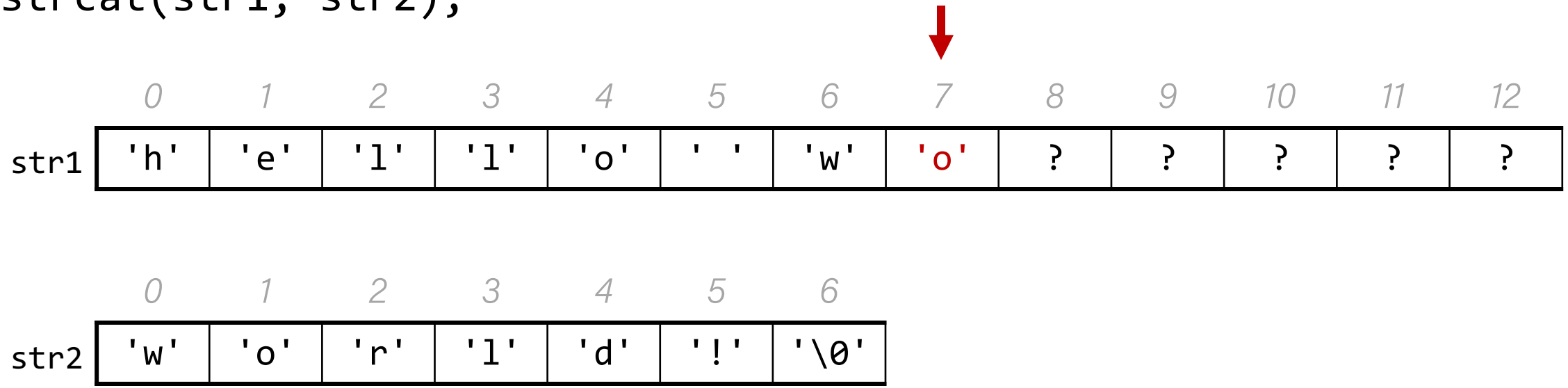

Concatenating Strings

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char str2[7];
strcpy(str2, "world!");

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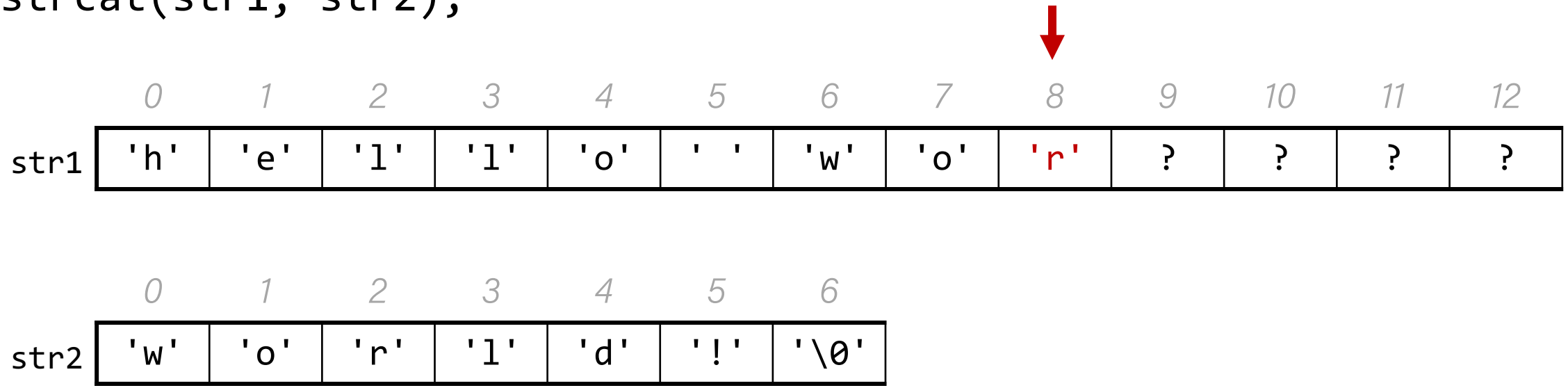

Concatenating Strings

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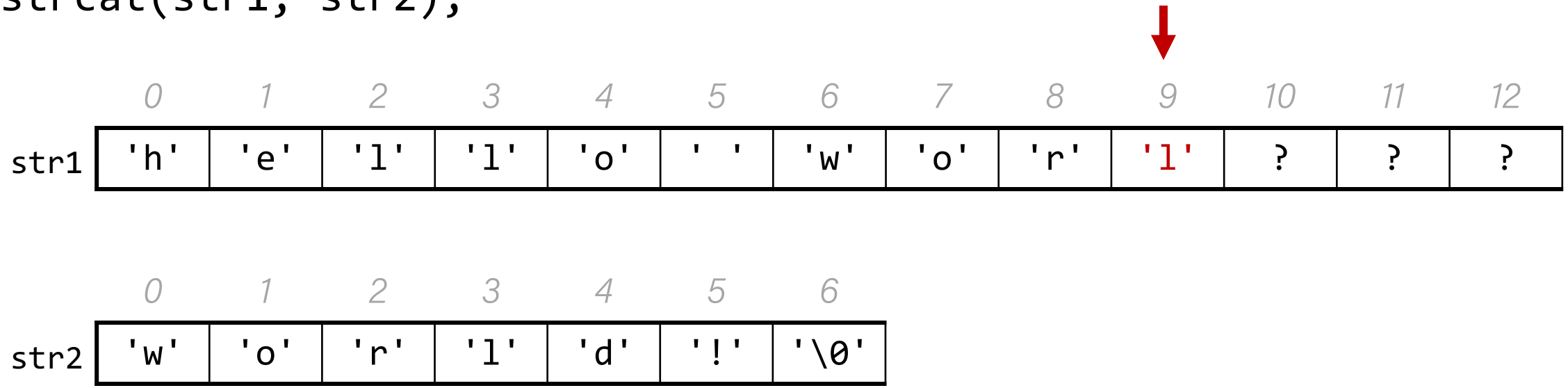

Concatenating Strings

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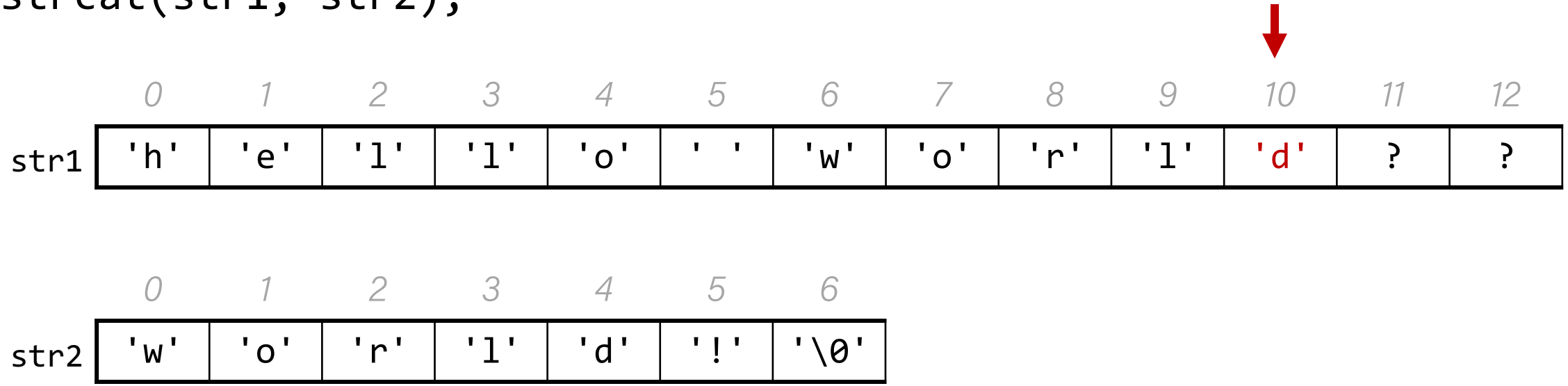

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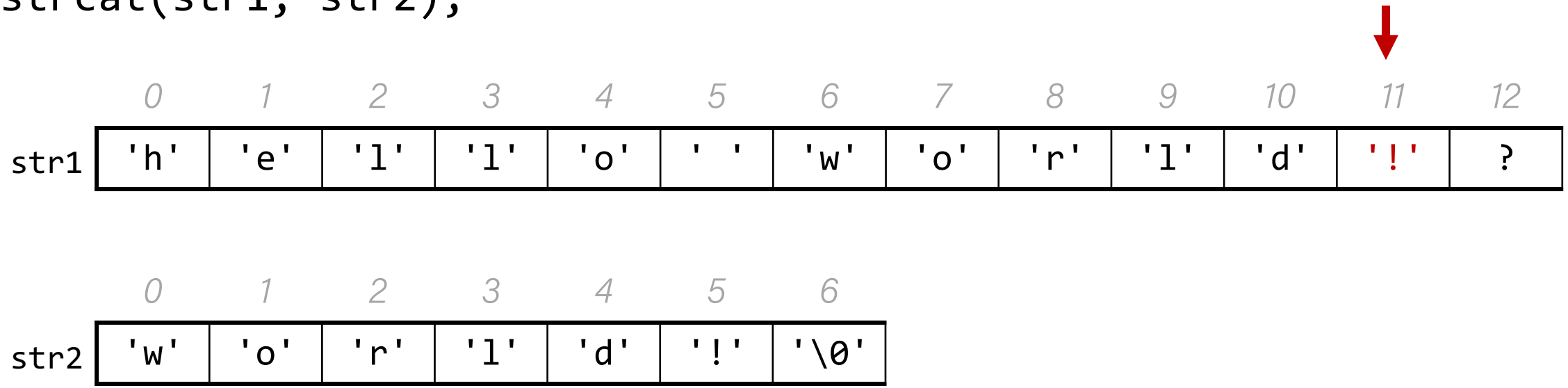

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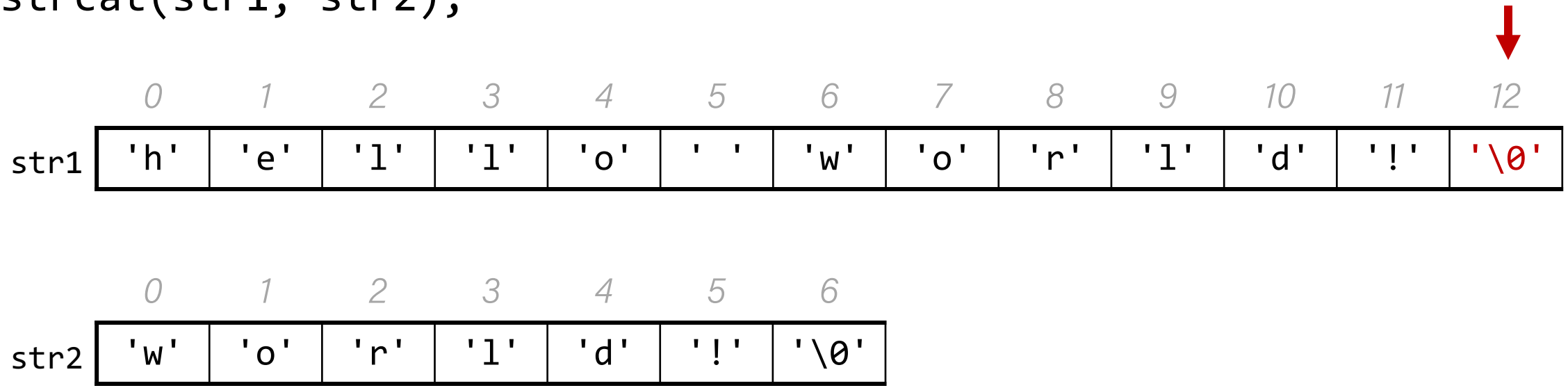

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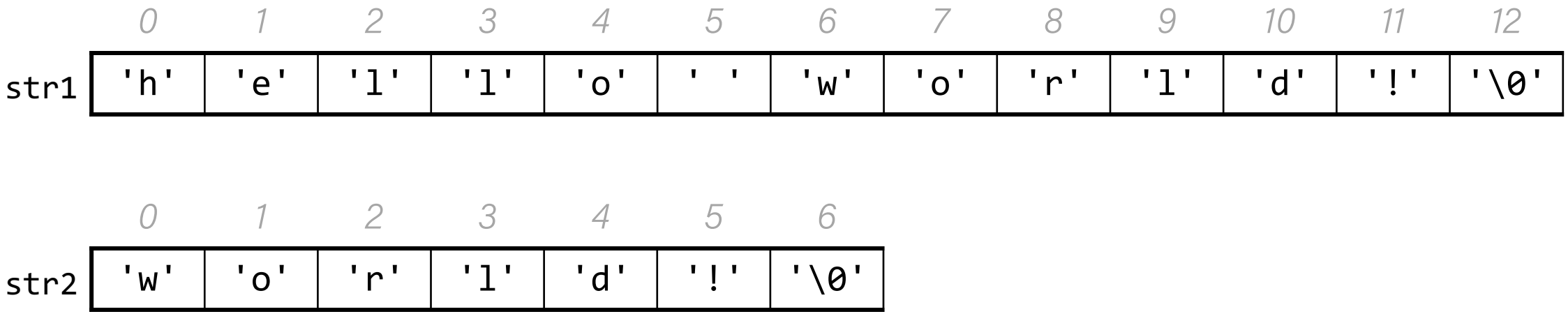


Substrings and `char *`

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

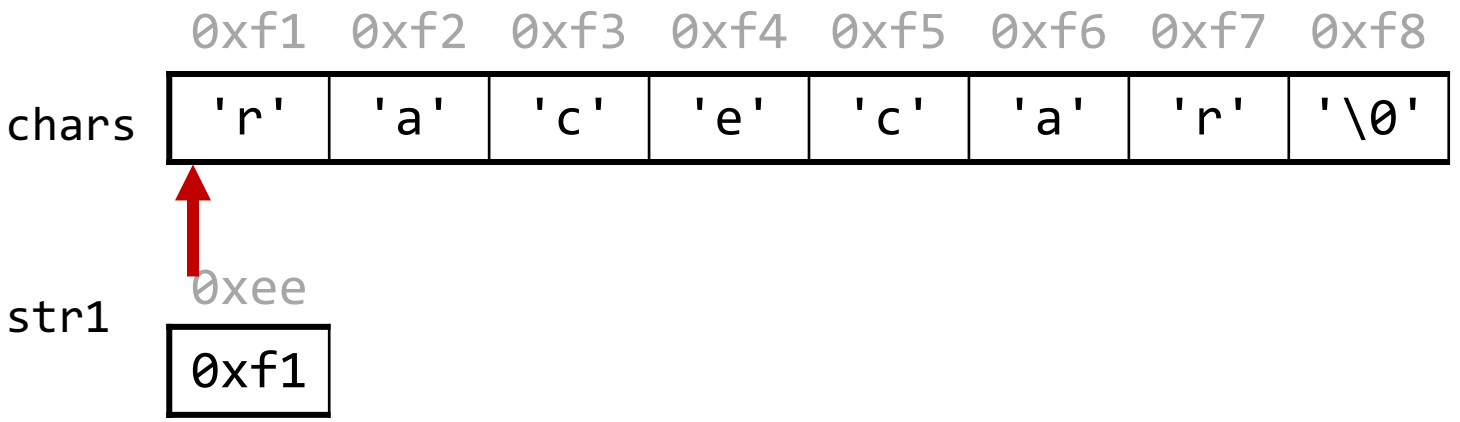
```
char myString[3];
myString[0] = 'H';
myString[1] = 'i';
myString[2] = '\0';

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

Substrings

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

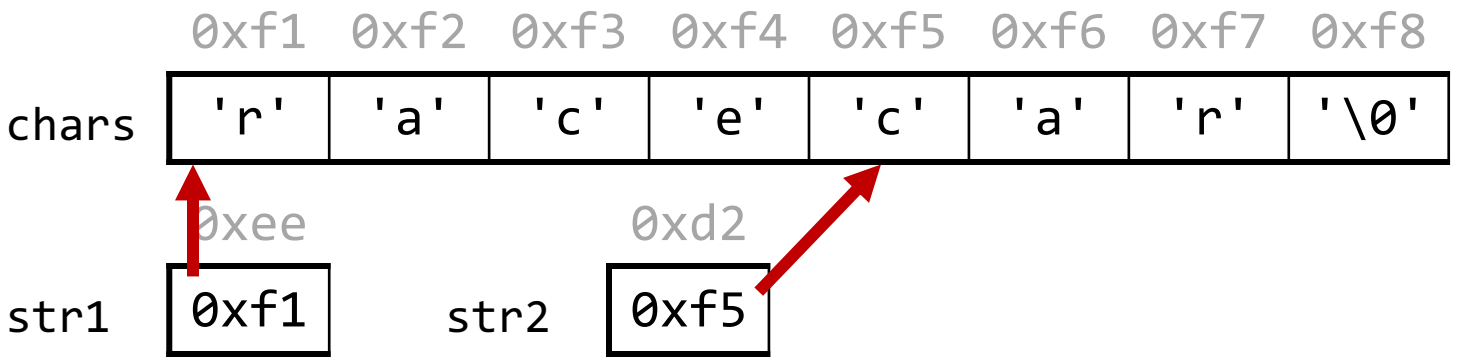
```
// Want just "car"
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
```



Substrings

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

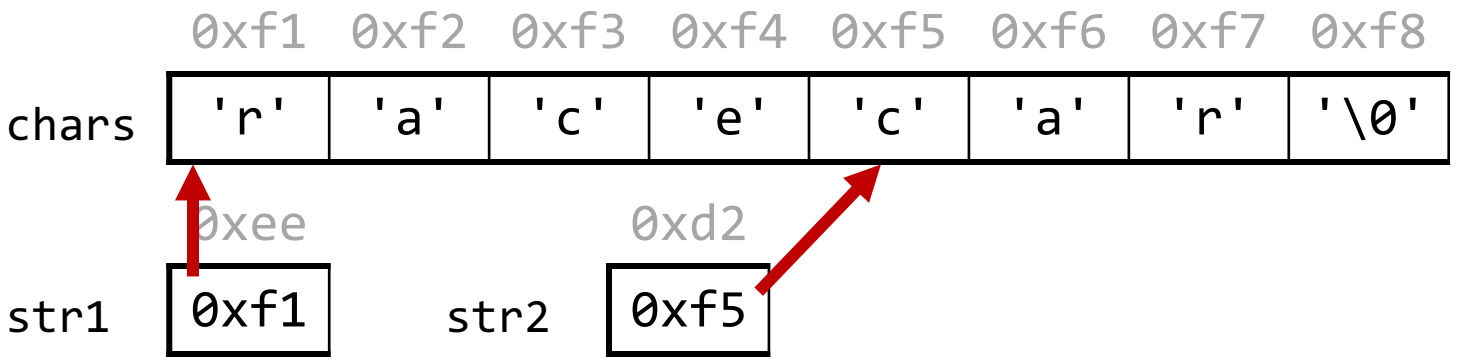
```
// Want just "car"
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
```



Substrings

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

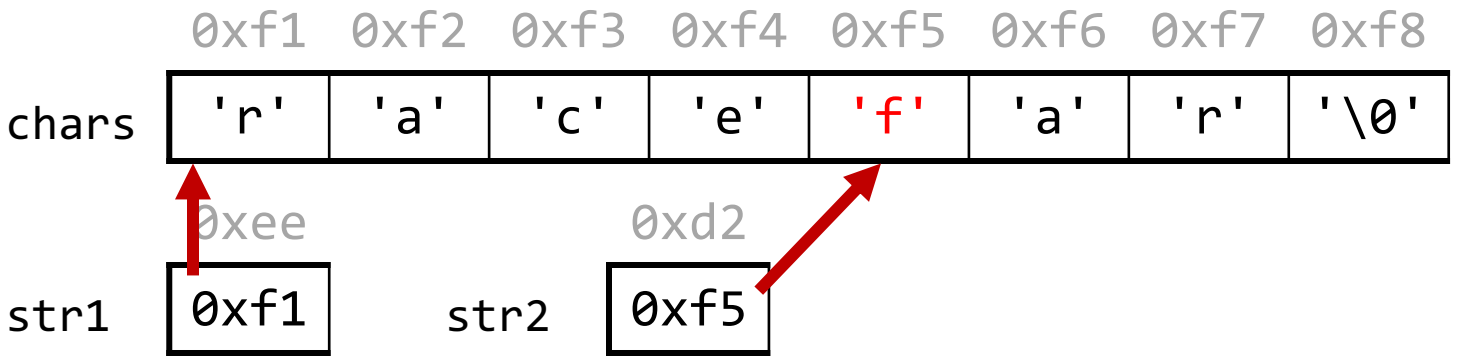
```
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
printf("%s\n", str1);           // racecar
printf("%s\n", str2);           // car
```



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!

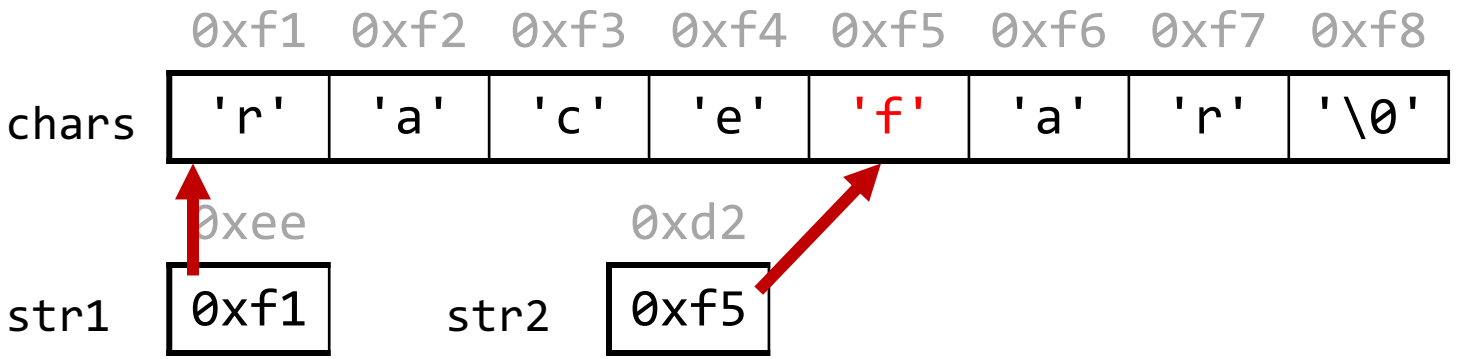
```
char chars[8];
strcpy(chars, "racecar");
char *str1 = chars;
char *str2 = chars + 4;
str2[0] = 'f';
printf("%s %s\n", chars, str1);
printf("%s\n", str2);
```



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
```



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.

```
// 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:

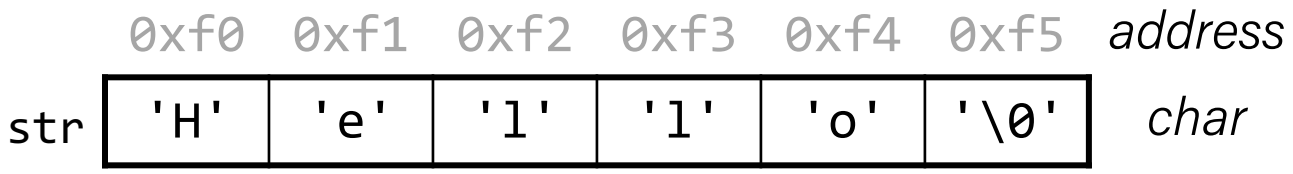
```
C
CO
COM
COMP
COMP2
COMP20
COMP201
 OMP201
  MP201
   P201
    201
     01
      1
```

Practice: Diamond

`diamond.c`

Key takeaways

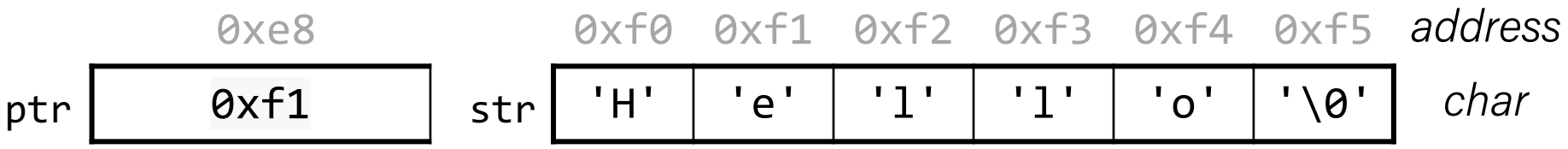
1. Valid strings are null-terminated.




```
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

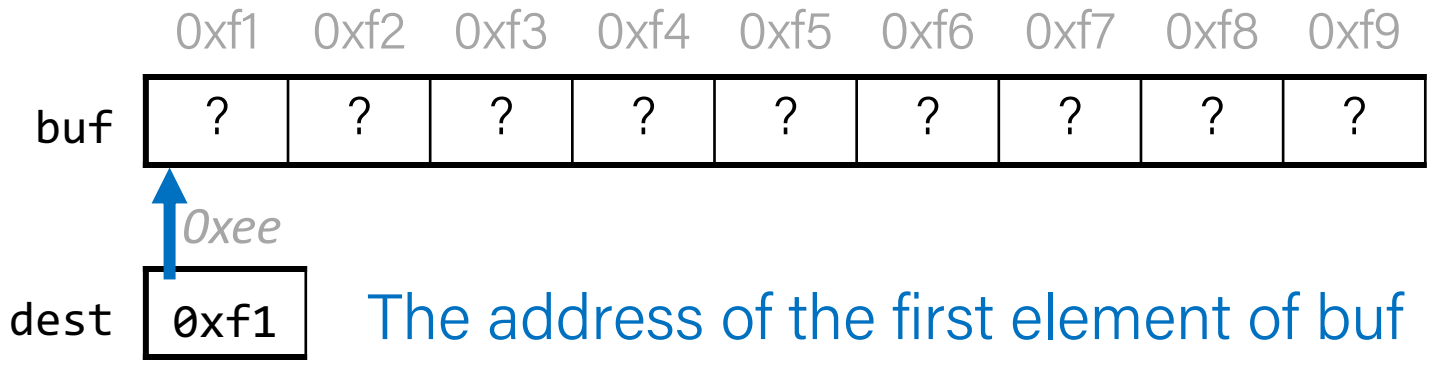
1. Valid strings are null-terminated.
2. An array name (and a string name, by extension) is the address of the first element.
3. When you pass a `char[]` as a parameter, it is automatically passed as a `char *` (pointer to its first character)

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`

```
1 char buf[6];
2 strcpy(buf, "Hello");
3 printf("%s\n", 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*