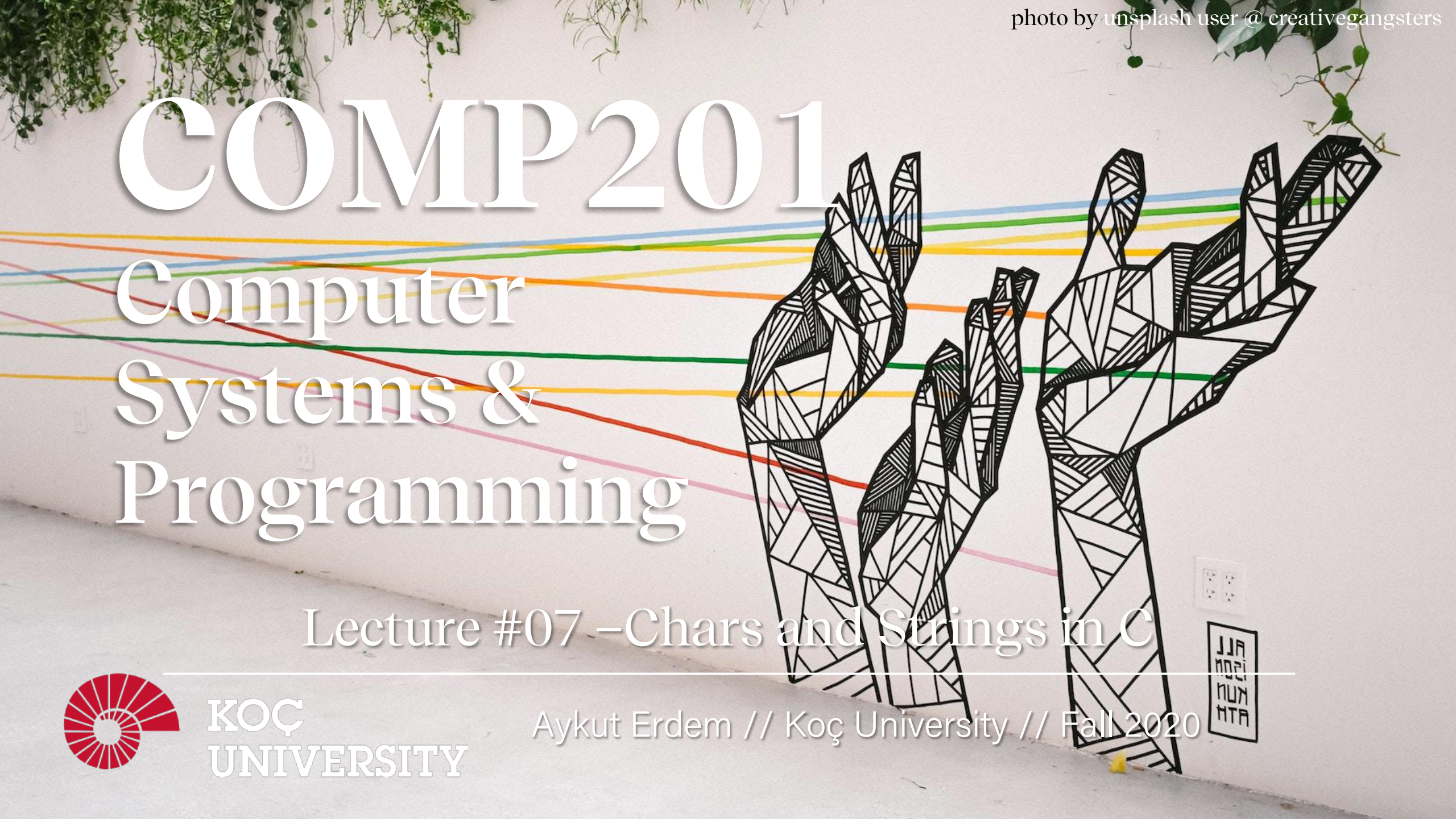

COMP201

Computer Systems & Programming

Lecture #07 –Chars and Strings in C

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Fall 2020

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

Plan for Today

- Characters
- Strings
- Common String Operations
  - Comparing
  - Copying
  - Concatenating
  - Substrings

Disclaimer: Slides for this lecture were borrowed from

—Nick Troccoli's Stanford CS107 class

—Swami Iyer's Umass Boston CS110 class

Lecture Plan

- Characters
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  - Comparing
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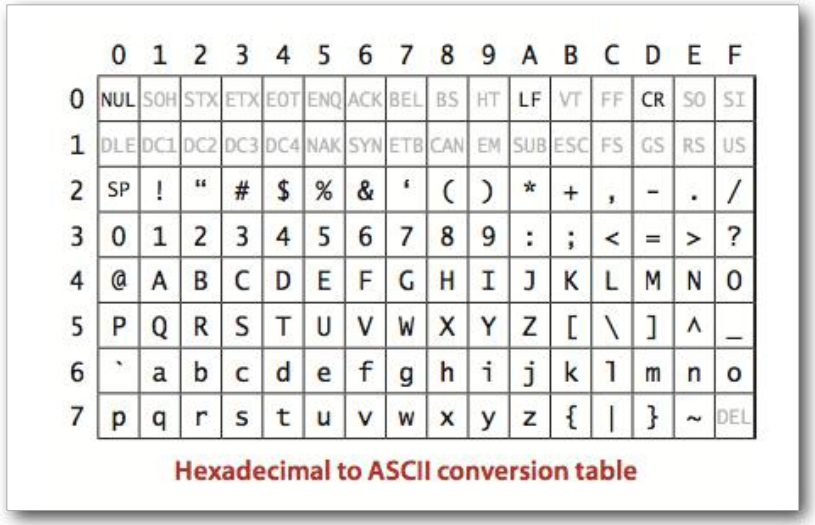
Char

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

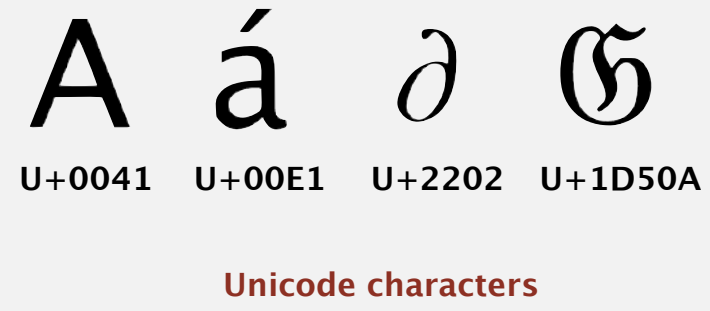
Hexadecimal to ASCII conversion table

- 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
```

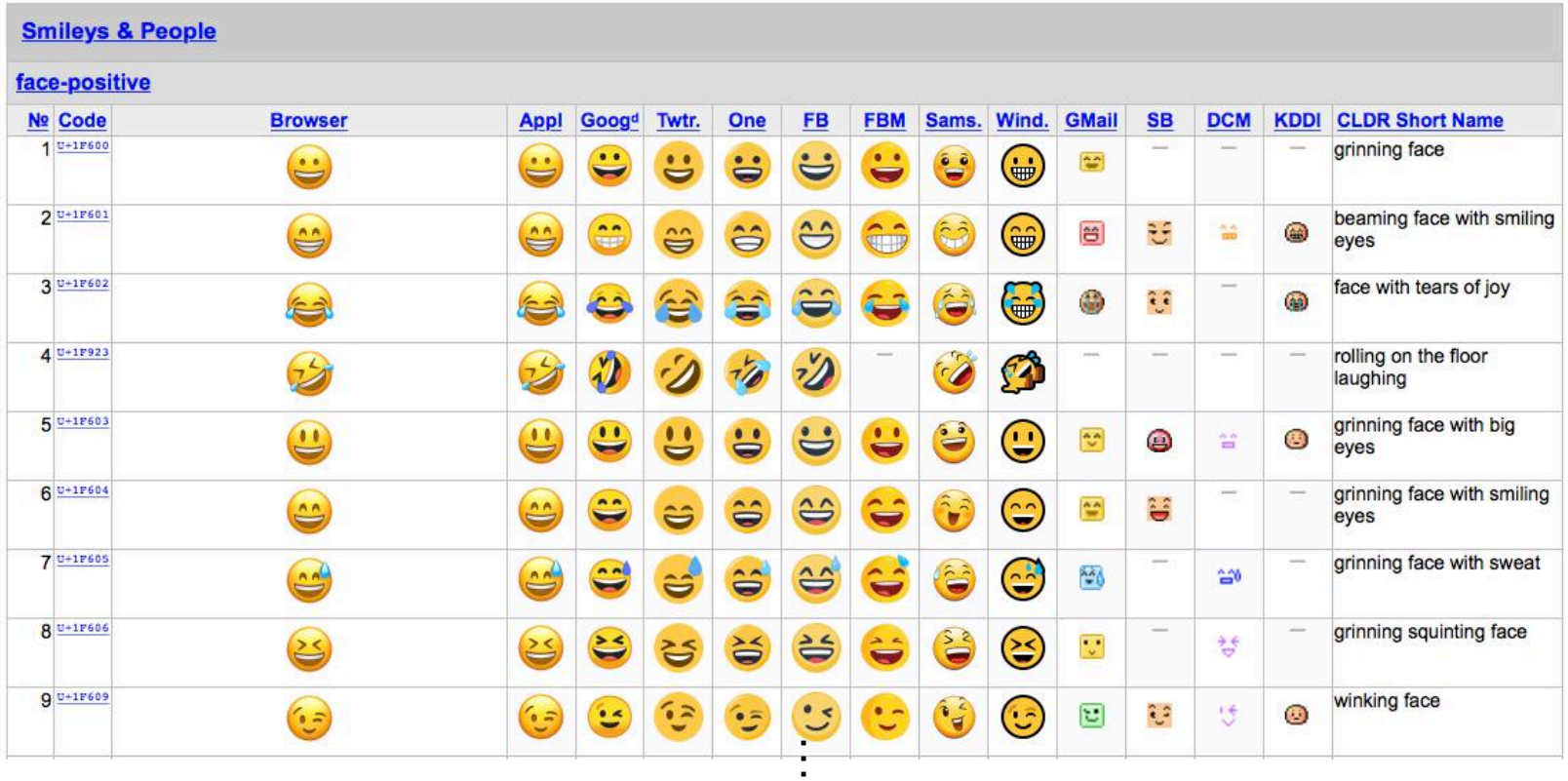
Unicode Transformation Formats

- 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, v5.0
  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
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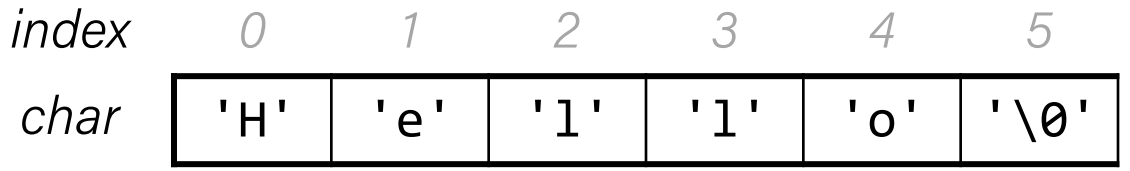
  - Substrings

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.

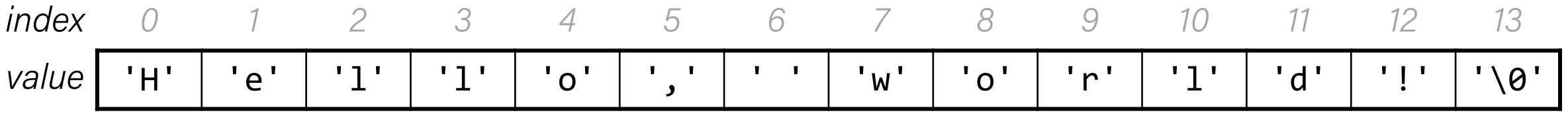
`"Hello"`



`'\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
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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

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, 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`**.

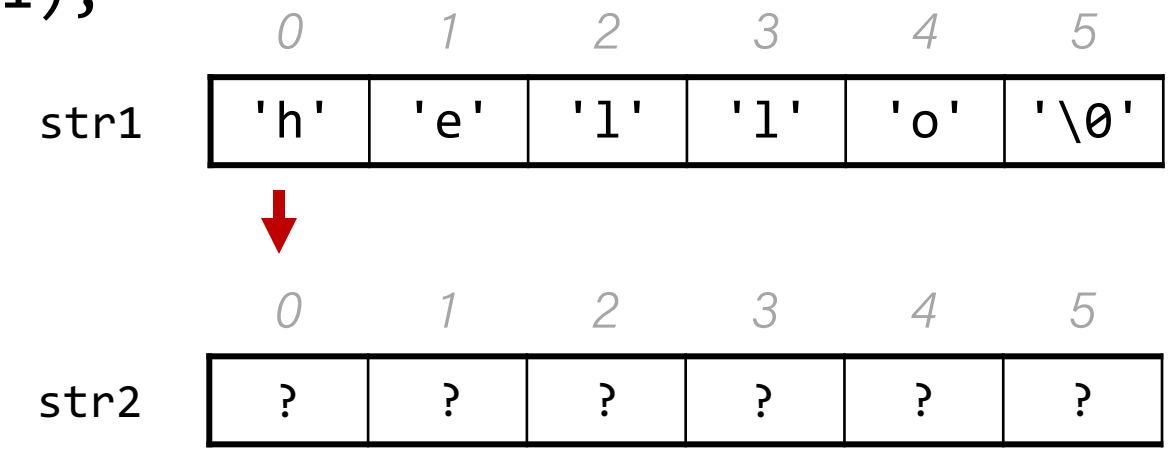
The string library: `strcpy`

`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`

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

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



Copying Strings – `strcpy`

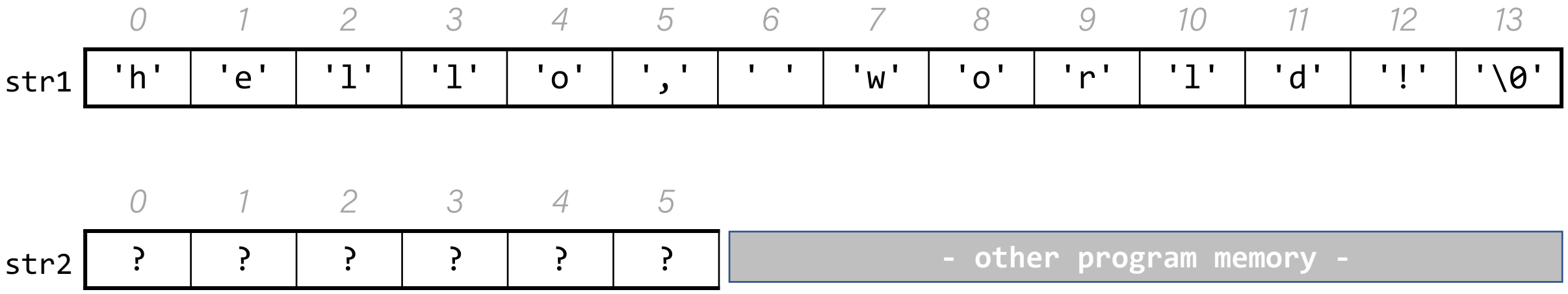
We must make sure there is enough space in the destination to hold the entire copy, *including the null-terminating character*.

```
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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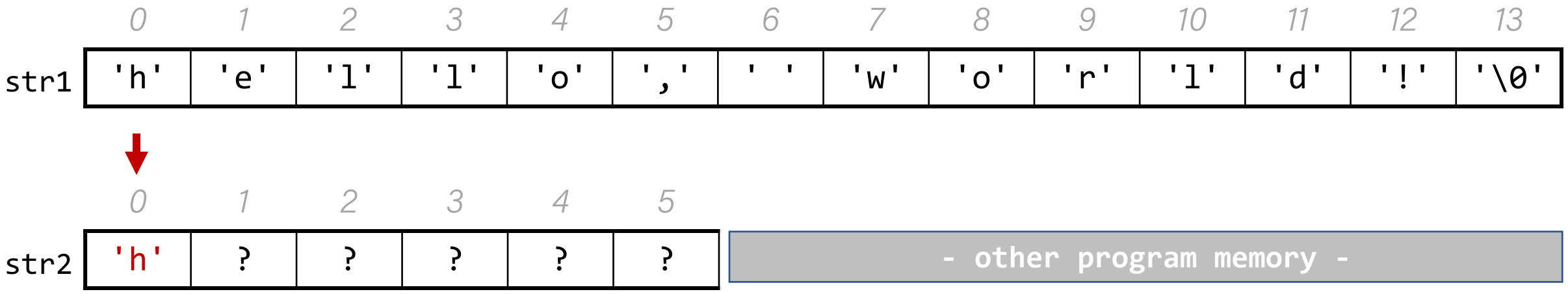

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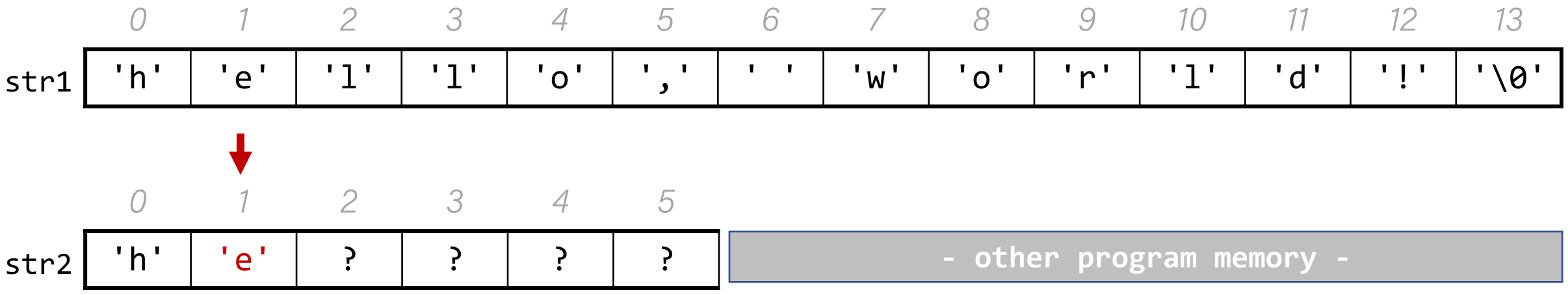

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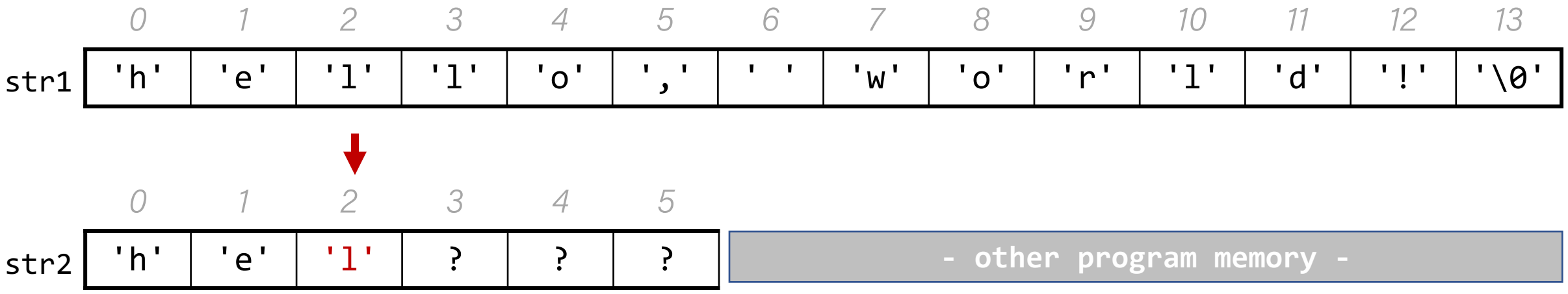

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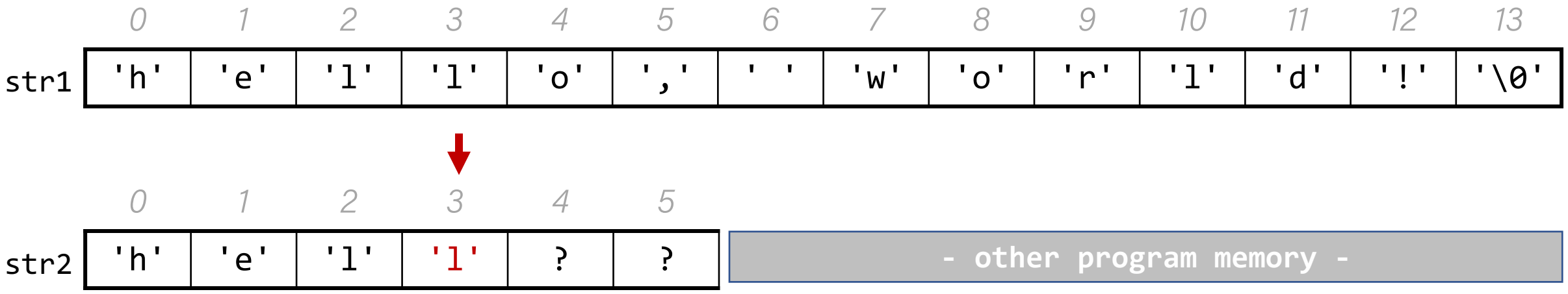

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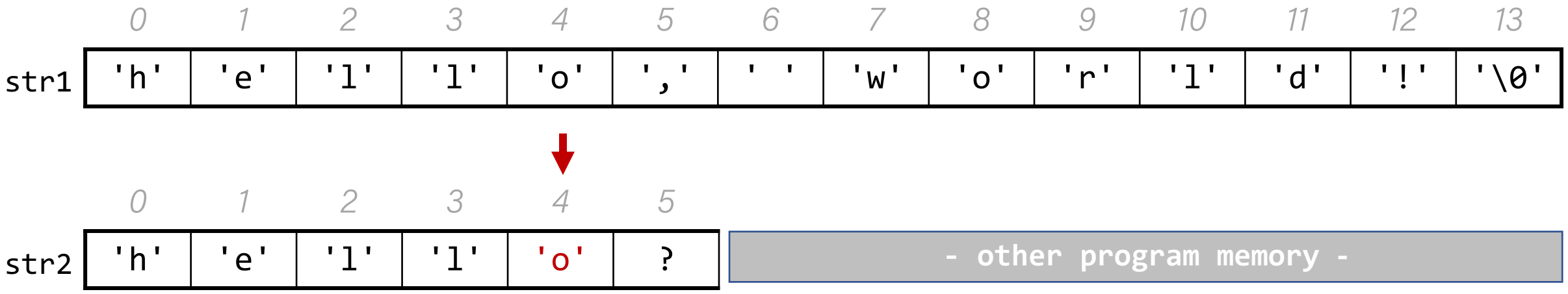

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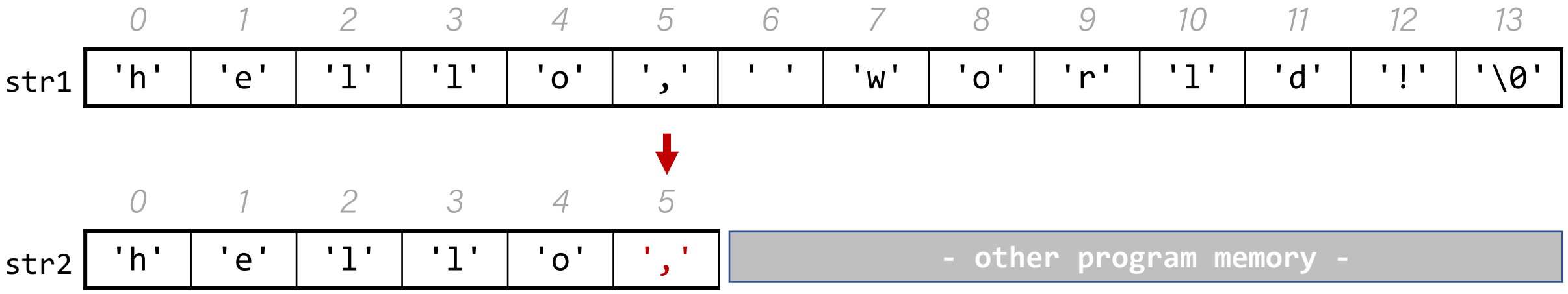

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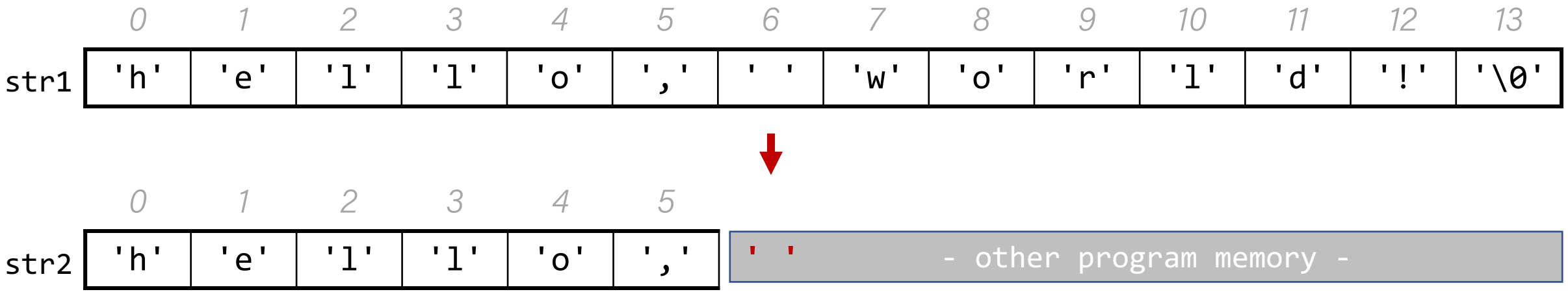

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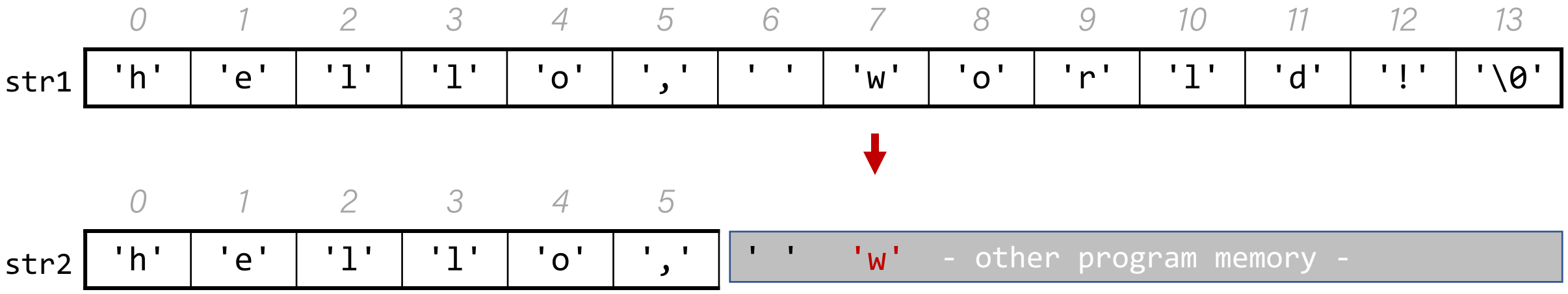

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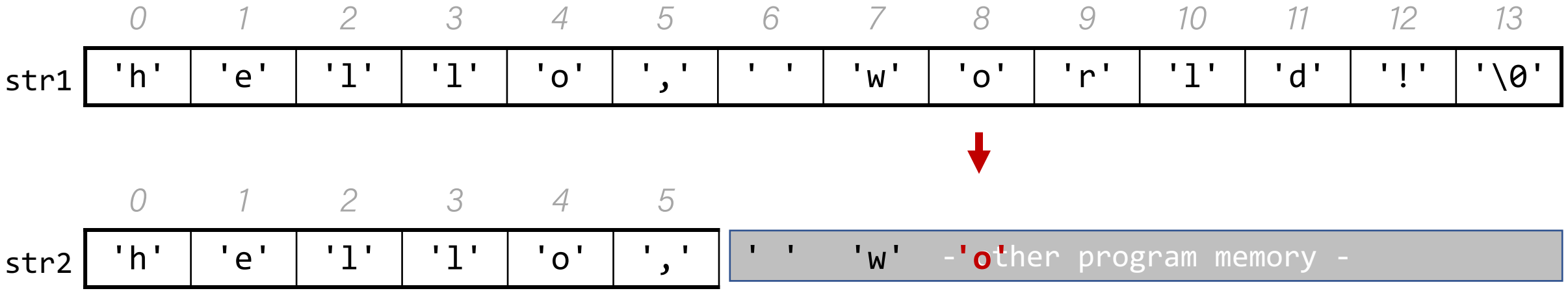

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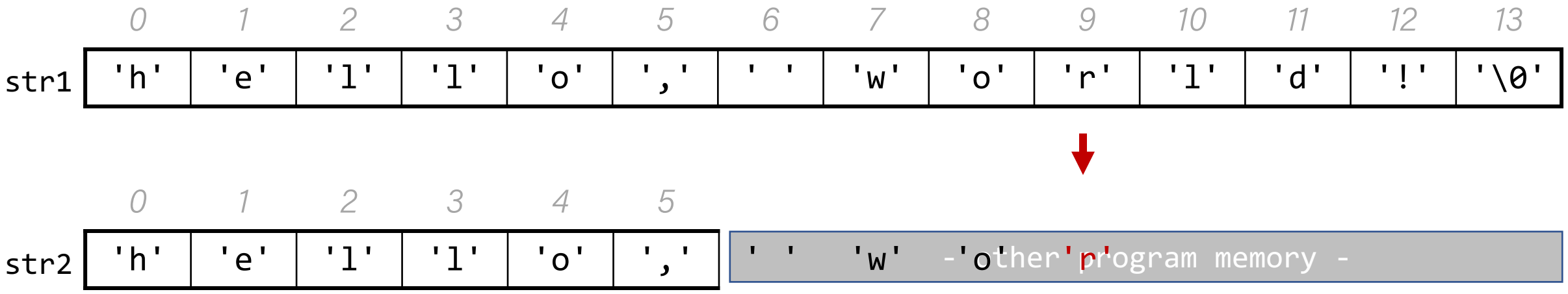

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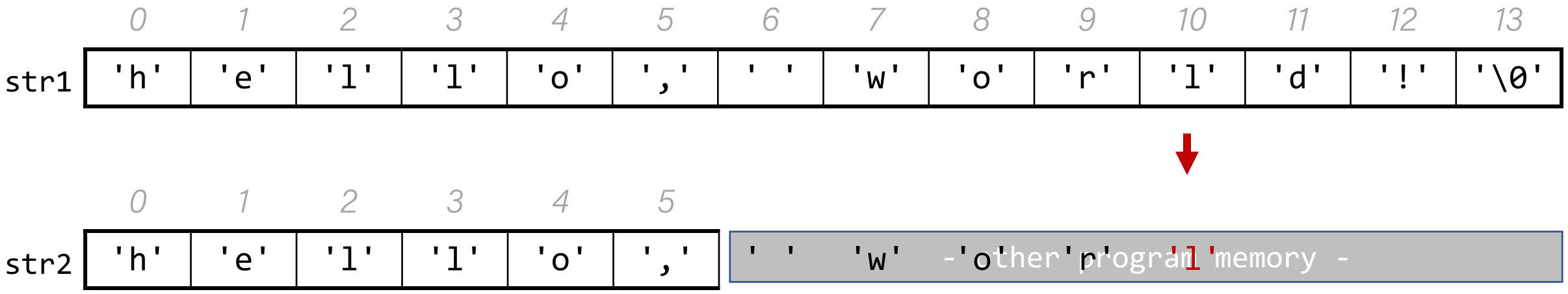

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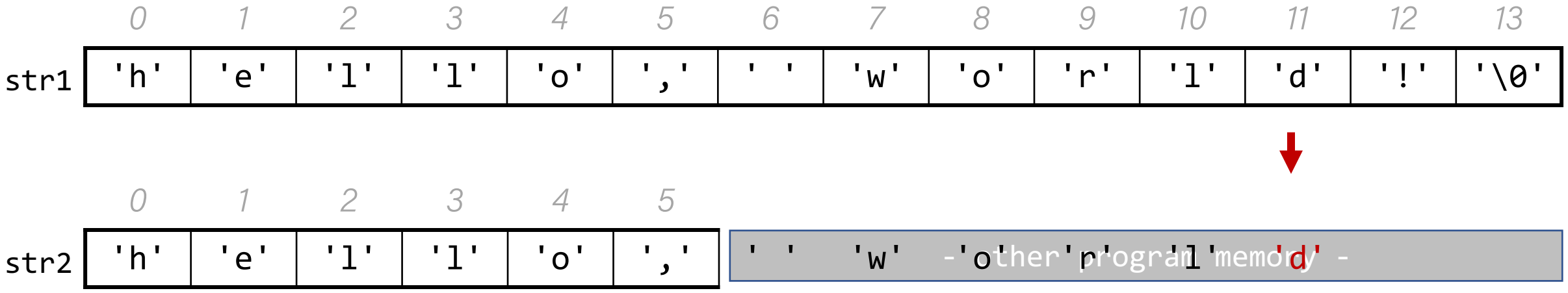

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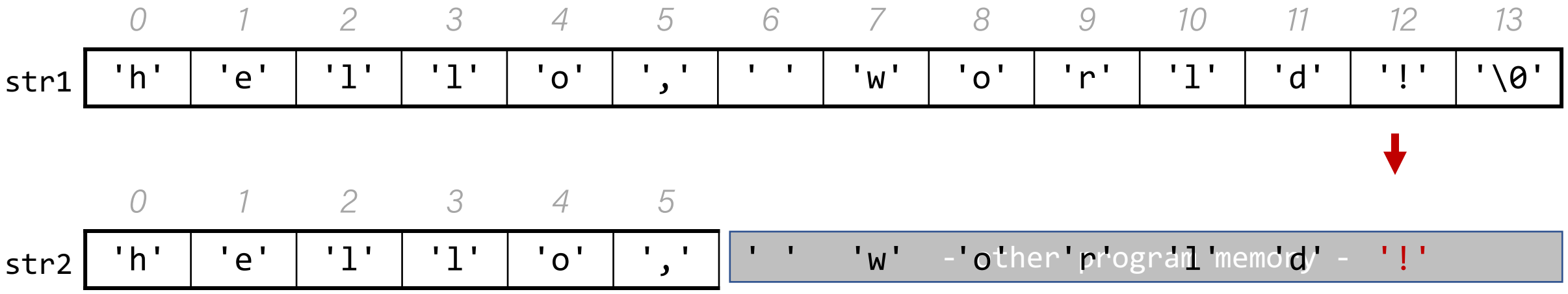

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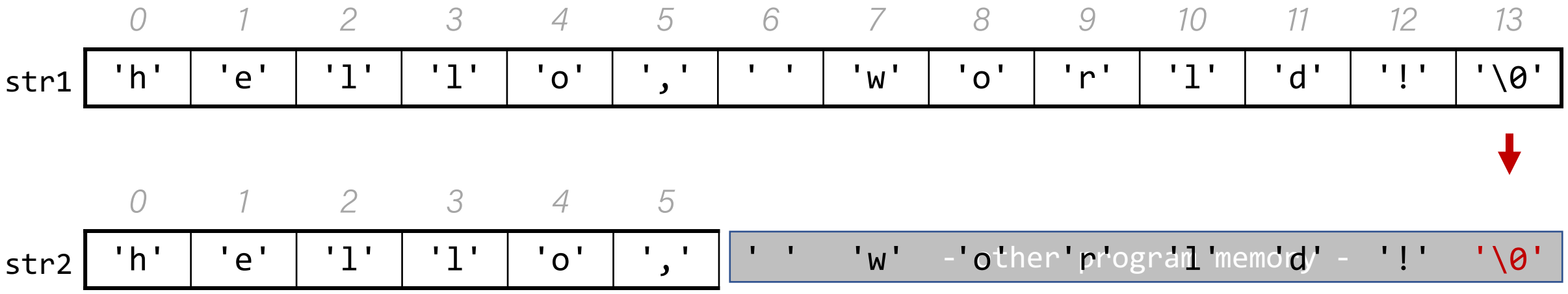
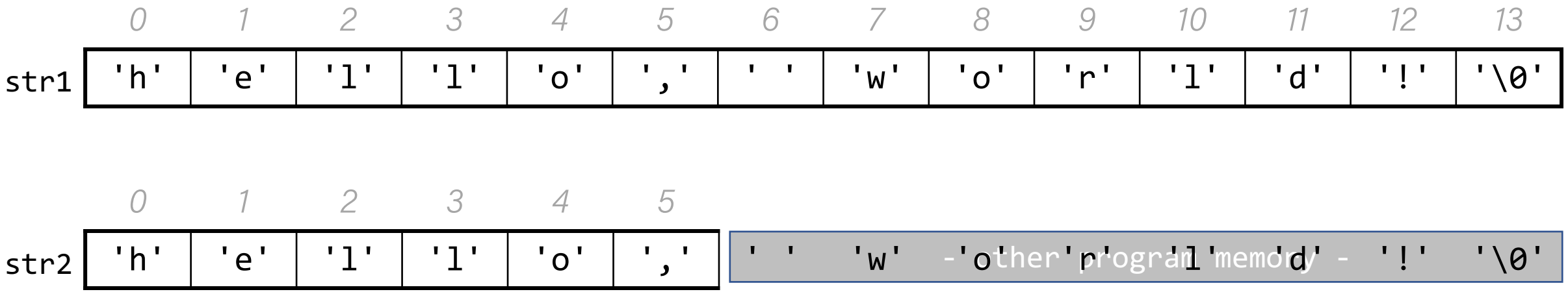
strcpy(str1, "hello, world!");
char str2[6];
strcpy(str2, str1);   // not enough space - overwrites other memory!
```



Copying Strings – Buffer Overflows

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



Copying Strings – `strncpy`

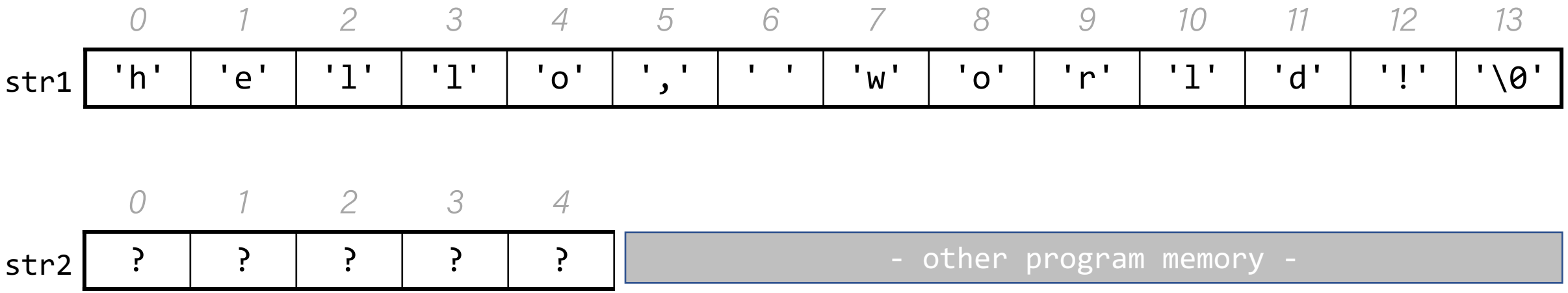
`strncpy(dst, src, n)`: copies at most the first n bytes from **src** into the string **dst**. If there is no null-terminating character in these bytes, then **`dst`** will *not be null terminated*!

```
// 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);
```



Copying Strings – strncpy

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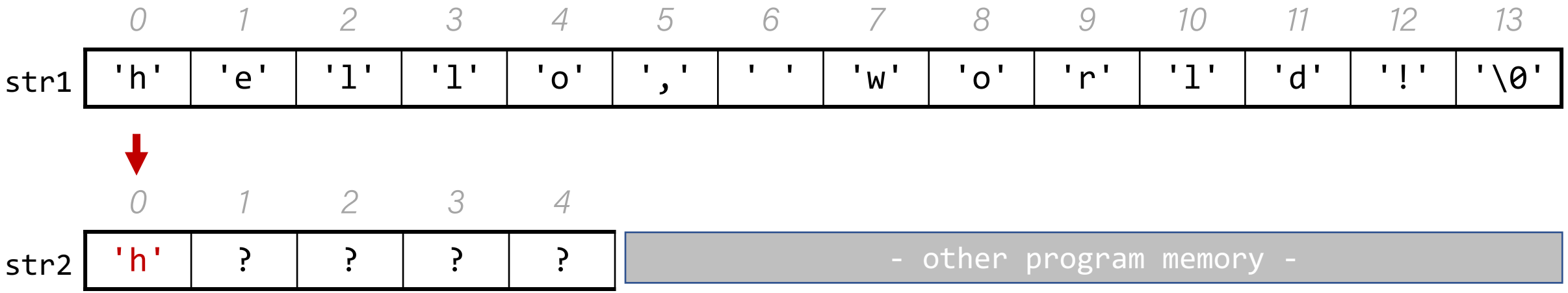

Copying Strings – strncpy

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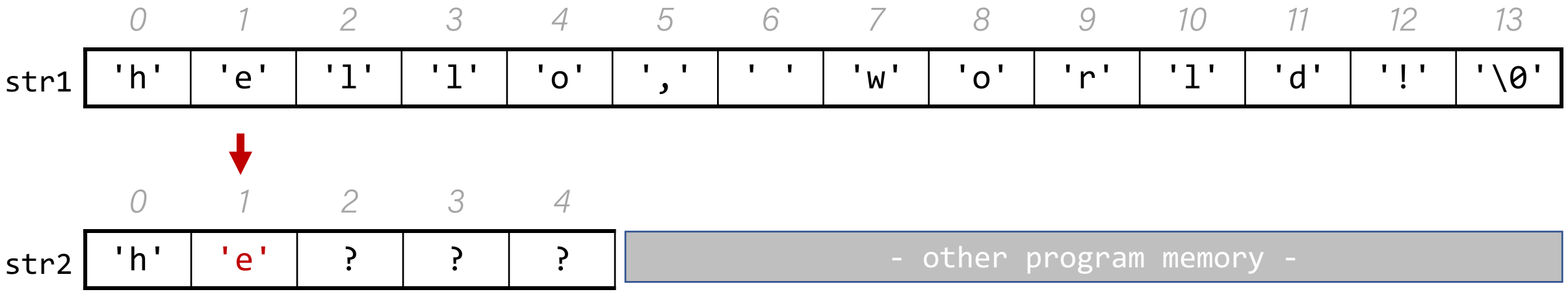

Copying Strings – strncpy

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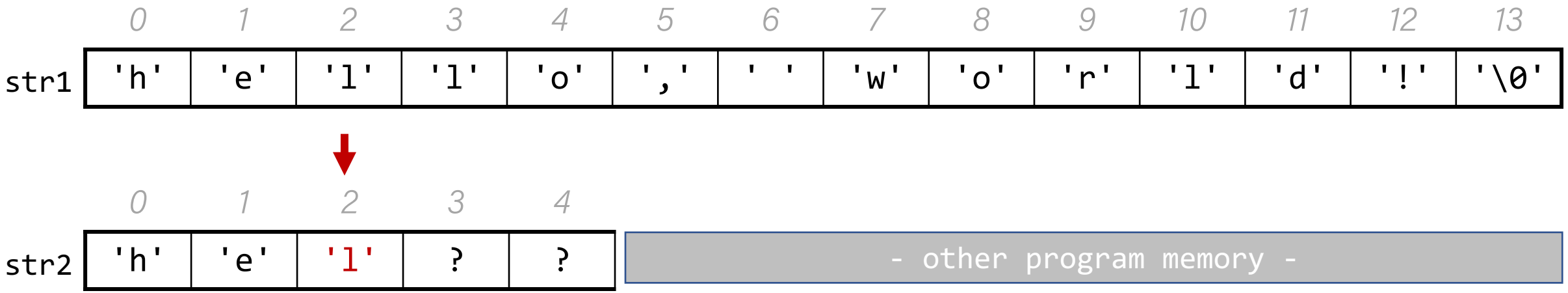

Copying Strings – strncpy

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int length = strlen(str2);
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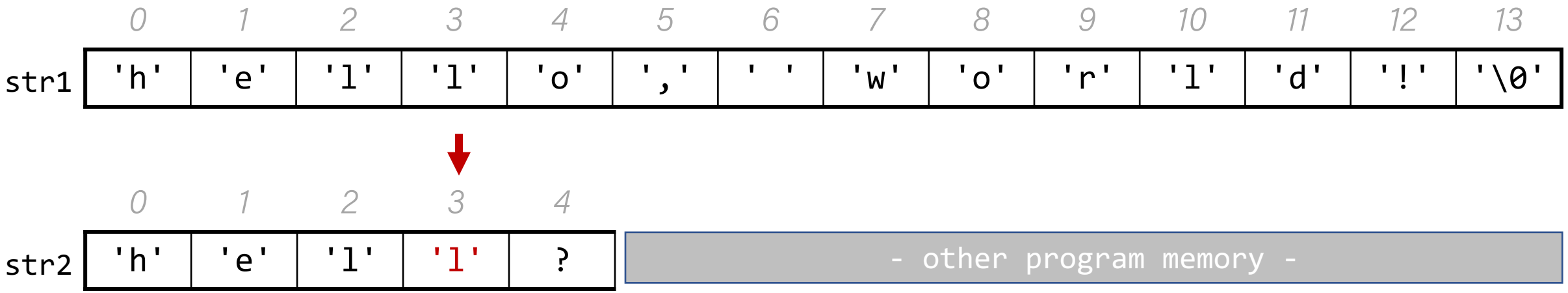

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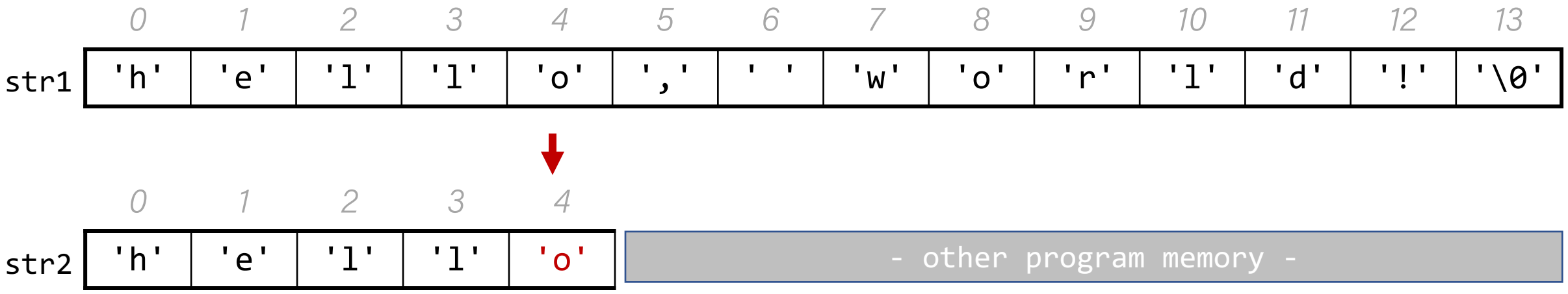

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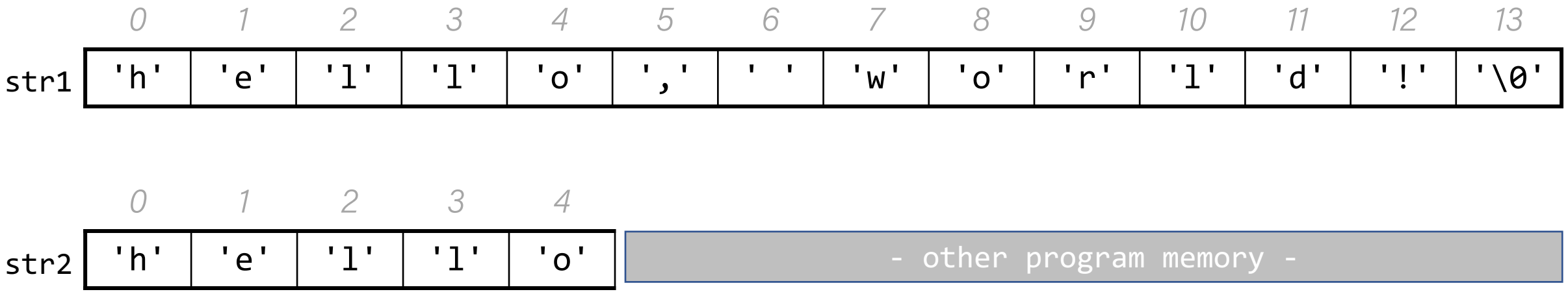

Copying Strings – strncpy

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int length = strlen(str2);
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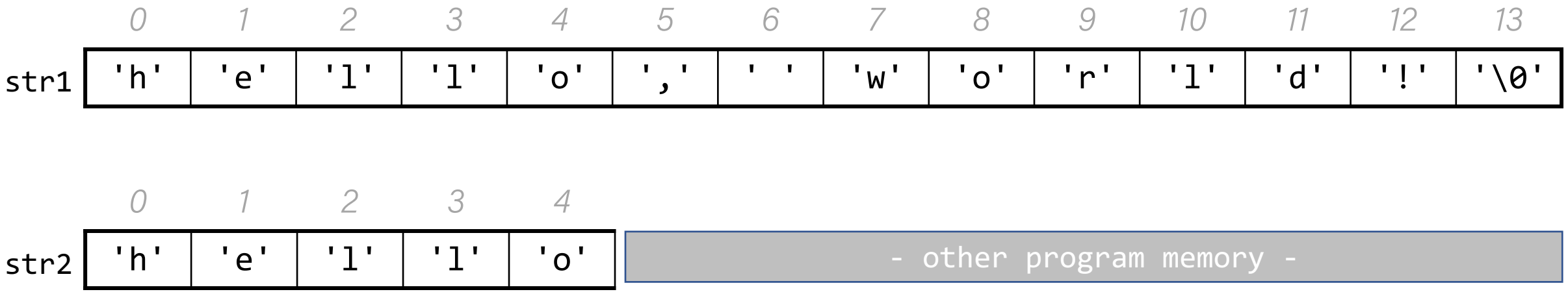

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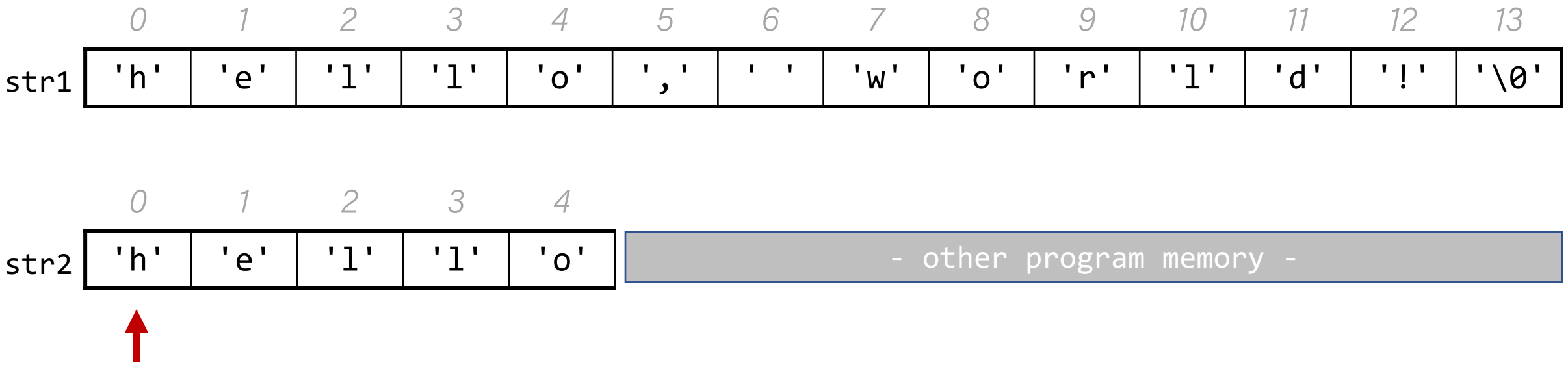

Copying Strings – strncpy

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int length = strlen(str2);
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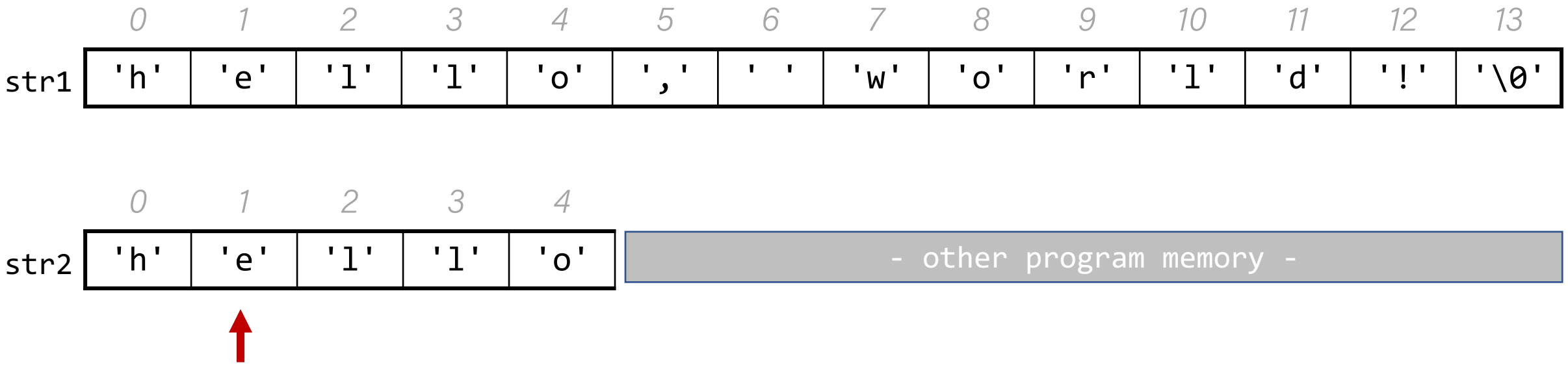

Copying Strings – strncpy

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int length = strlen(str2);
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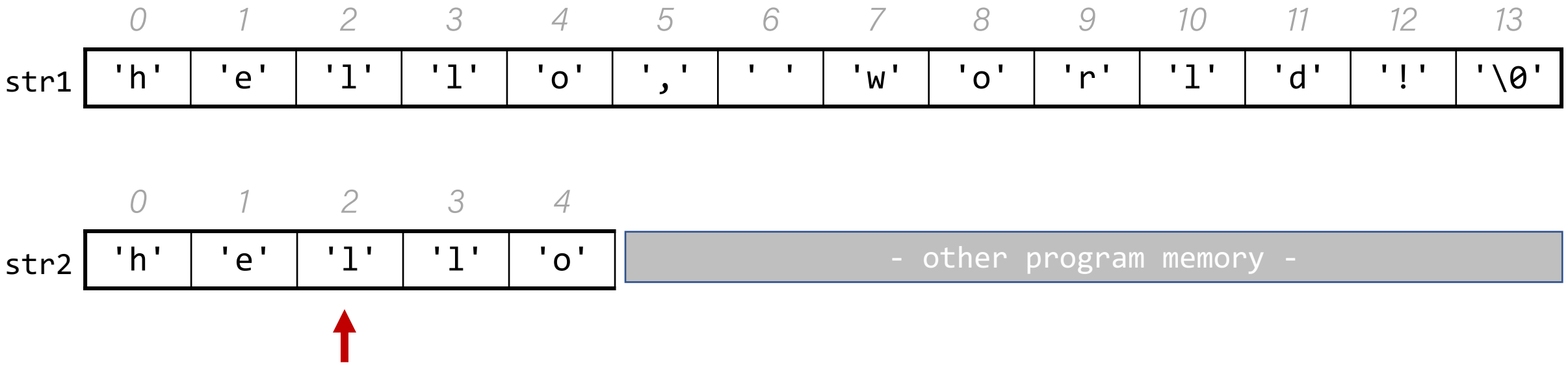

Copying Strings – strncpy

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

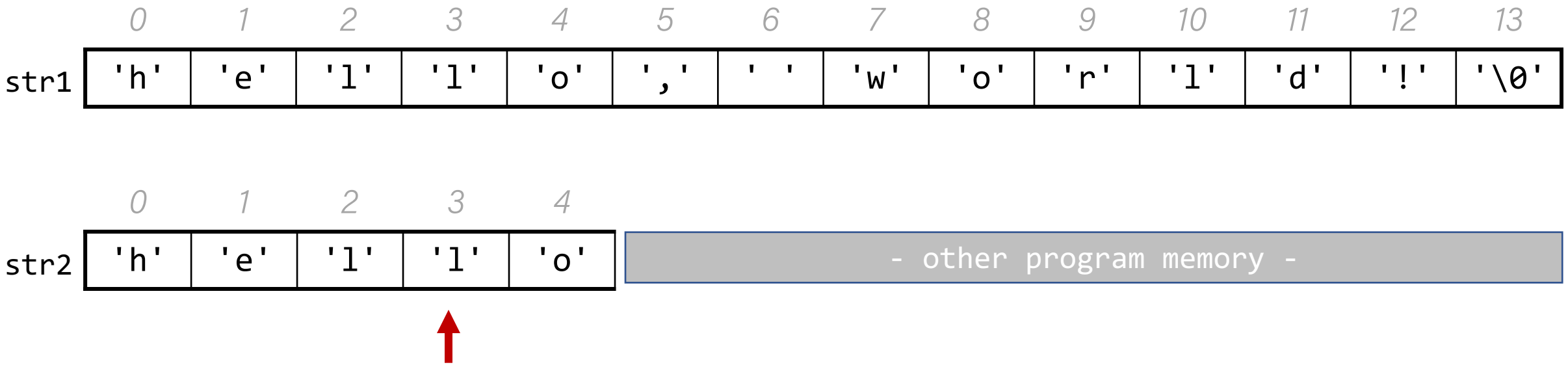

Copying Strings – strncpy

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int length = strlen(str2);
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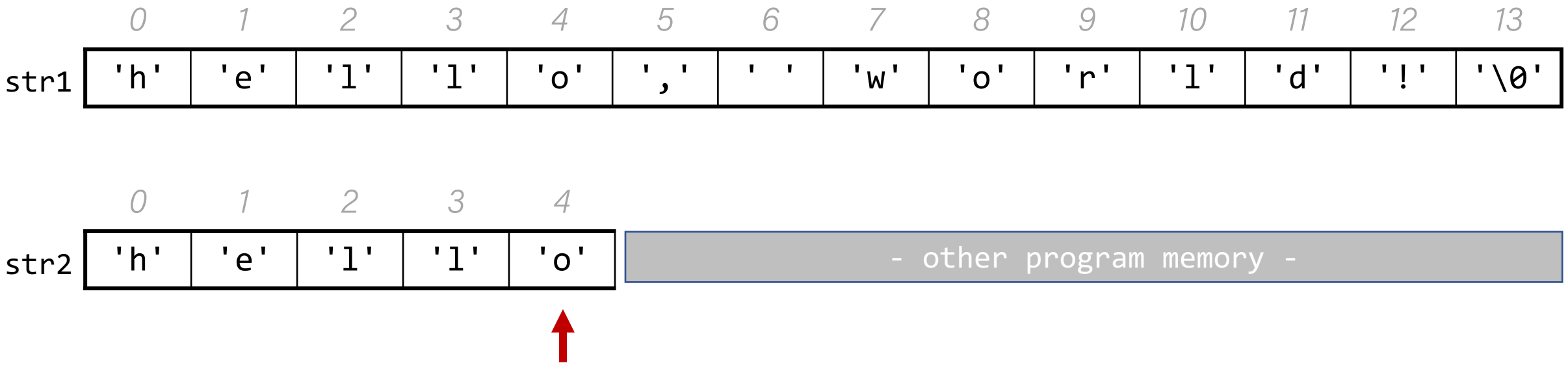

Copying Strings – strncpy

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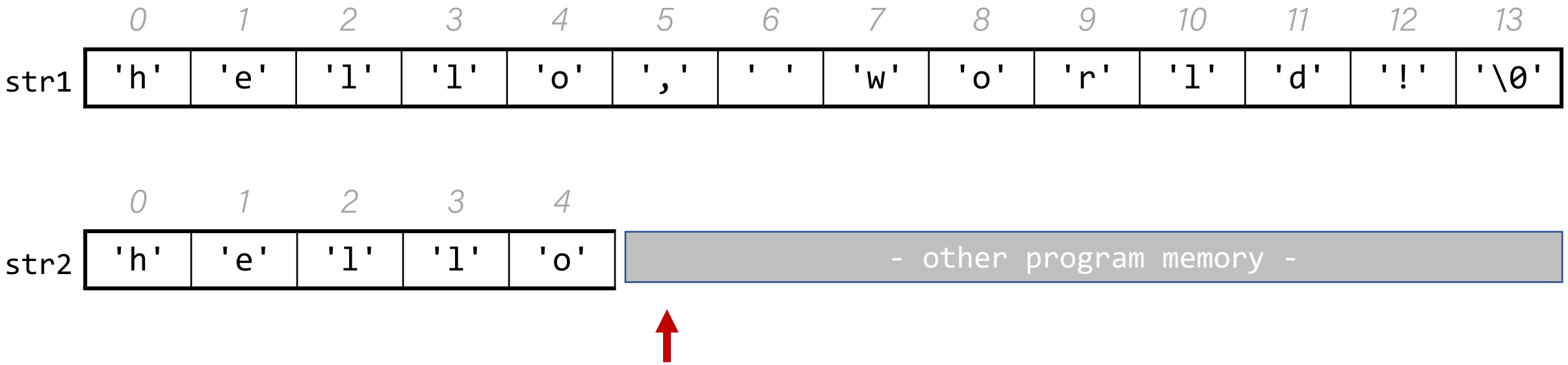

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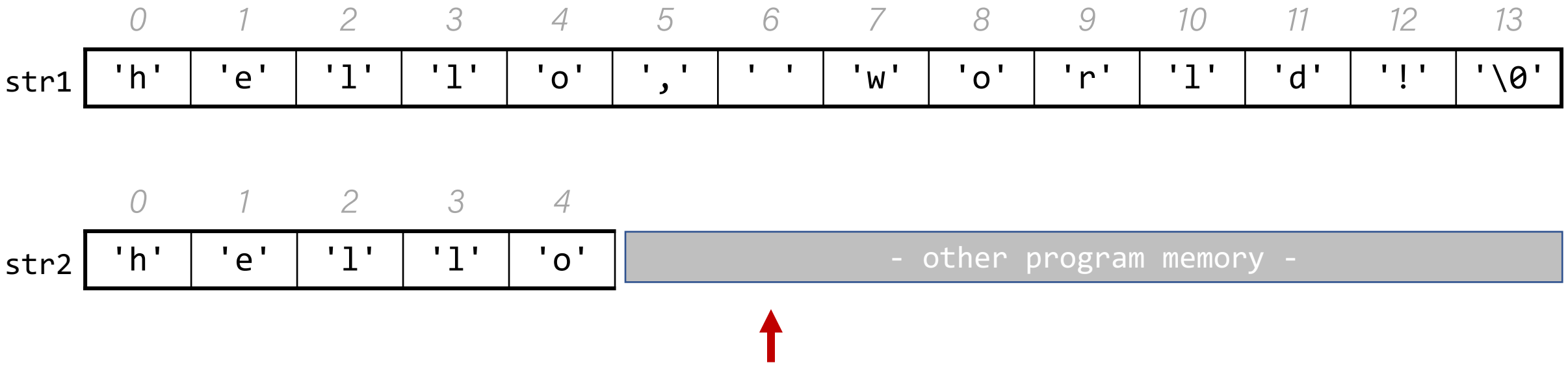

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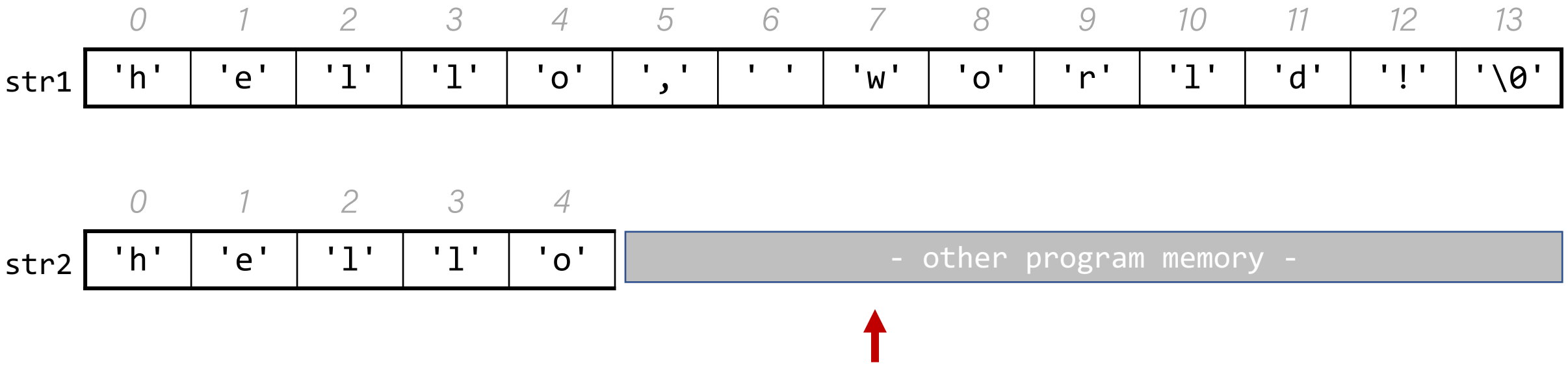

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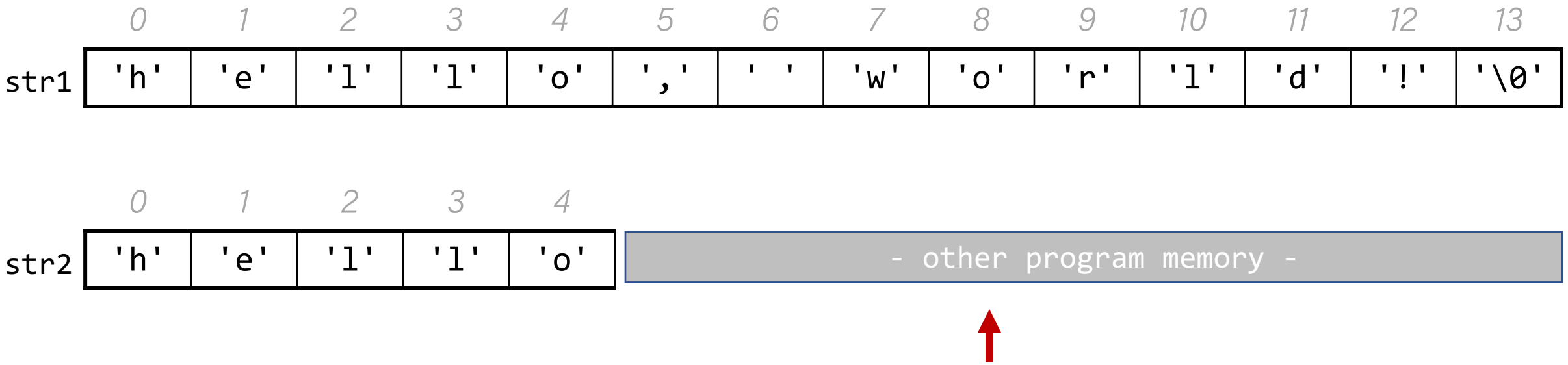
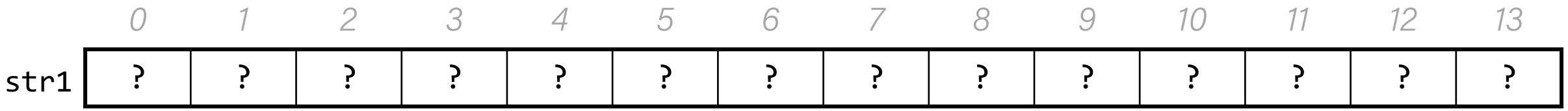


Copying Strings – `strncpy`

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



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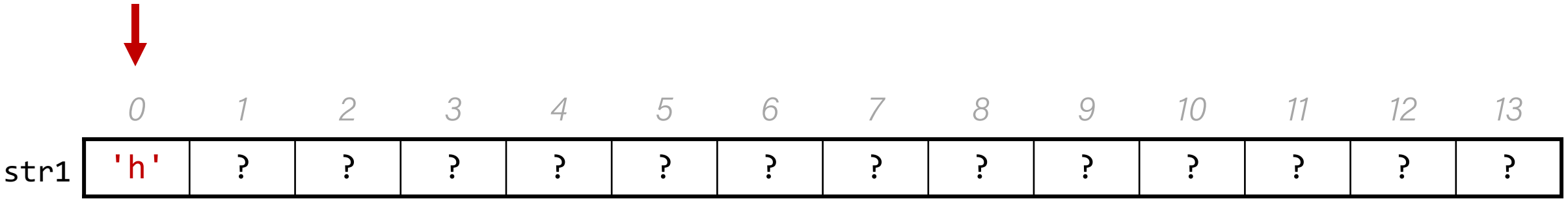

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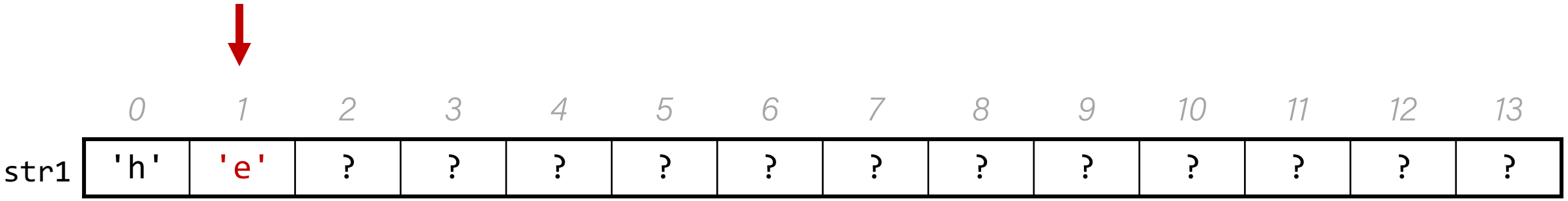

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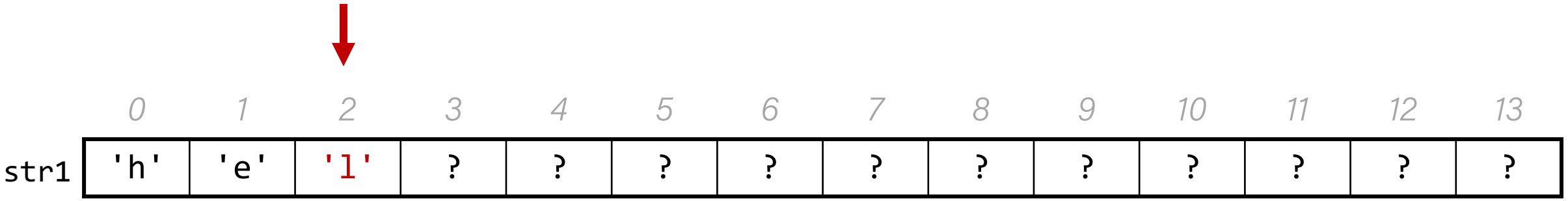

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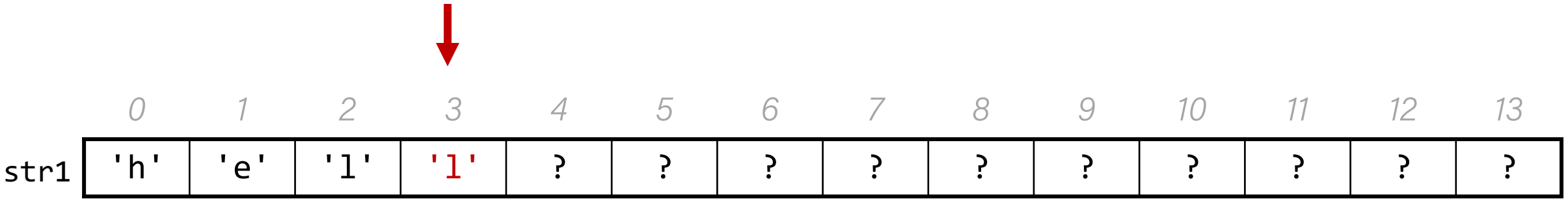

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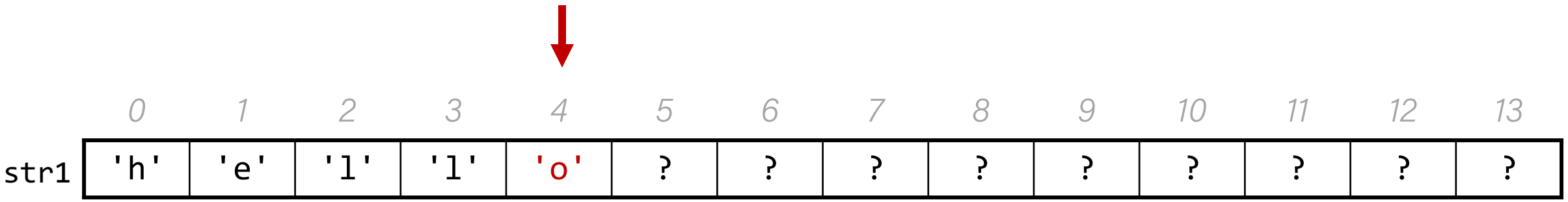

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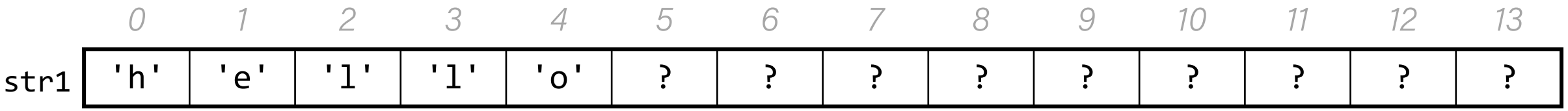

Copying Strings – strncpy

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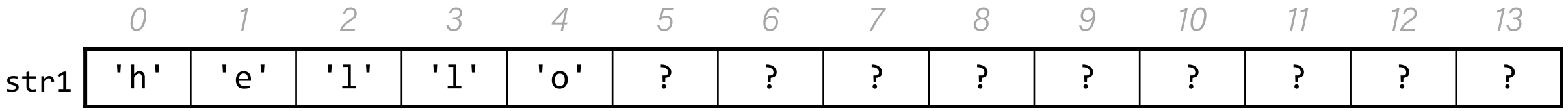

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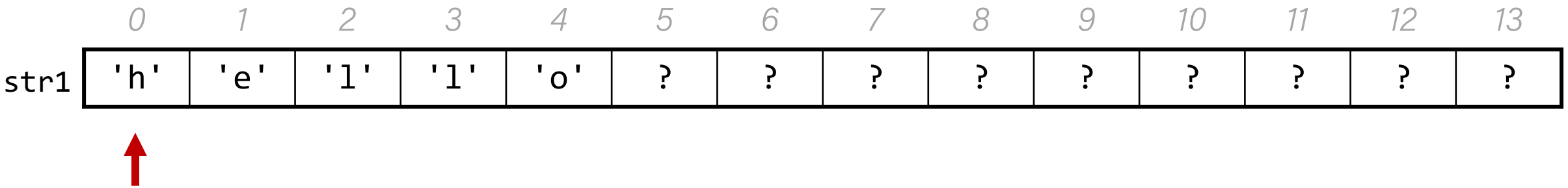

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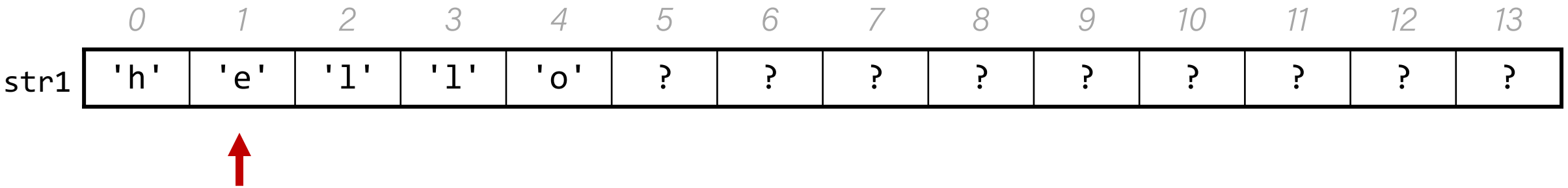

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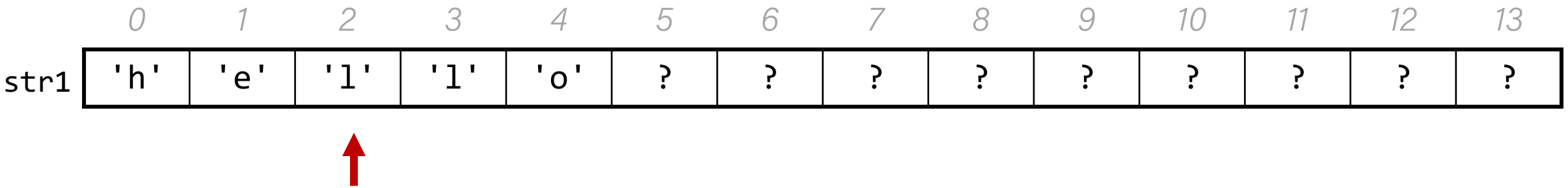

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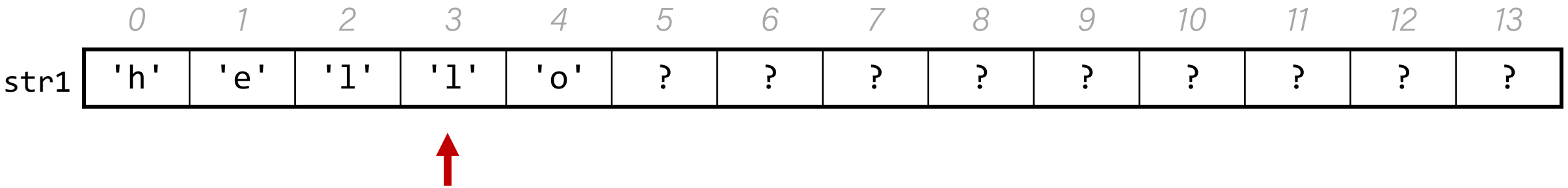

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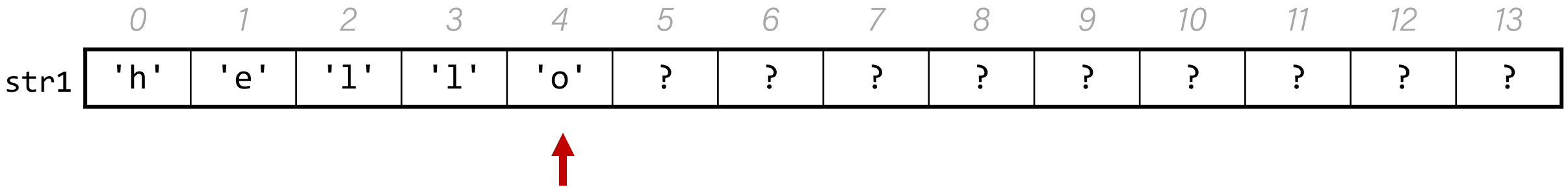

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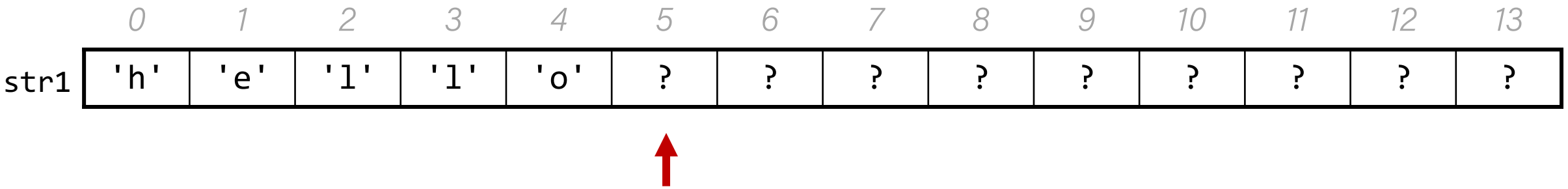

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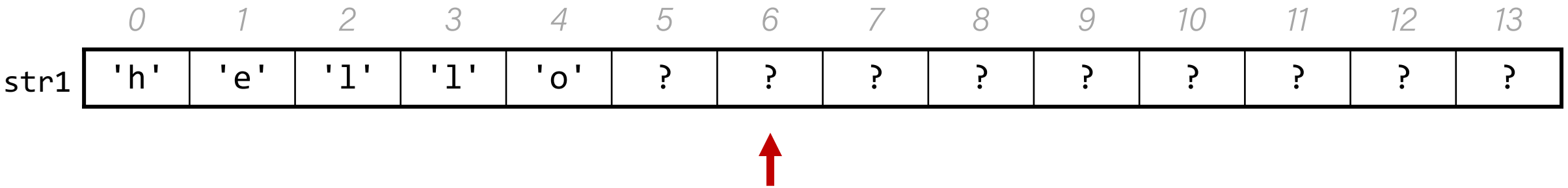

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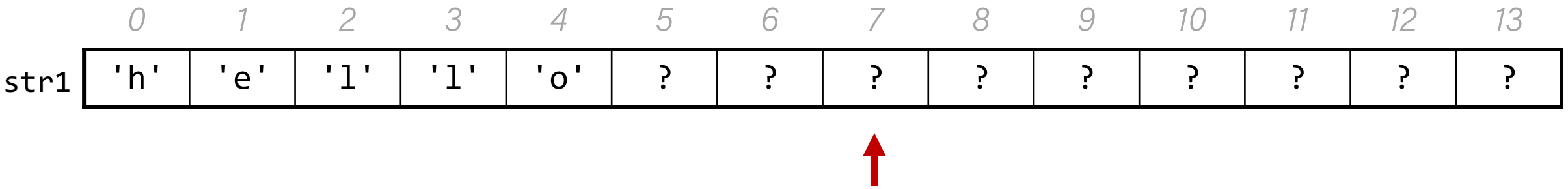

Copying Strings – `strncpy`

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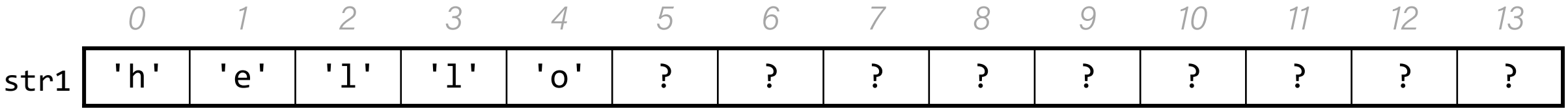


```
hello? ?J? ? ?
```

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
```

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

Recap

- Characters
- Strings
- Common String Operations
  - Comparing
  - Copying
  - Concatenating
  - Substrings

Next time: more strings