Introduction to Programming (C/C++)

04: C Advanced

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Last Lecture

- **Array & Pointer**
  - Pointer arithmetic, pointer as function argument, dynamic array

- **Function**
  - Call stack, pass-by-value, variable scope

C String

- An array of characters terminated with the null character `'\0'`

"Tea Garden"

T	e	a	\20	G	a	r	d	e	n	\0

C String

```
char s[] = “Tea Garden”;
```

C String

```
char s[] = “Tea Garden”;
```

```
char s[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’, ‘\0’};
```

C String

```
char s[] = “Tea Garden”;
```

```
char s[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’, ‘\0’};
```

```
char s[11] = “Tea Garden”;
```

C String

```
char s[] = “Tea Garden”;
```

```
char s[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’, ‘\0’};
```

```
char s[11] = “Tea Garden”;
```

Make sure enough space is allocated

C String

```
char s[] = “Tea Garden”;
```

```
char *s = “Tea Garden”;
```

C String

```
char s[] = “Tea Garden”;
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```
char *s = “Tea Garden”;
```

Allocates an 11-byte array on stack

C String

```
char s[] = “Tea Garden”;
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Allocates an 11-byte array on stack

```
char *s = “Tea Garden”;
```

Allocates a pointer on stack

C String

```
char s[] = “Tea Garden”;
```

Allocates an 11-byte array on stack

Compact way to initialize the array

```
char *s = “Tea Garden”;
```

Allocates a pointer on stack

C String

```
char s[] = “Tea Garden”;
```

Allocates an 11-byte array on stack

Compact way to initialize the array

```
char *s = “Tea Garden”;
```

Allocates a pointer on stack

String Literal (**read-only**)

C String

```
char s[] = “Tea Garden”;
```

Allocates an 11-byte array on stack

Compact way to initialize the array

```
char *s = “Tea Garden”;
```

Allocates a pointer on stack

String Literal (**read-only**)

```
s[0] = 'S';
```

```
s[0] = 'S';
```

Undefined Behavior

C String

```
const char *s = “Tea Garden”;
s[0] = ’S';
```

C String

```
const char *s = “Tea Garden”;

s[0] = 'S';
```

Error will be caught by the **compiler**

C String

```
char s[] = “Tea Garden”;
```

s	T	e	a	\20	G	a	r	d	e	n	\0

C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
```

s	T	e	a	\20	G	a	r	d	e	n	\0

C String

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char s[] = “Tea Garden”;
const char *const_char_p = s;
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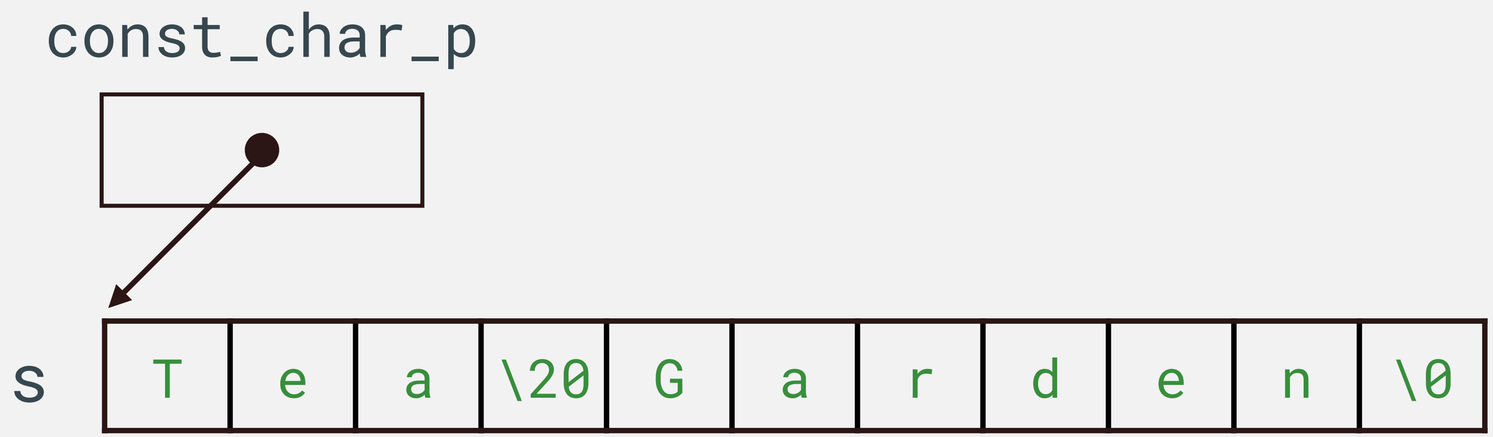
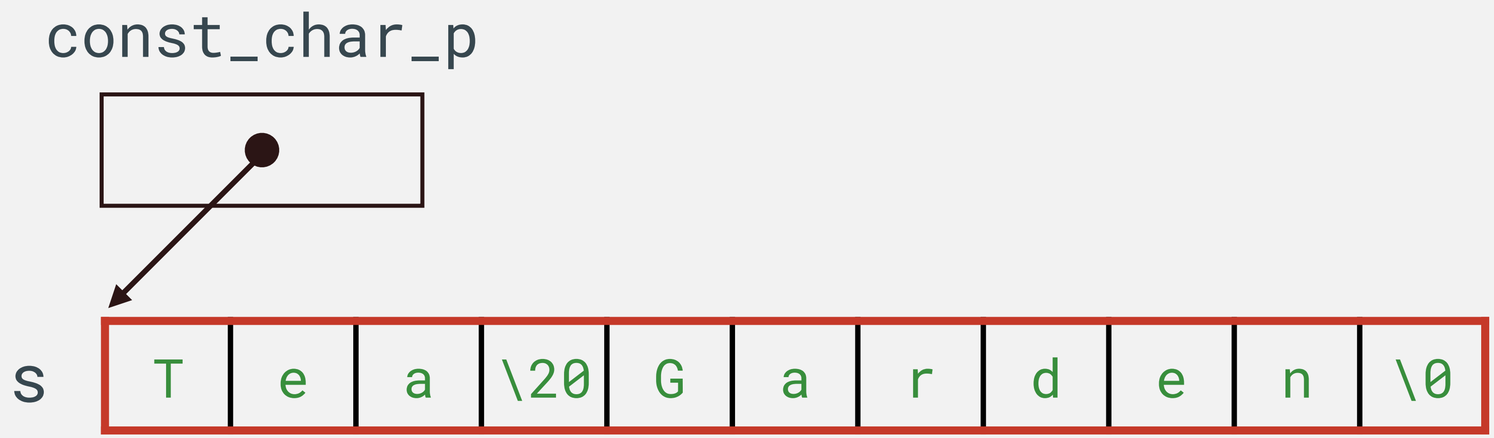


C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
```

The **content** in the char array is immutable



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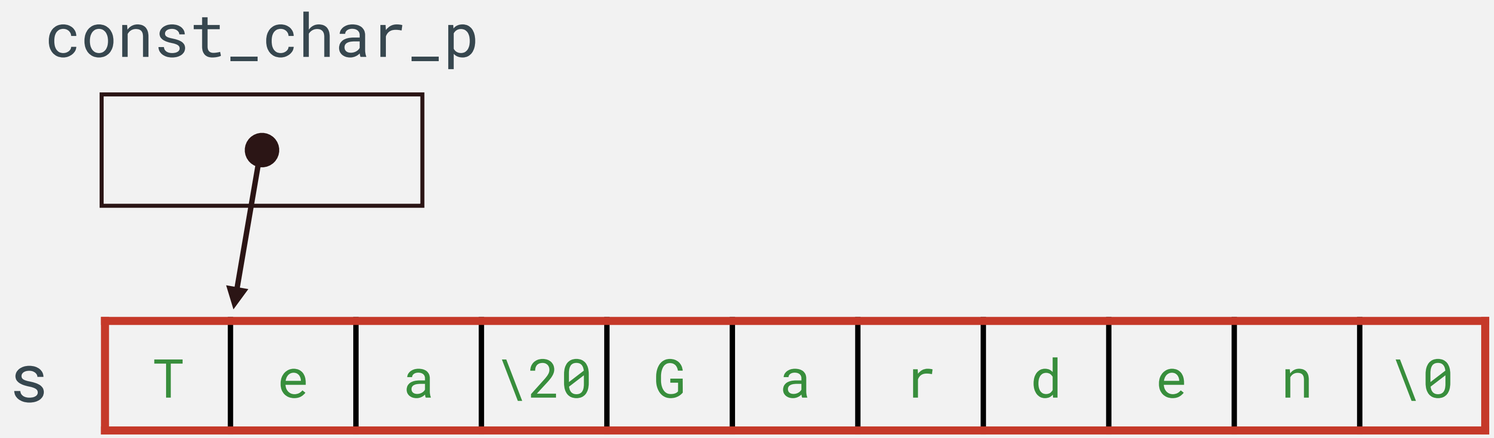

C String

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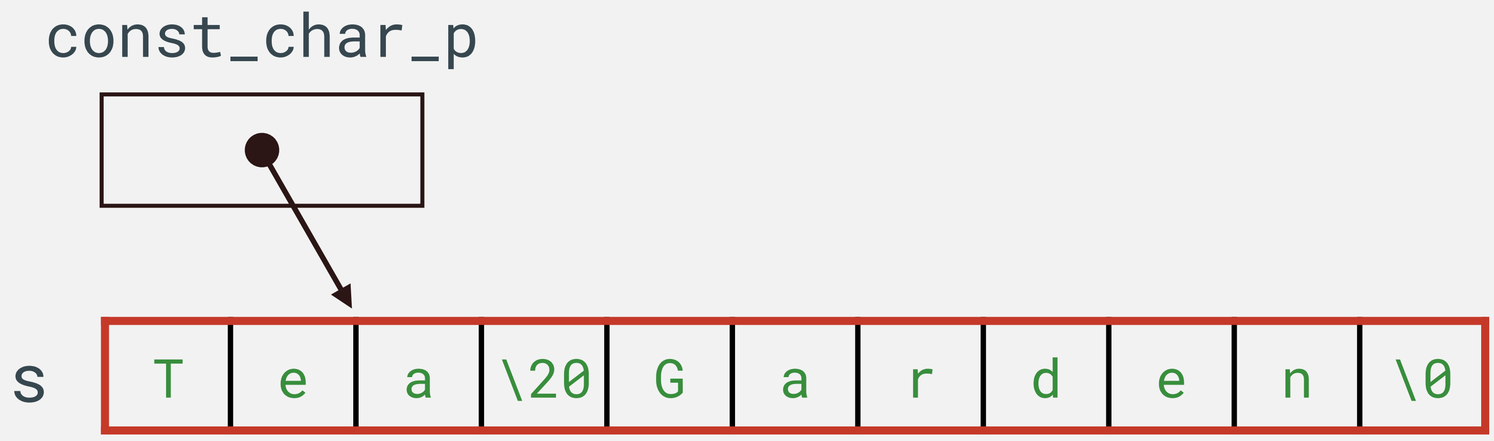
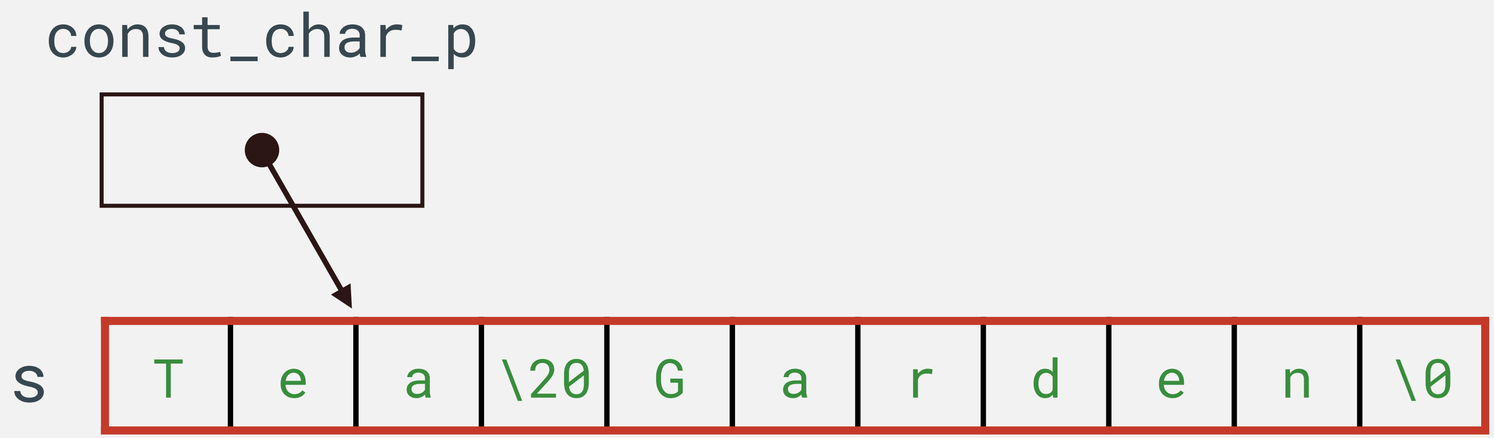


C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
const_char_p++;
```

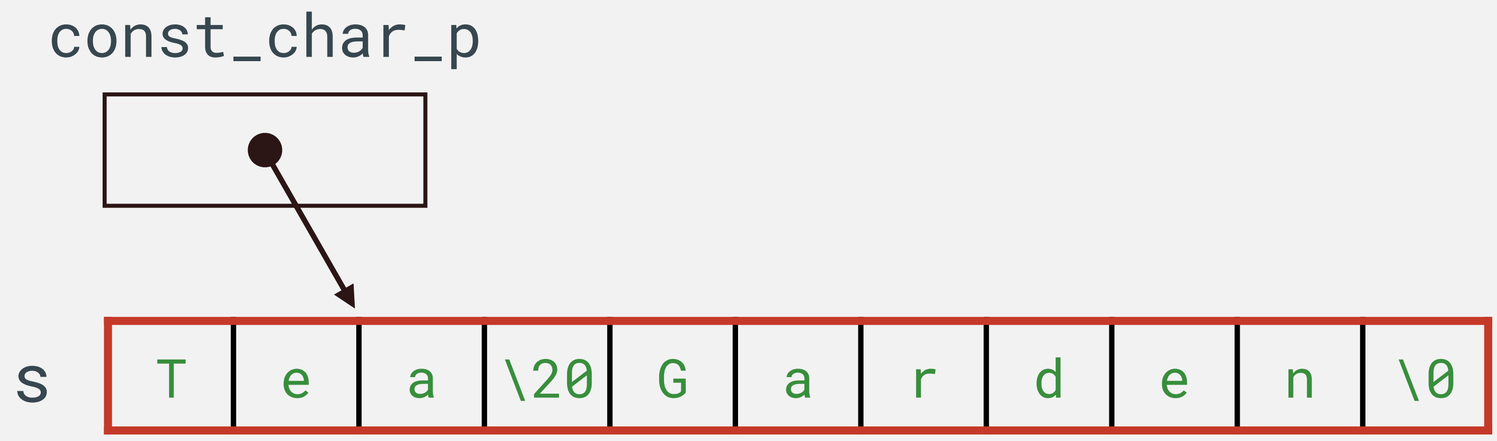
The **content** in the char array is immutable



C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
const_char_p++;
const_char_p[2] = ’n’;
```

The **content** in the char array is immutable



C String

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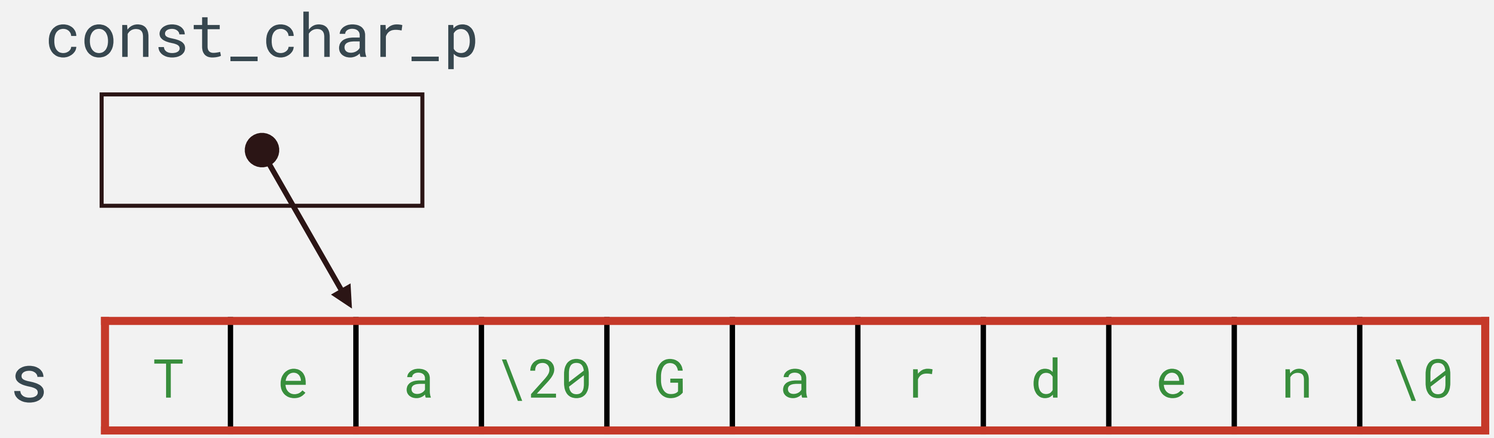

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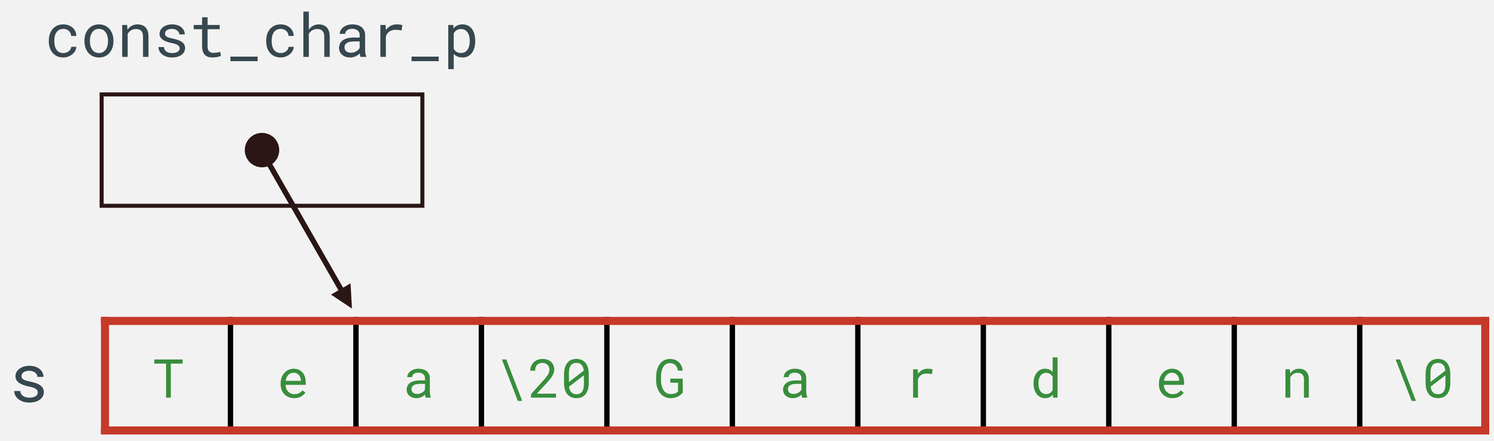

C String

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char const *char_const_p = s;
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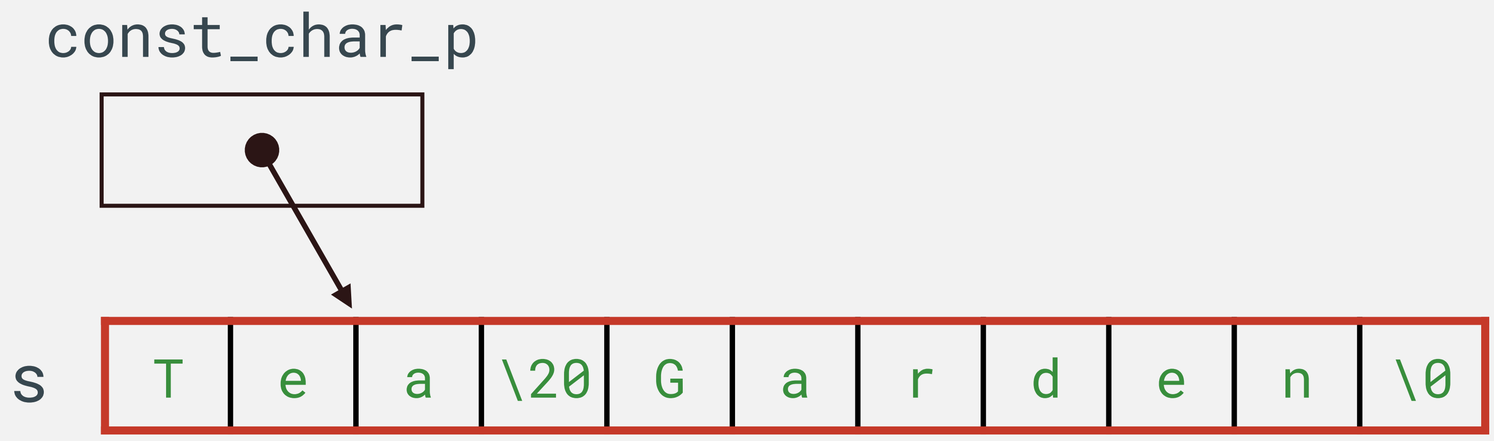

C String

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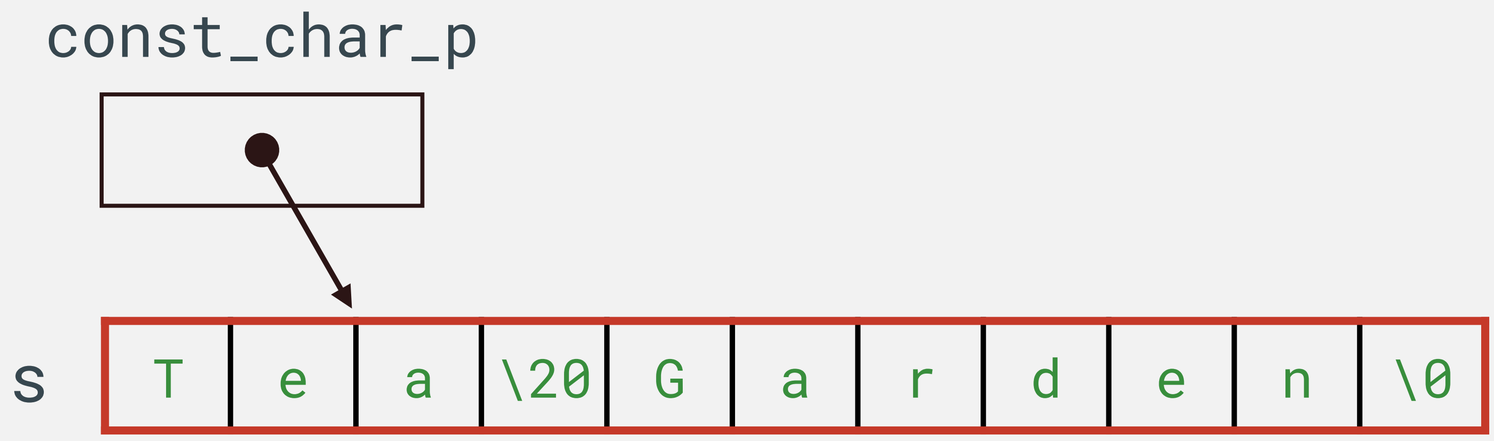
← The **content** in the char array is immutable

← Equivalent as above

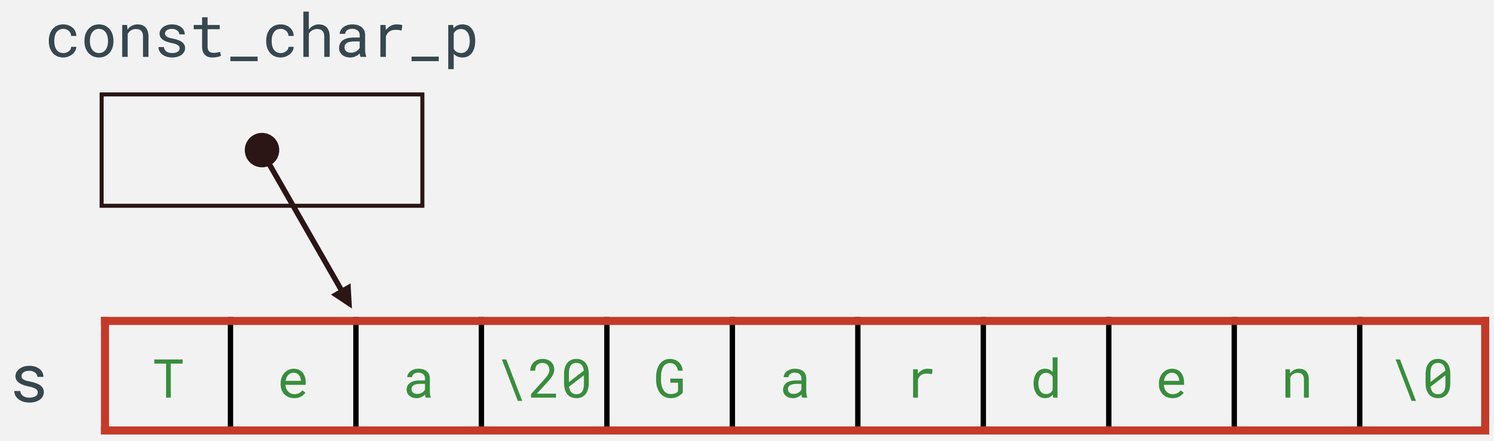


C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
```

The **content** in the char array is immutable

~~`char const *char_const_p = s;`~~ ~~Equivalent as above~~



C String

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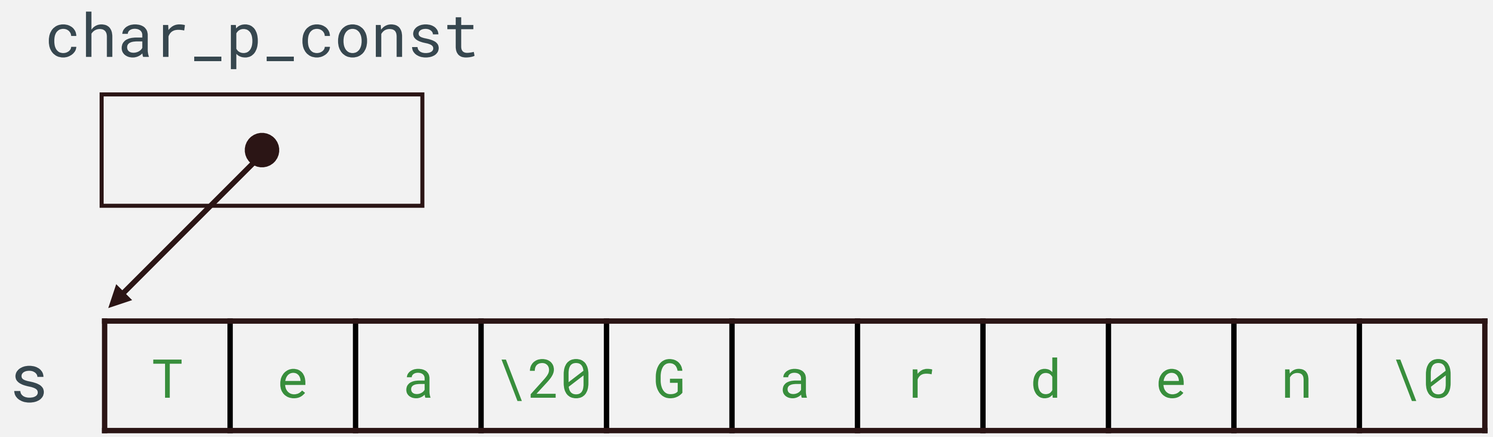
← The **content** in the char array is immutable

s	T	e	a	\20	G	a	r	d	e	n	\0

C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
char * const char_p_const = s;
```

The **content** in the char array is immutable

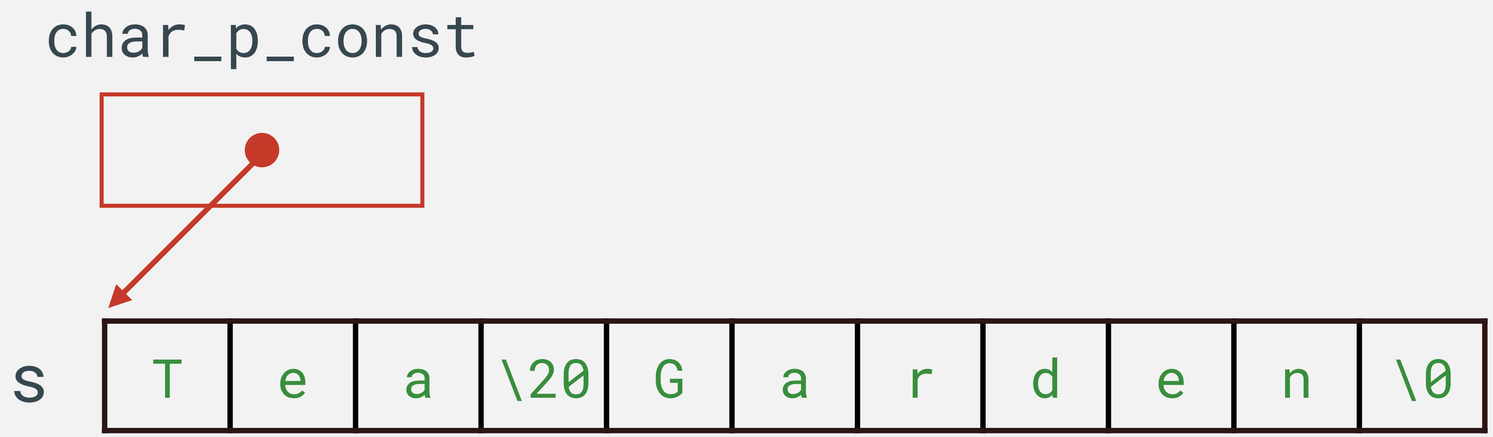


C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
char * const char_p_const = s;
```

The **content** in the char array is immutable

The **pointer** itself is immutable

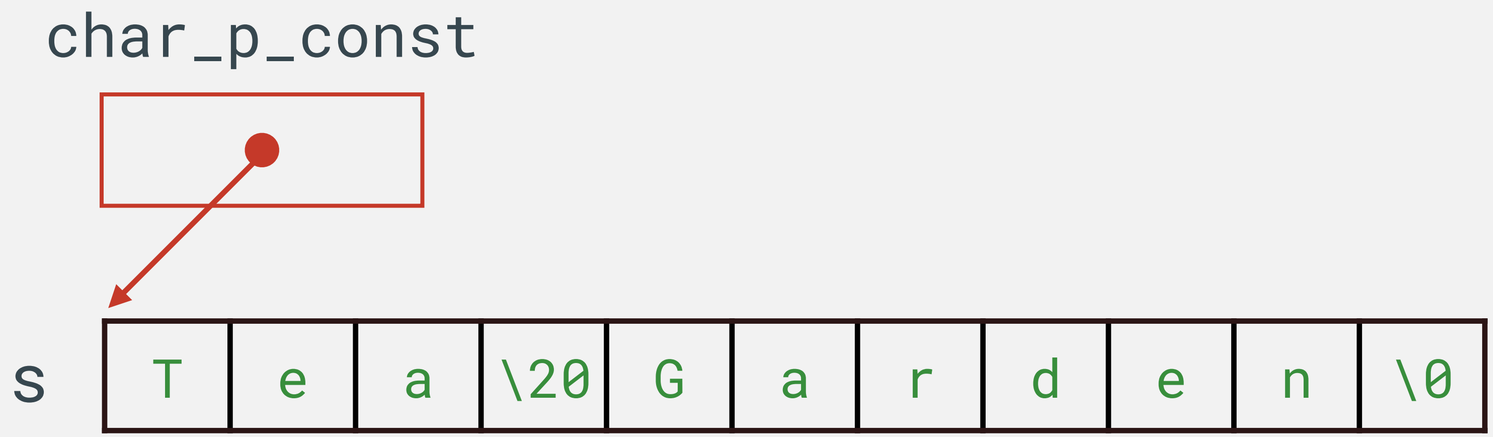


C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
char * const char_p_const = s;
char_p_const++;
*(char_p_const + 2) = ’n’;
```

The **content** in the char array is immutable

The **pointer** itself is immutable



C String

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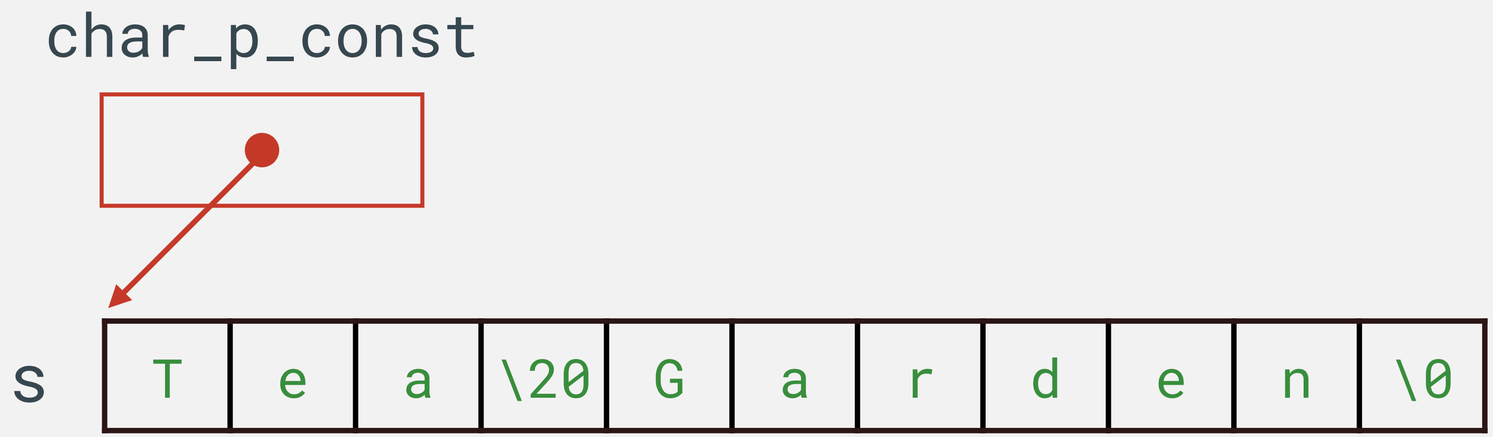
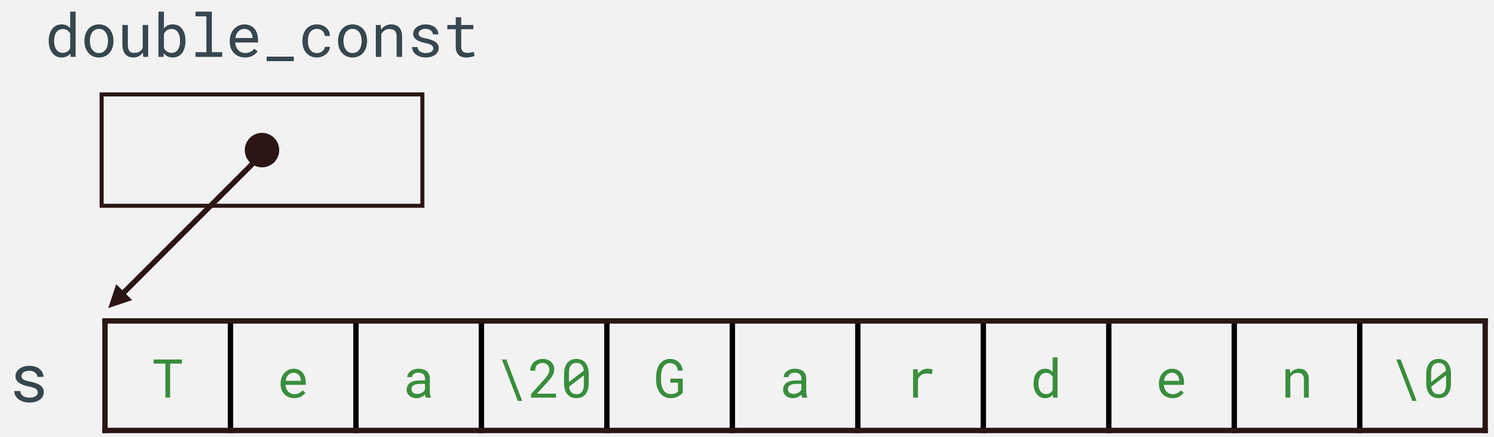


C String

```
char s[] = “Tea Garden”;
const char *const_char_p = s;
char * const char_p_const = s;
const char * const double_const = s;
```

The **content** in the char array is immutable

The **pointer** itself is immutable



C String

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char * const char_p_const = s;
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The **content** in the char array is immutable

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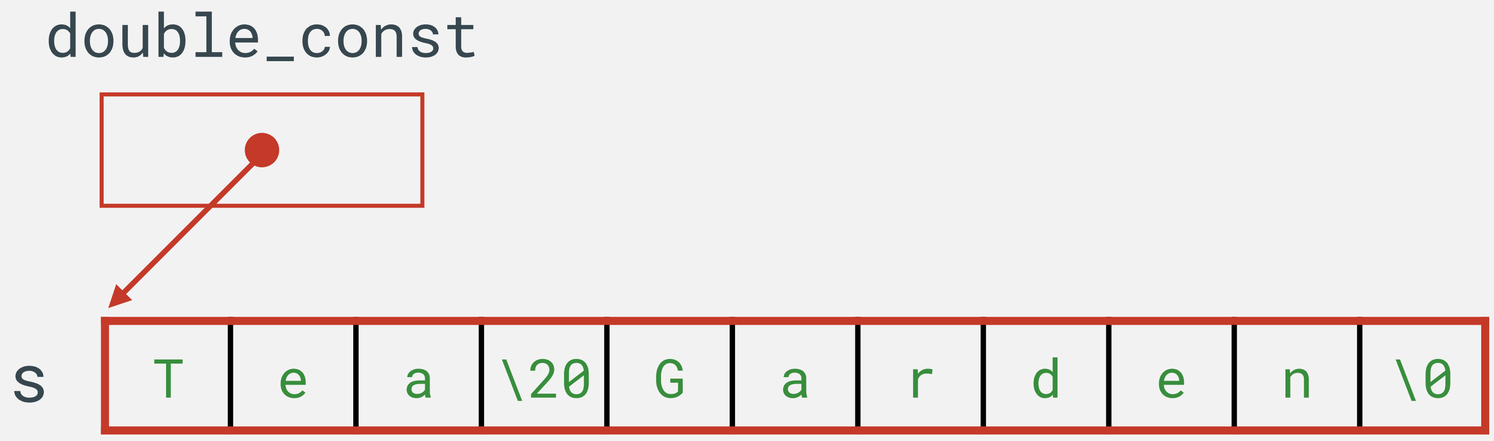

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
```

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
```

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
```

← Copies the pointer only

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

← Copies the first element only

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

← Copies the first element only

```
for (int i = 0; i < 20; i++)
  s2[i] = s1[i];
```

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

← Copies the first element only

```
int i = 0;
while (s1[i] != ‘\0’) {
  s2[i] = s1[i];
  i++;
}
```

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

← Copies the first element only

```
int i = 0;
while (s1[i] != ‘\0’) {
  s2[i] = s1[i];
  i++;
}
```

```
while (*s2_copy++ = *s1_copy++)
  ;
```

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

← Copies the first element only

```
strcpy(s2, s1); // #include <string.h>
```

String Copy

```
char s1[20] = “Tea Garden”;
char s2[20];
s2 = s1;
*s2 = *s1;
```

← Copies the pointer only

← Copies the first element only

```
strcpy(s2, s1); // #include <string.h>
```

Make sure s2 has enough space

String Compare

```
char s1[] = “Tea Garden”;
char s2[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’};


if (s1 == s2)
  printf(“Same String\n”);
```

String Compare

```
char s1[] = “Tea Garden”;
char s2[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’};


if (s1 == s2)
  printf(“Same String\n”);
```

← Compares the pointer (array address) only

String Compare

```
char s1[] = “Tea Garden”;
char s2[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’};

// #include <string.h>
if (strcmp(s1, s2) == 0)
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```

String Compare

```
char s1[] = “Tea Garden”;
char s2[] = {’T’, ‘e’, ‘a’, ‘ ’, ‘G’, ‘a’, ‘r’, ‘d’, ‘e’, ’n’};

// #include <string.h>
if (strcmp(s1, s2) == 0)
  printf(“Same String\n”);
else if (strcmp(s1, s2) < 0)
  printf(“s1 is smaller than s2\n”);
else
  printf(“s1 is greater than s2\n”);
```

String Length

```
char s1[] = “Tea Garden”;
printf(“s1 length = %u”, strlen(s1));
```

String Length

```
char s1[] = “Tea Garden”;
printf(“s1 length = %u”, strlen(s1));
```

‘\0’ **excluded**

Multi-Dimensional Array

```
int a[3][4];
```

Multi-Dimensional Array

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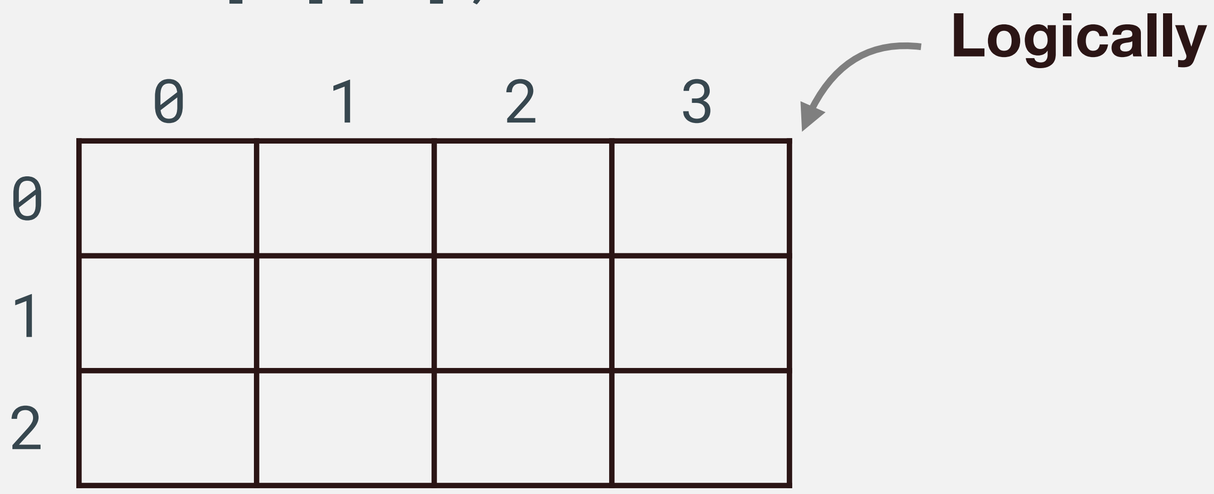

Multi-Dimensional Array

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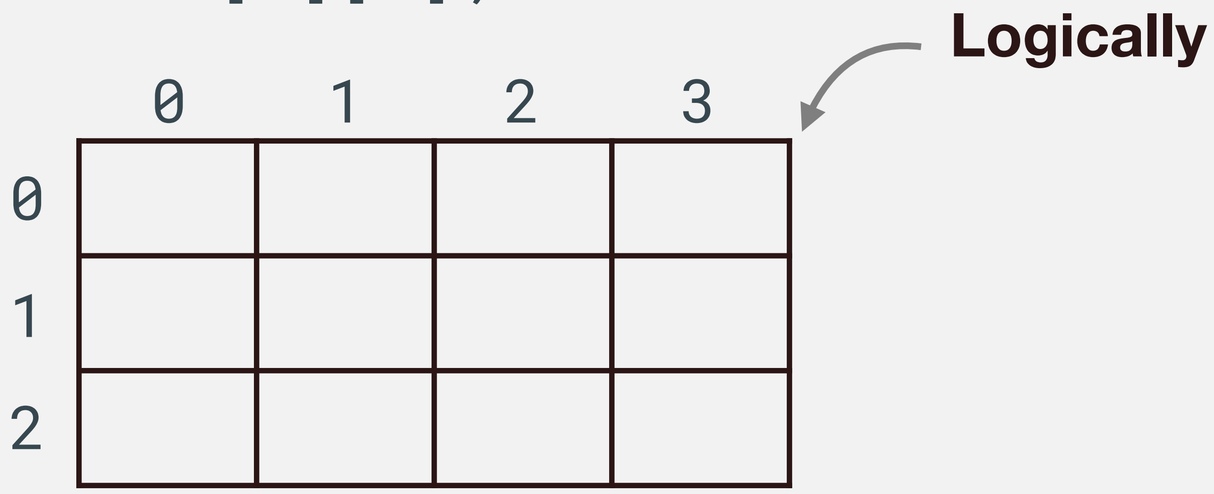

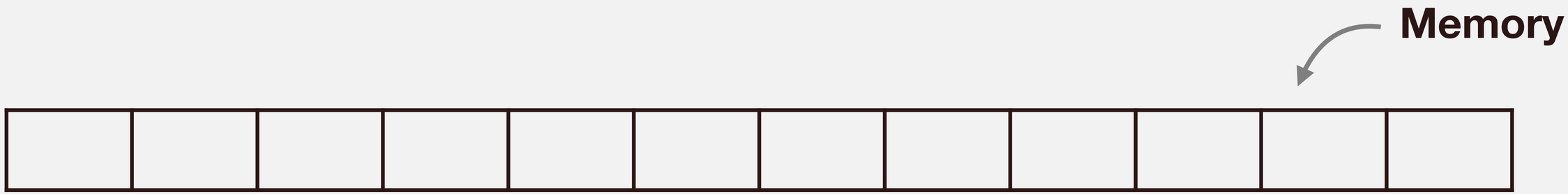

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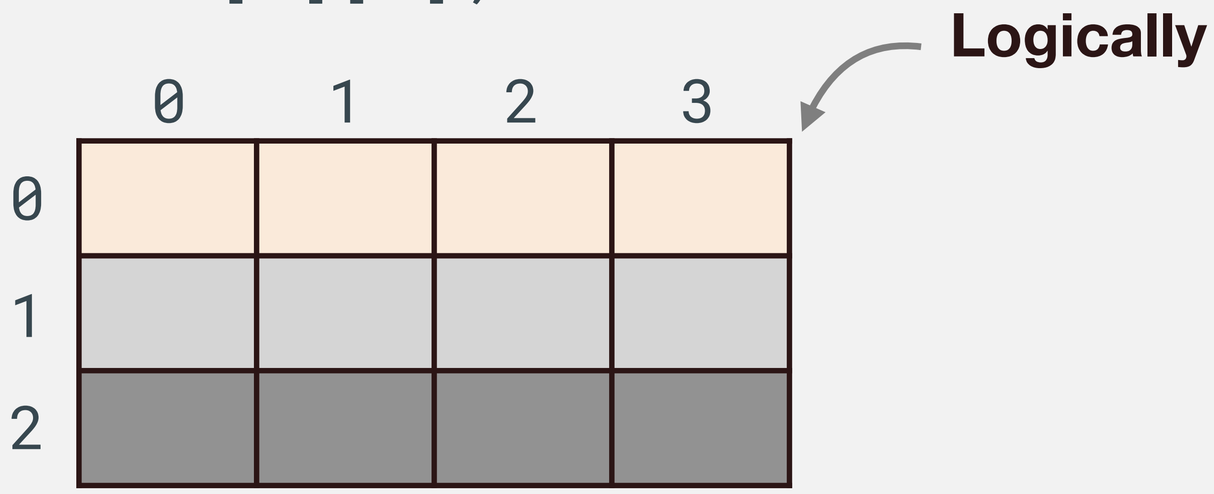

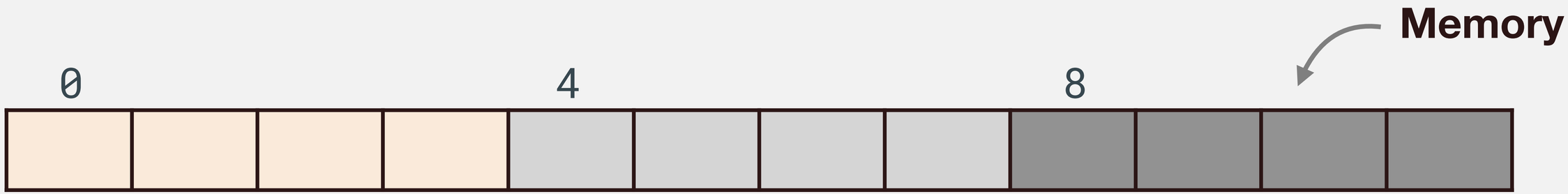

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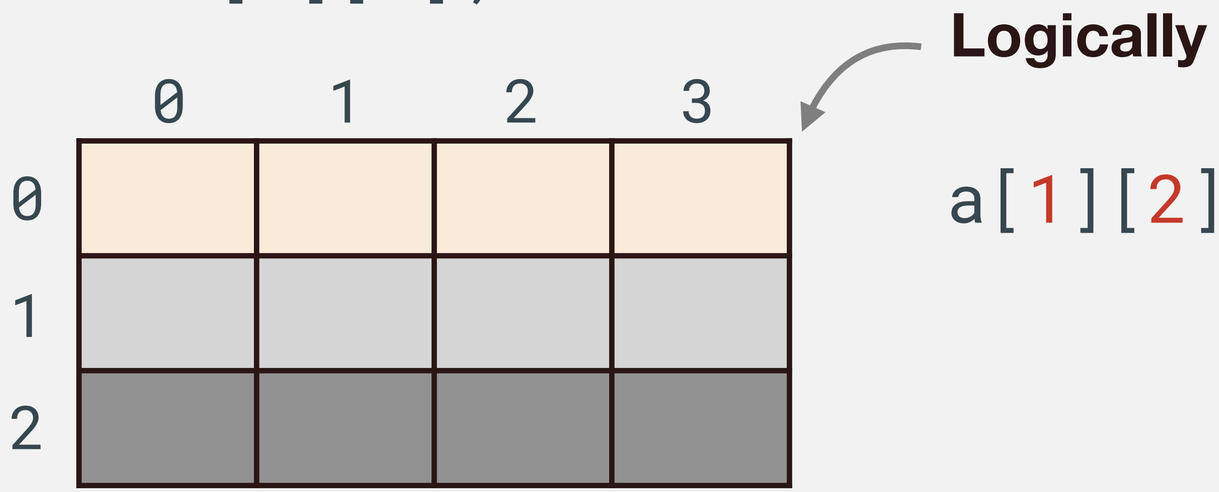
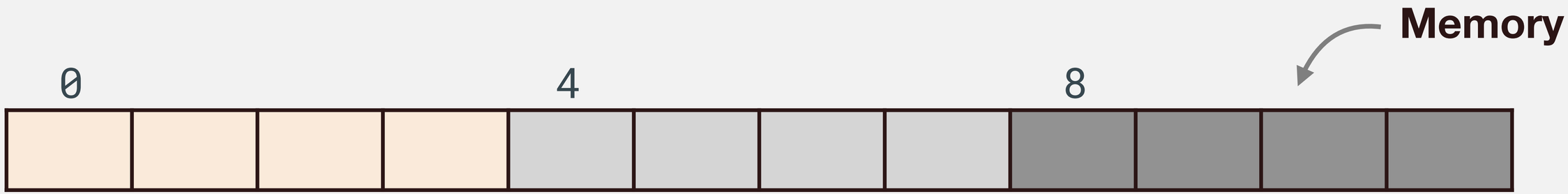



```
a[1][2] = 10;
```



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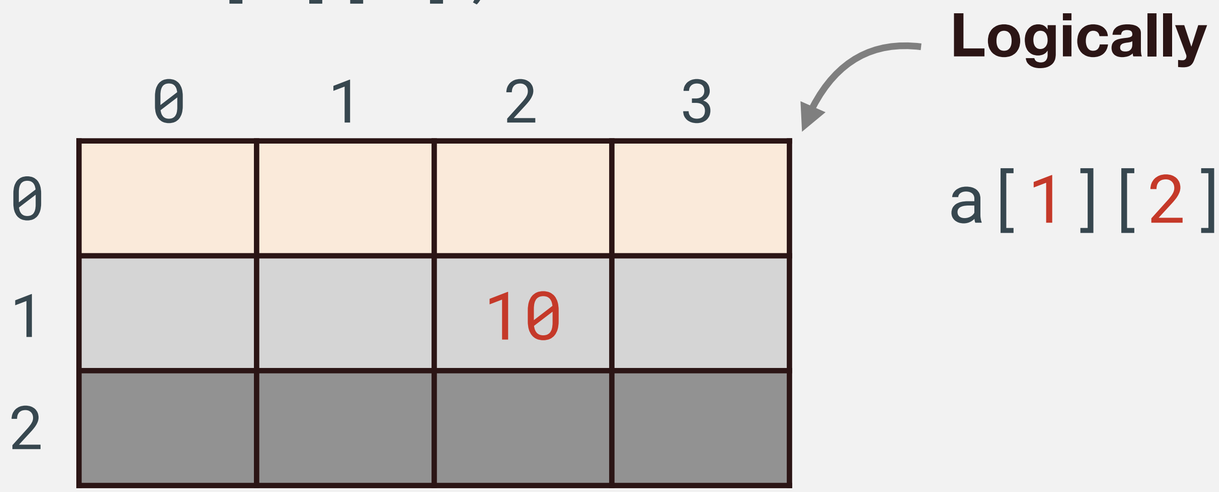


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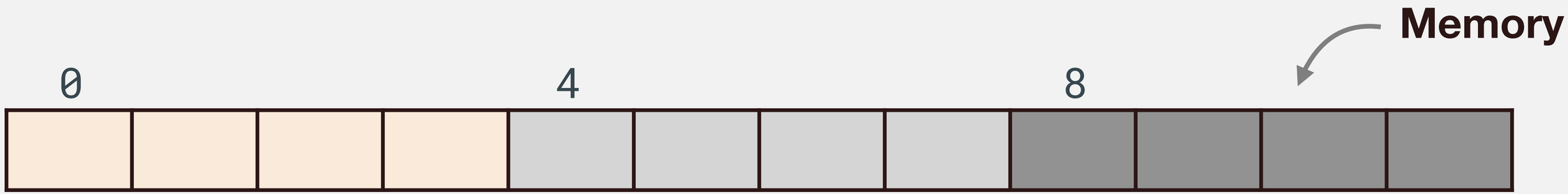

Multi-Dimensional Array

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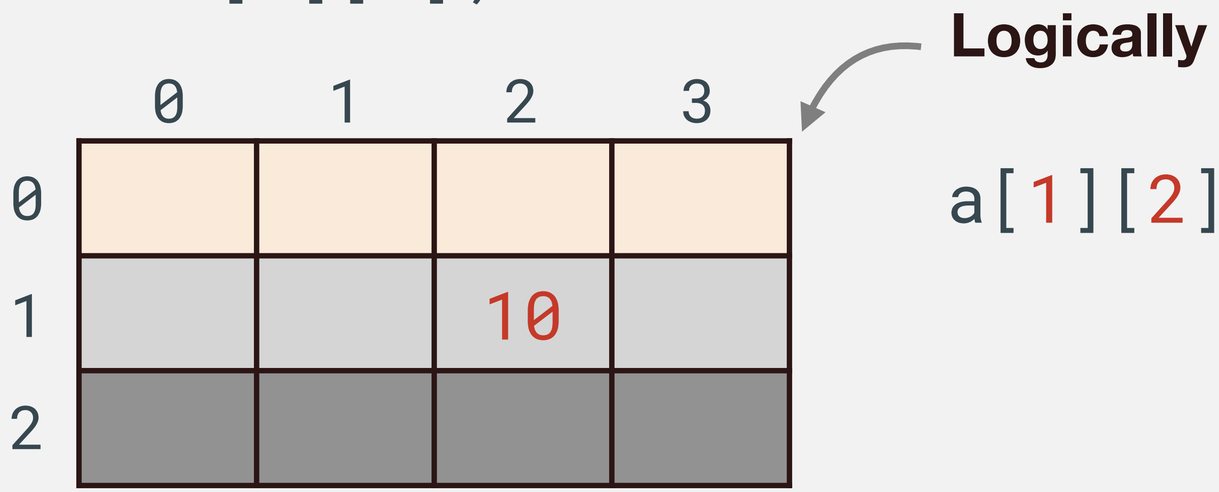



```
a[1][2] = 10;
```

Multi-Dimensional Array

```
int a[3][4];
```

Multi-Dimensional Array

```
int a[3][4];
a[1]
```

Multi-Dimensional Array

```
int a[3][4];
a[1]
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ◄---------- int *
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ◄---------- int *     a[1][2] = 10;
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ◄---------- int *      a[1][2] = 10; ≡ *(*a + 6) = 10;
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ◂---------- int *
a
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ◄---------- int *
a
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ←---------- int *
a ←--------------- int (*)[4]
```

Multi-Dimensional Array

```
int a[3][4];
a[1] <---------- int *
a <---------------- int (*)[4]
```

```
int (*a)[4]; vs int *a[4];
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ←---------- int *
a ←--------------- int (*)[4]
```

A pointer to a 4-int array

```
int (*a)[4]; vs int *a[4];
```

Multi-Dimensional Array

```
int a[3][4];
a[1] ←---------- int *
a ←--------------- int (*)[4]
```

A pointer to a 4-int array

```
int (*a)[4]; vs int *a[4];
```

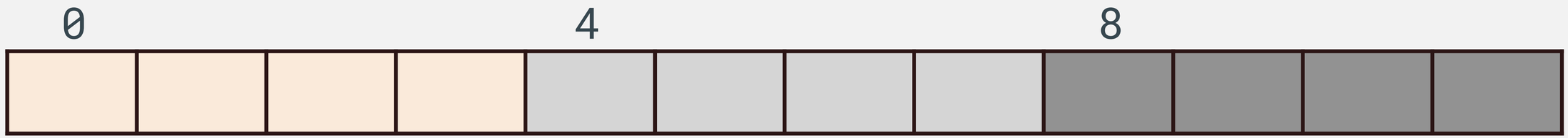
An array of 4 int pointers

Passing 2D-Array to Function

```c
#define R 3
#define C 4

int a[R][C];
...
int sum = ElementSum(a);
```

```c
int ElementSum(???) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```



Passing 2D-Array to Function

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      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int a[R][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int a[R][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int a[R][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Only the pointer is copied, not the array!

Passing 2D-Array to Function

```
int ElementSum(int a[][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int a[][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int a[][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int a[][C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Read Address

0x3E50 + 4 * (i * C + j)

0x3E50

Passing 2D-Array to Function

```
int ElementSum(int (*a)[C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

```
int ElementSum(int (*a)[C]) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Passing 2D-Array to Function

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int ElementSum(int *a) {
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Passing 2D-Array to Function

```
int ElementSum(int *a) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
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  }
  return sum;
}
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Passing 2D-Array to Function

```
int ElementSum(int *a) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i * C + j];
  }
  return sum;
}
```

```
int a[R][C];
...
int sum = ElementSum((int *)a);
```

Passing 2D-Array to Function

```
int ElementSum(int **a) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

Dynamically-Allocated 2D-Array

```
char *a[3];
```

Dynamically-Allocated 2D-Array

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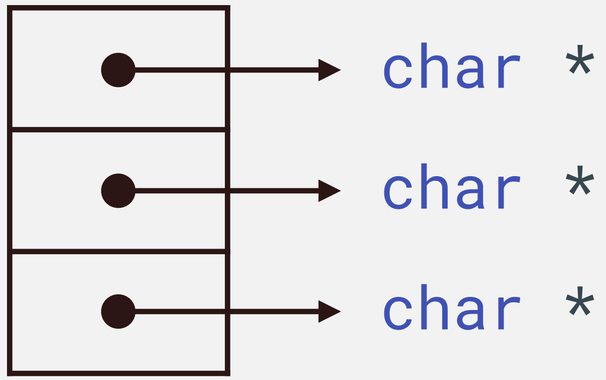
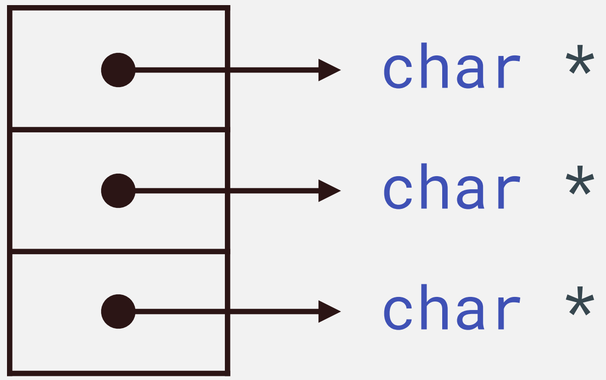


Dynamically-Allocated 2D-Array

```
char *a[3]; // a has type (char **)
```



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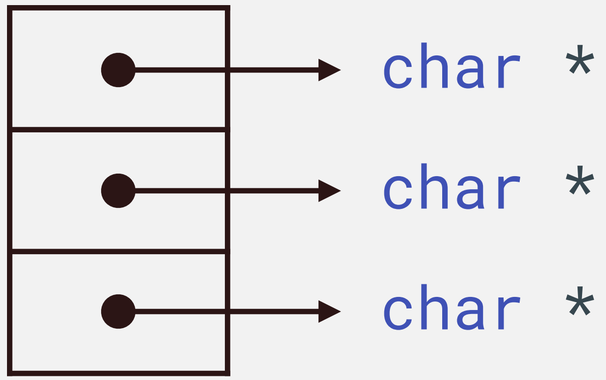
a is a pointer pointing to (`char *`)



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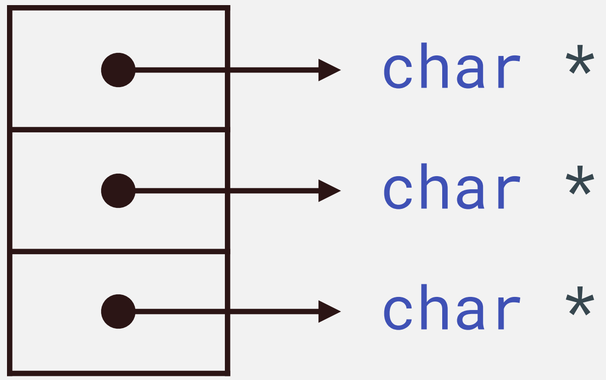

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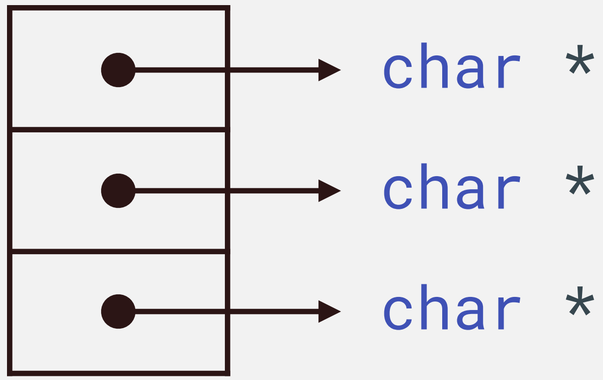


```
char **a = (char **)malloc(3 * sizeof(char *));
```

Multi-Dimensional Array vs. Pointer Array

```
char a[3][10] = {“Shui”, “zai”, “juan???”};
```

```
char *a[3] = {“Shui”, “zai”, “juan???”};
```

Multi-Dimensional Array vs. Pointer Array

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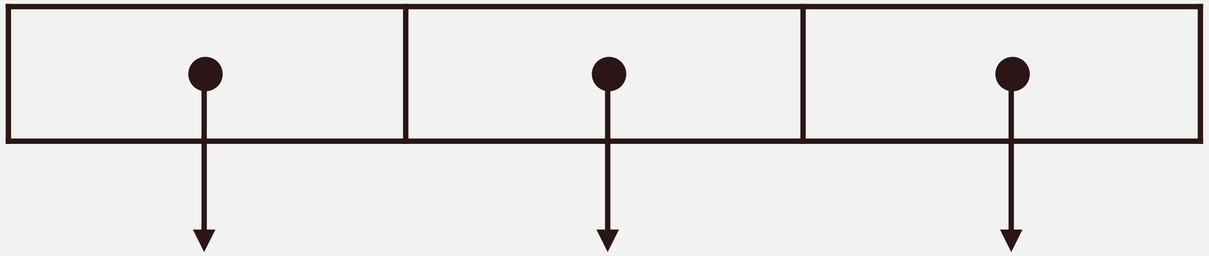

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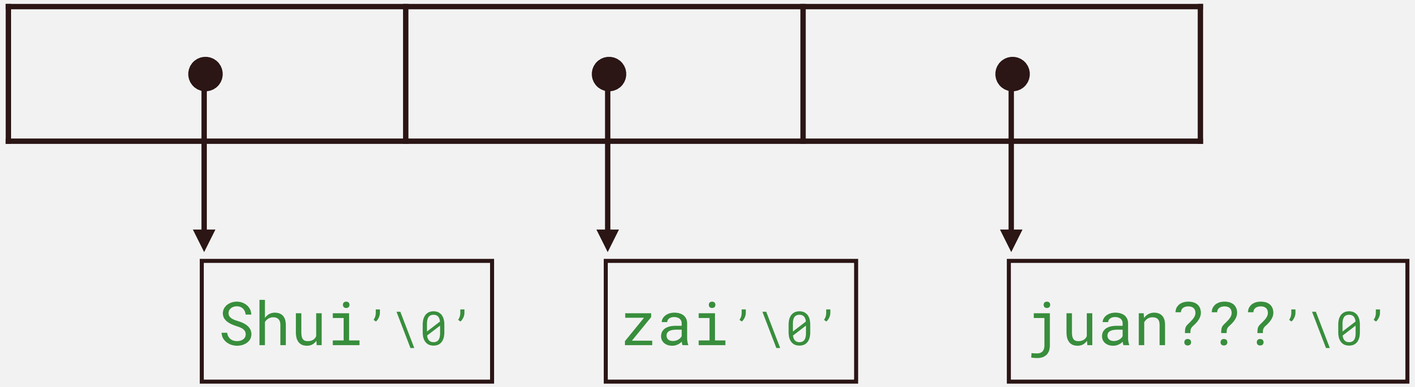

Passing 2D-Array to Function — Revisit

```c
#define R 3
#define C 4

int a[R][C];
...
int sum = ElementSum((int **)a);
```

```c
int ElementSum(int **a) {
  int sum = 0;
  for (int i = 0; i < R; i++) {
    for (int j = 0; j < C; j++)
      sum += a[i][j];
  }
  return sum;
}
```

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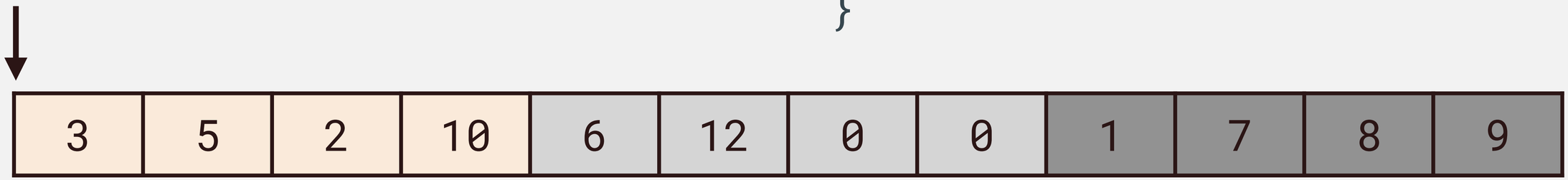
}
```

(int **)a



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(int **)a

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  }
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}
```
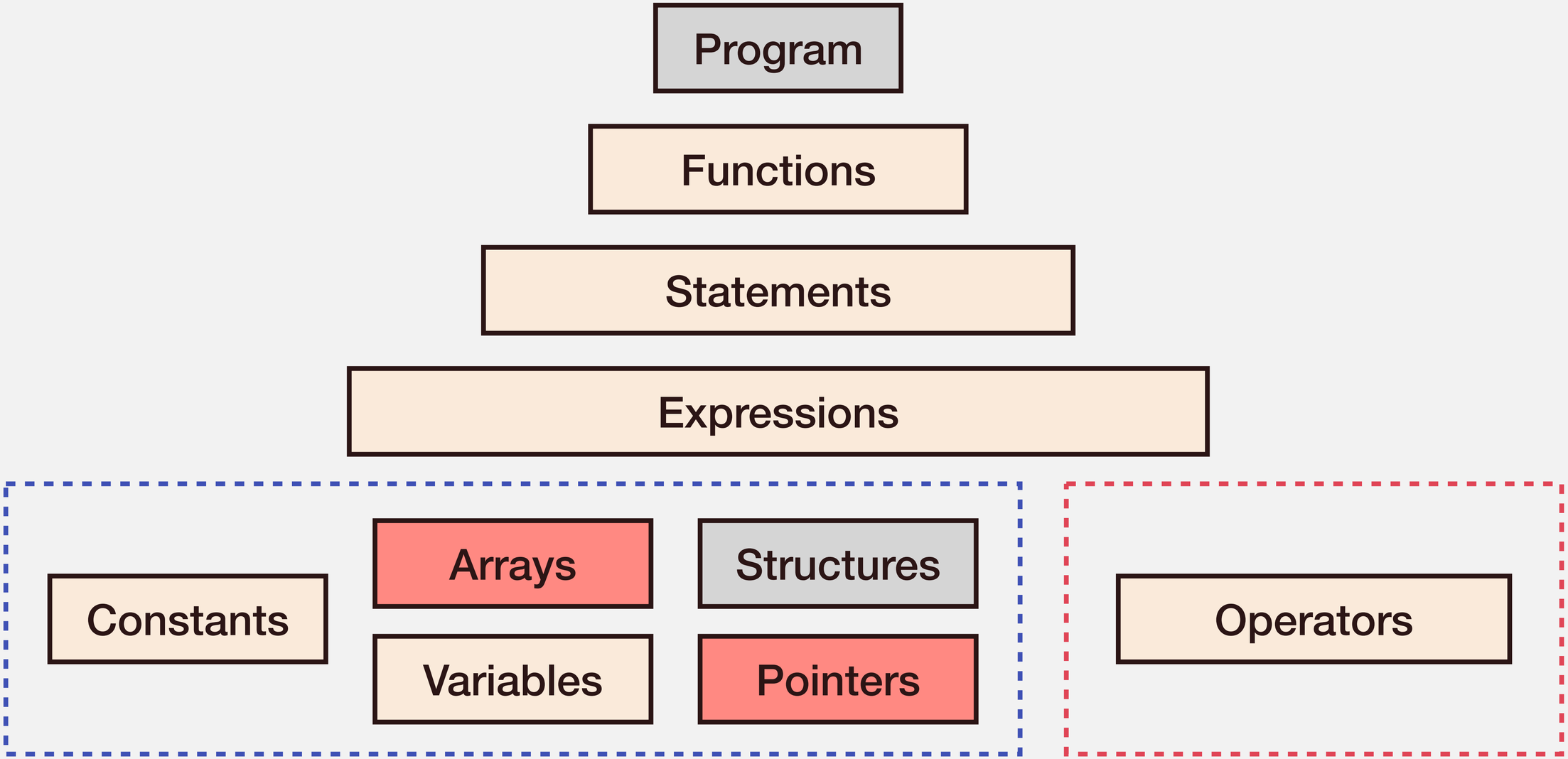
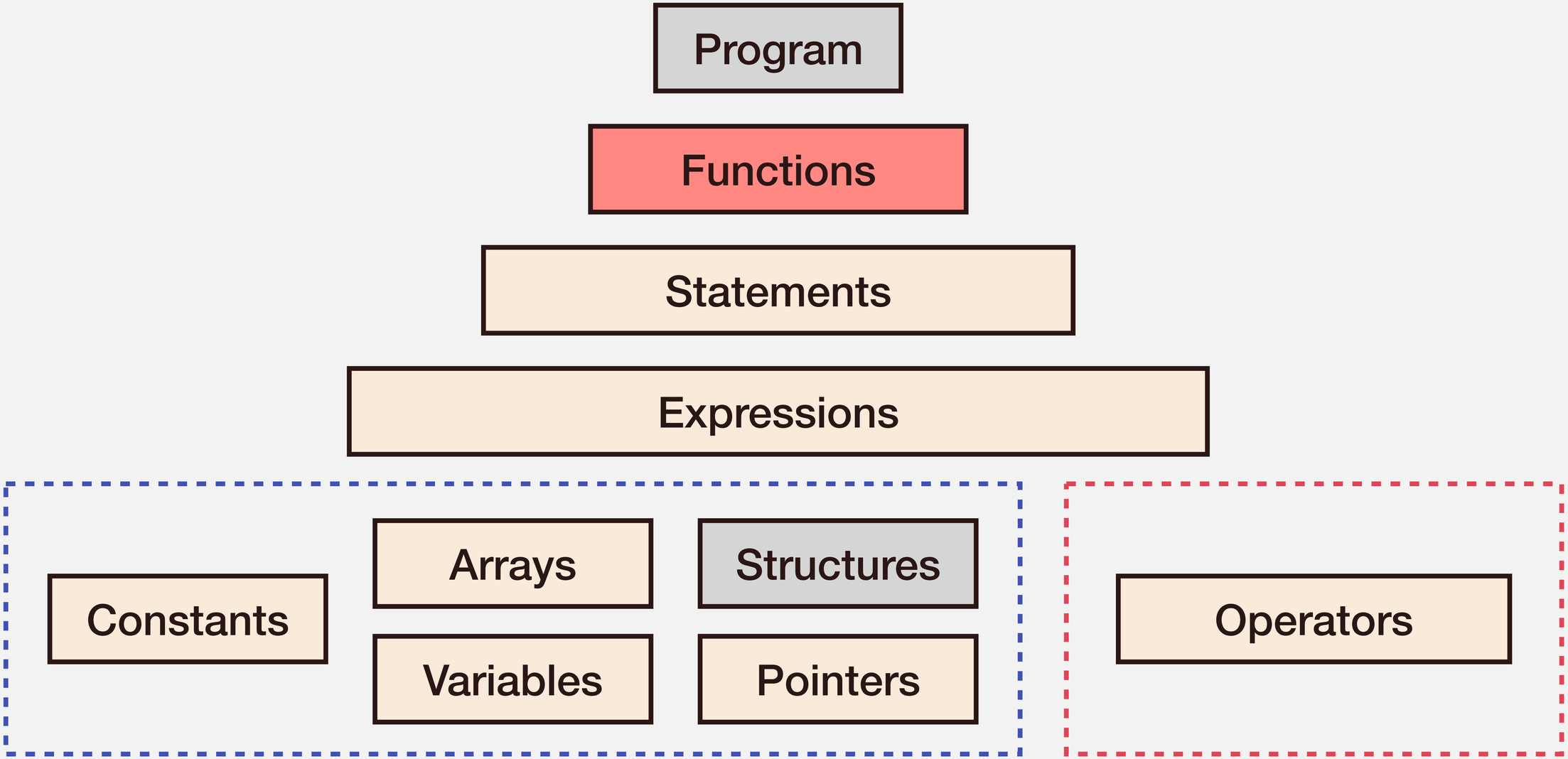

SegFault!

(int **)a

Road Map


Program
Functions
Statements
Expressions
Constants
Arrays
Variables
Structures
Pointers
Operators

Road Map


Program
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Recursion

- A function calls **itself**

Recursion

➜ A function calls **itself**

```
void func(...) {
  ...
  func(...)
}

int main() {
  func(...);
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recursively

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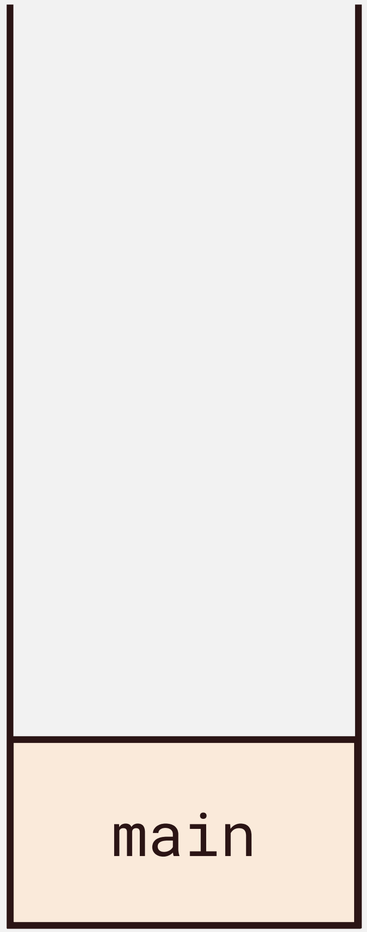

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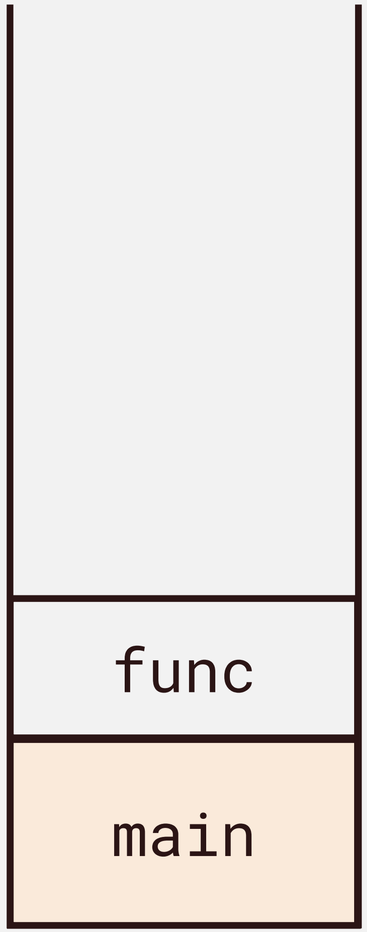

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```

recursively

Recursion

➜ A function calls **itself**

```
void func(...) {
  ...
  if (e)
    return;
  func(...)
}

int main() {
  func(...);
}
```

Recursion

➜ A function calls **itself**

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  if (e)
    return;
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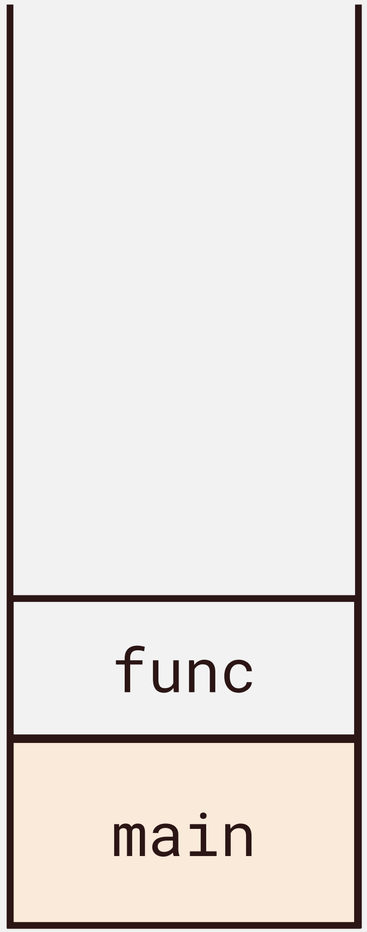
}

int main() {
  func(...);
}
```



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    return;
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}

int main() {
  func(...);
}
```
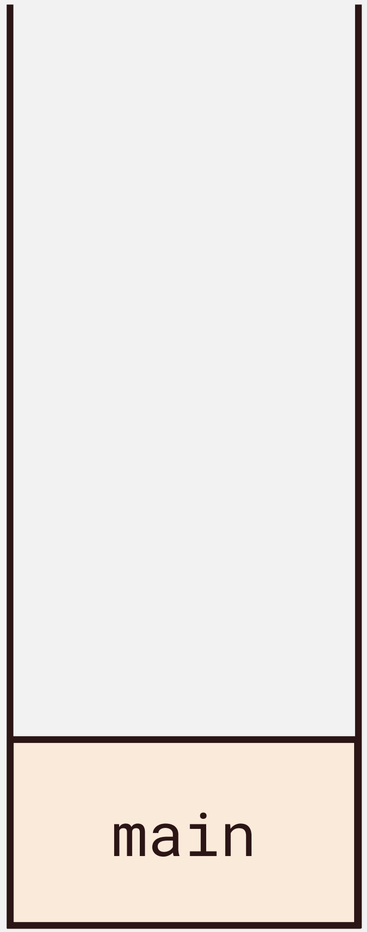
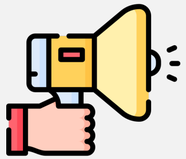



Divide and Conquer

- Break problem into (multiple) sub-problems of the **same type** until the sub-problems are easy to solve

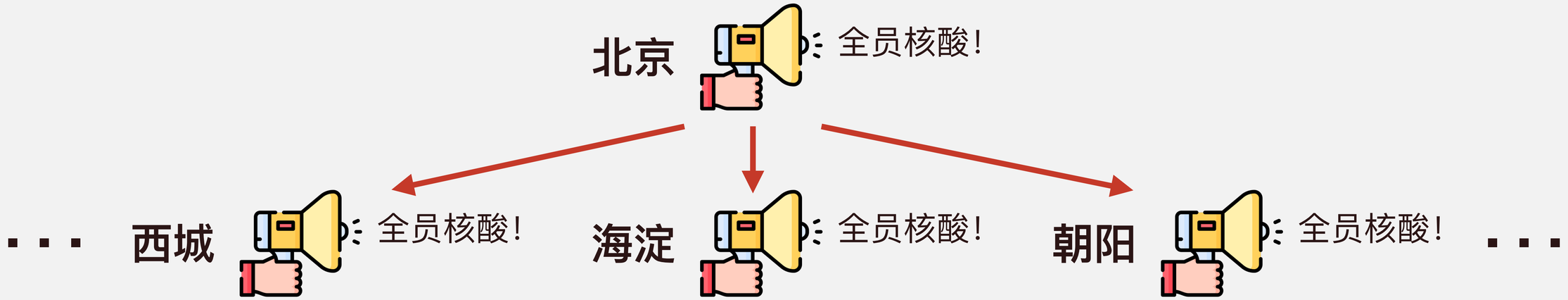
Divide and Conquer

北京

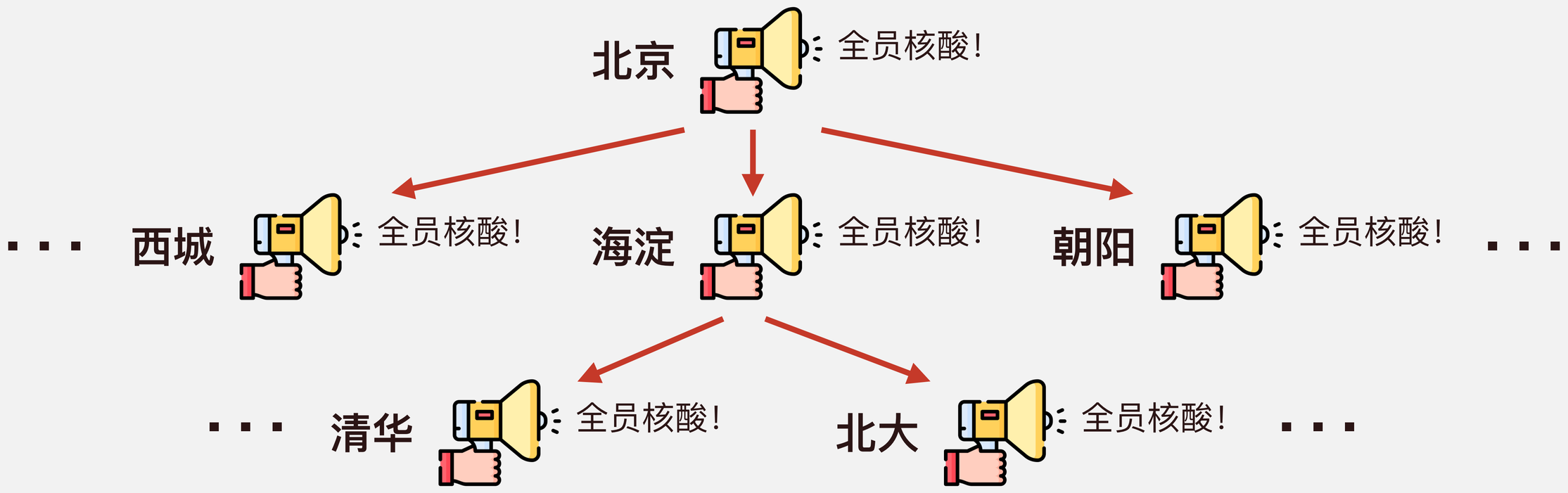


全员核酸！

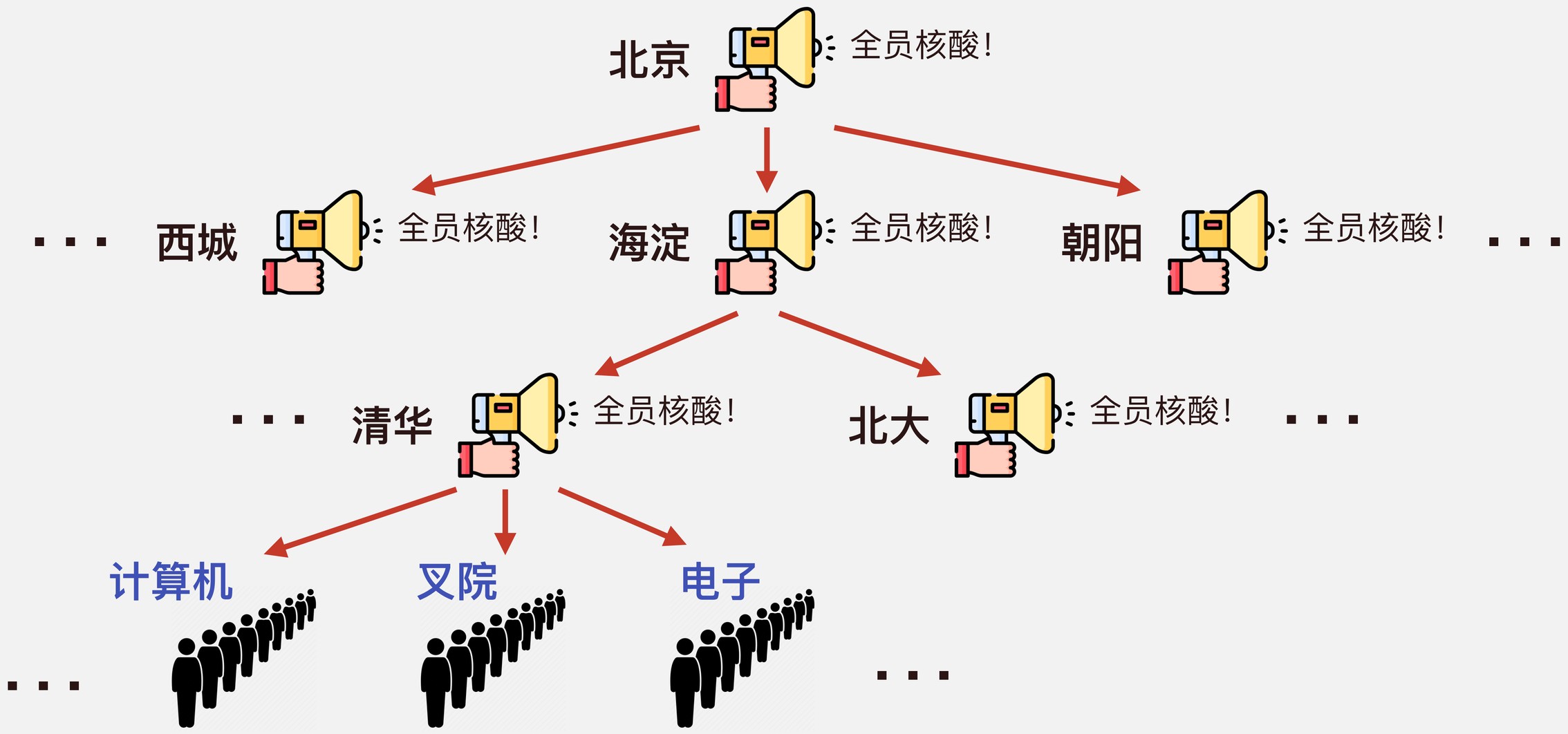
Divide and Conquer



Divide and Conquer



Divide and Conquer



Quicksort

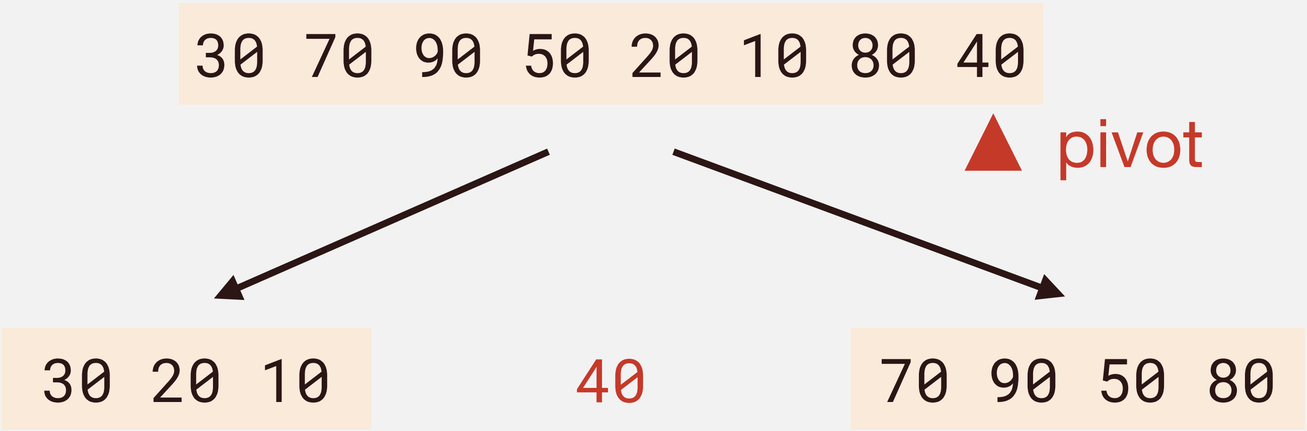
```
30 70 90 50 20 10 80 40
```

Quicksort

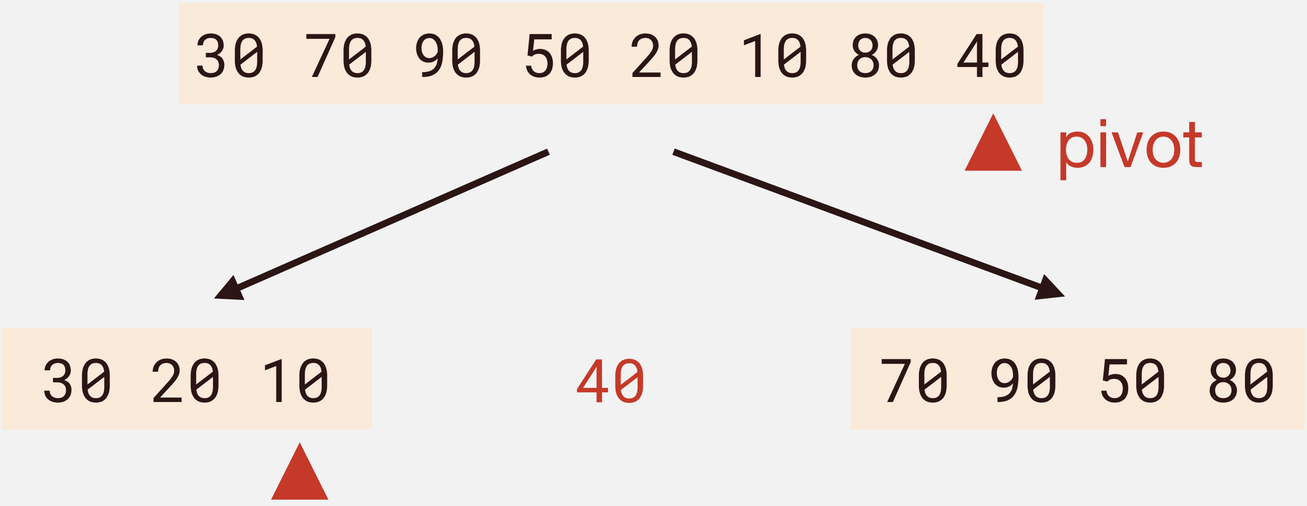
```
30 70 90 50 20 10 80 40
```

▲ pivot

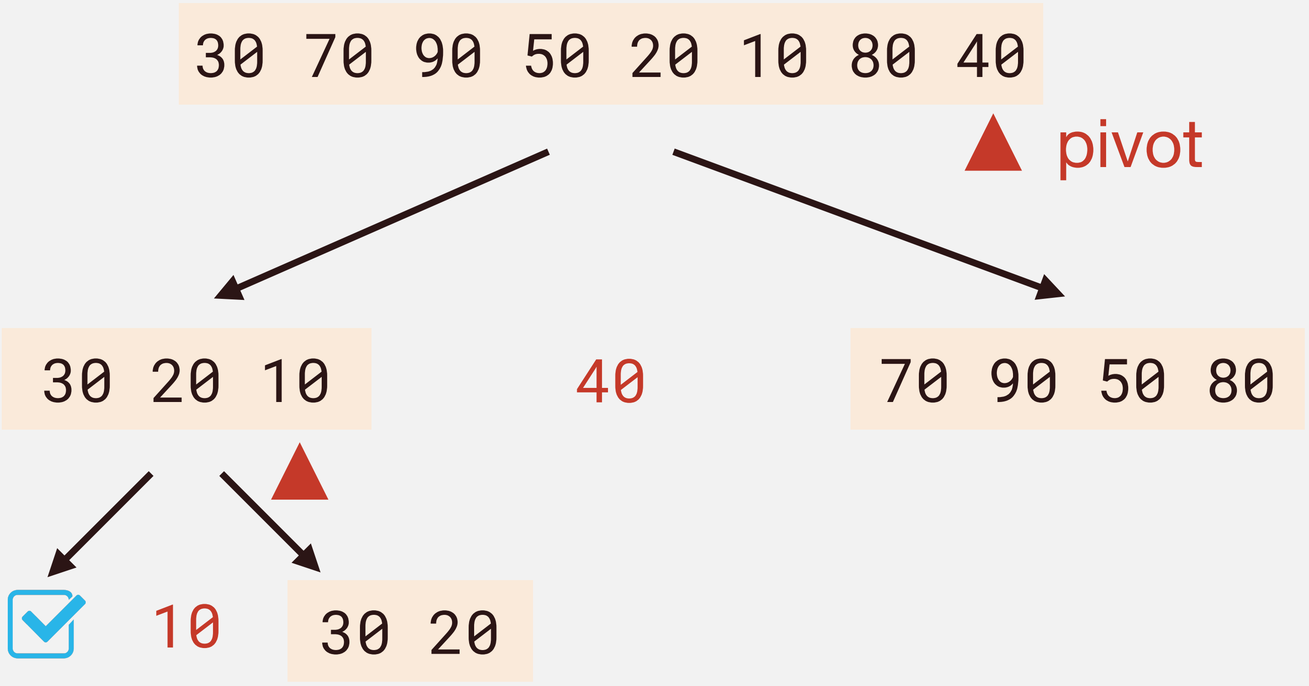
Quicksort



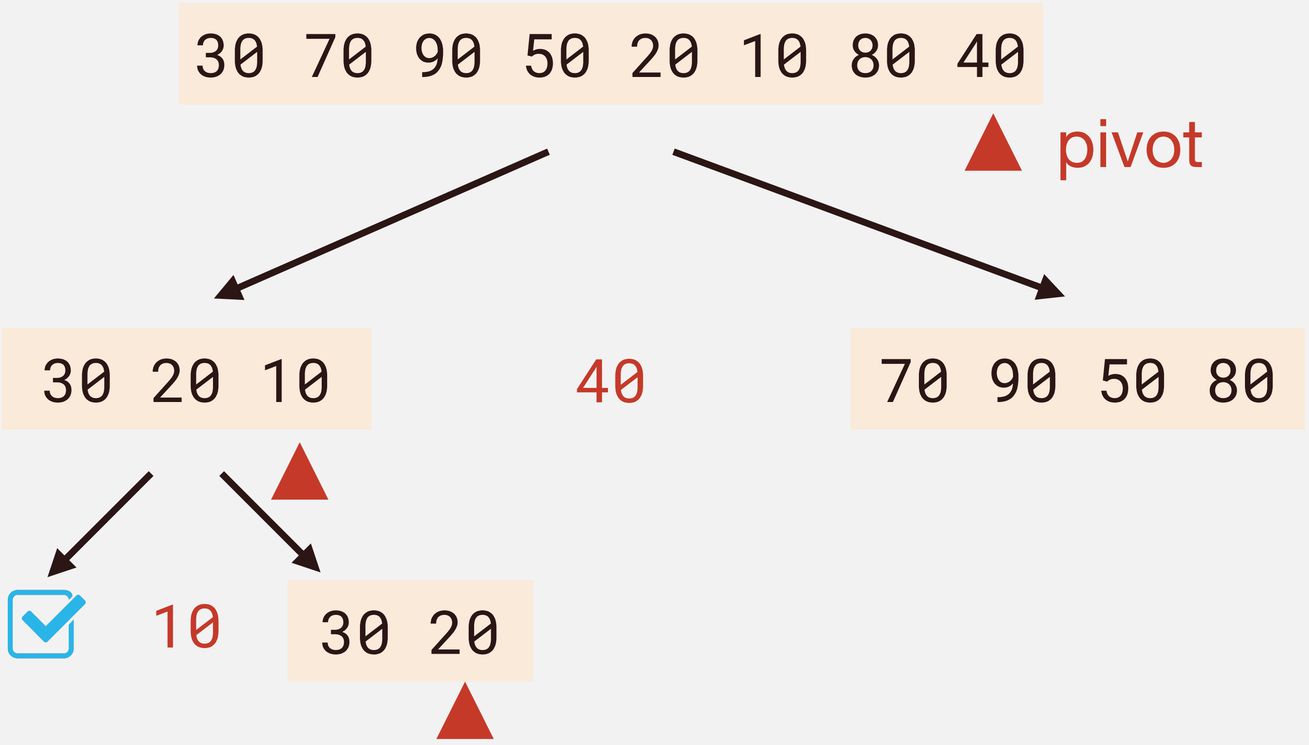
Quicksort



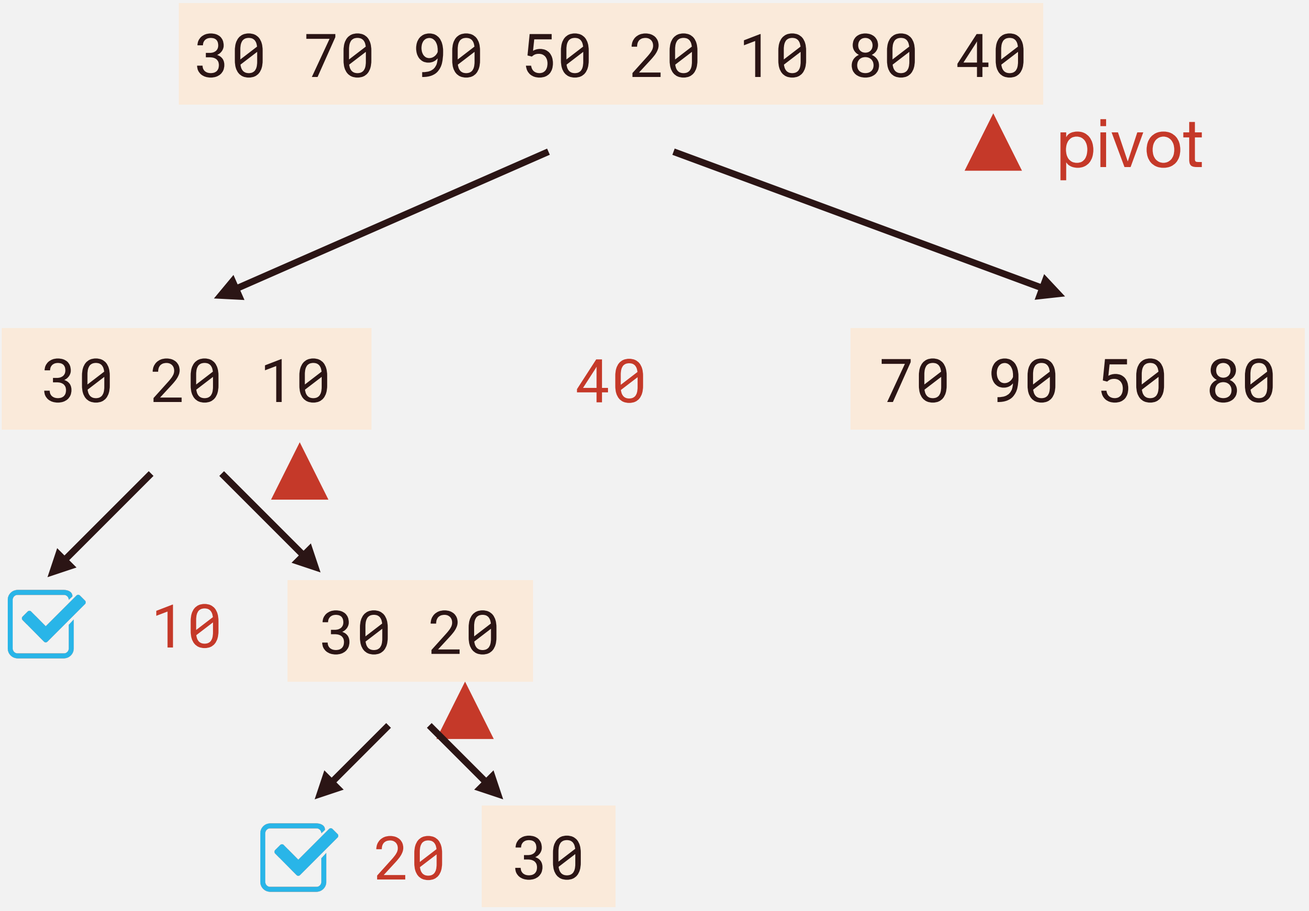
Quicksort



Quicksort



Quicksort



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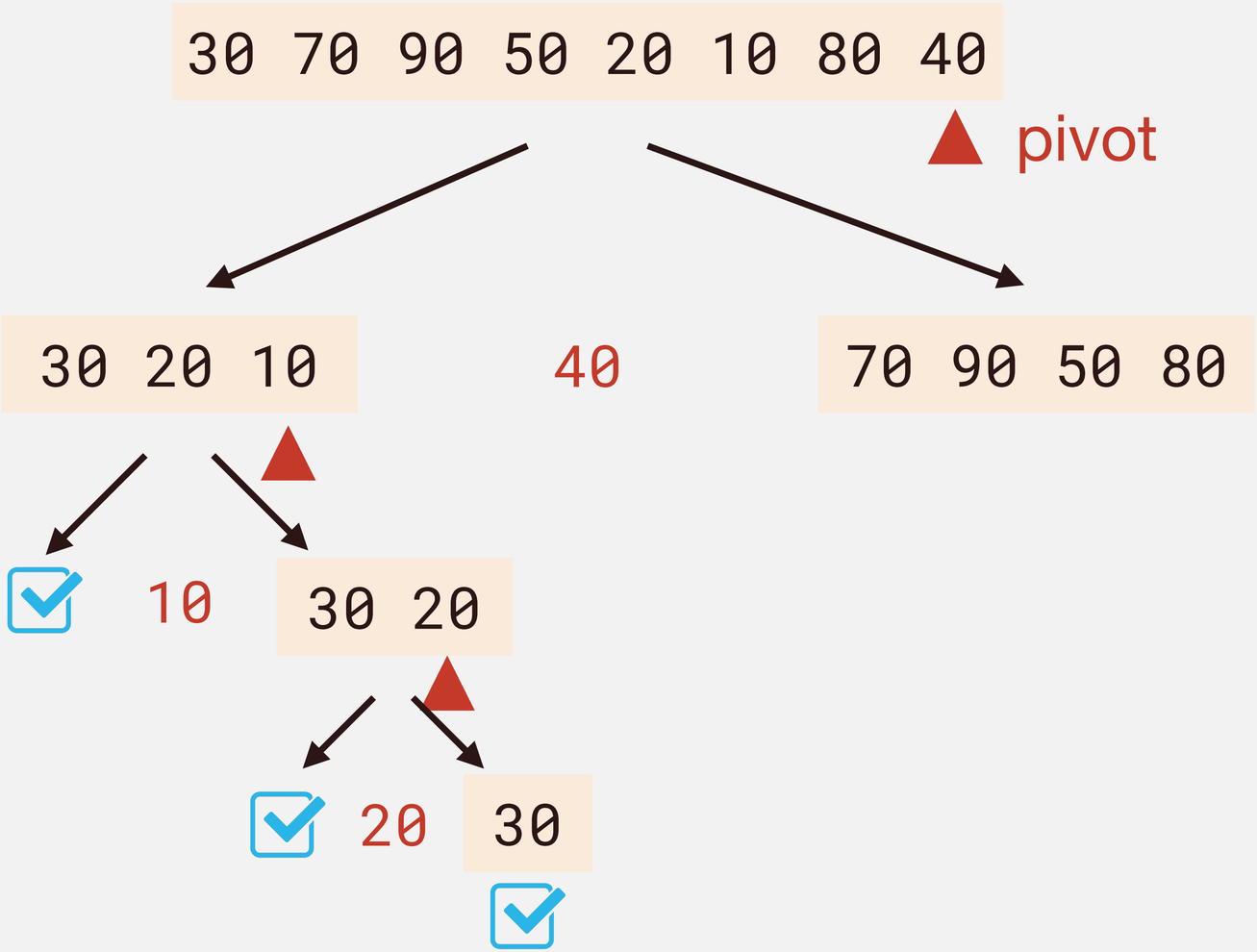
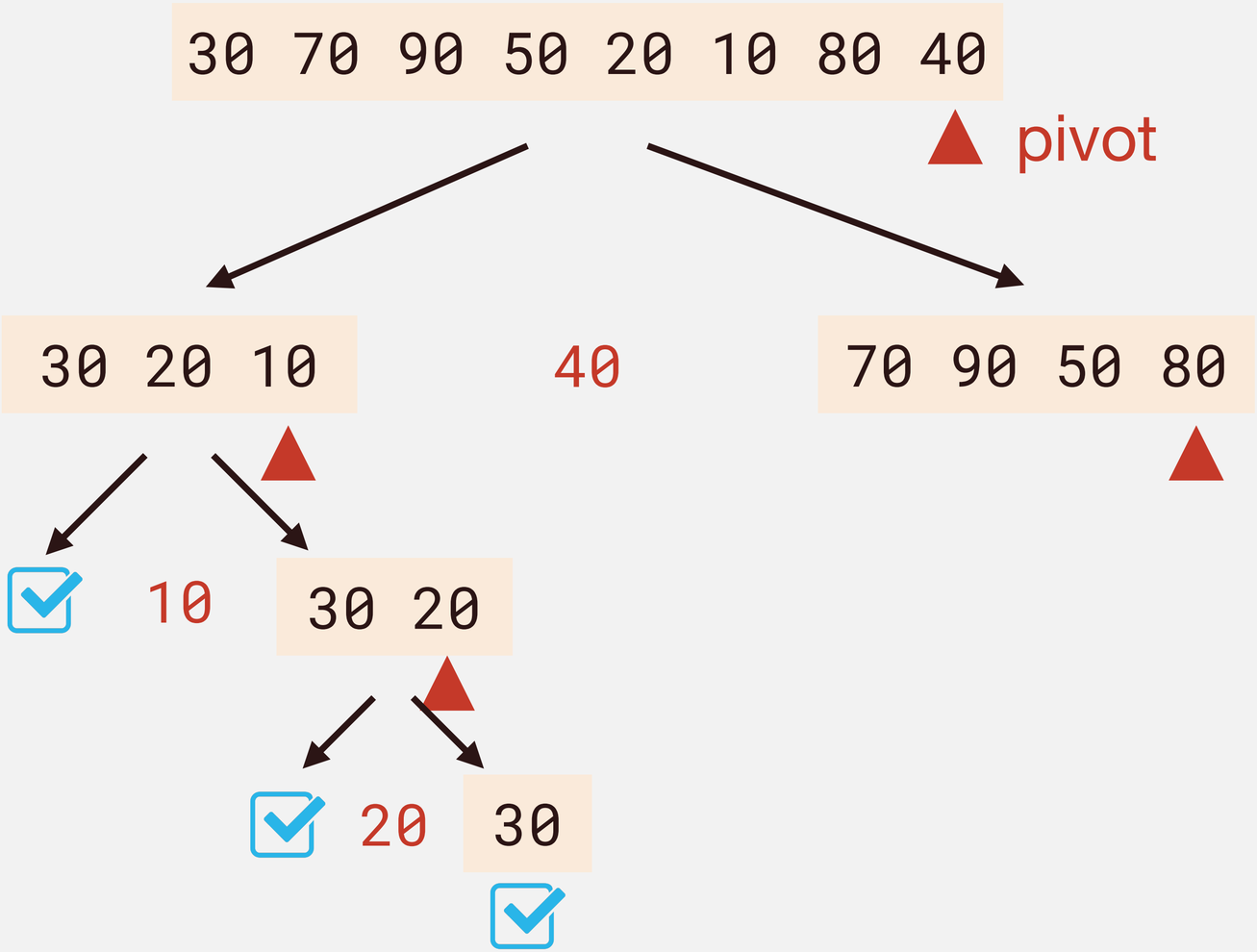
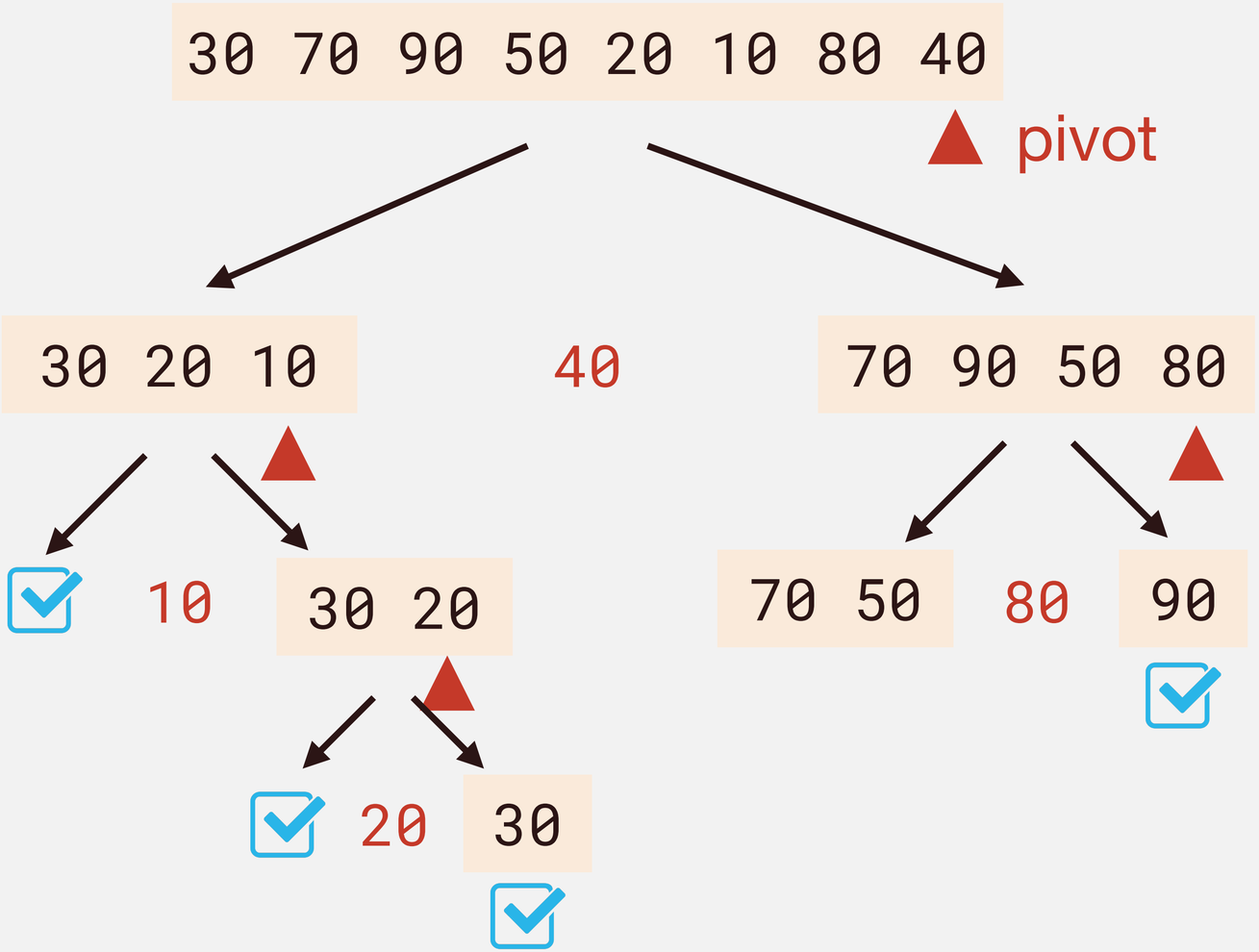


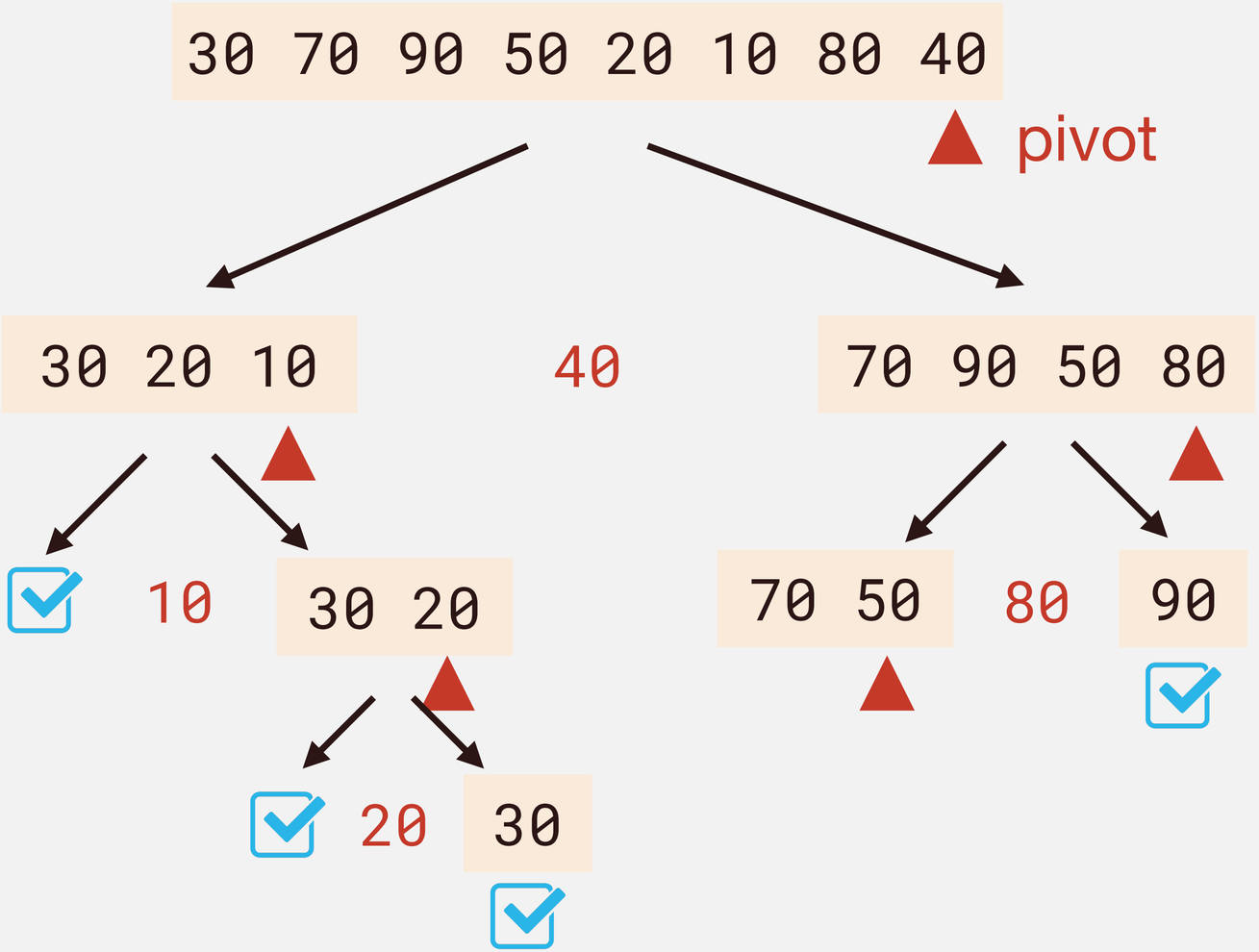
Quicksort



Quicksort


30 70 90 50 20 10 80 40
pivot
30 20 10
40
70 90 50 80
10
30 20
70 50
80
90
20
30

Quicksort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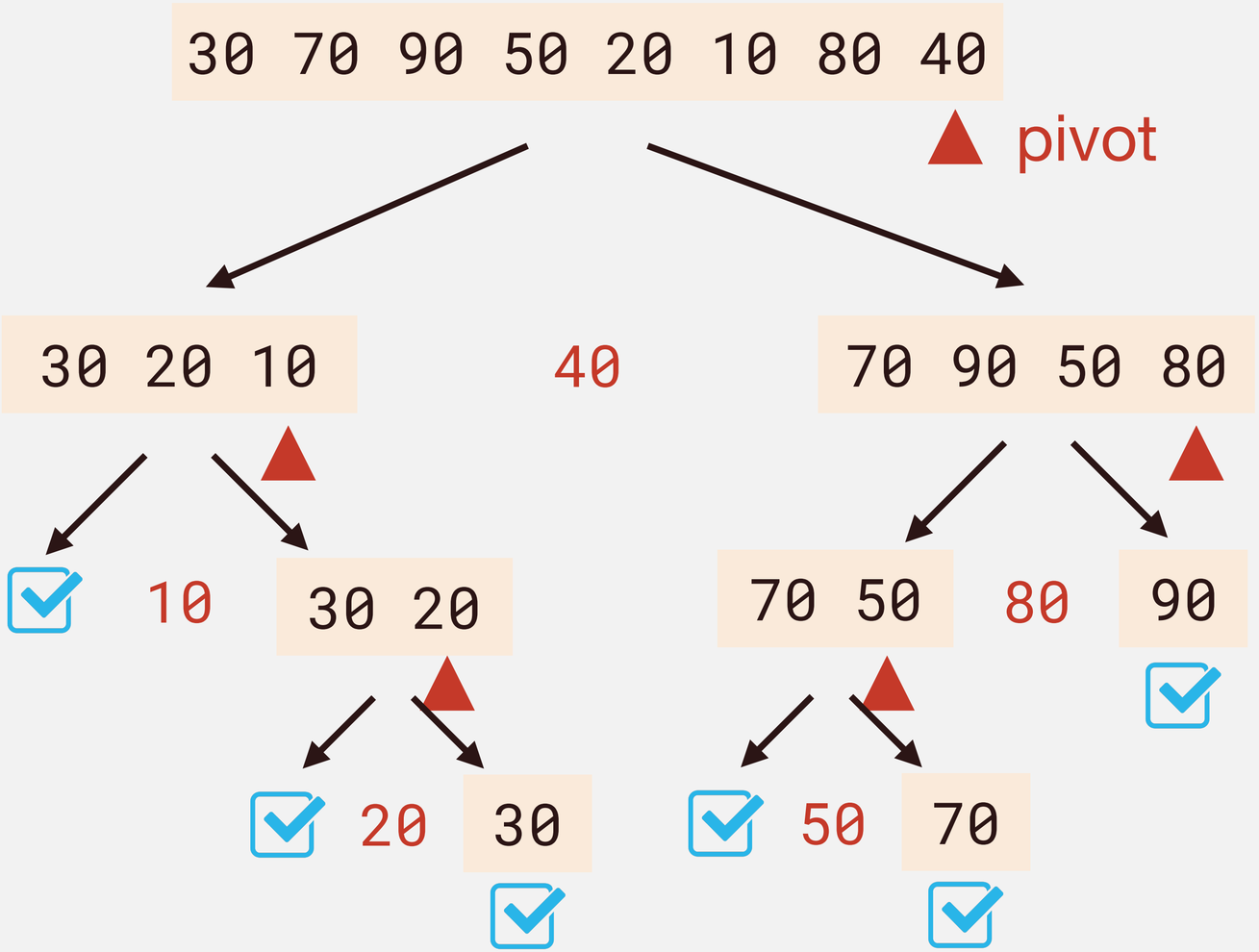
20
30

Quicksort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pivot
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40
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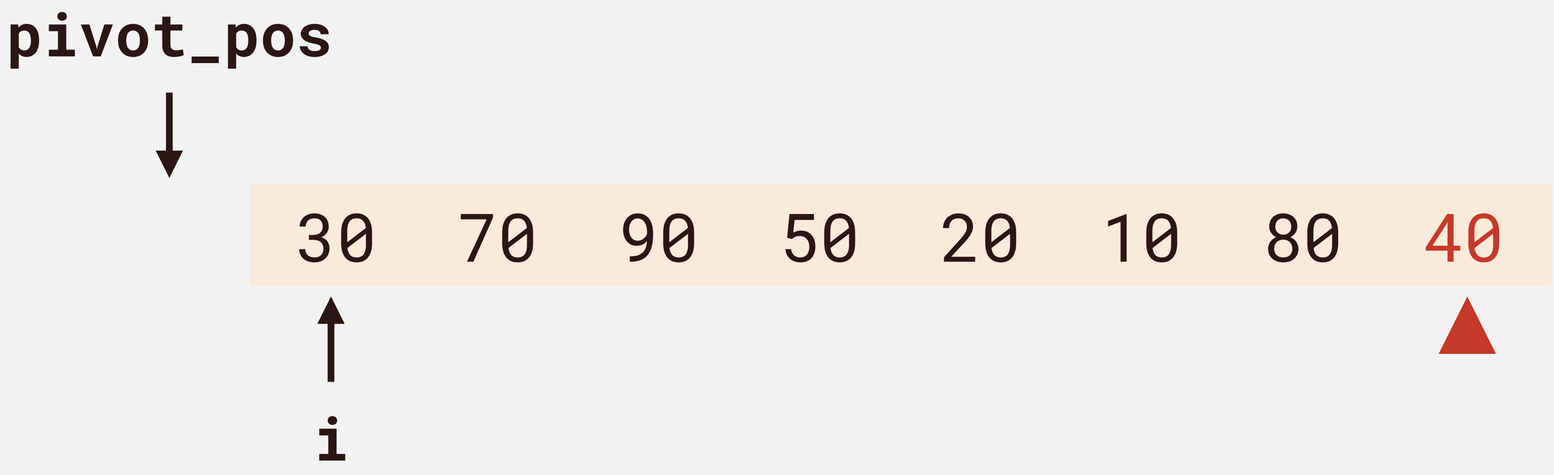
10
30 20
70 50
80
90
20
30
50
70

Quicksort

```
Quicksort(full_range) {
  Pick a pivot
  Rearrange around pivot
  Quicksort(before pivot)
  Quicksort(after pivot)
}
```

Rearrange Around Pivot



Rearrange Around Pivot

pivot_pos

30	70	90	50	20	10	80	40

i

30 < 40

Rearrange Around Pivot

```
pivot_pos
    ↓
 30  70  90  50  20  10  80  40
    ↑                       ▲
    i
```

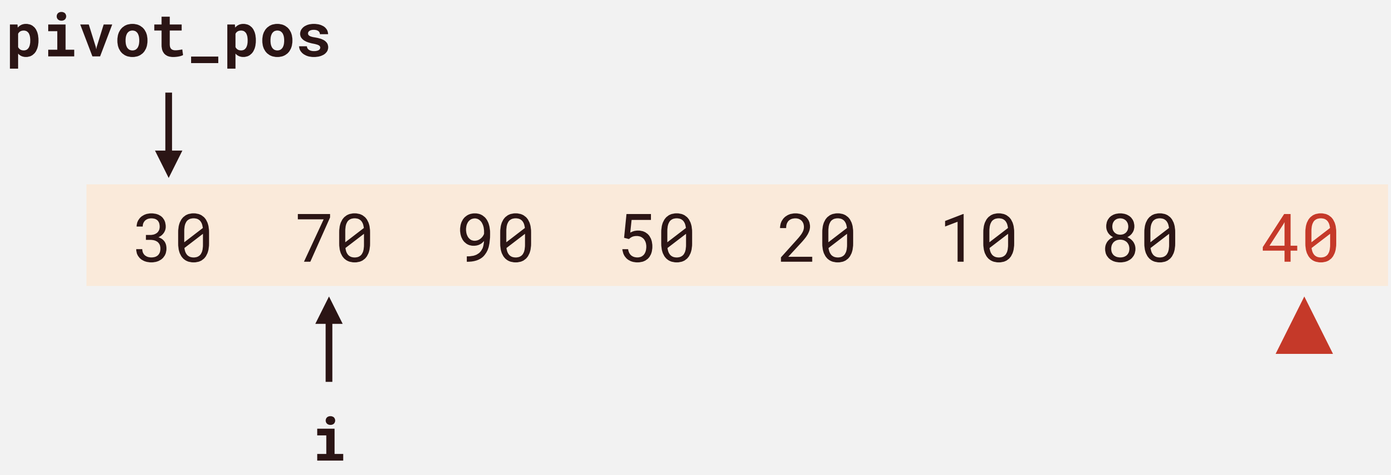
```
  30 < 40
++pivot_pos
```

Rearrange Around Pivot

```
pivot_pos
    ↓
 30  70  90  50  20  10  80  40
    ↑                       ▲
    i
```

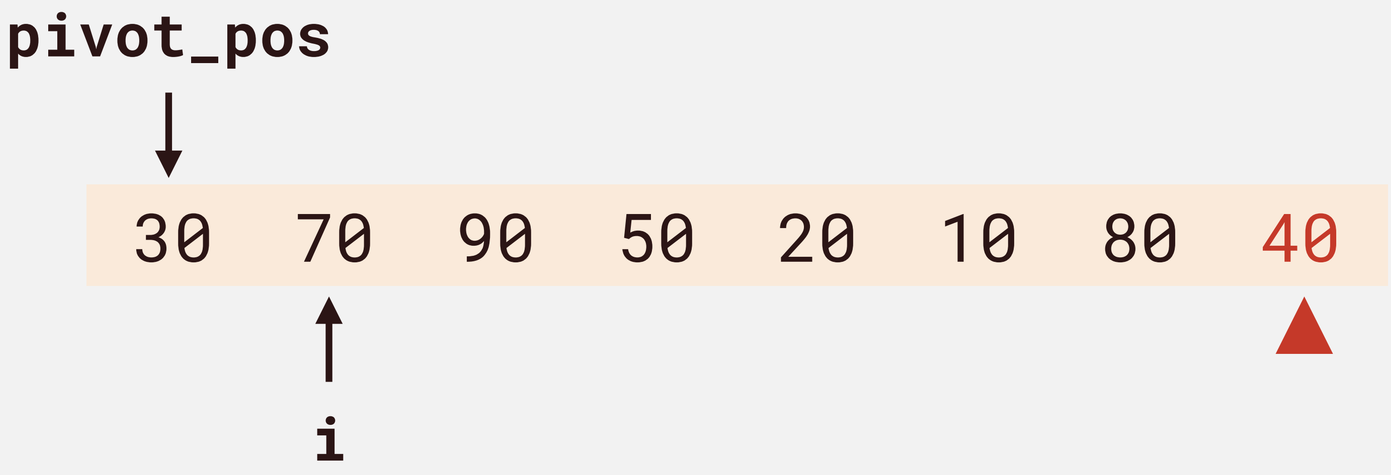
```
  30 < 40
++pivot_pos
    swap
```

Rearrange Around Pivot



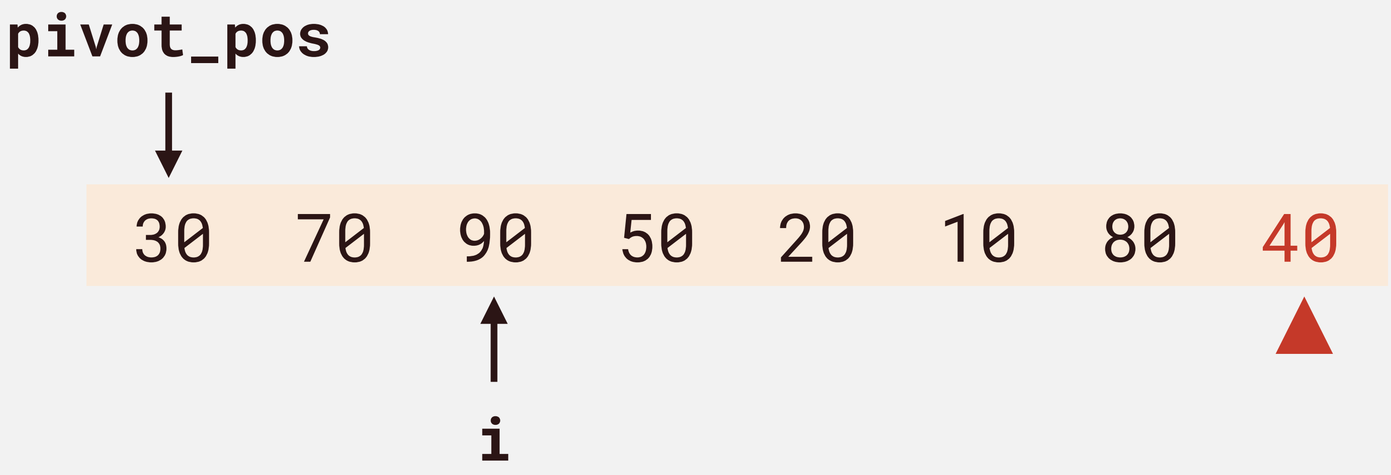

```
  30 < 40
++pivot_pos
    swap
```

Rearrange Around Pivot




```
  30 < 40   70 >= 40
++pivot_pos
    swap
```

Rearrange Around Pivot




```
  30 < 40   70 >= 40
++pivot_pos
    swap
```

Rearrange Around Pivot

```
pivot_pos
    ↓
 30   70   90   50   20   10   80   40
              ↑                     ▲
              i
```

```
  30 < 40   70 >= 40   90 >= 40
++pivot_pos
    swap
```

Rearrange Around Pivot

```
pivot_pos
    ↓
 30   70   90   50   20   10   80   40
                  ↑                  ▲
                  i
```

```
  30 < 40   70 >= 40   90 >= 40
++pivot_pos
    swap
```

Rearrange Around Pivot

```
pivot_pos
    ↓
 30   70   90   50   20   10   80   40
                  ↑                  ▲
                  i
```

```
  30 < 40   70 >= 40   90 >= 40   50 >= 40
++pivot_pos
    swap
```

Rearrange Around Pivot

```
pivot_pos
    ↓
 30   70   90   50   20   10   80   40
                      ↑            ▲
                      i
```

```
  30 < 40   70 >= 40   90 >= 40   50 >= 40
++pivot_pos
    swap
```

Rearrange Around Pivot

```
pivot_pos
    ↓
 30   70   90   50   20   10   80   40
                      ↑             ▲
                      i
```

```
  30 < 40   70 >= 40   90 >= 40   50 >= 40   20 < 40
++pivot_pos
    swap
```

Rearrange Around Pivot

pivot_pos

30	70	90	50	20	10	80	40

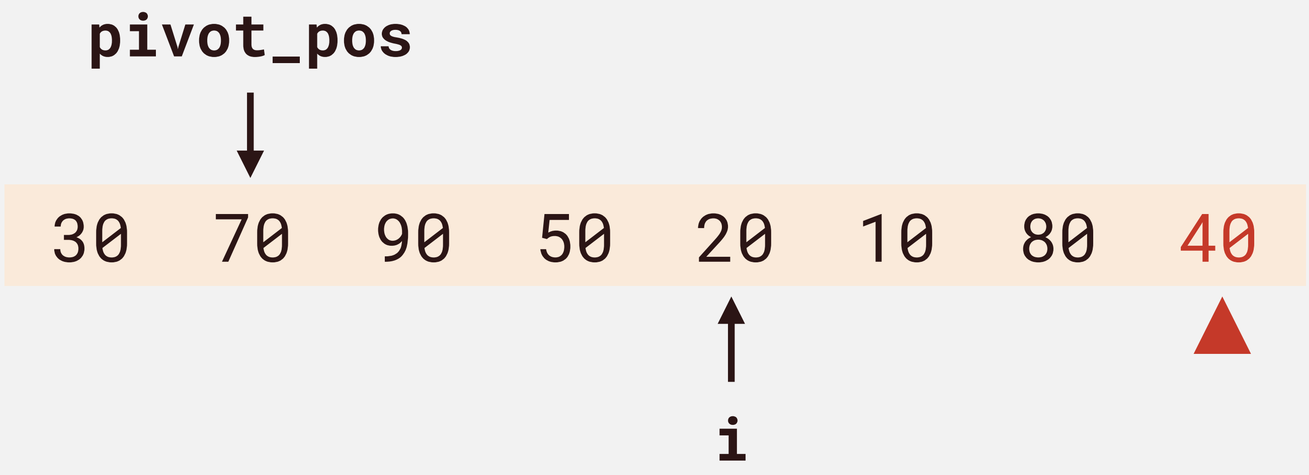
i

30 < 40 70 >= 40 90 >= 40 50 >= 40 20 < 40

++pivot_pos ++pivot_pos

swap

Rearrange Around Pivot



30 < 40	70 >= 40	90 >= 40	50 >= 40	20 < 40
++pivot_pos				++pivot_pos
swap				swap

Rearrange Around Pivot

pivot_pos

30	20	90	50	70	10	80	40

i

30 < 40 ++pivot_pos swap

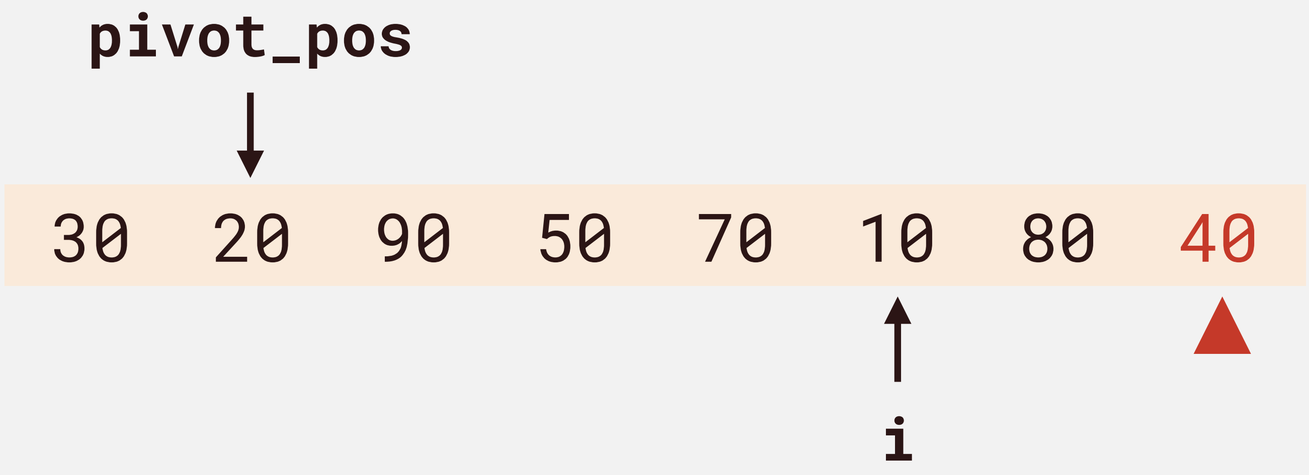
70 >= 40

90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

Rearrange Around Pivot



30 < 40 ++pivot_pos swap

70 >= 40

90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

Rearrange Around Pivot

pivot_pos

30	20	90	50	70	10	80	40

i

30 < 40 ++pivot_pos swap

70 >= 40

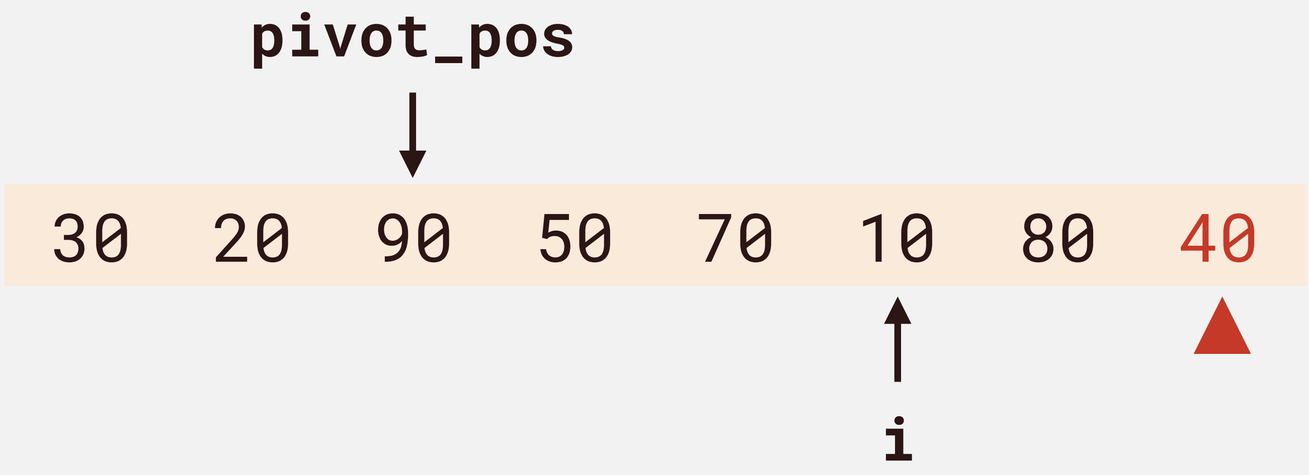
90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

10 < 40

Rearrange Around Pivot



30 < 40 ++pivot_pos swap

70 >= 40

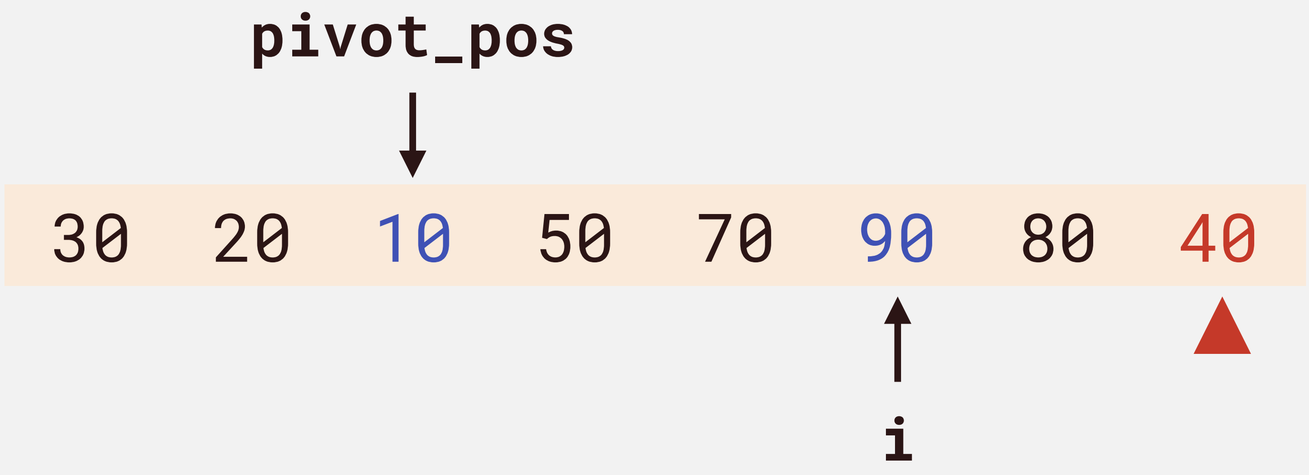
90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

10 < 40 ++pivot_pos

Rearrange Around Pivot



30 < 40 ++pivot_pos swap

70 >= 40

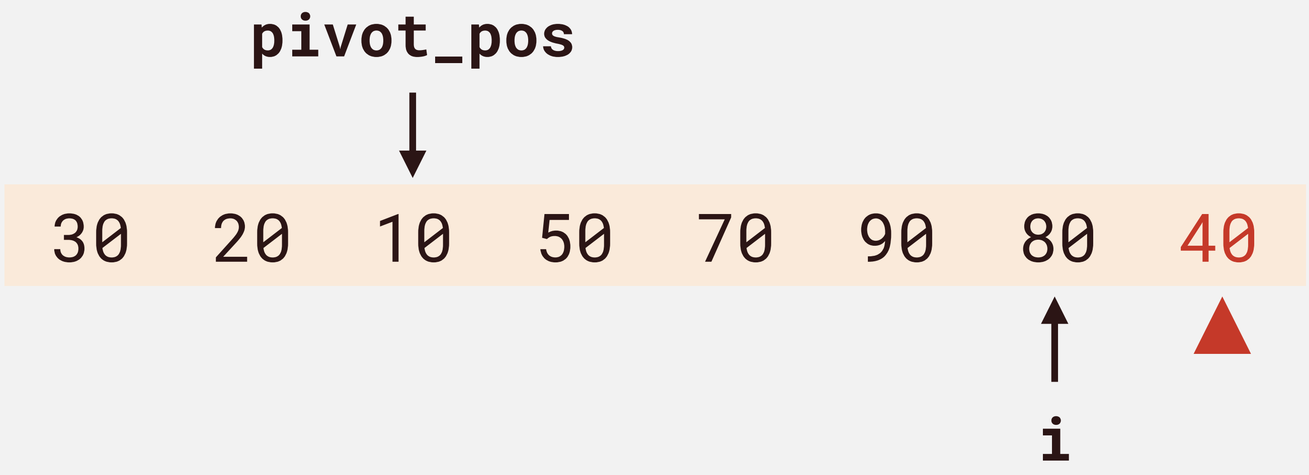
90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

10 < 40 ++pivot_pos swap

Rearrange Around Pivot



30 < 40	70 >= 40	90 >= 40	50 >= 40	20 < 40	10 < 40
++pivot_pos				++pivot_pos	++pivot_pos
swap				swap	swap

Rearrange Around Pivot

pivot_pos

30	20	10	50	70	90	80	40

i

30 < 40 ++pivot_pos swap

70 >= 40

90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

10 < 40 ++pivot_pos swap

final swap

Rearrange Around Pivot

pivot_pos

30 20 10 50 70 90 80 40

i

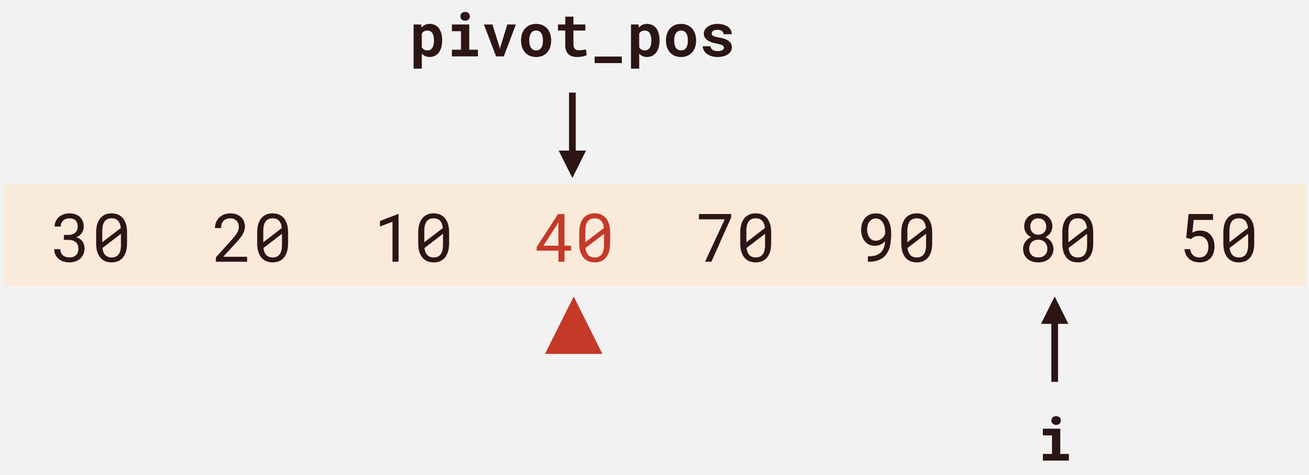
30 < 40 70 >= 40 90 >= 40 50 >= 40 20 < 40 10 < 40

++pivot_pos ++pivot_pos ++pivot_pos

swap swap swap

final swap

Rearrange Around Pivot



30 < 40 ++pivot_pos swap

70 >= 40

90 >= 40

50 >= 40

20 < 40 ++pivot_pos swap

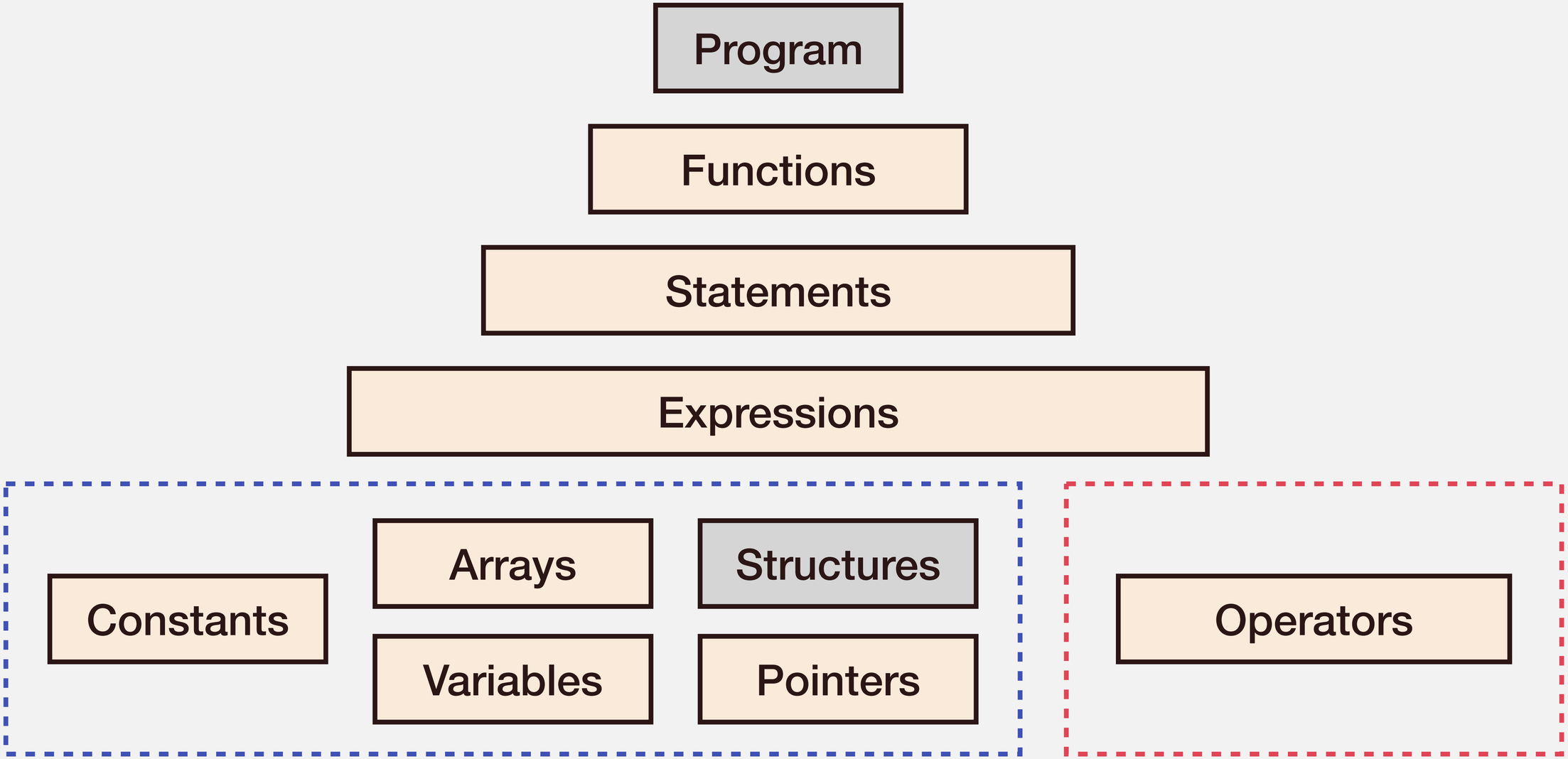
10 < 40 ++pivot_pos swap

final swap

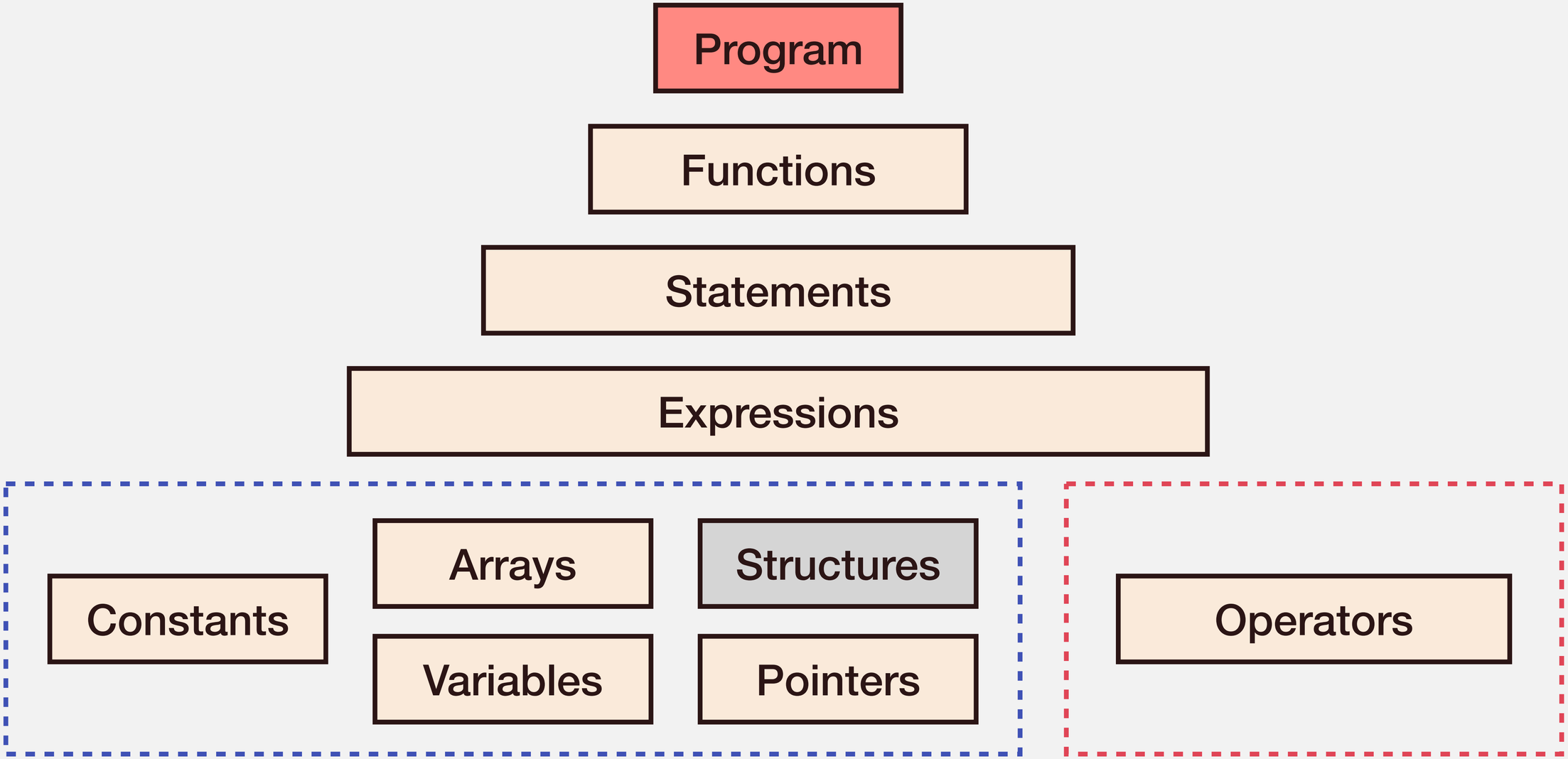
Quicksort

```
Quicksort(full_range) {
  Pick a pivot
  Rearrange around pivot
  Quicksort(before pivot)
  Quicksort(after pivot)
}
```

Road Map


Program
Functions
Statements
Expressions
Constants
Arrays
Variables
Structures
Pointers
Operators

Road Map


Program
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Single-File C Program

```c
#include <stdlib.h>
...
#define ERR_MSG “Wan le, bbq le”
...
int evil_global_var = 0;
...
void Quicksort(int *a, int l, int r);
...
int main() {
  ...
}
void Quicksort(int *a, int l, int r) {
  ...
}
```

1. Include header files
2. Define constants and macros
3. Global variables (**evil**)
4. Function prototypes
5. main
6. Function definition

Global Variables

- Declared and defined outside any function in a program

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  - Implicit coupling breaks modularity
  - No access control
  - Namespace pollution

Single-File C Program

```c
#include <stdlib.h>
...
#define ERR_MSG “Wan le, bbq le”
...

void Quicksort(int *a, int l, int r);
...

int main() {
  ...
}

void Quicksort(int *a, int l, int r) {
  ...
}
```

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Single-File C Program

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#include <stdlib.h>
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void Quicksort(int *a, int l, int r);
...
int main() {
  ...
}
void Quicksort(int *a, int l, int r) {
  ...
}
```

1. Include header files
2. Define constants and macros
3. Function prototypes
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Header Files (.h)

Source Files (.c)

Header File

sort_util.h

```
#ifndef __SORT_UTIL_H__
#define __SORT_UTIL_H__

#include <stdlib.h>

#define DEBUG_LEVEL 1

extern int evil_global_var;

void Quicksort(int *a, int l, int r);
void Mergesort(int *a, int l, int r);

#endif
```

Header File

sort_util.h

```
#ifndef __SORT_UTIL_H__
#define __SORT_UTIL_H__

#include <stdlib.h>

#define DEBUG_LEVEL 1

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sort_util.h

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#ifndef __SORT_UTIL_H__
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void Quicksort(int *a, int l, int r);
void Mergesort(int *a, int l, int r);

#endif
```

Prevent variables/functions from being declared multiple times

Header File

sort_util.h

```
#ifndef __SORT_UTIL_H__
#define __SORT_UTIL_H__

#include <stdlib.h>

#define DEBUG_LEVEL 1

extern int evil_global_var;

void Quicksort(int *a, int l, int r);
void Mergesort(int *a, int l, int r);

#endif
```

Header File

sort_util.h

```
#ifndef __SORT_UTIL_H__
#define __SORT_UTIL_H__

#include <stdlib.h>

#define DEBUG_LEVEL 1

extern int evil_global_var;

void Quicksort(int *a, int l, int r);
void Mergesort(int *a, int l, int r);

#endif
```

← **Declares** that the global variable is defined somewhere else

Source File

sort_util.c

```c
#include “sort_util.h”

#include <stdlib.h>

static void Swap(int *a, int i, int j) {
  ...
}

void Quicksort(int *a, int l, int r) {
  ...
}

void Mergesort(int *a, int l, int r) {
  ...
}
```

Source File

sort_util.c

```
#include “sort_util.h”
```

← The corresponding header file

```
#include <stdlib.h>

static void Swap(int *a, int i, int j) {
  ...
}

void Quicksort(int *a, int l, int r) {
  ...
}

void Mergesort(int *a, int l, int r) {
  ...
}
```

Source File

sort_util.c

```
#include “sort_util.h”
```

← The corresponding header file

```
#include <stdlib.h>
```

← Other function declarations needed for the implementation

```
static void Swap(int *a, int i, int j) {
  ...
}

void Quicksort(int *a, int l, int r) {
  ...
}

void Mergesort(int *a, int l, int r) {
  ...
}
```

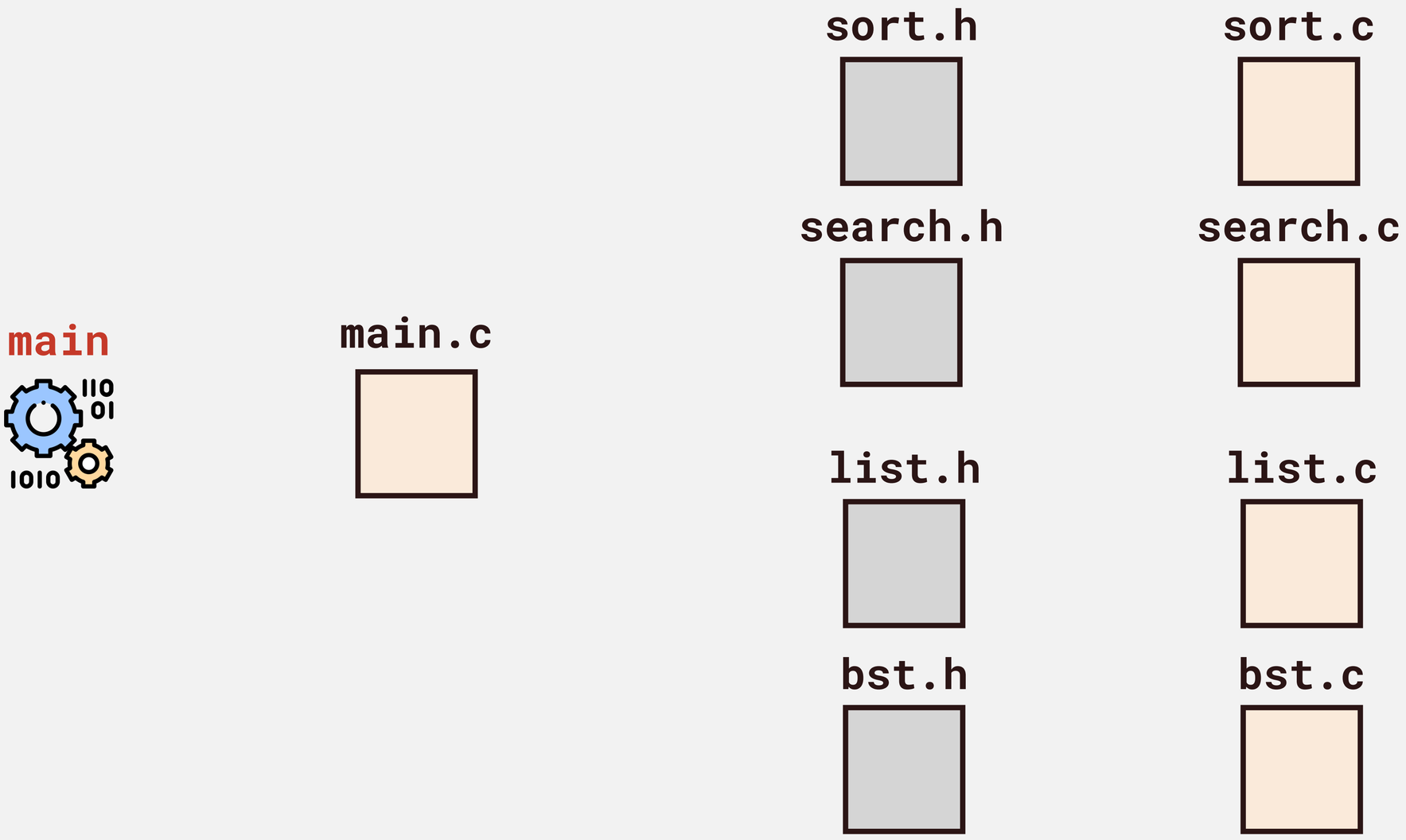
Source File

sort_util.c

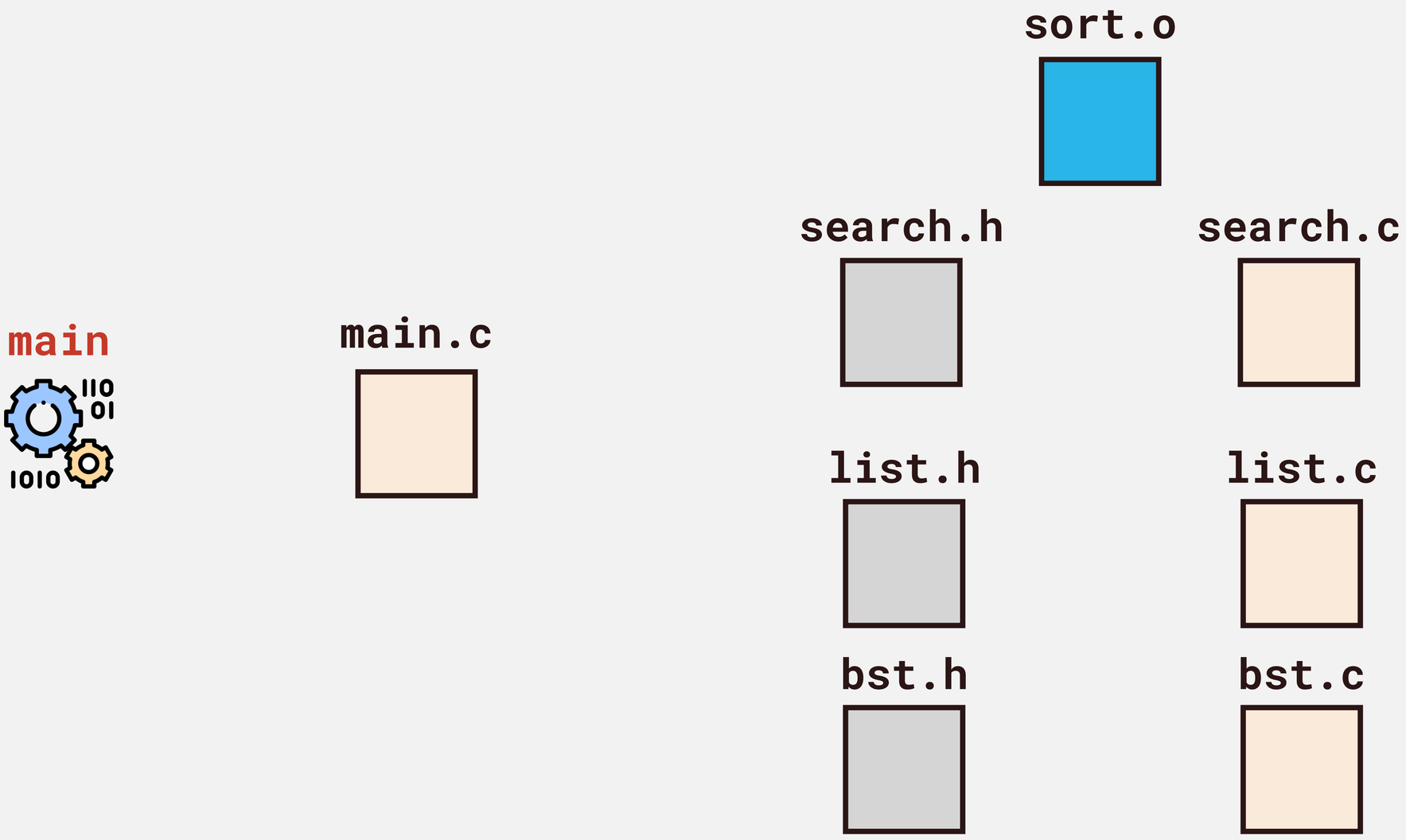
```
#include “sort_util.h”

#include <stdlib.h>

static void Swap(int *a, int i, int j) {
  ...
}

void Quicksort(int *a, int l, int r) {
  ...
}

void Mergesort(int *a, int l, int r) {
  ...
}
```

← Function is invisible outside the file

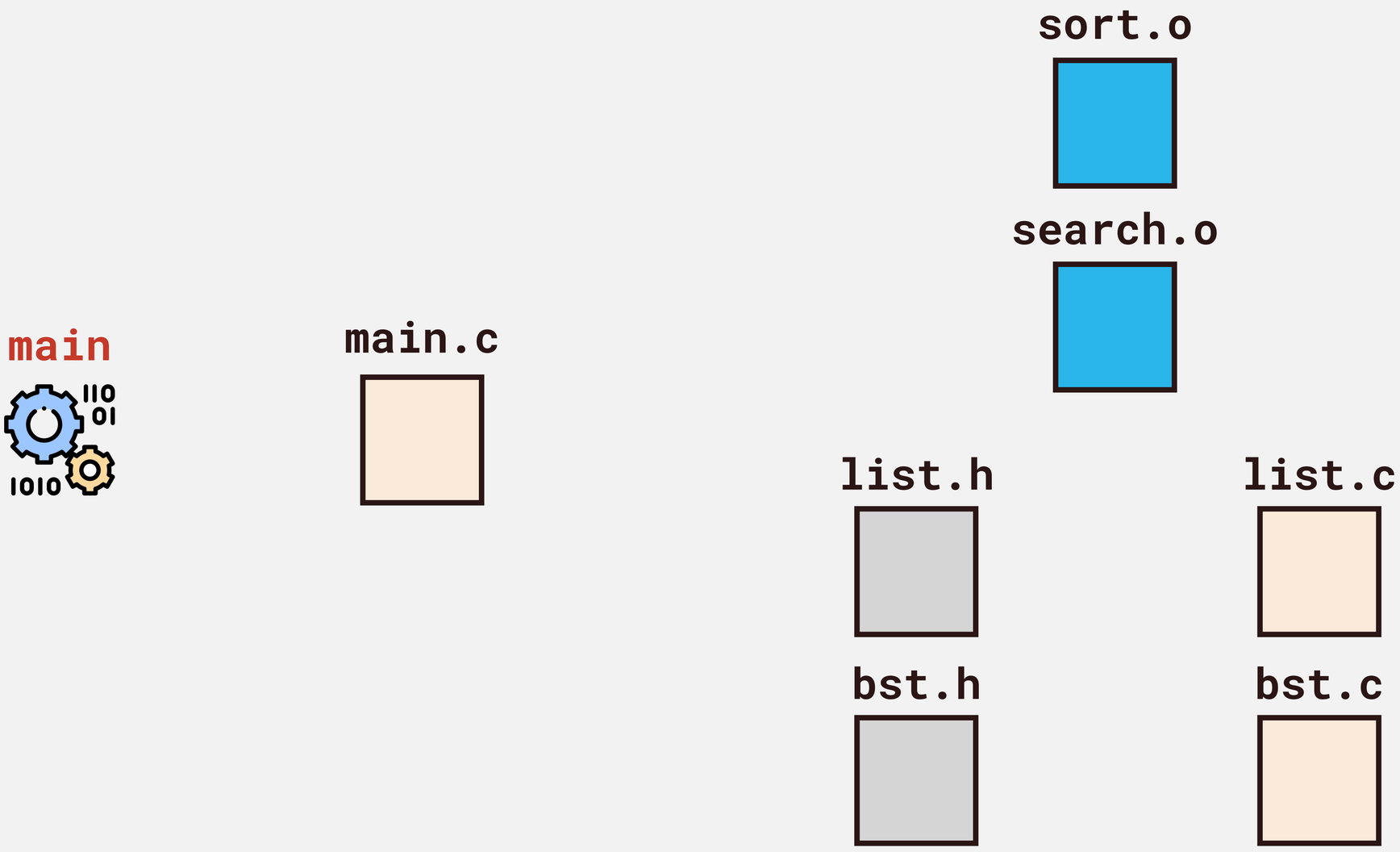
Multi-File C Program



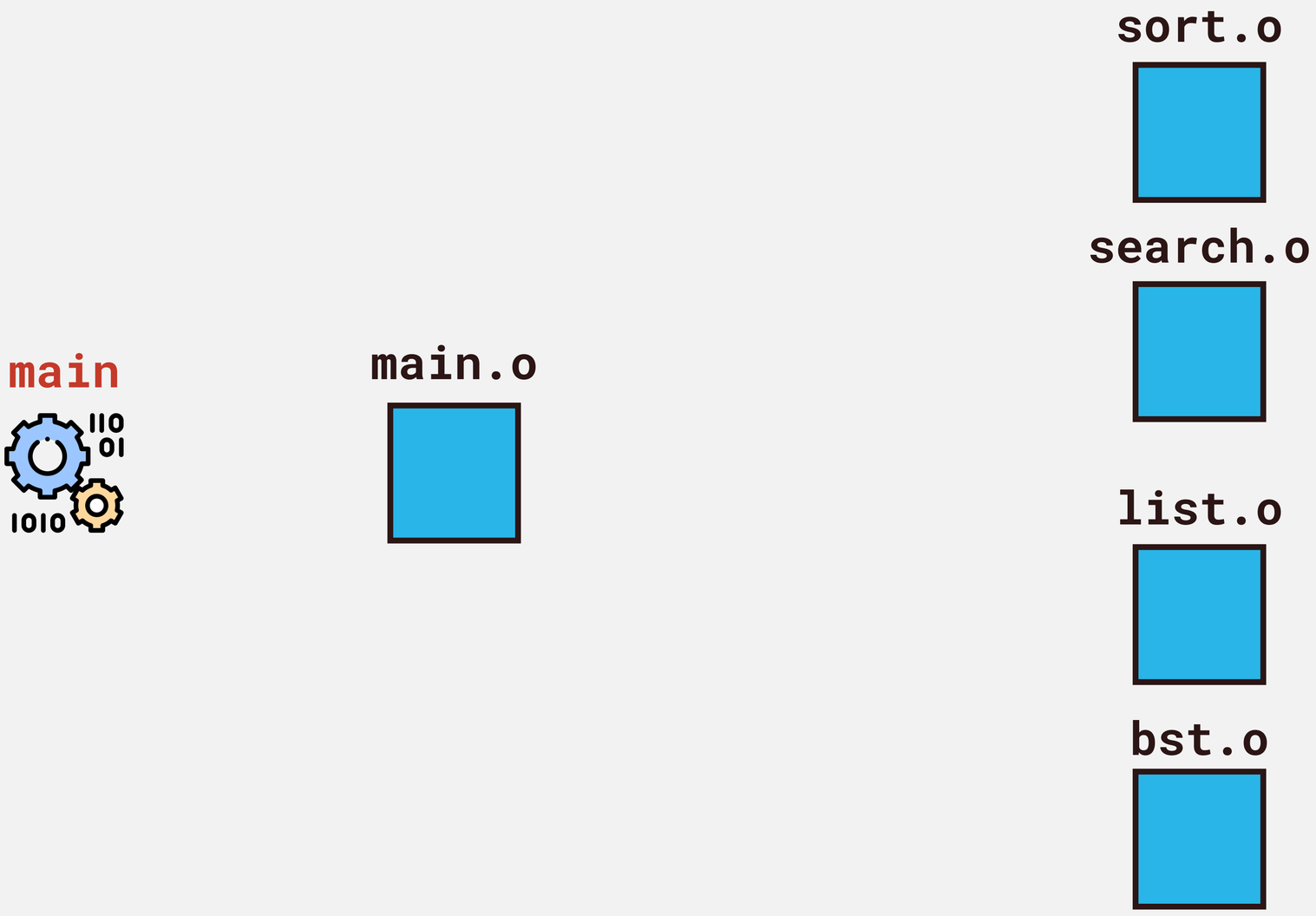
Multi-File C Program



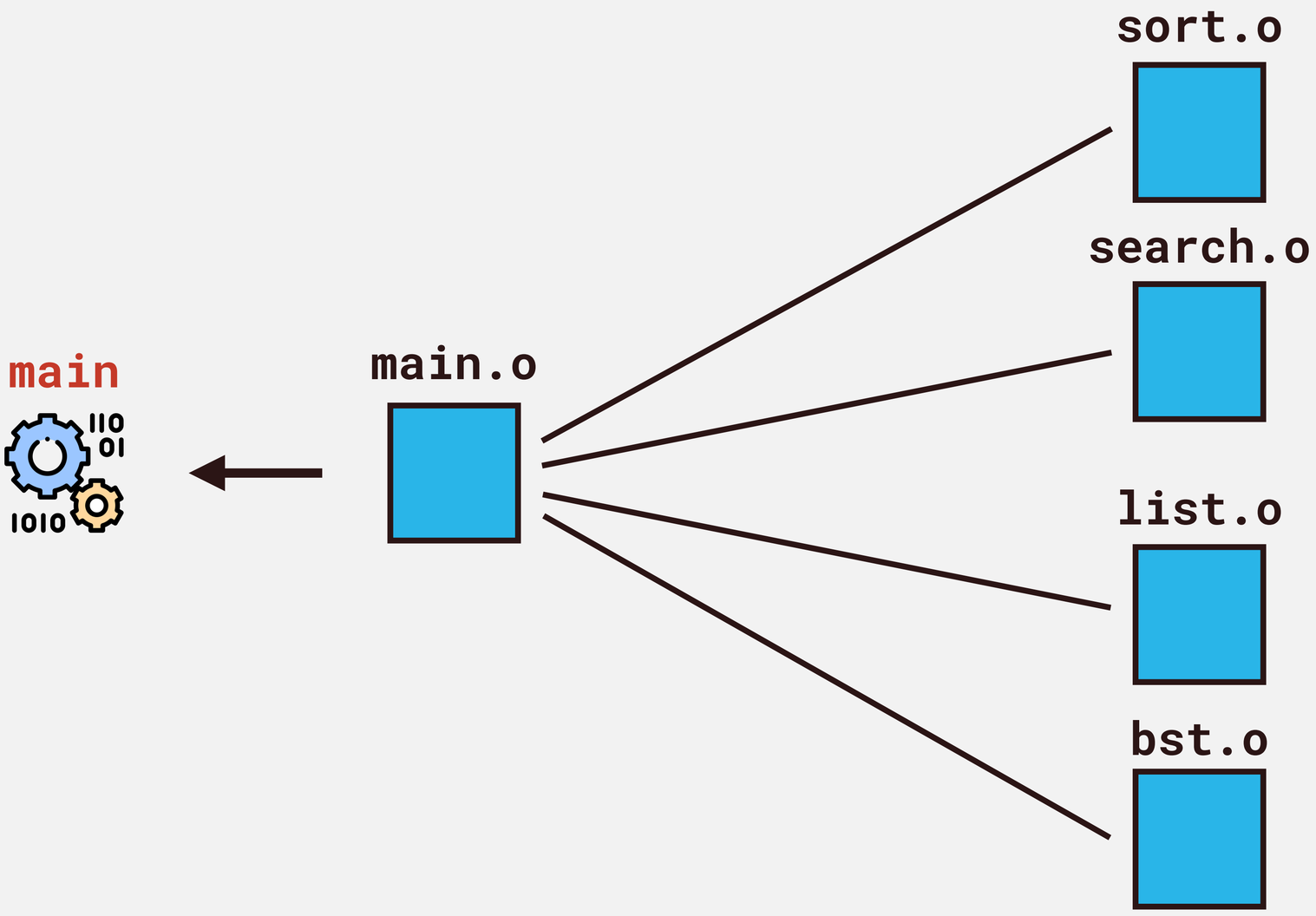
Multi-File C Program



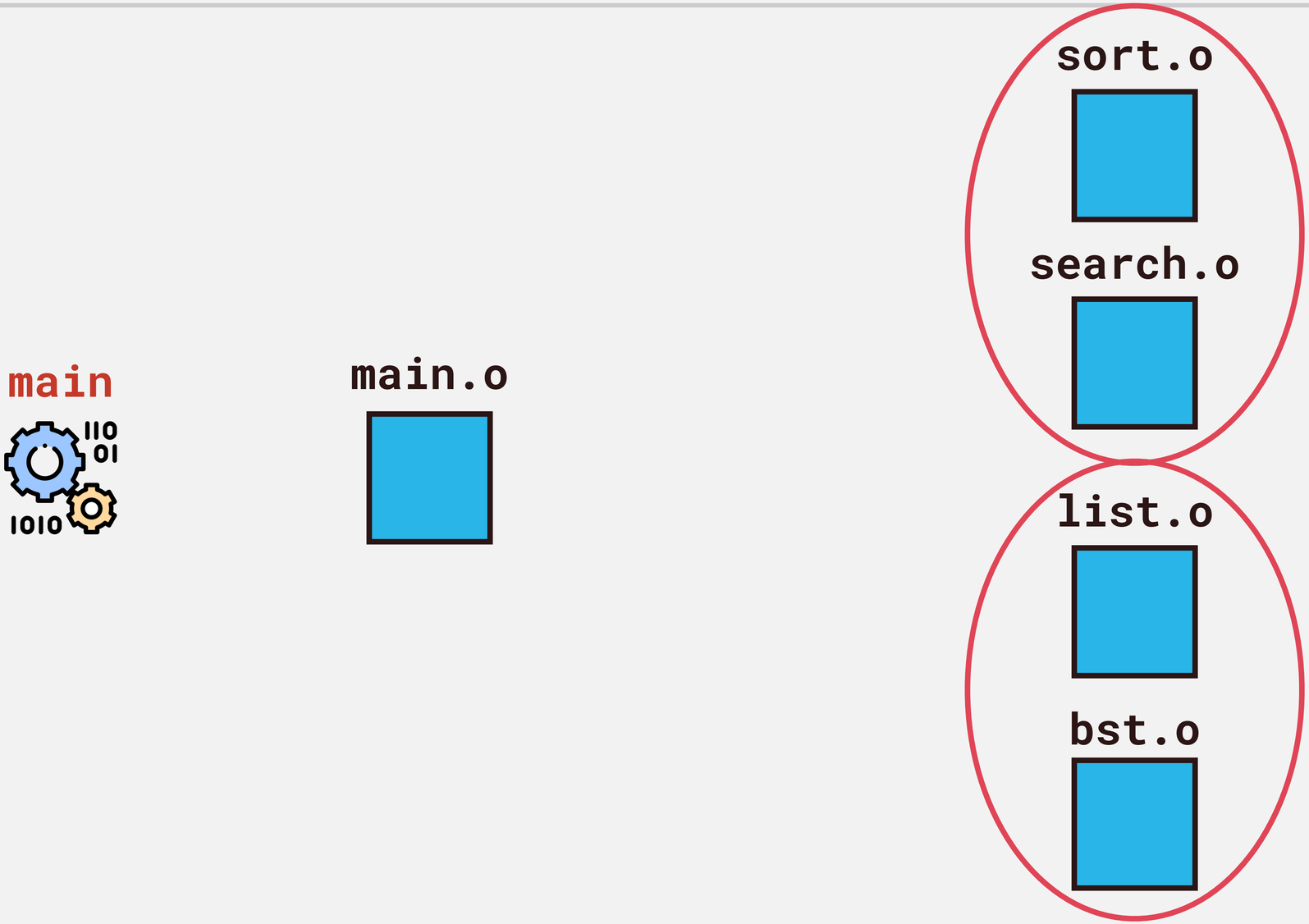
Multi-File C Program



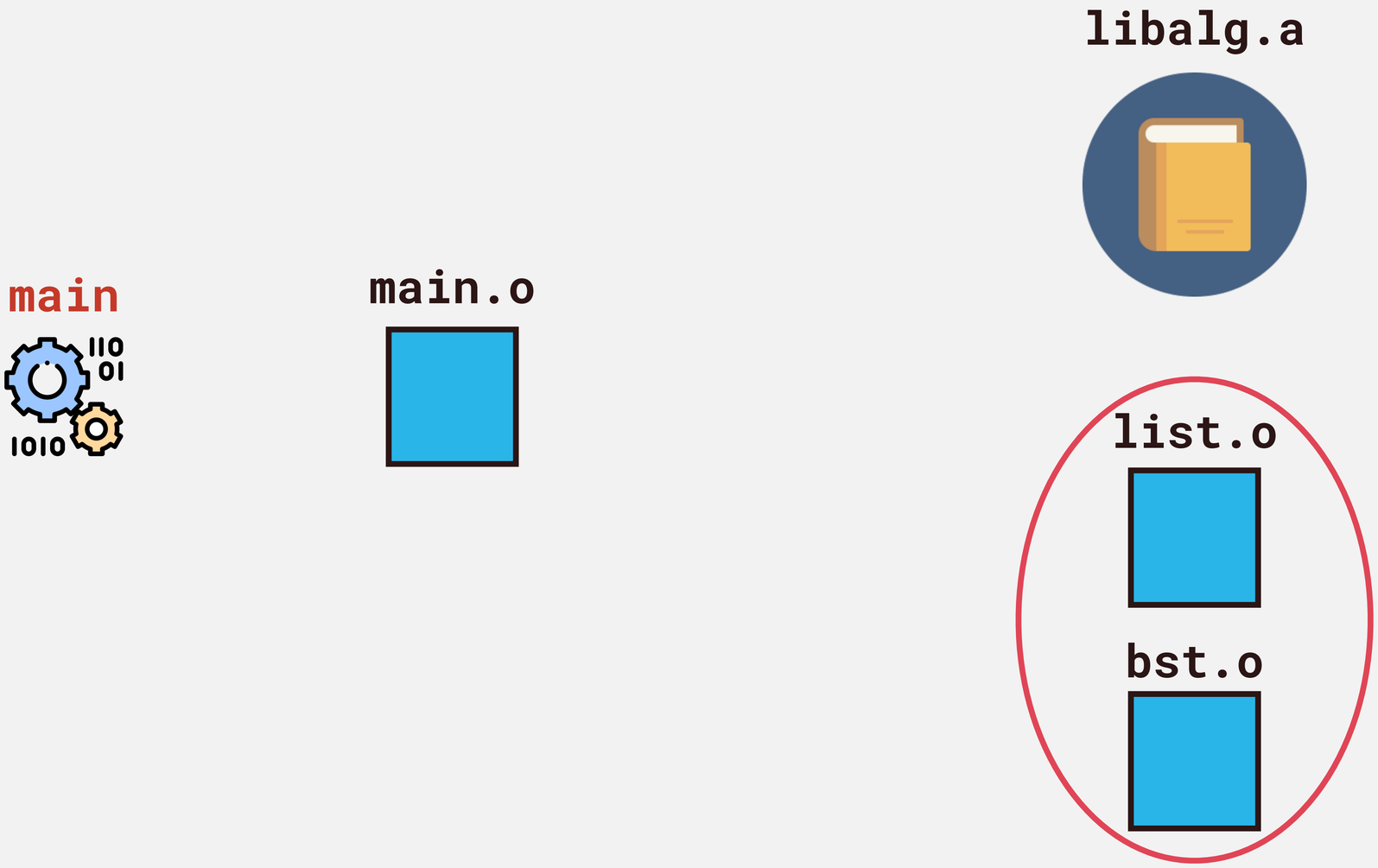
Multi-File C Program



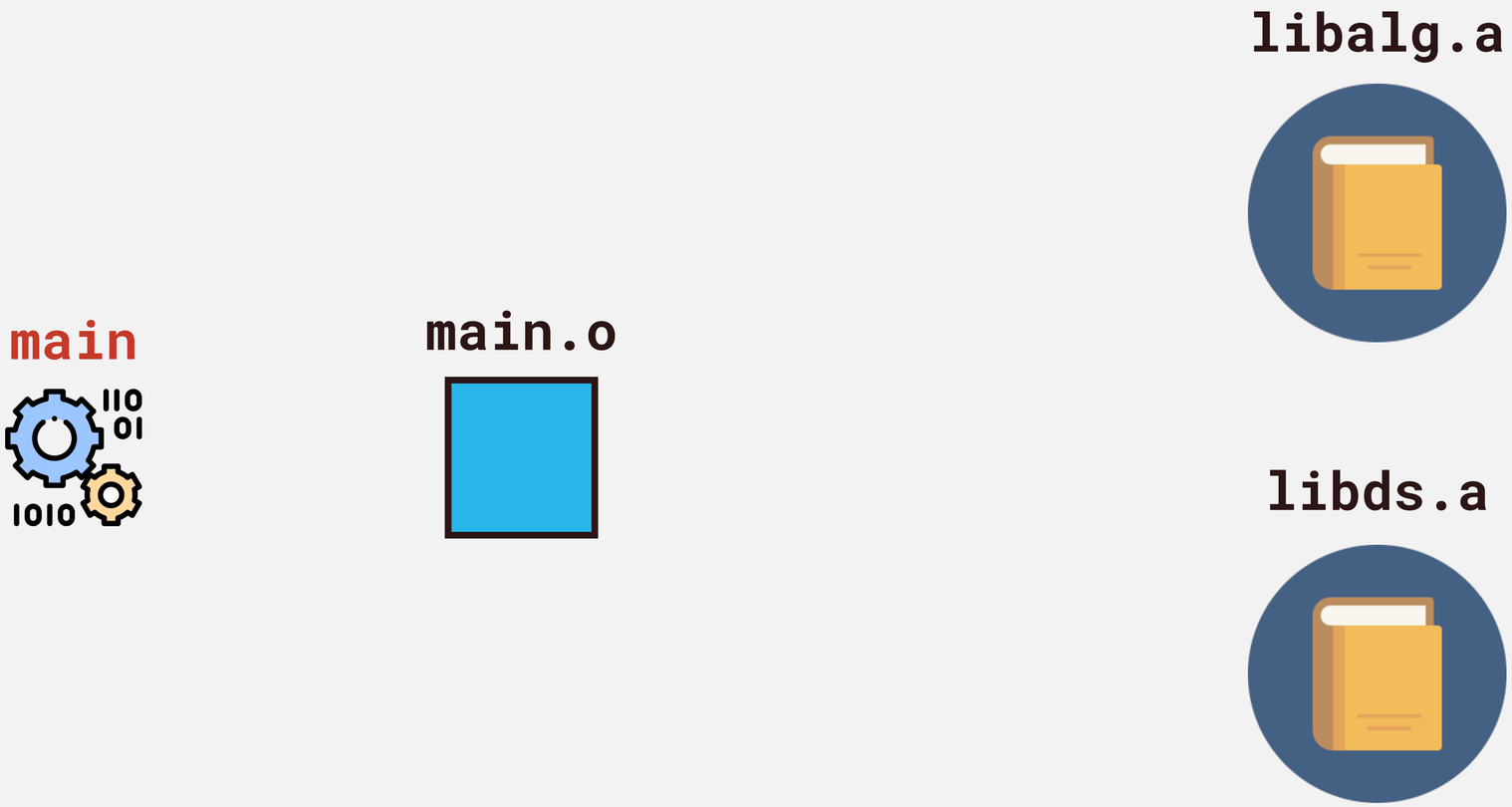
Libraries



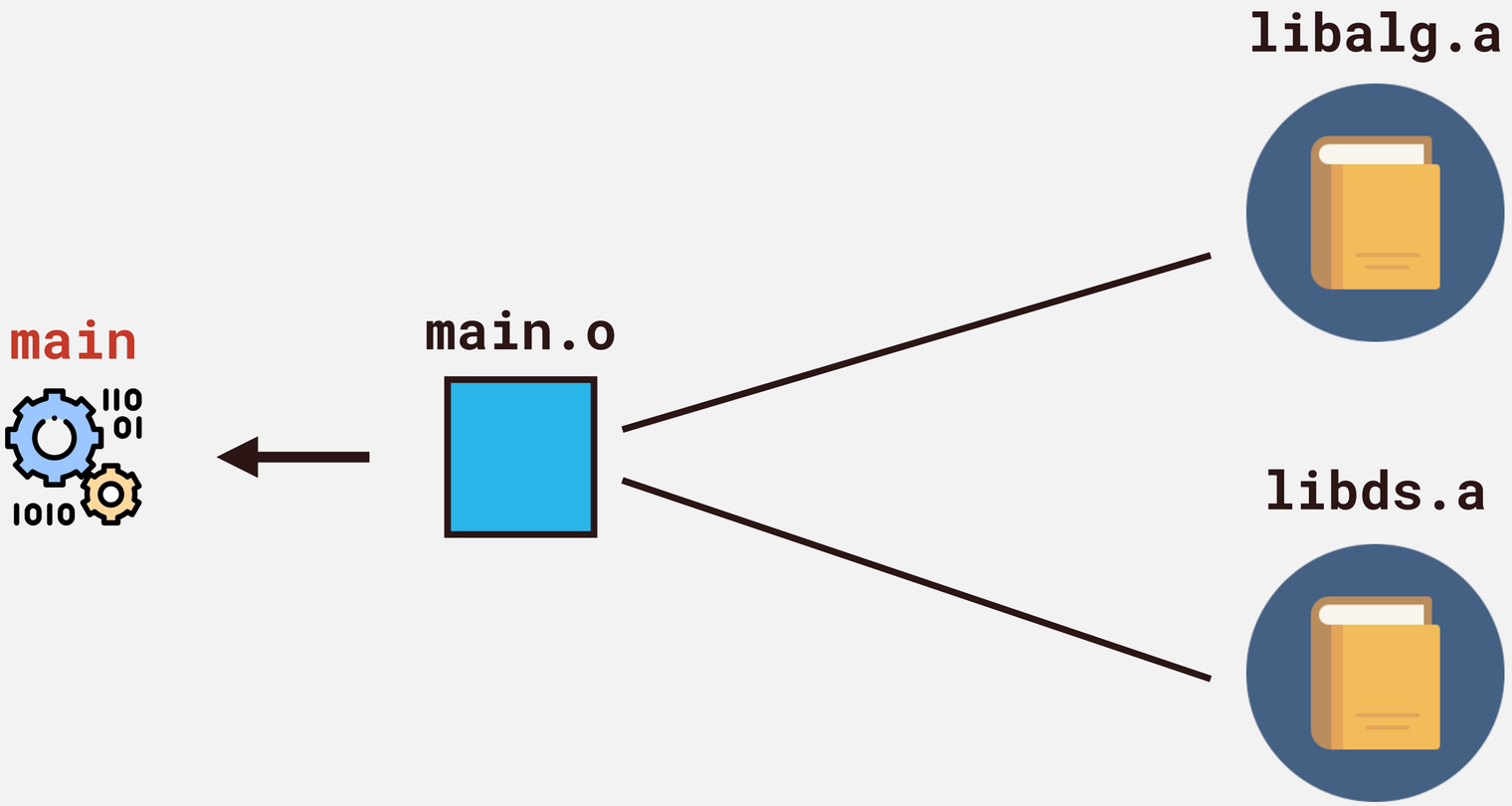
Libraries



Libraries



Libraries



Why Libraries?

prog1.c

prog2.c

sort.h

sort.c

search.h

search.c

list.h

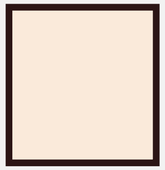
list.c

bst.h

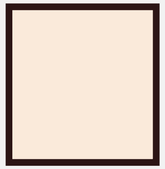
bst.c

Why Libraries?

prog1.c



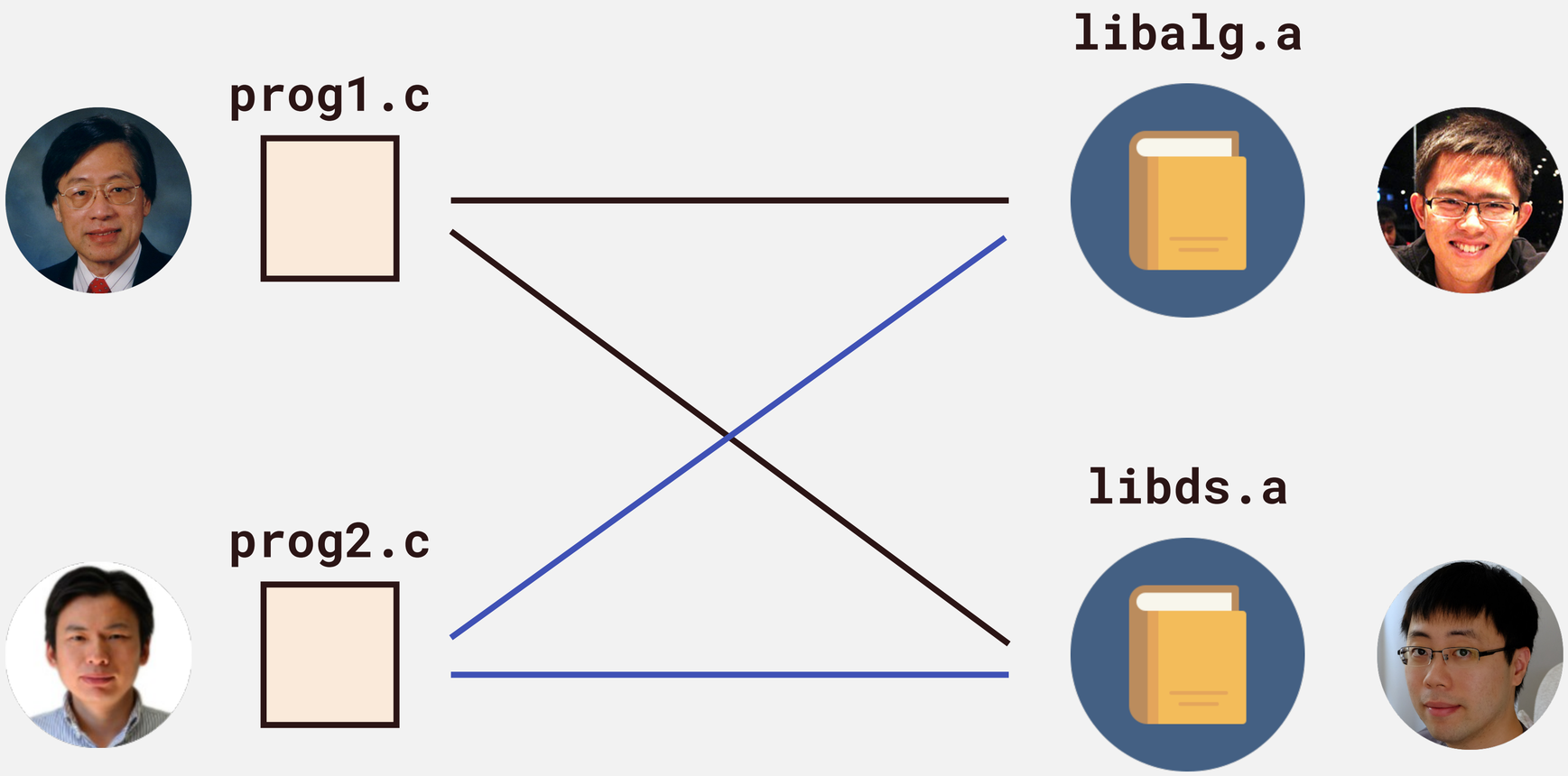
prog2.c



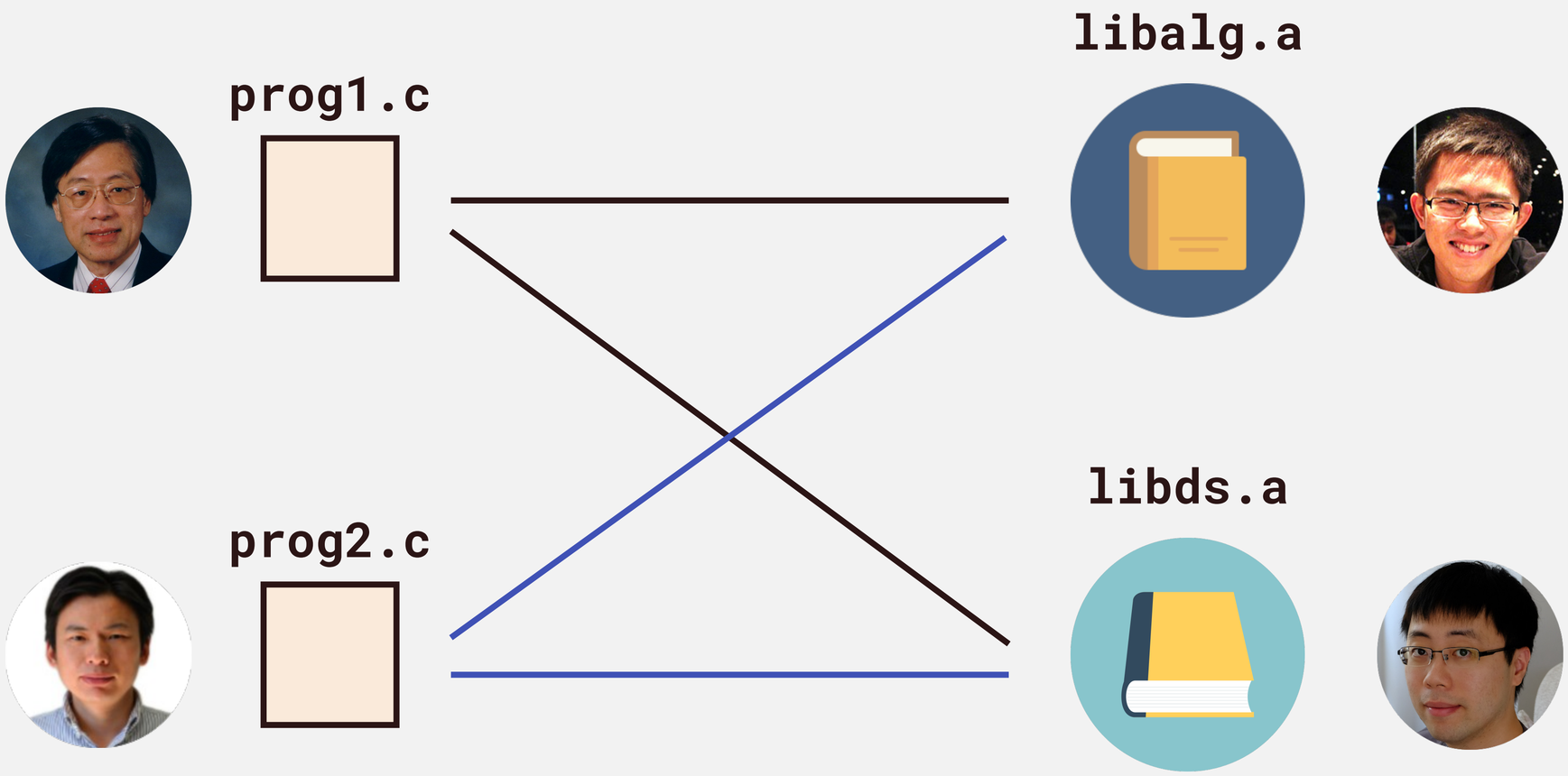
libalg.a

libds.a

Why Libraries?



Why Libraries?



Why Libraries?

- ➔ Speeds up compilation
- ➔ Facilitates collaboration and code reuse

Static Library

libfoo.a

```
void f() {
  ...
}
```

prog1.o

```
int main() {
  ...
  f();
}
```

prog2.o

```
int main() {
  f();
  …
}
```

Static Library

prog1

```
int main() {
  ...
  f();
}
```

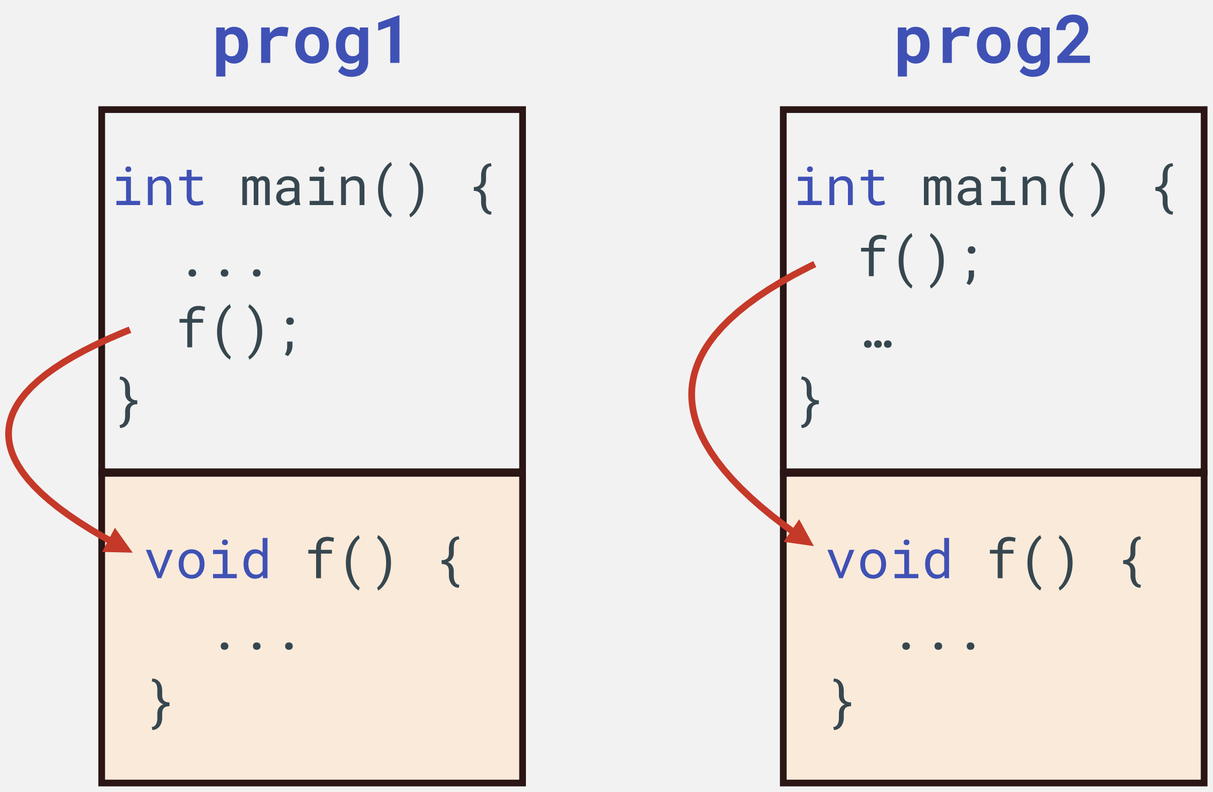
```
void f() {
  ...
}
```

prog2

```
int main() {
  f();
  …
}
```

```
void f() {
  ...
}
```

Static Library



Shared Library

libfoo.so

```
void f() {
  ...
}
```

prog1.o

```
int main() {
  ...
  f();
}
```

prog2.o

```
int main() {
  f();
  …
}
```

Shared Library

libfoo.so

```
void f() {
   ...
}
```

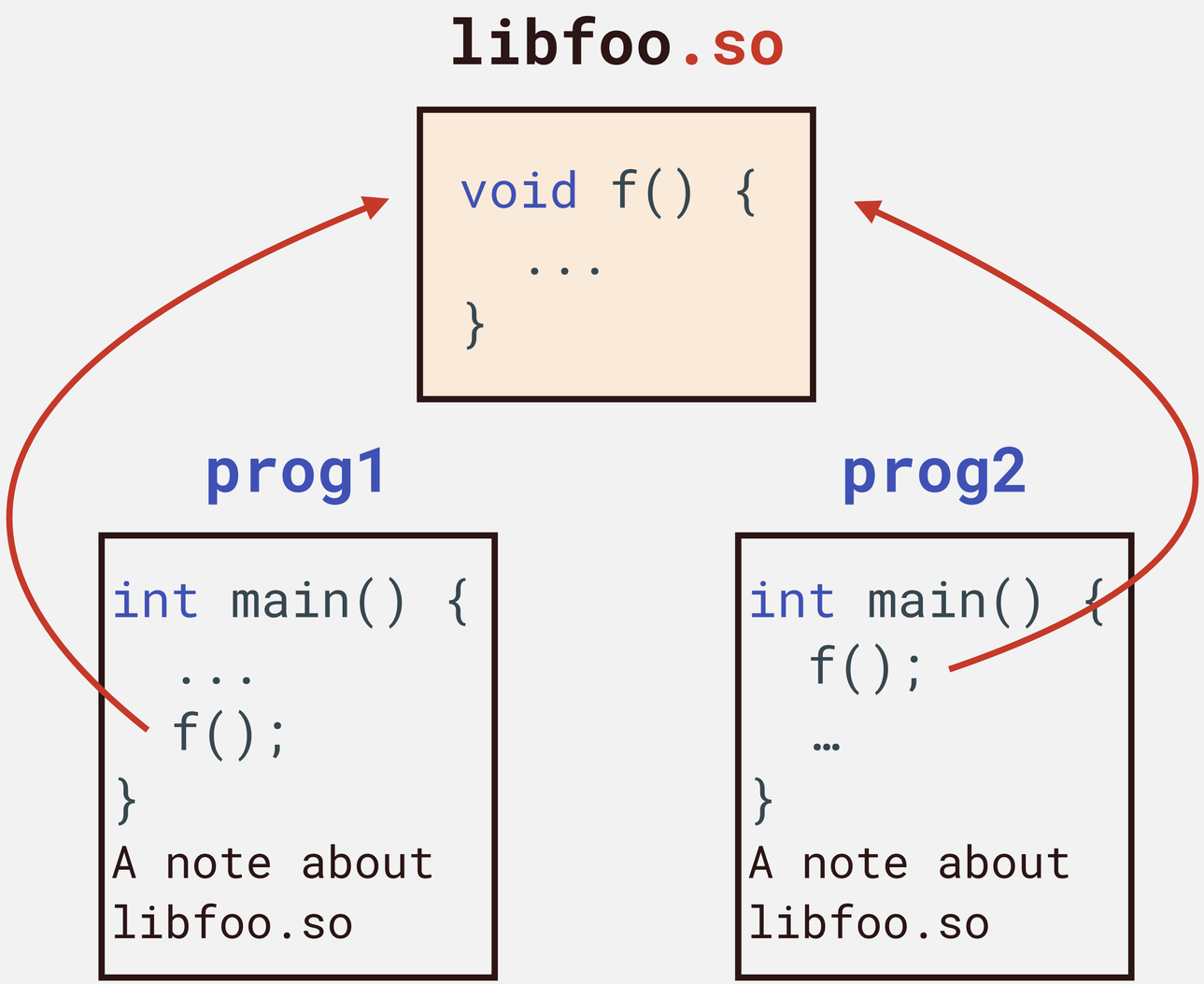
prog1

```
int main() {
   ...
   f();
}
A note about
libfoo.so
```

prog2

```
int main() {
   f();
   …
}
A note about
libfoo.so
```

Shared Library

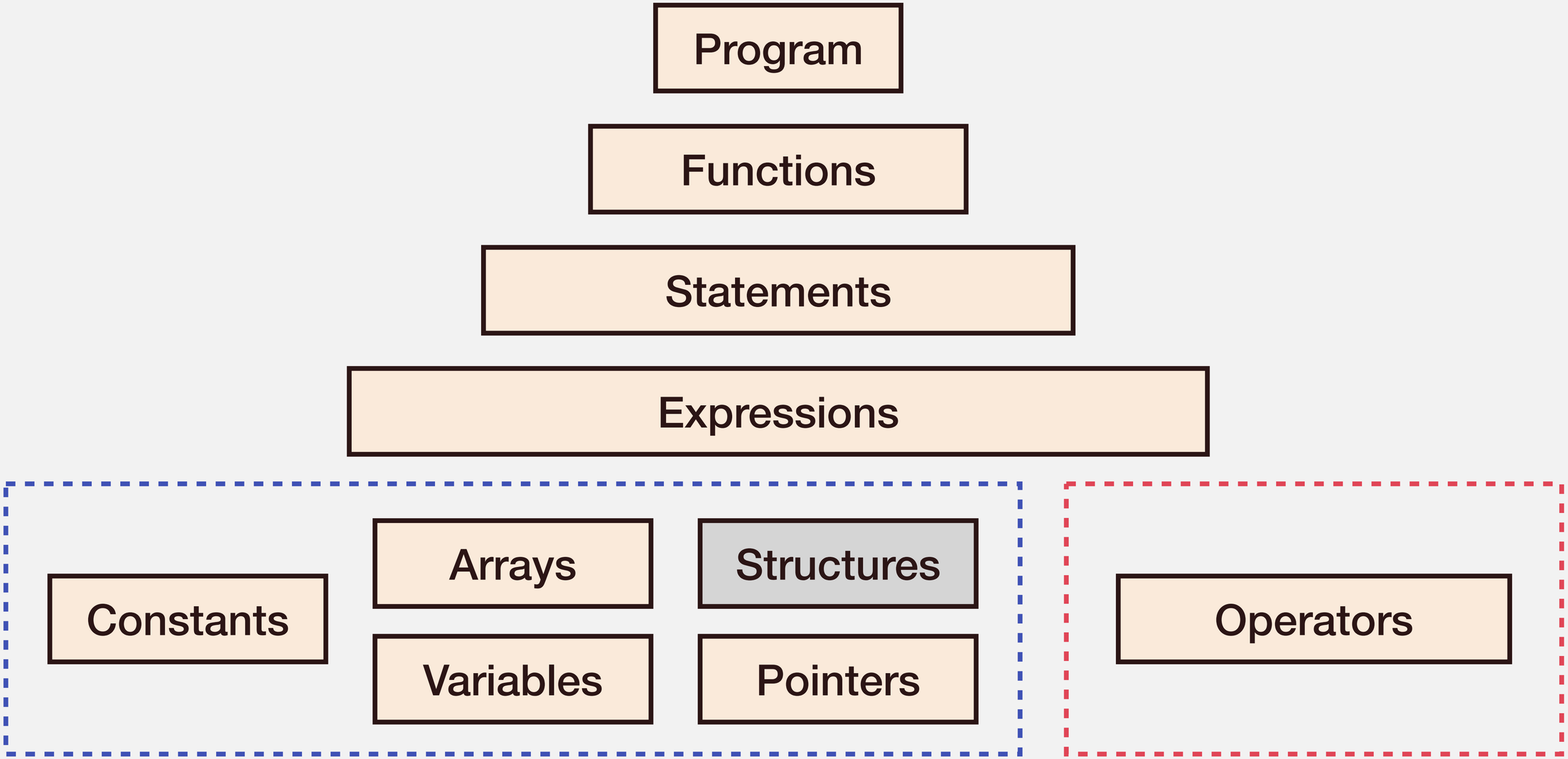


Use CMake

Summary

- **C String**
  - `char *`
- **Multi-Dimensional Array & Pointer Array**
  - `int a[M][N], int a[][N], int *a[M], int **a`
- **Recursion**
  - Divide and Conquer, quicksort
- **Multi-File C Program**
  - Header file, source file
  - Static/Shared library
  - Learn to use **CMake**

Road Map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