Pointers are variables, which contain the address of some other variables.

Declaration: \textit{datatype} *pointername;
\textit{e.g.} long * ptra;

The \textit{type} of a pointer depends on the type of the variable it points to. Every pointer points to some data type.
Sizes of basic data types

All data is stored in memory. But different data types occupy different amount of memory.

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For example, on some machine you may have

\[
\begin{align*}
\text{sizeof(int)} & = 4 \\
\text{sizeof(float)} & = 4 \\
\text{sizeof(double)} & = 8
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\]
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The `sizeof()` operator in C can be used to determine the number of bytes occupied by each data type.

For example, on some machine you may have

```
sizeof(int) = 4
sizeof(float) = 4
sizeof(double) = 8
```

These numbers are **NOT** the same for all machines. You should use the `sizeof()` operator instead of assuming the value.
```c
#include <stdio.h>

int main()
{
    int n;
    char c;
    int *ptrn;

    c='X';
    n=15;
    ptrn=&n;

    return 0;
}
```
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}
```
```c
#include <stdio.h>

int main()
{
    int n;
    char c;
    int *ptrn;

    c='X';
    n=15;
    //address of n
    //sizeof(ptrn) = 4
    ptrn=&n;

    return 0;
}
```

`sizeof(ptrn) = 4 bytes = 32 bits, since we have $2^{32}$ byte addresses.`
There are two unary operations to consider.

- The * operator: If ptra is a pointer variable, then *ptra gives you the content of the location pointed to by ptr.
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- The \(^*\) operator: If \(ptra\) is a pointer variable, then \(^*ptra\) gives you the content of the location pointed to by \(ptr\).
- The \& operator: If \(v\) is a variable, then \&\(v\) is the address of the variable.

In the previous code, what is \(^*ptrn\)?
Address Operations

There are two unary operations to consider.

- The \* operator: If `ptr` is a pointer variable, then `*ptr` gives you the content of the location pointed to by `ptr`.
- The \& operator: If `v` is a variable, then `&v` is the address of the variable.

In the previous code, what is `*ptrn`?

Caution: Declaration of a pointer also uses ‘\*’.
Outline

1. Pointers
2. Pointer Arithmetic
3. Arrays and Pointers
4. Passing Pointers to Functions
Problem: How do we do relative addressing? (for example, “next element” in an integer array)
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**Unary Pointer Arithmetic Operators**

- Operator `++`: Adds `sizeof(datatype)` number of bytes to pointer, so that it points to the next entry of the datatype.
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### Unary Pointer Arithmetic Operators

- **Operator `++`:** Adds `sizeof(datatype)` number of bytes to pointer, so that it points to the next entry of the datatype.
- **Operator `--`:** Subtracts `sizeof(datatype)` number of bytes to pointer, so that it points to the next entry of the datatype.
#include <stdio.h>

int main()
{
    int *ptrn;
    long *ptrlng;

    ptrn++; // increments by sizeof(int) (4 bytes)
    ptrlng++; // increments by sizeof(long) (8 bytes)

    return 0;
}

Pointers and integers are not interchangeable. (except for 0.) We will have to treat arithmetic between a pointer and an integer, and arithmetic between two pointers, separately.
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long *ptrlng;
```

### Binary Operations between a pointer and an integer

- `ptrlng+n` is valid, if n is an integer. The result is the following byte address
- `ptrlng + n*sizeof(long)`
- and **not** `ptrlng + n`.
- It advances the pointer by n number of longs.
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**Binary Operations between a pointer and an integer**

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   ```c
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   ```
   and *not* `ptrlng + n`.
   It advances the pointer by `n` number of `longs`.
2. `ptrlng-n` is similar.
Consider two pointers ptr1 and ptr2 which point to the same type of data.

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### Binary operations between two Pointers

1. Surprise: Adding two pointers together is not allowed!
Consider two pointers `ptr1` and `ptr2` which point to the same type of data.

```c
<datatype> *ptr1, *ptr2;
```

### Binary operations between two Pointers

1. **Surprise:** Adding two pointers together is not allowed!
2. `ptr1 - ptr2` is allowed, as long as they are pointing to elements of the same array. The result is

   \[
   \frac{ptr1 - ptr2}{\text{sizeof}(\text{datatype})}
   \]

   In other settings, this operation is undefined (may or may not give the correct answer).
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   \[
   \frac{ptr1 - ptr2}{\text{sizeof(datatype)}}
   \]

In other settings, this operation is undefined (may or may not give the correct answer).

Why all these special cases? These rules for pointer arithmetic are intended to handle addressing inside **arrays** correctly.
If we can subtract a pointer from another, all the relational operations can be supported!

**Logical Operations on Pointers**

1. \( \text{ptr1} > \text{ptr2} \) is the same as \( \text{ptr1} - \text{ptr2} > 0 \),
2. \( \text{ptr1} = \text{ptr2} \) is the same as \( \text{ptr1} - \text{ptr2} = 0 \),
3. \( \text{ptr1} < \text{ptr2} \) is the same as \( \text{ptr1} - \text{ptr2} < 0 \),
4. and so on.
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Arrays and Pointers

Array names essentially are pointers. Array elements are stored in contiguous (consecutive) locations in memory.

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3. `arr+i` is a pointer to `arr[i].` (`arr+i` is equivalent to `arr+i*sizeof(int).`)
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1. arr is a pointer to the first element of the array.
2. That is, *arr is the same as arr[0].
3. arr+i is a pointer to arr[i]. (arr+i is equivalent to arr+i*sizeof(int).)
4. *(arr+i), is equal to arr[i].
5. Question: What is &arr[i] equivalent to?
int arr[3];

arr[0] = *arr = *(arr+0)

arr[1] = *(arr+1)

arr[2] = *(arr+2)
Outline

1. Pointers
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Since pointers are also variables, they can be passed

- As input parameters to functions
- As return values from functions
Passing Pointers - Reason 1

Why do we pass pointer variables to functions?

Recall the swap function which took input integers. This function was unable to swap the variables inside `main()`.
Why do we pass pointer variables to functions?

Recall the swap function which took input integers. This function was unable to swap the variables inside main().

Suppose we want a swap function which is able to swap arguments inside the caller.

Main idea: Pass pointers!!
#include <stdio.h>

//Swap the contents of locations pointed to by the
//input pointers
void swap(int *pa, int *pb)
{
    int temp;

    temp = *pb;
    *pb = *pa;
    *pa = temp;
    return;
}

int main()
{
    int a = 1, b = 2;
    int *ptra = &a;
    int *ptrb = &b;

    printf(''a=%d b=%d'', a, b);

    swap(ptra, ptrb);  //equivalently, swap(&a, &b);

    //a and b would now be swapped
    printf(''a=%d b=%d'', a, b);
    return 0;
}

When swap(pa, pb) is called, the value of the pointers is copied
to the function. The value of the pointers is the address of a and
b, respectively.
```c
#include <stdio.h>

void swap(int *pa, int *pb) {
    int temp;
    temp = *pb;
    *pb = *pa;
    *pa = temp;
}

int main() {
    int a = 1, b = 2;
    int *ptra = &a;
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    swap (ptra, ptrb);
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scanf("%d", &n);
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`scanf` needs to change the content of `n`. This can be done by passing the address of `n`.
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**scanf**

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`scanf` needs to change the content of `n`. This can be done by passing the address of `n`.

**printf**

```c
printf("%d", n);
```

`printf` does not need to change the content of `n`. 
We have already seen that we can pass arrays as input to functions. We also have seen that arrays are essentially pointers.

We can pass pointers, where arrays are expected, and vice versa!
#include <stdio.h>

// Count number of elements in an integer array, until the first -1
int num_elts (int *a)
{
    int *p;
    p = a;

    while (*p != -1) {
        p++;
    }

    return p - a;
}

int main()
{
    int arr[] = {1, 2, 3, -1};
    printf("%d", num_elts(arr)); // Passing array as pointer
    return 0;
}
Schematic Diagram of num_elts

arr

1 2 3 -1
Schematic Diagram of num_elts

arr → 1 2 3 -1

p
Schematic Diagram of num_elts

arr→1 2 3 -1

p→
Schematic Diagram of num_elts

arr → 1 2 3 -1

p

p-arr = 3
If we changed the call to the following line,

```c
num_elts(arr+1);
```

the result is 2, since the `num_elts` will search in the subarray `{2,3,-1}`.
Passing a pointer to data, instead of passing the value of the data can be much faster.

This is used to reduce the slowdown due to function calling.

The decision to do this must be taken with care.
Programming with pointers has to be done with care. Common mistakes include

1. Crossing array boundaries - Suppose an array has 10 elements, and arr is pointing to the first element. If you do *(arr-1), or *(arr+11), you might get unpredictable behaviour.

2. “Dangling Pointers” - pointers that point to data that is not meaningful - for example, using a pointer without initializing it.
If there is an error in a program using pointers, when executing, you will most probably get “Segmentation Fault”.

There are several ways to find the error.

1. Go through the code carefully and see if you can locate the bug. (perfect!)

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1. Go through the code carefully and see if you can locate the bug. (perfect!)
2. Use a debugger like gdb to debug the code and step through the execution to locate the error. Examine the memory contents when you debug.
3. Insert printf statements to pinpoint where the code crashes. (When doing so, make sure to put “\n” at the end of the message - it might not print otherwise!)

---

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void merge_p(int *s, int *t, int *result, int size_s, int size_t)
{
    int *p = s;
    int *q = t;

    printf("Reached Point 0\n");

    while(p-s<size_s && q-t<size_t){
        //...
    }

    printf("Reached Point 1\n");

    if(p-s < size_s){
        while( p-s < size_s) {
            //...
        }
    }else if(q-t < size_t){
        while( q-t < size_t) {
            //...
        }
    }

    printf("Reached Point 2\n");

    return;
}