Pointers

Some of the slides have been adapted from Krithika Venkataramani who is a professor at IIT (India Institute of Technology)

Objectives

“Controlling complexity is the essence of computer programming.” (Brian Kernigan)

a)To learn about pointers and indirect addressing

b)To learn how to return function results through a function’s arguments

c)To understand the differences between call-by-value and call-by-reference

Outline

Pointers

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

Declaration: *datatype* *pointername;
e.g. long * ptra;

The *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

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sizeof(int) = 4
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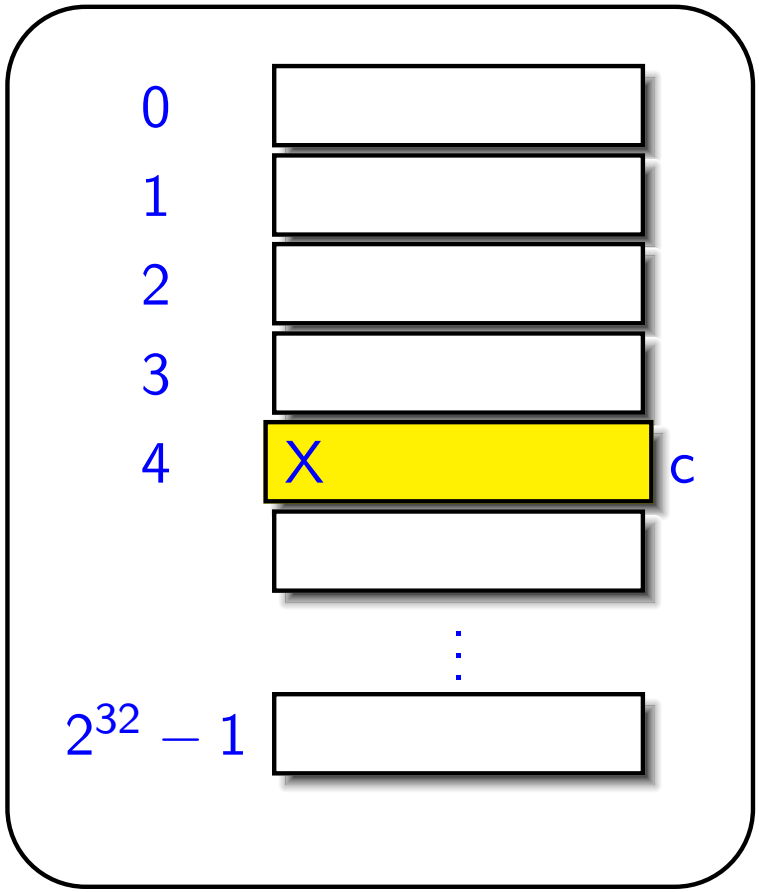
```

These numbers are NOT the same for all machines. You should use the `sizeof()` operator instead of assuming the value.

A Sample Program



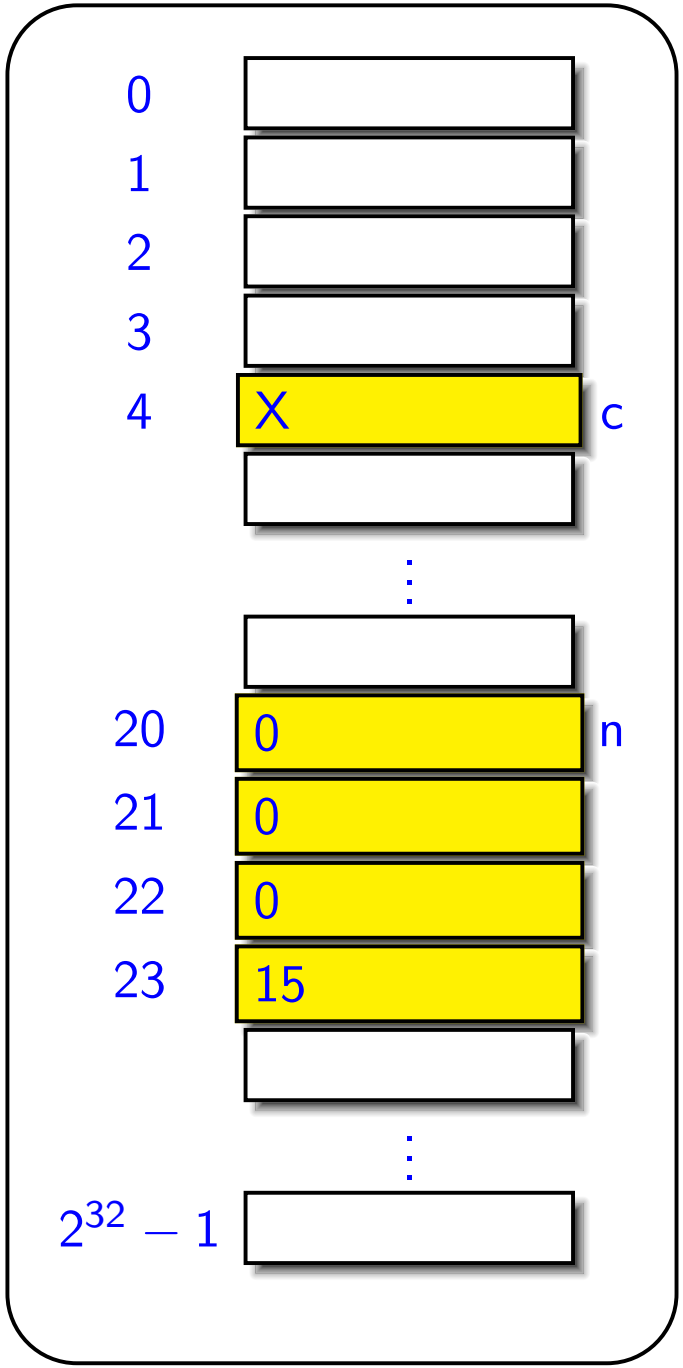
Memory Layout (Bytes)

```
#include <stdio.h>

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

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

    return 0;
}
```

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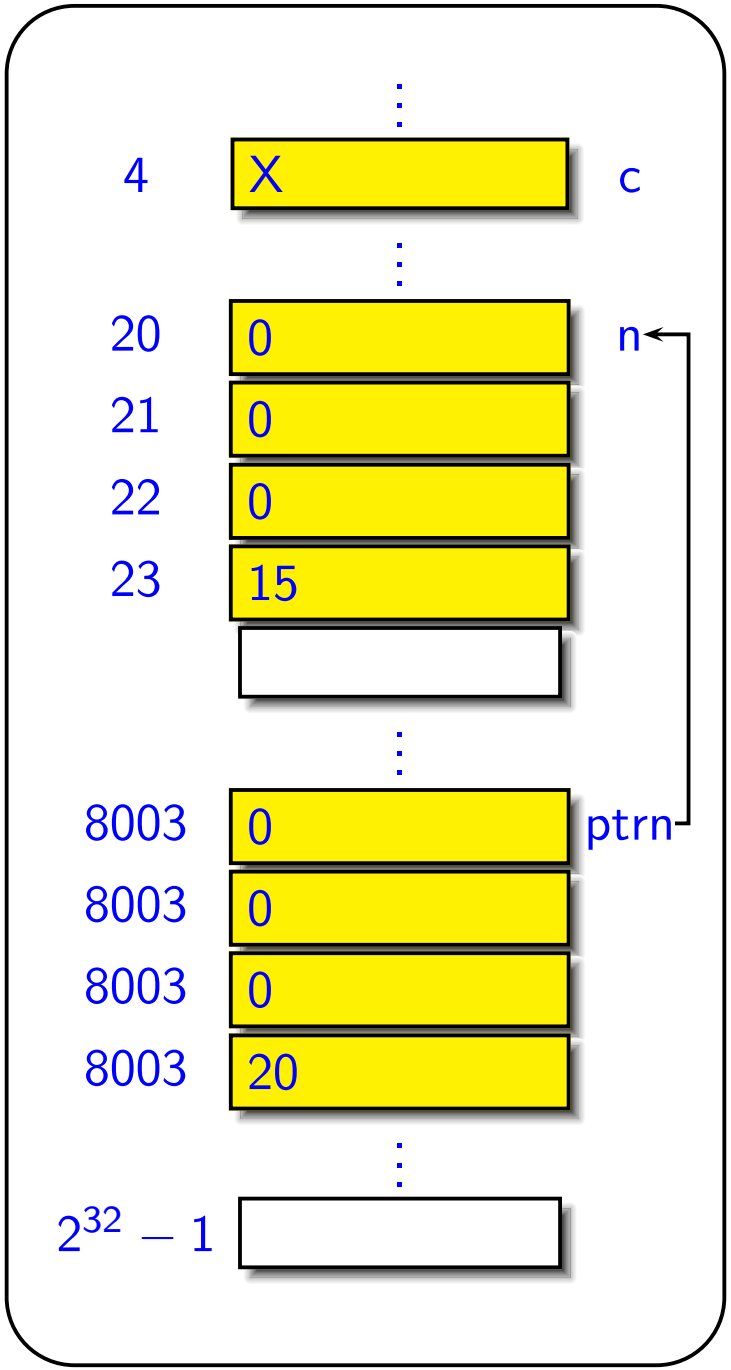



```c
#include <stdio.h>

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.

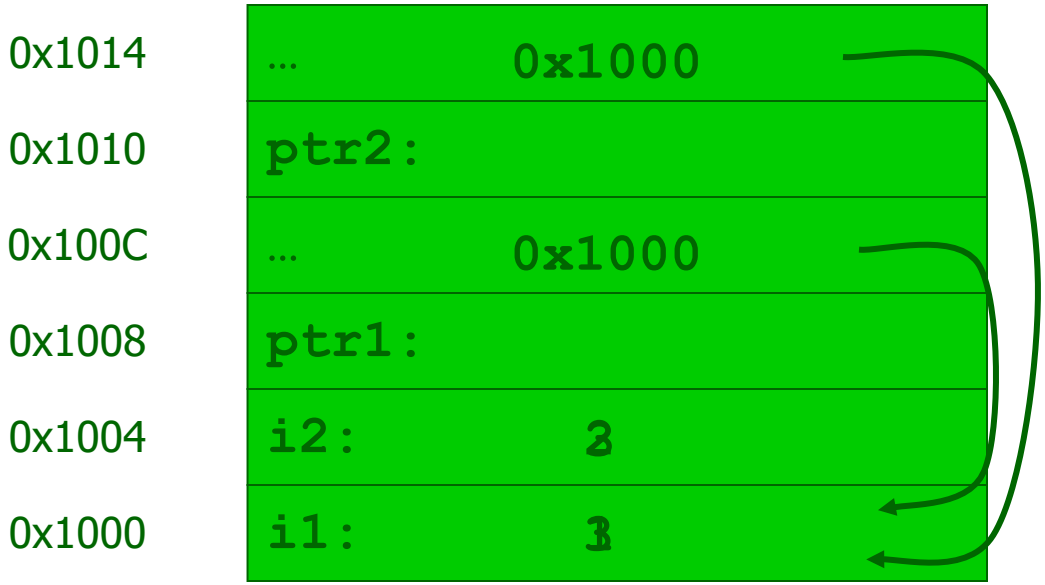
Using Pointers

```
int  i1;
int  i2;
int *ptr1;
int *ptr2;

i1 = 1;
i2 = 2;

ptr1 = &i1;
ptr2 = ptr1;

*ptr1 = 3;
i2 = *ptr2;
```



Using Pointers (cont.)

```
int  int1     = 1036;   /* some data to point to  */
int  int2     = 8;

int *int_ptr1 = &int1;  /* get addresses of data  */
int *int_ptr2 = &int2;

*int_ptr1 = int_ptr2;

*int_ptr1 = int2;
```

What happens?

Type check warning: `int_ptr2` **is not an** `int`

`int1` **becomes 8**

Using Pointers (cont.)

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int  int1     = 1036;   /* some data to point to  */
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int_ptr1 = *int_ptr2;

int_ptr1 = int_ptr2;
```

What happens?

Type check warning: `*int_ptr2` is not an `int *`

Changes `int_ptr1` – doesn't change `int1`

A Special Pointer in C

Special constant pointer `NULL`

- **Points to no data**
- **Dereferencing illegal – causes *segmentation fault***

- **To define, include `<stdlib.h>` or `<stdio.h>`**

Generic Pointers

void *: a "pointer to anything"

```
void   *p;
int     i;
char    c;
p = &i;
p = &c;
putchar(*(char *)p);
```

type cast: tells the compiler to "change" an object's type (for type checking purposes – does not modify the object in any way)

Dangerous! Sometimes necessary…

Lose all information about what type of thing is pointed to

- Reduces effectiveness of compiler's type-checking
- Can't use pointer arithmetic

Address Operations

There are two unary operations to consider.

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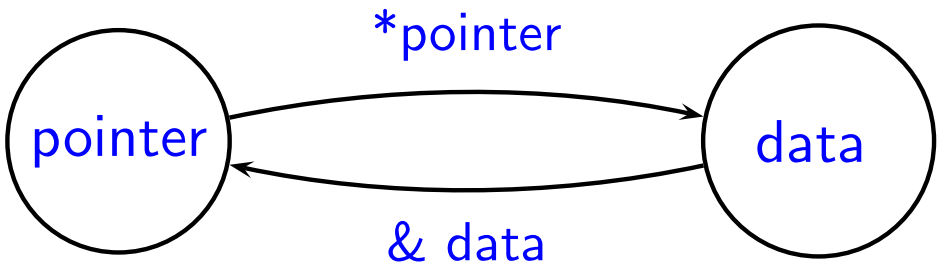

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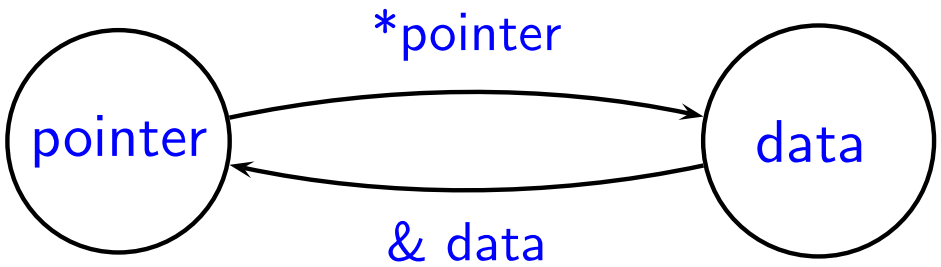

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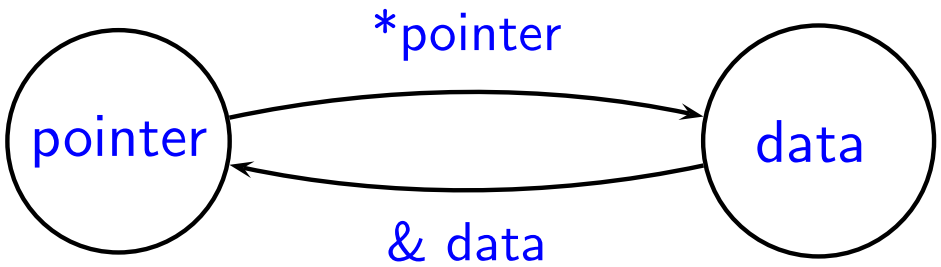

In the previous code, what is *ptrn?

Caution: Declaration of a pointer also uses '*'.

Review questions

a) A pointer variable contains as it's value the _____ of another varibale?

b)The three values that can be used to initialise a pointer are
- i)
- ii)
- iii)

c)The only integer that can be assigned to a pointers ?

Exercise

- What is the output of the following program segment?

```
int count = 10, *temp, sum = 0;
temp = &count;
*temp = 20;
temp = &sum;
*temp = count;
printf("count = %d, *temp = %d, sum = %d\n", count,*temp, sum );
```

Outline

Pointer Arithmetic

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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.

Pointer Arithmetic - Example 1

```
#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;
}
```

Pointer Arithmetic - II

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1. 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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2. `ptrlng-n` is similar.

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

$$\frac{\texttt{ptr1 - ptr2}}{\texttt{sizeof(}\textit{datatype}\texttt{)}}$$

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

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Why all these special cases? These rules for pointer arithmetic are intended to handle addressing inside arrays correctly.

Pointer Arithmetic - IV

If we can subtract a pointer from another, all the relational operations can be supported!

Logical Operations on Pointers

1. `ptr1` $>$ `ptr2` is the same as `ptr1 - ptr2 > 0`,
2. `ptr1` $=$ `ptr2` is the same as `ptr1 - ptr2 = 0`,
3. `ptr1` $<$ `ptr2` is the same as `ptr1 - ptr2 < 0`,
4. and so on.

Outline

Arrays and Pointers

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

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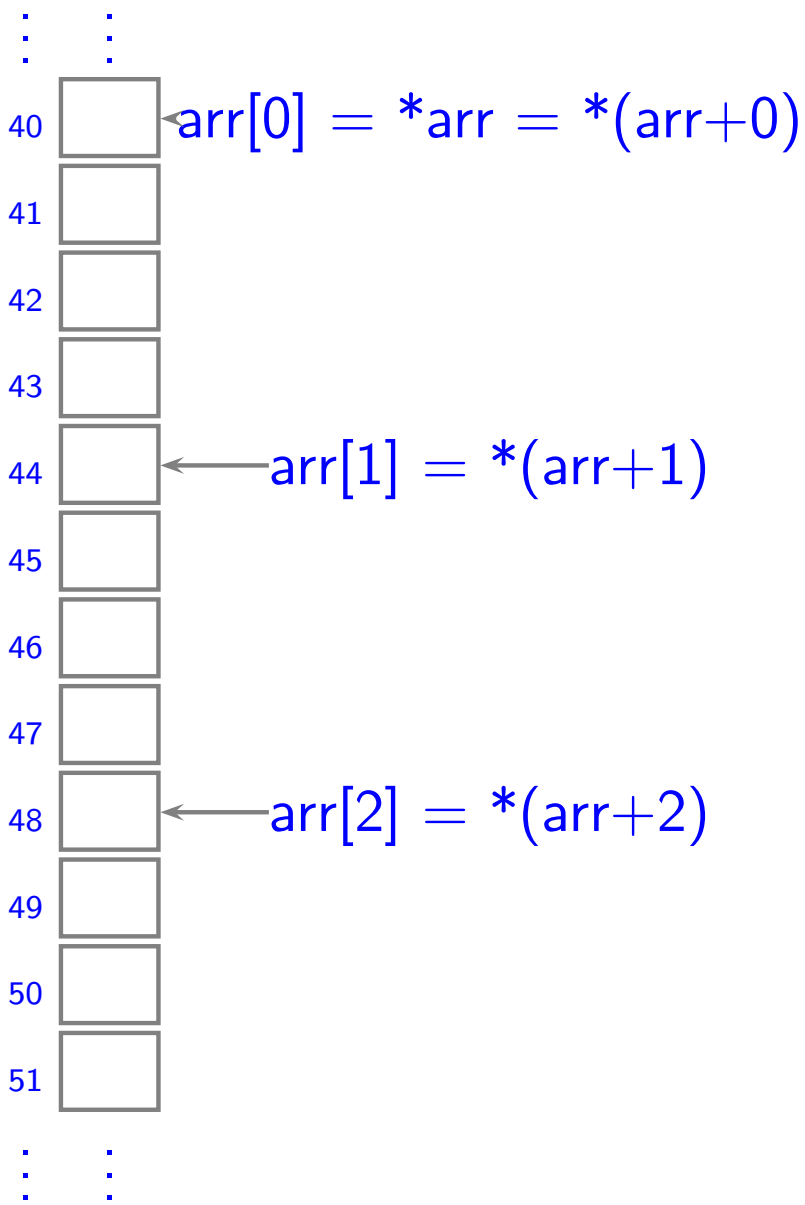
4. `*(arr+i)`, is equal to `arr[i]`.
5. Question: What is `&arr[i]` equivalent to?

Arrays and Pointers - Figure




```
int arr[3];
```

Outline

Passing Pointers to Functions

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()`.

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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!!

A Swap Program

```
#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;
}

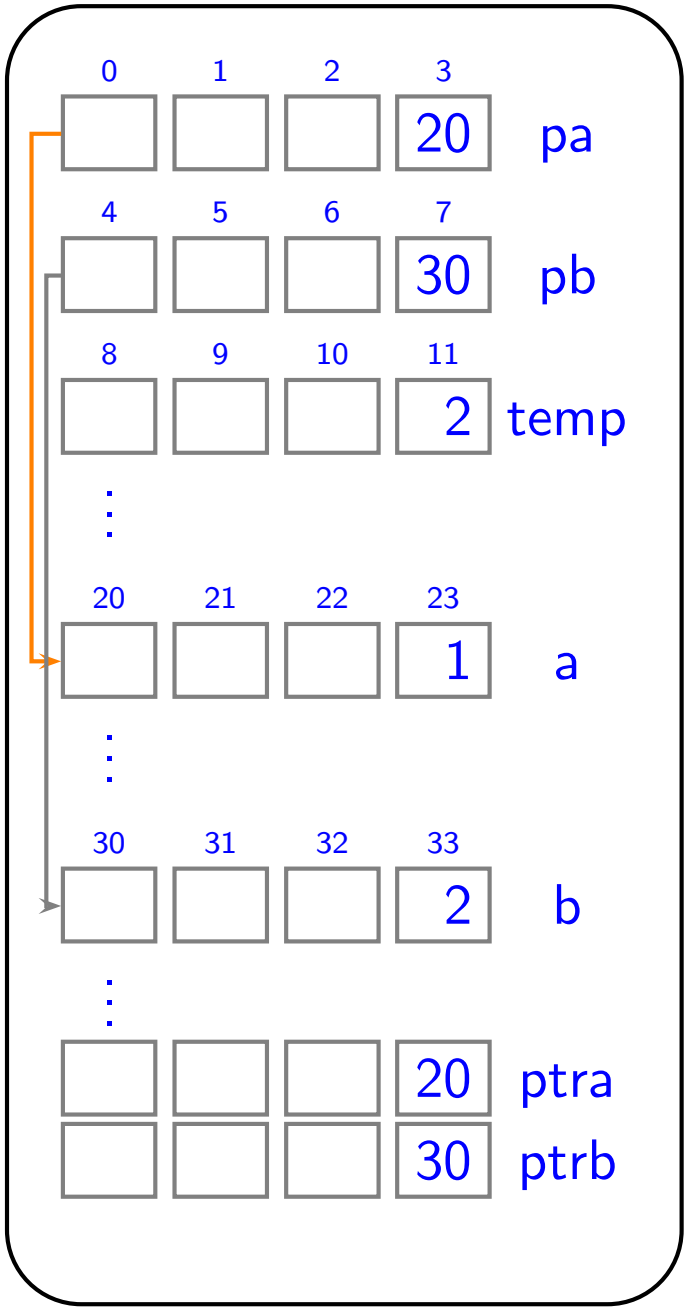
int main()
{
   int a = 1, b = 2;
   int *ptra = &a;
   int *ptrb = &b;

   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.

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   swap (ptra, ptrb);
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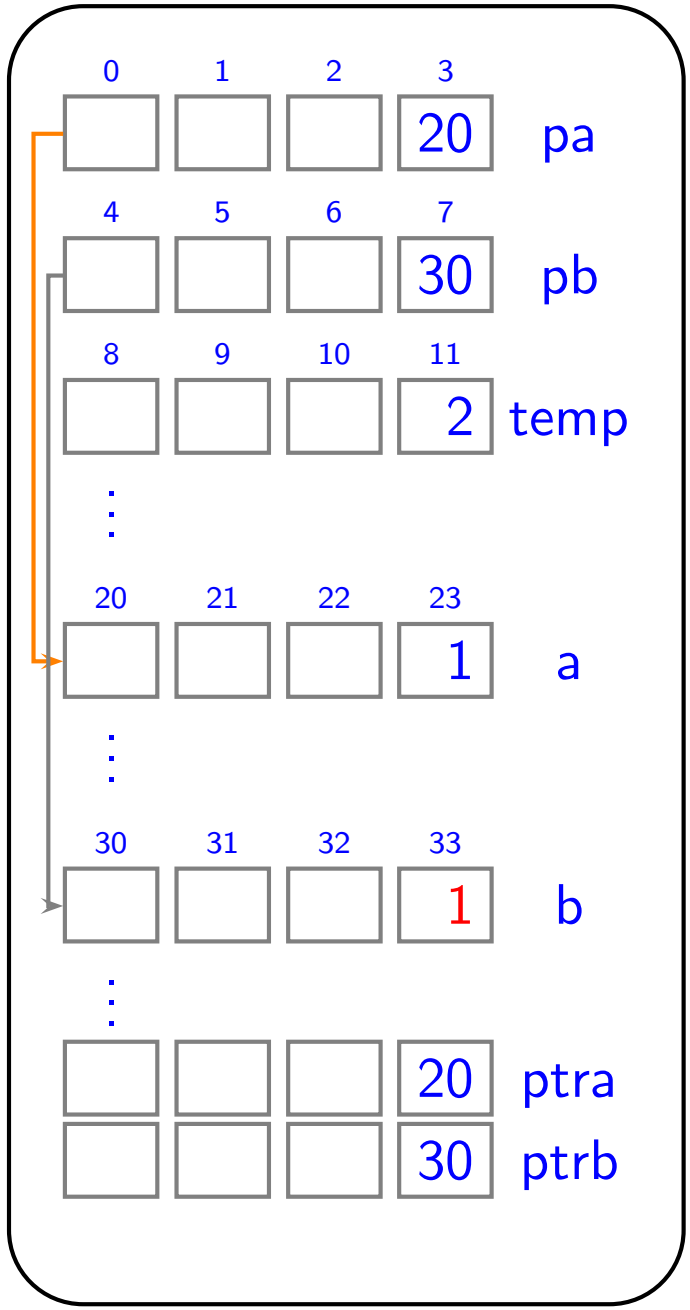


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#include <stdio.h>

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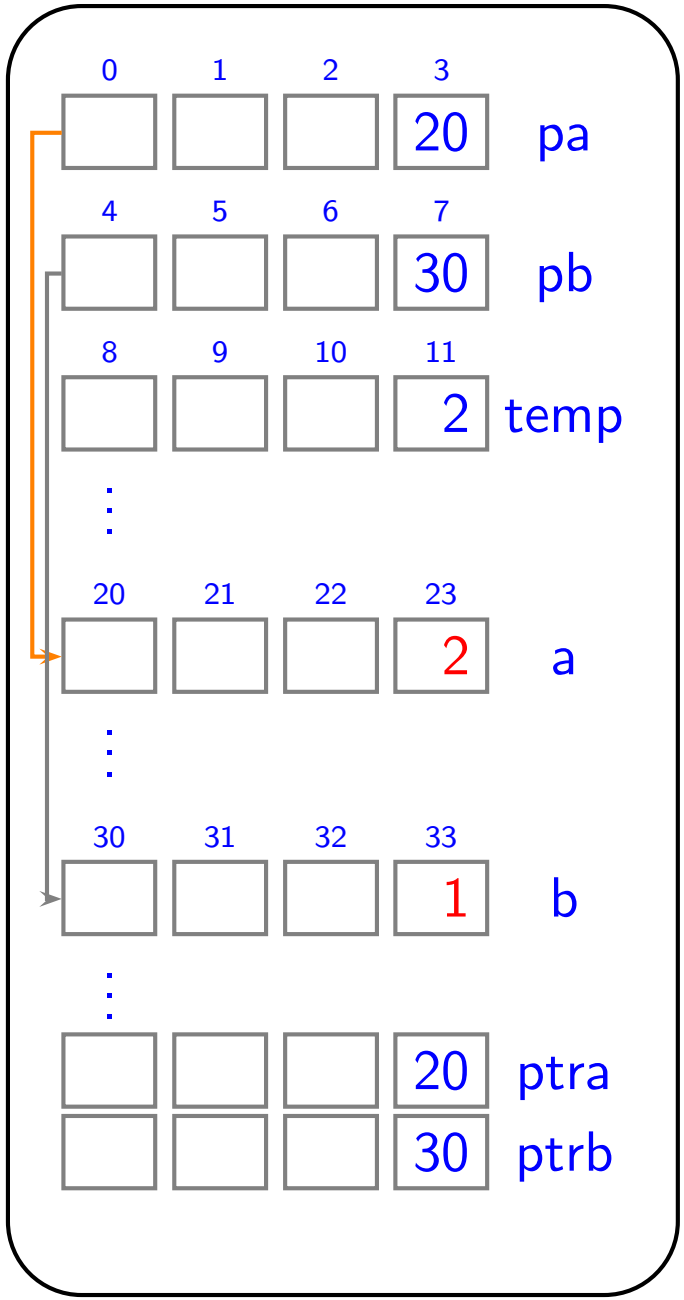


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scanf and printf

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printf

`printf(“%d”,n);`

`printf` does not need to change the content of `n`.

Passing arrays to functions

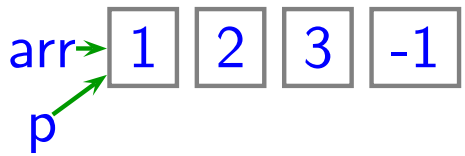
We have already seen that we can pass arrays as input to functions. We also have seen that arrays are essentially pointers.

We can pass pointers, where arrays are expected, and vice versa!

Passing arrays to functions

```c
#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



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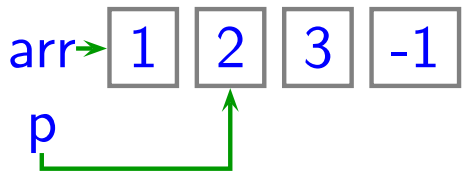

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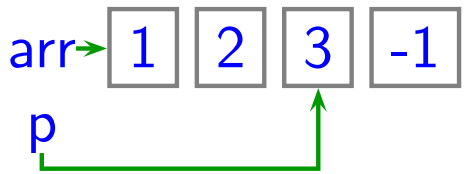

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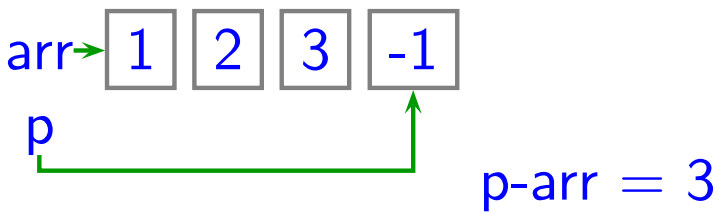

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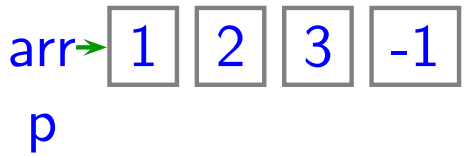

If we changed the call to the following line,

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

the result is 2, since the num_elts will search in the subarray {2,3,-1}.

Passing Pointers to Functions - Another Reason

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.

Common Mistakes in Pointer Programs

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.

Debugging Pointer Programs

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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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.

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[1] Some material in these slides has been taken from course notes by Arnab Bhattacharya.

Debugging Pointer Programs

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!)
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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Debugging using printf statements - Example

```
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;

}
```