Programming Abstraction in C++

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Chapter 2. Data Types

Outline

Introduction

Goal: Hierarchy of data types. Building new data types from atomic data types.

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Mechanisms for creating new types:

- Pointers: Memory address of a value (may be an address itself).
- Arrays: Collection of data values of the same type. Accessed by indices.
- Records: Collection of data values (may be of different types). Identified by names.

Outline

Enumeration types

Another atomic type defined by listing the elements in its domain.

Example. Definition

```
enum directionT {North, East, South, West}
```

`North, East, ...`: Enumeration constants

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variable declaration

```
directionT dir;
```

Enumeration types (cont.)

Assigning integers to enumeration constants:

Automatic
`North`$=0$, `East`$=1$, ...

Enumeration types (cont.)

Assigning integers to enumeration constants:

Automatic

`North` $= 0$, `East` $= 1$, ...

manual

```
enum coinT {
    Penny = 1,
    Nickel = 5,
    Dime = 10,
    Quarter = 25
};
```

Enumeration types (cont.)

semi-automatic

```
enum monthT {
    January = 1, February, March, April, May, June,
    July, August, September, October, November, December
};
```

Enumeration types (cont.)

semi-automatic

```
enum monthT {
    January = 1, February, March, April, May, June,
    July, August, September, October, November, December
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```

You can perform integer operations on values of an enumeration type

Example

```
directionT RightFrom(directionT dir) {
    return directionT((dir + 1) % 4);
}
```

Enumeration types (cont.)

semi-automatic

```
enum monthT {
    January = 1, February, March, April, May, June,
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```

A general type class: scalar types (enumeration types, characters, and various representations of integers).

Implicit conversion from a value of a scalar type into an integer.

Outline

Data and memory

Memory units:
bit (smallest)
byte (typically 8 bits, size of `char`)
word (size of `int`, 2 bytes or 4 bytes or others)

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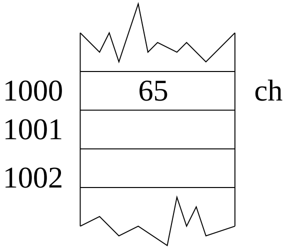
`sizeof` operator usage:

```
sizeof(int) sizeof x
```

returns the number of bytes.

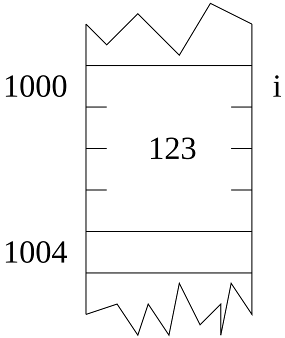
Example. Memory allocation

```
char ch;
ch = 'A';
```



Example (cont.)

```
int i;
i = 123;
```



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Pointers

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lvalue: An expression that refers to an internal memory location (can appear on the left side of an assignment).

lvalues: simple variables, `x = 1.0`

not lvalues: constants, arithmetic expressions (`x + 1`)

Pointers

Pointer variables

`int *p;`
pointer-to-int, base type is `int`

`char *cptr;`
pointer-to-char, base type is `char`

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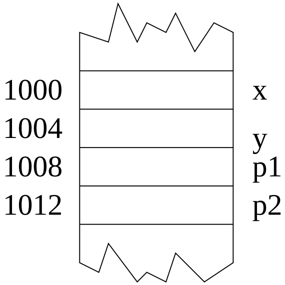
Operator & (address-of)

&x
memory address in which `x` (lvalue) is stored.

Example. * and &

`int x, y;` (lvalues)
`int *p1, *p2;` (pointer-to-int)



Example. * and &

`int x, y;` (lvalues)
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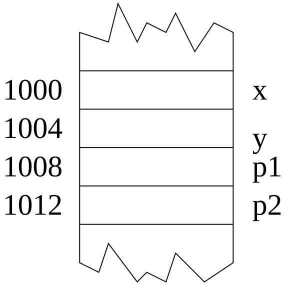
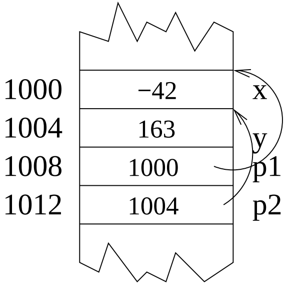


&x is 1000, &y is 1004

Example. * and &

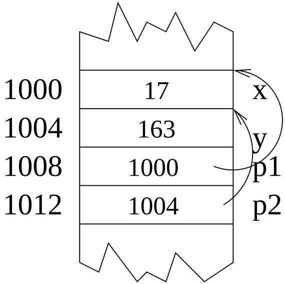
```
x = -42; y = 163;
p1 = &x; p2 = &y;
```



Example. * and &

Dereferencing

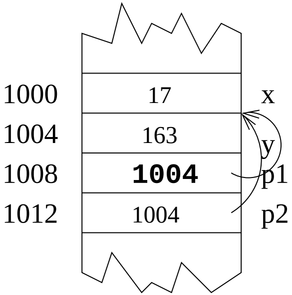
```
*p1 = 17
```

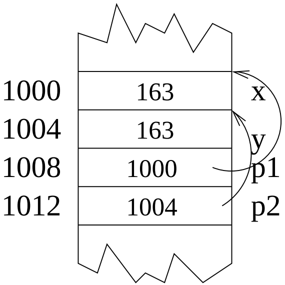


Example. * and &

Pointer assignment and value assignment

`p1 = p2;` and `*p1 = *p2;`





Pointers

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Do not use pointer variables whose values have not yet been initialized.

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An array is characterized by

- element type;
- array size (number of elements).

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Declaration

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style

Define a constant for array size.

Arrays

Example

```
const int N_JUDGES = 5;
double scores[N_JUDGES];
```

Element selection

```
scores[0] = 9.2;
```

array name and index

Passing arrays as parameters

Example.

```
double Mean(double array[], int n) {
    double total = 0;

    for (int i = 0; i < n; i++) {
        total += array[i];
    }
    return total / n;
}
```

Passing arrays as parameters

Example.

```
double Mean(double array[], int n) {
    double total = 0;

    for (int i = 0; i < n; i++) {
        total += array[i];
    }
    return total / n;
}
```

- use empty brackets (a pointer to the array, elements can be modified);
- pass the effective size as a parameter.

Example: gymjudge.cpp, p. 61

```
/*
 * File: gymjudge.cpp
 * ------------------
 * This program averages a set of gymnastic scores.
 */

#include <iostream>
#include "genlib.h"
#include "simpio.h"
```

Example: gymjudge.cpp

```
/* constants */
const int MAX_JUDGES = 100;
const double MIN_SCORE = 0.0;
const double MAX_SCORE = 10.0;

/* Private function prototypes */
void ReadAllScores(double scores[], int nJudges);
double GetScores(int judge);
double Mean(double array[], int n);
```

Example: gymjudge.cpp

```
int main() {
    double scores[MAX_JUDGES];

    cout << "Enter number of judges: " << endl;
    int nJudges = GetInteger();

    if (nJudges > MAX_JUDGES) Error("Too many judges");

    ReadAllScores(scores, nJudges);

    cout << "The average score is " << Mean(scores, nJudges) << endl;

    return 0;
}
```

Example: gymjudge.cpp

```
int main() {
    double scores[MAX_JUDGES];

    cout << "Enter number of judges: " << endl;
    int nJudges = GetInteger();

    if (nJudges > MAX_JUDGES) Error("Too many judges");

    ReadAllScores(scores, nJudges);

    cout << "The average score is " << Mean(scores, nJudges) << endl;

    return 0;
}
```

Remarks

- Basic structure: Declaration and initialization - input - compute - output;
- Robustness: Handle all possible inputs.

Example: gymjudge.cpp

```
/*
 * Function: ReadAllScores
 ...
 */

void ReadAllScores(double scores[], int nJudges) {
    for (int i = 0; i < nJudges; i++) {
        scores[i] = GetScore(i + 1);
    }
}
```

- Use empty brackets when passing an array as a parameter (pointer). Elements are modified.

Example: `gymjudge.cpp`

```
/*
 * Function: GetScore
 ...
 */

double GetScore(int judge) {
    while (true) {
        cout << "Score for judge #" << judge << ": " << endl;
        double score = GetReal();
        if (score >= MIN_SCORE && score <= MAX_SCORE) return score;
        cout << "That score is out of range. Try again." << endl;
    }
}
```

- Robustness, bullet-proof your program;
- Loop-and-half structure.

Multidimensional arrays

Array of arrays.

Multidimensional arrays

Array of arrays.

Two-dimensional arrays for matrices (rectangle structure).

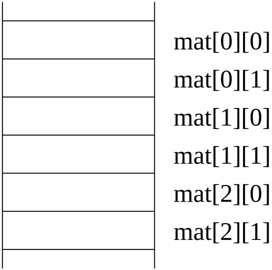
Example:

```
double mat[3][2]
```

An array of three arrays, each of which is an array of two floating-point numbers, representing a three-by-two matrix.

Multidimensional arrays (cont.)

Internal structure (row orientation)



Initializing arrays

```
double mat[3][2] = {
    { 1.0, 2.0 },
    { 2.0, 1.0 },
    { 3.0, 2.0 }
};
```

matrix:

$$\begin{bmatrix} 1.0 & 2.0 \\ 2.0 & 1.0 \\ 3.0 & 2.0 \end{bmatrix}$$

Multidimensional arrays (cont.)

In C++, it is more efficient to access elements in rows than in columns.

```
for (int i = 0; i < m; i++) {
    for (int j = 0; j < n; j++) {
        ... mat[i][j] ...
    }
}
```

is more efficient than

```
for (int j = 0; j < n; j++) {
    for (int i = 0; i < m; i++) {
        ... mat[i][j] ...
    }
}
```

Outline

Pointers and arrays

`int intList[5];`

- `intList` is identical to `&intList[0]`
- `&intList[i]` is the same as `intList + i*sizeof(int)`
- the prototype
  `int SumIntArray(int array[], int n)`
  works the same way as
  `int SumIntArray(int *array, int n)`
- `int intList[5]` allocates five consecutive words, whereas `int *p` allocates one word for an address
- a pointer allows you to create a new array as the program runs (dynamic allocation, later)

Outline

Records

A coherent collection of components of possibly different types. Each of these components is called a field or member of the record.

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Defining a new structured type

1. Define a structure, Including fields, names and types of the fields. This structure defines a model, but does not reserve any storage;

```
struct employeeRecordT {
    string name;
    string title;
    string ssn;
    double salary;
    int withholding;
};
```

2. Declare variables of the new type.

```
employeeRecordT empRec;
```

Records

Field selection
`empRec.title` (recordName.fieldName)
an lvalue

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Field selection
`empRec.title` (recordName.fieldName)
an lvalue

Initializing records

```
empRec.name = "Ebenezer Scrooge";
empRec.title = ...
```

or

```
employeeRecordT empRec = {
    "Ebenezer Scrooge", ...
};
```

Pointers to records

Often variables that hold structured data are declared to be pointers to records.

```
employeeRecordT *empPtr;
```

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`empPtr->salary` means `(*empPtr).salary`

What does `*empPtr.salary` mean?

Allocation

- Static allocation: Global variables that persist throughout the entire program.
- Automatic allocation: Local variables inside a function, allocated on the system stack and freed when the function returns.
- Dynamic allocation: Variables created while the program is running, allocated on the heap, the pool of memory available to a program.

Allocation

Example

```
employeeRecordT *empList = new employeeRecordT[1000];
```

Allocation

Example

```
employeeRecordT *empList = new employeeRecordT[1000];
```

Allocates an array of 1000 employee records in the heap and returns the pointer to the first record.

Deallocation

Coping with memory limitations.

Free pieces of memory when you are finished using them.

```
double *dptr = new double;
int *arr = new int[45];
    ...
delete dptr;
delete[] arr;
```

Deallocation

Coping with memory limitations.

Free pieces of memory when you are finished using them.

```
double *dptr = new double;
int *arr = new int[45];
    ...
delete dptr;
delete[] arr;
```

Don't worry about it for this course.

Examples

Declared arrays and dynamic arrays

`double dblArray[10];`

Memory is allocated automatically as part of declaration process. The elements are allocated as part of the frame for the function (on the stack). The size must be a constant.

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```
double dblArray[10];
```

Memory is allocated automatically as part of declaration process. The elements are allocated as part of the frame for the function (on the stack). The size must be a constant.

```
double *dblList;
dblList = new double[10];
```

Memory is not allocated until `new` is invoked. The elements are allocated on the heap. The size can be a variable.

Examples (cont.)

Dynamic array of *n* pointers to `employeeRecordT`

```
employeeRecordT **list;
list = new employeeRecordT*[n];
list[0] = new employeeRecordT;
```