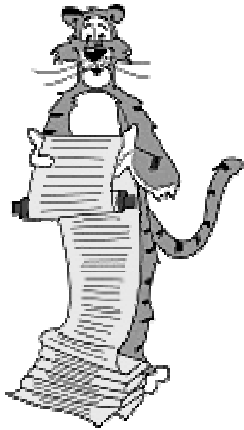


Lecture P4: Structs and Data Types



```
struct student {
    char name[20];
    int age;
    double salary;
} Hal, Bill;
```

Why Data Structures?

Goal: deal with large amounts of data.

- Organize data so that it is easy to manipulate.
- Time and space efficient.

Basic computer memory abstraction.

- Indexed sequence of bits.
- Address = index.

Need higher level abstractions to bridge gap.

- Array.
- STRUCT.**
- Linked list.
- Binary tree.
- Database.
- ...

addr	value
0	0
1	1
2	1
3	1
4	0
5	1
6	0
7	0
8	1
9	0
10	1
...	...
256GB	1

Structs

Fundamental data structure.

- HETEROGENEOUS collection of values (possibly different type).
 - Database records, complex numbers, linked list nodes, etc.
- Store values in FIELDS.
- Associate NAME with each field.
- Use struct name and field name to access value.

Built-in to C.

- To access rate field of structure x use x.rate
- Basis for building "user-defined types" in C.

name of field	id	rate	first	last
value	166316754	11.50	"Bill"	"Gates"

field field field field } struct

C Representation of C Students

student.c

```
#include <stdio.h>

struct student {
    char name[16];
    int grade;
};

int main(void) {
    struct student t;
    struct student x = {"Bill Gates", 60};
    struct student y = {"Steve Jobs", 70};

    if (x.grade > y.grade)
        t = x;
    else
        t = y;
    printf("Better student: %s\n", t.name);
    return 0;
}
```

struct declaration →

can initialize struct fields in declaration →

access structs as ordinary variables →

%s for string →

Typedef

User definition of type name.

- Put type descriptions in one place - makes code more portable.
- Avoid typing `struct` - makes code more readable.

```
typedef int Grade;
typedef char Name[16];

struct student {
    Name name;
    Grade grade;
};

typedef struct student Student;

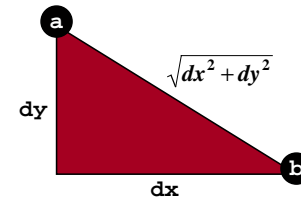
. . .

Student x = {"Bill Gates", 60};
```

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A Data Type: Points

Define structures for points in the plane, and operations on them.



random point with x and y coordinates between 0.0 and s

point data type

```
#include <math.h>
typedef struct {
    double x;
    double y;
} Point;

double distance(Point a, Point b) {
    double dx = a.x - b.x;
    double dy = a.y - b.y;
    return sqrt(dx*dx + dy*dy);
}

Point randomPoint(double s) {
    Point p;
    p.x = randomDouble(s);
    p.y = randomDouble(s);
    return p;
}
```

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Another Data Type: Circles

circle data structure

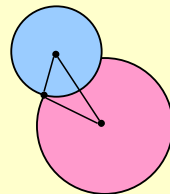
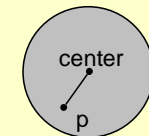
```
#include <math.h>
#define PI 3.1415

typedef struct {
    Point center;
    double radius;
} Circle;

int inCircle(Point p, Circle c) {
    return distance(p, c.center) <= c.radius;
}

double area(Circle c) {
    return PI * c.radius * c.radius;
}

int intersectCircles(Circle c, Circle d) {
    return distance(c.center, d.center) <= c.radius + d.radius;
}
```

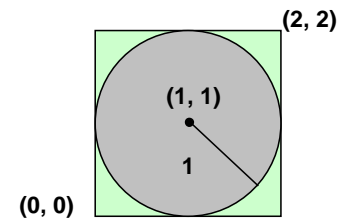


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Using Data Types: Estimating π

Monte Carlo estimate of π .

- Generate N random points in 2×2 square.
- Determine fraction that lie in unit circle.
- On average $\pi/4$ fraction should lie in circle.
- Use $4 \times$ fraction as estimate of π .



pi.c

```
#define N 100000

int main(void) {
    int i, cnt = 0;
    Point p = {1.0, 1.0};
    Circle c;
    c.center = p; c.radius = 1.0;

    for (i = 0; i < N; i++) {
        p = randomPoint(2.0);
        if (inCircle(p, c))
            cnt++;
    }

    printf("pi = %f\n", 4.0*cnt/N);
    return 0;
}
```

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Standard Data Type Implementation

Data type:

- Set of values and collection of operations on those values.

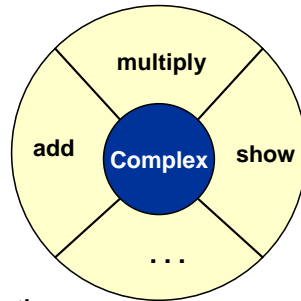
Example (built-in): int, double, char.

Example (user defined): complex numbers.

- Set of values: $4 + 2i$, $1.3 - 6.7i$, etc.
- Operations: add, multiply, show, etc.

Separate implementation from specification.

- INTERFACE: specifies allowed operations.
- IMPLEMENTATION: provides code for operations.
- CLIENT: uses data type as black box.



Intuition



Client



Interface

- volume
- change channel
- adjust picture
- decode NTSC, PAL signals



Implementation

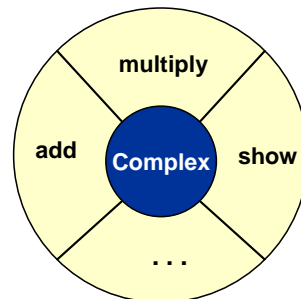
- cathode ray tube
- electron gun
- Sony Wega 36XBR250
- 241 pounds, \$2,500

Complex Number Data Type

Create data structure to represent complex numbers.

- See Sedgwick 4.8.
- Store in rectangular form: real and imaginary parts.

```
typedef struct {
    double re;
    double im;
} Complex;
```



Complex Number Data Type: Interface

Interface lists allowable operations on complex data type.

- Name interface with .h extension.

```
COMPLEX.h

typedef struct {
    double re;
    double im;
} Complex;

Complex COMPLEXadd (Complex a, Complex b);
Complex COMPLEXmult (Complex a, Complex b);
Complex COMPLEXpow (Complex a, Complex b);
Complex COMPLEXconj (Complex a);
double COMPLEXabs (Complex a);
double COMPLEXreal (Complex a);
double COMPLEXimag (Complex a);
Complex COMPLEXinit (double x, double y);
void COMPLEXshow (Complex a);
```

store in rectangular form

can't reuse +, * symbols

function prototypes

Complex Number Data Type: Client

Client program uses interface operations to calculate something:

```

client.c
#include <stdio.h>
#include "COMPLEX.h"

int main(void) {
    Complex a, b, c;

    a = COMPLEXinit( 5.0, 6.0);
    b = COMPLEXinit(-2.0, 3.0);
    c = COMPLEXmult(a, b);
    COMPLEXshow(a);
    printf(" * ");
    COMPLEXshow(b);
    printf(" = ");
    COMPLEXshow(c);
    printf("\n");
    return 0;
}
    
```

client can use interface

$$(5 + 6i) * (-2 + 3i) = -28 + 3i$$

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Complex Number Data Type: Another Client

Redo Mandelbrot with equivalent complex number update:

$$\begin{aligned}
 r &\leftarrow x, s \leftarrow y \\
 \text{while } (r^2 + s^2 \leq 4) \\
 r' &\leftarrow r^2 - s^2 + x \\
 s' &\leftarrow 2rs + y
 \end{aligned}$$

$$\begin{aligned}
 c &\leftarrow z = x + iy \\
 \text{while } (|c| \leq 2) \\
 c &\leftarrow c^2 + z
 \end{aligned}$$

```

clientmand.c
#define MAXIT 255
#include "COMPLEX.h"

int mand(Complex z) {
    int i = 0;
    Complex c = z;
    while (COMPLEXabs(c) <= 2.0 && i < MAXIT) {
        c = COMPLEXadd(COMPLEXmult(c, c), z);
        i++;
    }
    return i;
}
    
```

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Complex Number Data Type: Implementation

Write code for interface functions.

```

complex.c
#include <stdio.h>
#include <math.h>
#include "COMPLEX.h"

Complex COMPLEXadd(Complex a, Complex b) {
    Complex t;
    t.re = a.re + b.re;
    t.im = a.im + b.im;
    return t;
}

Complex COMPLEXmult(Complex a, Complex b) {
    Complex t;
    t.re = a.re * b.re - a.im * b.im;
    t.im = a.re * b.im + a.im * b.re;
    return t;
}
    
```

implementation and client need to agree on interface

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Complex Number Data Type: Implementation

Write code for interface functions.

```

complex.c (cont)
double COMPLEXabs(Complex a) {
    return sqrt(a.re * a.re + a.im * a.im);
}

void COMPLEXshow(Complex a) {
    printf("%f + %f i\n", a.re, a.im);
}

Complex COMPLEXinit(double x, double y) {
    Complex t;
    t.re = x;
    t.im = y;
    return t;
}
    
```

function in math library

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Compilation

Client and implementation both include COMPLEX.h

Compile jointly.

```
%gcc client.c complex.c -lm
```

← -lm flag needed on some systems to link math library

Or compile separately.

```
%gcc -c complex.c
```

```
%gcc -c client.c
```

```
%gcc client.o complex.o -lm
```

Unix

```
% gcc126 client.c complex.c
% a.out
(5.00 + 6.00 i) * (-2.00 + 3.00 i) = (-28.00 + 3.00 i)
```

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Client, Interface, Implementation



Client
couchpotato.c



Interface
#include "TV.h"



Implementation
#include tvplasma.c

client needs to know
how to use interface

implementation needs to know
what interface to implement

Implementation and client need to
agree on interface ahead of time.

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Can Change Implementation

Can use alternate representation of complex numbers.

- Store in polar form: modulus and angle.

$$z = x + iy = r(\cos \theta + i \sin \theta) = r e^{i\theta}$$

```
typedef struct {
    double r;
    double theta;
} Complex;
```

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Alternate Interface

Interface lists allowable operations on complex data type.

```
COMPLEX.h

typedef struct {
    double r;
    double theta;
} Complex;

Complex COMPLEXadd (Complex a, Complex b);
Complex COMPLEXmult (Complex a, Complex b);
Complex COMPLEXpow (Complex a, Complex b);
Complex COMPLEXconj (Complex a);
double COMPLEXabs (Complex a);
double COMPLEXreal (Complex a);
double COMPLEXimag (Complex a);
Complex COMPLEXinit (double x, double y);
void COMPLEXshow (Complex a);
```

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Alternate Implementation

Write code for interface functions.

```
complexpolar.c

#include "COMPLEX.h"
#include <math.h>
#include <stdio.h>

Complex COMPLEXabs(Complex a) {
    return a.r;
}

Complex COMPLEXmult(Complex a, Complex b) {
    Complex t;
    t.r = a.r * b.r;
    t.theta = a.theta + b.theta;
}
```

Some interface functions are now faster and easier to code.

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Alternate Implementation

Write code for interface functions.

```
complexpolar.c

Complex COMPLEXadd(Complex a, Complex b) {
    Complex t;
    double x, y;
    x = a.r * cos(a.theta) + b.r * cos(b.theta);
    y = a.r * sin(a.theta) + b.r * sin(b.theta);
    t.r = sqrt(x*x + y*y);
    t.theta = arctan(y/x);
    return t;
}
```

Others are more annoying.

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Multiple Implementations

Usually, several ways to represent and implement a data type.

How to represent complex numbers: rectangular vs. polar?

- Depends on application.
- Rectangular are better for additions and subtractions.
 - no need for arctangent
- Polar are better for multiply and modulus.
 - no need for square root
- Get used to making tradeoffs.

This example may seem artificial.

- Essential for many real applications.
- Crucial software engineering principle.

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Rational Number Data Type

See Assignment 3.

- You will create data type for Rational numbers.
- Add associated operations to Rational number data type.

```
typedef struct {
    int num;
    int den;
} Rational;
```

- Simple version relatively easy to implement.
- Improved implementation staves off overflow by:
 - reducing fractions
 - order of computation

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Conclusions

Basic computer memory abstraction.

- Indexed sequence of bits.
- Address = index.

Need higher level abstractions to bridge gap.

- Array.
 - homogeneous collection of values
- Struct.
 - heterogeneous collection of values

Data type.

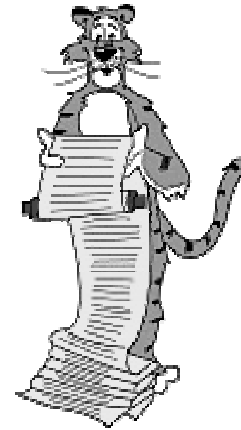
- Set of values and collection of operations on those values.

Client-interface-implementation paradigm.

- Consistent way to implement data types.

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Lecture P4: Supplemental Notes



Pass By Value, Pass By Reference

Arrays and structs are passed to functions in very DIFFERENT ways.

Pass-by-value:

- int, float, char, struct
- a COPY of value is passed to function

```
void mystery(Point a) {
    a.y = 17.0;
}

Point a = {1.0, 2.0};
mystery(a);
printf("%4.1f\n", a.y);
```

Unix

```
% a.out
1.0
```

"Pass-by-reference":

- arrays
- function has direct access to array elements

```
void mystery(double a[]) {
    a[1] = 17.0;
}

double a[] = {1.0, 2.0};
mystery(a);
printf("%4.1f\n", a[1]);
```

Unix

```
% a.out
17.0
```

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