Lecture P4: Structs and Data Types

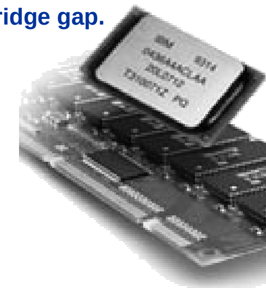
```
struct student {
  char name[20];
  int age;
  double salary;
} Hal, Bill;
```

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

name	grade
char[20]	int

student.c

```
#include <stdio.h>

struct student {
   char name[20];
   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

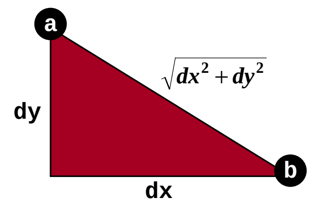
User definition of type name.

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

```
typedef int Grade;
typedef char Name[20];

struct student {
  Name name;
  Grade grade;
};

typedef struct student Student;

. . .

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


Geometry: Points

Define structures for points in the plane.



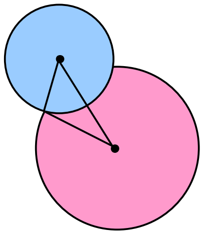
random point with x and y coordinates between –1 and 1

point data structure

```
#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(void) {
  Point p;
  p.x = randomDouble(-1.0, 1.0);
  p.y = randomDouble(-1.0, 1.0);
  return p;
}
```

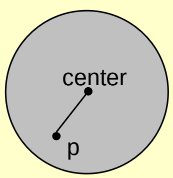

Geometry: Circles

Define structures for circles.



circle data structure

```
#include <math.h>

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

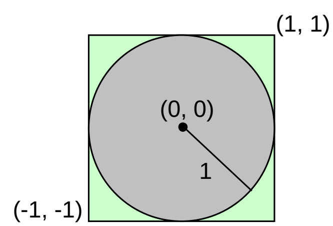



```
int inCircle(Point p, Circle c) {
  return distance(p, c.center) <= c.radius;
}

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


Geometry: Estimating Pi

Estimate pi.

- Generate N random points with x and y coordinates between -1.0 and 1.0.
- Determine fraction that lie in unit circle.
- On average pi / 4 fraction should lie in circle.
- Use 4 * fraction as estimate of pi.



pi.c

```
#define N 10000

int main(void) {
  int i, cnt = 0;
  Point p = {0.0, 0.0};
  Circle c;
  c.center = p; c.radius = 1.0;

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

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

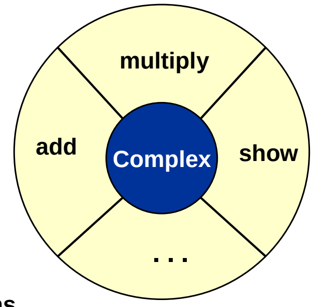
Data Types

Data type:

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

Example: Complex numbers.

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



Separate implementation from specification.

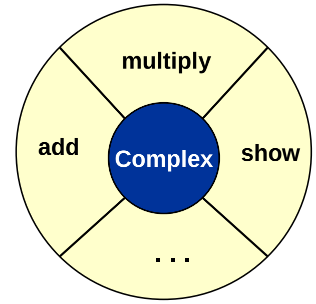
- INTERFACE: specify the allowed operations.
- IMPLEMENTATION: provide code for operations.
- CLIENT: code that uses operations.

Complex Number Data Type

Create data structure to represent complex numbers.

- See Sedgewick 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, Complex);
Complex COMPLEXmult  (Complex, Complex);
Complex COMPLEXpow   (Complex, Complex);
Complex COMPLEXconj  (Complex);
double  COMPLEXabs   (Complex);
double  COMPLEXreal  (Complex);
double  COMPLEXimag  (Complex);
Complex COMPLEXinit  (double, double);
void    COMPLEXshow  (Complex);
```

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 = COMPLEXinit(1.0, 2.0);
  Complex b = COMPLEXinit(3.0, 4.0);
  Complex c;

  c = COMPLEXmult(a, b);
  COMPLEXshow(c);

  return 0;
}
```

client can use interface

(1 + 2i) * (3 + 4i) = -5 + 10i

Complex Number Data Type: Client

Redo Mandelbrot assignment with complex numbers:

```
c ← z = x + iy
while(|c| ≤ 2)
  c ← c² + z
```

clientmand.c

```
#include "COMPLEX.h"
int mand(Complex z) {
  int i;
  Complex c = z;
  for (i = 0; i < 256; i++) {
    if (COMPLEXabs(c) > 2.0)
       return i;
    c = COMPLEXadd(COMPLEXmult(c, c), z);
  }
  return 255;
}

int main(void) {
. . .
  for (x = -1.5; x < 0.5; x += 0.01)
     for (y = -1.0; y < 1.0; y += 0.01)
        t = mand(COMPLEXinit(x, y));
. . .
}
```

better to avoid hardwired constants (refers to `return 255;`)

Complex Number Data Type: Implementation

Write code for interface functions.

complex.c

```
#include "COMPLEX.h"
#include <math.h>
#include <stdio.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 needs to know interface (refers to `#include "COMPLEX.h"`)

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 (refers to `sqrt`)

Compilation

Client and implementation both include COMPLEX.h

Compile jointly.

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

Or compile separately.

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

Can Change Implementation

Can use alternate representation of complex numbers.

- Store in polar form: modulus and angle.

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

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


Alternate Interface

Interface lists allowable operations on complex data type.

COMPLEX.h

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

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

polar representation

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.

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.

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.

Conclusions

Basic computer memory abstraction.

- Indexed sequence of bits.
- Address = index.

Need higher level abstractions to bridge gap.

- Array.
  - homogeneous collection of values
  - store values sequentially in memory
  - associate index with each value
- Struct.
  - heterogeneous collection of values
  - store values in fields
  - associate name with each field

Data type.

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

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
```