CSE 3302
Programming Languages

Data Types(cont.)

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Function Type in C

```
typedef int (*IntFunction)(int);

int square(int x) {return x*x;}

IntFunction f = square;

int evaluate(IntFunction g, int value){
    return g(value);
}
…
printf("%d\n",evaluate(f,3));
```


Function Type in ML

```
type IntFunction = int -> int;

fun square(x: int) = x * x;

val f = square;

Fun evaluate(g:IntFunction, value:int) = g value;
…
evaluate(f,3);
```


Vector, List

Functional languages:

- Vectors: like arrays, more flexibility, especially dynamic resizability.
- Lists: like vectors, can only be accessed by counting down from the first element.

Pointer

- A *pointer type* is a type in which the range of values consists of memory addresses and a special value, nil (or null)
- *Advantages:*
  - Addressing flexibility (address arithmetic, explicit dereferencing and address-of, domain type not fixed (void *))
  - Dynamic storage management
  - Recursive data structures
    - E.g., linked list

```
struct CharListNode
{ char data;
  struct CharListNode* next;
 };
 Typedef struct CharListNode* CharList;
```


Problems with Pointers

- Alias (with side-effect)

```
int *a, *b;
a=(int *) malloc(sizeof(int));
*a=2;
b=(int *) malloc(sizeof(int));
*b=3;
b=a;
*b=4;
printf("%d\n", *a);
```

Problems with Pointers

- Dangling pointers (dangerous)

```
int *a, *b;
a = (int *) malloc(sizeof(int));
*a = 1;
b = a;
free(a);
printf("%d\n", *b);
```


Problems with Pointers

- Garbages (waste of memory)

memory leakage

```
int *a;
a = (int *) malloc(sizeof(int));
*a=2;
a = (int *) malloc(sizeof(int));
```


Type System

- ***Type Constructors***:
  - Build new data types upon simple data types
- ***Type Checking***: The translator checks if data types are used correctly.
  - ***Type Inference***: Infer the type of an expression, whose data type is not given explicitly.
    e.g., x/y
  - ***Type Equivalence***: Compare two types, decide if they are the same.
    e.g., x/y and z
  - ***Type Compatibility:*** Can we use a value of type A in a place that expects type B?

  Nontrivial with user-defined types and anonymous types

Strongly-Typed Languages

- Strongly-typed: (Ada, ML, Haskell, Java, Pascal)
- – Most data type errors detected at translation time
- – A few checked during execution and runtime error reported (e.g., subscript out of array bounds).
- Pros:
- – No data-corrupting errors can occur during execution. (I.e., no unsafe program can cause data errors.)
- – Efficiency (in translation and execution.)
- – Security/reliability
- Cons:
- – May reject safe programs (i.e., legal programs is a subset of safe programs.)
- – Burden on programmers, may often need to provide explicit type information.

Weakly-typed and untyped languages

- Weakly-typed: C/C++
  - e.g., interoperability of integers, pointers, arrays.
- Untyped (dynamically typed) languages: scheme, smalltalk, perl
  - Doesn't necessarily result in data errors.
  - All type checking performed at execution time.
  - May produce runtime errors too frequently.

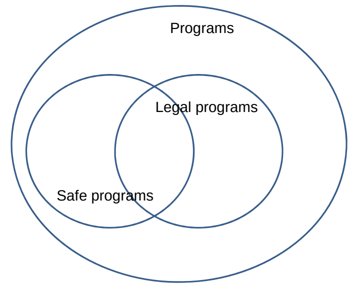
Security vs. flexibility

- Strongly-typed :
  - No data errors caused by unsafe programs.
  - Maximum restrictiveness, static type checking, illegal safe programs, large amount of type information supplied by programmers.
- Untyped:
  - Runtime errors, no data-corruptions. Legal unsafe programs.
  - reduce the amount of type information the programmer must supply.

Security vs. flexibility

- Strongly-typed :
- A type system tries to maximize both flexibility *and* security, where flexibility means: reduce the number of safe illegal programs & reduce the amount of type information the programmer must supply.
- Flexibility, no explicit typing or static type checking
  vs.
- Maximum restrictiveness, static type checking

Safe vs. Legal



Type Equivalence

- How to decide if two types are the same?
- Structural Equivalence
  - Types are sets of values
  - Two types are equivalent if they contain the same values.
- Name Equivalence

Structural Equivalence

```
• struct RecA {
      char x;
      int  y;
  }
• struct RecB {
      char x;
      int  y;                    Char X Int
  }
• struct RecC {
      char u;
      int  v;
  }
• struct RecD {
      int  y;                    Int X Char
      char x;
  }
```


But are they equivalent in these languages?

- In C:

```
struct RecA {
    char x;   int  y;
};
struct RecB {
    char x;   int  y;
};
struct RecA a;
struct RecB b;

b=a;
```

（ Error: incompatible types in assignment ）

But are they equivalent in these languages?

- In C:

```
struct RecA {
    char x;   int  y;
};
struct RecB {
    char x;   int  y;
};
struct RecA a;
struct RecB* b;

b=&a;
```

（ Warning: incompatible types in assignment ）

But are they equivalent in these languages?

- In C:

```
struct RecA {
    char x;   int  y;
};
struct RecB {
    char x;   int  y;
};
struct RecA a;
struct RecB* b;

b=(struct RecB*)&a;
```
(OK, but does not mean they are equivalent)

But are they equivalent in these languages?

- In Java:

```
class A {
    char x;   int  y;
};
class B {
    char x;   int  y;
};

A a = new B();
```
?

Equivalence Algorithm

- If structural equivalence is applied:

```
struct RecA {
       char x;   int  y;
};
struct RecB {
       char u;   int  v;
};
struct RecA a;
struct RecB b;

b=a;
```


Replacing the names by declarations

```
typedef struct {
    char x;   int  y;
} RecB;
RecB b;

struct {
    char x;   int  y;
} c;
```


Replacing the names by declarations

```
typedef struct { char x; char y } SubRecA;
typedef struct { char x; char y } SubRecB;

struct RecA {
    int ID;  SubRecA content;
};

struct RecB {
    int ID;  SubRecB content;
};
```


Replacing the names by declarations?

```
typedef struct CharListNode* CharList;
typedef struct CharListNode2* CharList2;

struct CharListNode {
    char data;   CharList  next;
};

struct CharListNode2 {
    char data;   CharList2  next;
};
```

Cannot do that for recursive types

```
typedef struct CharListNode* CharList;
typedef struct CharListNode2* CharList2;

struct CharListNode {
    char data;  struct CharListNode*  next;
};

struct CharListNode2 {
    char data;  struct CharListNode2*  next;
};
```

There are techniques for dealing with this

Structural Equivalence

- Can be complicated when there are names, anonymous types, and recursive types
- Simpler, and more strict rules:
  name equivalence

Name Equivalence

```
struct RecA  { char x;   int  y;   };
typedef struct RecA RecB;
struct RecA *a;
RecB *b;
struct RecA c;
struct {  char x;   int  y;   } d;
struct  {  char x;   int  y;   } e,f;
a=&c;        ( ok )
a=&d;        (Warning: incompatible pointer type)
b=&d;        (Warning: incompatible pointer type)
a=b;         ( ok. Typedef creates alias for existing name )
e=d;         ( error: incompatible types in assignment )
```


Type Equivalence in C

- Name Equivalence: `struct, union`
- Structural Equivalence: everything else
  - `typedef` doesn't create a new type

Example

```
struct A { char x; int y; };
struct B { char x; int y; };
struct { char x; int y;};
typedef struct A C;
typedef C* P;
typedef struct A * R;
typedef int S[10];
typedef int T[5];
typedef int Age;
typedef int (*F)(int);
typedef Age (*G)(Age);
          struct A and C
          struct A and B; B and  C
          struct A and struct { char x; int y;};
          P  and  R
          S  and  T
          int and  Age
          F  and  G
```


Type Equivalence in Java

- No `typedef:` so less complicated
- `class/interface:` new type (name equivalence, class/interface names)
- arrays: structural equivalence

Type Checking

- ***Type Checking***: Determine whether the program is correct in terms of data types.
  - ***Type Inference***: Types of expressions
  - ***Type Equivalence***: Are two types the same?
  - ***Type Compatibility:*** Relaxing exact type equivalence under certain circumstances

Example

```
long y;
float x;
double c;
x = y/2+c;
```

- `y` long,`2` is int, so promoted to long, `y/2` long.
- `c` is dobule, `y/2` is long, so promoted to double, `y/2+c` is double.
- `x` Is float, `y/2+c` is double, what happens?
  - C?
  - Java?

Example: C

```
struct RecA {int i; double r;};
int p( struct {int i;double r;} x)
{ ... }
int q( struct RecA x)
{ ... }

struct RecA a;
int b;

b = p(a);
b = q(a);
```


Type Conversion

- Use code to designate conversion?
  - No: automatic/implicit conversion
  - Yes: manual/explicit conversion
- Data representation changed?
  - No, just the type.
  - Yes

Example: Java

- Implicit conversion:
  - Representation change (type promotion, e.g., `int` to `double`)
  - No representation change (`upcasting`)
- Explicit conversion:
  - Representation change (`double x = 1.5; int y = (int)x`)
  - No representation change (`downcasting`)

Casting in Java

```
class A {public int x;}
class SubA extends A { public int y;}
A a1 = new A( );
A a2 = new A( );
SubA suba = new SubA( );
```

`a1 = suba;`	OK (upcating)
`suba = (SubA) a1;`	OK (downcasting)
`suba = a2;`	compilation error
`suba = (SubA) a2;`	compiles OK, runtime error
`a1.y;`	compilation error
`if (a1 instanceof SubA) { ((SubA) a1).y; }`	OK