CSE 3302
Programming Languages

Semantics (cont.)

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Symbol Table

- Symbol Table: maintain bindings. Can be viewed as functions that map names to their attributes.

Names $\xrightarrow{\textbf{SymbolTable}}$ **Attributes**

Static vs. Dynamic Scope

- Static scope (lexical scope):
  - scope maintained statically (during compilation)
  - follow the layout of source codes
  - used in most languages
- Dynamic scope:
  - scope maintained dynamically (during execution)
  - follow the execution path
  - few languages use it (The bindings cannot be determined statically, may depend on user input).
    - Lisp: considered a bug by its inventor.
    - Perl: can choose lexical or dynamic scope

Static Scope

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

x	*integer*, global
y	*character*, global

Static Scope

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

The symbol table in **p**:
the bindings available in **p**

x	*double*, local to **p**
	integer, global
y	*Character*, global

Static Scope

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

The symbol table in **q**:
the bindings available in **q**

x	*integer*, global
y	*integer*, local to **q**
	character, global

Static Scope

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

The symbol table in **main**:
the bindings available in **main**

x:
- *character,* local to **main**
- *integer,* global

y:
- *character,* global

Practice for Static Scope

```
int x,y;

void g(void) {
   x = x + 1;      // Point 1
   y = x + 1;
}

void f(void) {
   int x;
   y = y + 1;      // Point 2
   x = y + 1;
   g();
}

main() {
   x = 1;
   y = 2;          // Point 3
   f();
   g();
   printf("x=%d,y=%d\n",x,y);
}
```

Question 1:

Draw the symbol table at the given points in the program, using static scope?

Question 2:

What does the program print, using static scope?

What if dynamic scope is used?

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

x:
- *integer, 1,* global

y:
- *character, 'a',* global

What if dynamic scope is used?

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

The symbol table in **main**:
the bindings available in **main**

x:
- *character, 'b',* local to **main**
- *integer, 1,* global

y:
- *character, 'a',* global

What if dynamic scope is used?

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

The symbol table in **q**:
the bindings available in **q**

Output: 98

x:
- *character, 'b',* local to **main**
- *integer, 1,* global

y:
- *integer, 42,* local to **q**
- *character, 'a',* global

What if dynamic scope is used?

```
int x = 1;
char y = 'a';

void p(void) {
   double x=2.5;
   printf("%c\n",y);
}

void q(void) {
   int y = 42;
   printf("%d\n",x);
   p();
}

main() {
   char x = 'b';
   q();
}
```

The symbol table in **p**:
the bindings available in **p**

Output: 98
*

x:
- *double, 2.5,* local to **p**
- *character, 'b',* local to **main**
- *integer, 1,* global

y:
- *integer, 42,* local to **q**
- *character, 'a',* global

Practice for Dynamic Scope

```
int x,y;

void g(void) {
        x = x + 1;        <- Point 1
        y = x + 1;
}

void f(void) {
        int x;
        y = y + 1;        <- Point 2
        x = y + 1;
        g();
}

main() {
        x = 1;
        y = 2;            <- Point 3
        f();
        g();
        printf("x=%d,y=%d\n",x,y);
}
```

Question 1:

Draw the symbol table at the given points in the program, using dynamic scope?

Question 2:

What does the program print, using dynamic scope?

Overloading

- **What is overloading?**
- **Why overloading**?
- **What can be overloaded?**

Overload Resolution

- **Overload Resolution:** select one entity.
- **Name isn't sufficient in resolution:** need extra information (often data types)

Function/Method Overloading

- **C:** no overloading
- **C++/Java/Ada:** resolution by number and types of parameters.
  - Perfect if exact match exists;
  - No perfect match: different conversion rules
    - Ada: automatic conversions not allowed.
    - Java: conversions allowed in certain directions.
    - C++: automatic conversions more flexible.
  - e.g.,
    - `int sum(int a, int b) {…}`
    - `double sum(double a, double b) {…}`
    - `double sum(double a, int b) {…}`

  `sum(1); sum(1, 2);  sum(1.0, 2.0); sum(1, 2.0);`

Overload Resolution Example

(1) int sum(int, int);
(2) double sum(double, int);
(3) double sum(double, double);

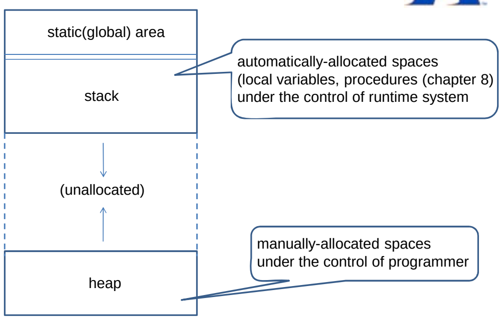
int x;
double y;

	C++	Java	Ada
x = sum(3,4);	1	1	1
y = sum(3,4);	1	1	0
x = sum(3,4.5);	0	0	0
y = sum(3,4.5);	0	3	0
x = sum(3.5,4);	2	0	0
y = sum(3.5,4);	2	2	2
x = sum(3.5,4.5);	3	0	0
y = sum(3.5,4.5);	3	3	3

Environment

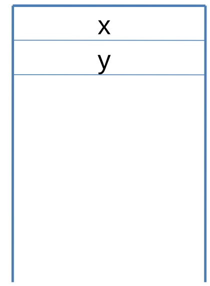
- **Location:** one specific attribute of names
- **Environment:** maintain bindings of names to locations
- **Static vs. dynamic**
  - FORTRAN: completely static
  - LISP: completely dynamic
  - Algol-descendants (C, C++, Ada, Java) : combination
    - global variables: static
    - local variables: dynamic

Stack-Based Allocations



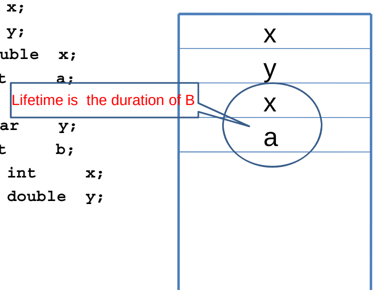
Example

```
A: { int   x;
     char  y;
  B: { double  x;
       int     a;
     }
  C: { char    y;
       int     b;
     D: { int     x;
          double  y;
        }
     }
}
```



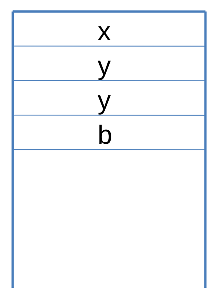
Example

```
A: { int   x;
     char  y;
  B: { double  x;
       int     a;
     }
  C: { char    y;
       int     b;
     D: { int     x;
          double  y;
        }
     }
}
```



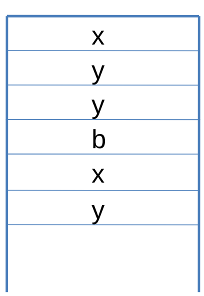
Example

```
A: { int   x;
     char  y;
  B: { double  x;
       int     a;
     }
  C: { char    y;
       int     b;
     D: { int     x;
          double  y;
        }
     }
}
```



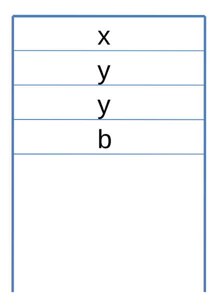
Example

```
A: { int   x;
     char  y;
  B: { double  x;
       int     a;
     }
  C: { char    y;
       int     b;
     D: { int     x;
          double  y;
        }
     }
}
```



Example

```
A: { int   x;
     char  y;
  B: { double  x;
       int     a;
     }
  C: { char    y;
       int     b;
     D: { int     x;
          double  y;
        }
     }
}
```



Heap-Based Allocation

- **C**

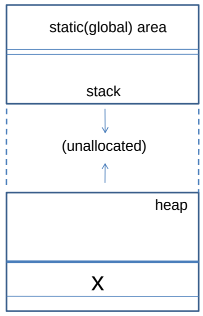
```
int *x;
x=(int *)malloc(sizeof(int));
free(x);
```

- **C++**

```
int *x;
x= new int;
delete x;
```

- **Java**

```
Integer x = new Integer(2);
//no delete
//need garbage collection)
```

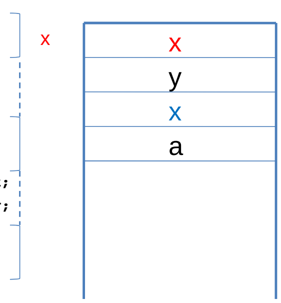


Scope vs. Lifetime

- Lifetime beyond scope:
  - alive in scope hole
  - alive outside scope
- Scope beyond lifetime (unsafe)

Example: Alive in scope hole

```
A: {  int    x;
      char   y;
   B: {  double  x;
         int     a;
      }
   C: {  char    y;
         int     b;
      D: {  int     x;
            double  y;
         }
      }
}
```



Example: Alive outside scope

```
int func(void) {
   static int counter = 0;
   counter += 1;
   return counter;
}

main()
{
   int i;
   int x;
   for (i=0; i<10; i++) { x=func(); }
   printf("%d\n", x);
}
```

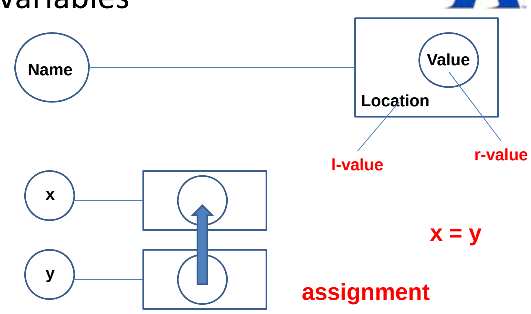
counter

Example: Scope beyond lifetime

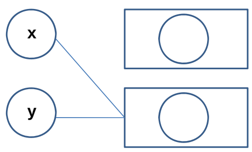
Dangling pointer:

```
int *x, *y, *z;

x=(int *) malloc(sizeof(int));
*x=2;
y=x;
free(x);

. . .

printf("%d\n",*y);
```


Box-and-Circle Diagram for Variables



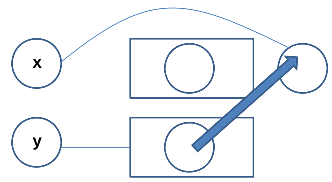
Assignment by sharing



Java:

```
Student x = new Student(“Amy”);
Student y = new Student(“John”);
x.setAge(19);
x = y;
y.setAge(21);
```


Assignment by cloning

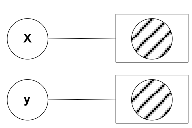


x = y

Aliases

```
(1) int *x, *y;
(2) x = (int *)malloc(sizeof(int));
(3) *x = 1;
(4) y = x;
(5) *y = 2;
(6) printf(“%d\n”,*x);
```

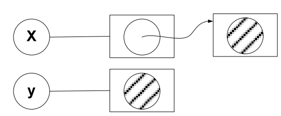
After line 1:



Aliases

```
(1) int *x, *y;
(2) x = (int *)malloc(sizeof(int));
(3) *x = 1;
(4) y = x;
(5) *y = 2;
(6) printf(“%d\n”,*x);
```

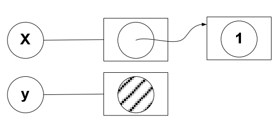
After line 2:



Aliases

```
(1) int *x, *y;
(2) x = (int *)malloc(sizeof(int));
(3) *x = 1;
(4) y = x;
(5) *y = 2;
(6) printf(“%d\n”,*x);
```

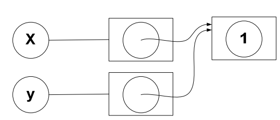
After line 3:



Aliases

```
(1) int *x, *y;
(2) x = (int *)malloc(sizeof(int));
(3) *x = 1;
(4) y = x;
(5) *y = 2;
(6) printf(“%d\n”,*x);
```

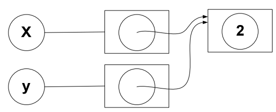
After line 4:



Aliases

```
(1) int *x, *y;
(2) x = (int *)malloc(sizeof(int));
(3) *x = 1;
(4) y = x;
(5) *y = 2;
(6) printf("%d\n",*x);
```

After line 5:



Practice for Aliases

```
(1) #include <stdio.h>
(2) main(){
(3)   int **x;
(4)   int *y;
(5)   int z;
(6)   x = (int**)malloc(sizeof(int*));
(7)   y = (int*)malloc(sizeof(int));
(8)   z = 1;
(9)   *y = 2;
(10)  *x = y;
(11)  **x = z;
(12)  printf("%d\n",*y);
(13)  z = 3;
(14)  printf("%d\n",*y);
(15)  **x = 4;
(16)  printf("%d\n",z);
(17)  return 0;
(18) }
```

Question 1:

Draw box-and-circle diagrams of the variables after line 11 and 15.

Question 2:

Which variables are aliases at each of those points?

Question 3:

What does the program print?

Dangling References

```
int *x, *y;
…
x = (int *)malloc(sizeof(int));
…
*x = 2;
…
y = x;
free(x);
/* *y is now a dangling reference */
…
printf("%d\n",*y); /*illegal reference*/
```


Dangling References

```
{int *x;
  { int y;
    y = 2;
    x = &y;
  }
/* *x is now a dangling reference */
}
```


Dangling References

```
int* dangle(void)
{ int x;
  return &x;
}
…

y = dangle();
/* *y is a dangling reference */
```