Introduction to Programming (CS 101)

Spring 2024

Lecture 9:

Functions and References (Part II)

Instructor: Preethi Jyothi

Based on material developed by Prof. Abhiram Ranade and Prof. Manoj Prabhakaran

Recap (IA)

What is the output of the following program?

```
int findPower(int base = 2, int exponent = 3) {
  int result = 1;
  for(int i = 0; i < exponent; i++, result *= base);
  return result;
}

main_program {
 cout << findPower(5);



}
```

5

25

125

625

Recap (IB)

What is the output of the following program?

```
int findPower(int base = 2, int exponent = 3) {
  int result = 1;
  for(int i = 0; i < exponent; i++, result *= base);
  return result;
}

main_program {
 cout << findPower(5);

 cout << findPower(findPower(5,1));


}
```

5

25

125

625

Recap (IC)

What is the output of the following program?

```
int findPower(int base = 2, int exponent = 3) {
  int result = 1;
  for(int i = 0; i < exponent; i++, result *= base);
  return result;
}

main_program {
 cout << findPower(5);

 cout << findPower(findPower(5,1));

 cout << findPower();
}
```

5

8

2

125

Recap (IIA)

What is the output of the following program?

```
int change(int k) {
 return(k+=2);
}

main_program {
 int i = 1;
 i = change(++i);
 cout << i;
}
```

1

2

3

4

Recap (IIB)

What is the output of the following program?

```
int change(int k) {
 {
  int k = 3;
  return(k+=2);
 }
}

main_program {
 int k = 1;
 k = change(++k);
 cout << k;
}
```

2

4

5

3

Function calls: Behaviour on the stack

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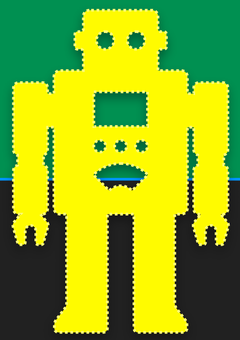
How function calls work: The stack

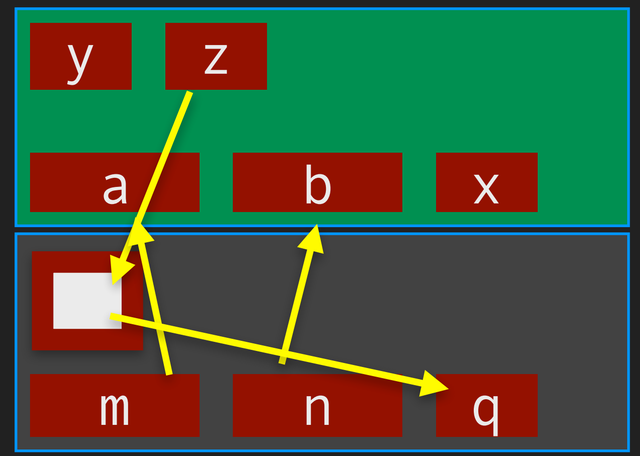
```
bool PFE(int a, int b) {
 bool x, y, z;
 // ...
 return z;
}
```

```
main_program {
  int m, n;
  bool q;
  //...
  q = PFE(m,n);
  //...
}
```



Processor

Memory

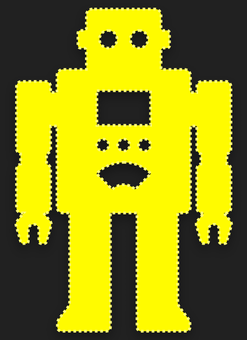


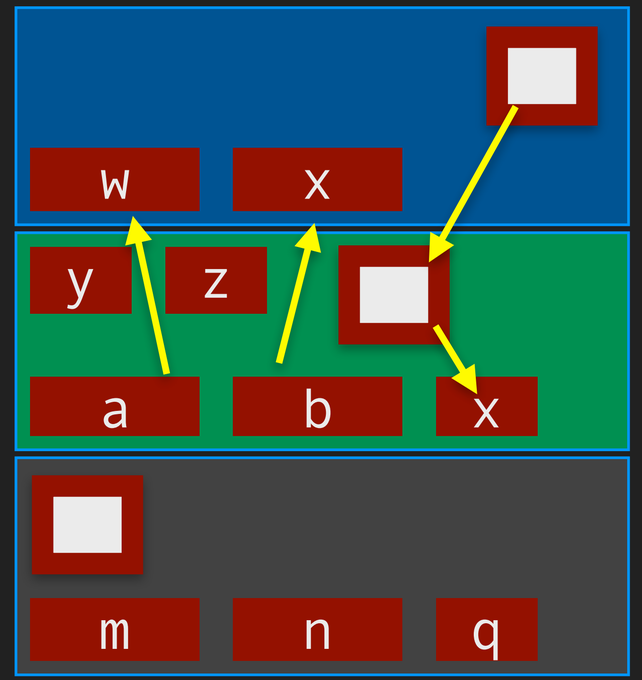
How function calls work: The stack

```
bool covers(int w, int x) {
  // ...
  return x==1;
}
```

```
bool PFE(int a, int b) {
  bool x, y, z;
  x = covers(a,b);
  y = covers(b,a);
  z = x && y;
  return z;
}
```

```
main_program {
  int m, n;
  bool q;
  //...
  q = PFE(m,n);
  //...
}
```



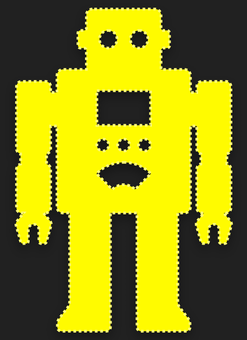


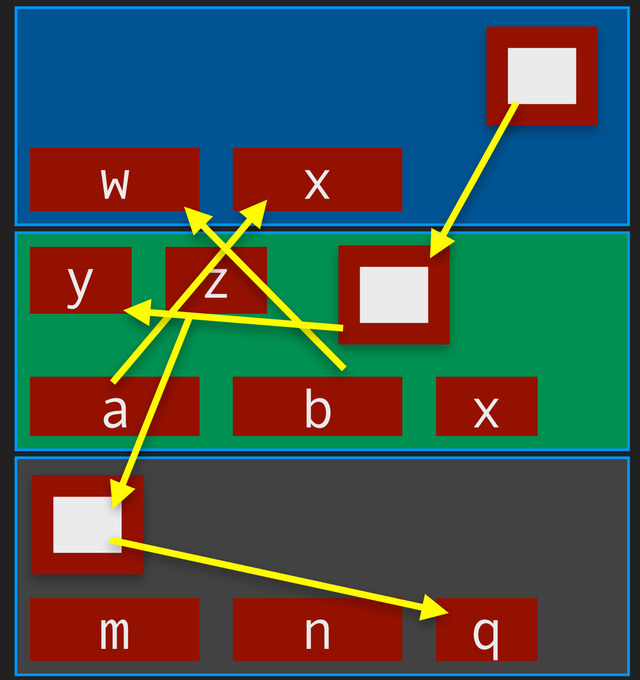
How function calls work: The stack

```
bool covers(int w, int x) {
  // ...
  return x==1;
}
```

```
bool PFE(int a, int b) {
 bool x, y, z;
 x = covers(a,b);
 y = covers(b,a);
 z = x && y;
 return z;
}
```

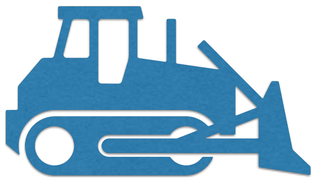
```
main_program {
  int m, n;
  bool q;
  //...
  q = PFE(m,n);
  //...
}
```

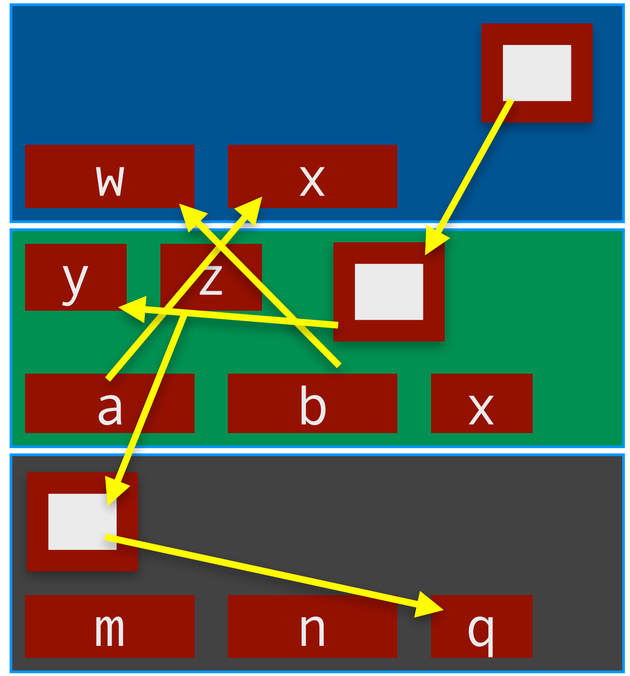




How function calls work: The stack

- When a function is called, it gets its own piece of memory at the top of the stack: its “frame”
- The inputs to the function (arguments) are copied on to the corresponding variables in its frame (parameters) from the frame below it (frame of the function which called it)
- While executing, the function uses only its own frame (we will cover exceptions like global variables, etc. later, and references next)
- When the function returns, the return value is copied into the frame below, and then its own frame is discarded





References

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Swapping

```
void swap(int p, int q) {
  int tmp;
  tmp = p; p = q; q = tmp;
}

int main() {
  int a, b, x, y;
  ...
  swap(a,b);
  swap(x,y);
}
```

- Does this work?
  - No! Only variables local to `swap` (i.e., `p, q`) are swapped and are destroyed when `swap` returns

Swapping

```
void swap(int& p, int& q) {
  int tmp;
  tmp = p; p = q; q = tmp;
}

int main() {
  int a, b, x, y;
  ...
  swap(a,b);
  swap(x,y);
}
```

p and q are **references** to the arguments

- Now `swap` works as desired. What do references enable?

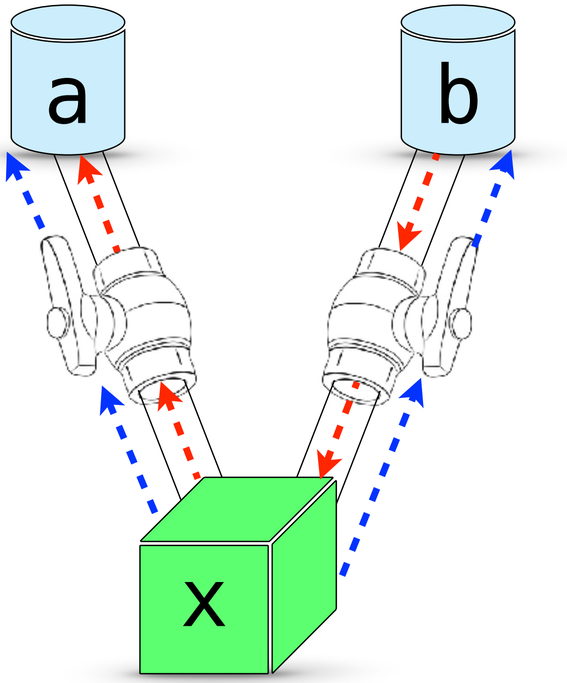
References (I)

- A variable `x` occupies a region in the memory
- Reference is like a tube (with a valve) to the space in memory, that allows information to flow in and out
- References allow the user to read and write to the memory locations

```
int& a = x;
int& b = x;
```

- You can read from and write to these tubes:

```
a = b + 1;
```




```
int x;
int &a = x;
int &b = x;
a = 10;
x++;
b == 11;
```

Is this expression `true` or `false`?

`true`

References (II)

- Cannot create a reference to an intermediate variable

```
int& a = x + 1; // throws a compiler error
```

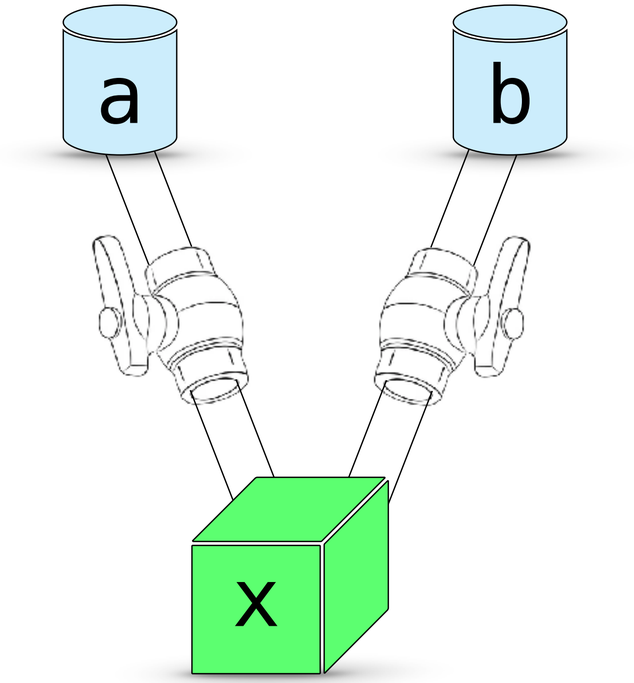
- Intermediate variables cannot be assigned values

```
x+1 = 3; // throws a compiler error
```

- References are valid lvalues (other than variables)

- Reference declarations have to be initialized

```
float& f1; // throws a compiler error
```



References (III)

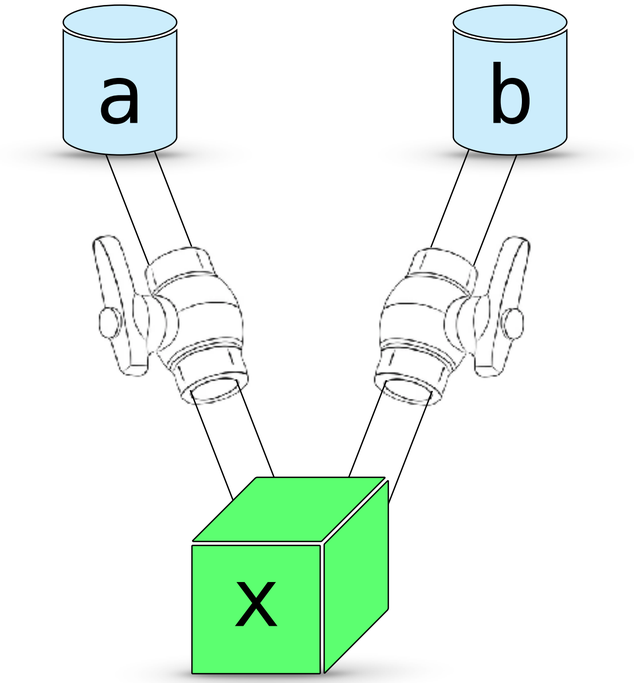
- A reference **has to be** bound to a variable during declaration and cannot be reattached later

```
int x, y;
int &a = x; // a is bound to x forever
a = y;      //copies value of y to x
```

- While declaring a reference, instead of specifying a variable to attach to, one can also specify a reference to attach to

- Example:

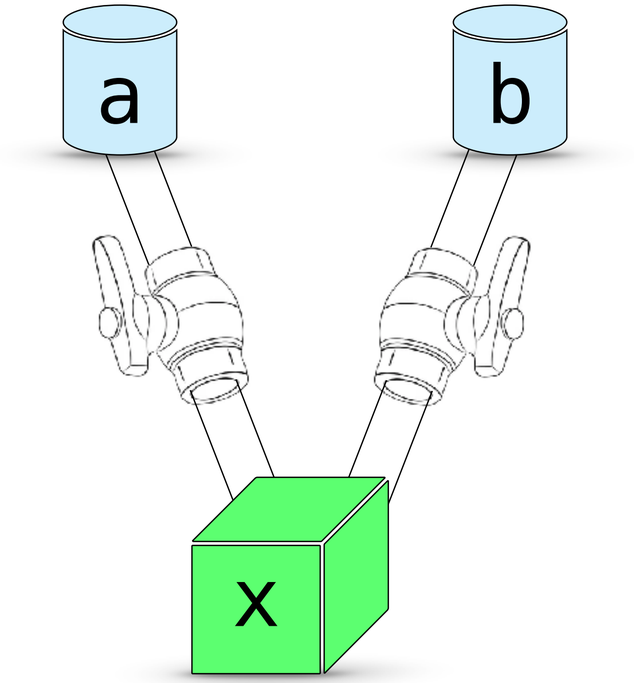
```
int x; int& a = x;
int& b = a; //b and a are attached to x
```



References (IV)

- When declaring multiple references, each one should be prefixed with the & sign

```
int &a = x, &b = x;
```



- Spaces around & are optional

```
int &a = x;
int& a = x;
int&a = x;
```

} all are the same

- You can mix non-reference variables and references in a declaration:

```
int x, & a = x;
```

Functions and References

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Swapping

```
void swap(int& p, int& q) {
  int tmp;
  tmp = p; p = q; q = tmp;
}

int main() {
  int a, b, x, y;
  ...
  swap(a,b);
  swap(x,y);
}
```

p and q are **references** to the arguments

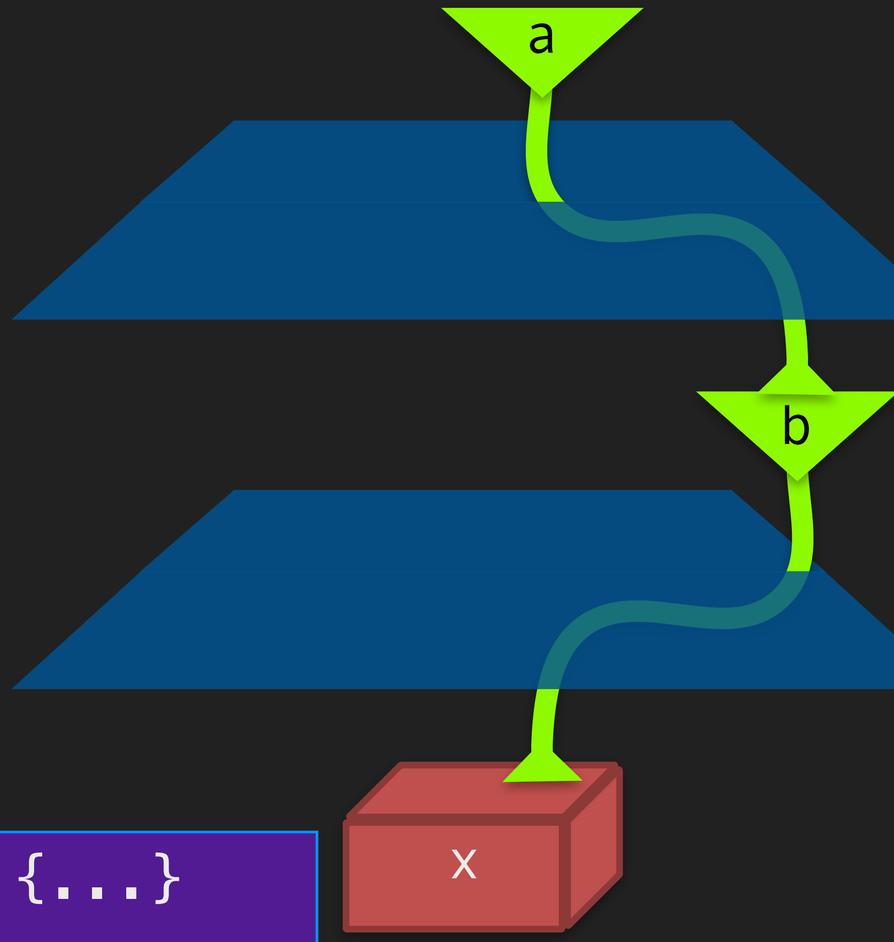
There once was a function, quite grand,
That passed variables by reference, not hand.
It changed what it saw,
Without any flaw,
Returning results as it planned!

- Your friendly neighbourhood LLM

- `swap` works as desired since `p` and `q`, being references to `a`, `b` and `x`, `y` will change the values in these respective variables.

Passing arguments by reference

- If a function's parameter is a reference (a tube), it will be attached to a memory location (a box), when the function is called
- The box is (typically) in the frame of the calling function
  - Note: the called function gets access to variables not in its frame!
  - The box can be further down in the stack too!




```
void h(int &a) {...}
```

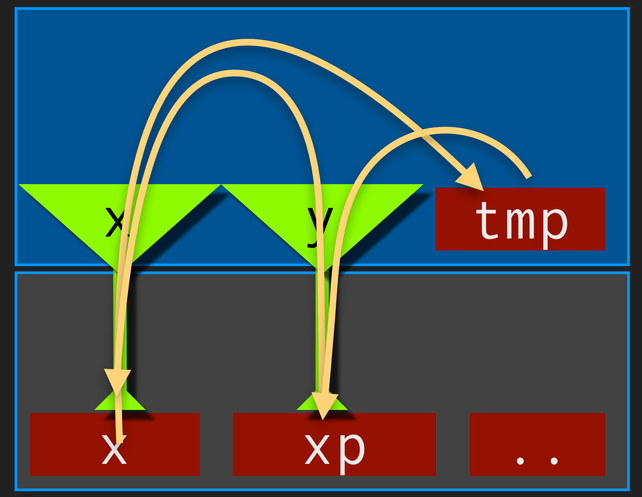
```
void f() {
  int x; ... g(x); ...
}
```

```
void g(int &b) {
  ...  h(b); ...
}
```

Example: Swapping

```
void swp(int& x, int& y) {
  int tmp; tmp=x; x=y; y=tmp;
}
```

```
int main() {
  int x, xp, y, yp, deg, degp;
  ...
  swp(x,xp); swp(y,yp); swp(deg,degp);
}
```



Implement post increment using references

- Demo code in class

Implement post increment using references

```
int postincr(int& m) {
  int old_m = m;
  m = m + 1;
  return old_m;
}

int main() {
  int x = 1;
  cout << postincr(x) << endl;
  cout << x << endl;
}
```

Recall: assigning an `int` reference to an `int` variable will appropriately assign the underlying value

Increments the value that `m` points to, i.e. the variable `x` in `main()`

Returns the old value stored in `x`

- `postincr(x)` works like the post-increment operator `x++`

Implement post increment using references

- What is the output of the following program?

```
int maxvalue(int& a, int& b) {
  return (a>b) ? a : b;
}

main_program {
  int i = 1;
  cout << maxvalue(1, 2);



}
```

Compiler Error

Implement post increment using references

- What is the output of the following program?

```
int maxvalue(int& a, int& b) {
  return (a>b) ? a : b;
}

main_program {
  int i = 1;
  cout << maxvalue(1, 2);

  cout << maxvalue(i++, i);


}
```

Compiler Error

Implement post increment using references

- What is the output of the following program?

```
int maxvalue(int& a, int& b) {
  return (a>b) ? a : b;
}

main_program {
  int i = 1;
  cout << maxvalue(1, 2);

  cout << maxvalue(i++, i);

  cout << maxvalue(++i, i);
}
```

2 output

Next class: More about References and Recursion

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