

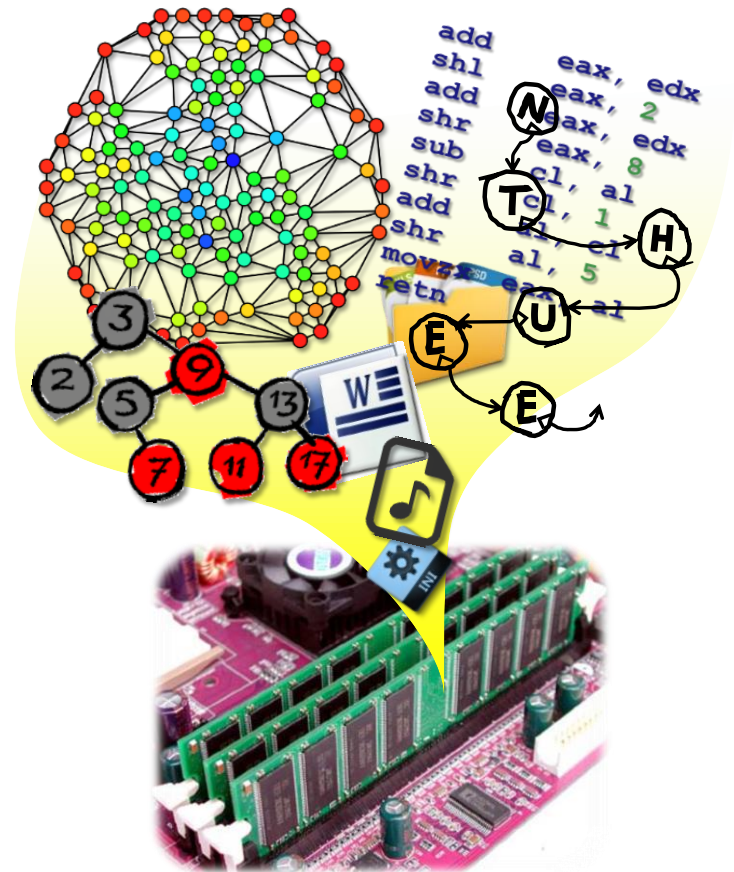
# Data Structures

Introduction to C++

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NTHU EE

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# Outline

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- **Computer and computer language**
- C++ language
- Variable
- I/O
- Function

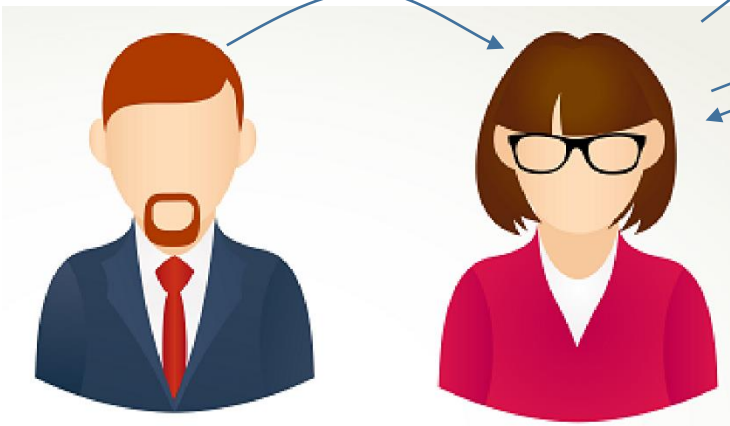


# Computer and Computer Language

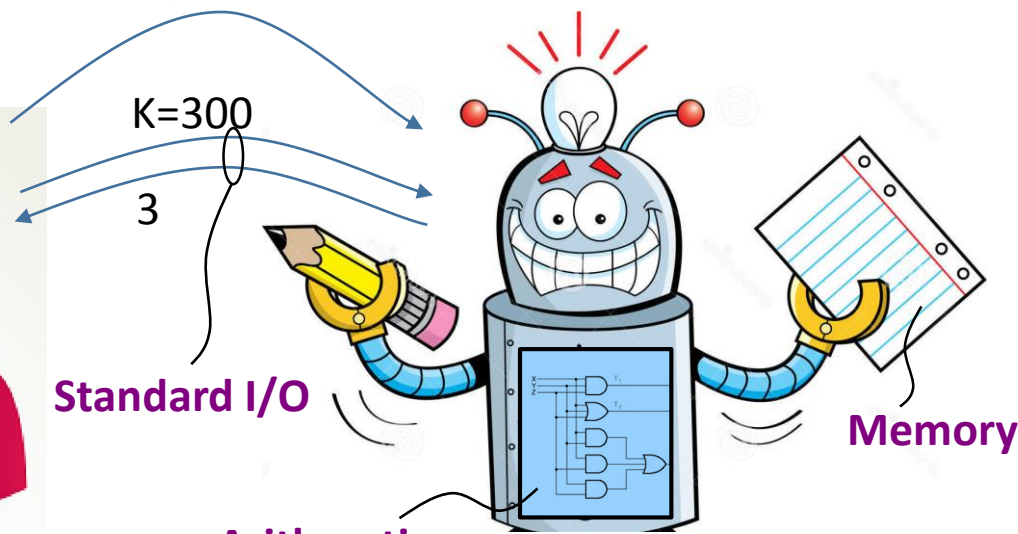
step by step describing how memory, arithmetic, and standard I/O are used to complete the task using **computer language**

.....

Please find the Kth digit of  $\pi$ , K=300



Human



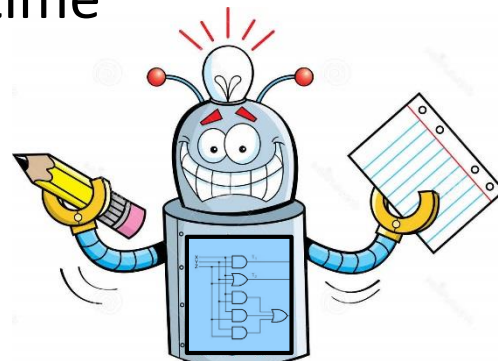
Computer

# Low-Level Computer Language — Machine Code



- Strings of 0s and 1s
  - Typically 8~32 bits per string (i.e., instruction)
  - Instruct computers to perform basic operations
    - Read or write memory
    - Additions, multiplications, etc.
    - Conditional branches
    - ...
- Directly understandable by computer
  - Defined at hardware design time
  - **Hardware-dependent**
- **Hardly readable** by humans

```
b580
2101
4862
f000 f95b
4862
6841
1c49
6041
bd01
b530
b087
f000 fa8c
```



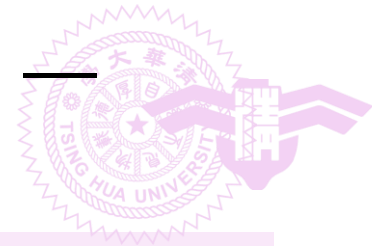


# Low-Level Computer Language — Assembly Language

- Mnemonic (助憶的東西) of machine code
  - A bit better readability for human
  - Non-structured languages
  - Hardware dependent
    - Generally one-to-one correspondence to machine code
- Assembler helps translate assembly language to machine code

```
PUSH R7, LR
MOVS R1, #1
LDR.N R0
BL 0xf95b
LDR.N R0
LDR R1, [R0, #4]
ADDS R1, R1, #1
STR R1, [R0, #4]
POP R0, PC
PUSH R4, R5, LR
SUB SP, SP, #0x1c
BL 0xfa8c
```

```
b580
2101
4862
f000 f95b
4862
6841
1c49
6041
bd01
b530
b087
f000 fa8c
```



# High-Level Computer Language

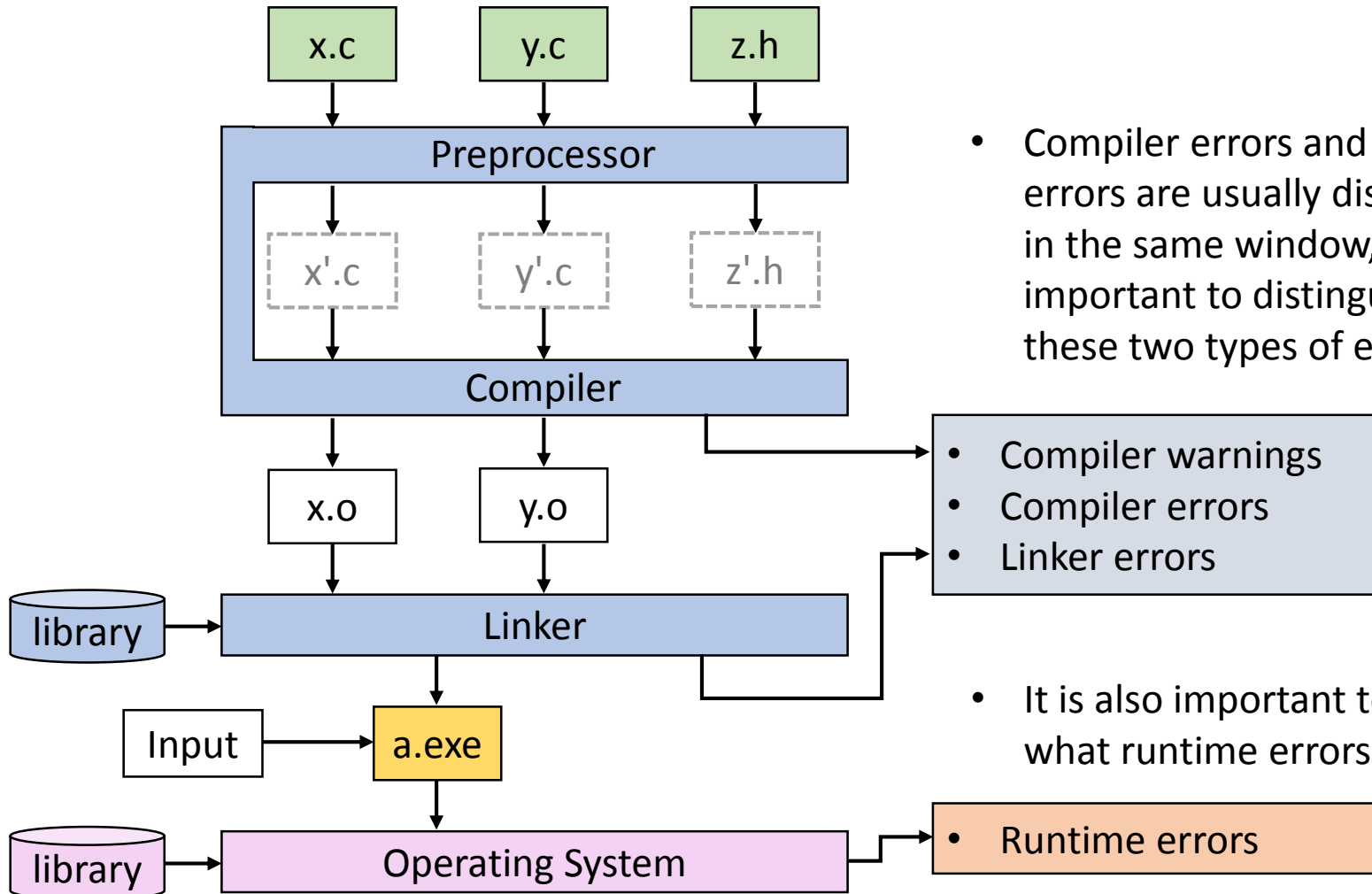
## e.g., C and C++

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- Enhanced human understandability
  - English keywords
  - Mathematical notations
- Enhanced programmability
  - **Hardware independent**
  - Single statement corresponds to multiple low-level instructions



# Ecosystems for High Level Language (e.g., C++)





# Some Exempling Errors

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- Compiler errors
  - Something undeclared
  - Jump to case label
  - Multi-line string
- Linker errors
  - Undefined reference to something
- Runtime errors
  - Segmentation fault
  - Overflow / underflow
  - Division by zero
  - Assertion





# Something Undeclared

- Example

```
doy.cpp: In function 'int main()':  
doy.cpp:25: 'DayOfYear' undeclared (first use this function)  
doy.cpp:25: (Each undeclared identifier is reported only once for  
each function it appears in.)  
doy.cpp:25: parse error before ';' token
```

- Meaning

- The compiler does not know what "DayOfYear" is

- Common causes

- Forgot to include the header file that defines the DayOfYear
- DayOfYear is misspelled
  - at the places where it is defined or used



# Something Undeclared

- Example

```
xyz.cpp: In function 'int main()':  
xyz.cpp:6: 'cout' undeclared (first use this function)  
xyz.cpp:6: (Each undeclared identifier is reported only once for  
each function it appears in.)
```

- Meaning

- The compiler does not know what "cout" is

- Common causes

- Forgot "#include <iostream>"
- Forgot "using namespace std;"



# Jump to Case Label

- Example

```
switch.cpp: In function 'int main()':  
switch.cpp:14: jump to case label  
switch.cpp:11: crosses initialization of 'int y'
```

- Common causes

- Declared a variable within a "case" inside a switch

- Solution

- Enclosing code for the case inside of braces



# Multi-Line String

- Example

Focus on warning or errors that appear first

```
string.cpp:7:12: warning: multi-line string literals are deprecated
string.cpp: In function 'int main()':
string.cpp:7: 'so' undeclared (first use this function)
string.cpp:7: (Each undeclared identifier is reported only once
for each function it appears in.)
string.cpp:7: parse error before 'Mary'
string.cpp:8:28: warning: multi-line string literals are deprecated
string.cpp:8:28: missing terminating " character
string.cpp:7:12: possible start of unterminated string literal
```

- Common causes

- Missing a quote mark at the end of a string

# Undefined Reference to Something



- Example

```
/tmp/cc2Q0kRa.o: In function 'main':  
/tmp/cc2Q0kRa.o(.text+0x18): undefined reference to 'Print(int)'  
collect2: ld returned 1 exit status
```

- Meaning

- **Linker** cannot find code named Print() that has an int argument in .o files (i.e., compilation is successful)

- Common causes

- Forgot to declare or define the Print() function
- Forgot to compile the .c file containing Print()
- Forgot to link the .o or library containing Print()
- Misspelled the function name
- Unmatched argument list



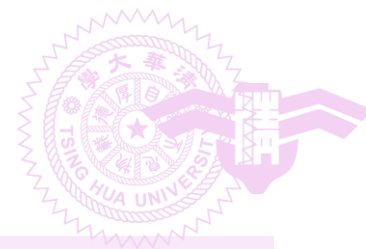
# Undefined Reference to Something

- Example

```
/usr/lib/crt1.o: In function '_start':  
/usr/lib/crt1.o(.text+0x18): undefined reference to 'main'  
collect2: ld returned 1 exit status
```

- Common causes

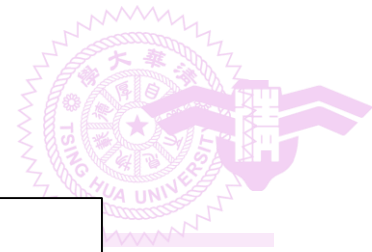
- The main function is missing
- The main function is misspelled



# Runtime Error

---

- Error not shown at the compile/link time
- Usually reported by the operating system
- Usually dependent on input data
  - Some test cases work, but some others do not
- Often dependent on systems
  - Errors can disappear then reappear from time to time



# Segmentation Fault

```
int * a = new int [10];  
for(int i=0; i<=10; i++) {  
    a[i] = i; // out of the range of a[]  
}  
...  
int sum = 0;  
for(int i=0; i<=10; i++) {  
    sum += a[i]; // out of the range of a[]  
}  
cout << "sum = " << sum << endl;
```

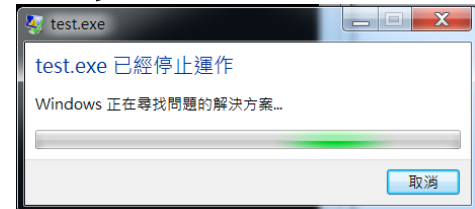
Many outcomes are possible because the contents in memory are corrupted.

sum = 55

Good result, but it is **just a luck**. In fact, this is the **most dangerous outcome!**

sum = 90

The program executes but a strange result is obtained. Usually hard to debug.



Runtime error (Segmentation fault) Usually hard to debug.





# Overflow / Underflow

```
int n;  
cin >> n;  
unsigned int s=0;  
for(int i=0; i<n; i++) {  
    s += 12345678;  
}  
cout << "12345678 * " << n << " = " << s << endl;
```

1000  
12345678 \* 1000 = 3755743408

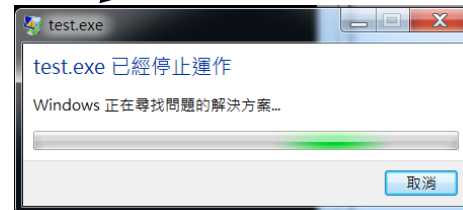
Strange result.  
No runtime error message.  
Usually hard to debug.



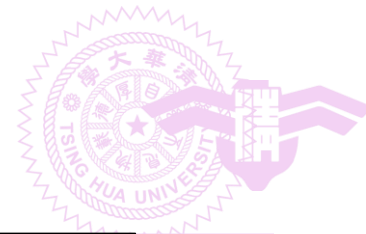
# Division by Zero

```
int a = 100;
for(int i=0; i<=10; i++) {
    int b;
    cin >> b;
    cout << a/(b-10) << endl; // error occurs once b = 10
}
```

For some inputs, the program works fine



For some other inputs, runtime error occurs (input data dependent)

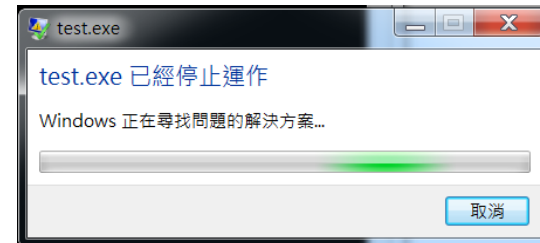


# Assertion

```
#include <assert.h> // assert()
int a = 100;
for(int i=0; i<=10; i++) {
    int b;
    cin >> b;
    assert(b!=10); // "assert" means "聲明"
    cout << a << "/" << b << " = " << a/(b-10) << endl;
}
```

15  
100/(15-10) = 20  
20  
100/(20-10) = 10  
10

Assertion failed: b!=10, file C:\main.cpp, line 14





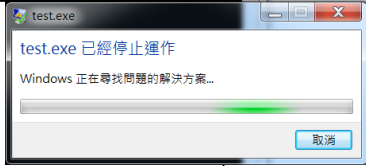
# Use assert() to Debug Runtime Errors

```
int * a = new int [10];  
for(int i=0; i<=10; i++) {  
    assert(i>=0 && i<10);  
    a[i] = i; // out of the range of a[]  
}  
...  
int sum = 0;  
for(int i=0; i<=10; i++) {  
    assert(i>=0 && i<10);  
    sum += a[i]; // out of the range of a[]  
}  
cout << "sum = " << sum << endl;
```

✗  
sum = 55  
sum = 90

Assertion failed: i>=0 && i<10,  
file C:\main.cpp, line 12

This application has requested the Runtime  
to terminate it in an unusual way.  
Please contact the application's support  
team for more information.



Runtime error



# Assertion

---

- Assertion has no effects if **NDEBUG** is defined
  - #define NDEBUG
  - Reduce the undesired overhead of assert() for the production version of the program
  - Be careful whether assert() is disabled or not
- It is a good practice to use assert() during program development
  - Assertion helps detecting hard-to-find errors
  - Assertion failure comes with its location information



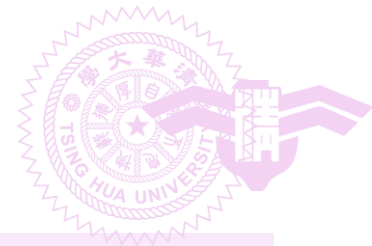
# Assert in Online Judge

- Online Judge shows very limited execution results
  - We cannot distinguish assertion failures from other runtime errors such as division by zero and segmentation faults
  - Thus standard `assert()` may be not very helpful for debugging
- We can define `assert()` ourselves

```
#include <stdlib.h>

// trigger "Time Limit Exceed" if assertion fails
#define check_a(x) if(!(x)) for(;;);

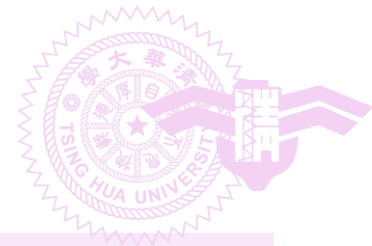
// trigger "Wrong Answer" if assertion fails
#define check_b(x) if(!(x)) {cout<<"L"<<__LINE__<<" Err" ;exit(0);}
```



# C++ Keywords (Vocabulary)

<code>alignas</code> (since C++11)	<code>else</code>	<code>requires</code> (concepts TS)
<code>alignof</code> (since C++11)	<code>enum</code>	<code>return</code>
<code>and</code>	<code>explicit</code>	<code>short</code>
<code>and_eq</code>	<code>export(1)</code>	<code>signed</code>
<code>asm</code>	<code>extern</code>	<code>sizeof</code>
<code>auto(1)</code>	<code>false</code>	<code>static</code>
<code>bitand</code>	<code>float</code>	<code>static_assert</code> (since C++11)
<code>bitor</code>	<code>for</code>	<code>static_cast</code>
<code>bool</code>	<code>friend</code>	<code>struct</code>
<code>break</code>	<code>goto</code>	<code>switch</code>
<code>case</code>	<code>if</code>	<code>template</code>
<code>catch</code>	<code>inline</code>	<code>this</code>
<code>char</code>	<code>int</code>	<code>thread_local</code> (since C++11)
<code>char16_t</code> (since C++11)	<code>long</code>	<code>throw</code>
<code>char32_t</code> (since C++11)	<code>mutable</code>	<code>true</code>
<code>class</code>	<code>namespace</code>	<code>try</code>
<code>compl</code>	<code>new</code>	<code>typedef</code>
<code>concept</code> (concepts TS)	<code>noexcept</code> (since C++11)	<code>typeid</code>
<code>const</code>	<code>not</code>	<code>typename</code>
<code>constexpr</code> (since C++11)	<code>not_eq</code>	<code>union</code>
<code>const_cast</code>	<code>nullptr</code> (since C++11)	<code>unsigned</code>
<code>continue</code>	<code>operator</code>	<code>using(1)</code>
<code>decltype</code> (since C++11)	<code>or</code>	<code>virtual</code>
<code>default(1)</code>	<code>or_eq</code>	<code>void</code>
<code>delete(1)</code>	<code>private</code>	<code>volatile</code>
<code>do</code>	<code>protected</code>	<code>wchar_t</code>
<code>double</code>	<code>public</code>	<code>while</code>
<code>dynamic_cast</code>	<code>register</code>	<code>xor</code>
	<code>reinterpret_cast</code>	<code>xor_eq</code>

A total of 86



# C++ Keywords (Vocabulary)

<code>alignas</code> (since C++11)	<code>else</code>	<code>requires</code> (concepts TS)
<code>alignof</code> (since C++11)	<code>enum</code>	<code>return</code>
<code>and</code>	<code>explicit</code>	<code>short</code>
<code>and_eq</code>	<code>export(1)</code>	<code>signed</code>
<code>asm</code>	<code>extern</code>	<code>sizeof</code>
<code>auto(1)</code>	<code>false</code>	<code>static</code>
<code>bitand</code>	<code>float</code>	<code>static_assert</code> (since C++11)
<code>bitor</code>	<code>for</code>	<code>static_cast</code>
<code>bool</code>	<code>friend</code>	<code>struct</code>
<code>break</code>	<code>goto</code>	<code>switch</code>
<code>case</code>	<code>if</code>	<code>template</code>
<code>catch</code>	<code>inline</code>	<code>this</code>
<code>char</code>	<code>int</code>	<code>thread_local</code> (since C++11)
<code>char16_t</code> (since C++11)	<code>long</code>	<code>throw</code>
<code>char32_t</code> (since C++11)	<code>mutable</code>	<code>true</code>
<code>class</code>	<code>namespace</code>	<code>try</code>
<code>compl</code>	<code>new</code>	<code>typedef</code>
<code>concept</code> (concepts TS)	<code>noexcept</code> (since C++11)	<code>typeid</code>
<code>const</code>	<code>not</code>	<code>typename</code>
<code>constexpr</code> (since C++11)	<code>not_eq</code>	<code>union</code>
<code>const cast</code>	<code>nullptr</code> (since C++11)	<code>unsigned</code>
<code>continue</code>	<code>operator</code>	<code>using(1)</code>
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<code>default(1)</code>	<code>or_eq</code>	<code>void</code>
<code>delete(1)</code>	<code>private</code>	<code>volatile</code>
<code>do</code>	<code>protected</code>	<code>wchar_t</code>
<code>double</code>	<code>public</code>	<code>while</code>
<code>dynamic_cast</code>	<code>register</code>	<code>xor</code>
	<code>reinterpret_cast</code>	<code>xor_eq</code>





# Operators

- Some keyboards lack of special characters, such as &, |, !, ^, ~, thus C++ offers these alternatives

Type	Keywords	Meaning
Logical operators	and	&&
	or	
	not	!
Bitwise operators	bitand	&
	bitor	
	xor	^
	compl	~
Compound assignment	and_eq	&=
	or_eq	=
	xor_eq	^=
Relational and comparison operators	not_eq	!=



# Branch and Loop

Type	Keywords
Boolean constants	true
	false
Two-way branch	if
	else
Multi-way branch	switch
	case
	default
	break
Loop	for
	do
	while
Unconditional branch	break
	continue
	return
	goto

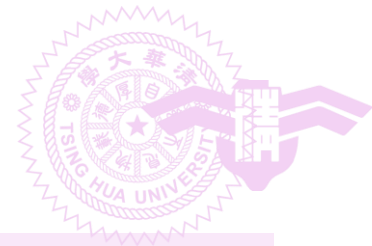
```
int s = 0, t = 0;
int n;
cin >> n;
for (;;) { // infinite loop
    // short-circuit evaluation
    if (n > 0 && 100/n)
        s += n;
    else if (n < 0)
        continue;
    else {
        t += n;
        if (t >= 200)
            break;
    }
    cin >> n;
}
cout << s << " " << t;
```



# Branch and Loop

Type	Keywords
Boolean constants	true
	false
Two-way branch	if
	else
Multi-way branch	switch
	case
	default
	break
Loop	for
	do
	while
Unconditional branch	break
	continue
	return
	goto

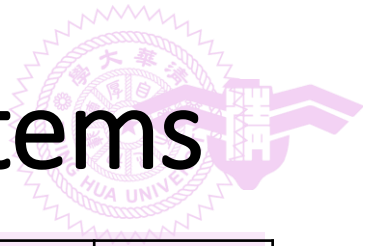
```
int a = 0;
int b = 0;
int upperab = 0;
int others = 0;
char c;
cin >> c;
switch ( c ) {
    case 'A':
        upperab ++;
        case 'a': //fall through
            a ++;
            break;
    case 'B':
        upperab ++;
        case 'b': //fall through
            b ++;
            break;
    default: //catch-all case
        others++;
}
```



# Fundamental Types

Type	Keywords
Type with an empty set of values	void
Boolean type	bool
Character type	char
	char16_t (C++11)
	char32_t (C++11)
	wchar_t
Integer type	int
Floating point type	float
	double

Type	Keywords
Size modifiers	short
	long
Signedness modifiers	signed
	unsigned
Storage class specifier	static
CV (const and volatile) type qualifier	const
	volatile
	mutable



# Integer Types in Common Systems

Signed Types	Minimum Guaranteed Range	Unsigned Types	Minimum Guaranteed Range	Bits
short short int signed short signed short int	$-2^{15}+1 \sim 2^{15}-1$	unsigned short unsigned short int	$0 \sim 2^{16}-1$	$\geq 16$
int signed signed int	$-2^{31}+1 \sim 2^{31}-1$	unsigned unsigned int	$0 \sim 2^{32}-1$	$\geq 32$
long long int signed long signed long int	$-2^{31}+1 \sim 2^{31}-1$	unsigned long unsigned long int	$0 \sim 2^{32}-1$	$\geq 32$
long long long long int signed long long signed long long int	$-2^{63}+1 \sim 2^{63}-1$	unsigned long long unsigned long long int	$0 \sim 2^{64}-1$	$\geq 64$



# Fixed Width Integer Types

- `#include <stdint.h>`

	Type name	Min value	Max value
Exact size	<code>int8_t</code>	<code>INT8_MIN</code>	<code>INT8_MAX</code>
	<code>int16_t</code>	<code>INT16_MIN</code>	<code>INT16_MAX</code>
	<code>int32_t</code>	<code>INT32_MIN</code>	<code>INT32_MAX</code>
	<code>int64_t</code>	<code>INT64_MIN</code>	<code>INT64_MAX</code>
Smallest type with at least the required size	<code>int_least8_t</code>	<code>INT_LEAST8_MIN</code>	<code>INT_LEAST8_MAX</code>
	<code>int_least16_t</code>	<code>INT_LEAST16_MIN</code>	<code>INT_LEAST16_MAX</code>
	<code>int_least32_t</code>	<code>INT_LEAST32_MIN</code>	<code>INT_LEAST32_MAX</code>
	<code>int_least64_t</code>	<code>INT_LEAST64_MIN</code>	<code>INT_LEAST64_MAX</code>
Fastest type with at least the required size	<code>int_fast8_t</code>	<code>INT_FAST8_MIN</code>	<code>INT_FAST8_MAX</code>
	<code>int_fast16_t</code>	<code>INT_FAST16_MIN</code>	<code>INT_FAST16_MAX</code>
	<code>int_fast32_t</code>	<code>INT_FAST32_MIN</code>	<code>INT_FAST32_MAX</code>
	<code>int_fast64_t</code>	<code>INT_FAST64_MIN</code>	<code>INT_FAST64_MAX</code>



# Unsigned Fixed Width Integer Types

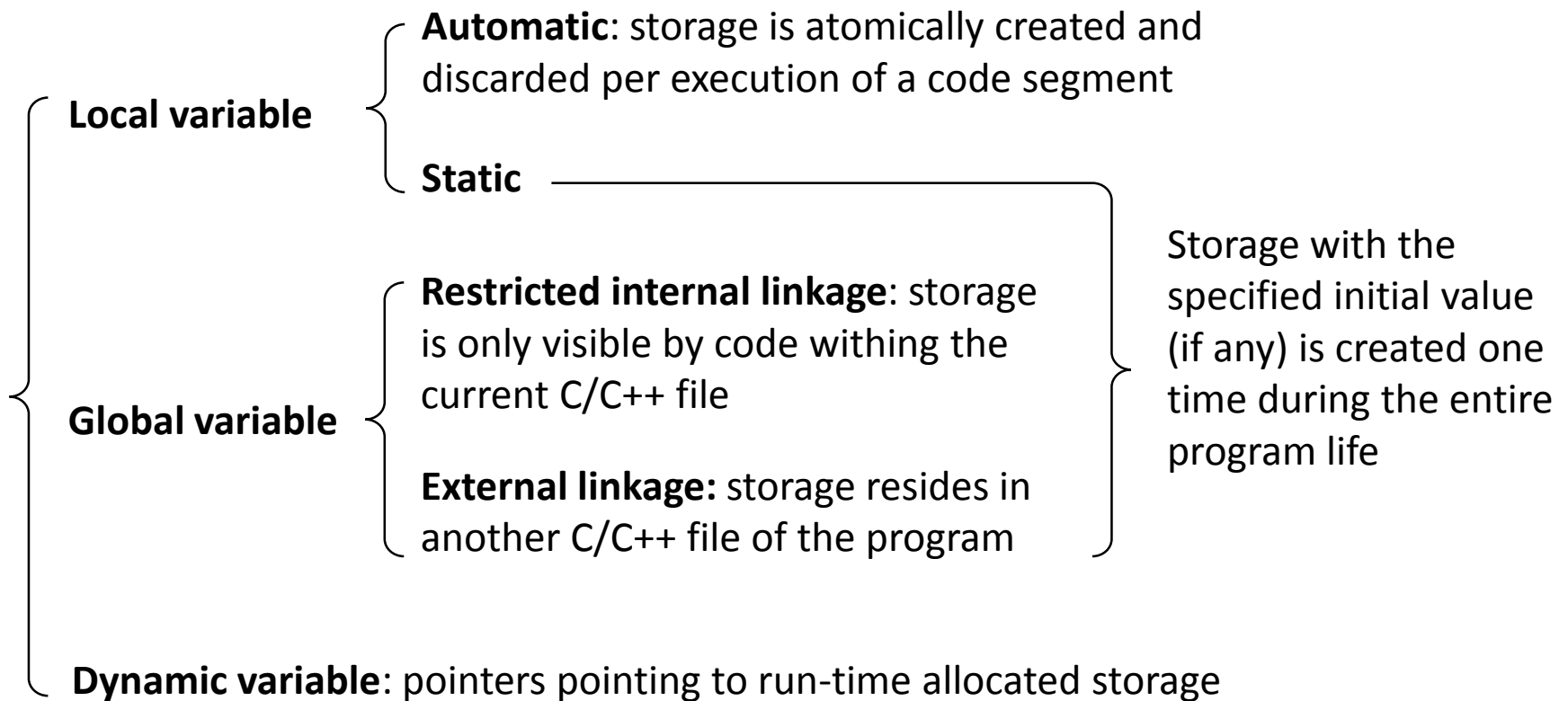
- `#include <stdint.h>`

	Type name	Min value	Max value
Exact size	<code>uint8_t</code>	<code>UINT8_MIN</code>	<code>UINT8_MAX</code>
	<code>uint16_t</code>	<code>UINT16_MIN</code>	<code>UINT16_MAX</code>
	<code>uint32_t</code>	<code>UINT32_MIN</code>	<code>UINT32_MAX</code>
	<code>uint64_t</code>	<code>UINT64_MIN</code>	<code>UINT64_MAX</code>
Smallest type with at least the required size	<code>uint_least8_t</code>	<code>UINT_LEAST8_MIN</code>	<code>UINT_LEAST8_MAX</code>
	<code>uint_least16_t</code>	<code>UINT_LEAST16_MIN</code>	<code>UINT_LEAST16_MAX</code>
	<code>uint_least32_t</code>	<code>UINT_LEAST32_MIN</code>	<code>UINT_LEAST32_MAX</code>
	<code>uint_least64_t</code>	<code>UINT_LEAST64_MIN</code>	<code>UINT_LEAST64_MAX</code>
Fastest type with at least the required size	<code>uint_fast8_t</code>	<code>UINT_FAST8_MIN</code>	<code>UINT_FAST8_MAX</code>
	<code>uint_fast16_t</code>	<code>UINT_FAST16_MIN</code>	<code>UINT_FAST16_MAX</code>
	<code>uint_fast32_t</code>	<code>UINT_FAST32_MIN</code>	<code>UINT_FAST32_MAX</code>
	<code>uint_fast64_t</code>	<code>UINT_FAST64_MIN</code>	<code>UINT_FAST64_MAX</code> 31



# Storage Class Specifier

- Classification based on the memory space holding variable values

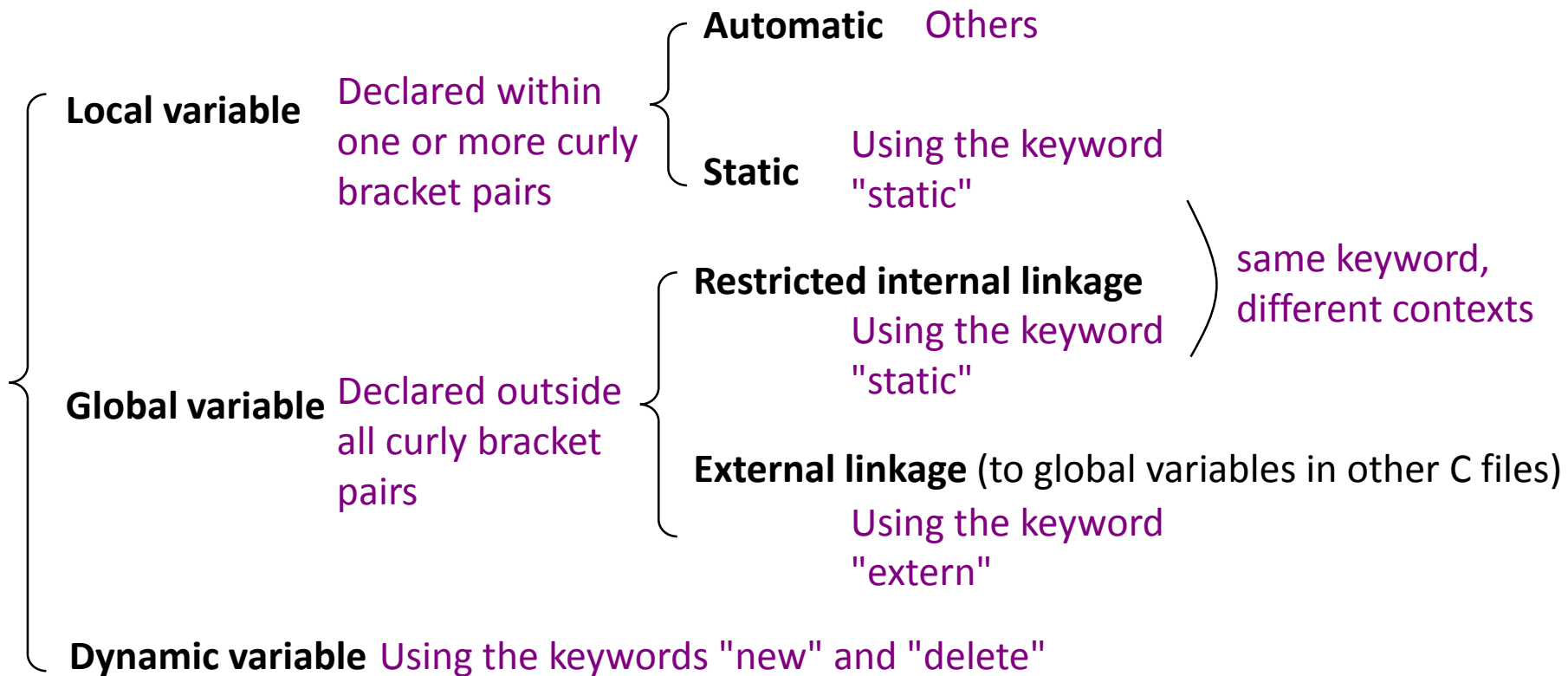






# Storage Class Specifier

- Anatomy according to the memory space holding variable values



```
int num = 0; // global variable
static int N; // global variable, restricted accessibility in this C file
int main ()
{
    cin >> N;
    // float y[N]; // wrong
    float * y = new float [N];
    ...
    cout << BinarySearch(y, 3.14, 0, N-1) << endl;
    cout << "Function invocation times: " << num << endl;
    delete[] y;
    return 0;
}
```

**main.c**

```
int BinarySearch(float * a, const int x, const int left, const int right)
{
    extern int num; // refer to a global variable outside this C file
    num ++;
    if(left>right) return -1;

    int middle = (left+right)/2; // automatic local variable

    if(x<a[middle])        return BinarySearch(a, x, left, middle-1);
    else if(x>a[middle])   return BinarySearch(a, x, middle+1, right);
    else                   return middle;
}
```

**BinarySearch.c**



# Variable's Scope

---

- **Scope**
  - **Visibility of a variable** declared in one place and used in another place
  - Each variable has its scope
- Four scope types
  1. File scope
  2. Namespace scope
  3. Local scope
  4. Class scope



```
#include <iostream>
using namespace std;
void func1();
int i = 11;
int j = 22;
int main()
{
    int i = 33;
    int j = 44;
    for(int i=0; i<3; i++){
        int j = i*j;
        cout << i << ", " << j << endl;
    }
    cout << i << ", " << j << endl;
    cout << ::i << ", " << ::j << endl;
    func1();
    return 0;
}
void func1()
{
    int i = 55;
    int j = 66;
    cout << i << ", " << j << endl;
}
```

File scope (global variables)

Local scope (in the main function)

Local scope (in the for loop)

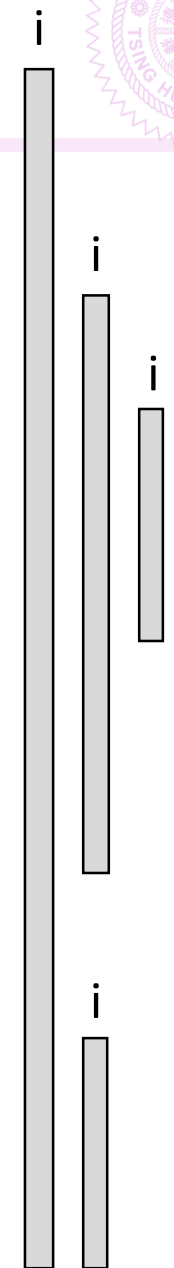
The i in the for loop is used

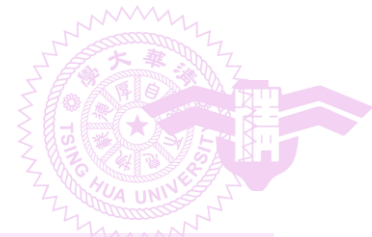
The ones in the main function are used

The ones of the file scope are referred (because of the :: operator)

Local scope (in the func1 function)

The ones in the func1 are used





```
#include <iostream>
using namespace std;
void func1();
int i = 11;
int j = 22;
int main()
{
    int i = 33;
    int j = 44;
    for(int i=0; i<3; i++){
        int j = i*i;
        cout << i << ", " << j << endl;
    }
    cout << i << ", " << j << endl;
    cout << ::i << ", " << ::j << endl;
    func1();
    return 0;
}
void func1()
{
    int i = 55;
    int j = 66;
    cout << i << ", " << j << endl;
}
```

File scope (global variables)

Local scope (in the main function)

Local scope (in the for loop)

The i in the for loop is used

The ones in the main function are used

The ones of the file scope are referred (because of the :: operator)

Local scope (in the func1 function)

The ones in the func1 are used

### Output

```
0, 0
1, 1
2, 4
33, 44
11, 22
55, 66
```



# Redefinition of Variables

```
void func1();
```

s1.h

```
#include <iostream>
using namespace std;
float PI = 3.14;
void func1()
{
    cout << "func1" << endl;
    cout << "2PI = " << 2*PI;
    cout << endl;
}
```

s1.cpp

```
#include <iostream>
#include "s1.h"
using namespace std;
float PI = 3.14;
int main()
{
    cout << "main" << endl;
    cout << "PI = " << PI << endl;
    func1();
    return 0;
}
```

main.cpp

Linker  
error

- A linker is designed to maintain a table collecting the source definition of global variables
- Since the name, PI, is defined from two sources, a linker complains that PI is defined multiple times.



# Link to External Variables

```
void func1();
```

s1.h

```
#include <iostream>
using namespace std;
float PI = -3.14;
extern float PI;
void func1()
{
    cout << "func1" << endl;
    cout << "2PI = " << 2*PI;
    cout << endl;
}
```

s1.cpp

```
#include <iostream>
#include "s1.h"
using namespace std;
float PI = 3.14;
int main()
{
    cout << "main" << endl;
    cout << "PI = " << PI << endl;
    func1();
    return 0;
}
```

main.cpp

```
main
PI = 3.14
func1
2PI = 6.28
```

Output

If we mean to refer to the predefined variable **external** to a source file, we need to use the keyword "**extern**" to explicitly show this intention.



# “Pure” File-Scope Variables

```
void func1();
```

s1.h

```
#include <iostream>
using namespace std;
static float PI = 5;
void func1()
{
    cout << "func1" << endl;
    cout << "2PI = " << 2*PI;
    cout << endl;
}
```

s1.cpp

```
#include <iostream>
#include "s1.h"
using namespace std;
float PI = 3.14;
int main()
{
    cout << "main" << endl;
    cout << "PI = " << PI << endl;
    func1();
    return 0;
}
```

main.cpp

```
main
PI = 3.14
func1
2PI = 10
```

Output

If we mean to defined a variable local to a source file, one solution is to use the keyword "static" to explicitly show this intention.





# Resolving Name Collisions

```
void func1();
```

s1.h

```
#include <iostream>
using namespace std;
float s1_Pi=5;
void func1()
{
    cout << "func1" << endl;
    cout << "2PI = "
        << 2 * s1_Pi;
    cout << endl;
}
```

s1.cpp

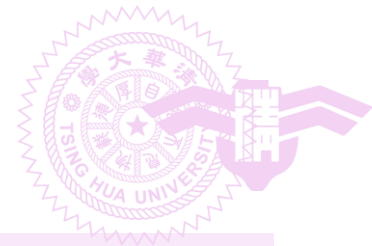
```
#include <iostream>
#include "s1.h"
using namespace std;
float PI = 3.14;
int main()
{
    cout << "main" << endl;
    cout << "PI = " << PI << endl;
    func1();
    return 0;
}
```

main.cpp

```
main
PI = 3.14
func1
2PI = 10
```

Output

Another solution is to rename the variable (e.g., adding a prefix "s1" in this example). Doing this of course avoids name collisions.



# Resolving Name Collisions

```
void func1();
```

s1.h

```
#include <iostream>
using namespace std;
namespace s1{
float PI=5;
void func1()
{
    cout << "func1" << endl;
    cout << "2PI = " << 2*PI;
    cout << endl;
}
}
```

s1.cpp

```
#include <iostream>
#include "s1.h"
using namespace std;
float PI = 3.14;
int main()
{
    cout << "main" << endl;
    cout << "PI = " << PI << endl;
    s1::func1();
    return 0;
}
```

main.cpp

```
main
PI = 3.14
func1
2PI = 10
```

Output

Another solution is to use the keyword "namespace" to specify a name (e.g., "s1" in this example). The name needs NOT be the file name). Doing this lets the associated variables and functions have a namespace scope and avoid name collisions.



# Value, Address, Pointer, and Reference

---

- Meanings of '&' and '\*' are context dependent
  - This is one main reason why many people have difficulties in understanding pointers and references in C++
- Context is common
  - 目的地是清大
  - 你的確在清大
  - 他的卻在交大

- **Declarations about variables**

- **int** a

- **Declare that** a is an integer

- **int \*** p

- **Declare that** p is a pointer. Specifically, a pointer to an integer

- **int &** r

- **Declare that** r is an alias (別名) of an integer

- **Operations on variables**

- &a

- **Get** the address of a

- \*p

- **Get** the thing that p points to

- If p is declared as int \*, get the int

- If p is declared as float \*, get the float

- **Declarations** (declare some thing)

- int a

- int \* p

- int & r

- **Operations** (get something)

- &a

- \*p

- **Declarations**

- int reference
- int \* value
- int & pointer

- **Operations**

- &address
- \*data

- float tmp
- float & name
- &address
- \*alias
- int pointer

- `if (*people == 10)`
- `if (2 *people == 20)`
- float & integer
- `if (K & R)`
- `if (& R)`
- `int * character`
- float alias
- `switch( & hello)`
- `x = y * (*z)`
- `& both + *none`
- `char * float_array`



- **double type**

- **& where**

- **int &address**

- **char &p\_char**

- **& p\_char**

- **\*non\_address**

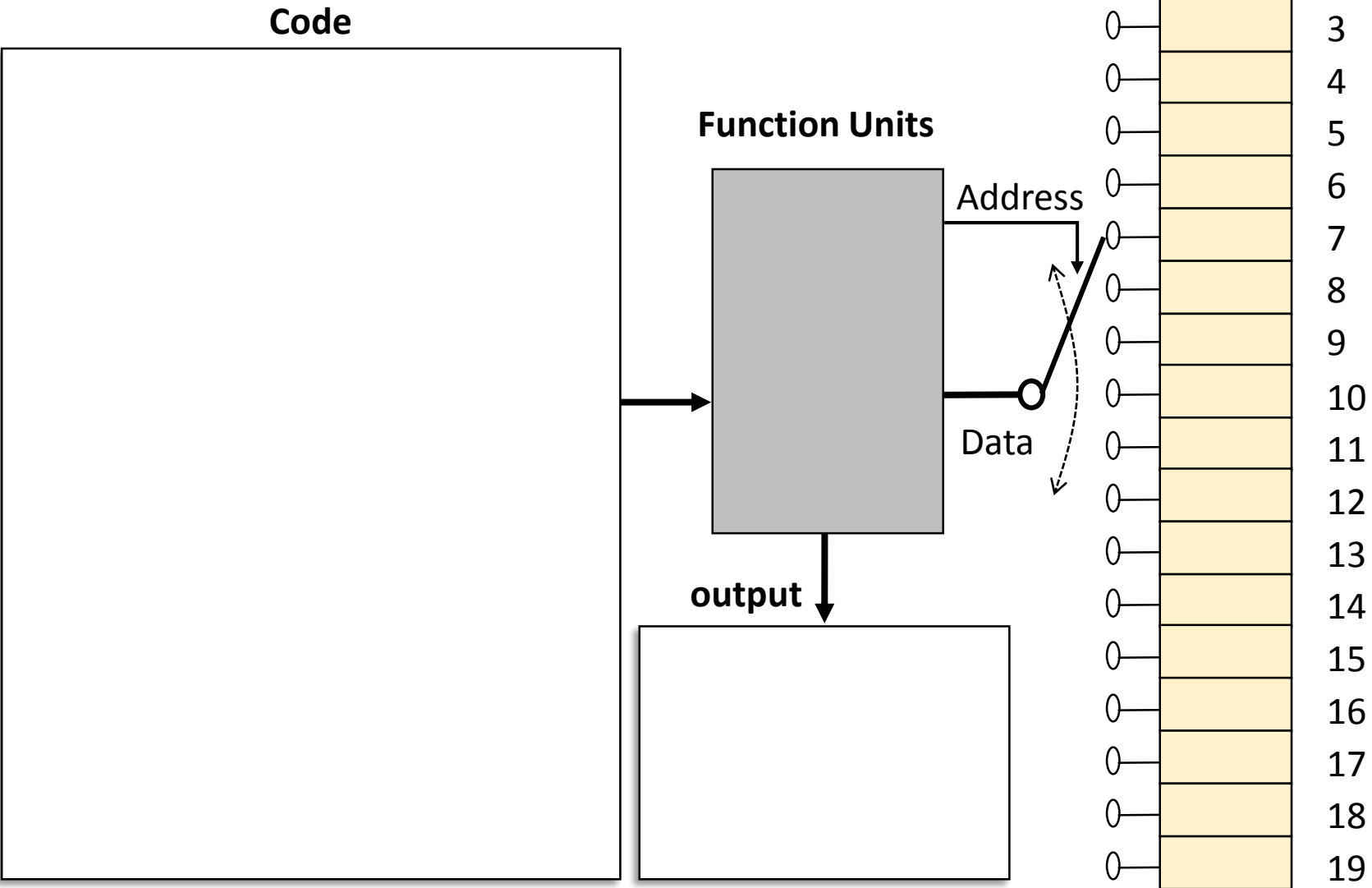
- **int \*ref**

- ***int & p***

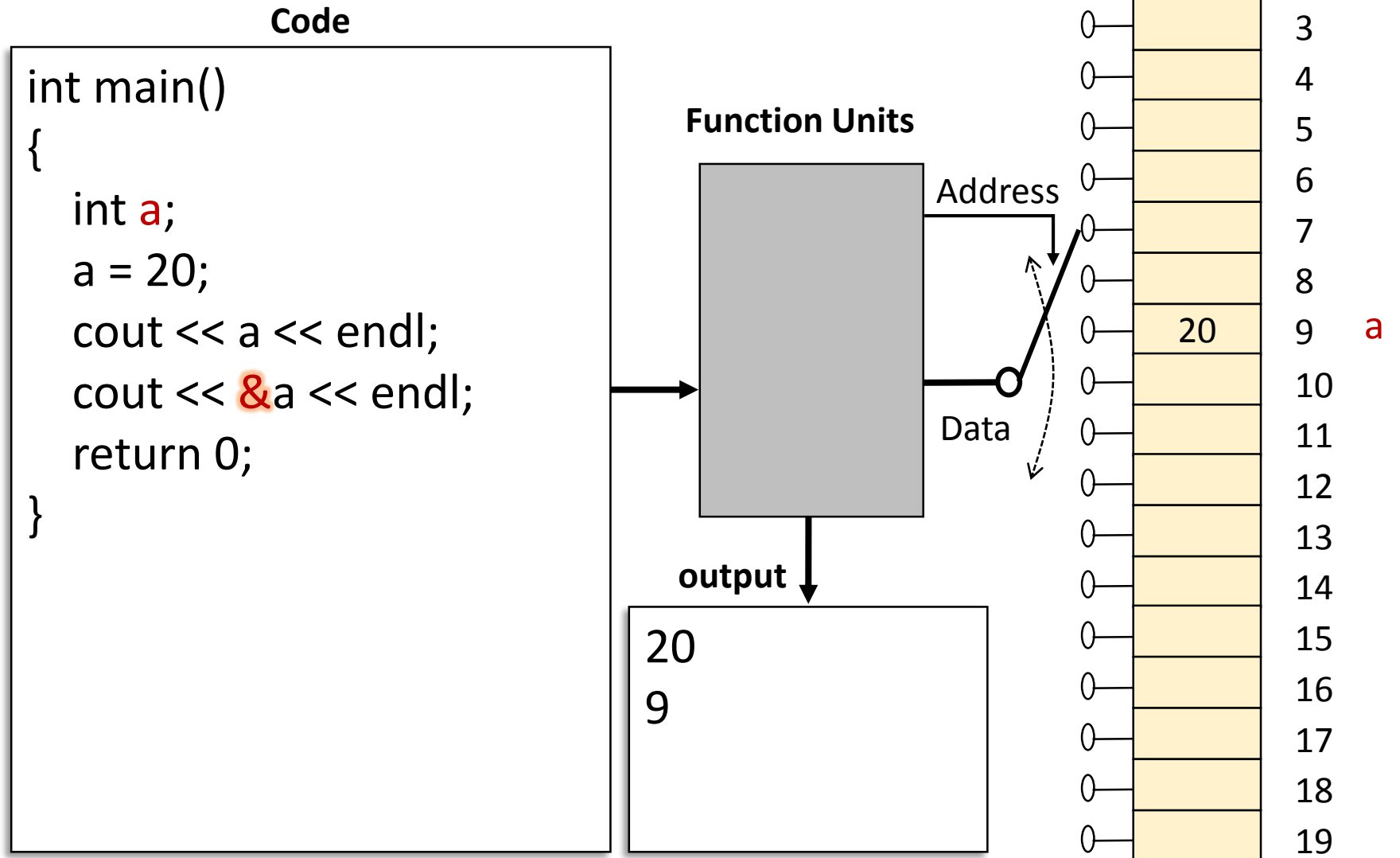
- **&ref**

- **int function**

# Simplified Computer Model



# Address

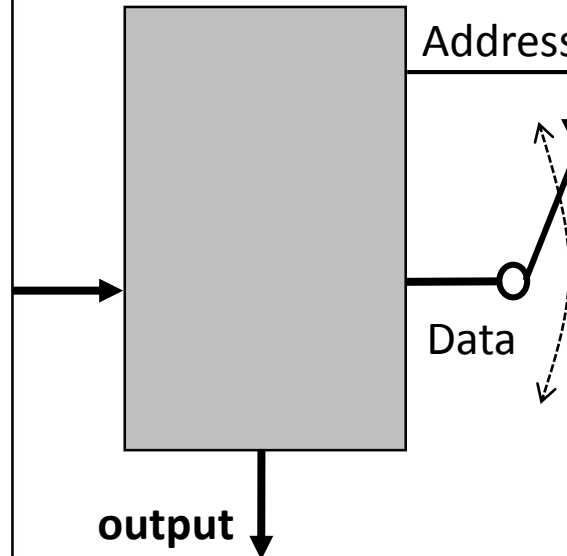


# Passed-by-Value

## Code

```
void t(int a);  
int main()  
{  
    int a = 20;  
    cout << &a << endl;  
    t(a);  
    return 0;  
}  
  
void t(int a)  
{  
    cout << a << endl;  
    cout << &a << endl;  
    return;  
}
```

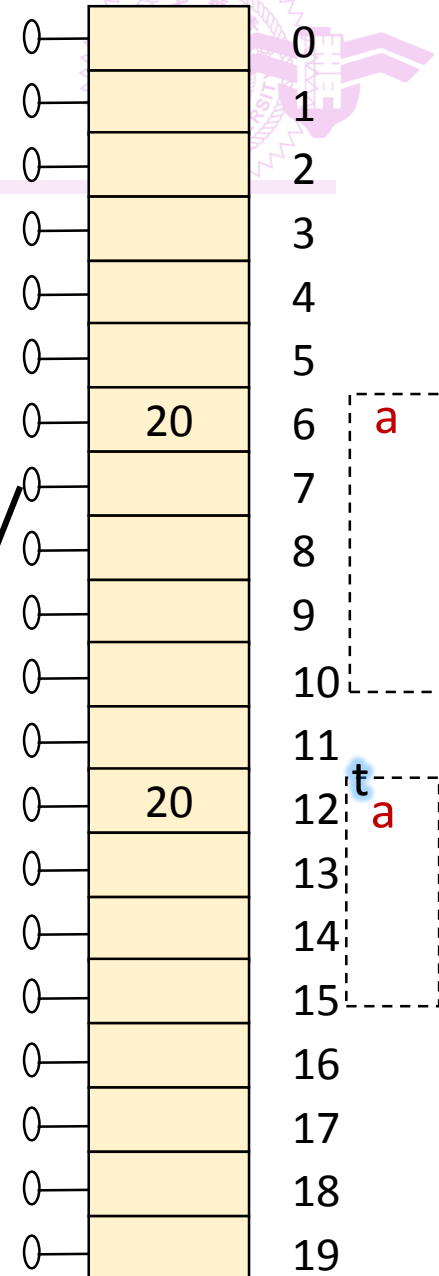
## Function Units



6  
20  
12

Diff. addresses

## Memory

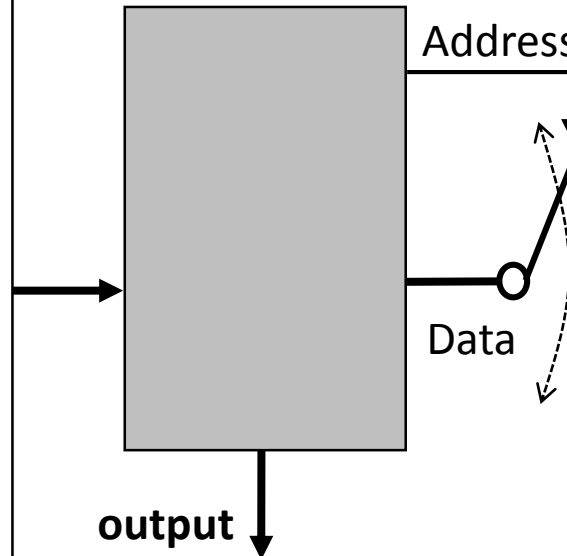


# Passed-by-Value

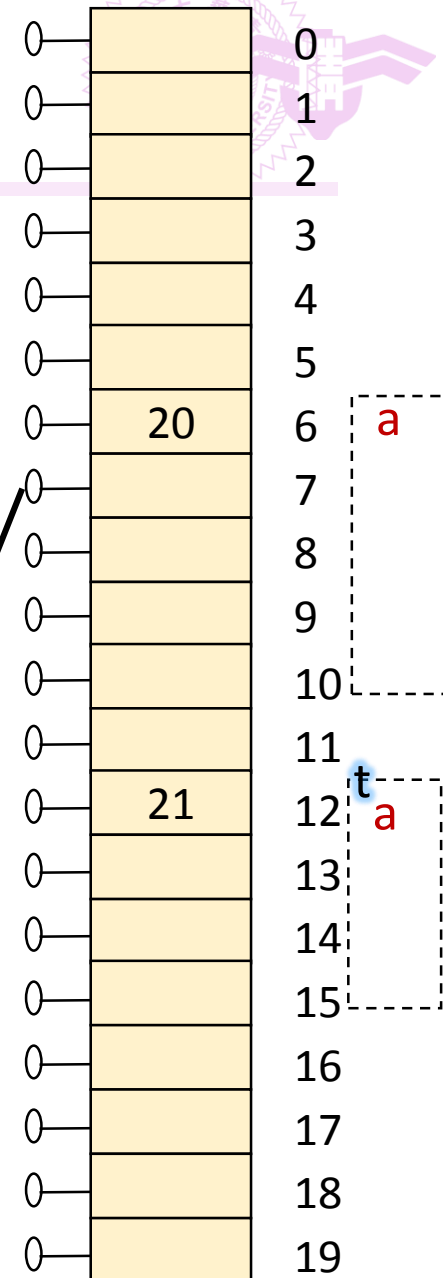
## Code

```
void t(int a);  
int main()  
{  
    int a = 20;  
    cout << a << endl;  
    t(a);  
    cout << a << endl;  
    return 0;  
}  
void t(int a)  
{  
    a = a+1;  
    cout << a << endl;  
    return;  
}
```

## Function Units



## Memory



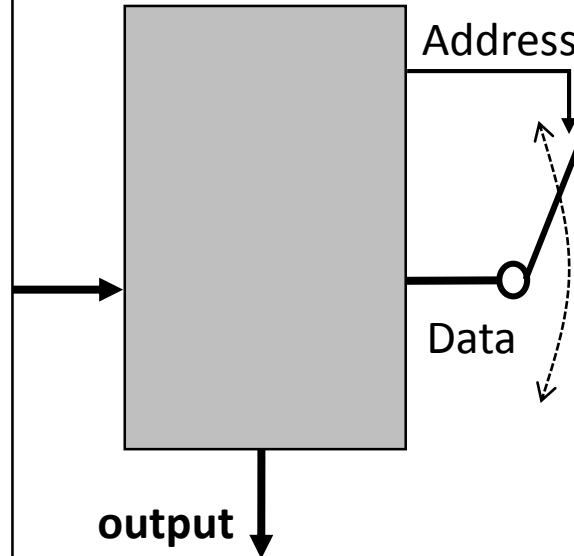
20  
21  
20

# Pointer

## Code

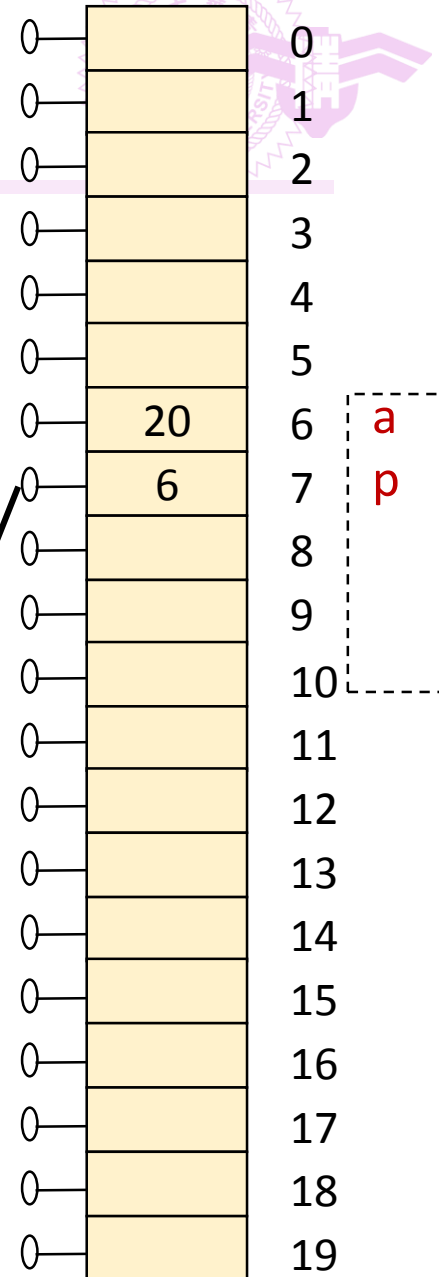
```
int main()
{
    int a = 20;
    int b;
    int * p = &a;
    cout << a << endl;
    cout << &a << endl;
    cout << p << endl;
    cout << &p << endl;
    cout << *p << endl;
    return 0;
}
```

## Function Units



20  
6  
6  
7  
20

## Memory

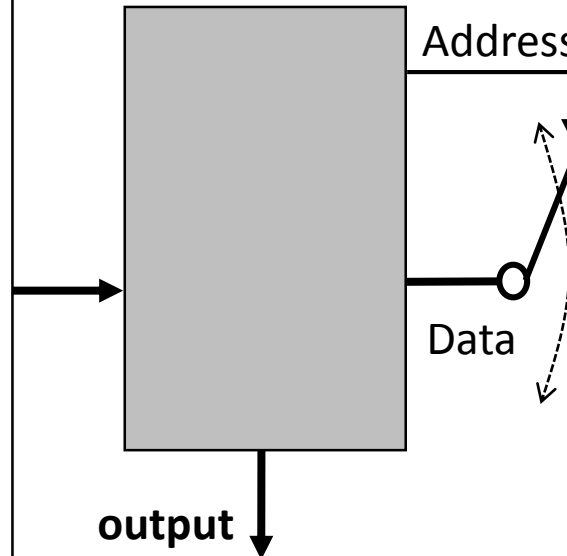


# Passed-by-Pointer

## Code

```
void t(int a);
int main()
{
    int a = 20;
    cout << &a << endl;
    t(&a);
    return 0;
}
void t(int * p)
{
    cout << p << endl;
    cout << &p << endl;
    cout << *p << endl;
    return;
}
```

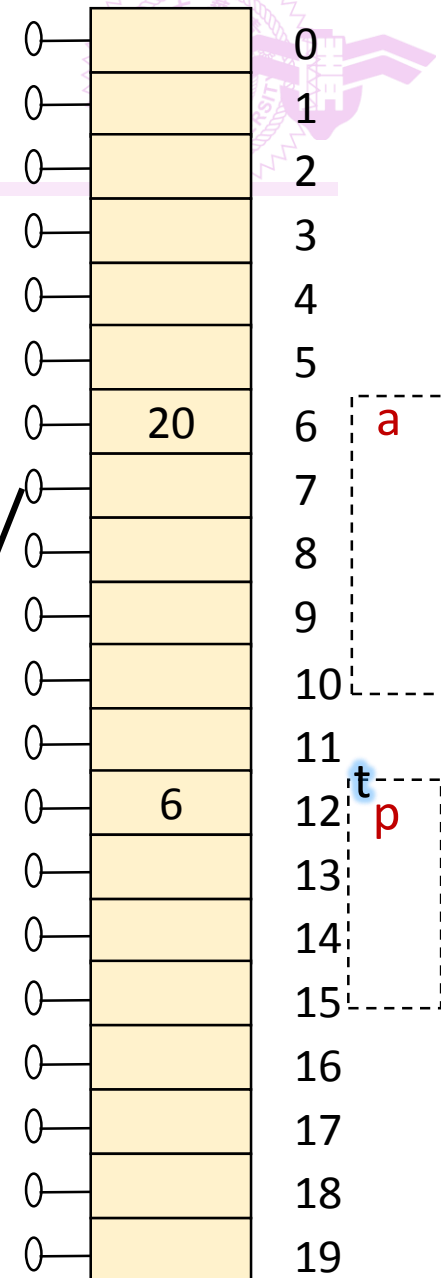
## Function Units



output

```
6
6
12
20
```

## Memory

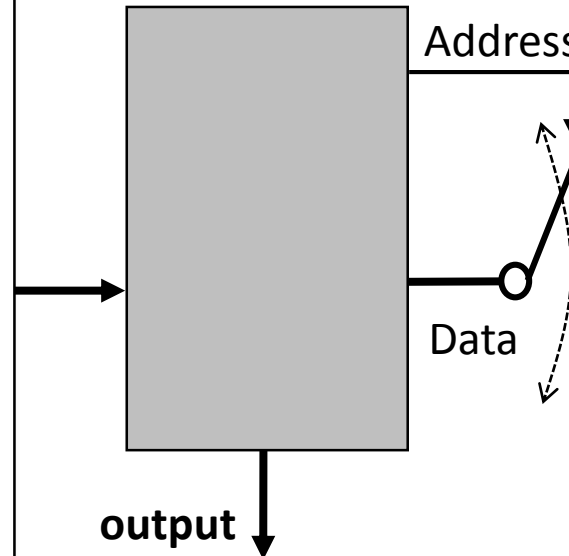


# Passed-by-Pointer

## Code

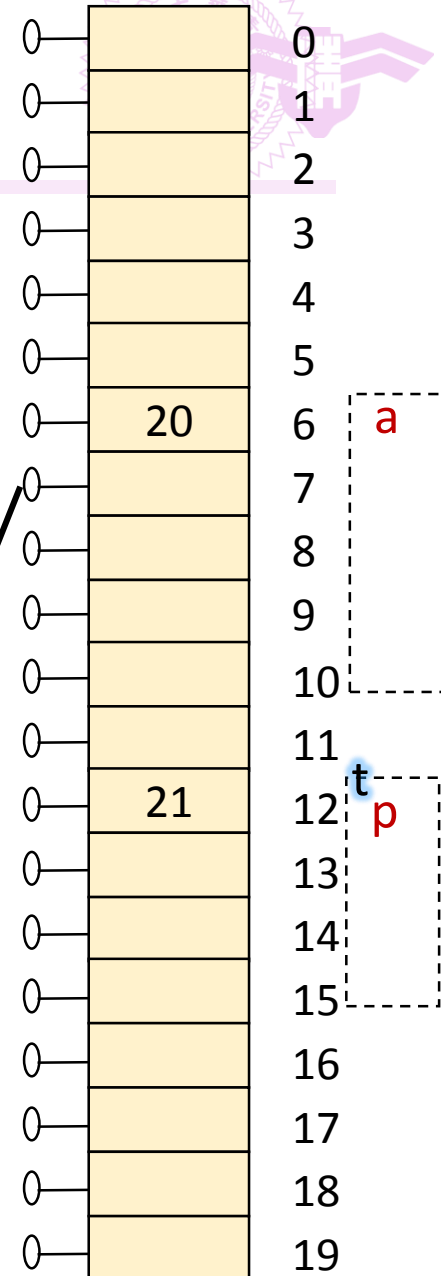
```
void t(int * p);
int main()
{
    int a = 20;
    cout << a << endl;
    t(&a);
    cout << a << endl;
    return 0;
}
void t(int * p)
{
    *p = *p+1;
    cout << *p << endl;
    return;
}
```

## Function Units



20  
21  
21

## Memory



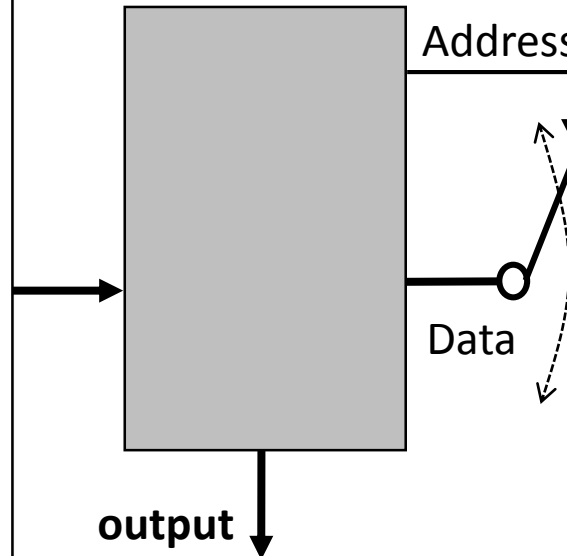


# Passed-by-Reference

## Code

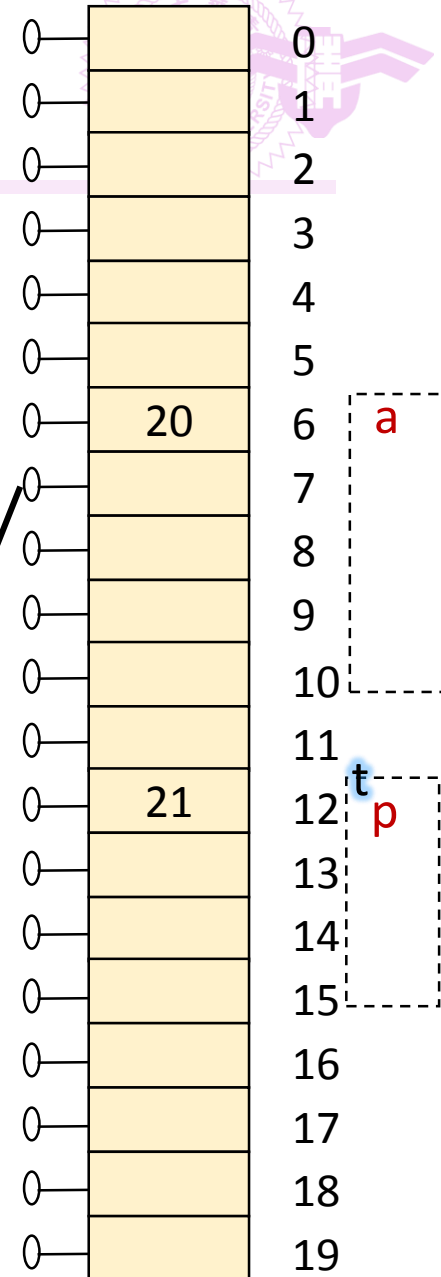
```
void t(int &r);  
int main()  
{  
    int a = 20;  
    cout << a << endl;  
    t(a);  
    cout << a << endl;  
    return 0;  
}  
void t(int &r)  
{  
    r = r+1;  
    cout << r << endl;  
    return;  
}
```

## Function Units



20  
21  
21

## Memory

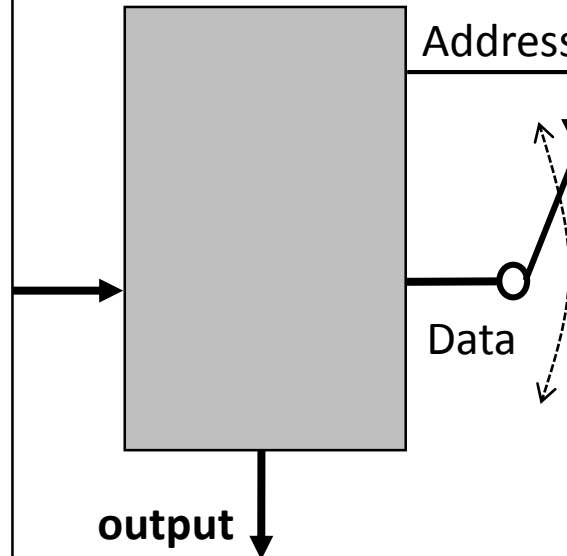


# Passed-by-Reference

## Code

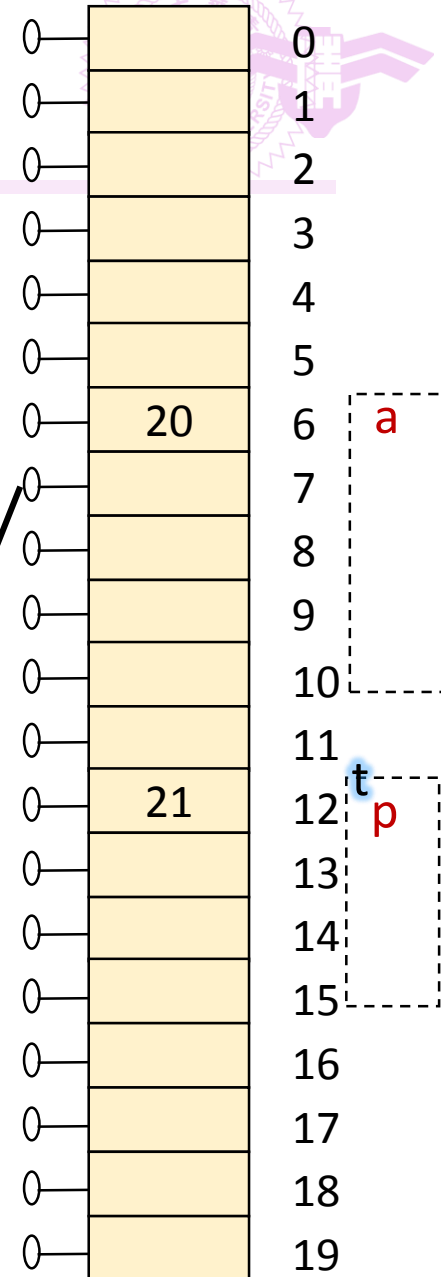
```
void t(int &a);  
int main()  
{  
    int a = 20;  
    cout << a << endl;  
    t(a);  
    cout << a << endl;  
    return 0;  
}  
void t(int &a)  
{  
    a = a+1;  
    cout << a << endl;  
    return;  
}
```

## Function Units



output  
20  
21  
21

## Memory



# Comments

- Two approaches
  - **Multiline** comments
    - `/*` comments
    - `*`  comments
    - `*`  comments
    - `*/`
    - Nested multiline comments is not supported
  - **Single line** comments (new features in C++)
    - `//` comments

```
#include <iostream>
using namespace std;
int main()
{
    int a = 0;
    /*
        /*
        a = 1;
        */
    a = 5;
    */
    cout << a << endl;
    return 0;
}
```

Compile error  
due to dangling  
\*/

```
#include <iostream>
using namespace std;
int main()
{
    int nest = /**/0*/*/1;
    cout << nest << endl;
    return 0;
}
```

No error but  
potentially a  
bug



# Input Output

- Include the system-defined header file *iostream*
- Use namespace *std*
  - Because *cin* and *cout* are in that namespace
- C++ I/O can be format-free

```
#include <iostream>
using namespace std;
int main()
{
    int a;
    float b;
    cout << "please enter a int and a float:"
         << endl;
    cin >> a >> b;
    cout << a << ", " << b << endl;
    return 0;
}
```

```
please enter a int and a float:
1 0.5
1, 0.5
```



# File Input Output

- Include the system-defined header file *fstream*

```
#include <iostream>
#include <fstream>
using namespace std;
int main()
{
    ofstream fout("my.txt");
    if(!fout) {
        // standard error device
        cerr << "cannot open my.txt" << endl;
        return 1;
    }
    int n = 50;
    float f = 20.3;
    fout << n << endl;
    fout << f << endl;

    return 0;
}
```



# File Input Output (cont'd)

```
#include <iostream>
#include <fstream>
using namespace std;
int main()
{
    ifstream fin("my.txt");
    if(!fin) {
        // standard error device
        cerr << "cannot open my.txt" << endl;
        return 1;
    }
    int n;
    float f;
    fin >> n >> f;

    cout << "n is " << n << endl;
    cout << "f is " << f << endl;
    return 0;
}
```

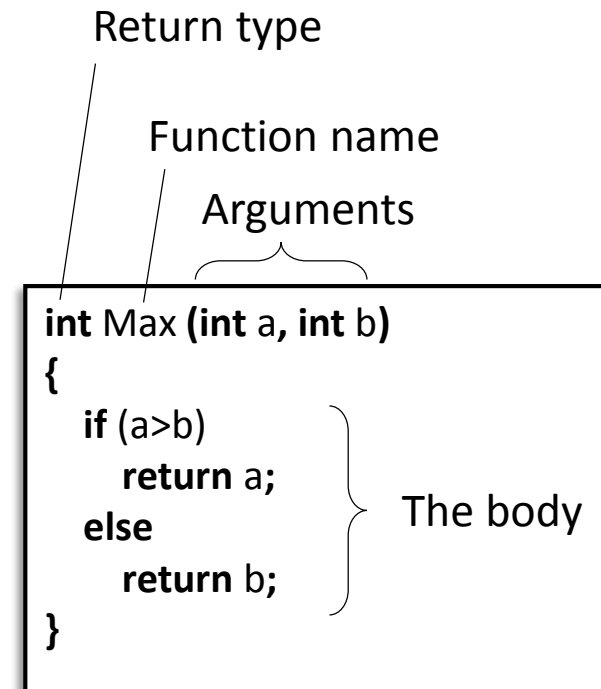
```
n is 50
f is 20.3
```

**Screen Output**



# Functions

- Two kinds
  - Regular functions
  - Member functions
    - Associated with specific C++ classes
- Function consists of
  - A function **name**
  - A list of **arguments** (aka **signature**)
    - We shall see why this list is called signature shortly
  - A **return type**
  - The **body**
    - Code that implements function





# Functions

- Return types
  - If a function is not meant to return anything
    - Use *void* to denote the return type
  - In C++, *main* function must return an *int*
- Common practices use *main* function's return value to indicate how a program exited
  - Zero means normal exit
  - Non-zero values are error codes that indicate abnormal termination

```
#include <iostream>
#include <fstream>
using namespace std;
int main()
{
    ifstream fin("my.txt");
    if(!fin) {
        // standard error device
        cerr << "cannot open my.txt" << endl;
        return 1;
    }
    int n;
    float f;
    fin >> n >> f;

    cout << "n is " << n << endl;
    cout << "f is " << f << endl;
    return 0;
}
```





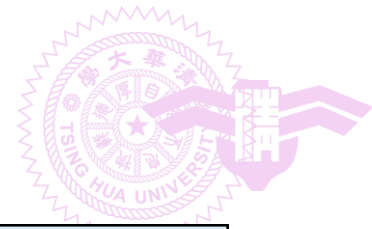
# Function Name Overloading

- C++ allows functions with
  - Same function name
  - Different input arguments (i.e., signatures)
- Example
  - a set of functions that finds the max value among arguments
- C++ compiler automatically performs **Name Mangling**
  - Add some **postfix** to the function name according to the **signature**
  - E.g, **Max\_i\_i\_i()**, **Max\_f\_f()**, **Max\_i\_i()**

```
int Max (int a, int b, int c)
{
}

int Max (float a, float b)
{
}

int Max (int a, int b)
{
    if (a>b)
        return a;
    else
        return b;
}
```



# Parameter Passing

- Three parameter-passing mechanism
  - Passed by value
  - Passed by pointer
  - Passed by reference
- Passed by **value**
  - Default mechanism (except for arrays)
  - An object is copied into functions local storage
  - Changing the values of such arguments do not affect the caller

A handy debugging trick

```
#include <iostream>
using namespace std;
#define PRINT(x) cout << #x " = " << x << endl;
void func1(int a, int *b, int &c, const int &d);
int main()
{
    int a=10, b=20, c=30, d=6;
    PRINT(a); PRINT(b); PRINT(c);
    func1(a, &b, c, d);
    PRINT(a); PRINT(b); PRINT(c);
    return 0;
}
void func1(int a, int *b, int &c, const int &d)
{
    a += d;
    *b += d;
    c += d;
    return;
}
```

By value

```
a = 10
b = 20
c = 30
a = 10
b = 26
c = 36
```

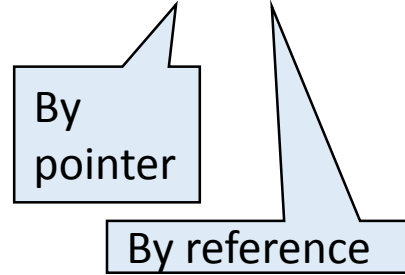
Screen Output



# Parameter Passing (cont'd)

- Passed by **pointer**
  - Efficient when a big object is passed
    - Copying the entire object can be slow
  - Function can change the object being passed
    - Caller clearly know this side effect
- Passed by **reference**
  - Almost the same as to pass-by-pointer in most cases
    - Efficiency
    - Allow side effects
  - Code is clearer 😊
  - Side effects are implicit ☹️

```
#include <iostream>
using namespace std;
#define PRINT(x) cout << #x " = " << x << endl;
void func1(int a, int *b, int &c, const int &d);
int main()
{
    int a=10, b=20, c=30, d=6;
    PRINT(a); PRINT(b); PRINT(c);
    func1(a, &b, c, d);
    PRINT(a); PRINT(b); PRINT(c);
    return 0;
}
void func1(int a, int *b, int &c, const int &d)
{
    a += d;
    *b += d;
    c += d;
    return;
}
```



```
a = 10
b = 20
c = 30
a = 10
b = 26
c = 36
```

Screen Output



# Parameter Passing (cont'd)

- Variant of passed-by-reference — Passed by **constant** reference
  - Resolve the side effect issues
  - Address are passed
  - Compiler enforces no changes can be made to the objects
- It is typically preferred to use
  - By reference
  - By constant reference
  - Except for passing tiny parameters
    - *char*
    - *bool*

```
#include <iostream>
using namespace std;
#define PRINT(x) cout << #x " = " << x << endl;
void func1(int a, int *b, int &c, const int &d);
int main()
{
    int a=10, b=20, c=30, d=6;
    PRINT(a); PRINT(b); PRINT(c);
    func1(a, &b, c, d);
    PRINT(a); PRINT(b); PRINT(c);
    return 0;
}
void func1(int a, int *b, int &c, const int &d)
{
    a += d;
    *b += d;
    c += d;
    return;
}
```

By **constant** reference

```
a = 10
b = 20
c = 30
a = 10
b = 26
c = 36
```

Screen Output