

CSC 347 - Concepts of Programming Languages

Safety

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Learning Objectives

- ❓ How do we make sure that we access memory correctly?
 - Understand memory access through pointers
 - Understand examples of unsafe behavior in C



Types in C

? What do you make of this program?

```
1 int main() {
2     int *p = (int*) malloc (sizeof(int));
3     *p = 2123456789;
4
5     printf("(float)*p = %f\n", (float)*p); /* loss of precision */
6     printf("*(float*)p = %f\n", *(float*)p); /* rubbish */
7
8     int i = 2;
9     char s[] = "three";
10
11     printf("i*s = %ld\n", i*(long)s);
12 }
```

```
1 $ clang -m32 typing-00.c && ./a.out
2 (float)*p = 2123456768.000000
3 *(float*)p = 96621069057346178268049192388430659584.000000
4 i*s = -1047484
```



Unsafe Memory Access

- Memory location contains data written at a given type (such as character array)
- The same memory location is read without permission or interpreted at an incompatible type (such as int)
- This is an *unsafe access*
- Scala prevents unsafe access by *throwing an exception*

```
1 val x : Int = "Hello".asInstanceOf[Int]
2 java.lang.ClassCastException: java.lang.String cannot be cast to java.lang.Integer
```



Array Bounds

? What do you make of the following program?

```
1 int main () {  
2     float f = 10;  
3     int a[] = { 10 };  
4     short i = 10;  
5  
6     printf ("f=%f, a[0]=%d i=%d\n", f, a[0], i);  
7     a[-1] = 2123456789; printf ("f=%f, a[0]=%d i=%d\n", f, a[0], i);  
8     a[1] = 2123456789; printf ("f=%f, a[0]=%d i=%d\n", f, a[0], i);  
9 }
```

```
1 $ clang -m32 typing-03.c && ./a.out  
2 f=10.000000, a[0]=10 i=10  
3 f=10.000000, a[0]=10 i=32401  
4 f=96621069057346178268049192388430659584.000000, a[0]=10 i=32401
```



Pointer Aliasing on the Stack

```
1 int main() {  
2     int x = 2123456789;  
3     double y = x;  
4     printf ("x=%d, y=%f\n", x, y);  
5     double *p = &x;  
6     double z = *p;  
7     printf ("x=%d, z=%f\n", x, z);  
8 }
```

```
1 $ gcc typing-06.c && ./a.out  
2 x=2123456789, y=2123456789.000000  
3 x=2123456789, z=38685644468023060038942720.000000
```



Pointer Aliasing on the Heap

```
1 int main() {  
2     int* ip = (int*) malloc (sizeof(int));  
3     *ip = 10;  
4     free(ip);  
5     float* fp = (float*) malloc (sizeof(float));  
6     *fp = 10;  
7     printf ("*fp=%f, *ip=%d\n", *fp, *ip);  
8     printf (" fp=%p,  ip=%p\n", fp, ip);  
9 }
```

```
1 $ gcc typing-07.c && ./a.out  
2 *fp=10.000000, *ip=1092616192  
3  fp=0x1063010,  ip=0x1063010
```



Function Pointers

```
1 void unsafeCommand () { printf ("ouch!\n"); }
2 void safeCommand ()   { printf ("hurray!\n"); }
3 int main () {
4     int diff = &unsafeCommand - &safeCommand;
5     void (*c) () = &safeCommand;
6     c();
7     c += diff;
8     c();
9 }
```

```
1 $ clang -m32 typing-04.c && ./a.out
2 hurray!
3 ouch!
```



Function Pointers with Arguments

```
1 void floatCommand (float f) { printf ("f=%f\n", f); }
2 void intCommand (int i)      { printf ("i=%d\n", i); }
3 int main () {
4     int diff = (void*)&intCommand - (void*)&floatCommand;
5     void (*c) (int) = &intCommand;
6     int j = 2123456789;
7     c(j);
8     c -= diff;
9     c(j);
10 }
```

```
1 $ clang -m32 typing-05.c && ./a.out
2 i=2123456789
3 f=96621069057346178268049192388430659584.000000
```

- C types are **difficult to read**, there are **tools** to help



Unsafer and Security

- Unsafer causes security problems



Safe Languages: Java and Scala

To be safe, Java and Scala do the following

- Disallow pointers into the stack
- Disallow pointer arithmetic
- Disallow explicit `free`
- Check array bounds
- Check type casts



Bounds Checking

Java

```
1 Object[] bs = new Object[4];  
2 Object b = bs[-1];
```

Scala

```
1 val bs = Array(1, 2, 3, 4)  
2 val b = bs[-1]
```

- Out-of-bounds access raises an exception

```
1 java.lang.ArrayIndexOutOfBoundsException: -1
```



Checked Casts

Java

```
1 class A { int x; }
2 class B extends A { float y; }
3 class C extends A { char c; }
4
5 static void f (B b) {
6     A a = b;          /* upcast always safe */
7 }
8
9 static void g (A a) {
10     B b = (B) a;      /* downcast must be checked */
11 }
12
13 f (new B());
14 g (new C());
```

Scala

```
1 class A(val x: Int)
2 class B(val y: Float) extends A(1)
3 class C(val c: Char) extends A(2)
4
5 /* upcast always safe */
6 def f (b: B) = { val a: A = b }
7 /* downcast must be checked */
8 def g (a: A) = { val b: B = a.asInstanceOf[B] }
9
10 f (new B(2.0))
11 g (new C('c'))
```

```
1 java.lang.ClassCastException: C cannot be cast to B
```

- Compare with [dynamic cast](#) in C++



Checked Array Assignment

Java

```
1 class A { int x; }
2 class B extends A { float y; }
3 class C extends A { char c; }
4
5 B[] bs = new B[1];
6 A[] as = bs;
7 as[0] = new C(); /* inconsistent write */
8 B b = bs[0];     /* reading always safe */
```

- Design flaw in Java: exception at runtime instead of compile error; more in a later lecture

```
1 java.lang.ArrayStoreException: C
```

Scala

```
1 class A(val x: Int)
2 class B(val y: Float) extends A(1)
3 class C(val c: Char) extends A(2)
4
5 val bs: Array[B] = new Array[B](1)
6 val as: Array[A] = bs /* compile error! */
7 as(0) = new C          /* inconsistent write */
8 b: B = bs(0)           /* reading always safe */
```

- Compile error: cannot assign `bs` to `as`



Summary

- Traditional systems languages are purposefully unsafe: Assembly, C, C++, Objective-C, C#-unmanaged, ...
- Recent application languages are meant to be safe: Java, Scheme, Javascript, Python, C#-managed, ...
- Recent systems languages attempt to isolate the unsafe bits: Rust, Go
- Even in safe languages, the overuse of dynamic checks allows program flaws to make it into production
- Overuse of `null` is considered [a billion dollar mistake](#)
- Which is better?
 - Security hole due to lack of null checks
 - Program crashes on null pointer reference