CS 4400
Computer Systems

LECTURE 9

Structs and alignment

Buffer overflow

Review: Structures

- In C, a user-defined type is accomplished with a `struct`.
- Example:

```
struct element {
        char name[10];
        char symbol[5];
        float weight;
        float mass;
};
```

- Declaration of a structure variable

```
struct element e1;
```

  – allocates contiguous storage for all structure members.

  – at least 10 + 5 + 2 * sizeof(float) bytes

Review: Structures

- Use typedef to avoid the awkward two-word type.

```
typedef struct element {
   char name[10];
   char symbol[5];
   float weight;
   float mass;
} ELT;

ELT e1;
```

- What is the difference in a structure and an array?

Review: Structures

```
ELT e1;
ELT* elt_ptr = &e1;
```

- To access a member of the structure variable, use the dot `.` operator.

```
e1.mass = 3.0;
strcpy(e1.name, “hydrogen”);
```

- As with objects in C++, the pointer operator `->` can be used with pointers to structures.

```
printf(“%s”, (*elt_ptr).symbol);
printf(“%s”, elt_ptr->symbol);
```

Review: Structures

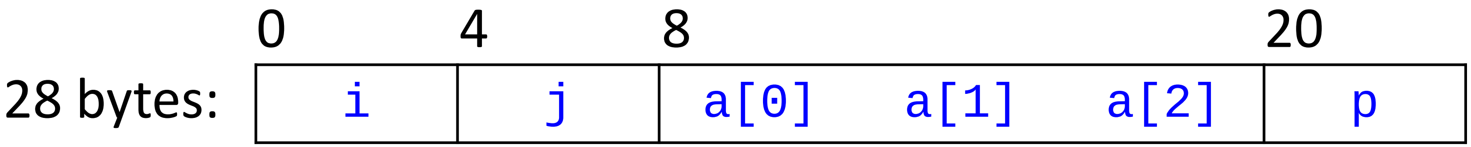
- A self-referential structure has a member that is a pointer of the same type as the structure itself.

```
typedef struct node {
   int data;
   struct node* next;
} NODE;
... x->next->next->data ...
```

Structs

- The compiler maintains information about each structure.
  - indicating byte offset of each field
- Example (IA32):

```
struct rec {
      int i;
      int j;
      int a[3];
      int* p;
};
```



0 4 8 20

28 bytes: i j a[0] a[1] a[2] p

- Generated code adds the appropriate offset.
  - suppose r (type struct rec *) is in %edx, to copy element r->i to element r->j:

```
movl (%edx),%eax
movl %eax,4(%edx)
```

Exercise: Structs

```
struct prob {
  int* p;
  struct {
    int x;
    int y;
  } s;
  struct prob* next;
};

void sp_init(struct prob* sp) {

  sp->s.x = _______________ ;

  sp->p = _________________ ;

  sp->next = ______________ ;
}
```

```
movl 8(%ebp),%eax
movl 8(%eax),%edx
movl %edx,4(%eax)
leal 4(%eax),%edx
movl %edx,(%eax)
movl %eax,12(%eax)
```

- Offset of each field?
- Total number of bytes?
- Fill in function, given assembly code for its body.

Question

What is the IA32 offset of field `f` in `struct d`?

A. 0
B. 4
C. 8
D. 12
E. 16
F. none of the above

```
struct a {
  int b;
  int c;
};

struct d {
  struct a* e;
  float f;
};
```

Unions

- Unions provide a way for a single object to be referenced according to multiple types.
- Example:

```
union u {
   char c;
   int i[2];
   double v;
} x;
x.v = 4.5;
printf(“%d %d\n”, x.i[0], x.i[1]);
```

- `sizeof(union u)` is the max size of any of its fields.
- Technically, you should only read the variant you wrote.

Unions

```
unsigned f2u(float f) {
  union {
    float f;
    unsigned u;
  } temp;
  temp.f = f;
  return temp.u;
}
```

```
movl 8(%ebp),%eax
```

- The byte offset of each field is 0.
- Example:

```
union rec {
        char c;
        int i[2];
        double v;
};    // 8 bytes
```

- Assembly code lacks any information about type.

Alignment

- Some systems restrict the addresses allowed for primitive types—they must be a multiple of k.
- Alignment restrictions simplify the interface between processor and memory.
  - avoids a 4-byte `int` straddling two 4-byte memory blocks

Alignment

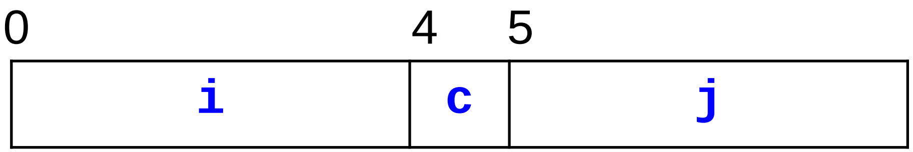
- Linux/IA32 alignment convention:
  - addresses of 1-byte data types are not restricted
  - addresses of 2-byte data types are multiples of 2
  - addresses of larger data types are multiples of 4

Struct Field Alignment

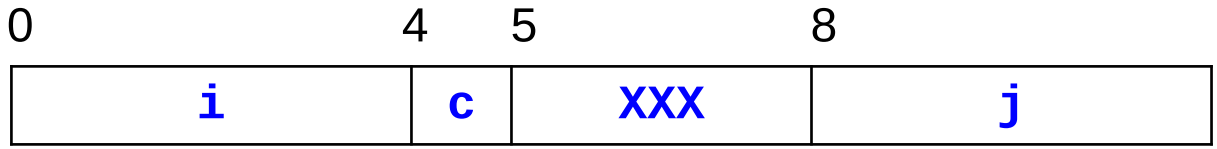
- The compiler may need to insert gaps in field allocation to ensure each structure element is aligned.
- Example:

```
struct S1 {
        int i;
        char c;
        int j;
};
```

- 9 bytes (unaligned):



- 12 bytes (aligned):



- Is a gap required if we make `char c` the third field?

Exercise: Struct Alignment

- Given the Linux/IA32 alignment policy, how is each structure aligned?

```
struct P1 { int i; char c; int j; char d; };

struct P2 { int i; char c; char d; int j };

struct P3 { short w[3]; char c[3]; }

struct P4 { short w[3]; char* c[3]; }

struct P5 { struct P1 a[2]; struct P2 *p };
```

Question

Given the Linux/IA32 alignment policy, what is the total number of bytes required for s?

A. 12
B. 16
C. 20
D. 24
E. 28
F. none of the above

```
struct {
  char a[3];
  short b;
  double c;
  char* d;
} s;
```

Question

If reordering of fields is allowed, is it possible to avoid padding at all in s?

```
struct {
  char a[3];
  short b;
  double c;
  char* d;
} s;
```

Packed Structs

- Many compilers support non-standard extensions for creating “packed” structs that contain no internal padding

- When and why is this useful? Harmful?

Packed Structs

- For gcc: `#pragma pack(n)`
  - Struct fields will be aligned to the minimum of their natural alignment and n
  - So, pack(1) creates structs with no padding
  - Use `#pragma pack()` to reset the compiler to normal padding behavior
  - Be careful: structs inside packed structs are not packed by default!

Out-of-Bounds Memory References

- C does no bounds checking for array references.
  - Do any programming languages perform bounds checking?

- Recall that the run-time stack is used to store local variables, as well as, register values and return address.
- What happens when an out-of-bounds element of a local array is written?
  - program “state” is potentially corrupted
  - examples?

Buffer Overflow

- A common source of state corruption.
- Typically: A char array is allocated to the stack, but a string is written which exceeds the allocated space.

```
char* gets(char* s) {
  int c; char* dest = s;
  while((c=getchar()) != '\n' && c != EOF)
    *dest++ = c;
  *dest = '\0';
  if(c == EOF)
    return NULL;
  return s;
}

void echo() {
  char buf[4];
  gets(buf);
  puts(buf);
}
```

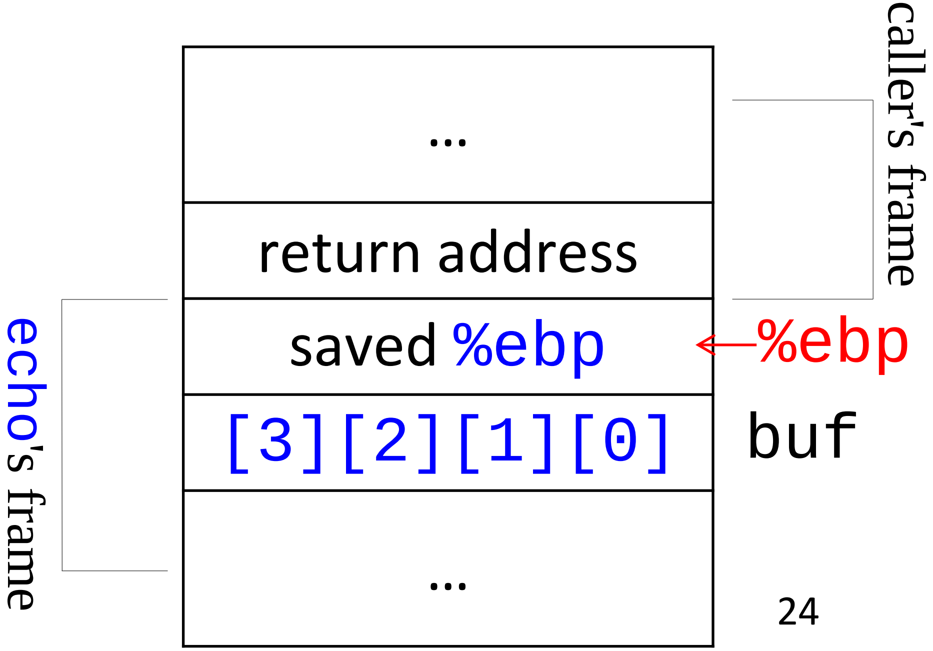
Any potential problems with `gets`?

Example: Buffer Overflow

```
void echo() {
  char buf[4];
  gets(buf);
  puts(buf);
}
```

```
echo:
  pushl %ebp              ;save to stack
  movl %esp,%ebp          ;set new fr_ptr
  subl $20,%esp           ;alloc space
  pushl %ebx              ;save to stack
  addl $-12,%esp          ;alloc more space
  leal -4(%ebp),%ebx      ;buf is %ebp-4
  pushl %ebx              ;push buf
  call gets
```

- What values of buf will corrupt the saved value of %ebp?
- What values will corrupt the return address?
- Alternative string-input functions: fgets(), gets_s(), getchar(), C++ I/O



Exploit Code

- When the byte encoding of executable code is fed into a program as an input string, buffer overflow can be used to get a program do something it otherwise would not.
  - Also include extra bytes to overwrite the return address with the address of this exploit code.
  - The effect of ret is to jump to (and execute) the exploit code.

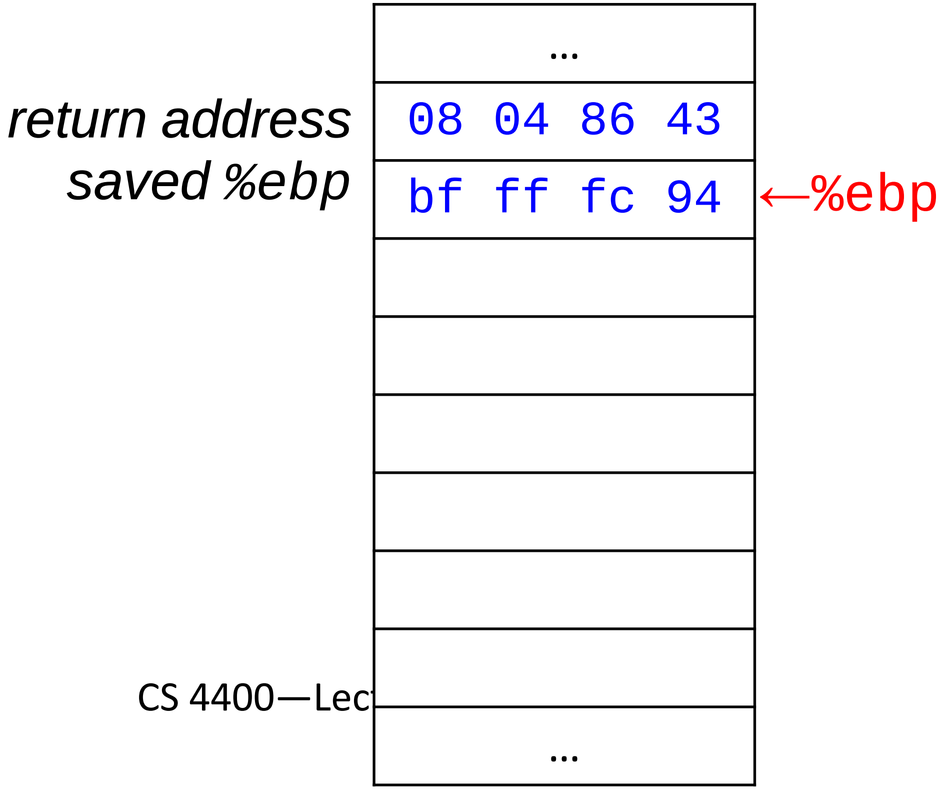
Exploit Code

- In Lab 3, you will get first-hand experience mounting a buffer-overflow attack.
  - Requires deep understanding of run-time stack organization, byte ordering, and instruction encoding.

Exercise: Buffer Overflow

```
char* getline() {
  char buf[8];
  char* result;
  gets(buf);
  result = malloc(strlen(buf)+1);
  strcpy(result, buf);
  return result;
}
```

```
Disassembly of getline:
push %ebp
mov %esp, %ebp
sub $16,%esp
push %esi
push %ebx
add $0xfffffff4,%esp
lea 0xfffffff8(%ebp),%ebx
push %ebx
... call gets …
```



…

return address 08 04 86 43

saved %ebp bf ff fc 94 ←%ebp

…

- If input is 012345678901,
  - program terminates with seg-fault.
  - Error occurs during return of getline.
  - Fill in stack just before add, and then after call to gets.
- To where does the program try to return?
- What registers have corrupted values?