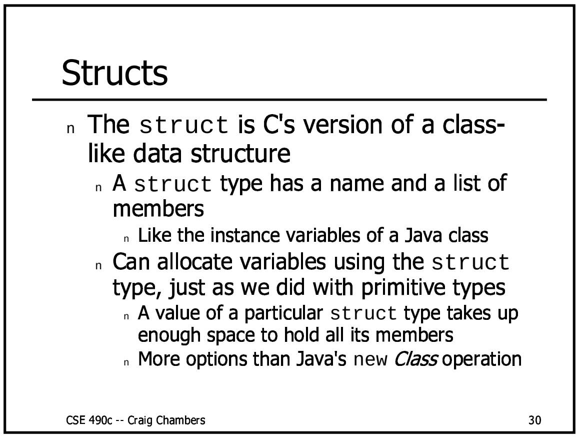
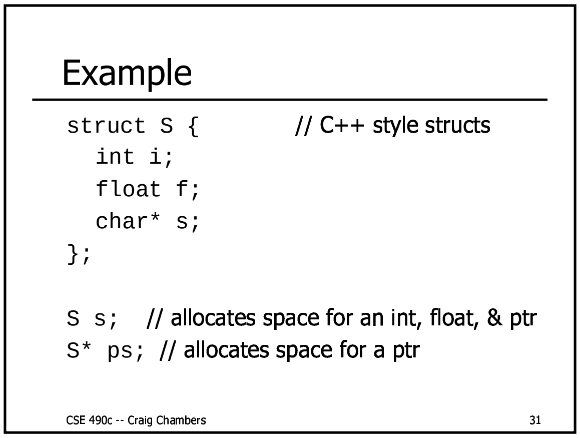


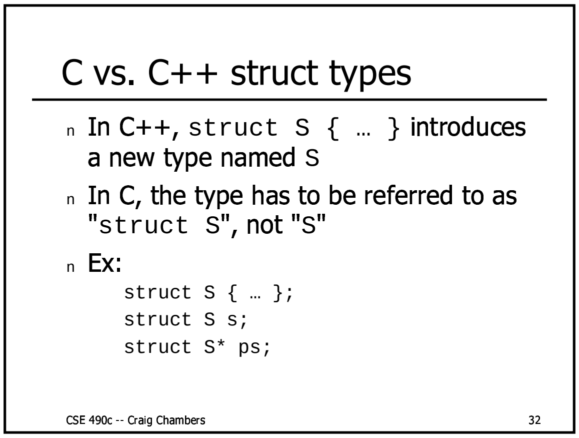
Structs

- The `struct` is C's version of a class-like data structure
  - A `struct` type has a name and a list of members
    - Like the instance variables of a Java class
  - Can allocate variables using the `struct` type, just as we did with primitive types
    - A value of a particular `struct` type takes up enough space to hold all its members
    - More options than Java's `new` *Class* operation



Example

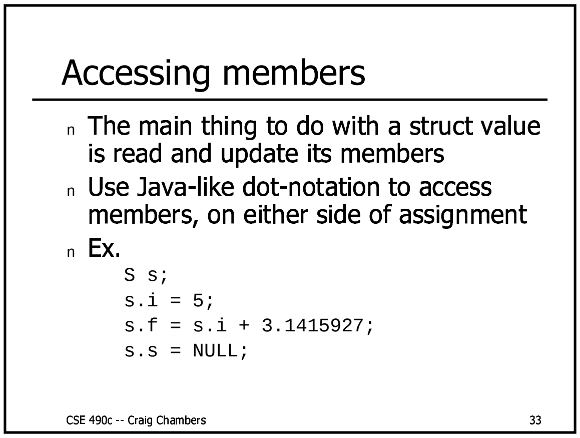
```
struct S {          // C++ style structs
  int i;
  float f;
  char* s;
};

S s;   // allocates space for an int, float, & ptr
S* ps; // allocates space for a ptr
```



C vs. C++ struct types

- In C++, `struct S { … }` introduces a new type named `S`
- In C, the type has to be referred to as "`struct S`", not "`S`"
- Ex:

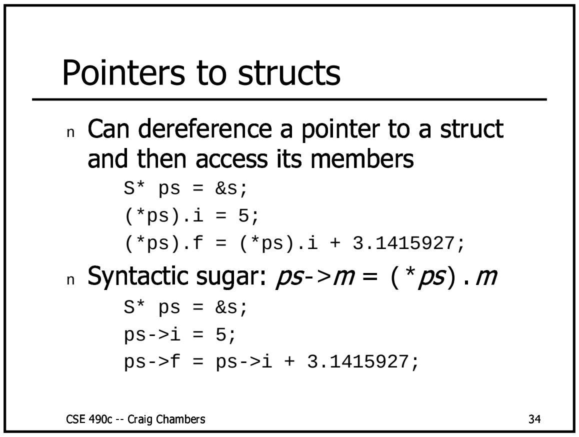
```
struct S { … };
struct S s;
struct S* ps;
```



Accessing members

- The main thing to do with a struct value is read and update its members
- Use Java-like dot-notation to access members, on either side of assignment
- Ex.

```
S s;
s.i = 5;
s.f = s.i + 3.1415927;
s.s = NULL;
```



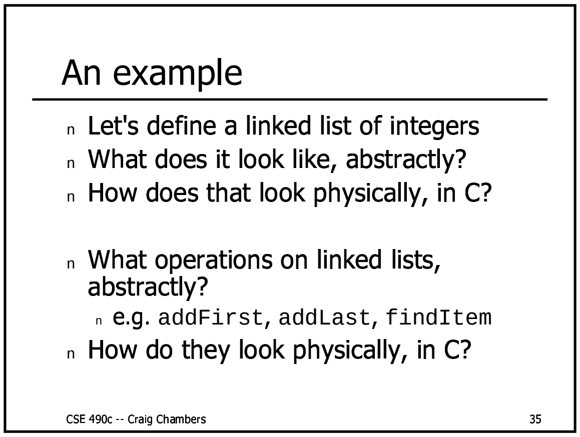
Pointers to structs

- Can dereference a pointer to a struct and then access its members

```
S* ps = &s;
(*ps).i = 5;
(*ps).f = (*ps).i + 3.1415927;
```

- Syntactic sugar: `ps->m` = `(*ps).m`

```
S* ps = &s;
ps->i = 5;
ps->f = ps->i + 3.1415927;
```



An example

- Let's define a linked list of integers
- What does it look like, abstractly?
- How does that look physically, in C?
- What operations on linked lists, abstractly?
  - e.g. `addFirst`, `addLast`, `findItem`
- How do they look physically, in C?

Data structure declarations

```
struct Link {
  int data;      // [why not int*?]
  Link* next;    // [why not Link?]
};

Link* emptyList = NULL;
```

An operation

```
Link* addFirst(Link* list, int data) {
  Link* newLink = new Link;
  // C: … = (Link*) malloc(sizeof(Link))
  newLink->data = data;
  newLink->next = list;
  return newLink;
}
```

Why not this?

```
Link* addFirst(Link* list, int data) {
  Link newLink;   // faster: no heap alloc!
  newLink.data = data;
  newLink.next = list;
  return &newLink;
}
```

Another operation

```
Link* addLast(Link* list, int data) {
  Link* lastLink = findLastLink(list);
  if (lastLink == NULL) {  // empty list
     return addBefore(list, data);
  } else {  // non-empty list
     addAfterLastLink(lastLink, data);
     return list;
  }
}
```

A helper

```
void addAfterLastLink(Link* lastLink,
                      int data) {
  Link* newLink = new Link;
  newLink->data = data;
  newLink->next = NULL;
  assert(lastLink->next == NULL);
  lastLink->next = newLink;
}
```

Another helper

```
Link* findLastLink(Link* list) {
  if (list == NULL) {  // empty list
     return NULL;
  } else if (list->next == NULL) {
     // last link
     return list;
  } else {
     return findLastLink(list->next);
  }
}
```

A non-recursive version

```
Link* findLastLink(Link* list) {
  if (list == NULL) {  // empty list
     return NULL;
  } else {
     while (list->next != NULL) {
        list = list->next;
     }
     return list;
  }
}
```

Another operation

```
Link* findItem(Link* list, int data) {
  if (list == NULL) {
     return NULL;  // NULL == not found
  } else if (list->data == data) {
     return list;  // found it
  } else {  // keep searching
     return findItem(list->next, data);
  }
}
```

A non-recursive version

```
Link* findItem(Link* list, int data) {
  for (;;) {
     if (list == NULL) {
        return NULL;  // NULL == not found
     } else if (list->data == data) {
        return list;   // found it
     } else {
        list = list->next; // keep searching
     }
  }
}
```

An improvement: list header

- Add an extra structure that points to the first and last `Links` in the list, for faster `addLast` behavior

```
struct List {
  Link* first;
  Link* last;
};
```

Revised operation

```
List* addLast(List* list, int data) {
  if (list == NULL) {  // empty list
     return addFirst(list, data);
  } else {  // non-empty list
     addAfterLastLink(list->last, data);
     list->last = list->last->next;
        // [why?]
     return list;
  }
}
```

Another revised operation

```
List* addFirst(List* list, int data) {
  Link* newLink = new Link;
  newLink->data = data;
  if (list == NULL) {  // create the list
     list = new List;
     list->first = NULL;
     list->last = newLink;
  }
  newLink->next = list->first;
  list->first = newLink;
  return list;
}
```

Doubly-linked lists

- Extend with a previous link

```
struct DLink {
    int data;
    DLink* prev;
    DLink* next;
};
```

- An exercise for the reader…
  - Lots of fun pointer surgery & splicing!

Multiple source files

- Bigger programs need to be broken up into multiple files
  - How does one file get access to things defined in other files?
- In Java:
  - User just writes `.java` source files
  - Compiler automatically looks in other `.class` files to see what they publicly export
- In C:
  - User needs to write both `.c` source files and `.h` *header files*

Header files

- Header files (redundantly) declare *public* functions and types that will be accessed by other *client* `.c` files
  - Anything not declared is implicitly private to the `.c` file
- Each `.c` file `#include`'s the `.h` files of the things it accesses
  - That way it sees the declarations of those things
- Anything not declared in `.h` files can't be accessed by other `.c` files (unless they cheat)

Example

- In `link.h`:

```
struct Link; // hide its body; allow Link* only
Link* addFirst(Link* list, int data);
                // no {…}! a prototype
… // other functions here
```

- In `link.c`:

```
#include "link.h"   // to verify consistency
… // full defs of struct Link, addFirst, etc.
```

- In `client.c`:

```
#include "link.h"   // access public decls
… // uses of Link*, calls of addFirst, etc.
```

Makefile dependencies

- `.c` files depend on the `.h` files they `#include`
- Add to `Makefile`

```
# standard dependency and action:
%.o: %.c
        gcc ${CFLAGS} –c $^
# additional dependencies:
link.o: link.h …
client.o: link.h …
```

- Have to keep these additional dependencies up-to-date as source files are edited…

makedepend

- `makedepend`: a tool to construct these extra dependencies automatically from the source files
  - `makedepend` *file*`.c`…
    - Adds/replaces extra dependences at end of existing `Makefile`
- Add a `depend` target to `Makefile`:

```
depend:
        makedepend ${SRCS}
```

- Also built into `gcc` as `gcc –MM` *file*`.c`…