CPSC 213

Introduction to Computer Systems

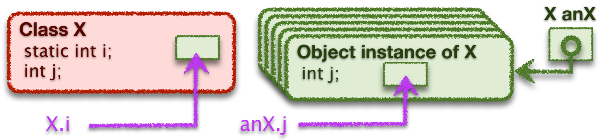
Unit 1c

Instance Variables and Dynamic Allocation

Reading For Next 3 Lectures

- Companion
  - 2.4.4-2.4.5
- Textbook
  - Structures, Dynamic Memory Allocation, Understanding Pointers
  - 2nd edition: 3.9.1, 9.9, 3.10
  - 1st edition: 3.9.1, 10.9, 3.11

Instance Variables



- Variables that are an instance of a class or struct
  - created dynamically
  - many instances of the same variable can co-exist
- Java vs C
  - Java: ***objects*** are instances of non-static variables of a ***class***
  - C: ***structs*** are named variable groups, instance is also called a struct
- Accessing an instance variable
  - requires a reference to a particular object (pointer to a struct)
  - then variable name chooses a variable in that object (struct)

Structs in C (S4-instance-var)

```
struct D {
  int e;
  int f;
};
```

≈

```
class D {
  public int e;
  public int f;
}
```

- A struct is a
  - collection of variables of arbitrary type, allocated and accessed together
- Declaration
  - similar to declaring a Java class without methods
  - name is “struct” plus name provided by programer
  - static `struct D d0;`
  - dynamic `struct D* d1;`
- Access
  - static `d0.e = d0.f;`
  - dynamic `d1->e = d1->f;`

Struct Allocation

```
struct D {
  int e;
  int f;
};
```

- Static structs are allocated by the compiler

`struct D d0;`

Static Memory Layout

```
0x1000: value of d0.e
0x1004: value of d0.f
```

- Dynamic structs are allocated at runtime
  - the variable that stores the struct pointer may be static or dynamic
  - the struct itself is allocated when the program calls **malloc**

`struct D* d1;`

Static Memory Layout

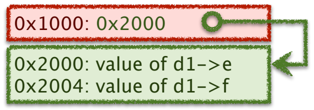
```
0x1000: value of d1
```

```
struct D {
  int e;
  int f;
};
```

- runtime allocation of dynamic struct

```
void foo () {
  d1 = (struct D*) malloc (sizeof(struct D));
}
```

- assume that this code allocates the struct at address 0x2000



Struct Access

```
struct D {
  int e;
  int f;
};
```

- Static and dynamic differ by an extra memory access
  - dynamic structs have dynamic address that must be read from memory
  - in both cases the offset to variable from base of struct is static

`d0.e = d0.f;`

```
m[0x1000] ← m[0x1004]
```

```
r[0]    ← 0x1000

r[1]    ← m[r[0]+4]
m[r[0]] ← r[1]
```

`d1->e = d1->f;`

```
m[m[0x1000]+0] ← m[m[0x1000]+4]
```

```
r[0]    ← 0x1000
r[1]    ← m[r[0]]
r[2]    ← m[r[1]+4]
m[r[1]] ← r[2]
```

load d1

```
struct D {
  int e;
  int f;
};
```

`d0.e = d0.f;`

```
r[0]    ← 0x1000

r[1]    ← m[r[0]+4]
m[r[0]] ← r[1]
```

```
ld $0x1000, r0  # r0 = address of d0
ld 4(r0), r1    # r0 = d0.f
st r1, (r0)     # d0.e = d0.f
```

`d1->e = d1->f;`

```
r[0]    ← 0x1000
r[1]    ← m[r[0]]
r[2]    ← m[r[1]+4]
m[r[1]] ← r[2]
```

load d1

```
ld $0x1000, r0  # r0 = address of d1
ld (r0), r1     # r1 = d1
ld 4(r1), r2    # r2 = d1->f
st r2, (r1)     # d1->e = d1->f
```

- The revised load/store base plus offset instructions
  - dynamic base address in a register plus a static offset (displacement)

```
ld 4(r1), r2
```

The Revised Load-Store ISA

- Machine format for base + offset
  - note that the offset will in our case always be a multiple of 4
  - also note that we only have a single instruction byte to store it
  - and so, we will store offset / 4 in the instruction
- The Revised ISA

Name	Semantics	Assembly	Machine
load immediate	r[d] ← v	ld $v, rd	0d-- vvvvvvvv
load base+offset	r[d] ← m[r[s]+(o=p*4)]	ld o(rs), rd	1psd
load indexed	r[d] ← m[r[s]+4*r[i]]	ld (rs,ri,4), rd	2sid
store base+offset	m[r[d]+(o=p*4)] ← r[s]	st rs, o(rd)	3spd
store indexed	m[r[d]+4*r[i]] ← r[s]	st rs, (rd,ri,4)	4sdi

Dynamic Allocation

Dynamic Allocation in C and Java

- Programs can allocate memory dynamically
  - allocation reserves a range of memory for a purpose
  - in Java, instances of classes are allocated by the **new** statement
  - in C, byte ranges are allocated by call to **malloc** procedure
- Wise management of memory requires deallocation
  - memory is a scare resource
  - deallocation frees previously allocated memory for later re-use
  - Java and C take different approaches to deallocation
- How is memory deallocated in Java?
- Deallocation in C
  - programs must explicitly deallocate memory by calling the **free** procedure
  - **free** frees the memory immediately, with no check to see if its still in use

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Considering Explicit Delete

- Lets look at this example

```
struct MBuf * receive () {
  struct MBuf* mBuf = (struct MBuf*) malloc (sizeof (struct MBuf));
  ...
  return mBuf;
}

void foo () {
  struct MBuf* mb = receive ();
  bar (mb);
  free (mb);
}
```

- is it safe to free mb where it is freed?
- what bad thing can happen?

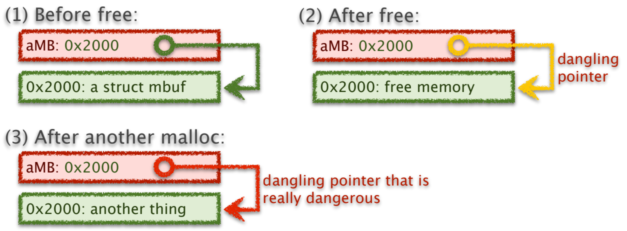
- Lets extend the example to see
  - what might happen in bar()
  - and why a subsequent call to bat() would expose a serious bug

```
struct MBuf * receive () {
  struct MBuf* mBuf = (struct MBuf*) malloc (sizeof (struct MBuf));
  ...
  return mBuf;
}

void foo () {
  struct MBuf* mb = receive ();
  bar (mb);
  free (mb);
}

void MBuf* aMB;

void bar (MBuf* mb) {
  aMB = mb;
}

void bat () {
  aMB->x = 0;
}
```

This statement writes to unallocated (or re-allocated) memory.

Dangling Pointers

- A dangling pointer is
  - a pointer to an object that has been freed
  - could point to unallocated memory or to another object
- Why they are a problem
  - program thinks its writing to object of type X, but isn’t
  - it may be writing to an object of type Y, consider this sequence of events



Avoiding Dangling Pointers in C

- Understand the problem
  - when allocation and free appear in different places in your code
  - for example, when a procedure returns a pointer to something it allocates
- Avoid the problem cases, if possible
  - restrict dynamic allocation/free to single procedure, if possible
  - don’t write procedures that return pointers, if possible
  - use local variables instead, where possible
    - we’ll see later that local variables are automatically allocated on call and freed on return
- Engineer for memory management, if necessary
  - define rules for which procedure is responsible for deallocation, if possible
  - implement explicit reference counting if multiple potential deallocators
  - define rules for which pointers can be stored in data structures
  - use coding conventions and documentation to ensure rules are followed

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Avoiding dynamic allocation

- If procedure returns value of dynamically allocated object
  - allocate that object in ***caller*** and pass pointer to it to ***callee***
  - good if caller can allocate on stack or can do both malloc / free itself

```
struct MBuf * receive () {
  struct MBuf* mBuf = (struct MBuf*) malloc (sizeof (struct MBuf));
  ...
  return mBuf;
}

void foo () {
  struct MBuf* mb = receive ();
  bar (mb);
  free (mb);
}
```

```
void receive (struct MBuf* mBuf) {
  ...
}

void foo () {
  struct MBuf mb;
  receive (&mb);
  bar (mb);
}
```

Reference Counting

- Use reference counting to track object use
  - any procedure that stores a reference increments the count
  - any procedure that discards a reference decrements the count
  - the object is freed when count goes to zero

```
struct MBuf* malloc_Mbuf () {
  struct MBuf* mb = (struct MBuf* mb) malloc (sizeof (struct MBuf));
  mb->ref_count = 1;
  return mb;
}

void keep_reference (struct MBuf* mb) {
  mb->ref_count ++;
}

void free_reference (struct MBuf* mb) {
  mb->ref_count --;
  if (mb->ref_count==0)
    free (mb);
}
```

- The example code then uses reference counting like this

```
struct MBuf * receive () {
  struct MBuf* mBuf = malloc_Mbuf ();
  ...
  return mBuf;
}

void foo () {
  struct MBuf* mb = receive ();
  bar (mb);
  free_reference (mb);
}

void MBuf* aMB = 0;

void bar (MBuf* mb) {
  if (aMB != 0)
    free_reference (aMB);
  aMB = mb;
  keep_reference (aMB);
}
```

Garbage Collection

- In Java objects are deallocated implicitly
  - the program never says free
  - the runtime system tracks every object reference
  - when an object is unreachable then it can be deallocated
  - a *garbage collector* runs periodically to deallocate unreachable objects
- Advantage compared to explicit delete
  - no dangling pointers

```
MBuf receive () {
  MBuf mBuf = new MBuf ();
  ...
  return mBuf;
}

void foo () {
  MBuf mb = receive ();
  bar (mb);
}
```

Discussion

- What are the advantages of C's explicit delete

- What are the advantages of Java's garbage collection

- Is it okay to ignore deallocation in Java programs?

Memory Management in Java

- Memory leak
  - occurs when the garbage collector fails to reclaim unneeded objects
  - memory is a scarce resource and wasting it can be a serous bug
  - its huge problem for long-running programs where the garbage accumulates
- How is it possible to create a memory leak in Java?
  - Java can only reclaim an object if it is unreachable
  - but, unreachability is only an approximation of whether an object is needed
  - an unneeded object in a hash table, for example, is never reclaimed
- The solution requires engineering
  - just as in C, you must plan for memory deallocation explicitly
  - unlike C, however, if you make a mistake, you can not create a dangling pointer
  - in Java you remove the references, Java reclaims the objects
- Further reading
  - http://java.sun.com/docs/books/performance/1st_edition/html/JPAppGC.fm.html

Ways to Avoid Unintended Retention

- imperative approach with *explicit reference annulling*
  - explicitly set references to NULL when referent is longer needed
  - add close() or free() methods to classes you create and call them explicitly
  - use try-finally block to ensure that these *clean-up* steps are always taken
  - ***these are imperative approaches; drawbacks?***
- declarative approach with *reference objects*
  - refer to objects without requiring their retention
  - store object references that the garbage collector can reclaim

```
WeakReference<Widget> weakRef = new WeakReference<Widget>(widget);
Widget widget                = weakRef.get() // may return NULL
```

  - different levels of reference stickiness

- soft	discarded only when new allocations put pressure on available memory
- weak	discarded on next GC cycle when no stronger reference exists
- phantom	unretrievable (get always returns NULL), used to register with GC reference queue

Using Reference Objects

- Creating a reclaimable reference
  - the Reference class is a template that be instantiated for any reference
  - store instances of this class instead of the original reference

```
void bar (MBuf mb) {
  aMB = new WeakReference<Mbuf>(mb);
}
```

  - allows the garbage collector to collect the MBuf even if aMB points to it
- This does not reclaim the weak reference itself
  - while the GC will reclaim the MBuf, it can't reclaim the WeakReference
  - the problem is that aMB stores a reference to WeakReference
  - not a big issue here, there is only one
  - but, what if we store a large collection of weak references?

Using Reference Queues

- The problem
  - reference objects will be stored in data structures
  - reclaiming them requires first removing them from these data structures
- The reference queue approach
  - a reference object can have an associated reference queue
  - the GC adds reference objects to the queue when it collects their referent
  - your code scans the queue periodically to update referring data structures

```
ReferenceQueue<MBuf> refQ = new ReferenceQueue<MBuf> ();

void bar (MBuf mb) {
  aMB = new WeakReference<Mbuf> (mb,refQ);
}

void removeGarbage () {
  while ((WeakReference<Mbuf> ref = refQ.poll()) != null)
    // remove ref from data structure where it is stored
    if (aMB==ref)
      aMB = null;
}
```