Threads

Java Threads

- A “thread” means computer code being executed.
- More than one thread can be executed virtually simultaneously (interleaved).
  - The code for the threads can be the **same**, or different.
  - Each thread has its own state, **sort of**.
  - Threads can **share variables**, and modify the variables they share.
- Programs with > 1 thread are called “concurrent programs”.
- With multiple “cores” (processors), threads can run physically simultaneously, in principle.

Multi-Processing

- e.g. Jaguar supercomputer at Oak Ridge National Lab:
  - 1,000,000,000,000,000 (1 quadrillion) floating-point operations per second (= 1 petaflop)
  - 182,000 AMD quad-core Opterons, running at 2.3 gigahertz
  - 362 terabytes of memory (with 578 terabytes per second of memory bandwidth)

Contrasts

	Jaguar SC	**Human Brain**
Capacity	1.69×10^{14} transistors among 728,000 processors + 362×10^{12} bits memory	100×10^{12} connections over 100×10^{9} neurons
Speed	2.3 GHz	1 kz

Timing of Threads

- Threads don't progress in lock-step fashion.
- One may be started and another stopped in an **unpredictable** fashion by the operating system.
- This behavior is called **asynchronous**.

Similar Idea: Processes

- A process is also code in execution.
- Typically processes don't share variables, although limited types of sharing are possible.
- Using multiple processes is common in, e.g. UNIX:

  generate | filter | test | display

- Processes are "heavy weight", threads are "light weight".
- "Weight" refers to the cost of switching the processor from one unit's state to another's.

Why are Threads Useful?

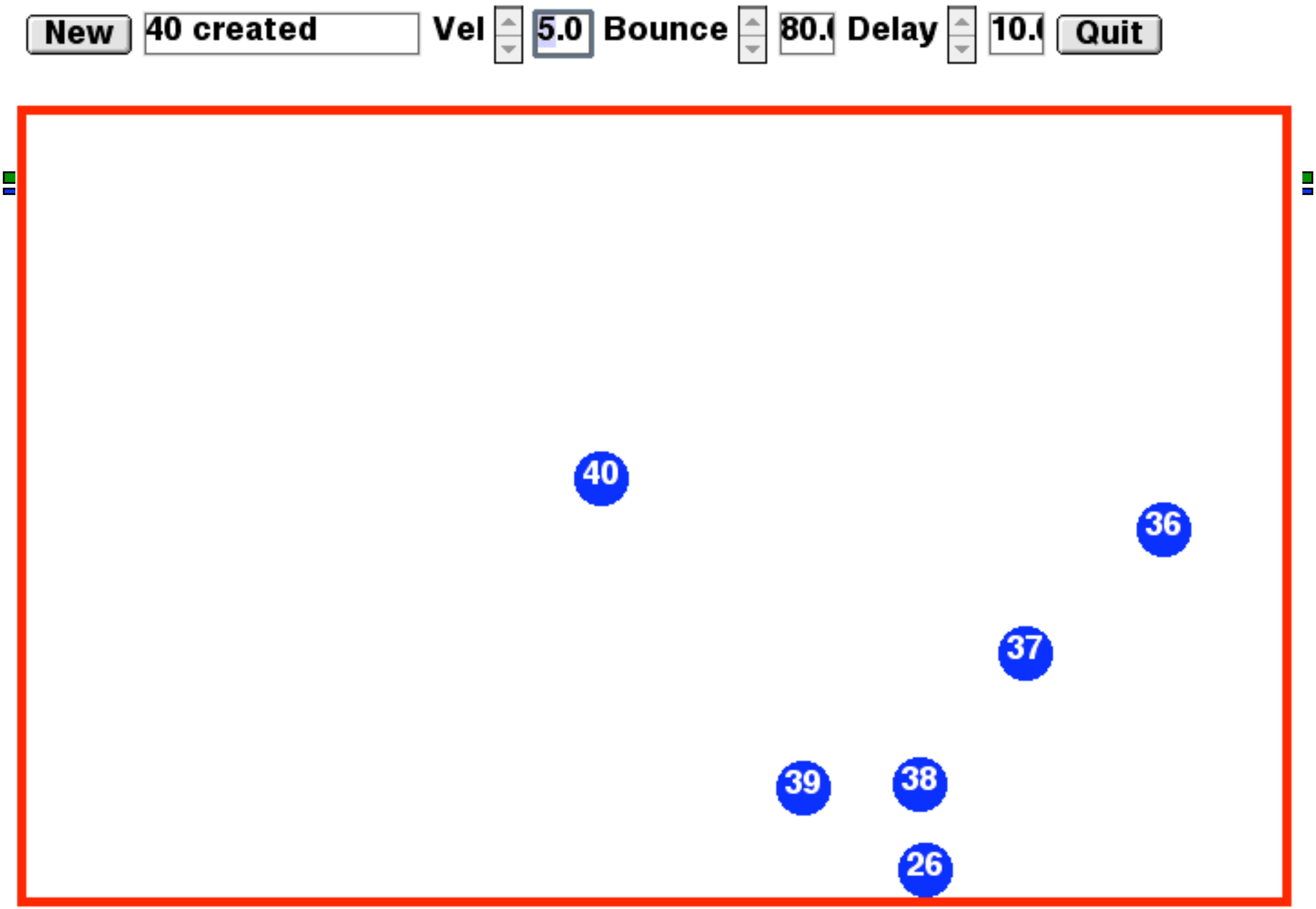
- May wish to have multiple activities going on at once.
- Don't want one activity's waiting (e.g. for an event) to stop the other activities.
- Example: On a user's desktop, there appear to be running simultaneously:
  - Several application programs:
    - A text editor
    - A browser, with several things going on
      - A couple of searches
      - An applet
      - A You-Tube video
- This is **only** doable on a 1-processor system with threads (or processes).

Thread Example

- On thread is a **computational** one, that occasionally needs to wait for input from the outside, say from an input stream of characters.
- Another thread may be a **graphical user interface**, responding to mouse events.
- We don't want **waiting** for input to hold up the graphics, or waiting for a click to hold up the computational thread.
- In fact, the click might tell the computational thread to alter its behavior.

Bouncing Balls Example

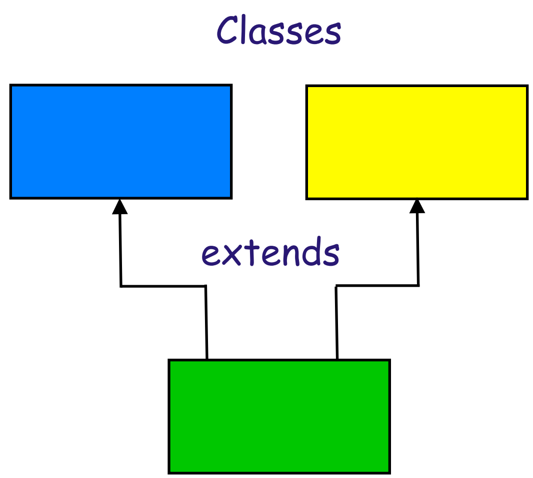
- Each ball is run by a separate thread.
- (This is for illustration. It is likely not the way you'd do a video game, because you want more precise control over timing and interactions.)
- Each thread can, in principal, be **interrupted** and re-started independently of the others.
- If a ball is "clicked" in mid-air, it will suspend, and resume if clicked a second time.


New
40 created
Vel
5.0
Bounce
80.(
Delay
10.(
Quit
40
36
37
39
38
26

Two Ways to Have Threads in Java

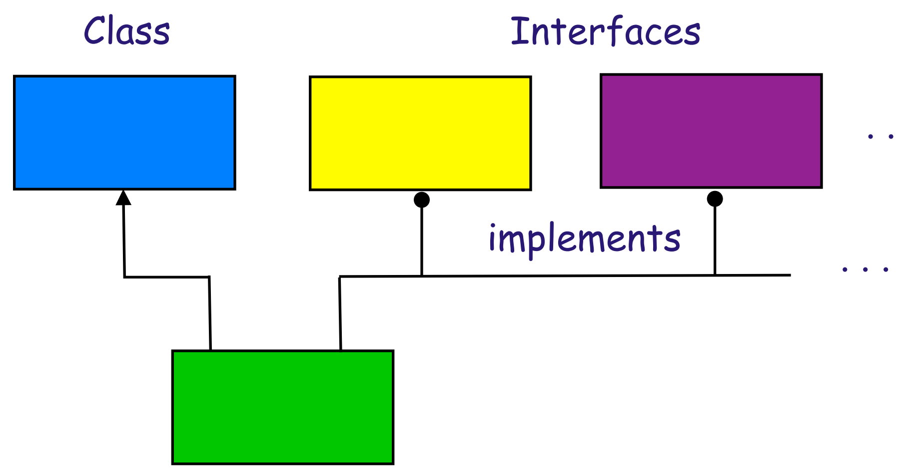
- extends Thread
  - Thread is a *base class* with threading capability.
- implements Runnable
  - Runnable is an *interface* that requires method
    - void run()
- **The latter is preferred**, because it does not take away the ability to inherit from another class (multiple inheritance is not allowed in Java).

Interface vs. Inheritance



Not legal in Java.

Legal in C++.



Legal in Java.

C++ has no concept of Interface.
Interface is an idiomatic use of inheritance.

Using “implements Runnable“

- The class that *implements* Runnable *still* needs to *contain* a Thread.
- This Thread is what controls starting and stopping.

Ball "extends Thread" Code

```
/**
 * Ball class represents ball's state information
 */

class Ball extends Thread // vs. Thread implements Runnable
  {
  double x, y;                              // this ball's coordinates
  double deltaX, deltaY;                    // this ball' velocities
  String myNumber;                          // ball's number as a string

  public Ball(...) // constructor {}

  /**
   * over-ride run() method in parent class (Thread)
   */

  public void run()
    {
    while( true )
      {
      move();                               // move the ball
      sleep(app.delay);                     // sleep (defined in Thread)
      }
    }
```

Ball “implements Runnable” Code

```
class Ball implements Runnable
{
Thread myThread;            // this ball's thread
double x, y;                // this ball's coordinates
double deltaX, deltaY;      // this ball' velocities
String myNumber;            // ball's number as a string

Ball(x, y, number)          // constructor
  {
  ...
  myThread = new Thread(this);     // make thread for Ball
  }

public void run()                  // run method for this Runnable
    {
    while( true )
      {
      move();                      // move the ball
      myThread.sleep(app.delay);   // sleep
      }
    }
...
}
```

Cautions about Threads

- Reasoning about concurrent programs is inherently more difficult than reasoning about sequential ones.
- They can exhibit **non-deterministic** behavior, when variables are shared among threads.

Non-Determinism

Suppose x == 1 initially.

Thread 1

x = x+2;

What is x now?

Thread 2

x = x*5;

Language Aspects

- Prior to Java, many languages did not have threads as part of the language.
- Those that did were mostly research vehicles.
- Some had add-on libraries for threads (such as pthreads or Posix-threads).
- Java is the most widely-used example where threads are integral to the language.
- The JVM (Java Virtual Machine) is the interpreter for Java's byte-code. It runs the threads.

Interesting Methods of Thread

`public void start()`

Causes this thread to begin execution;
The JVM calls the run method of this thread.

The result is that *two threads are running concurrently*:

the initiating thread (which returns from the call to the start method) and

the initiated thread (which executes its run method).

Throws:
IllegalThreadStateException - if the thread was already started.

Methods of Thread

```
public static Thread currentThread()
```

Returns a reference to the currently executing thread object.

Note: "executing" is more specific than "running":

"executing" means "has the processor"

"running" means "able to execute",
but not necessarily executing

Methods of Thread

```
public static void yield()
```

Causes the currently executing thread object to pause temporarily and allow other threads to execute.

Methods of Thread

```
public static void sleep(long millis)
                       throws InterruptedException
```

Causes the currently executing thread to sleep
(temporarily stop execution)
for the specified number of milliseconds.

Methods of Thread

`public void interrupt()`

Interrupts this thread.

Called by another thread having a reference to this one.

First the checkAccess method of this thread is invoked, which may cause a SecurityException to be thrown.

Methods of Thread

`public final void setPriority(int newPriority)`

Changes the priority of this thread.

First the checkAccess method of this thread is called with no arguments. This may result in throwing a SecurityException.

Otherwise, the priority of this thread is set to the smaller of the specified newPriority and the maximum permitted priority of the thread's thread group.

Methods of Thread

```
public final void join(long millis)
                  throws InterruptedException
```

Waits at most millis milliseconds for this thread to die.
A timeout of 0 means to wait forever.

Runnable

java.lang

Interface Runnable

Known Implementing Classes:

Thread, TimerTask

The Runnable interface should be implemented by any class whose instances are intended to be executed by a thread. The class must define a method of no arguments called run.

This interface is designed to provide a common protocol for objects that wish to execute code while they are active. For example, Runnable is implemented by class Thread.
Being active simply means that a thread has been started and has not yet been stopped.

In addition, Runnable provides the means for a class to be active while not subclassing Thread.
A class that implements Runnable can run without subclassing Thread by instantiating a Thread instance and passing itself in as the target.

In most cases, the Runnable interface should be used
if you are only planning to override the run() method and no other Thread methods.
This is important because classes should not be subclassed unless the programmer intends on modifying or enhancing the fundamental behavior of the class.

re. Applets

- As you have seen, applets implement Runnable.
- This is in part so the applet can carry out two activities **concurrently**:
  - The main activity or activities of the applet
  - The event-listening activities that deal with user events such as pushing a button, etc.
  - The latter call user-supplied methods, known as **listeners** or **call-backs**, enabling communication with the main activity through common variables.

Memory Allocation and Recycling

O(1) Addressing

- (Assume no "paging" nor "caching" for now).
- Linear Address Space:
  Memory is effectively like a big array.
- Each word is accessible in the same amount of time.
  - A **decoder tree** in logic permits this.
  - The time bound for decoding is actually O(log n).
  - However, the clock interval is designed to be long enough so that it **practically** is O(1).

How Memory is Used

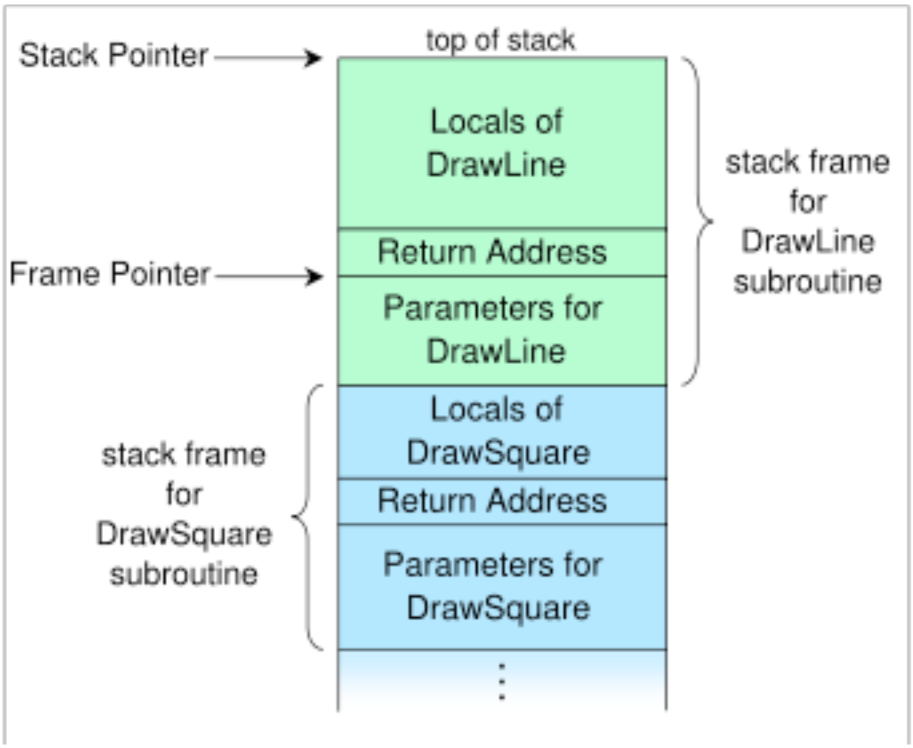
- Code
- Static variables:
  remain allocated throughout execution
- "Automatic" variables:
  e.g. arguments and local variables
  of nested functions
  These **cease to exist** after the
  function returns.
- Dynamic variables:
  instance variables of objects created
  during execution

Why "Automatic"?

- Automatic is not strictly necessary; dynamic could be used for it.
- However, due to **nested** calling discipline, reclamation of automatic is cheaper than dynamic in general.

Stack-Based Allocation

Low-overhead, but confining



From http://en.wikipedia.org/wiki/Call_stack

Heap-Based Allocation

More flexibility, but more overhead

Heap:

Space overheads:

Each block stores a size.

Free blocks also store a pointer to the “next” free block.

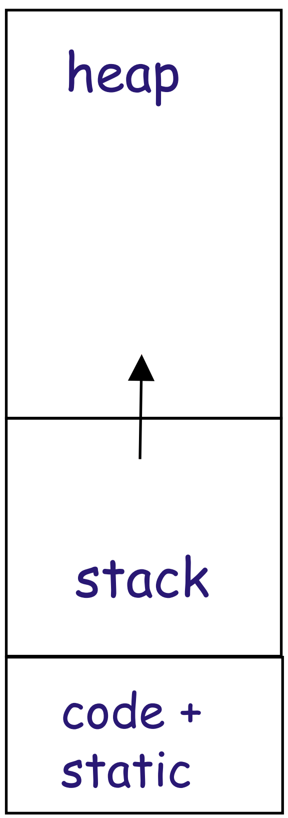
Time overheads:

Must *search* for an adequate free block.

Must *sub-divide* free blocks that are bigger than requirement.

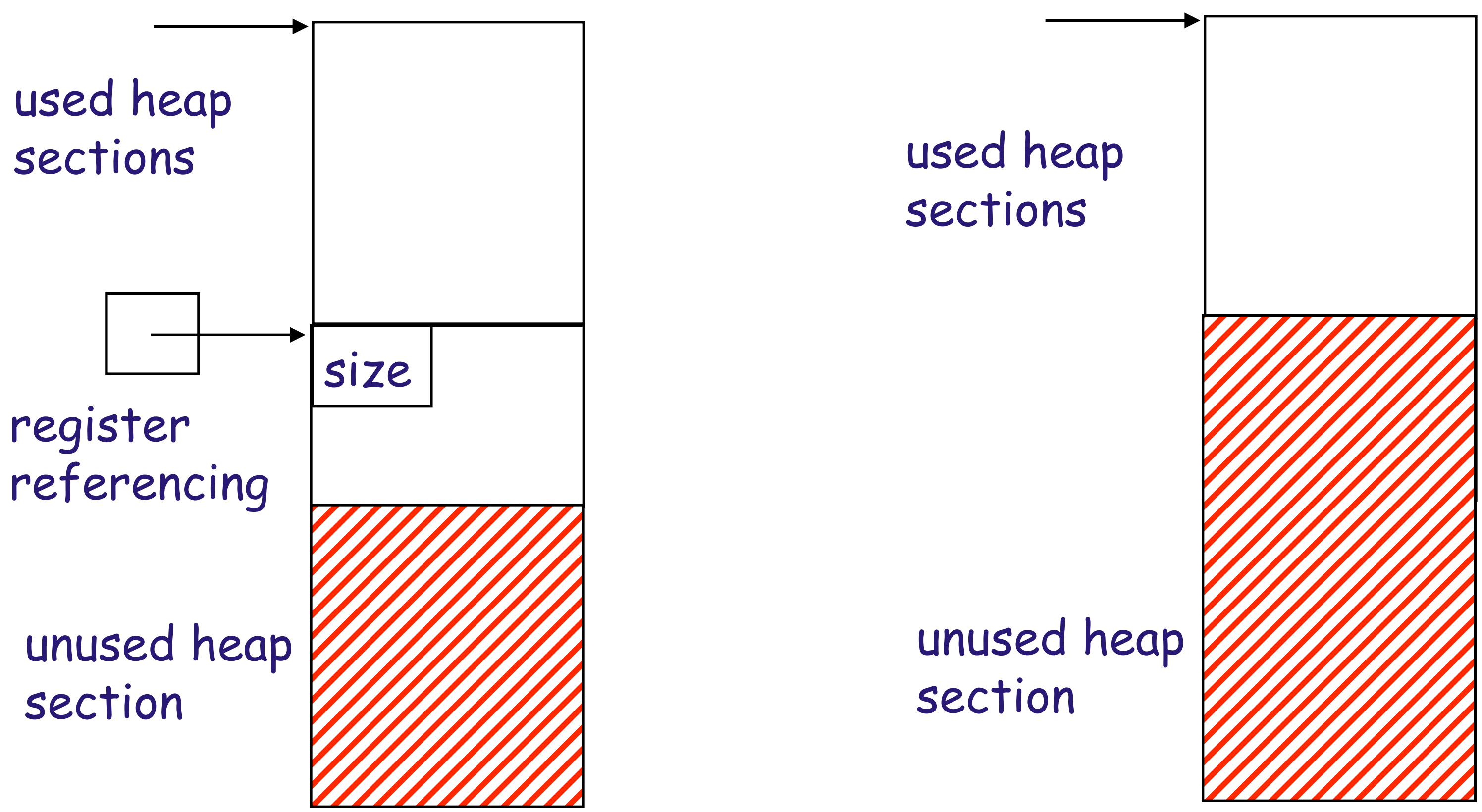
Must coalesce blocks as they become freed.

Memory is Pre-Divided

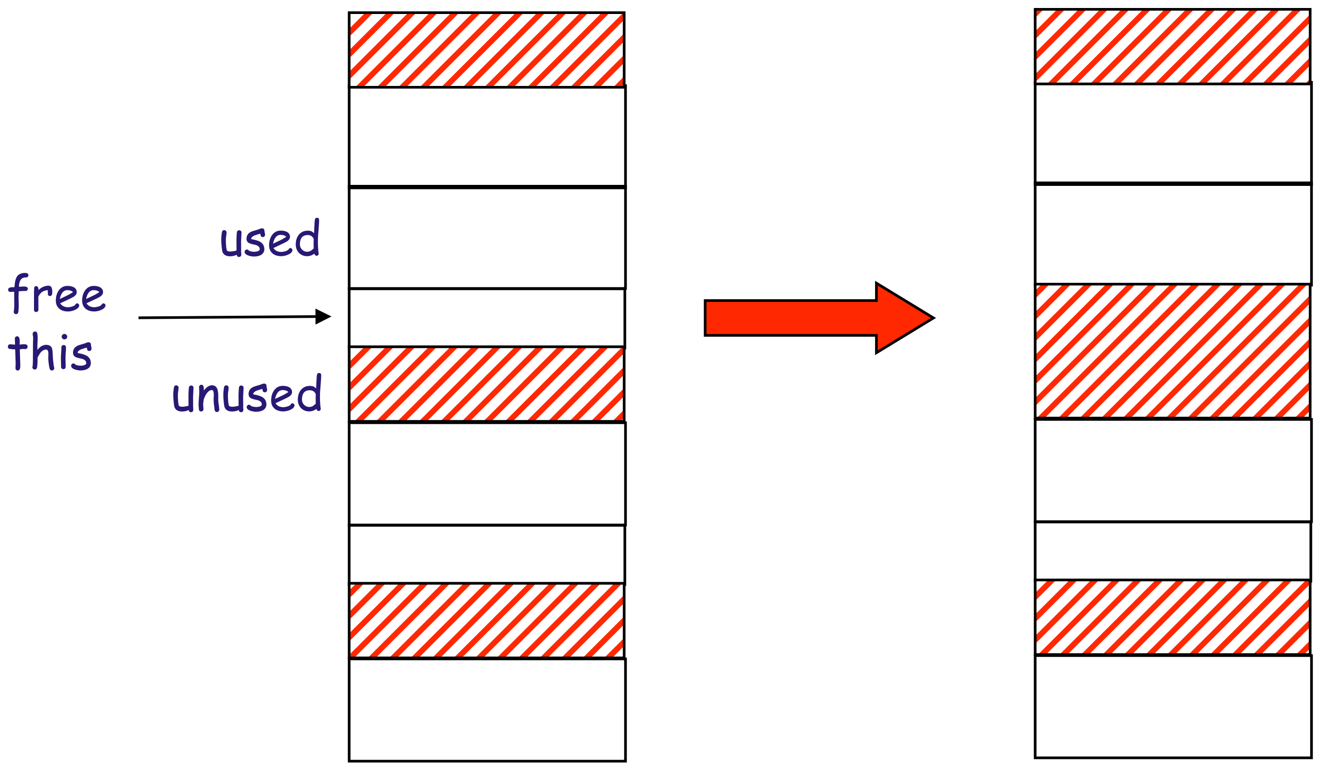


stack growth direction

The Recycling Aspect



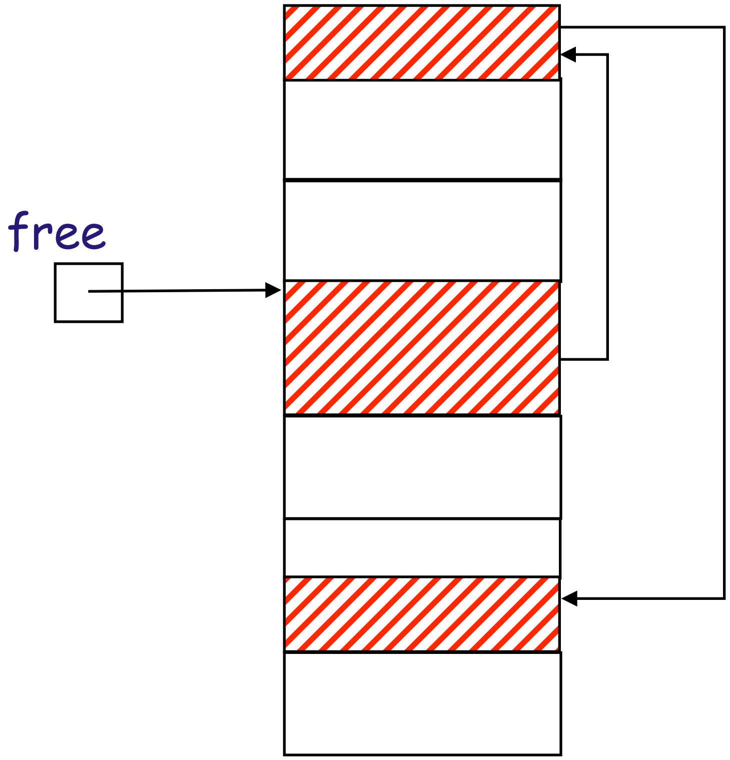
The Bigger Picture



There are never **adjacent** unused blocks.
They are always coalesced into one. (Why?)

Maintaining the "Free List"

Each unused block also has a size field.



Heap Issues

- Fragmentation (“checkerboarding”)
  - Why is this an issue?
- Allocation Policy:
  - First-fit
  - Best-fit
  - . . .

Approaches to Recycling Heap Memory

- Don't-do-it approach
- Programmatic approach
- Automatic approaches
  - Reference-Counting
  - Garbage collection
    - Mark-Sweep
    - Copying
    - Generational
    - others

Reference Counting

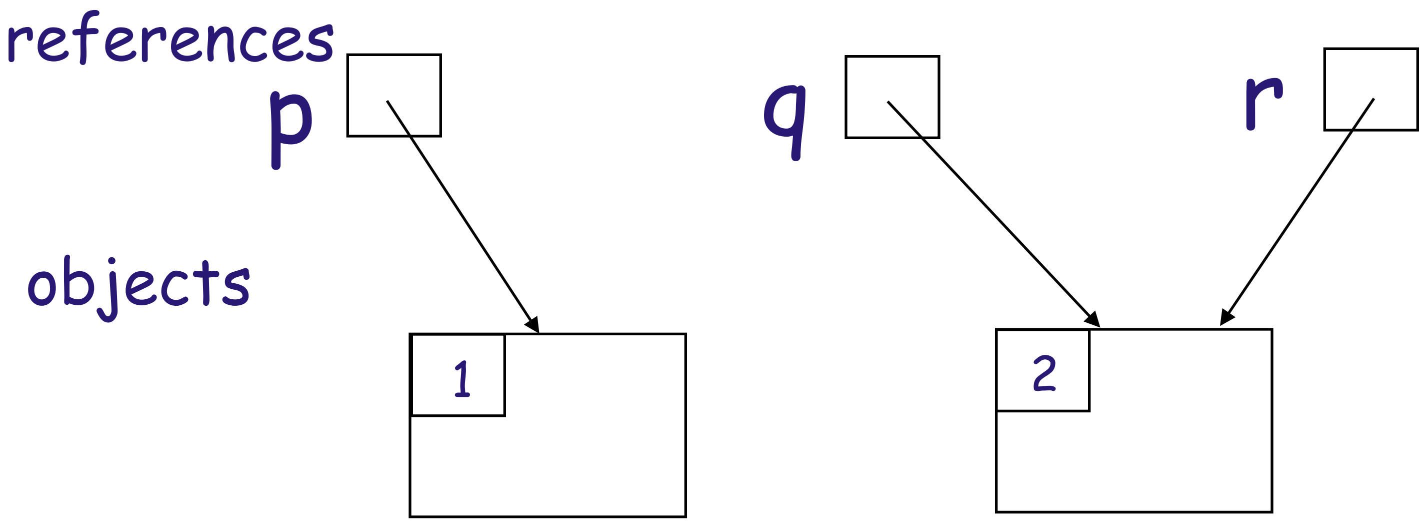
- Each object has an invisible reference count.

- An **invariant** is maintained:

  Reference count =

  # of references pointing to this object

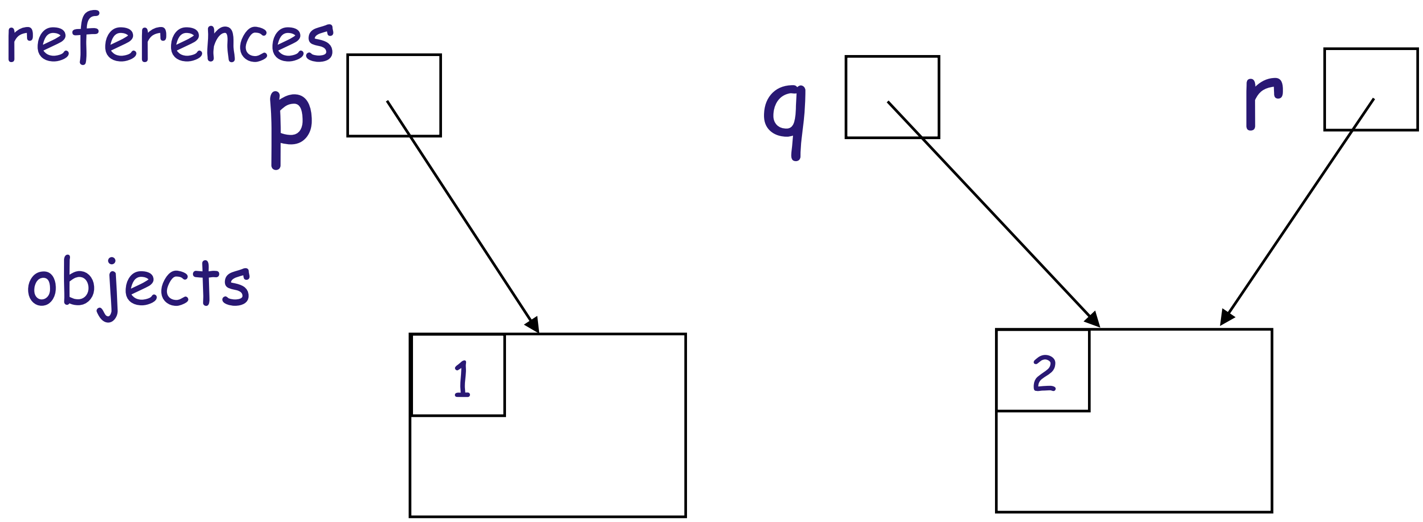
Reference Counting



What happens when we execute:

q = p;

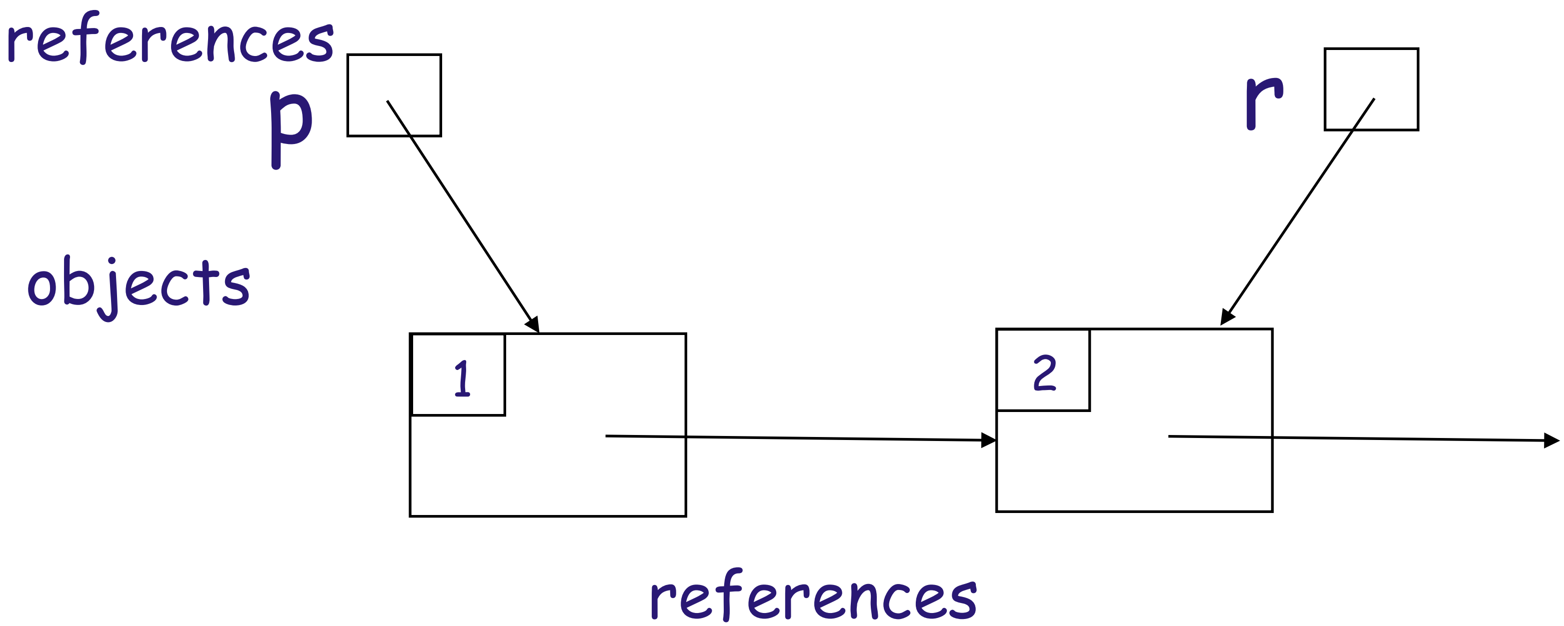
Reference Counting



What happens when we execute:

p = q;

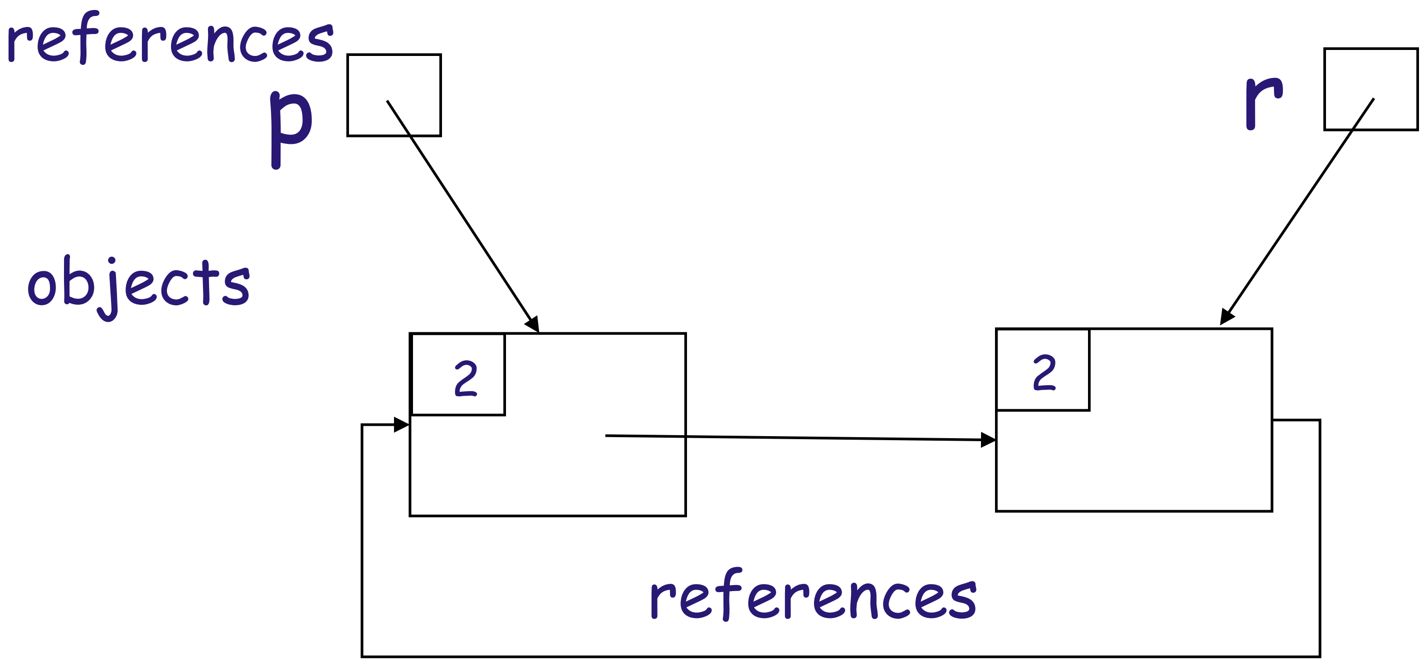
Linked List



What happens when we execute:

```
p = p.next;
```

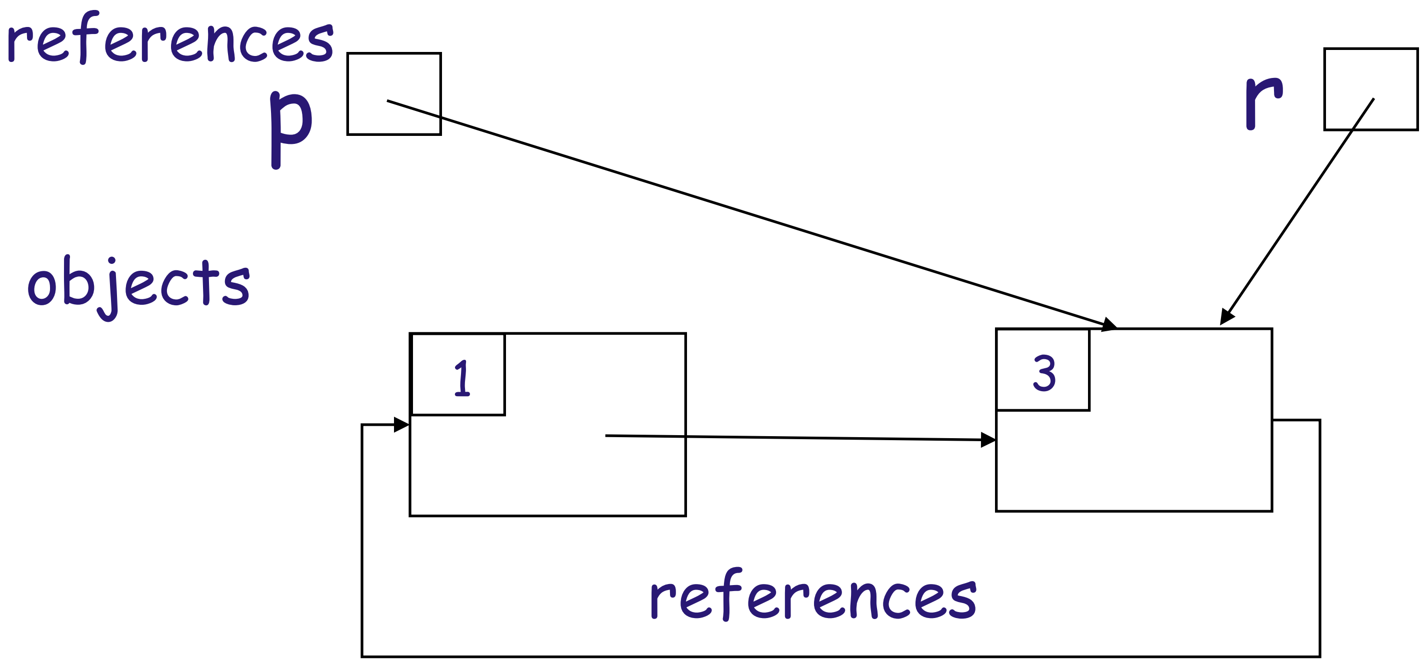
Circular Linked List



What happens when we execute:

p = r;

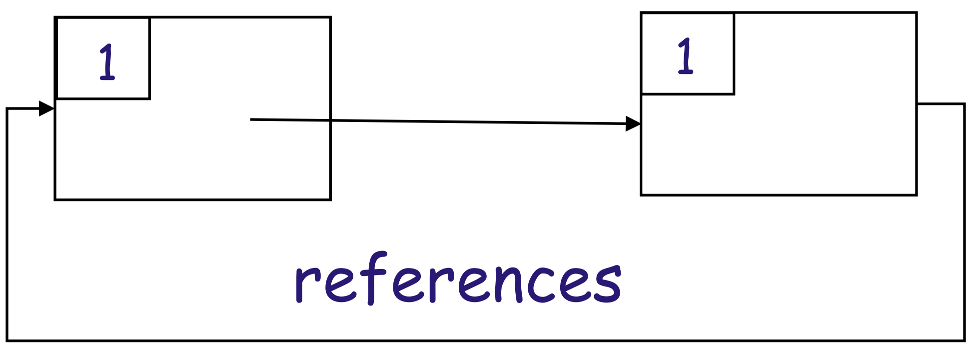
Circular Linked List



What happens when we execute:

p = null;
r = null;

Circular Linked List



Oops!

Garbage Collection

- Reference counting keeps track of what is accessible by modifying reference counts at each operation.
- Garbage collection does waits until memory is scarce, then determines what is accessible. The rest can become free memory.
- GC was invented by John McCarthy in conjunction with early Lisp implementation.

Garbage Collection

- is essentially a graph-search problem.
- Determine what is accessible from one or more "roots" of a directed graph.
- The complement of accessible is inaccessible, i.e. garbage.

Mark/Sweep Garbage Collection

- Do a search (say depth-first) from the roots of the "memory graph".
- Mark any reachable nodes as you go.
- (By making a pass over *all* nodes linearly through memory) Sweep up any unmarked nodes into the free list.
- (This all supposes that node entities are clearly identifiable. It requires that memory be maintained appropriately.)

Memory Overhead Comparison

- Reference counting:
  - One (arbitrary-size) integer per node
- Mark/sweep:
  - One bit per node

Time Overhead Comparison

- Reference counting:
  - A small tax on every operation
- Mark/sweep:
  - A big tax when memory runs out

Copying Garbage Collection

- Divide the memory into two half-spaces, say A and B.
- Work within one half-space (A or B) at any given time.
- Assuming using A now, when it comes time to collect garbage, perform a depth-first search, copying each used record from A to B. Then switch to using B.

Copying Advantages

- Trivial to **compact** as you copy. Relative locations do not get maintained. (Caution: Cannot rely on any absolute addresses.)
- This results in a single large unused chunk of memory on each collection.
- Real-time versions of copying have been devised.

Copying Disadvantages?

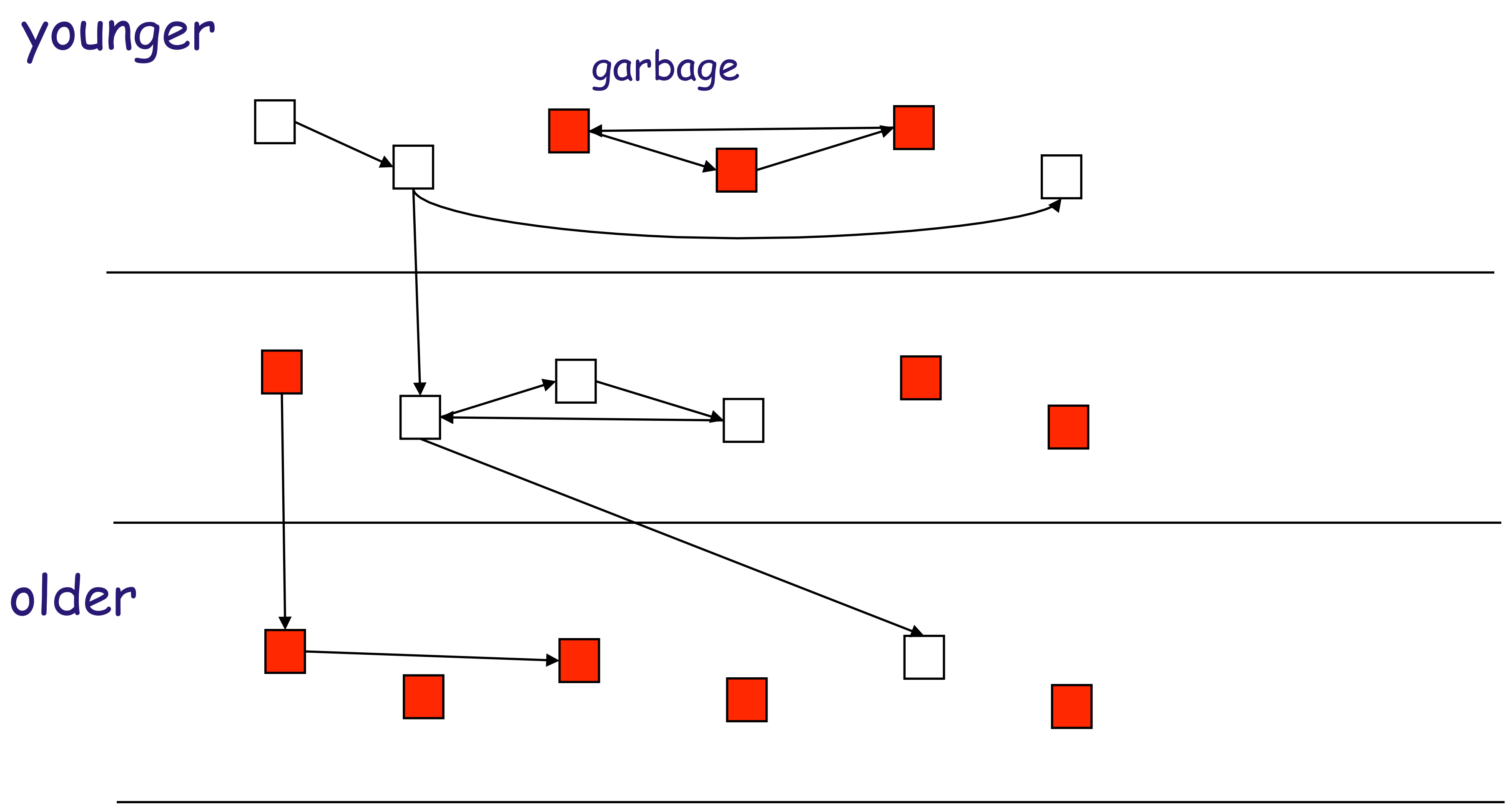
Generational Garbage Collection

- This is one of many heuristics used to reduce overhead in GC.
- It can be observed that some nodes are **ephemeral** (temporary and quickly become garbage), while others have great longevity.
- Thus devise a way to do a quick partial collection to pick up the ephemeral nodes, reserving a full GC until desperate.

Generational Garbage Collection

- The extension of the dichotomy ephemeral vs. long-lived is achieved by assigning nodes to **generations**.
- A node in the **youngest** generation is the most likely to become garbage.
- References can point from a younger to an older generation, but not vice-versa.
- If a node survives collection at one generation, it is promoted to the next generation.
- One generation is collected only if there is not enough freed by collecting younger generations.

Generational Garbage Collection



Food for Thought
(or indigestion?)

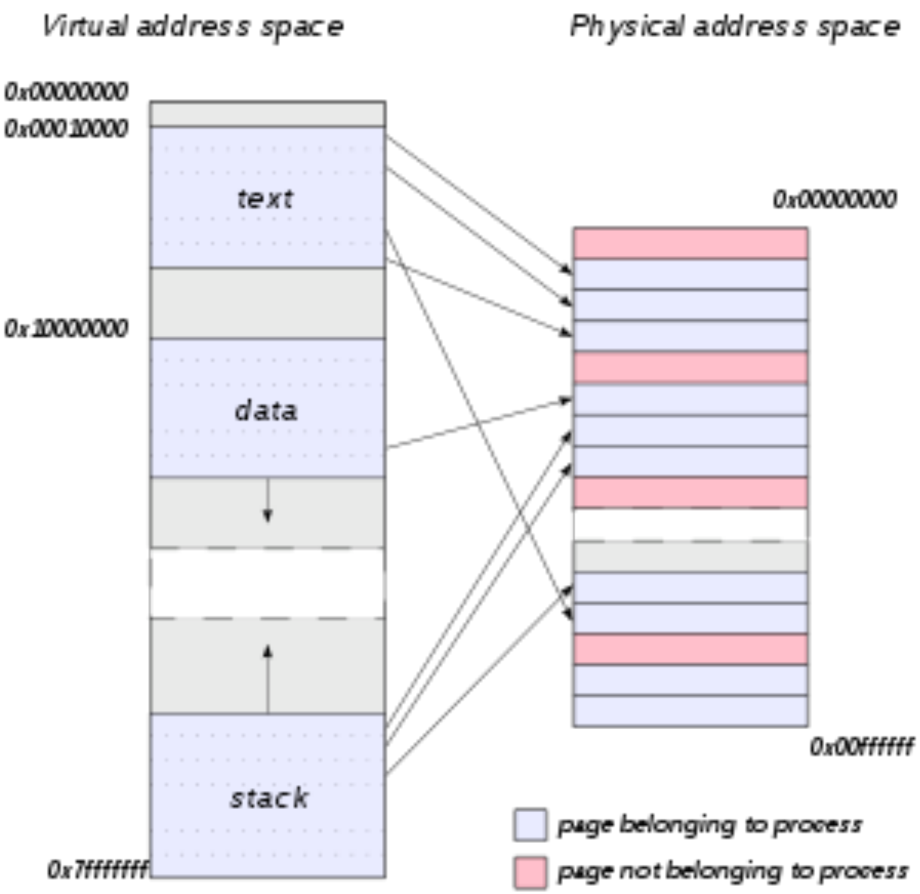
- How does the need for memory recycling impact the need to use threads?

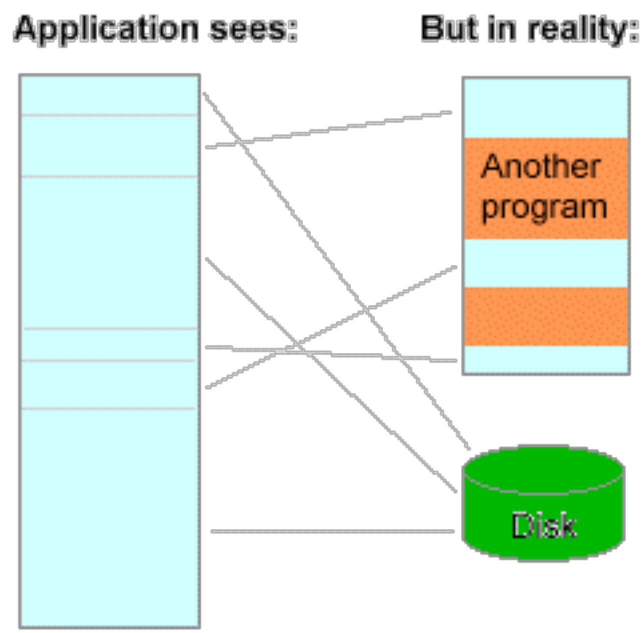
More Considerations

- Approaches to making memory larger/faster:
  - Paging, Virtual Memory
  - Caching
  - Each comes with its own set of issues

Paging

Purpose: Virtual memory, Sharing physical memory

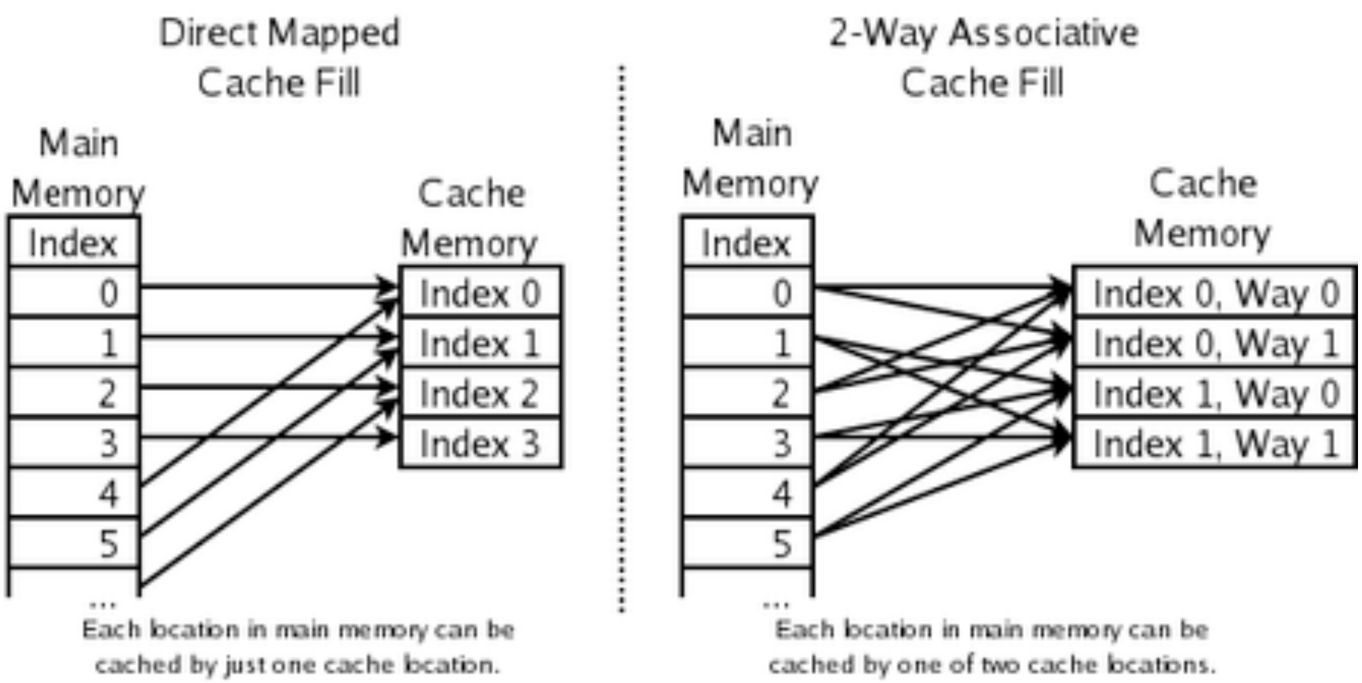




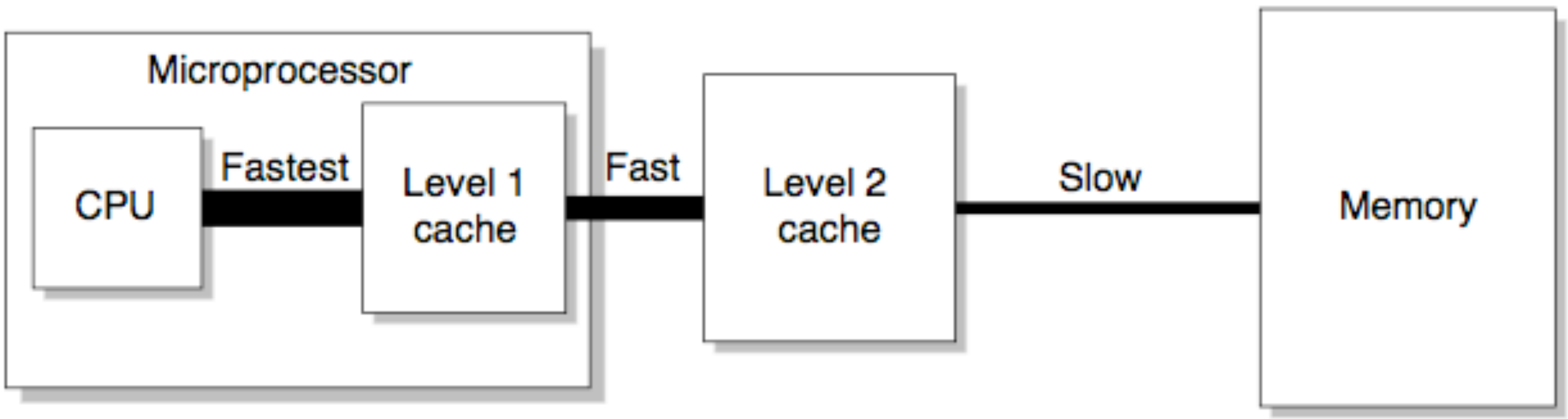
Caching

Purpose: Faster memory for faster execution

Analogous to hashing in some ways, but done in hardware.



Multi-Level Cache



Computer Memory Hierarchy

by Dan Lash (.com)