CS 153: Concepts of Compiler Design

November 28 Class Meeting

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San Jose State University

Fall 2017
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Extra-Credit Oral Presentations

- Let me know if your team would like to do an <u>oral presentation</u> for extra credit.
- Tell about your language.
  - Show some example programs.
- Describe its grammar
  - Show syntax diagrams.
- What Jasmin code do you generate?
  - Show some code diagrams.
- <u>Demo</u>: Compile, execute, and run some sample programs.

Extra-Credit Oral Presentations, *cont'd*

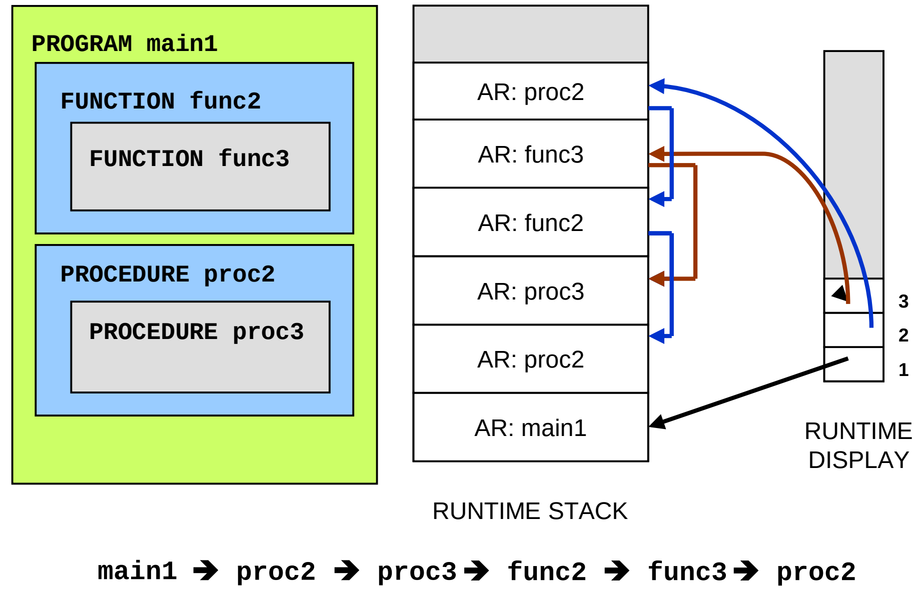
- Submit a note by Friday, Dec. 1 into Canvas: Assignments | Miscellaneous | Presentation if your team wants to present.
  - Choose either Dec. 5 or 7 to present.

- 15-20 minutes.

- Can add up to 50 points to each team member's total assignment score.

Static Scoping

- Pascal uses static (lexical) scoping.
- Scopes are determined at compile time by how the routines are nested in the source program.



- At runtime, variables are "bound" to their values as determined by the lexical scopes.
- The runtime display helps do the bindings.

Static Scoping in Java

- What value is returned by calling function **g()**?

What is the binding of this **x** with **static scoping**?

```
int x = 0;
int f() { return x ; }
int g() { int x = 1; return f(); }
```

Dynamic Scoping

- With dynamic scoping, runtime binding of variables to their values is determined by the call chain.
- To determine a variable's binding, search the call chain backwards starting with the currently active routine.
- The variable is bound to the value of the first declared variable found with the same name.

Hypothetical Dynamic Scoping in Java

- What value is returned by calling function `g()`?

What is the binding of this **x** with **dynamic scoping**?

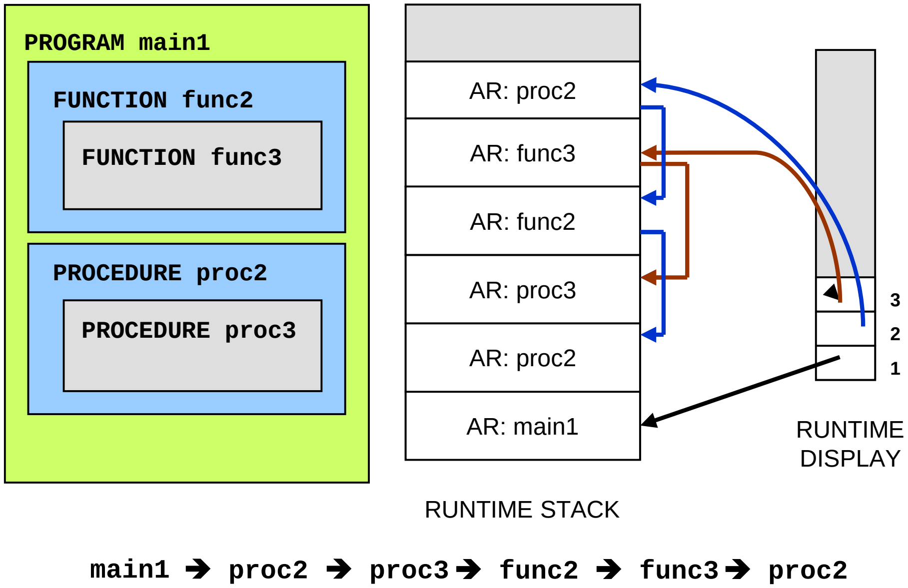
```
int x = 0;
int f() { return x ; }
int g() { int x = 1; return f(); }
```

- Call chain: `main` → `g` → `f`

How would you implement runtime dynamic scoping?

Runtime Memory Management

- In the "Pascal Virtual Machine", all local data is kept on the <u>runtime stack</u>.
  - All memory for the parameters and variables declared locally by a routine is allocated in the routine's <u>activation record</u>.



  - The memory is later <u>automatically deallocated</u> when the activation record is popped off the stack

Runtime Memory Management, *cont'd*

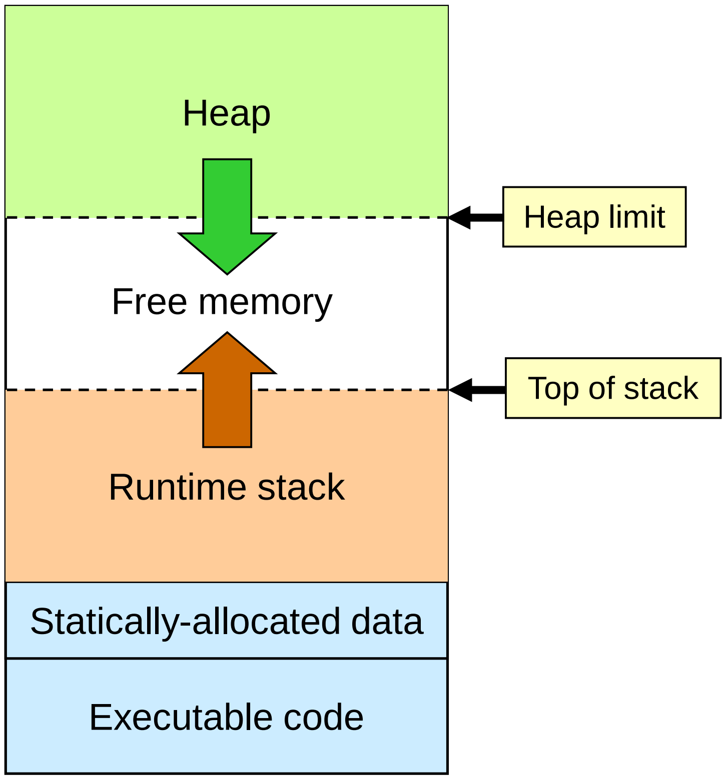
- What about <u>dynamically allocated data</u>?

- Memory for dynamically allocated data is kept in the "heap".

Runtime Memory Management, *cont'd*

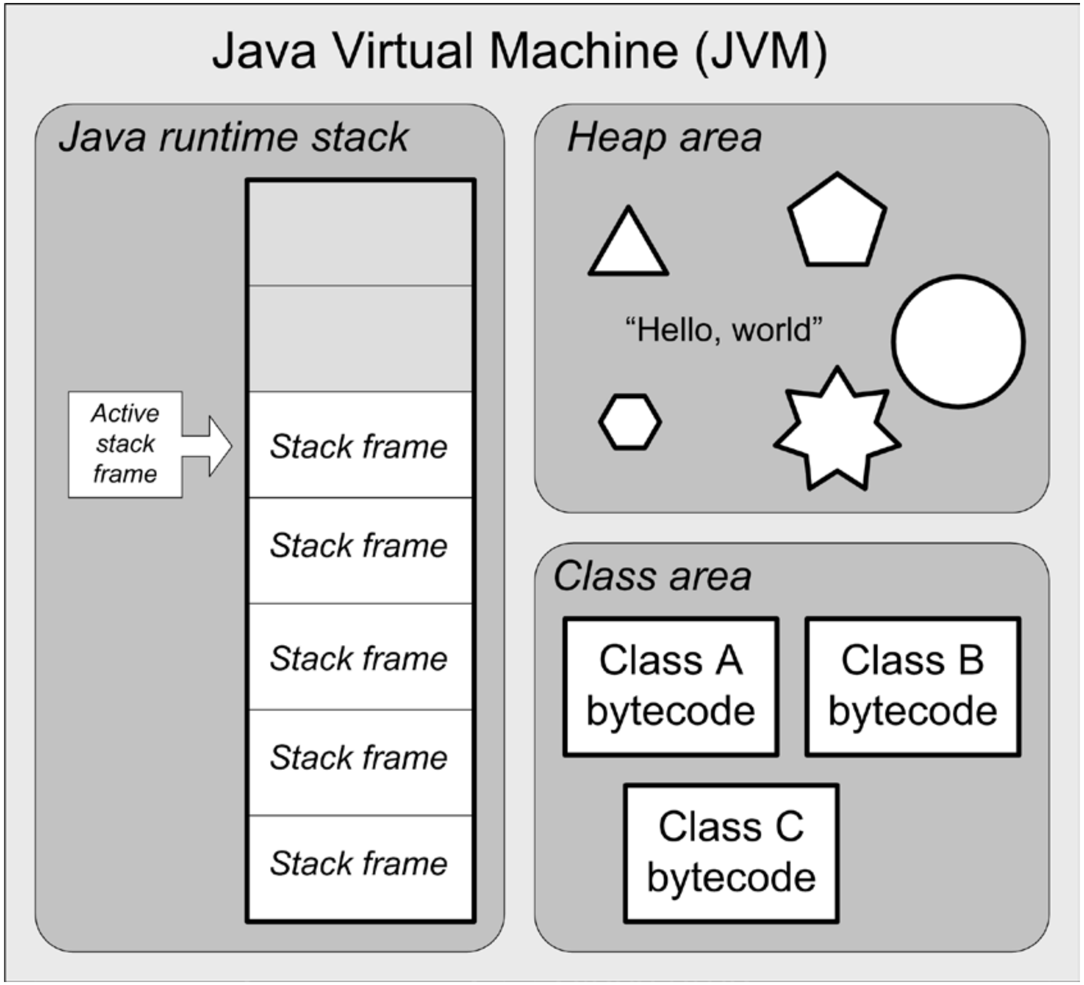
- Runtime memory can be divided into four partitions:

  1. Static memory
     - executable code
     - statically-allocated data
  2. Runtime stack
     - activation records that contain locally-scoped data
  3. Heap
     - dynamically-allocated data
     - such as Java objects
  4. Free memory



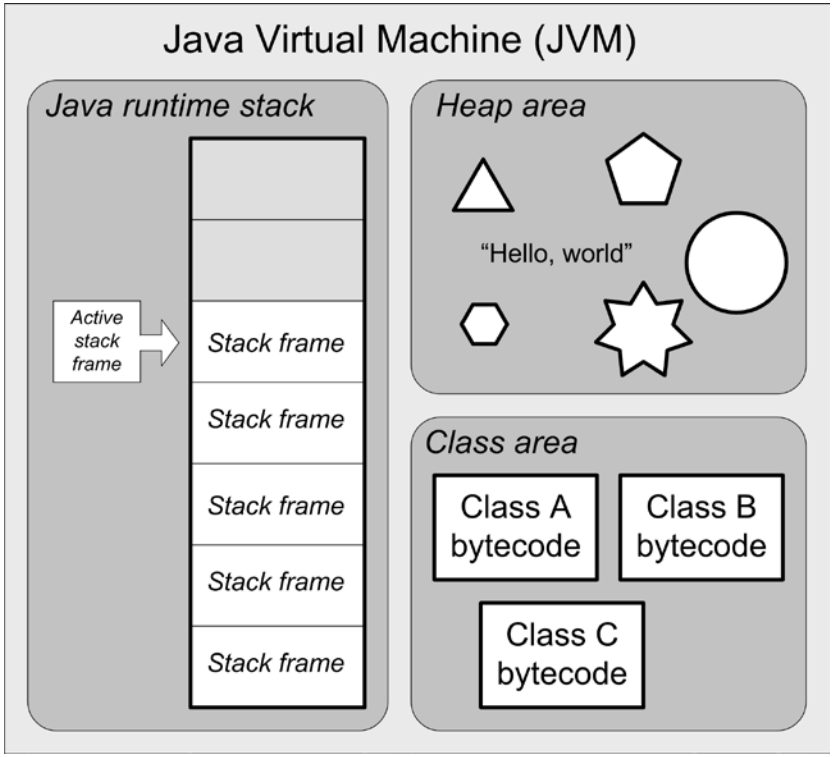
Avoid: **Heap-stack collision**
(Out of memory error)

Recall the JVM Architecture ...



Java Command-Line Arguments

- `java -Xms`*<size>* `-Xmx`*<size>*
  - `ms`: initial heap size
  - `mx`: maximum heap size
  - *<size>*: size in megabytes (`m`|`M`) or gigabytes (`g`|`G`)



  - Example: `java -Xms512M -Xmx2G HelloWorld`

Runtime Heap Management

- Handled by language-specific runtime routines.
- Pascal, C, and C++
  - Call new/malloc to allocate memory.
  - Call dispose/free to de-allocate.
- Java
  - Call new to allocate memory.
  - Set the initial and maximum heap size using the **`-Xms`** and **`-Xmx`** options.
  - Automatic garbage collection.

Runtime Heap Management, *cont'd*

- Keep track of all allocated blocks of memory and all free blocks.
- Free blocks are "holes" caused by freeing some of the dynamically allocated objects.

Runtime Heap Management, *cont'd*

- When a new block of memory needs to be allocated dynamically, where should you put it?
- You can allocate it at the <u>end of the heap</u>, and thereby expand the size of the heap.
- You can <u>find a hole</u> within the heap that's big enough for the block.

Runtime Heap Management, *cont'd*

- What's the <u>optimal</u> memory allocation strategy?
  - Find the <u>smallest possible hole</u> that the block will fit in.
  - <u>Randomly pick</u> any hole that's big enough.
- Should you periodically <u>compact the heap</u> to get rid of holes and thereby reduce the size of the heap?
- If allocated data moves due to compaction, how do you update references (pointers) to the data?

Garbage Collection

- Return a block of memory ("garbage") to unallocated status …
  - … when there are no longer any references to it.

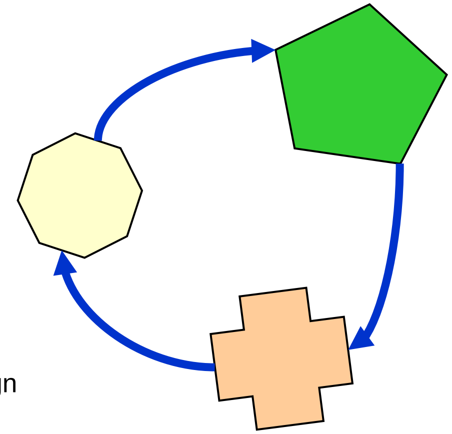
- Various algorithms to locate garbage.
  - reference counts
  - mark and sweep
  - stop and copy
  - generational

Automatic Garbage Collection

- Automatic garbage collection is great for programmers, because you don't have to think about it.
- But it can slow runtime performance unpredictably.
  - How?

Garbage Collection: Reference Counts

- Include a counter with each block of allocated memory.
  - Increment the counter each time a pointer is set to point to the block.
  - Decrement the counter whenever a pointer to the block is set to null (or to point elsewhere).
  - Deallocate the block when the counter reaches 0.
- Problem: Cyclic graphs
  - The reference counts never become 0.



Garbage Collection: Mark and Sweep

- Make a pass over the heap to mark all allocated blocks of memory that are reachable via pointers.
  - Various marking algorithms.
- Make a second pass to sweep (deallocate) blocks that are not marked.

Garbage Collection: Stop and Copy

- Partition the heap into two halves.
  - Allocate memory only in one half at a time.
- When an allocation fails to find a sufficiently large block of free memory …
  - Stop
  - Copy all allocated blocks to the other half of the heap, thereby compacting it.
  - Update all references to the allocated blocks.
    - How do you update pointer values?

Generational Garbage Collection: Theory

- Most objects are short-lived.
- Long-lived object are likely to last until the end of the run of the program,

Generational Garbage Collection: Practice

- Partition the heap into a new generation area and an old generation area.
  - Allocate new objects in the new generation area.
  - Keep track of how long an object lives.
  - Once an object lives past a predetermined threshold of time, migrate it to the old generation area.
- The old generation area stays fairly compacted.
- The new generation area needs compacting infrequently.

Aggressive Heap Management

- Aggressive heap management means doing garbage collection frequently, even when it's not necessary.
  - There's still adequate free space remaining in the heap area.
- <u>Keep the heap as small as possible.</u>
  - Improve reference locality.
  - Optimize the use of physical memory when multiple programs are running.
  - Reduce virtual memory paging.

Aggressive Heap Management: Tradeoff

- GC operations slow program performance.
- But paging to disk can be orders of magnitude slower.

Garbage Collection Research

- Entire books have been written about garbage collection.
- It's still an area with opportunities for research.
- You can become famous by inventing a better GC algorithm!
- Maybe some form of adaptive GC using machine learning?