# Programming in Java

## 2. Variables and Data Types

# Data Types

- In keeping with OOP, all data should be define in terms of objects
  - However, this is impractical from a hardware and processing perspective
  - Especially in 1994 when hardware performance was a processing bottleneck
- Java defines a set of primitive data types
  - These are specifically designed to be used by the stack (more on that in a moment)
  - They are all of a fixed size which is required for them to be on the stack
  - The fixed size is either 32 bits or 64 bits
  - This ensures that data can be moved in no more that two clock cycles
    - *On 32 bit architectures, moving 64 bits can take two clock cycles*
  - Primitive types are intended to allow for fast stack based computation
- There is one primitive type that is not used in computation
  - References to an allocated chunk of heap memory are 32 or 64 bit memory addresses
  - Java does not allow us to directly access these values so we don’t corrupt memory

# Data Types

- The different primitive data types are stored in different formats in memory
- Based on the type of data and its size
- Java can determine the type of data when looking at its string representation
  - Integer types are a series of digits without a decimal point like 49837
  - Float types are a series of digits with a decimal point or in scientific notation like 1.0 or 3.2E4
  - A character is a single Unicode utf-16 character in single quotes like ‘a’ or ‘♣’
  - A string is a series of Unicode utf-16 characters like “Hello world”
    - *Note that the table in the following slide is wrong – chars take values from 0 to 65,535, not 256*
  - ‘true’ and ‘false’ are logical values stored as a byte
- When using variables, we have to tell Java what type of data it contains

# The Standard Primitive Data Types

| TYPE | DESCRIPTION | DEFAULT | SIZE | EXAMPLE LITERALS | RANGE OF VALUES |
|---|---|---|---|---|---|
| boolean | true or false | false | 1 bit | true, false | true, false |
| byte | twos complement integer | 0 | 8 bits | (none) | -128 to 127 |
| char | unicode character | \u0000 | 16 bits | ‘a’, ‘\u0041’, ‘\101’, ‘\\’, ‘\’,’\n’,’ β’ | character representation of ASCII values 0 to 255 |
| short | twos complement integer | 0 | 16 bits | (none) | -32,768 to 32,767 |
| int | twos complement integer | 0 | 32 bits | -2, -1, 0, 1, 2 | -2,147,483,648 to 2,147,483,647 |
| long | twos complement integer | 0 | 64 bits | -2L, -1L, 0L, 1L, 2L | -9,223,372,036,854,775,808 to 9,223,372,036,854,775,807 |
| float | IEEE 754 floating point | 0.0 | 32 bits | 1.23e100f, -1.23e-100f, .3f, 3.14F | upto 7 decimal digits |
| double | IEEE 754 floating point | 0.0 | 64 bits | 1.23456e300d, -1.23456e-300d, 1e1d | upto 16 decimal digits |

Image Credit: https://www.geeksforgeeks.org/data-types-in-java

# Stack Versus Heap Memory

- This is standard architecture
- Usable memory for applications is divided into
  - The stack: Under the control of the OS
  - The heap: Under the control of the user
- The heap starts at the highest available memory address and grows down
- The stack starts at the lowest memory address and grows up
  - Up to the limit of the allocated stack memory
- The white space in the middle is available memory for the heap
- If it goes to zero then
  - When the heap tries to allocate memory an *out of memory* error is generated
  - This usually causes a program to terminate

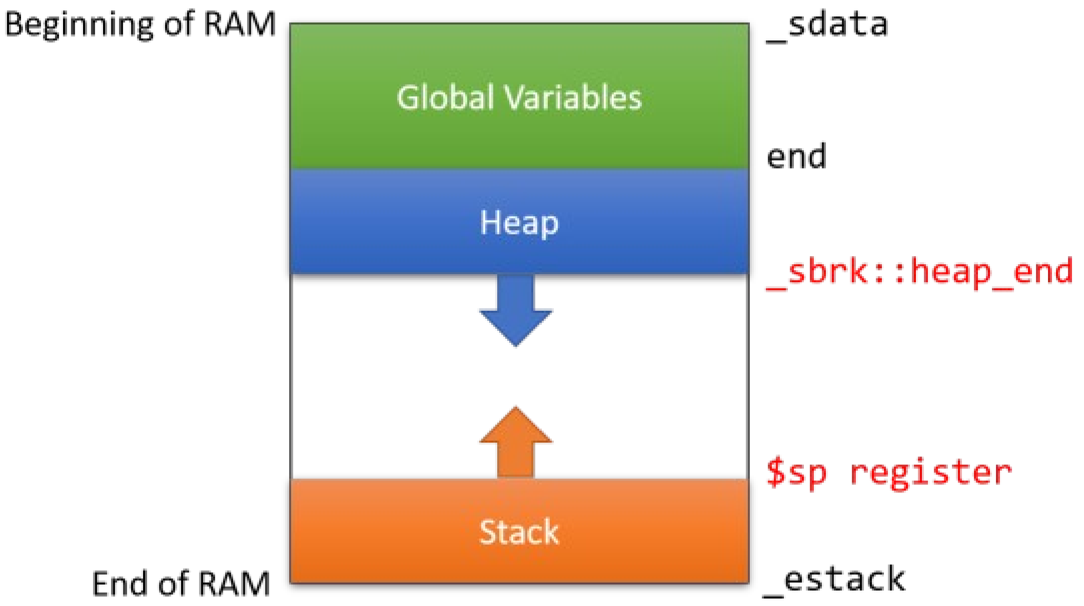



Image Credit: https://visualgdb.com/documentation/embedded/stackheap/

# Stack Versus Heap Memory

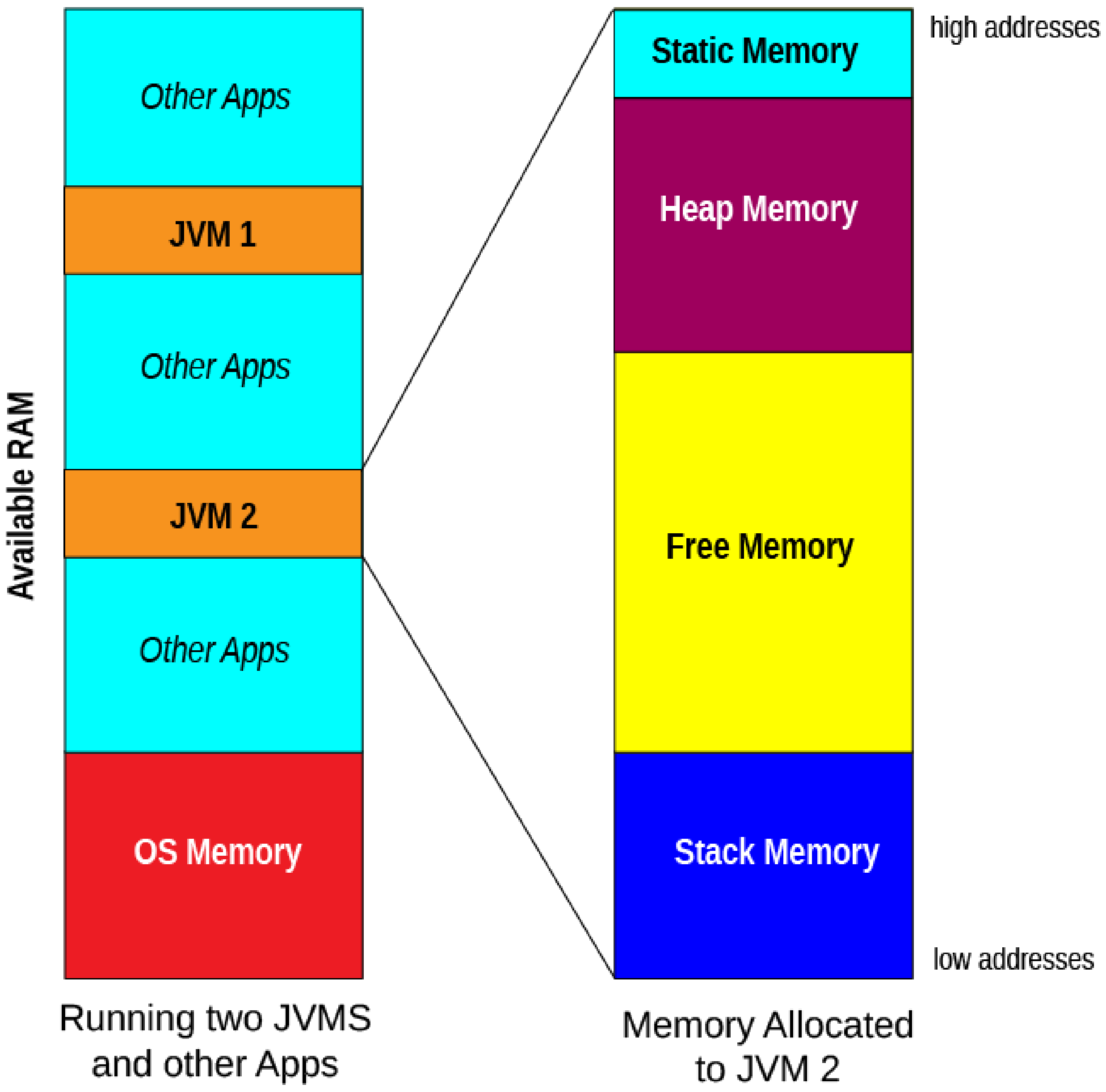
| Stack | Heap |
|---|---|
| Fixed in size (set by Operating System) | Can shrink/grow in size in real-time |
| Stack is contiguous memory (i.e., sequential memory addresses) | Heap memory is not contiguous (i.e., not sequential memory addresses) |
| Memory allocation and release is automatically managed | Memory allocation, use and release is up to the programmer |
| Memory allocation is fast: only the stack pointer needs to move | Slower than the stack, as space for dynamic variables needs to be found in real-time |
| Is a First-In-Last-Out (FILO) / Last-In-First-Out (LIFO) system | Heap variables not allocated sequentially, memory can become fragmented |
| Variables sizes are fixed at compile-time and cannot be resized | Variable sizes can be set at allocation time and can (somewhat) be resized |
| Variables in stack memory are always in scope (function-based memory allocation) | Heap memory has no scope but pointers to Heap memory do! |
| Size of variables in stack memory are known at compile time, so variables can have variable names | Size of variables not known until dynamically allocated, so Heap memory can only be accessed with pointers |



Image Credit: hhttps://cppbetterexplained.com

# Java Memory Management

- Memory in the JVM is handled exactly like an OS handles physical memory
- The size of the stack is fixed when the JVM starts up
  - This can be adjusted by tweaking the JVM parameters
- The static memory is where any data that remains in memory for the duration of the time the JVM is running is located



# Memory and Data

- There are three kinds of storage types in Java
- Static data
  - Also called permanent data
  - This is data that is initialized when the JVM starts up
  - It remains in memory until the JVM shuts down
  - This includes constants and interned data (we will define that later)
- Automatic data
  - This is data that is managed by the JVM on the stack
  - This data is primarily of local variables created during execution of a method
  - The stack removes these variables from memory when they go out of scope
- Managed data
  - This is data that is created on the heap in the code, usually with the “new” operator
  - It remains on the heap until it can no longer be accessed from the code
  - Inaccessible data is deleted from the heap when the garbage collector runs

# Type Safety

- All data values have a type
  - Its type determines how it is stored in memory
  - For a non-typed language, like Python
    - *A variable can be bound to any type of data*
    - *But data values still have types like in Java*
- In a strongly typed language, like Java, variables must have a type
  - The typed variable is allowed to store one specific type of data
  - This is to ensure that potential run time errors are caught at compile time, like trying to add a Boolean and a floating point number
- Literals are strings of characters in a program listing that can be parsed as data
  - Java has a set of rules to assign a type to a literal
  - This ensures that the wrong type of data is not assigned to a variable at run time
  - eg. ‘123’ is a 32 bit integer while ‘123L’ is a 64 bit integer
    - *Tip: Underscores can be added to any numeric literal for readability 898979211 =  898_878_211*
  - Any floating point literal is a double by default unless post-fixed with an ‘F’  eg. 89.3F

# Type Safety and Casting

- In certain cases, some data types can be converted to other data type
  - Integers can be assigned to longs since they are both integer data types
  - Floats can be assigned to doubles since they are both floating point data types
  - These are called *widening* conversion since the target is bigger than the source
  - *Narrowing* conversions where the target is smaller than the source are not allowed
  - Integer types can be assigned to floating point numbers but the will be a loss of precision
- We can override Java's rules by casting or allowing the conversion to take place
  - This may result in data loss or errors at runtime
  - eg. `int k = (int)1.9;` casts a float to an int
  - Casting a float to a non-float causes the fractional part to be truncated
  - Casting a 64 bit value to a 32 bit value may cause a loss of precision
- We can only cast between different numeric types
  - Java has no idea how to cast a String to a boolean or to an int for example

# Character Data

- Java was designed as an Internet language
  - At that time UFT-16 (16-bits per character) was the standard language encoding on the Internet
  - C and C++ were using ASCII 8-bit character encoding
  - Java source code and Java data both use UTF-16 encoding
  - It helps to think of the first byte of a Java character as an alphabet and the second to be a letter in the alphabet
    - *ASCII is a subset of UTF-16 where the first byte is zero*
  - However, UTF-16 has been replaced in the Internet world by the variable length encoding UTF-8

# Lab 2-1

## Data Types and Casting

# Variable Types

- Data is what is referenced by variables
- Variables, regardless of what type of data theh reference, are one of three types
  - Static
  - Automatic
  - Managed
- Every variable has two properties
- Lexical Scope
  - This just means where in the code a variable can be referenced from
  - Variables can only be used if Java can “see” them
  - The block of code where a variable can be seen is called its lexical scope
- Extent
  - This is the amount of time that a variable is in storage
  - Static variables have infinite extent
  - Automatic and managed variables are created and then destroyed with they go out of scope

# Automatic Variables

- Works the same way in most Programming languages
- All local variables in methods are automatic
- “Automatic” means that storage is automatically managed by the stack
- Braces are used by Java to indicate a lexical scope
  - An automatic variable scope is from the time it is declared until the closing brace } in the scope it is declared in
  - We can insert whatever addition scopes we want
  - { } in method bodies are a scope

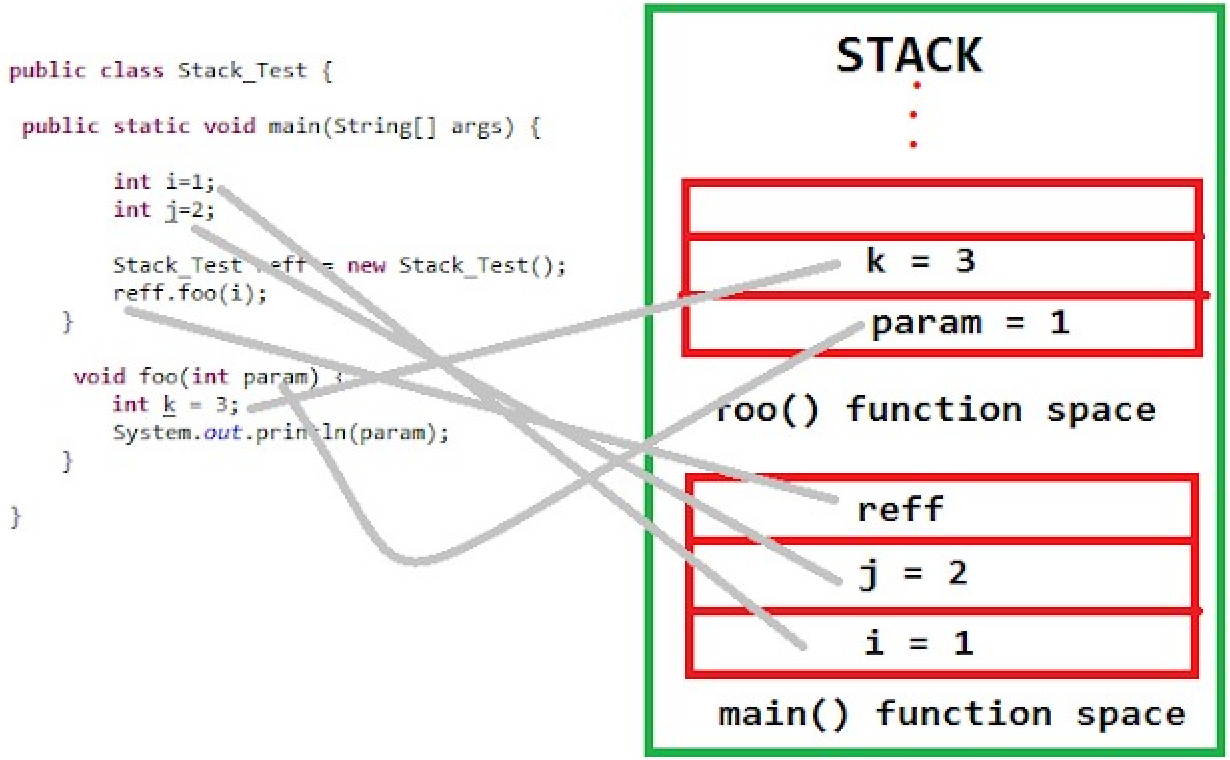





Image Credit: https://uniquejavacoder.blogspot.com/2020/05/java-stack-and-heap-java-memory.html

# Demo

## Automatic Variables and Scope

# Static Variables

- These are defined inside class definitions
  - Essentially these are global variables
  - At the time Java was designed, global variables were considered not proper OO
- Static variables are created when the class is loaded
  - The are also initialized when created
  - Either by using explicit initialization or defaulted to the “natural zero value”
    - *Natural zeros were 0 for numerics, null for references and false for booleans*
    - *Using the defaults is considered poor programming style*
- The variables exist while the JVM is running and are never destroyed
  - The variable is referenced using the *classname.variablename* where *classname* is the class in which it is defined
- The lexical scope of a static variable is determined by the class
  - If the class definition is visible to the some other code, then the variable can be referenced in that code
  - A static  variable is also in scope from any method inside the class it is defined in
  - Outside the class, it may need to be declared *public* – more on that later

# Demo

## Static Variables

# Managed Variables

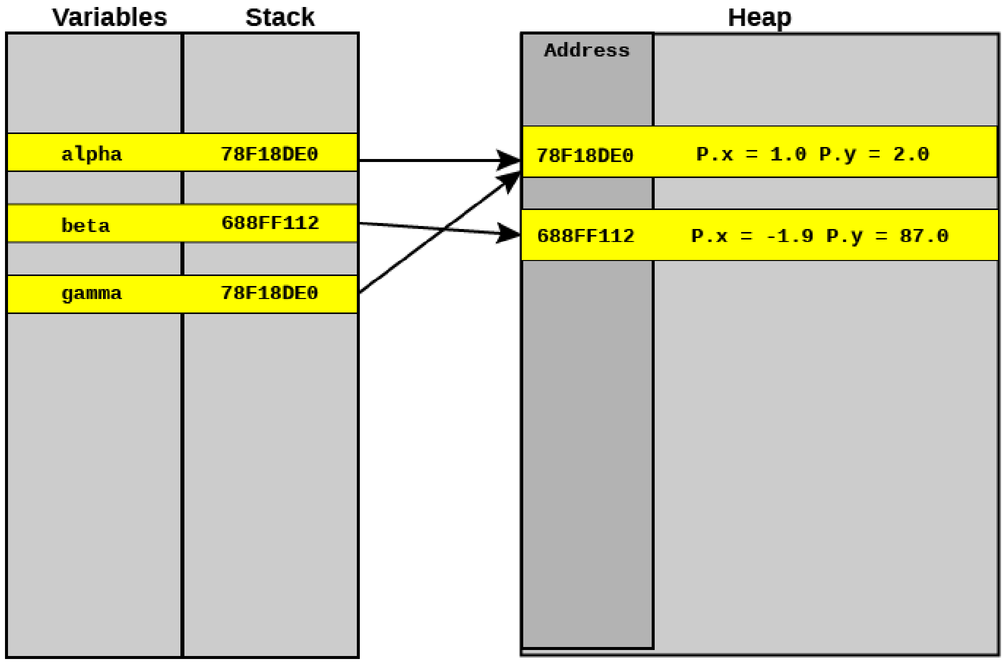
- Managed variables are created when our code executes
  - All user defined types (like classes) are managed
  - Strings and arrays are also managed, but will deal with those later
  - More typically, managed variables are called *objects*
- Objects are created on the heap
  - By using the *new* operator
  - *New* returns the memory location of the newly created object
  - This is called a reference to the object and is essentially an integer that we cannot modify
  - Objects live until they go out of scope
- The scope of an object
  - An object is in scope as long as there is at least one variable that refers to (contains the address) of the object
  - Once the object can not longer be referenced, is marked for deletion so its memory can be reclaimed
  - The JVM keeps track of how many variables refer to the object (the reference count)
  - The object's memory is reclaimed during a background process called garbage collection

# Instance Variables

- Classes can contain instance variables
  - These can be of any data type
  - The extent and scope of instance variables is the same as the object they belong to
  - Each object has its own copy of the instance variables
  - Below, 78718DE0 has a reference count of 2, while 688FF112 has a reference count of 1

```
lass P {
 float x;
 float y;
 P(int a, int b);


 alpha = new P(1.0,2.0);
 beta = new P(-1.9, 87.0);
 gamma  = alpha;
```



# Demo

## Managed Variables

# Final Variables

- Java does not have a *const* keyword but uses the modifier *final* in different contexts
- When used with a variable, it means that the variable cannot appear on the LHS of an assignment statement
  - The variable must be initialized when it is created
  - This is because memory for the final variable is located in a special permanent memory area
  - Since the value of the variable cannot change, a more efficient storage scheme is used
  - It can be thought of as a literal
  - The value is said to be *interned* in a constant storage pool in the heap static memory
  - When two final variables have the same value, they share the same interned constant as a value

# Lab 2-2

## Variable Types

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