Programming in Java

2. Variables and Data Types

Introduction

- This module is a technical overview of data types in Java
  - But not at the level of *“this is an integer, this is a float…”* - you should already know that
  - The emphasis is on how Java manages different data types and how they interact with the memory allocation system used in the JVM
- We also cover the different storage types of variables used in Java
  - How they are managed by the JVM at runtime
  - What is meant by lexical scope versus variable lifetime or extent
- We will also look at how complex data constructs or objects are managed in the JVM

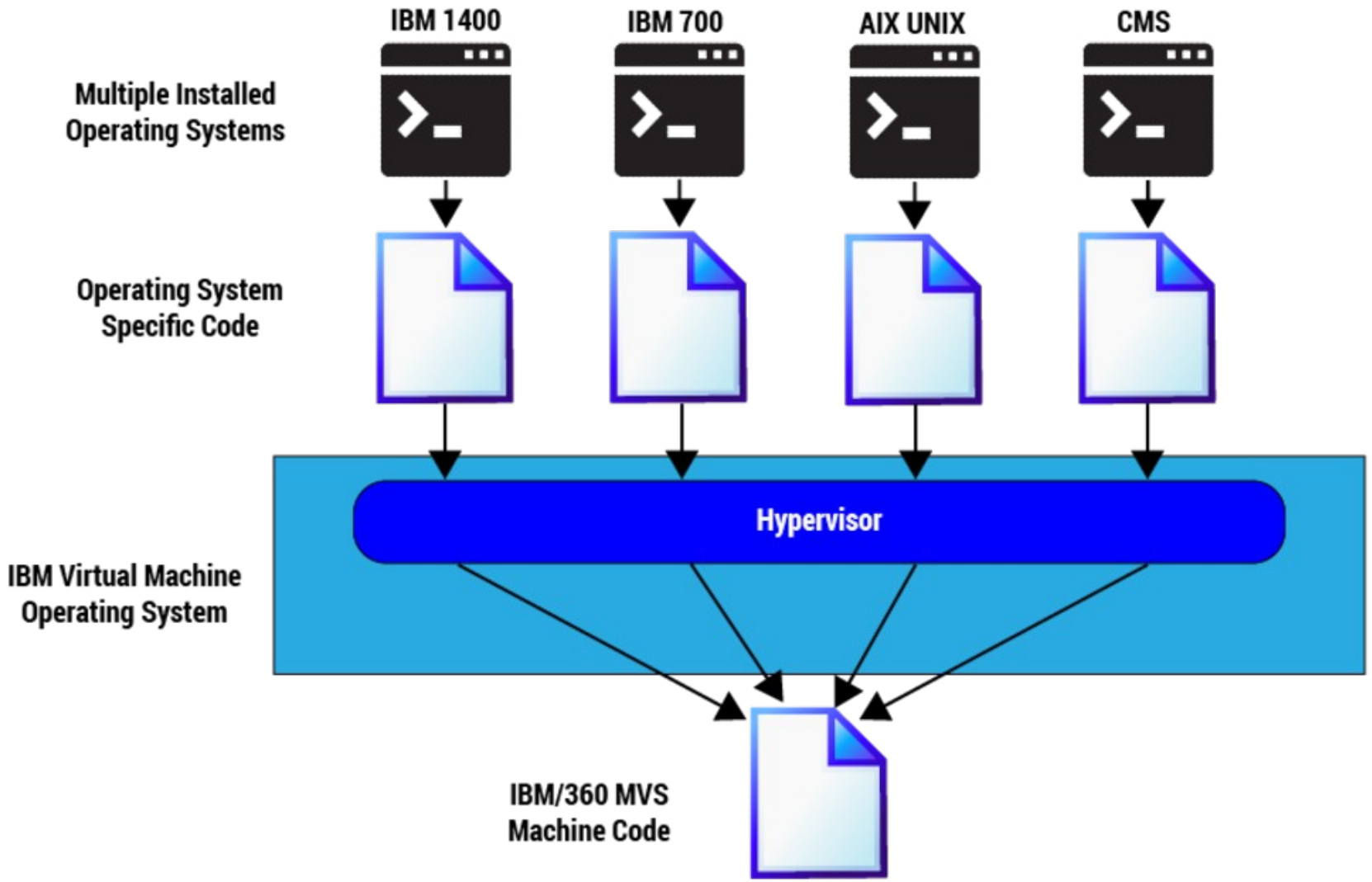
Virtual Machines

- When talking about the Java Virtual Machine, it is helpful to clarify what that is
- VMs are ubiquitous in modern software architectures
  - The JVM is not like those VMs
- There are two basic types of architecture called virtual machines
- The first is what we might call fan-in architecture which is the most common type in use
  - VMWare, Cloud computing and containers like Docker use this model
  - Characterized the use of a hypervisor
- The other is what we might call a fan-out architecture
  - It’s like a distributed hypervisor in reverse
  - It is implemented as a client (JVM) on a taget system

Fan-in VMs

- Developed by IBM for the IBM/370 MVS OS in 1972
  - Called the Virtual Machine Operating System VM/OS
  - Coined the term hypervisor
- IBM had a massive installed base of customers
  - Used different versions of the IBM mainframes, eg. 700 series, 1400 series
  - IBM wanted to retire all those models and move clients to the new IBM/370
  - IBM only rented hardware to clients so there would be minimal hardware costs
- The problem
  - Each OS used software tightly coupled to the underlying hardware
  - Moving would entail massive software rewrites and so customer balked
- The VM/OS could emulate all the legacy systems
  - Customer software from a IBM 1400 would run in the VM/OS emulating a 1400

IBM VM/OS


IBM 1400
IBM 700
AIX UNIX
CMS
Multiple Installed Operating Systems
Operating System Specific Code
Hypervisor
IBM Virtual Machine Operating System
IBM/360 MVS Machine Code

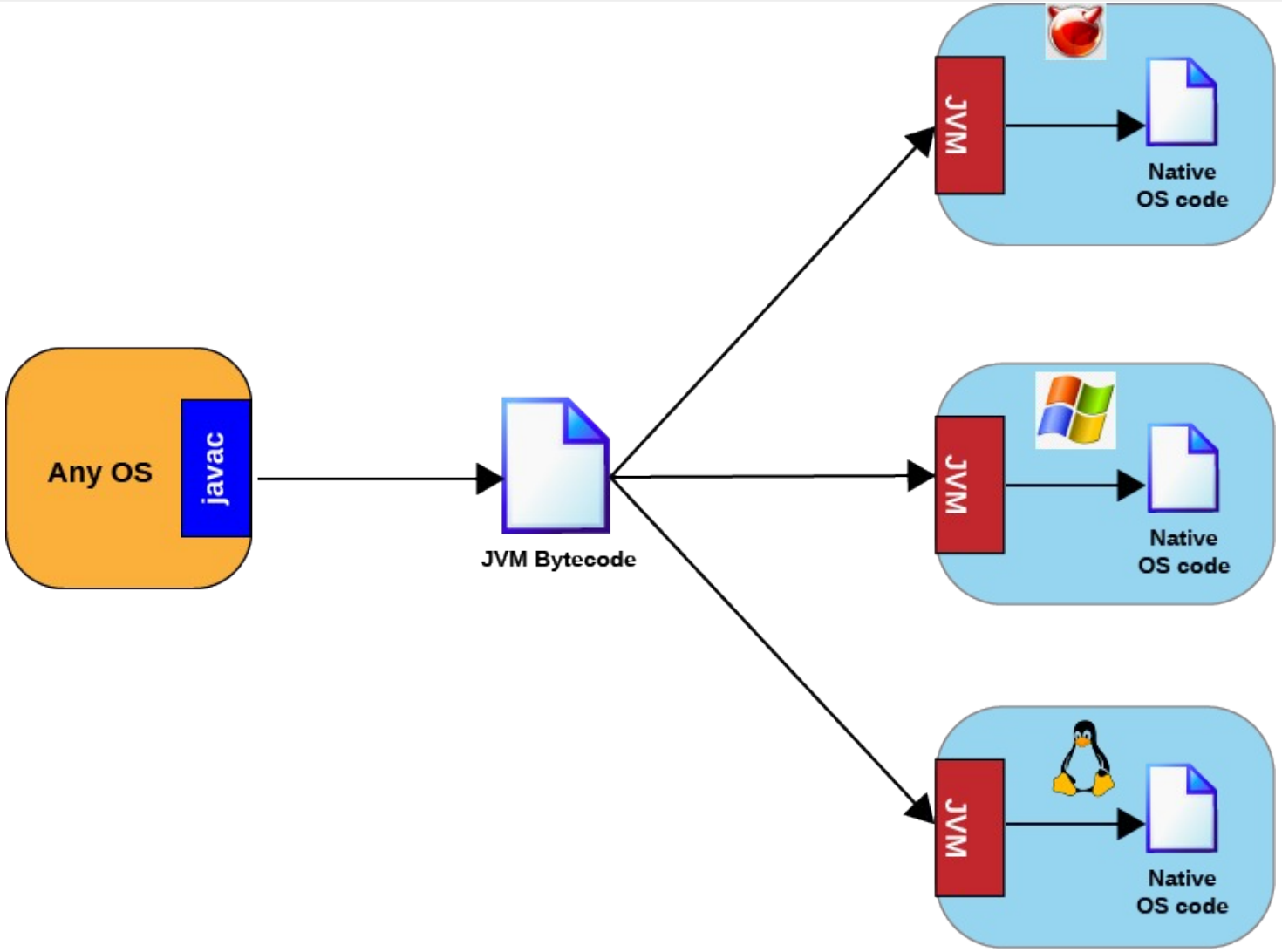
Time Traveling VMs

- John Titor was the name used by a person who claimed to be from the year 2036
  - His internet posts and interviews were very popular in 2000-2001
  - He claimed he traveled back in time to 1975 get an IBM 5100 portable computer
  - The computer ran APL and Basic
  - But it had an early version of a VM called an emulator that allowed it to be used to debug mainframes
  - He claimed this VM was needed to fix problem with the future legacy systems
  - Currently the Titor story is considered to be a literary experiment

Fan-out VMs

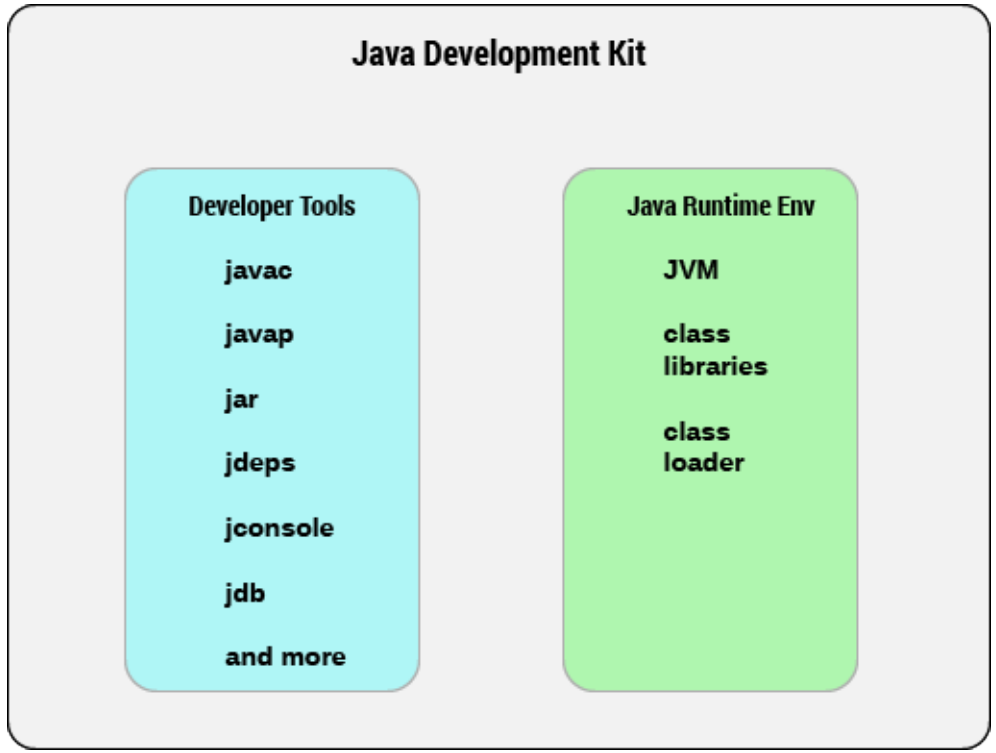
- Common write-once, run-anywhere model
- Application code is complied to a intermediate representation called bytecode
  - Sort of a generic assembler language
  - Makes it easy to translate into real assembler
- Client machines run the bytecode in an platform specific interpreter
  - The interpreter translates the bytecode into platform specific assembler
- Became very popular in the 1970s
  - Many early computer companies when belly up (like Wang laboratories)
  - Left users with masses of code that would run on those machines
  - Solution was to create a virtual version of the hardware that would compile source code into bytecode
  - Then run the bytecode on a PC or a Mac
- Since the original intent of Java was to run on multiple platforms
  - This was a natural model to design to

Java Architecture



The JRE

- The platform specific JRE consists of:
  - The JVM executable name *java*
  - Local copies of the Java Class libraries already in platform specific code
  - A class loader responsible for loading complied java classes into the JVM
- The JRE is all that is needed to run Java applications
- The Java Development Kit JDK
  - Contains a JRE
  - But also contains the java compiler and other development tools



Java Code Lifecycle

- Java source code in *.java files is compiled (hello.java)
- The bytecode output is in a *.class life (hello.class)
- The JVM starts
- The class loader loads the requested *.class files into the JVM
  - This is one reason the rule about public class name and file names
- If the source files are in a package structure
  - The compiler outputs a corresponding package structure for class files
- The problem is that this structure had to be sent somehow to a JRE
  - This could be very complicated
- The modern approach is to zip all the out put in to a Jar file
  - Just one thing to send to the JRE
  - Regular Jar files still need the local class libraries to run
  - Fat or Shaded Jar files, like the ones Spring produces, contain the needed libraries
  - Fat Jar files can run as standalone Java applications


Demo
Working with bytecode

Lab 2-1

Grokking Bytecode

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 tp 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

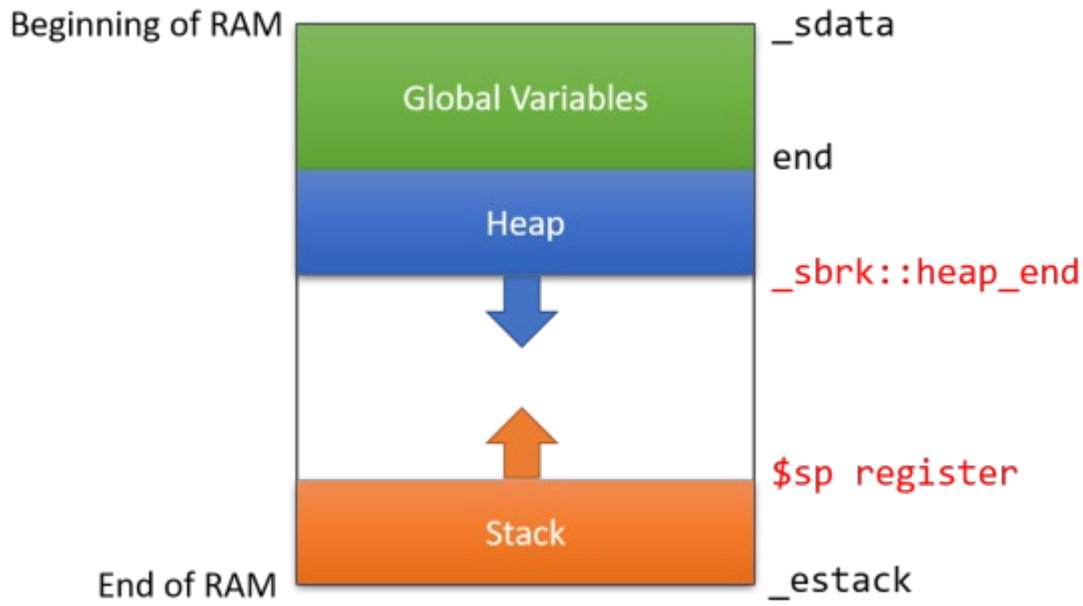


Image Credit: https://visualgdb.com/documentation/embedded/stackheap/

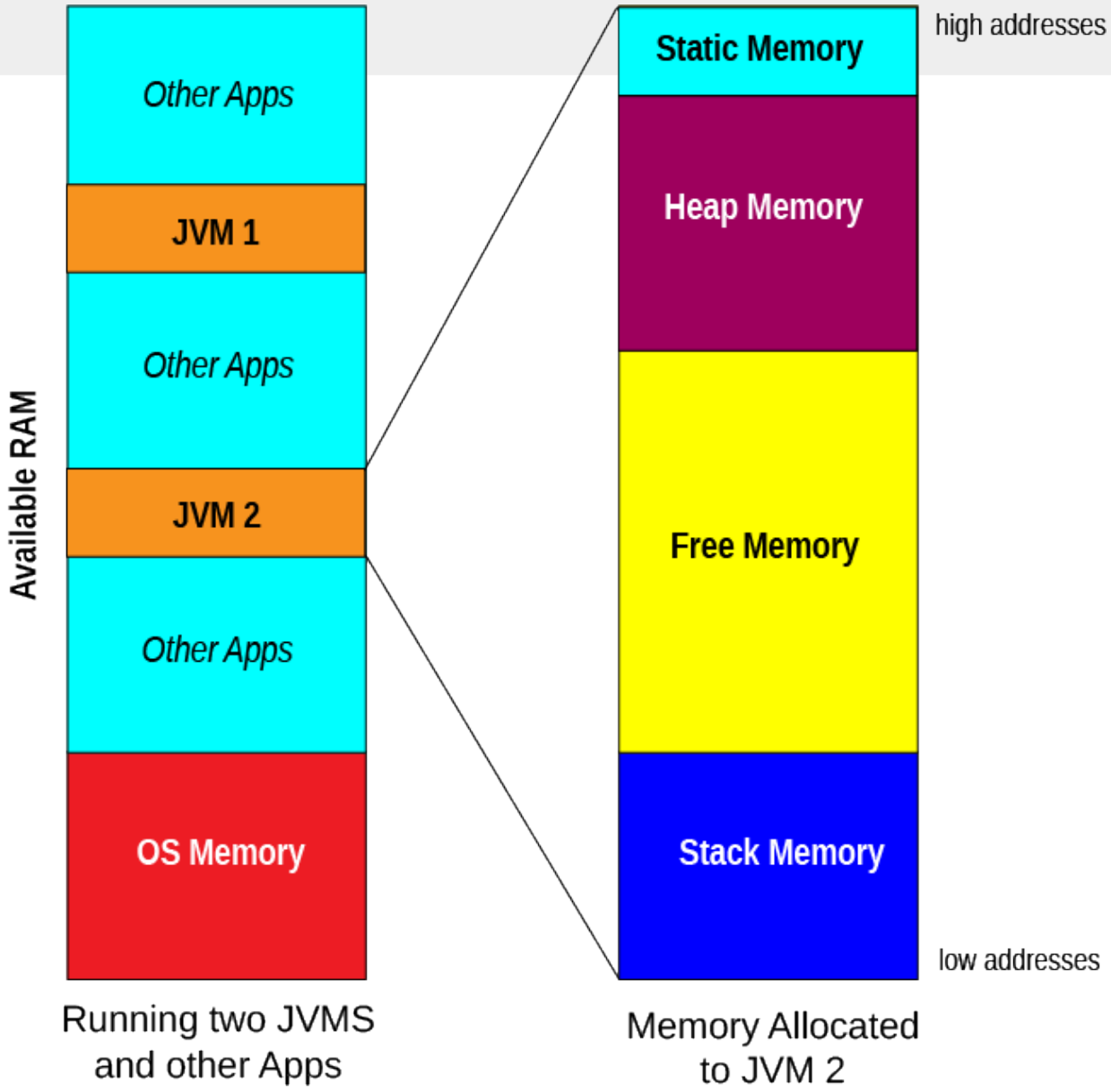
Stack Versus Heap Memory

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

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
  - 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 62 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 bit memory addresses
  - Java does not allow us to directly access these values so we don’t corrupt memory

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

Type Safety

- All data has a type
  - It has to because its type determines how it is stored in memory
- An an untyped language, like Python
  - A variable can be bound to any type of data
- In a strongly typed language, like Java, variables have a type
  - The typed variable is only allowed to bind to a 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
  - Floats can be assigned to double
  - 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 2-2

Data Types and Casting

Variable Types

- Data is what is referenced by variables
- Variable, regardless of what type of data the 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

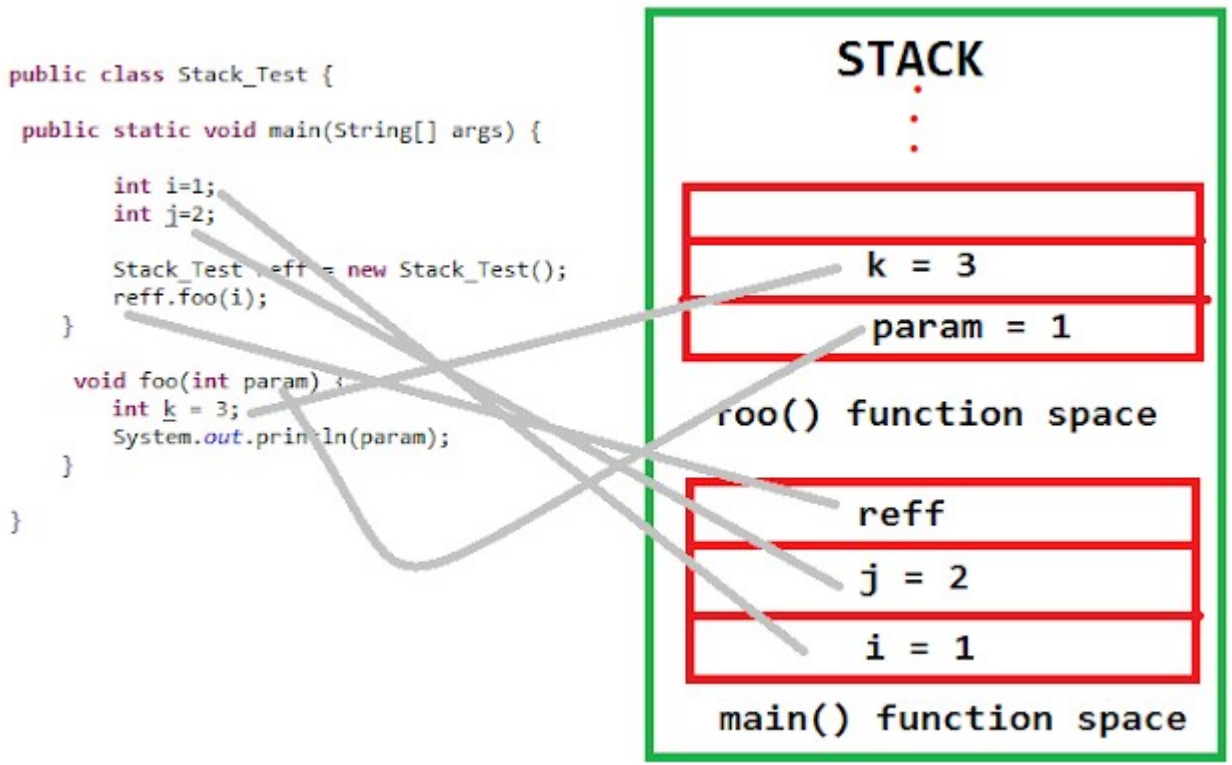


Image Credit: https://uniquejavacoder.blogspot.com/2020/05/java-stack-and-heap-java-memory.html

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 OO
- The 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 is defined
- The lexical scope of a static variable is determined by the class
  - If the class definition is visible to the code, then the variable can be referenced
  - The 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

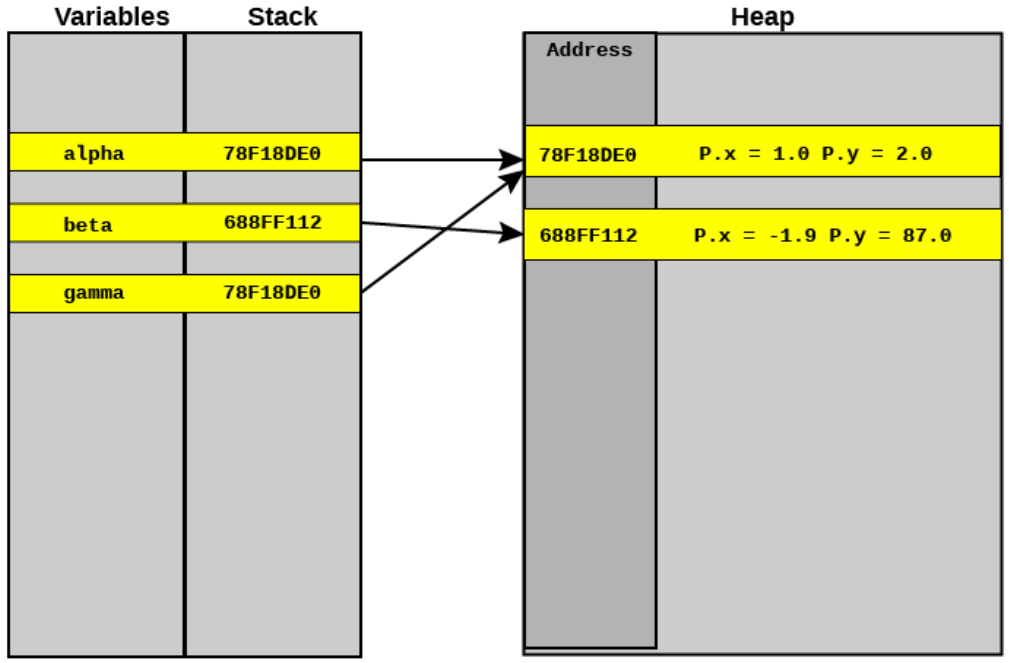
- Managed variables are create by our code
  - All user defined types are managed
  - Strings and arrays are also managed, but will deal with those later
  - More typically, managed variables are called *objects*
- Objects are created on the heap
  - By using the *new* operator
  - *New* returns the 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 something 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 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 *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 2-3

Variable Types


Java™