ALTERNATES TO JAVA REFLECTION AND UNSAFE USAGE

Chandra Guntur

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- **Java Champion**
- **JUG Leader**: NJ JavaSIG, NYJavaSIG and NYJavaSIG Hands-On Workshops
- **Speaker**: Several technology conferences and JUGs
- **Contributor** to the open sourced **eclipse-collections** and **java-katas**
- Active on **blogging** and **tweeting** about Java
- **JCP Executive Committee** secondary representative for BNY Mellon

CODE KATA LINK

https://github.com/c-guntur/java-katas/tree/master/java-handles

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AGENDA

- Java Reflection
  - Usage until now
  - New alternates - A Code Kata
- `sun.misc.Unsafe`
  - Usage until now
  - New alternates - A Code Kata

JRuby

2006-2007

JRuby

CAN THE JVM EASE THE JRUBY (OR ANY OTHER DYNAMIC LANGUAGE) IMPLEMENTATION?

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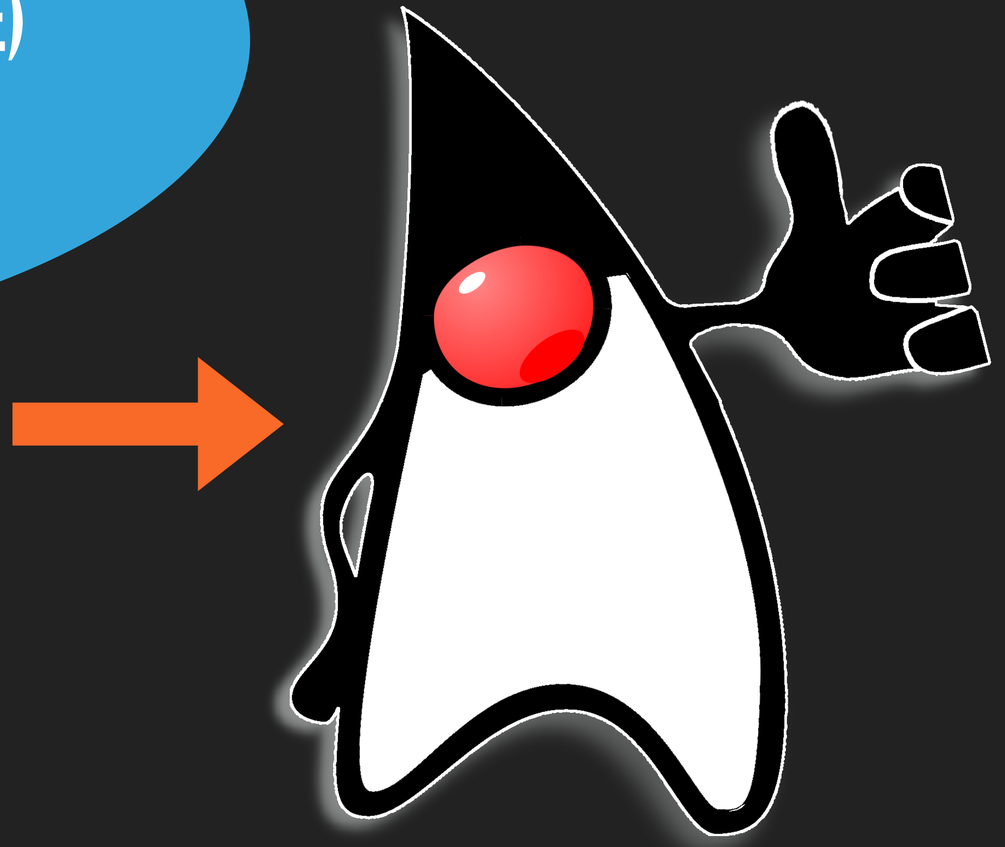
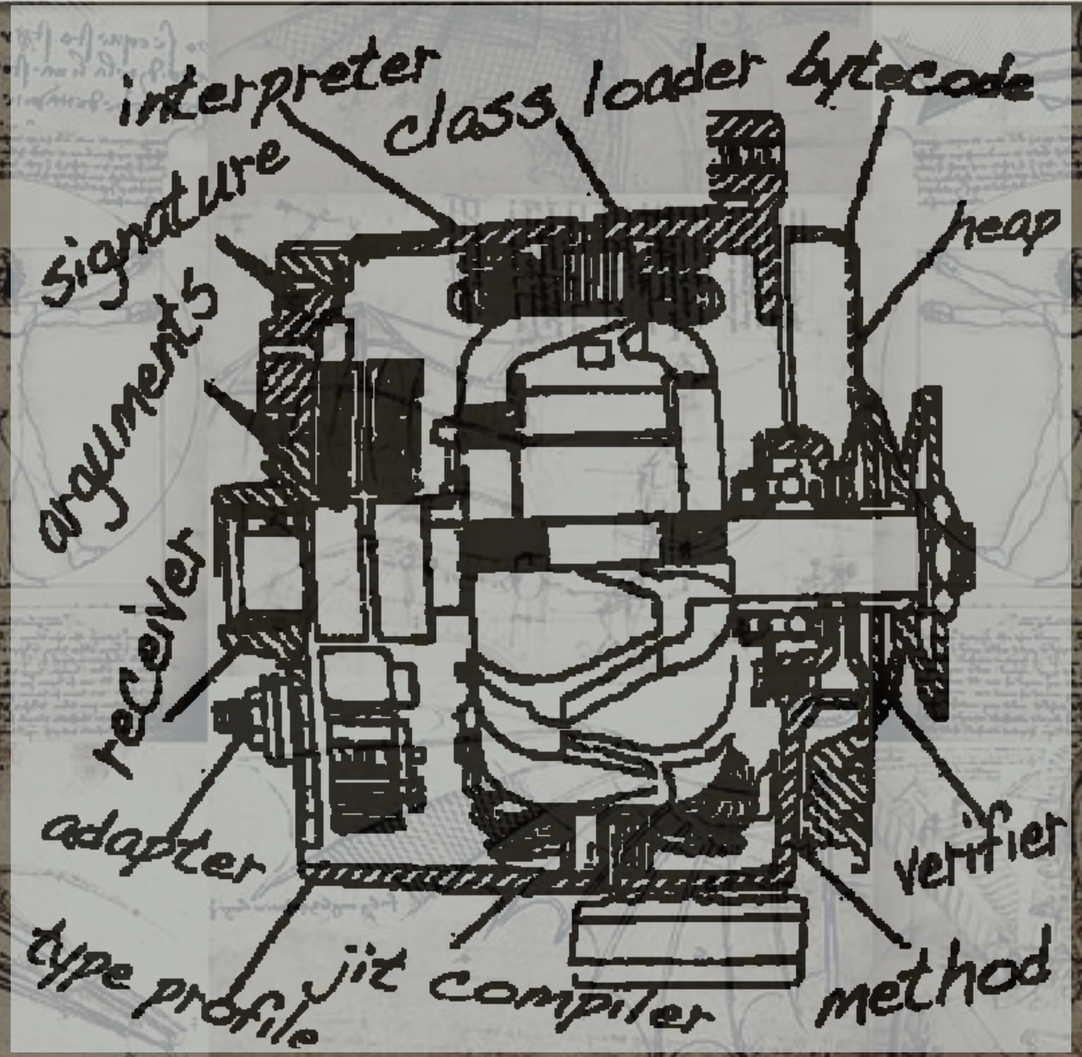


FUTURE ORIENTED CHANGES

IN JAVA

(A STEP BACK IN TIME)

Da Vinci Machine Project



Background Image credit: https://waldinadotcom.files.wordpress.com/2015/04/leonardo-da-vinci-5.jpg

Foreground Image credit: https://openjdk.java.net/projects/mlvm/images/leonardo_vm.png

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Future-Oriented Changes in Java - Circa 2006

- JSR-292 [*] - Multi-Language Virtual Machine
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[*] JSR details: https://www.jcp.org/en/jsr/detail?id=292

[*] Read more at: https://groups.google.com/forum/#!topic/jvm-languages/28Oko4KGiQQ

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- Core features introduced in Java 7:
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REFLECTION

FAIREST IS ~~SNOW WHITE~~ THE DUKE (THE NEW STORY)

Every morning, the Evil Queen asked the Magic Mirror the question: *"Magic mirror in my hand, who is the fairest in the land?".*

The mirror always replied: *"My Queen, you are the fairest in the land."*

The Queen was always pleased with that, because the magic mirror never lied.

But, when **Duke** reached of age, he became as fair as the day and even more fairer than the Queen and when the Queen asked her mirror, it responded: *"My Queen, you are the fairest here, so true. But **Duke** is a thousand times fairer than you."* !


REFLECTION
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- Bypasses accessibility and instantiation rules

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[*] Reflection drawbacks: https://docs.oracle.com/javase/tutorial/reflect/

WHAT CHANGED?

Reflection Replacement: MethodHandles (Java 7)

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- The references are called Method Handles
- A call via a handle is as fast as a statically linked Java call
- A bit more verbose than reflection code

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  - `java.lang.invoke.MethodHandle`
  - `java.lang.invoke.MethodType`

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- Enclosed in a MethodHandles factory class
- Performs access checks and security manager interactions
  - If allowed, creates a method handle reference

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Has several **lookup** methods such as :

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Has several **lookup** methods such as :

- `findGetter`
- `findStaticSetter`
- `findVirtual`
- `findConstructor`
- `...`

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MethodHandle - “Executor”

- Direct executable reference to an underlying method
- Not distinguished by name of method or class
- Immutable and stateless

https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/lang/invoke/MethodHandle.html

MethodHandle - “Executor”

Special invoker methods :

- `invoke`
- `invokeExact`
- `invokeWithArguments`
- `...`

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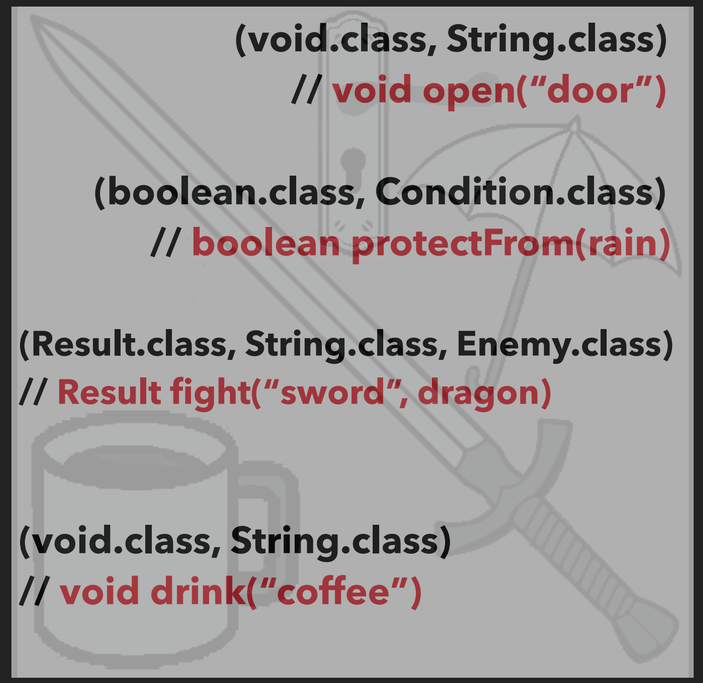
MethodType - “Discriminator”



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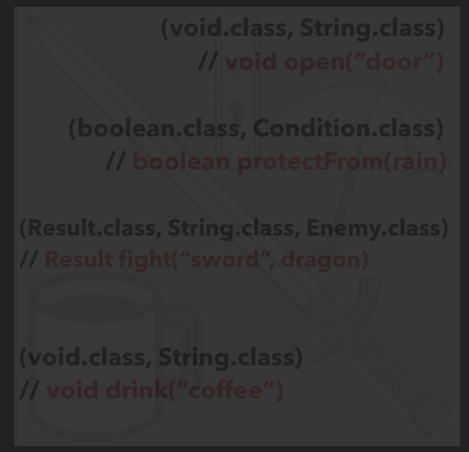

- Represents return type & input parameters of a method :
  - First parameter of a method type is **return type**
  - Other parameters are input **parameter types**
- Immutable

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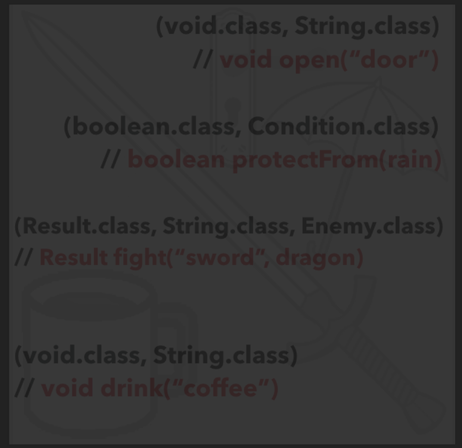

- Primitives, arrays and void (return) values are types :
  - `int.class`
  - `double.class`
  - `void.class`
  - `int[].class`
  - `...`

CODING TIME !

Search: Use `MethodHandles.Lookup` to search for methods

Execute: Use MethodHandle methods to execute the method.

- `invoke()`
- `invokeExact()`
- `invokeWithArguments()`
- …

Get Handle: Acquire a MethodHandle **using**:

- Method **type** approach =>
  - Describe the method to create a `MethodType`
  - `find***()` method to extract a `MethodHandle`

Approach 1

Get Handle: Acquire a MethodHandle using:

- Method **signature** approach =>
  - Get a `Method` instance by name and arity
  - `unreflect()` the method to extract a `MethodHandle`

Approach 2

UNSAFE

HANSEL AND GRETEL AND THE DUKE (THE NEW STORY)

Hansel, Gretel and **Duke** stood stunned for a moment, and then, without caution or hesitation, they ran to the house and began stuffing their faces full of candy.

"What little pretties have come to my house today?" screeched an odd voice.

The **three** stopped short and stared at one another – each was messy and covered in candy.

"Oh, **three** little ones to enjoy!" the voice screeched again. Hansel, Gretel and **Duke** turned and stared at a very small woman with scraggly hair wearing a long pink dress and a purple robe. She was very strange looking and smelled quite funny – a little too sweet.

The old woman then invited Hansel, Gretel and **Duke** into her house.


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- Low level memory information and direct memory access

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- Object, Class, Array, field and static field manipulation
- Avoiding initialization/constructor calls
- Faster serialization/deserialization
- … and many other uses !

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Unsafe Replacement: VarHandle (Java 9)

- JSR-292 led to lightweight references to attributes

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- The references are called VarHandles
- Standard replacements for features in :
  - `java.util.concurrent.atomic.*`
  - `sun.misc.Unsafe`

Unsafe Replacement: VarHandle (Java 9)

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- Field and array index element access
- Memory fences for fine-grained control of memory ordering
- A strong reachability-fence operation for an object

Unsafe Replacement: VarHandles - 4 Goals

Safety

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JVM cannot be placed in a corrupt memory state

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- in both fields and arrays:
  - **Either** content data types must match
  - **Or** content data must be 'castable' to field type

- and in arrays:
  - Array indexes must exist in order to be written to/accessed

GOAL 1

Unsafe Replacement: VarHandles - 4 Goals

Integrity

GOAL 2

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Field access rules cannot be violated

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- Same rules as for `getfield` and `putfield` byte codes

Integrity

GOAL 2

Field access rules cannot be violated

- Same rules as for `getfield` and `putfield` byte codes
- A final field cannot be updated or modified

Unsafe Replacement: VarHandles - 4 Goals

Performance

GOAL 3

Performance

Performance must be similar to `Unsafe` operations

GOAL 3

Unsafe Replacement: VarHandles - 4 Goals

Usability

GOAL 4

Usability

GOAL 4

New API should be:

Usability

GOAL 4

New API should be:

- Friendlier and humane

Usability

GOAL 4

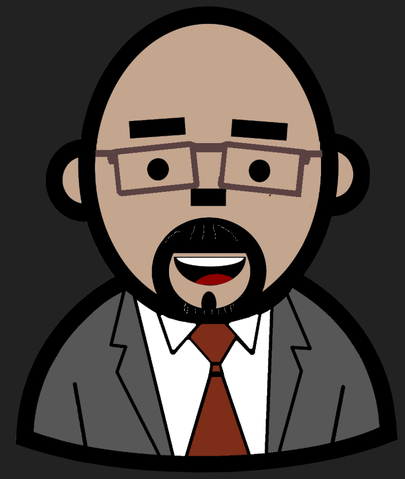
New API should be:

- Friendlier and humane
- More consistent than `Unsafe` APIs

CODING TIME !

- Get a `MethodHandles.Lookup` via :
  - `lookup().in(requestedLookupClass)`
  - `privateLookupIn(targetClass, lookup)`
- Find a `VarHandle` :
  - For fields :
    - `findVarHandle(receiverClass, attributeName, attributeType)`
  - For array elements :
    - `arrayElementVarHandle(arrayClass)`

Thank you !



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Appendix 1 - MethodHandle - Compilation and Execution

- MethodHandles are dynamically & strongly typed. They are immutable and have no visible state.
- Each MethodHandle reports its type via a type descriptor.
- The type descriptor is of type MethodType whose structure is a series of classes.
- The first of the types is the return type (including void.class, for methods with no returns).
- MethodHandles have special invoker methods invoke(), invokeExact() etc.
- The invoke() method can accept a range of calls that match the MethodType.
- Both invoke(), invokeExact() **compile** to an invokevirtual instruction.
- The MethodHandle instance itself is pushed onto the stack prior to the arguments being padded.
- On first execution, links via instruction names symbolically resolved & legality of the call verified.
- Post-linkage, method handle's type is checked to match type descriptor.
- The invoke() may method additionally invoke an asType() to adapt to the defined MethodType.
- The invoke() may thus create a secondary "exact" MethodHandle if a right candidate is found.

Appendix 2 - MethodHandle - Limits

- The JVM imposes on all methods and constructors of any kind an absolute limit of 255 stacked arguments.
- This limit can appear more restrictive in certain cases:
  - A long or double argument counts (for purposes of arity limits) as two argument slots.
  - A non-static method consumes an extra argument for the object on which the method is called.
  - A constructor consumes an extra argument for the object which is being constructed.
  - Since a method handle's invoke method (or other signature-polymorphic method) is non-virtual, it consumes an extra argument for the method handle itself, in addition to any non-virtual receiver object.
- Thus some method handles can't be created, because of the JVM limit on stacked arguments.
- Attempts to create such method handles lead to an IllegalArgumentException.
- In particular, a method handle's type must not have an arity of the exact maximum 255.

Appendix 3 - VarHandle - Compilation and Execution

- VarHandles are dynamically & strongly typed. They are immutable and have no visible state.
- VarHandle provides access to a variable via one of several access modes.
- The access modes include plain read/write access, volatile read/write access, and compare-and-set.
- A VarHandle has
  - a variable type T - the type of variable referenced by this VarHandle
  - a list of coordinate types $CT_1 \ldots CT_n$ - types of coordinate expressions that jointly locate the variable
- VarHandle calls compile to an invokevirtual instruction.
- VarHandles expose getters, setters and compareAndSet/Exchange operations with each access mode.
- In addition VarHandle has static memory fence operations.
- Breaking with Core Reflection, VarHandle access checks are performed only once on creation.
- VarHandles to non-public variables/members of non-public classes should be handled with care.

Appendix 4 - VarHandle - Access Modes

Memory Ordering	Access	Notes
plain	read/write	Atomic only for references and lower primitives (below 32 bit)
opaque	read/write	Only atomic for the same variable
acquire	read	Subsequent load & storage order not changed before access
release	write	Prior load and storage order not changed before access
volatile	read/write	Fully ordered operations on variables in memory

Plain reads and writes guarantee bitwise atomicity for references and primitives under 32 bits.

Opaque operations are bitwise atomic and coherently ordered with respect to access to the same variable.

Acquire and Release operations are Opaque. Acquire reads ordered only after matching Release writes.

Volatile operations are fully ordered with respect to each other.

Appendix 5 - VarHandle - Fences

- Fences are operators that provide fine-grained control over memory ordering.
- VarHandle API provides five static methods for fencing operations.
- Fences are temporary protective barriers around memory.

Fence	Notes
fullFence()	**Loads and stores** before the fencing will not be re-ordered with **loads and stores** after.
acquireFence()	**Only loads** before the fencing will not be re-ordered with **loads and stores** after.
releaseFence()	**Loads and stores** before the fencing will not be re-ordered with **only stores** after.
loadLoadFence()	**Only loads** before the fencing will not be re-ordered with **only loads** after.
storeStoreFence()	**Only stores** before the fencing will not be re-ordered with **only stores** after.