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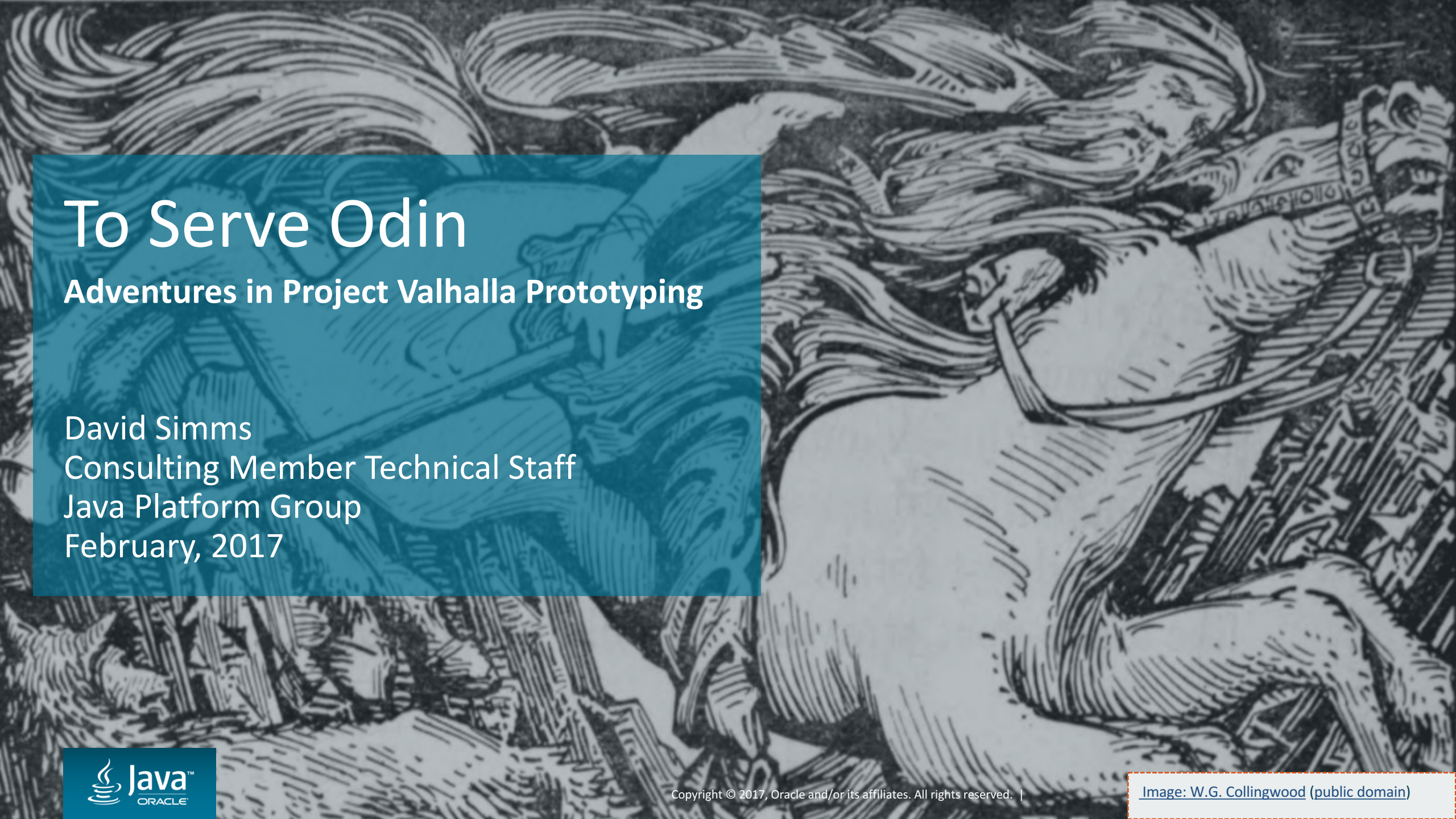

To Serve Odin

Adventures in Project Valhalla Prototyping

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Project Valhalla

Generic Specialization and Value Types

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Introduction

- Project Page: http://openjdk.java.net/projects/valhalla/
  - Links to mailing lists, repository(s), OpenJDK Wiki, Presentations etc...
- Brian Goetz: ”Adventures in Parametric Polymorphism” – JVMLS, Aug 2016
  - https://www.youtube.com/watch?v=Tc9vs_HFHVo
  - http://www.oracle.com/technetwork/java/jvmls2016-goetz-3126134.pdf

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Project Goals

Why…Three major goals

- Align JVM memory layout behavior with the cost model of modern hardware
- Extend generics to allow abstraction over all types, including primitives, values, and even void
- Enable existing libraries **especially the JDK** to compatibly evolve to fully take advantage of these features

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"Valhalla may be motivated by performance considerations, but a better way to view it as enhancing abstraction, encapsulation, safety, expressiveness, and maintainability **without** giving up performance."

– Brian Goetz, Java Language Architect
– http://mail.openjdk.java.net/pipermail/valhalla-spec-experts/

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A War on Two Main Fronts

What…

- Generic Specialization
  - Just say ’no’ to boxing: ”`java.util.Map<long, U>`”
- Value Types
  - Code your own primitive types, ”Codes like a class, works like an int”
  - Pure data, no identity, logically seen as ”pass by value”
  - No polymorphism
  - Immutable
  - Not nullable

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Generic Specialization

Model 3 Implementation

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Model 3

…and counting

- Truth is, we are probably up to ”model 9” at this point
  - Always end up back at ”model 3+some-variant” as far as implementation so far...
- Q: Why is this so hard ? A: Object Model still not done…
  - “`Foo<any U>`”, what is the top type, when “`U=int`” ?
  - “`Foo<int>, Foo<String>`” are these “`Foo`” ?
    - Common super type would be ? ”Any” interface
  - Migration and Compatibility
    - Do parameterized types need to box primitives when dealing with existing code ?
  - Nasty cases keep rearing their ugly heads

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Box of “Any”

```
public class Box<any T> {

    T t;

    public Box() {
    }

    public Box(T t) {
        this.t = t;
    }

    T get() { return t; }

    void set(T t) { this.t = t;}

}
```

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Current Implementation

Model 3 Specializer

- Mostly implemented in Java with the JDK, minor Hotspot VM changes
- At compile time: Javac is free to create a ”template class” with all manor of new prototype class file changes
  - bytecodes, constant pool forms, etc
  - Name mangling scheme: “`Foo<int>`” == “`Foo${I}`” for “specialized class”
- At run time: class load hook within the JVM up-call to the Model 3 Specializer
  - Responsible for converting prototype forms into ”legal” VM class file
  - Dump runtime class generation: “`-Dvalhalla.dumpProxyClasses=<dir>`”

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Realizing Parameterized Types

Constant Pool Specialization

- Transforming bytecode to accommodate all types, is too hard
  - Consider primitive types, value types and objects, bytecode syntax differs for each family.
  - E.g. “`anewarray`” vs “`newarray`”, “`if_acmpeq`” vs “`dcmp…if`”
- Introduced parameterization to the constant pool and specialize the pool
  - New to the constant pool: GenericClass, ParameterizedType, TypeVar, etc…
  - Consolidate required transforms to a few constant pool entries
- Instructions operating on parameterized types, use “generic bytecode” to be specialized later*

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Realizing Parameterized Types

Generic instructions

- **”typed”** bytecode
  - “typed <TypeVarIndex>”
- Prefixes “a” bytecodes, treating those as wildcard instructions
- Transformation when specializing to a concrete type
  - Specializing to int: “typed **<TypeVar>**; areturn” ➔ “nop; nop; nop; ireturn”
  - Attempt to keep the shape of the surrounding bytecode, preserve local/stack size
- *Actual transformation leave some part to the VM: => “typed **I**; areturn”
  - VM Experiment with multiple dispatch tables switched via “typed” bytecode

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Box of “Any” versus Box of int, Constant Pool

```
//class Box<any T>

#8 = TypeVar              // T/Ljava/lang/Obj
#11 = TypeVar             // T/_
#12 = ParameterizedType   // LBox<T/_>
#13 = Class               // "Box<T>"
#15 = NameAndType         // t:T
#16 = Fieldref            // "Box<T>".t:T
#24 = MethodDescriptor    // (T/Ljava/lang/Ob
#29 = MethodDescriptor    // ()T/Ljava/lang/O

LBox;:
  Tvar  Flags  Bound
  T     [ANY]  Ljava/lang/Object;
```

```
//class Box<int>

#8 = Utf8           I
#11 = Utf8          I
#12 = Utf8          LBox$${I};
#13 = Class         // "Box$${I}"
#15 = NameAndType   // t:I
#16 = Fieldref      // "Box$${I}".t:I
#24 = Utf8          (I)V
#29 = Utf8          ()I
```

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Box of “Any” versus Box of int, Bytecode

```
//class Box<any T>.set(T);

public void set(T);
    descriptor: (TT;)V
    flags: ACC_PUBLIC
    Code:
      stack=2, locals=2, args_size=2
         0: aload_0
         1: typed   // T/Ljava/lang/Object;
         4: aload_1
         5: putfield // Field t:T
         8: return
      LineNumberTable:
        line 9: 0
    Signature: #40
// (TT;)V
```

```
//class Box<any T>.set(T);

public void set(T);
    descriptor: (I)V
    flags: ACC_PUBLIC
    Code:
      stack=2, locals=2, args_size=2
         0: aload_0
         1: nop
         2: nop
         3: nop
         4: iload_1
         5: putfield  // Field t:I
         8: return
      LineNumberTable:
        line 9: 0
    Signature: #40
// (TT;)V
```

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“Any” interface and Arrays 2.0

Type injection for kicks

- Model 3 experiment with common super type “any interface”: “Foo<any T>” = “Foo<any>”
- Experiment with Arrays 2.0 ideas, all arrays implement “Arrayish<any T>”
  - Which is itself a generic “any” type…
  - …which needs specialization…
  - …at VM boot time, before the runtime specializer can be run
- Interface dispatch via “extra super” feature
  - VM allowed an extra type to be injected into klass at runtime, kind of a “trait”
- Probably won’t survive ☺

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Arrayish

```
public interface Arrayish<any T> {

    default int arraySize();

    default T arrayGet(int index);

    default void arraySet(int index, T element);
}
```

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Nestmates

One compilation unit, many “crass”, aren’t we in the same class, can I see your bits ?

- Specialization creates multiple types at runtime from a single class
  - “crass” has been a term thrown around
- Difference in Java versus VM access rules
  - Javac today generates bridges to enable access for inner/outer classes
  - Not specific to Valhalla, moving out into JDK10
  - http://openjdk.java.net/jeps/181
- Allow class file to describe “nest members” (Valhalla prototype attribute)

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Value Types

A bucket of bytecodes

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Point Value

```
public __ByValue final class Point {

    final int x;
    final int y;

    private Point(int x, int y) {
        this.x = x;
        this.y = y;
    }

    public int getX() { return x; }
    public int getY() { return y; }

    public boolean isSamePoint(Point that) {
        return this.getX() == that.getX() && this.getY() == that.getY();
    }

    public String toString() {
        return "Point: x=" + getX() + " y=" + getY();
    }

    public static Point createPoint(int x, int y) {
        return __Make Point(x, y);
    }
}
```

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Value Types

Repository State, what is working today

- Q Type descriptors
- “Level-0” prototype bytecodes
  - Prototype Javac support, you can take it out for a drive
- Flattened all the things: arrays, fields, compositions
- Interpreter
  - Calls to C++ code instead of assembler or code generation
- Initial C2 support
- Naïve heap allocation

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Value Types

Repository State, what is not working just yet

- No verifier support, must run with "`-noverify`"
- X86_64 only
- No optimization, no C1
- Primitive fields only
- Object Model – still a can of worms
  - Common super type ? Common descriptor ?
  - Implement Interface ?
  - Boxed values passed through pre-existing code, what is "synchronized(boxedValue)" ?

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bytecodes.hpp

```
_vload                  = 203, // 0xcb
_vstore                 = 204, // 0xcc
_vaload                 = 205, // 0xcd
_vastore                = 206, // 0xce
_vnew                   = 207, // 0xcf
_vreturn                = 210, // 0xd2
_vgetfield              = 211, // 0xd3
_typed                  = 212, // 0xd4
_invokedirect           = 213, // 0xd5
_vdefault               = 214, // 0xd6
_vwithfield             = 215, // 0xd7
_vbox                   = 216, // 0xd6
_vunbox                 = 217, // 0xd7

// JVM Internal…
_fast_qgetfield,
_fast_qputfield,
                                        // 15 value-type bytecodes, yippie…
```

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Value Bytecodes

Some points of interest

- "`vnew`" – offers atomic construction
  - Address current issues with "`new`" and "`invoke init()`", needs all args on stack
- "`vdefault`" – offers simple "all fields are zero" construction
  - Provides some efficiency compare to "`vnew`"
- "`vwithfield`" – C.O.W. field setter
  - Combine with "`vdefault`" to help code patterns like "`p.x += 3`"
- "`invokedirect`" – monomorphic method invocation
- Are not atomic by default*
  - `vaload, vastore, qgetfield, qputfield`

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Current Work

...and what's next

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“typed” Bytecode Experiments

Current Work

- Rename a2b, semantically similar “MH.asType()”
- Replace most of the “v” bytecodes
  - since there are so few free bytecodes
- “extended bytecodes”
  - allow “typed” to switch “BCSet”
  - allows alias existing bytecode
    - Consider “Point”, its 2 int fields can be aliased as a long
    - E.g. “typed Point; aload_0” ➔ “nop; nop; nop; lload_0”

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Thread Local Buffering

Current Work

- Remove naïve heap allocation, reduce GC pressure in general
- Thread local value buffer pages
- Interpreter frame activation records its current
- Simple push/pop model on frame entry/return
- Spill to heap
- Investigating cost of TLGC
  - ‘Cause “jmp” (why couldn’t Java bytecode rid us of “goto” ?!)
  - Looks at Stack/LVT entries, copy those, toss everything else

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Reference Fields in Values

Current Work

- Re-enable embedding oops
- oopmap generation is already there
  - will need further adjustment with value thread local buffering, expose inner oop refs
  - Conditional allocation, could be heap oop, could be value buffer.
- Some further GC barrier considerations
  - GC write barriers don't care if destination is a buffer, so we are "mostly good"
  - Avoid root scan pollution, live Stack/LVT entries (common for TLGC of value buffers)
  - Ensure klass mirror referenced / unreferenced appropriately
- Refactor "`ValueKlass::value_store()`" et al.

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Current Work

- C2
  - Optimizations
  - Integration with value buffering: i2c, deoptimization, etc
- Verifier sanity check
  - Look for obvious holes in the current byte-code, but deferring implementation
- Rebasing to JDK10
  - Last sync to JDK9, was when ? “Merge Bankruptcy”
  - Some of ideas won’t be coming

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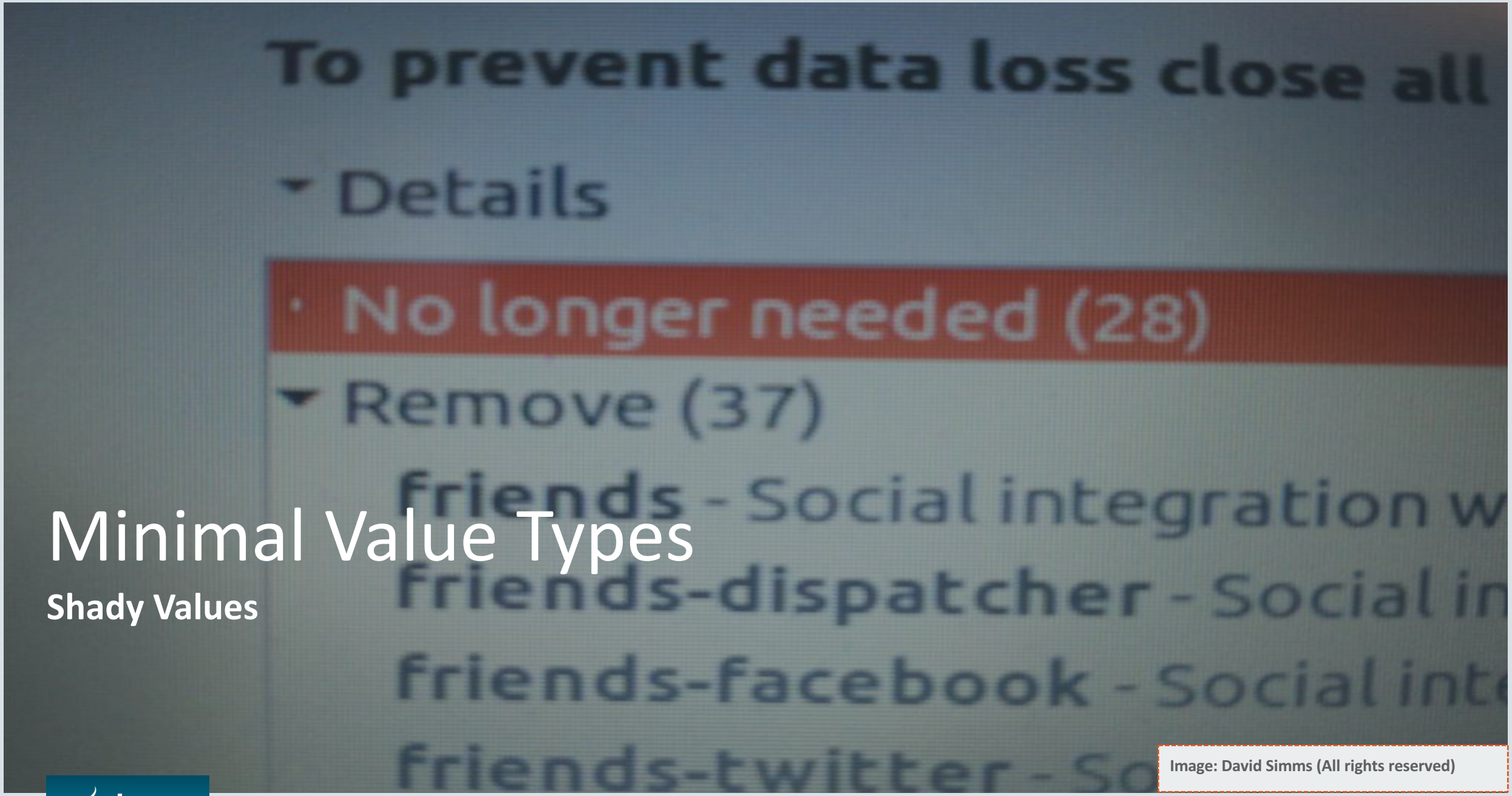

Minimal Value Types

Shady Values

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Minimal Value Types

A path to release

- Up to 15 new byte codes + unfinished type system = shipping with JDK10 ?
  - Ah, yeah, no. Doh !
  - Changes to JLS and JVMS need to be pretty much set in stone…
  - …and the path for getting that done is non-trivial in itself
- Folks have waited a long time, and you have something that walks at least
  - True, and we want to get those bits out the door…

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How do you release a specification compliant JDK/JVM then ?

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Shady Values

Keep it in the shadows…

- The answer to quicken the path to release: make no specification changes
- Hide all the new JVM toys under MethodHandles
  - All new bytecodes become JVM internal, not visible to specification
  - Provide an experimental API that returns a method handle for value type operations
  - Gives end-users enough to play with
- Language: Runtime Annotation `@jvm.internal.value.DeriveValueType`
  - Value Capable Class (VCC), follows same rules as “value-based” classes
- http://cr.openjdk.java.net/~jrose/values/shady-values.html

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Point Value Capable Class

```
@jvm.internal.value.DeriveValueType
public final class Point {

    final int x;
    final int y;

    private Point(int x, int y) {
        this.x = x;
        this.y = y;
    }

    public int getX() { return x; }
    public int getY() { return y; }
}
```

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Derive Value Type (DVT)

Encountering the `DeriveValueType` annotation

- JVM may or may not validate the VCC
  - Similar rules to Value Types and “value-based classes”
- Derive’s a structurally equivalent value type (DVT) which is field compatible with the VCC (Point$Value)
- User can query an API if there is a DVT class associated with VCC
  - j.l.i.MethodHandles support DVT/array classes
- Further API for obtaining and using the DVT, and boxing via VCC
- Supports data only, method invocation limited to VCC
  - Current limitations: primitives only, no composition (MVT1.0)

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jdk.experimental.value.ValueType API

```
public class ValueType<T> {

    // Query methods...
    static boolean classHasValueType(Class<?> x);
    static <T> ValueType<T> forClass(Class<T> x);

    // Class/type query...Useful for j.l.i.MethodHandles
    Class<T> boxClass();
    Class<?> sourceClass();
    Class<?> valueClass();
    Class<?> arrayValueClass();
    Class<?> arrayValueClass(int dims);

    // Operations…next slide…
```

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jdk.experimental.value.ValueType API

```
    // Operations…

    MethodHandle defaultValueConstant();
    MethodHandle substitutabilityTest();
    MethodHandle substitutabilityHashCode();
    MethodHandle findWither(String name, Class<?> type);
    MethodHandle unbox();
    MethodHandle box();
    MethodHandle newArray();
    MethodHandle arrayGetter();
    MethodHandle arraySetter();
    MethodHandle newMultiArray(int dims);

}
```

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Example: Flat array storage…

```
Class<?> VCC = Point.class;
MethodHandles.Lookup lookup = MethodHandles.lookup();

ValueType<?> VT = ValueType.forClass(VCC);
Class<?> vTArrayClass = VT.arrayValueClass();
MethodHandle setMh = MethodHandles.arrayElementSetter(vTArrayClass);
MethodHandle getMh = MethodHandles.arrayElementGetter(vTArrayClass);

//Setup an array...it will be flattened, important to me here...
int arrSize = w * h;
Object arr = MethodHandles.arrayConstructor(vTArrayClass).invoke(arrSize);
for (int i = 0 ; i < arrSize; i++) {
  // Construct VCC, arraySetter will unbox for me...
  Point p = new Point(i, 0);
  setMh.invoke(arr, i, p);
}
// Give me a point...
Point apoint = getMh.invoke(arr, (w-1));
```

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MVT 1.1

Moving forward, stretch goals…

- Open up experimental access to “Valhalla Value Types” (VVT)
  - ability to dynamically generate byte codes which refer directly to QTypes
  - allow methods that operate directly on the value type
- Experiment layout optimizations
- Allow composition / references
- Explore “typed acmp”
- Common descriptor, “P-Type” or “U-Type” experiments

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