Java Futures
Mid 2019 edition

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JAVA EVOLUTION

As Java approaches middle age…

- Java has been around for almost 25 years
  - … and been declared dead many times
- But, Java is still the world most popular programming platform
  - And we want Java to be vibrant and relevant for the next 25 years too
- We plan to (continue to) do this by
  - Staying relevant to the problems people want to solve
  - Staying relevant to the hardware people want to run on
  - Keeping the promises we've made to our users
  - Staying consistent to our principles
  - Co-evolve the JVM and the Java Language to work together

Keeping our promises

- The prime directive is: **Compatibility**
- Java is successful today because code written 25 years ago *just works*
  - Keeping our promises is how we keep our users
  - Even though this takes longer, costs more, and constrains our options
- Example: Generics
  - Codebases could gradually migrate to generics
    - A given class could be generifed now, later, or never
    - Graceful degradation at the boundary
    - No flag days
- Example: Lambdas
  - Existing libraries using single-method interfaces could automatically work with lambdas, without recompiling

First, do no harm

- Language features are forever
  - Each language feature interacts with every other (including future ones!)
  - Must pick very carefully
- If we don't know the right answer, the right answer is:
  - ***DO NOTHING (for now)***
  - Generics got this right – waited 10 years until we had the right story, rather than reaching for something like C++ templates
  - Lambdas too – we'd probably not be very happy if we'd implemented the proposals circa 2005-2006
- Whatever the feature, the goal is the same
  - *Make it easier to build and maintain reliable programs*

So, we're clearly not done

- All of this is to say: we're not done evolving Java
- Java needs to continue to evolve to
  - Adapt to new problems
  - Adapt to new hardware
  - Meet ever-rising developer expectations
- We'll never be done
  - But we're also mindful that a language can get "full"
  - Hence, we have to pick and choose features carefully

IN THE LAST YEAR (OR SO) …

Rapid Release Cadence

Feature releases every 6 months

- Moved to a 6-month, time-driven release cycle
  - Already delivered three (almost four!) releases under this plan!
- Earlier releases had been feature-driven, with releases every 2-4 years
  - Difficult to accurately plan release dates
  - Perception of slow progress
  - Small features “stuck” behind big ones
  - Significant release management overhead
- More agile, lower overhead
  - Features are late-bound to a release, when they are ready
  - OK to miss the train

New Release Cadence

9, 10, 11, 12 …

- Java 9 – released Sept 2017
  - 3 ½ years in the making
  - Over 90 JEPs
  - Somewhat disruptive release…
- Java 10 – March 2018 (new, and already old!)
  - 6 months in the making, 12 JEPs
- Java 11 – Sept 2018
  - First “LTS” release under new cadence, 17 JEPs
- Java 12 – March 2019
- Java 13 – already in “rampdown”
- Java 14 – already under development

Preview Features

Provisional status for language and platform features

- Because language features are forever, we have to get them right
  - With 2-4 year release cycles, that's a lot of time to get feedback
  - With 6mo release cycle, there's less time
  - We often get limited feedback on EA builds
- New risk-reduction mechanism: *Preview Features*
  - Complete, fully-specified features – not "experimental"
  - Opportunity to gather broader feedback, while there's still time to pull the emergency brake cord
  - Should "graduate" quickly to permanent features, or be withdrawn
  - Risky to use in production, as they may change (or even go away!)
- *Most language features will go through a round of Preview*

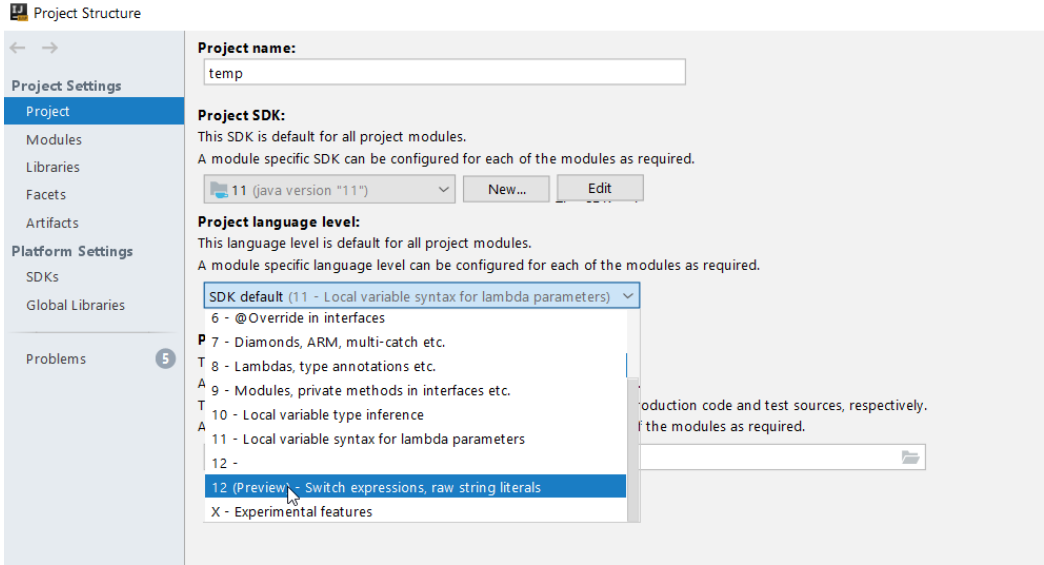
Preview Features

Provisional status for language and platform features

- Preview features described in JEP 12
  - Requires opt-in on compiler + launcher to turn them on

```
javac –enable-preview –release 12 Foo.java
java –enable-preview Foo
```

- IDE support too!



Current Initiatives

- Project Amber
  - Adapting to rising developer expectations
  - Right-sizing language ceremony
- Project Valhalla
  - Adapting to modern hardware
  - Value types, generic specialization
- Project Loom
  - Adapting to rising scale expectations
  - Fibers and continuations
- Project Panama
  - Better interop with native code and data
- … and more

Local Variable Type Inference

Added In Java 10 (three versions ago already!)

- Extend type inference to local var declaration (still just static typing)

```
URL url = new URL("http://www.oracle.com/");
URLConnection conn = url.openConnection();
Reader reader = new BufferedReader(
        new InputStreamReader(conn.getInputStream()));
```

- becomes

```
var url = new URL("http://www.oracle.com/");
var conn = url.openConnection();
var reader = new BufferedReader(
        new InputStreamReader(conn.getInputStream()));
```

- Gives users option to elide type information
  - Frequently, variable name is more useful than the type anyway

Local Variable Type Inference

- For local variables only (not fields or method return types)
- Not “just” syntactic sugar
  - Some types are not denotable
    - Intersection types, capture types, anonymous class types
  - These get special treatment
- `var c = this.getClass()`
  - `Class<cap<? extends ThisClass>>`
- `var nums = List.of(1, 2, “three”)`
  - `List<? extends Serializable & Comparable<...>>`

Local Variable Type Inference

- LVTI was one of the most commonly requested features
- …but there was also significant (and vocal) angst about it
  - "Will enable bad developers to write bad code"
  - "Just giving in to fashion"
- So far, seems to be working fine
  - Takes some time for people to get used to something new
  - Takes time to fully understand how a new feature will affect how we code
  - Takes some time for best practices to emerge
    - `http://openjdk.java.net/projects/amber/LVTIstyle.html`
    - `http://openjdk.java.net/projects/amber/LVTIFAQ.html`
  - We expect to publish similar documents for most new features

CLEARED FOR TAKE-OFF

Switch Enhancements

Preview feature in 12 + 13

- A significant fraction of `switch` statements want to be expressions
  - Assign to a common target in each arm
  - Unnecessarily indirect, error-prone
- The need to "break" on each case is irritating
  - And worse, error-prone
- Been exploring `switch` enhancements through *pattern matching*
- JEP 325 “sediments out” some of these enhancements
  - Expression form of `switch`
  - Single-consequence, fallthrough-free form of `case` for statement switches
  - Streamlining multiple case labels

Switch Enhancements

Typical use of switch to simulate an expression

```
int numLetters;
switch (day) {
    case MONDAY:
    case FRIDAY:
    case SUNDAY:
       numLetters = 6;
       break;
    case TUESDAY:
       numLetters = 7;
       break;
    case THURSDAY:
    case SATURDAY:
       numLetters = 9;
       break;
    case WEDNESDAY:
       numLetters = 10;
       break;
    default: throw new UnexpectedDayException(day);
}
```

Switch Enhancements

Expression switch, using simplified case labels

```
int numLetters
    = switch (day) {
        case MONDAY, FRIDAY, SUNDAY -> 6;
        case TUESDAY -> 7;
        case THURSDAY, SATURDAY -> 8;
        case WEDNESDAY -> 9;
        // no default needed
    };
```

Switch Enhancements

What's new?

- Two orthogonal enhancements to switch
  1. Can use `switch` as either expression or statement
     - Expression switches must be exhaustive
     - In expression switches, break takes a value (`break "foo"`)
  2. Streamlined case clauses (`case` label `->` consequence)
     - Single consequence (only one thing on RHS), but can be a block
     - No fallthrough allowed
     - Can specify multiple labels on one line
     - Break rarely needed (unless using blocks)
     - Works with both expression and statement forms
- (And ready for pattern matching, when it's ready)

Multi-line String Literals

Preview feature in 13

- Multi-line strings require quotes and concatenation on each line
  - Error-prone for snippets of JSON, SQL, HTML
  - Manual mangling → introduces errors, harder to read
- If we could just cut and paste in a snippet of JSON..
  - Easier to read, eliminates places for bugs to hide
- Originally was going to be a preview feature for 12
  - But was withdrawn and revised

Multi-line String Literals

```
String html = "<html>\n" +
              "  <body>\n" +
              "    <p>Hello World.</p>\n" +
              "  </body>\n" +
              "</html>\n";
```

Multi-line String Literals

```
String html = """
..............<html>
..............   <body>
..............     <p>Hello World.</p>
..............   </body>
..............</html>
              """;
```

ON THE BOARD

Pattern matching

Phase I: Type patterns in instanceof (JEP 305)

- We write test-and-extract code all the time

```
if (obj instanceof Integer) {
    int intValue = ((Integer) obj).intValue();
    // use intValue
}
```

- Type name is repeated in both instanceof test and cast
  - Irritating, error-prone
  - Obfuscates business logic
- Yes, we could do flow typing
  - But there's a better answer: *pattern matching*
  - A *pattern* fuses testing, conditional extraction, and binding to variables

Pattern matching

Type patterns in instanceof

- We can write a *type pattern* as a type name, plus a variable name:
  - `Integer intValue`
  - Looks like a variable declaration (not by accident)
- You can put a pattern on the RHS of `instanceof`
  - Now can rewrite our test-and-extract code to use type patterns

```
if (obj instanceof Integer intValue) {
    // use intValue
}
```

- Other kinds of patterns too, and other constructs that can use them
  - Type patterns in instanceof will be first
  - Nearly 100% of casts will just disappear

Pattern matching

Type patterns in instanceof

- Pattern matching works nicely with short-circuiting boolean AND (&&)
  - Almost all `equals()` methods can become a single expression
  - Simplifies control flow
  - Binding variables only in scope where they would be “definitely assigned”

```
public boolean equals(Object o) {
    return (o instanceof ThisClass t)
        && this.size == t.size
        && Objects.equals(this.name, t.name);
}
```

Pattern Matching

Phase II: Type patterns in switch

```
String formatted = "unknown";
if (constant instanceof Integer) {
    int i = (Integer) constant;
    formatted = String.format("int %d", i);
}
else if (constant instanceof Byte) {
    byte b = (Byte) constant;
    formatted = String.format("byte %d", b);
}
else if (constant instanceof Long) {
    long l = (Long) constant;
    formatted = String.format("long %d", l);
}
else if (constant instanceof Double) {
    Double d = (Double) constant;
    formatted = String.format("double %f", d);
}
// Short, Character, Float, Boolean
else if (constant instanceof String) {
    String s = (String) constant;
    formatted = String.format("String %s", s);
}
```

Pattern Matching

Type patterns in switch

```
String formatted;
switch (constant) {
    case Integer i:
        formatted = String.format("int %d", i);
        break;
    case Byte b:
        formatted = String.format(“byte %d", b);
        break;
    case Long l:
        formatted = String.format(“long %d", l);
        break;
    case Double d:
        formatted = String.format(“double %f", d);
        break;
    case String s:
        formatted = String.format("String %s", s);
         break;
    // Short, Character, Float, Boolean
    default:
        formatted = "unknown";
}
```

Pattern Matching

Type patterns in expression switch

```
String formatted =
    switch (constant) {
        case Integer i -> String.format("int %d", i);
        case Byte b    -> String.format(“byte %d", b);
        case Long l    -> String.format(“long %d", l);
        case Double d  -> String.format(“double %f", d);
        case String s  -> String.format("String %s", s);
        // Short, Character, Float, Boolean
        default -> "unknown";
    }
```

Records

“Plain old data” classes

- Many classes are just “dumb” aggregating wrappers for some data
  - Well-understood how to model data as objects
  - But, modeling overhead is high
  - Lots of tedious, error-prone boilerplate code
    - Constructors, accessors, Object methods
- Claim: this boilerplate is needed because we’re writing at the wrong level of abstraction
  - We’re writing classes, which are very general
  - We need a way of saying “this class is merely a container for this data”
  - By giving up the flexibility to decouple representation from interface contract, compiler can safely fill in the boilerplate
  - Because we’ve already communicated the semantics

Records

Many classes are just “dumb data holders”

```
class Point {
    final int x;
    final int y;
}
```

```
class Point {
    public Point(int x, int y) {
        this.x = x;
        this.y = y;
    }

    @Override
    public boolean equals(Object o) {
        if (this == o) return true;
        if (o == null || getClass() != o.getClass())
            return false;

        Point point = (Point) o;
        if (x != point.x) return false;
        return y == point.y;

    }

    @Override
    public int hashCode() {
        int result = x;
        result = 31 * result + y;
        return result;
    }

    @Override
    public String toString() {
        return "Point{x=" + x + ", y=" + y + '}';
    }
}
```

Records

- Records give us some pleasant boilerplate reduction
  - But are not *about* boilerplate
  - A record says, declaratively: “I am a simply a carrier for my data”
  - The boilerplate reduction derives from this semantic commitment
  - Allows compiler to infer state-driven methods – and more (stay tuned)
- Similar to the trade we make with enums
  - Give up control over instance creation
  - Gain a lot of functionality for free – because we made a semantic concession

Sealed Types

- Records give us one half of *algebraic data types* (product types)
- The other half (sum types) is useful too!
- A sum type is a discriminated union
  - Shape = Circle | Rect
- Allows compiler to reason about exhaustiveness
  - “A Shape is either a Circle or a Rect”
- A sealed type may only be extended by a limited set of types

Sealed Types

```
record Point(int x, int y) { }

sealed interface Shape { }

record Circle(Point center, int radius) implements Shape { }
record Rect(Point ll, Point ur) implements Shape { }
```

Pattern Matching, again

Phase III: Deconstruction patterns, nested patterns, and more

- Records and pattern matching go very well together
  - We can freely decompose a record into its data
- A *deconstruction pattern* is like the opposite of a constructor
  - Performs a type test, and if it passes, extracts and binds components

```
if (shape instanceof Circle(var center, var radius)) {
    // use center, radius
}
```

- Deconstruction patterns are class members, just like constructors
  - We're not magically guessing based on field names
  - Classes designed for deconstruction would provide a deconstructor
  - Records will get them for free

Pattern Matching

Deconstruction patterns

- Deconstruction patterns can work in switch too
  - And will work nicely with sealed classes

```
Shape s = ...
Float area = switch (s) {
    case Circle(var center, var r) -> PI * r * r;

    case Rect(Point p1, Point p2)
        -> (p2.x – p1.x) * (p2.y – p1.y);

    // Exhaustive switch over sealed type, no default needed!
    default -> ...
}
```

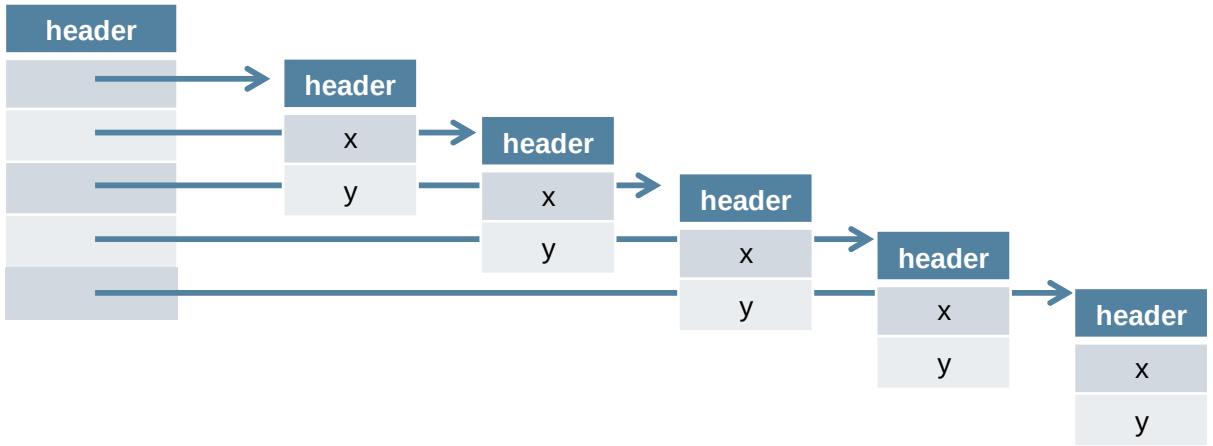
Project Valhalla

- Project Valhalla aims to *reboot the layout of data in memory*
- Why is this so important?
- Over the past 25 years, hardware has changed a lot
  - Relative cost of memory fetch vs arithmetic has increased by 200-1000x
  - Indirections (pointer fetches) are hazardous to performance
- Java data structures are so "pointery" because of *object identity*
  - Identity is needed for polymorphism, mutability, locking
  - Not all objects need that!
  - But all objects pay for it

Data Layout

The data layout we have

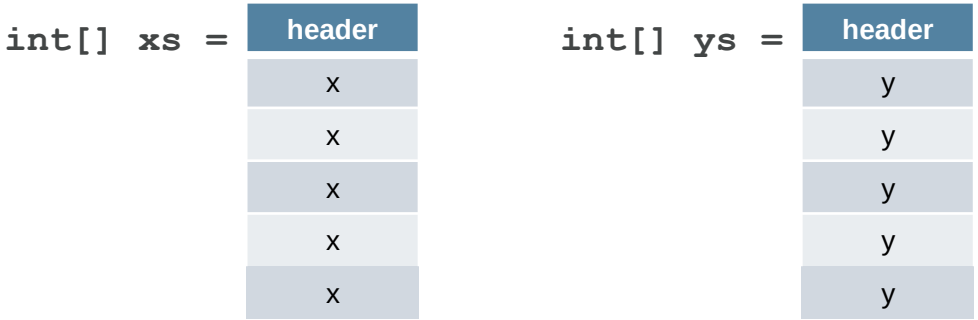
```
final class Point {
    final int x;
    final int y;
}

Point[] pts =
```



Data Layout

What we don't want people to do

- Some developers will do this …

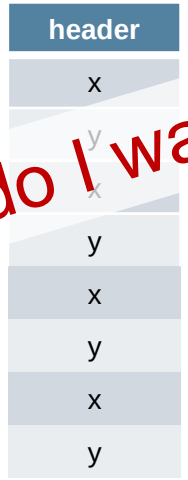


  - Less readable, more error-prone → less maintainable
- Stems from bad choice: "abstraction or performance, pick one"
- But, we can't automatically figure out that a data structure will never rely on identity
  - Need some help from the programmer

Data Layout

The data layout we want

```
inline class Point {
    int x;
    int y;
}

Point[] pts =
```



What code do I want to write to get this layout?

Value Types

Our starting point

- Value types are “pure data” aggregates
  - Just data, no identity
  - Equality comparison based on state (since there is no identity)
  - No representational polymorphism (superclasses or subclasses)
  - Not mutable
  - Not nullable*
- By giving up on identity, mutability, polymorphism, we get…
  - Values *routinely flattened into arrays, other values, objects*
  - No object header needed
  - Aggregates (with behavior) that have runtime behavior of primitives

*Some possible relaxation may be needed here for migration compatibility

Value Types

- But, unlike primitives
  - Can have methods, fields
  - Can implement interfaces
  - Can use encapsulation to hide representation
  - Can be generic
- General rubric for answering “how would it work” questions
  - “What Would Int Do”
- Could equally describe them as
  - Faster objects (with restrictions)
  - User-defined primitives (with fields, methods, encapsulation, etc)

Codes like a class, works like an int

Value Types

Who wants value types?

- Application writers
  - Can reason about locality and footprint of data-intensive code
- Library writers
  - Efficient and expressive implementations of smart pointers, numerics, cursors, value-wrappers like `Optional`
  - More efficient collections
- Compiler writers
  - Efficient substrate for language features like tuples, multiple return, built-in numeric types, wrapped native resources
- Everyone wants value types!

Project Valhalla

Current Status

- Been running more than four years
  - In that time, we've built five rounds of prototypes
  - Each aimed at investigating a particular aspect of the problem
- The current prototype ("LW1") has validated the VM underpinnings
  - Flattened layout
  - JIT optimizations
  - Enough language support
- The next prototype ("LW2") should be good enough for experimentation
  - Including erased generics over values
  - But not (yet) specialized generics over values
  - EA soon!

Project Valhalla

Sample results

- Consider matrix multiplication with complex elements
  - How do we model Complex? With a class

```
public class Complex {

    private final double re;
    private final double im;

    ...

    public Complex add(Complex that) {
        return new Complex(this.re + that.re, this.im + that.im);
    }

    public Complex mul(Complex that) {
        return new Complex(this.re * that.re - this.im * that.im,
                           this.re * that.im + this.im * that.re);
    }
}
```

Project Valhalla

Sample results

- We can multiply these in the obvious way
  - But with lots of allocation and indirection

```
public Complex[][] multiply() {
        int size = A.length;
        Complex[][] R = new Complex[size][size];
        for (int i = 0; i < size; i++) {
            for (int j = 0; j < size; j++) {
                Complex s = new Complex(0, 0);
                for (int k = 0; k < size; k++) {
                    s = s.add(A[i][k].mul(B[k][j]));
                }
                R[i][j] = s;
            }
        }
        return R;
    }
}
```

Project Valhalla

Sample results

- JMH benchmark results (mainstream i7 system)
  - Take with appropriate skepticism

Metric	Boxed	Value	Factor
Time/op (ms)	3609	298	12.1
Allocation/op (MB)	3823	3.8	1006
Instructions	7.8G	2.5G	3.1
Instructions/cycle	1.02	2.63	2.6

Summary

Lots of stuff in the pipeline!

- Amber already delivering
  - LVTI, Expression Switch
- Lots more coming
  - Records, sealed types, pattern matching
- Valhalla starting to bear fruit
  - After years in the lab, getting solid results with real code
  - EA builds in the next year
- Panama and Loom also making tremendous strides
- Come back next year to gauge our progress!

Q & A