Processing Java UDFs in a C++ Environment

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Programming languages split

JVM-based data analytics ecosystem

liberal use of UDFs

APACHE hadoop

APACHE Spark™

Flink

Software components that do not use the JVM

“native code”

VERTICA

Wildfire

- HTAP prototype from IBM Research [CIDR2017]
- C++ columnar engine
- Spark as user-facing front end
- data analytics through SparkSQL queries
- SparkSQL queries can contain Scala UDFs

Goal: Execute Scala UDFs inside SparkSQL queries on the Wildfire C++ engine.

Java Native Interface

JVM

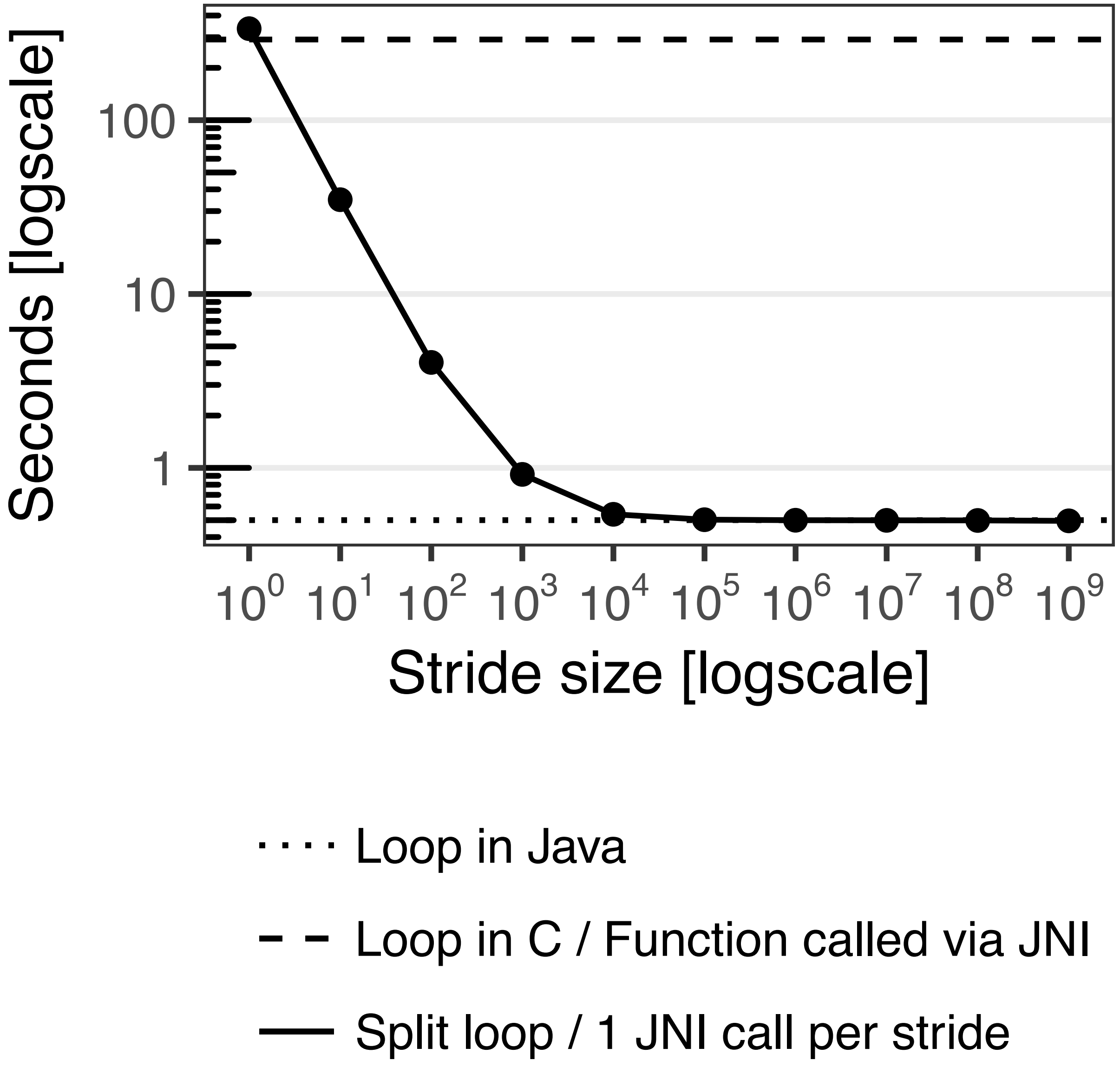
Java Native Interface (JNI)

native code

JNI overheads

```
int udf(int i) {
    return i;
}
```

- Simple Java function called in a loop
- 1 billion iterations
- JNI overhead: 2 orders of magnitude
- Splitting the loop (strided execution) hides the overhead



- JNI calls have significant overhead
- Execute tuple-based UDF in a strided fashion

SparkSQL UDFs

Usage in Spark

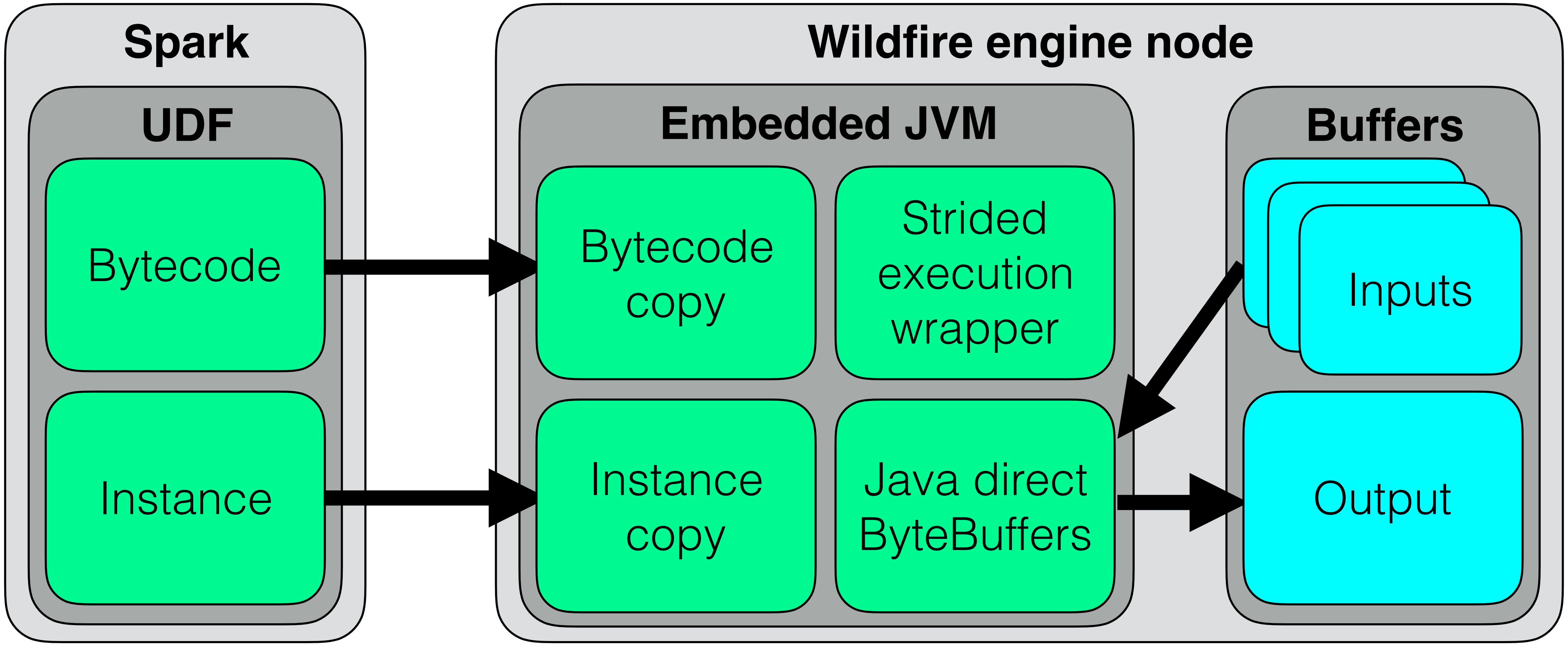
```
var offset = 10
sqlContext.udf.register("add_offset", (i: Int) => i + offset)
sqlContext.sql("SELECT add_offset(i) FROM table").show()
```

Java class representation

```
public final class SparkProgramm$$anonfun$run$1
    extends scala.runtime.AbstractFunction1$mcII$sp
    implements scala.Serializable {
  public SparkProgram$$anonfun$run$1(scala.runtime.IntRef);
  public final int apply(int);
  ...
}
```

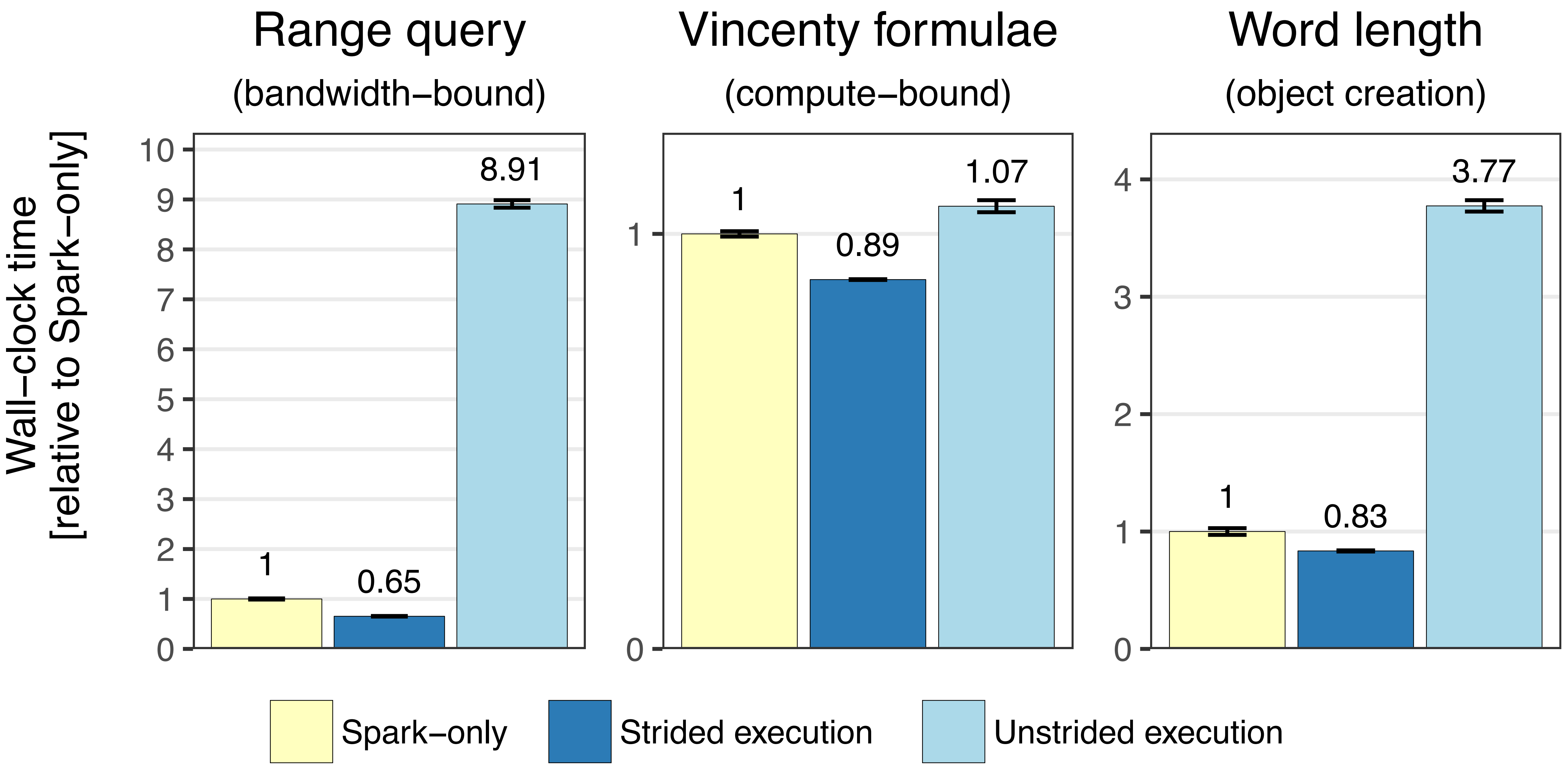
SparkSQL UDFs represented both as Java class and instance.

Embedded JVM



- Instantiate UDF in embedded JVM
- JIT-compile strided execution wrapper
- Wrap engine buffers as Java direct ByteBuffers

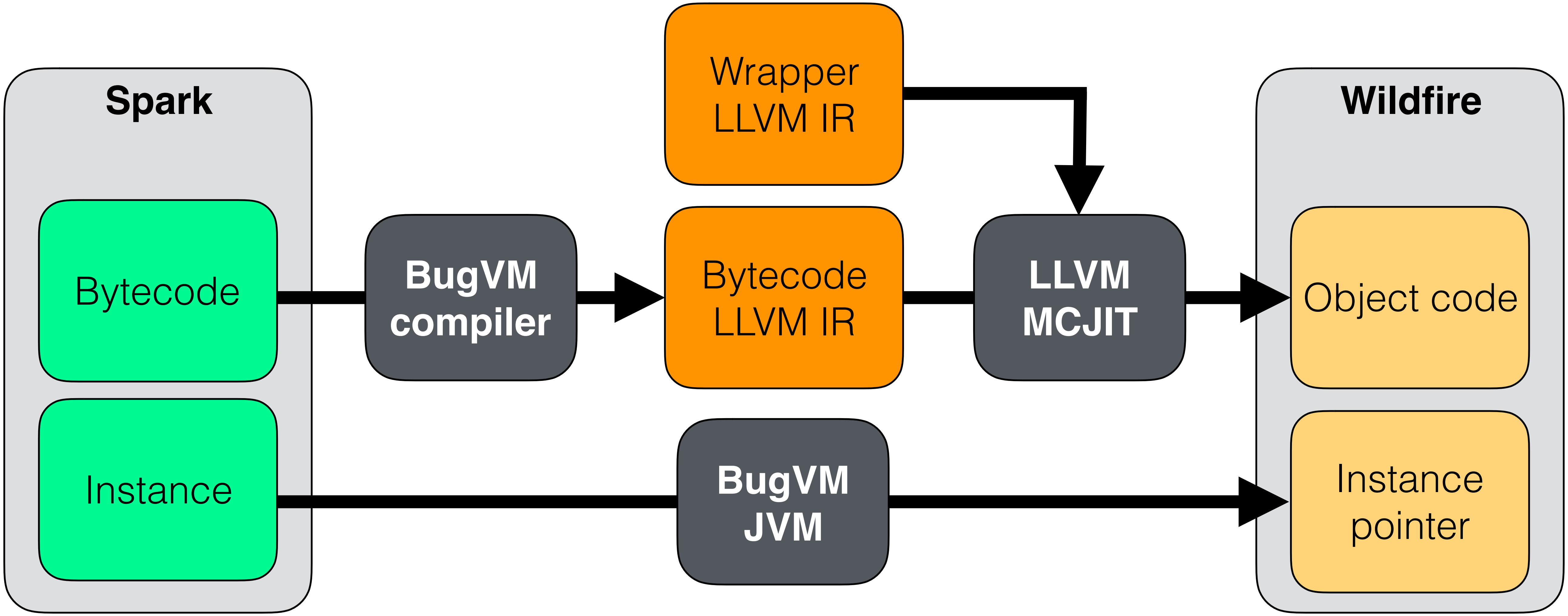
Embedded JVM performance



- Comparable performance to execution in Spark
- Strided execution is key to fast performance

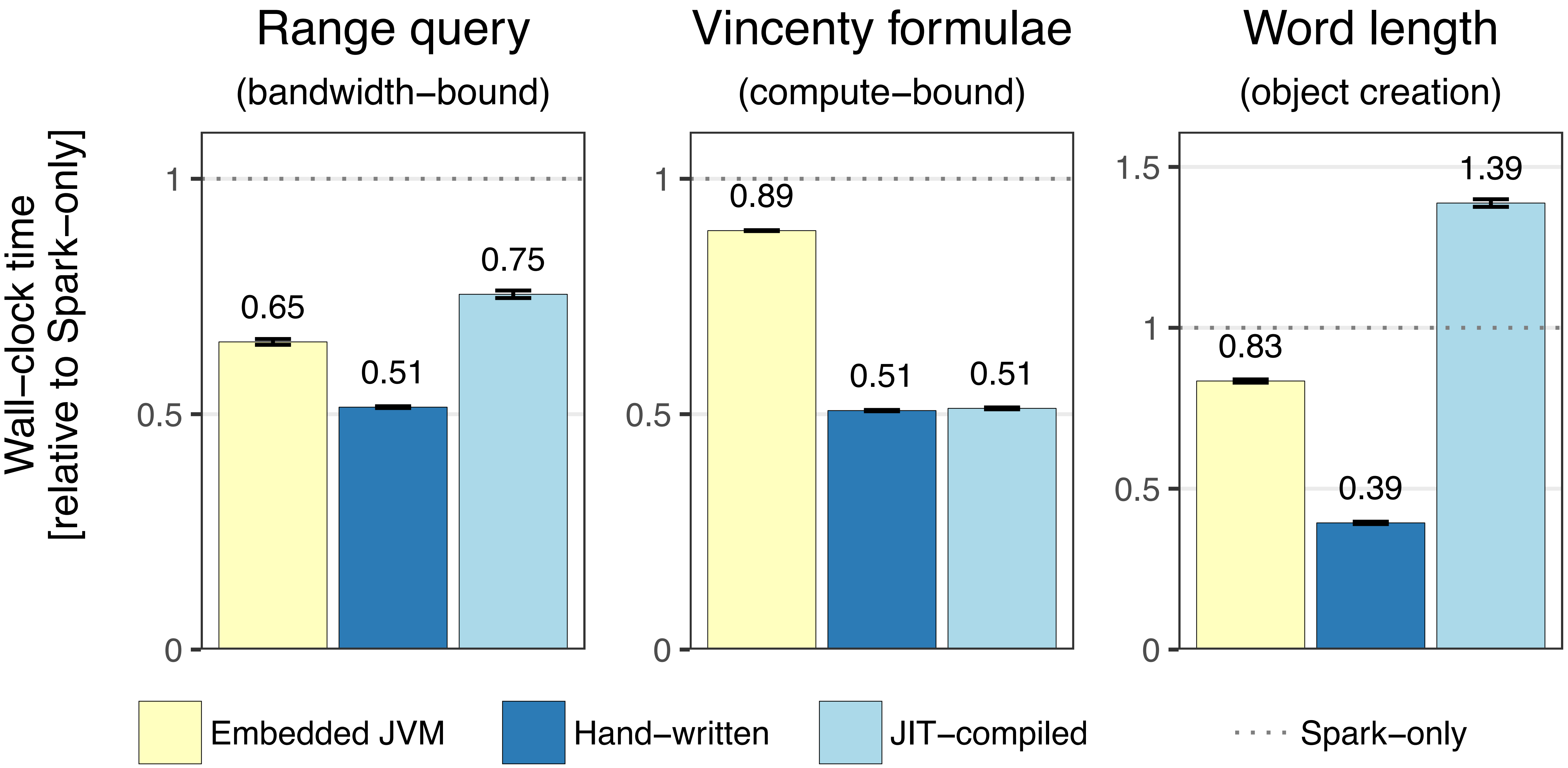
Can we do better?

JIT compilation to machine code



- Compile bytecode to LLVM IR
- Generate wrapper LLVM IR
- Link both to object code
- Deserialize instance
- Dynamically load and execute object code

JIT compilation performance



Compilation to machine code is beneficial if UDF is computationally heavy and does not create objects.

Word length UDF optimizations

UDF wrapper

```
for $i$ ← 1 to size of input do
    javaString ← CreateJavaString($input_i$)
    $output_i$ ← WordLengthUdf(javaString)
    CheckForJavaException()
    ReleaseJavaObject(javaString)
end
```

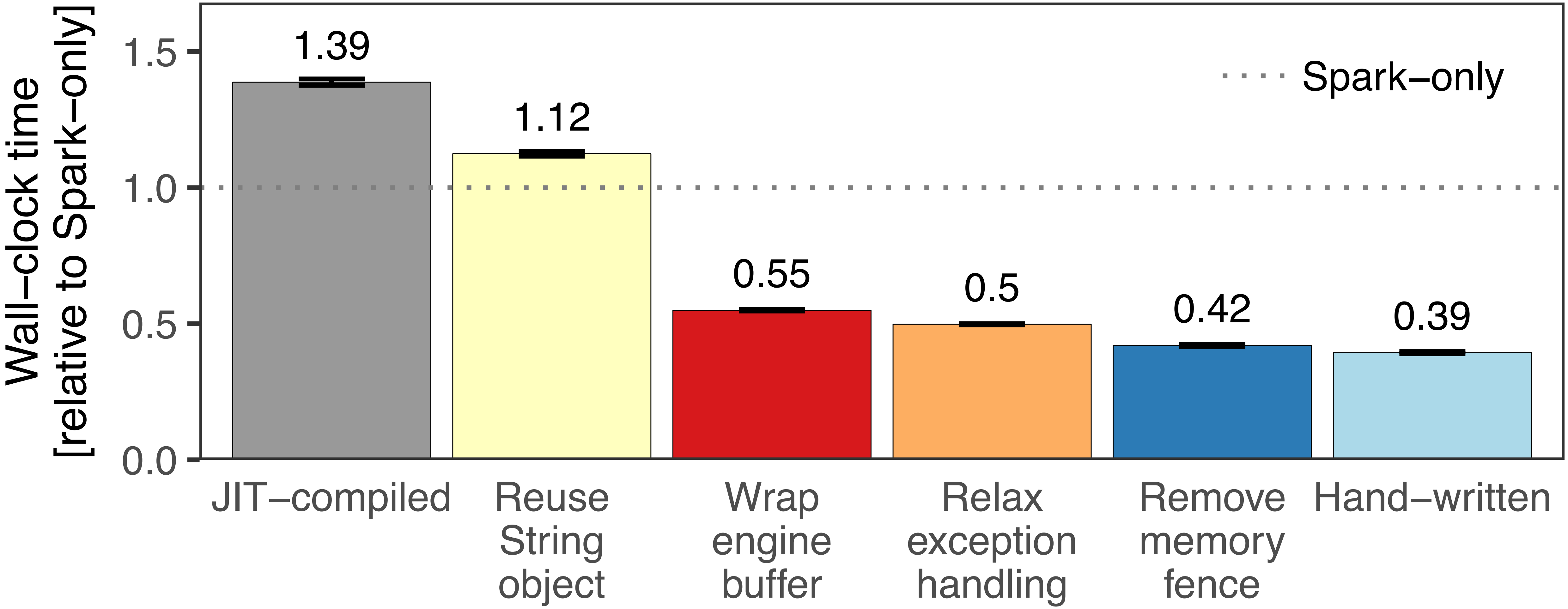
Optimizations

1. Reuse *javaString* object
2. Eliminate data copies when creating *javaString*
3. Remove memory fence
4. Relax exception handling

These optimizations violate Java language guarantees (e.g., immutability of Strings)!

We can apply them because we know that the UDF does not leak or retain the String object.

Word length UDF performance



These optimizations violate Java language guarantees!

Summary

- Transparent strided execution of tuple-based SparkSQL UDFs inside a C++ engine
- Comparable performance to execution in Spark
- Java direct ByteBuffers simplify passing data between C++ code and the embedded JVM
- Compilation to machine code is beneficial if UDF is computationally heavy and does not create objects

Backup

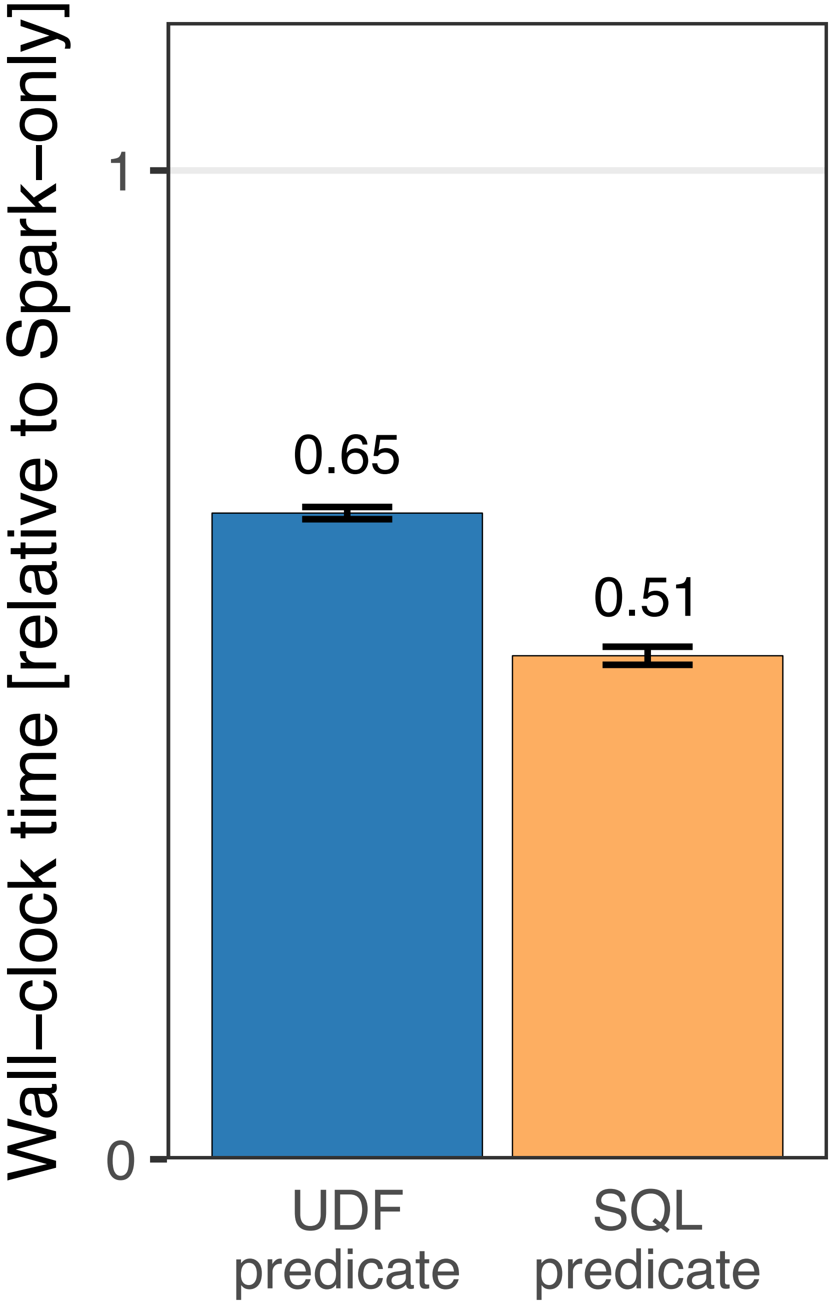
Comparison with SQL

Range query with UDF predicate

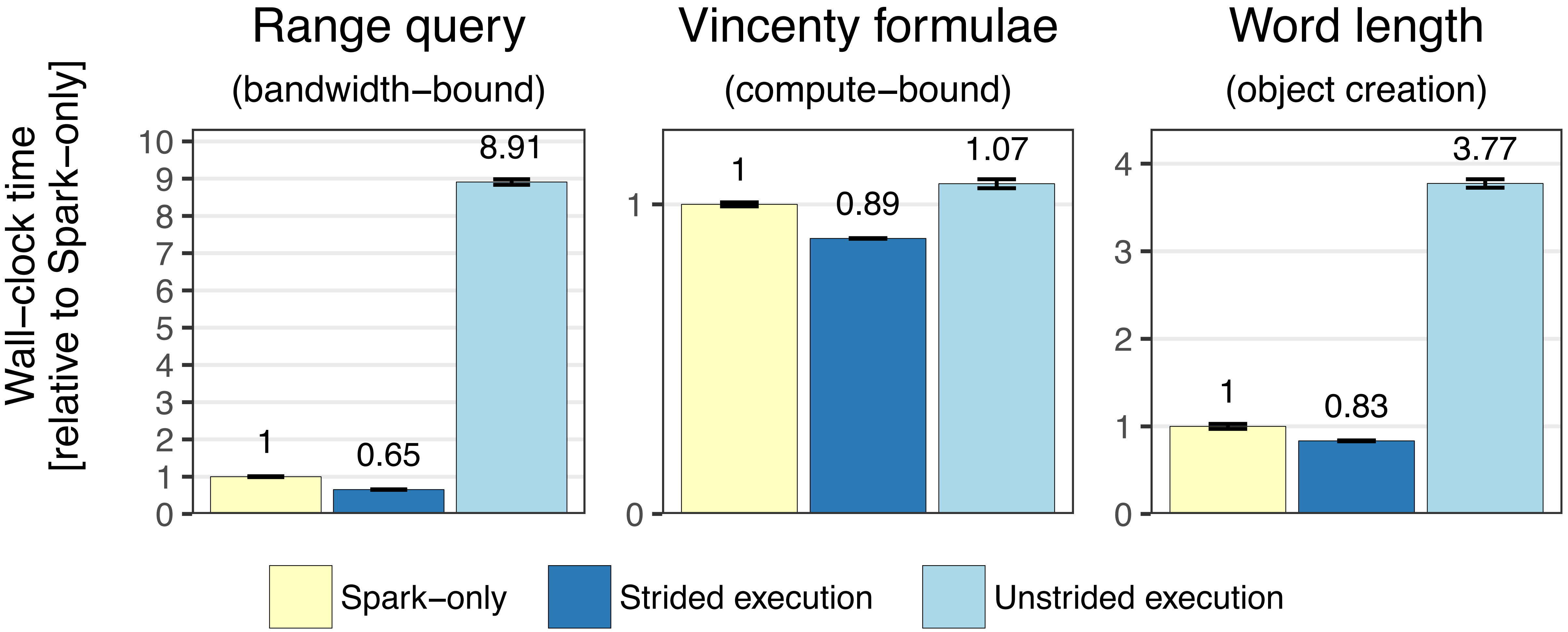
```
-- def filter(a: Int, low: Int, high: Int)
--            = low < a && a < high
SELECT sum(a) FROM R
WHERE filter(a, min, max)
```

Range query with SQL predicate

```
SELECT sum(a) FROM R
WHERE min < a AND a < max
```



Embedded JVM performance



- 2.5B integers (10 GB)
- Stride size 4096

- 64M points (1 GB)
- Stride size 512

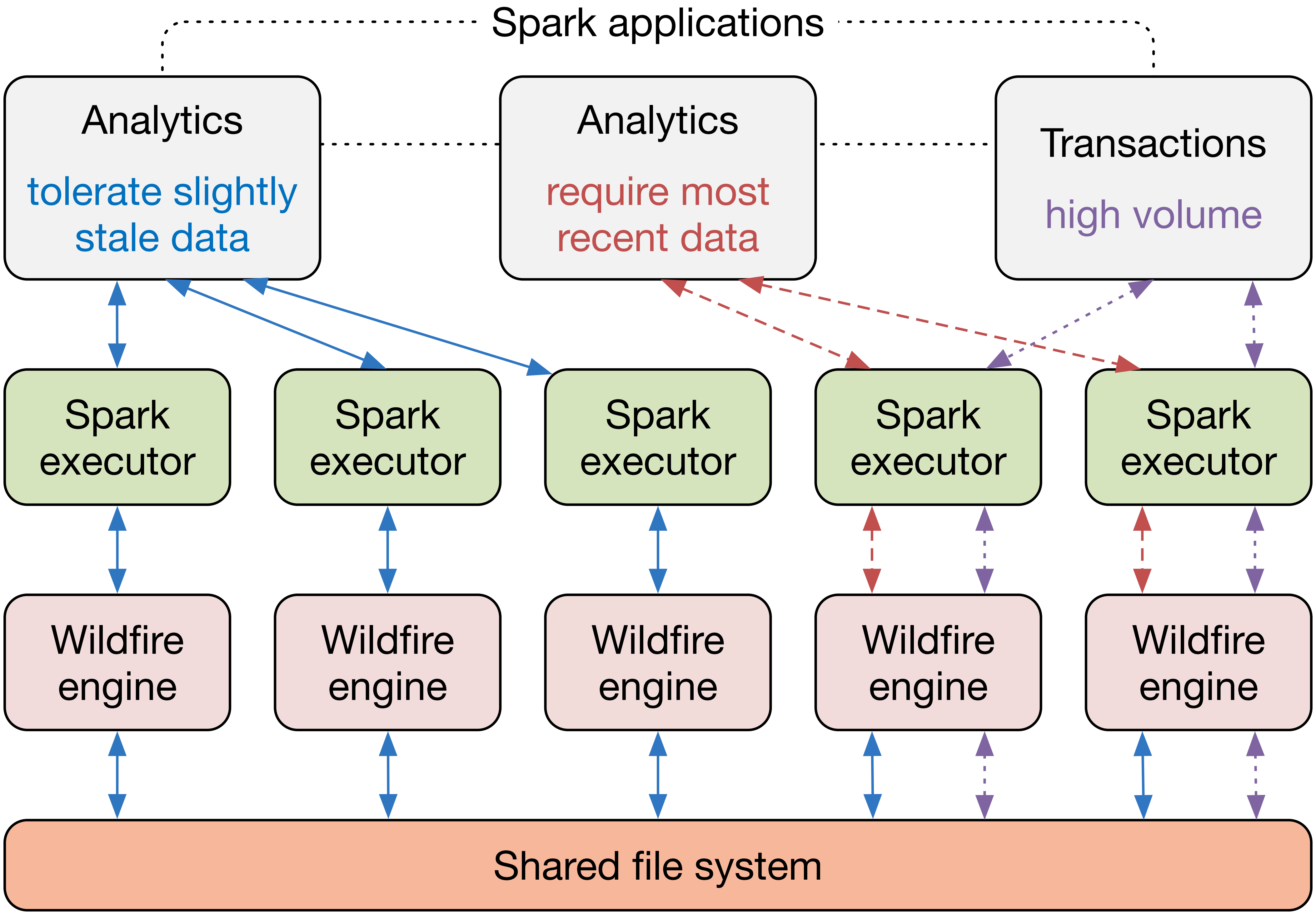
- 80M words (1 GB)
- Stride size 1024
- Word length follows poisson distribution

- Intel Xeon X7560, 2.27 GHz, 512 GB RAM
- Oracle JDK 112
- Data stored as uncompressed Parquet files with RLE/PLAIN encoding

State of the art

- Impala: supports C++ UDFs (fast) and unmodified Hive UDFs (tuple-based, slow, discouraged)
- Vertica: *User-defined Transform Functions* that process multiple rows via an iterator
- Tupleware: UDFs in LLVM-based languages

Wildfire system architecture



Java direct ByteBuffers

- Wraps memory that is not managed by the JVM
- Access in Java through typed getter and setter methods
- JVM will make “best effort” to avoid unnecessary data copies
- Primitive types: equivalent to typed array
- String objects: data must be copied into temporary array

Strided execution wrapper

```
public class StridedExecutionWrapper {
  public static void wrapUdf(
      UdfClass udfInstance,
      int numRows,
      ByteBuffer output,
      ByteBuffer auxiliaryOutput,
      ByteBuffer[] inputs,
      ByteBuffer[] auxiliaryInputs) {
    for (int i = 0; i < numRows; ++i) {
      output.putX(udfInstance.apply(
          inputs[0].getX(), … ,inputs[N].getX()));
  }
}
```

Supported types

Supported

- Primitive types (no extra copies)
- Strings (copy into temporary array)

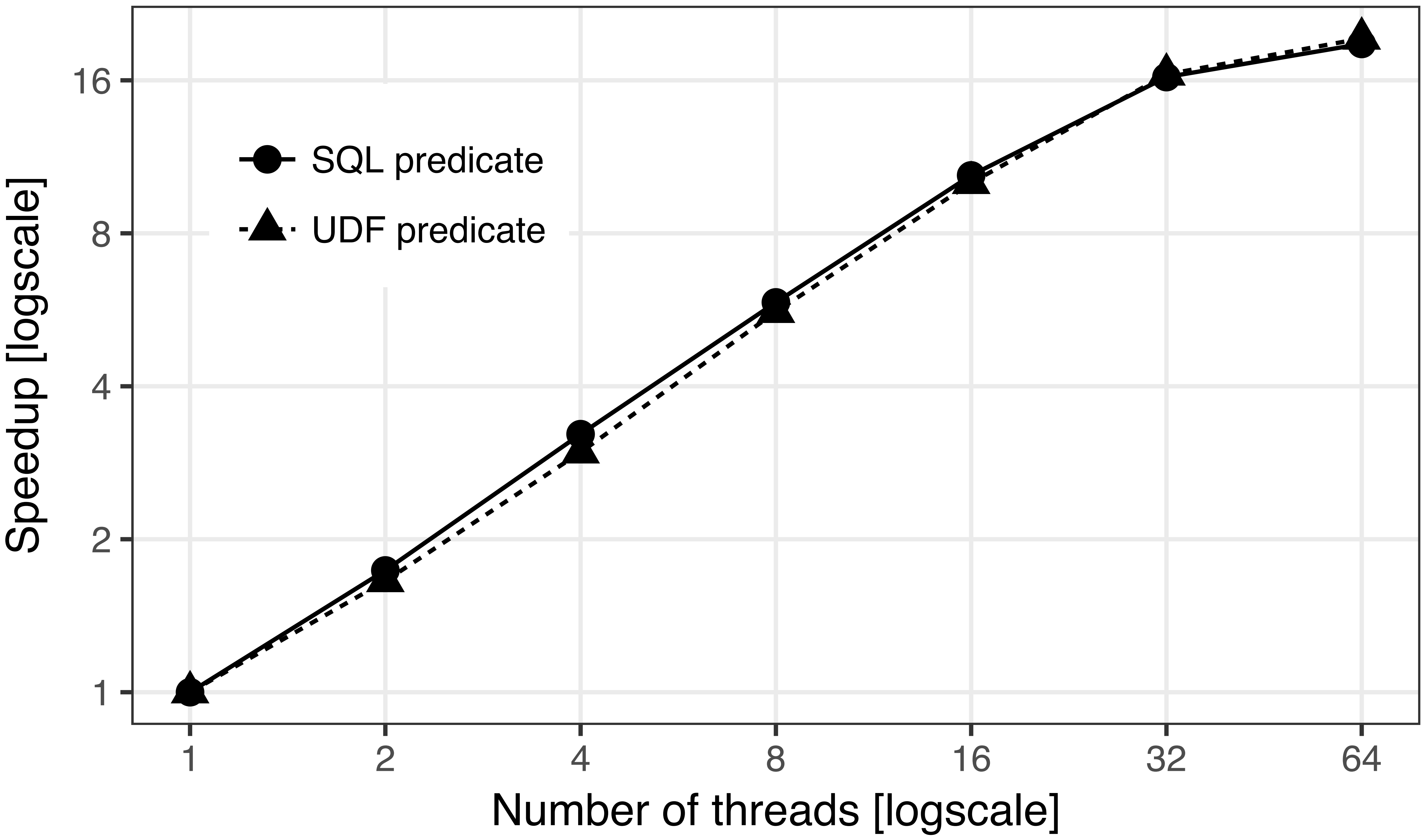
Not supported in prototype

- User-defined types require object creation (straightforward if type can be decomposed into primitives)
- Complex nested types cannot be used with scalar UDFs

Security considerations

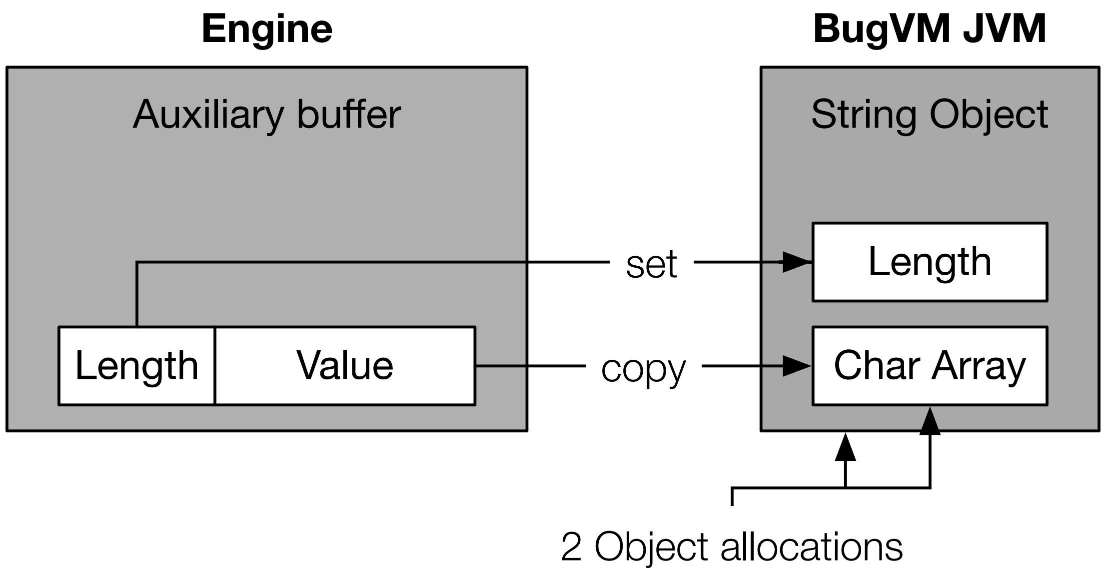
- UDFs must not crash database
- typically executed in separate process
- JVM offers similar separation
- errors conditions are signalled as exceptions
- UDFs can further be restricted through Java SecurityManagers

Thread scaling



Modified Java String implementation

Default implementation



Engine

BugVM JVM

Auxiliary buffer

String Object

Length

Value

set

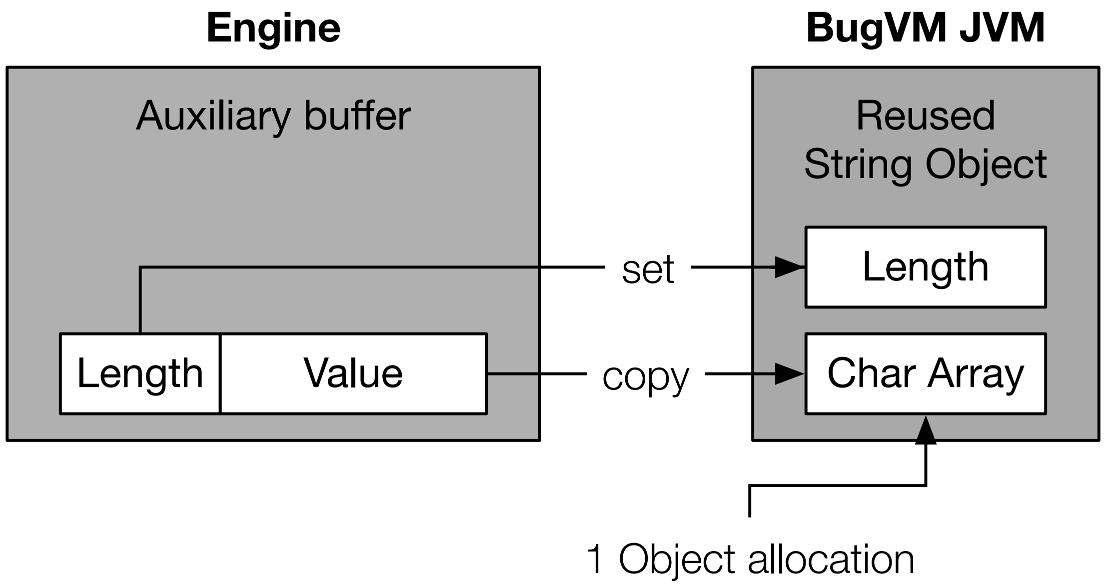
copy

Length

Char Array

2 Object allocations

Reuse string buffer



Engine

BugVM JVM

Auxiliary buffer

Reused String Object

Length

Value

set

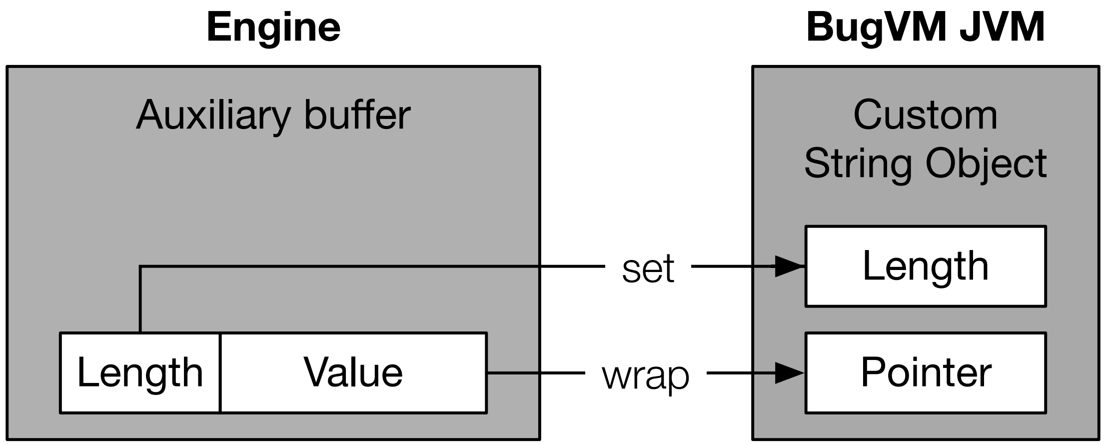
copy

Length

Char Array

1 Object allocation

Wrap engine buffer



Engine

BugVM JVM

Auxiliary buffer

Custom String Object

Length

Value

set

wrap

Length

Pointer