Lessons from a DSL where all you have is ranges

John Loughran Colvin
In the beginning
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There were variables and functions:
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alias add = (a, b) => a + b;
auto x = 2;
auto y = 2;
auto z = add(x, y);
```
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auto y = 2;
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```

And it was ... ok.
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There were more variables:
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```javascript
alias add = (a, b) => a + b;
auto x0 = 2;
auto y0 = 2;
auto z0 = add(x0, y0);
auto x1 = 3;
auto y1 = 3;
auto z1 = add(x1, y1);
```
JUST AFTER THE BEGINNING

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```

... and it was starting to feel a bit off
And then
AND THEN

There were more functions:
And then

There were more functions:

```
alias add = (a, b) => a + b;
alias timesBy2 = a => a << 1;
auto x0 = 2;
auto y0 = 2;
auto z0 = add(x0, y0);
auto x1 = 3;
auto y1 = 3;
auto z1 = add(x1, y1);
auto \( \zeta \) = timesBy2(add(z0, z1));
```
What’s the problem?
What’s the problem?

Iteration

&

Composition
What a Range?
What a Range?

An aggregate that defines empty, front and popFront
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An aggregate that defines empty, front and popFront.

Do we have anything? What do we have? Go to the next one.
What a Range?

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iota(100)
  .map!(i => i * rand())
  .filter!(i => i % 2)
  .writeln;
What a Range?

An aggregate that defines empty, front and popFront

Do we have anything? What do we have? Go to the next one.

```scala
iota(100)
  .map!(i => i * rand())
  .filter!(i => i % 2)
  .writeln;
```

There are other primitives for going backwards, getting an element by offset, saving the current position.

For C++ programmers, it’s like a begin/end pair of iterators.
What’s our problem?
What's our problem?

Iteration

&

Composition
Goal

- We wanted to allow people who are not currently programmers to do bulk data processing and glue systems together.

- The usual slice-and-dice work that happens in Excel every day, but without the limitations of Excel and the horrors that grow to work around those limitations.

- We needed a language that was easy to use, hard to abuse and expressed the thought at hand clearly.
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Or Equivalent
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- Mutable state opens up the potential for monstrous code and awful bugs
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- No proper pipeline programming (unless we effectively re-implement what we want as a DSL inside python)
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Or Equivalent

- Imperative programming is the hard part, not the easy part.

- Mutable state opens up the potential for monstrous code and awful bugs

- No proper pipeline programming (unless we effectively re-implement what we want as a DSL inside python)

- These languages weren’t designed for trivial interoperability with other systems (but that’s another talk...)

What did we do?
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- Created a Variable type (was minimally wrapped code.dlang.org/packages/taggedalgebraic, now totally custom) supporting some basics like string, delegate, int, Variable[string], Variable[] plus an open-ended variant type.
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- Created a parse-tree-walking interpreter to recursively build Variables to get the result.
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- Created a parse-tree-walking interpreter to recursively build Variables to get the result.

- The next step was going to be getting array expressions really sorted, e.g. \( a = b + c \) where all are arrays, including index matching for indexed data.
And then I went on holiday
And then I went on holiday

And then I got ill
And then I went on holiday

And then I got ill

And then I came back...
And everything was different!
And everything was different!

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- Added first-class support for ranges.
- Wrapped a large chunk of the D standard library.
- A project was being started to try and use the language in an important piece of day-to-day operations.
- Later on, we decided that maybe modules, if/else, scopes, not overwriting live stack frames and so on were also useful features.
SIL Examples

```plaintext
alias add = (a, b) => a + b;
alias timesBy2 = a => a << 1;
auto x0 = 2;
auto y0 = 2;
auto z0 = add(x0, y0);
auto x1 = 3;
auto y1 = 3;
auto z1 = add(x1, y1);
auto ζ = timesBy2(add(z0, z1));
```
add = (a, b) => a + b
										
timesBy2 = a => a * 2
x0 = 2
y0 = 2
z0 = add(x0, y0)
x1 = 3
y1 = 3
z1 = add(x1, y1)
q = timesBy2(add(z0, z1))
SIL Examples

add = (a, b) => a + b

timesBy2 = a => a * 2

xs = [2, 3]
ys = [2, 3]

zs = zip([xs, ys])
  |> map(p => add(p[0], p[1]))

q = zs
  |> sum
  |> timesBy2
Ranges Save the Day

We didn’t have much to work with, but phobos ranges and algorithms are great.

```
weeklyClose = readCsvTable("dailyOHLC.csv")
  |> applyToCol("date", parseDates)
  |> byRow
  |> filter(x => x.date.dayOfWeek == Day.friday)
  |> map(x => [x.date, x.close])
  |> tableFromPairs
  |> writeCsv("weeklyClose.csv")
```
Ranges Save the Day

We didn’t have table literals, only \texttt{mkTable} that returns an empty table and \texttt{addEntry}
Ranges Save the Day

We didn’t have table literals, only `mkTable` that returns an empty table and `addEntry`

```scala
tableFromPairs(a) => a
  |> fold(
      (newT, p) => newT
      |> addEntry(p[0], p[1]),
      mkTable()
  )
```
Ranges Save the Day

We didn’t have table literals, only mkTable that returns an empty table and addEntry

tableFromPairs(a) => a
     |> fold(
         (newT, p) => newT
         |> addEntry(p[0], p[1]),
         mkTable()
     )

superSecretHedgeFundTable = [
    [“a”, 1],
    [“b”, 2],
    [“c”, 3]] |> tableFromPairs
Ranges Save the Day

We didn’t have any built-in functions that operated on the values of a table.
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```haskell
apply(tIn, func) => tIn |> keyValPairs
    |> fold(
        (tOut, p) => tOut
            |> replaceEntry(p.key, func(p.value)),
            tIn
    )
```

```
{“a” : 3, “b” : 4} |> apply(x => x * 2)
// gives {“a” : 6, “b” : 8}
```
Ranges Save the Day

No proper dataframes? No problem, e.g.
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```javascript
getRow(t, i) => {
    ks = keys(t)
    vs = values(t)
    in zip([ks, vs |> map(v => v[i]])
        |> tableFromPairs
}

{"a" : [3, 4], "b" : [7, 8]} |>getRow(1)
// gives {"a" : 4, "b" : 8}
```
Don’t be clever

Locals and scopes are quite nice

```
split(hay, needle) => ( 
    i => [hay[0 : i], hay[i : $]]
  )(hay |> indexOf(needle) |> value)
```
**Don’t be clever**

Locals and scopes are quite nice

```js
split(hay, needle) => (  
  i => [hay[0 : i], hay[i : $]]  
)(hay |> indexOf(needle) |> value)
```

v.s.

```js
split(hay, needle) => {  
  i = hay |> indexOf(needle) |> value  
in [hay[0 : i], hay[i : $]]
}
```
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    return r.map!(x => x * v);
}
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    return r.map!(x => x * v);
}

We can easily create lambdas that capture context, (just a struct
with an opCall).
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This is not a problem with capturing by value in lambdas, it’s a problem with map.
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    static struct Callable {
        T v;
        auto opCall(ElementType!R x) {
            return x * v;
        }
    }
    auto c = Callable(x);
    return r.map!c;
}
auto scale(R, T)(R r, T v) 
if (isInputRange!R 
    && is(typeof(r.front * v))) {
    static struct Callable {
        T v;
        auto opCall(ElementType!R x) {
            return x * v;
        }
    }
    return r.map!(Callable(v));
}
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    static struct Callable {
        T v;
        auto opCall(ElementType!R x) {
            return x * v;
        }
    }
    static Callable c;
    c = Callable(v);
    return r.map!c;
}
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    static struct Callable {
        T v;
        auto opCall(ElementType!R x) {
            return x * v;
        }
    }
    static Callable c;
    c = Callable(v);
    return r.map!c;
}
auto a = r.save.scale(3);
auto b = r.save.scale(4);
assert(a == r.scale(3));  // nope...
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    zip(r, repeat(v)).map!(p => p[0] * p[1]);
}
auto scale(R, T)(R r, T v)
if (isInputRange!R
    && is(typeof(r.front * v))) {
    zip(r, repeat(v)).map!(p => p[0] * p[1]);
}
What are they bad for?
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- Good at walking, not good at wandering
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• Good performance is reliable when the code is trivial. Theoretical savings, practical catastrophes
What are they bad for?

- Good at walking, not good at wandering
- Good performance is reliable when the code is trivial. Theoretical savings, practical catastrophes
- Writing your own ranges is really, really interesting.
std.range.generate

?
std.range.generate

• I didn’t know about it until today.
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Can’t skip, can’t stop.
auto map(alias foo, R)(R r)
{
    return r.betterGen!(R, typeof(foo(ElementType!R.init)),
    (s) { with (s)
    {
        if (input.empty)
            return stop;
        return val(foo(input.front))
            .popInput;
    }});
}
betterGen

auto filter(alias foo, R)(R r) {
    return r.betterGen!(R, ElementType!R, (s) { with (s) {
        if (input.empty)
            return stop;
        auto inFront = input.front;
        if (foo(inFront))
            return val(inFront)
                .popInput();
        return nothing
                .popInput;
    }});
}
betterGen

// YES THIS IS NONSENSE, I KNOW
auto chunkBy(alias foo = (a, b) => a == b, R)(R r) {
    return IterState!(R, /*something*/,
    (s) {
        if (s.input.empty)
            return s.stop;
        auto inFront = s.input.front;
        return s.val(
            s.input
            .until!(x => !foo(inFront, x)));
    }
}
Implicit Conversions

```cpp
taxi blah()
{
    if (rand() % 2)
        return null;

    if (auto a = rand() % 2)
        return nullable(iota(3).map!(x => x + a));
}
```
Types of iteration

A commonly described split:

- Internal
- External
INTERNAL ITERATION
INTERNAL ITERATION

The iteration happens *inside* the code of `forEach` in JavaScript:

```javascript
[1, 2, 3].forEach(x => console.log(x))
```
Internal Iteration

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`sum` in numpy (Python):

```python
np.array([1, 2, 3]).sum()
```
**Internal Iteration**

The iteration happens *inside* the code of `forEach` in JavaScript:

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[1, 2, 3].forEach(x => console.log(x))
```

**sum** in numpy (Python):

```python
np.array([1, 2, 3]).sum()
```

**opApply** in D:

```d
struct S {
    int opApply(int delegate(ref int a) dg) {
        foreach (i; 0 .. 5) dg(i);
        return 0;
    }
}
```

```d
foreach (i; S()) writeln(i);
```
EXTERNAL ITERATION
**EXTERNAL ITERATION**

The iteration happens *outside* the code of a pair of iterators in C++:

```cpp
std::vector<int>::iterator begin, end;
```
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A generator in python:

```python
[x * 5 for x in range(30)]
```
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A range of directory entries in D

```d
dirEntries("/usr/lib/", "libphobos*.so.*");
```
**External Iteration**

The iteration happens *outside* the code of a pair of iterators in C++:

```cpp
std::vector<int>::iterator begin, end;
```

A generator in python:

```python
[x * 5 for x in range(30)]
```

A range of directory entries in SIL:

```python
dirEntries("/usr/lib/", "libphobos*.so.*")
```
Which is this?

```cpp
foreach (x; iota(100))
    writeln(x);
```

Or this?

```cpp
auto a = [1, 2, 3];
for (int i = 0; i < N, ++i)
    printf("%i\n", a[i]);
```
**Which is this?**

```
foreach (x; iota(100))
    writeln(x);

auto a = [1, 2, 3];
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```

They are clearly both internal and external

- The loop is iterating
- The iterable is being iterated
“Sure, I know how to iterate over my stuff, I even know some different ways, just tell me what you want done and I’ll make it happen”

Great when you know everything you want to do per-element up-front.
INTERNAL

“Sure, I know how to iterate over my stuff, I even know some different ways, just tell me what you want done and I’ll make it happen”

Great when you know everything you want to do per-element up-front.

EXTERNAL

“I have no idea what you want, don’t even try and explain it me. Just tell me when you want me to spit out the next item”

Composable, you can build up the work in pieces
“I have no idea what you want, don’t even try and explain it me. Just tell me when you want me to spit out the next item”

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“I iterate things”

EXTERNAL

“I have no idea what you want, don’t even try and explain it me. Just tell me when you want me to spit out the next item”

Composable, you can build up the work in pieces
INTERNAL

“I iterate things”

EXTERNAL
INTERNAL

“I iterate things”

EXTERNAL

“I can be iterated”
Most Ranges are Both

- They iterate a source range (internal)
- They are iterable (external)
- Internal aspect is trivial for map, not trivial for e.g. filter or cache
OMG! Who cares?
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- Internal iteration is a closed model
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- Internal iteration is a closed model
- External iteration is composable
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• This is the same pattern as many things in D: allowing choices to be pushed further and further up the call stack.
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- Internal iteration is a closed model
- External iteration is composable
- This is the same pattern as many things in D: allowing choices to be pushed further and further up the call stack.
- This is also the unix philosophy. Do one thing and do it well.
OMG! Who cares?

• Internal iteration is a closed model

• External iteration is composable

• This is the same pattern as many things in D: allowing choices to be pushed further and further up the call stack.

• This is also the unix philosophy. Do one thing and do it well.

• Everything else is someone else’s problem.
double[] vecMul(double[] a, double[] b) in (a.length == b.length) {
    auto r = new double[](a.length);
    r[] = a[] * b[];
    return r;
}
How many things does this function do?

```c
void vecMul(double[] a, double[] b, double[] r)
in (a.length == b.length)
in (r.length == b.length)
{
    r[] = a[] * b[];
    return r;
}
```
How many things does this function do?

```cpp
auto vecMul(double[] a, double[] b) in (a.length == b.length)
{
    return zip(a, b)
        .map!(t => t.rename!("elA", "elB"))
        .map!(p => elA * elB);
}
```
This effect is fractal
What if `with` was an expression?

```javascript
iota(1000)
  .enumerate
  .map!(expand!((index, value) => index + value))
```

```javascript
iota(1000)
  .enumerate
  .map!(p => with(p) index + value)
```
Come work at Symmetry Please.
Come work at Symmetry Please.

Now.
Come work at Symmetry Please.

Now.

Please.