Experience Report: Paradise
A two-stage DSL embedded in Haskell

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Credit Suisse: ~40,000 people: A large financial services firm

Securities Division: ~6,000 people:

- Buys and sells financial products, including derivatives:
  - Potentially complex instruments based on underlying real asset(s), e.g.
    - Right to buy/sell some stock at price y at time z
    - Pay out x for every day in period z that some interest rate is above y
  - Used to hedge against liabilities, or “take a view” on market movements

Global Modelling and Analytics Group: ~140 people

- Writes and delivers “analytics” for:
  - Pricing (what is this worth?)
  - Risk analysis (how will this value change if the market moves by x?)
Delivering analytics

Pricing models
Before the trade is made
*Run by traders and sales staff*
Excel, custom applications

Valuation models
For “booked” trades
*Run by automated systems*
C++, F#

Low-level analytic code
C++
Excel as a platform for pricing models

- Users like it
  - Familiar
  - Can tweak it themselves
- Can be good for development too
  - Rapid prototyping
- BUT: a reusability nightmare
  - No modularity
  - No abstraction
  - No automated change tracking
Pricing Models

Excel Spreadsheet

Addin interface

Low-level analytics

A functional language

Must be pure
Paradise

- Generate pricing models
- Two DS(E)Ls
  - Model: describe how the addin calls are plumbed together
  - View: describe how the UI is laid out
- Target-independent
  - Excel
  - C#
  - Future: web application?
- Not specific to finance or pricing models
  - But that’s all we use it for
How does it work

- A two stage language: like Pan (Elliott et al)
  - The Paradise program is compiled into a Haskell executable
  - When run the Haskell executable produces the spreadsheet etc

- Type system distinguishes the stages
  - Second-stage is denoted by a type constructor “E”

- The bits with “Haskell” types (Double, [], ...) run at Haskell runtime (stage 1)

- The bits with “Paradise” types (E Double, ...) build an AST that will be compiled into the stage 2 program – Excel, C# etc

- The Paradise library contains
  - A type-safe interface to stage 2 + helper functions
  - a compiler for the Paradise DSL
A very simple example

```haskell
data Adder = Adder { 
    x :: E Double, 
    y :: E Double, 
    z :: E Double 
}

adder = do 
    x <- input 2 
    y <- input 3 
    z <- output (x+y) 
    return Adder{..}

instance Viewable Adder where 
    view Adder{..} = 
        column [row [label "x", view x], 
                row [label "y", view y], 
                row [label "x+y", view z]]
```

Data structure

<p>| | | | |</p>
<table>
<thead>
<tr>
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<tr>
<td>A</td>
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<td>2</td>
<td>y</td>
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<tr>
<td>3</td>
<td>x+y</td>
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<tr>
<td>4</td>
<td>5</td>
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</tbody>
</table>
Two adders

data TwoAdders = TwoAdders {
    adder1 :: Adder,
    adder2 :: Adder,
    result :: E Double
}

twoAdders = do
    adder1 <- adder
    adder2 <- adder
    result <- output (z adder1 + z adder2)
    return TwoAdders{..}

instance Viewable TwoAdders where
    view TwoAdders{..} = row [view adder1,
                               view adder2,
                               view result]
The E type

This is all we expose to the users

data E a = E Exp

data Exp = EVar ... | ELit ... | ELam ... | EApply ...

instance Num (E Int) where ...
instance Num (E Double) where ...
instance IsString (E String) where ...

(++) :: E String -> E String -> E String

...
Higher-order functions

- Second-stage array type: \( E \) (Array \( a \))

\[
\text{map} :: (\text{IsEType} \ a, \text{IsEType} \ b) \\
\rightarrow (E \ a \rightarrow E \ b) \\
\rightarrow E \ (\text{Array} \ a) \\
\rightarrow E \ (\text{Array} \ b)
\]

- User writes normal-looking functions
  - Higher-order abstract syntax
  - \( E \) type is abstract so the functions must be parametric
- Turned into explicit lambdas (ELam) for the backend
Embedding issues

- The stage-2 language is quite restricted
  - Can overload:
    - numeric literals, numeric operations, and string literals
  - Can’t overload:
    - If-then-else, Boolean literals, Eq/Ord type classes: we roll our own alternatives
    - Pattern-matching, general recursion, list comprehensions: we do without

- (Un)observable sharing
  - We have a combinator in the state monad
  - We recently decided to also use stable names + unsafePerformIO

- Haskell is still a great language for embedding
  - Static typing + type classes make distinguishing stages 1+2 easy
  - Can write code that is overloaded between the two stages
  - Type classes let us mimic the target language’s type system
Gradually rolling it out across the group

Most of our problems have been with Excel
- Slow
- Unreliable
- Not designed as a compilation target

Modellers appreciate the type-safety and abstraction

Turn-around of changes can be an issue
- No longer instantly visible in the sheet

Lifecycle management is more complicated
- Paradise library changes can break models (or fix them)
- We have a runtime support library: requires a careful binary release process
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Why not GADTs?

- Trade-off between effort and safety
- The Excel backend plays fast and loose with types
- We annotate our terms with our own type information (at the value level)
  - Can run a typechecking pass
- So trade-off is between errors at Haskell compile time and at stage 1 runtime
  - Of course, we had to write our own typechecker