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# Implementing Python in Haskell, twice!

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Melbourne Python Users  
Group, Monday 7 July 2014

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# Is this about Haskell or Python?

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It's a bit of both

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# Overview

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- ❖ Motivation
- ❖ Parsing Python
- ❖ Translating Python to Haskell
- ❖ Bytecode compilation and interpretation
- ❖ Future directions

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# Motivation

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- ❖ A fun way to kill time.
- ❖ Haskell is particularly good for writing compilers.
- ❖ Python is a (mostly) simple language to implement.

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# Lexical analysis

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- ❖ I use Alex (like Lex/Flex) for lexical analysis.
- ❖ Lexical analysis takes the input source program text, the filename (for error messages), and breaks the source up into a sequence of tokens:

```
lex :: String -> Filename -> Either ParseError [Token]
```

- ❖ Python's lexical structure is well defined:

[https://docs.python.org/3/reference/lexical\\_analysis.html](https://docs.python.org/3/reference/lexical_analysis.html)

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# Parsing

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- ❖ I use Happy (like Yacc/Bison) for parsing.
- ❖ Parsing takes the input source program text, the filename (for error messages), and builds an abstract syntax tree:

```
parseModule :: String -> Filename  
             -> Either ParseError (ModuleSpan, [Token])
```

- ❖ Python's grammar is well defined:

<https://docs.python.org/3/reference/grammar.html>

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# Parsing

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- ❖ Internally the parser calls the lexer and processes the generated sequence of tokens.

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# language-python

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- ❖ Eventually I'd written a lexer, parser and pretty printer.
- ❖ Support for both Python 2.x and 3.x.
- ❖ Could parse the CPython test suite.
- ❖ The result is a library called language-python:

`https://github.com/bjpop/language-python`

- ❖ Now what?

# berp: translating Python to Haskell

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- ❖ Thought experiment: what would it take to translate Python into Haskell?
- ❖ Okay, what is the semantics of Python?

```
while True:  
    try:  
        1/0  
    except:  
        break  
    finally:  
        continue
```

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```
while True:  
    try:  
        1/0  
    except:  
        break  
    finally:  
        continue
```

SyntaxError:  
'continue' not  
supported inside  
'finally' clause

---

# berp: translating Python to Haskell

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- ❖ The real trick is in encoding Python’s imperative effects into a pure language (state, control flow, mutable values, input / output).
- ❖ Haskell’s monad (transformers) provide an elegant way to combine different effects together.

# berp: translating Python to Haskell

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- ❖ An example, recursive factorial using an accumulator:

```
def fac(n, acc):  
    if n == 0:  
        return acc  
    else:  
        return fac(n - 1, n * acc)
```

# berp: translating Python to Haskell

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- ❖ translated into Haskell by berp:

```
def _s_fac 2 none
  (\ [_s_n, _s_acc] ->
    ifThenElse
      (do _t_6 <- read _s_n
         _t_6 == 0)
      (do _t_7 <- read _s_acc
         ret _t_7)
      (do _t_0 <- read _s_fac
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n == 0:

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return acc

# berp: translating Python to Haskell

---

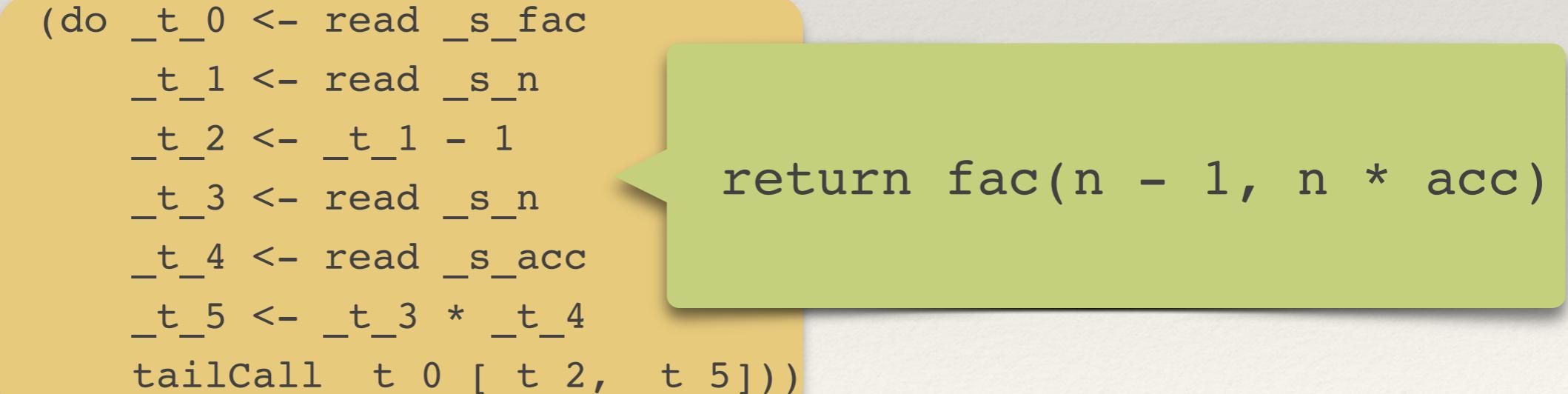
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return fac(n - 1, n * acc)
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---

# berp: translating Python to Haskell

---

- ❖ Berp has some cute party tricks:
  - Tail call optimisation, `fac` runs in constant stack space.
  - `callcc` (call with current continuation, borrowed from Scheme).

# berp: translating Python to Haskell

---

- ❖ callCC example in berp:

```
>>> def f():
...     count = 0
...     k = callCC(lambda x: x)
...     print(count)
...     if count < 3:
...         count = count + 1
...         k(k)
...
>>> f()
0
1
2
3
```

---

# Is Haskell a good target for Python compilation?

---

- ❖ Pros:
  - We get to use the Haskell runtime features for free: garbage collection, threads, I/O.
- ❖ Cons:
  - The runtime representation of Python state (in berp) is pretty heavy weight (slow).
  - Python uses a lot of mutation. Haskell compilers are not optimised for this.

# blip: a bytecode compiler and interpreter

---

- ❖ Having pursued the berp thought experiment far enough I decided to try making a bytecode compiler and interpreter.
- ❖ I started by writing a program to read .pyc files generated by CPython. Then used it to reverse engineer the meaning of the bytecode.

---

# blip: a bytecode compiler and interpreter

---

- ❖ Bytecode for the factorial function:

```
0 LOAD_FAST 0
3 LOAD_CONST 1
6 COMPARE_OP 2
9 POP_JUMP_IF_FALSE 19
12 LOAD_FAST 1
15 RETURN_VALUE
16 JUMP_FORWARD 21
19 LOAD_GLOBAL 0
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28 BINARY_SUBTRACT
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n == 0

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---

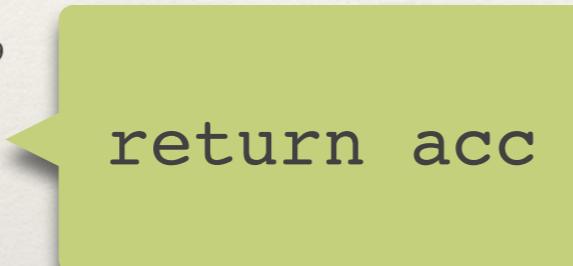
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return acc

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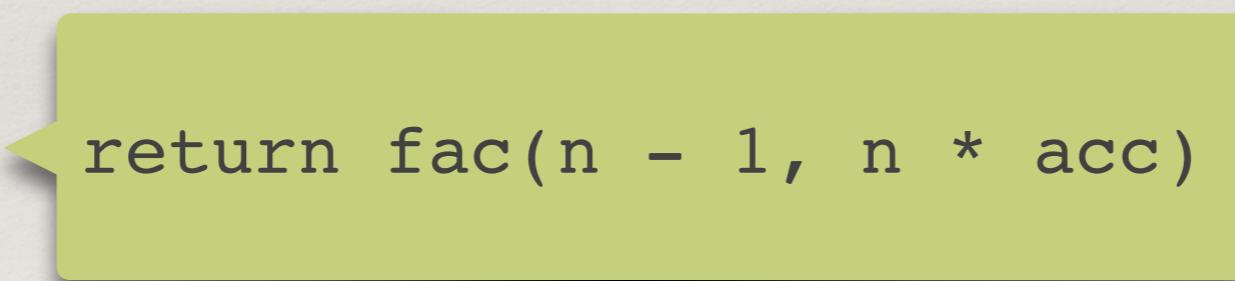
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return None

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return None

dead code

# blip: a bytecode compiler and interpreter

---

- ❖ It turns out that CPython uses a very straightforward compilation scheme. Easy to emulate in Haskell:

```
compileExpr :: ExprSpan -> Compile ()  
compileExpr (CondExpr {..}) = do  
    compile ce_condition  
    falseLabel <- newLabel  
    emitCodeArg POP_JUMP_IF_FALSE falseLabel  
    compile ce_true_branch  
    restLabel <- newLabel  
    emitCodeArg JUMP_FORWARD restLabel  
    labelNextInstruction falseLabel  
    compile ce_false_branch  
    labelNextInstruction restLabel
```

---

# blip: a bytecode compiler and interpreter

---

- ❖ Blip generates bytecode which is compatible with CPython.
- ❖ I originally used CPython to test the generated bytecode.
- ❖ Then I decided to write a bytecode interpreter in Haskell too.

# blip: a bytecode compiler and interpreter

---

- ❖ Evaluating the bytecode is reasonably straightforward:

```
evalOneOpCode :: HeapObject -> Opcode -> Word16 -> Eval ()  
evalOneOpCode (CodeObject {..}) opcode arg =  
    case opcode of  
        CALL_FUNCTION -> do  
            functionArgs <- replicateM (fromIntegral arg)  
                popValueStack  
            functionObjectID <- popValueStack  
            functionObject <- lookupHeap functionObjectID  
            callFunction functionObject $ reverse functionArgs  
        JUMP_ABSOLUTE -> setProgramCounter $ fromIntegral arg  
    ... etcetera ...
```

---

# blip: a bytecode compiler and interpreter

---

- ❖ I've implemented about half of the bytecode instructions so far. Many of them are simple manipulations of the stack.
- ❖ However, implementing attribute lookup completely and correctly is quite difficult.

# blip: a bytecode compiler and interpreter

---

- ❖ Time for a little demo:

```
$ blip
Berp version 0.2.1, type control-d to exit.
>>> def fac(n):
...     if n <= 1:
...         return 1
...     else:
...         return fac(n - 1) + fac(n - 2)
...
>>> x = 0
>>> while x < 10:
...     print(fac(x))
...     x = x + 1
...
1
1
2
3
5
8
13
21
34
55
```

---

# Future directions

---

- ❖ Complete the byte code interpreter
- ❖ Add language extensions:
  - ❖ Tail call optimisation?
  - ❖ Algebraic types, pattern matching?
- ❖ Possibly optimise execution by compiling to machine code.

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# Source code

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- ❖ <https://github.com/bjpop/language-python>
- ❖ <https://github.com/bjpop/berp>
- ❖ <https://github.com/bjpop/blip>