How to write a programming language

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artificialworlds.net/blog

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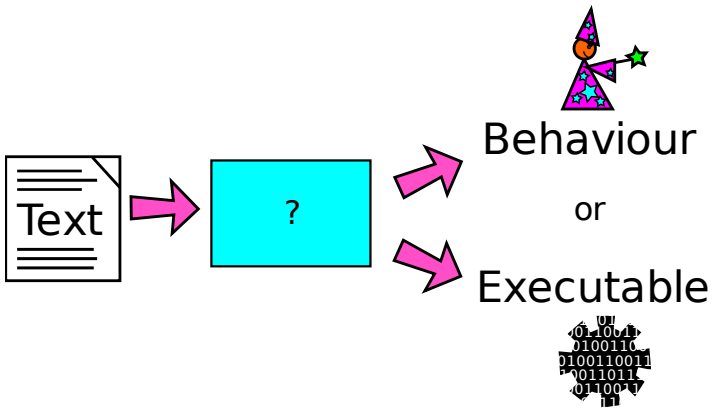
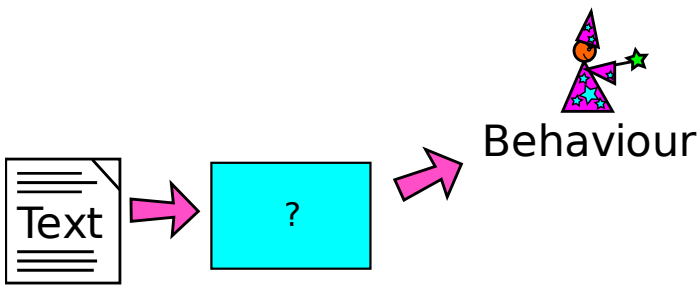
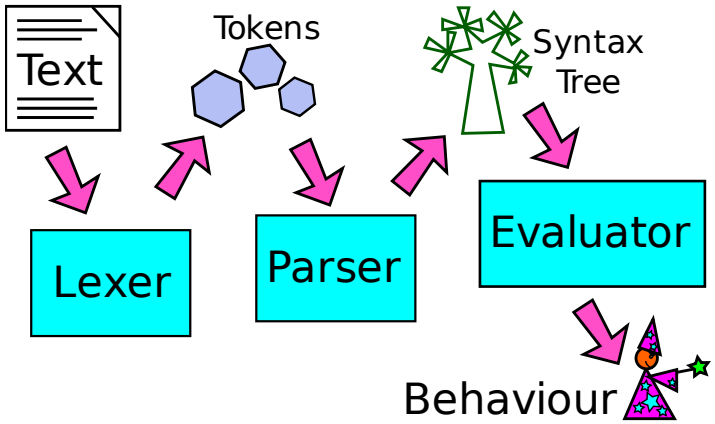
What is a programming language?



What is a programming language?



What is a programming language?



Introducing Cell

Cell is a programming language with:

- Short implementation
- (Hopefully) understandable implementation

There is nothing else good about it.

github.com/andybalaam/cell

Introducing Cell

```
num1 = 3;

square = {:(x) x * x;};

num2 = square( num1 );
```

Introducing Cell

Cell has four expression types:

- Assignment `x = 3`
- Operations `4 + y`
- Function calls `sqrt( -1 )`
- Function definitions
  `{:(x, y) x*x + y*y;}`

Introducing Cell

The coolest thing about Cell is:

- `if` is a function, not a keyword

More at: github.com/andybalaam/cell

Introducing Cell

- `if` is a function, not a keyword

```
if(
    is_even( 2 ),
    { print "Even!"; },
    { print "Odd."; }
);
```

More at: github.com/andybalaam/cell

Introducing Cell - Scope

```
x = "World!";
myfn = {
    x = "Hello, ";
    print( x );
};
myfn();
print( x );
```

Introducing Cell - Scope

```
x = "World!";
myfn = {
    x = "Hello, ";
    print( x );
};
myfn();
print( x );
```

```
Hello,
```

```
World!
```

Introducing Cell - Scope

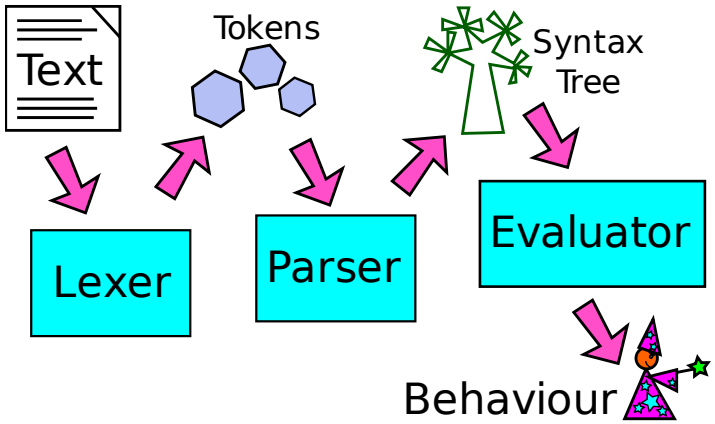
```
outerfn = {
    x = 12;
    innerfn = {
        print(x);
    };
    innerfn;
};

thing = outerfn();
thing();
```

Introducing Cell - Scope

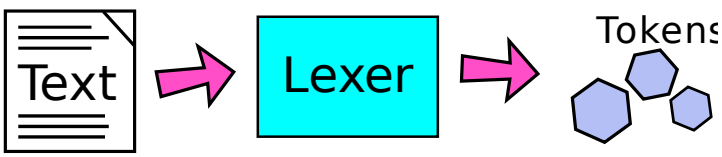
```
outerfn = {
    x = 12;
    innerfn = {
        print(x);
    };
    innerfn;
};

thing = outerfn();
thing();
```

```
12
```

A programming language



Lexing



Lexers emit tokens

```
foo = "bar";
```

becomes:

```
("symbol", "foo")
("="     , ""   )
("string", "bar")
(";"     , ""   )
```

Lexers emit tokens

```
200 - 158
```

becomes:

```
("number", "200")
("operator", "-"   )
("number", "158")
```

Cell's lexer

Lexing in Cell consists of identifying:

- Numbers: 12, 4.2
- Strings: "foo", 'bar'
- Symbols: baz, qux_Quux
- Operators: +, -
- Other punctuation: (, }

Cell's lexer (40 lines)

```
import re

from pycell.peekablestream import PeekableStream


def _scan(first_char, chars, allowed):
    ret = first_char
    p = chars.next
    while p is not None and re.match(allowed, p):
        ret += chars.move_next()
        p = chars.next
    return ret


def _scan_string(delim, chars):
    ret = ""
    while chars.next != delim:
        c = chars.move_next()
        if c is None:
            raise Exception("A string ran off the end of the program.")
        ret += c
    chars.move_next()
    return ret


def lex(chars_iter):
```

```
    chars = PeekableStream(chars_iter)
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n":              pass          # Ignore white space
        elif c in "(){},;=:":       yield (c, "")  # Special characters
        elif c in "+-*/":           yield ("operation", c)
        elif c in ("'", '"'):       yield ("string", _scan_string(c, chars))
        elif re.match("[.0-9]", c): yield ("number", _scan(c, chars, "[.0-9]"))
        elif re.match("[_a-zA-Z]", c):
            yield ("symbol", _scan(c, chars, "[_a-zA-Z0-9]"))
        elif c == "\t":
            raise Exception("Tab characters are not allowed in Cell.")
        else:
            raise Exception("Unrecognised character: '" + c + "'.")
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": ...
        elif c in "+-*/": ...
        elif c in "(){},;=:": ...
        elif c in ("'", '"'): ...
        elif re.match("[.0-9]", c): ...
        elif re.match("[_a-zA-Z]", c): ...
        else: ...
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": pass
        elif c in "+-*/": ...
        elif c in "(){},;=:": ...
        elif c in ("'", '"'): ...
        elif re.match("[.0-9]", c): ...
        elif re.match("[_a-zA-Z]", c): ...
```

```
        else: ...
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": pass
        elif c in "+-*/": yield ("operation", c)
        elif c in "(){},;=:": ...
        elif c in ("'", '"'): ...
        elif re.match("[.0-9]", c): ...
        elif re.match("[_a-zA-Z]", c): ...
        else: ...
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": pass
        elif c in "+-*/": yield ("operation", c)
        elif c in "(){},;=:": yield (c, "")
        elif c in ("'", '"'): ...
        elif re.match("[.0-9]", c): ...
```

```
        elif re.match("[_a-zA-Z]", c): ...
        else: ...
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": pass
        elif c in "+-*/": yield ("operation", c)
        elif c in "(){},;=:": yield (c, "")
        elif c in ("'", '"'):
            yield ("string", _scan_string(c, char
        ...
```

Cell's lexer

```
def _scan_string(delim, chars):
    ret = ""
    while chars.next != delim:
        c = chars.move_next()
        if c is None:
            raise Exception(...)
        ret += c
    chars.move_next()
```

```
    return ret
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": pass
        elif c in "+-*/": yield ("operation", c)
        elif c in "(){},;=:": yield (c, "")
        elif c in ("'", '"'): yield ("string...
        elif re.match("[.0-9]", c):
            yield ("number", _scan(c, chars, "[.0
        ...
```

Cell's lexer

```
def _scan(first_char, chars, allowed):
    ret = first_char
    p = chars.next
    while p is not None and re.match(allowed, p):
        ret += chars.move_next()
        p = chars.next
    return ret
```

Cell's lexer

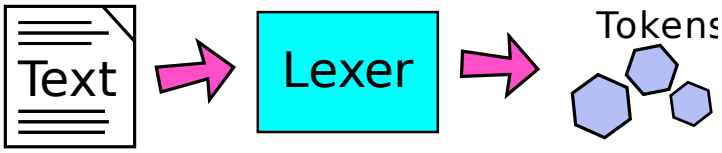
```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": pass
        ...
        elif re.match("[_a-zA-Z]", c):
            yield (
                "symbol",
                _scan(c, chars, "[_a-zA-Z0-9]")
            )
        ...
```

Cell's lexer

```
def lex(chars):
    while chars.next is not None:
        c = chars.move_next()
        if c in " \n": ...
        elif c in "+-*/": ...
        elif c in "(){},;=:": ...
        elif c in ("'", '"'): ...
        elif re.match("[.0-9]", c): ...
```

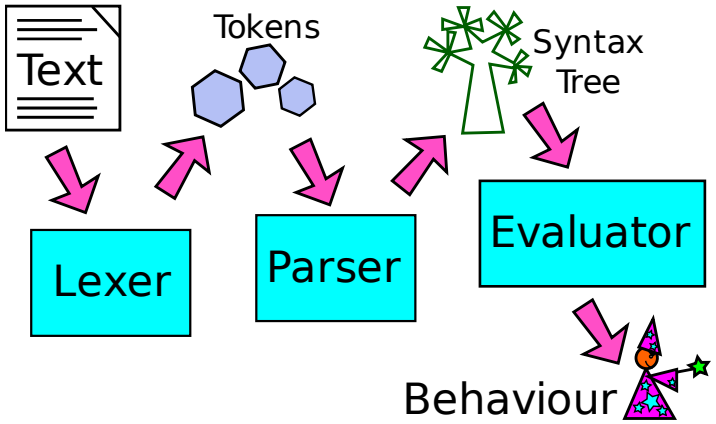
```
        elif re.match("[_a-zA-Z]", c): ...
        else: raise Exception(...)
```

Cell's lexer

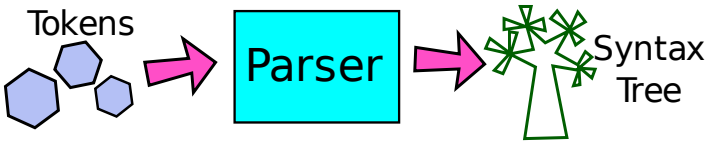



```
assert (
    list(lex('print("Hello, world!");'))
    ==
    [ ("symbol", "print")
    , ("(", "")
    , ("string", "Hello, world!")
    , (")", "")
    , (";", "")
    ]
)
```

A programming language



Parsing



Parsing

```
x = 3 + 4;
```

becomes:

```
Assignment:
    Symbol: x
    Value:
```

```
        Operation:
            Type: +
            Arguments:
                3
                4
```

Parsing

```
print( x + 2 );
```

becomes:

```
FunctionCall:
    Function: print
    Arguments:
        Operation:
            Type: +
            Arguments:
                x
                2
```

Parsing

```
print( x + 2 );
```

becomes:

```
("call",
    ("symbol", "print"),
```

```
    [
        ("operation",
            "+",
            ("symbol", "x"),
            ("number", "2")
        )
    ]
)
```

Cell's parser (81 lines)

Cell's parser

```
def parse(tokens):
    parser = Parser(tokens, ";")
    while parser.tokens.next is not None:
        p = parser.next_expr(None)
        if p is not None:
            yield p
```

```
        parser.tokens.move_next()
```

Cell's parser

```
class Parser:
    def __init__(self, tokens, stop_at):
        self.tokens = tokens
        self.stop_at = stop_at
```

Cell's parser

```
def next_expr(self, prev):
    self.fail_if_at_end(";")
    typ, value = self.tokens.next
    if typ in self.stop_at:
        return prev
    self.tokens.move_next()
```

```
    # ...
```

Cell's parser

```
def next_expr(self, prev):
    # ...
    if prev is None and typ in (# ...
    elif typ == "operation": # ...
    elif typ == "(": # ...
    elif typ == "{": # ...
    elif typ == "=": # ...
    else: # ...
```

Cell's parser

```
def next_expr(self, prev):
    # ...
    if prev is None and typ in (
      "number", "string", "symbol"):
        return self.next_expr((typ, value))
    elif typ == "operation": # ...
```

```
    elif typ == "(": # ...
    elif typ == "{": # ...
    elif typ == "=": # ...
    else: # ...
```

Cell's parser

```
def next_expr(self, prev):
    # ...
    if prev is None and typ in (...
    elif typ == "operation":
        nxt = self.next_expr(None)
        return self.next_expr(
            ("operation", value, prev, nxt))
    elif typ == "(": # ...
    elif typ == "{": # ...
    elif typ == "=": # ...
    else: # ...
```

Cell's parser

```
def next_expr(self, prev):
    # ...
    if prev is None and typ in (...
    elif typ == "operation": # ...
    elif typ == "(":
        args = self.multi_exprs(",", ")")
```

```
        return self.next_expr(("call", prev, args
    elif typ == "{": # ...
    elif typ == "=": # ...
    else: # ...
```

Cell's parser

```
def multi_exprs(self, sep, end):
    ret = []
    self.fail_if_at_end(end)
    typ = self.tokens.next[0]
    if typ == end:
        self.tokens.move_next()
    else:
        # ...
    return ret
```

Cell's parser

```
def multi_exprs(self, sep, end):
    # ...
    else:
        arg_parser = Parser(self.tokens, (sep, en
        while typ != end:
```

```
            p = arg_parser.next_expr(None)
            if p is not None:
                ret.append(p)
            typ = self.tokens.next[0]
            self.tokens.move_next()
            self.fail_if_at_end(end)
    return ret
```

Cell's parser

```
def next_expr(self, prev):
    # ...
    elif typ == "(": # ...
    elif typ == "{":
        params = self.parameters_list()
        body = self.multi_exprs(";", "}")
        return self.next_expr(("function", params
    elif typ == "=": # ...
    else: # ...
```

Cell's parser

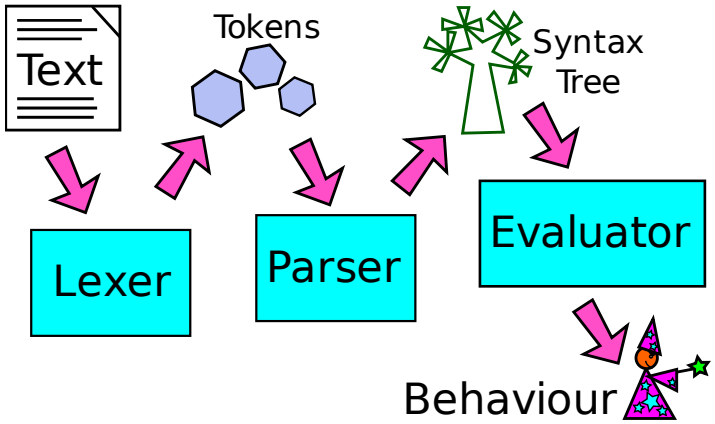
```
def next_expr(self, prev):
    # ...
    elif typ == "(": # ...
    elif typ == "{": # ...
    elif typ == "=":
```

```
        if prev[0] != "symbol":
            raise Exception(...)
        nxt = self.next_expr(None)
        return self.next_expr(("assignment", prev
    else: # ...
```

Cell's parser

```
def next_expr(self, prev):
    # ...
    elif typ == "(": # ...
    elif typ == "{": # ...
    elif typ == "=": # ...
    else:
        raise Exception("Unexpected token: " ...
```

A programming language



Recap - Lexing

```
foo = "bar";
```

becomes:

```
("symbol", "foo")
("="     , ""   )
("string", "bar")
(";"     , ""   )
```

Recap - Parsing

```
print( x + 2 );
```

becomes:

```
("call",
```

```
    ("symbol", "print"),
    [
        ("operation",
            "+",
            ("symbol", "x"),
            ("number", "2")
        )
    ]
)
```

Recap - Cell

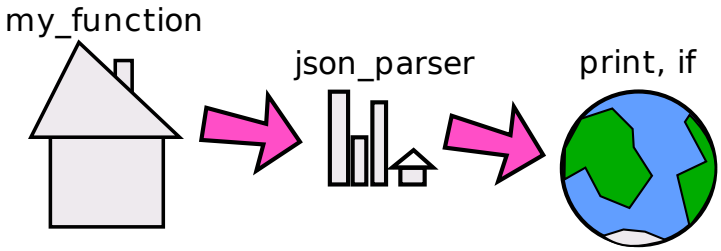
```
num1 = 3;

square = {:(x) x * x;};

num2 = square( num1 );
```

Recap - Cell, scope

```
outerfn = {
    x = 12;
    innerfn = {
        print(x);
```

```
    };
    innerfn;
};

thing = outerfn();
thing();
```

Environments



Environments

```
class Env:
    # ...
    def get(self, name):
        if name in self.items:
```

```
            return self.items[name]
        elif self.parent is not None:
            return self.parent.get(name)
        else:
            return None
```

Environments

```
class Env:
    # ...
    def set(self, name, value):
        self.items[name] = value
```

Cell's evaluator (94 lines)

Cell's evaluator

```
def eval_expr(expr, env):
    typ = expr[0]
    if typ == "number": ...
    elif typ == "string": ...
    elif typ == "none": ...
    elif typ == "operation": ...
    elif typ == "symbol": ...
    elif typ == "assignment": ...
    elif typ == "call": ...
    elif typ == "function": ...
    else: ...
```

Cell's evaluator

```
def eval_expr(expr, env):
...
if typ == "number":
    return ("number", float(expr[1]))
```

Cell's evaluator

```
def eval_expr(expr, env):
...
elif typ == "string":
    return ("string", expr[1])
```

Cell's evaluator

```
def eval_expr(expr, env):
...
elif typ == "none":
```

```
    return ("none",)
```

Cell's evaluator

```
def eval_expr(expr, env):
...
elif typ == "operation":
    return _operation(expr, env)
```

Cell's evaluator

```
def _operation(expr, env):
    arg1 = eval_expr(expr[2], env)
    arg2 = eval_expr(expr[3], env)
```

```
    if expr[1] == "+":
        return ("number", arg1[1] + arg2[1])
    elif expr[1] == "-":
        return ("number", arg1[1] - arg2[1])
    # ...
    else:
        raise Exception("Unknown operation: " + e
```

Cell's evaluator

```
def eval_expr(expr, env):
...
elif typ == "symbol":
    name = expr[1]
    ret = env.get(name)
    if ret is None:
        raise Exception("Unknown symbol '%s'." %
    else:
        return ret
```

Cell's evaluator

```
def eval_expr(expr, env):
...
elif typ == "assignment":
```

```
    var_name = expr[1][1]
    if var_name in env.items:
        raise Exception("Overwriting '%s'." % var
    val = eval_expr(expr[2], env)
    env.set(var_name, val)
    return val
```

Cell's evaluator

```
def eval_expr(expr, env):
...
elif typ == "call":
    return _function_call(expr, env)
```

Cell's evaluator

```
def _function_call(expr, env):
    fn = eval_expr(expr[1], env)
```

```
    args = list((eval_expr(a, env) for a in expr[
    if fn[0] == "function": ...
    elif fn[0] == "native": ...
    else: ...
```

Cell's evaluator

```
args = list((eval_expr(a, env) for a in expr[2]))
...
if fn[0] == "function":
    params = fn[1]
    fail_if_wrong_number_of_args(expr[1], params,
    body = fn[2]
    fn_env = fn[3]
    new_env = Env(fn_env)
    for p, a in zip(params, args):
        new_env.set(p[1], a)
    return eval_list(body, new_env)
```

Cell's evaluator

```
args = list((eval_expr(a, env) for a in expr[2]))
...
```

```
if fn[0] == "function": ...
elif fn[0] == "native":
    py_fn = fn[1]
    params = inspect.getargspec(py_fn).args
    fail_if_wrong_number_of_args(expr[1], params[
    return fn[1](env, *args)
```

Cell's evaluator

```
args = list((eval_expr(a, env) for a in expr[2]))
...
if fn[0] == "function": ...
elif fn[0] == "native":
else:
    raise Exception( "Not a function: %s" % str(f
```

Cell's evaluator

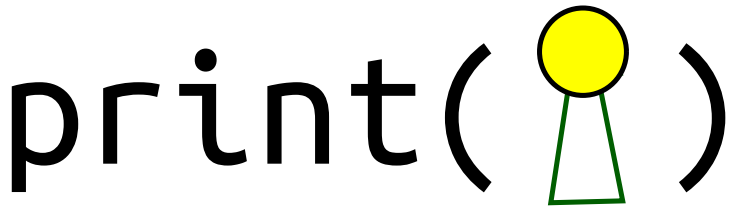
```
def eval_expr(expr, env):
...
```

```
elif typ == "function":
    return ("function", expr[1], expr[2], Env(env
```

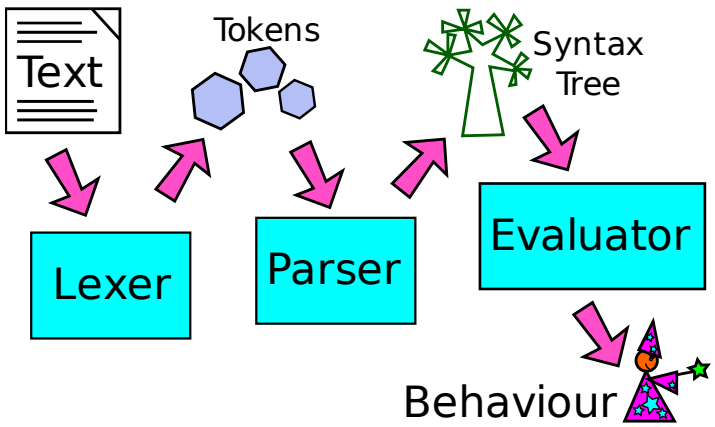
Cell's evaluator

```
def eval_expr(expr, env):
...
else:
    raise Exception("Unknown expression type: " +
```

End result: value + side effects



A programming language



Discussion

github.com/andybalaam/cell