Odds

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The Team

Alexandra - The Manager

Alex - The System Architect

Danny - The Language Guru

Lilly - The Tester

The Process

Branch, add a feature

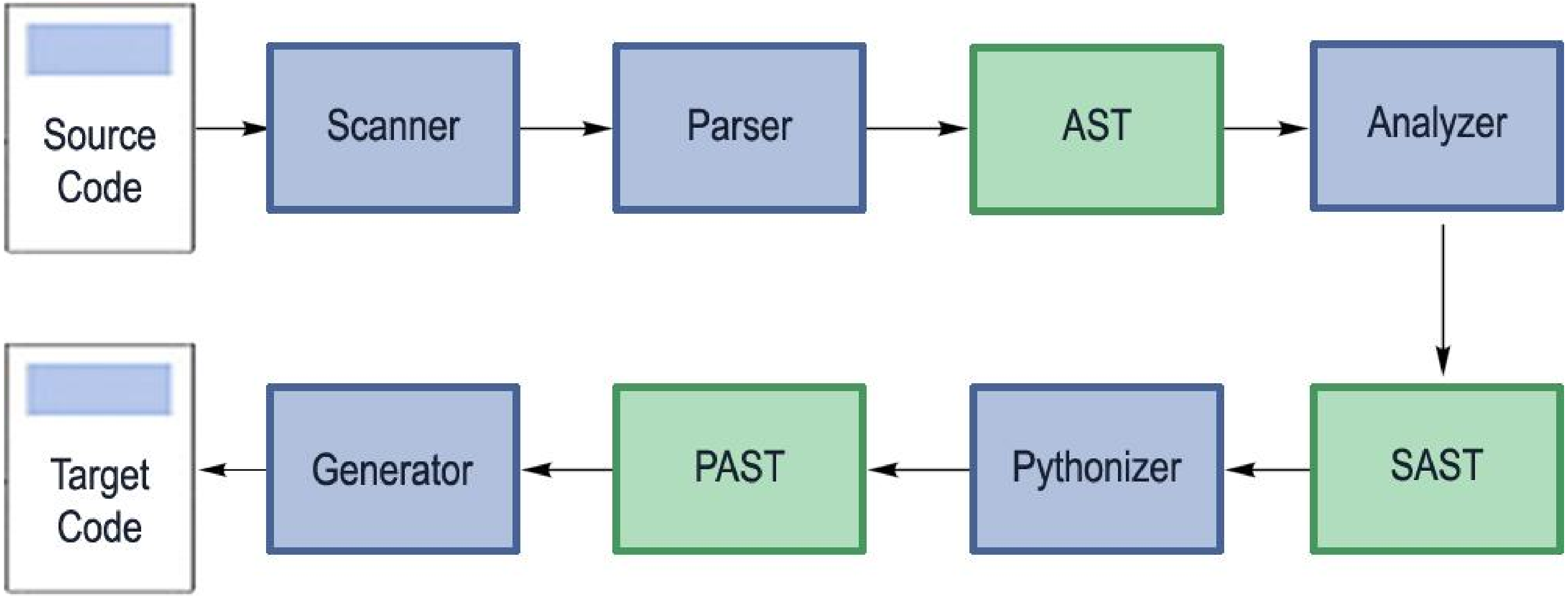
Make a pull request

Travis

Merge with master

Repeat

The Process


Source Code
Scanner
Parser
AST
Analyzer
SAST
Pythonizer
PAST
Generator
Target Code

Language Description

"A simple mathematical distribution language."

Odds is a functional programming language that centers around mathematical distributions, and expresses operations on them in a direct and uncomplicated way.

Challenges

Functional → Imperative

- Static Scoping
- Immutable data
- Anonymous Functions

Challenges

Type Inference → Type Ignorant

- Python is type ignorant - catches errors at runtime
- Odds catches type errors at compile time
- Hindley Milner type inference, no runtime errors in generated python

Distribution type

- When to make conversion to python function calls?

Static Scoping

Python doesn't have static scoping, it has dynamic scoping

We mimic "static scoping" with a table →

each id corresponds to a "statically scoped" id

Keep integer value at top, every time we create a new id, replace name in python with id_integer

This also makes variables immutable, any assignment leads to a new statically scoped id

Static Scoping

do a = 5

do adda = (x) -> return x + a

do a = 10

do print(adda(0))

do adda = (x) -> return x + a

do print(adda(0))

a	a_0
adda	adda_1
x	x_2

Static Scoping

```
do a = 5

do adda = (x) -> return x + a

do a = 10

do print(adda(0))

do adda = (x) -> return x + a

do print(adda(0))
```

a	a_3
adda	adda_1
x	x_2

Static Scoping

do a = 5

do adda = (x) -> return x + a

do a = 10

do print(adda(0))

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adda	adda_1
x	x_2

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do a = 5

do adda = (x) -> return x + a

do a = 10

do print(adda(0))

do adda = (x) -> return x + a

do print(adda(0))
```

a	a_3
adda	adda_4
x	x_5

Static Scoping

do a = 5

do adda = (x) -> return x + a

do a = 10

do print(adda(0))

do adda = (x) -> return x + a

do print(adda(0))

a	a_3
adda	adda_4
x	x_5

Static Scoping

```
do a = 5
do adda = (x) -> return x + a
do a = 10
do print(adda(0))
do adda = (x) -> return x + a
do print(adda(0))
```

```
a_0 = 5
a_0
def adda_1(x_2):
    return (x_2 + a_0)
adda_1
a_3 = 10
a_3
print(adda_1(0))
def adda_4(x_5):
    return (x_5 + a_3)
adda_4
print(adda_4(0))
```

Anonymous Functions

do call = (f, x) -> return f(x)

do y = call((x) -> return x + 2, 4)

do print(y)

... how does this work?

Anonymous Functions

Python doesn’t have anonymous functions

As we move from sast → past

- pull up anonymous functions one statement
- replace occurrence of anonymous function with function name

Anonymous Functions

Odds

```
do call = (f, x) -> return f(x)
do y = call((x) -> return x + 2, 4)
do print(y)
```

Python

```
def call_0(f_1, x_2):
    return f_1(x_2)
call_0
def _anon_3(x_4):
    return (x_4 + 2)
y_5 = call_0(_anon_3, 4)
y_5
print(y_5)
```

Anonymous Functions

Odds

```
do call = (f, x) -> return f(x)
do y = call((x) -> return x + 2, 4)
do print(y)
```

Prints “6”

Python

```
def call_0(f_1, x_2):
    return f_1(x_2)
call_0
def _anon_3(x_4):
    return (x_4 + 2)
y_5 = call_0(_anon_3, 4)
y_5
print(y_5)
```

Anonymous Functions

What else can we do?

“caking” → calling the function immediately after it is declared

Odds

```
do magic = (()-> return 42)()

do magic = (() -> return 40)() + 2
```

Python

```
def _anon_0():
    return 42
magic_1 = _anon_0()
magic_1
def _anon_2():
    return 40
magic_3 = (_anon_2() + 2)
magic_3
```

Everything Is An Expression

In python, most things are statements.

Not in Odds, because we are a functional language!

Everything Is An Expression

So, we needed to replace all instances of “python non-expressions” in odds with their expression value (an id)

Similar to anonymous functions...

Whenever we have an expression in odds which is not an expression in python (assignment, conditionals)

Assign expression value to temporary id, replace expression instance with id

Everything Is An Expression

Conditionals need to be encapsulated in a “conditional” function which returns the value of the conditional evaluation

Everything Is An Expression

Odds

```
do x = y = z = if true then 4 else 2
```

Python

```
def _cond_0():
    if True:
        return 4
    return 2
z_1 = _cond_0()
y_2 = z_1
x_3 = y_2
x_3
```

Type Inference

Python is not type checked; it is ‘type ignorant’. Odds is type checked.

Odds has no type annotations. Problem: how to get type information with which to check?

Solution: Hindley-Milner style type inference →

- variables start out unconstrained
- constrain where and when possible to a type
- If the variable has been constrained and there is a type mismatch, throw a compile-time error at that user!

Type Inference

Simple Case

Odds

```
do n = 2

do success = n + 2
```

'n' must be a Num

'n + 2' is OK because 'n' is a number. 'success' must also be a number.

Sast Printer Output

```
do Num n_0 = 2
do Num success_1 = Num n_0 + 2
```

Program passes Semantic Checking!

Type Inference

Slightly harder case...

'x' and 'y' are unconstrained because they are parameters

```
do and = (x, y) ->
    do result = x && y
    do success = x || y
    return result
```

Is 'x && y' valid? We don't know what types 'x' and 'y' are...

What do we do?

Type Inference

Solution!

Odds

‘`x`’ and y are unconstrained, so on ‘`x && y`’ make ‘`x`’ a Bool and make ‘`y`’ a Bool. ‘`result`’ must also be a Bool.

```
do and = (x, y) ->
    do result = x && y
    do success = x || y
    return result
```

Type Inference

Solution!

Odds

‘x’ and y are unconstrained, so on ‘x && y’ make ‘x’ a Bool and make ‘y’ a Bool. ‘result’ must also be a Bool.

```
do and = (x, y) ->
    do result = x && y
    do success = x || y
    return result
```

‘x || y’ is OK because ‘x’ and ‘y’ are Bools

Type Inference

Solution!

Odds

```
do and = (x, y) ->
    do result = x && y
    do success = x || y
    return result
```

'x' and y are unconstrained, so on 'x && y' make 'x' a Bool and make 'y' a Bool. 'result' must also be a Bool.

'x || y' is OK because 'x' and 'y' are Bools

Sast Printer

```
do and_0(Bool x_1, Bool y_2 => Bool) ->
  do Bool result_3 = Unconst x_1 && Unconst y_2
  do Bool success_4 = Bool x_1 || Bool y_2
  return Bool result_3
```

'and' must be a function that takes 2 Bools and returns a Bool.

Type Inference

Now all we have to do is generalize the process we just outlined:

1. If assigning a literal to a var - do x = 2 - give the var the type of the literal.

Type Inference

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1. If assigning a literal to a var - do x = 2 - give the var the type of the literal.
2. If a var is included in some sort of operation - x && y - ensure that the var is the appropriate type, in this case Bool. If a var is not the appropriate type - If x or y is not a Bool - spit out an error.

Type Inference

Now all we have to do is generalize the process we just outlined:

1. If assigning a literal to a var - do x = 2 - give the var the type of the literal.
2. If a var is included in some sort of operation - x && y - ensure that the var is the appropriate type, in this case Bool. If a var is not the appropriate type - If x or y is not a Bool - spit out an error.
3. If the type of a var is not known - i.e. because the var is a parameter - place constraints on its type where possible. For example:

```
/* var x has unknown type. The function add_two adds 2
to the   argument it is fed and returns */
do a _num = add_two(x)
/* We know x must now be a Num */
```

Type Inference

Generalization was a challenge; there are many corner cases…
What about constraining recursive functions?

‘inf_recursion’ expected to return Num

‘inf_recursion’ returns a Bool

```
do inf_recursion = () ->
  do inf_recursion() + 2
  return true
```

Error!

```
Semantic error:
  Invalid return type in function 'inf_recursion':
    type 'Num' expected to be returned, but type 'Bool' returned instead.
```

Distributions

"A distribution is a measurable set of data to which a function of a discrete variable is applied. This function will map the set of data to a new set of outcomes."

Distributions

Two Type: Continuous and Discrete

Continuous:

Declare minimum, maximum, and the weight to apply to the range of

```
do dist = <0, 10> | (x) -> return 1 | /* Uniform Distribution */
```

Discrete:

Have two lists, variables and the respective weights of the variables

```
do vals = [1, 2, 3]
do weights = [0.1, 0.5, 0.4]
do discrete = |<vals, weights>|
```

Distributions

Operations:

Addition, multiplication, exponentiation between distributions -- use cross product

Operations with constants -- apply value and operation to each element of distribution

```
|*   |+   |**
```

Distributions

The probability density function of X, the lifetime of a certain type of electronic device (measured in hours), is given by

$$f(x) = \begin{cases} \dfrac{10}{x^2} & x > 10 \\ 0 & x \le 10 \end{cases}$$

Find $P\{X > 20\}$.

```
do d = <0, 400> | return if x <= 10 then 0 else 10 / x ** 2 |
do print(1 - P(20, d))
do print(d)
```

Set min and max of distribution, mimic infinity with large number

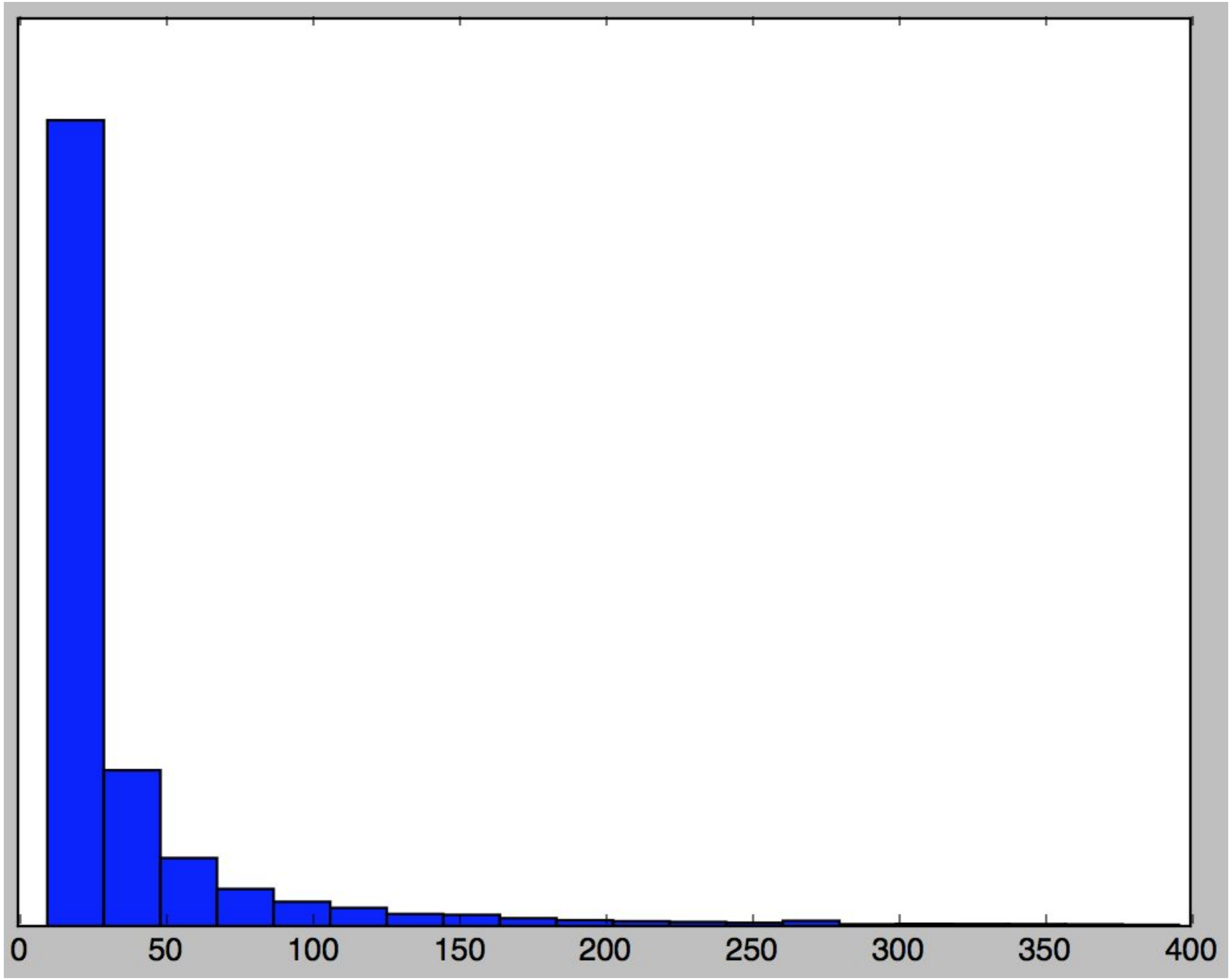
The probability density function

```
do d = <0, 400> | return if x <= 10 then 0 else 10 / x ** 2 |
do print(1 - P(20, d))
do print(d)
```

P(20, d) will calculate the probability that X (in d) < 20, works the same way as normal distribution table

Subtract from 1 to get P(X>20)

do print(d)



Lottery Question

You can buy one ticket to one of four different lotteries:

Lottery One:

90% chance of winning \$2, 8% → \$50, 2% → \$5,000, 1% → \$10,000

Lottery Two:

Distributed with $1/x$ along 5->100

Lottery Three:

Distributed with $1/x*x$ along 10->400

Lottery Four:

99.9% chance of winning \$1, 0.1% → \$1,000,000

Lottery Question

Which ticket should you buy?

... examine expected value

... sort dists by expected value

merge sort!

buy ticket to lottery with the highest expected value for their distribution

Lottery Question

You have 10 dollars. You can buy a ticket to four different lotteries:

Lottery One: 90% chance of winning \$2, 8% of \$50, 2% of \$5,000, 1% of \$10,000

Lottery Two: Distributed with 1/x along [5, 100]

Lottery Three: Distributed with 1/x*x along [10, 400]

Lottery Four: 99.9% chance of winning \$1, 0.1% of winning \$1,000,000

Lottery Question

```
do lot_winnings_one = [2,50,5000,10000]
do lot_probs_one = [.90, .08, .02, .01]
do lot_one = |<lot_winnings_one, lot_probs_one>|

do lot_two = <5,100> | (x) -> return 1 / x |

do lot_three = <10, 400> | (x) -> return 1 / x * x |

do lot_winnings_four = [1, 1000000]
do lot_probs_four = [.999, .001]
do lot_four = |<lot_winnings_four, lot_probs_four>|
```

```
do merge_sort = (l) ->

    do merge = (lists) ->
        /* get two lists */
        do l1 = head(lists)
        do l2 = head(tail(lists))

        /* if either list is empty, return the list */
        return if len(l1) == 0 then l2 else if len(l2) == 0 then l1
            /* otherwise merge */
            else (() ->
                do h1 = head(l1) do t1 = tail(l1)
                do h2 = head(l2) do t2 = tail(l2)
                return if E(h1) <= E(h2) then h1 :: merge([t1, h2 :: t2])
                    else h2 :: (merge([h1 :: t1, t2]))
            )()

    do halve = (l) -> return
        if len(l) <= 1 then [l, []]
        else (() ->
            do h = head(l) do t = tail(l)
            do halves = halve(t)
            do t1 = head(halves) do t2 = head(tail(halves))
            return [h :: t2, t1]
        )()

    return
        if len(l) <= 1 then l
        else (() ->
            do halves = halve(l)
            do l1 = head(halves) do l2 = head(tail(halves))
            return merge([merge_sort(l1), merge_sort(l2)])
        )()
```

```
do merge_sort_45(List[Dist] l_46 => List[Dist]) ->
  do merge_47(List[List[Dist]] lists_48 => List[Dist]) ->
    do Unconst l1_49 = Func(List[Any] => Any) head(List[Unconst] lists_48)
    do Unconst l2_50 = Func(List[Any] => Any) head(Func(List[Any] => List[Any]) tail(List[Unconst] lists_48))
    return
      if Func(List[Any] => Num) len(List[Dist] l1_49) == 0 then
        List[Dist] l2_50
      else

        if Func(List[Any] => Num) len(List[Dist] l2_50) == 0 then
          List[Dist] l1_49
        else
          {_anon_60( => List[Dist]) ->
            do Dist h1_61 = Func(List[Any] => Any) head(List[Dist] l1_49)
            do List[Dist] t1_62 = Func(List[Any] => List[Any]) tail(List[Dist] l1_49)
            do Dist h2_63 = Func(List[Any] => Any) head(List[Dist] l2_50)
            do List[Dist] t2_64 = Func(List[Any] => List[Any]) tail(List[Dist] l2_50)
            return
              if Func(Dist => Num) E(Dist h1_61) <= Func(Dist => Num) E(Dist h2_63) then
                Func(Any, List[Any] => List[Dist]) cons(Dist h1_61, Func(List[List[Dist]] => List[Unconst]) merge_47([List[Dist] t1_62, Func(Any, List[Any] => List[Dist]) cons(Dist h2_63, List[Dist] t2_64)]))
              else
                Func(Any, List[Any] => List[Dist]) cons(Dist h2_63, Func(List[List[Dist]] => List[Unconst]) merge_47([Func(Any, List[Any] => List[Dist]) cons(Dist h1_61, List[Dist] t1_62), List[Dist] t2_64]))
}Func( => List[Dist]) _anon_60()

  do halve_69(List[Any] l_70 => List[List[Any]]) -> return
      if Func(List[Any] => Num) len(List[Unconst] l_70) <= 1 then
        [List[Unconst] l_70, []]
      else
        {_anon_78( => List[List[Any]]) ->
          do Unconst h_79 = Func(List[Any] => Any) head(List[Unconst] l_70)
          do List[Unconst] t_80 = Func(List[Any] => List[Any]) tail(List[Unconst] l_70)
          do Unconst halves_81 = Func(List[Unconst] => Unconst) halve_69(List[Unconst] t_80)
          do Unconst t1_82 = Func(List[Any] => Any) head(List[Unconst] halves_81)
          do Unconst t2_83 = Func(List[Any] => Any) head(Func(List[Any] => List[Any]) tail(List[Unconst] halves_81))
          return [Func(Any, List[Any] => List[Unconst]) cons(Unconst h_79, List[Unconst] t2_83), List[Unconst] t1_82]
}Func( => List[List[Any]]) _anon_78()
  return
    if Func(List[Any] => Num) len(List[Dist] l_46) <= 1 then
      List[Dist] l_46
    else
      {_anon_90( => List[Dist]) ->
        do List[List[Unconst]] halves_91 = Func(List[Any] => List[List[Any]]) halve_69(List[Dist] l_46)
        do List[Unconst] l1_92 = Func(List[Any] => Any) head(List[List[Unconst]] halves_91)
        do List[Unconst] l2_93 = Func(List[Any] => Any) head(Func(List[Any] => List[Any]) tail(List[List[Unconst]] halves_91))
        return Func(List[List[Dist]] => List[Dist]) merge_47([Func(List[Unconst] => Unconst) merge_sort_45(List[Unconst] l1_92), Func(List[Unconst] => Unconst) merge_sort_45(List[Unconst] l2_93)])
}Func( => List[Dist]) _anon_90()
```

Lottery Question

So which one should you buy? Let’s run the program!