Design and implementation of ps11 - Lisp-like programming language which compiles to Pyramid Scheme

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Keywords: syntax tree; Pyramid Scheme; lisp; compilation

I. INTRODUCTION

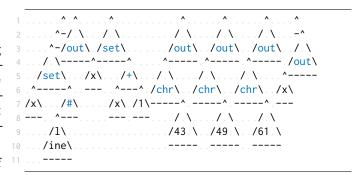
In ancient Egypt, pyramids were constructed as the resting places of deceased pharaos, containing not only their mummified remains but also an assortment of keywords and type literals the pharaoh will need in their journey though afterlife. Pyramid Scheme (PS) is a variant of the Scheme dialect of Lisp, which honours these ancient traditions and accompanies *us* thorough our journey of computation.

PS was designed by Conor O'Brien, in the early 2017 (date of the earliest commit to the GitHub repository). It is a turing-complete esoteric programming language (esolang)² which uses tree-like, as opposed to a serial code structure. Compilers make use of an intermediate representation of the language in the form of an abstract syntax tree (AST). In contrast to most contemporary languages / frameworks, which build on top of the existing infrastructure to create "the stack" of software, Pyramid Scheme aims to shed any unnecessary abstractions, including that of the AST. The computation in pPramid scheme is therefore represented as a literal syntax tree (LST) of ascii-art pyramidal constructs.

Pyramid Scheme is supported by the "Try It Online!" repository of online interpreters, and, like many other esolangs, has been featured in many Code Golfing challenges.

A. Pyramid Scheme

The original and, so far, the only implementation of PS is written in Ruby. The LST of the program is first parsed and then mapped to a recursive evaluation chain. An example of one such program can be seen in Listing 1.



Listing 1. A simple Pyramid Scheme program. It takes one input from stdin – (set x (# stdin)), increments it by one – (set x (+ x 1)) and prints the result computation to the command line.

PS parser reads the body of each pyramid verbatim, concatenated line by line.⁸ The parser begins at the tip (^), and walks down the left (/) and the right (\) side, collecting the characters in-between. When the two sides run out, it first checks for the presence of the pyramid base (-),⁹ and then for the tips of the child pyramids, if present. The pyramids may connect *only* on these corners, such that, for example, the first pyramid with chr (which constructs a character + to be printed) in Listing 1 rightfully does not consider the pyramid 1 of the set branch as its child.

Note, however, that this allows for an existence of direct connection between neighbouring branches of the LST – in Listing 1, for example, the first print statement (out keyword), shares the node x with its neighbouring branch. This is an interesting parallel to the phenomenon of the lateral gene transfer observed in genetics, and suggests a more-proper description of the PS to be that of a Ewok village syntax tree (EWST). ^{10,11} Although this is undoubtedly one of the more

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interesting and powerful features of PS, it has not yet been implemented in the project described herein shortly, and therefore will not be considered further, but left for future work.

The specification of the pyramid structure does not preclude the existence of a pyramid with no content. Such a height-0 pyramid is falsey and evaluates to 0.¹²¹³ A pyramid with no content *does* however both evaluate its children, and pass them as an its output. This make the height-0 pyramid an important construct for code packing, as can be seen in the first branch in Listing 1

There are two types operators in PS: ones which implicitly evaluate both of their children, as well as those which do this only under certain circumstances. The first group maps very closely to its underlying Ruby implementation. There are basic binary arithmetic and comparison operators: +, *, -, /, ^, =, ! and <=>. Keyword out prints all of its inputs and chr converts number to a character. The keyword arg indexes arrays (or input arguments), and keywords # and " convert back and forth from and to a string. # character also allows one prompt user for input if given a (semi)keyword line. 141

The second group of operators conditionally evaluates only one of their children. set sets the variable denoted by its left child to the evaluated right one. loop and do evaluate the right child subtree as long as the left one evaluates to true (with the difference being when is the check made – before and after right subtree evaluation respectively). Finally? evaluates the right subtree only if the left one evaluates to true, else it evaluates to zero.

- II. PSLL
- A. Bracket structure
- B. Syntactic sugar

The above specification is, in principle, enough to create fully fully functional PS programs. Certain tasks are, however, still rather cumbersome. This section outlines these cases, as well as syntactic sugar constructs introduced to psl1 to alleviate them. All of these are implemented as local (or semi-local) expansion macros, as described in Section III B. Despite authors best efforts, this introduces some sharp edges into the language (see Section II C).

Implicit bracket expansion Each bracket must have exactly three elements. For small expressions this is almost always the case, but becomes problematic for larger, flow-control and loop structures where each such expression can contain an arbitrarily large number of sub-expressions (see **[info]** for an example of such expression). Hence a bracket containing > 2 other brackets gets expanded as follows:

```
( a (out a 1) a (out a 2) a (out a 3) a (out a 4) a (out a 5) a ) is interpreted as:
```

```
( (((out . 1) . (out . 2)) . . ((out . 3) . (out . 4))) . . (out . 5) .)
```

Each neighbouring pair or elements of the parent gets put together into a bracket, until the length of the parent is less than 2. This results in a (literal) balanced binary tree in the final PS code, and so for a parent bracket of N sub-expressions will result in a tree of height $\mathcal{O}(\log_2(N))$.

String literals Single characters can be created in RDM with the chr keyword (Ruby . to_i.chr). It is also possible to construct longer strings in RDM since Ruby's "+" sign overloads string concatenation. The string "hello" is therefore:

```
(+, (+, (+, (+, (chr. 72), (chr. 101)), (chr. 108)), ...(chr. 108)), (chr. 111))
```

psll introduces string literals, such that (set s "hello") expands into the above code. Note that this is a very left-child heavy tree. To balance it, the above string could also be made by recursively concatenating its binary split:

```
(+ (+ (chr .72) (chr .101))
... (+ (chr .108) (+ (chr .108)) (chr .111)))
such that "hello"= "he"+ "llo"= ("h"+ "e")+ ("l"+ "lo")=....
```

Array literals

Rolling sum and product

def keyword

Semi-local

C. Sharp edges

As mentioned at the beginning of Section II B, the introduction of syntactic sugar into psll introduces some edge cases which one ought to watch out for.

Underscore keyword _

Escape characters Because " is used for strings, and [] for arrays...

- III. COMPILER
- A. Abstract syntax tree
- B. Local macro expansion
- C. Optimisation
- IV. EXAMPLE PROGRAMS
- A. Pseudorandom number generation
- B. Bubble sort
- C. Chess engine

```
1 (set.a.0).//.Flip-flop
 2 (set. N. 10) (set. j. 0) // N. of. iteration. and loop.counter
 3 (loop (! . (= . j . N)) . (
           .// Do some work...
            (out.j.(chr.32)).//.Print.j.and.space
           (out a. (chr. 10)).//.Print.a.and.newline
            (set.a.(!.a)).//.Flip.a
 8 (set.j.(+.j.1))
  9 )) (set test "hi")
  1 (set.newline."\n")
 2 (set.nil.(arg.999))
 4 // Array to be sorted
 5 (set.a.[3.1.4.1.5.9.2.6.5.3.5])
 7 // .Get .array .length
 8 // This will be: (len a N)
 9 (set. N. 0) . // . Pointer . into . the . array
 10 // Increment pointer until goes off the end
11 (loop (! (= (arg a a N) nil)) (set N (+ N 1)))
13 //.Bubble.sort.the.array
14 (do.again.(
15 .. (set again 0)
16 .. (set. n. 0) .//. Position. pointer
17 ...(loop.(!.(!.(<=>.n.(-.N.1)))).(.//.For.all.pairs
18 ....(set.this.(arg.a.n))
19 .... (set.next.(arg.a.(+.n.1)))
20 ....//.This.and.next.need.swapping
21 ....(set.swap.(!.(<=>.(<=>.this.next).-1)))
22 . . . . (?. swap. (
23 .....(set.again.1).//.Will.need.to.go.again
24 ..... (set b []) // Start b as an empty array
25 . . . . . . // . Add . prefix . of . a
26 .....(set.1.0)
28 ..... (set b (+ b (- ((arg a l) nil) (nil nil))))
29 .....(set.l.(+.l.1))
30 . . . . . ))
31 .....Add.two.elements,.swapped
32 .....(set.b.(+.b.(-.((arg.a.(+.n.1)).nil).(nil.nil))))
33 . . . . . . (set.b.(+.b.(-.((arg.a.(+.n.0)).nil).(nil.nil))))
34 . . . . . . // . Add . suffix . of . a
35 . . . . . . (set . l . (+ . n . 2))
      _{1} _{2} _{3} _{4} _{5} _{1} _{5} _{5} _{5} _{1} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} _{5} 
37 .....(set b.(+ b.(-.((arg.a.l).nil).(nil.nil))))
38 .....(set l.(+.l.1))
39 . . . . . ))
40 .... (set.a.b)
          · (( a
41 . .
42 ... (set.n.(+.n.1)).//.Increment.position.pointer
       .(out.(*.a.",").newline).//.Print.b.+.newline
44
45 ))
```

V. CONCLUSIONS AND OUTLOOK

"Program in Pyramid Scheme! Teach your friends! Have them teach their friends! Then have those friends teach their friends!"

- Joined pyramids

Finally, I think every programmer shares a certain latent interest in the underlying structure and of the languages they use every day. I would encourage them to scratch that itch and learn more about. If you come from a formal computer science background this may not be new to you, but many of us, myselfincluded, learned programming through other ways. There are plenty of resources to start, but I'm inclined to mirror the advice of Casey Muratori: 15 "Look at all of the resources on these topics in in the following way: rather than reading what someone tells you about how to build a compiler (...) start programming one without knowing what you're doing (...) and see what you can learn. When you cannot make forward progress (...) [look for] solution to that particular problem you're having. (...) Now you have some context to evaluate what people what you (...) whereas if you read about stuff without ever actually having encountered a problem yet, then you're just gonna you have no idea [whether its valuable]." If you really want a starting point though, I recommend David Beazley's ply and sly projects. 16-19

REPRODUCIBILITY

At the time of writing, the commit SHA of the main Pyramid Scheme GitHub repo¹ is:

fd183d296f08e0cba8bf55da907697eaf412f6a7 and the psll repo:

ea6c6d2e9c8278cc752894a9aff43f7d44bd93a9

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 $^{^2} Pyramid\ scheme.\ \texttt{https://esolangs.org/wiki/Pyramid_Scheme.}$

³Linda Torczon and Keith Cooper. *Engineering A Compiler*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 2nd edition, 2007.

⁴Bryan Cantrill. *Zebras All the Way Down*. Uptime 2017, https://youtu.be/fE2KDzZaxvE.

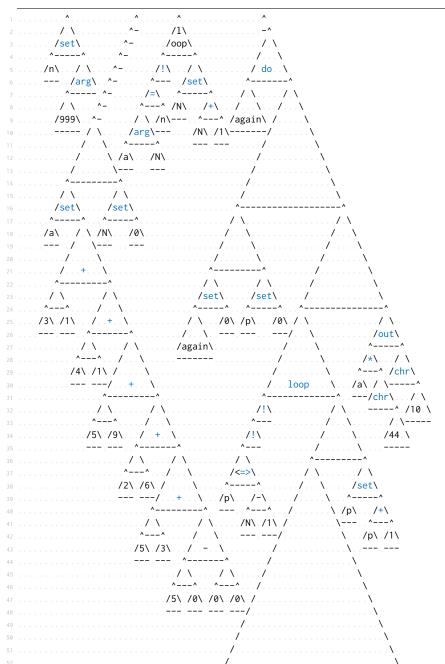
⁵Casey Muratori. The thirty million line problem. https://youtu.be/k ZRE7HIO3vk, 2018.

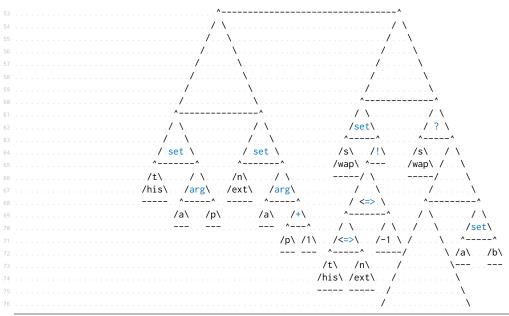
⁶Try it online! https://tio.run.

 $^{^7\}mathrm{Code}$ golf stackexchange. https://codegolf.stackexchange.com.

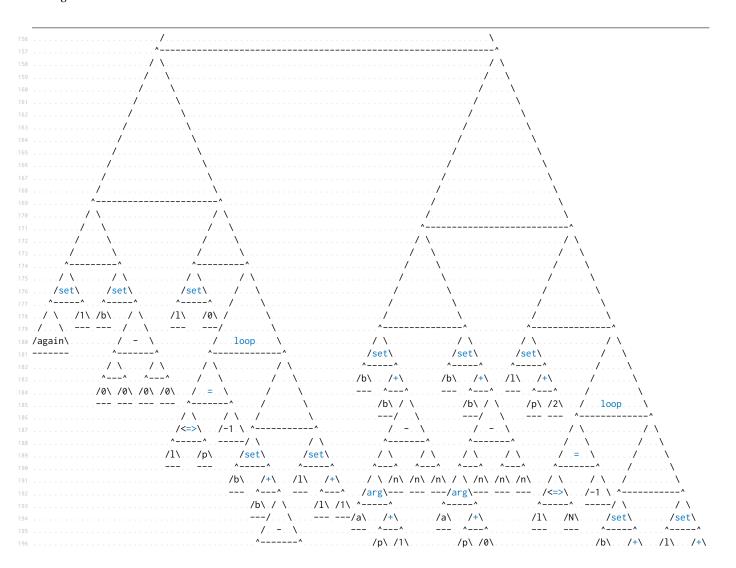
- $^8\text{Hence},$ for example, the bottom pyramid in the first stack in Listing 1 contains the (semi)keyword 1ine, as opposed to two words: 1 and ine. $^9\text{Note}$ that the base of the pyramid is a dash (0x2d), not an underscore.
- ¹⁰Patrick J. Keeling and Jeffrey D. Palmer. Horizontal gene transfer in eukaryotic evolution. *Nature Reviews Genetics*, 2008.
- ¹¹Zachary Weinersmith. Ewok village of life. SMBC, https://www.smbc-comics.com/comic/2012-04-08.
- 12 The term "height-0" can be ambiguous since the pyramid itself has height of 2 characters. In this work the pyramid's height, however, is the number of lines of the text in its body.
- ¹³Conor O'Brien. Pyramid scheme negation. https://codegolf.stack exchange.com/questions/147513/pyramid-scheme-negation.
- ¹⁴Words line, (as well as stdin, readline) are referenced to as semikeywords since they have a keyword meaning only when they're an input of the # command.
- ¹⁵Jonathan Blow and Casey Muratori. Q&a: Making programming language parsers. https://youtu.be/lcF-HzlfYKE, Starting at minute

- 8.00, 2020.
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- ¹⁷David Beazley. Sly (sly lex-yacc). GitHub repository, https://github.com/dabeaz/sly.
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- ¹⁹ John Levine, Doug Brown, and Tony Mason. *lex & yacc*. O'Reilly Media, Inc., 2nd edition.
- $^{20} The \, lex \, \& \, yacc \, page. \, http://dinosaur.compilertools.net.$
- ²¹Blaine Rodgers. High-octane rumble simulation engine. GitHub repository, https://github.com/PaperclipBadger/high-octane-rum ble-simulation-engine, 2017.
- ²²Jonathan Blow and Casey Muratori. Making programming language parsers. https://youtu.be/MnctEW1oL-E, 2020.





Listing 2. Bubble sort in Pyramid Scheme. Lines 1-155. This listing has been split into two sections. Lines 156-230 can be found in Listing 3.





Listing 3. Bubble sort in Pyramid Scheme. Lines 156-230. This listing has been split into two sections. Lines 1-155 can be found in Listing 2. The indentation of this listing has been reduced, and the middle section of an otherwise empty pyramid has been omitted for readability.