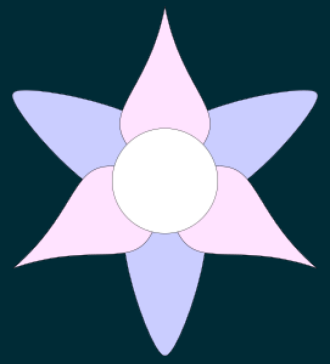
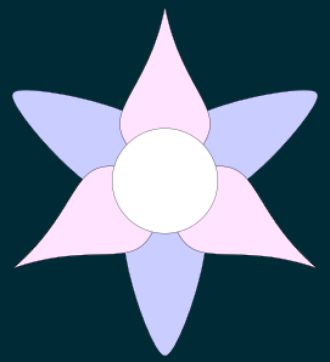


LILIUM

A LISP-LIKE REGISTER MACHINE

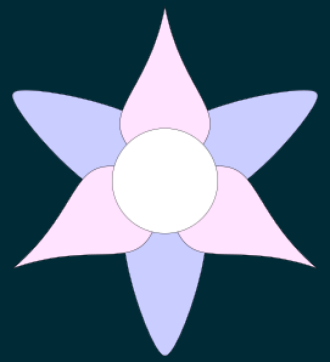
Michael Pucher, 01425215

cluosh / lilium



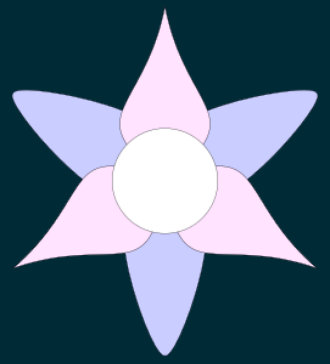
DEVELOPMENT HISTORY

- Starting with last years course
- First version: Flex/Bison/C++ -> limited prototype
- Second version: Boost Spirit/C++ -> C++ template hell
- Final version: Rust



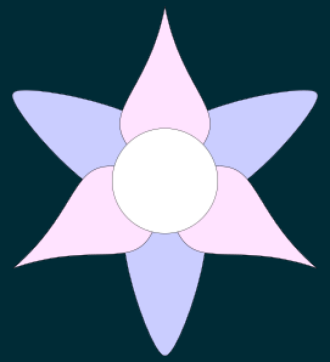
ARCHITECTURE

- Register machine
- LISP-like language
- Translated to bytecode
- Token-threaded dispatch



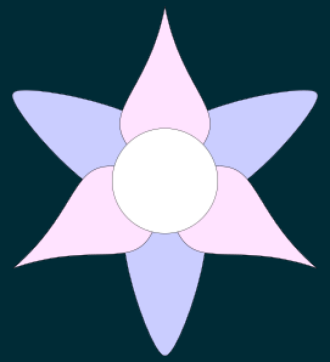
ARCHITECTURE (CONT'D)

- Only call stack
- 256 registers for each stack frame



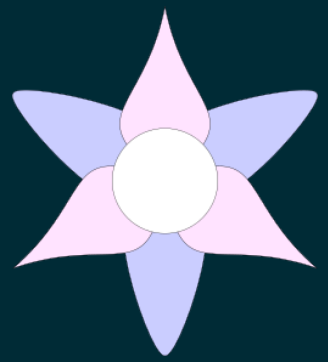
CALLING CONVENTIONS

- r0 has return address
- r1 has return value
- r2 etc. for arguments
- Special mov instruction for arguments



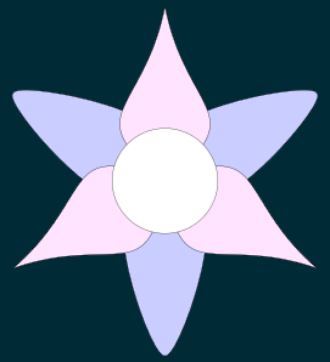
BYTECODE

- 4-byte instructions
- 1-byte opcode
- Usually one byte target register
- Rest for operands



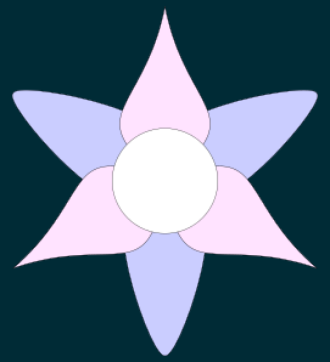
BYTECODE DISASSEMBLY

```
0x00000: mov 4 1
0x00001: ld 5 0
0x00002: gt 3 4 5
0x00003: jtf 3 0x3
0x00004: mov 3 2
0x00005: jmf 0xd
0x00006: mov 6 1
0x00007: ld 7 1
0x00008: sub 5 6 7
0x00009: mov 7 2
0x0000a: mov 8 1
0x0000b: mul 6 7 8
0x0000c: mvo 2 5 255
0x0000d: mvo 3 6 255
0x0000e: call 0x0
0x0000f: ldr 4
0x00010: ld 5 0
0x00011: add 3 4 5
0x00012: mov 1 3
```



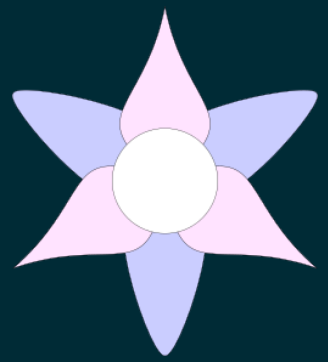
FEATURES

- Basic arithmetics: `(+ 1 2), (* 1 2)`
- Basic logic: `(& 0 1), (| 0 1), (~ 0)`
- Basic comparison: `(== 1 1), (> 1 0)`
- Function definition: `(def fun (a b) (+ a b))`
- Variable assignment: `(let ((a 3)) (+ a 4))`
- Conditionals: `(if (> a 3) (fa a) (fb b))`
- Read/print integers: `(read), (write 123)`



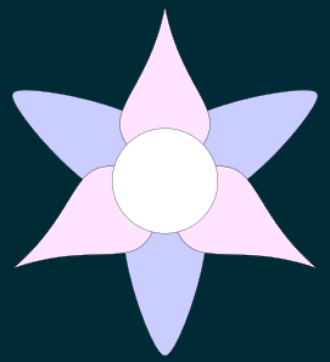
IMPLEMENTATION

- Rust (nightly)
- lalrpop as LR(1) parser generator



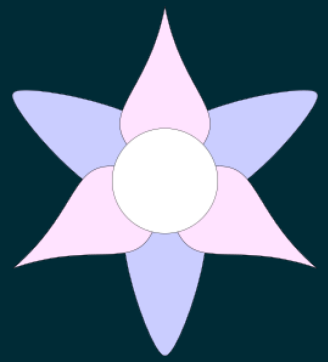
LALRPOP GRAMMAR

```
expression: Expression = {
    "(let" "(" <a:assignments> ")" <b:expressions> ")" => {
        Expression::VariableAssignment(a,b)
    },
    "(" <o:op_binary> <l:expression> <r:expression> ")" => {
        Expression::BinaryOp(o, Box::new(l), Box::new(r))
    },
    ...
};

identifier: String = {
    r"[a-zA-Z]+" => <>.to_string(),
};
```



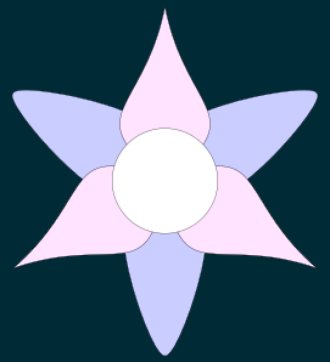
TOKEN-THREADING IN RUST

- Rust performs bound checks on...
  - array access
  - *match* statements
  - basically everthing
- Can we get computed goto C performance?



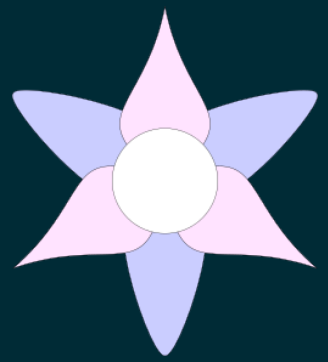
UNSAFE AND INLINE ASSEMBLY

- Array access without bound check -> use **unsafe**
- Token-Threading -> use **asm**
- Comparison of dispatchers in Rust: https://pliniker.github.io/post/dispatchers/



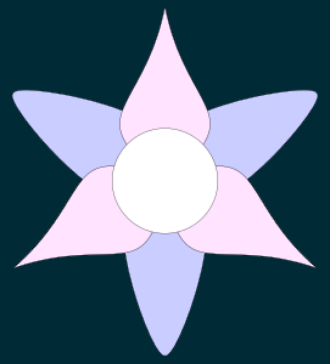
TOKEN-THREADING IN RUST

```
#[cfg(target_arch = "x86_64")]
macro_rules! dispatch {
    ($vm:expr, $pc:expr, $jumptable:expr) => {
        unsafe {
            let opcode = $vm.code
                .get_unchecked($pc).opcode;
            let addr = *$jumptable
                .get_unchecked(opcode as usize);
            asm!("jmpq *$0"
                 :
                 : "r"(addr), "{rdx}"($pc)
                 :
                 : "volatile");
        }
    }
}
```



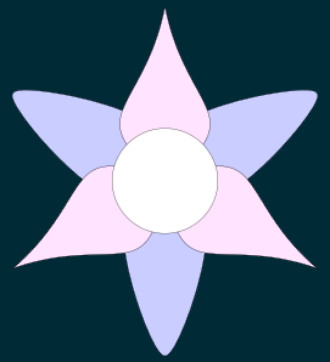
DISPATCH LOOP

```
dispatch!(&thread, pc, ops);

do_and_dispatch!(&thread, ops, "op_ld", pc, {
    pc = op_ld(thread, pc);
});

do_and_dispatch!(&thread, ops, "op_ldb", pc, {
    pc = op_ldb(thread, pc);
});

do_and_dispatch!(&thread, ops, "op_ldr", pc, {
    pc = op_ldr(thread, pc);
});
```



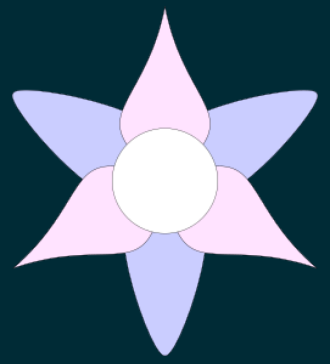
GENERATED CODE

```
op_add:
    movzbl    2(%rax,%rdx,4), %edi
    addq    %rsi, %rdi
    movzbl    3(%rax,%rdx,4), %ebx
    addq    %rsi, %rbx
    movzbl    1(%rax,%rdx,4), %eax
    addq    %rsi, %rax
    movq    (%rcx,%rbx,8), %rsi
    addq    (%rcx,%rdi,8), %rsi
    movq    %rsi, (%rcx,%rax,8)
    movq    32(%r15), %rax
    movzbl    4(%rax,%rdx,4), %eax
    incq    %rdx
    movq    112(%rsp,%rax,8), %rax
    jmpq    *%rax
```

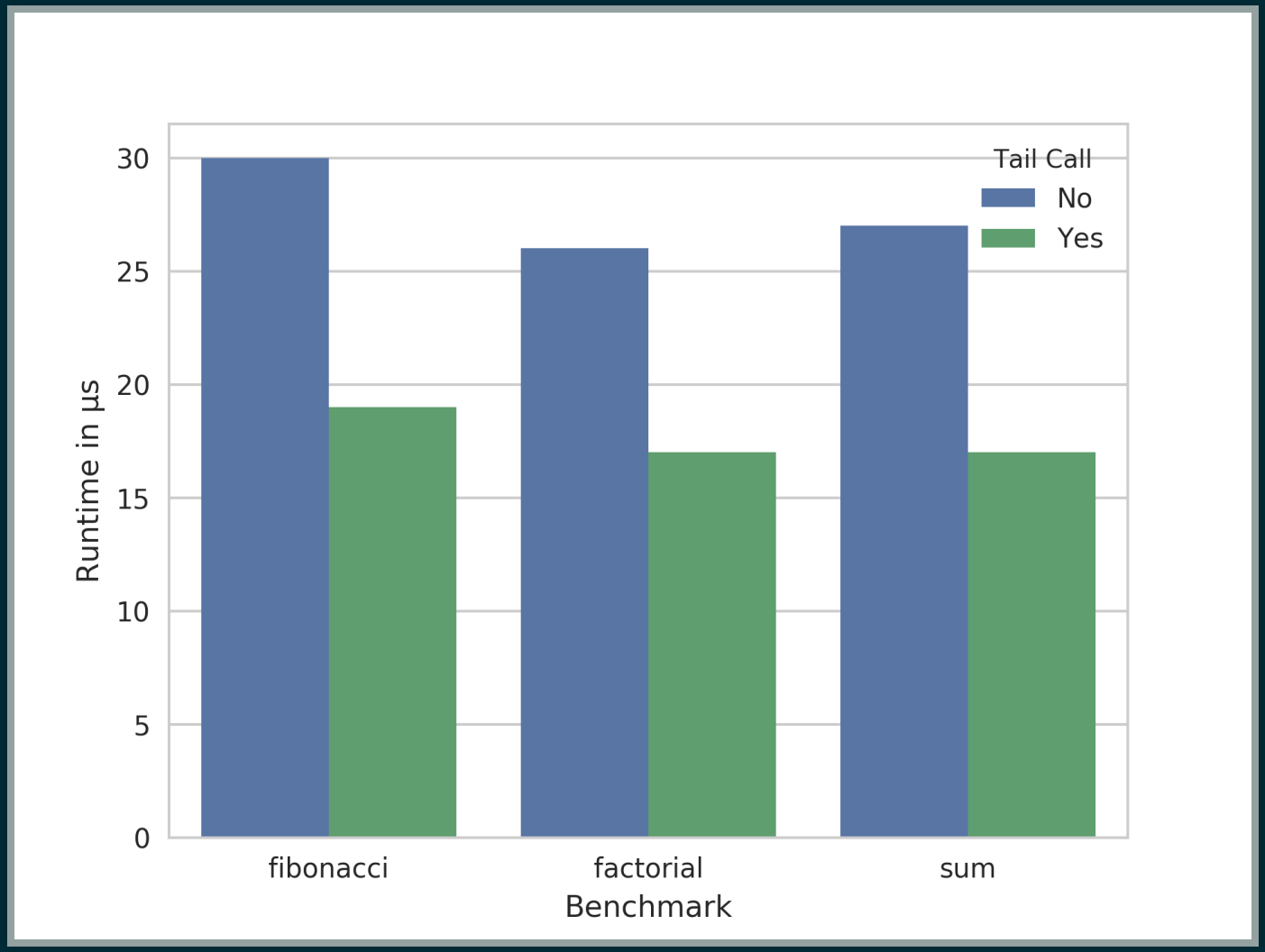


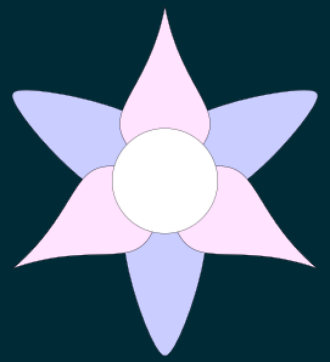
TAIL CALL OPTIMIZATION

- Stack depth is limited
- Therefore tail calls needed for loops
- Easy to implement
- Performance win!



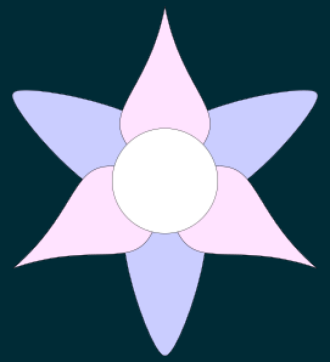
TAIL CALL RUNTIME





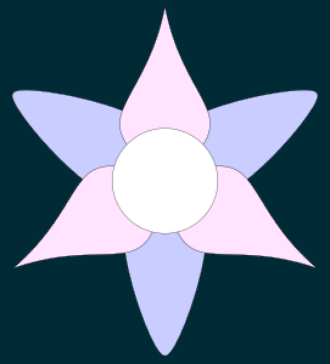
PERFORMANCE COMPARISON

- Fibonacci in Lilium, SBCL and Java
- Modified for SBCL (because of BigNums)
- Java version iterative (tail call equivalent)

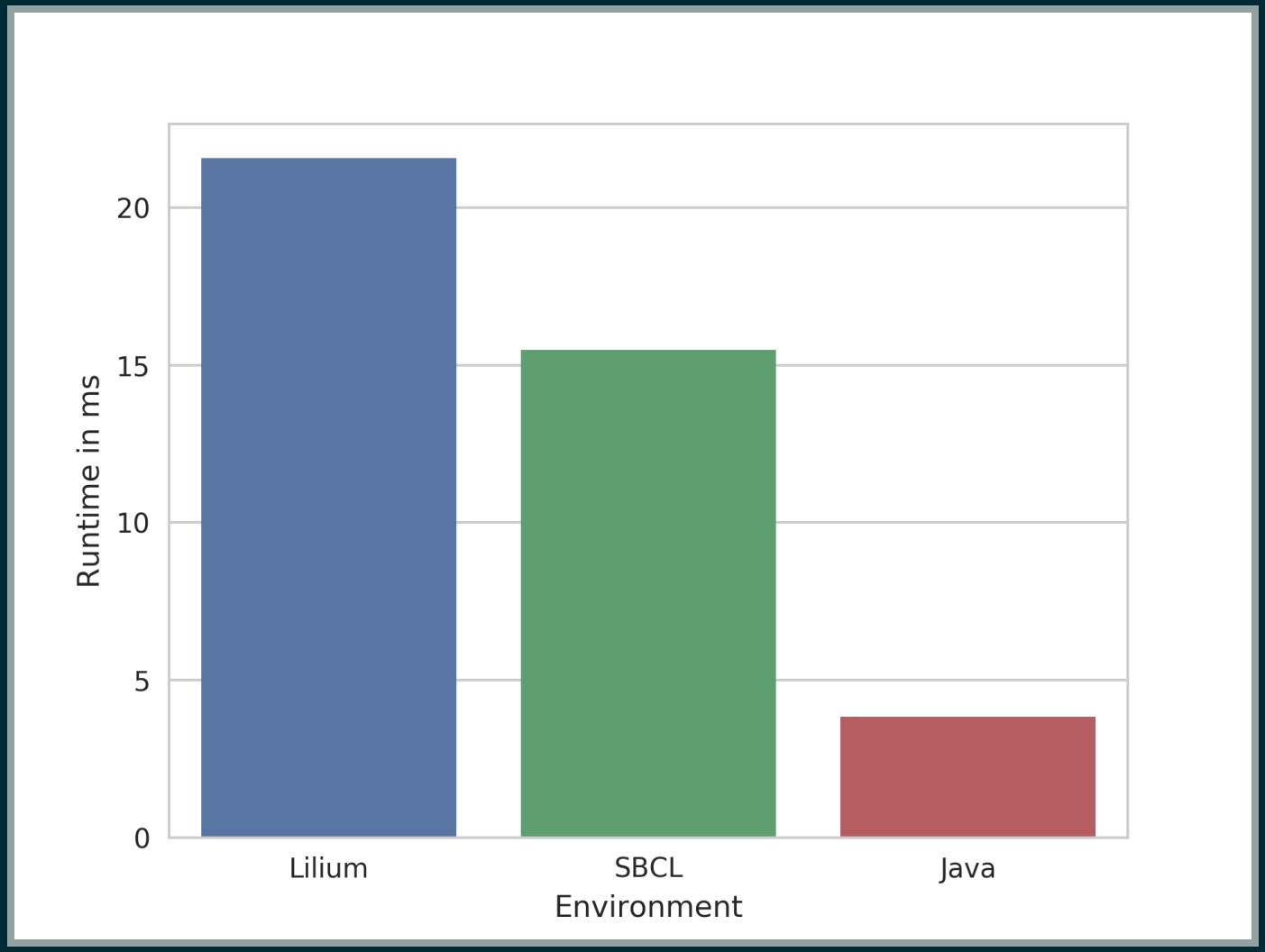


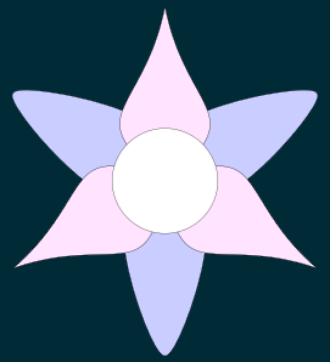
VERSIONS

- OpenJDK 64-Bit Server VM (build 9+181, mixed mode)
- SBCL 1.4.0



FIBONACCI(1000000) RUNTIME





REASONS FOR BAD PERFORMANCE

- Register allocation very basic -> lots of moves
- OP machine code with lots of memory access
- Token-threading alone is no silver bullet