# How to make an optimizing compiler in a few months

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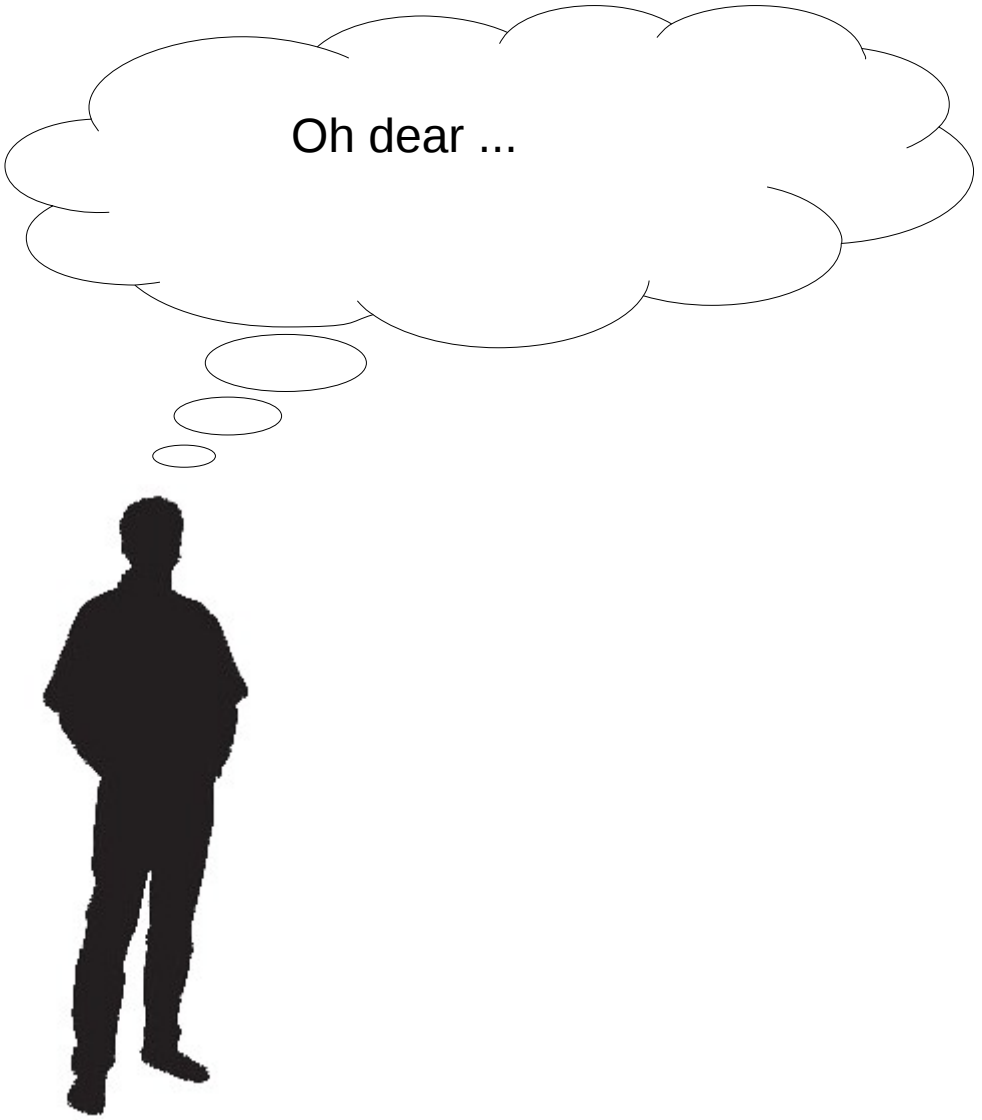
Erlang, Haskell,
Smalltalk,
O'meta ?
We want a
new compiler ...


Oh dear ...


C ...


With delivery as soon as possible ...

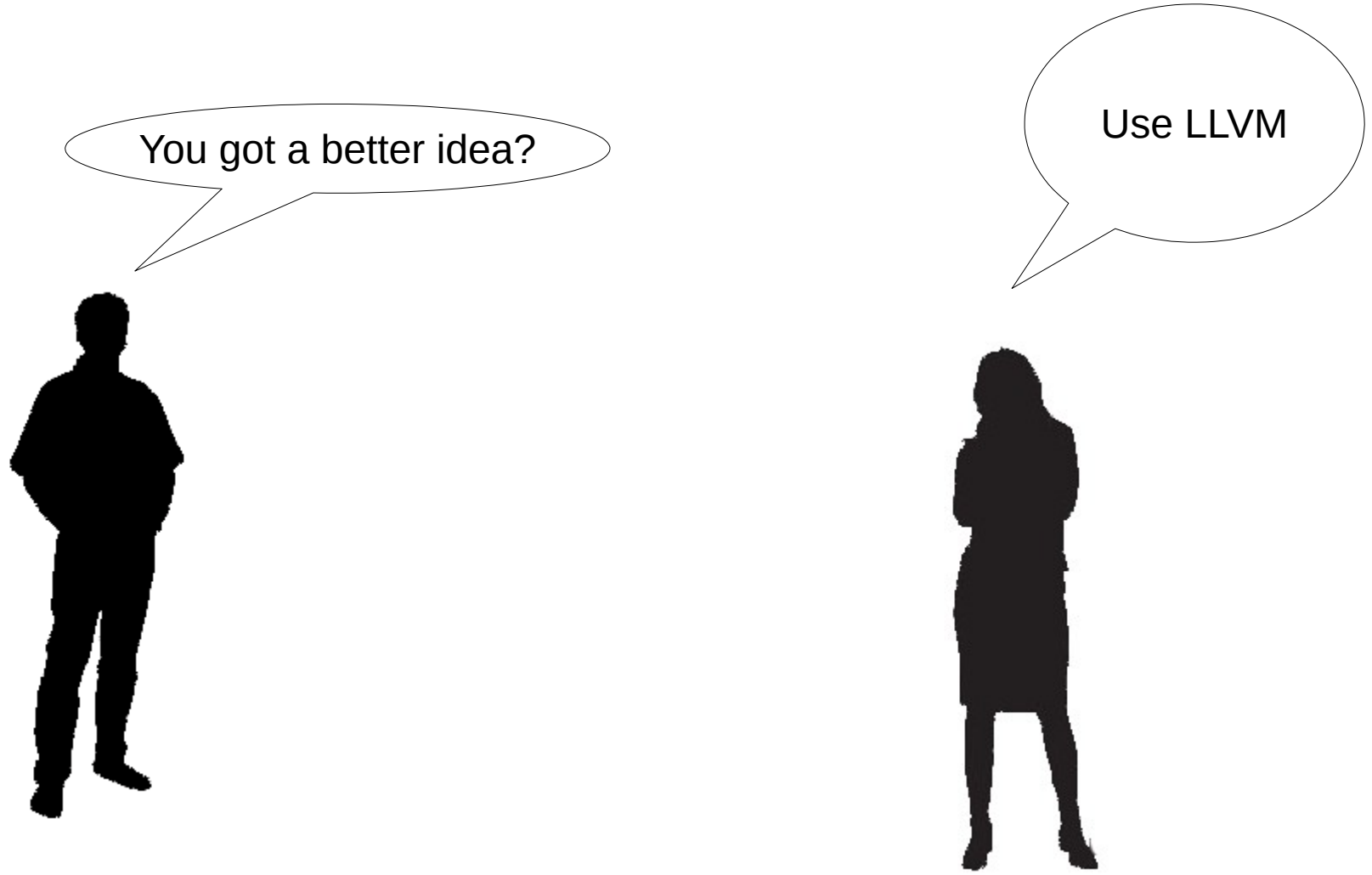

I want to write a native code compiler
For which processor?

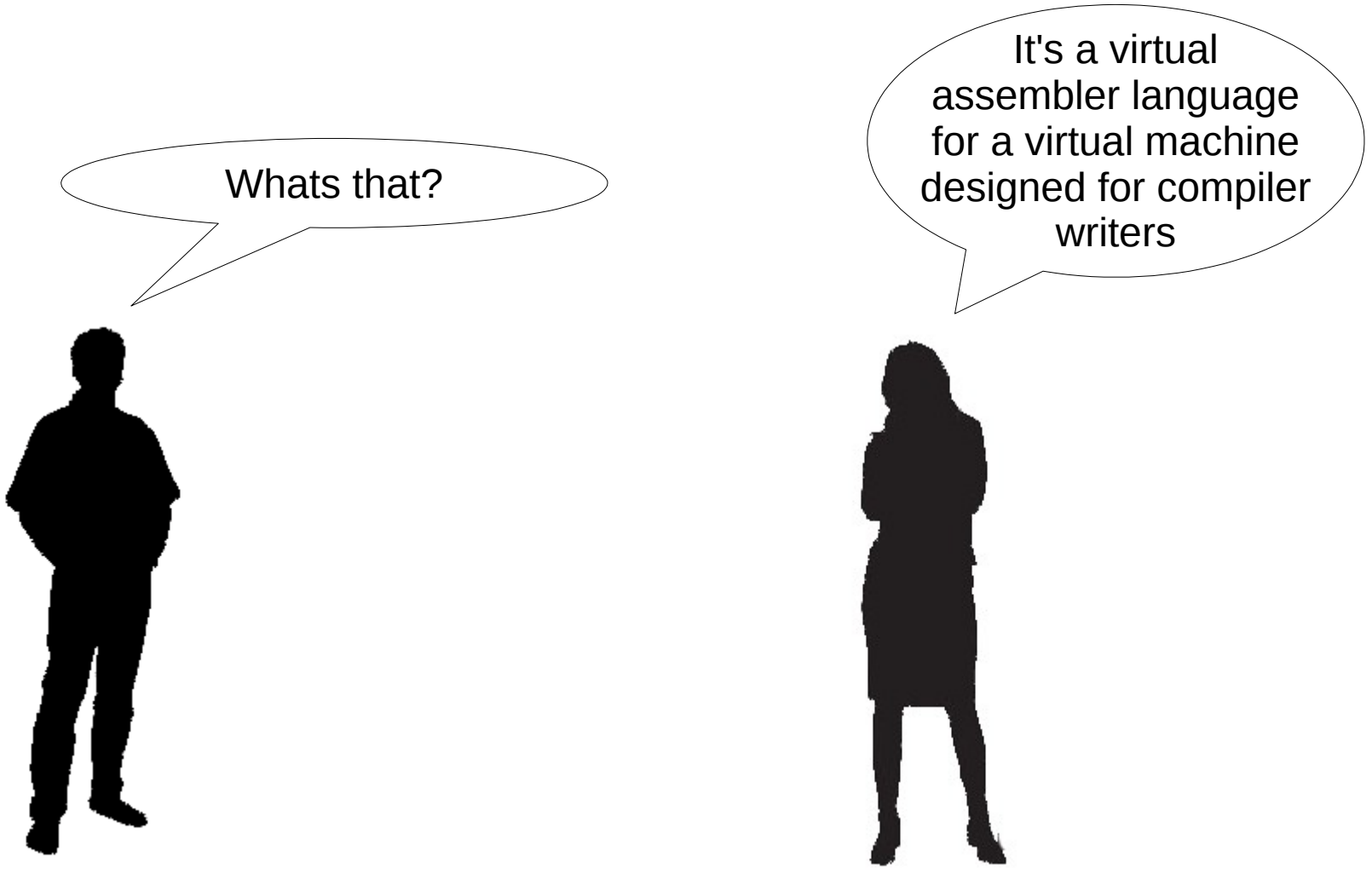
X86? MIPS?
ARM? ADM??
POWERQUICK????
32 bit? 64 bit?
Calling sequences?

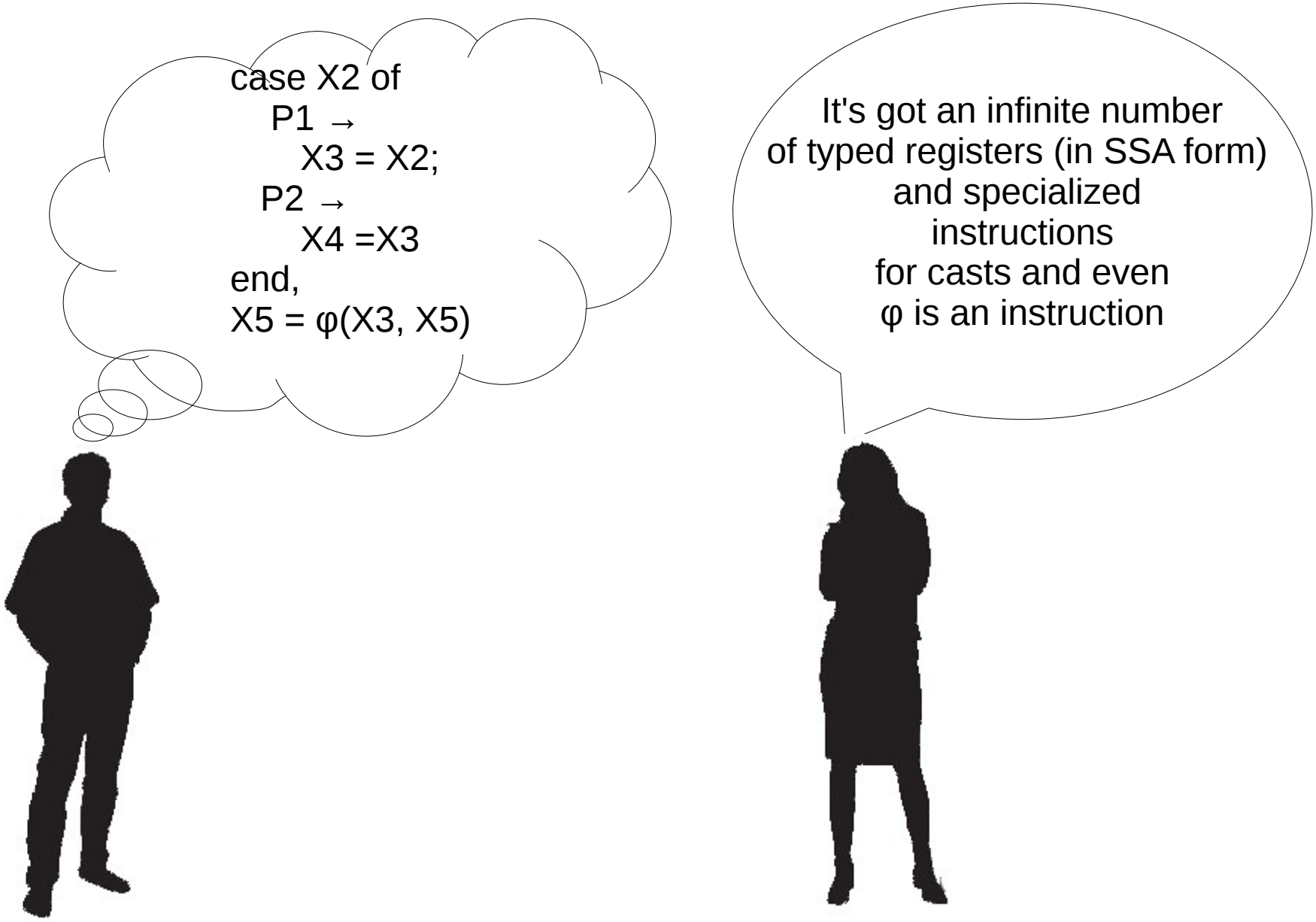
Not very portable then!

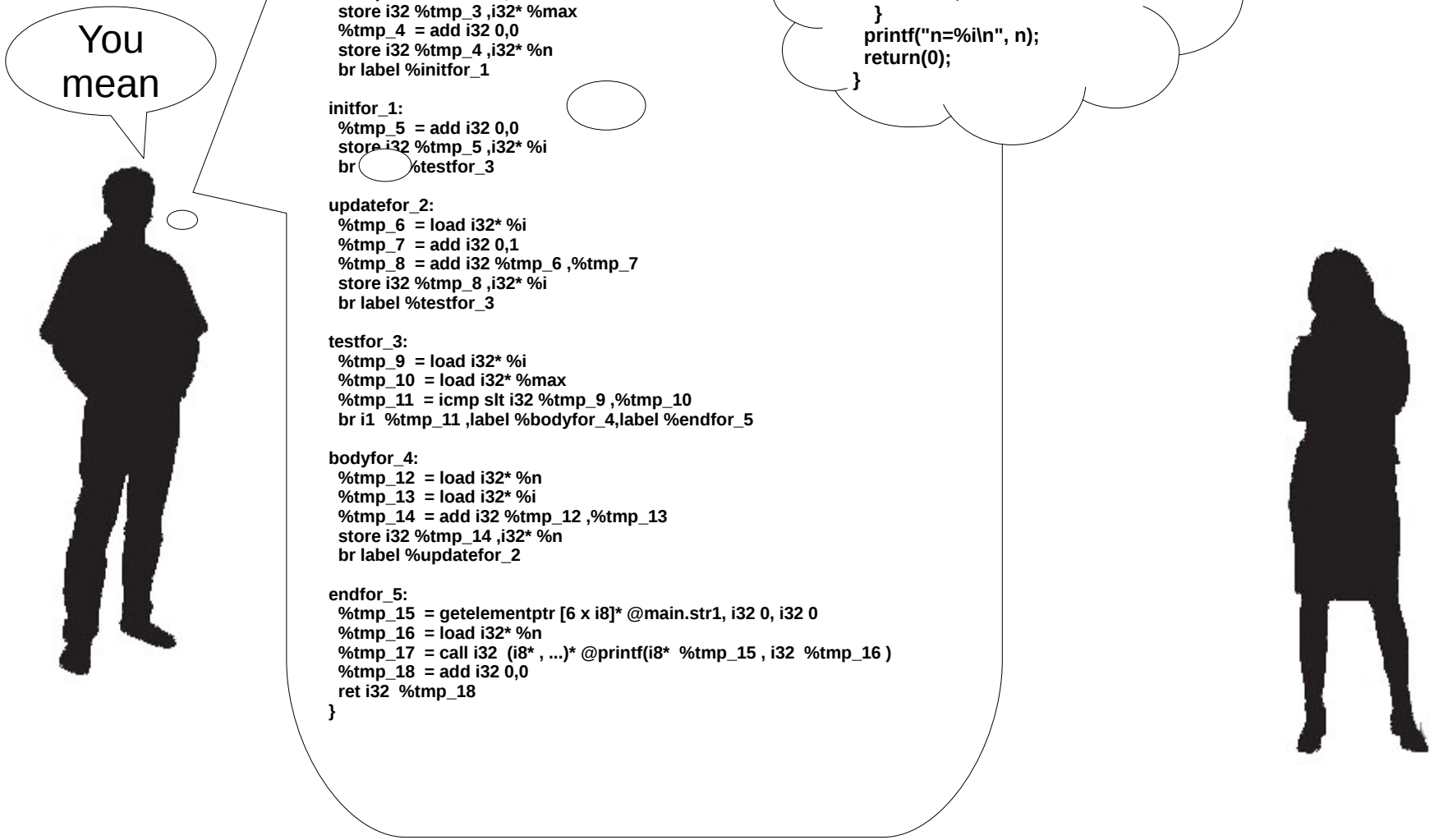
You're right. I'll invent my own virtual machine, you know, like .net, the JVM or pcode. The I'll interpret the VM

Not very fast then!


You got a better idea?
Use LLVM


Whats that?
It's a virtual assembler language for a virtual machine designed for compiler writers


case X2 of
P1 →
X3 = X2;
P2 →
X4 =X3
end,
X5 = φ(X3, X5)
It's got an infinite number
of typed registers (in SSA form)
and specialized
instructions
for casts and even
φ is an instruction


You mean
define i32 @main() nounwind {
;;return register
%tmp_1 = alloca i32 ,align 4
%i = alloca i32 ,align 4
%max = alloca i32 ,align 4
%n = alloca i32 ,align 4
%tmp_2 = add i32 0,0
store i32 %tmp_2 ,i32* %i
%tmp_3 = add i32 0,100000000
store i32 %tmp_3 ,i32* %max
%tmp_4 = add i32 0,0
store i32 %tmp_4 ,i32* %n
br label %initfor_1
initfor_1:
%tmp_5 = add i32 0,0
store i32 %tmp_5 ,i32* %i
br
testfor_3
updatefor_2:
%tmp_6 = load i32* %i
%tmp_7 = add i32 0,1
%tmp_8 = add i32 %tmp_6 ,%tmp_7
store i32 %tmp_8 ,i32* %i
br label %testfor_3
testfor_3:
%tmp_9 = load i32* %i
%tmp_10 = load i32* %max
%tmp_11 = icmp slt i32 %tmp_9 ,%tmp_10
br i1 %tmp_11 ,label %bodyfor_4,label %endfor_5
bodyfor_4:
%tmp_12 = load i32* %n
%tmp_13 = load i32* %i
%tmp_14 = add i32 %tmp_12 ,%tmp_13
store i32 %tmp_14 ,i32* %n
br label %updatefor_2
endfor_5:
%tmp_15 = getelementptr [6 x i8]* @main.str1, i32 0, i32 0
%tmp_16 = load i32* %n
%tmp_17 = call i32 (i8* , ...)* @printf(i8* %tmp_15 , i32 %tmp_16 )
%tmp_18 = add i32 0,0
ret i32 %tmp_18
}
int main()
{
int i=0, max=100000000,n=0;
for(i = 0; i < max; i = i + 1){
n = n + i;
}
printf("n=%i\n", n);
return(0);
}

# ZAPBAR

- Front-end in Erlang

  Erlang → LLVM assembler
- Middle-end

  LLVM opt
- Back-end

  Gecode (Constraint logic programming)

# Sum 1..1000000

```
> timer:tc(lists, sum, [lists:seq(1,1000000)]).
{74037,500000500000}
```

74 ms

# C

```
int printf(const char * format, ...);

int main()
{
  int i, max=1000000, sum=0;
  for(i = 0; i <= max; i = i + 1){
    sum = sum + i;
    }
  printf("sum 1..%i = %i\n", max, sum);
  return(0);
}
```

This shows
shows a run
of the compiler
(which is written in Erlang)

```
./wow.sh test2.c
Scanning:test2.c
Eshell V5.8  (abort with ^G)
1> Pass 1:ecc_normalize_function_heads
Pass 1:ecc_normalize_function_heads took:5524
us
Pass 2:ecc_make_prototypes
Type signatures are:
declare i32  @printf(i8* , ...)
declare i32  @main()
Pass 2:ecc_make_prototypes took:1153 us
Pass 3:ecc_lift_vars
Pass 3:ecc_lift_vars took:687 us
Pass 4:ecc_fix_scopes
Pass 4:ecc_fix_scopes took:631 us
Pass 5:ecc_fold_types
Pass 5:ecc_fold_types took:465 us
Pass 6:ecc_gen_llvm
Pass 6:ecc_gen_llvm took:773 us
Pass 7:ecc_asm_llvm
Pass 7:ecc_asm_llvm took:204 us
Created : (ok) test2.ll
```

# test2.ll

```
; Compiled by the amazing Ericsson C->LLVM compiler
; Hand crafted in Erlang
; ModuleID = 'test2.c'

target datalayout = "e-p:32:32:32-i1:8:8-i8:8:8-i16:...
target triple = "i386-pc-linux-gnu"

; Sock it to me baby

;; globals
declare i32  @printf(i8* , ...)

@main.str1 = private constant [16x i8] c"sum 1..%i =
%i\0A\00"

;; code
define i32 @main() nounwind {
  ;;return register

  %tmp_1  = alloca i32 ,align 4
  %i  = alloca i32 ,align 4
  %max  = alloca i32 ,align 4
  %sum  = alloca i32 ,align 4
  %tmp_2  = add i32 0,1000000
  store i32 %tmp_2 ,i32* %max
  %tmp_3  = add i32 0,0
  store i32 %tmp_3 ,i32* %sum
  br label %initfor_1

initfor_1:
  %tmp_4  = add i32 0,0
  store i32 %tmp_4 ,i32* %i
  br label %testfor_3

updatefor_2:
  %tmp_5  = load i32* %i
  %tmp_6  = add i32 0,1
  %tmp_7  = add i32 %tmp_5 ,%tmp_6
  store i32 %tmp_7 ,i32* %i
  br label %testfor_3

testfor_3:
  %tmp_8  = load i32* %i
  %tmp_9  = load i32* %max
  %tmp_10  = icmp sle i32 %tmp_8 ,%tmp_9
  br i1  %tmp_10 ,label %bodyfor_4,label %endfor_5

bodyfor_4:
  %tmp_11  = load i32* %sum
  %tmp_12  = load i32* %i
  %tmp_13  = add i32 %tmp_11 ,%tmp_12
  store i32 %tmp_13 ,i32* %sum
  br label %updatefor_2

endfor_5:
  %tmp_14  = getelementptr [16 x i8]* @main.str1, i32 0, i32 0
  %tmp_15  = load i32* %max
  %tmp_16  = load i32* %sum
  %tmp_17  = call i32  (i8* , ...)* @printf(i8*  %tmp_14 , i32  %tmp_15 ,
i32  %tmp_16 )
  %tmp_18  = add i32 0,0
  ret i32  %tmp_18
}
```

This is the output
of the complier
as you can see the code
is unoptimized

# > opt -std-compile-opts -S $test2.ll >  test2_opt.ll


```
; ModuleID = 'test2.ll'
target datalayout = "e-p:32:32:32-i1:8:8-i8:8:8-i16:16:16-i32:...
target triple = "i386-pc-linux-gnu"

@main.str1 = private constant [16 x i8] c"sum 1..%i = %i\0A\00"

declare i32 @printf(i8* nocapture, ...) nounwind

define i32 @main() nounwind {
endfor_5:
  %tmp_17 = tail call i32 (i8*, ...)*
     @printf(i8* getelementptr inbounds ([16 x i8]* @main.str1, i32 0, i32 0),
             i32 1000000,
             i32 50005000) nounwind ;
  ret i32 0
}
```

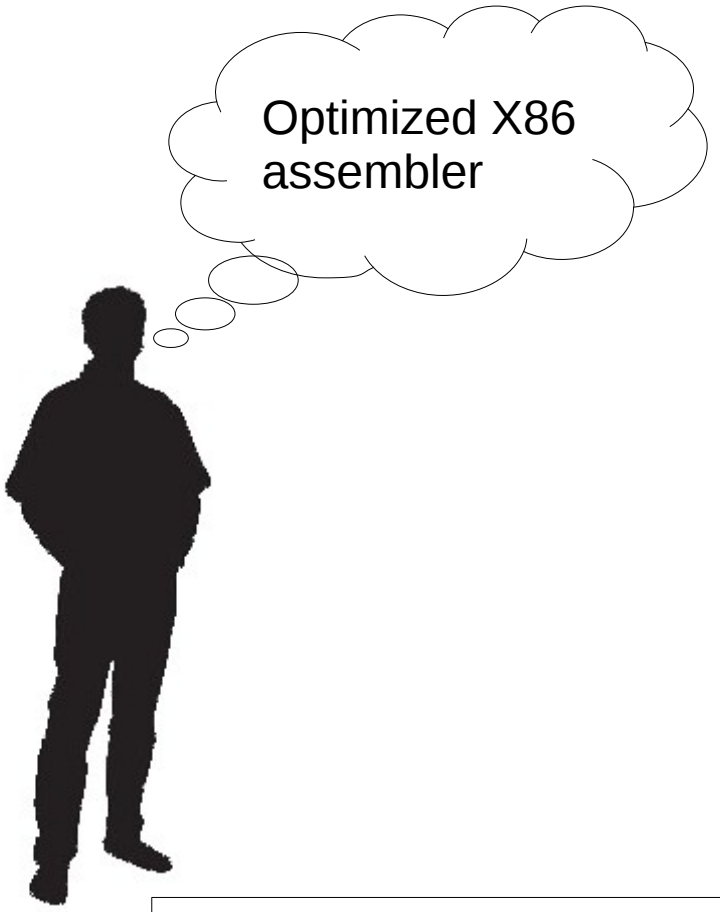
The optimizer has detected the loop in the assembler program and unrolled the loop

This is optimized assembler
It was produced by the program “opt”  which is part
of the LLVM distribution

# “A large number of optimizations are perfomed on the assember code”

llvm-as < /dev/null | opt -std-compile-opts -disable-output -debug-pass=Arguments
Pass Arguments:  -preverify -domtree -verify -lowersetjmp -globalopt -ipsccp -deadargelim -instcombine -simplifycfg -basiccg -prune-eh -inline -functionattrs -argpromotion -domtree -domfrontier -scalarrepl -simplify-libcalls -instcombine -jump-threading -simplifycfg -instcombine -tailcallelim -simplifycfg -reassociate -domtree -loops -loopsimplify -domfrontier -loopsimplify -lcssa -loop-rotate -licm -lcssa -loop-unswitch -instcombine -scalar-evolution -loopsimplify -lcssa -iv-users -indvars -loop-deletion -loopsimplify -lcssa -loop-unroll -instcombine -memdep -gvn -memdep -memcpyopt -sccp -instcombine -jump-threading -domtree -memdep -dse -adce -simplifycfg -strip-dead-prototypes -print-used-types -deadtypeelim -globaldce -constmerge -preverify -domtree -verify

# >llc test2_opt.ll -o test2_opt.s




```
        .file   "test2_opt.ll"
        .text
        .globl  main
        .align  16, 0x90
        .type main,@function
main:                                   # @main
# BB#0:                                 # %endfor_5
        subl  $12, %esp
        movl $50005000, 8(%esp)      # imm = 0x2FB0408
        movl $10000, 4(%esp)         # imm = 0x2710
        movl $.Lmain.str1, (%esp)
        call   printf
        xorl   %eax, %eax
        addl  $12, %esp
        ret
        .size  main, .-main

        .type .Lmain.str1,@object
        .section     .rodata.str1.1,"aMS",@progbits,1
.Lmain.str1:                            # @main.str1
        .asciz         "sum 1..%i = %i\n"
        .size  .Lmain.str1, 16


        .section     .note.GNU-stack,"",@progbits
```

Now we use
one of the built-in LLVM backends to produce optimised X86 32 bit code

# ECC passes

- Parsing and type normalization
- Normalize heads
- Make prototypes
- Lift vars
- Fix scopes
- Fold Types
- Compile to LLVM
- Render assembled code

# Parsing

- 955 lines of yrl - derived from a parser written by Tony Rogvall

# Type normalisation

- Convert boustrophedonic types to Erlang terms
- int *p[10]

  {arrayOf, 10,{pointerTo, int}}
- int (*p)[10]

  {pointerTo, {arrayOf,10,int}}

# Boustrophodonic

Of or relating to text written from left to right and right to left in alternate lines. [1]

Examples are the rongo-rongo script of Easter Island, some of those in the Etruscan language, a few early Latin inscriptions and some ancient Greek texts created in a transitional period at about 500BC before which writing ran from right to left but afterwards from left to right. The word is itself from the Greek meaning “as the ox ploughs”. [1]

From βούς—bous, "ox" + στρέφειν—strephein, "to turn" (cf. strophe) [2]

[1] http://www.worldwidewords.org/weirdwords/ww-bou1.htm

[2] wikipedia

# Normalize heads

- Merge K&R style heads with ANSI

  ```
  int foo(int i, int j) {...}
  ```

  and

  ```
  int foo(i, j)
    int i, j;
    {…}
  ```

  are identical after normalisation

# make prototypes

- make prototypes for all functions

  Use the specified form if given

  If not supplied use the derived type signature

# Lift vars

```
foo(){
  char *c=”abc”;
  bar(“123”);
  ...
```

```
foo(){
  int i = 6;
  ...
```

```
foo(){
  static int i = 6;
  …
```

---

```
static char *tmp1=”abc”;
static char *tmp2=”123”
foo(){
  char *c;
  c = tmp1;
  bar(tmp2);
  ...
```

```
foo(){
  int i;
  i = 6;
```

```
int tmp23 = 6;
foo(){
  /* rename i as
     tmp23 */
```

# Simple compiler

```
compile_statement(#'FOR'{init=Init,test=Test,update=Update,body=Body}) ->
      {_,InitCode}             = compile_statement(Init),
      {_,UpdateCode}           = compile_statement(Update),
      {{_Type,Reg}, TestCode} = compile_rval(Test),
      BodyCode                 = compile_compound(Body),
      InitLabel                = new_label("initfor"),
      UpdateLabel              = new_label("updatefor"),
      TestLabel                = new_label("testfor"),
      BodyLabel                = new_label("bodyfor"),
      EndLabel                 = new_label("endfor"),
      Code = [{br,InitLabel},
           InitLabel,   InitCode,  {br,TestLabel},
           UpdateLabel, UpdateCode,{br,TestLabel},
           TestLabel,   TestCode,  {br,{eTYPE,i1}, Reg,
                                    BodyLabel, EndLabel},
           BodyLabel,   BodyCode,  {br,UpdateLabel},
           EndLabel],
      {void(),C};
```

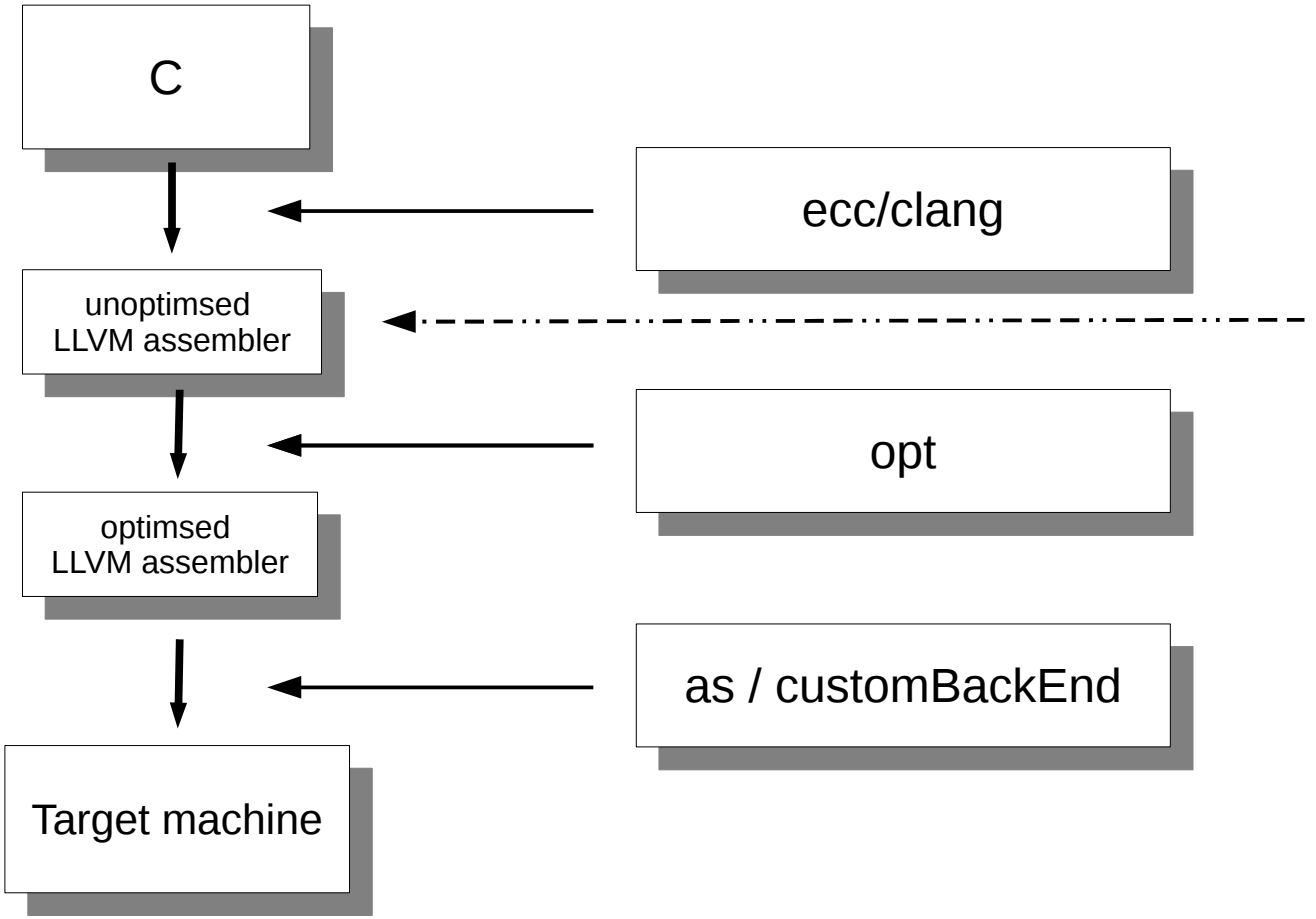
```
    br init
init:    ...
    br test
update:
   ..    br test
test:
   …
  br true body; false end
body:
   ...
   br update
end:
```

Compiling a for loop

# Statistics

```
 186    531   5067 ecc_asm_llvm.erl
 112    322   2889 ecc_compile.erl
 803   2671  24296 ecc_cpp.erl
 108    330   2362 ecc_cpp_eval_expr.erl
  56    109    927 ecc_db.erl
  25     51    560 ecc.erl
 231    846   7366 ecc_fix_scopes.erl
  61    220   1746 ecc_fold_types.erl
 333   1168  10534 ecc_gen_llvm.erl
 223    621   5520 ecc_lib.erl
 107    302   3213 ecc_lift_vars.erl
  38     93    932 ecc_make_db.erl
  73    271   2400 ecc_make_prototypes.erl
  82    259   2746 ecc_normalize_function_heads.erl
 156    500   5129 ecc_parser.erl
 101    355   3478 ecc_typedefs.erl
  40     86   1044 record_compiler.erl
 955   3388  39131 ecc_gram.yrl
3690  12123 119340 total
```

# Summary




This code can be crap just has to be correct

# Stuff I haven't mentioned

- JIT is easy
- Gecode
- “inline C” in Erlang
- “inline X” in Erlang
- Integration with Erlang (ie make bitcode in Erlang not using llvm-as, and integration with BEAM)

# Status

- Will be released as open source
- Needs more work
- “tricky bits done”
- Probably should be rewritten (again - this will be the 5'th rewrite)

# Questions