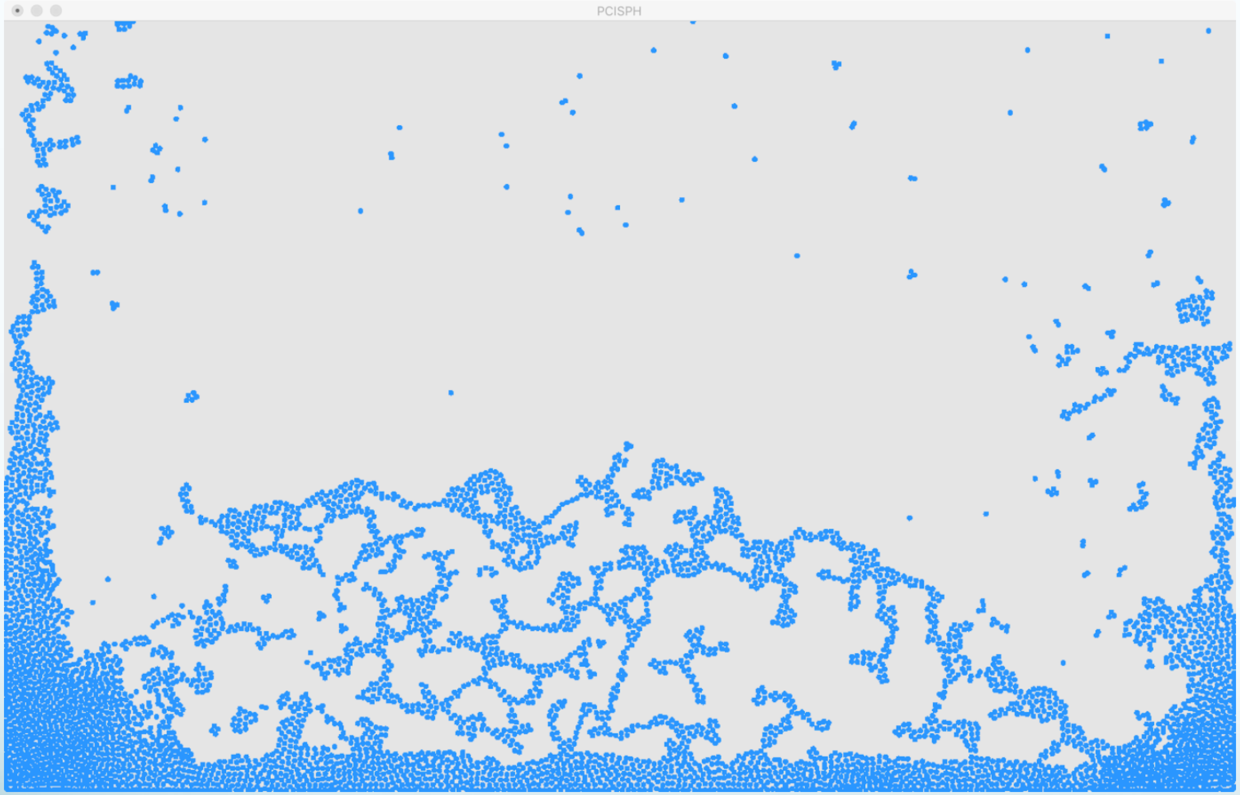
shux

A physics simulation language for Lagrangian physics

Our Team

- Lucas **S**chuermann: Manager, physics dude
- John **H**ui: Language guru
- Mert **U**ssakli: Code slave
- Andy **X**u: System architect

Inspiration



Growing field of particle-based numerical physics solvers

- Fluid dynamics
- Granular flow
- Deformables

Main features

- Everything good about C, redesigned for easy implementation of particle-based Lagrangian physics solvers
- Mostly immutable (unless you cheat) types for concurrency
- Simple functional syntax
  - Maps, filters, lambdas
  - Namespaces
  - Lookback and generators (*what are those?!*)
- Easy bindings to OpenGL through extern declarations

Immutability

```
int x = 1;

var int y = 2;

y = 3; /* this is OK */

x = 5; /* this is not OK */
```

Allows for guaranteed safety in concurrent settings!

Map!

```
kn addOne(int x) int {
	x+1
}
kn main() int {
	int[5] x = [1,2,3,4,5];
	int[5] xPlusOne = x @ addOne;
	0
}
```

Filters

```
kn lessThanThree(int  x) bool {
      x < 3
}
kn main() int  {
      int[5] array = [2,3,4,5,6];
      int[] filtered = array :: lessThanThree
      0
}
```

λs

`(low key type inferred)`

```
kn main() int {
     int[5] x = [1,2,3,4,5];
     bool[5] b = x @ (int i) -> {
          i % 2 == 0
     }
}
```

Namespaces

```
ns constants = {
   ns physical_params = {
            let vector <2> grav= (0.0, -9.81);
      }
   ns = solver_params = {
            let scalar dt = 0.001;
      }
      scalar y = constants ->
                physical_params -> grav[1];
}
```

Everything is an expression

```
int y = 2
int x = if y == 2
```

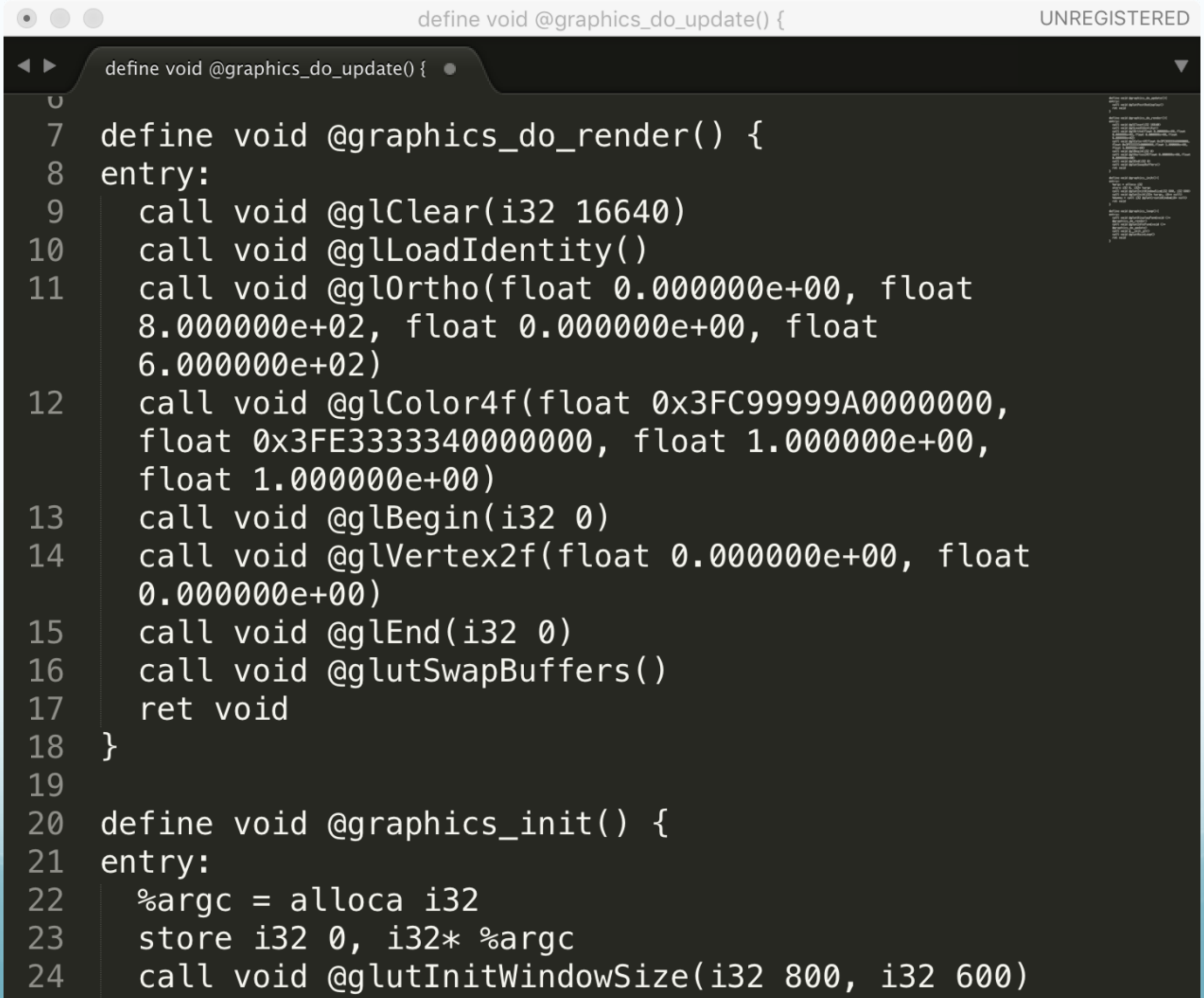
The lookback feature and generators

```
gn fib() int {

      int y = (y..1 : 1) + (y..2 : 1);

      y

}

kn main() int {

      int fib5 = do 5 fib( );

      0

}
```

Native LLVM OpenGL Binding

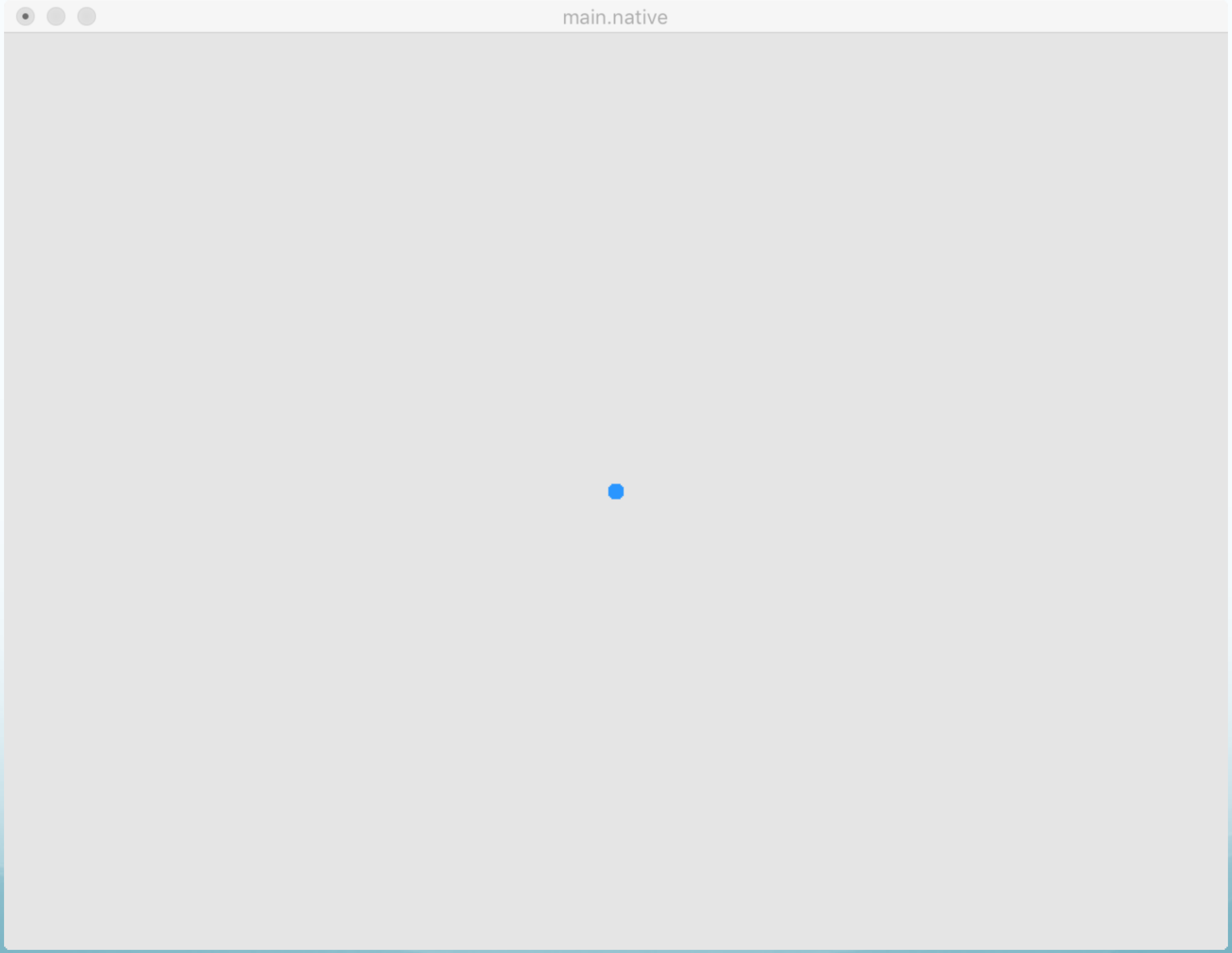
```
extern graphics_init();
extern graphics_loop(scalar[] points_buf);
kn main() int {
   graphics_init();
   ...
   graphics_loop(...);
   0
}
```

LLVM<>OpenGL Implementation Excerpt



```
define void @graphics_do_render() {
entry:
  call void @glClear(i32 16640)
  call void @glLoadIdentity()
  call void @glOrtho(float 0.000000e+00, float 8.000000e+02, float 0.000000e+00, float 6.000000e+02)
  call void @glColor4f(float 0x3FC99999A0000000, float 0x3FE3333340000000, float 1.000000e+00, float 1.000000e+00)
  call void @glBegin(i32 0)
  call void @glVertex2f(float 0.000000e+00, float 0.000000e+00)
  call void @glEnd(i32 0)
  call void @glutSwapBuffers()
  ret void
}

define void @graphics_init() {
entry:
  %argc = alloca i32
  store i32 0, i32* %argc
  call void @glutInitWindowSize(i32 800, i32 600)
```

LLVM<>OpenGL Simple Demonstration

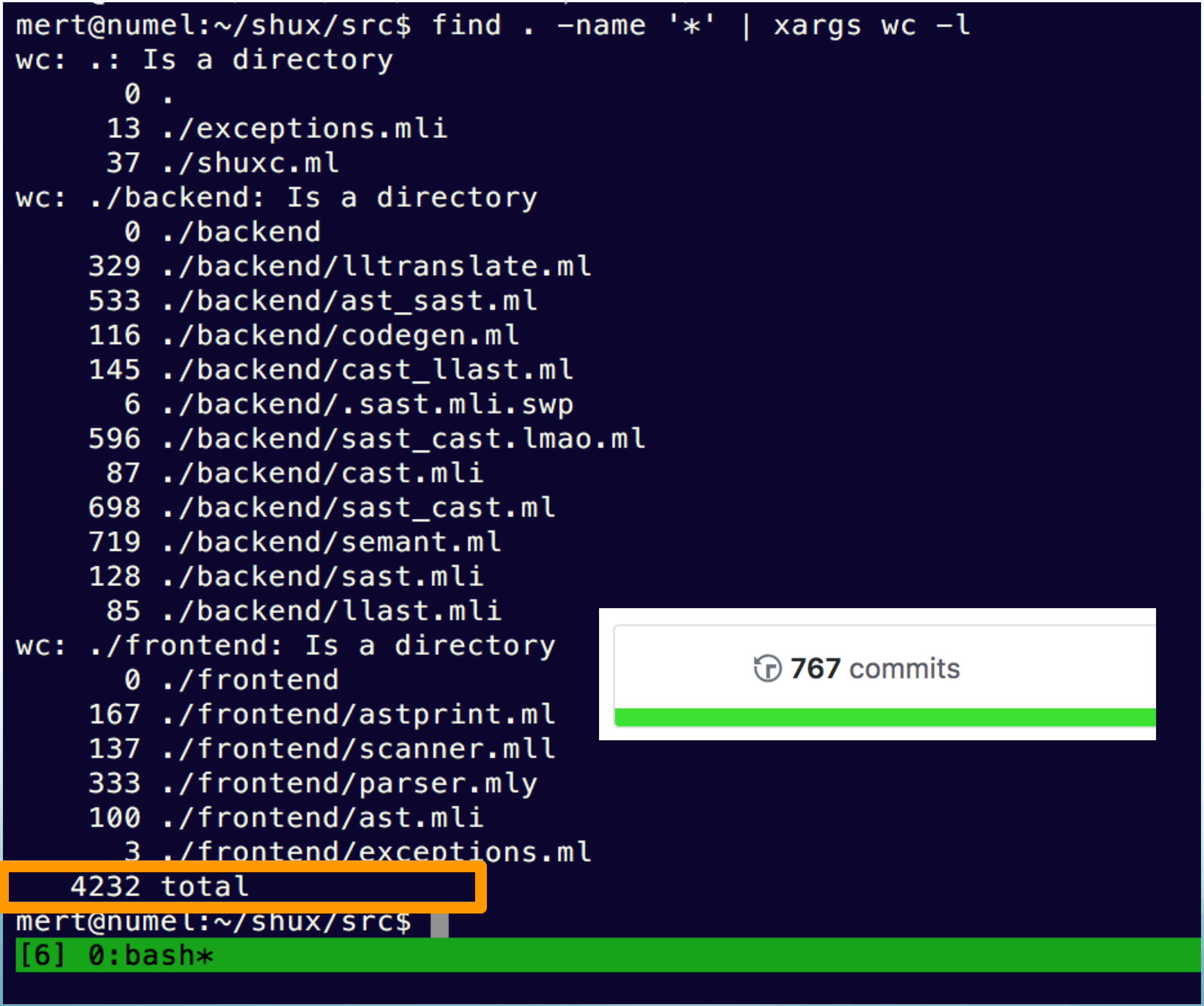


Workflow

- To get all of this working in LLVM, we implemented a pipeline with several layers of translation.
- Goal is to convert code with semantics most distant from C as close as possible to C before generating LLVM IR.

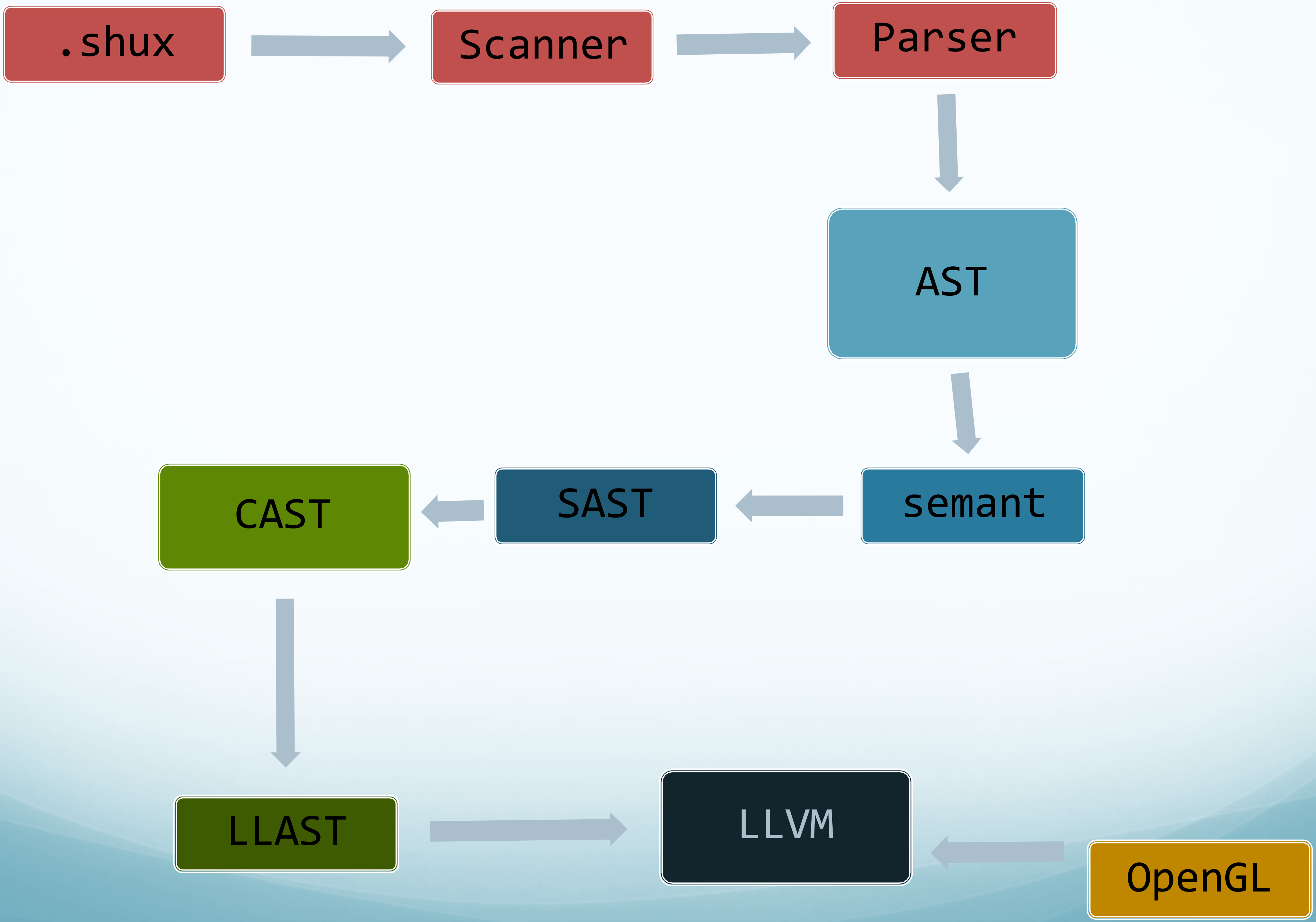
How Crazy Were We?

See next slide...

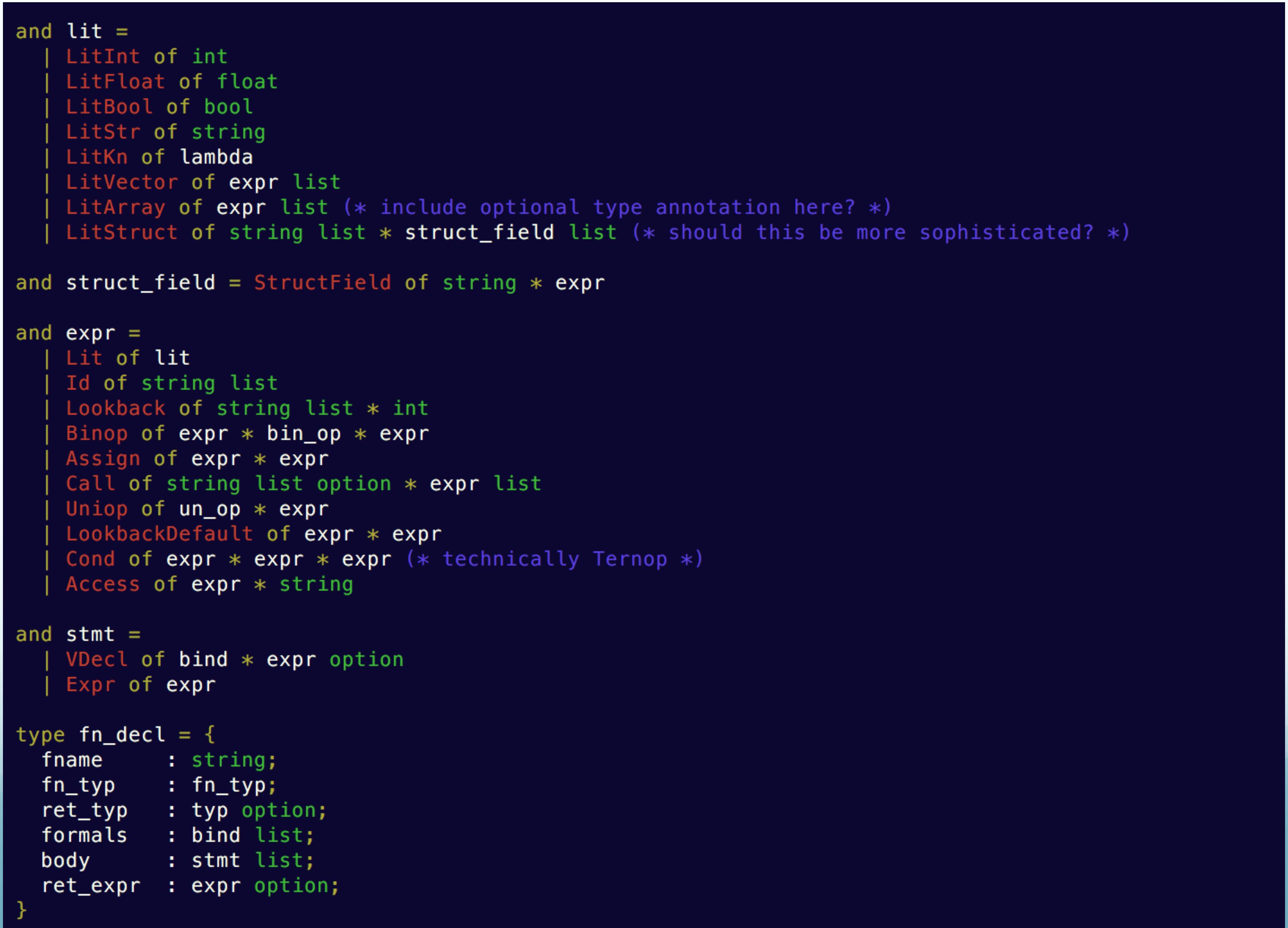


```
mert@numel:~/shux/src$ find . -name '*' | xargs wc -l
wc: .: Is a directory
       0 .
      13 ./exceptions.mli
      37 ./shuxc.ml
wc: ./backend: Is a directory
       0 ./backend
     329 ./backend/lltranslate.ml
     533 ./backend/ast_sast.ml
     116 ./backend/codegen.ml
     145 ./backend/cast_llast.ml
       6 ./backend/.sast.mli.swp
     596 ./backend/sast_cast.lmao.ml
      87 ./backend/cast.mli
     698 ./backend/sast_cast.ml
     719 ./backend/semant.ml
     128 ./backend/sast.mli
      85 ./backend/llast.mli
wc: ./frontend: Is a directory
       0 ./frontend
     167 ./frontend/astprint.ml
     137 ./frontend/scanner.mll
     333 ./frontend/parser.mly
     100 ./frontend/ast.mli
       3 ./frontend/exceptions.ml
    4232 total
mert@numel:~/shux/src$ 
[6] 0:bash*
```

767 commits


.shux
Scanner
Parser
AST
semant
SAST
CAST
LLAST
LLVM
OpenGL

AST

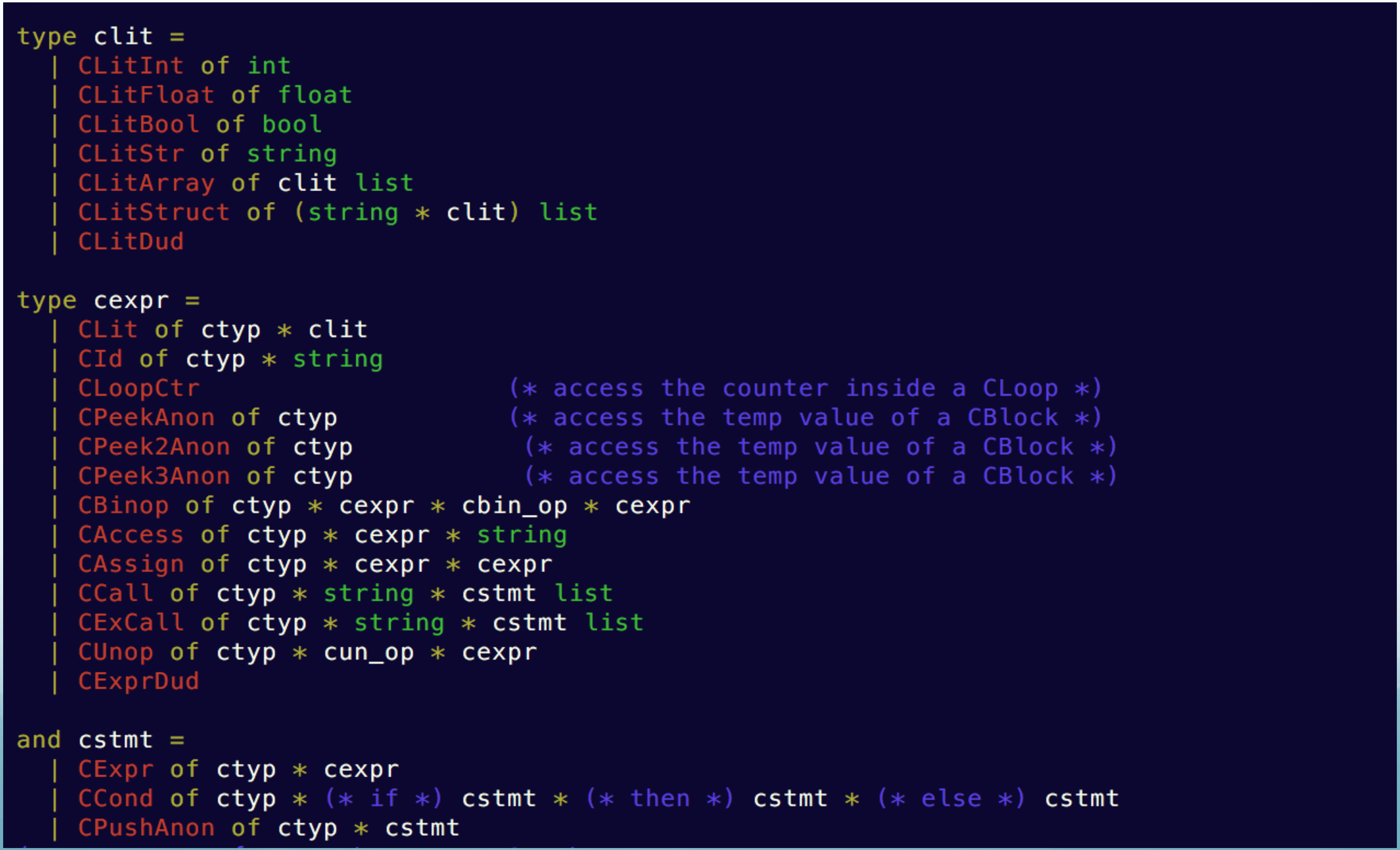


```
and lit =
  | LitInt of int
  | LitFloat of float
  | LitBool of bool
  | LitStr of string
  | LitKn of lambda
  | LitVector of expr list
  | LitArray of expr list (* include optional type annotation here? *)
  | LitStruct of string list * struct_field list (* should this be more sophisticated? *)

and struct_field = StructField of string * expr

and expr =
  | Lit of lit
  | Id of string list
  | Lookback of string list * int
  | Binop of expr * bin_op * expr
  | Assign of expr * expr
  | Call of string list option * expr list
  | Uniop of un_op * expr
  | LookbackDefault of expr * expr
  | Cond of expr * expr * expr (* technically Ternop *)
  | Access of expr * string

and stmt =
  | VDecl of bind * expr option
  | Expr of expr

type fn_decl = {
  fname     : string;
  fn_typ    : fn_typ;
  ret_typ   : typ option;
  formals   : bind list;
  body      : stmt list;
  ret_expr  : expr option;
}
```

SAST

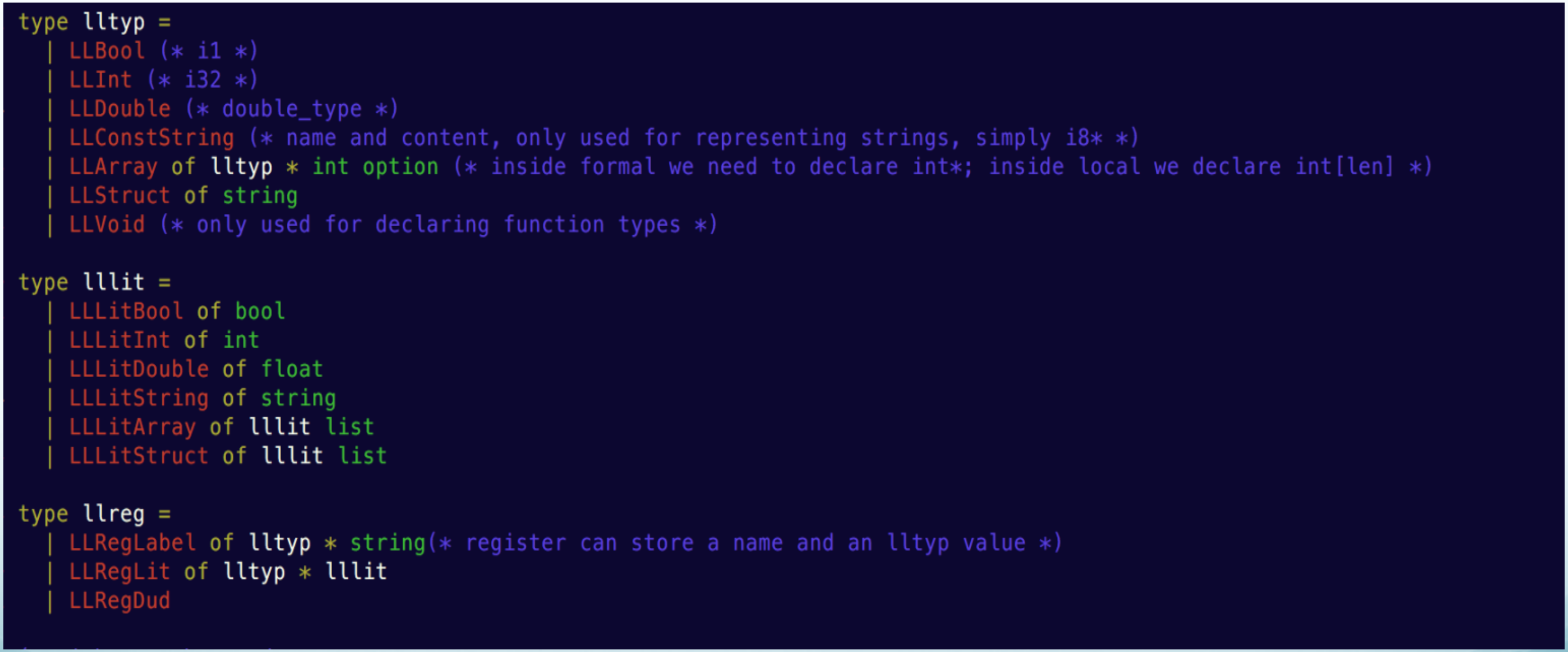
```
type slit =
   | SLitInt of int
   | SLitFloat of float
   | SLitBool of bool
   | SLitStr of string
   | SLitKn of slambda
   | SLitArray of sexpr list
   | SLitStruct of string * ((string * sexpr) list)

and sexpr =
   | SLit of styp * slit
   | SId of styp * string * sscope
   | SLookback of styp * string * int
   | SAccess of styp * sexpr * string
   | SBinop of styp * sexpr * sbin_op * sexpr
   | SAssign of styp * sexpr * sexpr
   | SKnCall of styp * string * (sexpr * styp) list
   | SGnCall of styp * string * (sexpr * styp) list
   | SExCall of styp * string * (sexpr * styp) list
   | SLookbackDefault of styp * int * sexpr * sexpr
   | SUnop of styp * sun_op * sexpr
   | SCond of styp * sexpr * sexpr * sexpr
   | SLoopCtr (* CLoopCtr, useful for recursion *)
   | SPeek2Anon of styp
   | SExprDud

and slambda = {
  slret_typ   : styp;
  slformals   : sbind list;
  slinherit   : sbind list;
  sllocals    : sbind list;         (* no lookback, const-ness not enforced *)
  slbody      : (sexpr * styp) list;
  slret_expr  : (sexpr * styp) option;
}
```

CAST



```
type clit =
  | CLitInt of int
  | CLitFloat of float
  | CLitBool of bool
  | CLitStr of string
  | CLitArray of clit list
  | CLitStruct of (string * clit) list
  | CLitDud

type cexpr =
  | CLit of ctyp * clit
  | CId of ctyp * string
  | CLoopCtr                    (* access the counter inside a CLoop *)
  | CPeekAnon of ctyp           (* access the temp value of a CBlock *)
  | CPeek2Anon of ctyp           (* access the temp value of a CBlock *)
  | CPeek3Anon of ctyp           (* access the temp value of a CBlock *)
  | CBinop of ctyp * cexpr * cbin_op * cexpr
  | CAccess of ctyp * cexpr * string
  | CAssign of ctyp * cexpr * cexpr
  | CCall of ctyp * string * cstmt list
  | CExCall of ctyp * string * cstmt list
  | CUnop of ctyp * cun_op * cexpr
  | CExprDud

and cstmt =
  | CExpr of ctyp * cexpr
  | CCond of ctyp * (* if *) cstmt * (* then *) cstmt * (* else *) cstmt
  | CPushAnon of ctyp * cstmt
```

LLAST



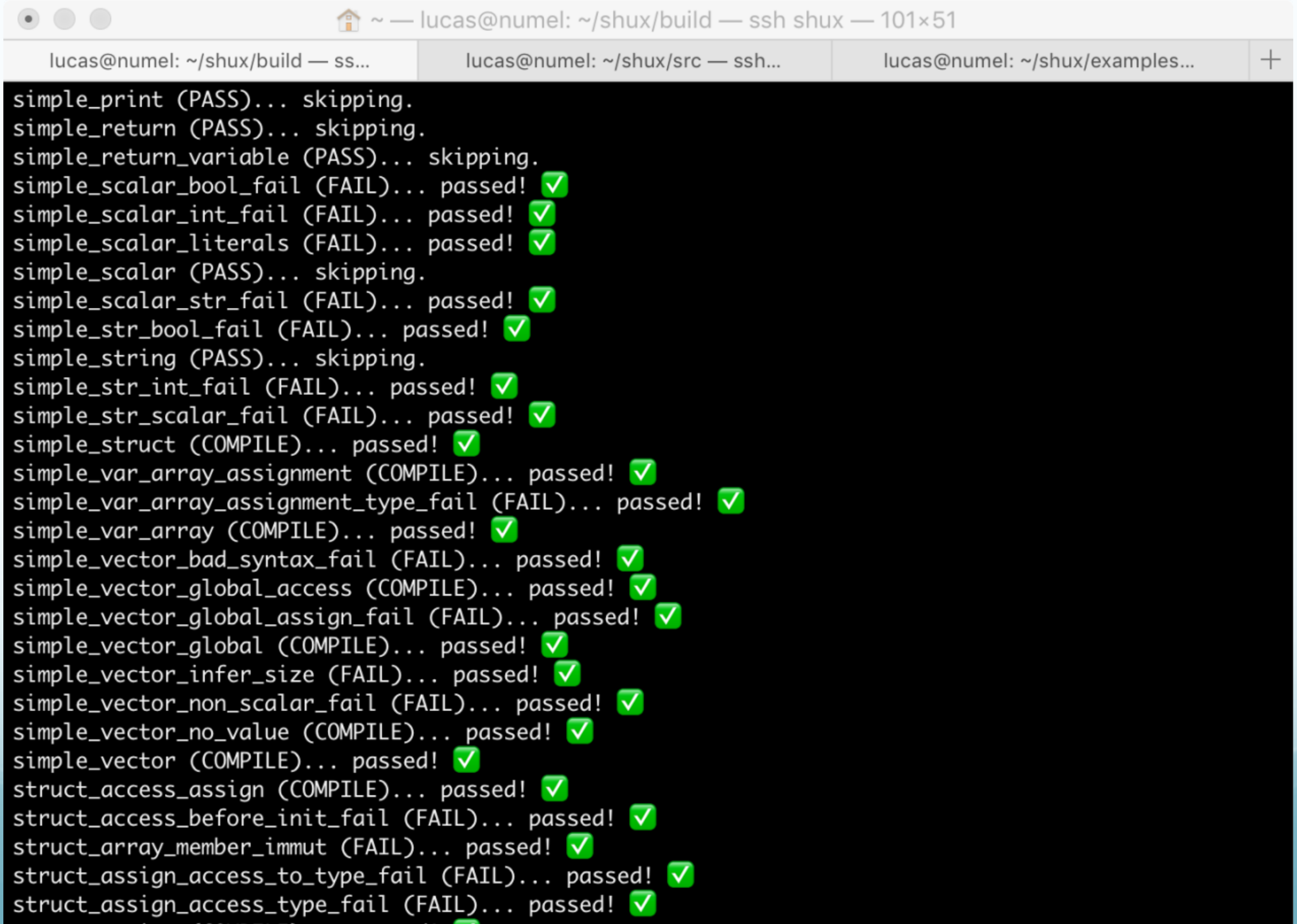
```
type lltyp =
  | LLBool (* i1 *)
  | LLInt (* i32 *)
  | LLDouble (* double_type *)
  | LLConstString (* name and content, only used for representing strings, simply i8* *)
  | LLArray of lltyp * int option (* inside formal we need to declare int*; inside local we declare int[len] *)
  | LLStruct of string
  | LLVoid (* only used for declaring function types *)

type lllit =
  | LLLitBool of bool
  | LLLitInt of int
  | LLLitDouble of float
  | LLLitString of string
  | LLLitArray of lllit list
  | LLLitStruct of lllit list

type llreg =
  | LLRegLabel of lltyp * string(* register can store a name and an lltyp value *)
  | LLRegLit of lltyp * lllit
  | LLRegDud
```

Case Study: Lookback

```
gn bar(int a, int b) int {
            int x = a + x..1
: 3;
            int y= b + y ..2
: 2 ;
            x+y
}
```

```
struct gn_bar = {
            int ctr; int[2] a; int[2] b;
      int[2] x; int[2] y;
}
kn bar(struct gn_bar gns) int {
            gns.x[gns.ctr] = gns.a[gns.ctr] +
            (ctr <= 1) ? gns.x[(gns.ctr-1)%2] : 3;
            gns.y[gns.ctr] = gns.b[gns.ctr] +
            (ctr <= 2) ?  gns.y[(gns.ctr-2)%2] : 2;
            gns.x[gns.ctr] + gns.y[gns.ctr]
}
```

Testing Environment



```
simple_print (PASS)... skipping.
simple_return (PASS)... skipping.
simple_return_variable (PASS)... skipping.
simple_scalar_bool_fail (FAIL)... passed! ✅
simple_scalar_int_fail (FAIL)... passed! ✅
simple_scalar_literals (FAIL)... passed! ✅
simple_scalar (PASS)... skipping.
simple_scalar_str_fail (FAIL)... passed! ✅
simple_str_bool_fail (FAIL)... passed! ✅
simple_string (PASS)... skipping.
simple_str_int_fail (FAIL)... passed! ✅
simple_str_scalar_fail (FAIL)... passed! ✅
simple_struct (COMPILE)... passed! ✅
simple_var_array_assignment (COMPILE)... passed! ✅
simple_var_array_assignment_type_fail (FAIL)... passed! ✅
simple_var_array (COMPILE)... passed! ✅
simple_vector_bad_syntax_fail (FAIL)... passed! ✅
simple_vector_global_access (COMPILE)... passed! ✅
simple_vector_global_assign_fail (FAIL)... passed! ✅
simple_vector_global (COMPILE)... passed! ✅
simple_vector_infer_size (FAIL)... passed! ✅
simple_vector_non_scalar_fail (FAIL)... passed! ✅
simple_vector_no_value (COMPILE)... passed! ✅
simple_vector (COMPILE)... passed! ✅
struct_access_assign (COMPILE)... passed! ✅
struct_access_before_init_fail (FAIL)... passed! ✅
struct_array_member_immut (FAIL)... passed! ✅
struct_assign_access_to_type_fail (FAIL)... passed! ✅
struct_assign_access_type_fail (FAIL)... passed! ✅
```

Testing Environment

- A large suite of automated unit tests were used to thoroughly test every semantic aspect of the language
- When changes were made to frontend or code was added for lower level translations, the suite was run
- Over 150(!) tests allowed us to rigorously verify syntax and steps through CAST generation.

The Good News: What Works

We have a fully implemented:

- Frontend
- Semantic checker
- AST to SAST translation
- SAST to CAST translation
- CAST to LLAST… (to be continued)
- Translation from LLAST to LLVM

Frontend □

- Fully tested and robust parser
- Handles a number of edge cases discovered through tests
- Completed very early on in development to ensure testing further down the line

Semantic Checker □

- shux has a strict type checking system, but at the same time maps, filters and generators, expressions complicate type-checking
- Lambdas have type inference
- The goal for the strict type system was readability and ease of translation
- semant.ml is 719 lines of OCaml
- Lookback values are an exception to the rule
    - int x = x..1; /* accessed while being defined */

AST to SAST □

- Makes all types in all expressions explicit. Important for translating an expression-based language.
- Does heavy-lifting for further stages of translation
  - Lookback values
  - Hoisting declarations above expressions in functions and lambdas
  - Get rid of option types.
  - Separating semantics:
    - kernel calls vs generator calls
    - float operands and int operands

SAST to CAST □

@John the orator

CAST to LLAST □

@John the orator

LLAST To LLVM □

- All the LLVM binding specific usage is abstracted in previous levels of translation
- Hide the registers from levels above
- Only operate on stack variables
- Passing by reference in LLVM
  - Array
  - String
  - Structs
- Using global namespace

The Bad: Or, The Perils of Ambition: Real-World Tests

- Multi-stage pipeline led to many, many, many blocking portions of development or propagating work from changes
- Time was spent fleshing out an amazing sheer volume of code
- We fell a bit sort on demos to show because we were more focused on designing, implementing, and testing a full pipeline

Future Work

- Testing and bugfixes for last two stages of the pipeline, relating to:
- More fully compiled complex usages of the language to generate results
- Finishing filters
- More robust standard library: further graphics calls, gridding, vector operations baked in (dot, matmul, etc)

make_sure_you_start_early.png