EXERCISE 5

LLVM MEMORY REVIEW

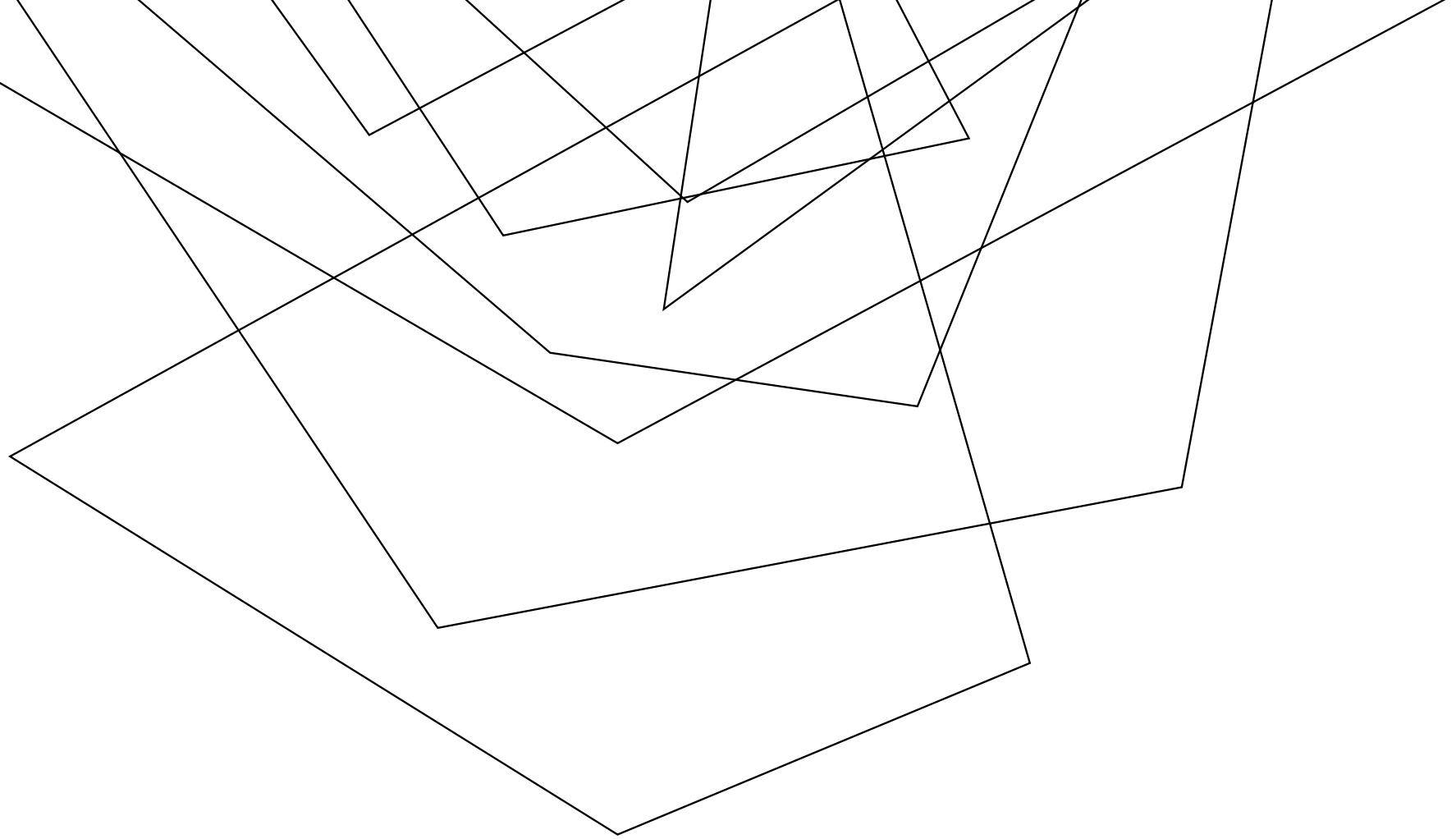
Write your name and answer the following on a piece of paper

- *Write the LLVM bitcode for the following c code*

```
int a;
int main(int argc){
  a = argc + 2;
  return a;
}
```

EXERCISE 5 SOLUTION

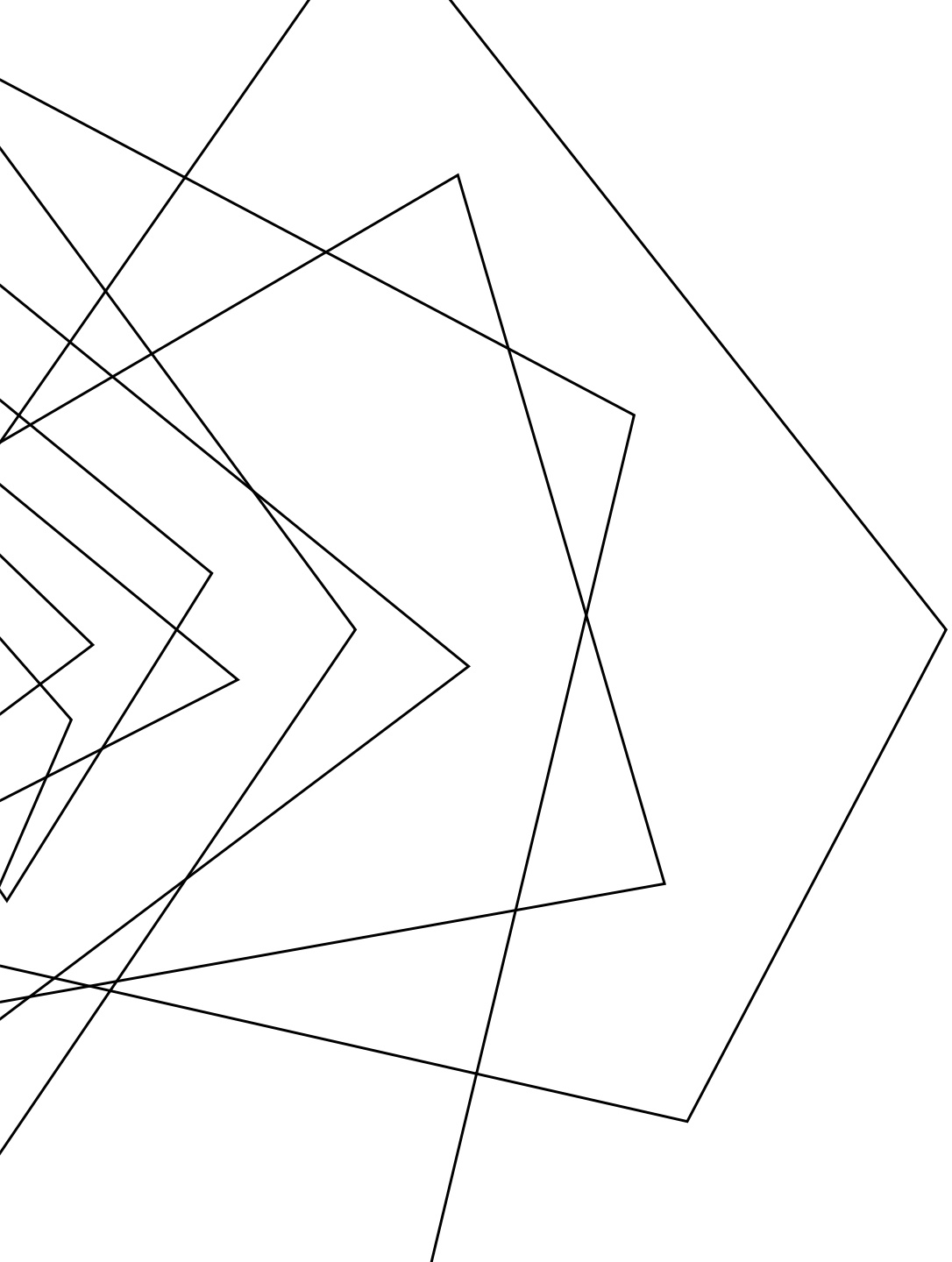
LLVM MEMORY REVIEW



LLVM CALLS

EECS 677: Software Security Evaluation

Drew Davidson



CLASS PROGRESS

WE’RE ALMOST READY TO DO STATIC ANALYSIS

LAST TIME: LLVM MEMORY

REVIEW: LAST LECTURE

DESCRIBED LLVM'S CONCEPT OF NAMED MEMORY

- No mathematical relationship between distinct named memory items
- Guaranteed mathematical relation WITHIN named memory items (as exploited by GEP)

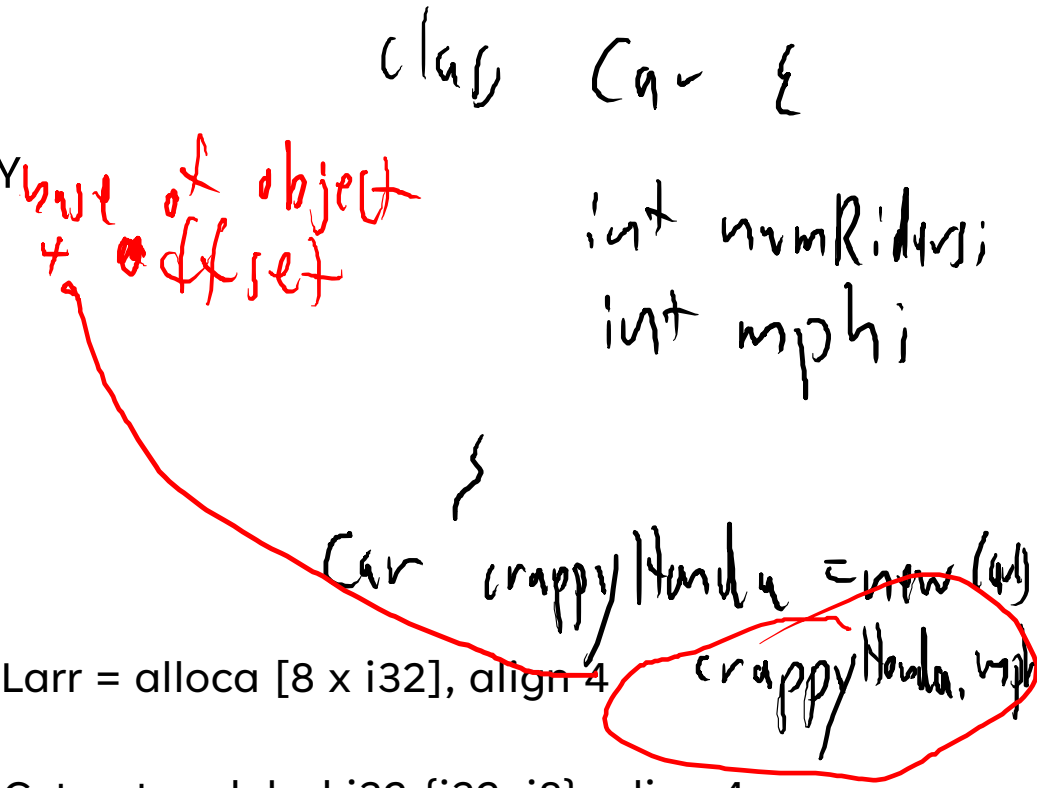
DECLARING MEMORY

- Local memory:

  %ptrL = alloca i32, align 4
- Global memory:

  @ptrG = global i32 2, align 4
- (Global) constant: Guaranteed mathematical relation

  @ptrC = constant i32 2, align 4



%ptrLarr = alloca [8 x i32], align 4

%ptrGstruct = global i32 {i32, i8}, align 4

@ptrCstructs = constant [2 x {i8, i32}]
[{i8, i32} {i8 1, i32 2}, {i8, i32}{ i8 3, i32 4}] ,
align 4

LAST TIME: LLVM MEMORY

REVIEW: LAST LECTURE

DECLARING MEMORY

- Local memory:

  %ptrL = alloca i32, align 4

- Global memory:

  @ptrG = global i32 2, align 4

- (Global) constant: Guaranteed mathematical relation

  @ptrC = constant i32 2, align 4

%ptrLarr = alloca [8 x i32], align 4

%ptrGstruct = global i32 {i32, i8}, align 4

@ptrCstructs = constant [2 x {i8, i32}]
[{i8, i32} {i8 1, i32 2}, {i8, i32}{ i8 3, i32 4}] ,
align 4

ACCESSING MEMORY

- Store scalar:

```
store i32 1, i32* %ptrL
```

- Global memory:

```
%reg = load i32, i32* @ptrG
```

- Load index of aggregate type

```
%eltPtr = getelementptr [2 x {i8, i32}],
    [2 x {i8, i32}]* @ptrCstructs, i64 0, i64 0, i32 1
%res = load i32, i32* %ret
```

FOLLOW-UP WHAT IS THE #0 HERE?

REVIEW: LAST LECTURE

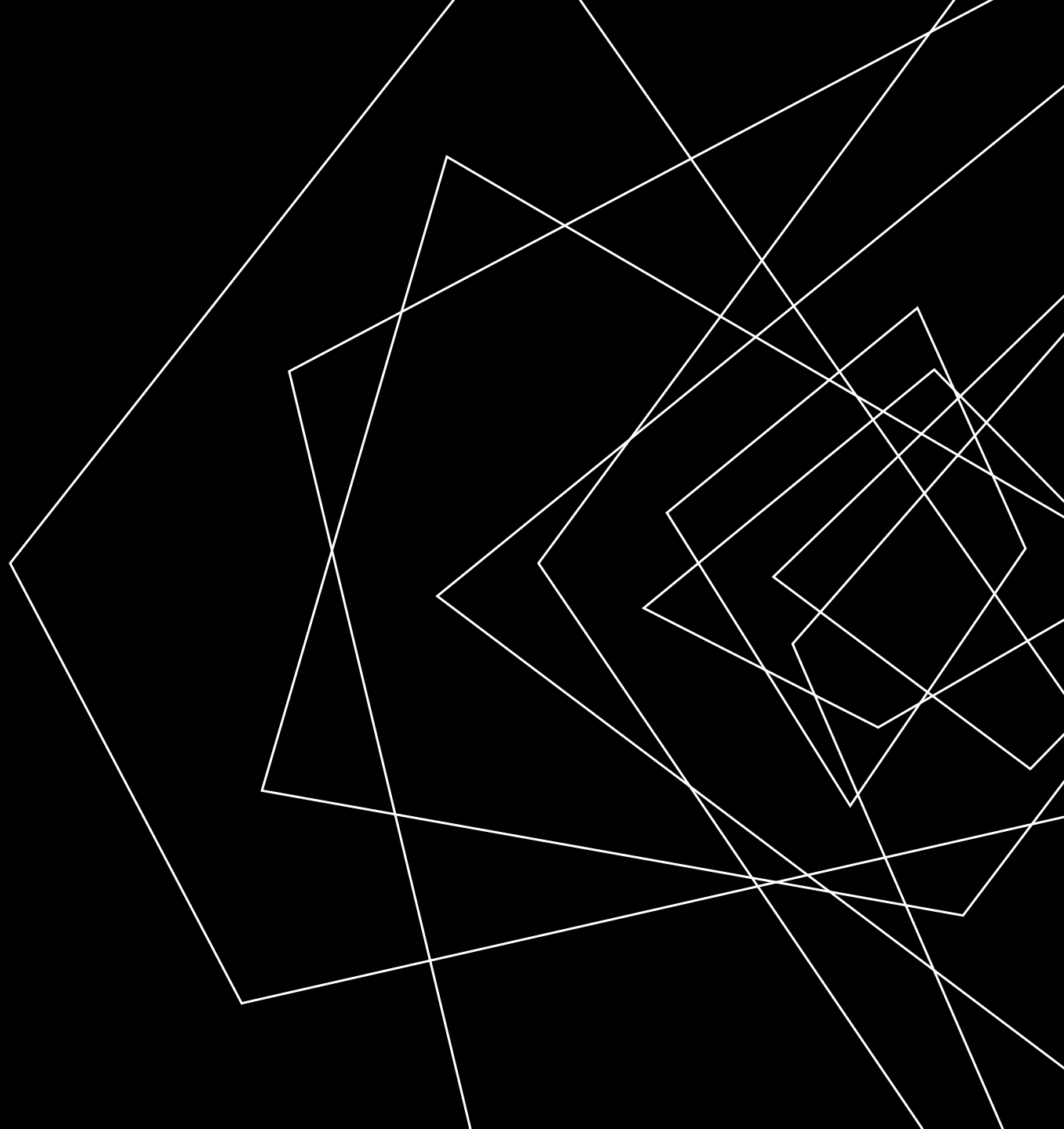
```
define i32 @main() #0 {
  ...
}
```

It’s an alias for an attribute list

```
attributes #0 = { optnone }
```

LECTURE OUTLINE

- The GEP Instruction and Intuition
- Function calls



GETELEMENTPTR

THE DREADED GEP

LET ME SIMPLIFY THIS A BIT WITH A SLIGHT REFORMAT OF GEP

base array index Field traversal

```
<result> = getelementptr <ty_work>, <ty_src> <src>, <idxtype> <siblingidx>, [<idxtype> <fieldidx>]+
```

HERE IS MY EXPLANATION OF THIS VERSION OF GEP:

Assume **base** is a pointer into some array of somethings (possibly a nested data structure)
- Arg 1: `<ty_work>`: Specify the type of the somethings
- Arg 2: `<ty_src> <src>`: **base** address to start your computation
- Arg 3: `<idxtype> <siblingidx>`: **array index** to jump forward from the **base** address (end of optional arguments)
- Arg 4+: `<idxtype> <fieldidx>`: **field traversal** to index into the fields of the nested data structure

GETELEMENTPTR

THE DREADED GEP

LET ME (MAYBE?) SIMPLIFY THIS A BIT WITH A SLIGHT REFORMAT OF GEP

base array index Field traversal

```
<result> = getelementptr <ty_work>, <ty_src> <src>, <idxtype> <siblingidx>, [<idxtype> <fieldidx>]+
```

7	7	7

```
getelementptr %T2, ptr @ptr_n1,  i64 0,   i64 0
```

Very generic format to capture the large variety of ways that you need to index into memory

Basic GEP invocations handle simple cases

Complex GEP invocations handle complex cases

GETELEMENTPTR: PICTORIALLY

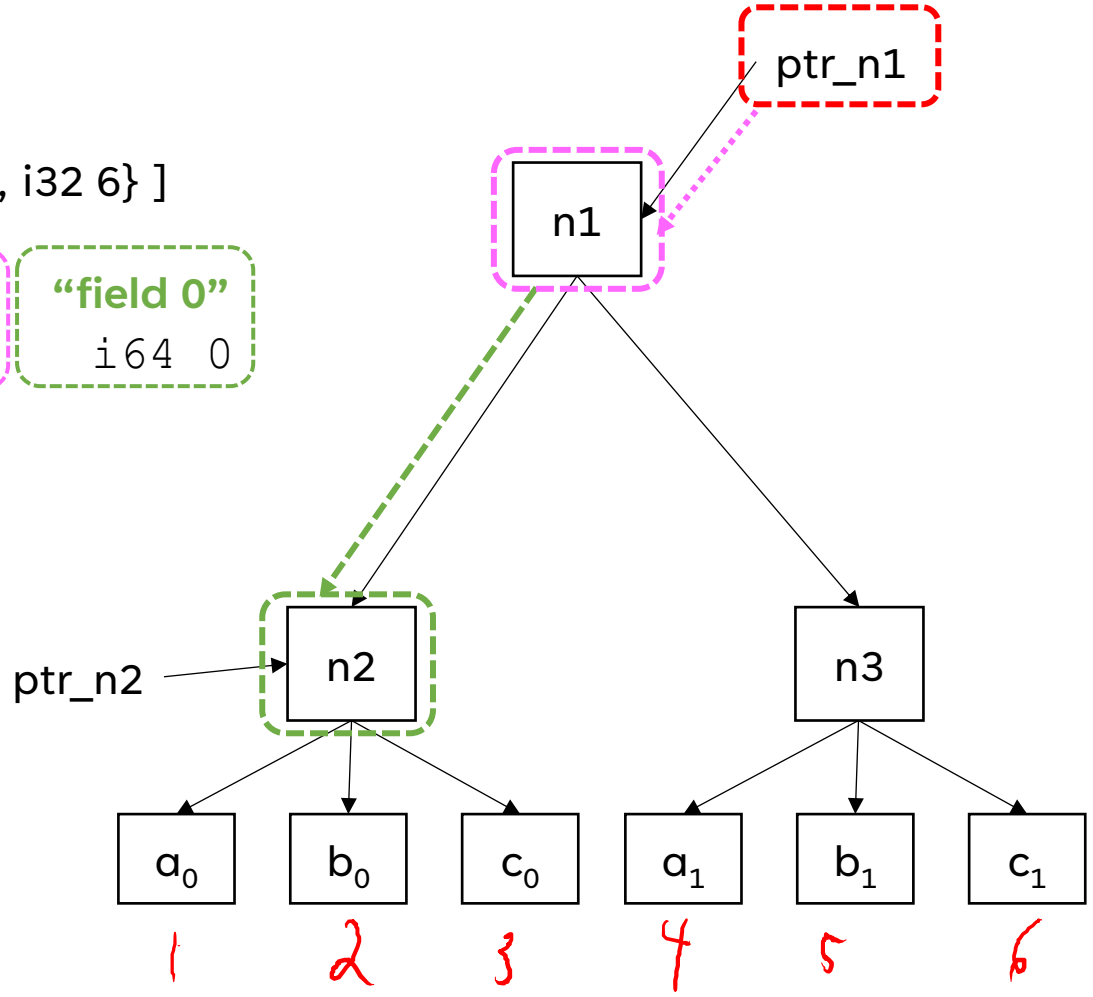
THE DREADED GEP

Can be helpful to walk through memory as a tree

```
%T1 = type { i32, i32, i32 }
%T2 = type [ 2 x %T1 ]
@ptr_n1 = global %T2 [ { i32 1, i32 2, i32 3 }, { i32 4, i32 5, i32 6} ]
```

```
ptr_n2 = getelementptr %T2, ptr @ptr_n1, i64 0, i64 0
```

"base addr" "sibling 0" "field 0"



GETELEMENTPTR: PICTORIALLY

THE DREADED GEP

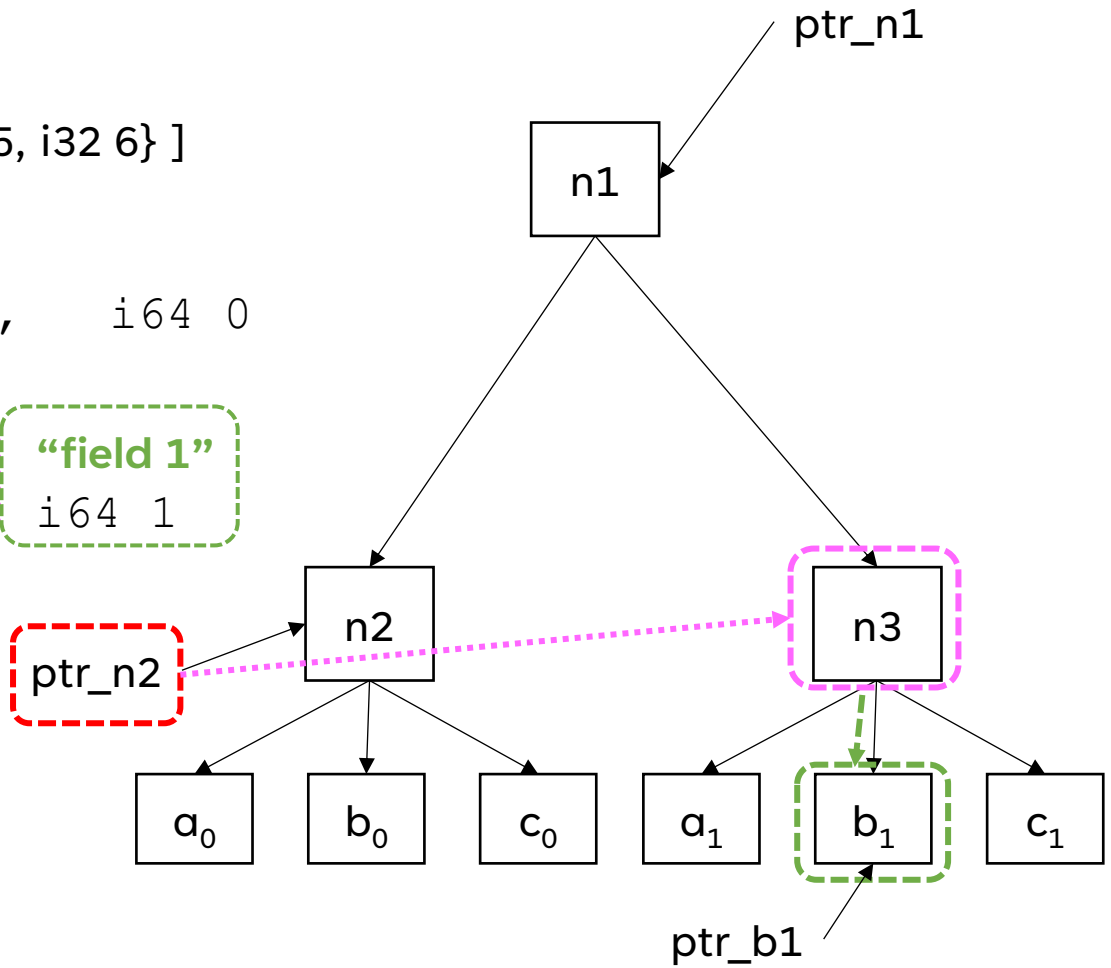
Can be helpful to walk through memory as a tree

```
%T1 = type { i32, i32, i32 }
%T2 = type [ 2 x %T1 ]
@ptr_n1 = global %T2 [ { i32 1, i32 2, i32 3 }, { i32 4, i32 5, i32 6} ]
```

```
ptr_n2 = getelementptr %T2, ptr @ptr_n1,  i64 0,   i64 0
```

```
ptr_b1 = getelementptr %T1, ptr @ptr_n2,  i64 1,   i64 1
```

"base addr" "sibling 1" "field 1"



GETELEMENTPTR: PICTORIALLY

THE DREADED GEP

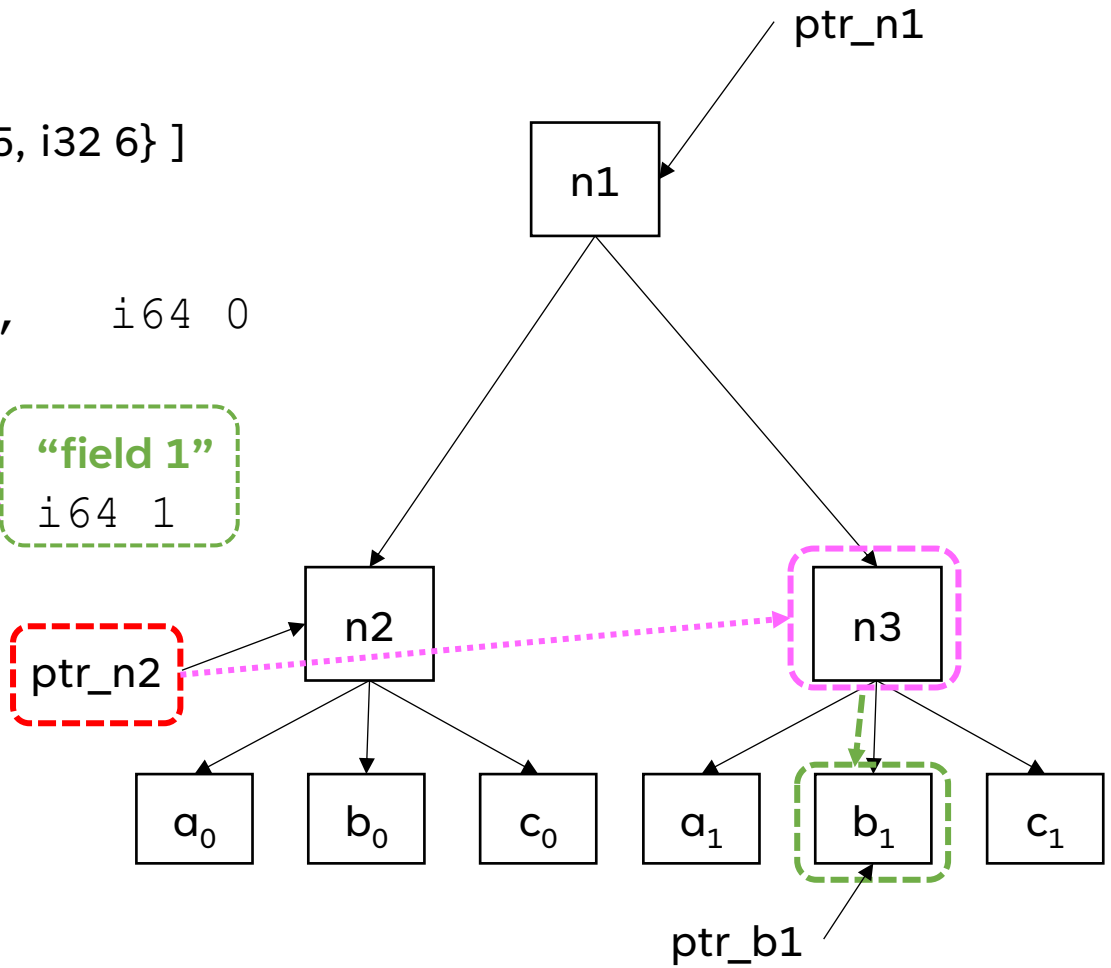
Can be helpful to walk through memory as a tree

```
%T1 = type { i32, i32, i32 }
%T2 = type [ 2 x %T1 ]
@ptr_n1 = global %T2 [ { i32 1, i32 2, i32 3 }, { i32 4, i32 5, i32 6} ]
```

```
ptr_n2 = getelementptr %T2, ptr @ptr_n1,  i64 0,   i64 0
```

```
ptr_b1 = getelementptr %T1, ptr @ptr_n2,  i64 1,   i64 1
```

"base addr" "sibling 1" "field 1"



GETELEMENTPTR: YA GOTTA HANDLE C

THE DREADED GEP

MY THEORY: GEP IS DESIGNED TO ACCOMMODATE THE NEEDS OF C SOURCE CODE

```
struct Inner {
  int32_t a;
  int8_t b;
  char c;
};
struct Outer{
  int32_t k;
  struct Inner m;
}

struct Outer v[3];
int main(){
  v[2].m.c = ‘X’;
}
```

SOME TIME WITH GEP

LLVM BITCODE

```
char getThirdElt(char arr[4]){
        return arr[2];
}

char getThirdOff(char * ptr){
        return ptr[2];
}
```

```
define i8 @getThirdElt([4 x i8]* %arrPtr) {
  %eltPtr = getelementptr [4 x i8], [4 x i8]* %arrPtr, i64 0, i64 2
  %res = load i8, i8* %eltPtr, align 1
  ret i8 %res
}
```

```
define i8 @getThirdOff(i8* %ptr) {
  %eltPtr = getelementptr inbounds i8, i8* %ptr, i64 2
  %res = load i8, i8* %eltPtr, align 1
  ret i8 %res
}
```

WRITING “INTERESTING” PROGRAMS

LLVM BITCODE

We can now write Turing complete programs

But these programs are very Boring!

We need to interact with external functionality

LLVM CALLS

LLVM BITCODE

General syntax

call <callee sig> <function name> (<argList>)

```
%res = call  i32(i32,i32)      @max      (i32 1, i32 2)
```

Somewhat surprisingly, does not (always) require the full function signature of the callee!

Constrained Syntax

call <return type> <function name> (<argList>)

```
%res = call  i32          @max      (i32 1, i32 2)
```

The general syntax IS required if a function has varargs

```
%len = call i32 (i8*, ...) @printf(i8* %strPtr, i32 123)
```

LLVM EXTERNAL CALLS

LLVM BITCODE

EXAMPLE

```
%len = call i32 (i8*, ...) @printf(i8* %strPtr, i32 123)
```

LLVM ATOI

LLVM BITCODE

To the Terminal!

LLVM PRINTF

LLVM BITCODE

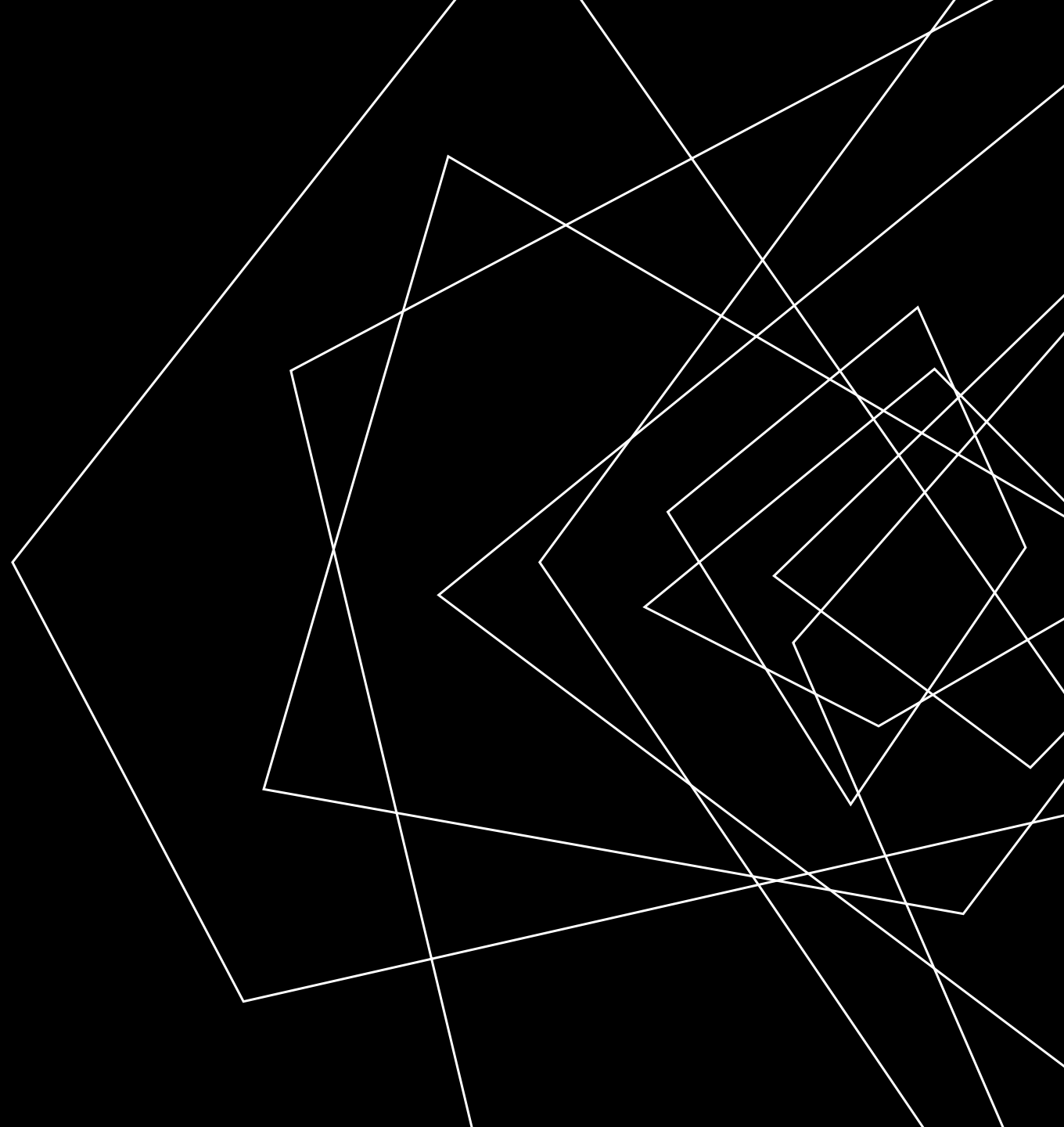
To the Terminal!

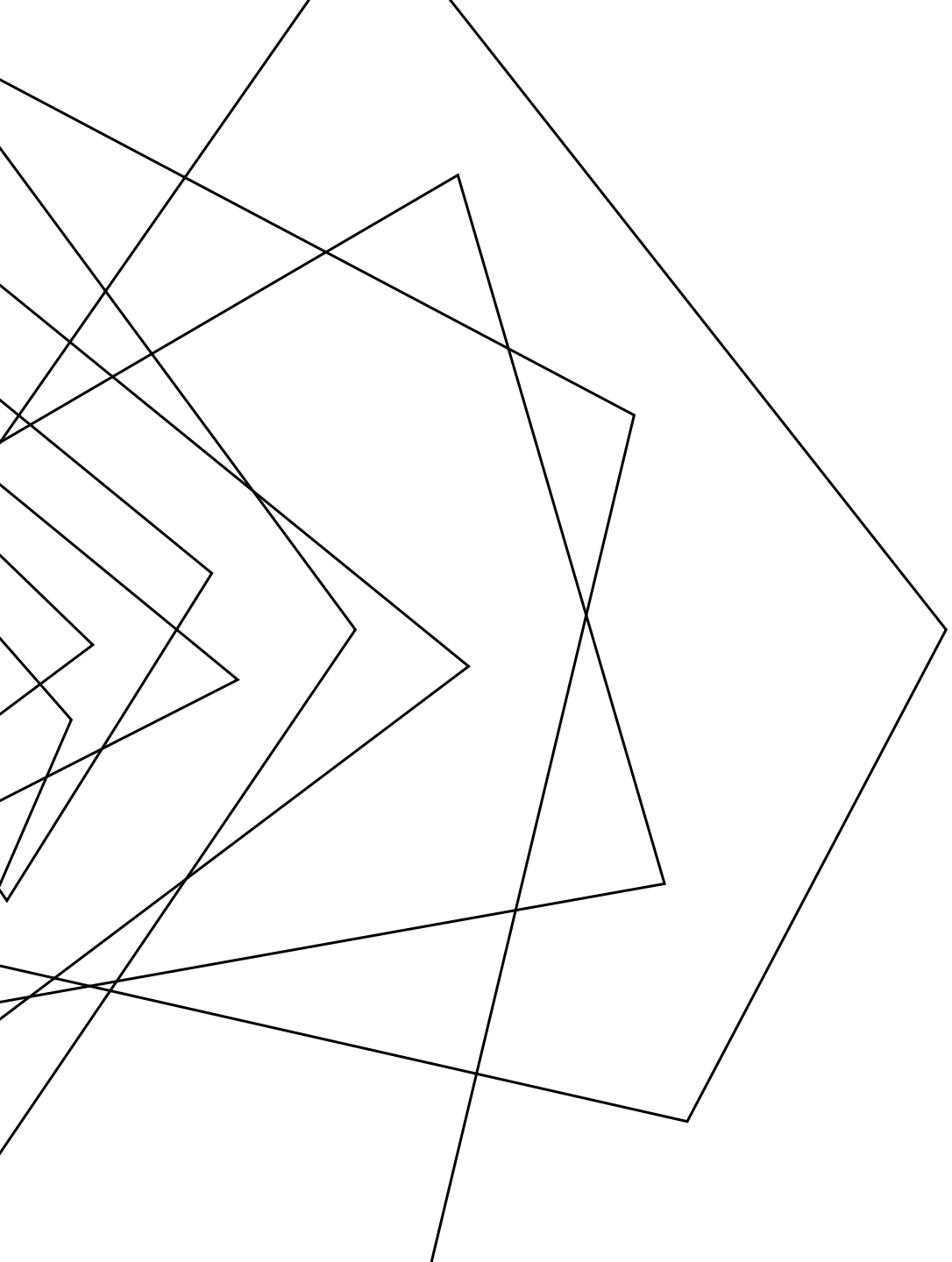
RUNNING THE LLVM TOOLS: CLANG

LLVM BITCODE

```
clang -S -emit-llvm foo.c -o foo.ll -disable-O0-optnone
```

WRAP-UP





NEXT TIME

WRITING AN ANALYSIS