Repurposing LLVM analyses in MLIR: *Also there and back again across the Tower of IRs*

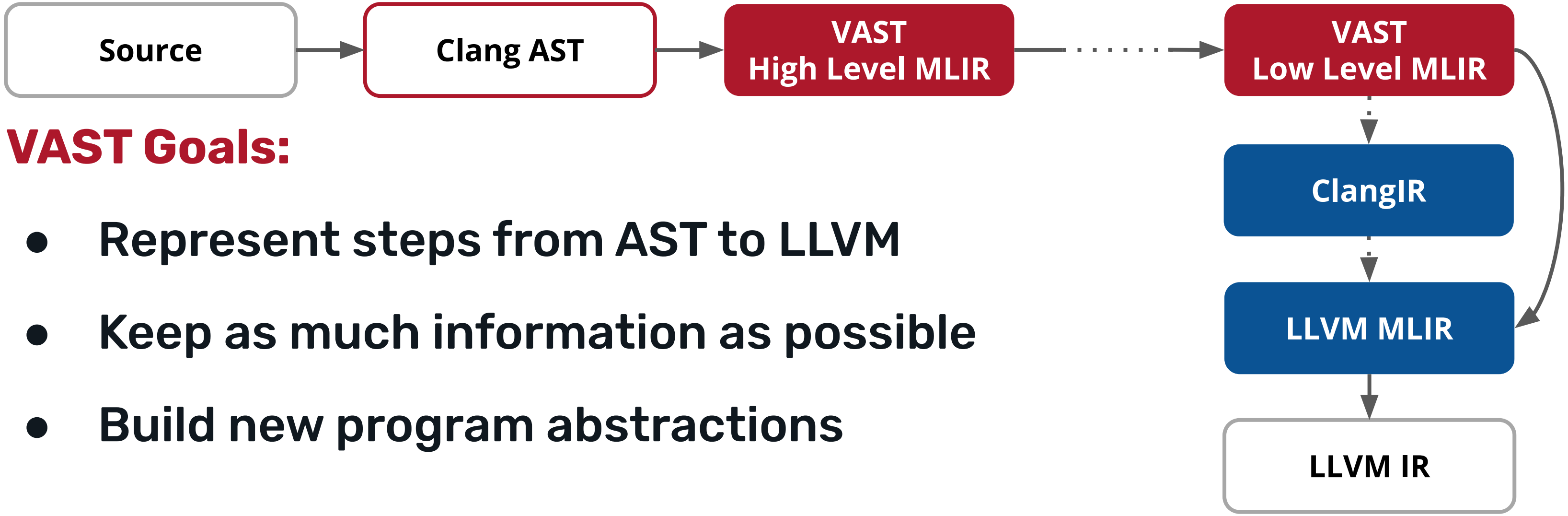
EuroLLVM 2024, 10th April, Henrich Lauko

VAST: Program analysis-focused compiler

- MLIR-based compiler for C/C++
- github.com/trailofbits/vast or try on compiler explorer

VAST: Program analysis-focused compiler

- MLIR-based compiler for C/C++
- github.com/trailofbits/vast or try on compiler explorer



VAST Goals:

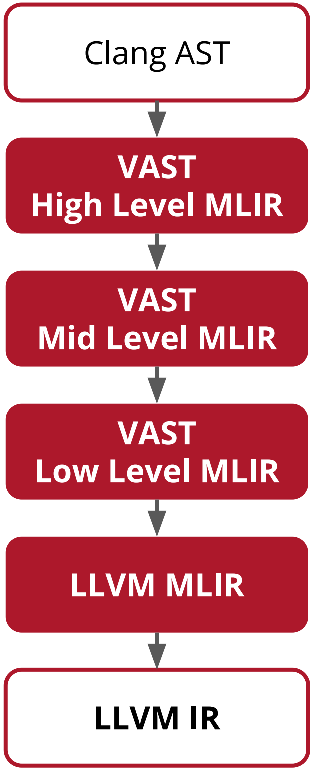
- Represent steps from AST to LLVM
- Keep as much information as possible
- Build new program abstractions

Re-use existing LLVM analyses, don't re-invent!

Goal: Want MLIR to benefit from pre-existing LLVM tools

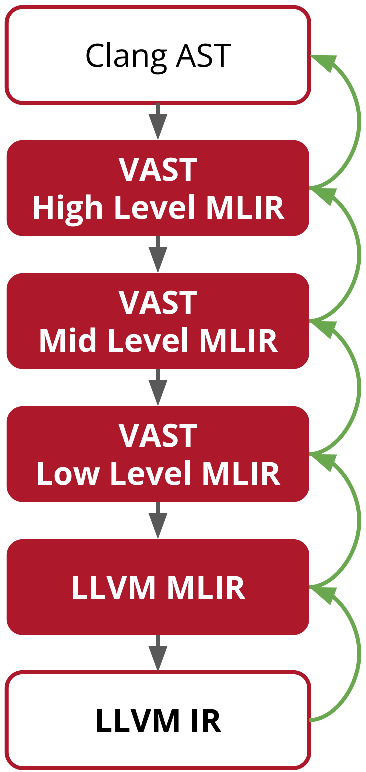
Solution: Lift LLVM analysis results into MLIR

Tower of IRs: Top-down view



MLIR Snapshots

Tower of IRs: Bottom-up view

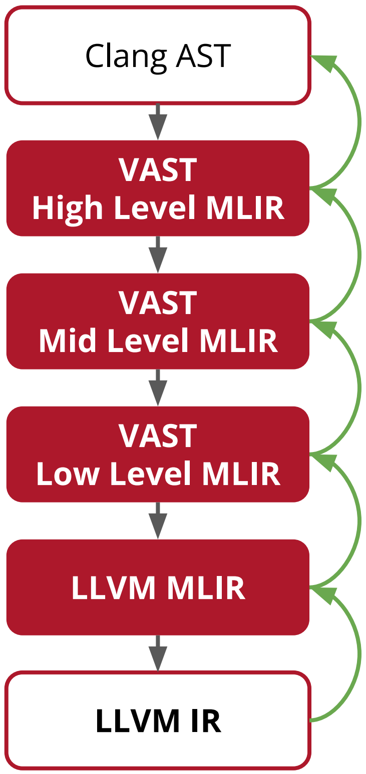


MLIR Snapshots + Provenance Links

=

Bidirectional mapping between MLIR modules

Tower of IRs: Bottom-up view

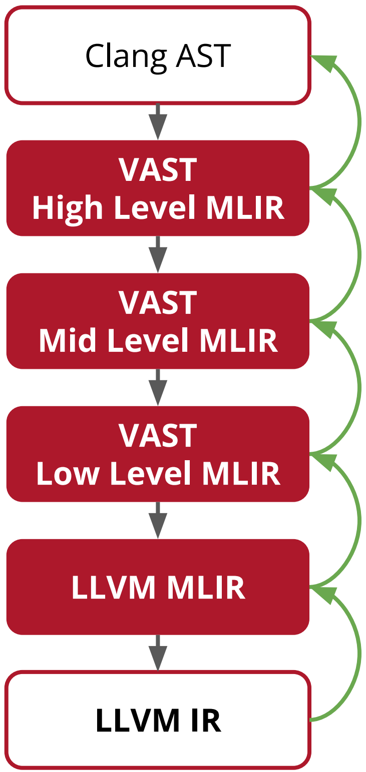


MLIR Snapshots + Provenance Links

=

Bidirectional mapping between MLIR modules

Tower of IRs: The *real* multi-level IR



MLIR Snapshots + Provenance Links

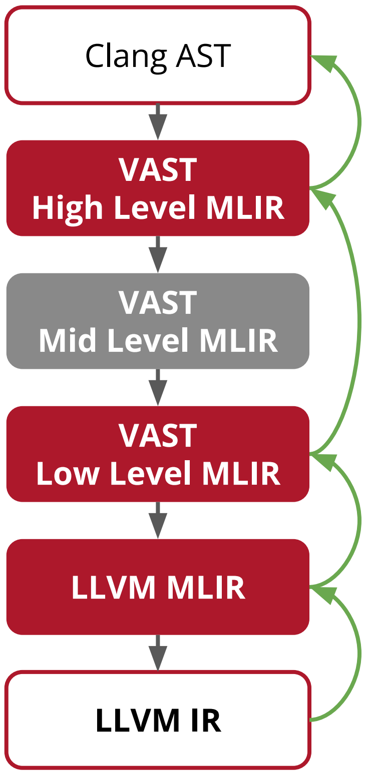
=

Bidirectional mapping between MLIR modules

=

Multi-Level IR

Tower of IRs: The *real* multi-level IR



MLIR Snapshots + Provenance Links

=

Bidirectional mapping between MLIR modules

=

Multi-Level IR

VAST Passes

```
splice-trailing-scopes
hl-to-hl-builtin
hl-dce
hl-lower-elaborated-types
hl-lower-typedefs
hl-to-std-types
lower-value-categories
```

```
emit-abi
lower-abi
hl-to-ll-vars
hl-to-ll-cf
hl-to-lazy-regions
hl-to-ll-geps
fn-args-to-alloca
... to-llvm
```

The approach is versatile

`mlir::generateLocationsFromIR`

```
This function generates new locations from the given IR by
snapshotting the IR to the given output stream, and using the
printed locations within that file.
```

Let’s have some fun()

```c
void fun() {
  int a = 2;
  int b = a + 3;
  int c = b * 13;
}
```

© Constants based on today's integer sequence: https://oeis.org/A100424

A sieve transform applied three times to the positive integers.

Let’s have some fun()

```c
void fun() {
    int a = 2;
    int b = a + 3;
    int c = b * 13;
}
```

```
vast-front -vast-emit-mlir=hl
```

```
%2 = hl.var “c” : !hl.value<!hl.int> {
    %4 = hl.ref %1 : !hl.lvalue<!hl.int>
    %5 = hl.implicit_cast %4 LValueToRValue : !hl.int
    %6 = hl.const #hl.integer<13> : !hl.int
    %7 = hl.mul %5, %6 : !hl.int
    hl.value.yield %7 : !hl.int
} loc(source:4)
```

© Constants based on today's integer sequence: https://oeis.org/A100424

A sieve transform applied three times to the positive integers.

Let's have some fun()

```
1: void fun() {
2:    int a = 2;
3:    int b = a + 3;
4:    int c = b * 13;
5: }
```

opt -vast-hl-lower-types

```
15: %2 = hl.var “c” : !hl.value<si32> {
16:    %4 = hl.ref %1 : !hl.lvalue<si32>
17:    %5 = hl.implicit_cast %4 LValueToRValue : si32
18:    %6 = hl.const #hl.integer<13> : si32
19:    %7 = hl.mul %5, %6 : si32
20:    hl.value.yield %7 : si32
21: } loc(high-level:15)
```

Let's have some fun()

```
1: void fun() {
2:    int a = 2;
3:    int b = a + 3;
4:    int c = b * 13;
5: }
```

```
opt -vast-emit-abi

opt -vast-lower-abi

opt -vast-hl-to-ll-func
```

- Skip snapshots of transformations that don't impact the interesting parts of MLIR
- Or we have identity maps between unchanged modules

Let's have some fun()

```
void fun() {
    int a = 2;
    int b = a + 3;
    int c = b * 13;
}
```

```
opt -vast-hl-to-ll-vars
%9  = ll.uninitialized_var : !hl.lvalue<si32>
%10 = hl.ref %8 : !hl.lvalue<si32>
%11 = hl.implicit_cast %10 LValueToRValue : si32
%12 = hl.const #hl.integer<13> : si32
%13 = hl.mul %11, %12 : (si32, si32) -> si32
%14 = ll.initialize %9, %13 loc(hl-to-ll-func:21)
opt -vast-hl-to-ll-cf
opt -vast-hl-to-lazy-regions
opt -vast-hl-to-ll-geps
```

Let's have some fun()

```
1: void fun() {
2:    int a = 2;
3:    int b = a + 3;
4:    int c = b * 13;
5: }
```

```
opt -vast-hl-lower-value-categories
10: %6 = ll.alloca : !ll.ptr<si32>
11: %7 = ll.load %2 : si32
13: %8 = hl.const #hl.integer<13> : si32
14: %9 = hl.mul %7, %8 : (si32, si32) -> si32
15: ll.store %6, %9 loc(hl-to-ll-geps:15)
```

Let's have some fun()

```
1: void fun() {
2:    int a = 2;
3:    int b = a + 3;
4:    int c = b * 13;
5: }
```

```
-vast-to-llvm

11: %8  = llvm.mlir.constant(1 : index)
12: %9  = llvm.alloca %8 x i32
13: %10 = llvm.load %4
14: %11 = llvm.mlir.constant(13 : i32)
15: %12 = llvm.mul %10, %11
16: llvm.store %12, %9 loc(hl-lower-value-categories:15)
```

Let’s have some fun()

```
1: void fun() {
2:    int a = 2;
3:    int b = a + 3;
4:    int c = b * 13;
5: }
```

```
define void @fun() {
  %1 = alloca i32, i64 1, align 4
  store i32 2, ptr %1, align 4
  %2 = alloca i32, i64 1, align 4
  %3 = load i32, ptr %1, align 4
  %4 = add i32 %3, 3
  store i32 %4, ptr %2, align 4
  %5 = alloca i32, i64 1, align 4
  %6 = load i32, ptr %2, align 4
  %7 = mul i32 %6, 13
  store i32 %7, ptr %5, align 4
  ret void
}
```

Dependence analysis

```
1: void fun() {
2:   int a = 2;
3:   int b = a + 3;
4:   int c = b * 13;
5: }
```

```
define void @fun() {
  %1 = alloca i32, i64 1, align 4
  store i32 2, ptr %1, align 4
  %2 = alloca i32, i64 1, align 4
  %3 = load i32, ptr %1, align 4
  %4 = add i32 %3, 3
  store i32 %4, ptr %2, align 4
  %5 = alloca i32, i64 1, align 4
  %6 = load i32, ptr %2, align 4
  %7 = mul i32 %6, 13
  store i32 %7, ptr %5, align 4
  ret void
}
```

Walk back the Tower of IRs

```
1: void fun() {
2:    int a = 2;
3:    int b = a + 3;
4:    int c = b * 13;
5: }
```

```
store i32 %4, ptr %2, align

llvm.store %7, %4

%8 = ll.initialize %3, %7

%1 = hl.var "b" : si32 = {
  ...
  hl.value.yield %7 : si32
}

%1 = hl.var "b" : !hl.lvalue<!hl.int>
```

Gather dependencies across layers

Genericity of the approach

Similar approach **is applicable beyond VAST** in other tools.

Need to be **cautious about** the aggressiveness of **transformations**.

Overly aggressive transformations may **hinder cross-layer linking**.

There and back again across the tower of IRs

Leverage LLVM-based analyses in MLIR toolchains

https://github.com/trailofbits/vast

Single layer on compiler-explorer, the tower soon.