VAST: MLIR for program analysis of C/C++

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Hi everyone

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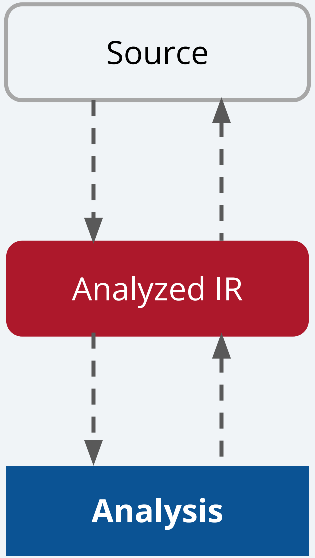
VAST – MLIR library for program analysis

https://github.com/trailofbits/vast

Today’s IRs don’t meet analysis needs

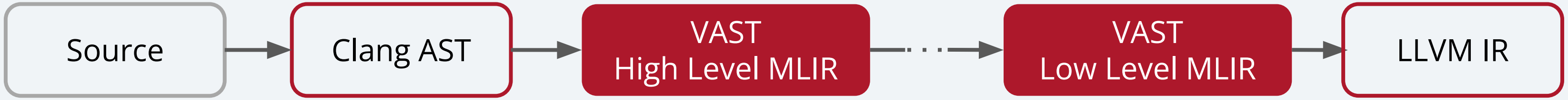
- **Program analysis:**
  - Static analysis and source base queries
  - Fuzzing, abstract interpretation, symbolic execution
  - Program models and instrumentation
- **An orthogonal problem to optimization:**
  - We need truthful information about program semantics
  - Optimizations are destructive transformations
  - Challenge is to relate results back to source



We need a program analysis-focused IR

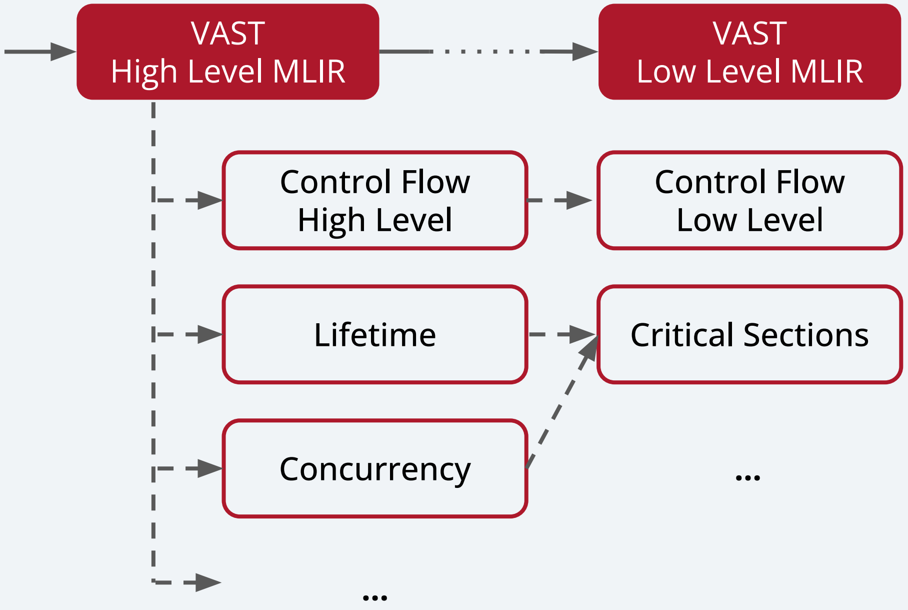
- **Analysis of source code level (semgrep, weggli):**
  - Lacks semantic awareness
- **Analysis at Clang AST level (ast-matcher):**
  - Too complex for more heavy-duty/interpretation based analysis
  - Not a complete source of truth
- **Analysis at LLVM IR level (sanitizers, KLEE):**
  - A collection of IR flavours/dialects – intrinsic-based dialects
  - Too low-level for some analyses
  - Hard to relate to source after optimization, e.g. ABI is already lowered

MLIR is the future of program analysis



- **VAST – MLIR library for program analysis:** https://github.com/trailofbits/vast
- **Views of the source code at the various stages of translation to LLVM**
- **Various stages are interesting for different analyses:**
  - A high-level control flow with a lowered types
  - Analysis of lifetimes of high-level code, in concurrent environments

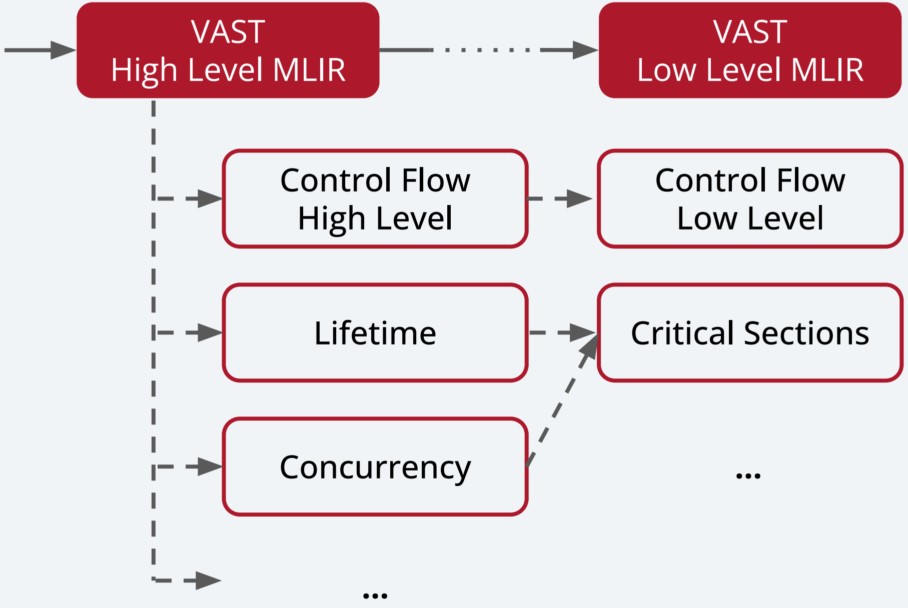
Semantic dialects tailored to analysis goals



```
hl.func external @loop_simple () -> !hl.void {
    %0 = hl.var "i" : !hl.lvalue = {
      %1 = hl.const #hl.integer<0> : !hl.int
      hl.value.yield %1 : !hl.int
    }
    hl.for {
      %1 = hl.ref %0 : !hl.lvalue
      %2 = hl.implicit_cast %1 LValueToRValue :
          !hl.lvalue -> !hl.int
      %3 = hl.const #hl.integer<100> : !hl.int
      %4 = hl.cmp slt %2, %3 : !hl.int, !hl.int
          -> !hl.int
      hl.cond.yield %4 : !hl.int
    } incr {
      %1 = hl.ref %0 : !hl.lvalue
      %2 = hl.post.inc %1 : !hl.lvalue -> !hl.int
    } do {
    }
    hl.return
}
```

Our vision for program analysis

Semantic dialects tailored to analysis goals



```
llvm.func @loop_simple() {
  %0 = llvm.mlir.constant(1 : index) : i64
  %1 = llvm.alloca %0 x i32 : (i64) -> !llvm.ptr<i32>
  %2 = llvm.mlir.constant(0 : i32) : i32
  llvm.store %2, %1 : !llvm.ptr<i32>
  hl.for {
    %3 = llvm.load %1 : !llvm.ptr<i32>
    %4 = llvm.mlir.constant(100 : i32) : i32
    %5 = llvm.icmp "slt" %3, %4 : i32
    hl.cond.yield %5 : si32
  } incr {
  } do {
  }
}
```

Provenance dialects

```
struct Point {
    int x, y, z;
};

Point add(Point a, Point b) {
    ...
}
```

LLVM

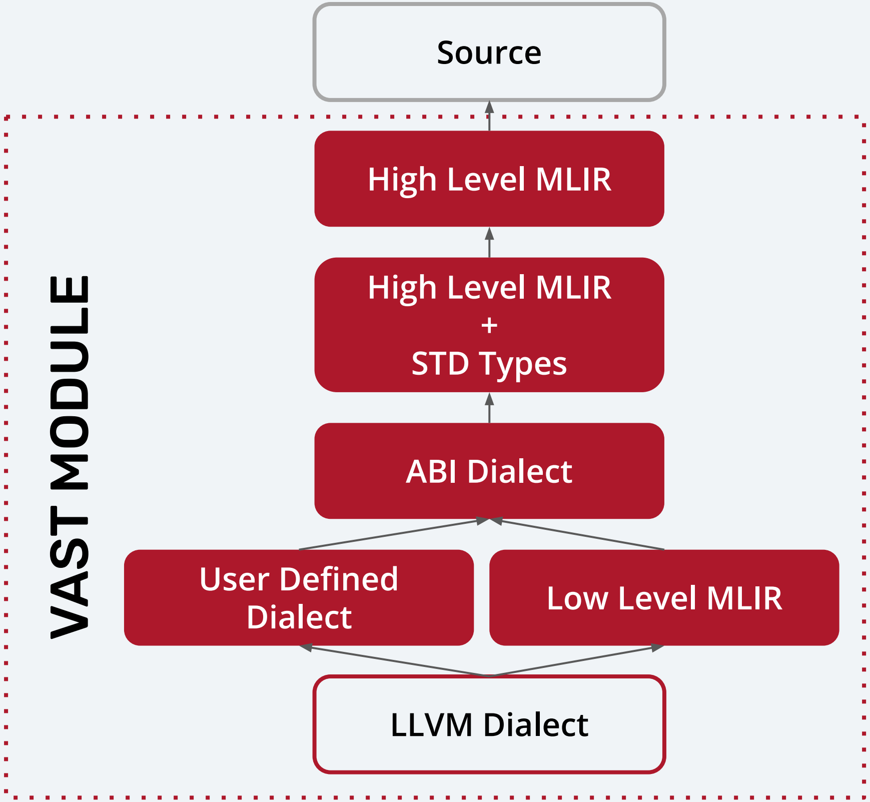
```
define {i64, i32} @add(i64 a1, i32 a2,
                       i64 b1, i32 b2)
```

VAST ABI Lowering

```
func add(Point a, Point b) -> Point {
  abi.entry { // prologue
    [a1: i64, a2: i32] = abi.lower(a)
    [b1: i64, b2: i32] = abi.lower(b)
  } body -> [i64, i32] {
    // use a1, a2, b1, b2
    // return {r1: i64, r2: i32}
  } abi.return { // epilogue
    return abi.lift(r1, r2): Point
  }
}
```

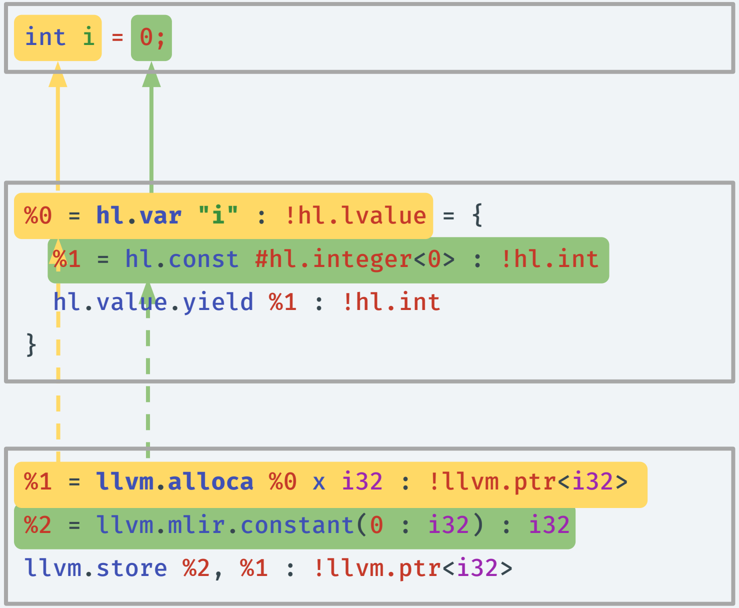
Our vision for program analysis

Tower of IRs



Our vision for program analysis

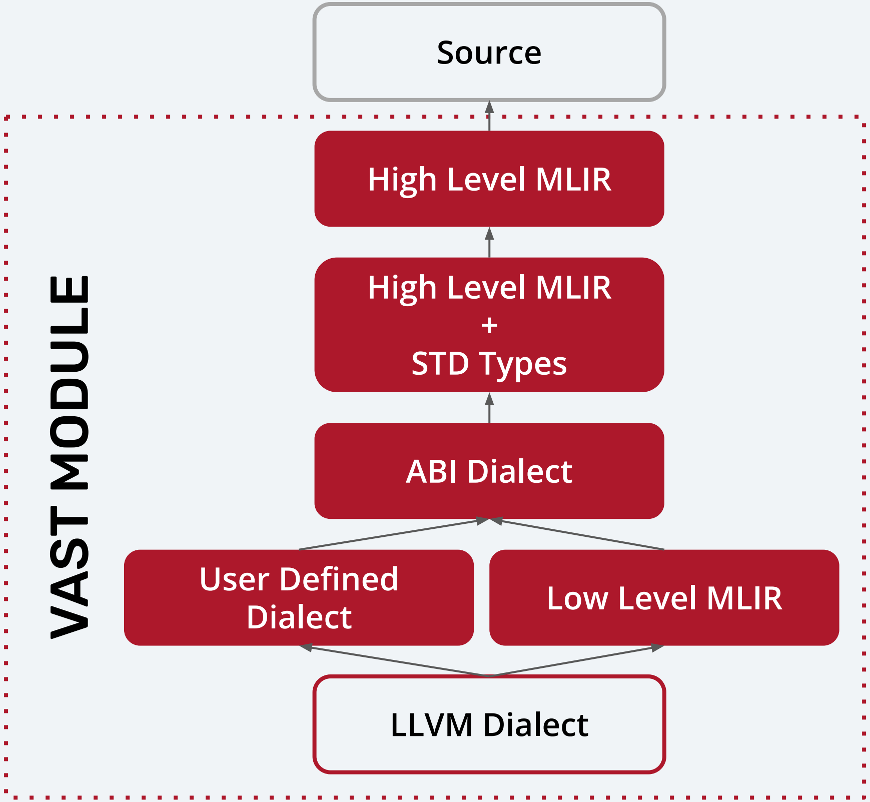
Tower of IRs



```
int i = 0;
```

```
%0 = hl.var "i" : !hl.lvalue = {
  %1 = hl.const #hl.integer<0> : !hl.int
  hl.value.yield %1 : !hl.int
}
```

```
%1 = llvm.alloca %0 x i32 : !llvm.ptr<i32>
%2 = llvm.mlir.constant(0 : i32) : i32
llvm.store %2, %1 : !llvm.ptr<i32>
```



VAST MODULE

Source

High Level MLIR

High Level MLIR + STD Types

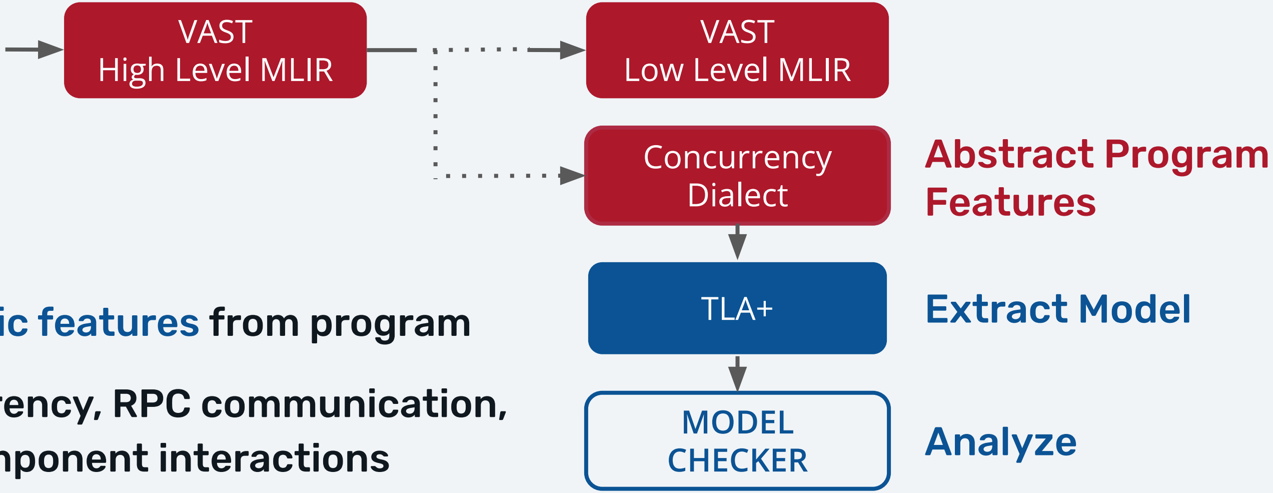
ABI Dialect

User Defined Dialect

Low Level MLIR

LLVM Dialect

Sometimes compilation isn't the goal

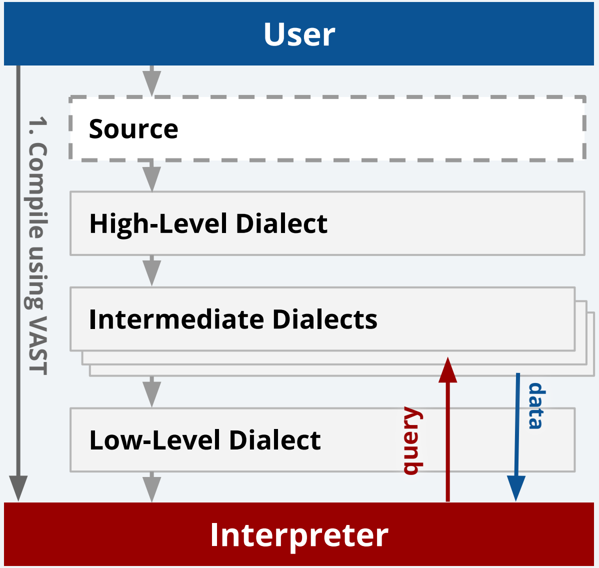


- **Extract specific features from program**
- **Model concurrency, RPC communication, protocols, component interactions**
- **Use tower to report analysis results**

Distribution Statement "A" (Approved for Public Release, Distribution Unlimited)

How we want to analyze programs

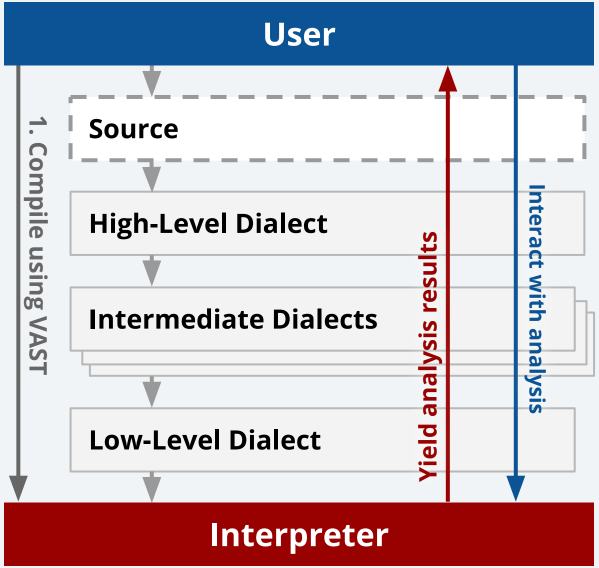
- Want efficiency of LLVM IR and expressivity of source
- Requires all representations
- Use tower of IRs to get high-level view



Distribution Statement "A" (Approved for Public Release, Distribution Unlimited)

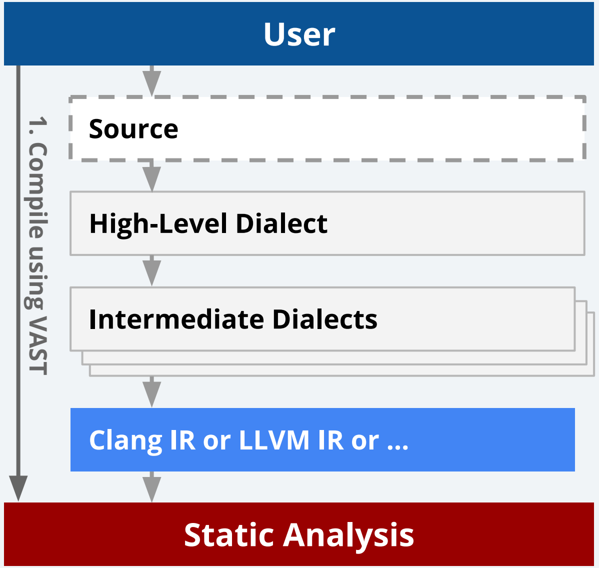
What about human-in-the-loop?

- Want efficiency of LLVM IR and expressivity of source
- Requires all representations
- Use tower of IRs to get high-level view
- Present the user what he recognizes

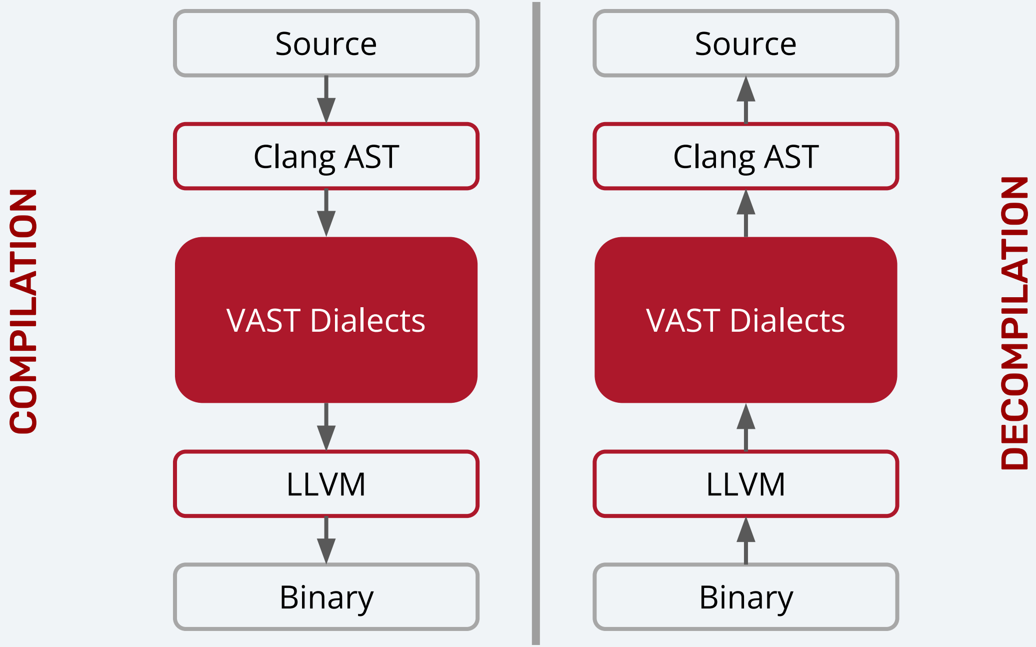


VAST gives you a tower, not a silo

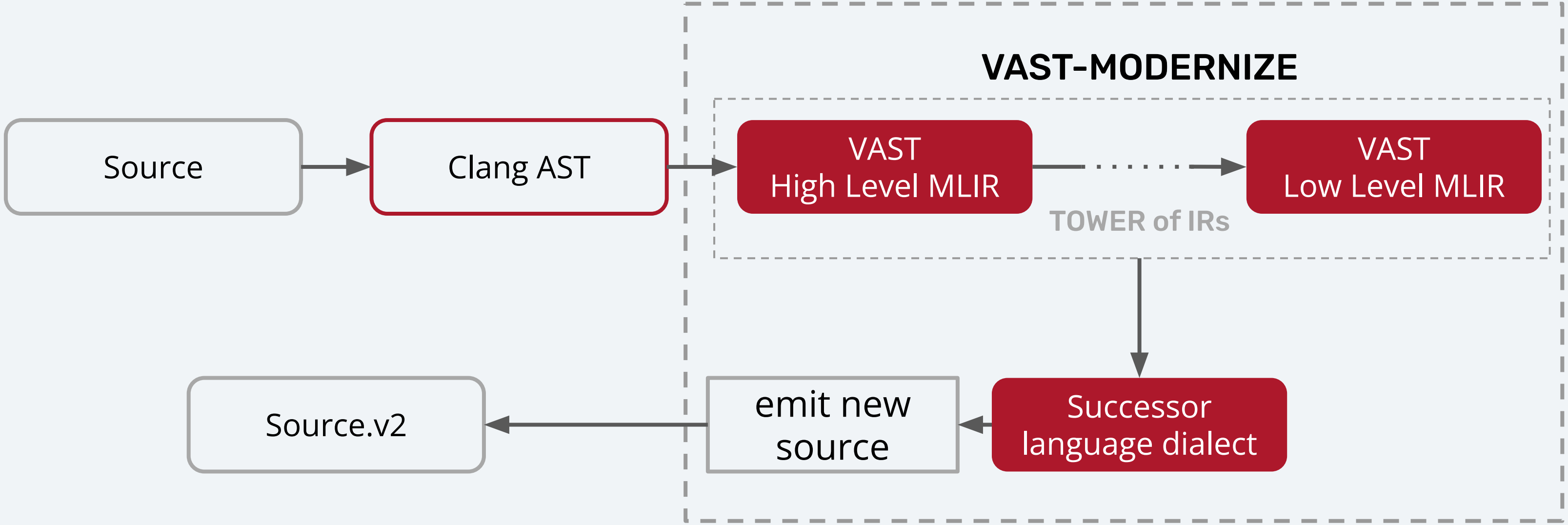
- **Information rich dialects**
- **Lower dialects to other tool's dialects**
- **For example Clang IR or LLVM IR**
- **Allows to leverage high-level MLIR for smoother instrumentation and easier program analysis**



Decompilation



Transpiling with VAST



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CPP to CPP2 declarative parameters

```
void f(const X& x) {
    g(x);
}
```

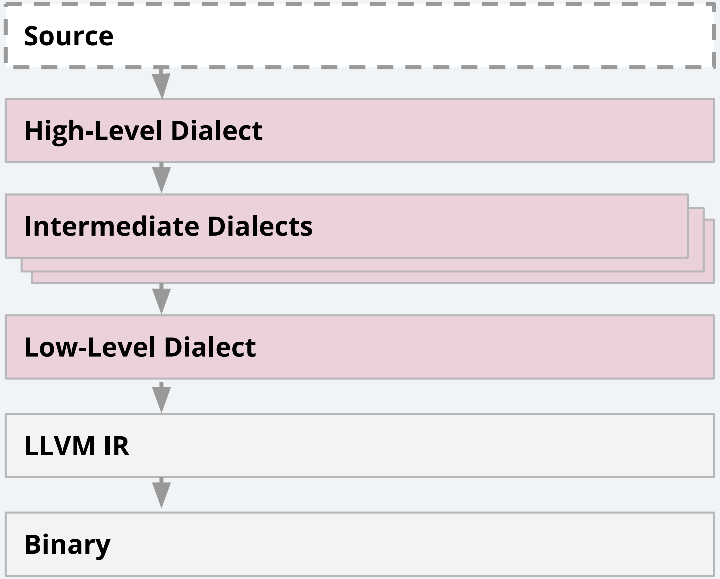
→

```
void f(in X x) {
    g(x);
}
```

```
hl.func @f(%x : !hl.ref<!hl.lvalue<!hl.struct<"X">>, const>) {
  %0 = hl.call @g(%x) : (!hl.ref<!hl.lvalue<!hl.struct<"X">>, const>)
     -> !hl.void
}
```

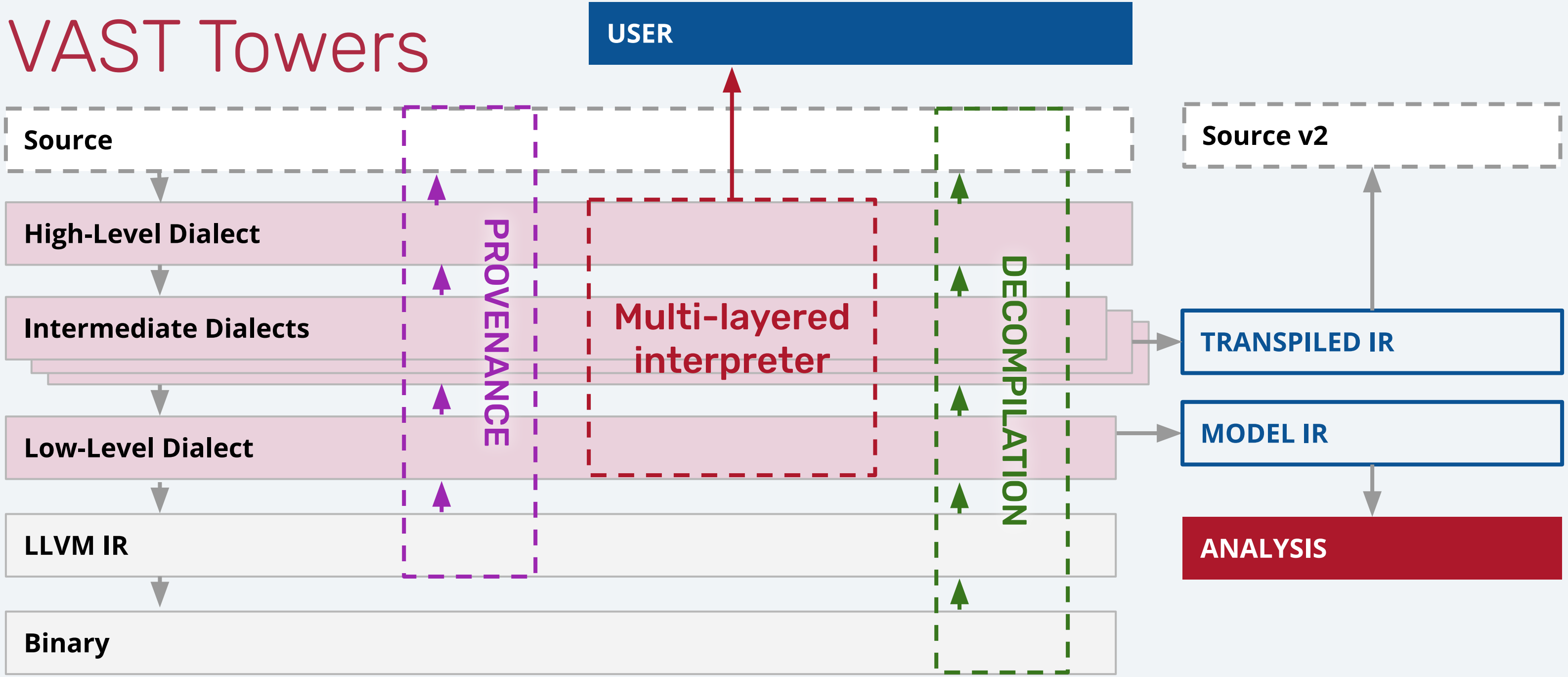
```
hl.func @f(%x : !par.in<!hl.lvalue<!hl.struct<"X">>>) {
  %0 = hl.call @g(%x) : (!par.in<!hl.lvalue<!hl.struct<"X">>>)
     -> !hl.void
}
```

VAST Tooling



- **Compilation description dialects**
- **Configurable codegen**
  - How to represent provenance
  - How to lower unsupported primitives
- **MLIR interactive editing tool (REPL)**
- **MLIR query tool**

VAST Towers



VAST open source at: https://github.com/trailofbits/vast