Fortran alias in LLVM

An experiment

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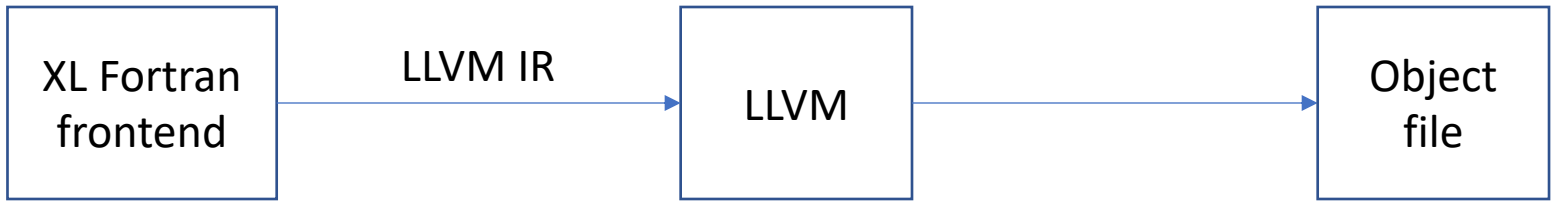
Agenda

- Background
- Observations
- Next step

Background

- Problem: Representing Fortran alias information in LLVM IR
- Compilation:



- Representation of alias information in IR
  - Considered TBAA and ScopeAlias/NoAlias metadata (MD)
  - Used ScopeAlias/NoAlias MD, as Fortran rules result in more refined aliasing than the natural TBAA representation

Alias representation

- A memory instruction (load, store, call) is annotated with `alias.scope` and `noalias` MD
- `alias.scope` MD is a set of MD nodes where each element node represents a symbol that may alias the memory read from/written to
- `noalias` MD is a set of MD nodes where each element node represents a symbol that is definitely not aliased with the memory read from/written to

Alias representation: Example

```
subroutine sub(arg)
 integer :: arg
 integer, target :: tgt
 integer, pointer :: ptr
 ptr => tgt
 tgt = arg
 ptr = tgt + 1
end subroutine sub
```

```
Alias(arg)  : {arg}
Alias(tgt)  : {tgt, ptr}
Alias(ptr)  : {tgt, ptr}
Alias(d-ptr): {d-ptr, d-ptr%addr}
...
```

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Alias(tgt)  : {tgt, ptr}         NoAlias(tgt): {d-ptr%addr, d-ptr, arg}
Alias(ptr)  : {tgt, ptr}         NoAlias(ptr): {d-ptr%addr, d-ptr, arg}
Alias(d-ptr): {d-ptr, d-ptr%addr}
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Alias(d-ptr): {d-ptr, d-ptr%addr}
...
```

```
!2 = distinct !{!2, !"domain: sub"}
!4 = distinct !{!4, !2, !"d-ptr%addr"}
!6 = distinct !{!6, !2, !"tgt"}
!8 = distinct !{!8, !2, !"ptr"}
!11 = distinct !{!11, !2, !"arg”}
!23 = distinct !{!23, !2, !"d-ptr"}
!21 = !{!11}                    ; {arg}
!22 = !{!4, !6, !8, !23}        ; NoAlias(arg)
!24 = !{!6}                     ; {tgt}
!25 = !{!4, !23, !11}           ; NoAlias(tgt)
                                ; NoAlias(ptr)
!26 = !{!8}                     ; {ptr}
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                                ; NoAlias(ptr)
!26 = !{!8}                     ; {ptr}
```

```
%_val_arg_ = load i32, i32* %_val_.arg_, align 4,          !alias.scope !21, !noalias !22
store i32 %_val_arg_, i32* %tgt, align 4,                  !alias.scope !24, !noalias !25  ; tgt = arg
...
%_val_tgt_ = load i32, i32* %tgt, align 4,                 !alias.scope !24, !noalias !25
%_add_tmp = add nsw i32 %_val_tgt_, 1
store i32 %_add_tmp, i32* %"_val_d-ptr%addr_", align 4,    !alias.scope !26, !noalias !25  ; ptr = tgt + 1
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Observations

- No performance degradation for the workloads that we ran.
- Achieved moderate to significant improvement in execution performance for several workloads (2% – 200%).
- Compile-time performance degraded significantly for some workloads (1x – >500x).
- The size of the IR increased significantly (1.4x – 10x).

	compile time increase	performance improvement	IR size increase
workload 1	1.8x	1x	1.4x
workload 2	4x	1.2x	3.2x
workload 3	15.5x	1x	2.5x
workload 4	6.6x	1.9x	8.7x

Observations

- Compile-time performance
  - Each alias query (`ScopedNoAliasAAResult::mayAliasInScopes`) involves partitioning an MD set based on the domains of the MD elements. Pre-partitioning the MD sets and maintaining the partitions on updates can help.
  - Intersection of `noalias` sets is $O(n^2)$ as MD elements do not have any ordering. Defining some order on the elements can help significantly.
  - Some optimizations do not scale well when the size of the working instruction set increases. Example: SCEV functions.
- Size of LLVM IR
  - The `noalias` MD requires a flattened set of MD nodes. A hierarchical representation can reduce memory footprint.

Next steps

- Goal: An LLVM representation that is a natural fit for Fortran aliasing and that scales for large workloads.
  - In terms of expressive power, ScopedAlias/NoAlias seems more suitable for Fortran than TBAA.
  - ScopedAlias/NoAlias in its current state does not scale. Are there any suggestions to enhance the metadata implementation in LLVM to achieve more efficient alias operations (e.g. query, intersection) and a smaller memory footprint?

- Call for collaboration
  - We are interested in learning about other Fortran aliasing experiments and observations.
  - We would like to further explore either enhancing or replacing the LLVM representation to make it work better for Fortran. We would love to work closely with the community on this.

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