# All About Alias Analysis

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# Motivation

- Store to load forwarding (GVN, EarlyCSE)

```
*x = 0;                 *x = 0;
*y = 1;                 *y = 1;
return *x;   ------>    return 0;
```

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- Do x and y alias?

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- Dead Store Elimination (DSE)

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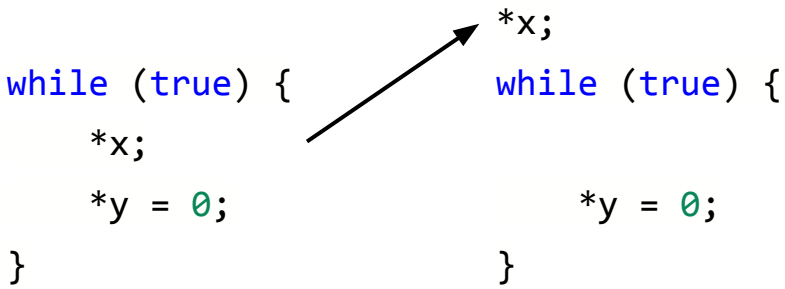
- Loop Invariant Code Motion (LICM)

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# Agenda

- Memory accesses/locations/effects, provenance
- Aliasing and AA usage
- Alias analysis providers
- Derived analyses

# Memory accesses

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  - Not an access: getelementptr
- What does it access (MemoryLocation)?
- How does it access (ModRefInfo)?
  - NoModRef
  - Ref (read)
  - Mod (write)
  - ModRef (read+write)

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- Base pointer
- Size
- Metadata (!tbaa, !noalias, etc.)

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| --- | --- |
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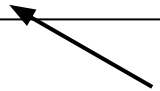

Does this mean you can access **all** memory?

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  - other (globals, captured pointers, etc.)

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  - argmem
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  - target_memN
  - other (globals, captured pointers, etc.)
- Observable effects only
  - Read/write of alloca not observable outside call

# MemoryEffects

- Examples:
  - llvm.memcpy: memory(argmem: readwrite)
  - llvm.assume: memory(inaccessiblemem: readwrite)

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Depends on provenance

# Aliasing

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unsigned y;
if (&y == &x + 1) {
    *(&x + 1) = 42;
}
```



alias(&y, &x + 1) == NoAlias

because access at &x + 1 is UB

# alias(Loc1, Loc2)

- NoAlias
- MayAlias
  - Don't know
- MustAlias
  - Alias and start at same address
- PartialAlias
  - Alias, but may start at different addresses
  - Carries optional offset between base pointers

# getModRefInfo()

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- getModRefInfo(Inst1, Inst2)
  - Can Inst1 read/write memory accessed by Inst2?
  - Excluding read-read cases.
  - Inst2 is usually a call.

# -passes=aa-eval -print-all-alias-modref-info

```
define void @test(ptr %arg1, ptr %arg2) {
 %alloca = alloca i32
 store i32 1, ptr %alloca
 store i32 2, ptr %arg1
 store i32 3, ptr %arg2
 call void @call()
 ret void
}

declare void @call()
```

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```
NoAlias:  i32* %alloca, i32* %arg1
NoAlias:  i32* %alloca, i32* %arg2
MayAlias: i32* %arg1, i32* %arg2

NoModRef:  Ptr: i32* %alloca    <->  call void @call()
Both ModRef:  Ptr: i32* %arg1   <->  call void @call()
Both ModRef:  Ptr: i32* %arg2   <->  call void @call()
```

# Cycles

```
void test(unsigned *p, size_t size) {
   for (size_t i = 1; i < size; ++i) {
       p[i] = p[i - 1] * 2;
   }
}
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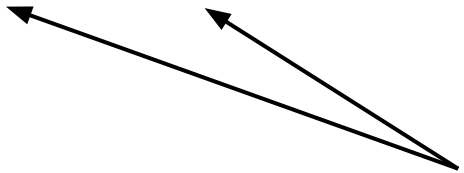

NoAlias ... on the same iteration!

MayAlias in cross-iteration mode

# Caching and BatchAA

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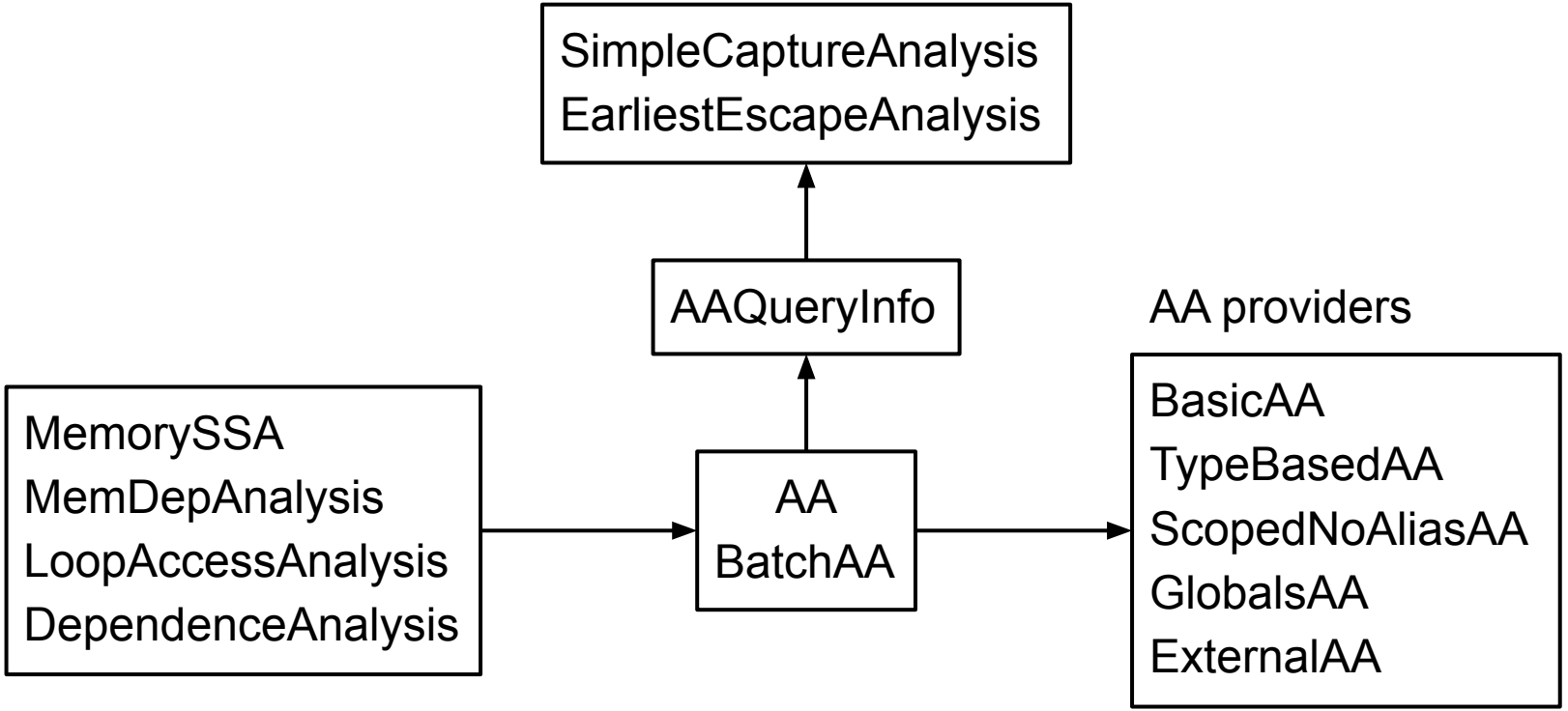
- Normal AA uses separate AAQI per query
  - Caching only during recursive AA calls
- BatchAA uses shared AAQI for all queries
  - Use whenever possible
  - No invalidation support

# BatchAA: Erase XOR Insert

- Can use BatchAA across instruction erasure
- Can use BatchAA across instruction insert
- But not both
- Erase then insert may reuse pointer


SimpleCaptureAnalysis
EarliestEscapeAnalysis
AAQueryInfo
AA providers
MemorySSA
MemDepAnalysis
LoopAccessAnalysis
DependenceAnalysis
AA
BatchAA
BasicAA
TypeBasedAA
ScopedNoAliasAA
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- ExternalAA
  - Extension point: E.g. for address space aliasing on GPUs

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  - Recursion through phi, select, getelementptr
- Implements:
  - Provenance based reasoning
  - Capture based reasoning
  - Offset based reasoning
  - ...

# BasicAA: Provenance based reasoning

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- getUnderlyingObject()
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  - Offset / inbounds does not matter
- isIdentifiedObject(): Does not alias with other identified objects
  - alloca
  - global variable
  - call with noalias return (allocator)
  - noalias or byval argument

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- Obj1 != Obj2 &&  isIdentifiedObject(Obj1) && isIdentifiedObject(Obj2)
  - => NoAlias
  - For example: Two allocas don't alias

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- Obj1 != Obj2 &&  isIdentifiedObject(Obj1) && isIdentifiedObject(Obj2)
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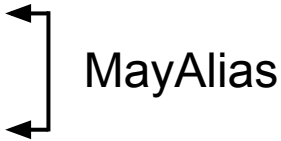
- Obj1 != Obj2 && isa<Argument>(Obj1) && isIdentifiedFunctionLocal(Obj2)
  - => NoAlias
  - isIdentifiedFunctionLocal() excludes globals
  - For example: An argument and an alloca don't alias

# BasicAA: Capture based reasoning

```
%a = alloca i32
call void @escape_ptr(ptr %a)
%b = call ptr @get_ptr()
```



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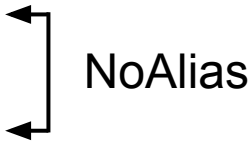

# Escape source

- Can only alias with previously escaped object
  - call return value (with some exceptions)
  - load
  - inttoptr
  - extractvalue, extractelement

# Is it captured before?

```
void test() {
   unsigned x;
   *x;
   if (cond) {
       *x;
       escape(&x);
   } else {
       escape(&x);
   }
   *x;
}
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# Is it captured before?

```
void test() {
   unsigned x;                          Simple
   *x; <------------------------------  yes
   if (cond) {
       *x; <--------------------------  yes
       escape(&x);
   } else {
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   *x; <------------------------------  yes
}
```

# Is it captured before?

```
void test() {
   unsigned x;                          Simple                    CapturesBefore
   *x; <-------------------------------- yes                       no
   if (cond) {
       *x; <---------------------------- yes                       no
       escape(&x);
   } else {
       escape(&x);
   }
   *x; <-------------------------------- yes                       yes
}
```

# Is it captured before?

```
void test() {
   unsigned x;                          Simple      EarliestEscape    CapturesBefore
   *x; <------------------------------- yes                           no
   if (cond) {  <------ Nearest common dominator of escapes
       *x; <------------------------------ yes                       no
       escape(&x);
   } else {
       escape(&x);
   }
   *x; <------------------------------- yes                           yes
}
```

# Is it captured before?

```
void test() {
   unsigned x;                          Simple      EarliestEscape    CapturesBefore
   *x; <------------------------------- yes         no                no
   if (cond) {  <-- Nearest common dominator of escapes
       *x; <------------------------------- yes     yes               no
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# CaptureAnalysis

- SimpleCaptureAnalysis
  - Not context sensitive
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  - Not context sensitive
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- EarliestEscapeAnalysis
  - Cached nearest common dominator of escapes
  - Supports invalidation

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- Decompose chain of getelementptrs (and indices)
  - BasePtr + ConstOffset + Scale1*Var1 + ...

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- Subtract BasePtr + Offset2 from both:
  - Access 1 at Offset1 - Offset2
  - Access 2 at 0

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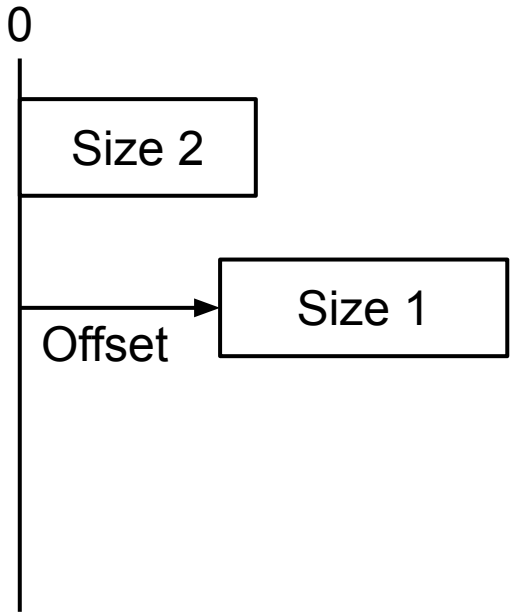


NoAlias if:

Offset >= Size 2

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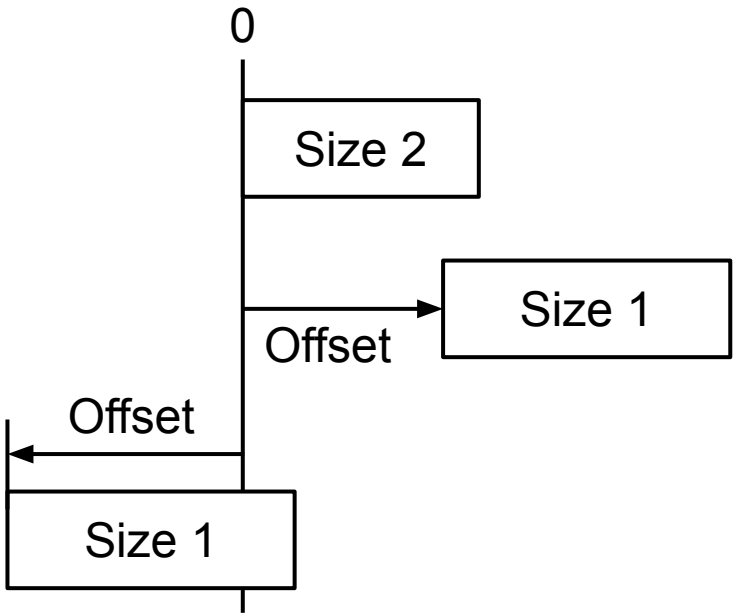


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-Offset >= Size 1

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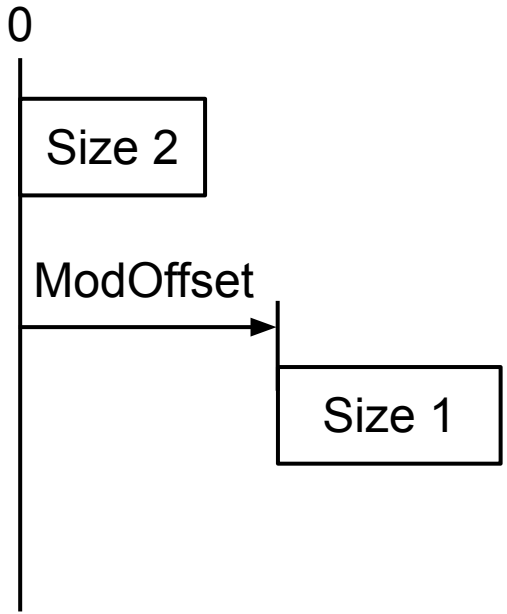

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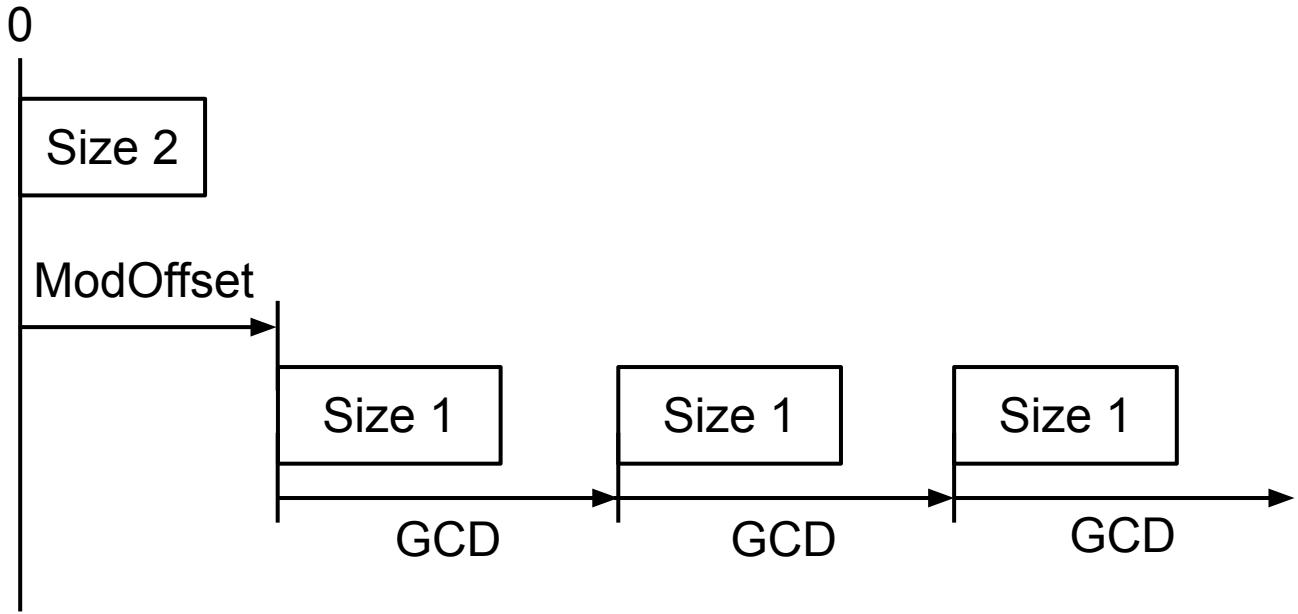




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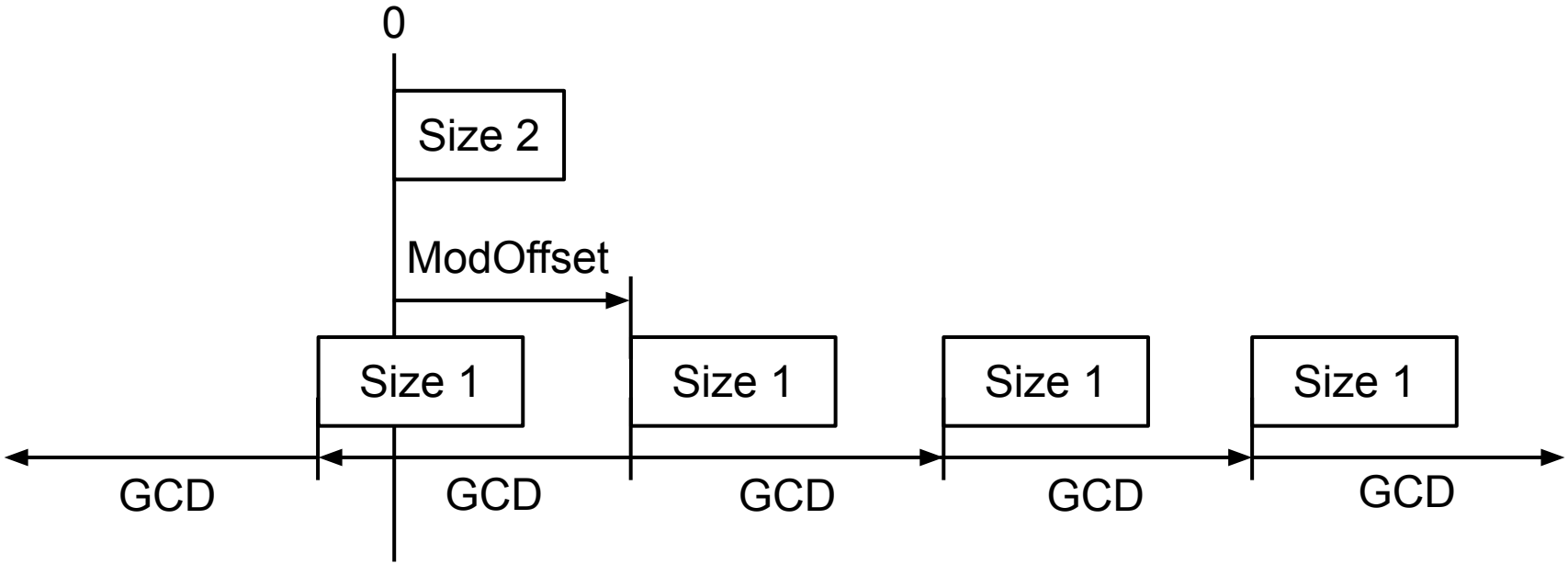




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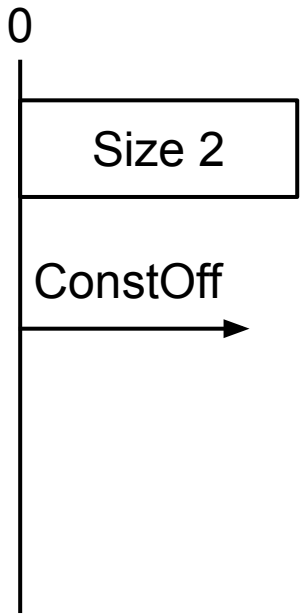

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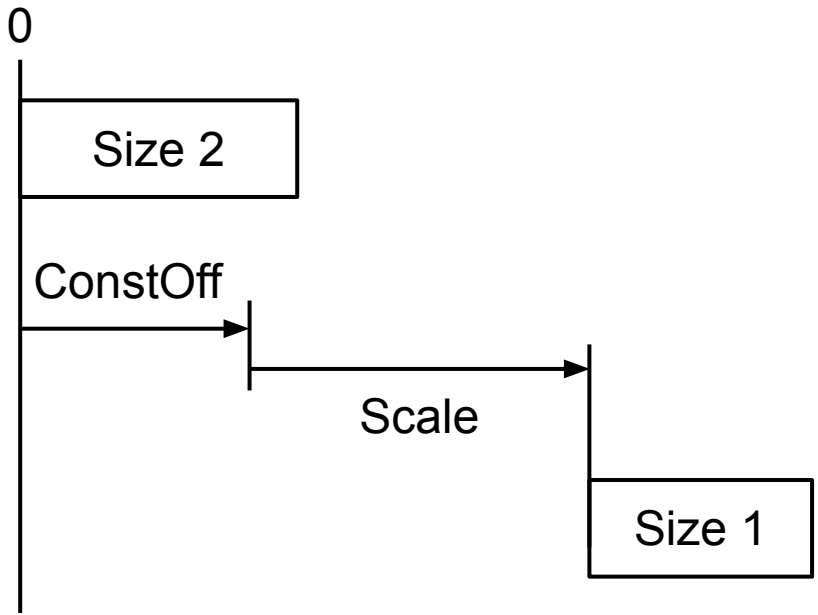

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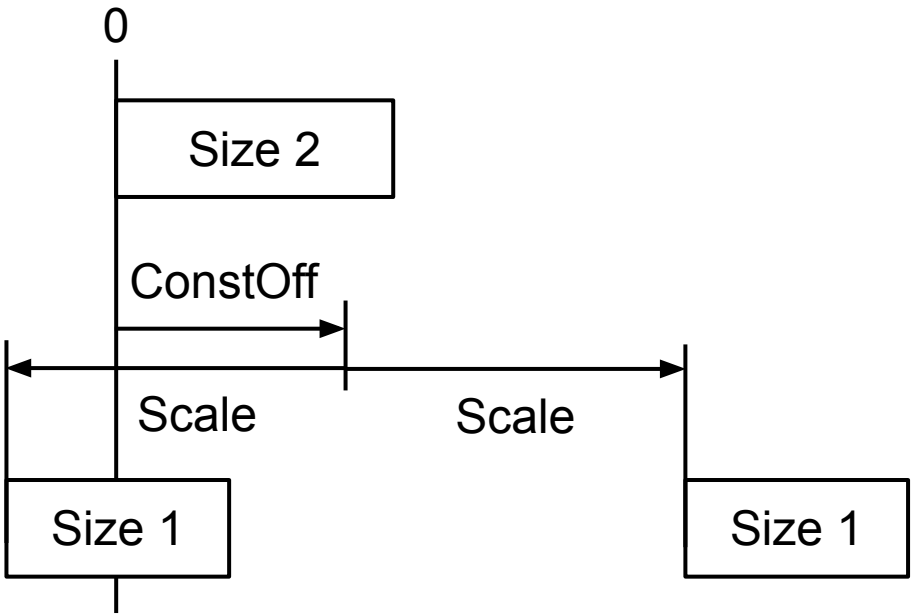

# BasicAA: Offset based reasoning

- Real implementation is more complicated
- Reason: Overflow
- Careful tracking of inbounds, nuw, nsw and negations

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- LoopAccessAnalysis (LAA)
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  - Main user: Loop vectorization
- DependenceAnalysis
  - Like LAA, but can reason about nested loops / multi-dimensional accesses
  - No current users in default pipeline
  - Work in progress to fix correctness issues

# MemorySSA

- Memory versioning
- NewVersion = MemoryDef(PreviousVersion)
- NewVersion = MemoryPhi({block,PreviousVersionInBlock}, ...)
- MemoryUse(DepVersion)

# MemorySSA

```
define void @test(i1 %c, ptr %p) {          ; -passes='print<memoryssa><no-ensure-optimized-uses>'
entry:
 %a = alloca i32, align 4
 ; 1 = MemoryDef(liveOnEntry)
 store i32 1, ptr %a, align 4
 br i1 %c, label %if, label %join

if:
 ; 2 = MemoryDef(1)
 store i32 0, ptr %p, align 4
 br label %join

join:
 ; 3 = MemoryPhi({entry,1},{if,2})
 ; MemoryUse(3)
 %load.p = load i32, ptr %p, align 4
 ; MemoryUse(3)
 %load.a = load i32, ptr %a, align 4
 ret void
}
```

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# MemorySSA clobber walker

- getClobberingMemoryAccess(MemoryAccess)
  - Find dominating clobber of any memory read/written by the access (excluding access)
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# Future directions

- Support encoding more aliasing information in IR
  - Full restrict patches
- Improve compile-time
  - And/or our use of the compile-time budget
- Better reasoning about loop-varying pointers
  - SCEVAA exists, but not used. Expensive.

# Thank You!

Questions?