Safely Optimizing Casts between Pointers and Integers

EuroLLVM'19

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Pointers and Integers

	Assembly (x86-64, ARM, ..)	LLVM IR
Pointer	$[0, 2^{64})$	$[0, 2^{64})$ + *provenance*
Integer	$[0, 2^{64})$	$[0, 2^{64})$ + ?

Casting

Miscompilation w/ Int-Ptr Casting

Wrong if integer carries provenance

```
char p[1],q[1]={0};
int ip = (int)(p+1);
int iq = (int)q;
if (iq == ip) {
  *(char*)iq = 10;
  print(q[0]);
}
```

int. eq. prop.

```
char p[1],q[1]={0};
int ip = (int)(p+1);
int iq = (int)q;
if (iq == ip) {
  *(char*)(int)(p+1)=10;
  print(q[0]);
}
```

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Wrong if integer doesn't carry prov.

cast elim.

```
char p[1],q[1] = {0};
int ip = (int)(p+1);
int iq = (int)q;
if (iq == ip) {
  *(p+1) = 10;
  print(q[0]);
}
```

constant prop.

```
char p[1],q[1] = {0};
int ip = (int)(p+1);
int iq = (int)q;
if (iq == ip) {
  *(p+1) = 10;
  print(0);
}
```

Our Suggestion

- Provenance makes integer optimizations hard to explain.

```
r = (i + j) - k   ⇔   r = i + (j - k)
```
prov. + prov.? / prov. – prov.?

```
r = (int)(float)j   ⇨   r = j
```
provenance in float types?

	Assembly (x86-64, ARM, ..)	LLVM IR
Pointer	$[0, 2^{64})$	$[0, 2^{64})$ + *provenance*
Integer	$[0, 2^{64})$	$\mathbf{[0, 2^{64})}$

- **OOPSLA'18, Reconciling High-level Optimizations and Low-level Code in LLVM**

Proposed Semantics

```
ptrtoint (addr, prov)   := addr
inttoptr (addr)         := (addr, full)
```

How to Block 'Guessed Access'

```
char p = 0;
f();   *(char*)(0x100)=1;
print(p);
```

```
char p = 0;
f();
print(0);
```

- Even if &**p** is **0x100, f()** shouldn't update **p** to **1**
- We define that each allocation creates 2 blocks
  1. **p** creates two blocks **0x100**, **0x200**
  2. One of them (e.g. **0x100**) is nondet. Invalidated
  3. Now we start twin-execution by run the following code
  4. Guessed access like **f()** raises UB in one of them

Performance Issue

Problem

- (char*)(int)p → p removes 13% of ptrtoints, 40% of inttoptrs from SPEC2017rate+test-suite
- Disabling it hurts performance

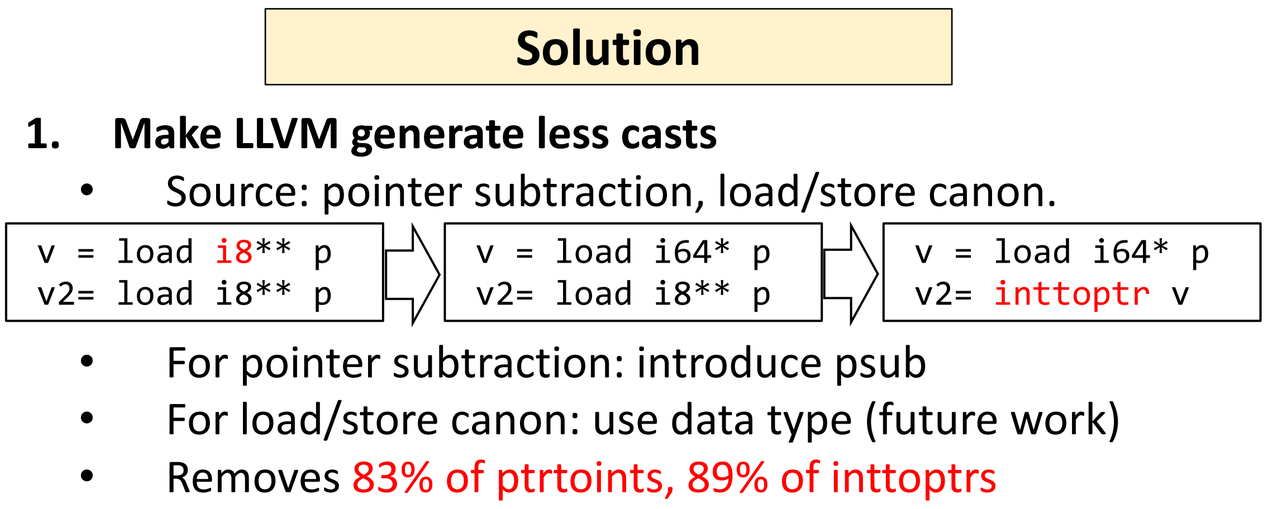
Solution

1. **Make LLVM generate less casts**
   - Source: pointer subtraction, load/store canon.

```
v = load i8** p          v = load i64* p          v = load i64* p
v2= load i8** p    ⇨     v2= load i8** p    ⇨     v2= inttoptr v
```

   - For pointer subtraction: introduce psub
   - For load/store canon: use data type (future work)
   - Removes 83% of ptrtoints, 89% of inttoptrs
2. **Conditionally perform cast elimination if sound**
   - icmp (i2p (p2i p)), q → icmp p, q if prov(p)=prov(q)
   - … (list available at github.com/aqjune/eurollvm19)

Evaluation



Performance Change of SPEC2017rate

- Implemented on LLVM 8.0
- SPEC2017rate: <0.2% slowdown
- LLVM test-suite: 0.1% avg slowdown
- https://github.com/aqjune/eurollvm19