Lecture 10
Pointer Analysis

1. Datalog
2. Context-insensitive, flow-insensitive pointer analysis
3. Context sensitivity

Readings: Chapter 12

Pointer Analysis to Improve Security

- Top web application security vulnerabilities
  - SQL injection, cross-site scripting
- User input accessing databases
- Information flow analysis (taint analysis)
- Sound analysis that found errors in 8 out of 9 apps

PQL

p_1 = *req*.getParameter ( );
stmt.executeQuery (p_2);

p_1 and p_2 point to same object?
Pointer alias analysis

Automatic Analysis Generation

Programmer:
Security analysis
in 10 lines

PQL

Compiler writer:
Ptr analysis
in 10 lines

Datalog

bddbddb
(**BDD**-**b**ased
deductive **d**ata**b**ase)
with
Active Machine Learning

1000s of lines
1 year tuning

BDD operations

BDD: 10,000s-lines library

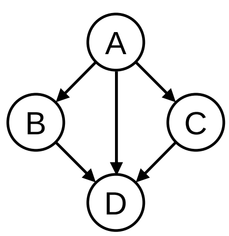
Goals of the Lecture

- Pointer analysis
  - Interprocedural, context-sensitive, flow-insensitive
    (Dataflow: intraprocedural, flow-sensitive)
- Power of languages and abstractions
- Elegant abstractions
  - Logic programming
  - BDDs: Binary decision diagrams
    (Most-cited CS paper a few years ago)

1. Datalog Basics

- $p(X_1, X_2, \ldots X_n)$
  - p is a predicate
  - $X_1, X_2, \ldots X_n$ are terms such as variables or constants
- A predicate can be viewed as a relation

Example: Call graph edges Predicate vs. Relation



calls(A,B)
calls(A,C)
calls(A,D)
calls(B,D)
calls(C,D)

Predicates

- Calls (x,y): x calls y is true
- Ground atoms: predicates with constant arguments

Relations

- Calls (x,y) : x, y is in a “calls” relationship
- Extensional database: tuples representing facts

Datalog Programs: Set of Rules (Intensional DB)

- H :- B_1 & B_2 … & B_n
- LHS is true if RHS is true
  - Rules define the intensional database
- Example: Datalog program to compute call*
  - transitive closure of calls relation
  - calls*(*x*, *y*) if *x* calls *y* directly or indirectly
  - calls* (*x*, *y*) :- calls (*x*, *y*)
  - calls* (*x*, *z*) :- calls* (*x*, *y*) & calls* (*y*, *z*)
- Result:
  - set of ground atoms inferred by applying the rules until no new inferences can be made

Datalog vs. SQL

- SQL
  - Imperative programming:
    - join, union, projection, selection
  - Explicit iteration
- Datalog: logical database language
  - Declarative programming
  - Recursive definition: fixpoint computation
  - Negation can lead to oscillation
  - Stratified: only negate one “stratum” at a time

2. Flow-insensitive Points-to Analysis

- Alias analysis:
  - Can two pointers point to the same location?
  - *a, *(a+8)
- Points-to analysis:
  - What objects does each pointer points to?
  - Two pointers cannot be aliased
    if they must point to different objects

How to Name Objects?

- Objects are dynamically allocated
- Use finite names to refer to unbounded # objects
- 1 scheme: Name an object by its allocation site

```
main () {            f () {
    p = f();             A: a = new O ();
    q = f();             B: b = new O ();
}                        return a;
                     }
```

Points-To Analysis for Java

- Variables ($v \in V$): local variables in the program
- Heap-allocated objects ($h \in H$)
  - has a set of fields ($f \in F$)
  - named by allocation site

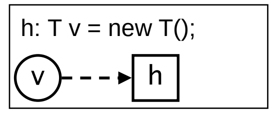
Program Abstraction

- Allocations h: v = new c
- Store $v_1.f = v_2$
- Loads $v_2 = v_1.f$
- Moves, arguments: $v_1 = v_2$
- Assume: a (conservative) call graph is known a priori
  - Call: formal = actual
  - Return: actual = return value

Pointer Analysis Rules

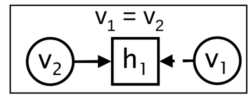
Object creation

pts(v, h) :- “h: T v = new T()”.



Assignment

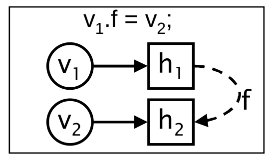
$pts(v_1, h_1)$:- “$v_1 = v_2$” & $pts(v_2, h_1)$.



Store

$hpts(h_1, f, h_2)$:- “$v_1.f = v_2$” &

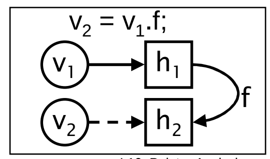
$pts(v_1, h_1)$ & $pts(v_2, h_2)$.



Load

$pts(v_2, h_2)$:- “$v_2 = v_1.f$” &

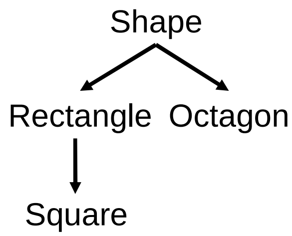
$pts(v_1, h_1)$ & $hpts(h_1, f, h_2)$.



Pointer Alias Analysis

- Specified by a few Datalog rules
  - Creation sites
  - Assignments
  - Stores
  - Loads
- Apply rules until they converge

Virtual Method Invocation




```
void draw (shape s)  {
      int i = s.lines();
      …
}
```

- Class hierarchy analysis cha (t, n, m)
  - Given an invocation v.n (…), if v points to object of type t, then m is the method invoked
  - t's first superclass that defines n

Pointer Analysis Can Improve Call Graphs

Discover points-to results and methods invoked on the fly

hType (h, t): h has type t

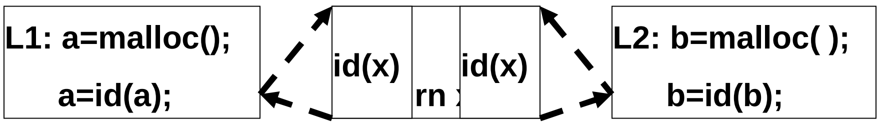
actual (s, i, v): v is the ith actual parameter in call site s.

formal (m, i, v): v is the ith formal parameter declared in method m.

invokes (s, m) :- "s: v.n (…)" & pts (v, h) &
hType (h, t) & cha (t, n, m)

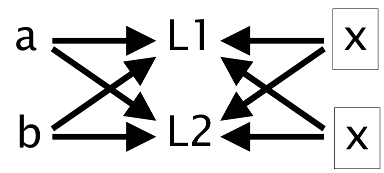
pts(v, h) :- invokes (s, m) &
formal (m, i, v) & actual (s, i, w) &
pts (w, h)

3. Context-Sensitive Pointer Analysis



context-sensitive

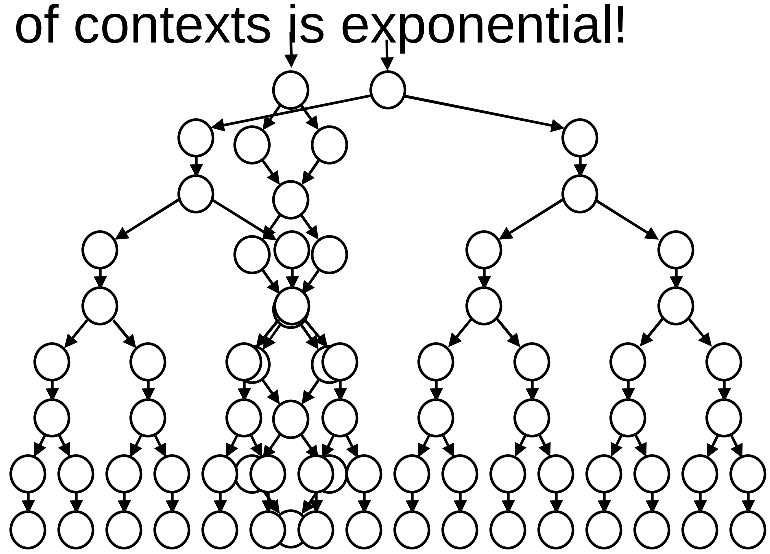
context-insensitive



Advanced Compilers

L10: Pointer Analysis

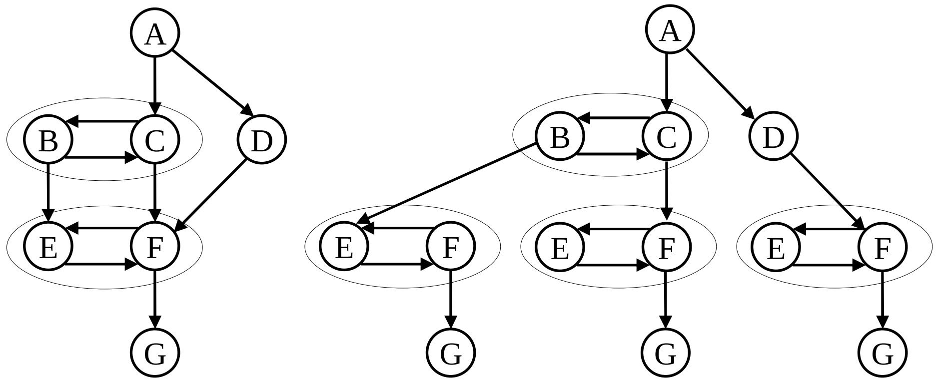
Even without recursion, # of contexts is exponential!



Advanced Compilers

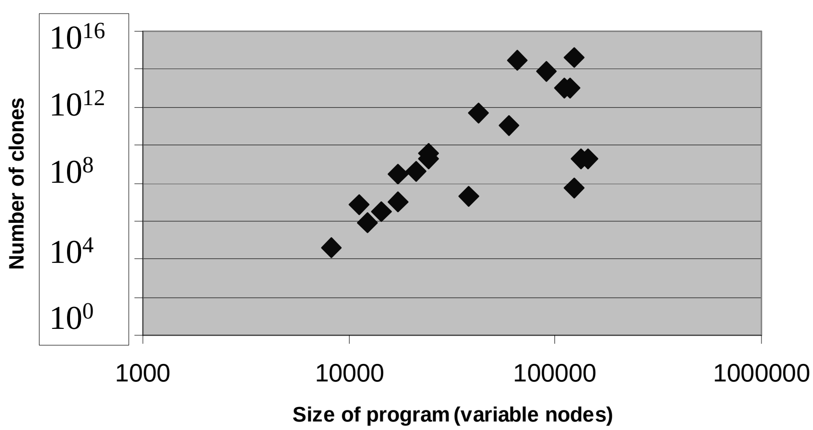
L10: Pointer Analysis

Recursion



Top 20 Sourceforge Java Apps

Number of Clones



Cloning-Based Algorithm

- Whaley&Lam, PLDI 2004 (best paper award)
- Apply the context-insensitive algorithm to the program to discover the call graph
- Find strongly connected components
- Create a “clone” for every context
- Apply the context-insensitive algorithm to cloned call graph
- Lots of redundancy in result
- Exploit redundancy by clever use of BDDs (binary decision diagrams)

Automatic Analysis Generation

Programmer:
Security analysis
in 10 lines

PQL

↓

Compiler Writer:
Ptr analysis in 10 lines

Datalog

↓ **bddbddb**
(**BDD**-**b**ased
deductive **d**ata**b**ase)
with
Active Machine Learning

1000s of lines
1 year tuning

BDD operations

BDD: 10,000s-lines library