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UNIVERSITÄT DES SAARLANDES

Interprocedural Data Flow Analysis

Static Program Analysis

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Interprocedural Reaching Definitions

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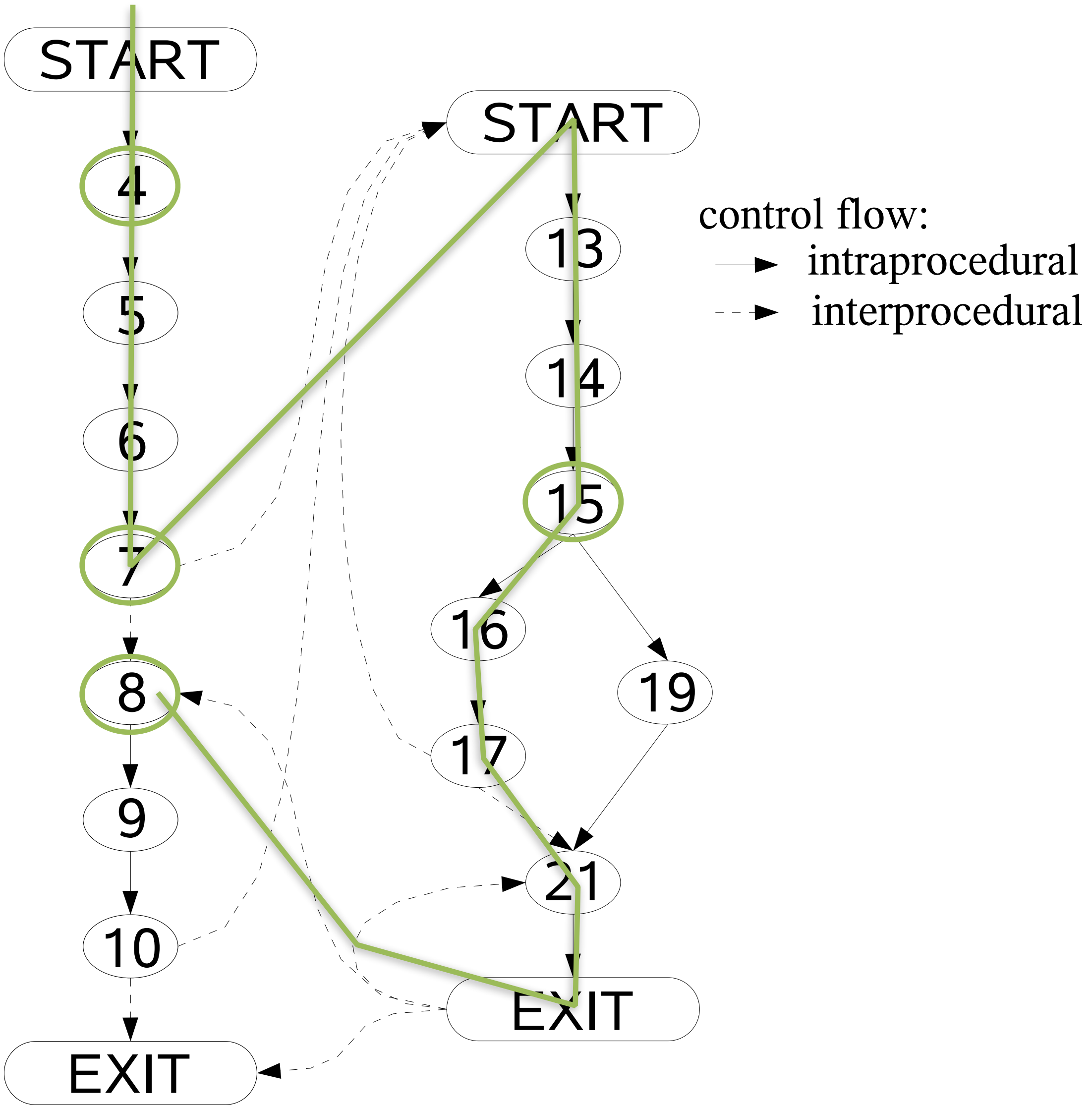
Global Variables

```
(1)  int a, b, c;

(3)  void q () {
(4)    int z=1;
(5)    a=2;
(6)    b=3;
(7)    p(4, z);
(8)    z=a;
(9)    c=5;
(10)   p(6, c);
(11) }

(12) void p(int x,int &y) {
(13)   static int d = 6;
(14)   a=c;
(15)   if(x) {
(16)     d=7;
(17)     p(8, x);
(18)   } else {
(19)     b=9;
(20)   }
(21)   y =0;
(22) }
```

call-by-value

call-by-reference

Interprocedural Control Flow Graph



Analyzing Interprocedural Programs

- $RD_{IMOP}(n) = \bigcup_{p=\langle n^s_0, \ldots , n\rangle} [p](\emptyset)$
- where p are inter procedurally realizable paths (impossible in general)
- interprocedural minimal-fixed-point (IMFP) solution is computed
- However, impossible to check for interprocedurally realizable paths

- Procedures can be inlined
  – replace calls by the called procedure
  – resulting program can be analyzed like an intraprocedural one
  – not possible in the presence of recursion
  – even without the size of the inlined programs may grow exponentially
  – not feasible in practice

Analyzing Interprocedural Programs (cont.)

- Compute effects of procedures
  - represented in a transfer function
  - maps flow information at a call site from the call to the return
  - call statements are ordinary statements with transfer functions
  - intraprocedural techniques can be applied

- Explicit encoding of calling context of a procedure
  - procedure is analyzed for each calling context separately
  - in the presence of recursion the set of calling contexts may be infinite
  - depending on the encoding of the calling context

Effect Calculation

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- functional approach [SP81]
- maps the data flow information at the entry of a procedure to the information that holds at the exit
- computed function can be used in the transfer functions at the call statements
- intraprocedural data flow analysis can then be used in a second pass
- first pass is a data flow analysis where the data flow information are functions and the transfer functions are function compositions
- For some data flow problems the resulting data flow information is infinite function compositions and therefore not computable
- For a large class of data flow problems these computed functions reduce to simple mappings where the composition can be computed instantly

Context Encoding

- call strings capture the “history” of calls that lead to a node n
- abstraction of the call stack
- lattice elements combine calling context and intraprocedural data flow facts
- transfer functions extended to handle the additional calling context
- length of the call strings can be limited to a certain length k
- call string longer than k are shortened such that the “oldest” elements are removed first
- overcomes limitations of recursion
- maybe imprecise

Call Strings

- calling context $c \in C$ encoded through data flow facts that hold at the entry to procedure $p \in P$
- data flow facts c′ at the exit of the procedure stored in mapping $C \times P \rightarrow C$
- At every call node n of a procedure p the data flow facts c are then bound to data flow facts c′ = bind(c) that hold at the entry node of p
- If the effect of p for c′ has already been computed, it can be reused from the mapping which contains the data flow facts c′′ holding at the exit of p
- After back-binding the effect to the call site, the effect $c''' = \text{bind}^{-1}(c'')$ holds at the exit of the call node n

Interprocedural Data Dependence

- Let $G = (N^*, E^*, n^s{}_0, n^e{}_0)$ be an ICFG. A node $m \in N^*$ is data dependent on node $n \in N^*$, if
  - there is an interprocedurally matched path p from n to m in the ICFG,
  - there is a variable v, with $v \in def(n)$ and $v \in ref(m)$, and
  - for all nodes $k \neq n$ of path p, $v \notin def(k)$ holds.

- At call sites the global variables are modeled as call-by-value-result parameters, which is correct without call-by-reference parameters and aliasing
- GMOD(p): the set of all variables that might be modified if procedure p is called.
- GREF(p): the set of all variables that might be referenced if procedure p is called.

Effect Calculation

- $\text{bind}^{-1}(S, p) = S - \text{locals}(p)$
- $\text{GMOD}(n) = \text{bind}^{-1}(\text{GMOD}(p))$
- $\text{GREF}(n) = \text{bind}^{-1}(\text{GREF}(p))$

- $\text{GMOD}(q) = \text{IMOD}(q) \cup \bigcup_{p \in \text{calls}(q)} \text{bind}^{-1}(\text{GMOD}(p), p)$
- $\text{GREF}(q) = \text{IREF}(q) \cup \bigcup_{p \in \text{calls}(q)} \text{bind}^{-1}(\text{GREF}(p), p)$

- $\text{def}(n) = \text{GMOD}(n)$
- $\text{ref}(n) = \text{GMOD}(n) \cup \text{GREF}(n)$

Example Interprocedural Data Dependences

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