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UNIVERSITÄT DES SAARLANDES

Interprocedural Data Flow Analysis

Static Program Analysis

Christian Hammer

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Interprocedural Reaching Definitions

```
int a, b, c;

void q () {
  int z=1;
  a=2;
  b=3;
  p(4, z);
  z=a;
  c=5;
  p(6, c);
}
```

```
void p(int x,int &y) {
  static int d = 6;
  a=c;
  if(x) {
    d=7;
    p(8, x);
  } else {
    b=9;
  }
  y =0;
}
```

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Interprocedural Reaching Definitions

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(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 Reaching Definitions

Global Variables

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

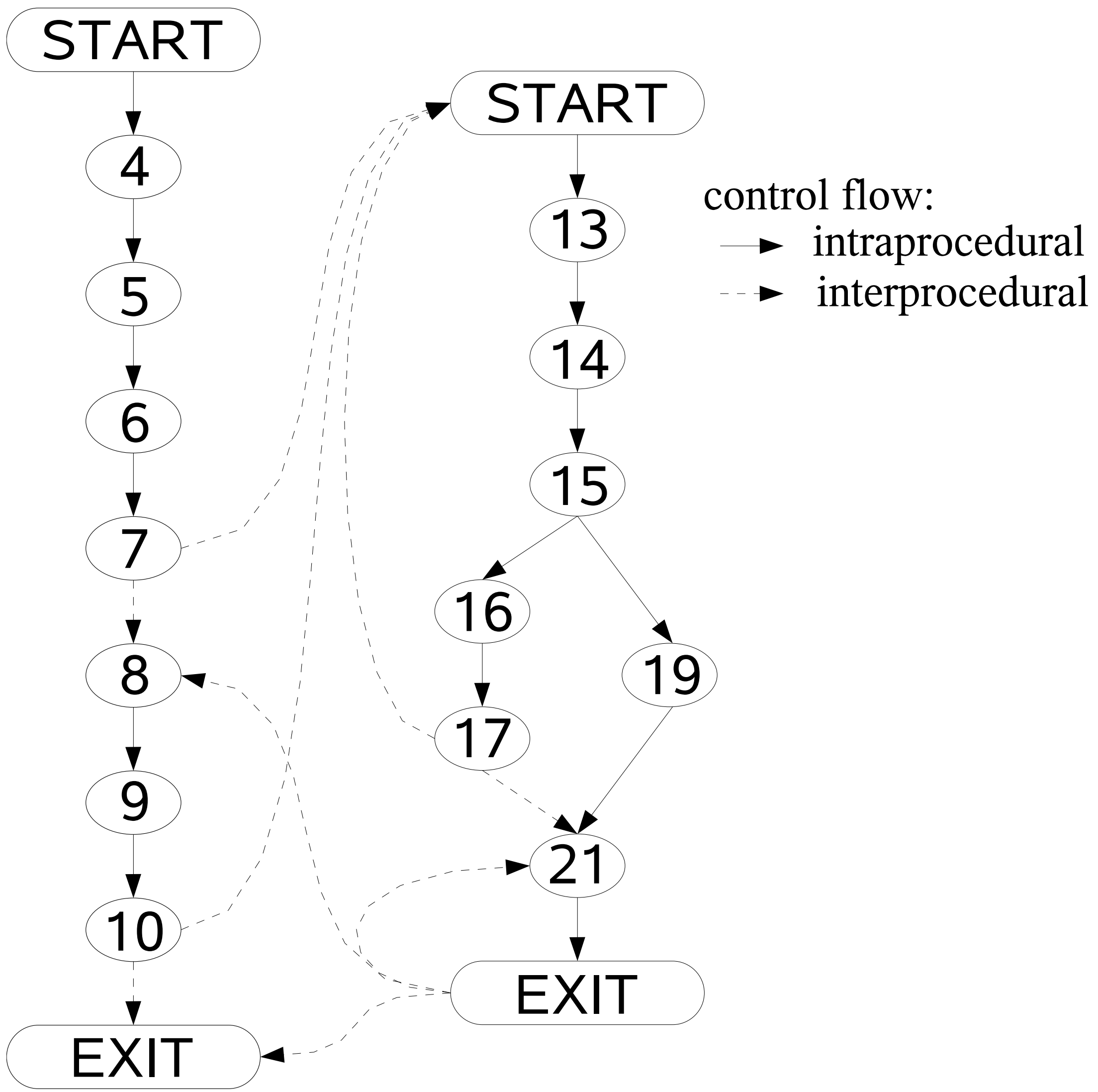
(3)  void q () {
(4)    int z=1;
(5)    a=2;
(6)    b=3;
(7)    p(4, z);
(8)    z=a;
(9)    c=5;
(10)   p(6, c);
(11) }
```

```
(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) }
```

- definition of a (line 5) reaches 6–7 but not 8–11 (killed by 14 through call in 7), also reaches 13–14 but not 15–22
- definition of c in line 9 reaches 13–22 through call in line 10.

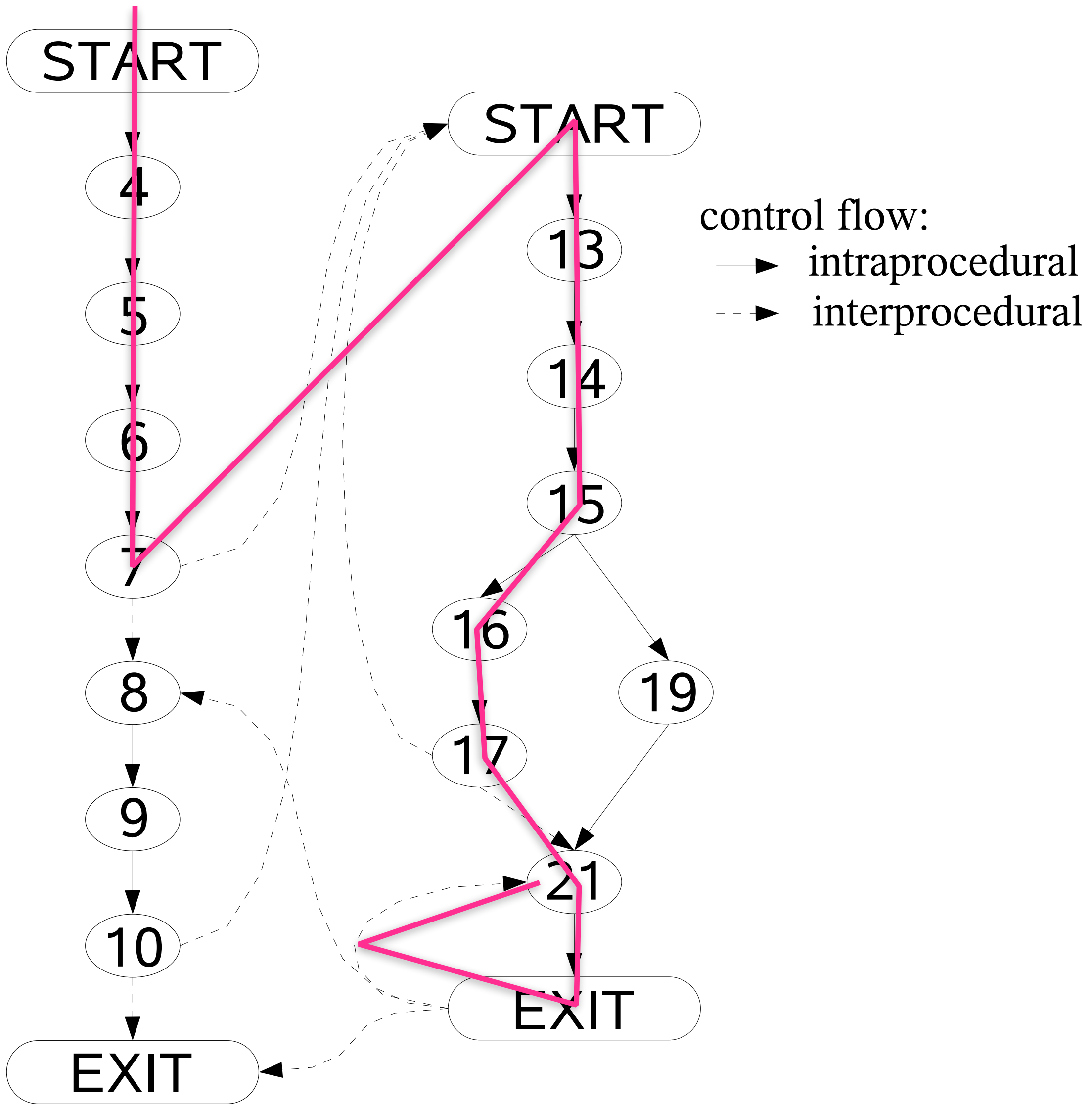
- More complex are the definitions of global b: the definition in line 6 can- not reach lines 8–10 or 21, as line 19 kills it —any call of p must execute line 19 to terminate the recursion. Also, the definition in line 19 reaches line 13–19, as it might reach the call in line 10 by procedure p returning from the call in line 7.
- The variable d is global and only visible inside procedure p. the definition in line 16 may reach lines 13–16 because of the call in line 17. Through procedure p returning from the call in line 7, both definitions (line 13 and 16) may reach lines 8–10 and therefore also line 13–16 and 18–22.
- Locals like z are (usually) only visible in procedures they are defined in. Call-by-value parameters are like locals, with a definition at the proce- dure entry: x is defined in line 12.
- Call-by-reference introduces a simple form of aliasing and make other- wise invisible variables available in called procedures.

Interprocedural Control Flow Graph



- *Control Flow Graph* $G_p = (N_p, E_p, n^s{}_p, n^e{}_p)$ for each procedure *p*. An interprocedural control flow graph (ICFG) is a directed graph $G = (N^*, E^*, n^s{}_0, n^e{}_0)$, where $N^* = \bigcup_p N_p$ and $E^* = E^C \cup \bigcup_p E_p$
- *call* and *return edges* in E^C: A call edge e $\in E^C$ is going from a call node $n \in N_p$ to the START node $n^s{}_q$ of the called procedure q. A return edge e $\in E^C$ is going from the EXIT node $n^e{}_q$ of the called procedure q back to the immediate successor of the call node $n \in N_p$
- *unrealizable paths* possible if leaving a function on a different node than the call's successor

Interprocedural Control Flow Graph



Inter-procedurally Realizable Path

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Edges from E_p are marked with the empty word ε and edges from E^C are marked according to their source and target nodes

return edge

entry node

$$
\begin{aligned}
M &\rightarrow MM \\
&\mid\ (^{n_p^s}_{m}\, M\,)^{n_p^s}_{m} \qquad \forall (^{n_p^s}_{m} \in \Sigma \\
&\mid\ \epsilon
\end{aligned}
$$

call edge

call node

$$
\begin{aligned}
R &\rightarrow MR \\
&\mid\ (^{n_p^s}_{m}\, R \qquad \forall (^{n_p^s}_{m} \in \Sigma \\
&\mid\ \epsilon
\end{aligned}
$$

$$
\begin{aligned}
L &\rightarrow LM \\
&\mid\ L\,)^{n_p^s}_{m} \qquad \forall (^{n_p^s}_{m} \in \Sigma \\
&\mid\ \epsilon
\end{aligned}
$$

$$
\begin{aligned}
I &\rightarrow L \\
&\mid\ R
\end{aligned}
$$

An interprocedurally realizable path I is an interprocedurally right- or left-balanced path.

Interprocedural Reachability, Witness

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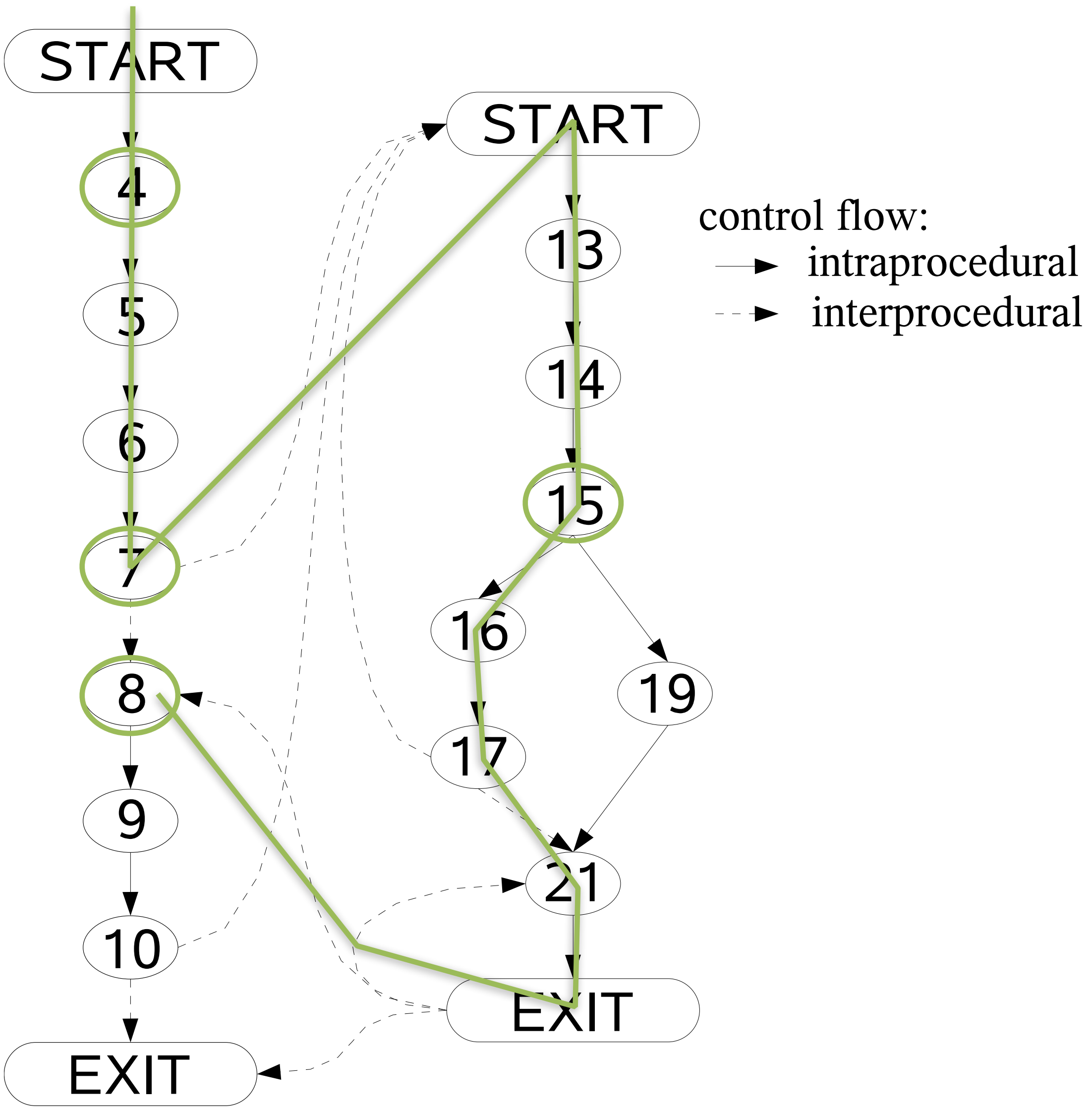
- A node n is interprocedurally reachable from node m, iff an interprocedurally realizable path from m to n in the ICFG exists, written as $m \rightharpoonup^*_R n$.
- A sequence $\langle n_1, \ldots, n_k \rangle$ of nodes is called an interprocedurally (realizable) witness, iff n_k is interprocedurally reachable from n_1 via an interprocedurally realizable path $p = \langle m_1, \ldots, m_l \rangle$ with:
  - $m_1 = n_1$, $m_l = n_k$, and
  - $\forall 1 \leq i < k\ \exists x,y\colon x<y \wedge m_x = n_i \wedge m_y = n_i + 1$.

Interprocedural Control Flow Graph



Interprocedural Control Flow Graph