Lab: SVFIR and Control-Flow Reachability

(Week 2)

Yulei Sui

School of Computer Science and Engineering

University of New South Wales, Australia

Quiz-1 + Lab-Exercise-1 + Assignment-1

- A set of quizzes on WebCMS (5 points) due on **Week 3 Tuesday 23:59**
  - LLVM compiler and its intermediate representation
  - Code graphs (including ICFG and PAG)
- Lab-Exercise-1 (5 points) due on **Week 3 Tuesday 23:59**
  - Implement a graph traversal on a general graph
- Assignment-1 (20 points) due on **Week 4 Tuesday 23:59**
  - **Control-flow**: Implement a context-sensitive graph traversal on a CodeGraph (i.e., ICFG) and collect **feasible** paths from a source to a sink node on the ICFG.
  - **Data-flow**: Implement field-sensitive Andersen's inclusion-based constraint solving for points-to analysis
  - Implement a taint checker **using control-flow and data-flow analysis**.

Quiz-1 + Lab-Exercise-1 + Assignment-1

- A set of quizzes on WebCMS (5 points) due on **Week 3 Tuesday 23:59**
  - LLVM compiler and its intermediate representation
  - Code graphs (including ICFG and PAG)
- Lab-Exercise-1 (5 points) due on **Week 3 Tuesday 23:59**
  - Implement a graph traversal on a general graph
- Assignment-1 (20 points) due on **Week 4 Tuesday 23:59**
  - **Control-flow**: Implement a context-sensitive graph traversal on a CodeGraph (i.e., ICFG) and collect **feasible** paths from a source to a sink node on the ICFG.
  - **Data-flow**: Implement field-sensitive Andersen's inclusion-based constraint solving for points-to analysis
  - Implement a taint checker **using control-flow and data-flow analysis**.
  - **Specification and code template**: `https://github.com/SVF-tools/Software-Security-Analysis/wiki/Assignment-1`
  - **SVF APIs for control- and data-flow analysis** `https://github.com/SVF-tools/Software-Security-Analysis/wiki/SVF-API`

Understanding LLVM-IR and SVF-IR

- (1) Compile C programs under `SVFIR/src` into their LLVM IR and print their SVF IR (PAG, ICFG, Constraint Graph).
  - `https://github.com/SVF-tools/Software-Security-Analysis/wiki/SVFIR`
  - Understand the mapping from a C program to its corresponding LLVM IR
  - Understand the mapping from LLVM IR to its corresponding SVF IR
- (2) Generate and visualize the graph representation of SVF IR (e.g., `example.ll.pag.dot`, `example.ll.icfg.dot`, `consG.ll.dot`).
  - `https://github.com/SVF-tools/Software-Security-Analysis/wiki/SVFIR#4-visualize-icfg-constraint-graph-and-svfirpag-graph`
- (3) Write code to iterate SVFVars and print nodes/edges of PAG and ICFG.
  - `https://github.com/SVF-tools/Software-Security-Analysis/blob/main/SVFIR/SVFIR.cpp#L74-L98` (C++)
  - `https://github.com/SVF-tools/SVF-Python/tree/main/demo` (Python)
- (4) More about LLVM IR and SVF's graph representation
  - LLVM language manual `https://llvm.org/docs/LangRef.html`
  - SVF website `https://github.com/SVF-tools/SVF`

Context-Sensitive Control-Flow Reachability (Algorithm)

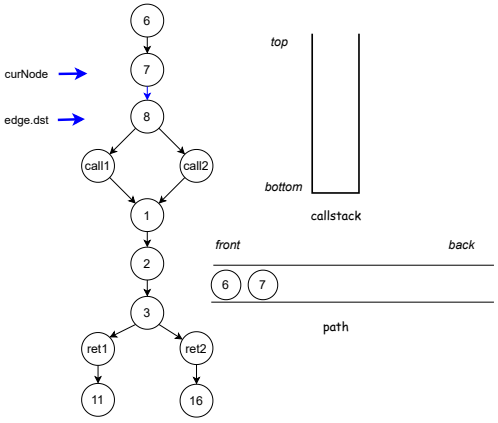
Algorithm 1: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



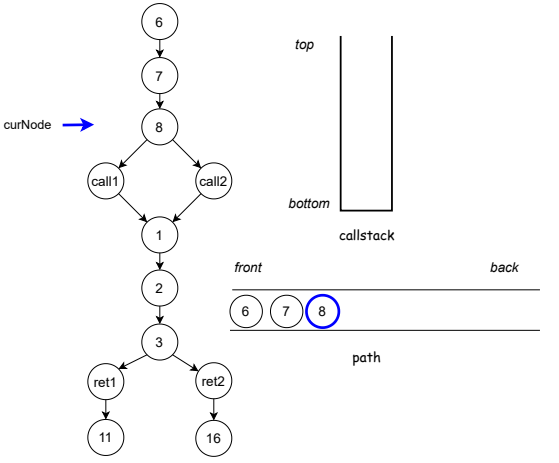
Algorithm 2: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

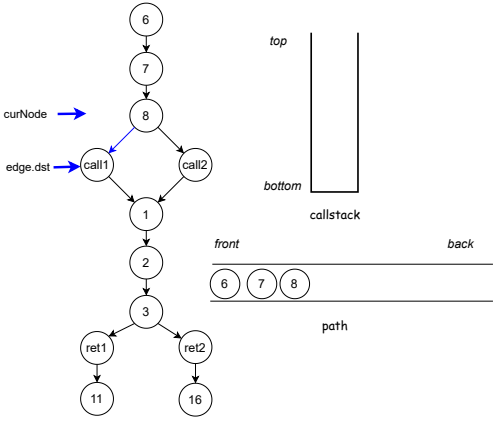


Algorithm 3: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode   snk : ICFGNode   path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩   visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4        return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8        collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10       if edge.isIntraCFGEdge() then
11           dfs(edge.dst, snk);
12       else if edge.isCallCFGEdge() then
13           callstack.push_back(edge.getCallSite());
14           dfs(edge.dst, snk);
15           callstack.pop_back();
16       else if edge.isRetCFGEdge() then
17           if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18               callstack.pop_back();
19               dfs(edge.dst, snk);
20               callstack.push_back(edge.getCallSite());
21           else if callstack == ∅ then
22               dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



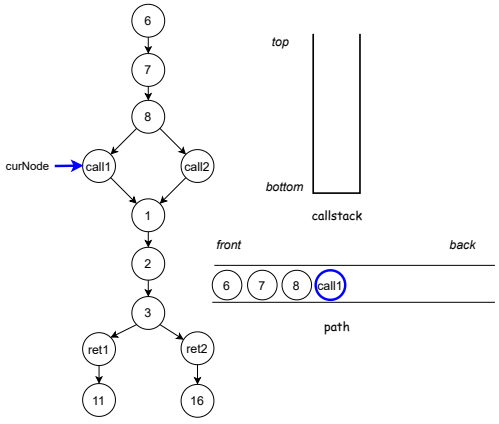
Algorithm 4: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

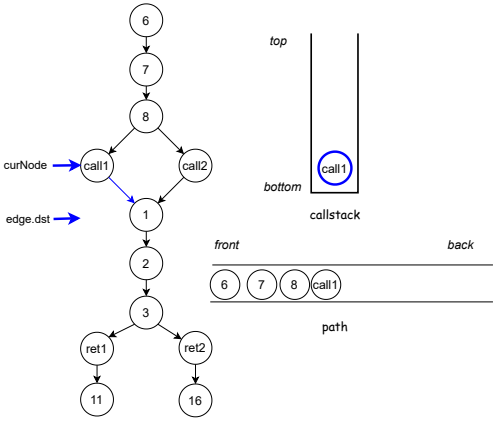


Algorithm 5: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode   snk : ICFGNode   path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩   visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



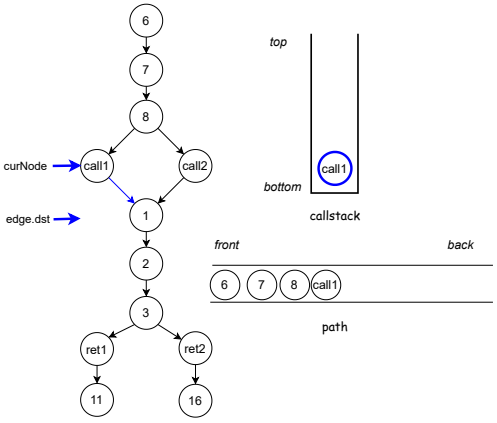
Algorithm 6: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



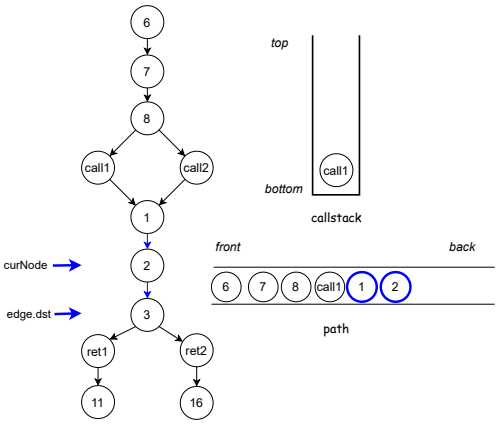
Algorithm 7: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



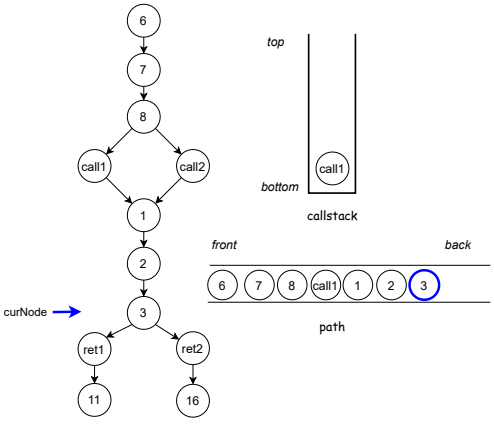
Algorithm 8: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

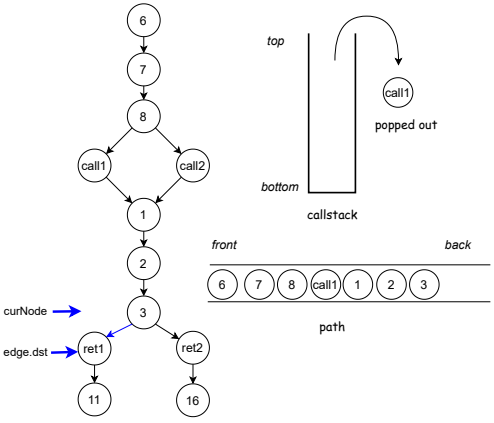


Algorithm 9: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode   snk : ICFGNode   path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩   visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



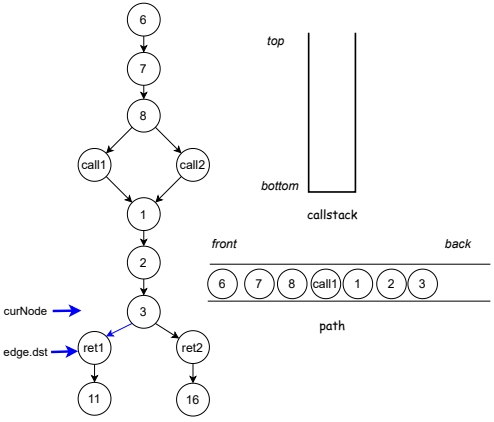
Algorithm 10: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



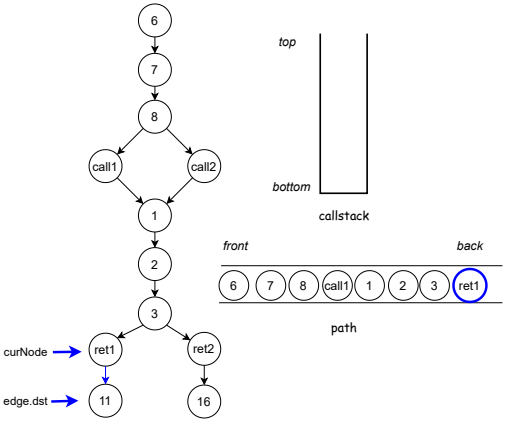
Algorithm 11: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

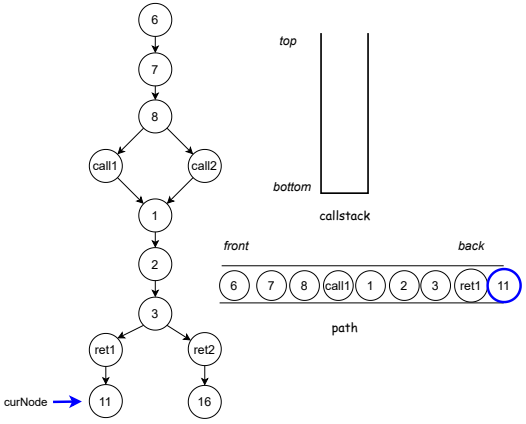


Algorithm 12: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode  snk : ICFGNode  path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩  visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

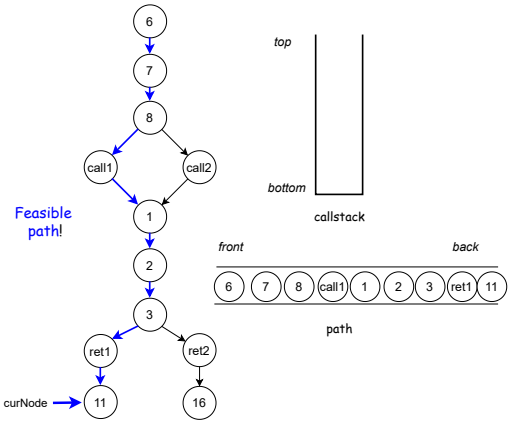


Algorithm 13: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode   snk : ICFGNode   path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩   visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4        return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8        collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10       if edge.isIntraCFGEdge() then
11           dfs(edge.dst, snk);
12       else if edge.isCallCFGEdge() then
13           callstack.push_back(edge.getCallSite());
14           dfs(edge.dst, snk);
15           callstack.pop_back();
16       else if edge.isRetCFGEdge() then
17           if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18               callstack.pop_back();
19               dfs(edge.dst, snk);
20               callstack.push_back(edge.getCallSite());
21           else if callstack == ∅ then
22               dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



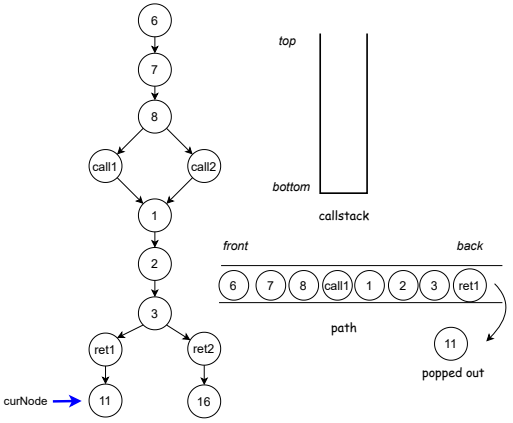
Algorithm 14: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



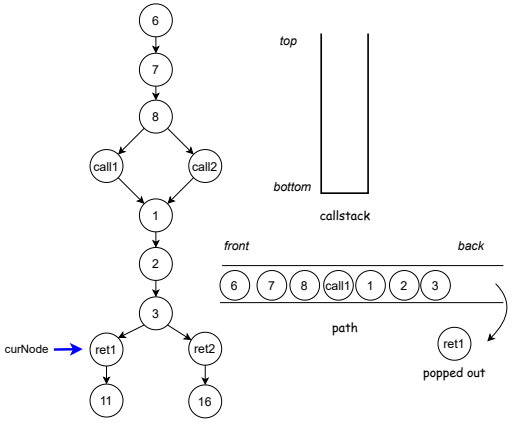
Algorithm 15: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



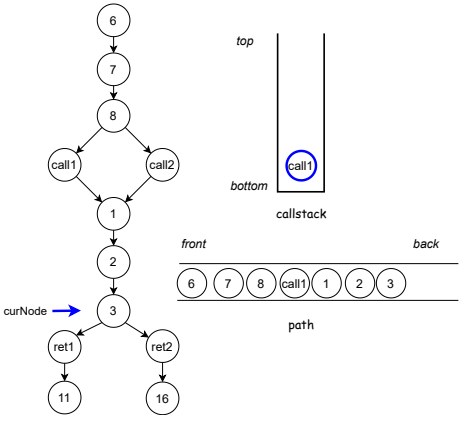
Algorithm 16: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



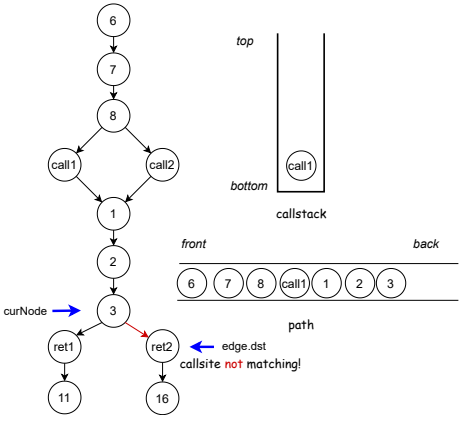
Algorithm 17: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



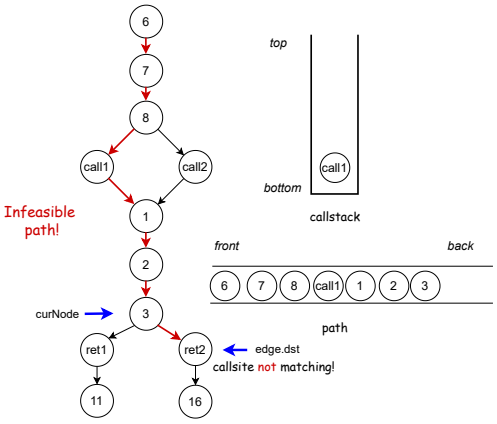
Algorithm 18: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



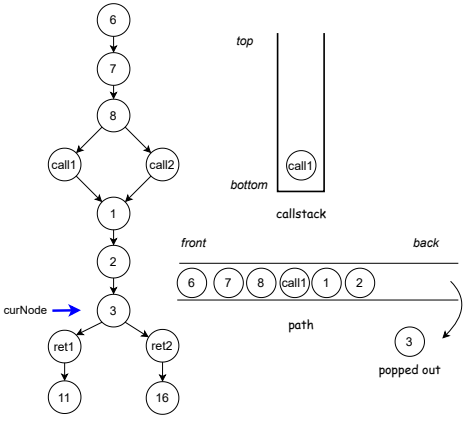
Algorithm 19: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



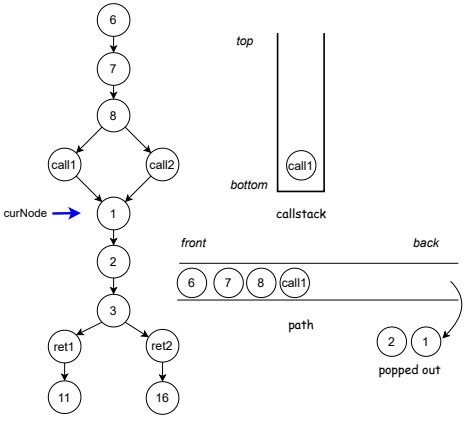
Algorithm 20: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



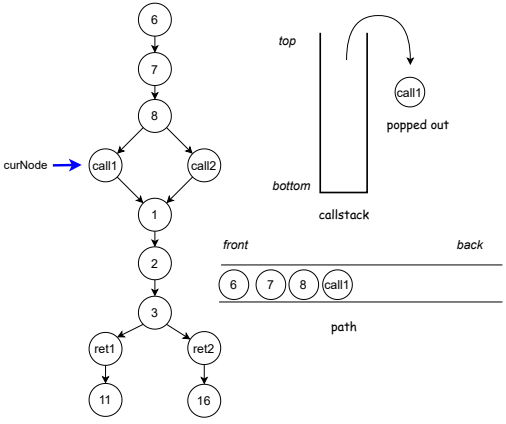
Algorithm 21: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

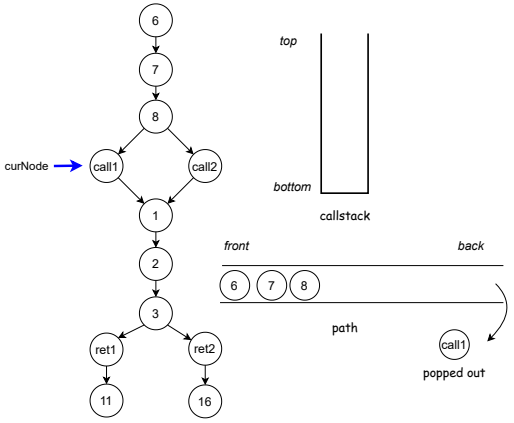


Algorithm 22: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode  snk : ICFGNode  path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩  visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



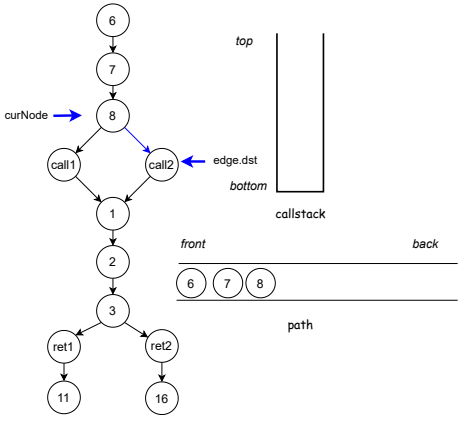
Algorithm 23: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG



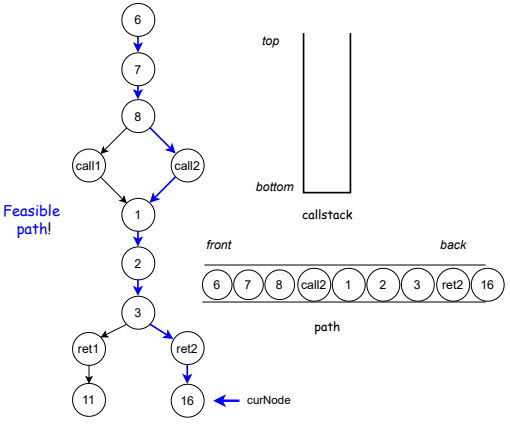
Algorithm 24: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

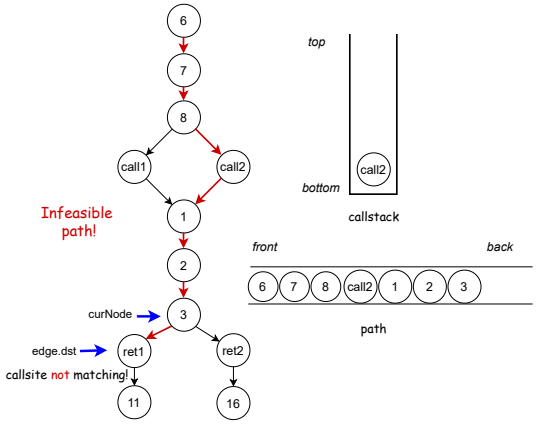


Algorithm 25: 1 Context sensitive control-flow reachability

```
Input : curNode : ICFGNode  snk : ICFGNode  path : vector⟨ICFGNode⟩
        callstack : vector⟨SVFInstruction⟩  visited : set⟨ICFGNode, callstack⟩;
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

Context-Sensitive Control-Flow Reachability

A feasible path from node 6 to node 11 on ICFG

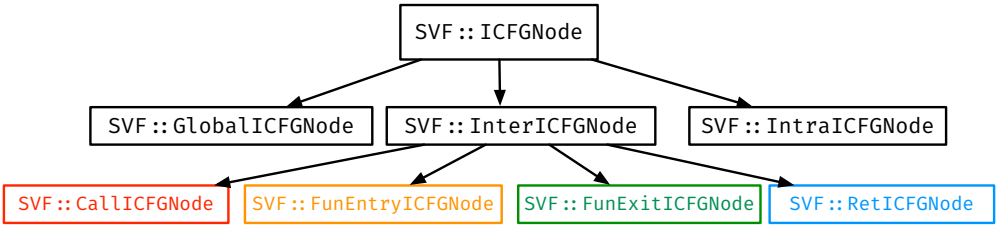


Algorithm 26: 1 Context sensitive control-flow reachability

Input : curNode : ICFGNode snk : ICFGNode path : vector⟨ICFGNode⟩
callstack : vector⟨SVFInstruction⟩ visited : set⟨ICFGNode, callstack⟩;

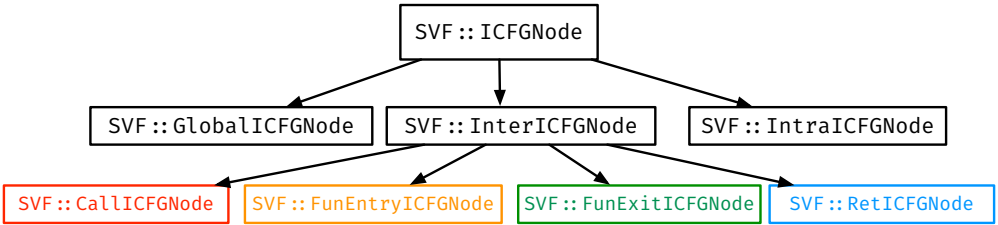
```
1  dfs(curNode, snk)
2    pair = ⟨curNode, callstack⟩;
3    if pair ∈ visited then
4      return;
5    visited.insert(pair);
6    path.push_back(curNode);
7    if src == snk then
8      collectICFGPath(path);
9    foreach edge ∈ curNode.getOutEdges() do
10     if edge.isIntraCFGEdge() then
11       dfs(edge.dst, snk);
12     else if edge.isCallCFGEdge() then
13       callstack.push_back(edge.getCallSite());
14       dfs(edge.dst, snk);
15       callstack.pop_back();
16     else if edge.isRetCFGEdge() then
17       if callstack ≠ ∅ && callstack.back() == edge.getCallSite() then
18         callstack.pop_back();
19         dfs(edge.dst, snk);
20         callstack.push_back(edge.getCallSite());
21       else if callstack == ∅ then
22         dfs(edge.dst, snk);
23   visited.erase(pair);
24   path.pop_back();
```

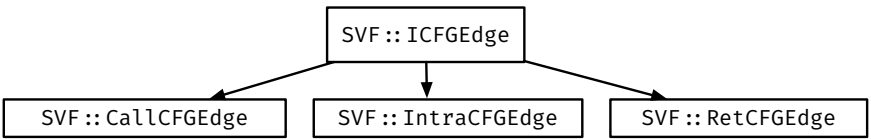
ICFG Node and Edge Classes



https://github.com/SVF-tools/SVF/blob/master/include/Graphs/ICFGNode.h

ICFG Node and Edge Classes





https://github.com/SVF-tools/SVF/blob/master/include/Graphs/ICFGEdge.h

`SVFUtil::cast` and `SVFUtil::dyn_cast`

- C++ Inheritance: see slides in Week 1 Lab.
- Casting a **parent** class pointer to pointer of a **Child** type:
  - `SVFUtil::cast`
    - Casts a pointer or reference to an instance of a specified class. This cast fails and aborts the program if the object or reference is not the specified class at runtime.
  - `SVFUtil::dyn_cast`
    - "Checked cast" operation. Checks to see if the operand is of the specified type, and if so, returns a pointer to it (this operator does not work with references). If the operand is not of the correct type, a null pointer is returned.
    - Works very much like the dynamic_cast<> operator in C++, and should be used in the same circumstances.
- Example: accessing the attributes of the child class via casting.
  - `RetICFGNode* retNode = SVFUtil::cast<RetICFGNode>(ICFGNode);`
  - `CallCFGEdge* callEdge = SVFUtil::dyn_cast<CallCFGEdge>(ICFGEdge);`

“Casting” from Parent to Child in Python

- Python is a **dynamically typed language**:
  - No cast is required to call a method or access an attribute of an object.
  - A method can be called without declaring the object’s type in code, as long as the object is of the correct type at runtime.
- **Dynamic Typing $\neq$ No Discipline**:
  - **Adding type hints** is highly recommended to improve **readability** and **tooling support**.
  - This enables code completion, bug detection, and better maintainability.
- `isinstance()` and `typing.cast`:
  - Use `isinstance()` to narrow the type at runtime and assist IDE.
  - Use `typing.cast()` to explicitly annotate the expected type.
- Example: narrowing and annotating types for better IDE inference.
  - `if isinstance(node, RetICFGNode):` # IDE infers node is RetICFGNode
  - `call_edge = typing.cast(CallCFGEdge, edge)` # IDE infers call_edge is CallCFGEdge