Graph Representation of Code

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SVF : Static Value-Flow Analysis Framework for Source Code

A scalable, precise and on-demand interprocedural program dependence analysis framework for both sequential and multithreaded programs.

- The SVF project
  - **Publicly available** since early 2015 and actively maintained: `http://svf-tools.github.io/SVF`.
  - Implemented on top of LLVM compiler (the latest version 10.0.0) with over 100 KLOC C/C++ code and **530+ stars with 30+ contributors** and over 1K commits on Github.
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- Value-Flow Analysis: resolves **both control and data dependence**.
  - Does the information generated at program point A flow to another program point B along some execution paths?
  - Can function F be called either directly or indirectly from some other function F'?
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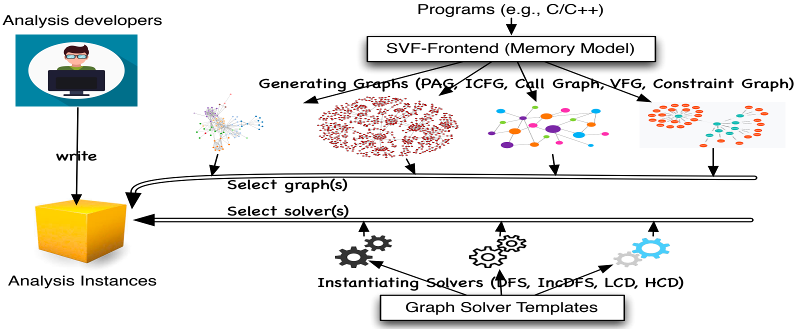
- Key features of SVF
  - **Sparse**: compute and maintain the data-flow facts where necessary
  - **Selective** : support mixed analyses for precision and efficiency trade-offs.
  - **On-demand** : reason about program parts based on user queries.

SVF: Design Principle



- Serving as an open-source foundation for building practical static source code analysis
  - Bridge the gap between research and engineering
  - Minimize the efforts of implementing sophisticated analysis (extendable, reusable, and robust via layers of abstractions)
  - Support developing different analysis variants (flow-, context-, heap-, field-sensitive analysis) in a sparse and on-demand manner.

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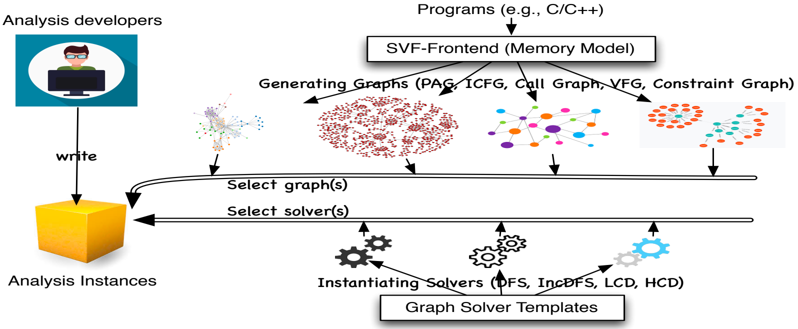

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  - Support developing different analysis variants (flow-, context-, heap-, field-sensitive analysis) in a sparse and on-demand manner.
- Client applications:
  - Static bug detection (e.g., memory leaks, null dereferences, use-after-frees and data-races)
  - Accelerate dynamic analysis (e.g., Google's Sanitizers and AFL fuzzing)

Graph Representation of Code

- What is a graph representation of code?
  - Representing a program's control-flow (i.e., execution order) and/or data-flow (variable definition and use relations) using nodes and edges of a graph.

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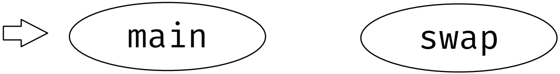
  - Representing a program’s control-flow (i.e., execution order) and/or data-flow (variable definition and use relations) using nodes and edges of a graph.
- Why a graph representation?
  - Abstracting code from low-level complicated instructions
  - Applying general graph algorithms
  - Easy to maintain and extend

Call Graph

```
define i32 @main() #0 {
entry:
%a1 = alloca i8, align 1
%b1 = alloca i8, align 1
%a = alloca i8*, align 8
%b = alloca i8*, align 8
store i8* %a1, i8** %a, align 8
store i8* %b1, i8** %b, align 8
call void @swap(i8** %a, i8** %b)
ret i32 0
}
define void @swap(i8** %p, i8** %q) #0
{
entry:
%0 = load i8** %p, align 8
%1 = load i8** %q, align 8
store i8* %1, i8** %p, align 8
store i8* %0, i8** %q, align 8
ret void
}
```

Program calling relations between methods



Call Graph

https://github.com/svf-tools/SVF/wiki/Analyze-a-Simple-C-Program#3-call-graph

Call Graph

```
define i32 @main() #0 {
1 entry:
2 %a1 = alloca i8, align 1
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4 %a = alloca i8*, align 8
5 %b = alloca i8*, align 8
6 store i8* %a1, i8** %a, align 8
7 store i8* %b1, i8** %b, align 8
8 call void @swap(i8** %a, i8** %b)
9 ret i32 0
}
define void @swap(i8** %p, i8** %q) #0
{
10 entry:
11 %0 = load i8** %p, align 8
12 %1 = load i8** %q, align 8
13 store i8* %1, i8** %p, align 8
14 store i8* %0, i8** %q, align 8
15 ret void
}
```
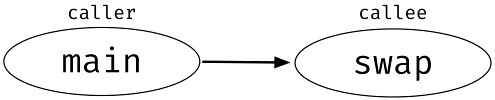

- each node represents a program method
- each edge represents a calling relation between two program methods



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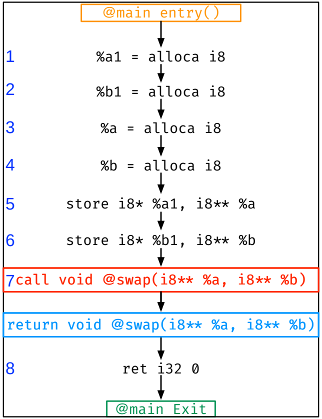
Control Flow Graph

Program execution order between instructions.

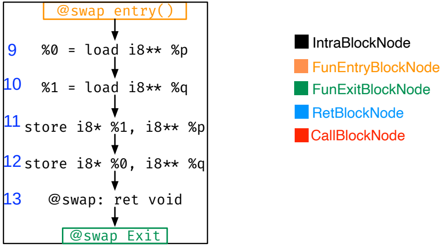
- Intra-procedural control-flow graph: control-flow graph within a program method.
- Inter-procedural control-flow graph: control-flow graph across program methods.

Intra-procedural Control Flow Graph



Program execution order between instructions

- Each node represents an instruction or a statement
- Each edge represents a control-flow dependence between two nodes



https://github.com/svf-tools/SVF/wiki/Analyze-a-Simple-C-Program#4-interprocedural-control-flow-graph

Inter-procedural Control Flow Graph (ICFG)

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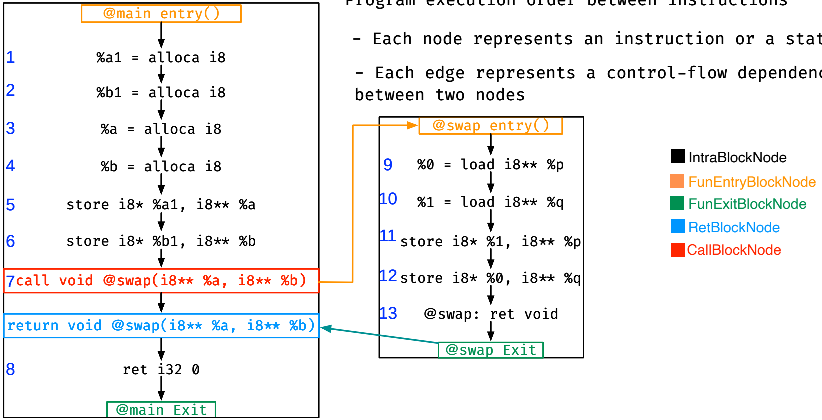

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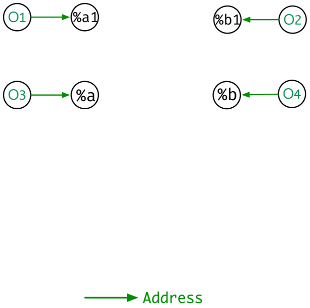
Constraint Graph (or Program Assignment Graph)

- Constraint Graph represents the assignment constraints between variables at the instruction level.
- Constraint Graph and Program Assignment Graph (PAG) are essentially the same.
- The difference is that PAG can not be changed while you can add edges or nodes on the Constraint Graph to perform constraint solving.

Constraint Graph (or Program Assignment Graph)

```
Program Assignment relation between two variables
   - each node represent a pointer or an object
   - each edge represents two nodes dependence or constraint relation
```

```
define i32 @main() #0 {
entry:
%a1 = alloca i8, align 1        O1
%b1 = alloca i8, align 1        O2
%a = alloca i8*, align 8        O3
%b = alloca i8*, align 8        O4
store i8* %a1, i8** %a, align 8
store i8* %b1, i8** %b, align 8
call void @swap(i8** %a, i8** %b)
ret i32 0
}
```



alloca instruction allocates typed integer
8 bytes of memory object as O_1 O_2 O_3 O_4

https://github.com/svf-tools/SVF/wiki/Analyze-a-Simple-C-Program#5-pag

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Address Store

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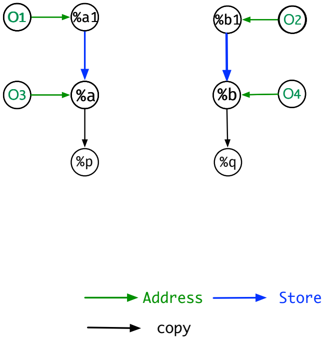

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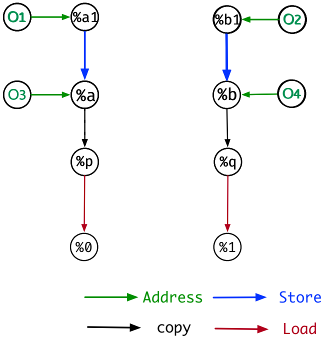

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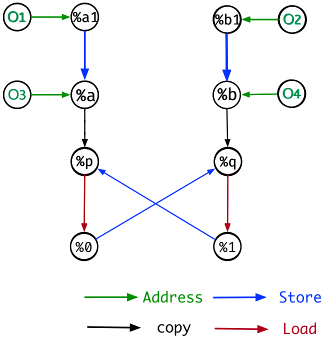

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What's next?

- (1) Compile two C programs (`swap.c` and `example.c`) into their LLVM IR.
  - A guide can be found here https://github.com/SVF-tools/SVF-Teaching/wiki/CodeGraph#2-llvm-ir-generation
  - Understand the mapping from a C program to its corresponding LLVM IR.
- (2) Generate and visualize the graph representation of LLVM IR (`swap.ll` and `example.ll`).
  - https://github.com/SVF-tools/SVF-Teaching/wiki/CodeGraph#3-run-and-debug-your-codegraph
- (3) Write code to iterate nodes and edges of ICFG and PAG and print their contents.
  - https://github.com/SVF-tools/SVF-Teaching/blob/main/CodeGraph/CodeGraph.cpp#L65-L82
- (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