DDPA

A Higher-Order Demand-Driven Program Analysis

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Some Program Analyses

	push forward	demand-driven
first order	abstract interpretation data flow analysis	CFL-reachability reverse data flow analysis
higher order	kCFA CFA2 PDCFA ΓCFA	

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POLYFLOW$_{\text{CFL}}$

DDPA By Example

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let id x = x;;
let s1 = id 1;;
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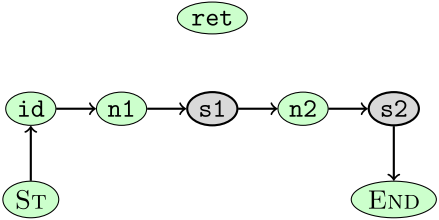
Initial graph before any calls wired:



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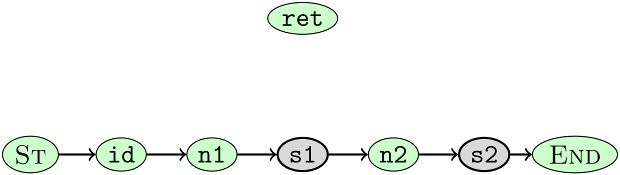


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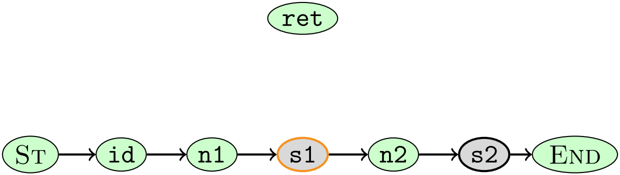
Analyze call site s1

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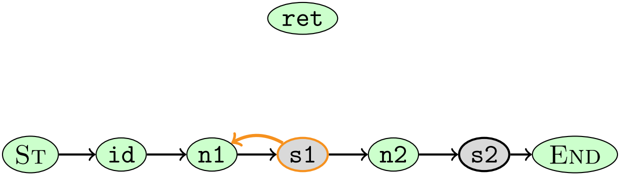
Look backward to find function `id`

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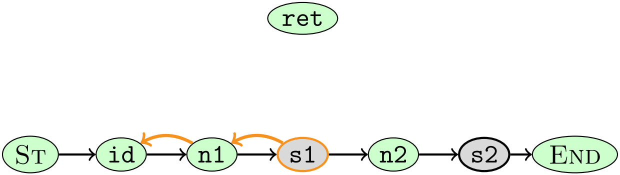


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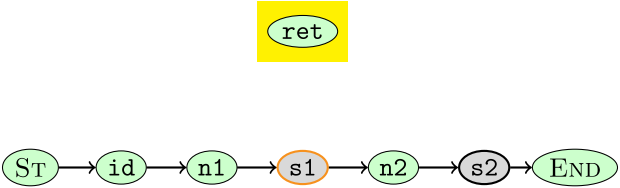


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DDPA By Example

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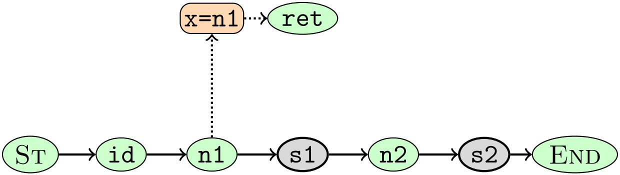
Bind argument `n1` to parameter `x`

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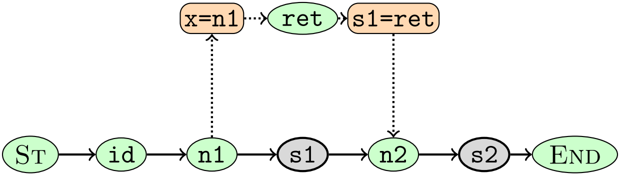
DDPA By Example

Analyze call site `s1`

Assign result `ret` to call site `z1`

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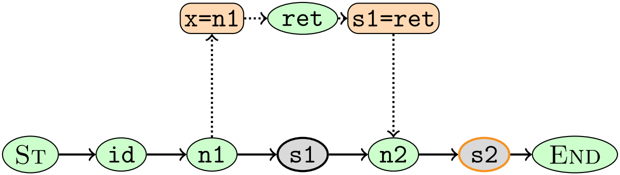
DDPA By Example

Analyze call site s2

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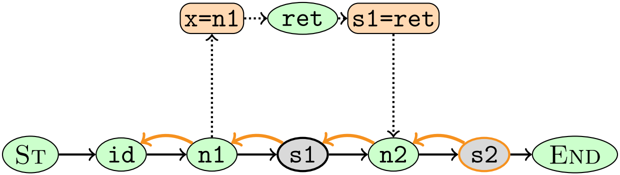


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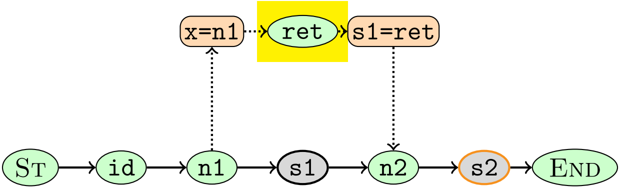


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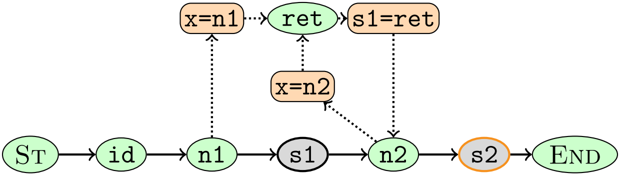
Analyze call site `s2`

Bind argument `n2` to parameter `x`

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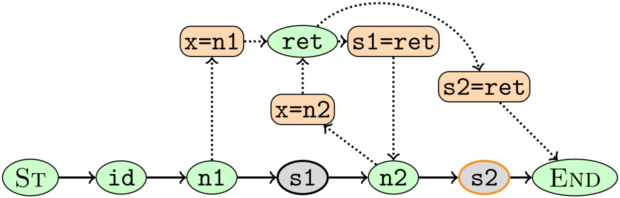


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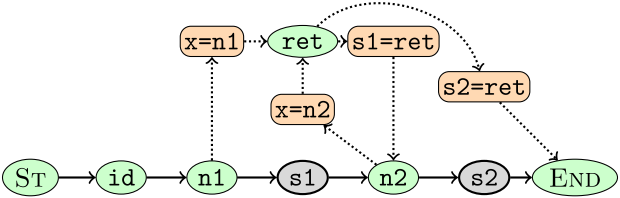
CFG construction complete

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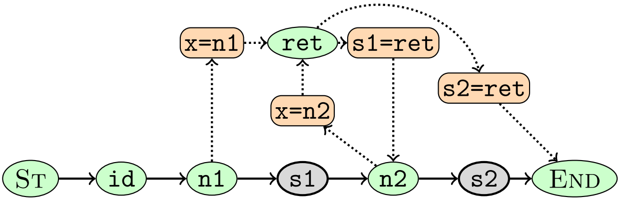
  - (Flow-sensitivity comes for free)

Call Stack Alignment for Context-Sensitivity

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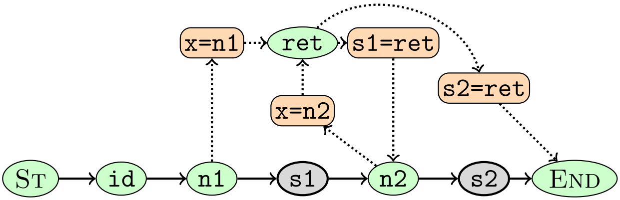
Look up s2 from end of program

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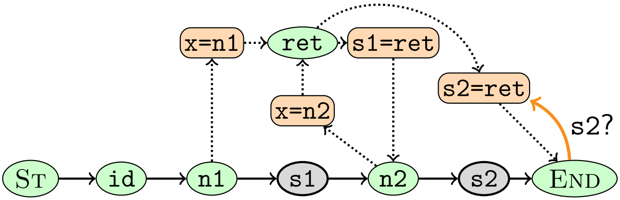


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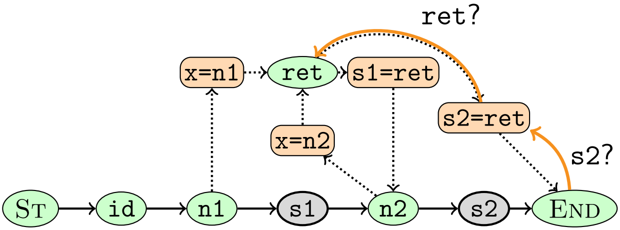


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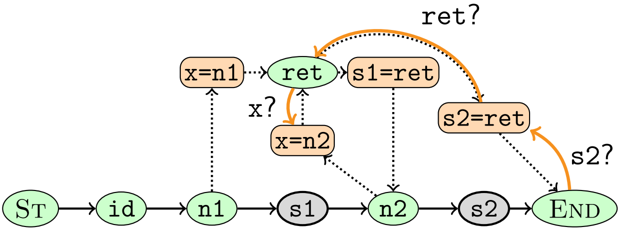


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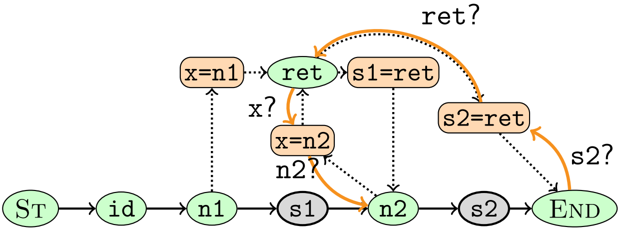


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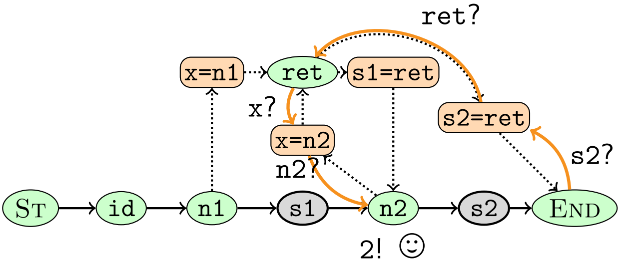


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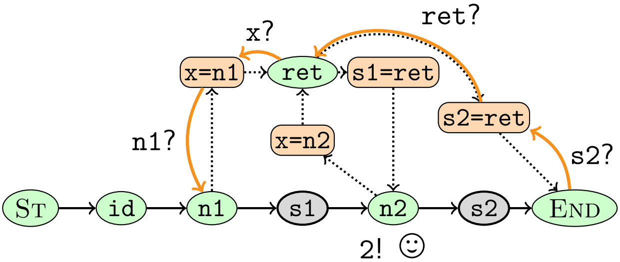


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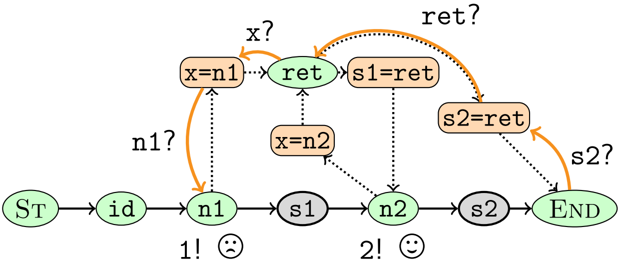


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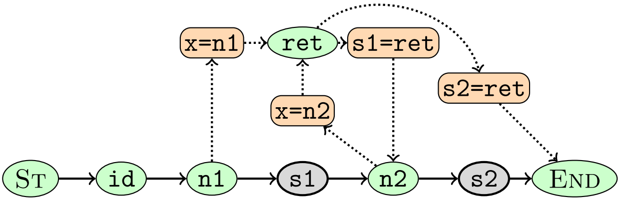


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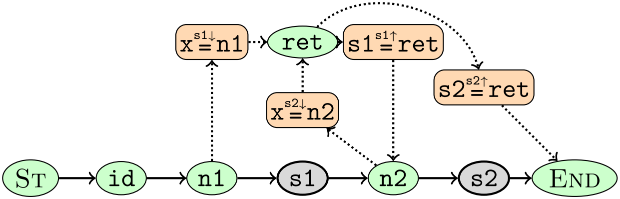


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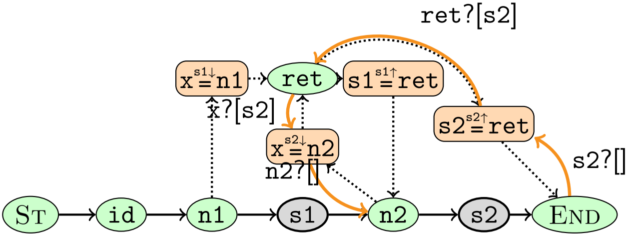


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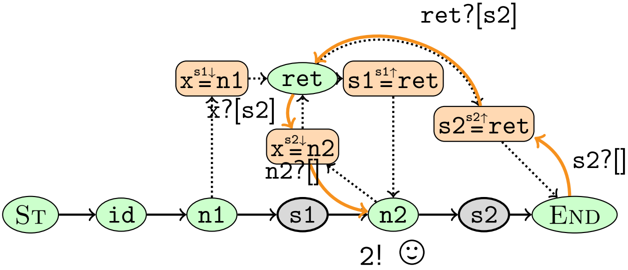


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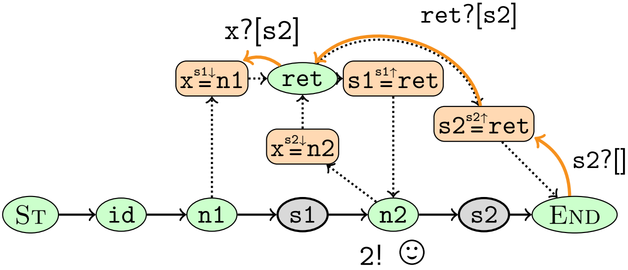


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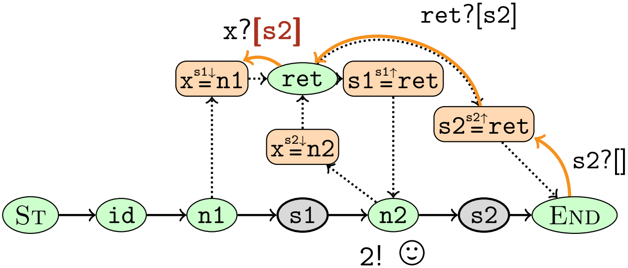


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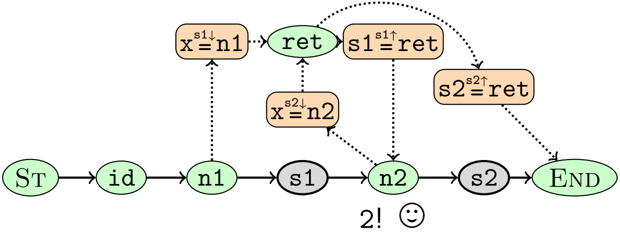


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- DDPA:
  - Also uses PDS: lookup decision $\equiv$ automata reachability
  - PDS stack is not call stack
  - We need the PDS stack for something else...

Handling Non-Local Variables

Non-local example: K-combinator

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k = fun v -> (k0 = fun j -> (r = v;);); 
a = 1;  f = k a;
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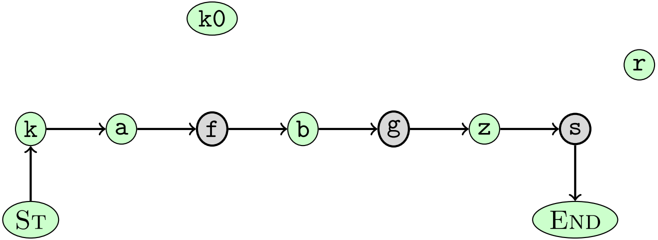
Non-Local Variable Lookup

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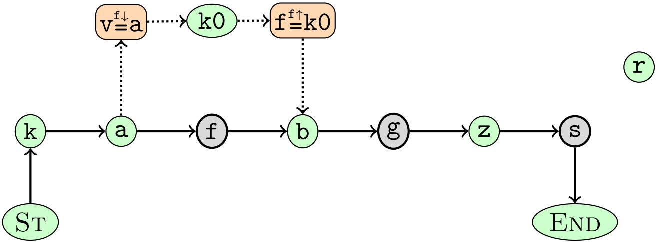
Analyze call site `f`.

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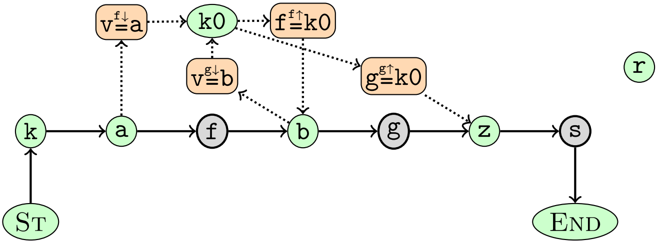


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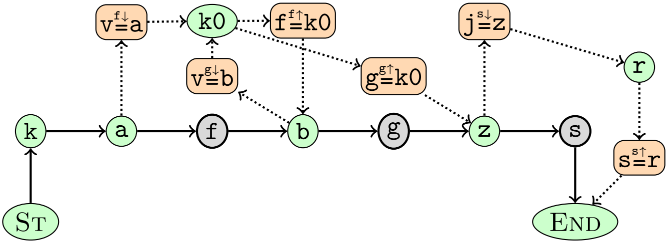
Non-Local Variable Lookup

Analyze call site `s`.

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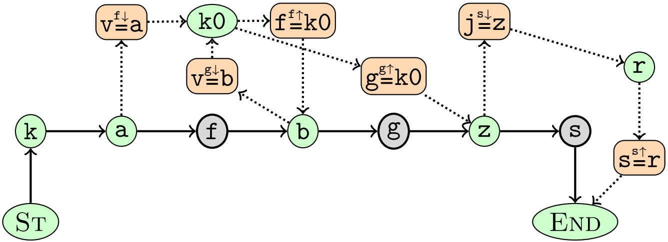
Look up s from end of program.

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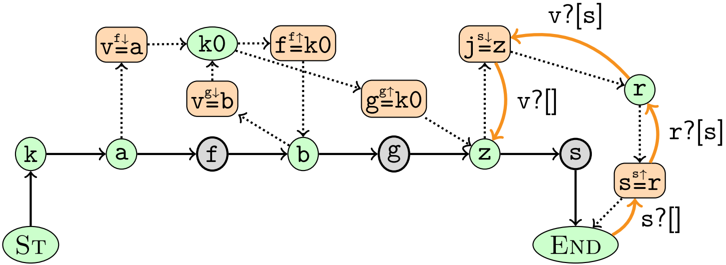


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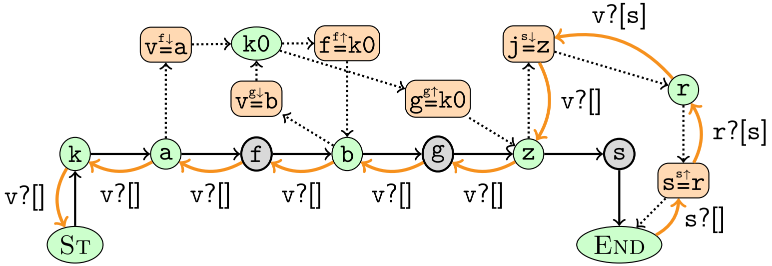


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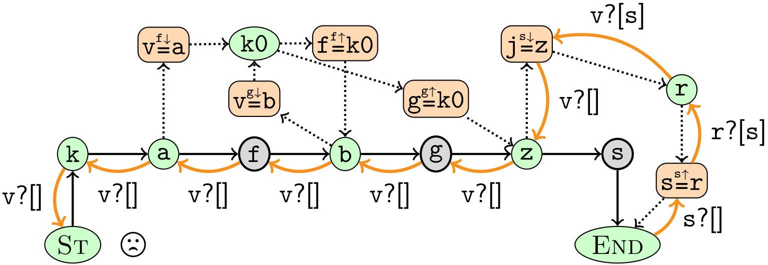


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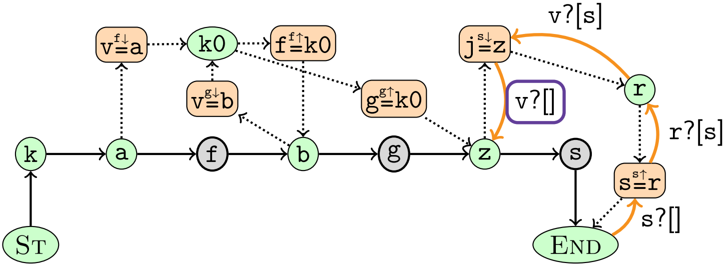


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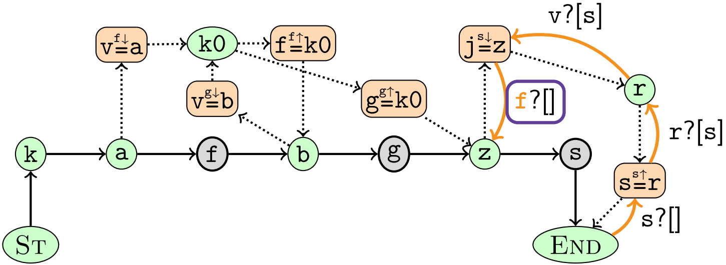


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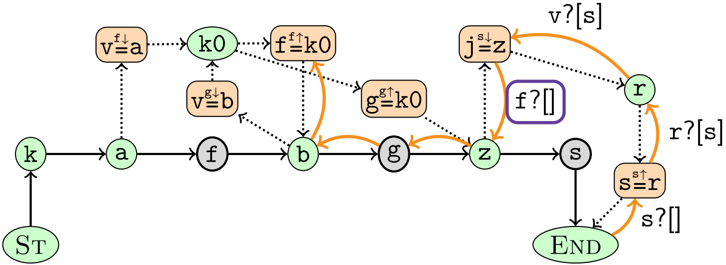


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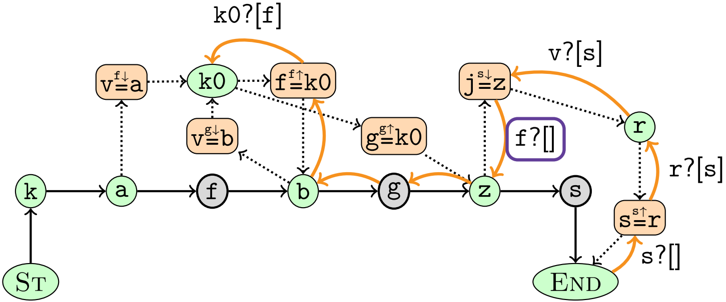


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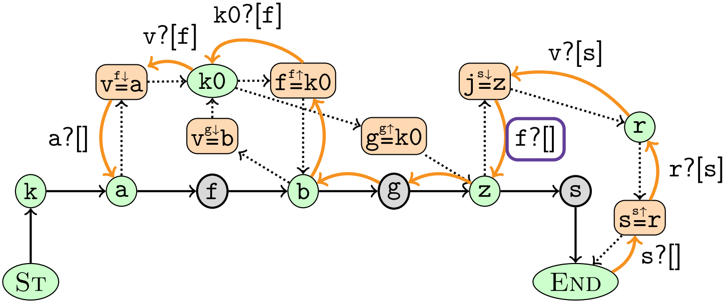


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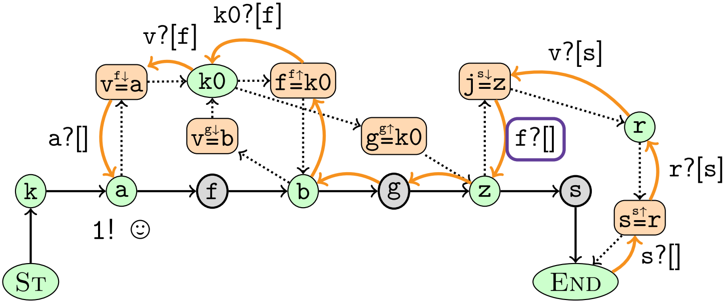


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  - kDDPA: maximum call stack depth k
  - Lookup still translates to PDS reachability decision problem

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- Theorem: kDDPA (for fixed k) has polynomial time bound
- Lemma: both CFG and PDS are monotonically increasing over analysis
    - Allows for analysis to be purely additive – efficient sharing
    - Observe we have reduced program analysis to incremental (PDS) model checking - fast!

Source / CFG / PDS - the whole analysis

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x = {};
f = fun i -> ( r = i );
z = f x;
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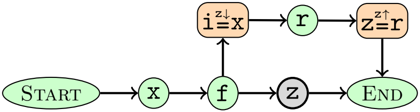

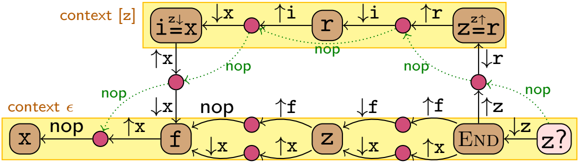

- Build both CFG and PDS incrementally; above is final result

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- Practically speaking, expressiveness appears similar

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  - Path-sensitivity – paths validated by PDS
  - Heap-sensitive state including may/must alias information
- Lazily constructs PDS according to regular definition
- Looks to be reasonabily efficient

Future Work

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- Better call stack model for performance
- Application to existing languages

Conclusions

- DDPA: first flow-sensitive, demand-driven, higher-order program analysis
- Program analysis based on incremental model checking
  - Promising for efficiency
- Appears comparable in expressiveness with state-of-the-art forward analyses
- Code: `https://github.com/JHU-PL-Lab/odefa`