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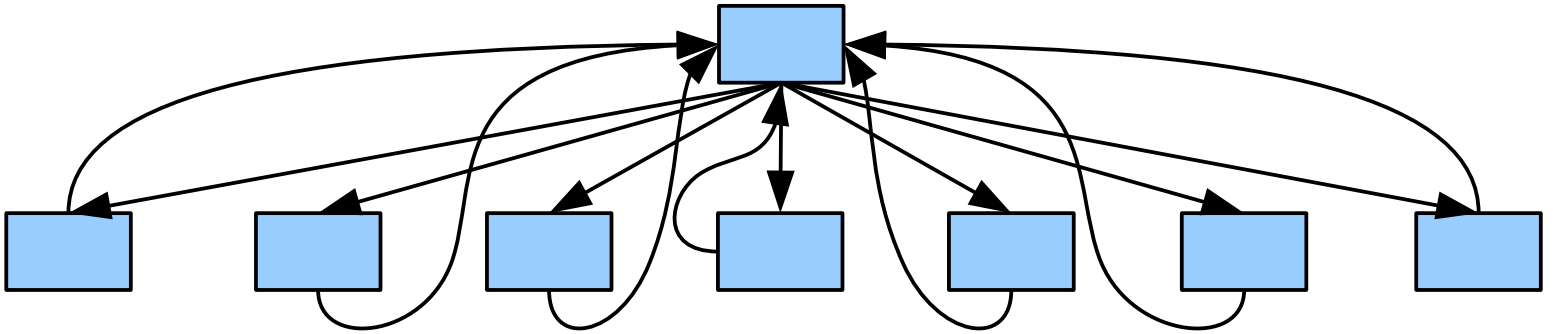
  - Tolerate errors.
  - Manage memory / resources.

e.g. Reverse Engineering

Static CFG (from e.g. Apple Fairplay):



This is the result of a control flow flattening obfuscation.

[http://tigress.cs.arizona.edu/transformPage/docs/flatten/]

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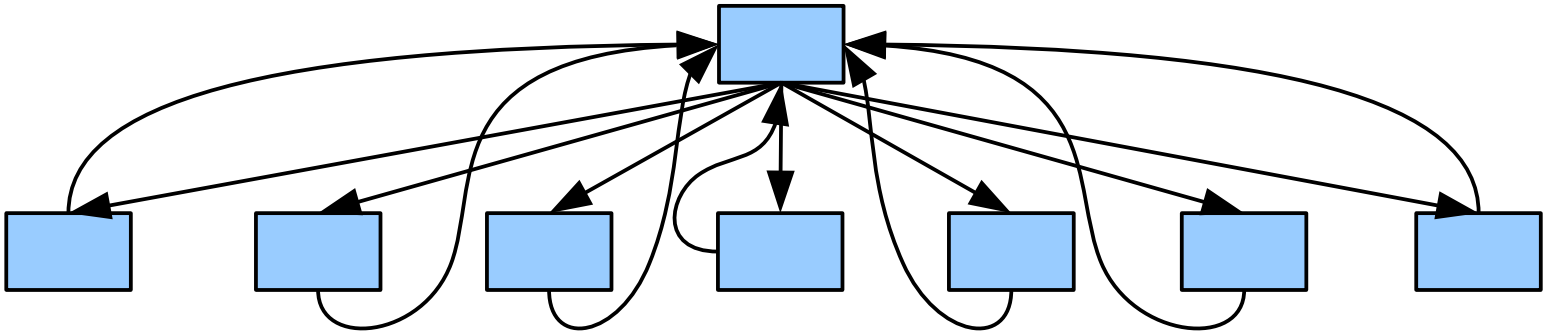
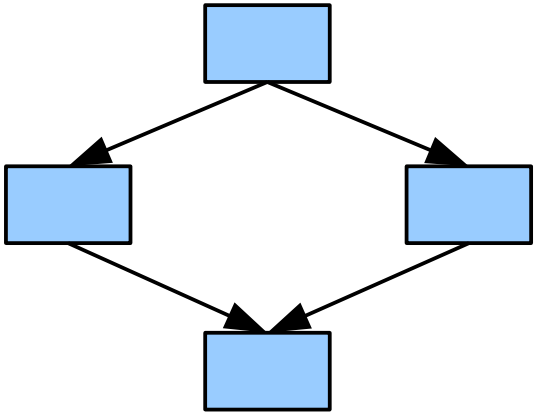


Dynamically Simplified CFG:



How?

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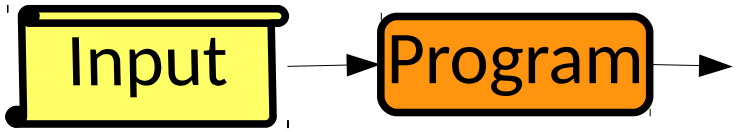

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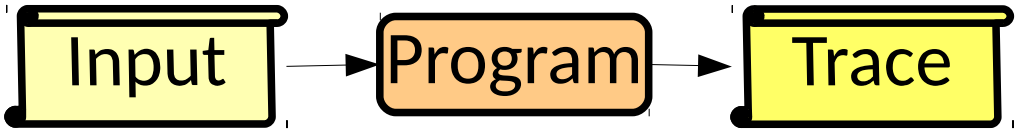

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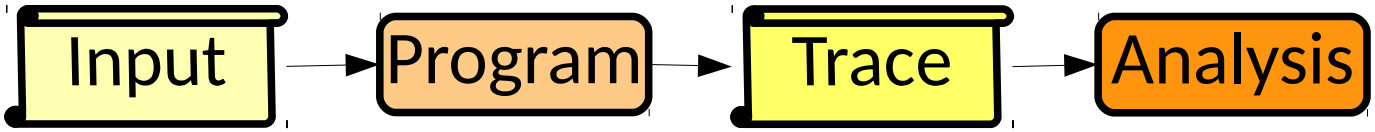

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- Can do both
  - Lightweight recording
  - Instrument a replayed instance of the execution

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Some analyses only make sense *online*.
Why?

Simple Idea: Basic Block Profiling

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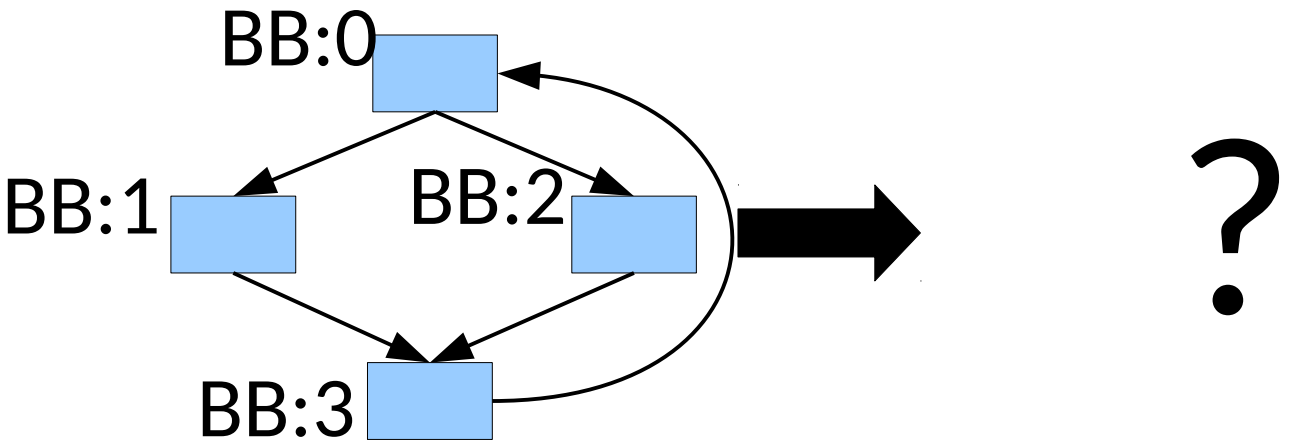

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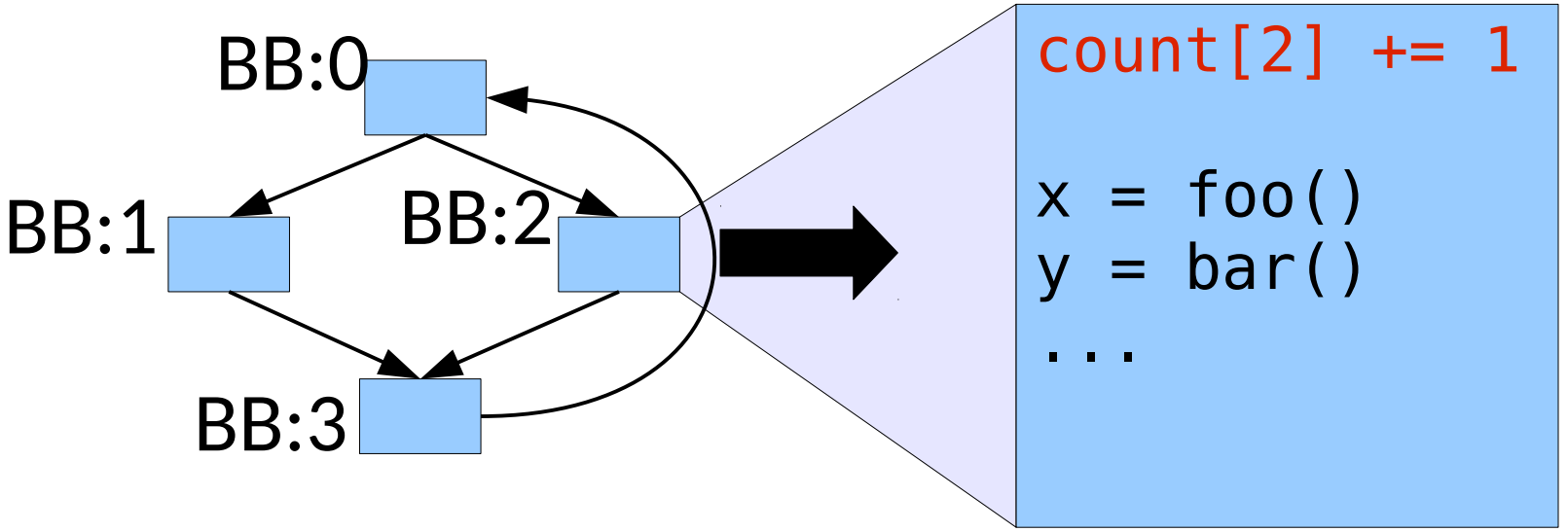

Start:

```
for i in BBs:
  count[i] = 0
```

End:

```
for i in BBs:
  print(count[i])
```

Simple Idea: Basic Block Profiling

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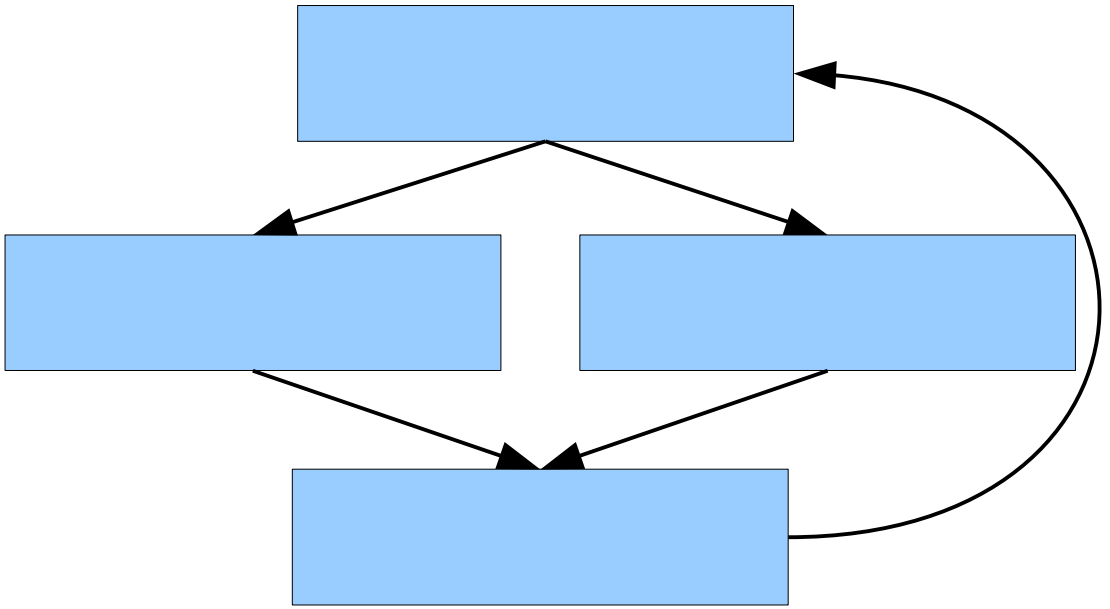

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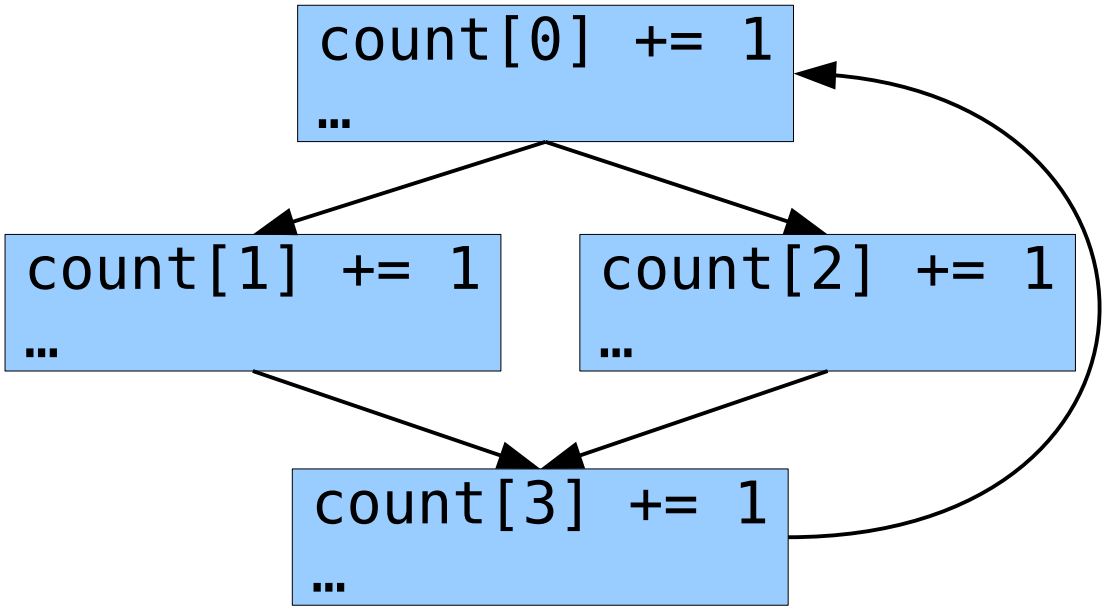

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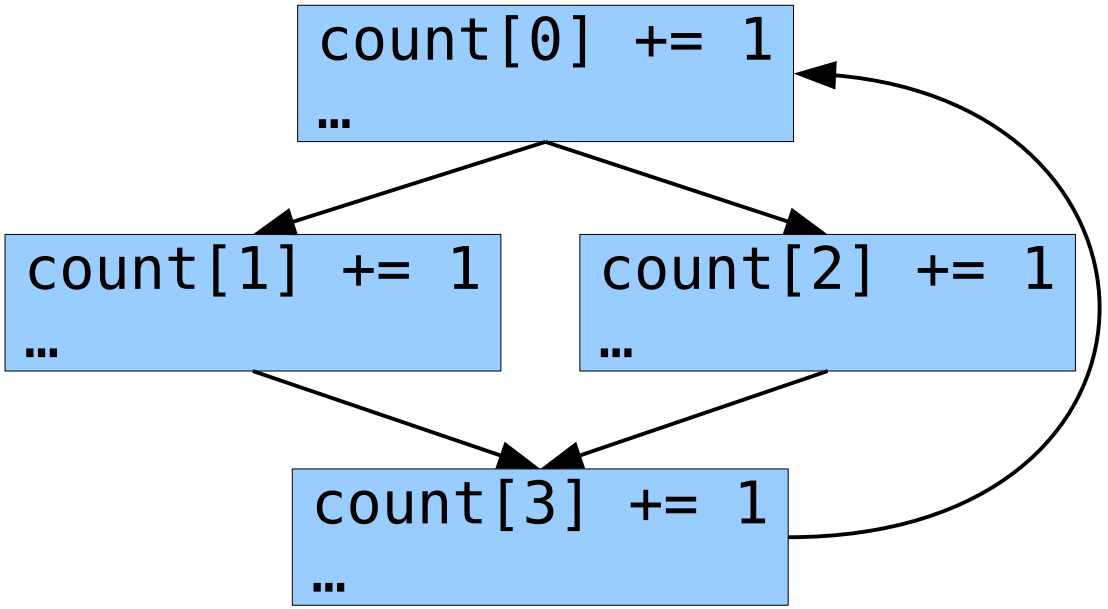

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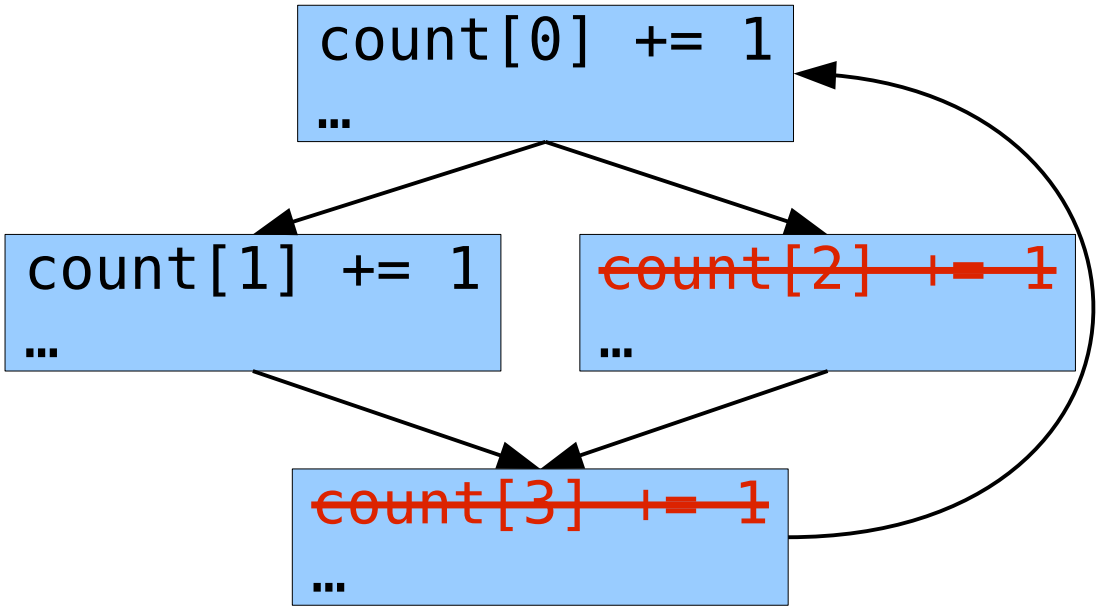

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count[0] = count[3]
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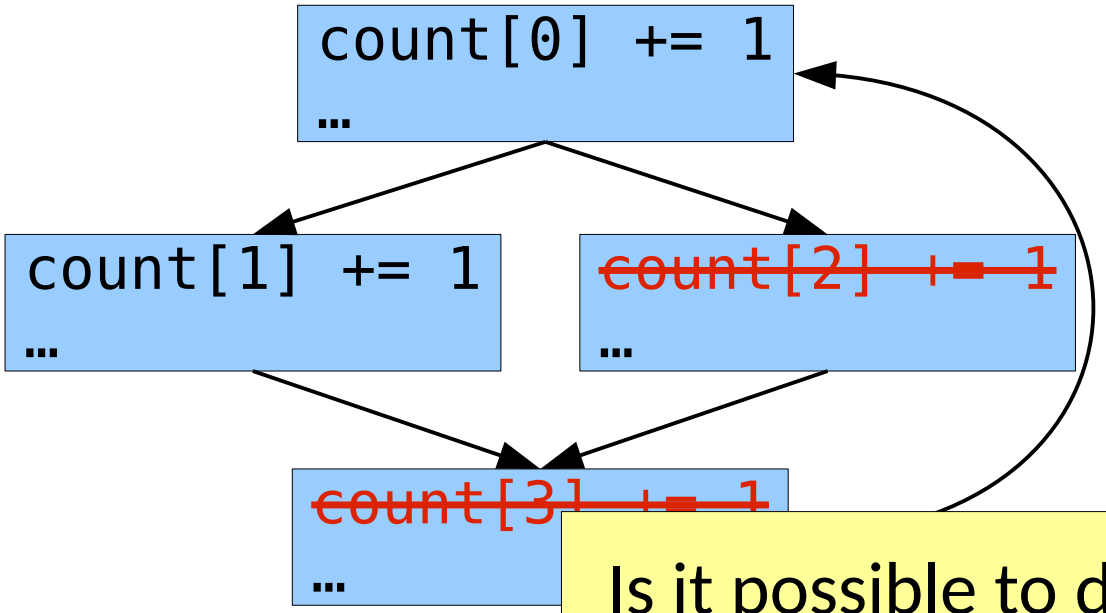

Is it possible to do even better?

  - Can we do better?

```
count[0] = count[3]
count[2] = count[0] - count[1]
```

Efficiency Tactics

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Path Profiling

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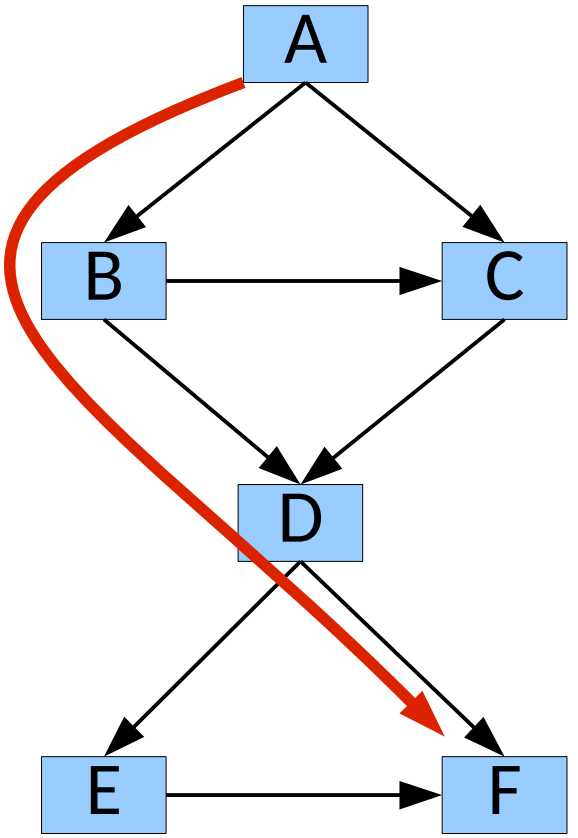

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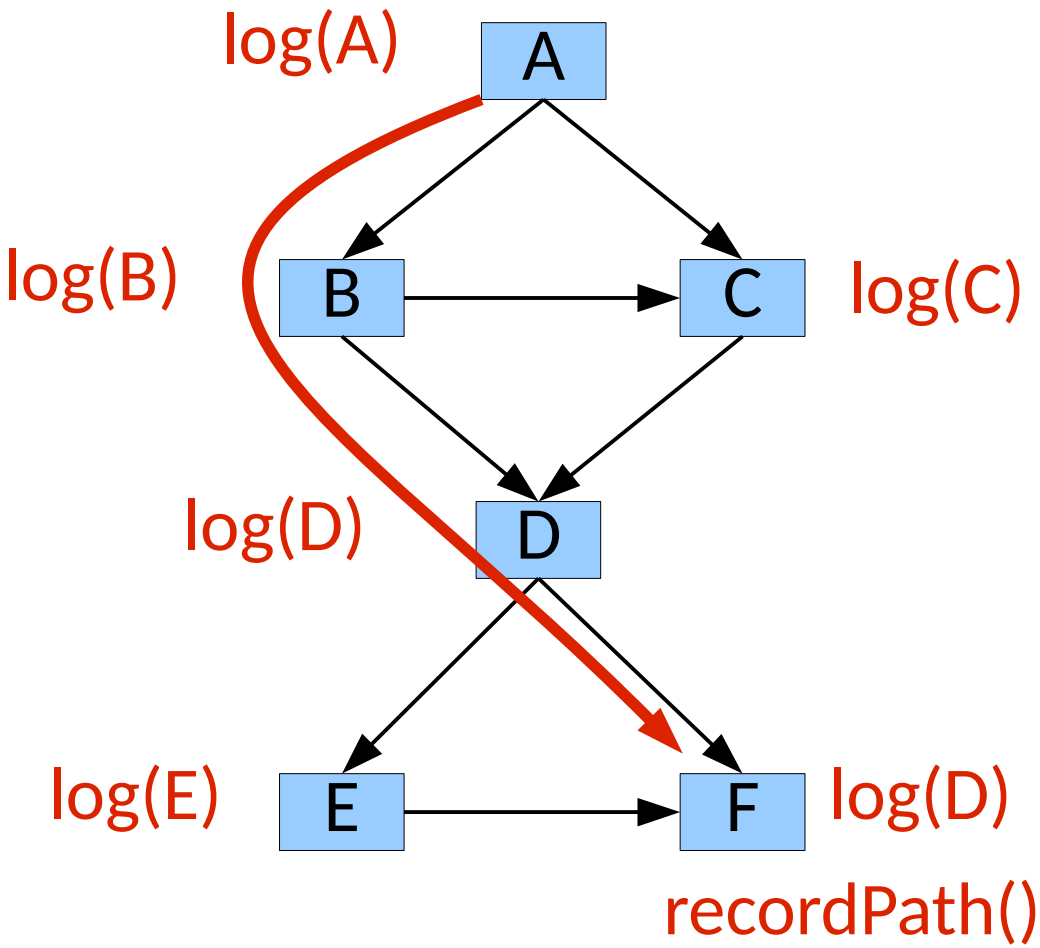

Path Profiling

- **Goal:** How often does an acyclic path execute?
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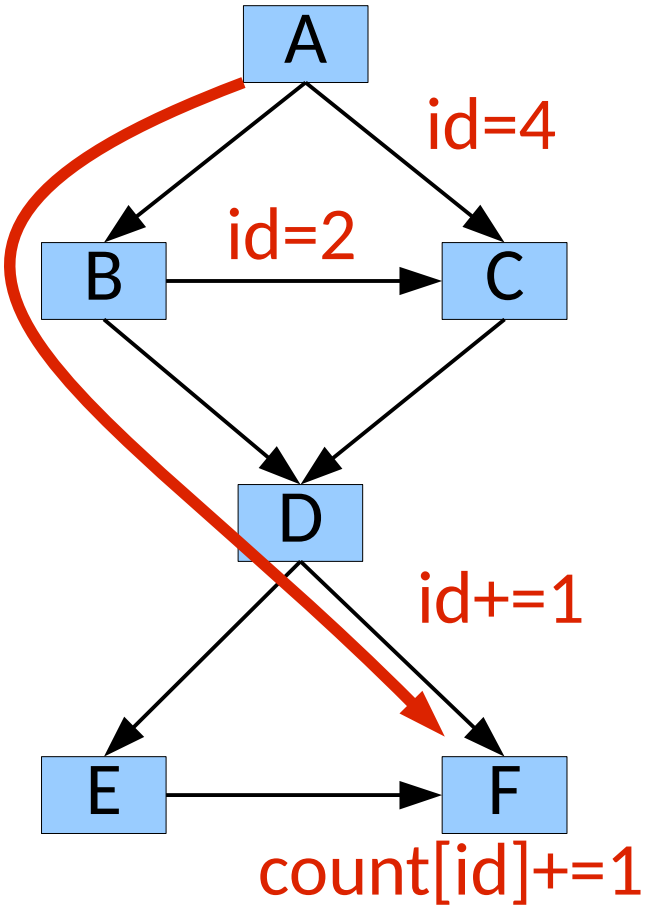
  - Could *encode the paths*

Path	Encoding
ABDEF	0
ABDF	1
ABCDEF	2
ABCDF	3
ACDEF	4
ACDF	5



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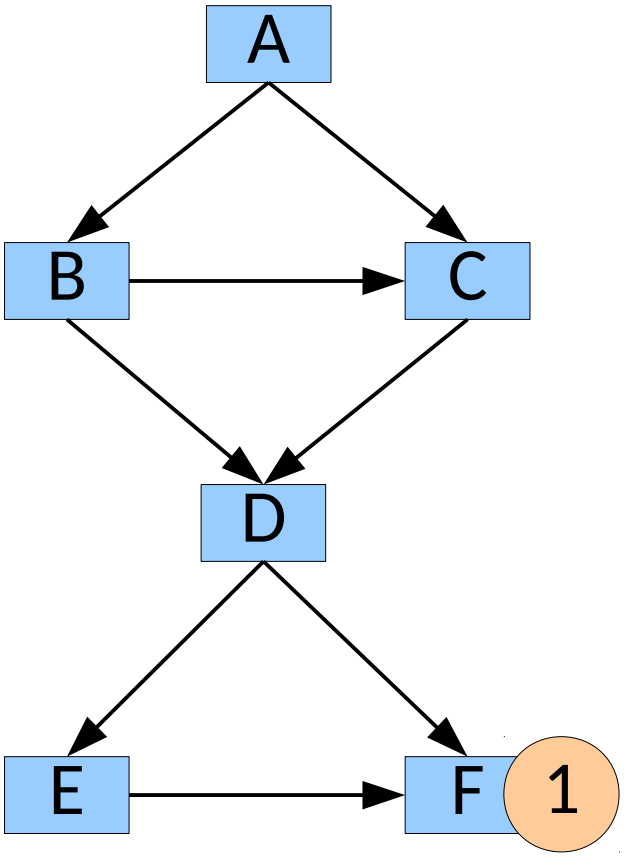

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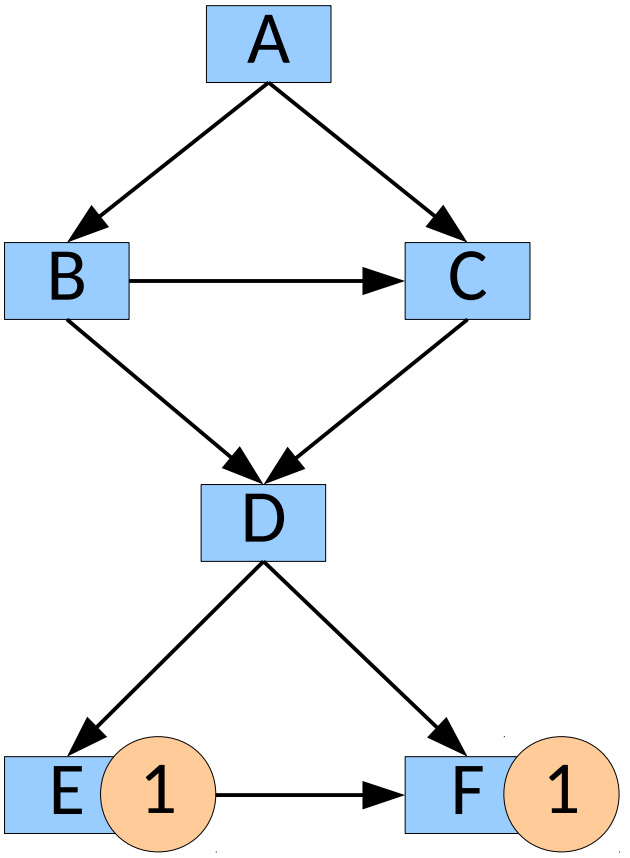

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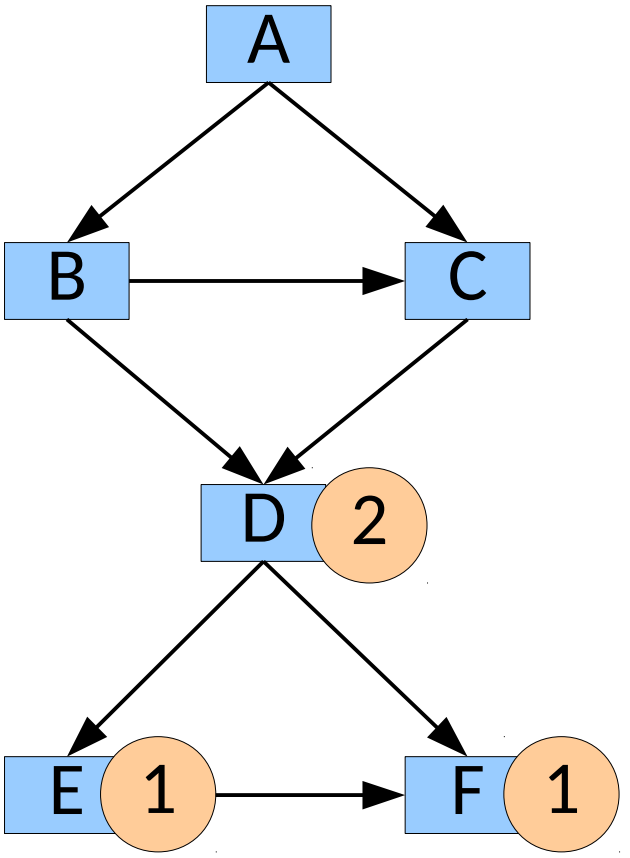

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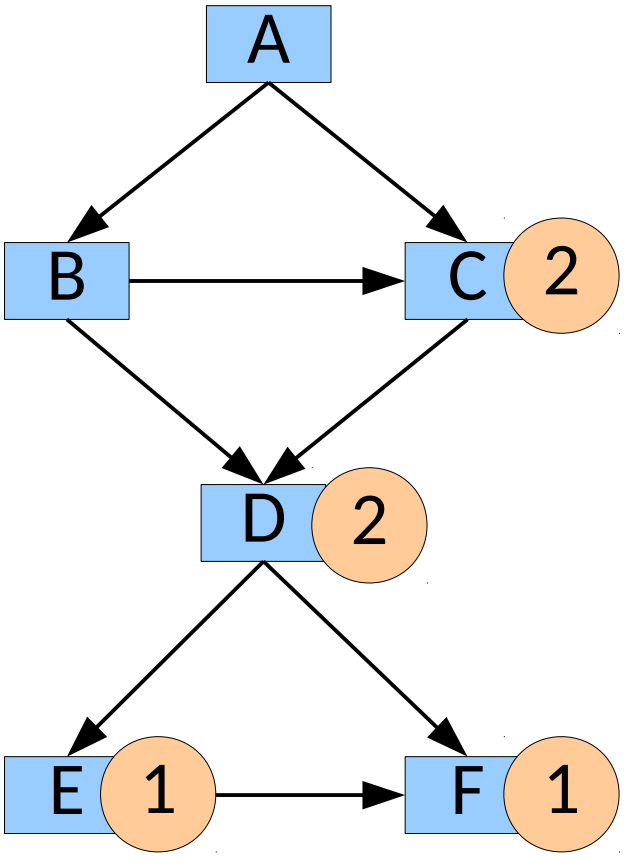

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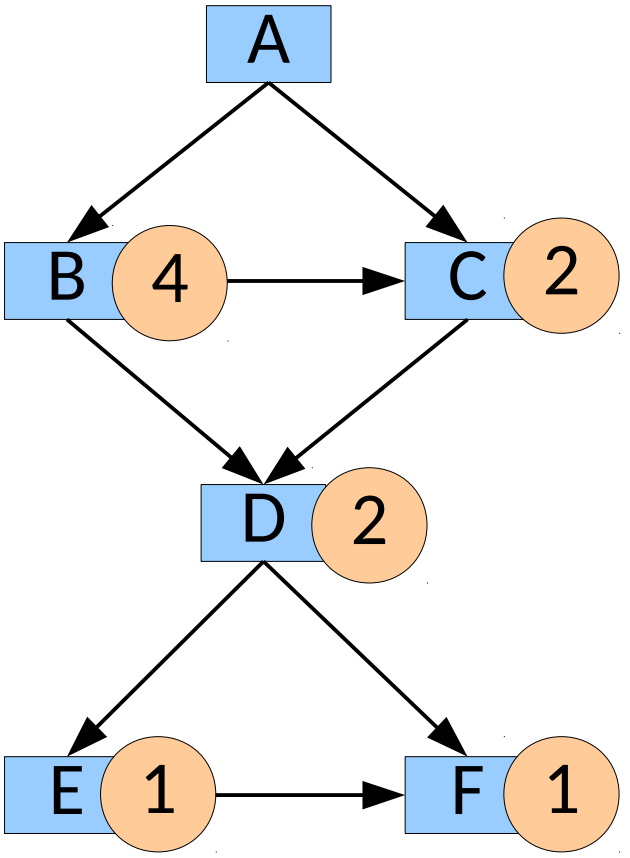

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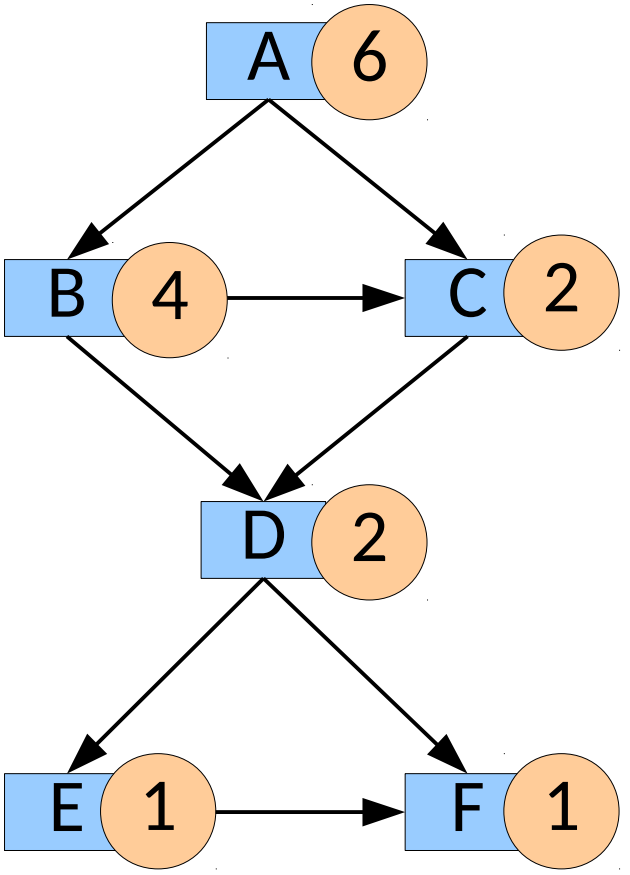

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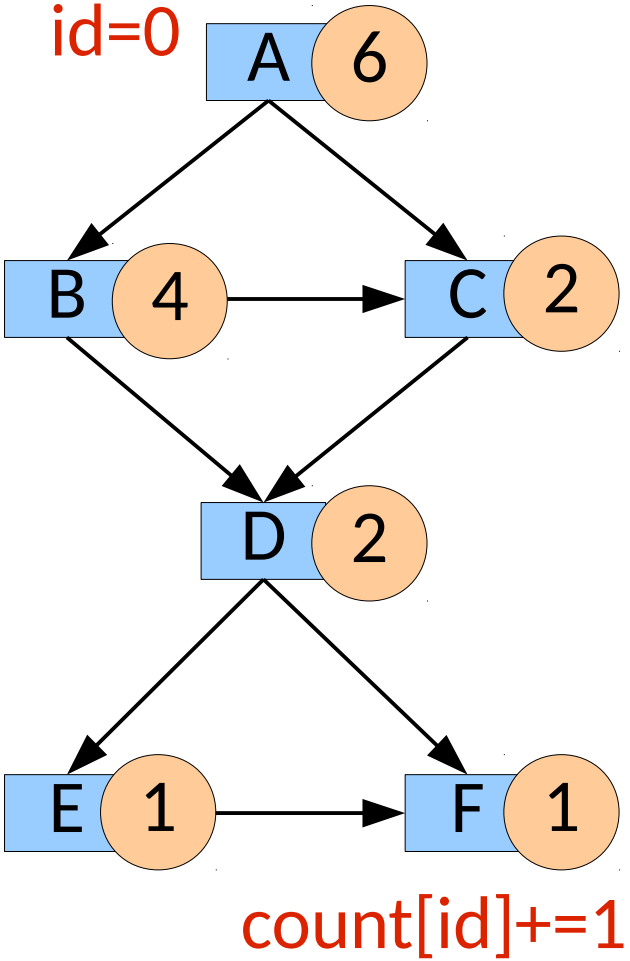

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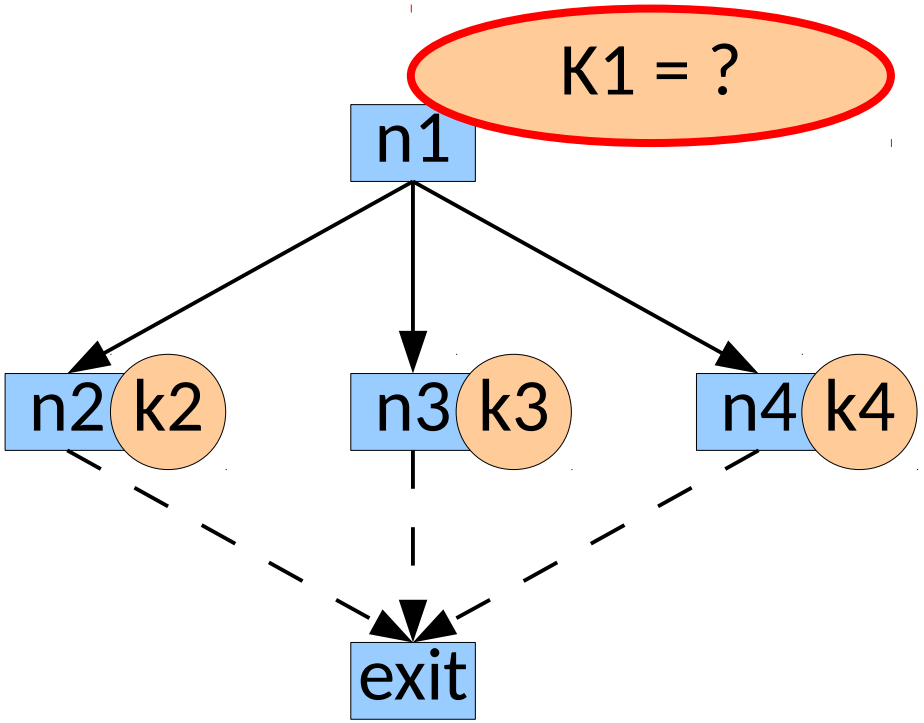

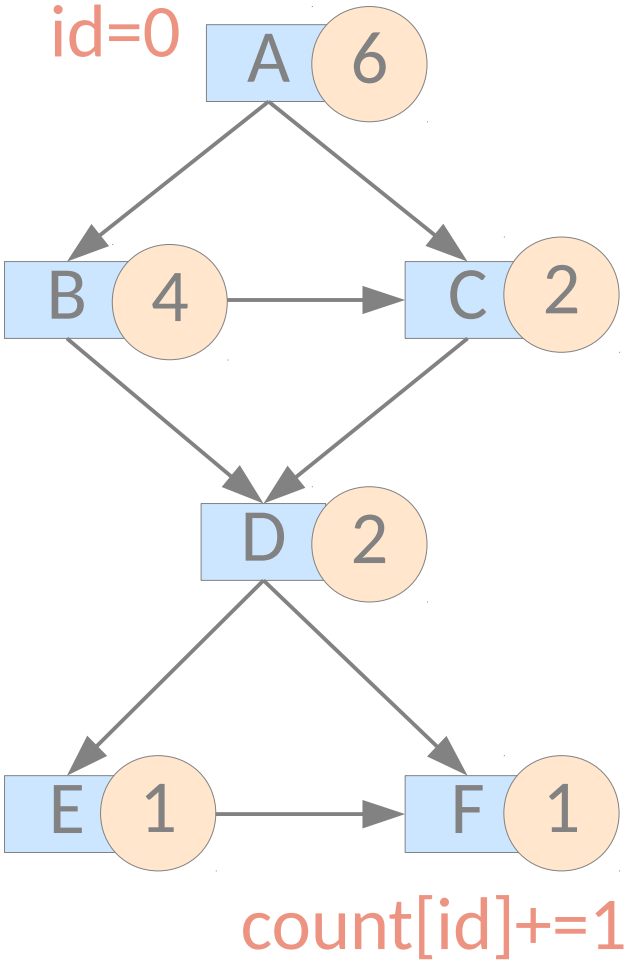

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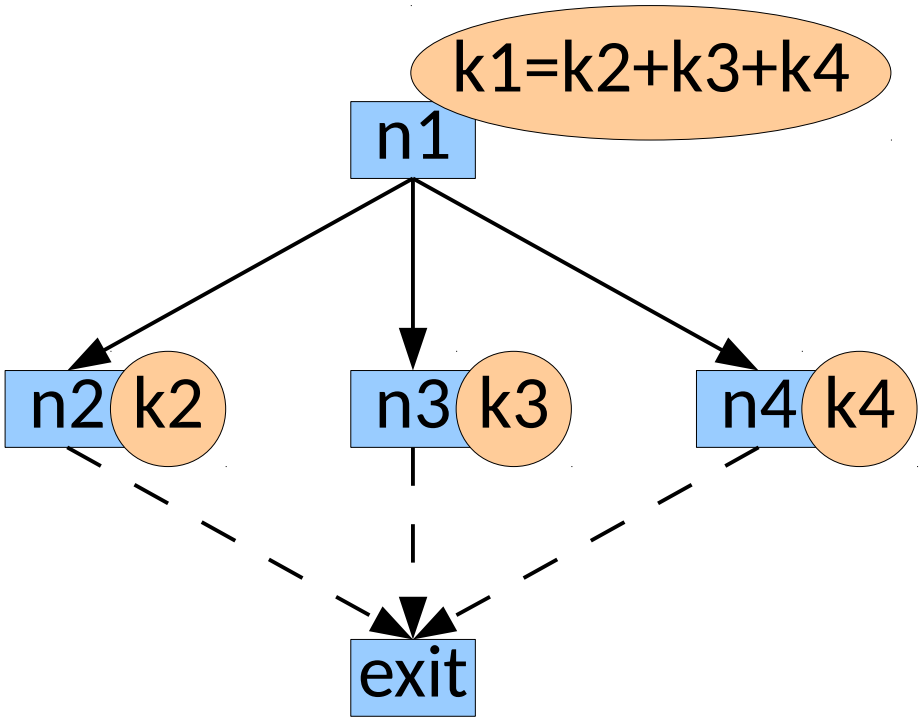

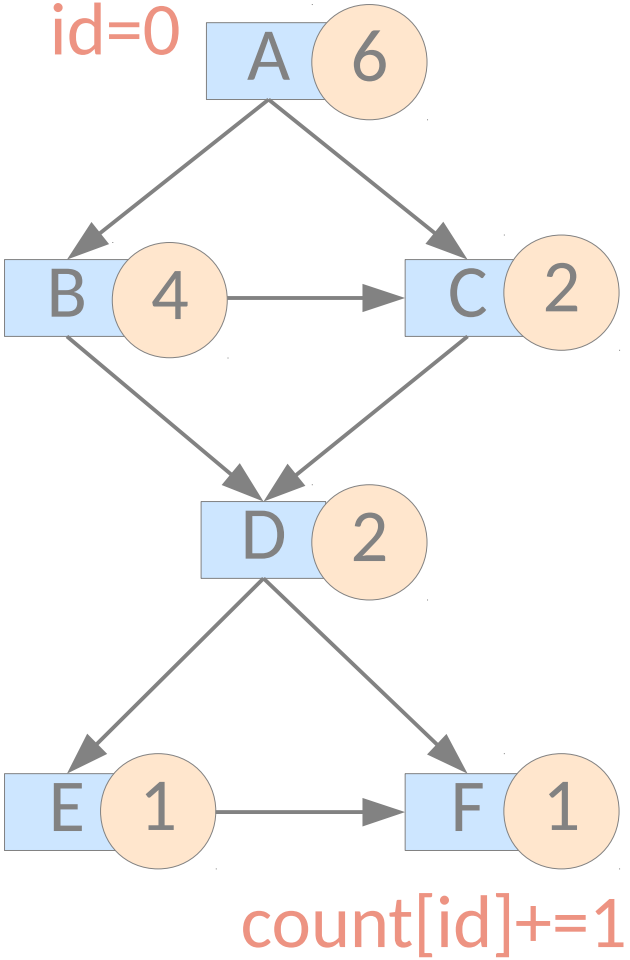

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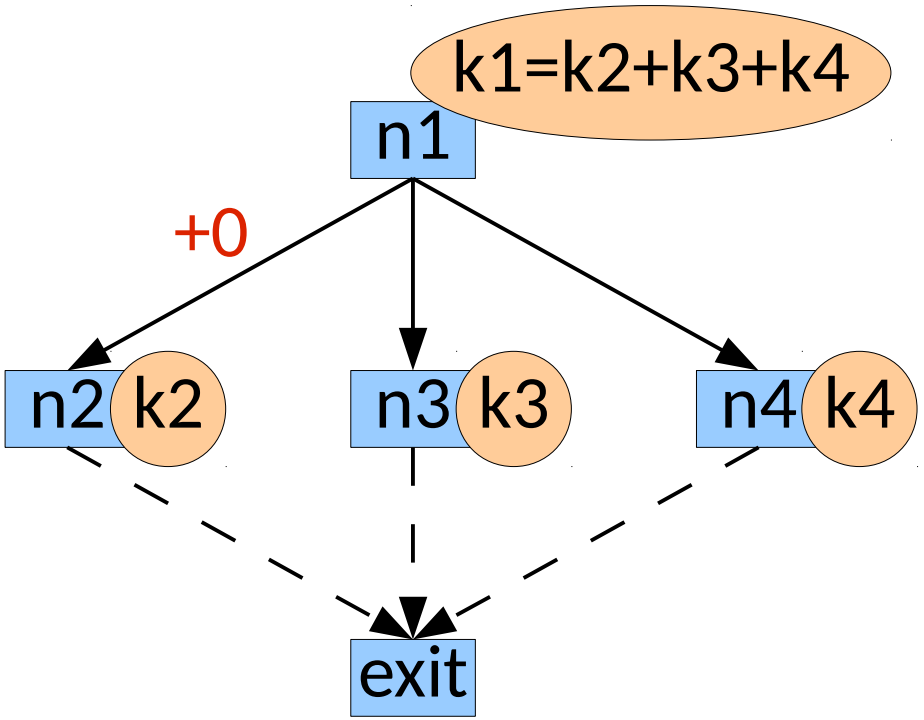

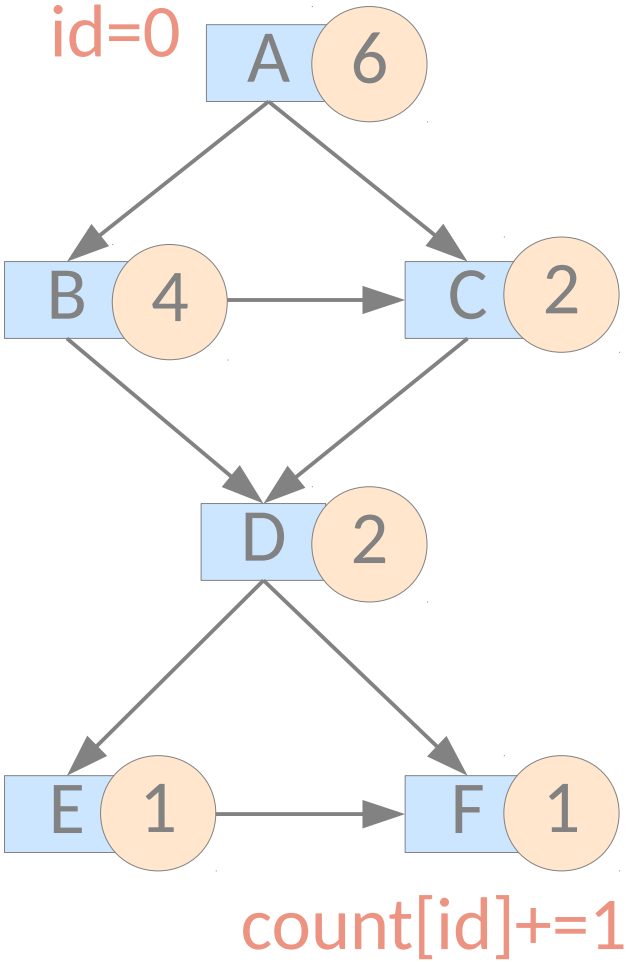

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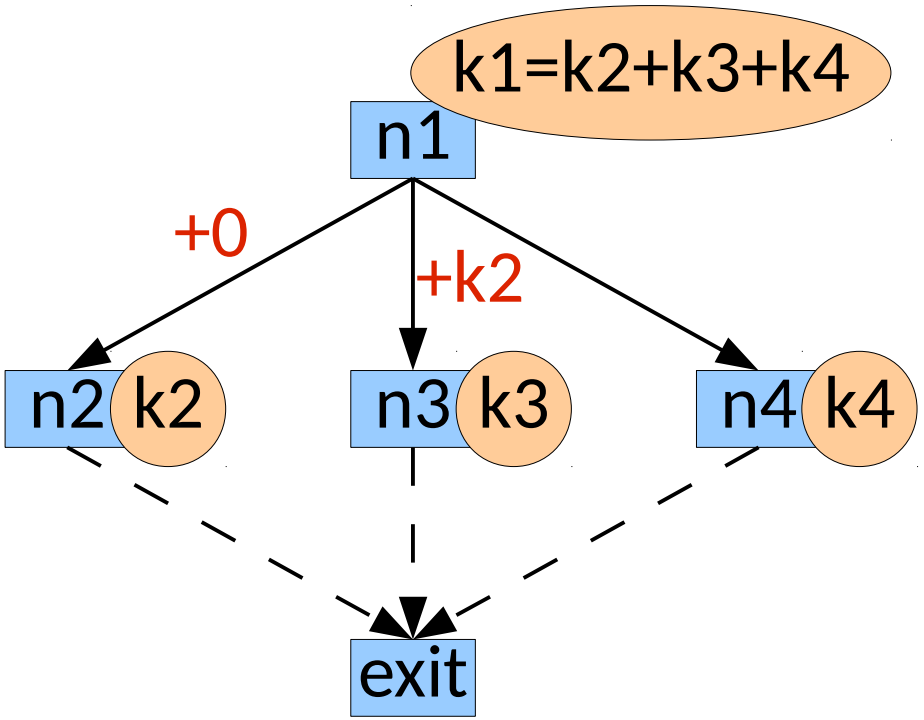

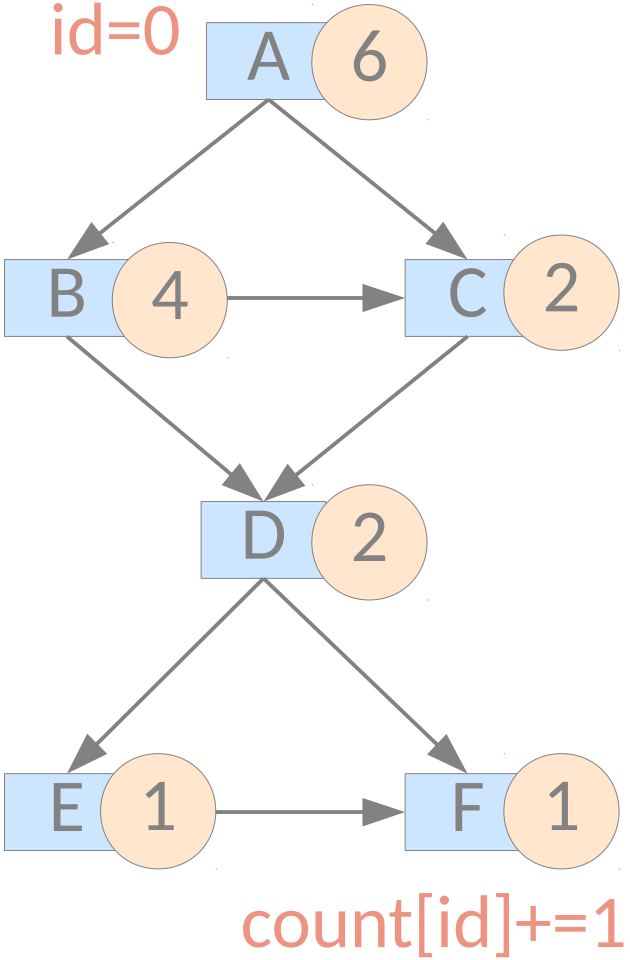

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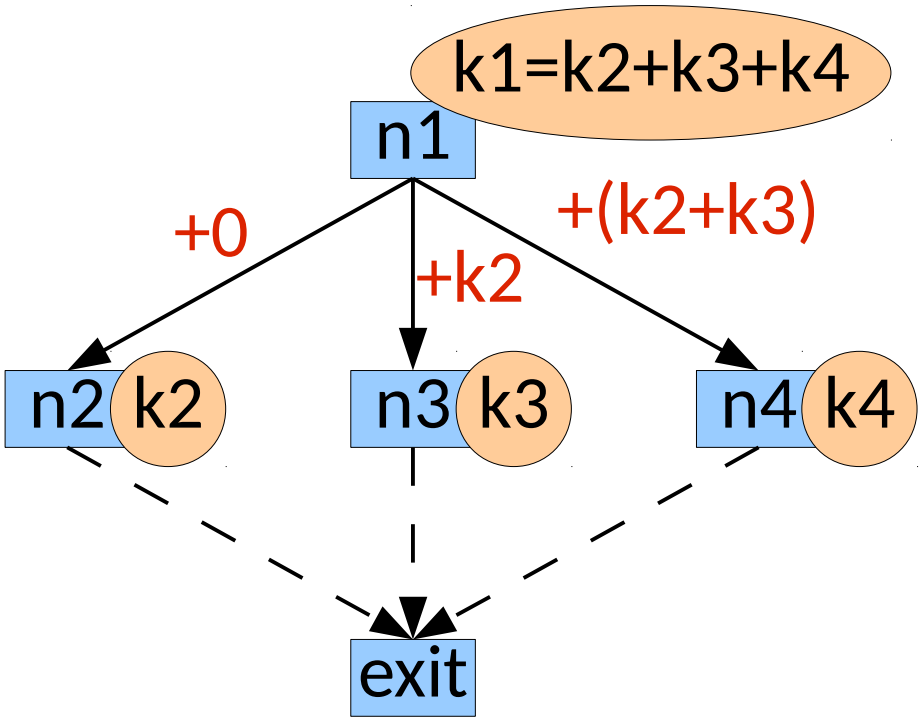

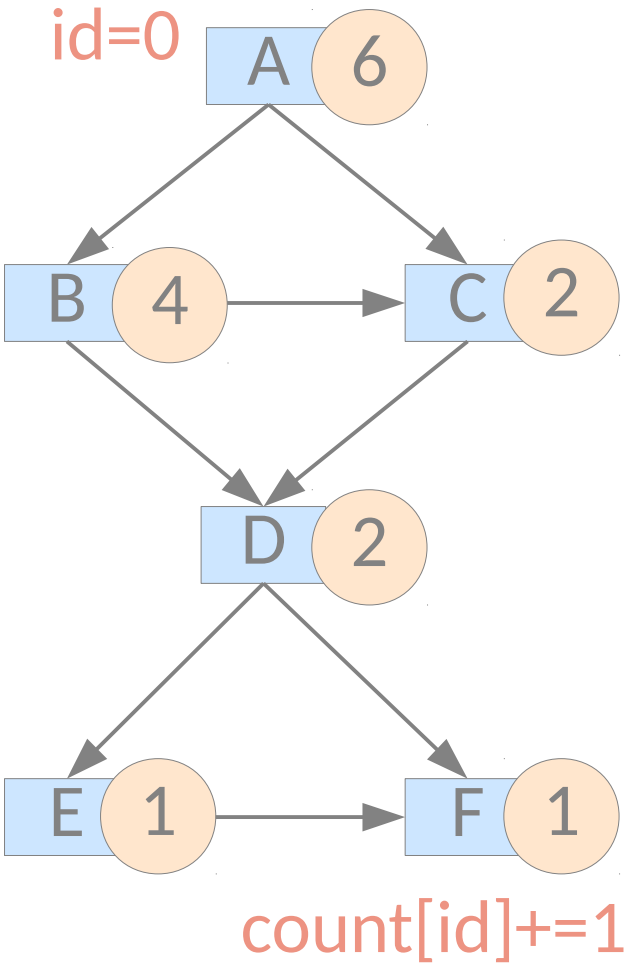

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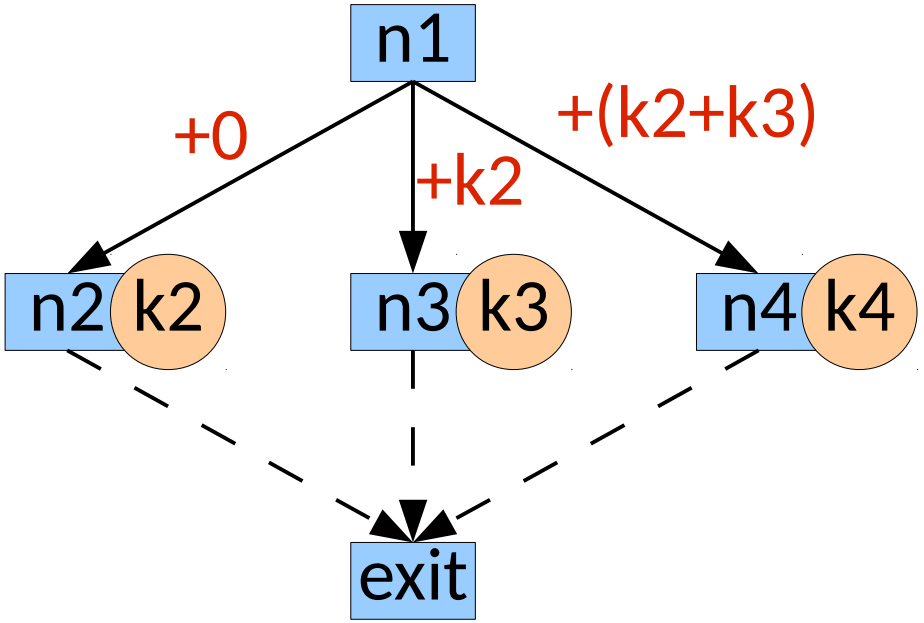

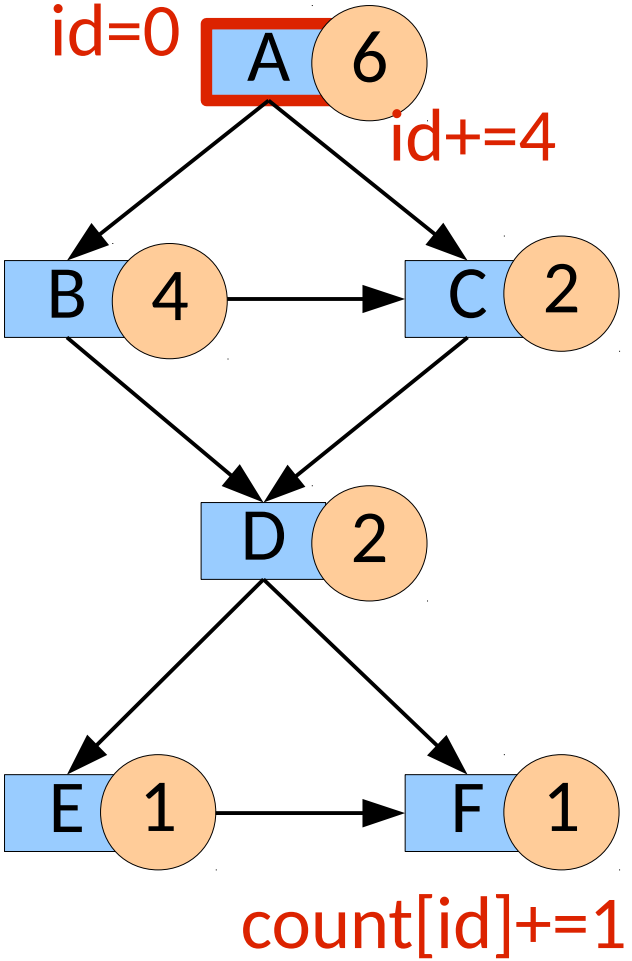

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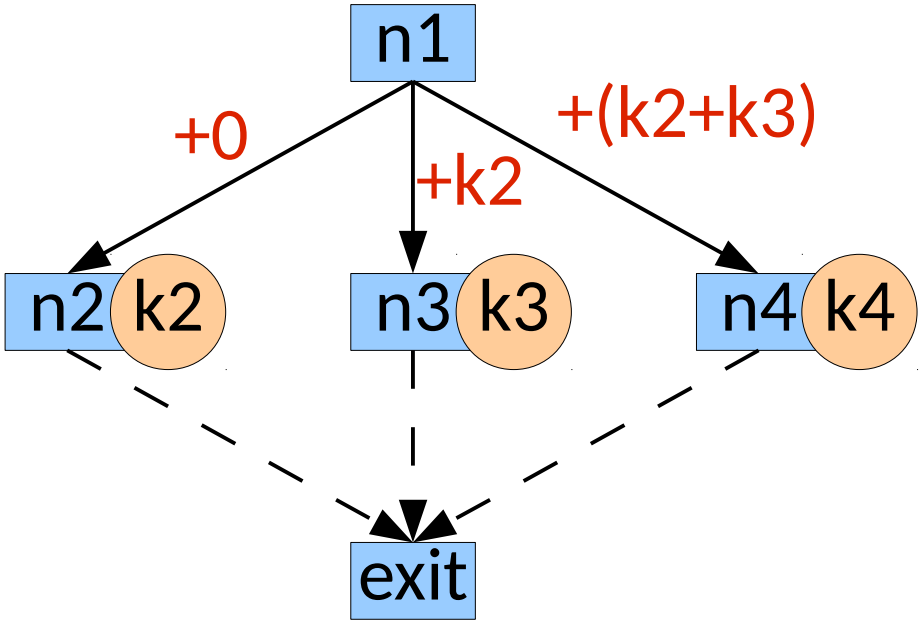

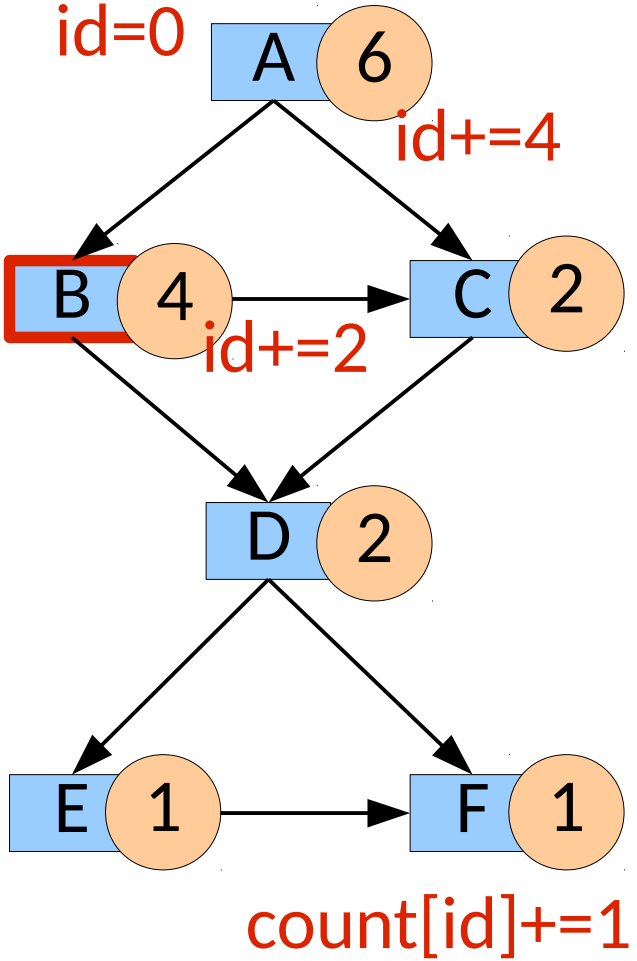

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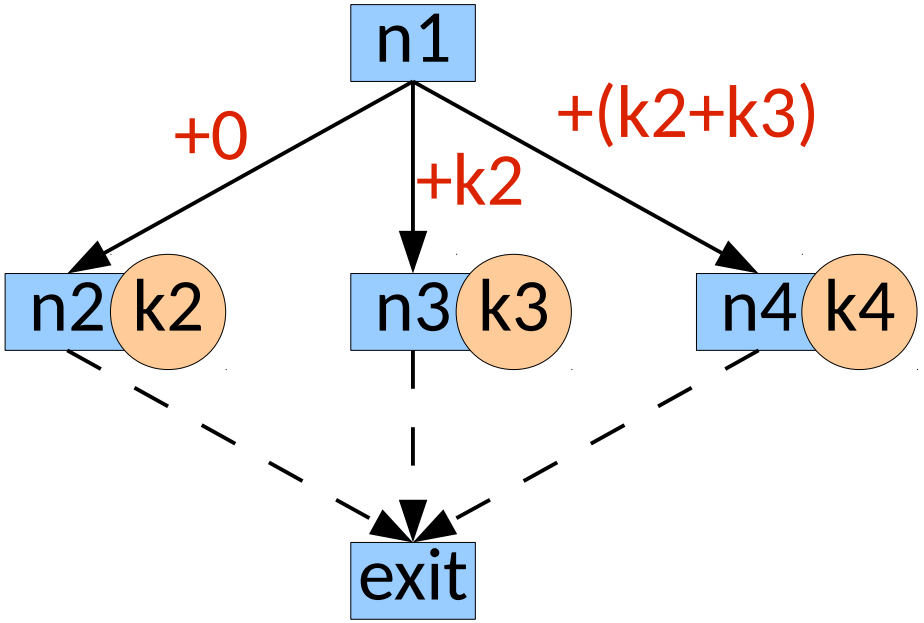

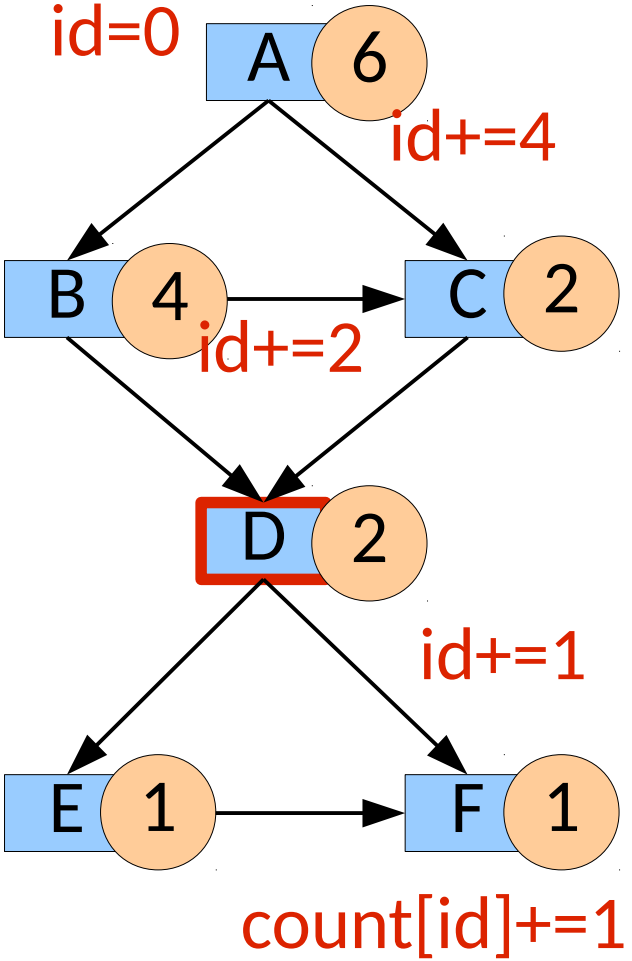

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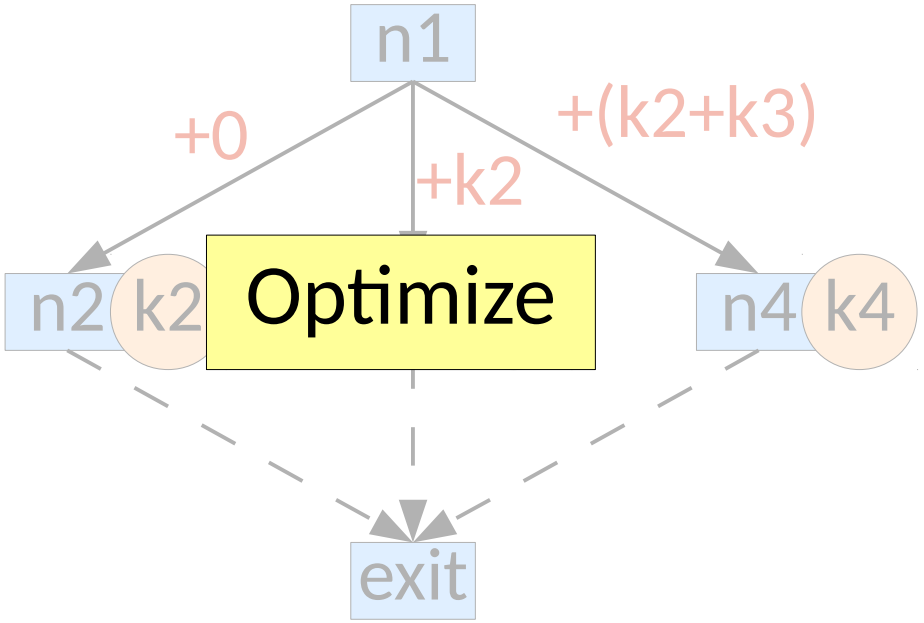
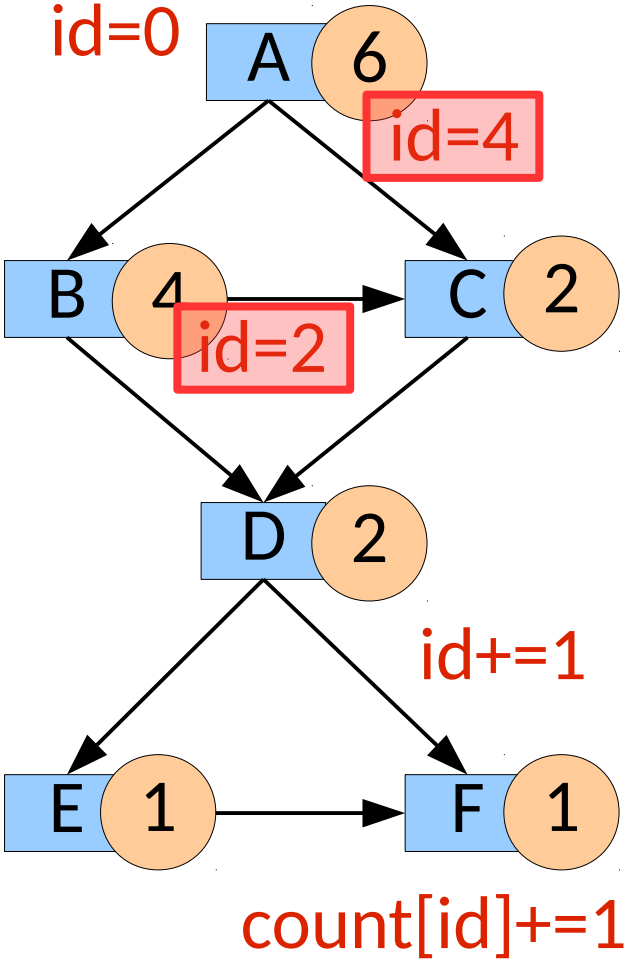
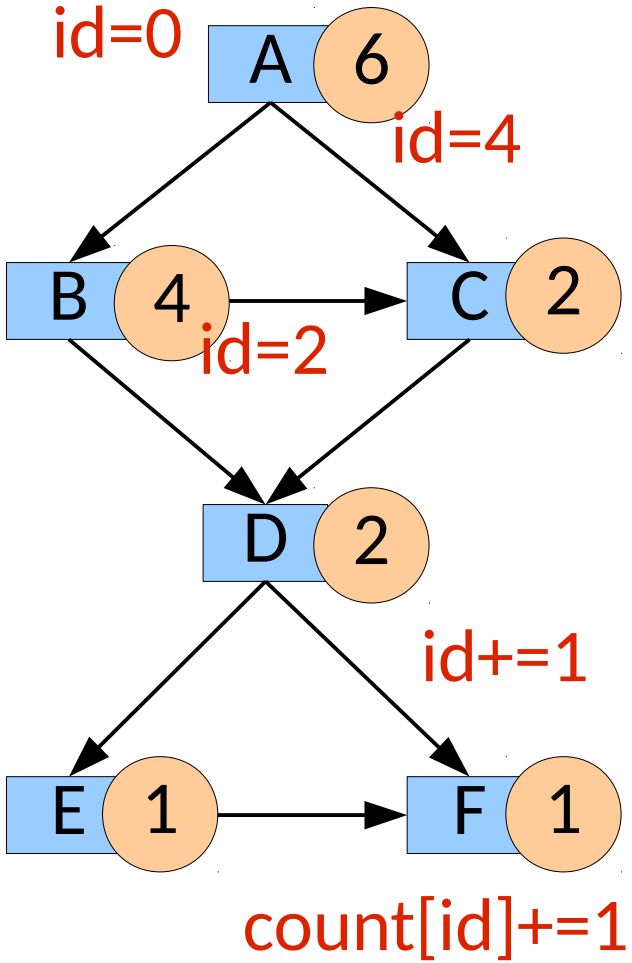




Path Profiling: Decoding

How do we know which IDs map to which paths?



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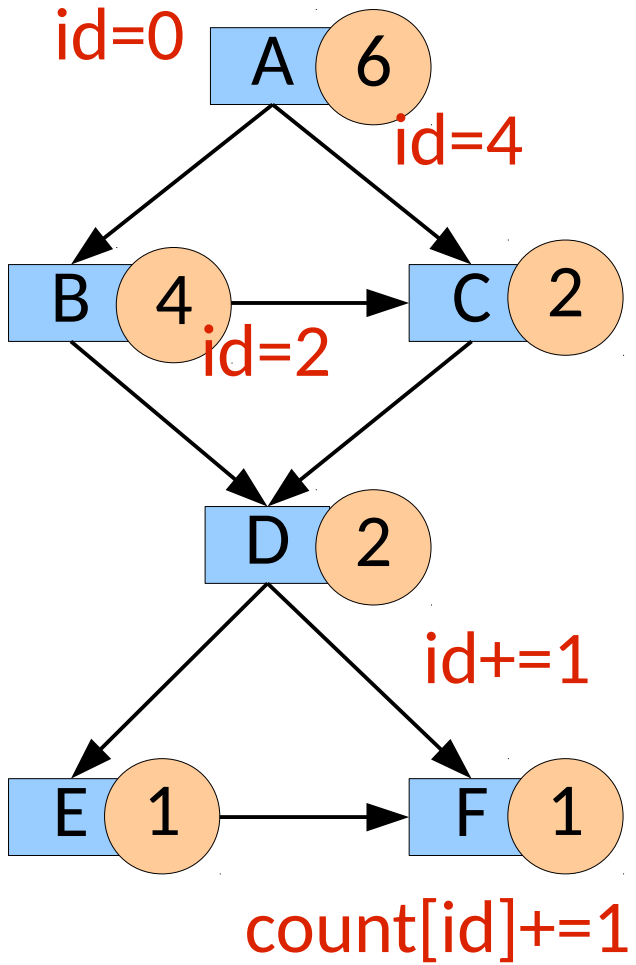

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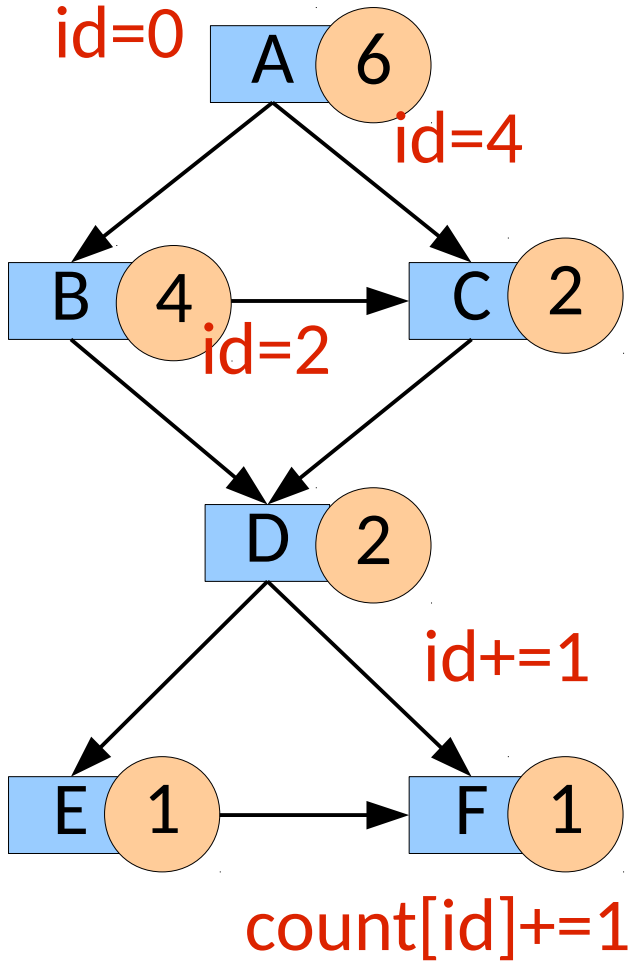

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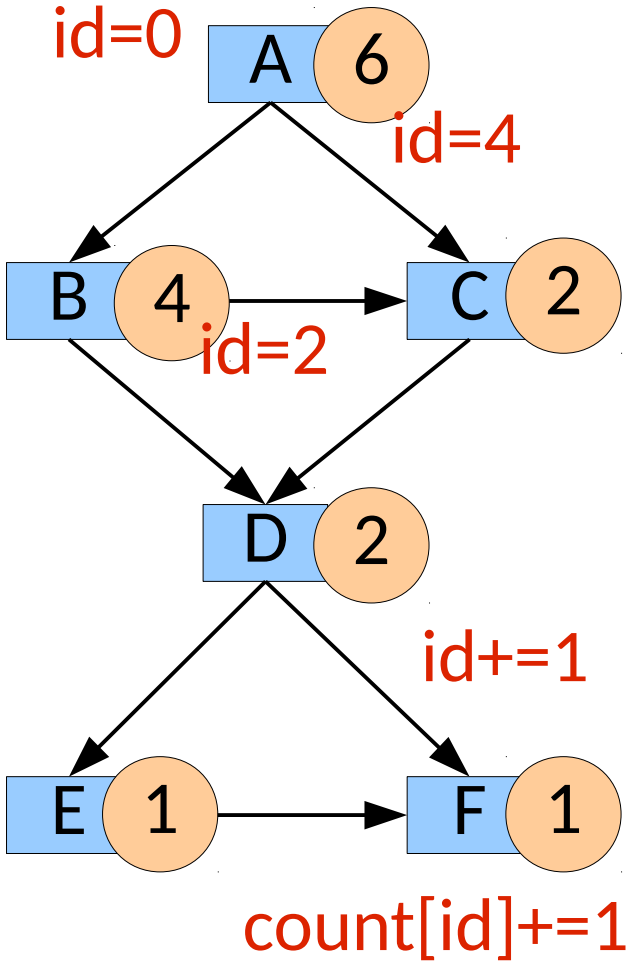

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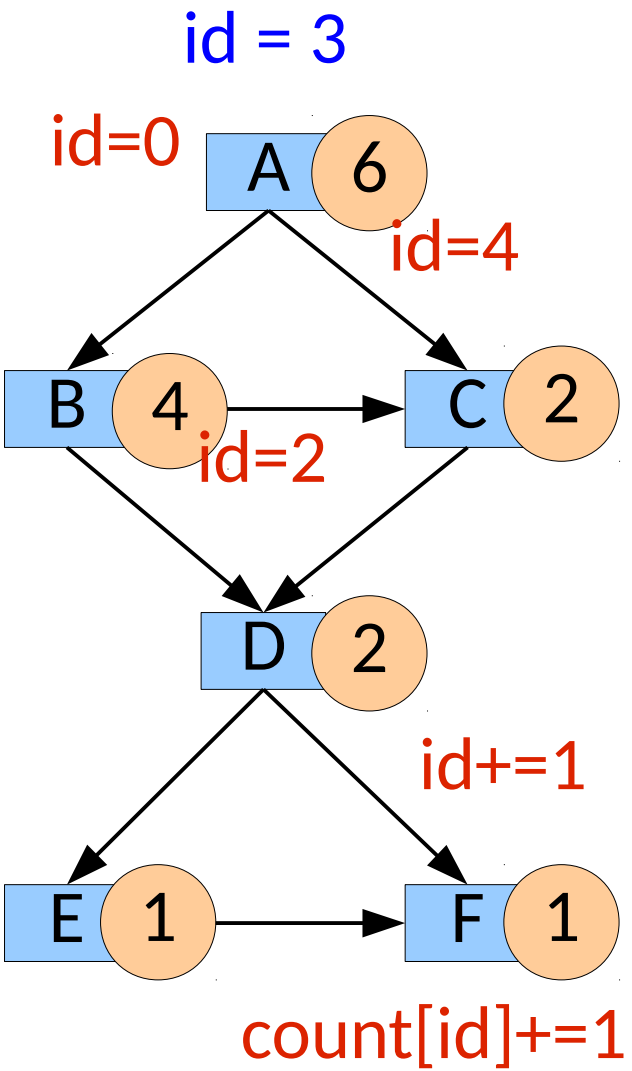

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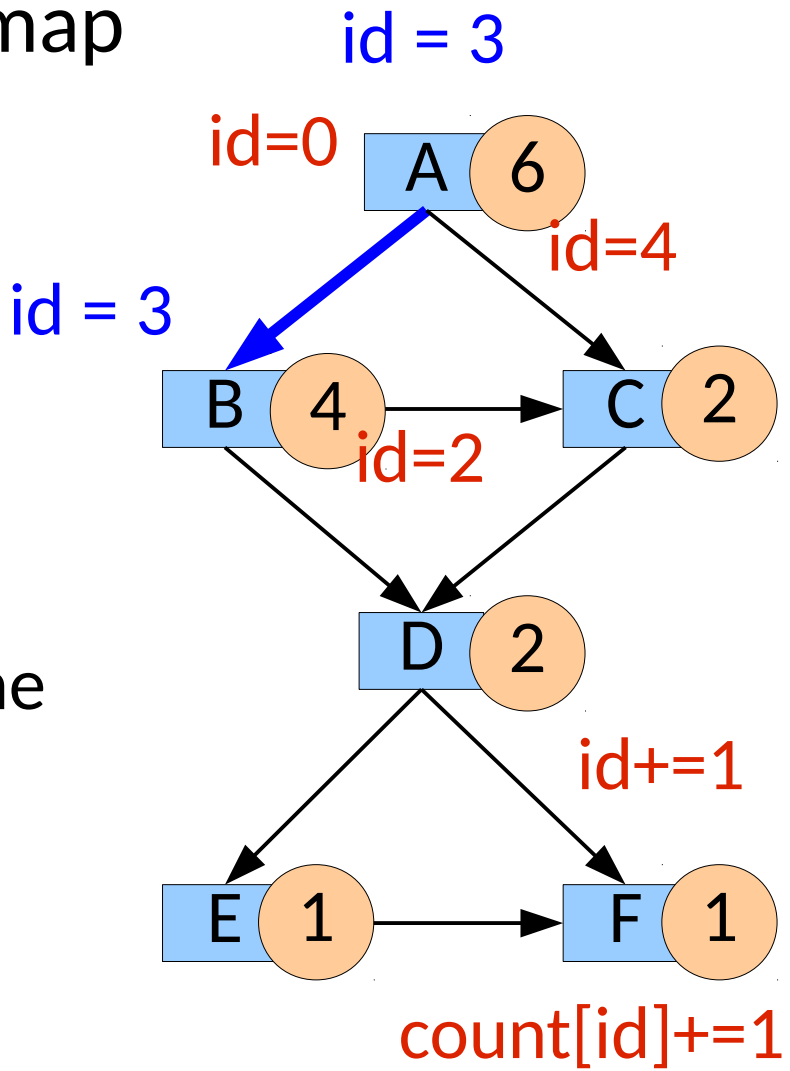

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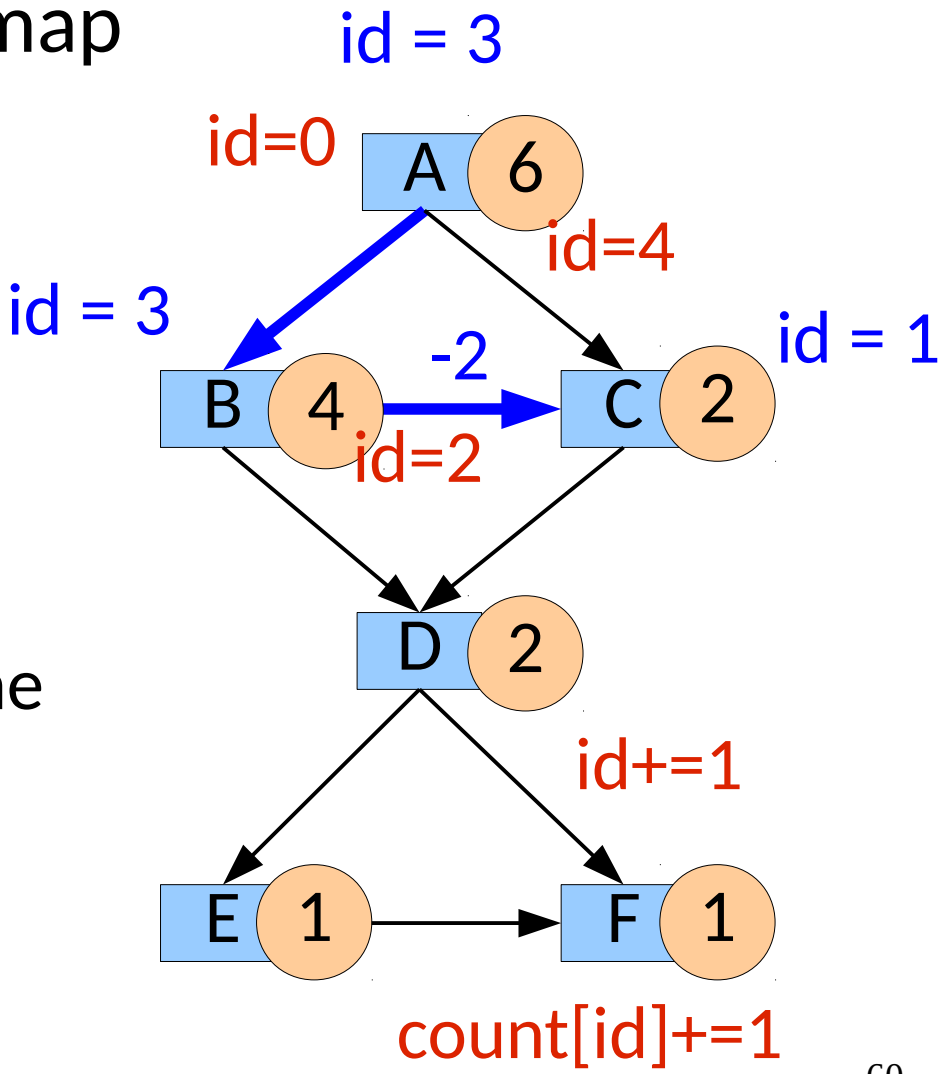

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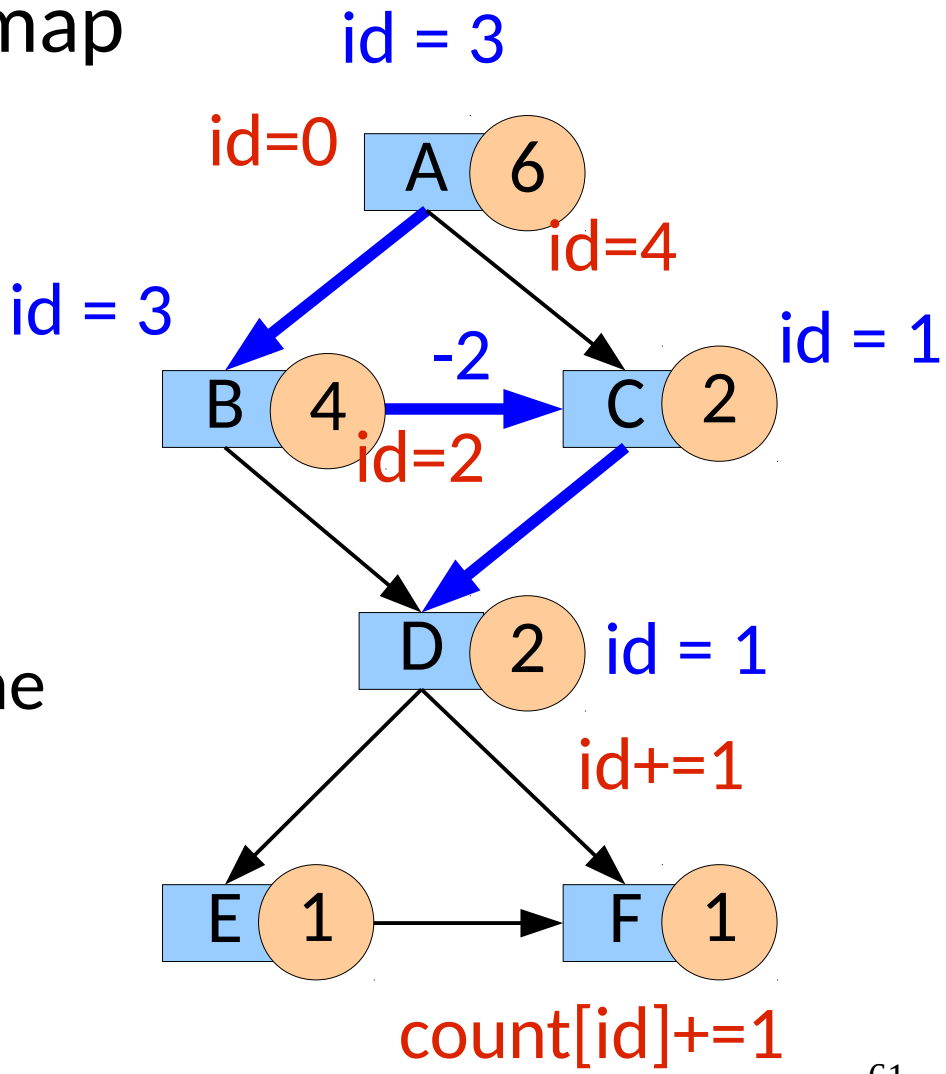

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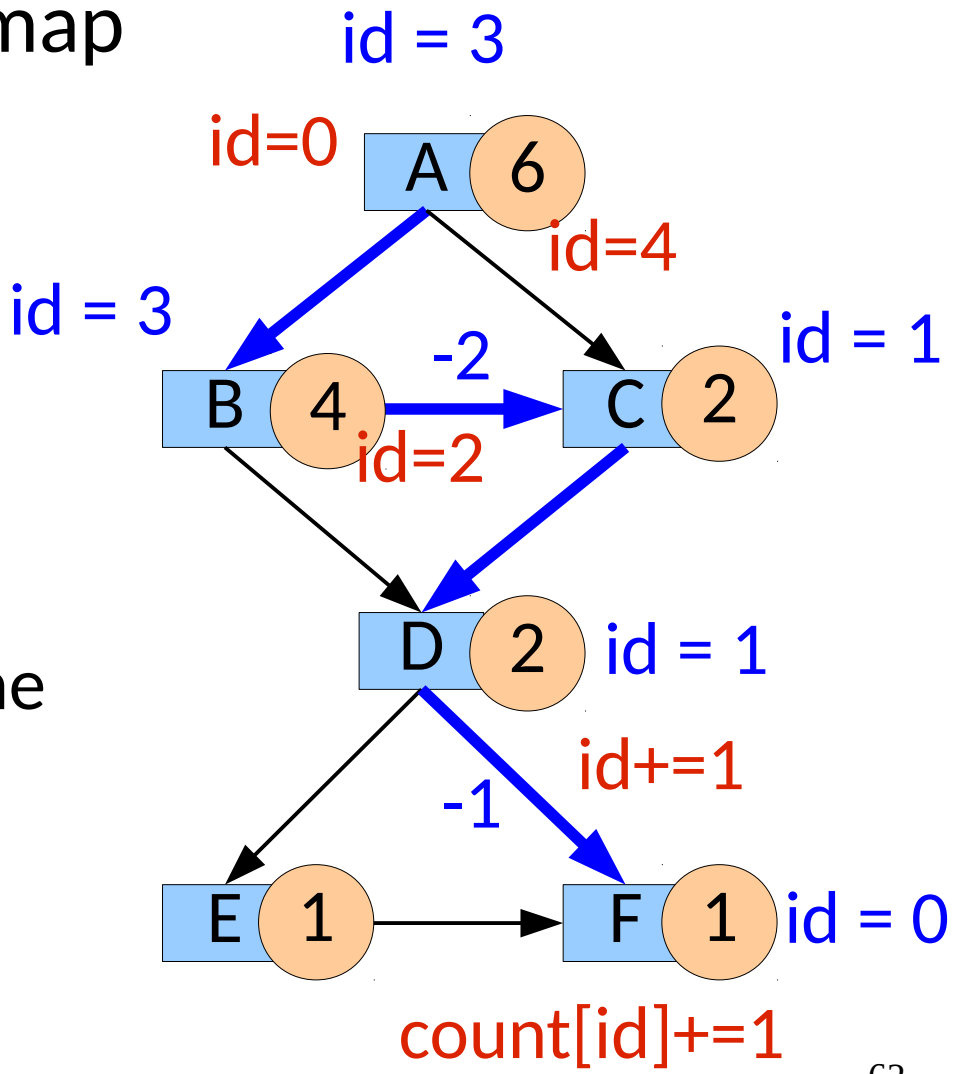

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107.mgrid	872.0	6.3	3.2	2.0	1035.2	1.0	7.7	133.5
110.applu	715.0	71.0	12.0	5.9	2111.4	1.1	99.1	44.8
125.turb3d	1066.0	5.5	7.4	0.7	2952.8	1.1	0.0	56.5
141.apsi	492.0	7.7	1.8	4.2	599.3	1.1	3.5	84.0
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What can/can't you infer from these results?

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What can/can't you infer from these results?

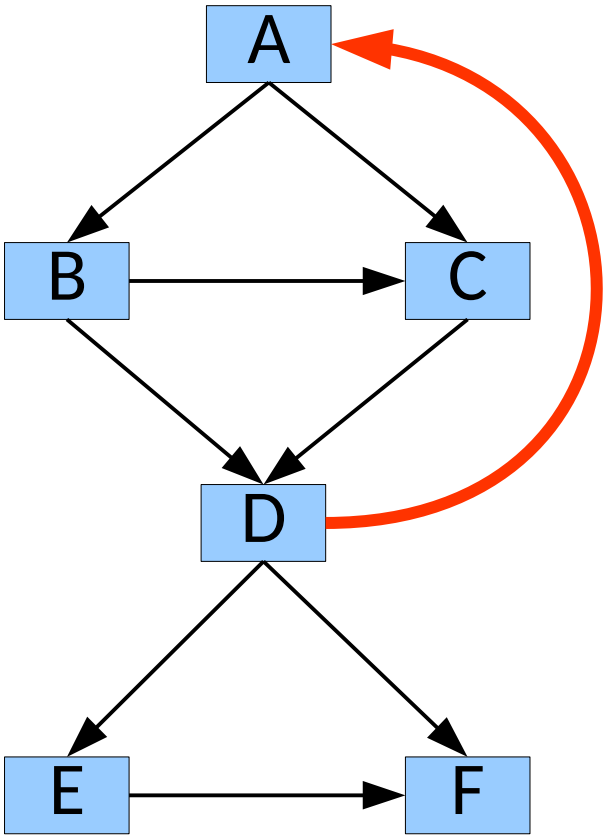
What would you add or change to the evaluation?

Path Profiling

Are there cases where this approach fails?

Path Profiling

- What about loops / cycles?



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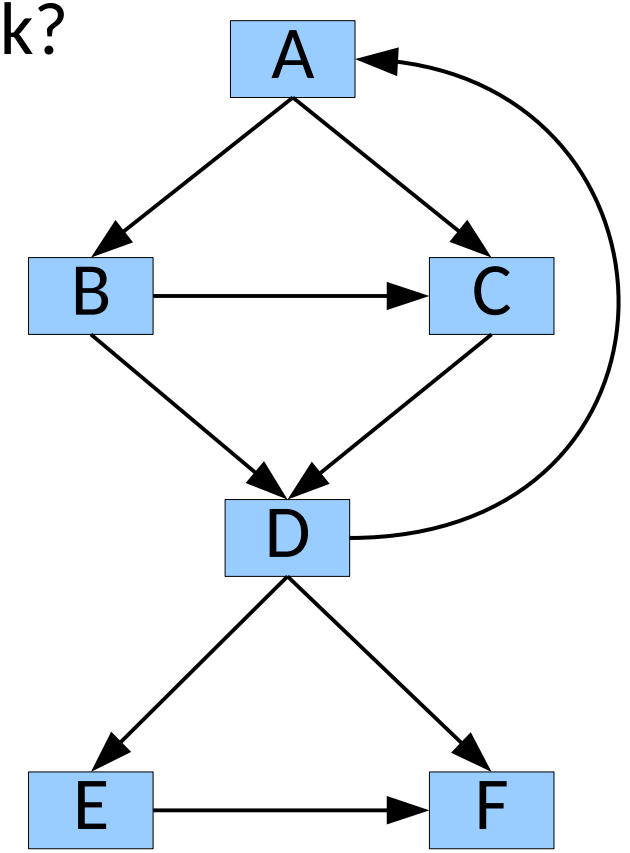

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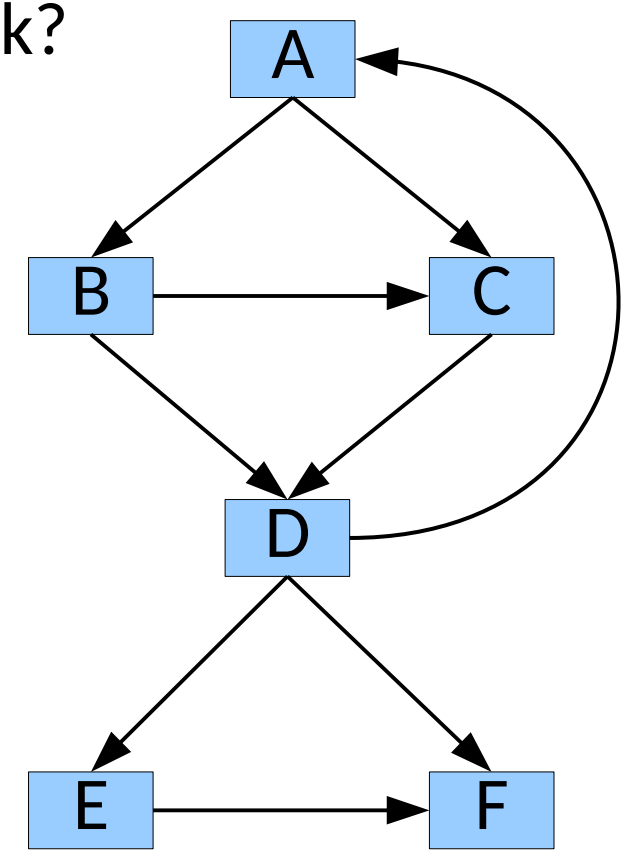

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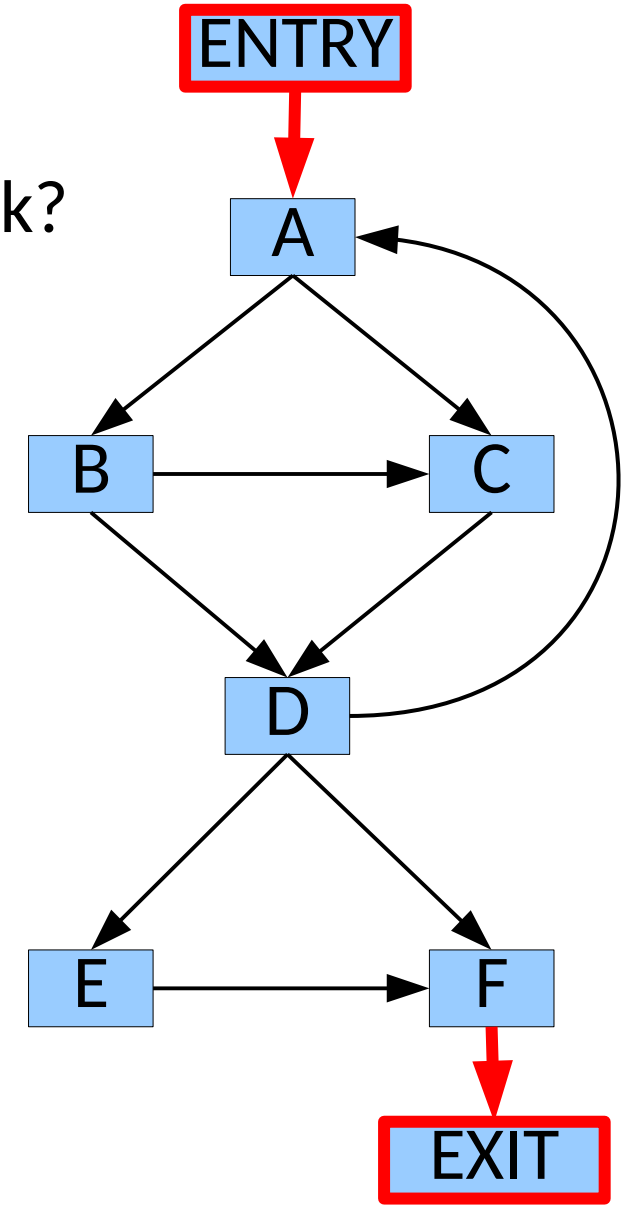

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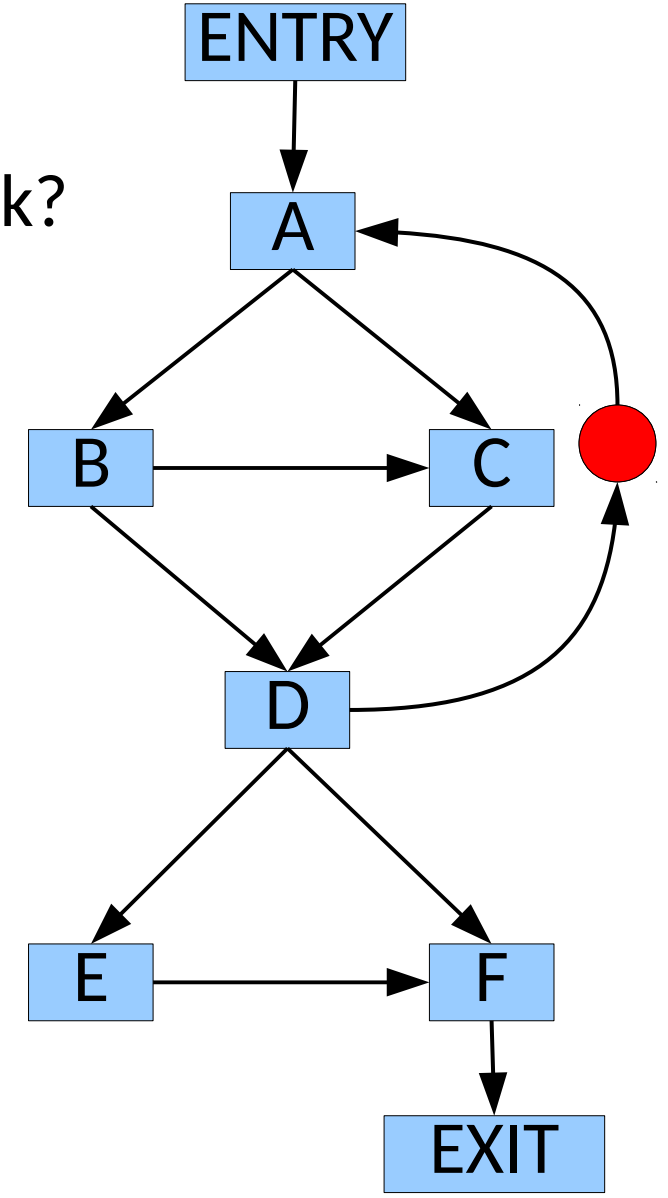

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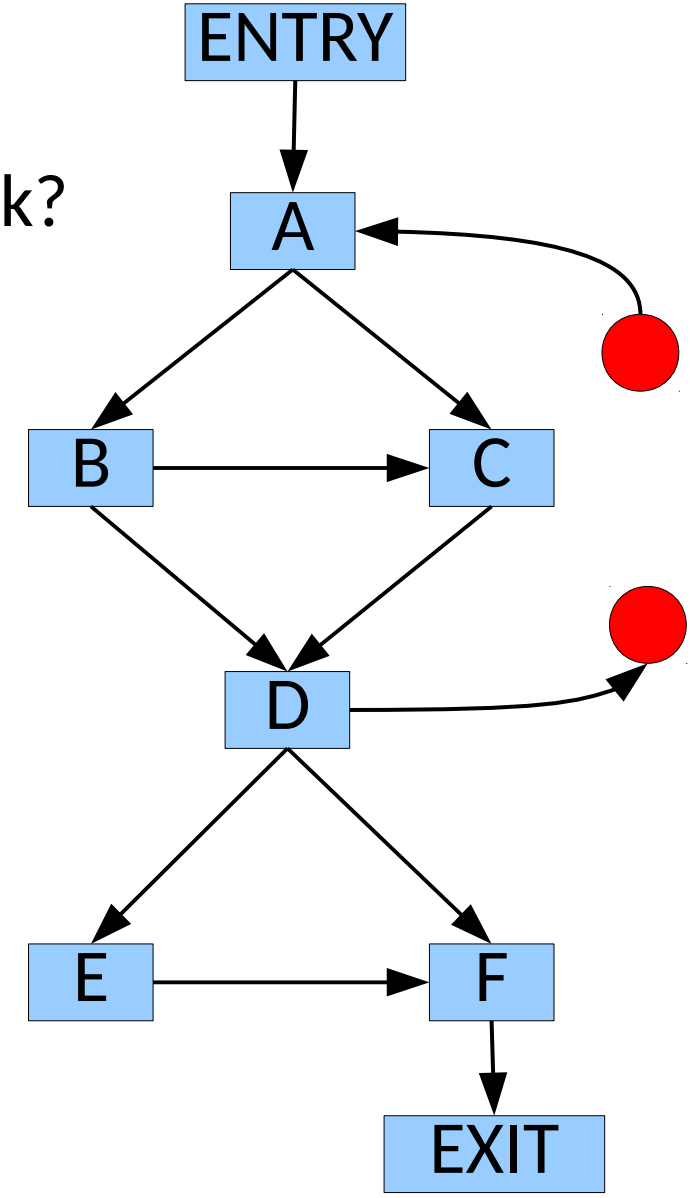

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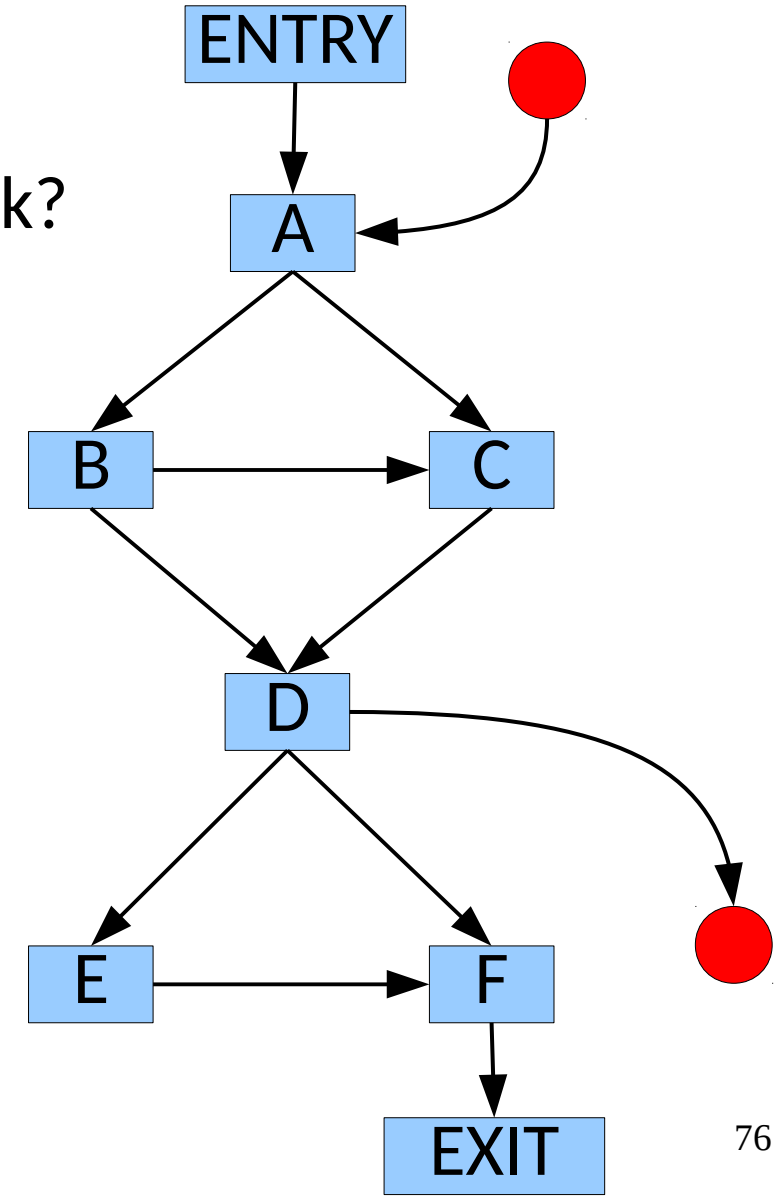

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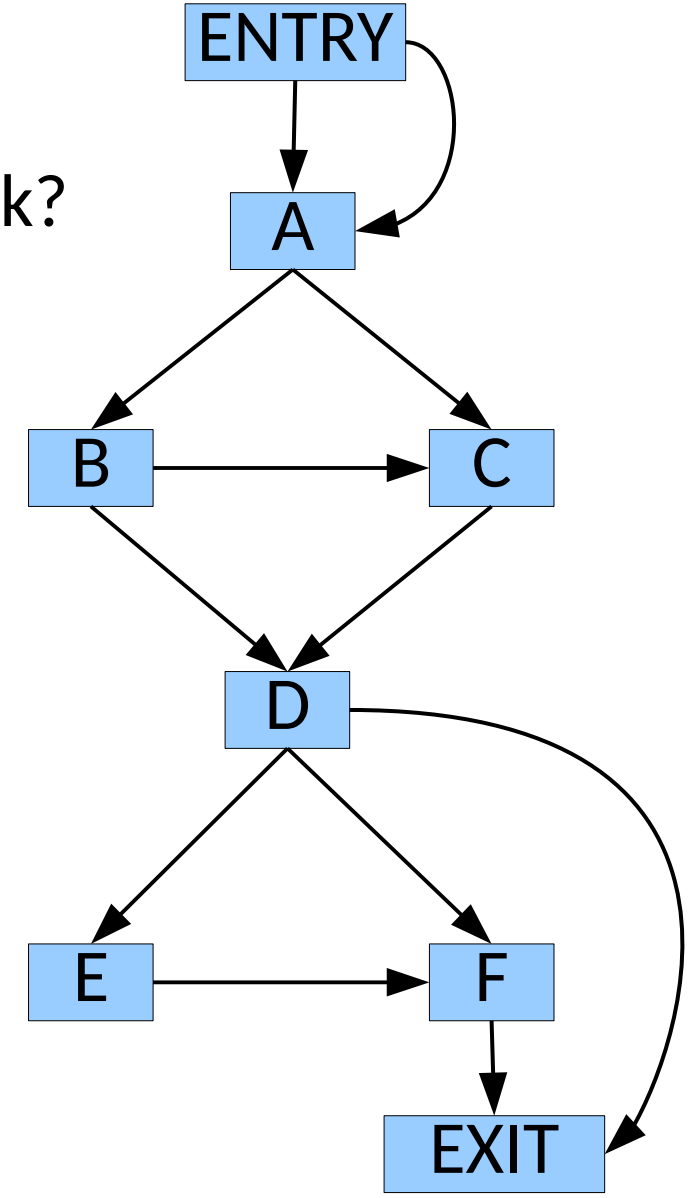

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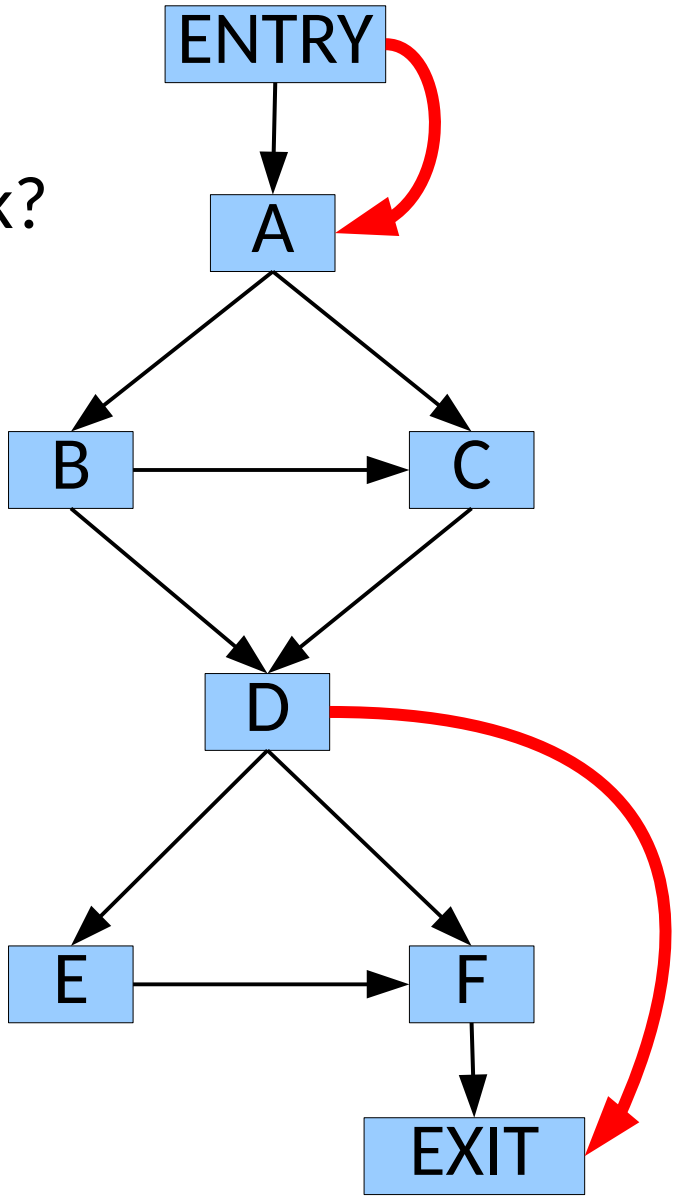
What do these edges encode?



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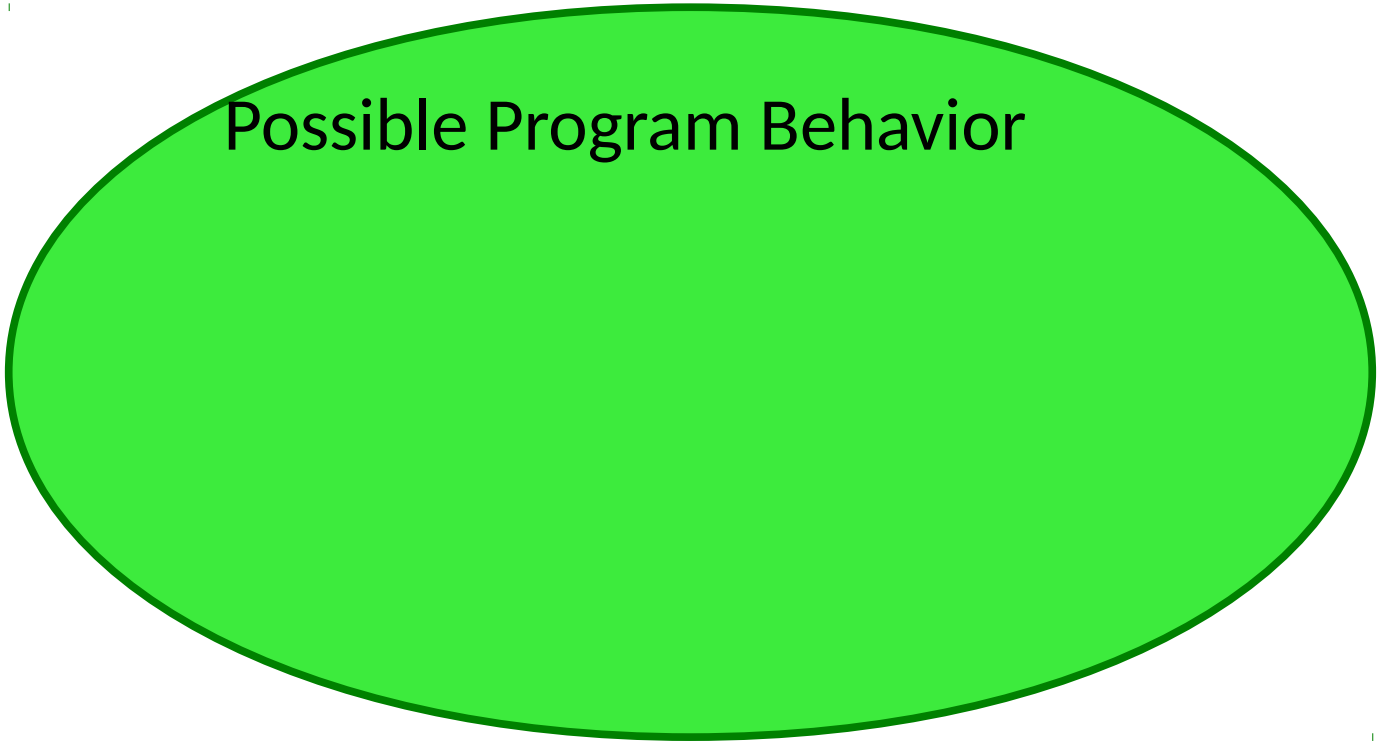
  - "What were frequent paths for this input"
  - "What were frequent paths for this set of inputs"
- What if you don't have an input for the behavior you want to analyze?

Approximation

Modeled program behaviors



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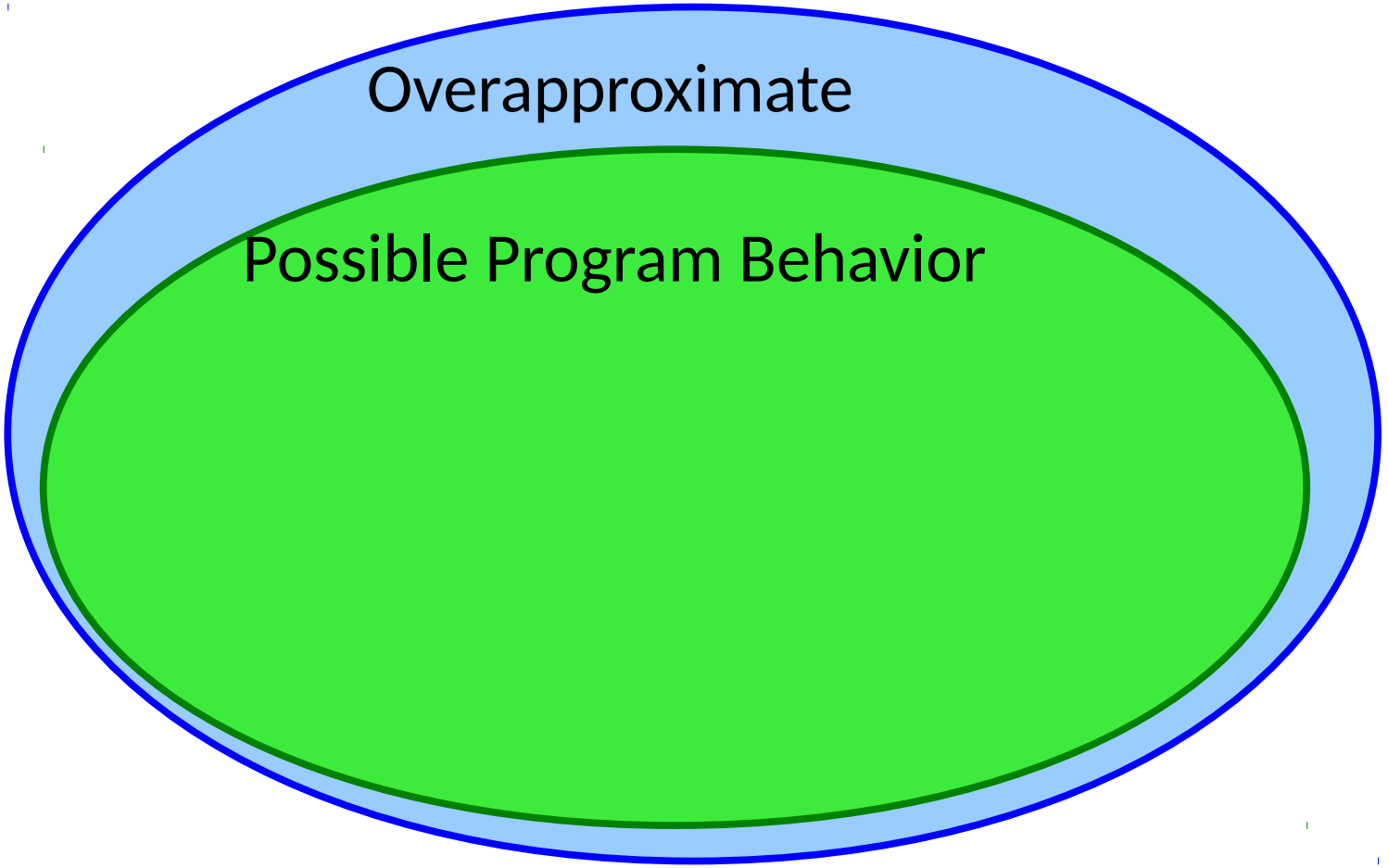
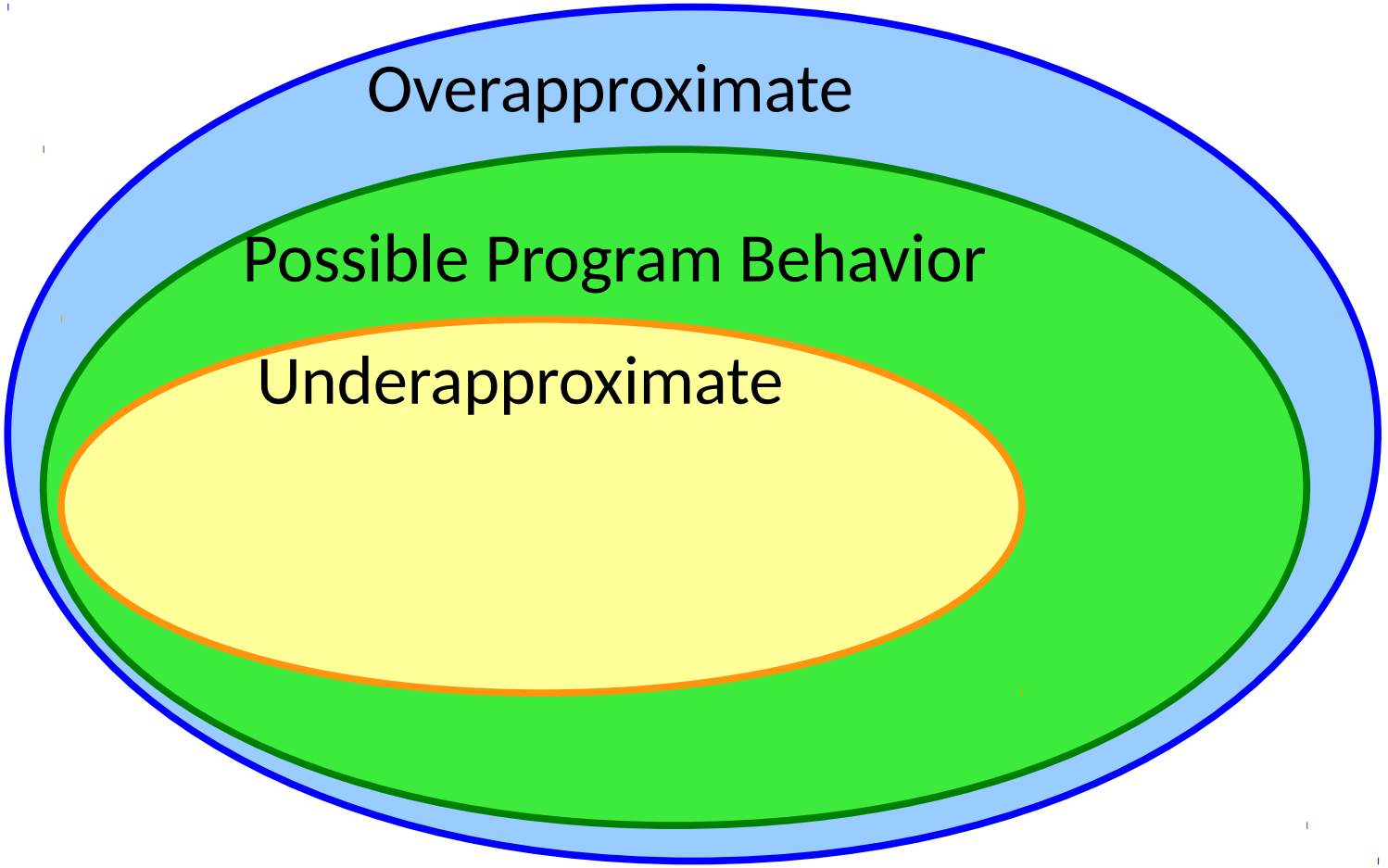


Consider some behaviors possible when they are not.

Approximation

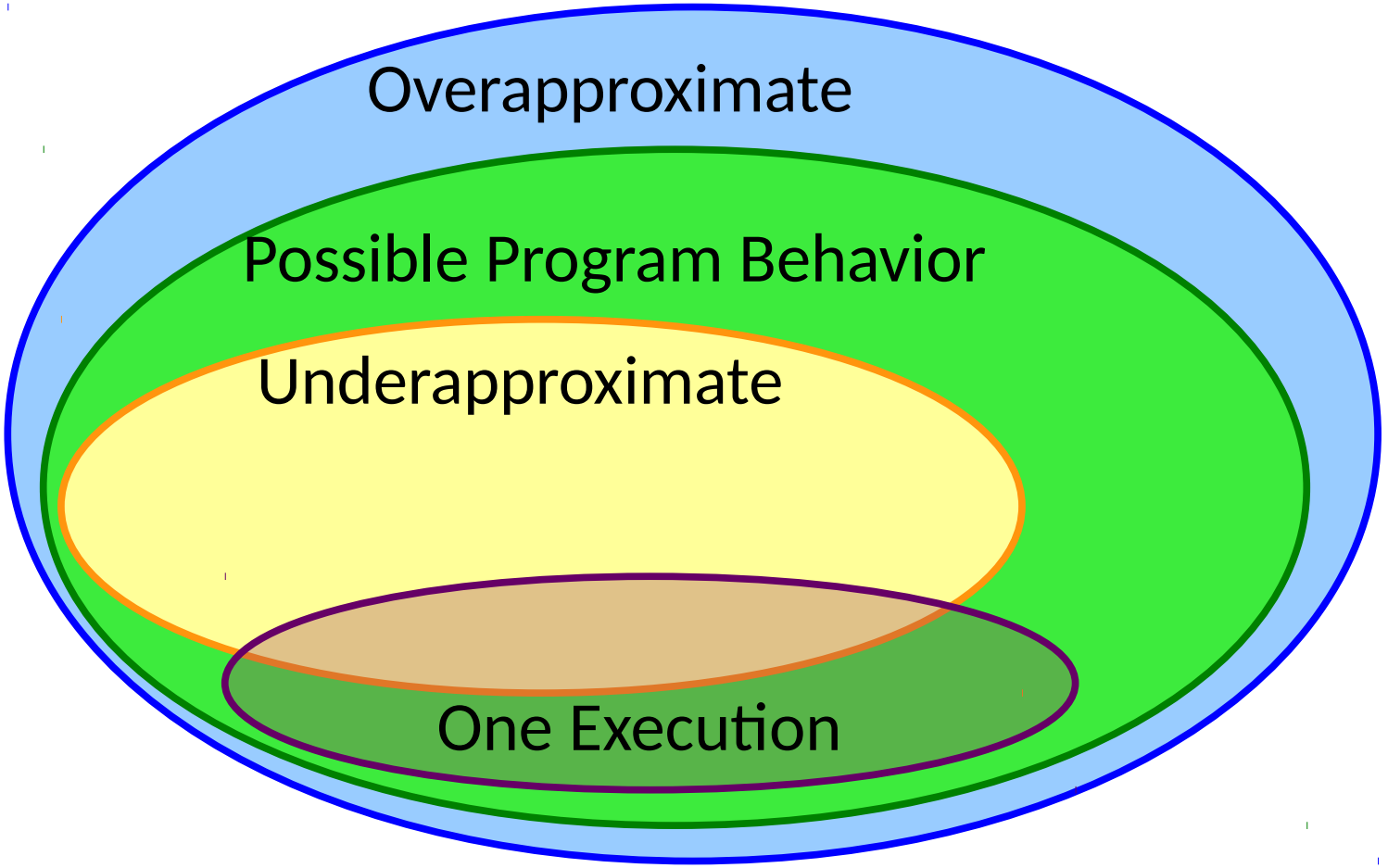
Modeled program behaviors



Ignore some behaviors that *are* possible.

Approximation

Modeled program behaviors



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  - Analyzed ⊆ Feasible

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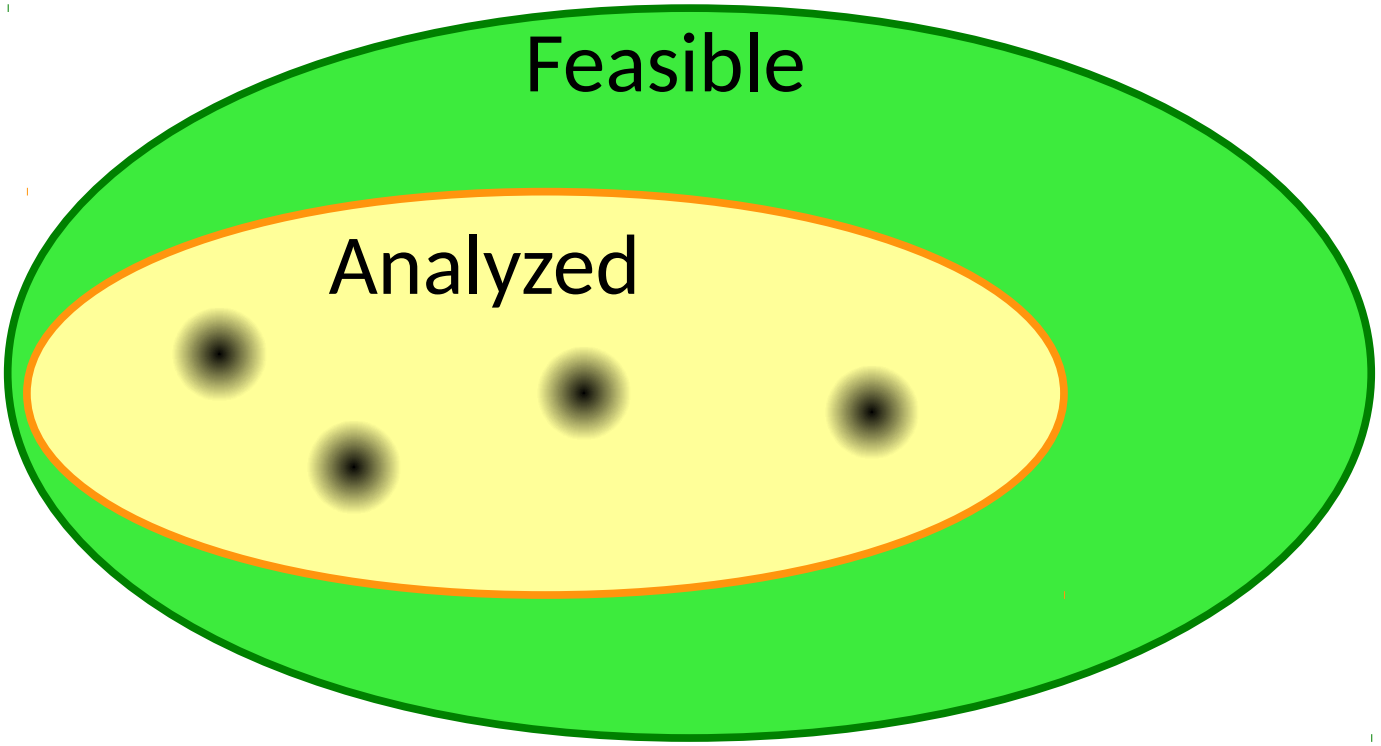
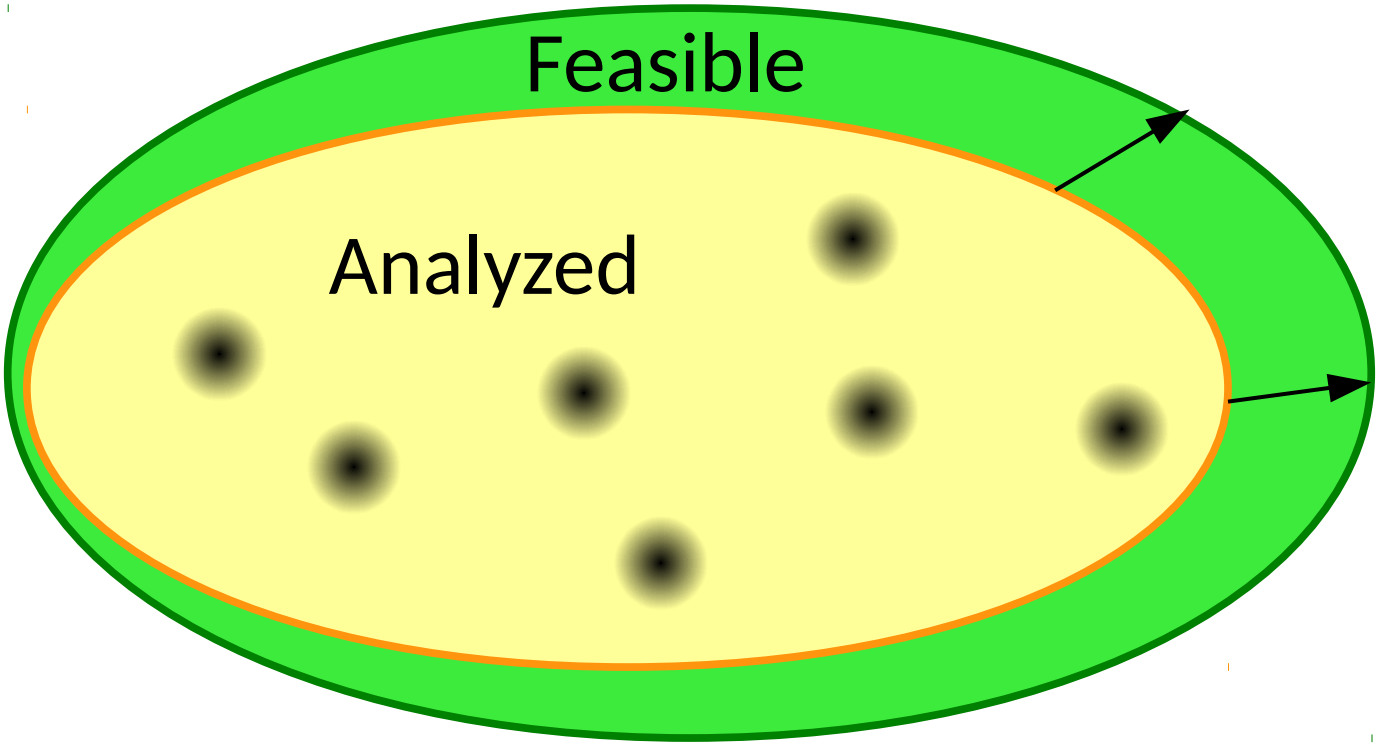


Approximation

- Dynamic Analysis
  - Analyzed ⊆ Feasible
  - As # tests ↑, Analyzed → Feasible



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- Source / IR Instrumentation
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  - During (re)compilation
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- Static Binary Rewriting
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  - Applies to arbitrary binaries
  - Imprecise IR info, but more complete *binary* behavior
- Dynamic Binary Instrumentation
  - Valgrind, Pin, Qemu (& other Vms)
  - Can adapt at runtime, but less info than IR

Phases of Dynamic Analysis

In general, 2-3 phases occur:

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Very, ***very*** common mistake to mix 1 & 2.

Static Instrumentation

1) Compile whole program to IR
2) Instrument / add code directly to the IR
3) Generate new program that performs tracing/analysis
4) Execute

Dynamic Binary Instrumentation

1) Compile program as usual
2) Run program under analysis framework

(Valgrind, PIN, Qemu, etc)

- Instrument & execute in same command:
- Fetch & instrument each basic block individually
- Execute each basic block

```
valgrind --tool=memcheck ./myBuggyProgram
```

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- Address Sanitizer is a built-in dynamic analysis component in the `clang` compiler
- Static instrumentation
- Finds:
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  - {heap,stack,global}-buffer overflows
- Used extensively in Google programs like Chrome

Example: Address Sanitizer

How?

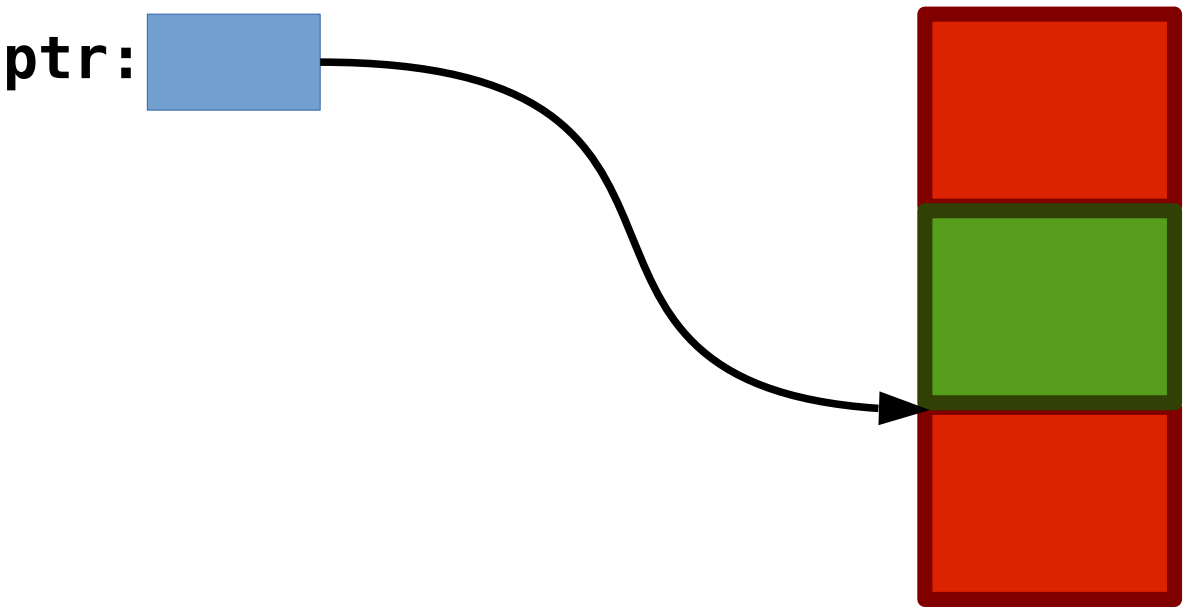
- Replaces `malloc` & `free`

Example: Address Sanitizer

How?

- Replaces `malloc` & `free`
- Memory around malloced chunks is *poisoned*

```
ptr = malloc(sizeof(MyStruct));
```



Example: Address Sanitizer

How?

- Replaces `malloc` & `free`
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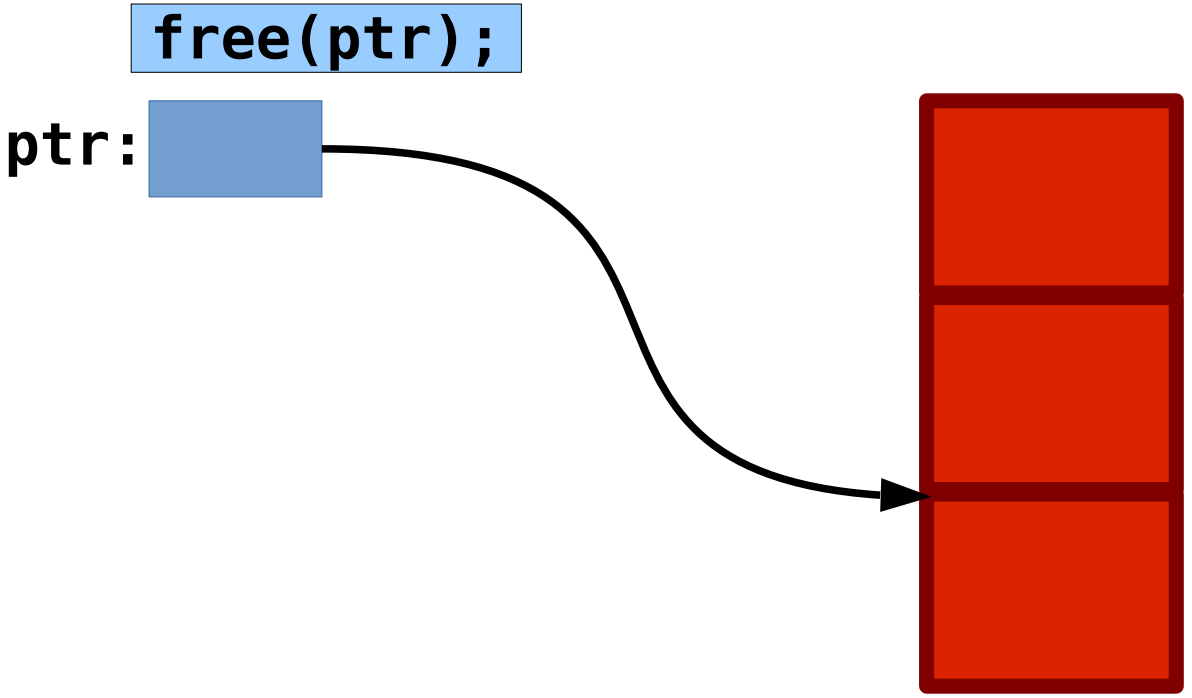
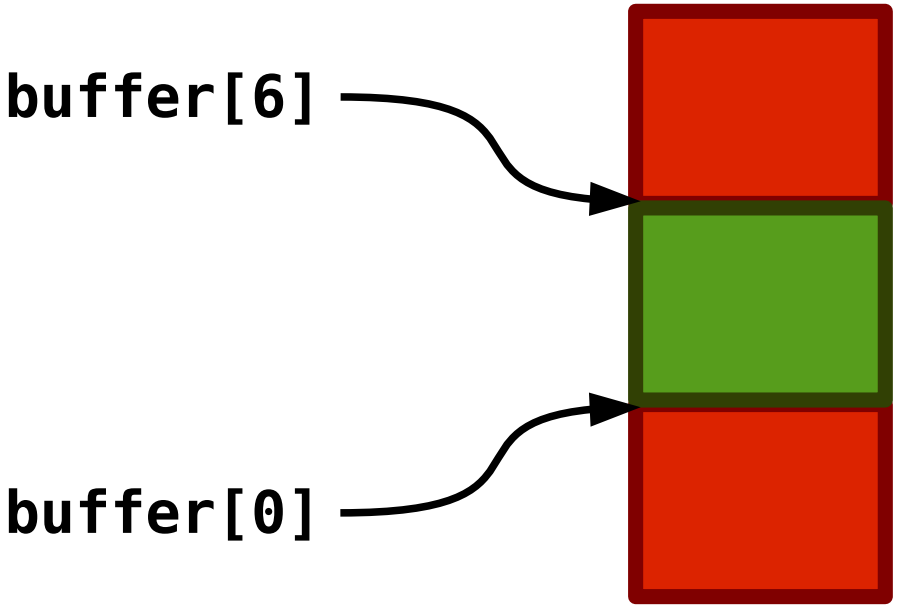


Example: Address Sanitizer

How?

- Replaces `malloc` & `free`
- Memory around malloced chunks is *poisoned*
- Freed memory is *poisoned*
- Space around buffers is *poisoned*

```
void foo() {
  int buffer[5];
}
```



Example: Address Sanitizer

How?

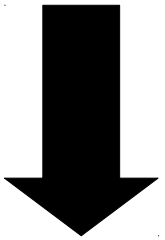
- Replaces `malloc` & `free`
- Memory around malloced chunks is *poisoned*
- Freed memory is *poisoned*
- Space around buffers is *poisoned*
- Any access of a poisoned value reports an error.

...

Example: Address Sanitizer

How?

```
*address = ...
```



Instrumentation

Example: Address Sanitizer

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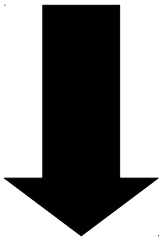

Instrumentation

```
if (IsPoisoned(address)) {
  ReportError(address, kAccessSize, kIsWrite);
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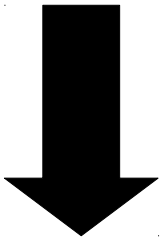

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if (IsPoisoned(address)) {
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Difficult! Why?

- Instrumenting every memory access is costly
- Tracking the status of *all memory* is tricky

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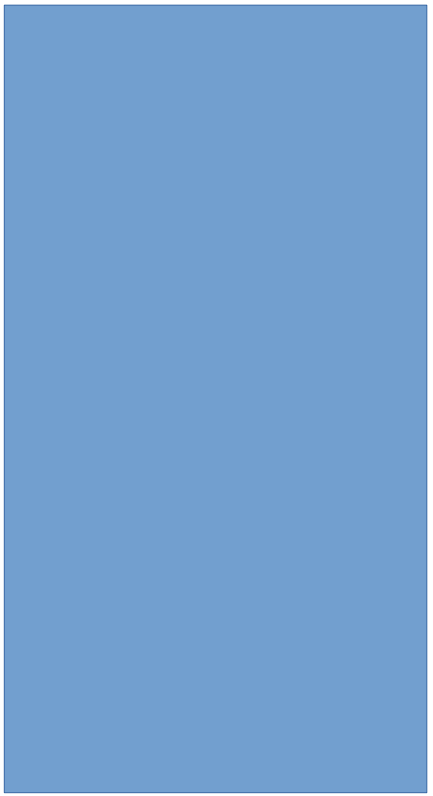
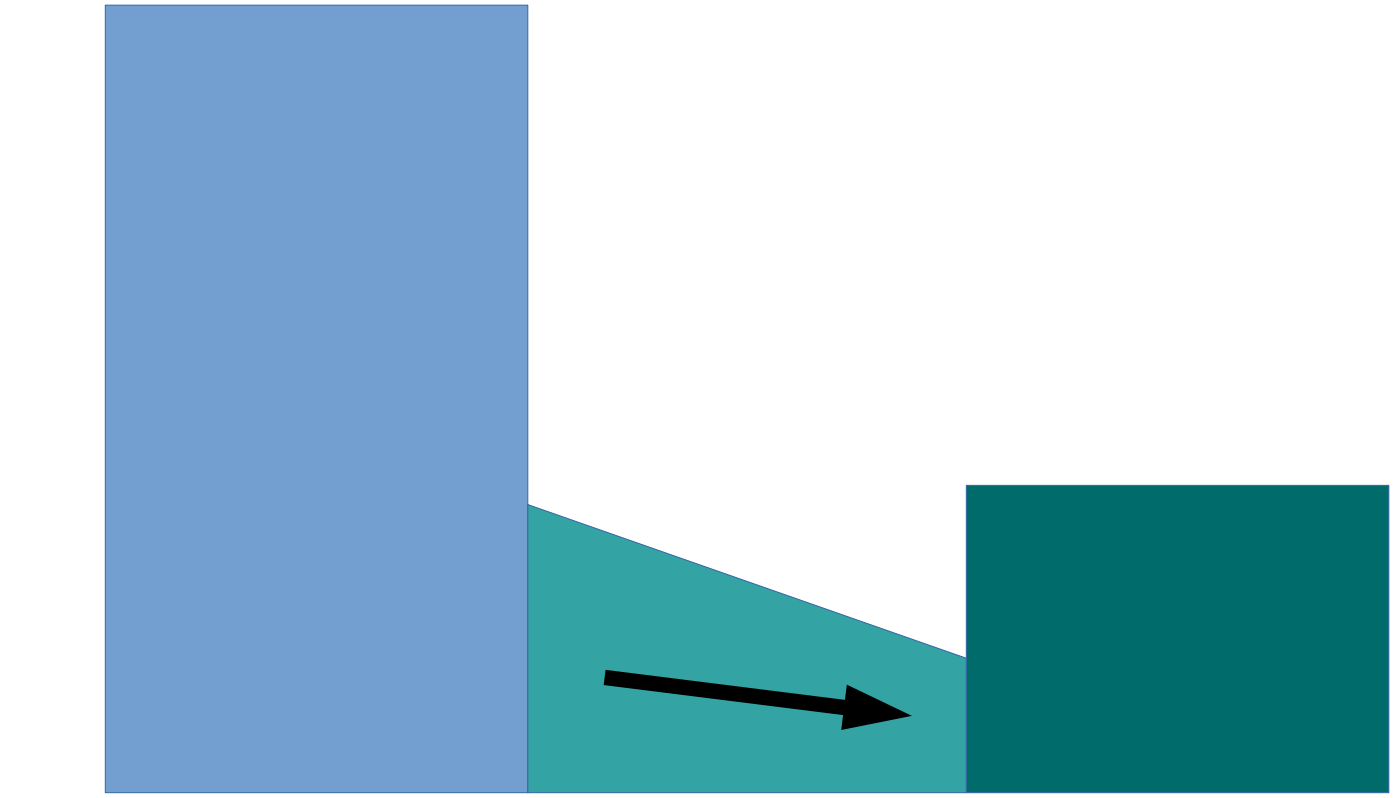


Application Memory

Need to know whether *any byte* of application memory is poisoned.

Example: Address Sanitizer

- Maintain 2 views on memory:



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Where have you encountered this before?
(Think OS)

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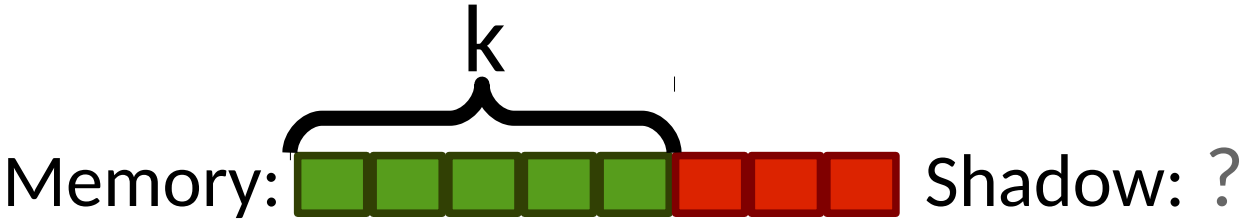
  - In an 8 byte chunk, only first k may be addressable



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Memory:  Shadow: 0

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Memory:  Shadow: -1

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  - All 8 bytes unpoisoned: shadow value is 0.
  - All 8 bytes poisoned: shadow value is negative.
  - First k bytes are unpoisoned: shadow value is k.

Memory:  Shadow: 5

Example: Address Sanitizer

- (64bit) Shadow Mapping:
  - Preallocate large block of memory
  - Shadow = (Mem >> 3) + 0x7fff8000;

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- (64bit) Shadow Mapping:
  - Preallocate large block of memory
  - Shadow = (Mem >> 3) + 0x7fff8000;
- The shadow memory itself must also be considered poisoned.

Why?!

Dynamic Analysis

- Analyze the actual/observed behaviors of a program.

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- Analyze the actual/observed behaviors of a program.
- Modify the program's behavior in order to collect information.
- Analyze this information either online or offline.

Moving Forward

- Yet often you will want to deeply analyze a program without running it at all…