

關於生命週期的一點事兒

The relationship of Lifetimes and DataFlow

Rnic / H.-S. Zheng

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Audience

- 讀過 Rust Book
- 想要了解編譯器怎麼看待 Lifetimes
- 對編譯器有那麼一點興趣
- ~~想要輕鬆駕馭 Rust's Lifetimes~~
- ~~想要快快樂樂寫 Rust~~

Outline

- 1. Introduction
 - Example1
 - Basic Lifetimes Concepts
- 2. Borrow Checker
 - Collaborate with Data Flow
 - Example2
 - Datafrog (a datalog engine used in Polonius)

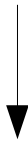
Compilation of Rust

Rust Code

```
let foo: T = Foo {};  
let bar: T = Bar {};  
  
let mut p = &foo;  
  
if cond {  
    println!("{}", *p);  
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    p = &bar;  
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}  
  
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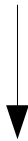


HIR

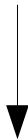
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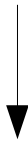
MIR



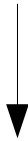
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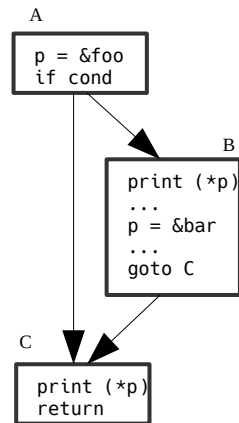
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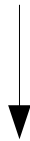
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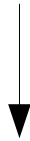
Control Flow Graph

Compilation of Rust

Rust Code



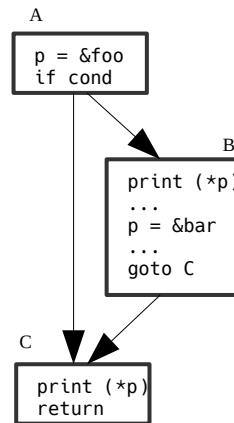
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Control Flow Graph



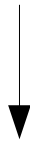
Borrow checker

Theorem: Data Flow Analysis

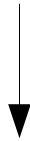
Tool: Datafrog

Compilation of Rust

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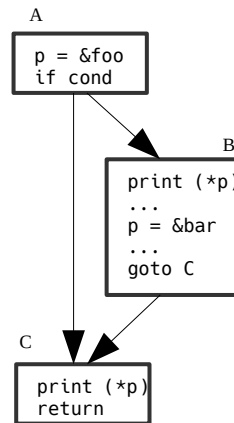
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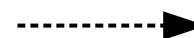


Control Flow Graph

Documents

NLL RFC:
2094-nll

Polonius:
an-alias-based-formulation
-of-the-borrow-checker



Borrow checker

Theorem: Data Flow Analysis

Tool: Datafrog

Example

```
fn list_not(mut head: Option<Box<ListNode>>) -> Option<Box<ListNode>>
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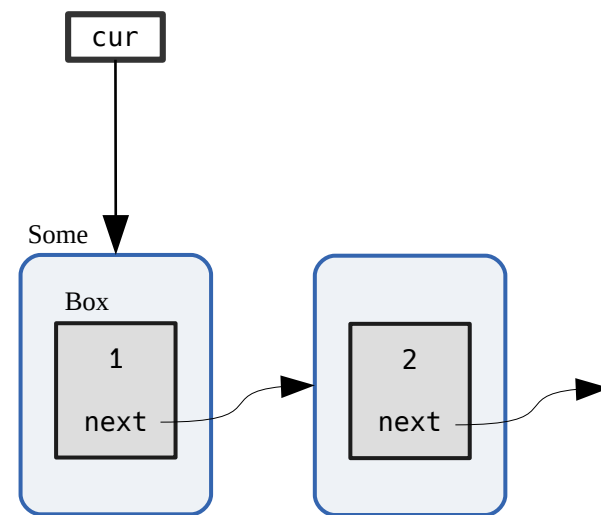
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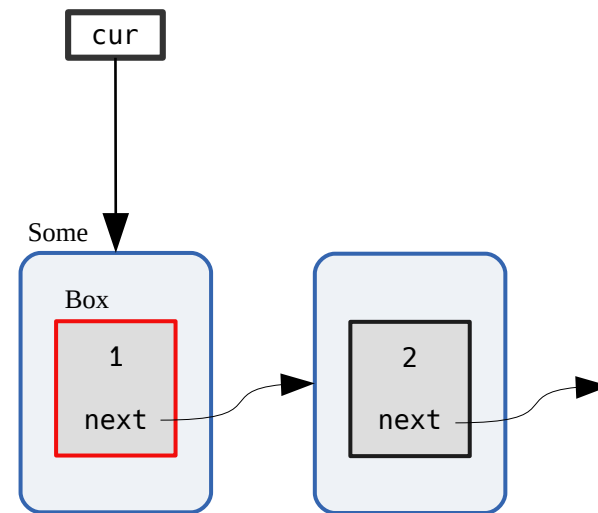


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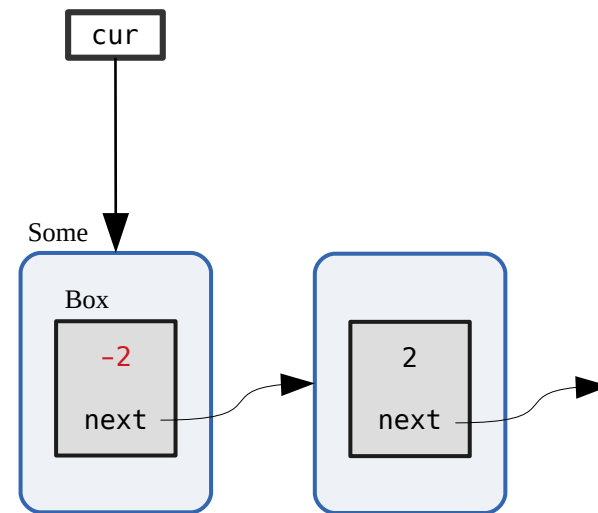
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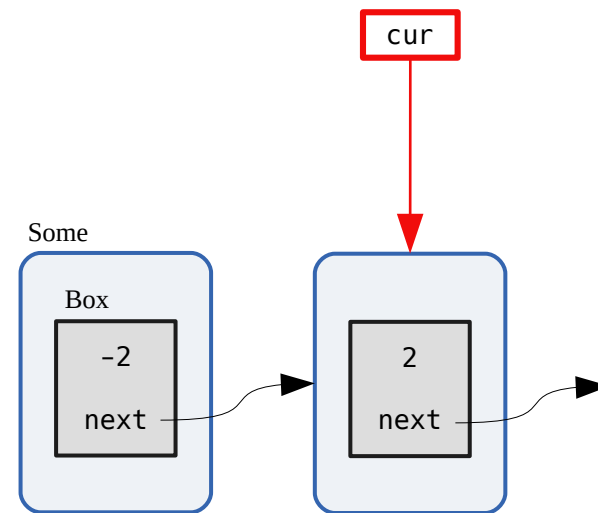
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依照使用區間判斷

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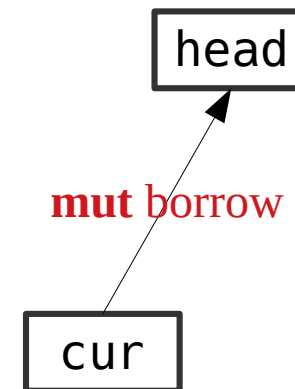
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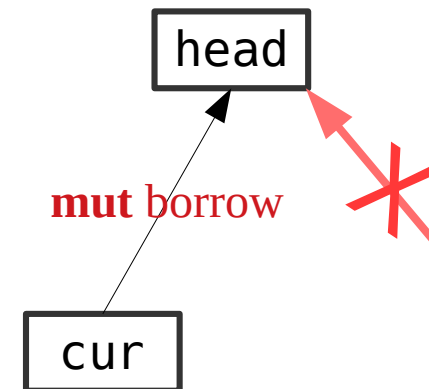
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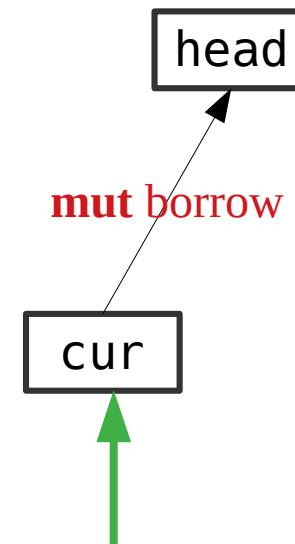
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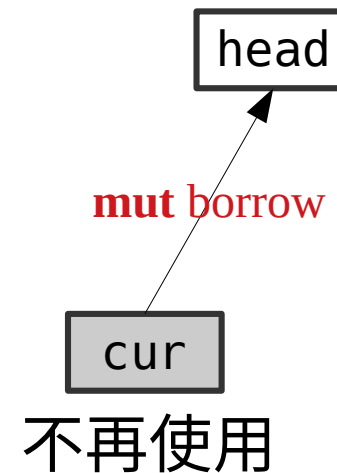
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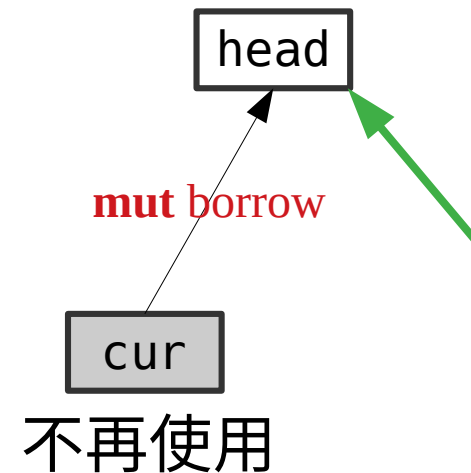


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```



依照使用區間判斷

```
fn list_not(mut head: Option<Box<ListNode>>) -> Option<Box<ListNode>>
```

```
{
```

```
    let mut cur = &mut head;
```

`cur` only used here

```
    while let Some(nodeBox) = cur.as_mut() {
```

```
        nodeBox.val = !nodeBox.val;
```

```
        cur = &mut nodeBox.next;
```

```
    }
```

head

```
}
```

head

mut borrow

cur

不再使用

Borrow

P_0 : **let** r : $\&T$

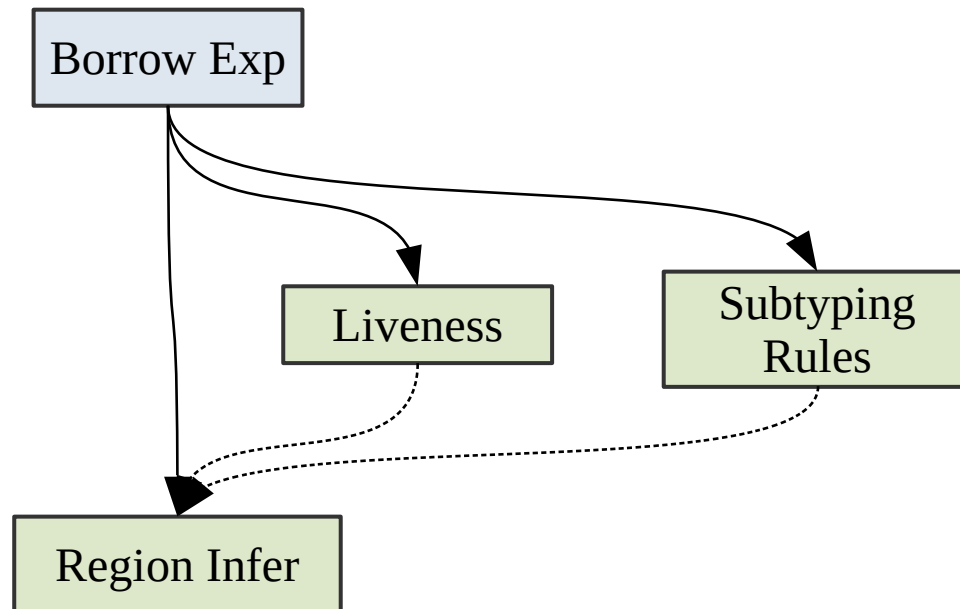
P_1 : $r = \&x$;

Borrow Exp

Borrow

P_0 : **let** r : $\&'0$ T

P_1 : $r = \&'1$ x ;



Borrow

 $P_0 : \text{let } r : \&'0 \text{ T}$
 $P_1 : r = \&'1 x;$

Borrow Exp

Liveness

Subtyping
Rules
 $'0 : \{ P_1, P_2, \dots \}$
 $('1 : '0) @ P_1$

Region Infer

 $'0 : \{ P_1, P_2, \dots \}$
 $'1 : \{ P_1, \dots \}$

Borrow

Each Borrow expression will
corresponding to each Loan

```

Loan L0 {
  point: P1,
  path: x,
  kind: shared
  region: '1 {
    P1 ...
  }
}
  
```

$P_0 : \text{let } r : \&'0 \text{ T}$

$P_1 : r = \&'1 x;$

Borrow Exp

Liveness

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Region Infer

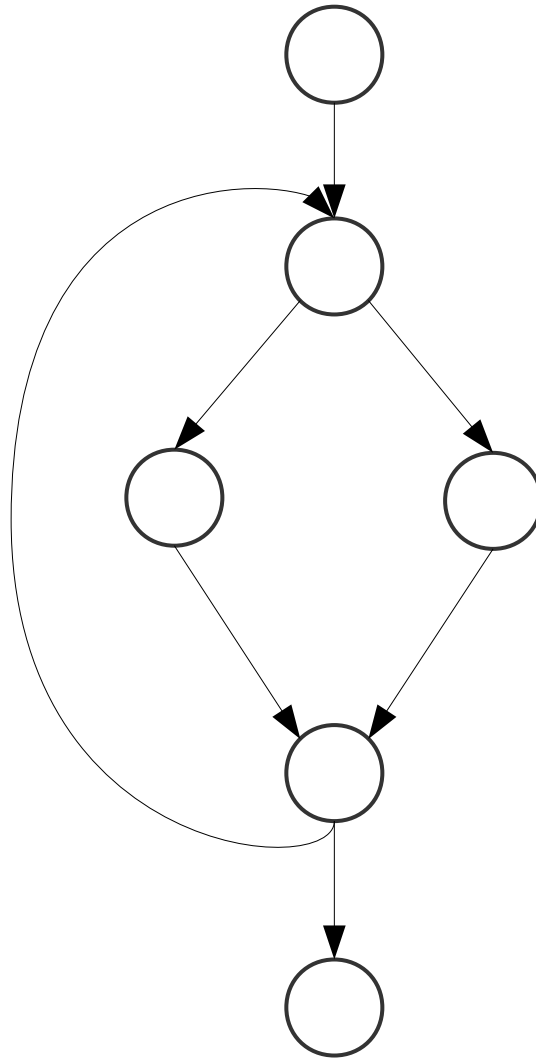
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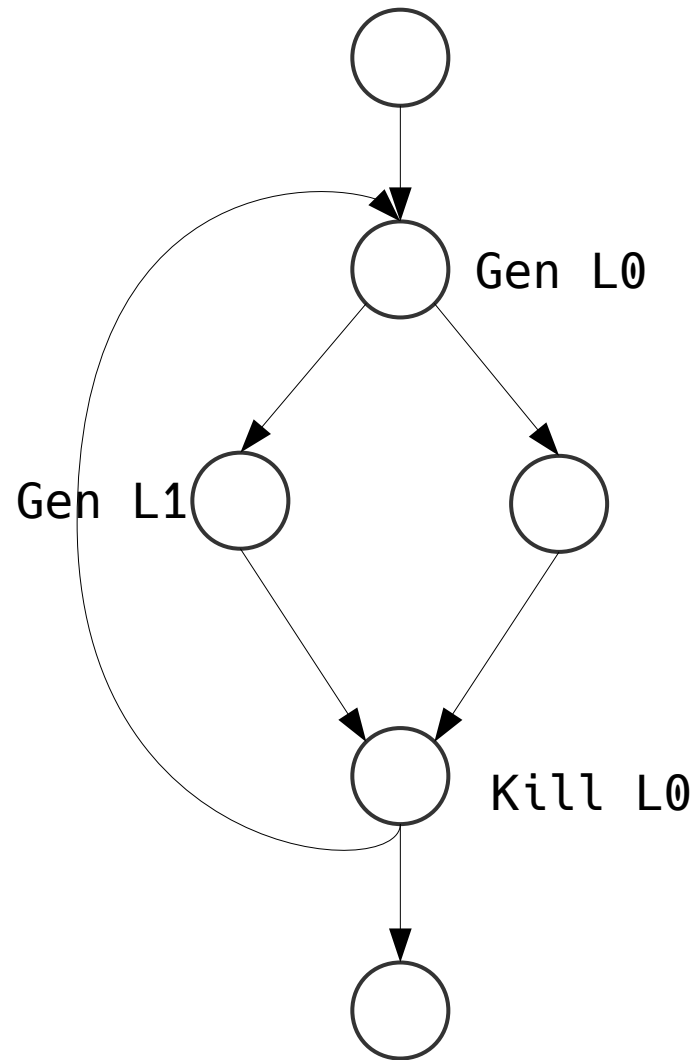
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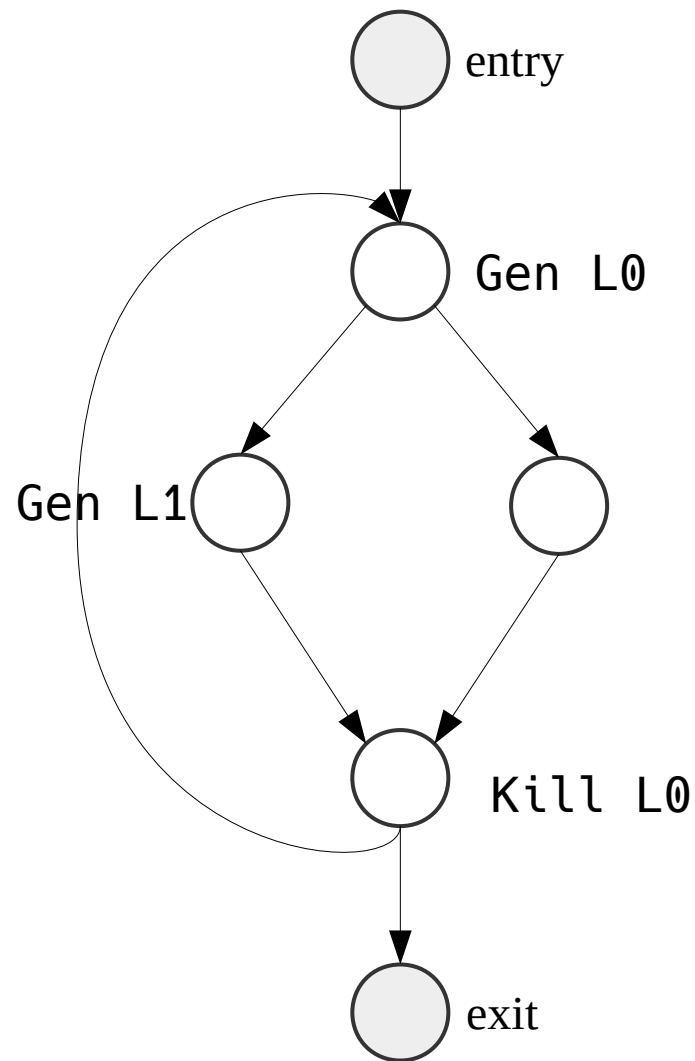
The Data Flow of the Loan



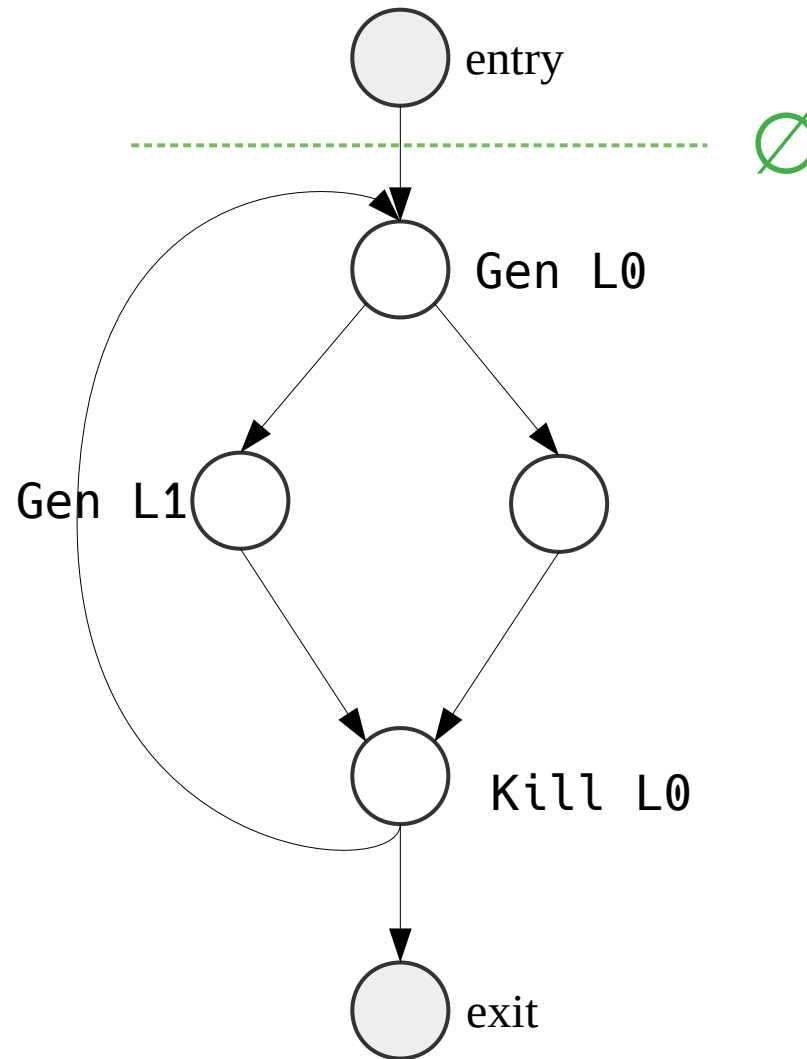
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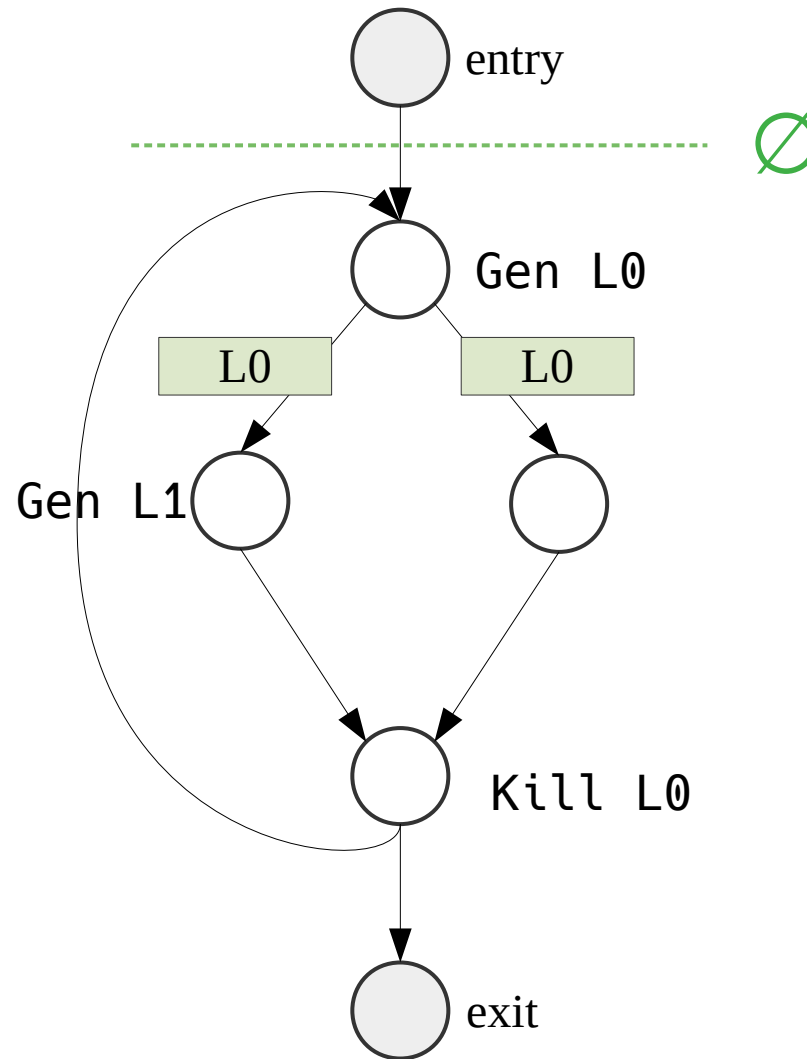
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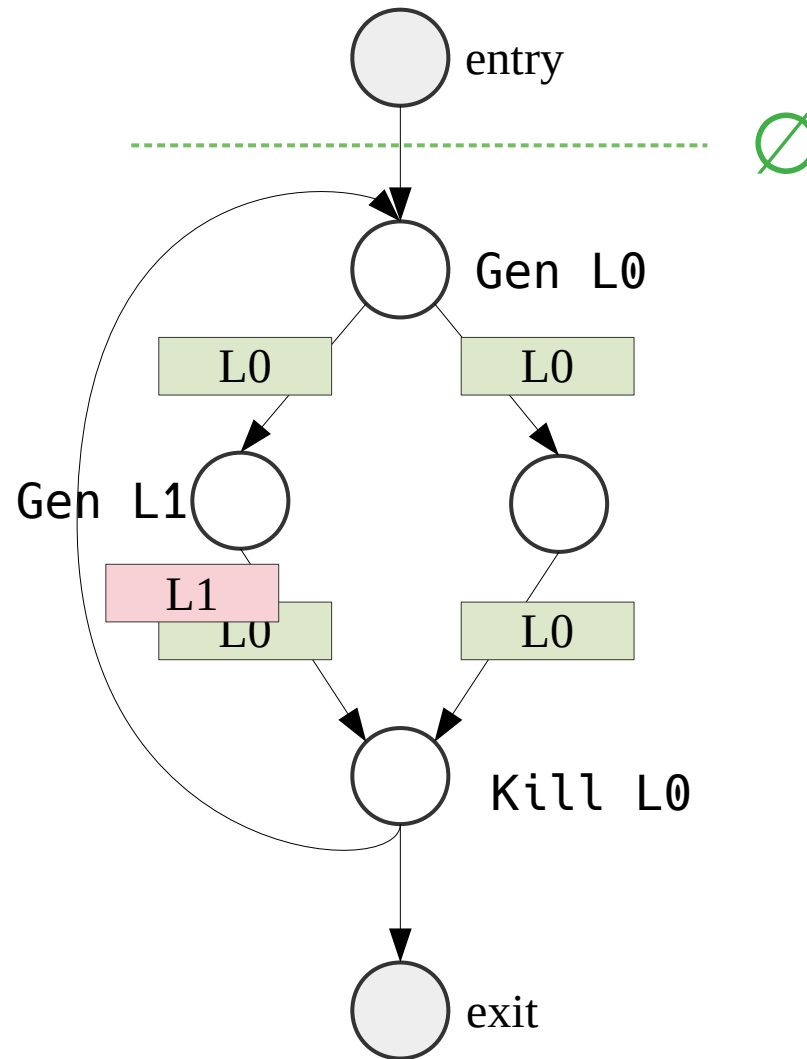
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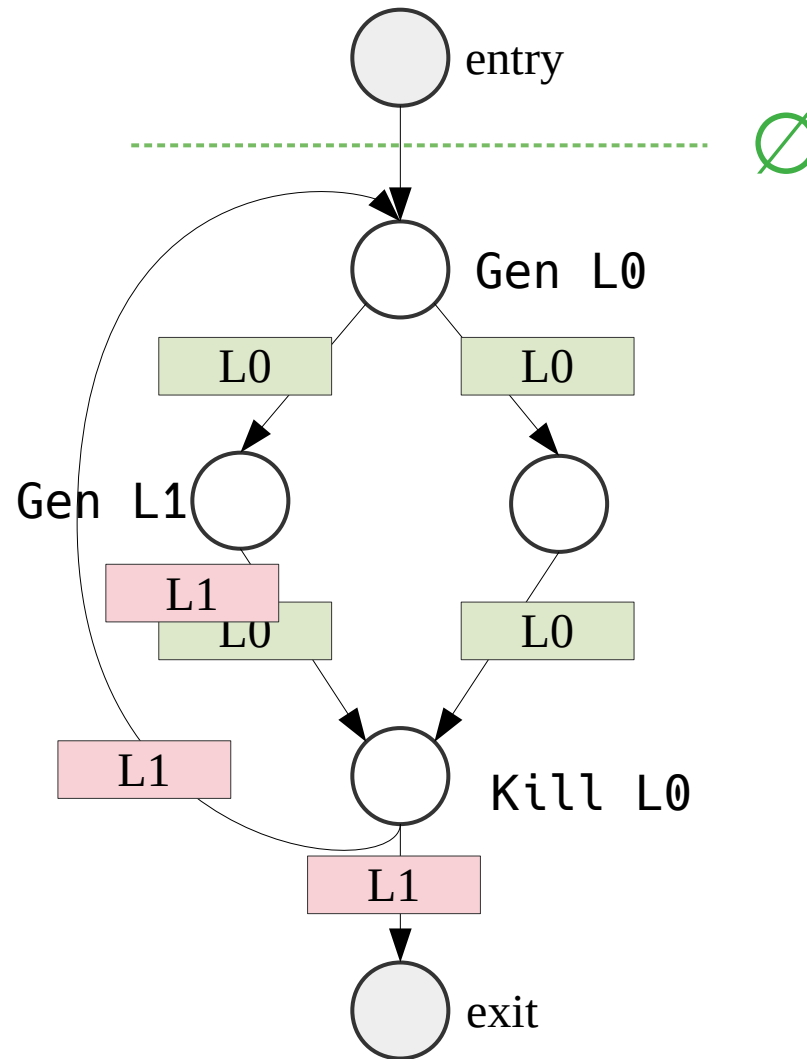
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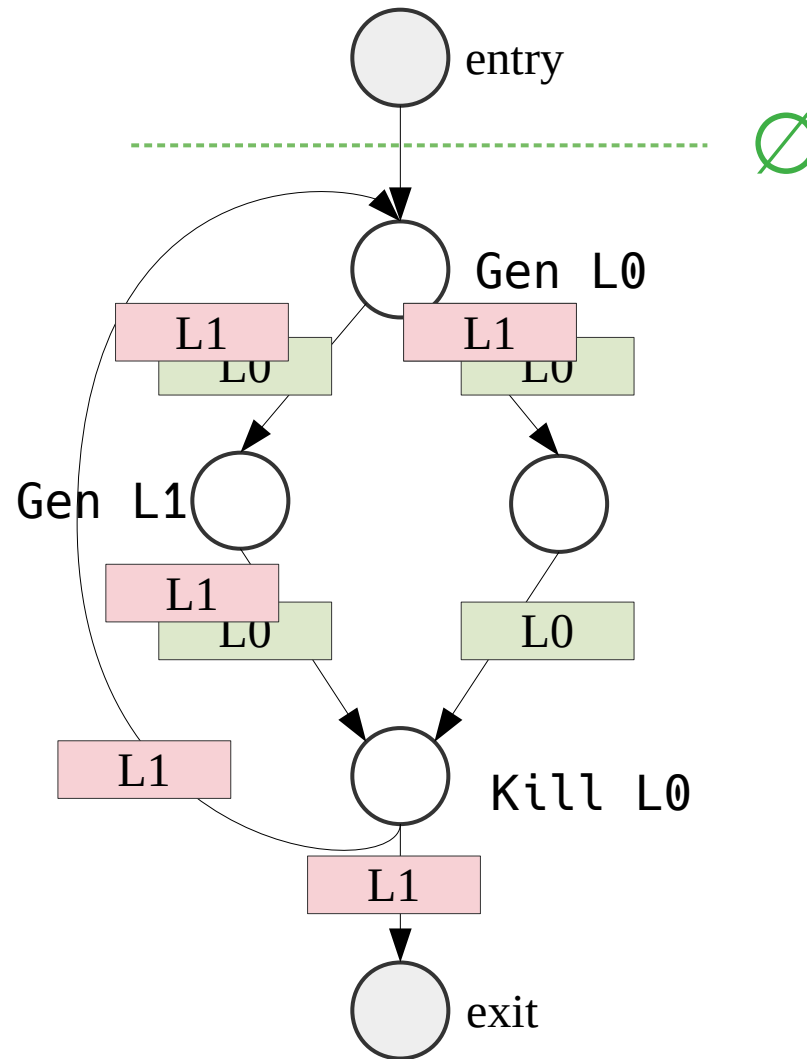
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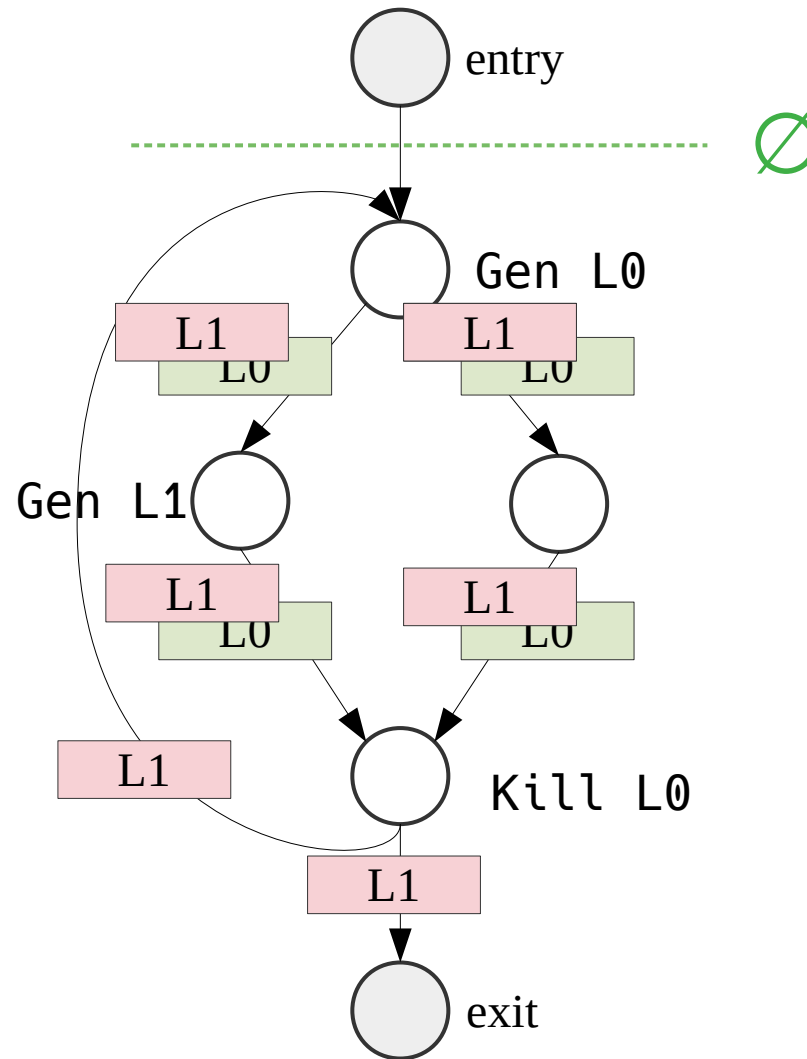
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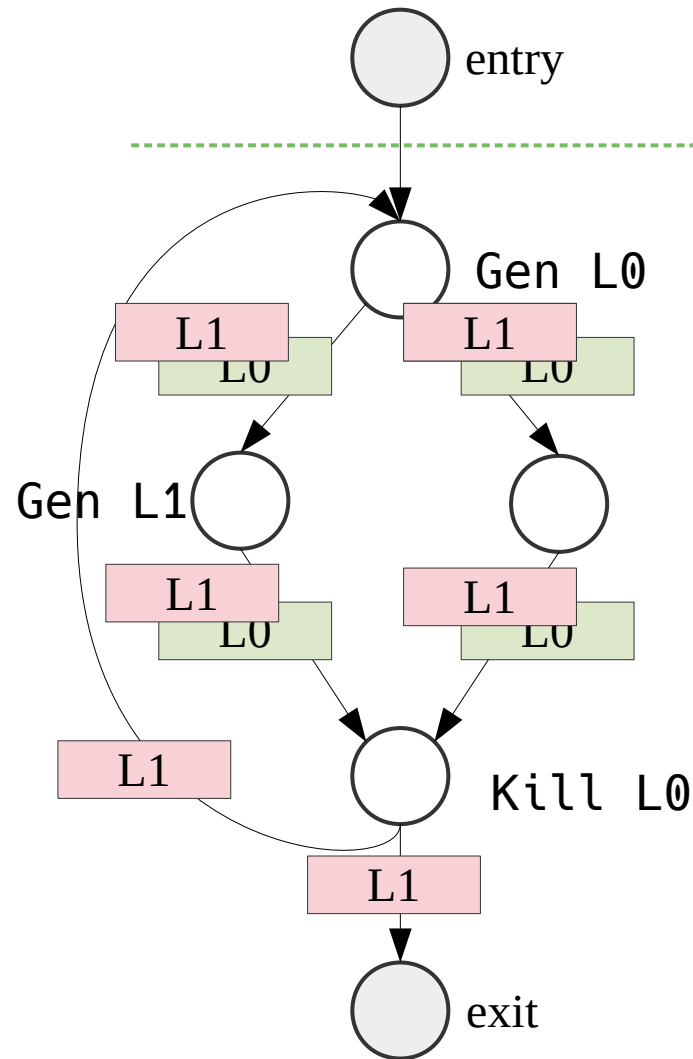


The Data Flow of the Loan



The Data Flow of the Loan

Key: which loan live at which points



When all the sets are stable, that's mean **the state is not changed anymore**, then the data flow computation is complete.

When to Gen, Kill

Gen Loan :

If it's a borrow expression, then gen a Loan

Kill Loan :

- 1) $LV = \text{Loan}_i . \text{path}$
- 2) $\text{point} \notin \text{Loan}_i . \text{region}$

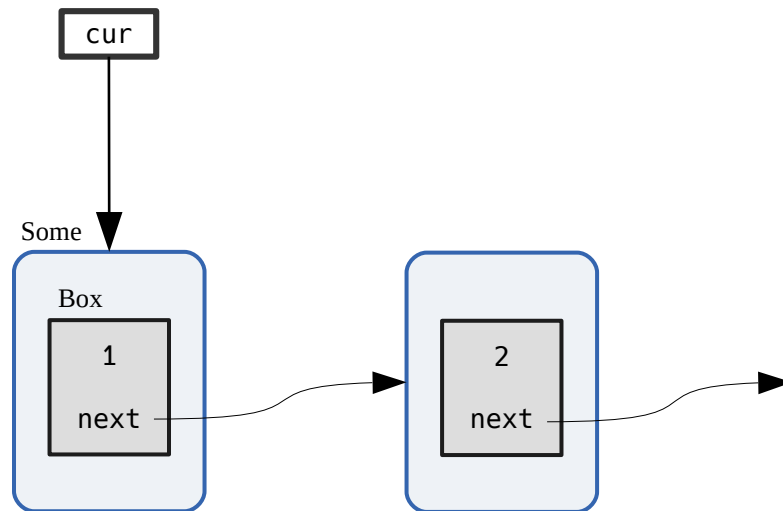
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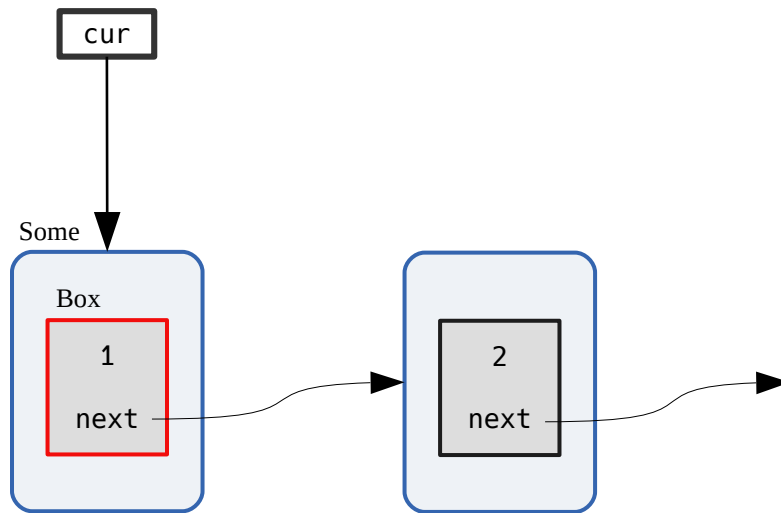
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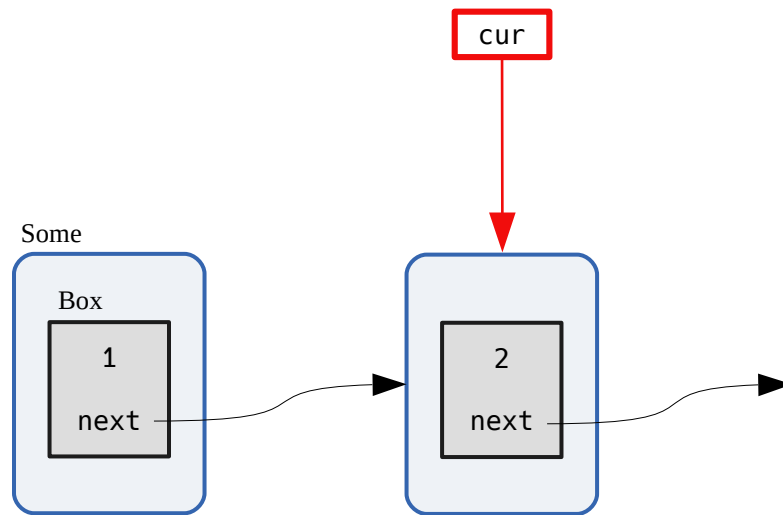
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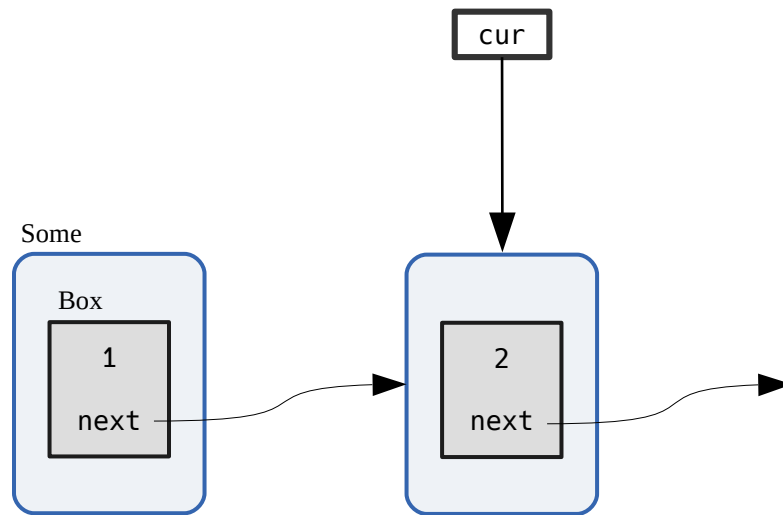
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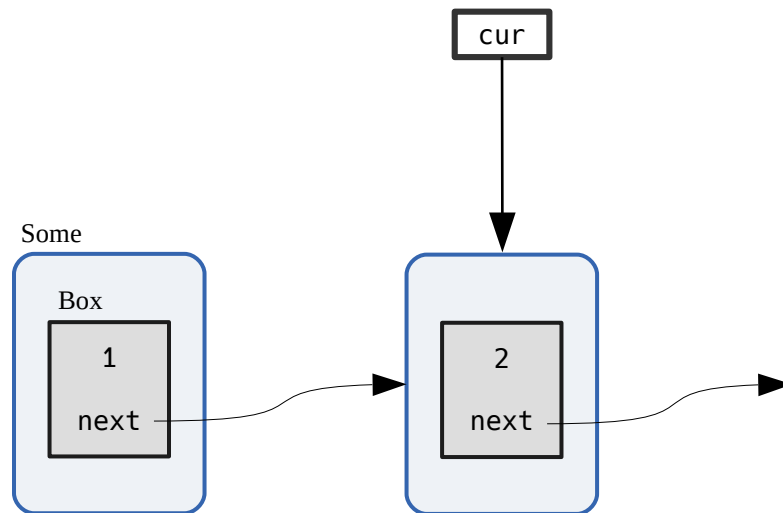
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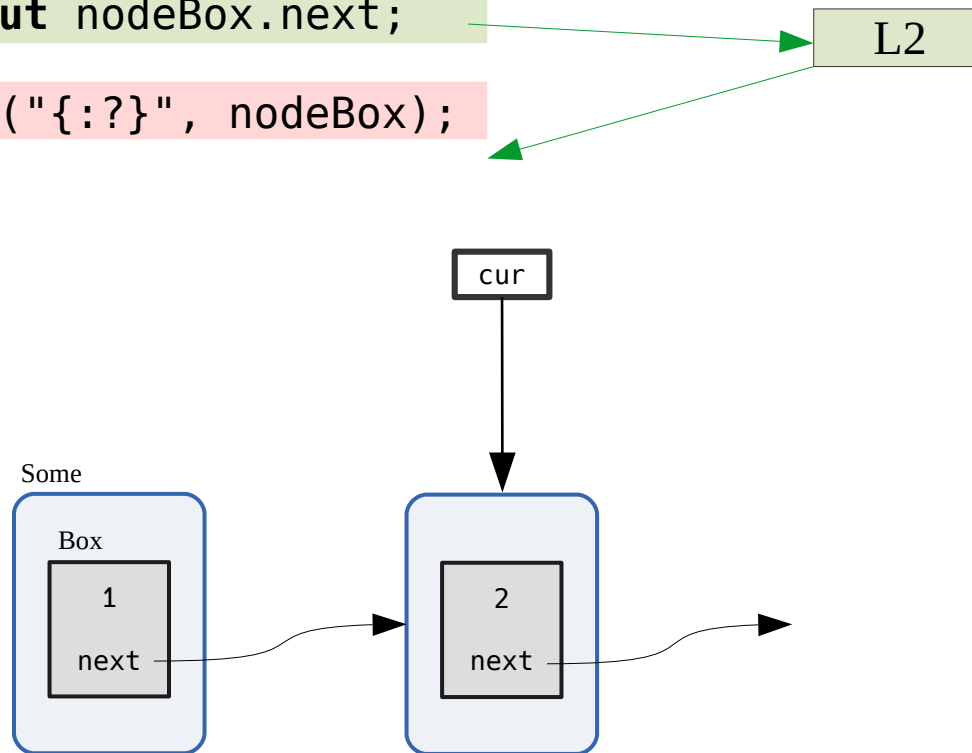
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L2

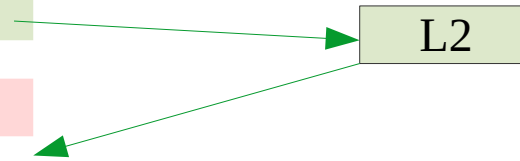
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Example

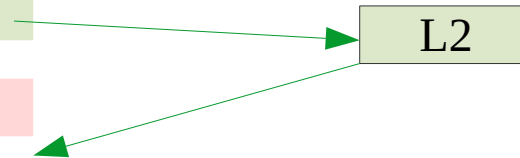
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Why **L2** live at this point ?

Example

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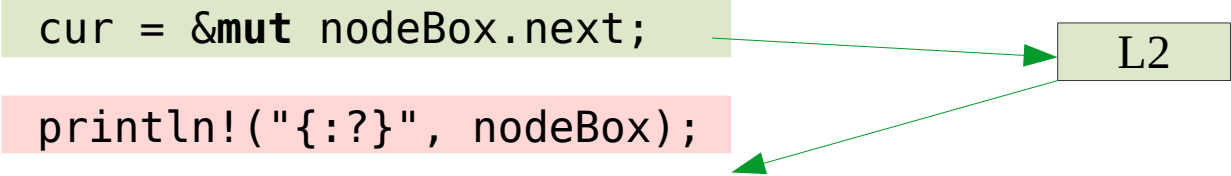


Why **`L2'** live at this point ?

1. no assignment to { nodeBox, nodeBox.next }
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Why **`L2'** live at this point ?

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It is rejected in the current borrow checker, but it is accepted by the Polonius borrow checker in the future.

參考題目

Leetcode : remove linked list elements

Datafrog

The tool used in Rust's new borrow checker called
Polonius

Idea

- ▶ 每次都往前推論一步，直到每個節點都達到穩態即推論完畢

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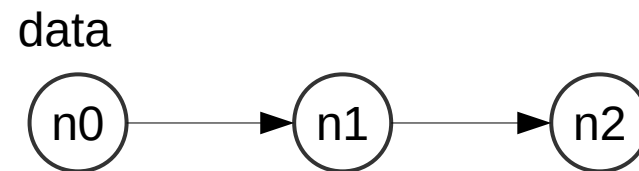
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- ▶ 抽出每次推論的一小步 (Induction)

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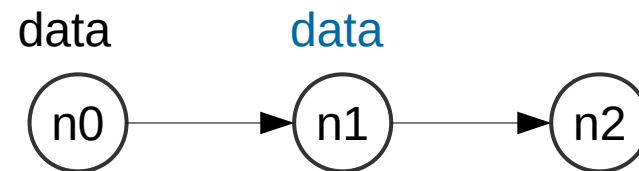
$$\frac{N(a, x) \cdot e(a, b)}{N(b, x)}$$



Idea

- ▶ 每次都往前推論一步，直到每個節點都達到穩態即推論完畢
- ▶ 抽出每次推論的一小步 (Induction)

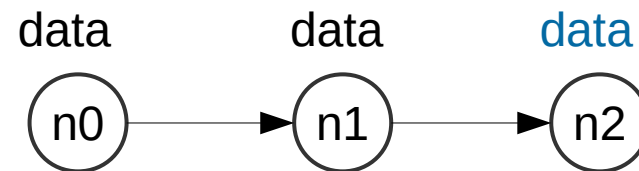
$$\frac{N(a, x) \cdot e(a, b)}{N(b, x)}$$



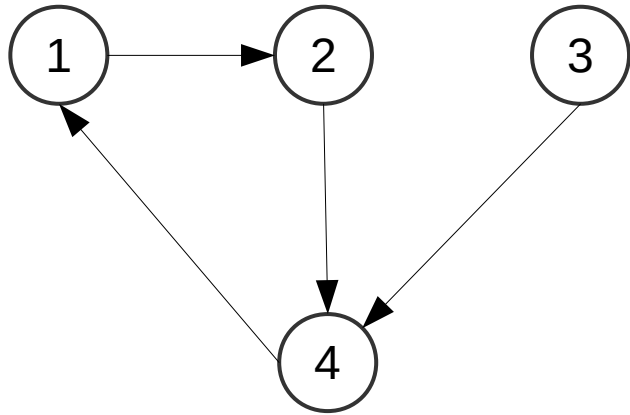
Idea

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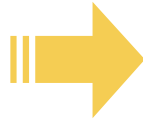
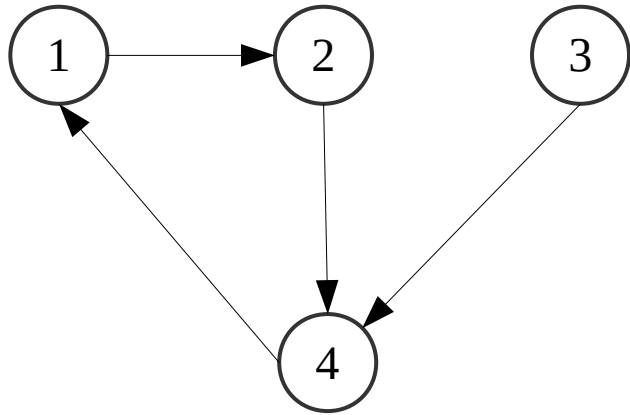
$$\frac{N(a, x) \cdot e(a, b)}{N(b, x)}$$



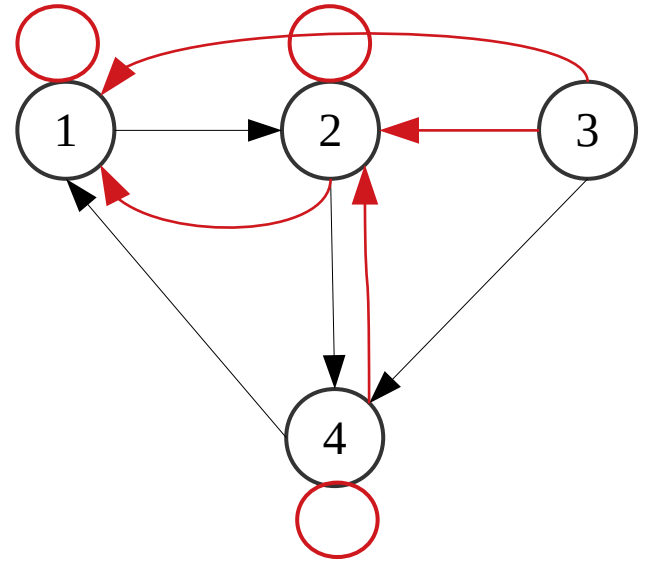
Example . Transitive Closure



Example . Transitive Closure



$$\frac{e(a,b) \quad e(b,c)}{e(a,c)}$$



Implementation – Initial

```
// create a iteration context
let mut iteration = Iteration::new();

// create some variables for later use
let v_edges  = iteration.variable::<(u32, u32)>("edges");
let v_redges = iteration.variable::<(u32, u32)>("reverse edges");

// load the initial variables
v_edges.insert(edges.into());

// start iteration
while iteration.changed() {

    ...

}


let result = v_edges.complete();
```

Implementation – Initial

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// load the initial variables
v_edges.insert(edges.into());

// start iteration
while iteration.changed() {
     Writing Rules here
}

let result = v_edges.complete();
```

Implementation – Writing Rules

```
while iteration.changed() {  
    // reverse edges for mapping  
    v_redges.from_map(&v_edges, |&(a, b)| (b, a));  
  
    // e(a,c) <- e(a,b), e(b,c)  
    v_edges.from_join(&v_redges, &v_edges, |_b, &a, &c| (a, c));  
}
```

Implementation – Writing Rules

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while iteration.changed() {  
    // reverse edges for mapping  
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$$\frac{e(a,b) \quad e(b,c)}{e(a,c)}$$

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}
```

$$\frac{e(a,b)}{e(b,c)} \frac{e(b,c)}{e(a,c)}$$



$$\frac{e(a,b)}{r(b,a)}$$

$$\frac{r(b,a)}{e(b,c)} \frac{e(b,c)}{e(a,c)}$$

Implementation – Writing Rules

```

while iteration.changed() {
    // reverse edges for mapping
    v_redges.from_map(&v_edges, |&(a, b)| (b, a));

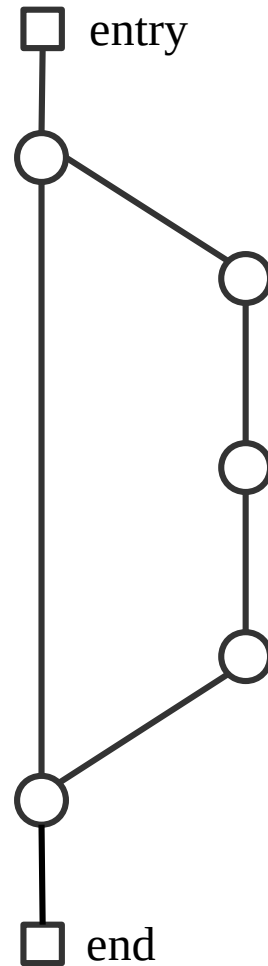
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    v_edges.from_join(&v_redges, &v_edges, |_b, &a, &c| (a, c));
}

```

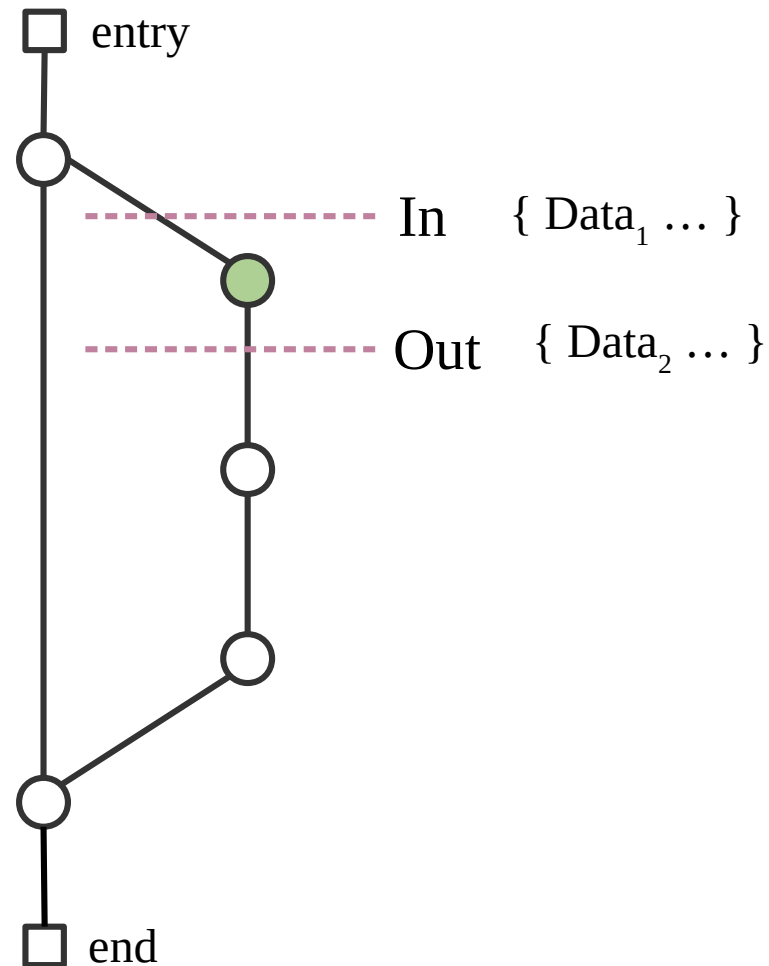
$$\frac{e(a,b)}{e(b,c)} \quad \Rightarrow \quad \frac{e(a,b)}{r(b,a)} \quad \frac{r(\textcolor{red}{b}, \textcolor{green}{a})}{e(\textcolor{red}{b}, \textcolor{blue}{c})} \quad \frac{e(a,c)}{e(a,c)}$$

QA

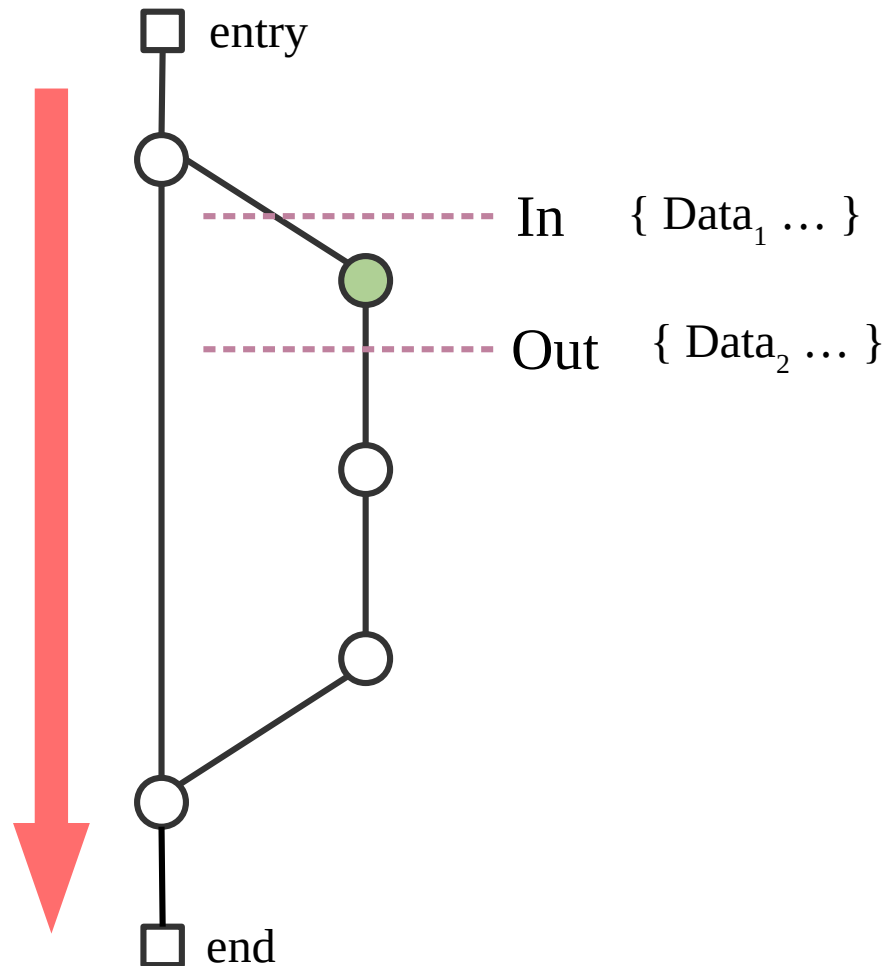
Data Flow Concepts $\langle D, V, \wedge, F \rangle$



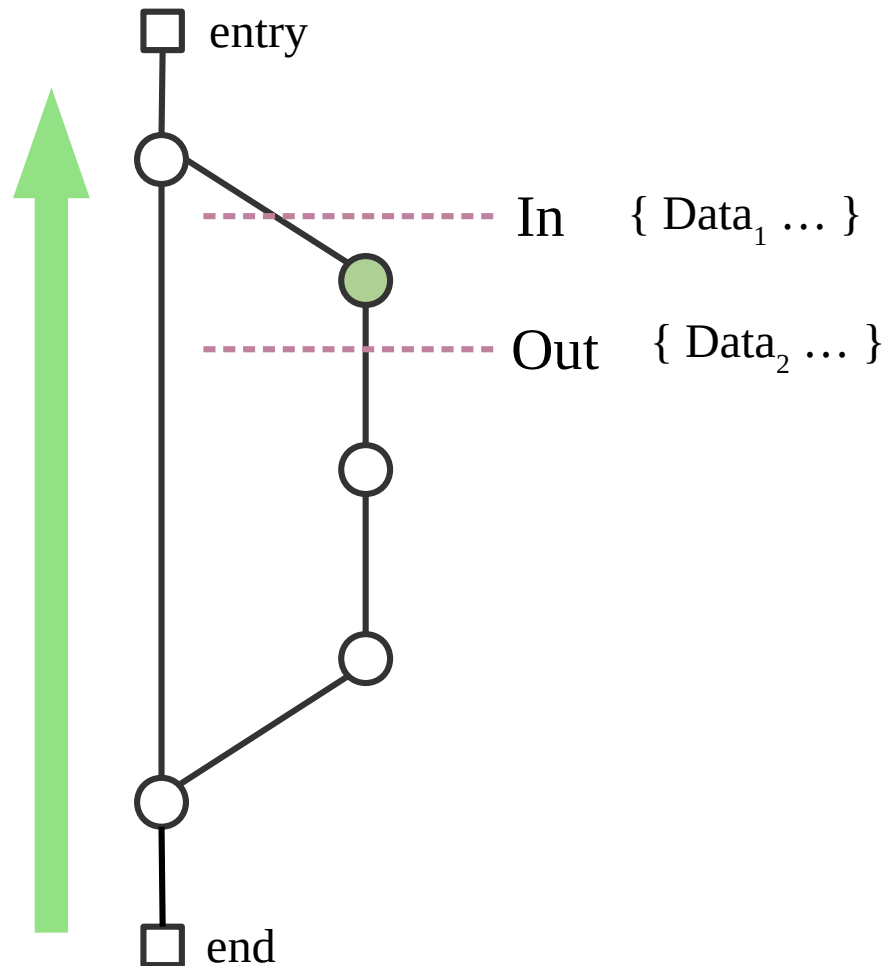
Data Flow Concepts $\langle D, \mathbf{V}, \Lambda, F \rangle$



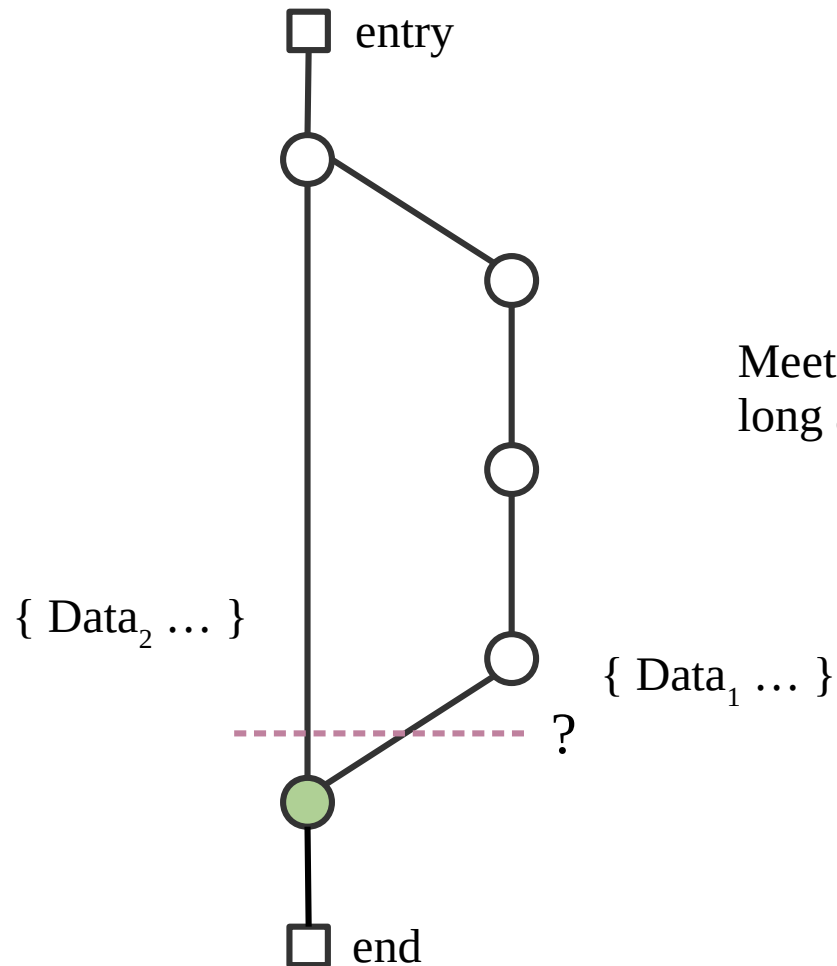
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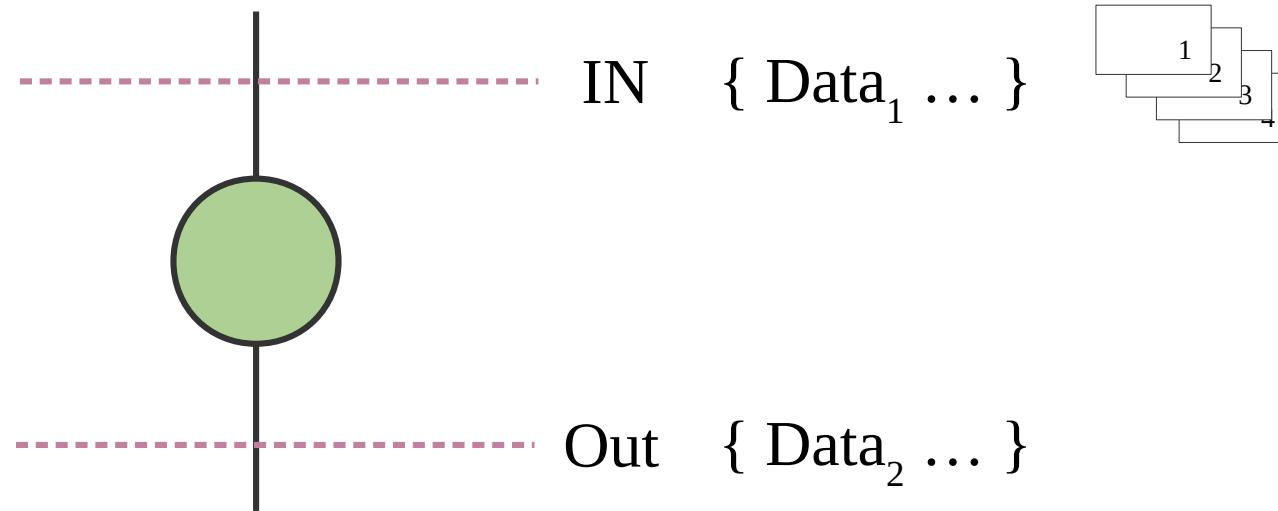


Data Flow Concepts $\langle D, V, \mathbf{\Lambda}, F \rangle$

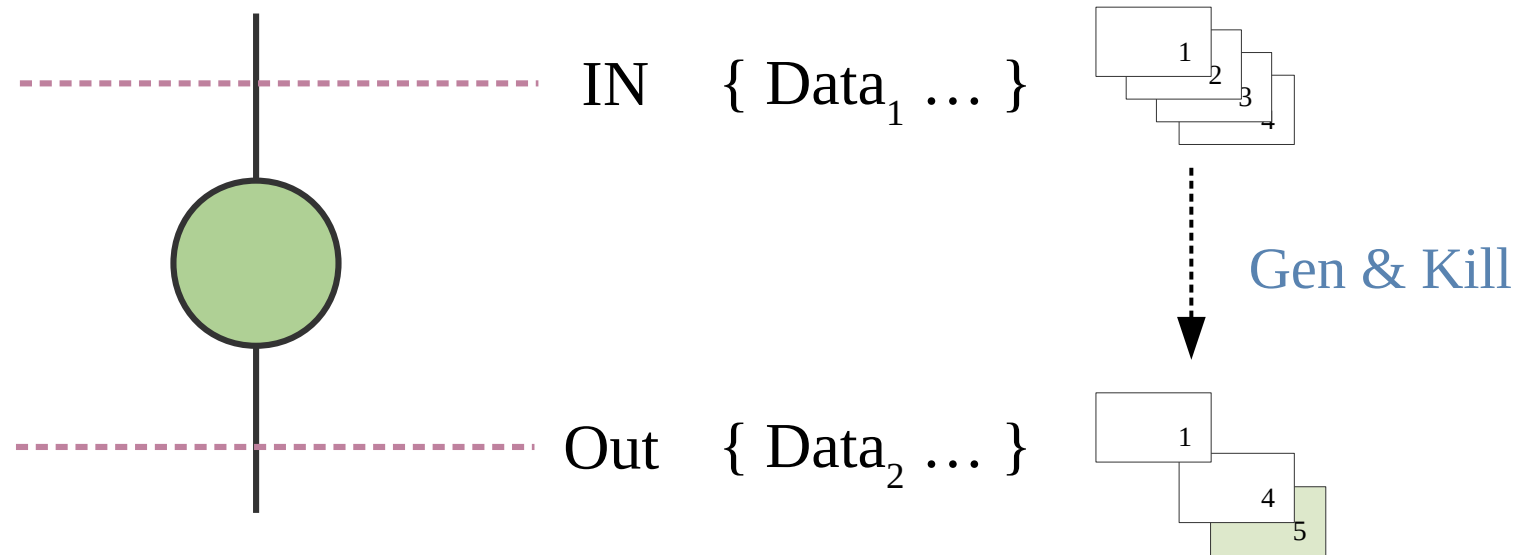


Meet operator can be union, intersection, as long as it can make $(V, \mathbf{\Lambda})$ semilattice.

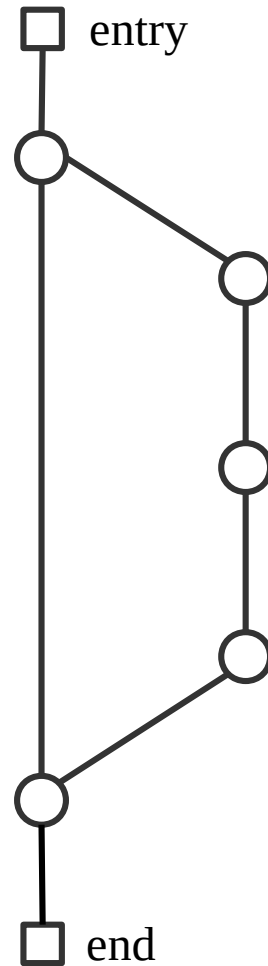
Data Flow Concepts $\langle D, V, \wedge, \mathbf{F} \rangle$



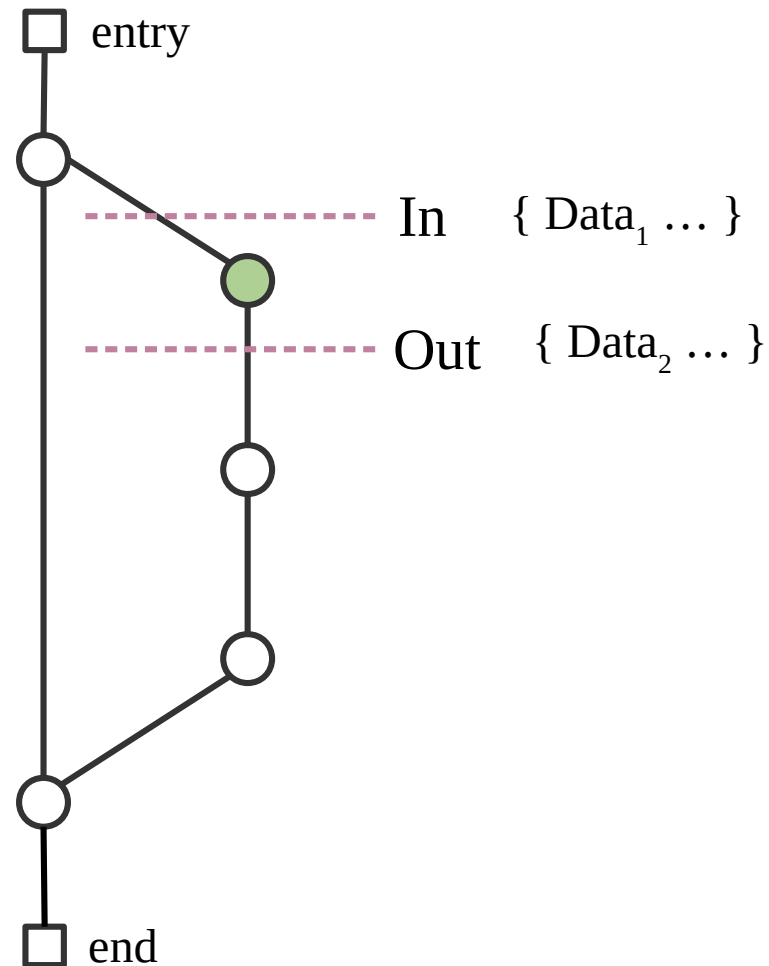
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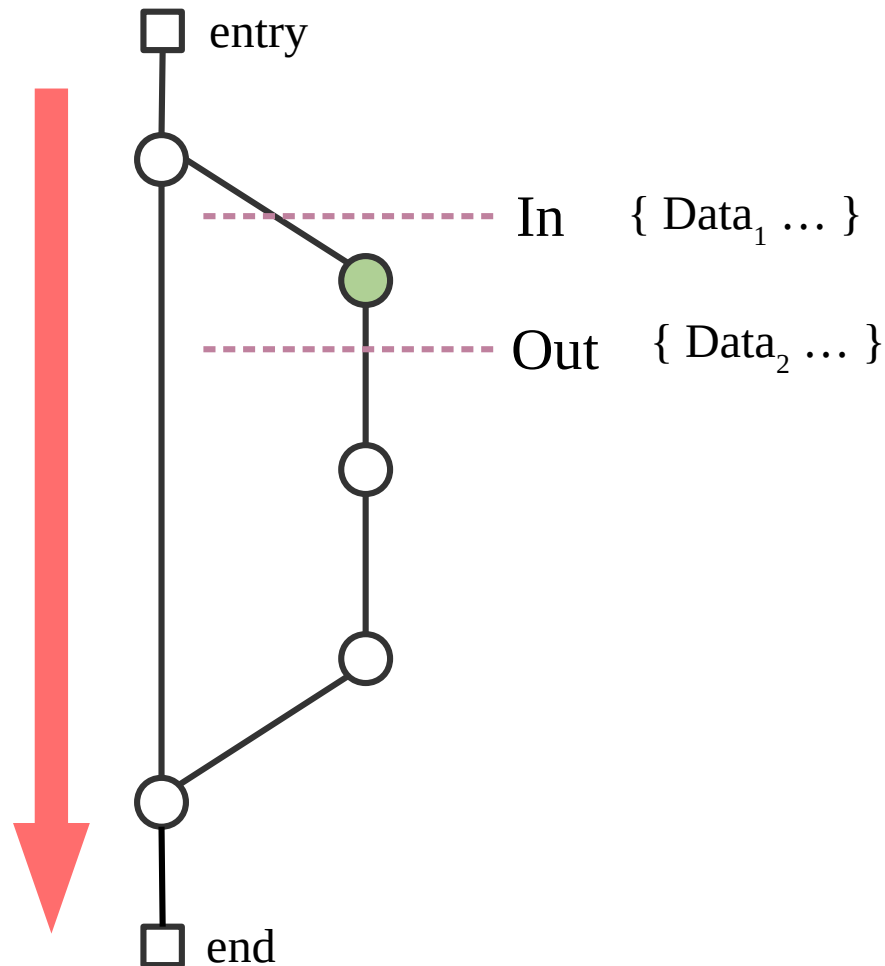
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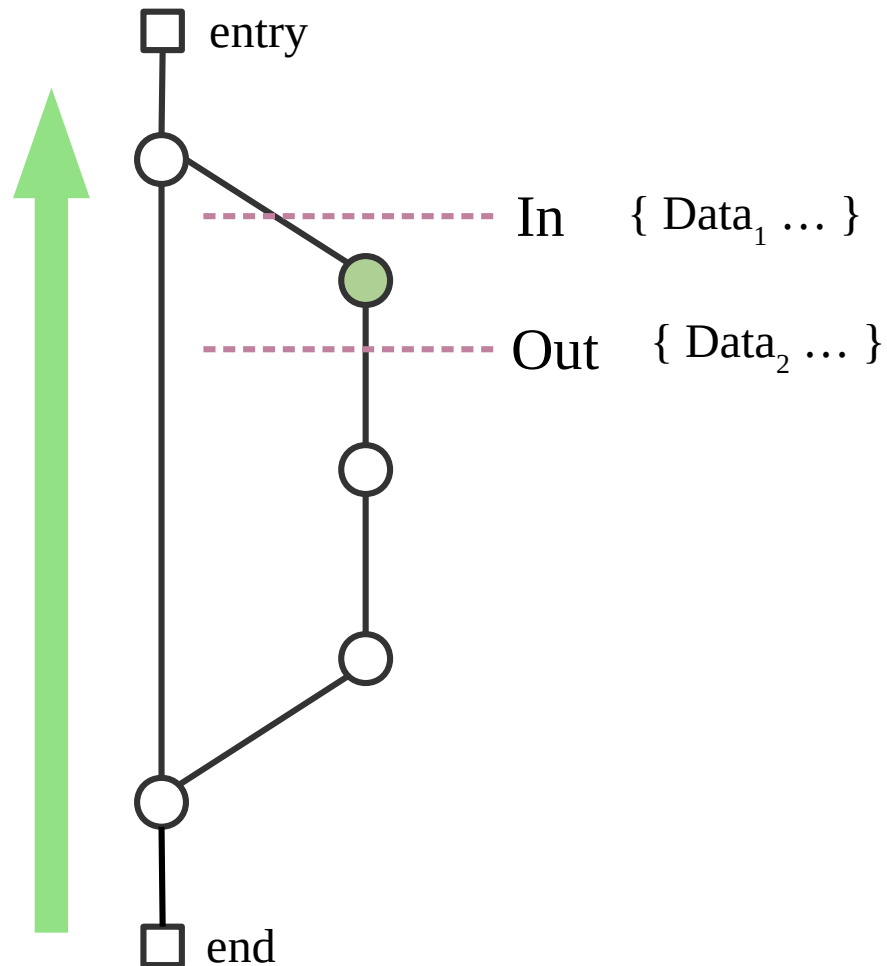
Data Flow Concepts $\langle D, \mathbf{V}, \Lambda, F \rangle$



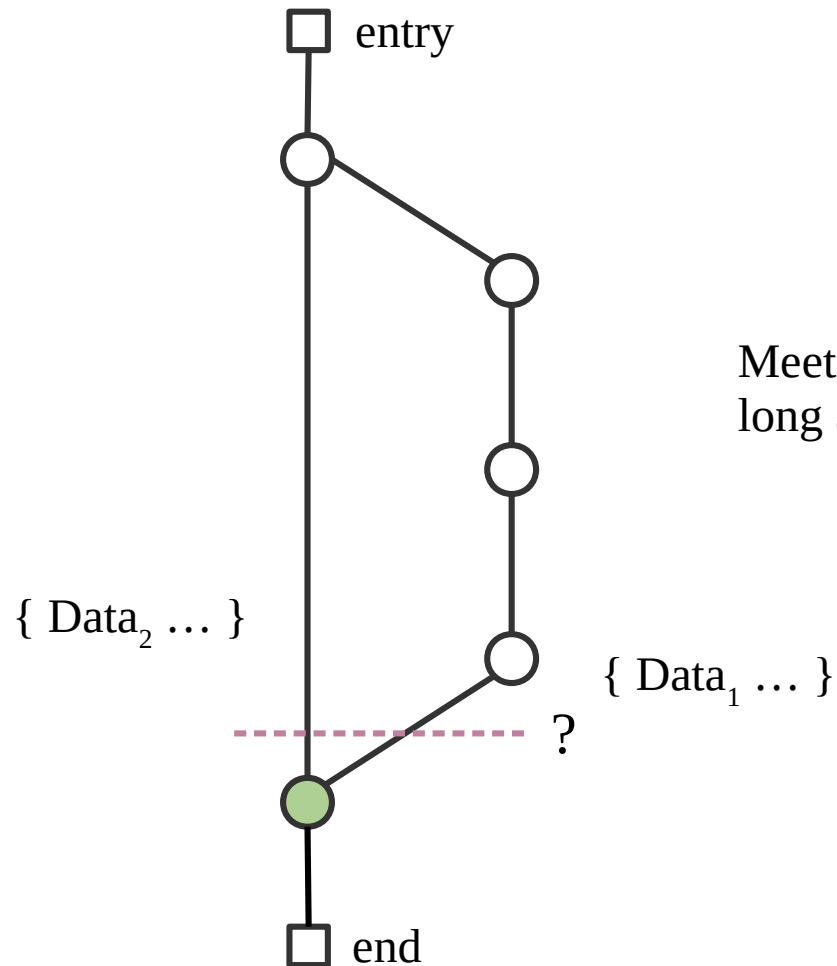
Data Flow Concepts $\langle \mathbf{D}, V, \Lambda, F \rangle$



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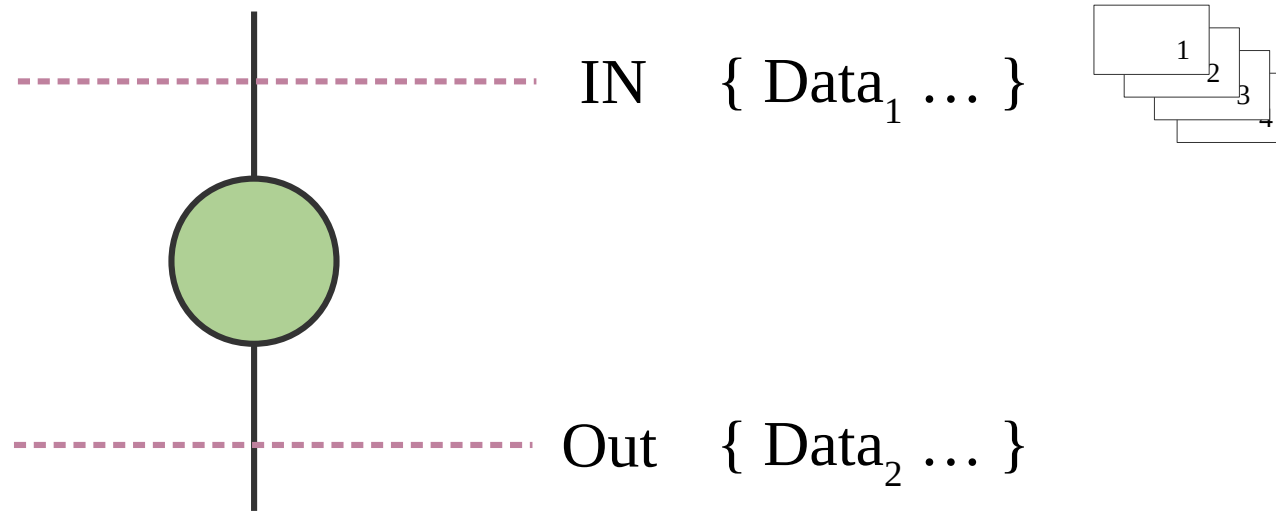


Data Flow Concepts $\langle D, V, \mathbf{\Lambda}, F \rangle$



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Data Flow Concepts $\langle D, V, \wedge, \mathbf{F} \rangle$



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