# Fully Automated Shape Analysis Based on Forest Automata

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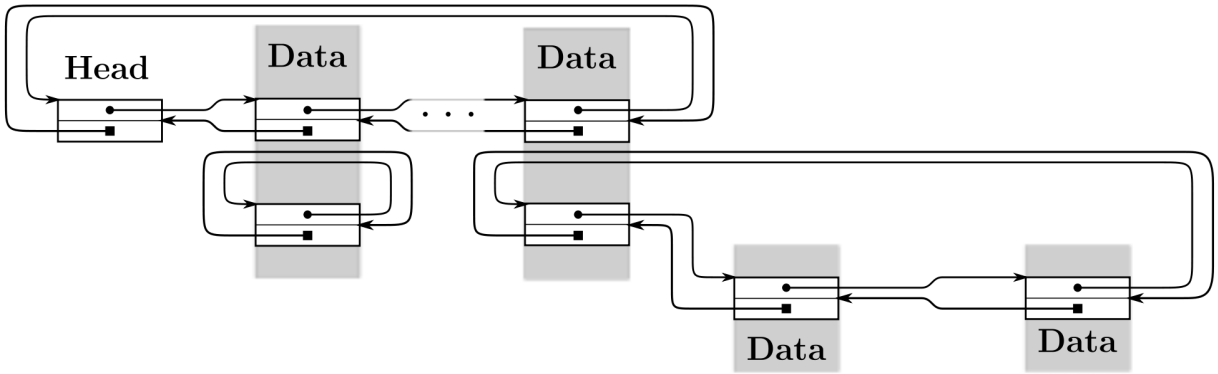
# Shape Analysis

- Precise shape analysis:
  - a notoriously difficult problem
    - dealing with $\infty$ sets of complex graphs
  - many different solutions: logic, automata, ...



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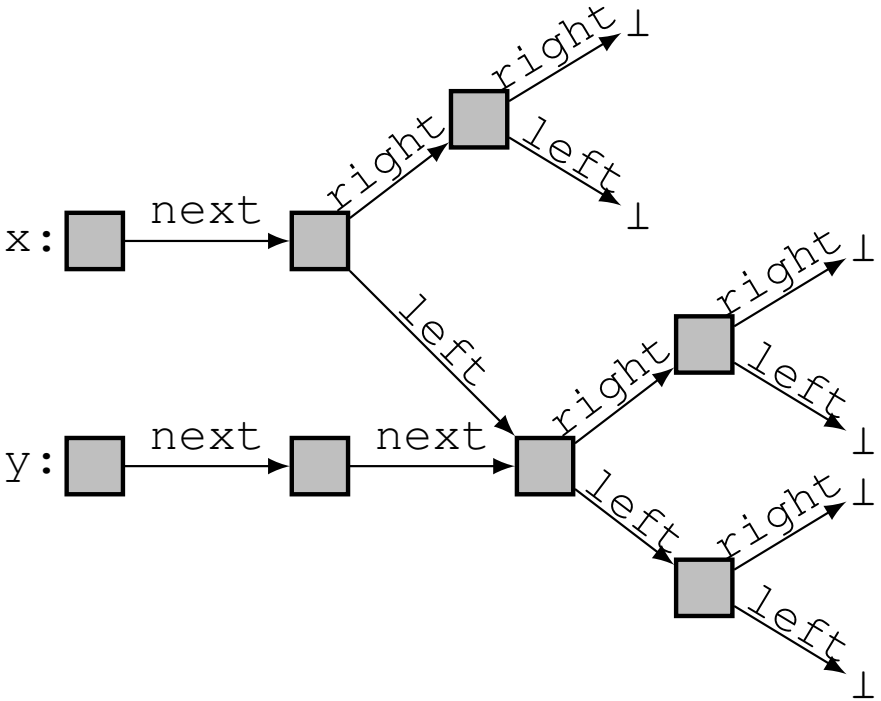
  and
  - TA-based representation of sets of heaps

# Heap Representation

- Forest decomposition of a heap



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nodes referenced:
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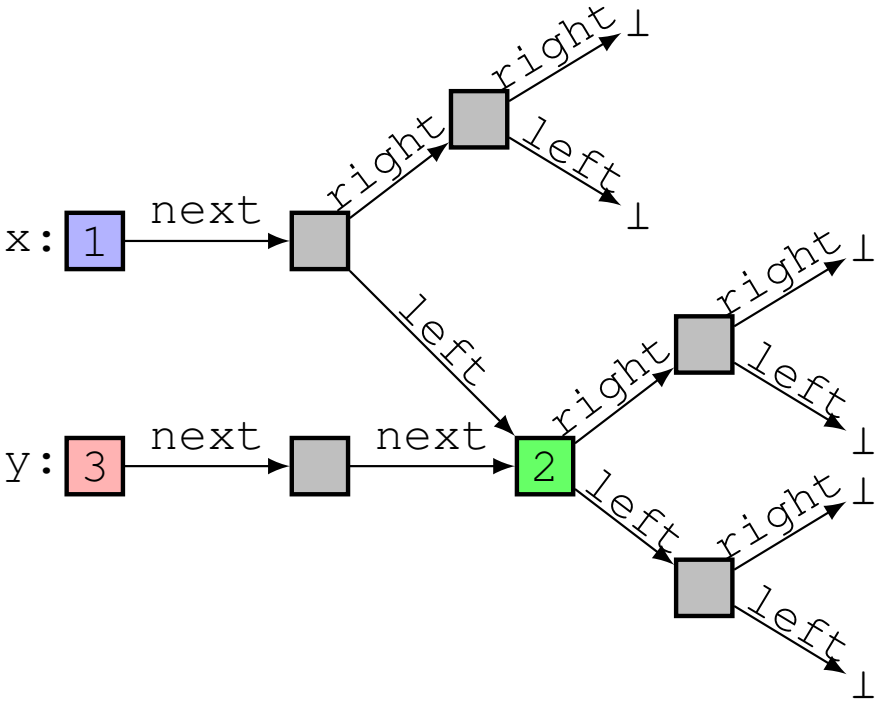

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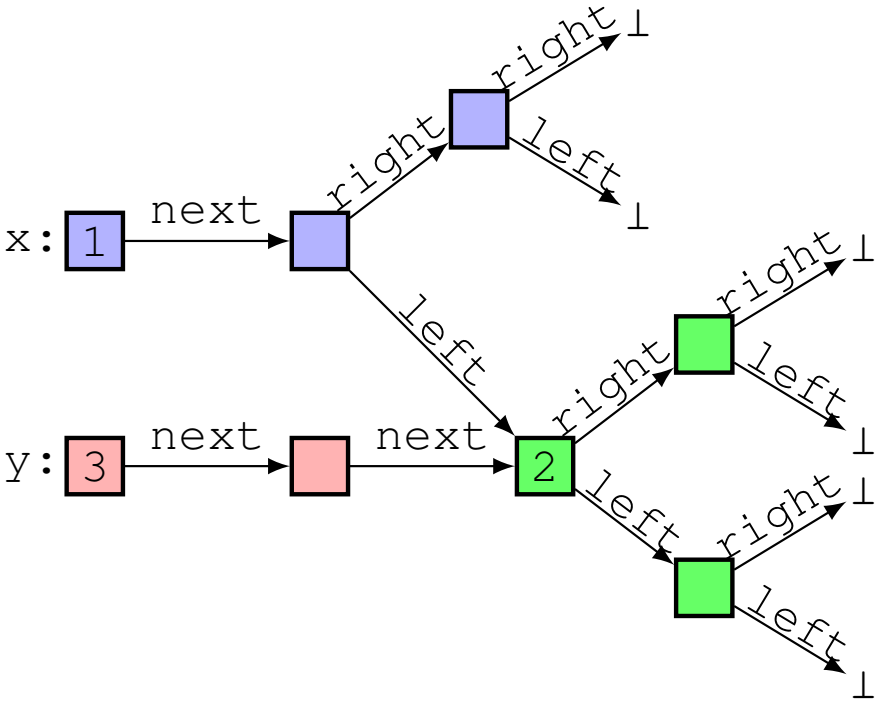

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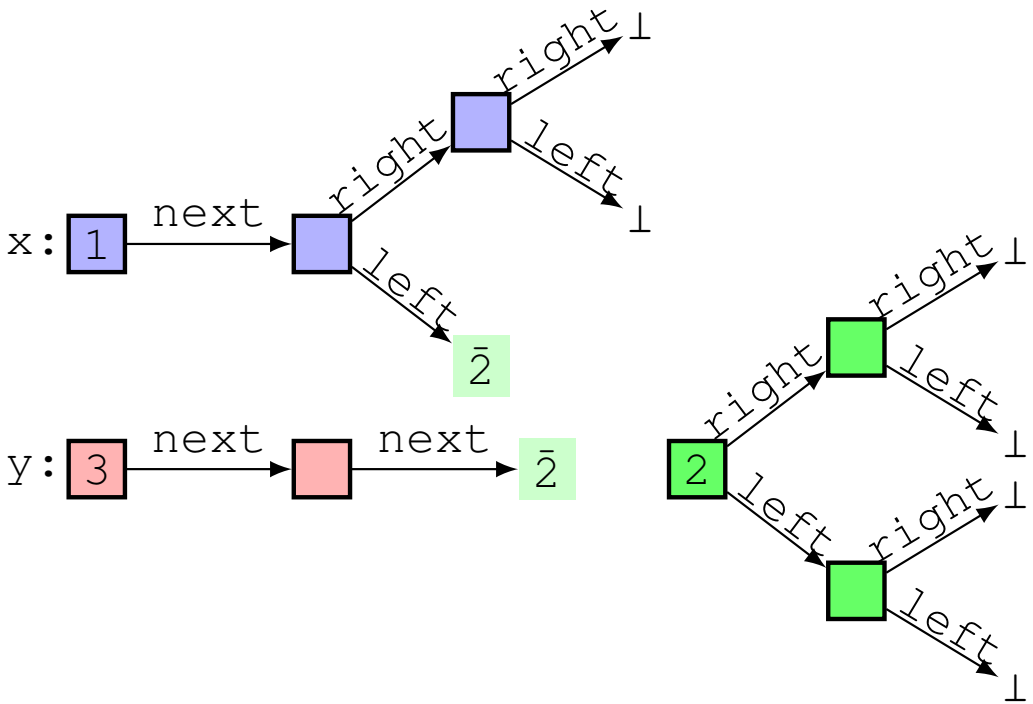

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  - Sets of heaps:
    - tree automata to represent sets of tree components
    - tuple of tree automata $(TA_1, \ldots, TA_n) \rightsquigarrow$ **forest automaton** (FA)

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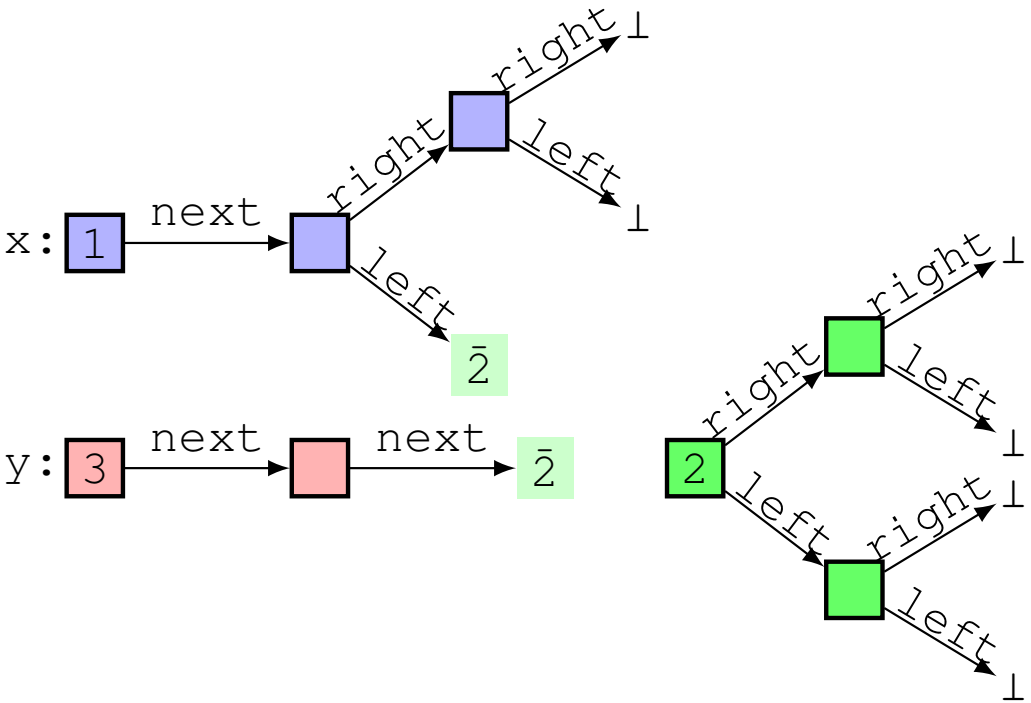
Cartesian semantics



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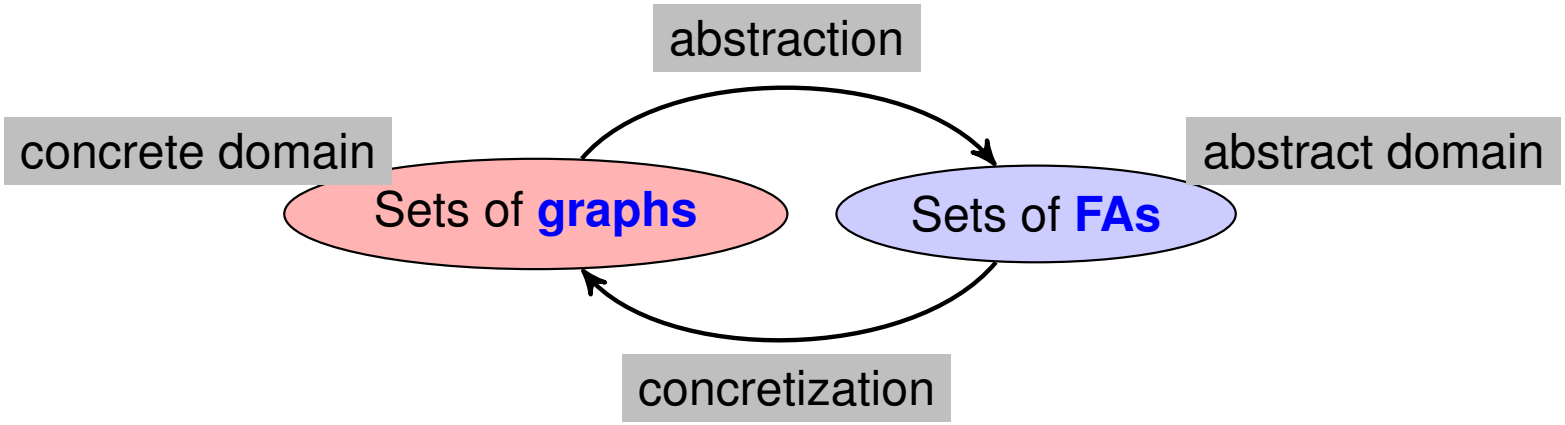

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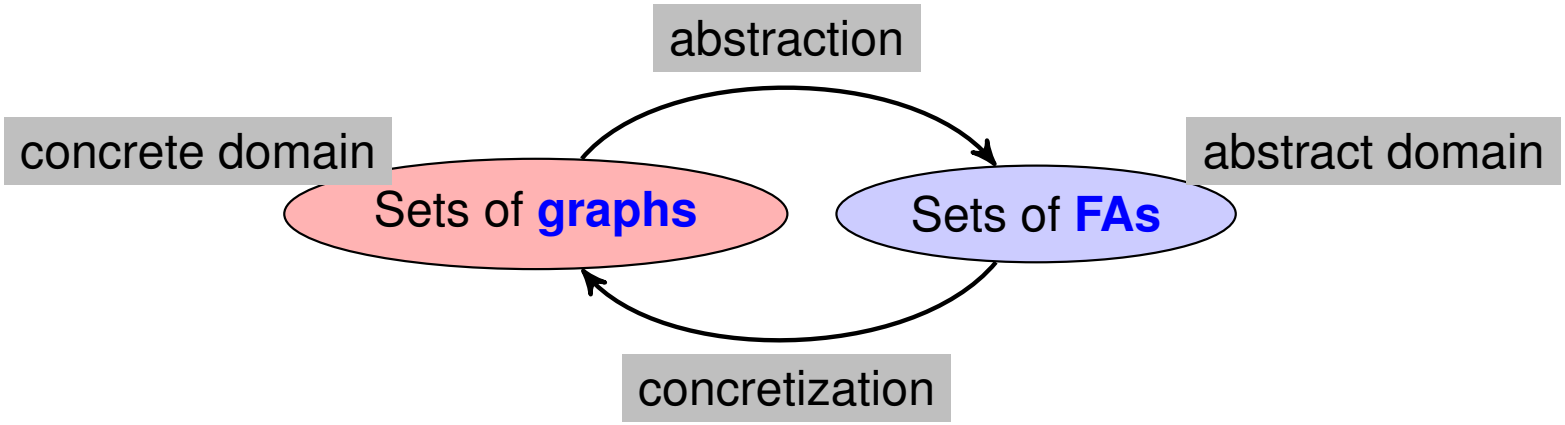


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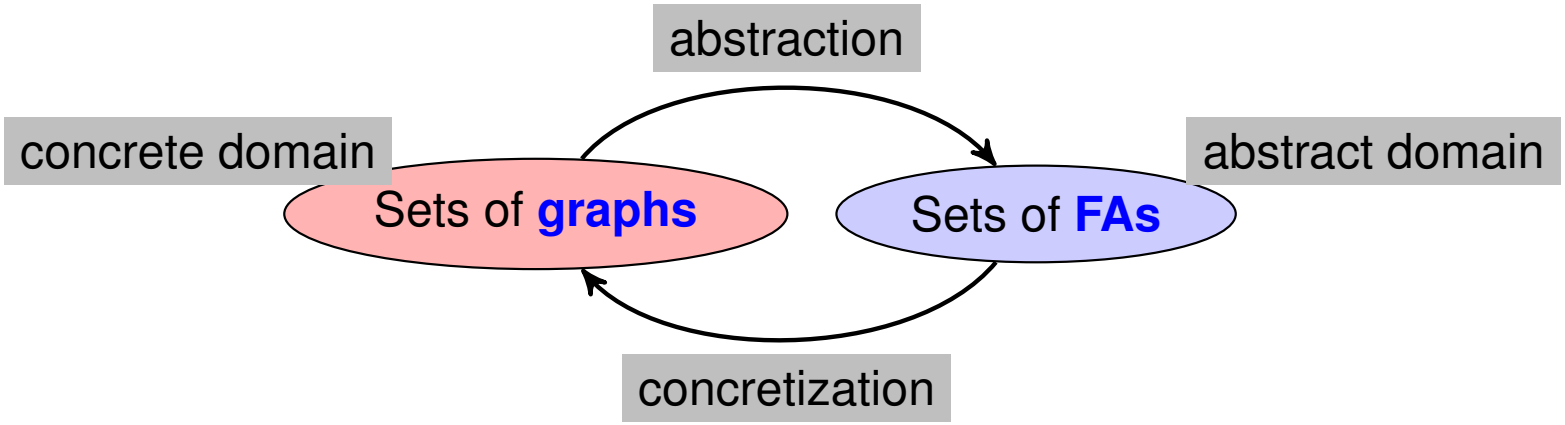


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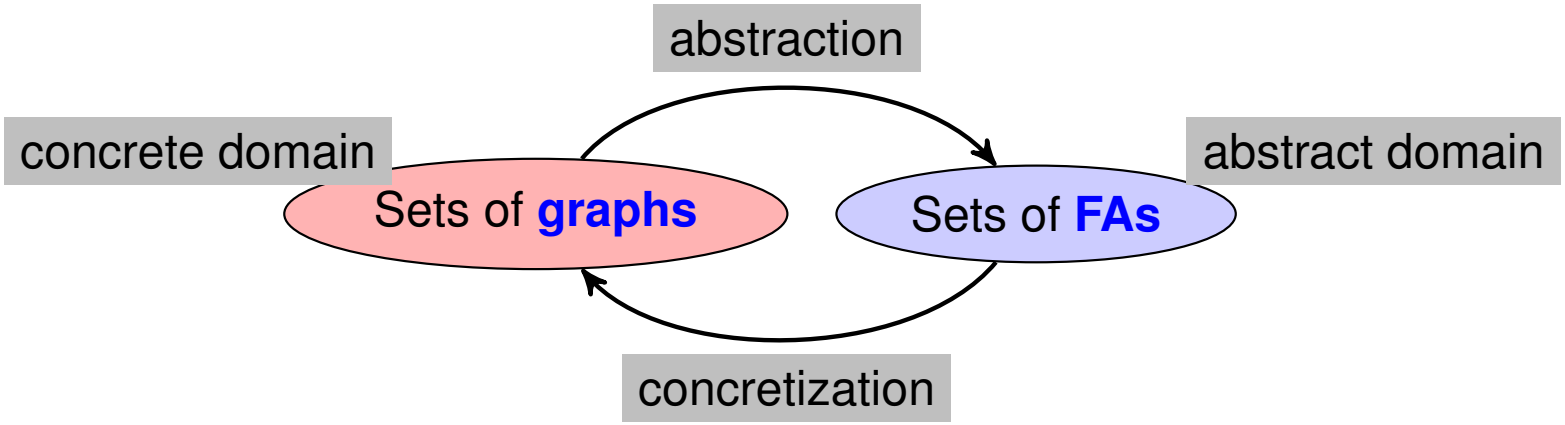


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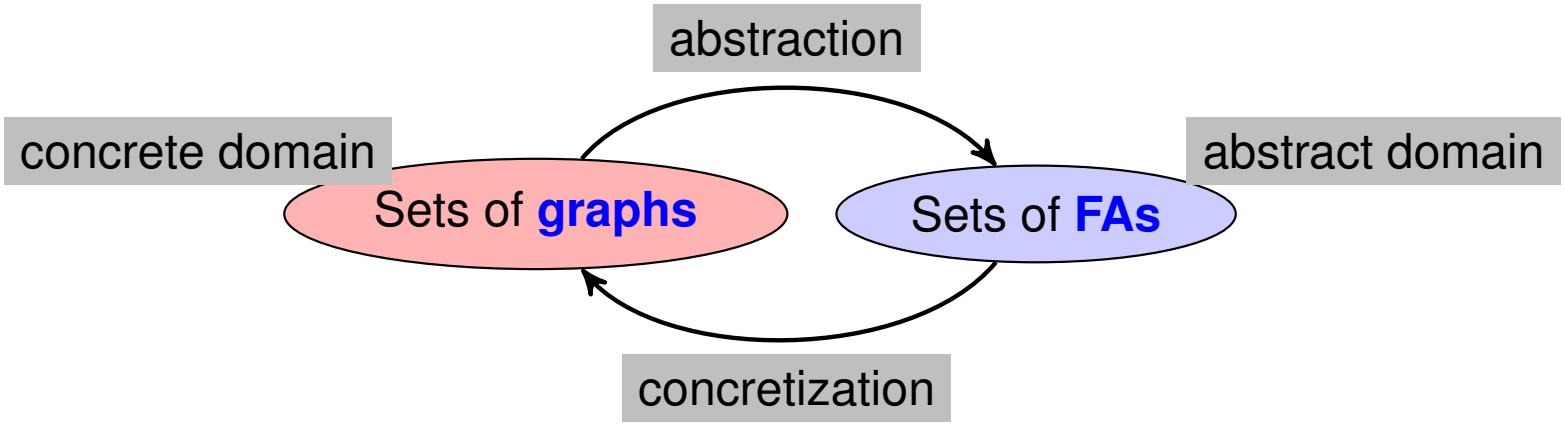


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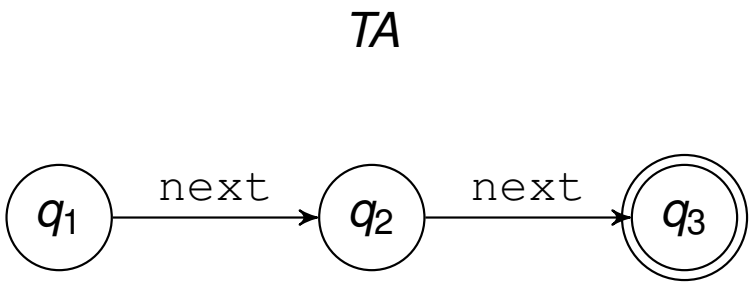

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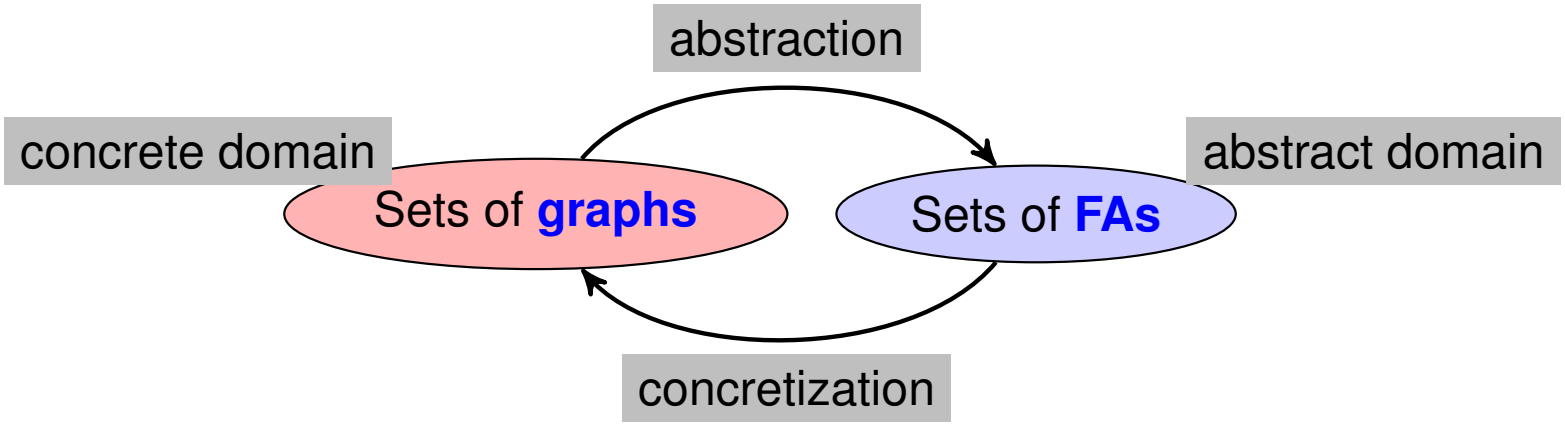


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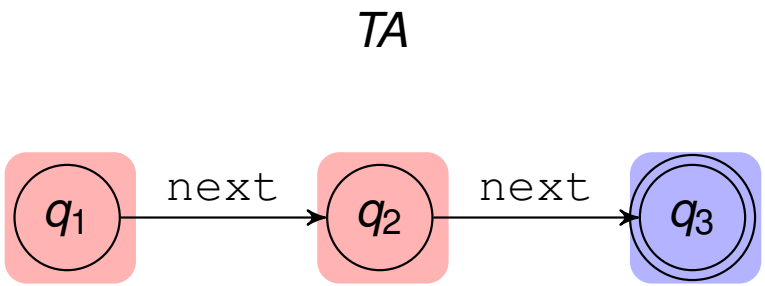

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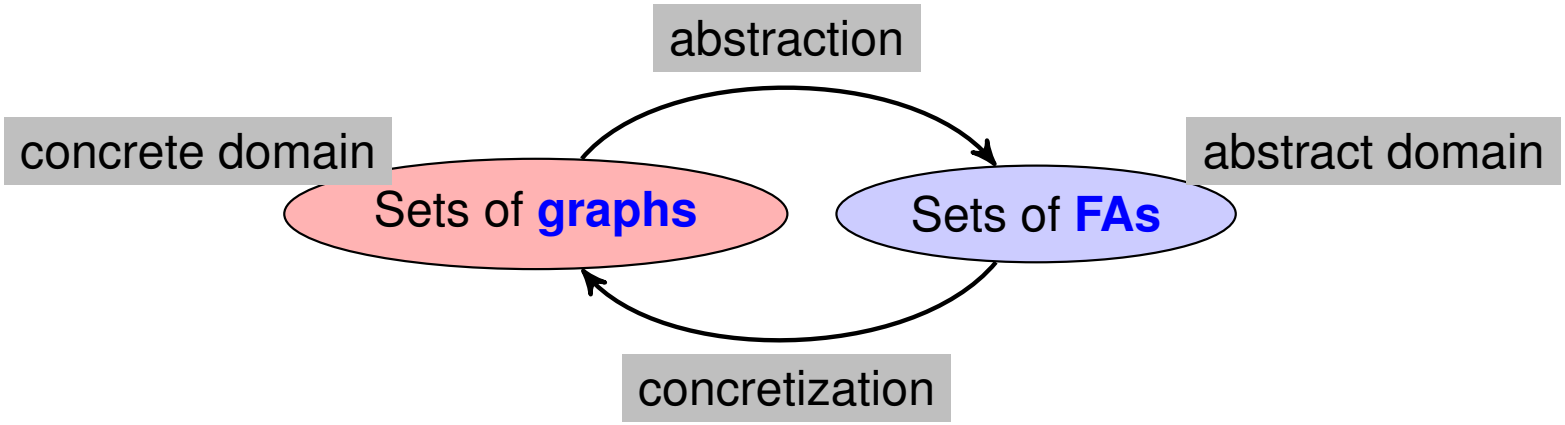


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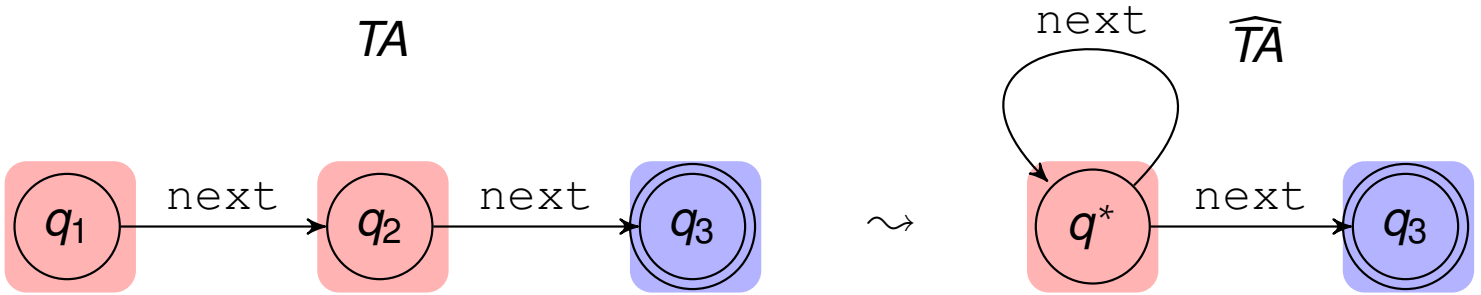

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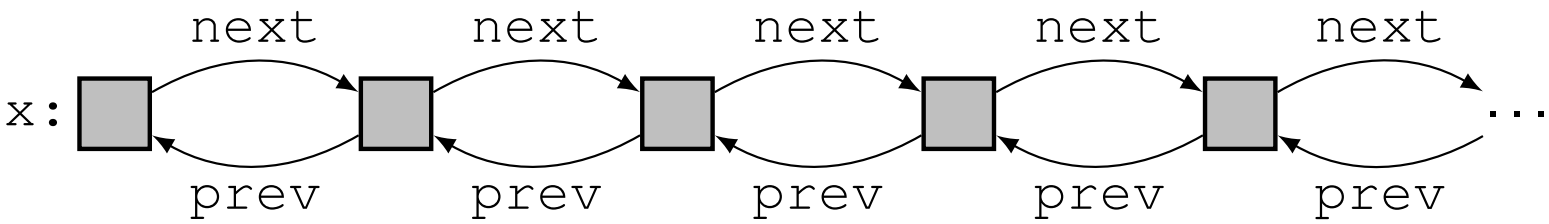

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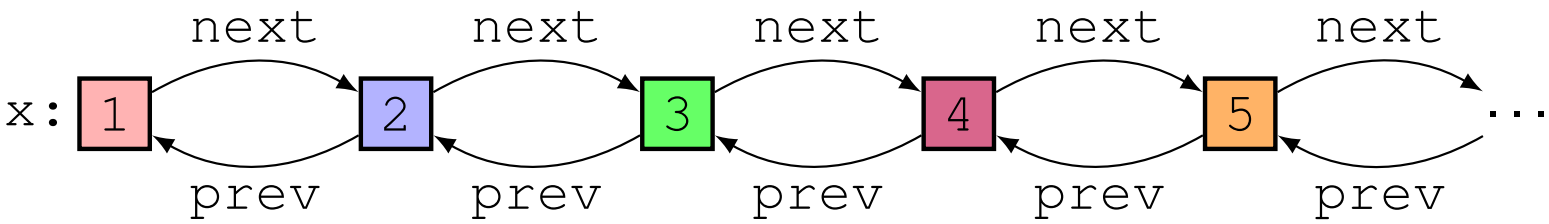

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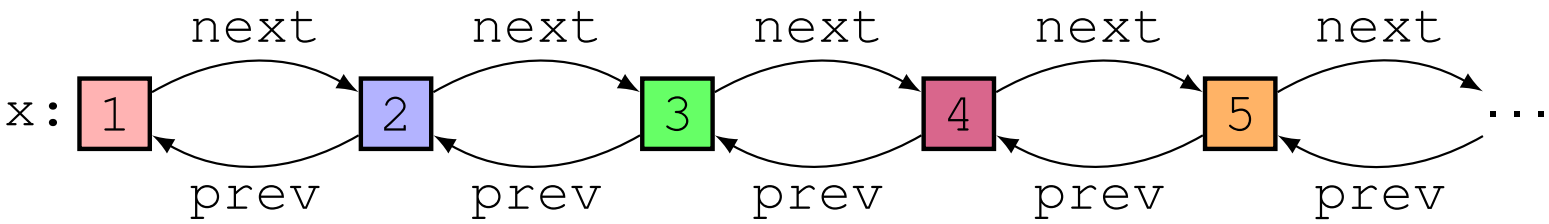


- doubly linked lists (DLLs), lists of circular lists,
- trees with parent pointers,
- skip lists, ...

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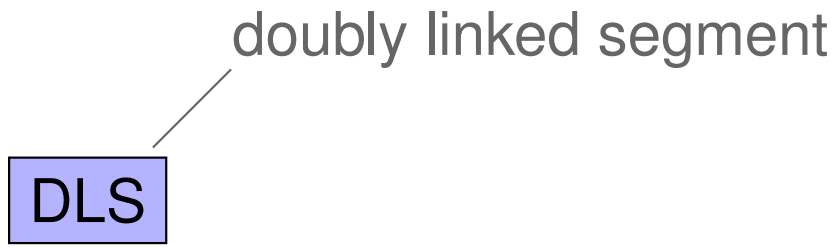


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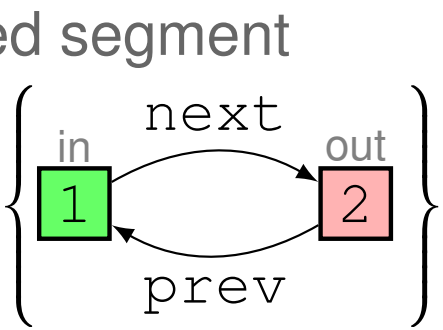

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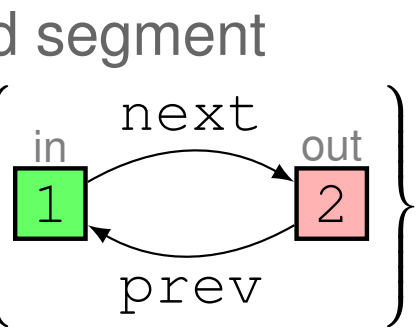


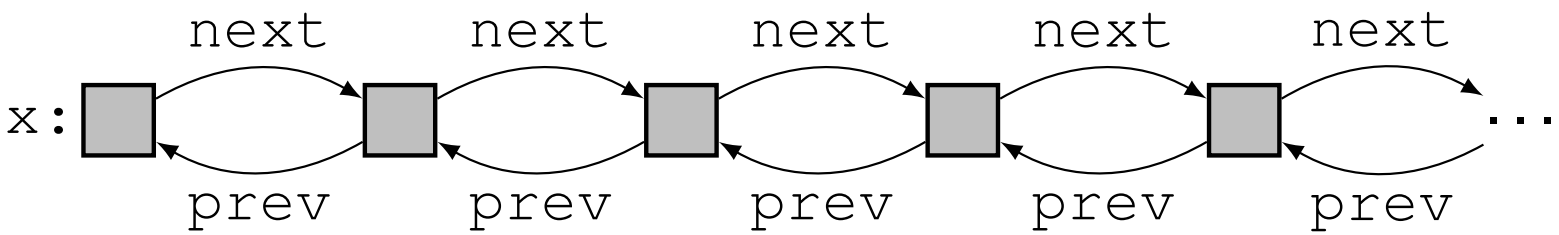

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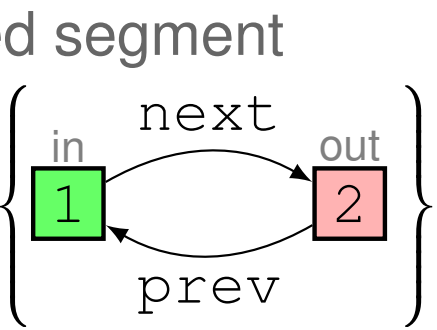


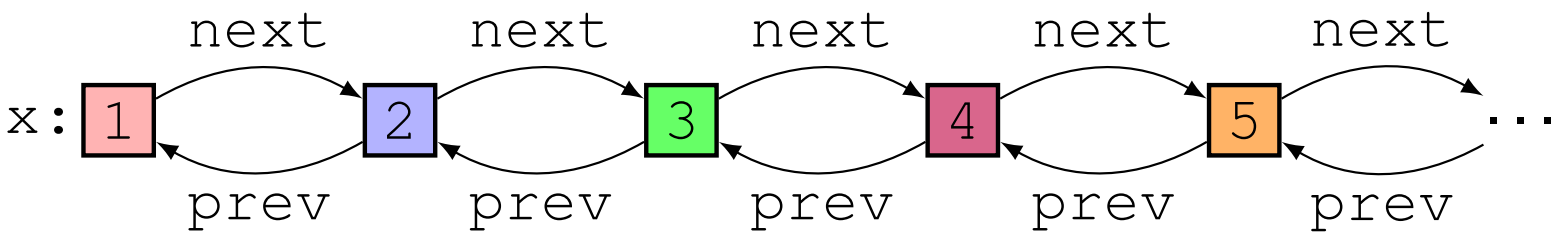

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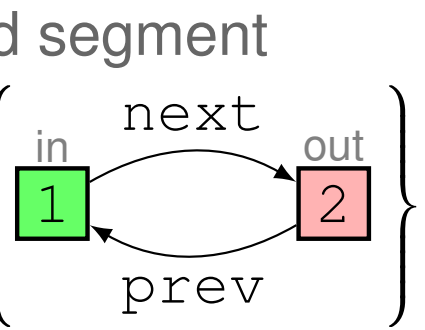


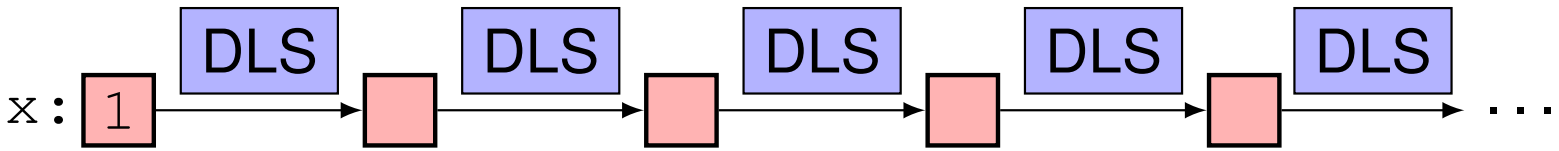

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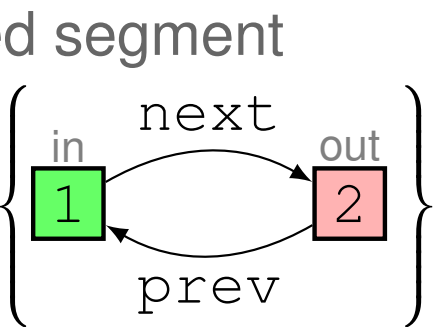


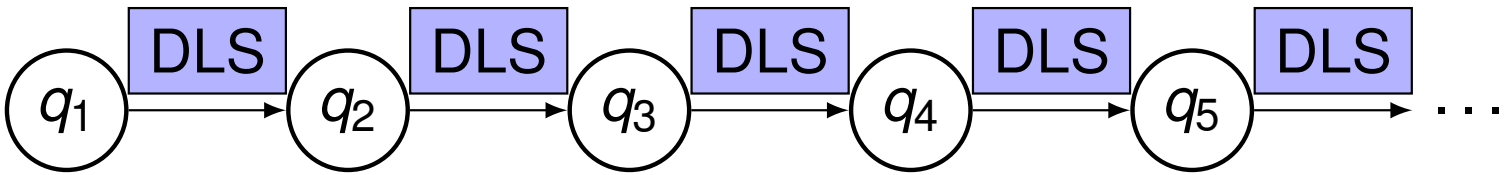

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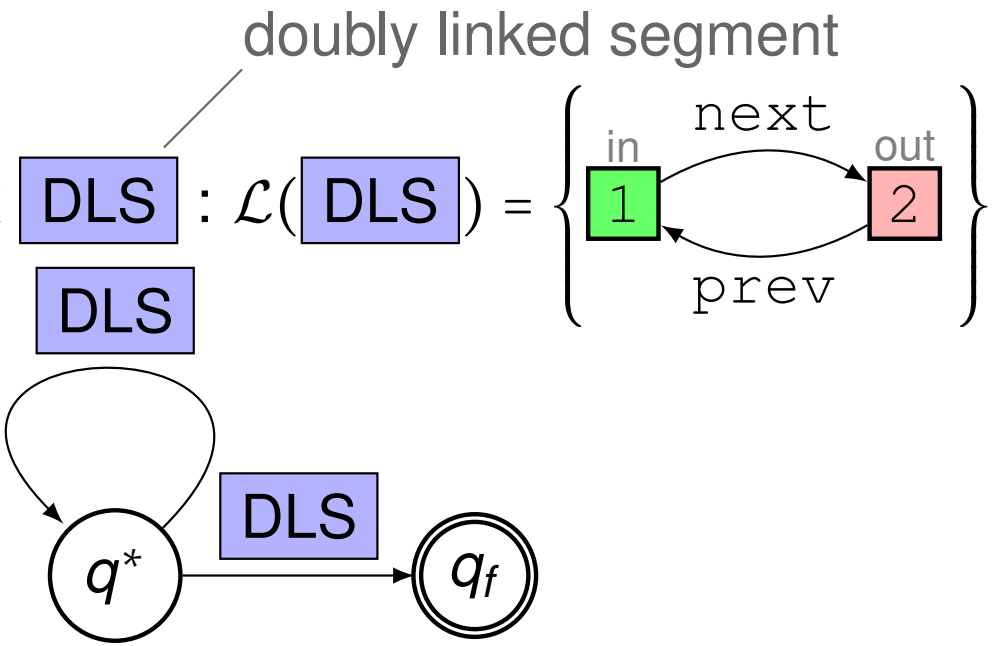

# Learning of Boxes

## The Challenge

Where to get the boxes?

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Where to get the boxes?

CAV'11 — database of boxes

here — automatic learning

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## Task of the learning algorithm

Identify suitable subgraphs of the heap to be folded into boxes.

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**Task of the learning algorithm**

Identify suitable subgraphs of the heap to be folded into boxes.

- suitable subgraph:
  - when replaced with box , in-degree of some cutpoint drops to 1,
  - acceleration $\rightsquigarrow$ FA looping over box
    - representing heaps with unboundedly many cut-points

# Learning of Boxes

- suitable subgraph: compromise between

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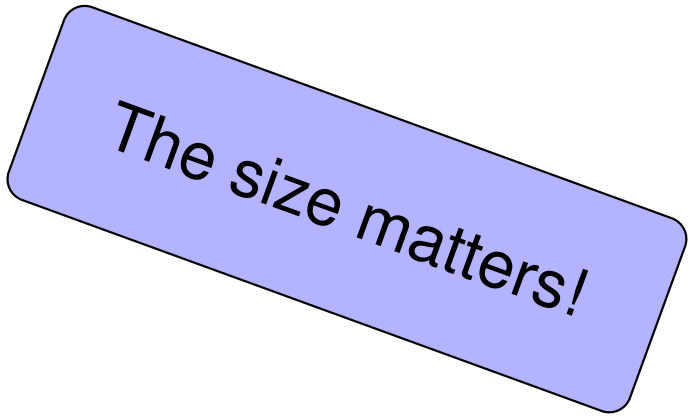
- suitable subgraph: compromise between
  - small size
    - reusability — acceleration can collapse states
  - large size
    - effectively hide cutpoints — subgraphs with small interfaces



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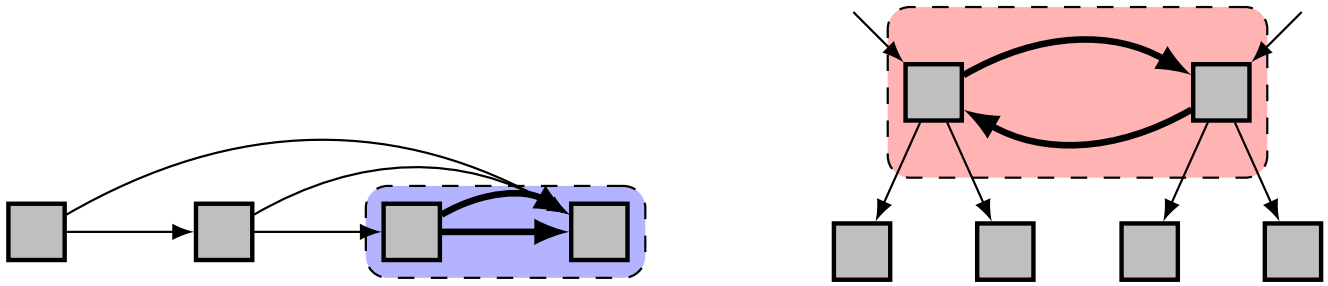
1. building stones — smallest subgraphs meaningful to be folded:



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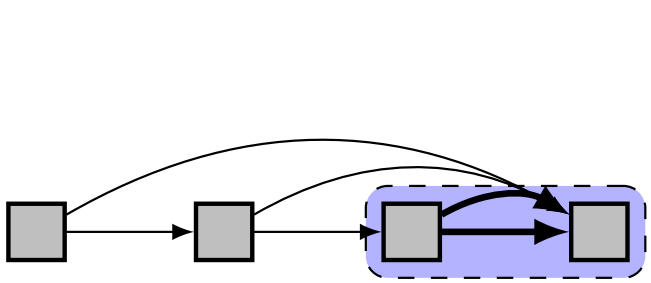
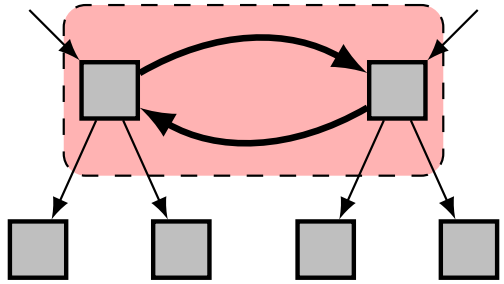
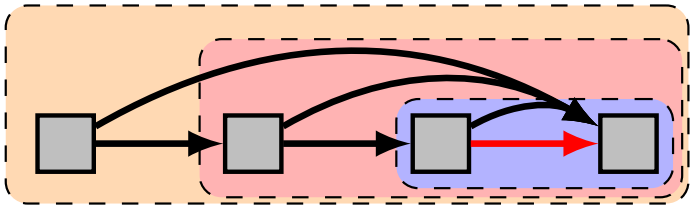




2. handle interface
   - compose intersecting subgraphs

prevent $\infty$ nesting



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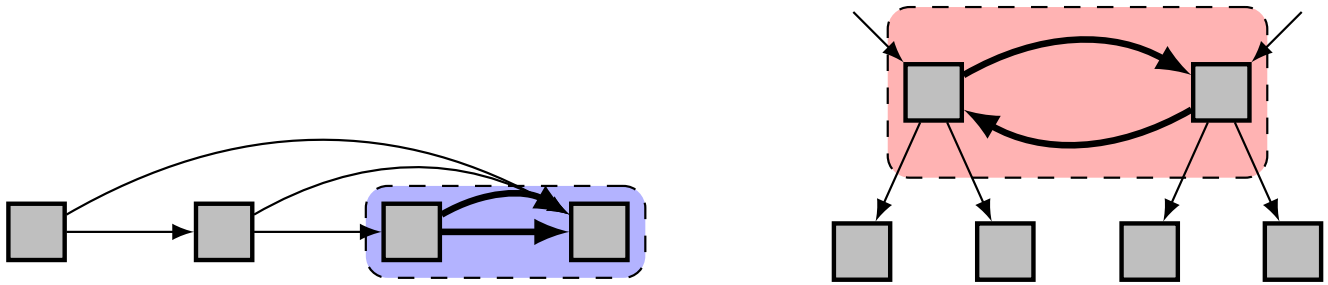

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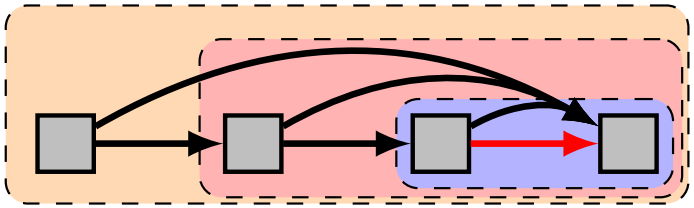
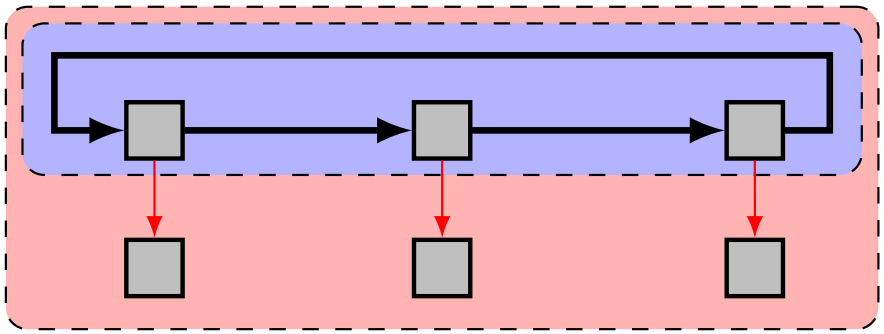


   - enclose paths from inner nodes to leaves

prevent ∞ interface nodes



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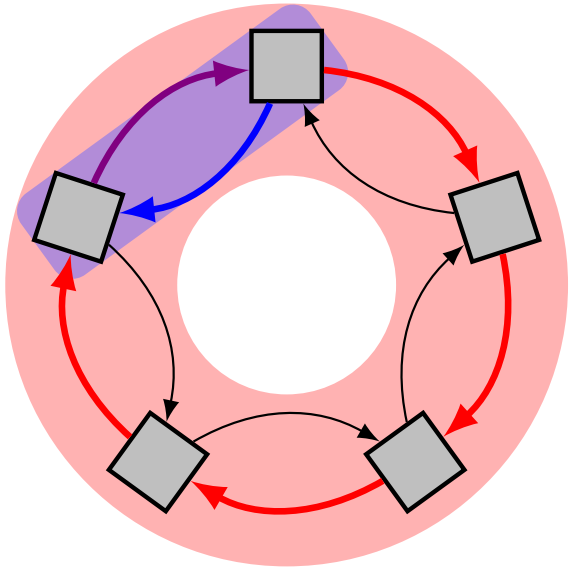

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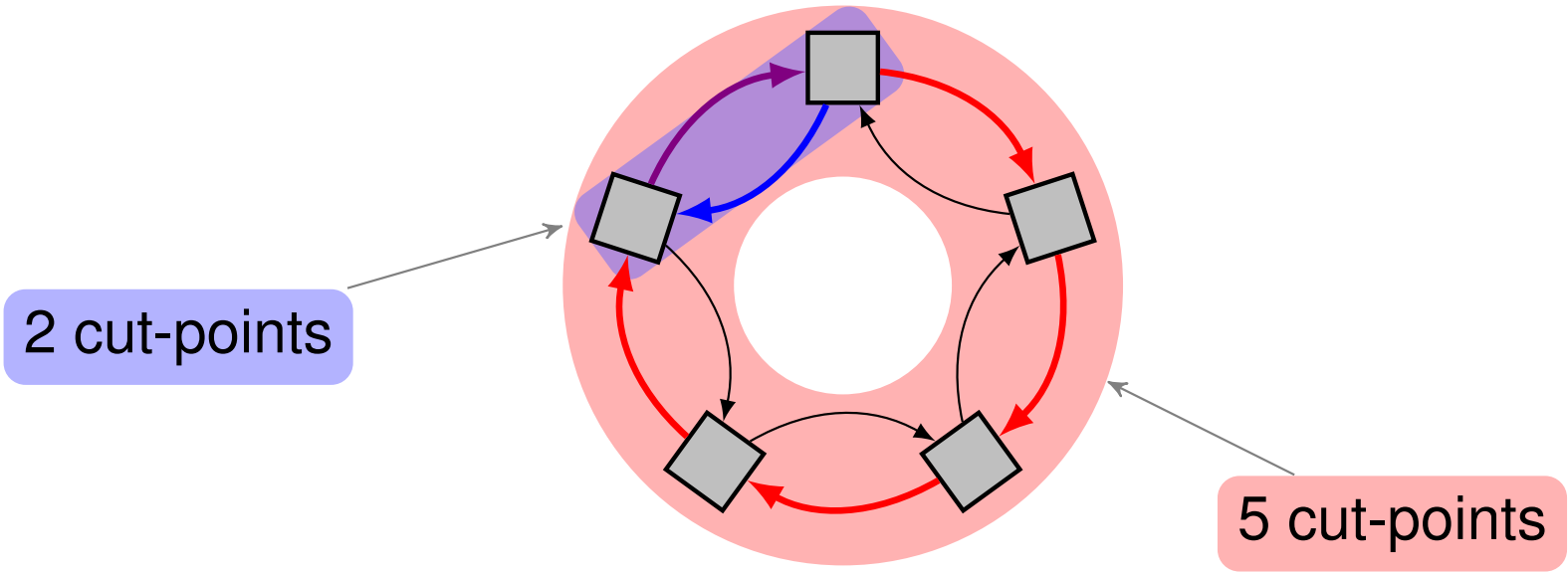

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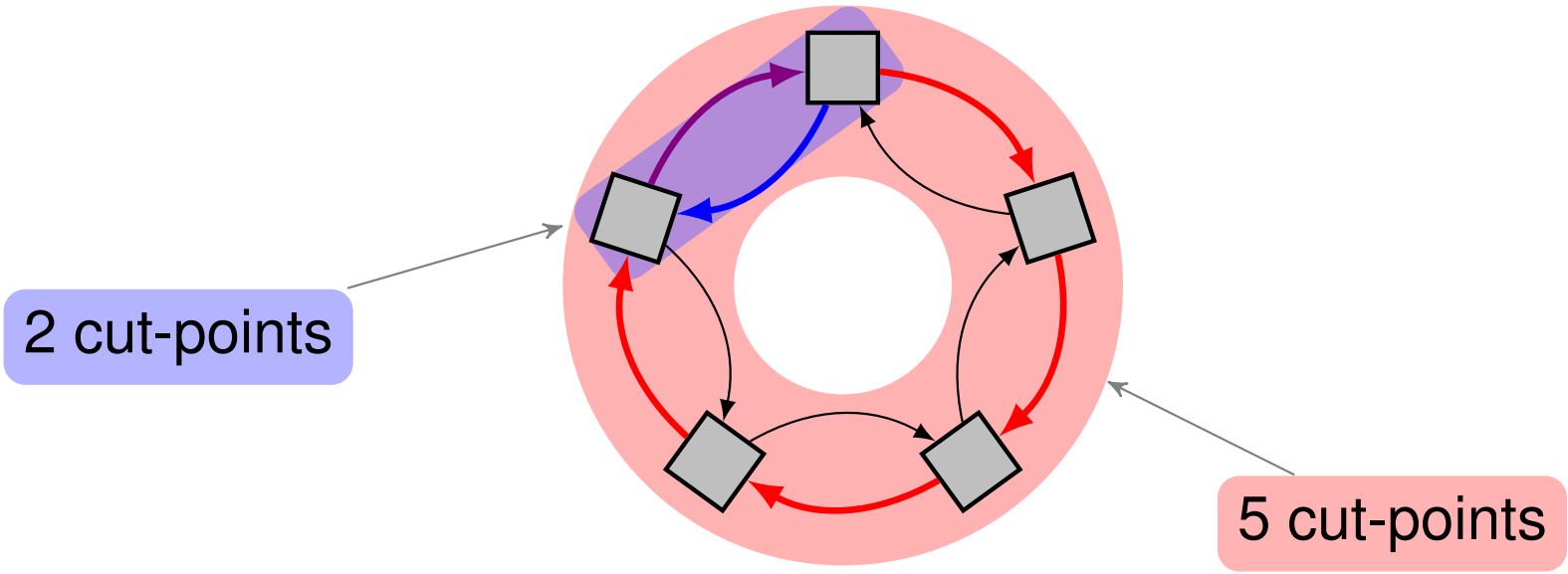


- prefer subgraphs with less cut-points

# Learning inside Acceleration

- learning and folding of boxes in the acceleration loop

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**The Goal**

Fold boxes that will, after acceleration, appear on cycles of automata.

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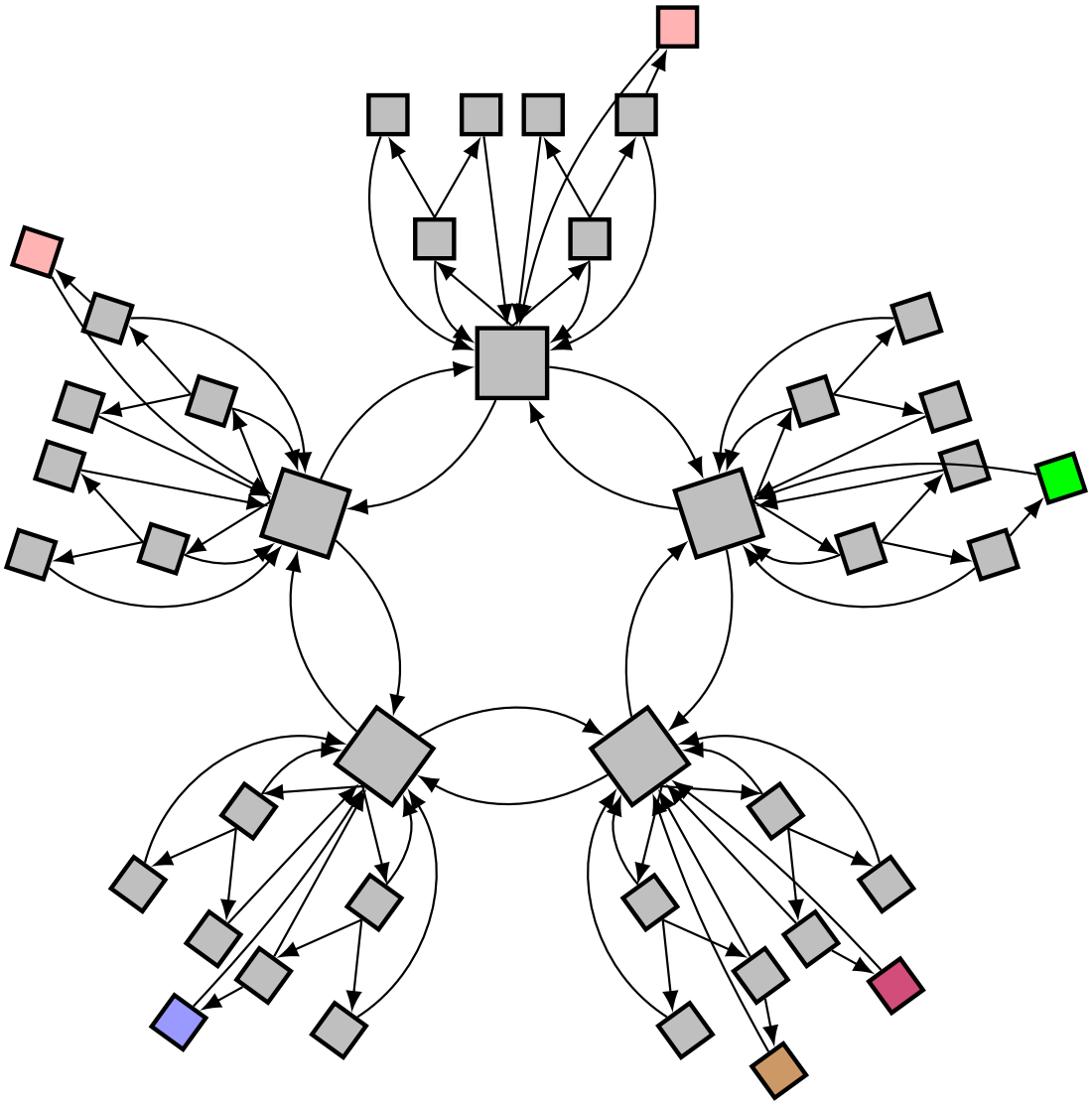
1 **Algorithm:** Acceleration Loop
2 *Unfold solo boxes*
3 **repeat**
4 *Accelerate*
5 *Fold*
6 **until** *fixpoint*

not on a cycle

# Learning of Boxes: Example



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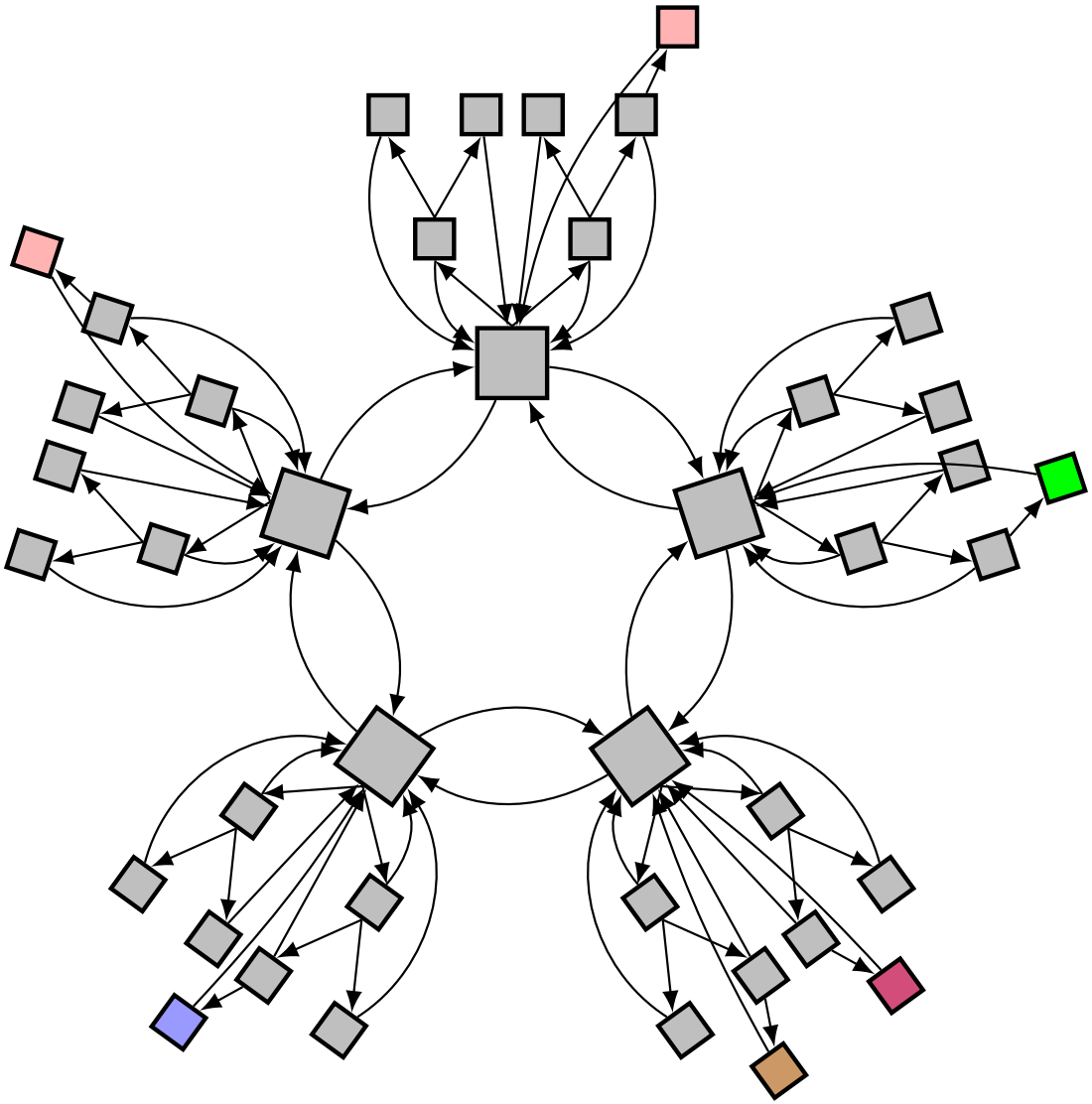

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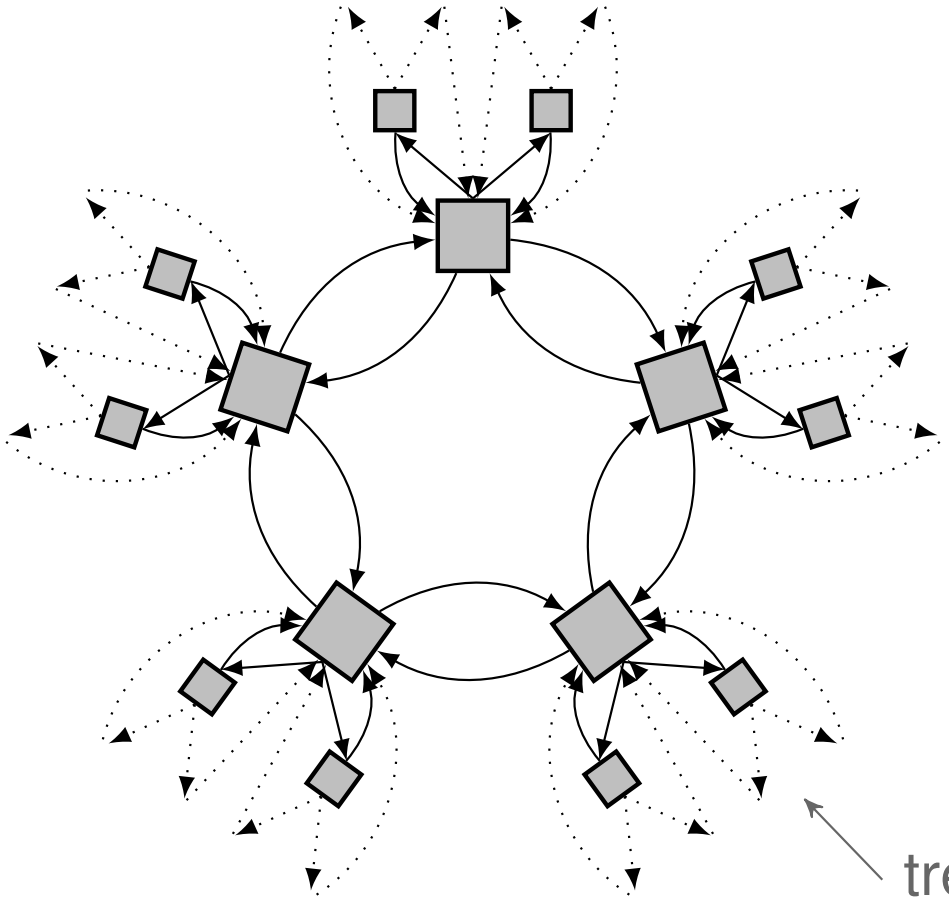

tree with root ptrs of any height

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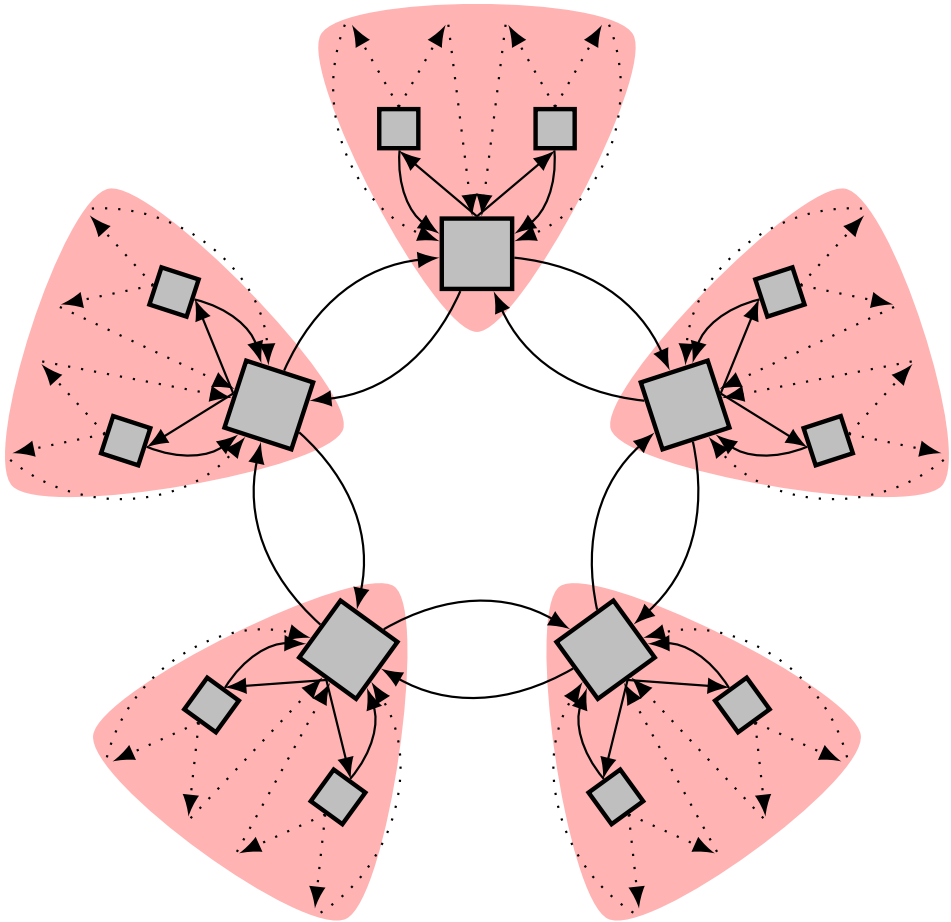

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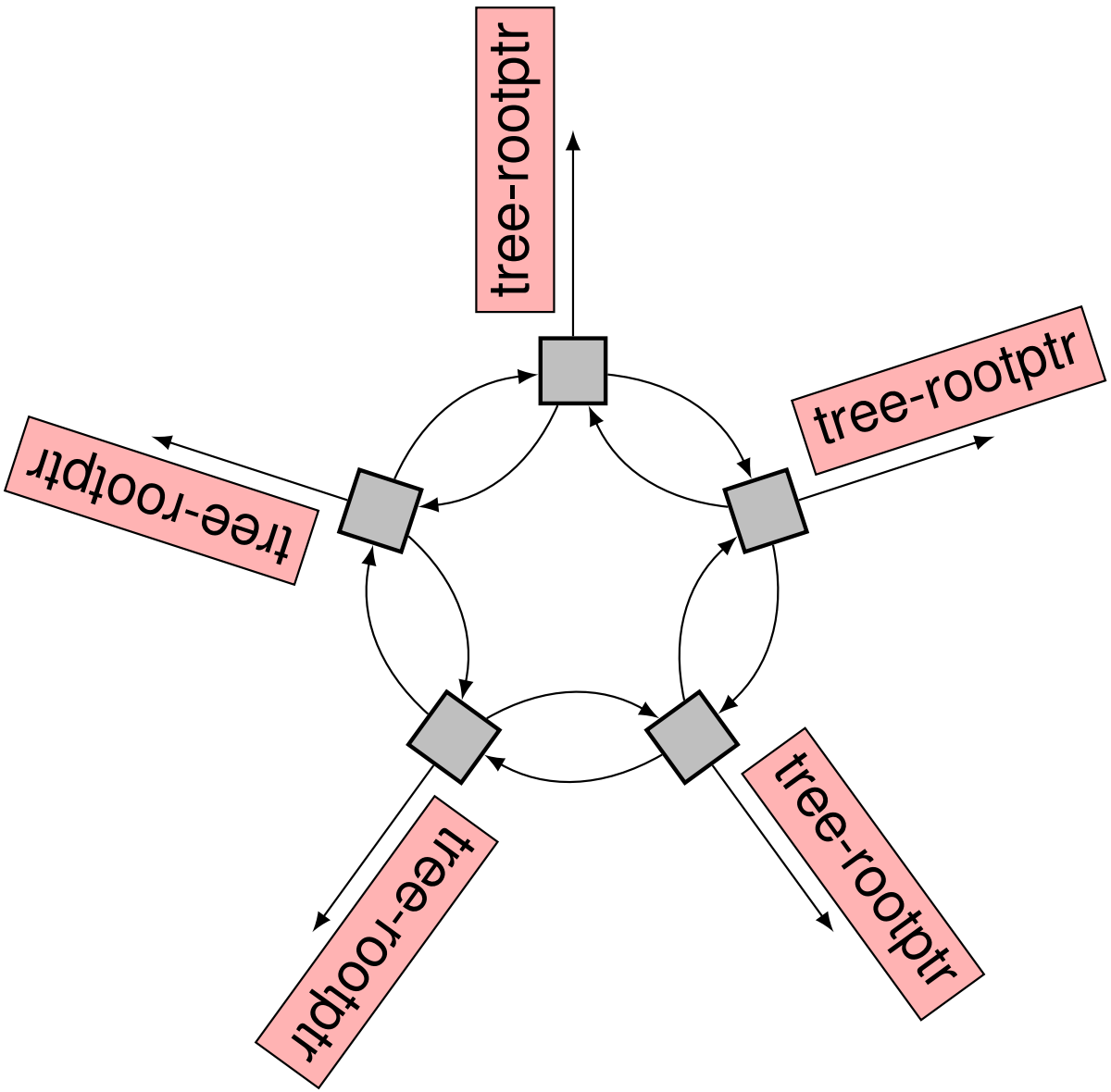


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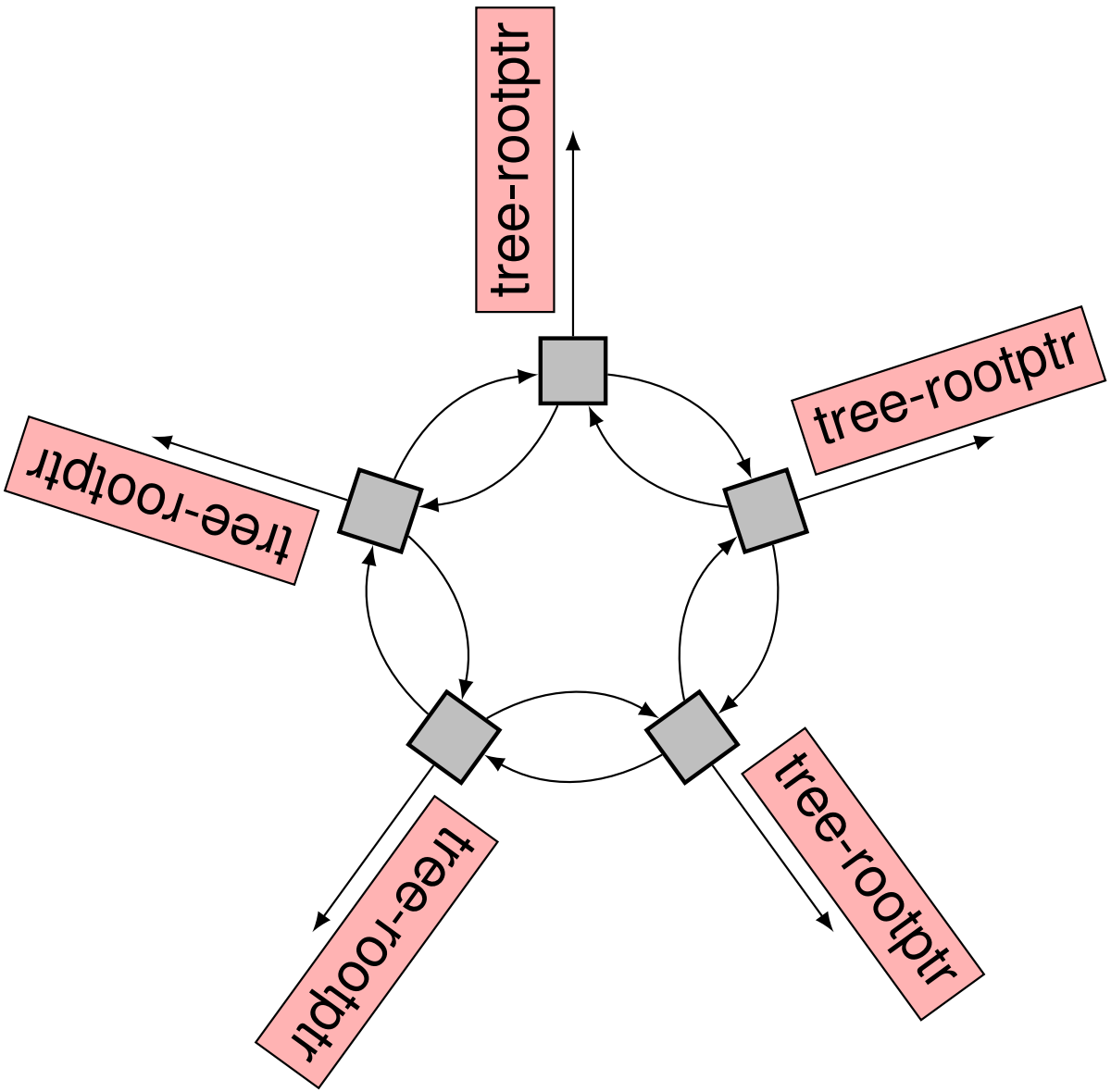


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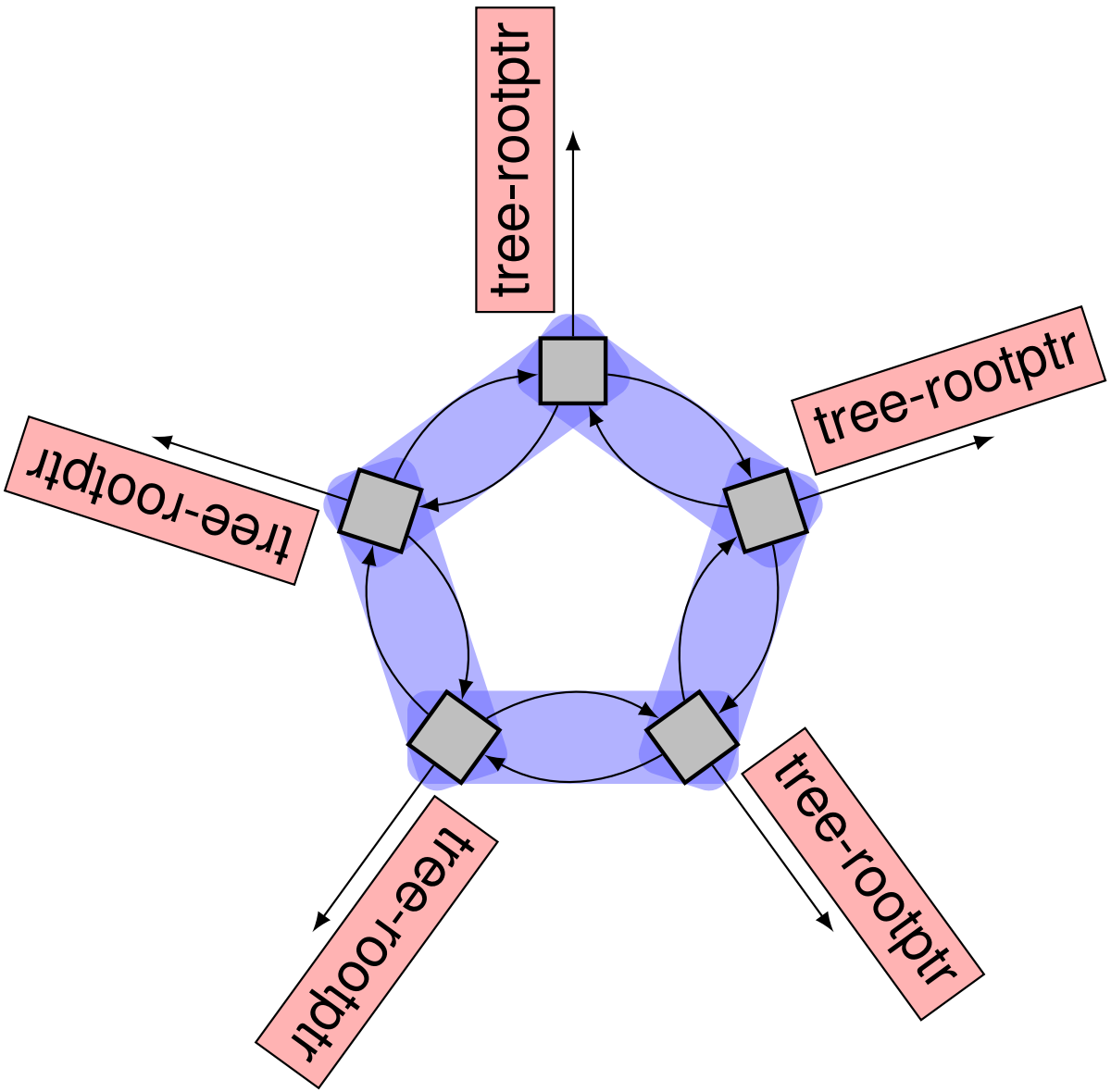


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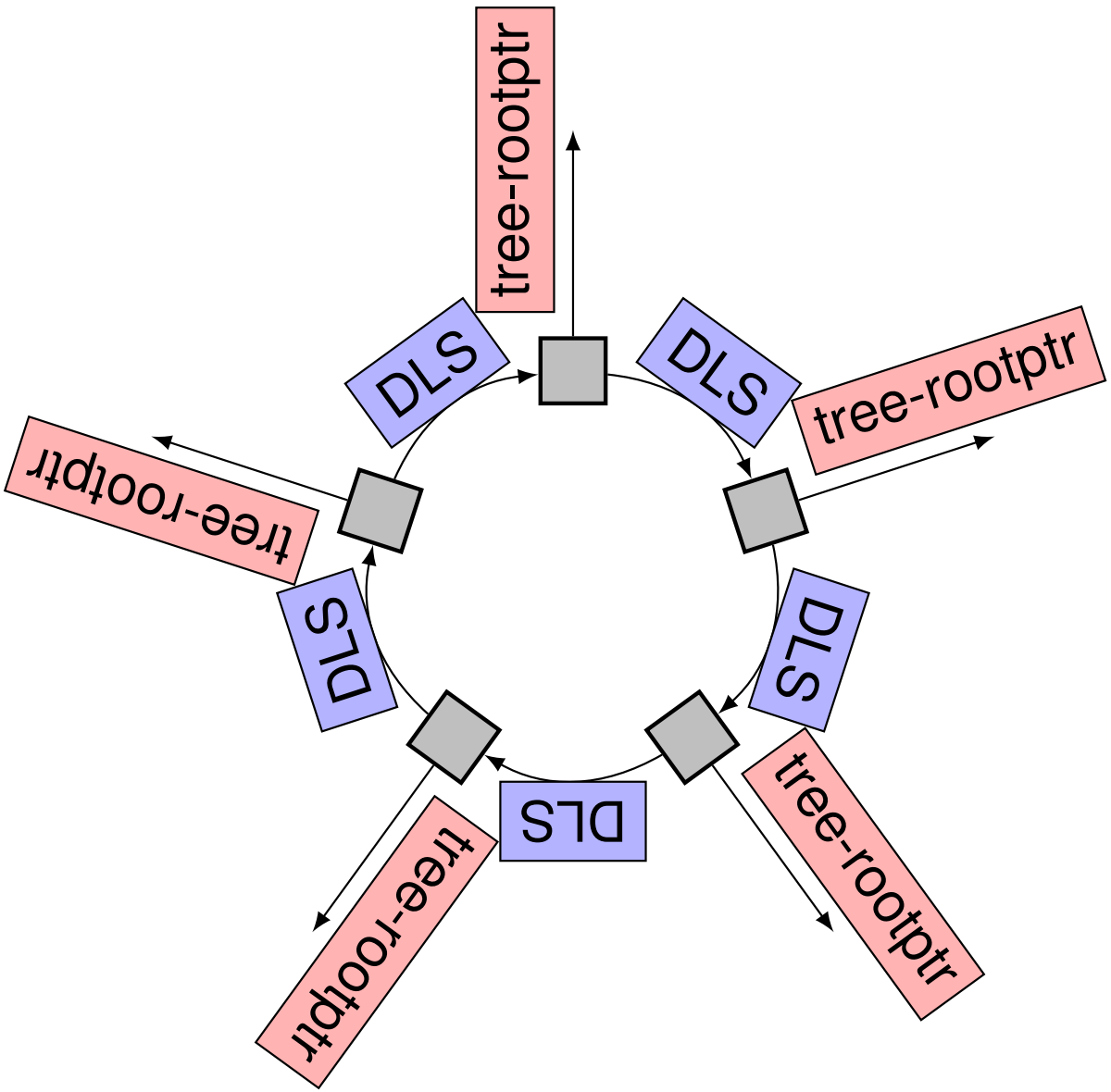


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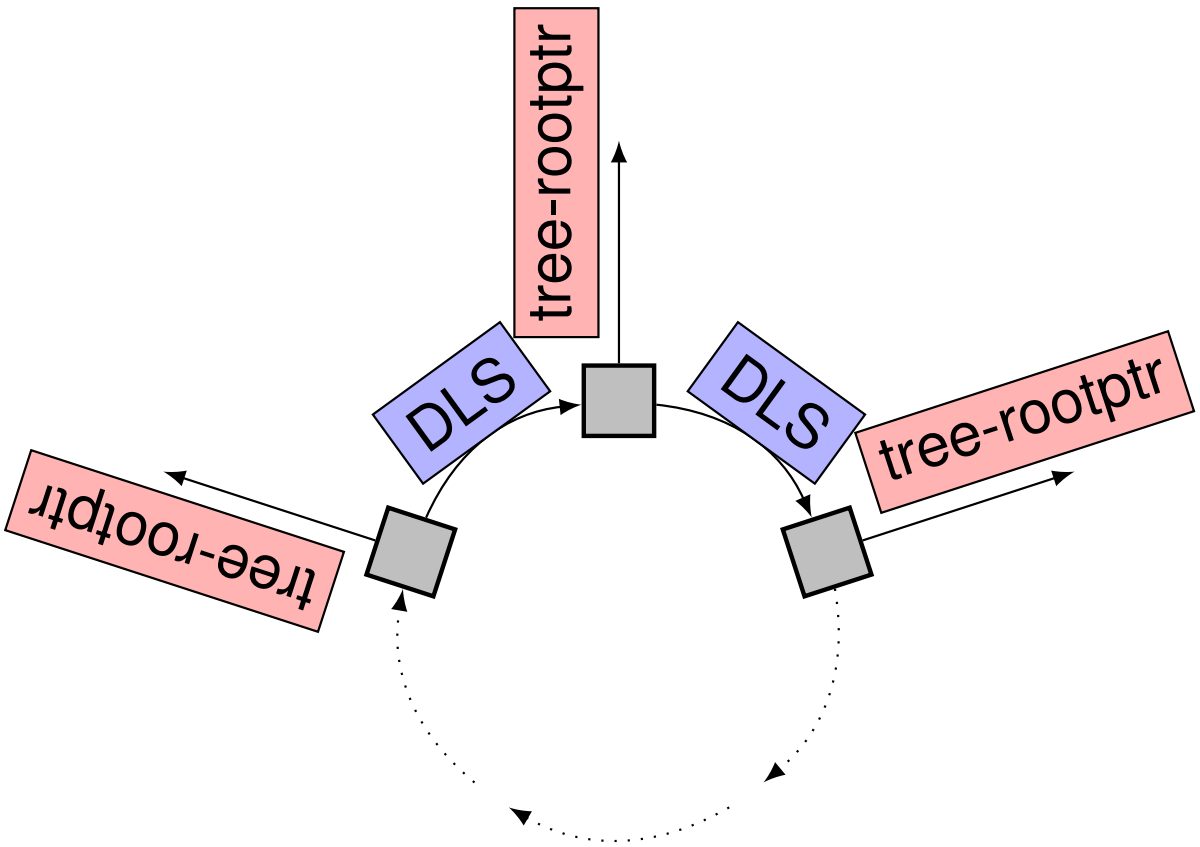


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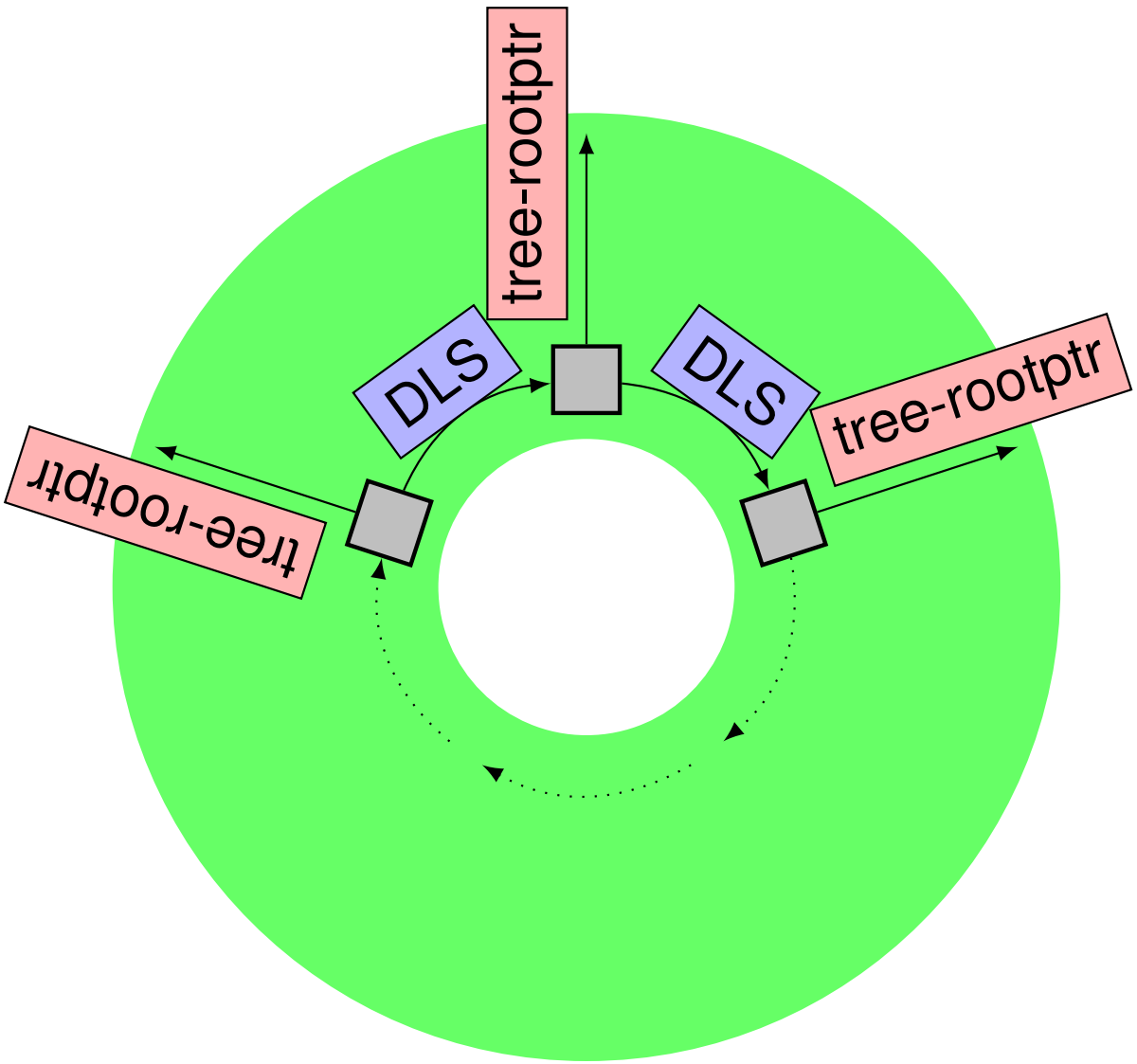


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# Learning of Boxes: Example

circular-DLL-of
-trees-rootptr

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Table : Results of the experiments [s]

| Example | **FA** | Predator | Example | **FA** | Predator |
|---|---|---|---|---|---|
| SLL (delete) | 0.04 | 0.04 | DLL (reverse) | 0.06 | 0.03 |
| SLL (bubblesort) | 0.04 | 0.03 | DLL (insert) | 0.07 | 0.05 |
| SLL (mergesort) | 0.15 | 0.10 | DLL (insertsort$_1$) | 0.40 | 0.11 |
| SLL (insertsort) | 0.05 | 0.04 | DLL (insertsort$_2$) | 0.12 | 0.05 |
| SLL (reverse) | 0.03 | 0.03 | DLL of CDLLs | 1.25 | 0.22 |
| SLL+head | 0.05 | 0.03 | DLL+subdata | 0.09 | T |
| SLL of 0/1 SLLs | 0.03 | 0.11 | CDLL | 0.03 | 0.03 |
| SLL$_{\text{Linux}}$ | 0.03 | 0.03 | tree | 0.14 | Err |
| SLL of CSLLs | 0.73 | 0.12 | tree+parents | 0.21 | T |
| SLL of 2CDLLs$_{\text{Linux}}$ | 0.17 | 0.25 | tree+stack | 0.08 | Err |
| skip list$_2$ | 0.42 | T | tree (DSW) Deutsch-Schorr-Waite | 0.40 | Err |
| skip list$_3$ | 9.14 | T | tree of CSLLs | 0.42 | Err |

timeout

false positive

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- a follow-up work:
  - tracking ordering relations
    - P. Abdulla, L. Holík, B. Jonsson, O. Lengál, C.Q. Tring, and T. Vojnar. **Verification of Heap Manipulating Programs with Ordered Data by Extended Forest Automata.** To appear in *Proc. of ATVA'13*.

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