A Concurrent Program Logic with a Future and History

Roland Meyer, Thomas Wies, Sebastian Wolff

[OOPSLA'22]

Motivation

"***Programs = Algorithms + Data Structures***"

–Niklaus Wirth, 1978

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Verification via Separation Logic (SL)

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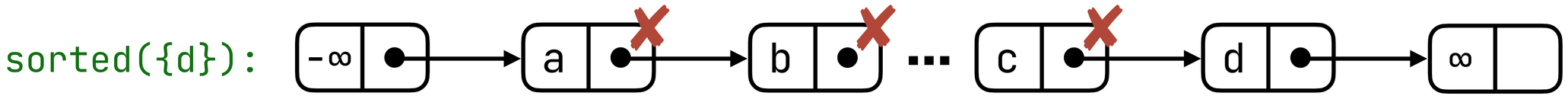
Verification via Separation Logic (SL)

Automation

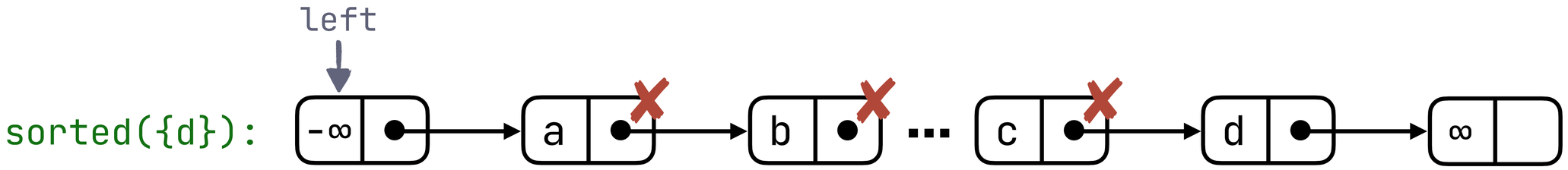
Verification Challenge 1: **Complex Unbounded Updates**

Verification Challenge 2: **Linearizability**

Example: Unbounded Removal



Example: Unbounded Removal



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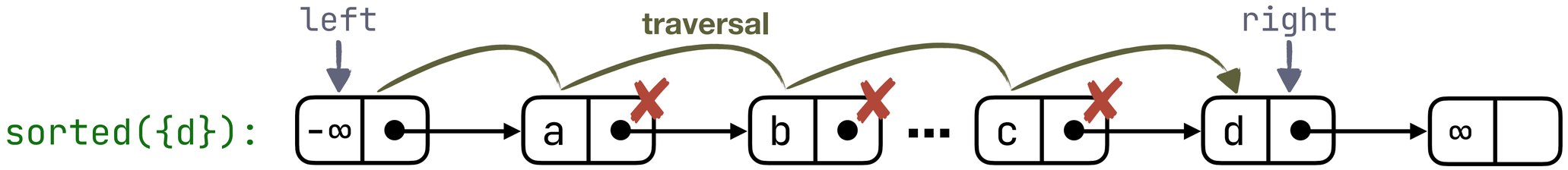
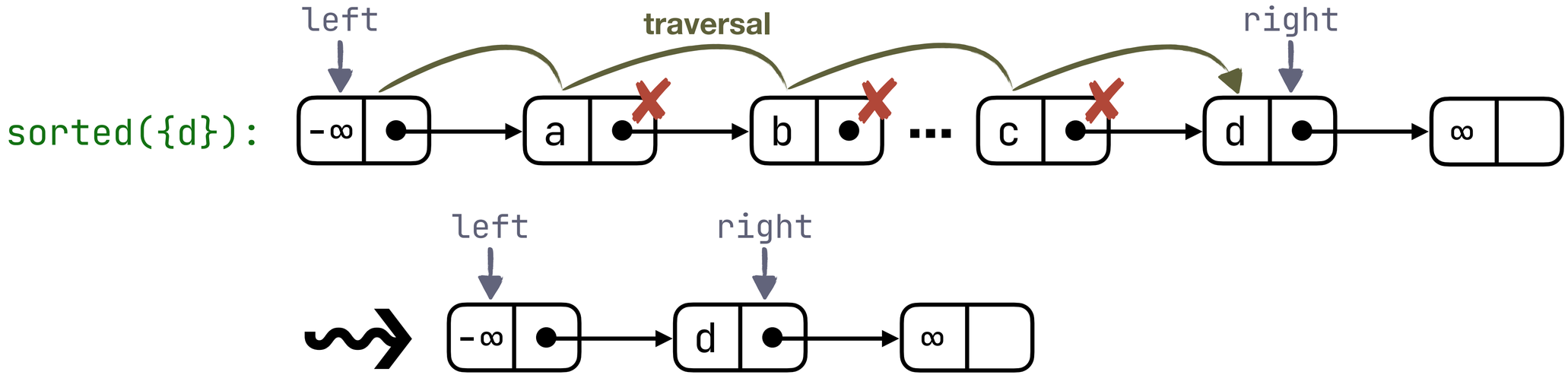


Example: Unbounded Removal



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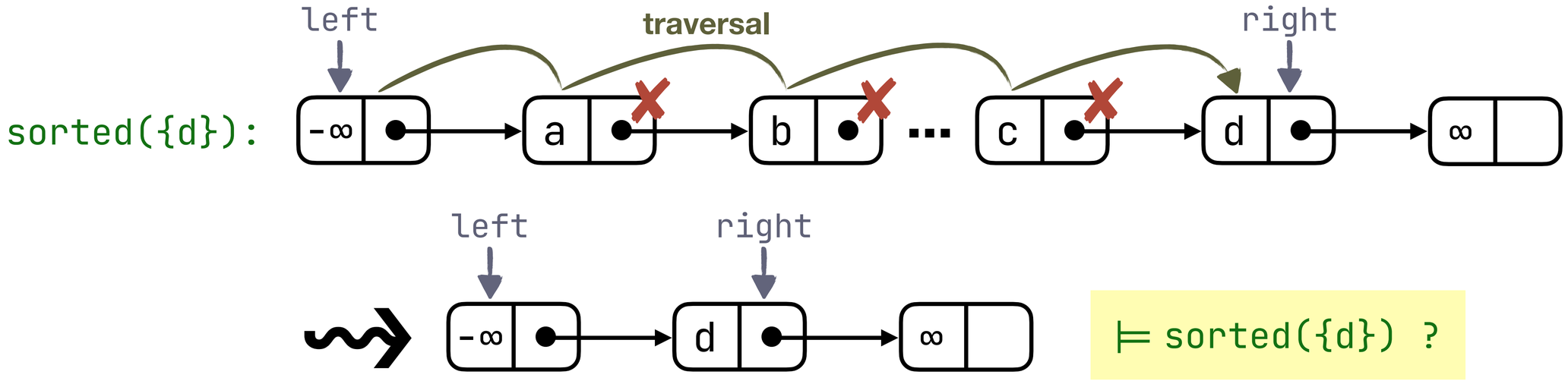

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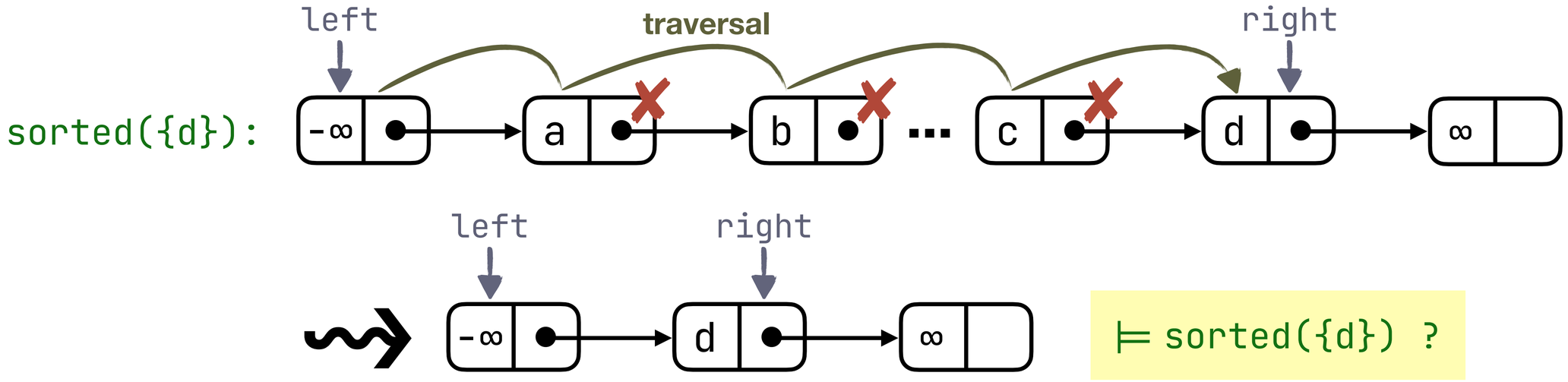

Classical Reasoning

- traversal : 

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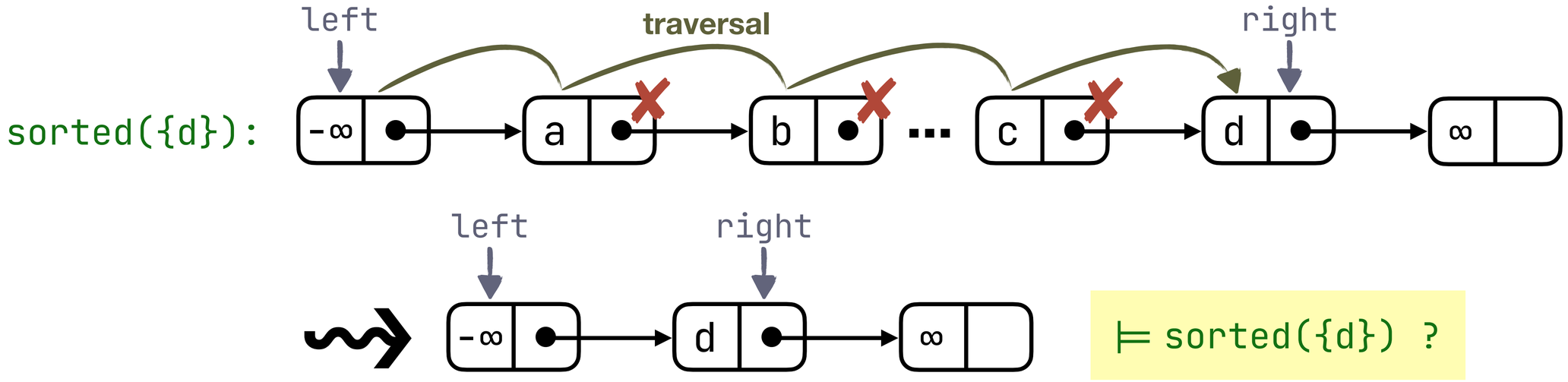
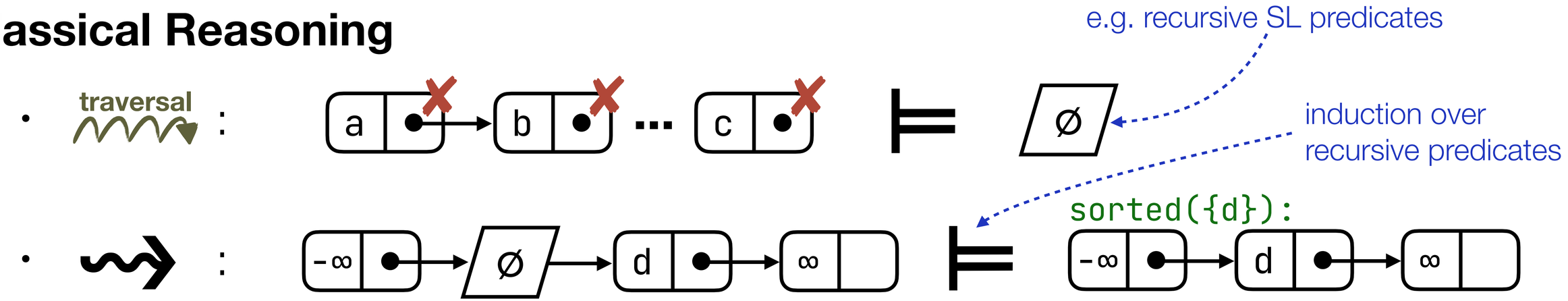


Classical Reasoning



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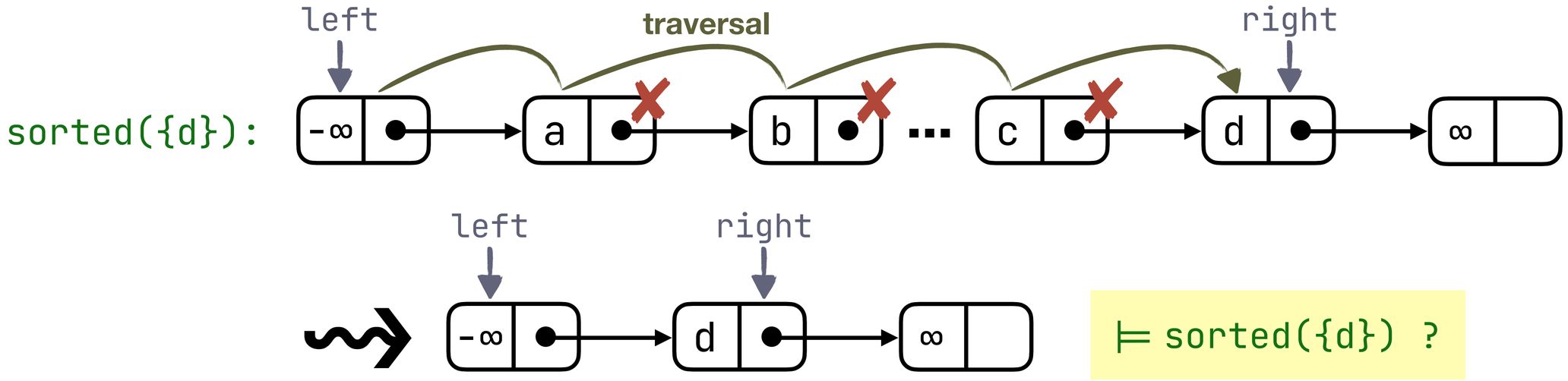
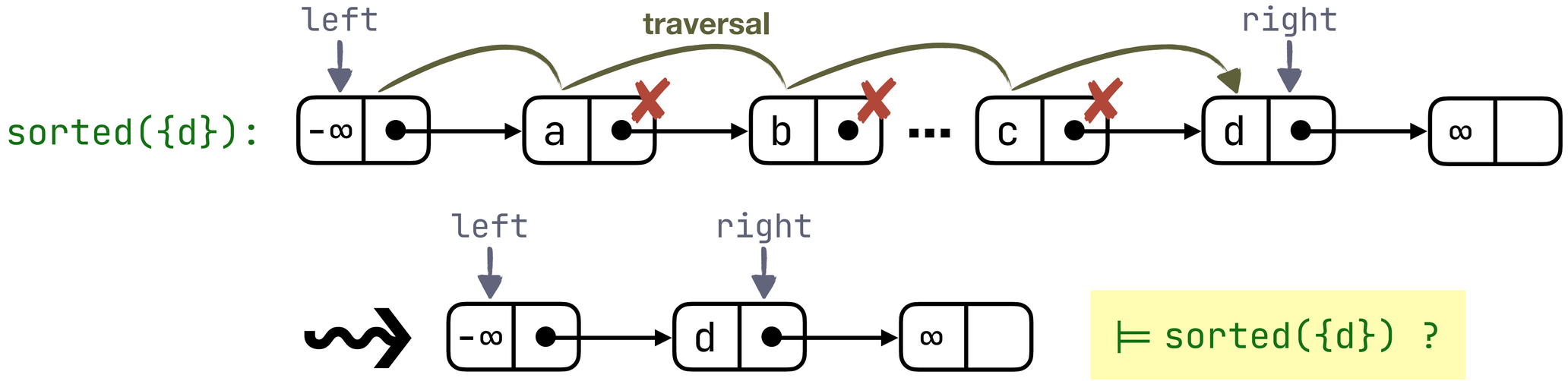


Contribution: Ghost Update Chunks

Example: Unbounded Removal



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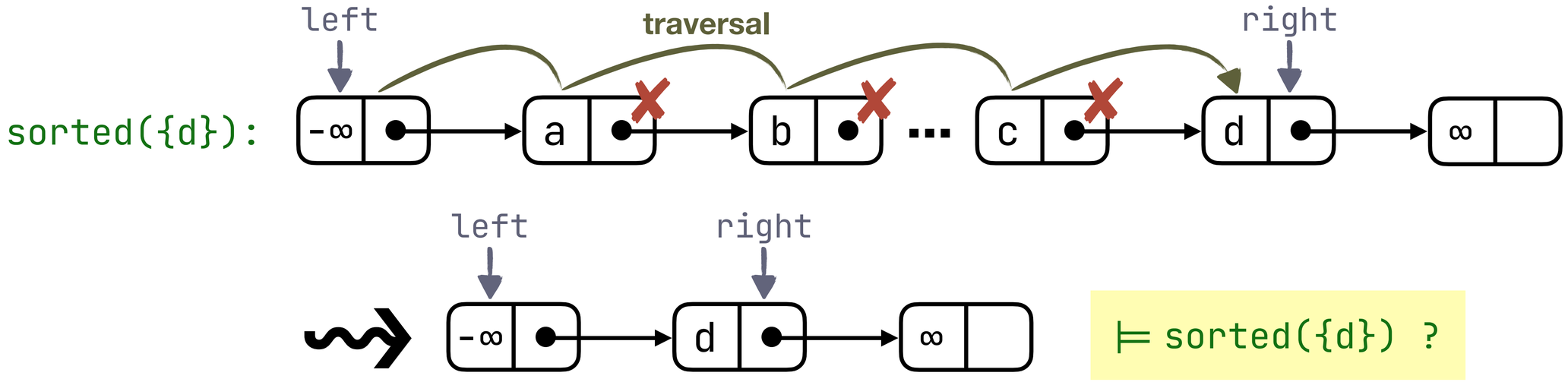

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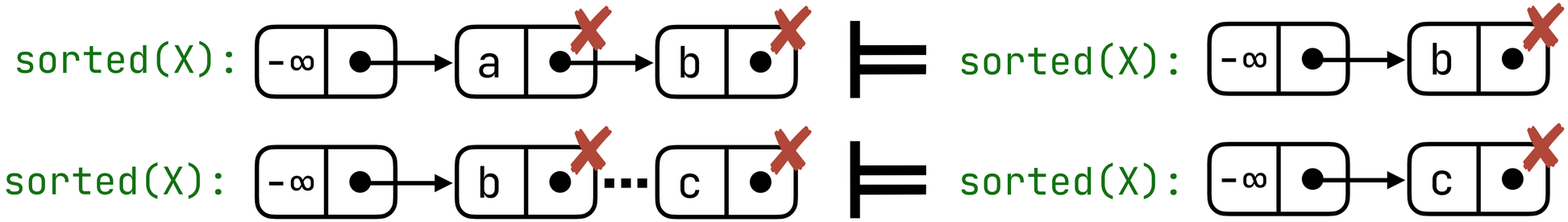

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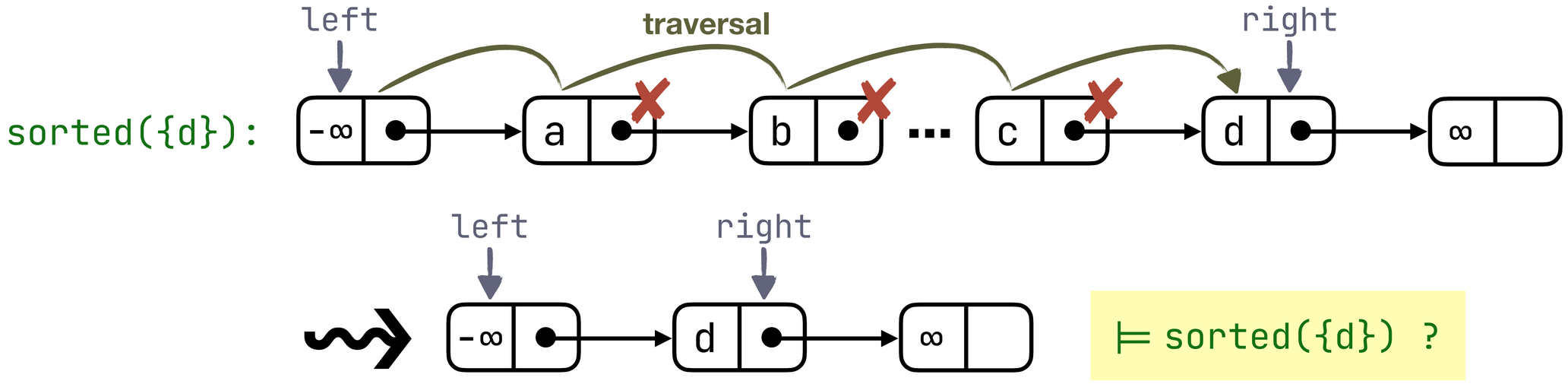

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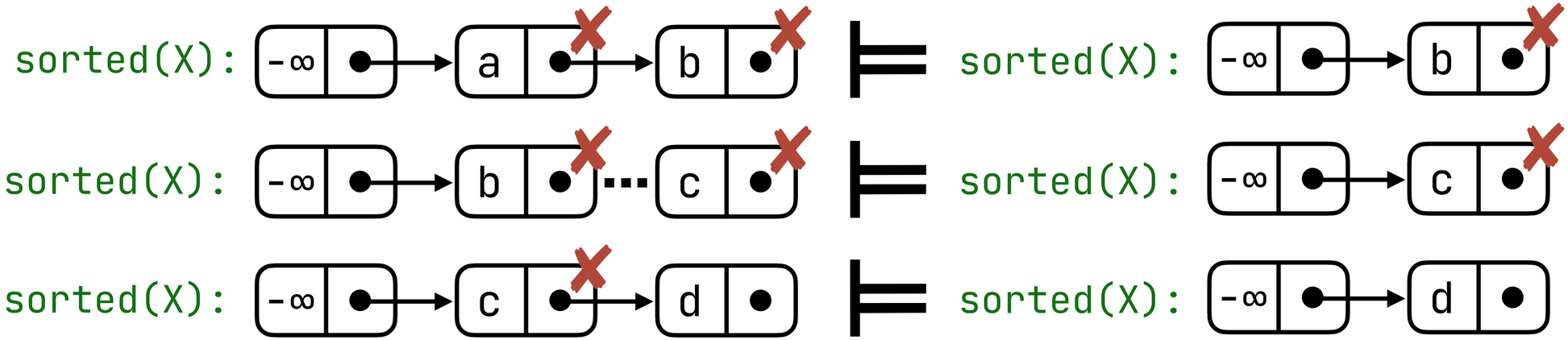

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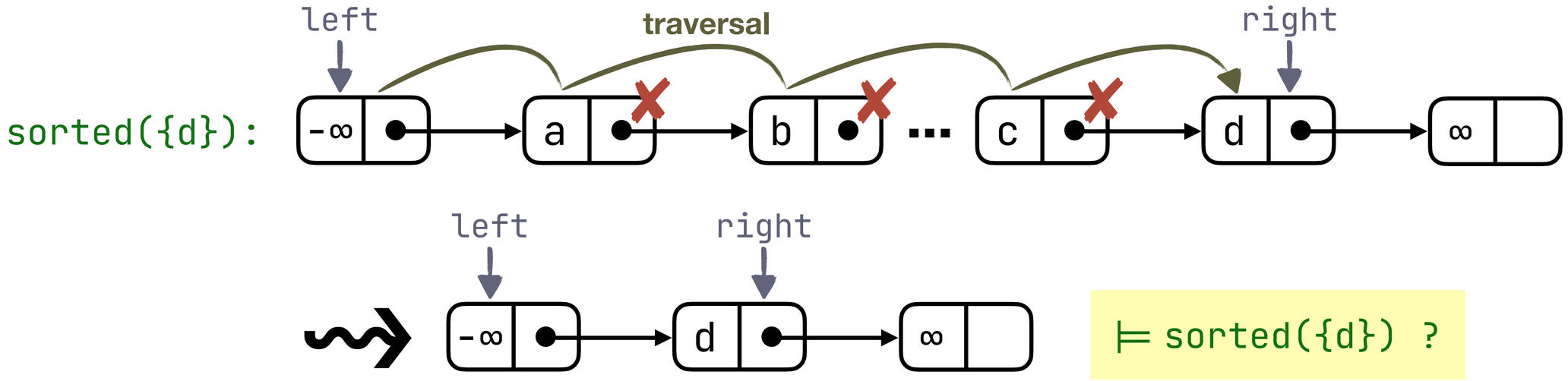

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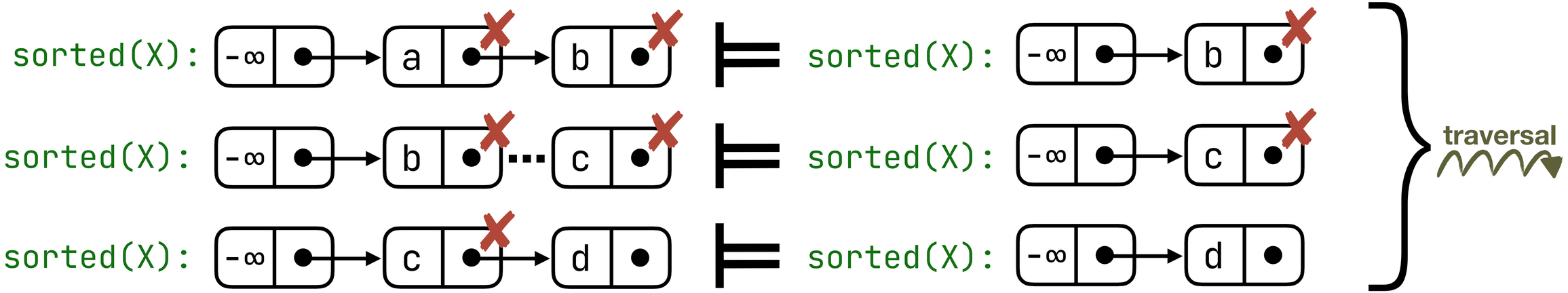
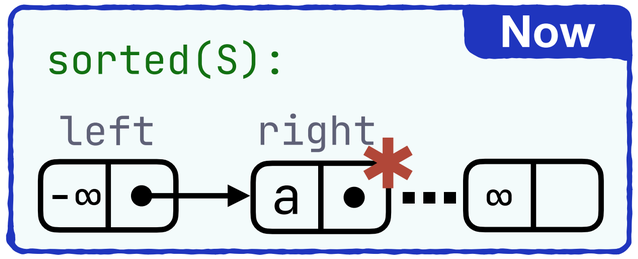


Ghost Update Chunks

```
// traversal step 1
```

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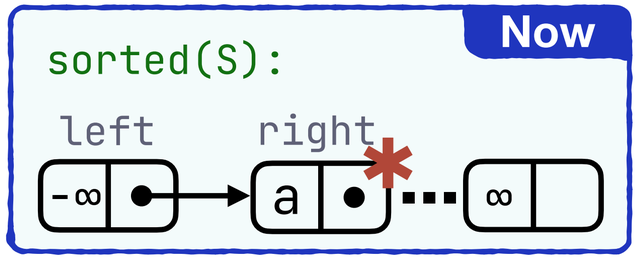
assume(right→mark);
next := right→next;
```

```
right := next;
```

Ghost Update Chunks

```
// traversal step 1
```

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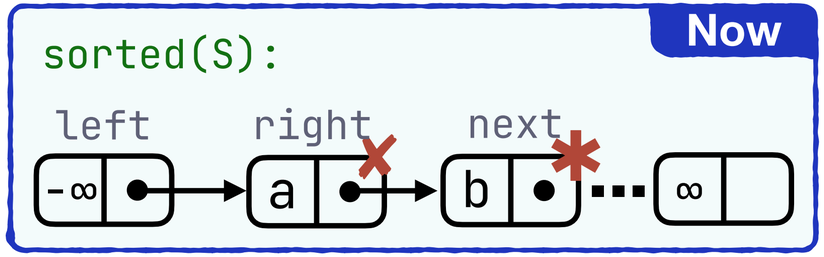


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Ghost Update Chunks

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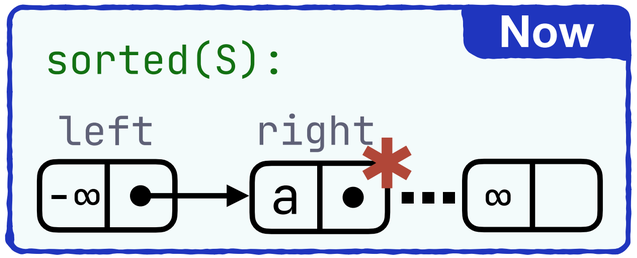


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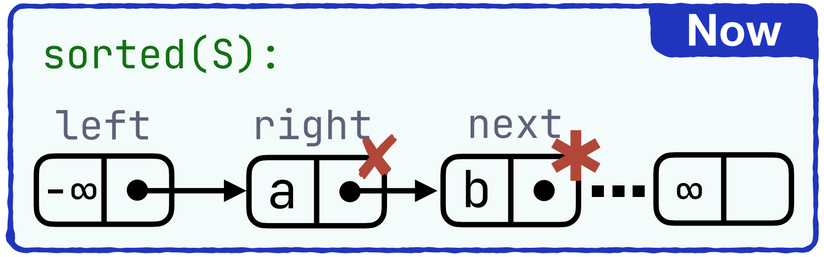

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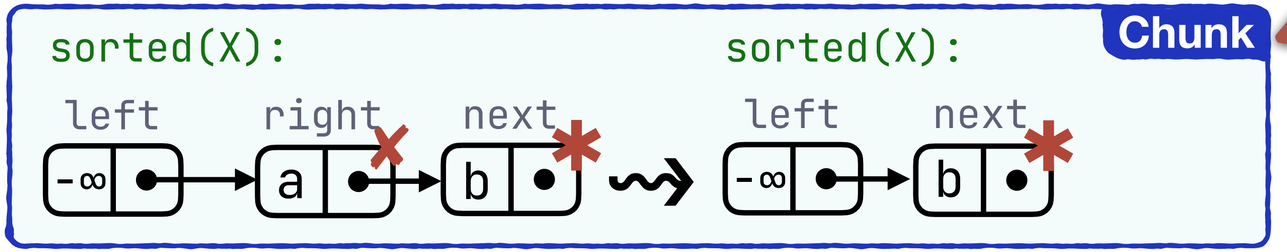

INTRO

```
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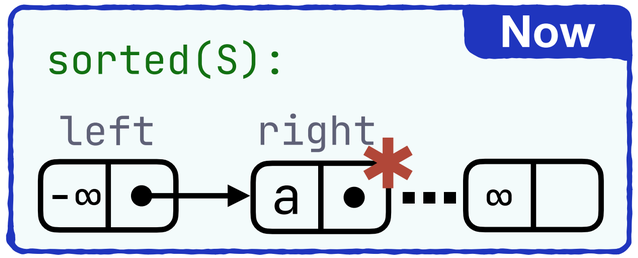
```

Ghost Update Chunks

```
// traversal step 1
```

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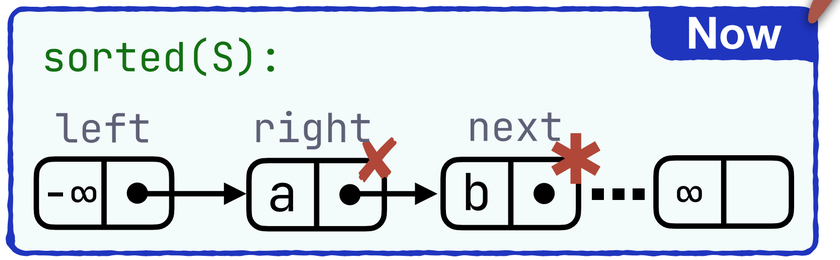
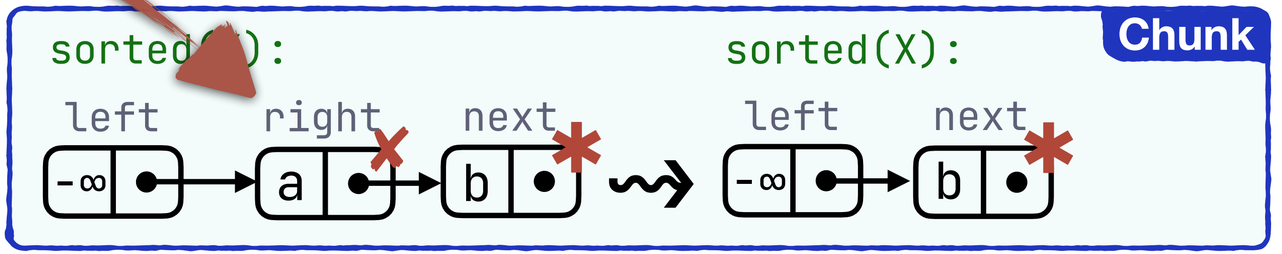


DISCHARGE

*

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```
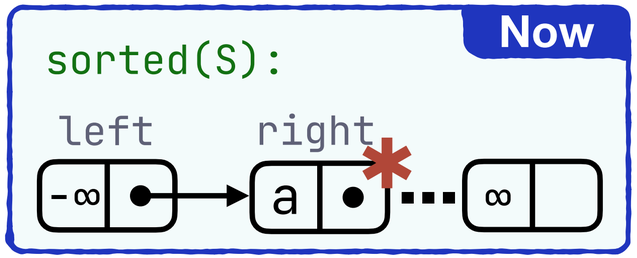

Ghost Update Chunks

```
// traversal step 1
```

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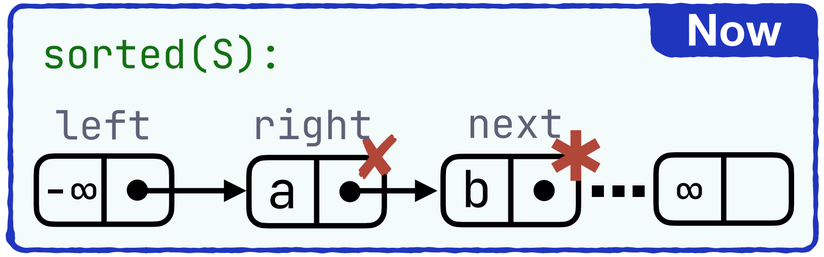


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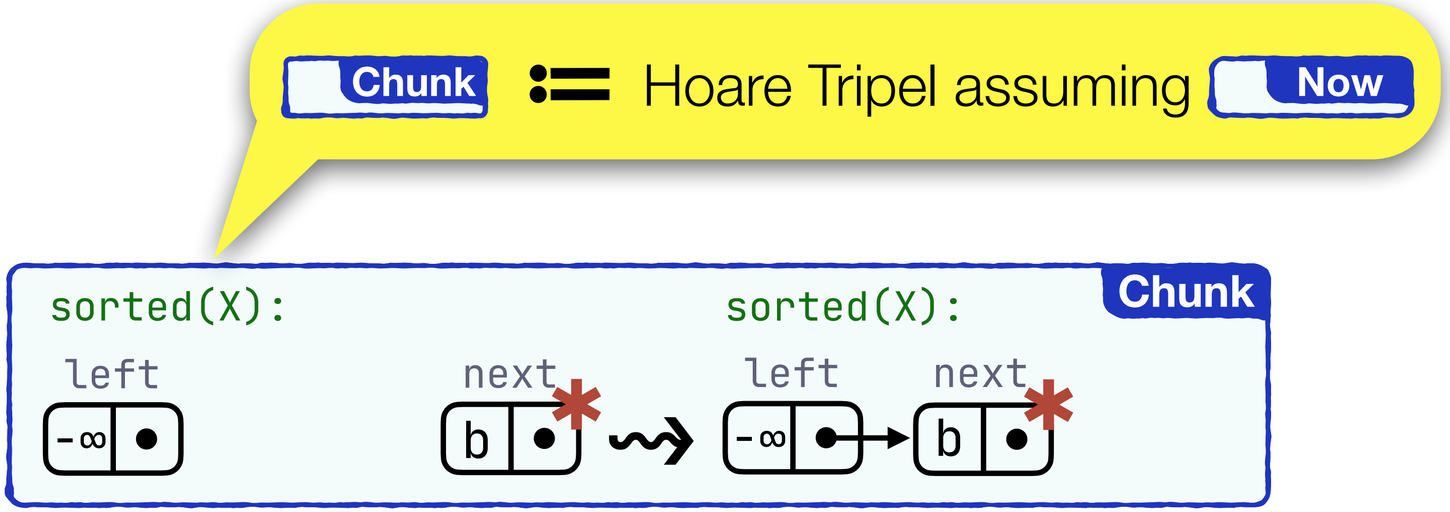

Ghost Update Chunks

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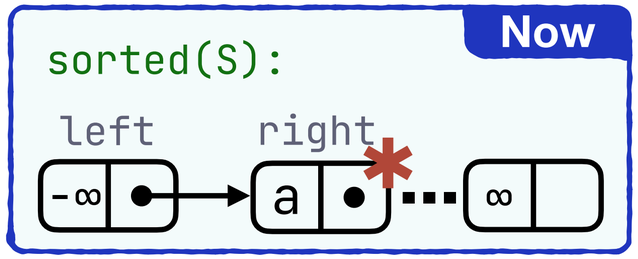


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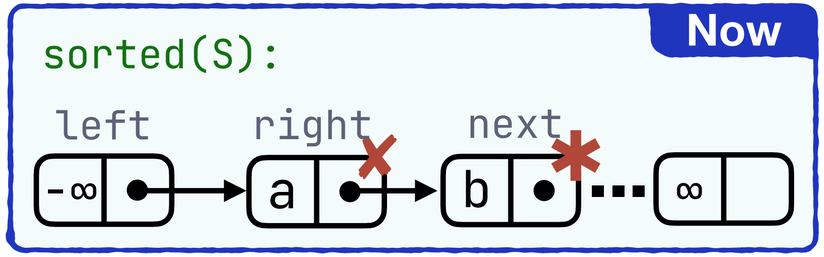

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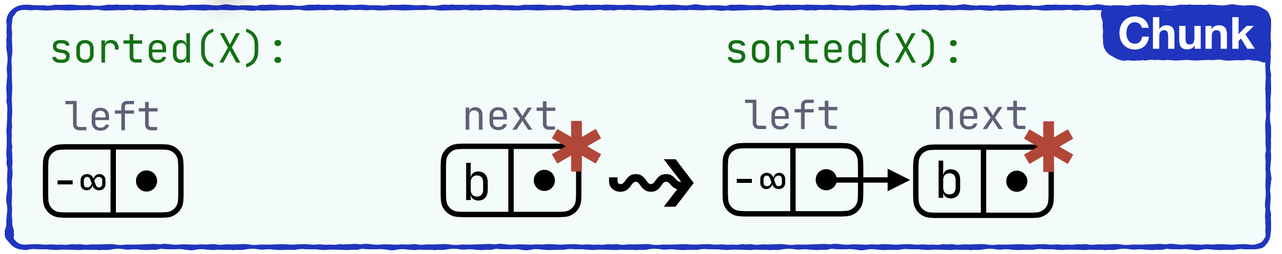
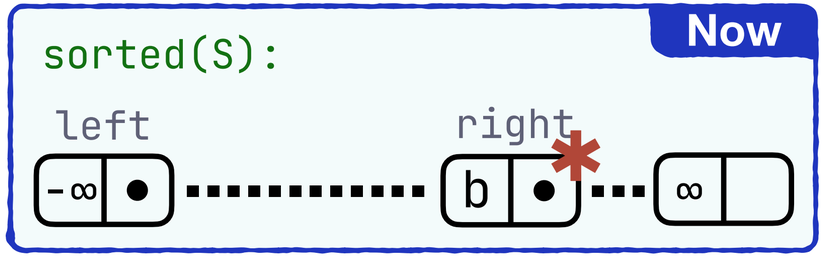


Chunk ≔ Hoare Tripel assuming Now

```
right := next;
```



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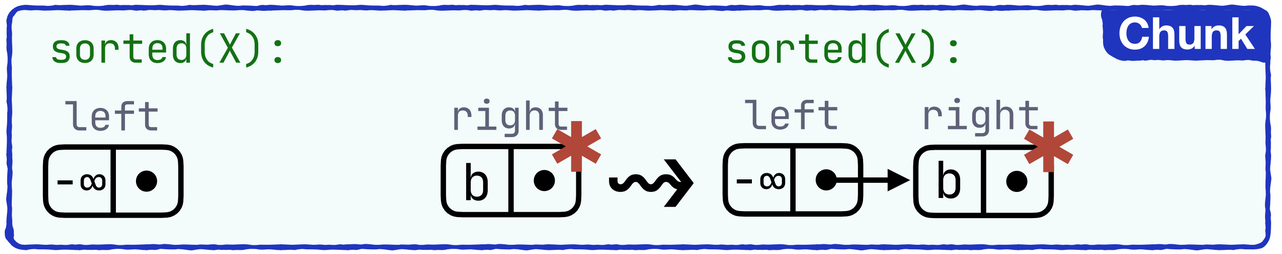
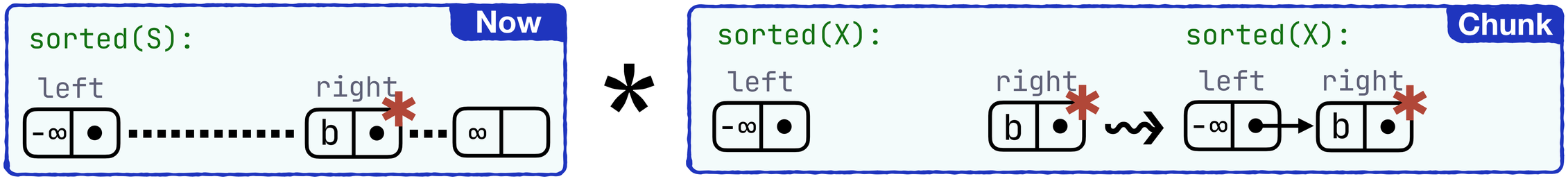


Ghost Update Chunks

```
// traversal step 1 2
```

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```

```
right := next;
```

Ghost Update Chunks

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// traversal step 1 2
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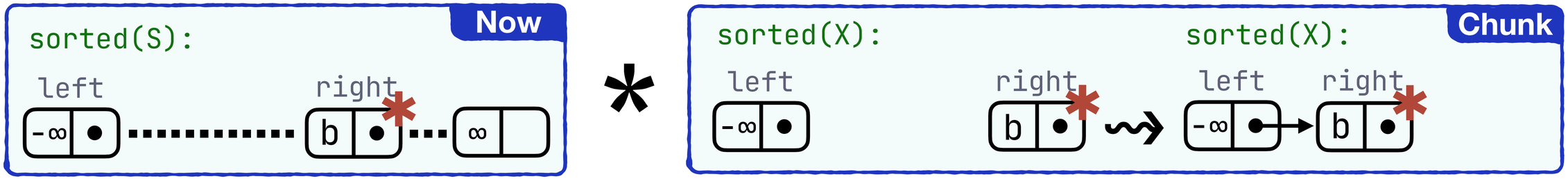


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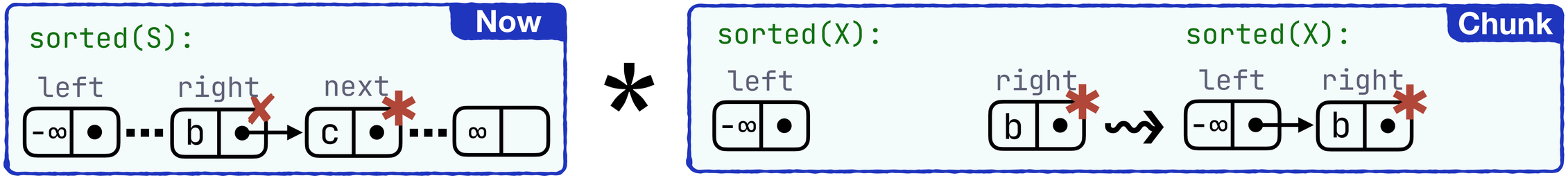


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```

Ghost Update Chunks

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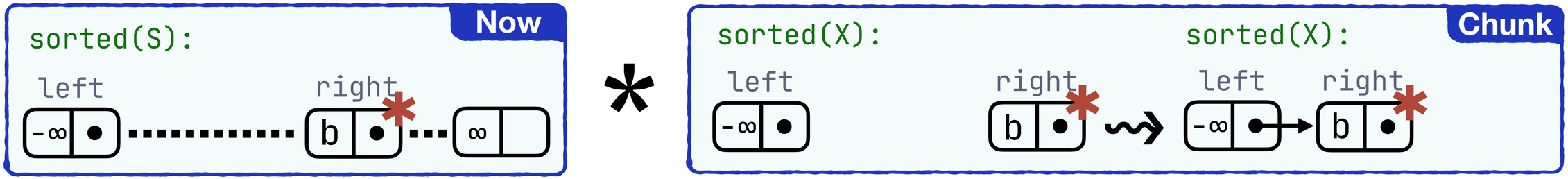


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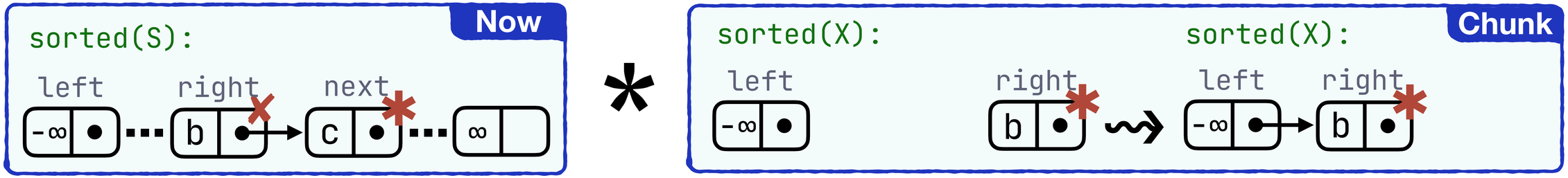


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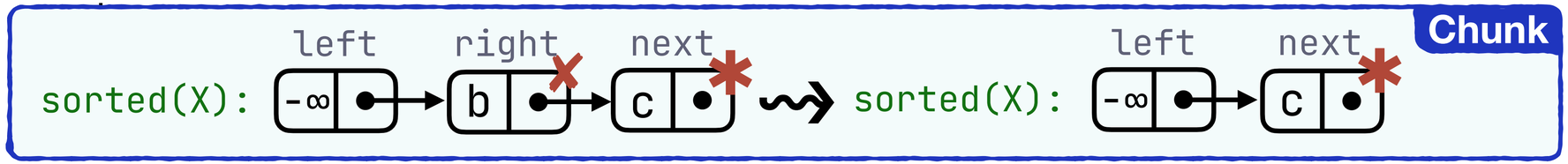

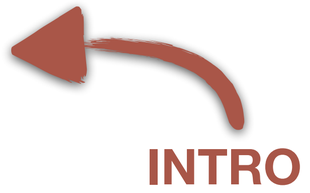

Ghost Update Chunks

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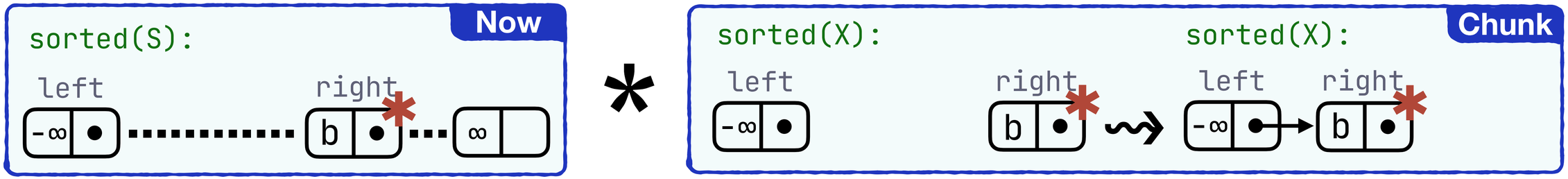


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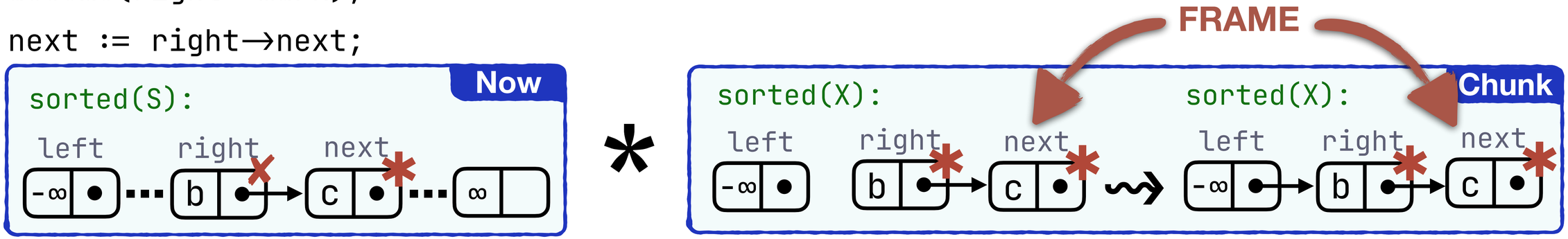


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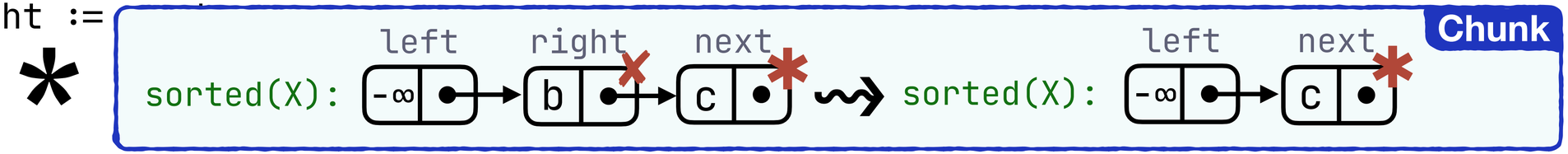

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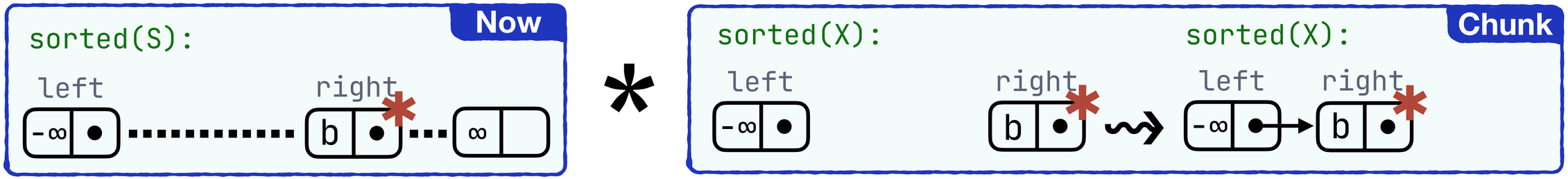


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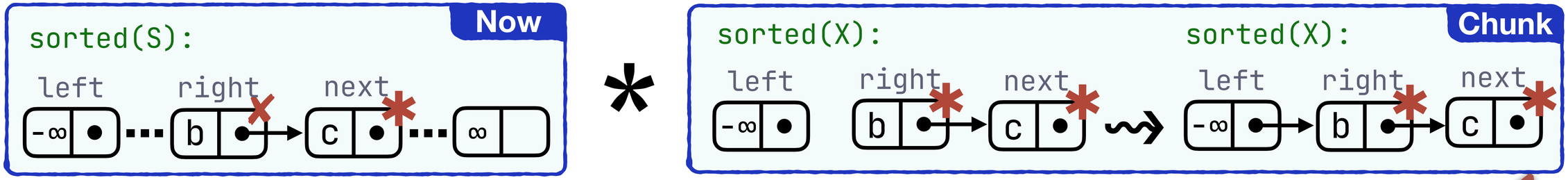


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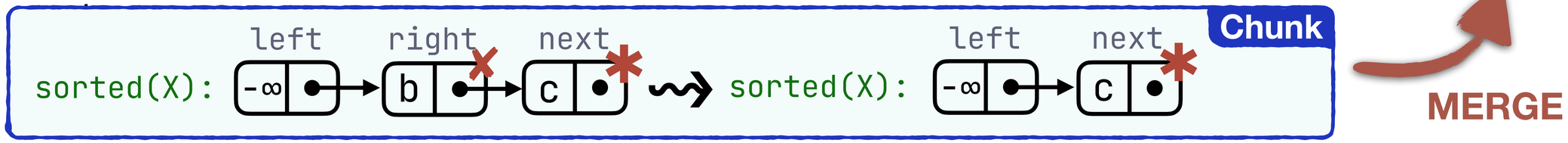
```

*



Ghost Update Chunks

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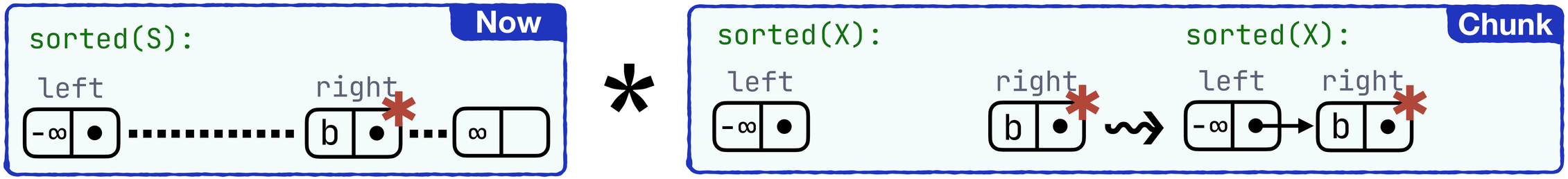


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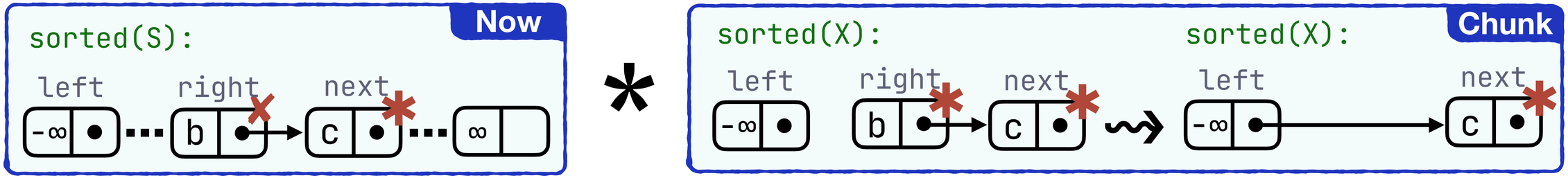


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Ghost Update Chunks

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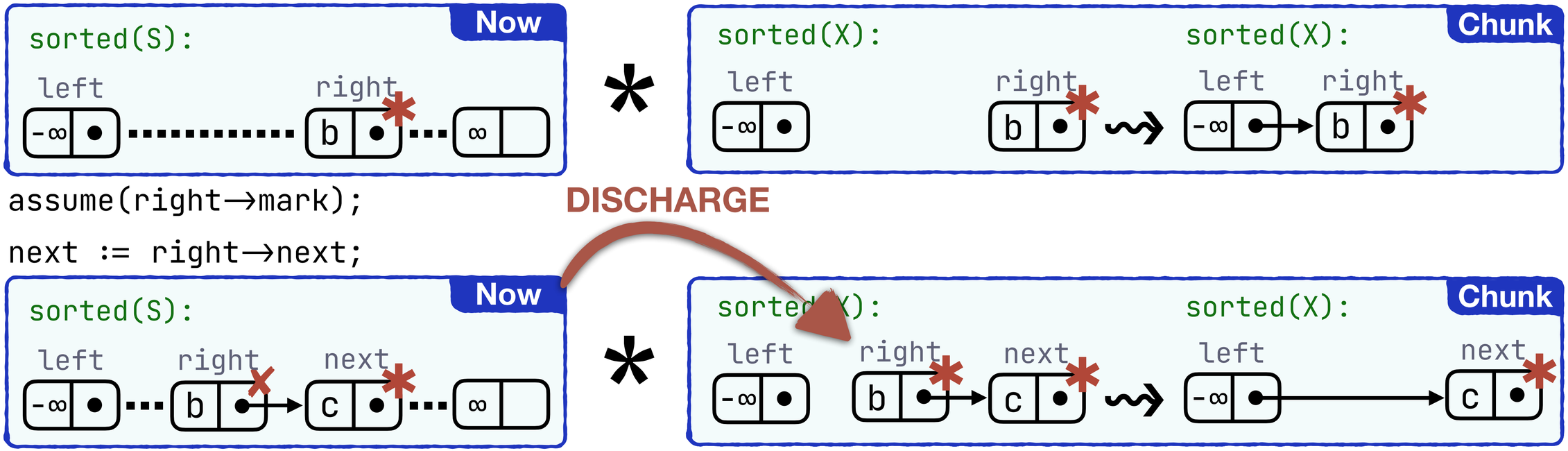


```
assume(right→mark);
```

DISCHARGE

```
next := right→next;
```



```
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Ghost Update Chunks

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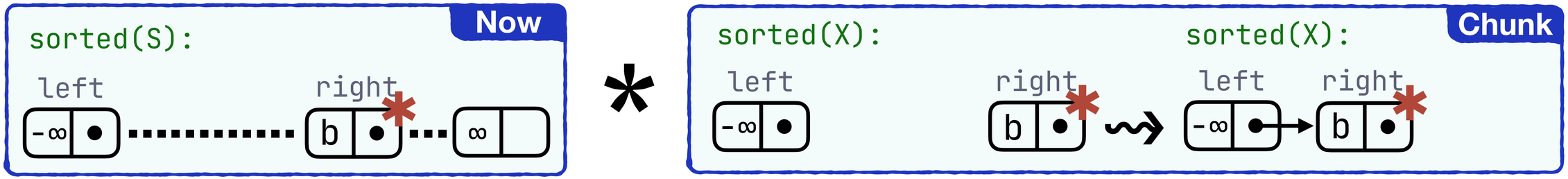
```

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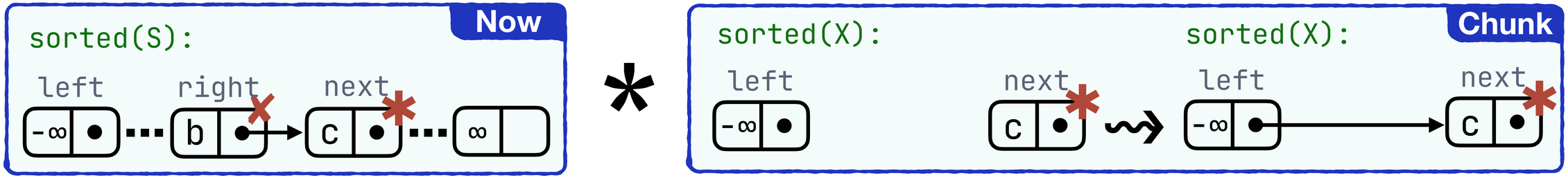


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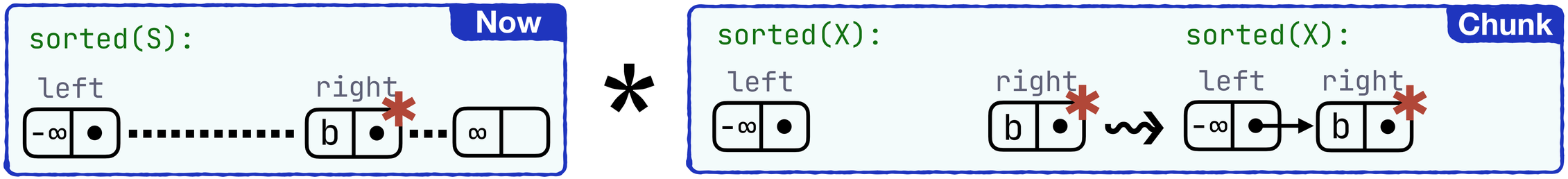


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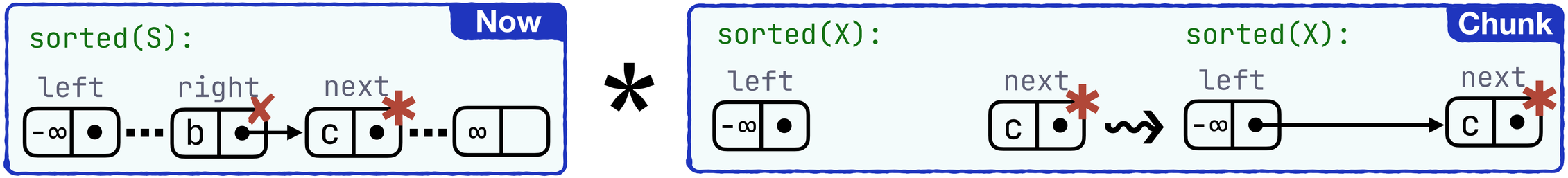


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right := next;
```
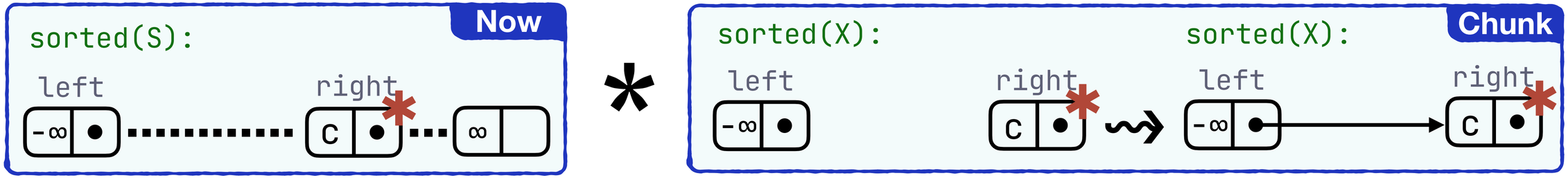
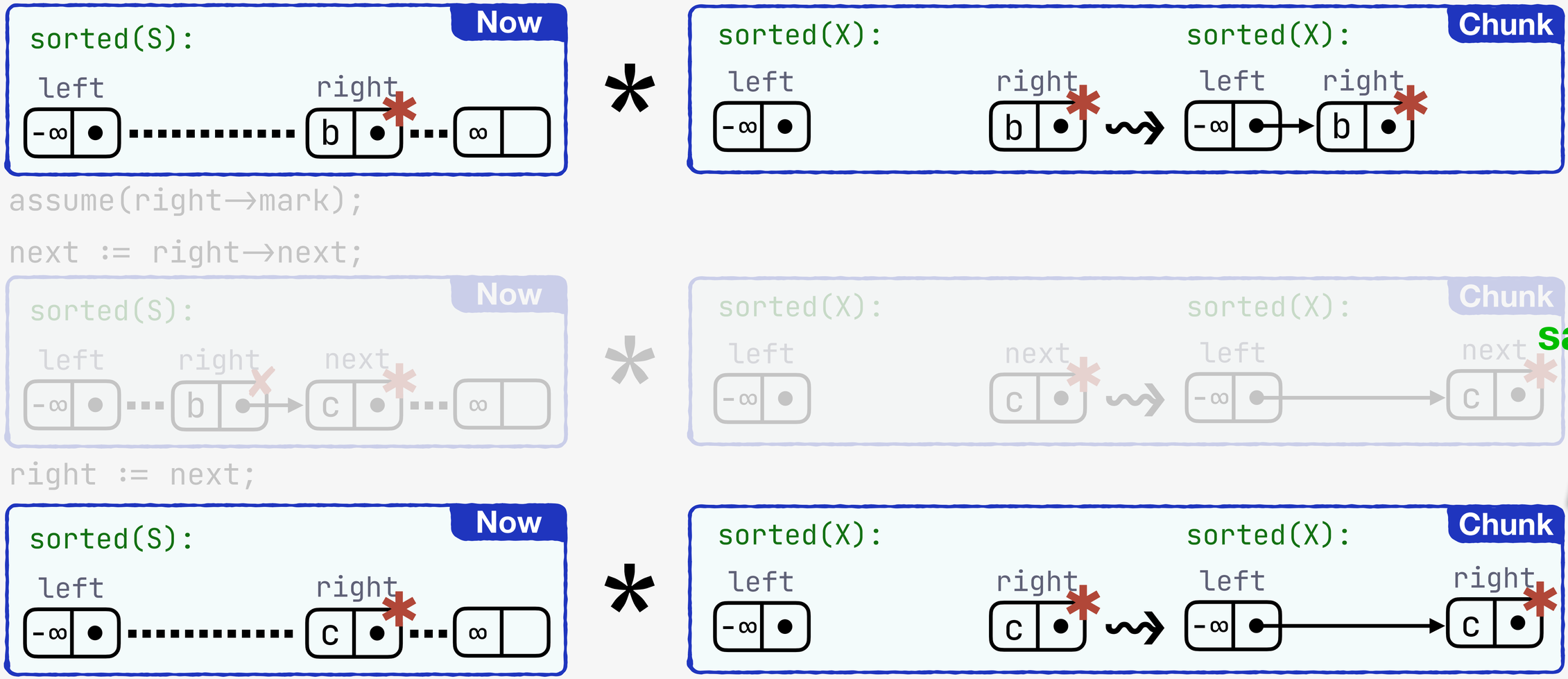
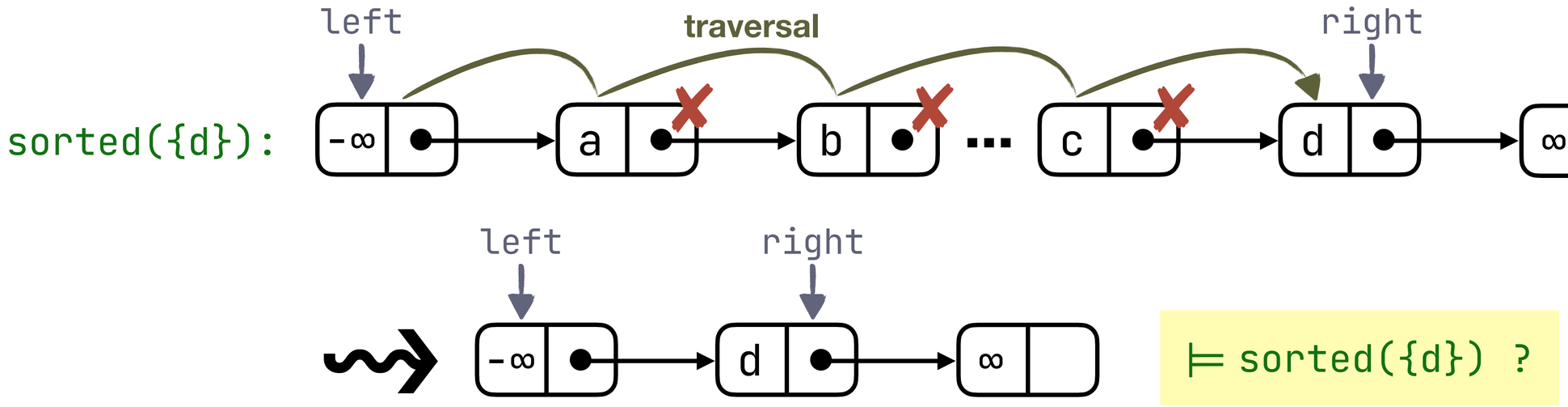



Ghost Update Chunks

```
// traversal step 1 2 k+1
```



Example: Unbounded Removal



Contribution: Ghost Update Chunks

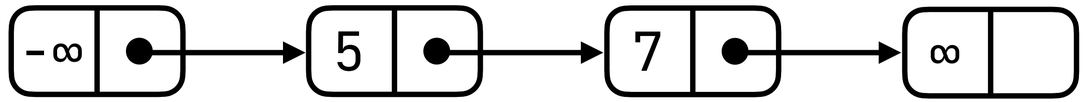
- formalization in abstract SL
- usage patterns: INTRO, MERGE, FRAME, DISCHARGE
- implementation

Verification Challenge 1: Complex Unbounded Updates

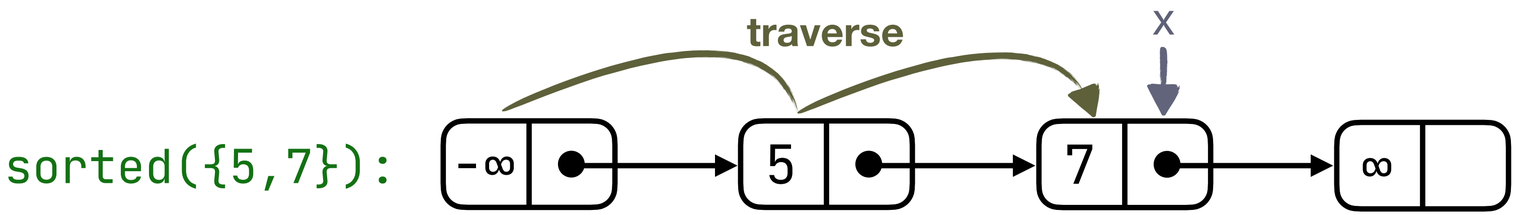
Verification Challenge 2: **Linearizability**

Example: `contains(7)`

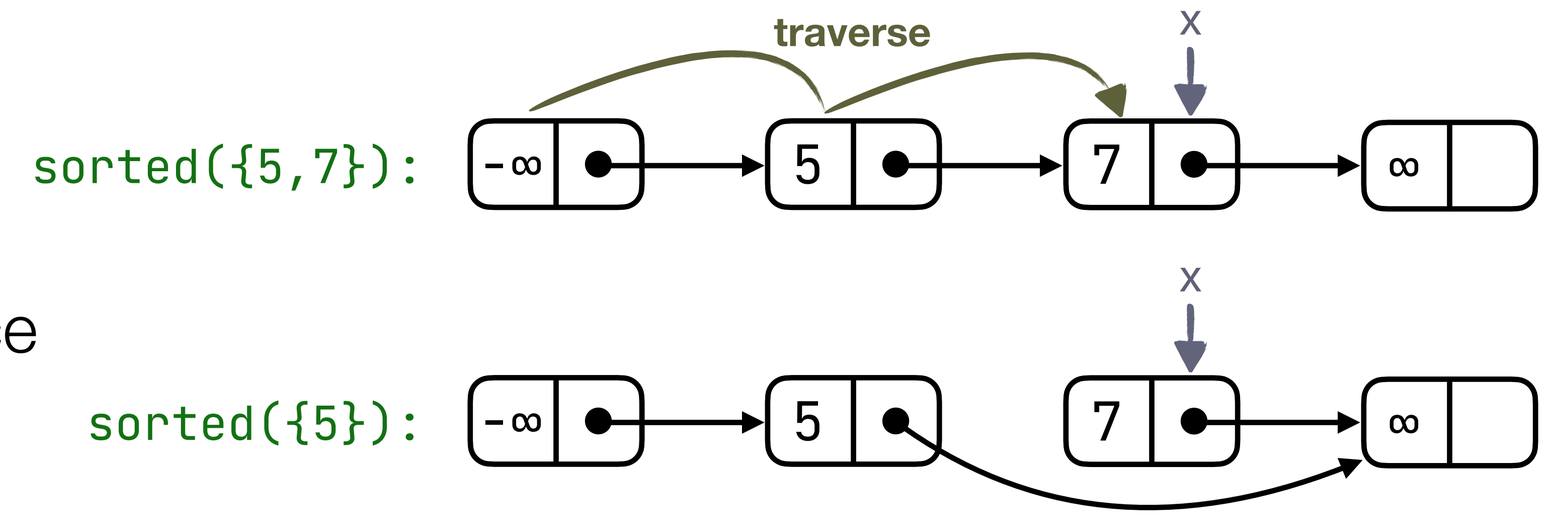
`sorted({5,7}):`



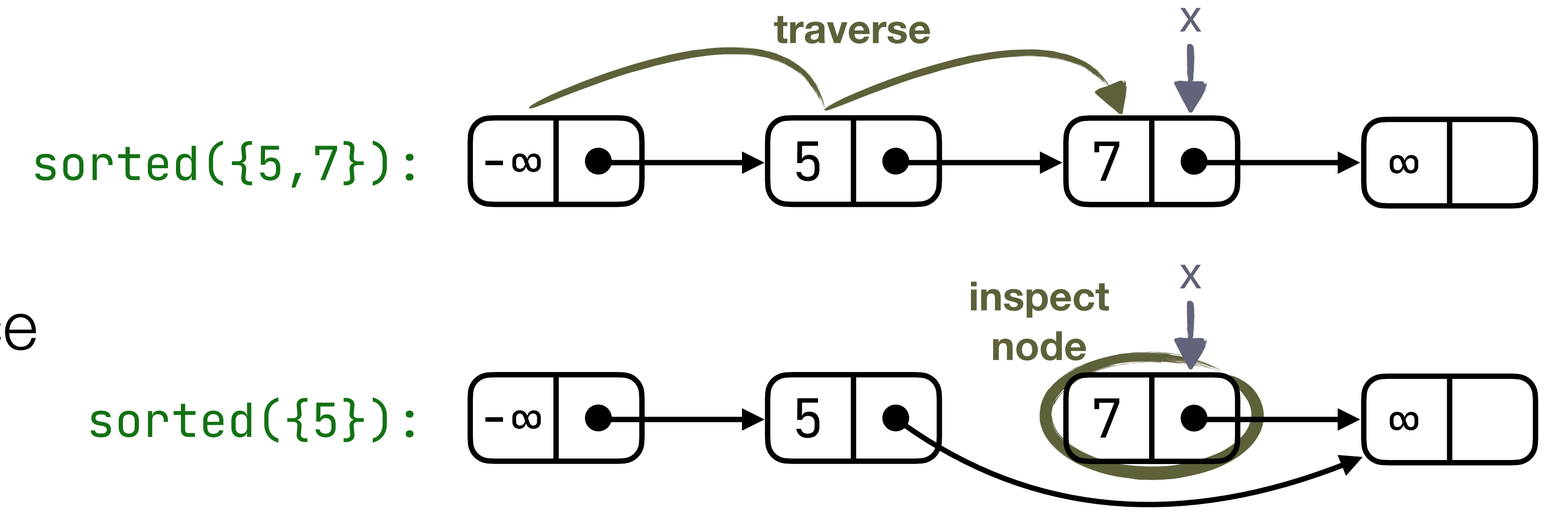
Example: `contains(7)`



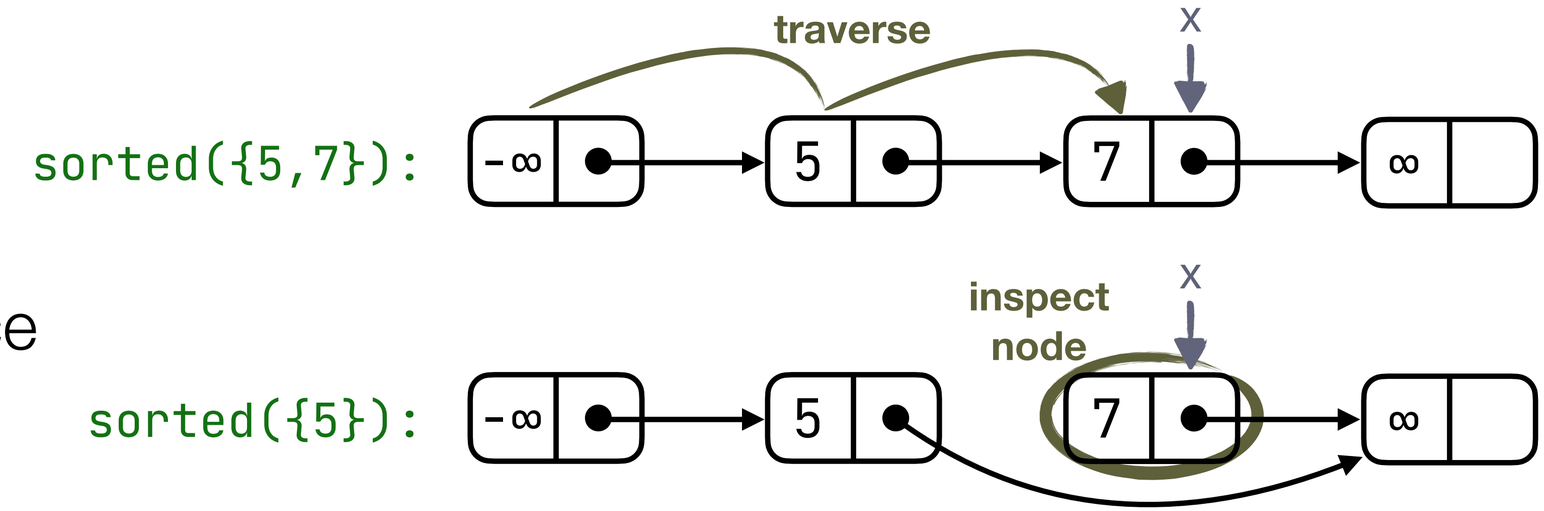
Example: `contains(7)`



Example: `contains(7)`

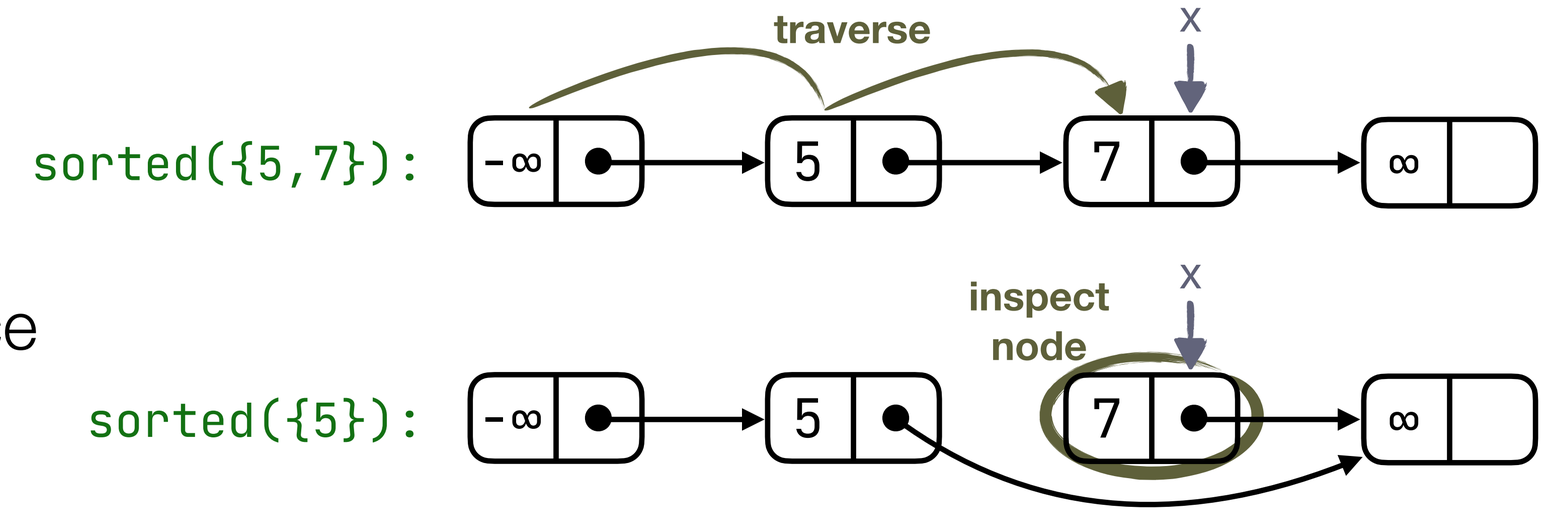


Example: `contains(7)`



$\models$ `sorted({7,...})` at some point ?

Example: `contains(7)`



$\models$ `sorted({7,...})` `at some point ?`

Classical Reasoning

- traverse : prophecy about outcome of inspect node ("case split")

automation ?

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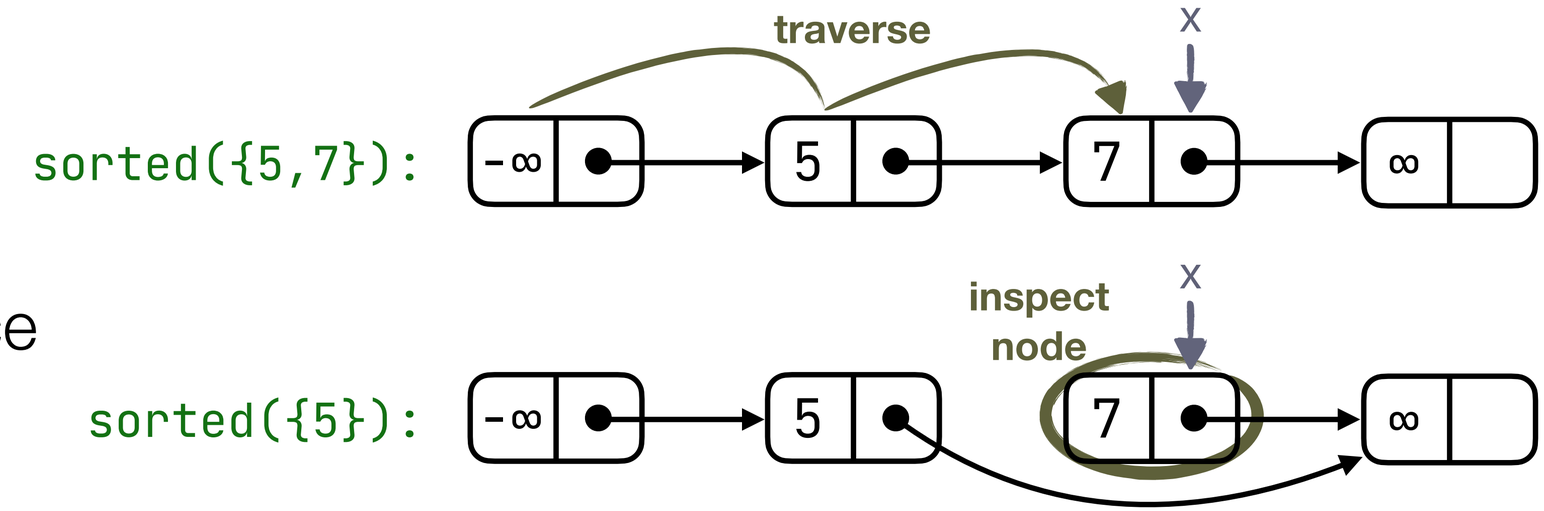


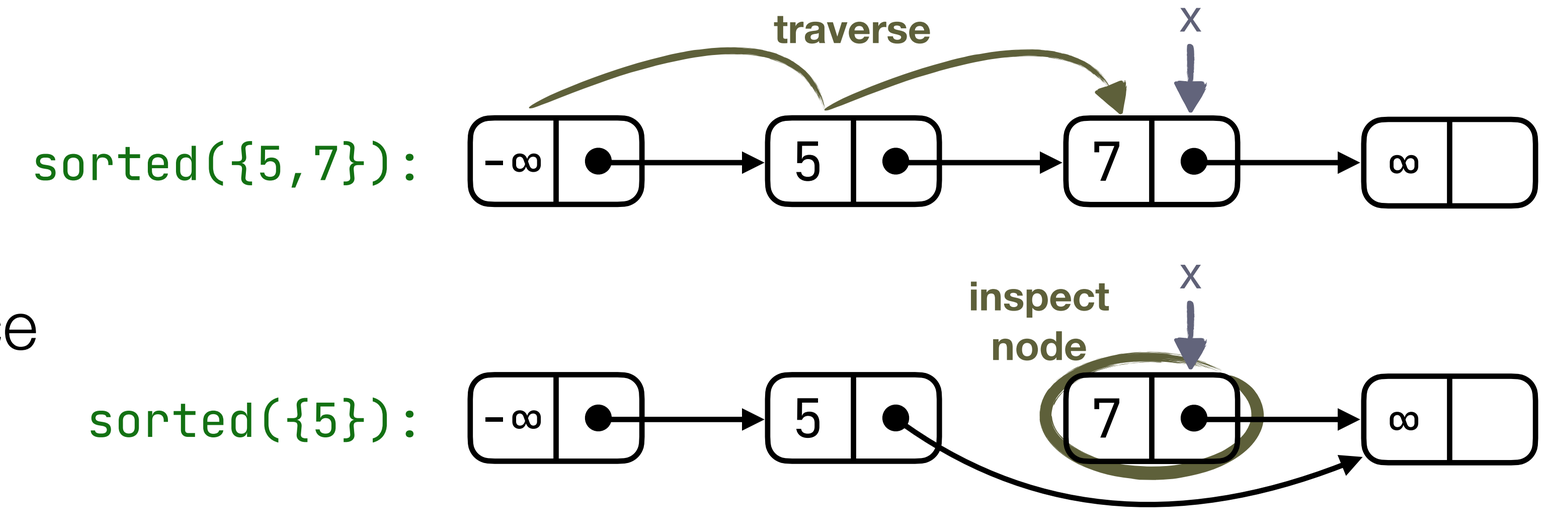
$\models$ `sorted({7,...})` at some point ?

Classical Reasoning

- traverse : prophecy about outcome of inspect node ("case split")
- inspect node : reconcile outcome with prophecy

automation ?

Example: `contains(7)`



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Contribution: Past Reasoning

- traverse : record past state

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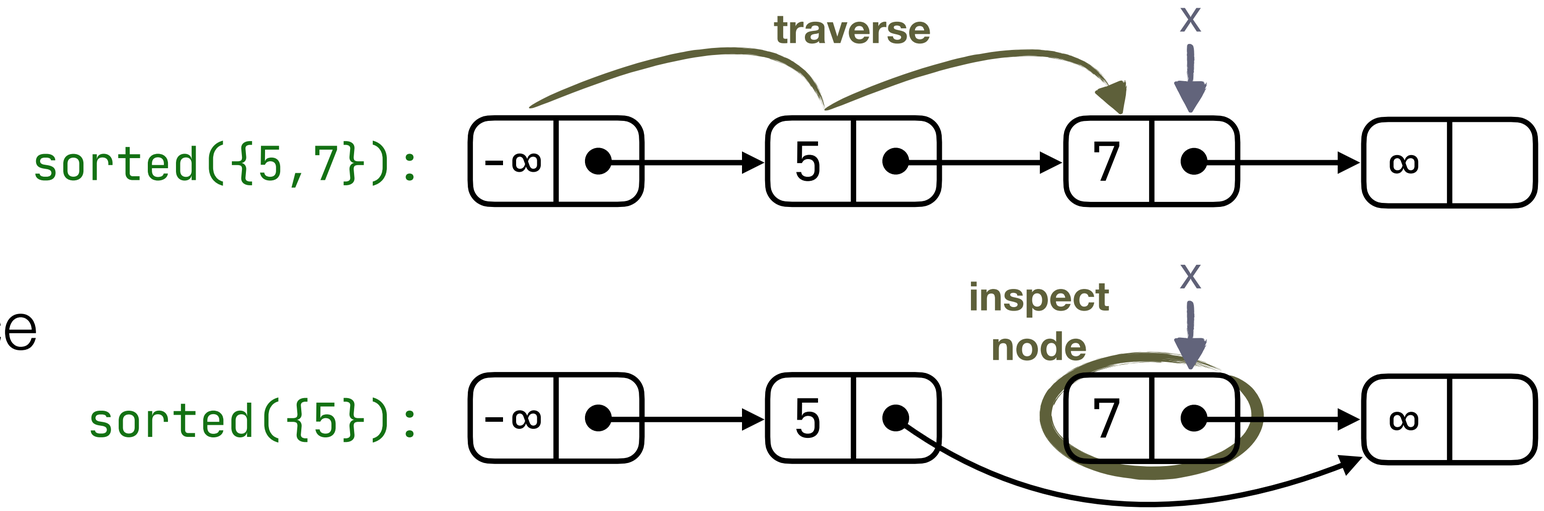

interference

$\rightsquigarrow$

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Contribution: Past Reasoning

- traverse : record past state
- inspect node : propagate outcome into past state

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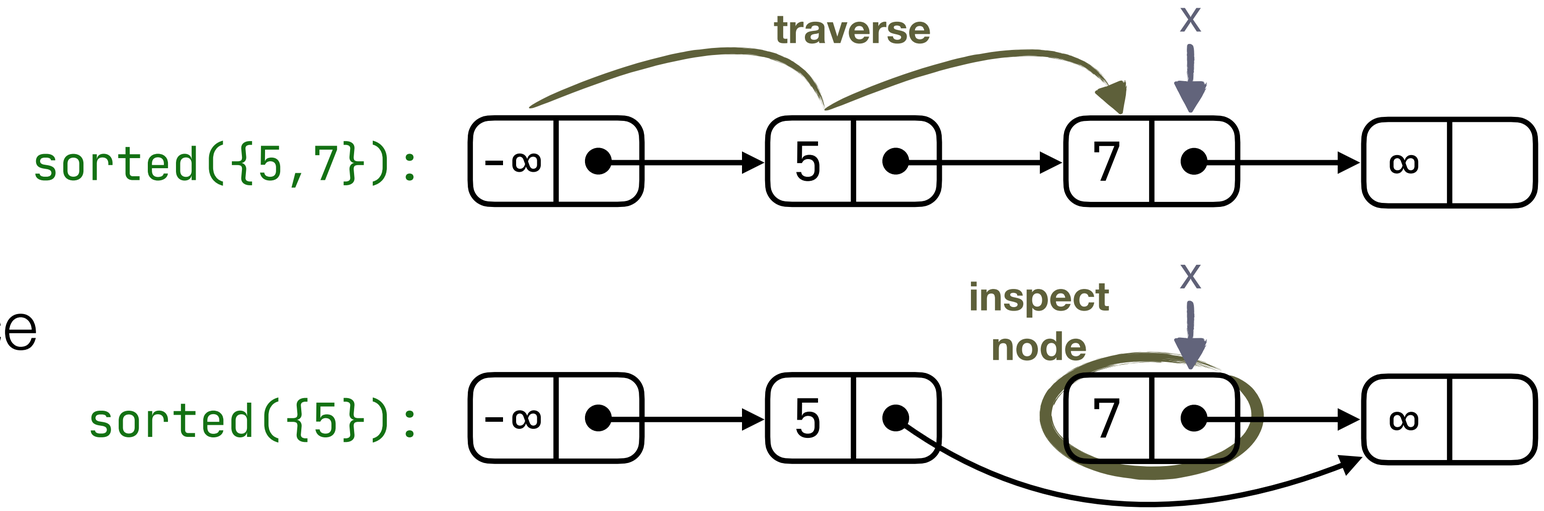

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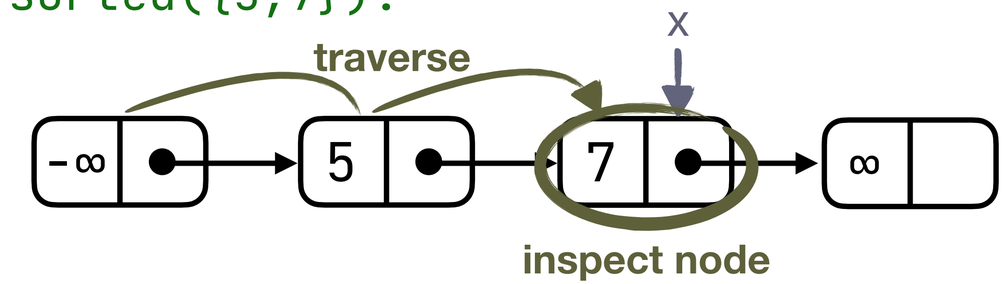
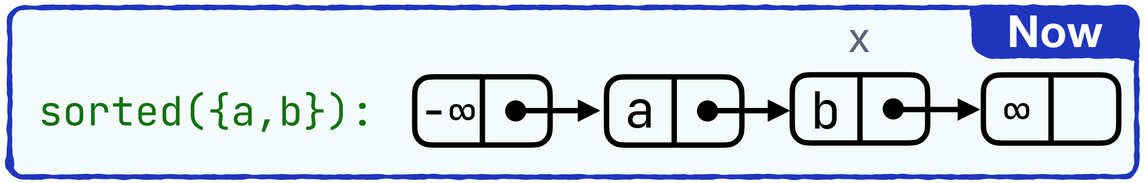


Past Reasoning

```
//  ...
x = /* a→next */
```




```
if (x→key == k) {
```

```
   return true;
} else { /* continue traversal */ }
```

Past Reasoning

Past ≔ Now in some (previous) state of the execution

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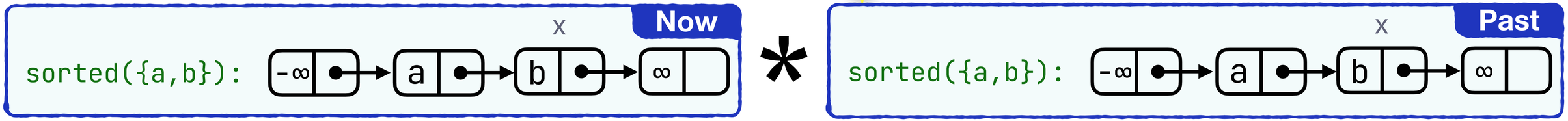


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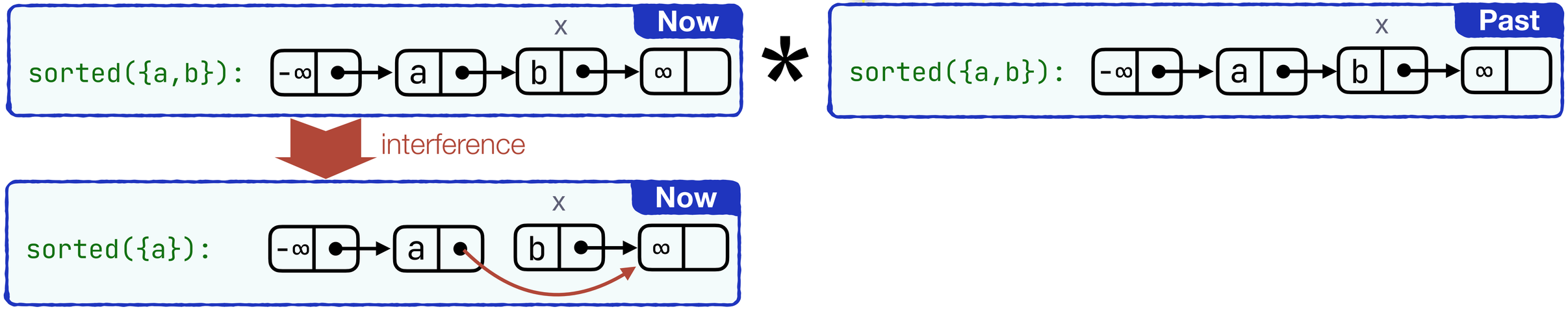


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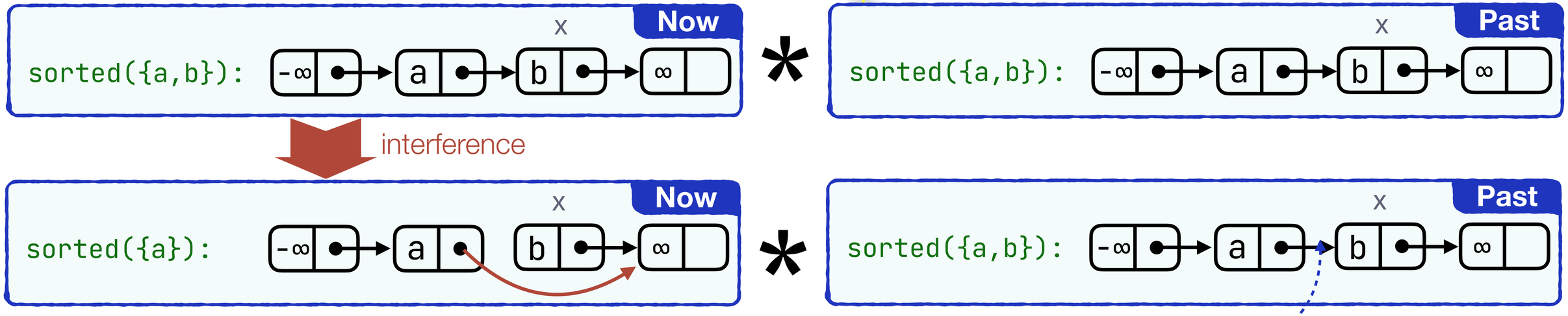


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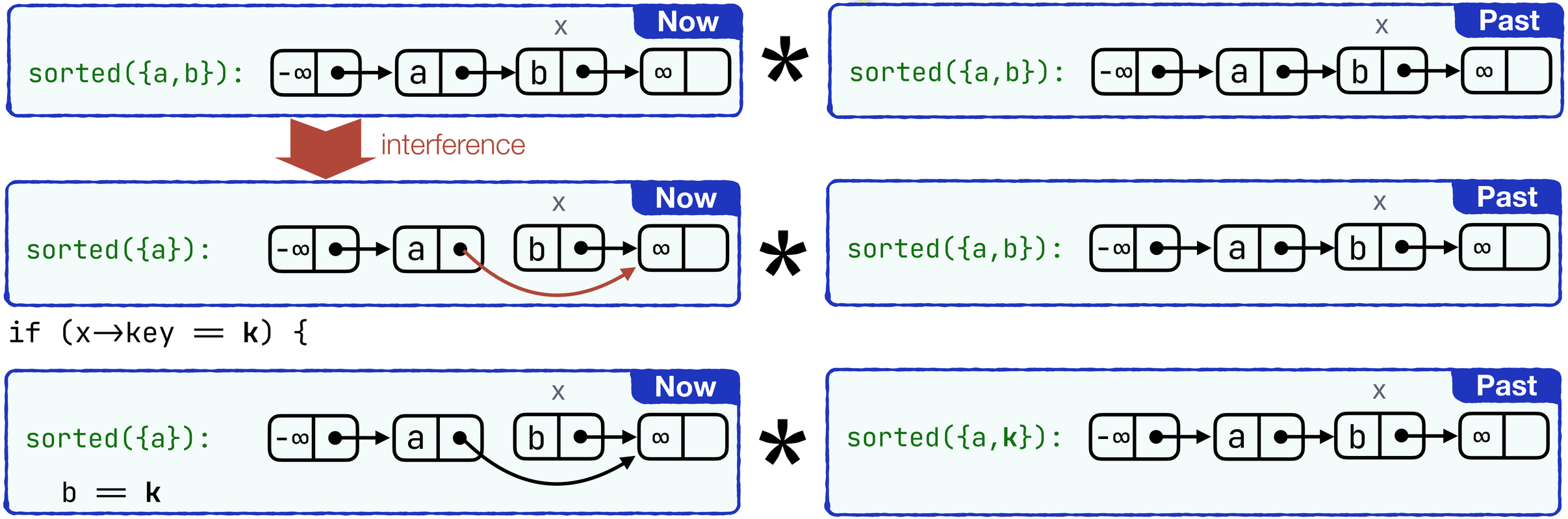


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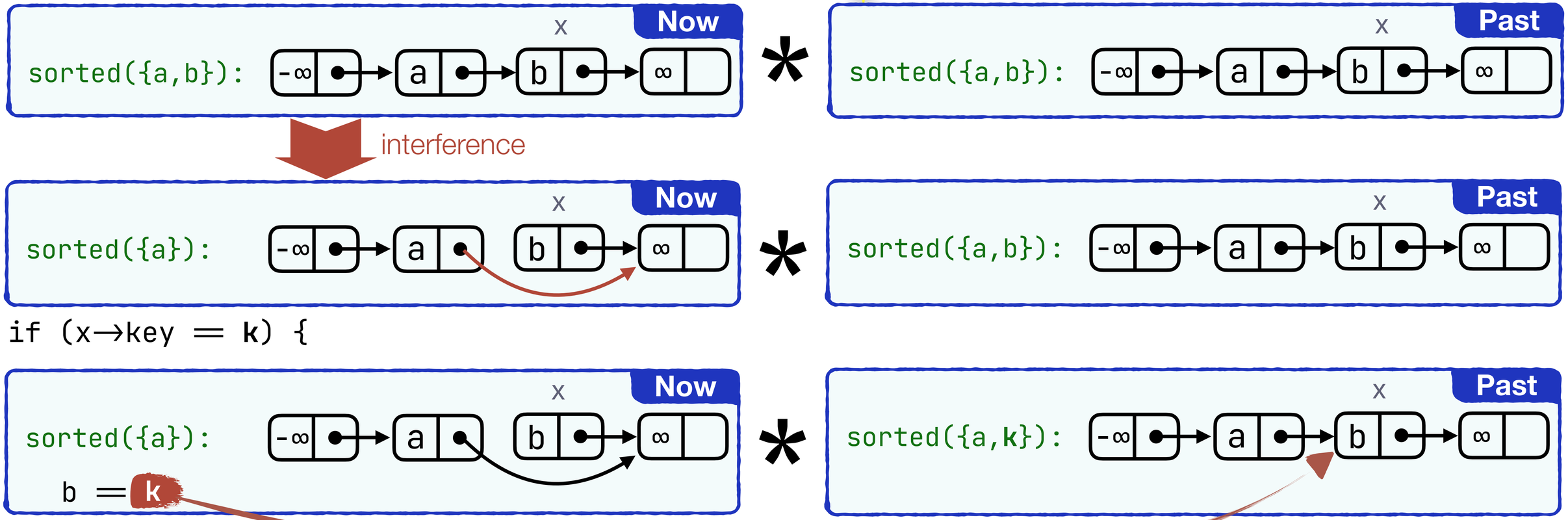


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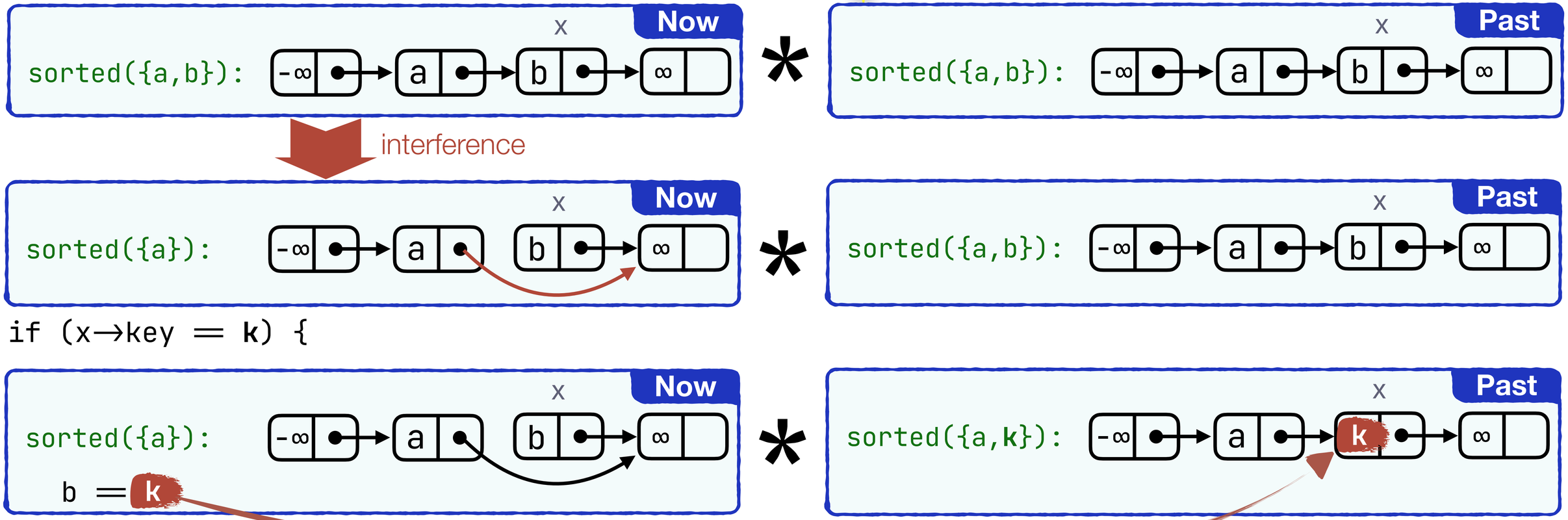


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⊨ sorted({k,...}) at some point !

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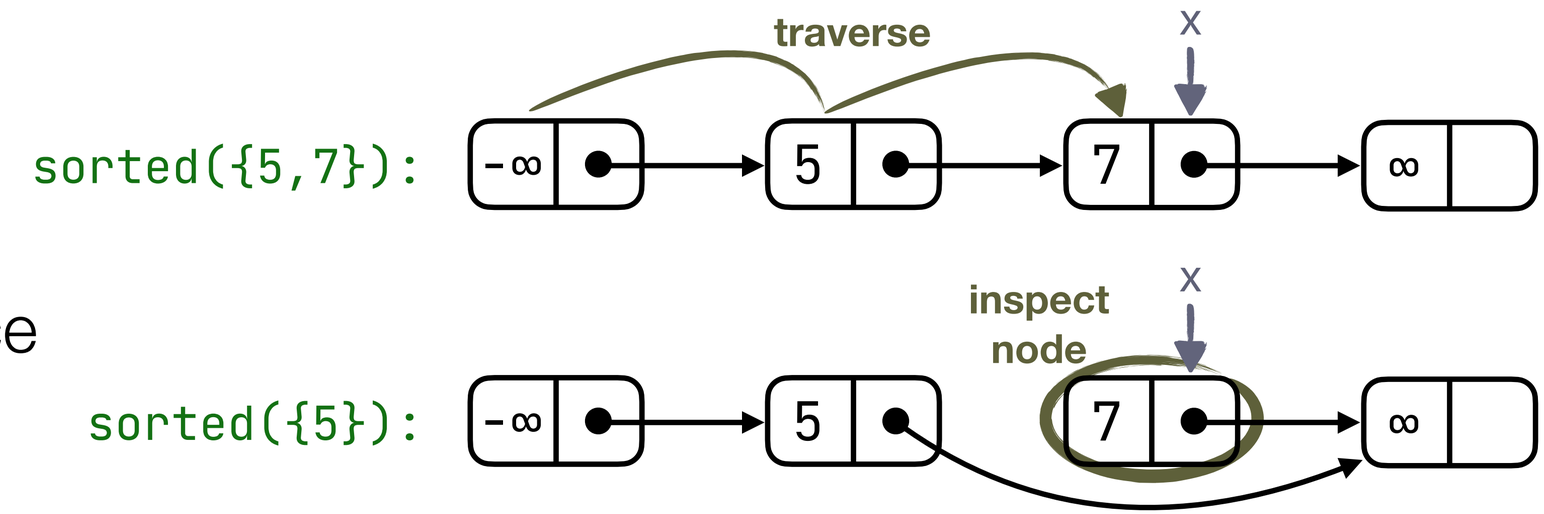

interference

$\rightsquigarrow$

$\models$ `sorted({7,...})` at some point ?

Contribution: Past Reasoning

- formalization in abstract SL
- light-weight instance of hindsight reasoning
- implementation

Recap:
A Concurrent Program Logic with a Future and History

- program logic with
  - chunks ⇝ complex unbounded updates via simple ones
  - pasts ⇝ lightweight hindsight reasoning in SL
  - tool ⇝ first to verify challenging examples like Harris' set

Benchmark	Lineariz.
Fine-Grained set	46*s* ✓
Lazy set	77*s* ✓
FEMRS tree (no maintenance)	130*s* ✓
Vechev&Yahav 2CAS set	125*s* ✓
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ORVYY set	47*s* ✓
Michael set	306*s* ✓
Harris set	1378*s* ✓

Recap:
A Concurrent Program Logic with a Future and History

Thanks

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