

# Real-time, Fine-grained Version Control with CRDTs



@nathansobo



# Teletype

Real-time collaborative editing  
package for Atom

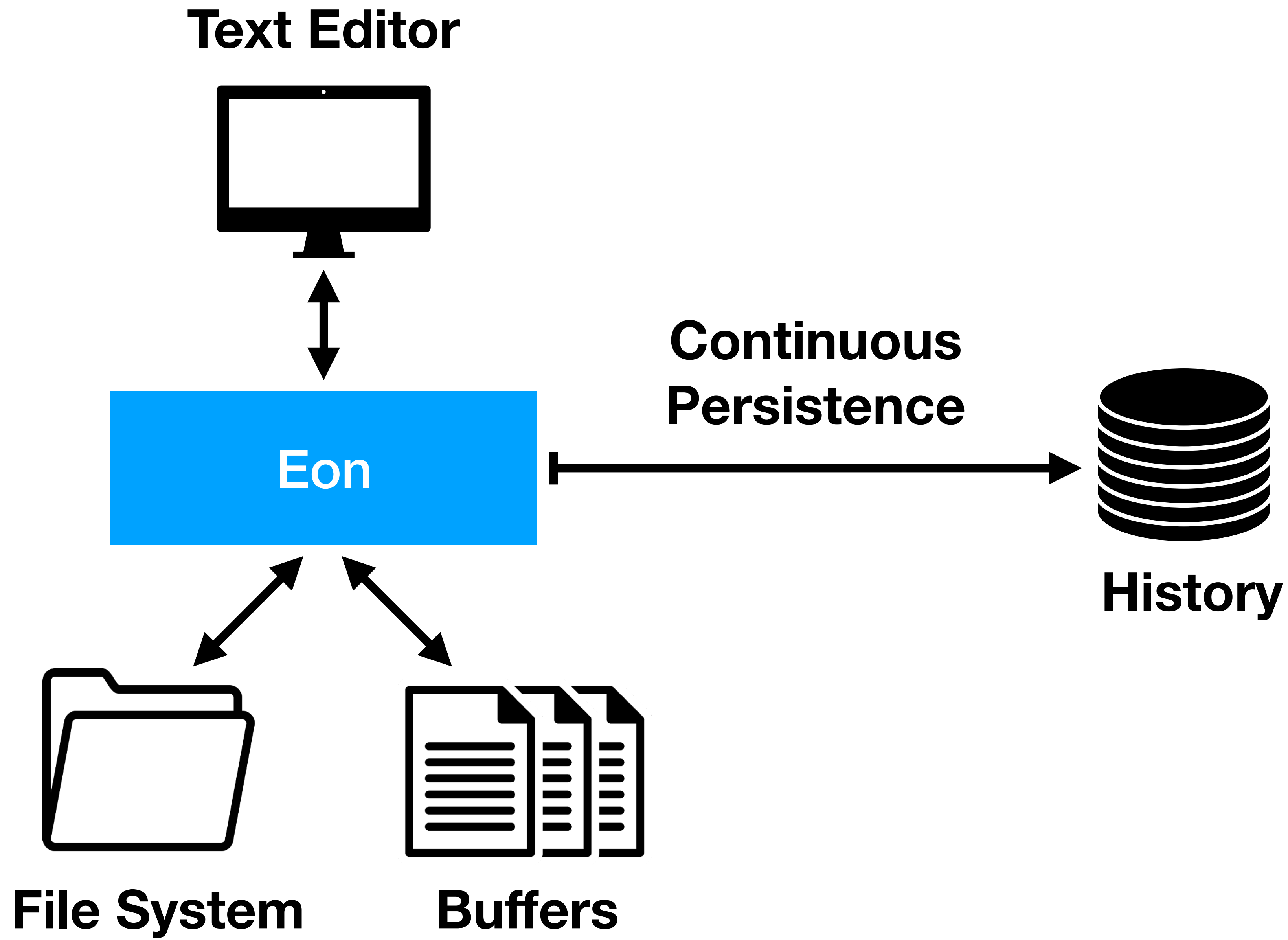




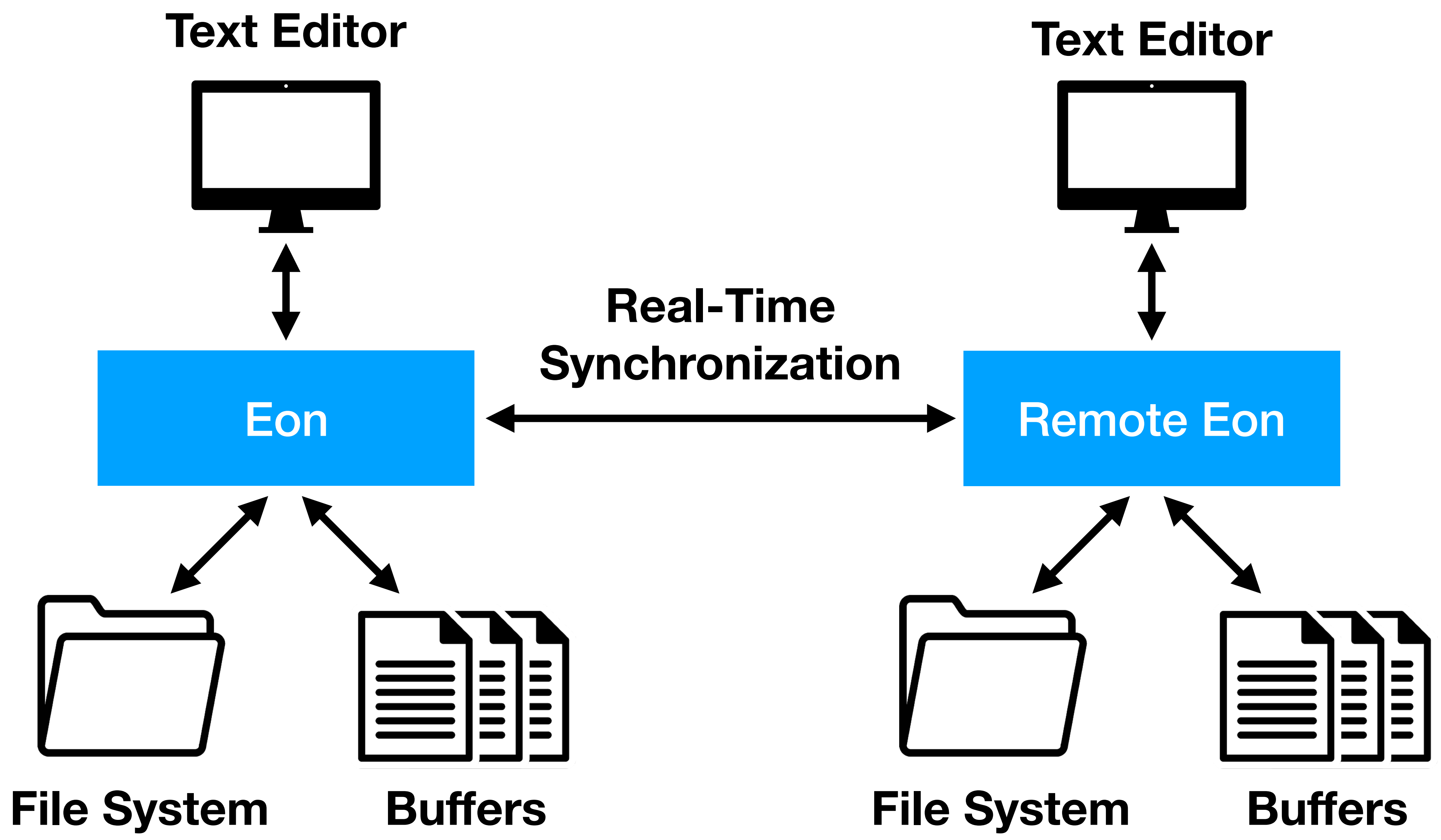


# **Eon** *Real-time Distributed Version Control*

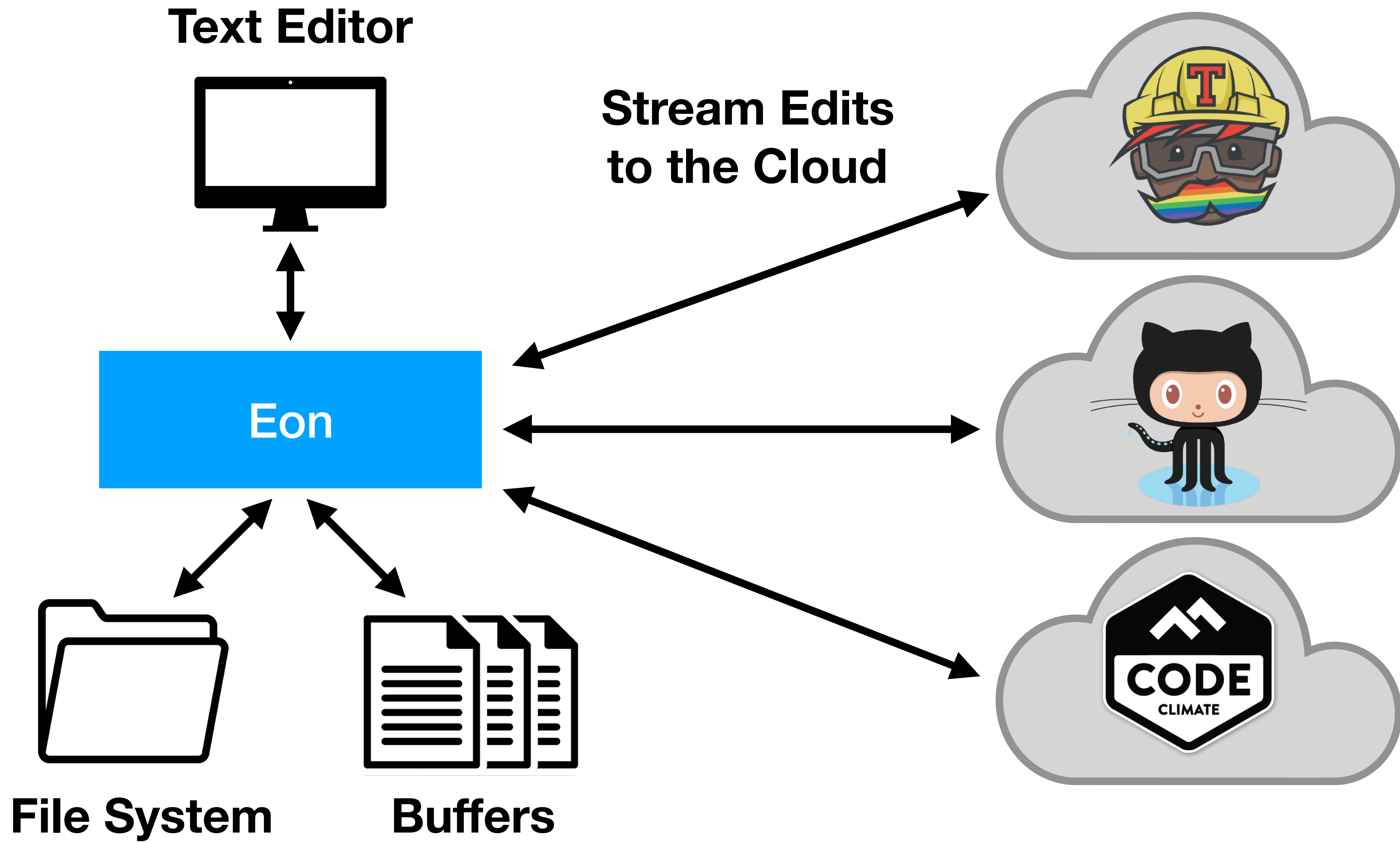




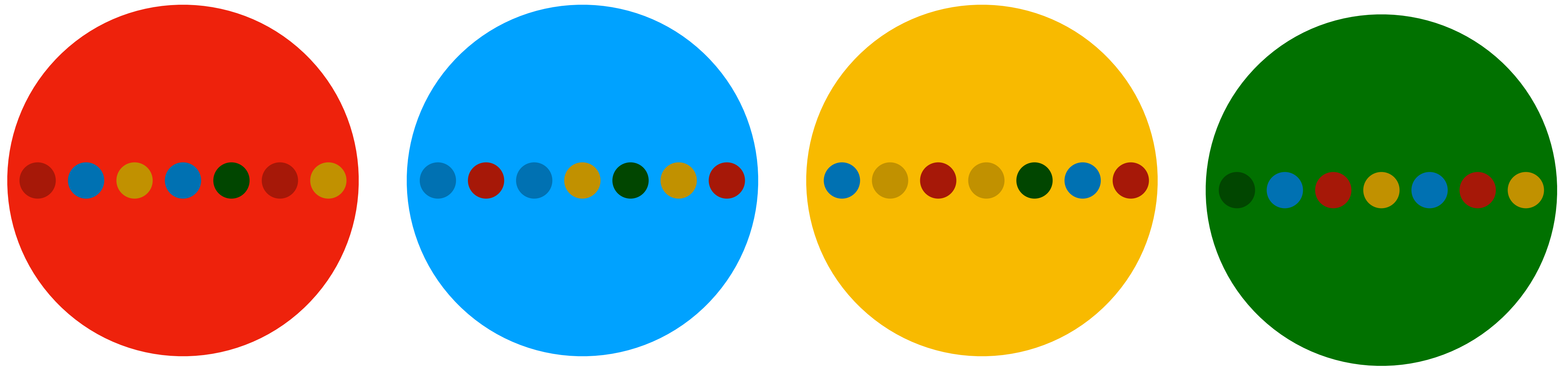










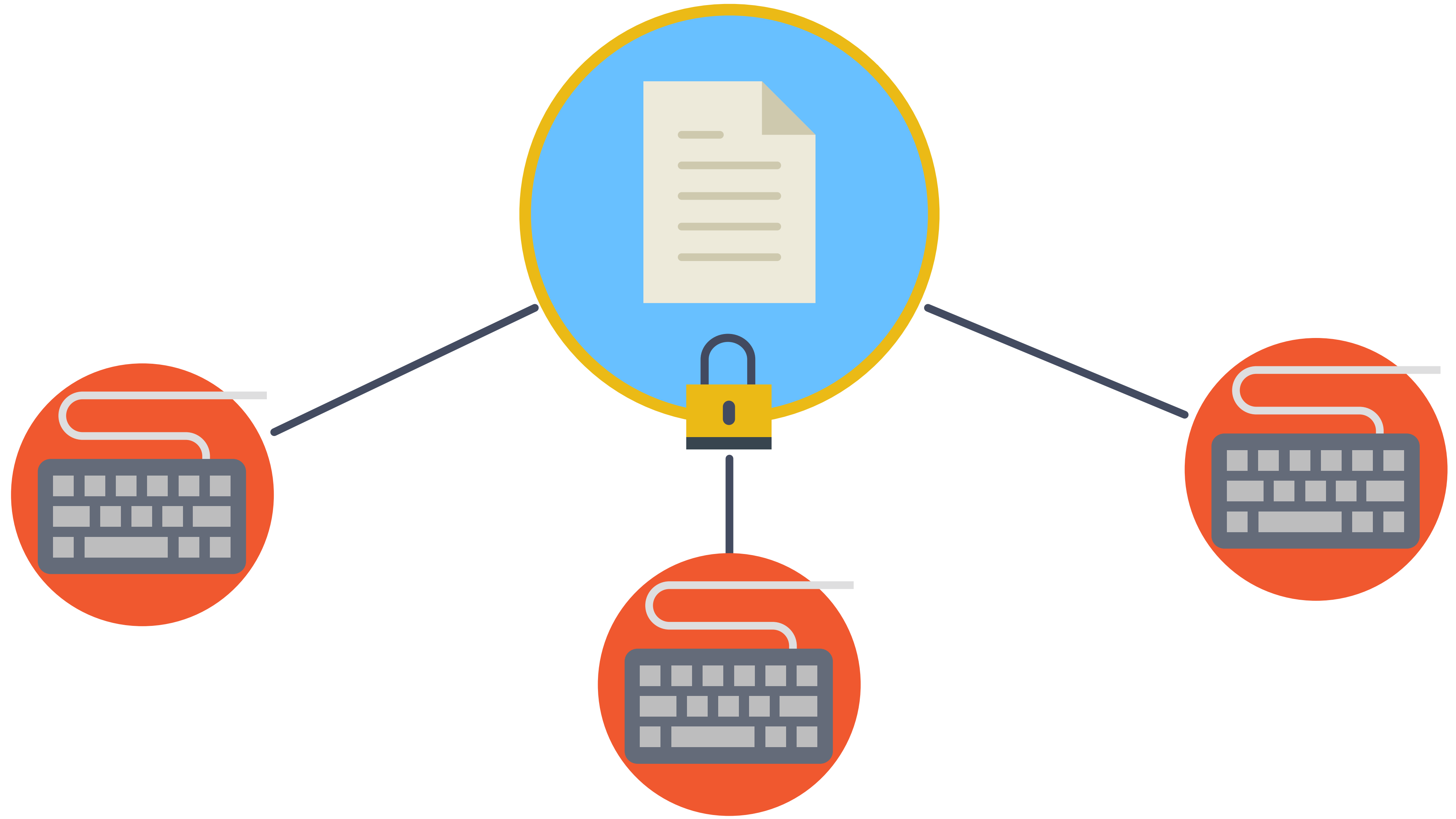


# CRDTs

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*Conflict-Free Replicated Data Types*







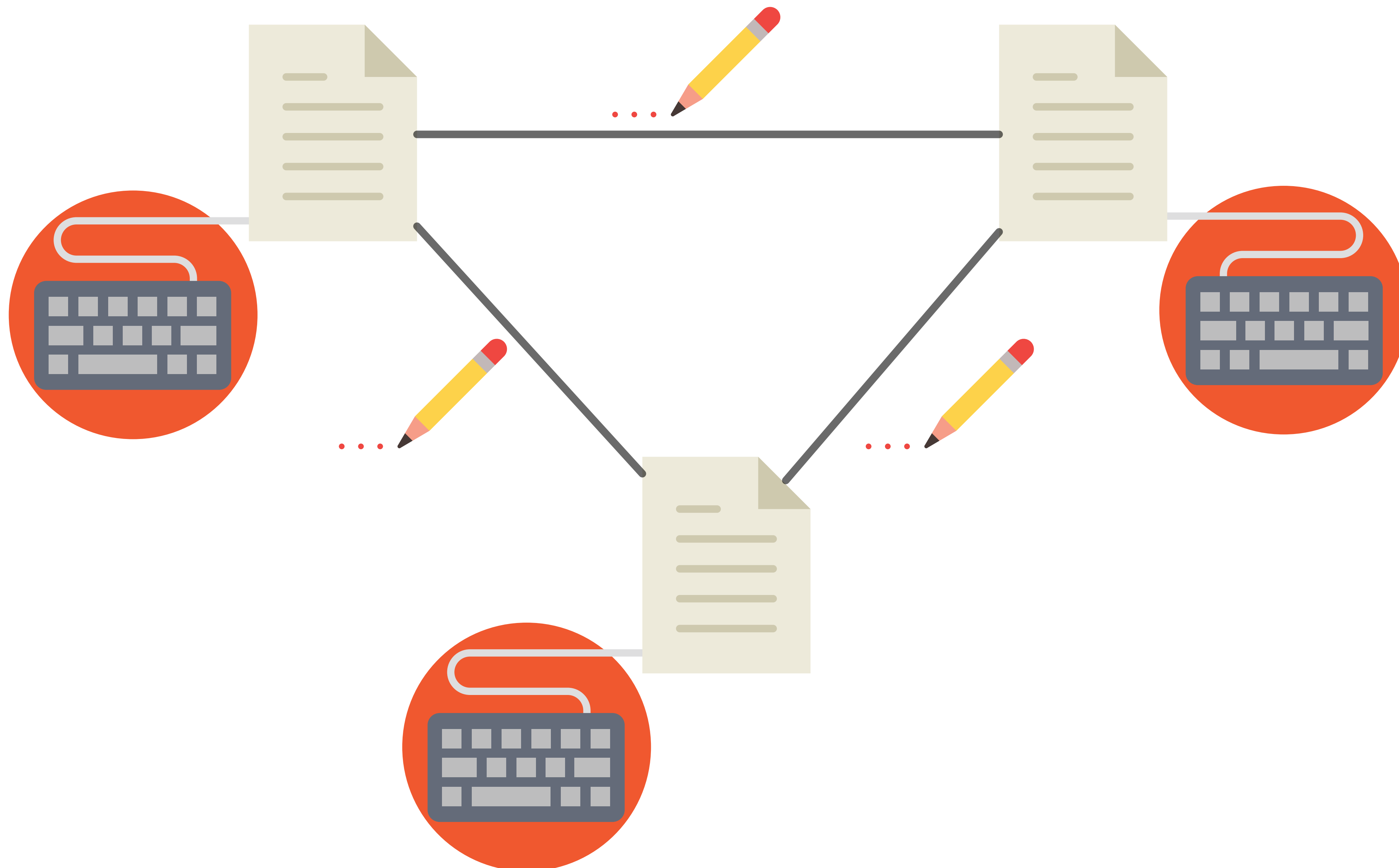


**Boulder  
Colorado**

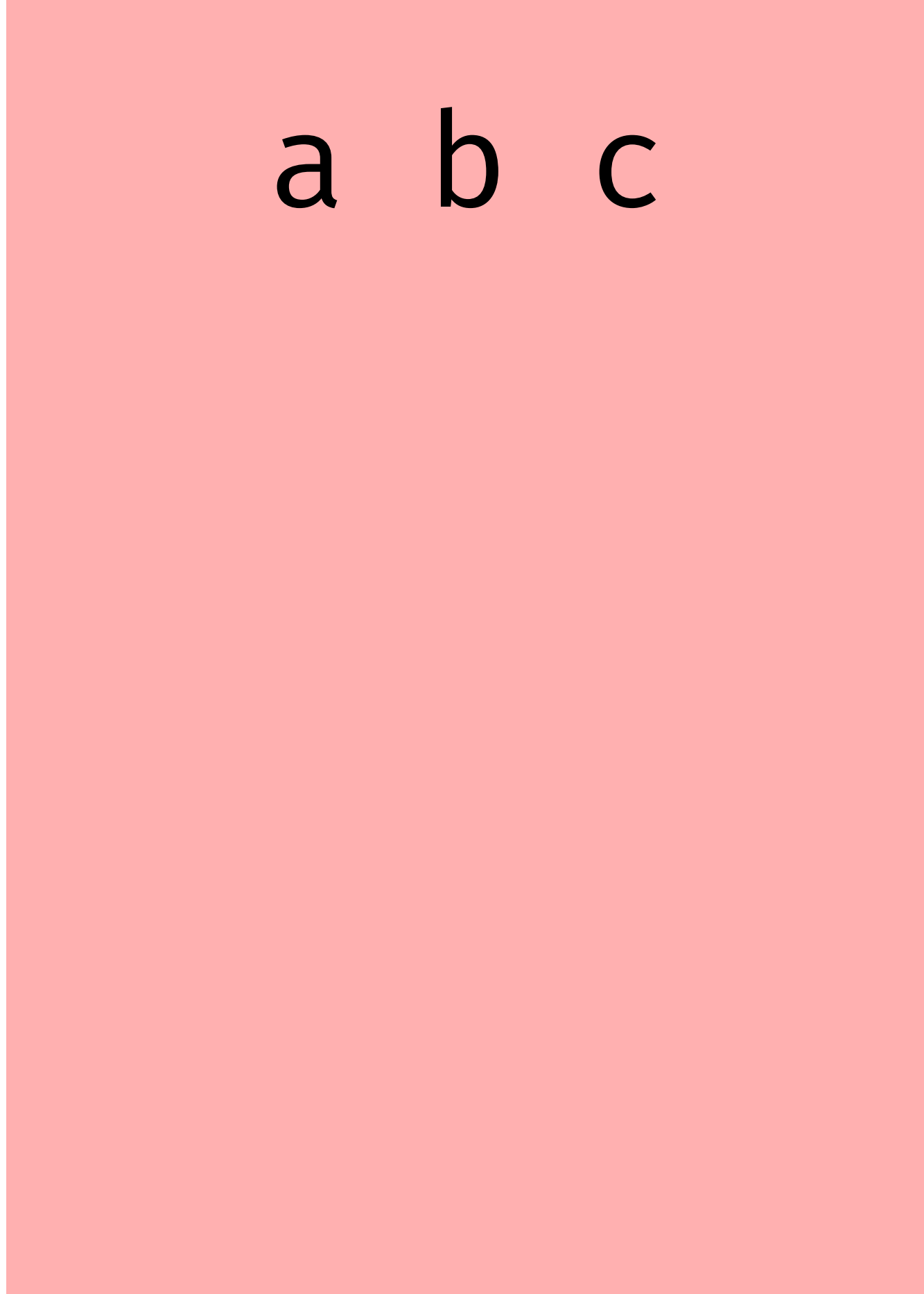
**Gambettola  
Italy**

**~30 ms at the speed of light**











a b c

```
insert(x, 1)
```

a x b c

a b c

```
insert(y, 2)
```

a b y c



a b c

insert(x, 1)

a x b c

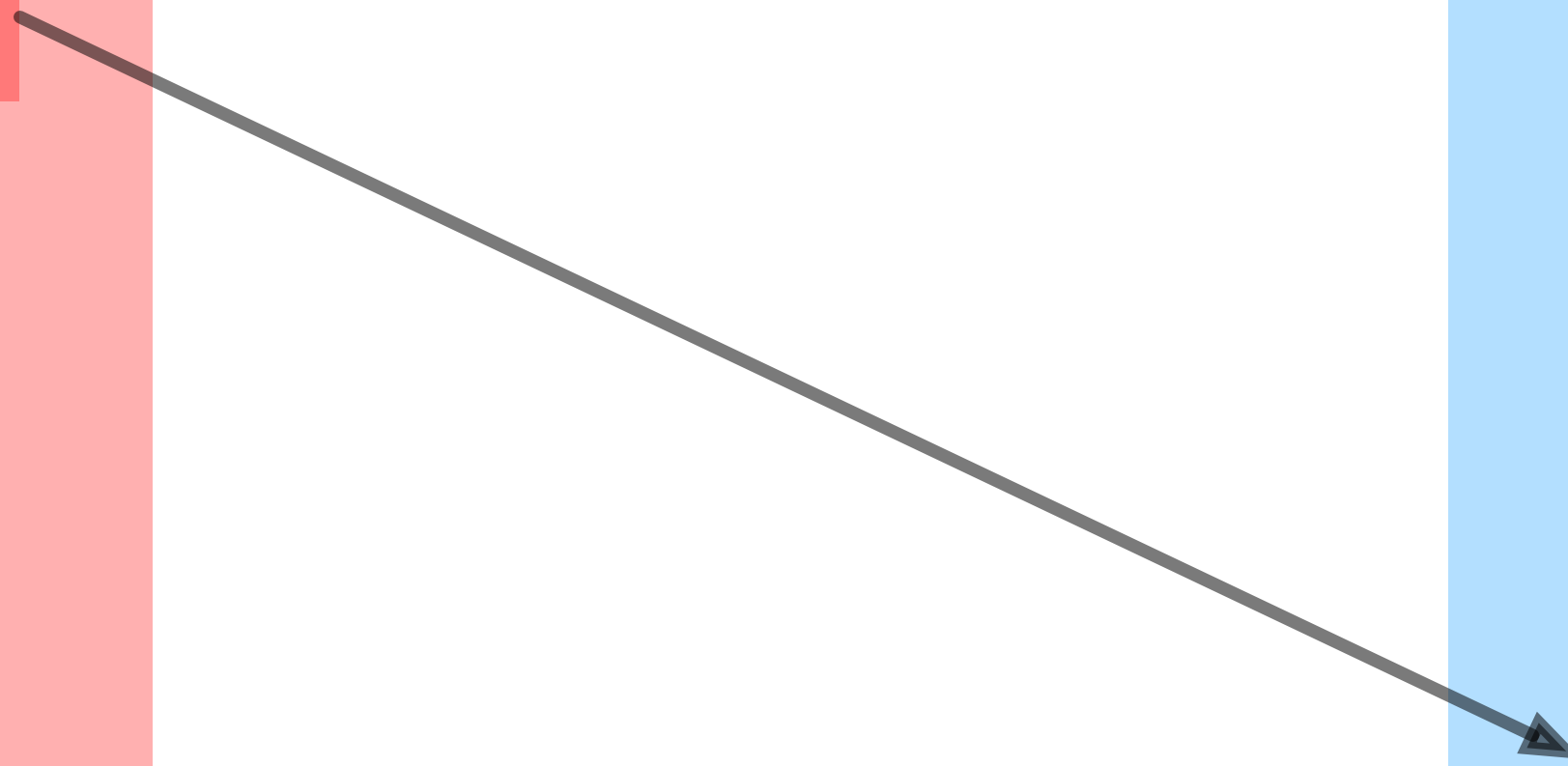
a b c

insert(y, 2)

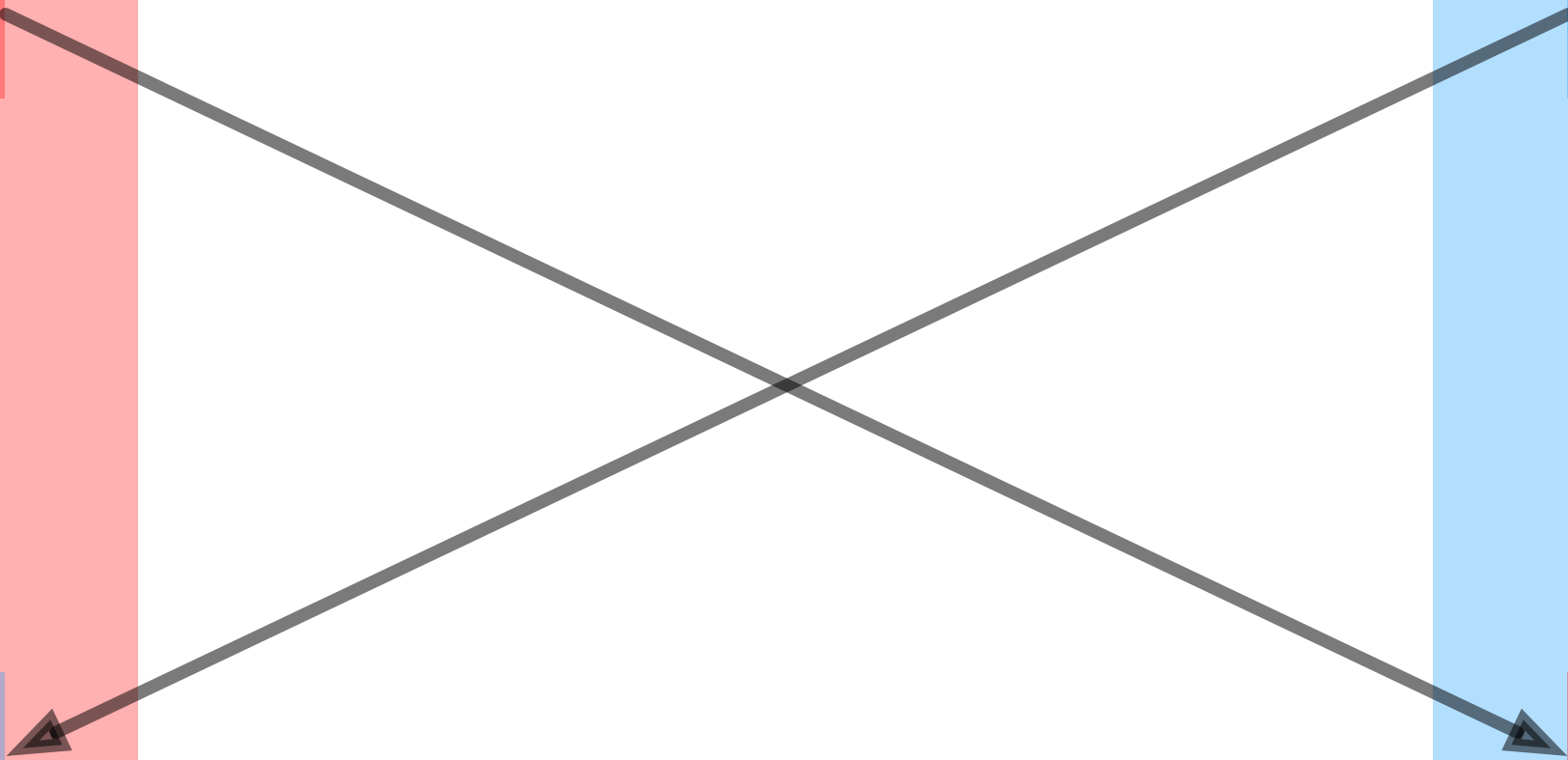
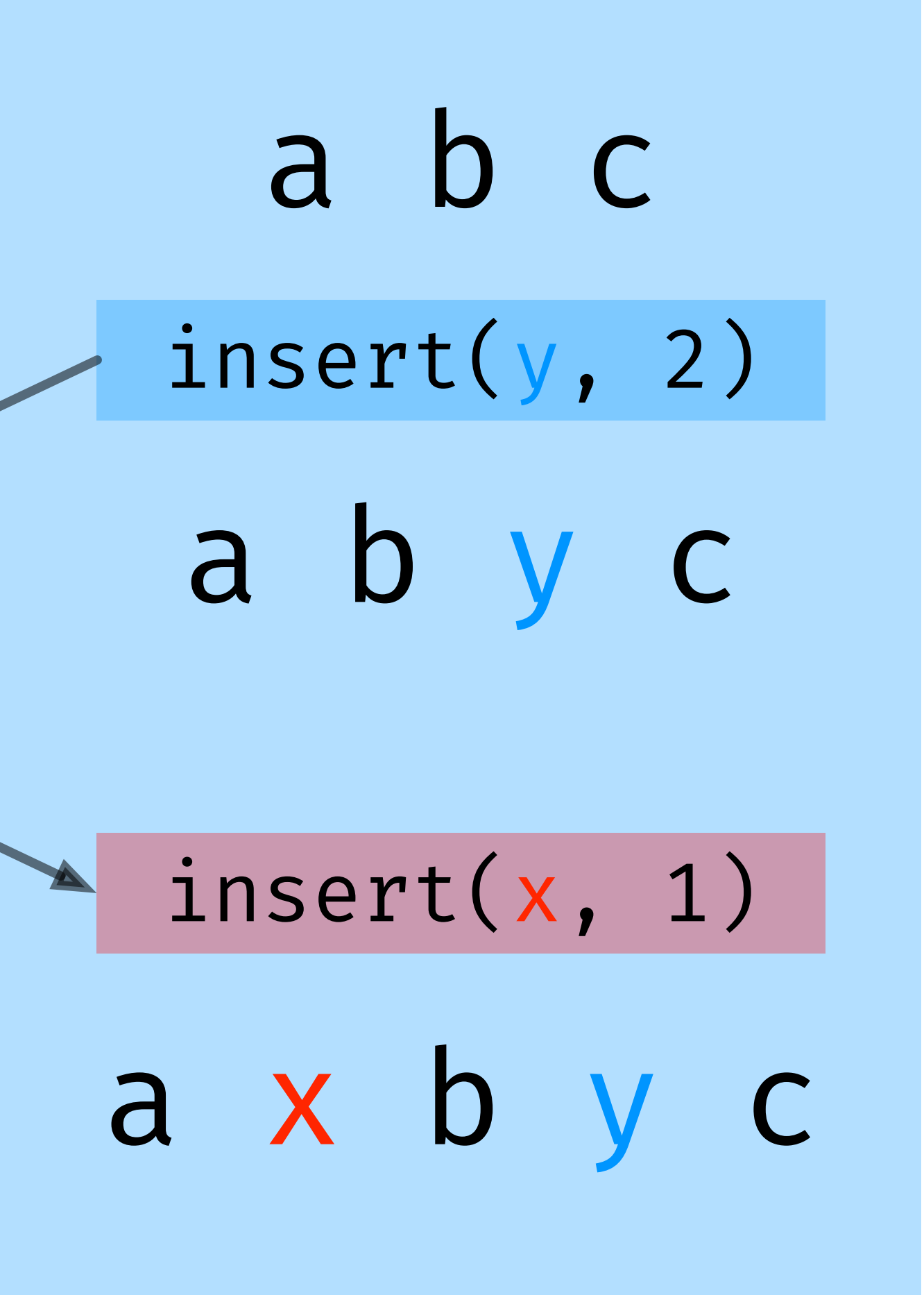
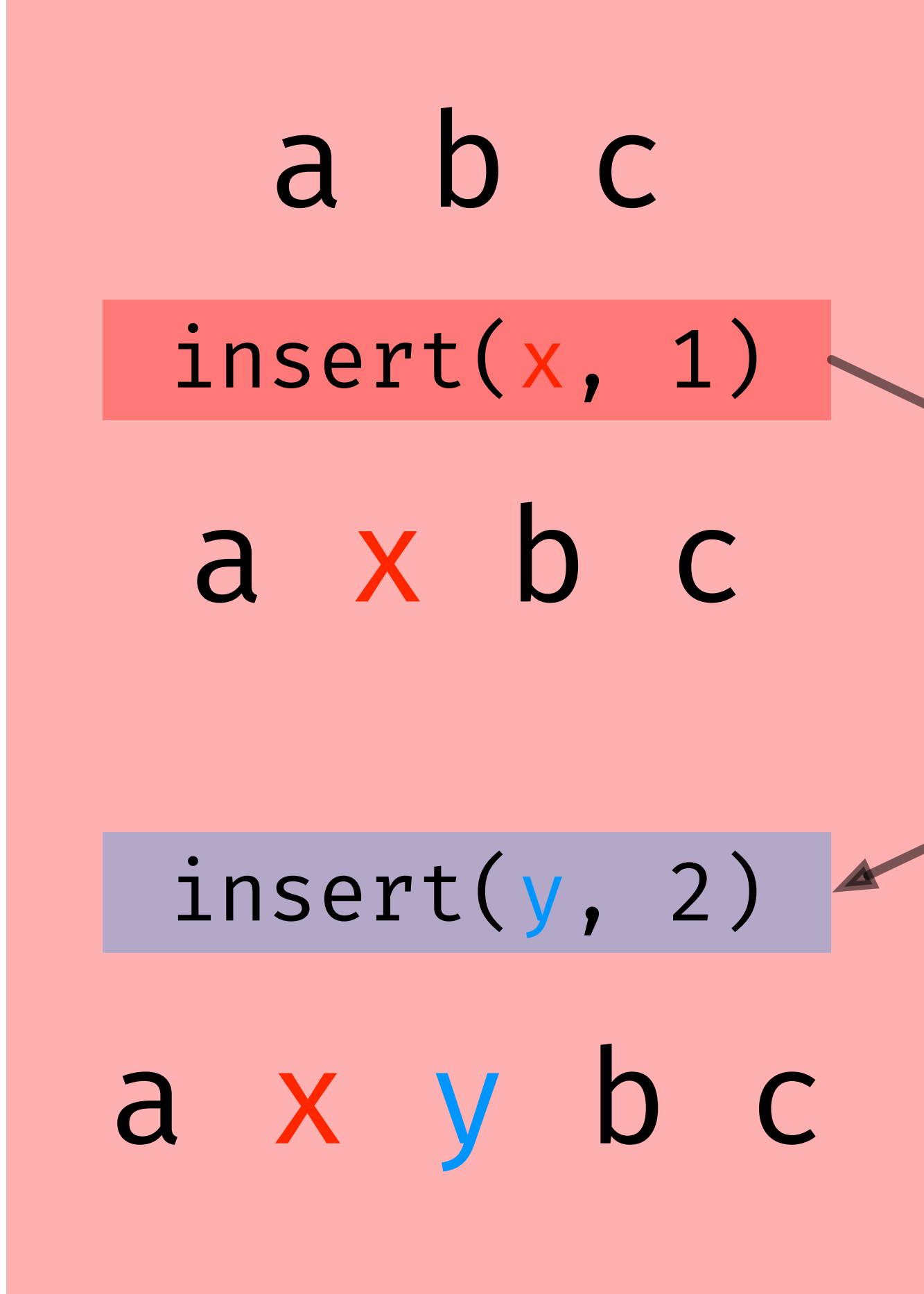
a b y c

insert(x, 1)

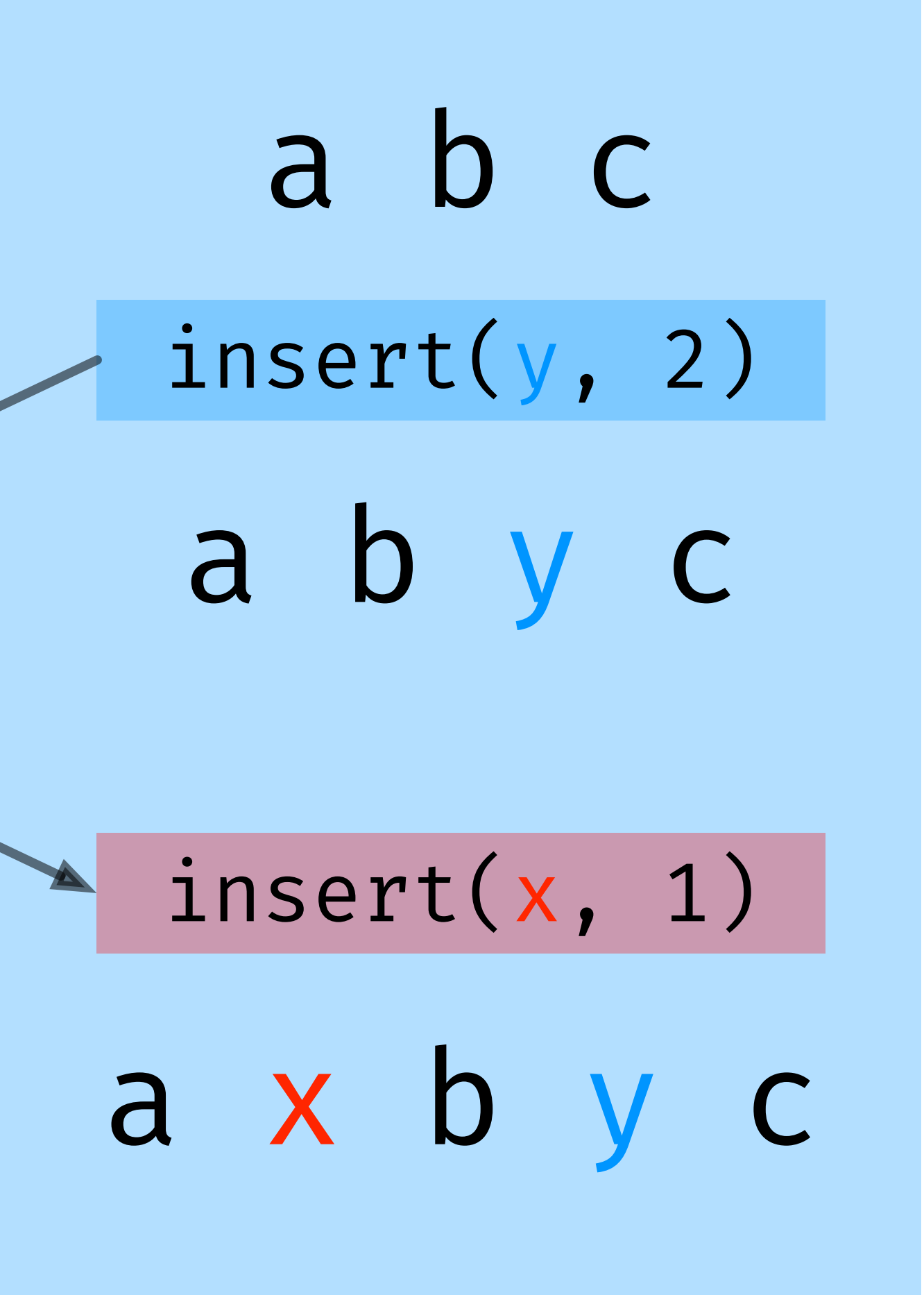
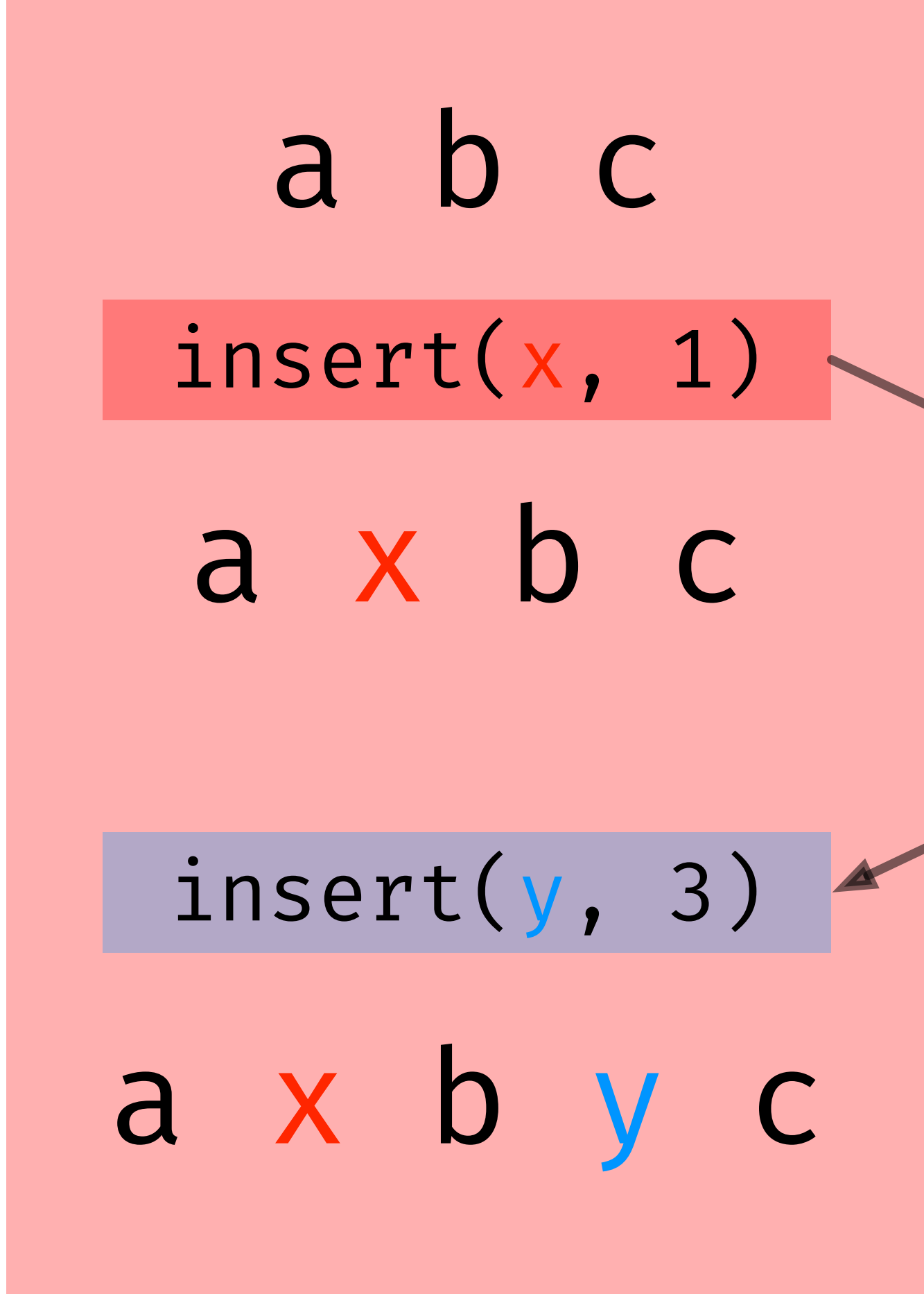
a x b y c





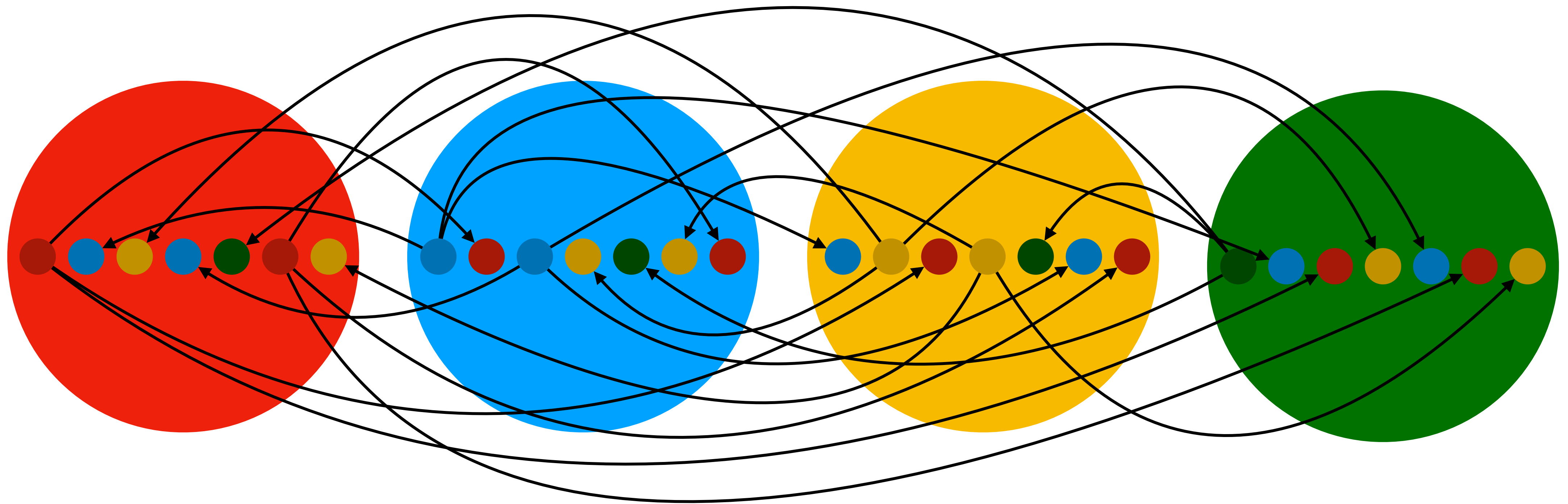






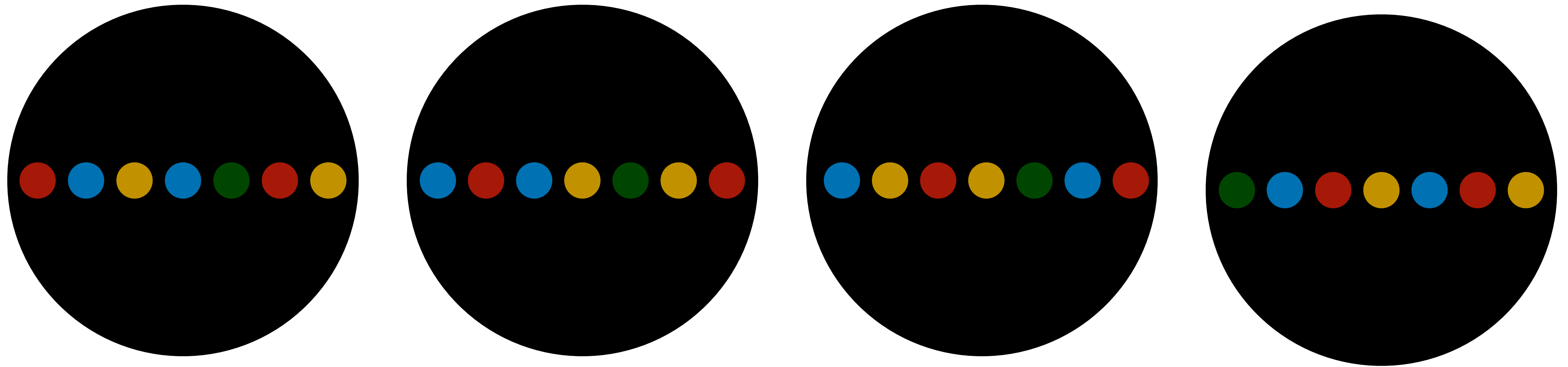
  **Operational Transformation**





***Concurrent operations  
are commutative***





*All replicas converge to  
the same state*





# A CRDT for Text

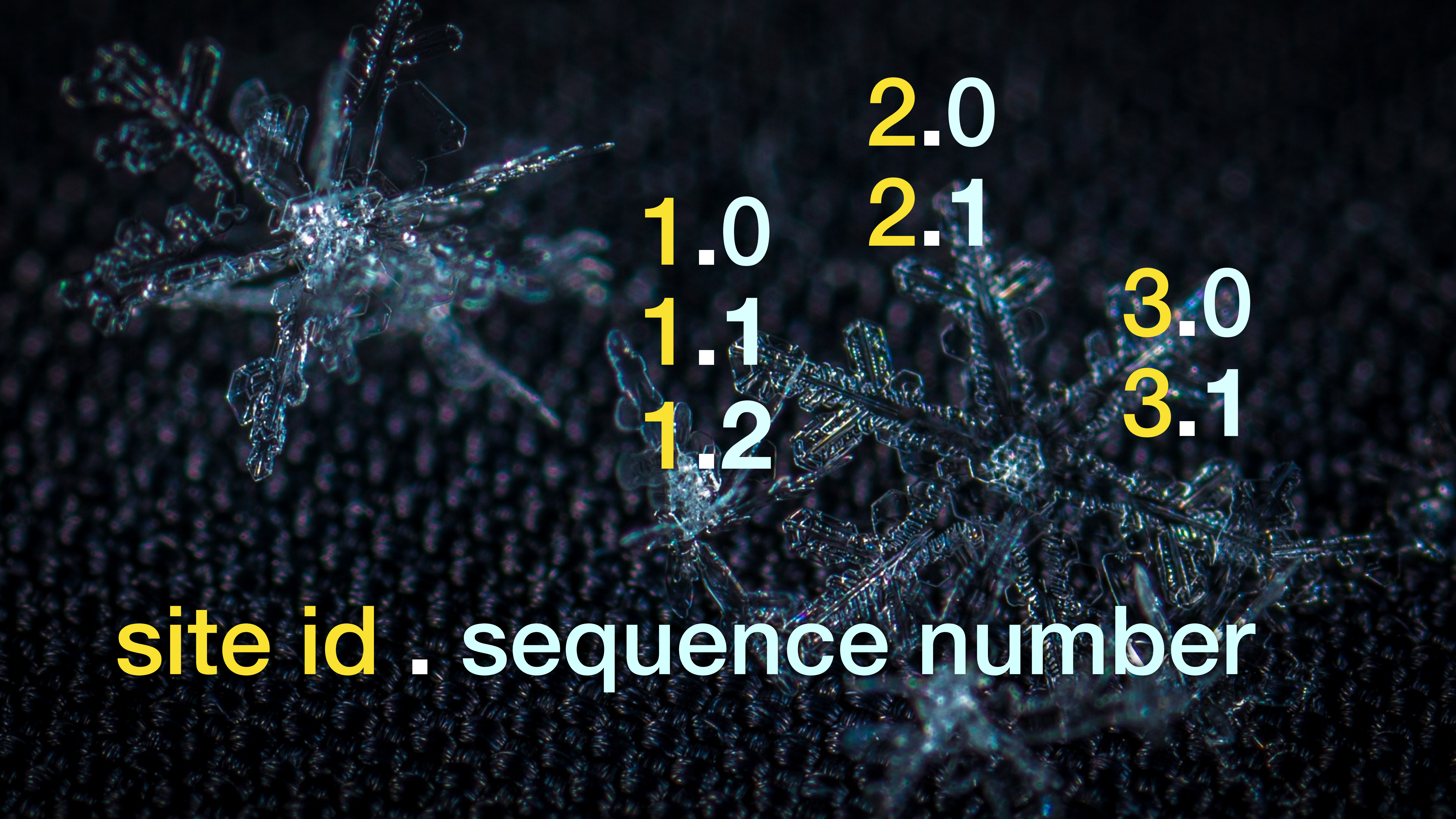




# Unique Identifiers

**site id** . sequence number





2.0

1.0

2.1

1.1

3.0

1.2

3.1

**site id** . **sequence number**



# Insertions

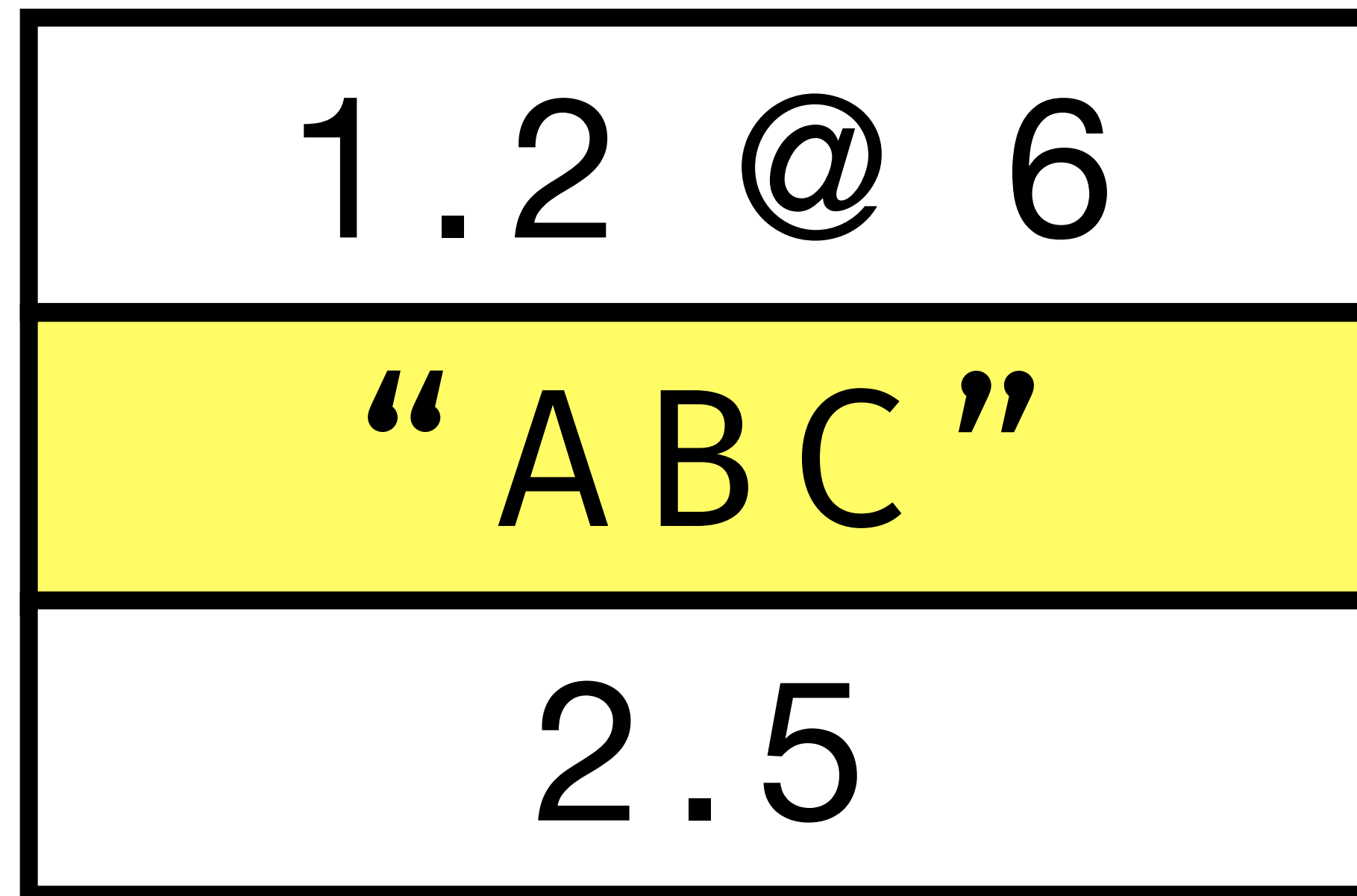
1.2 @ 6

“ABC”

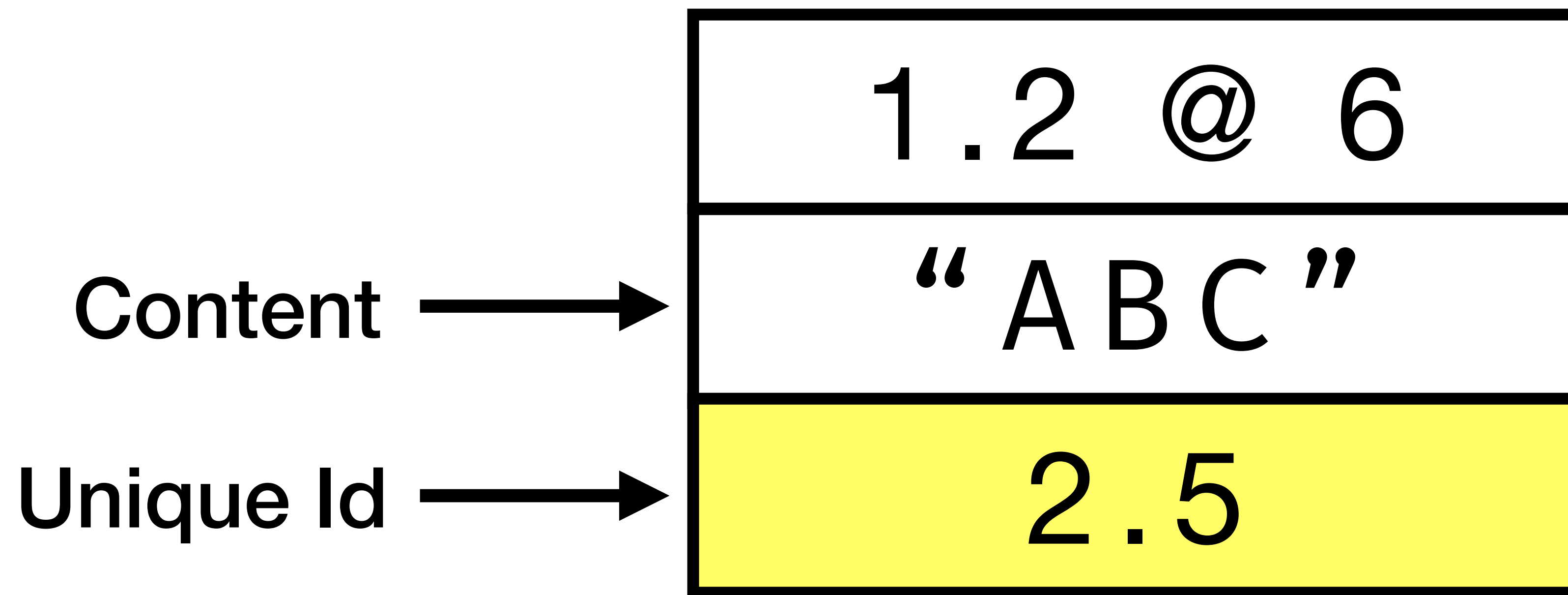
2.5



**Content**









**Location**



1 . 2 @ 6

**Content**



“ A B C ”

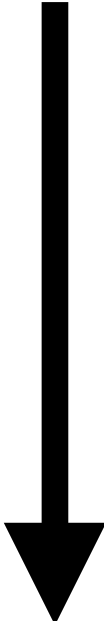
**Unique Id**



2 . 5



Parent insertion id



Location



1.2 @ 6

Content



"ABC"

Unique Id



2.5

1.2 @ 6
"ABC"
2.5



Parent insertion id

Offset within parent insertion



Location



1 . 2 @ 6

Content

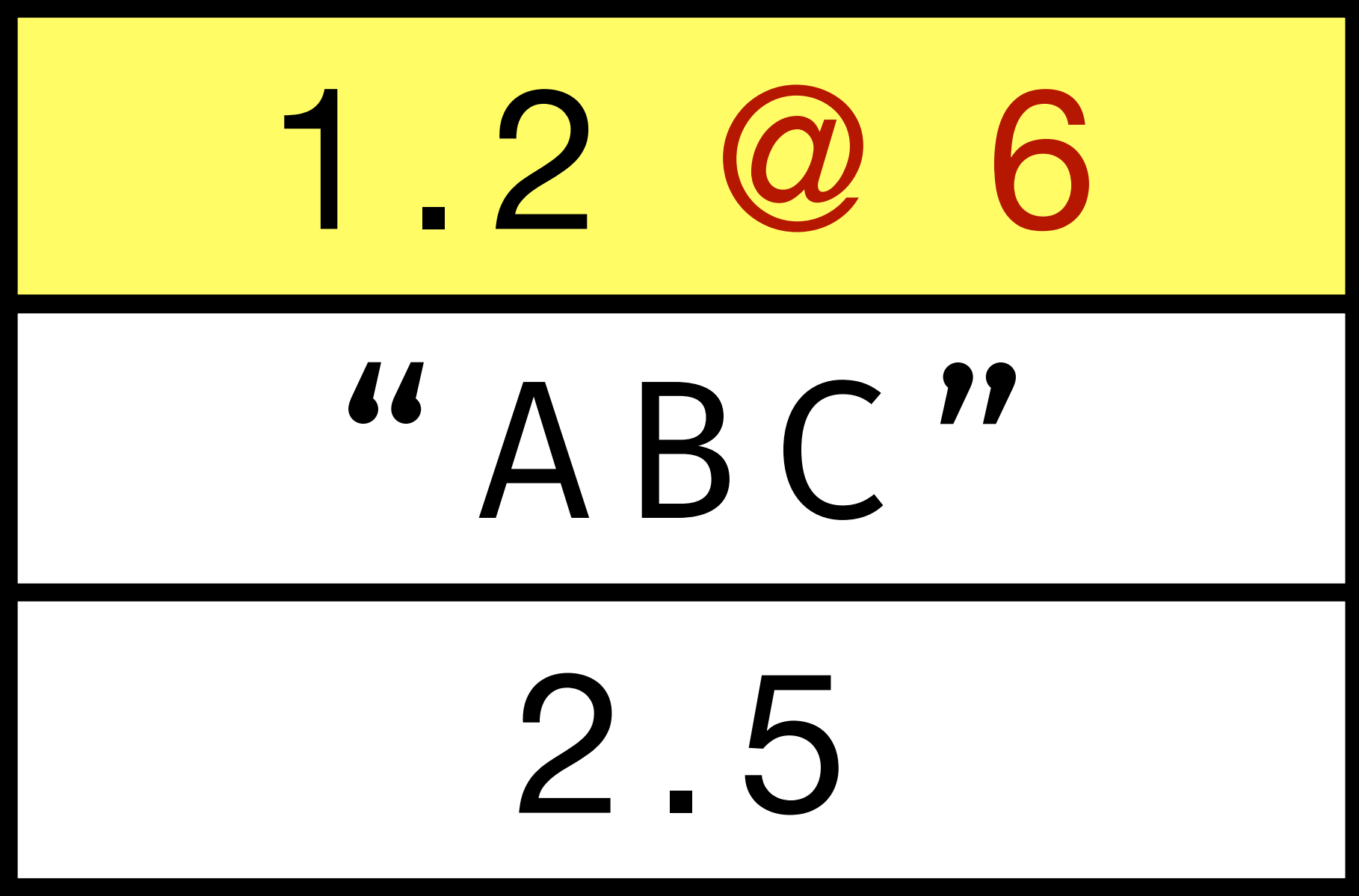


" A B C "

Unique Id



2 . 5





# Site 1

0.0 @ 0
ABC
1.0

ABC

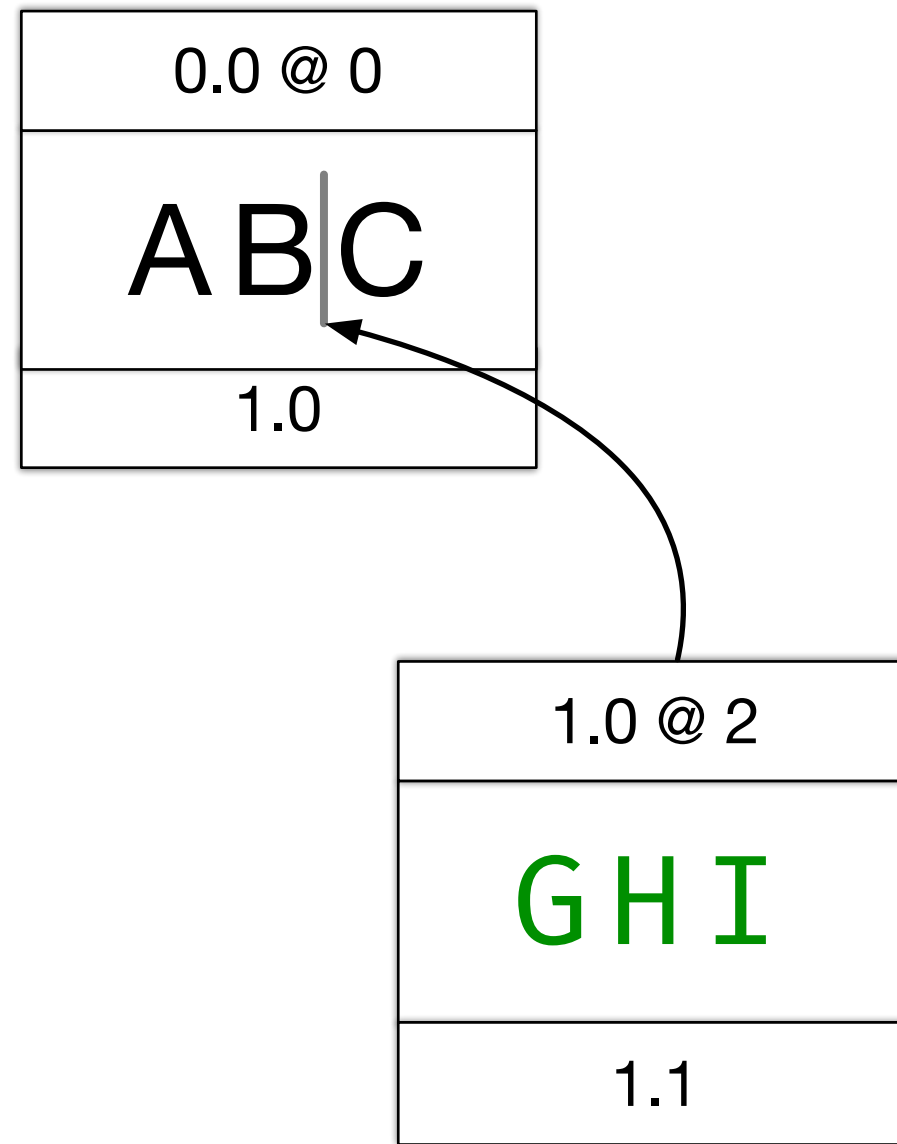
# Site 2

0.0 @ 0
ABC
1.0

ABC

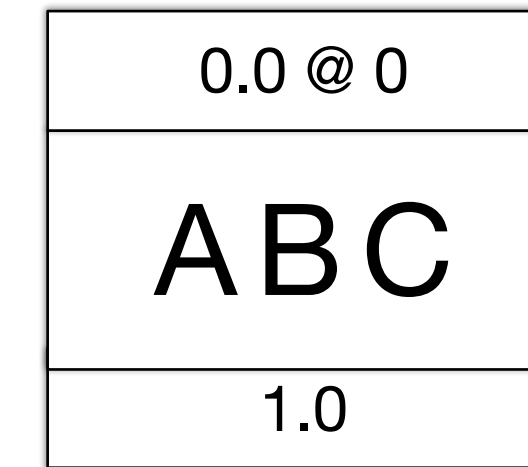


# Site 1



ABGHIC

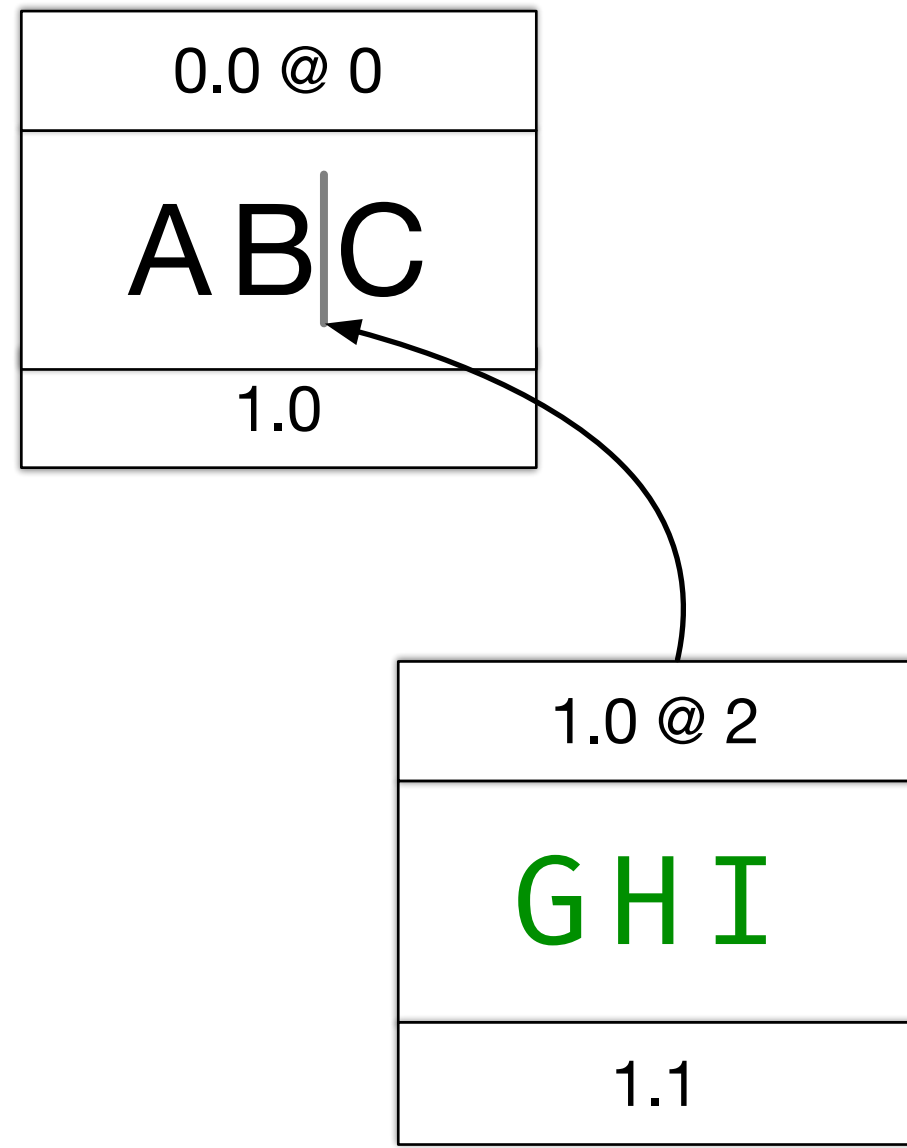
# Site 2



ABC

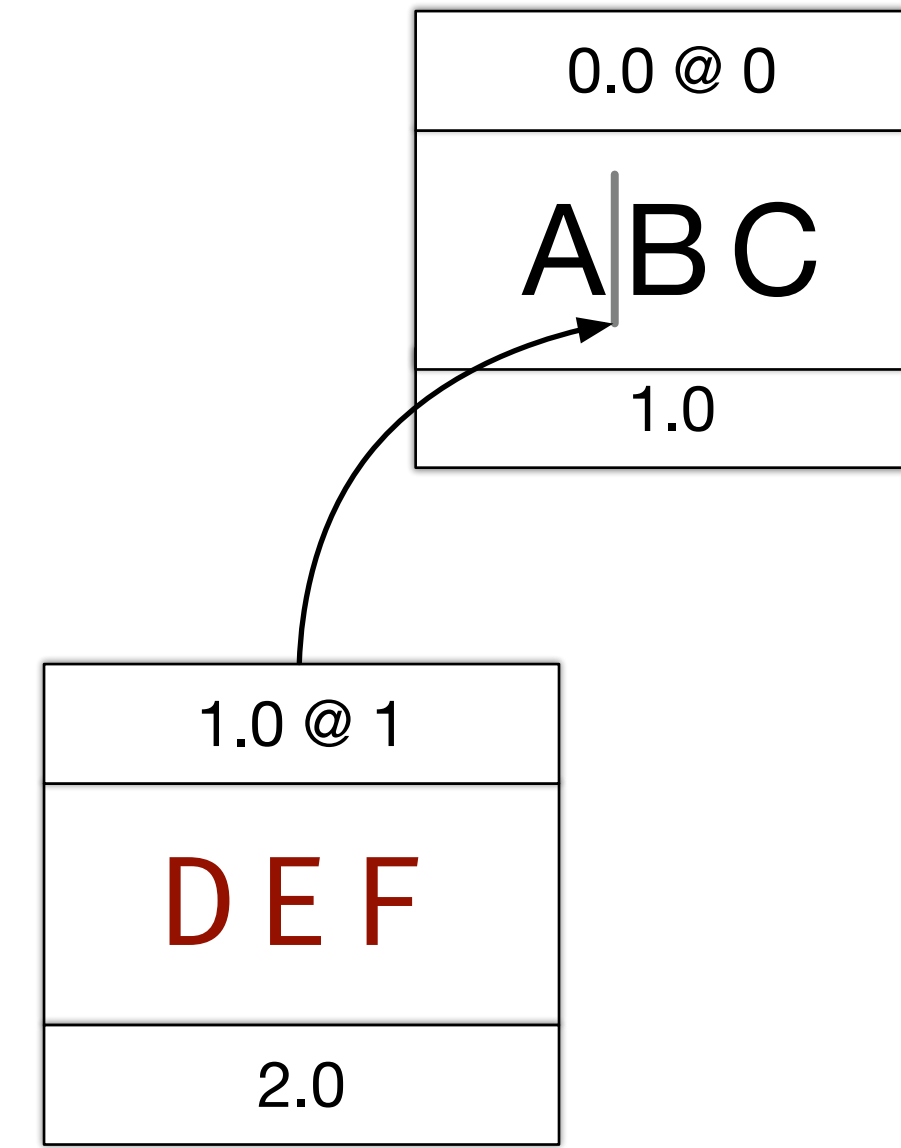


# Site 1



ABGHIC

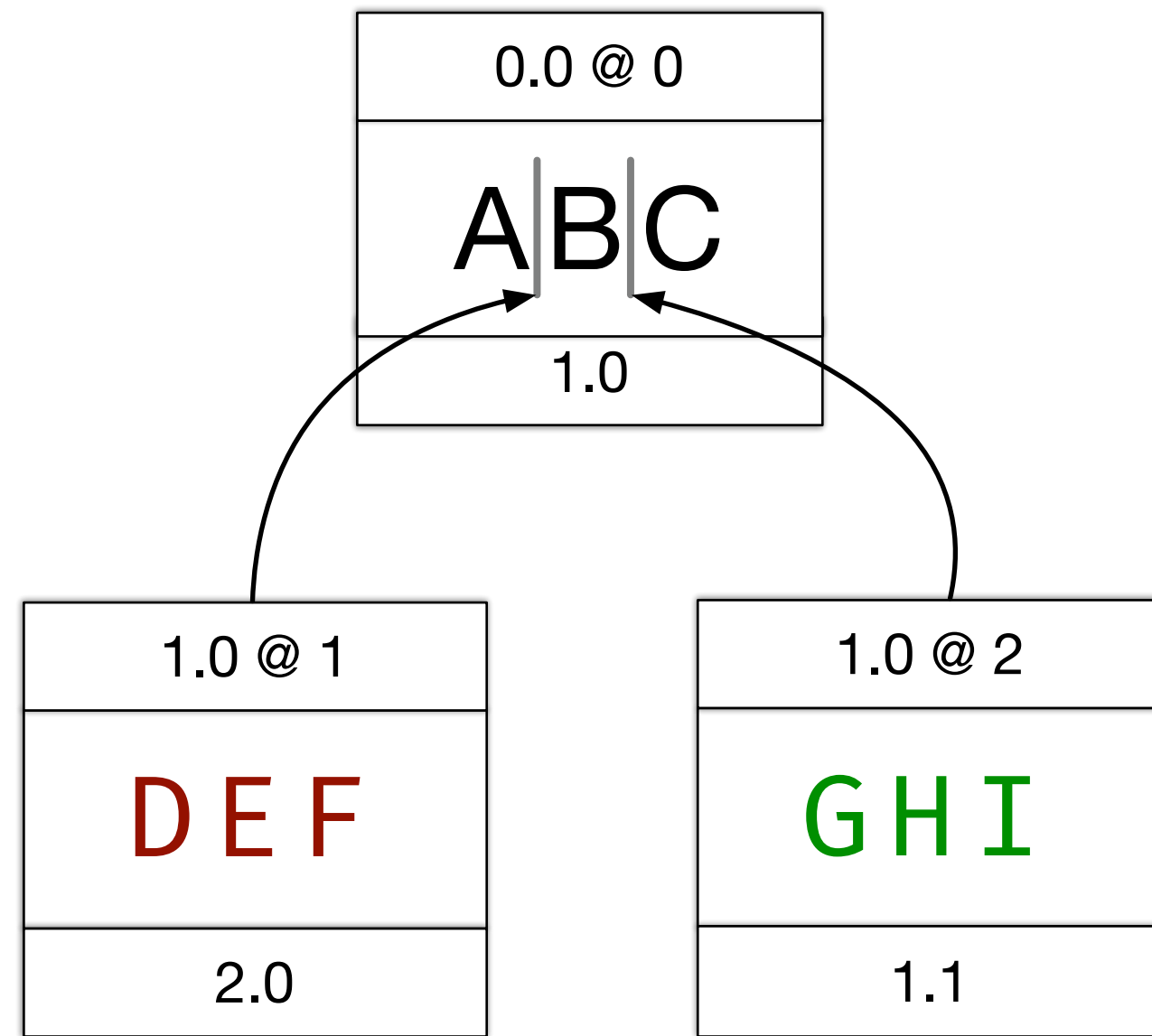
# Site 2



ADEFBC

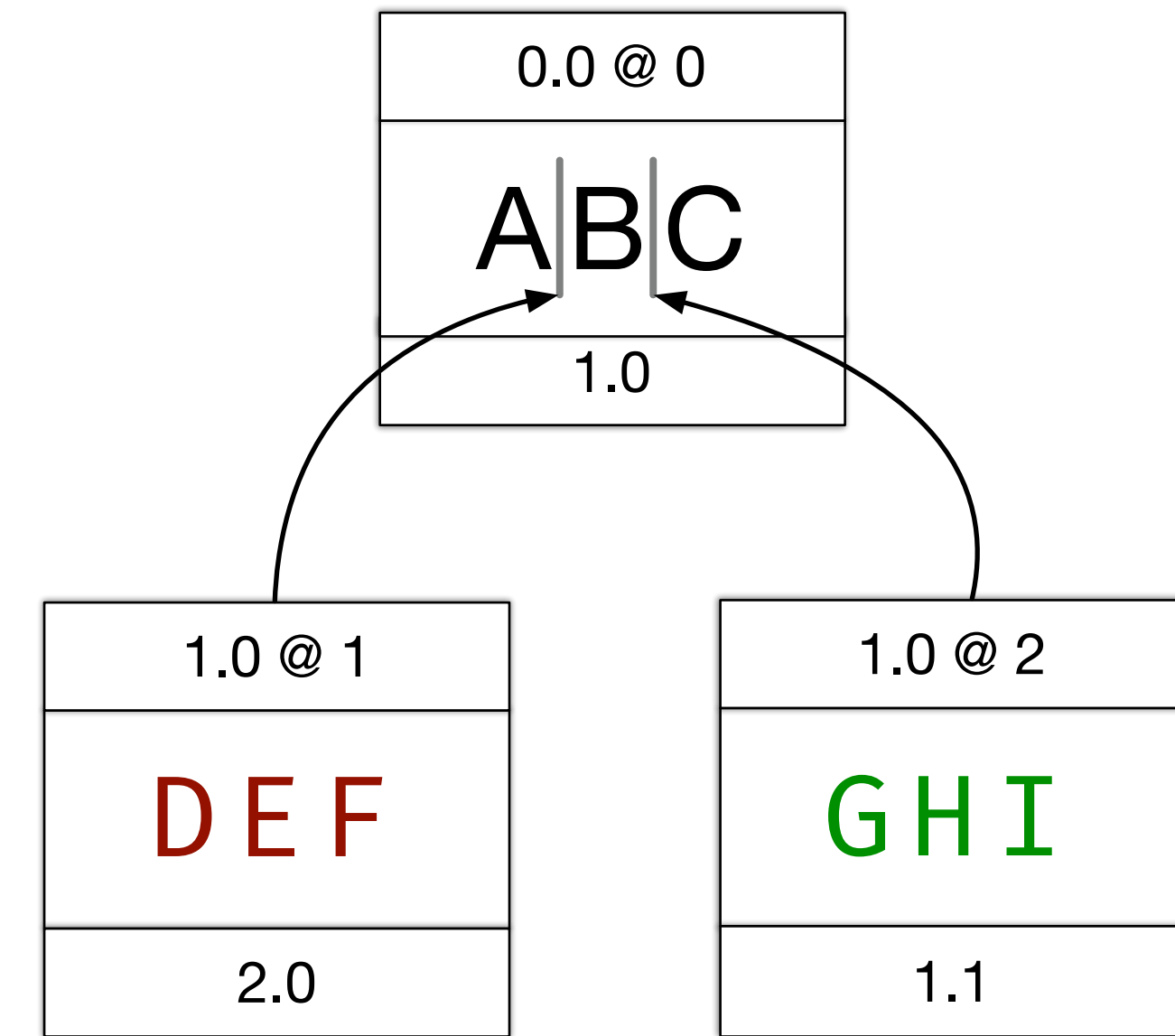


# Site 1



ADEFBGHIC

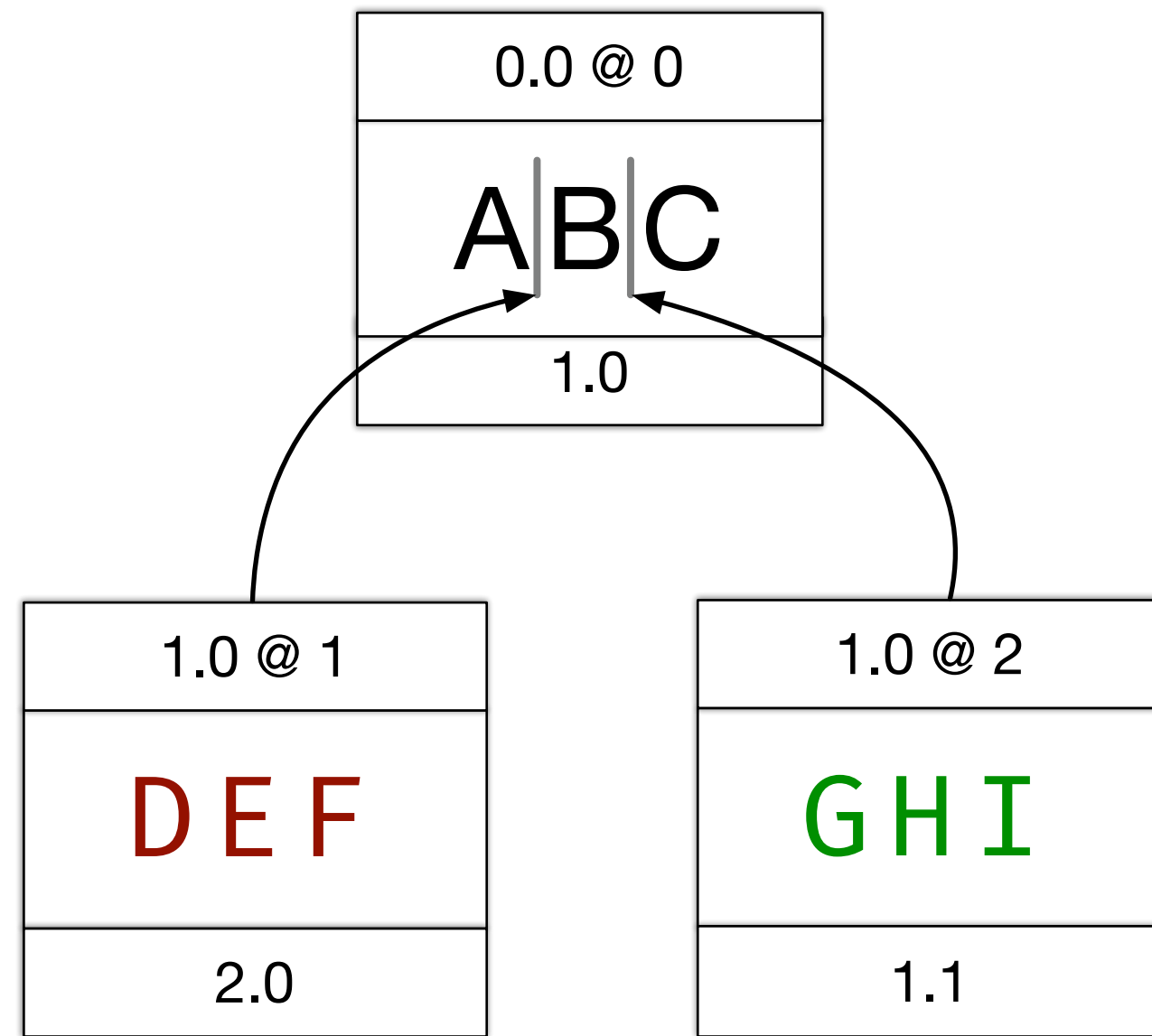
# Site 2



ADEFBGHIC

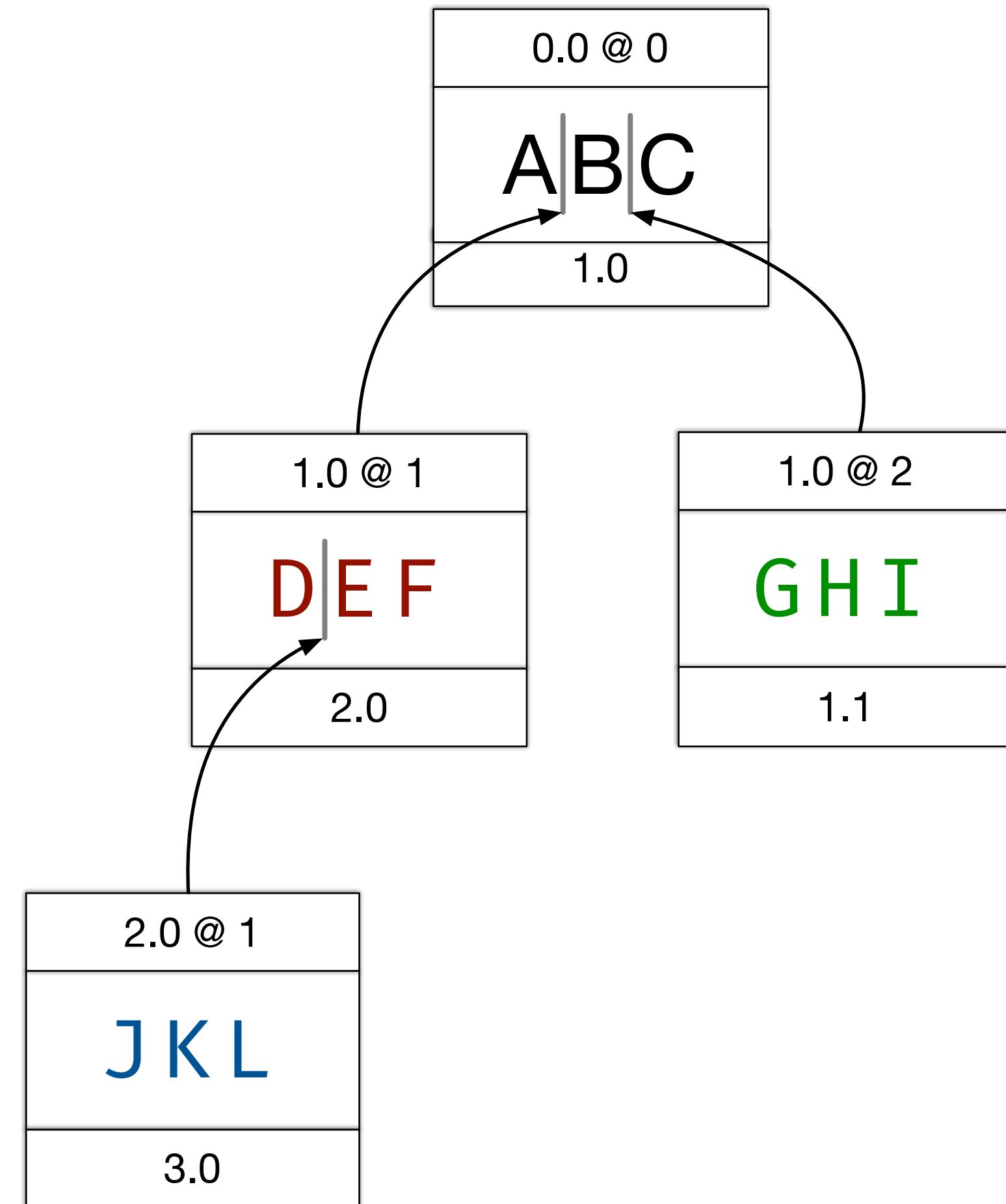


# Site 1



ADEFBGHIC

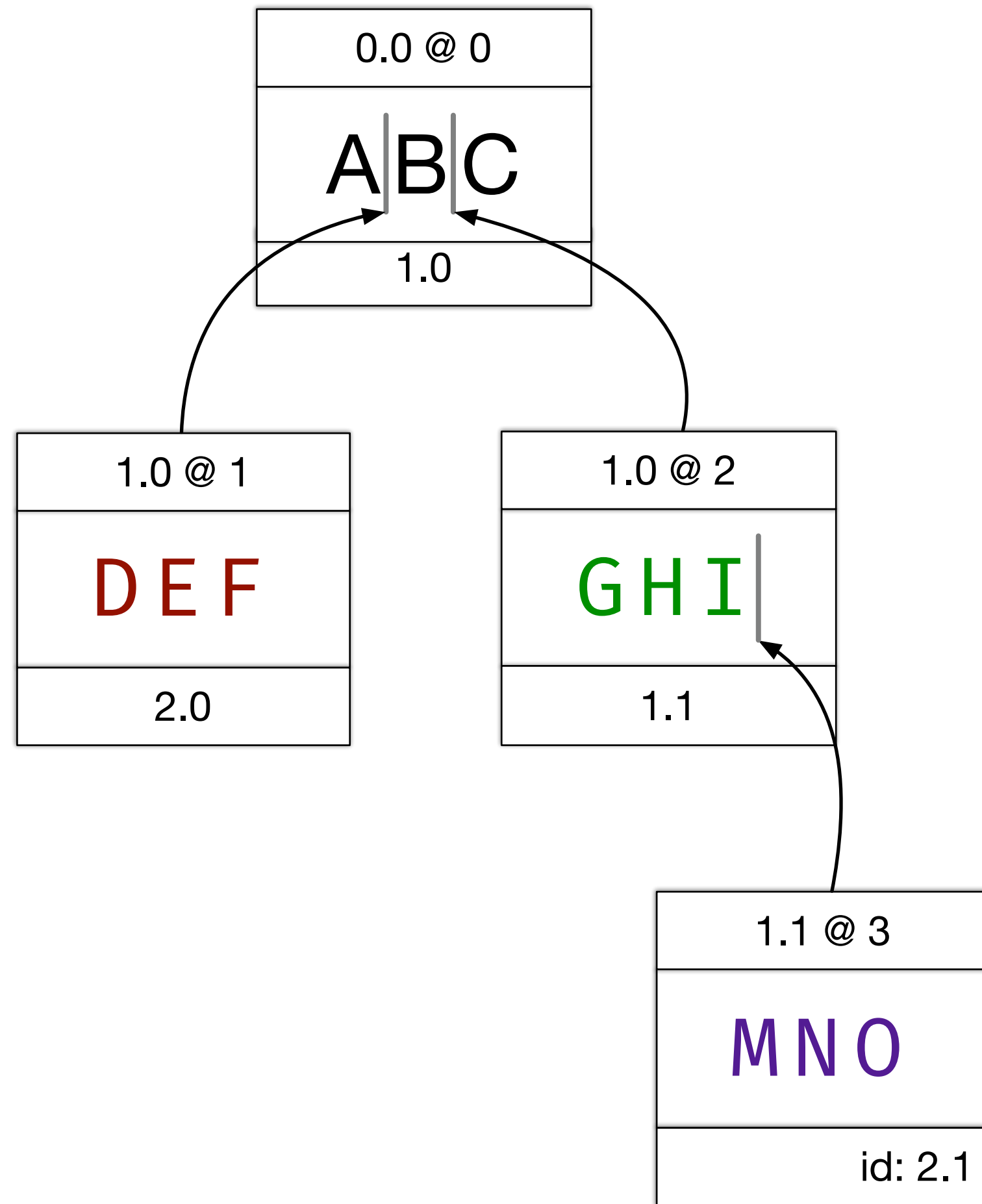
# Site 2



ADJKLEFBGHIC

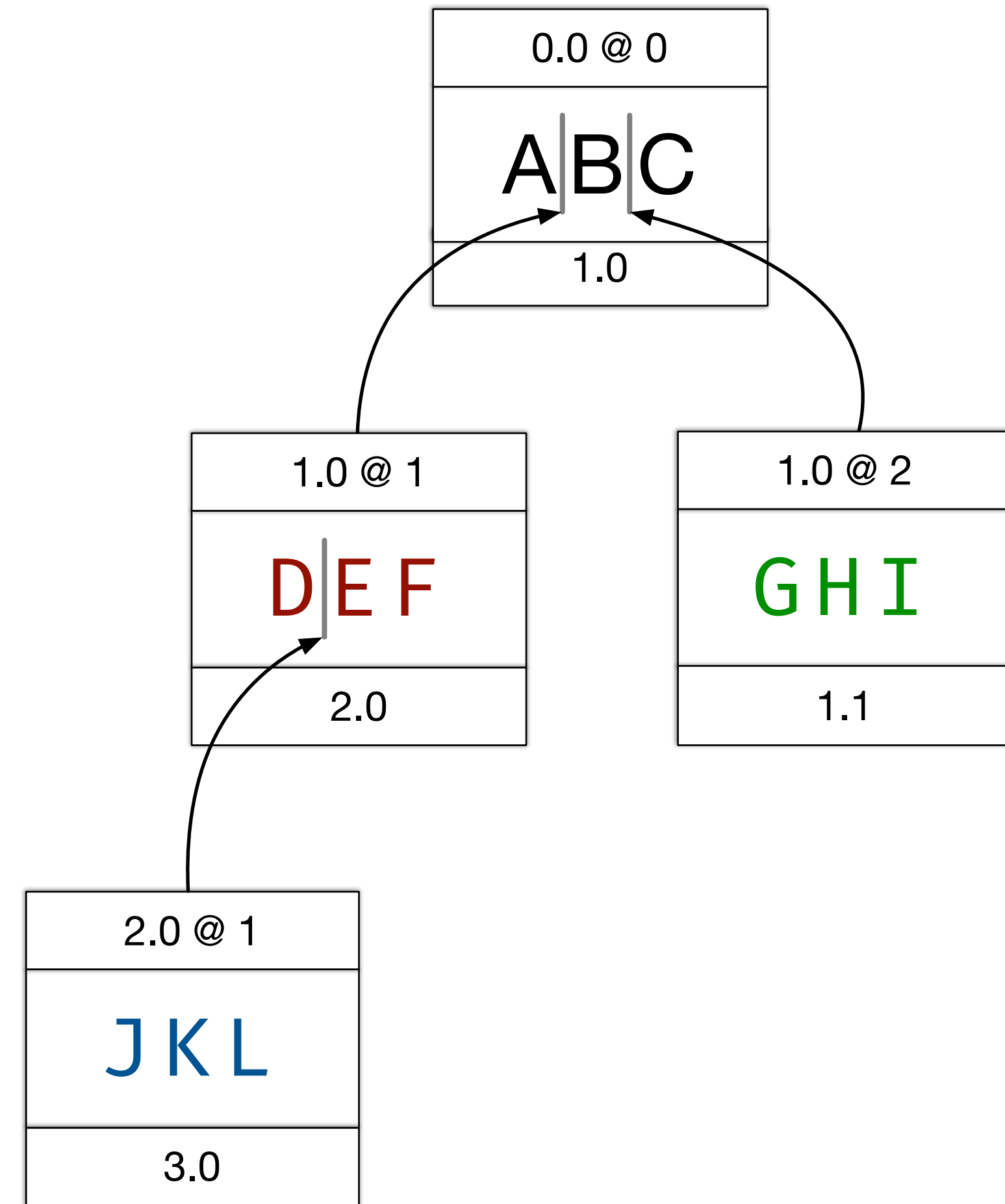


# Site 1



ADEFBGHICMNO

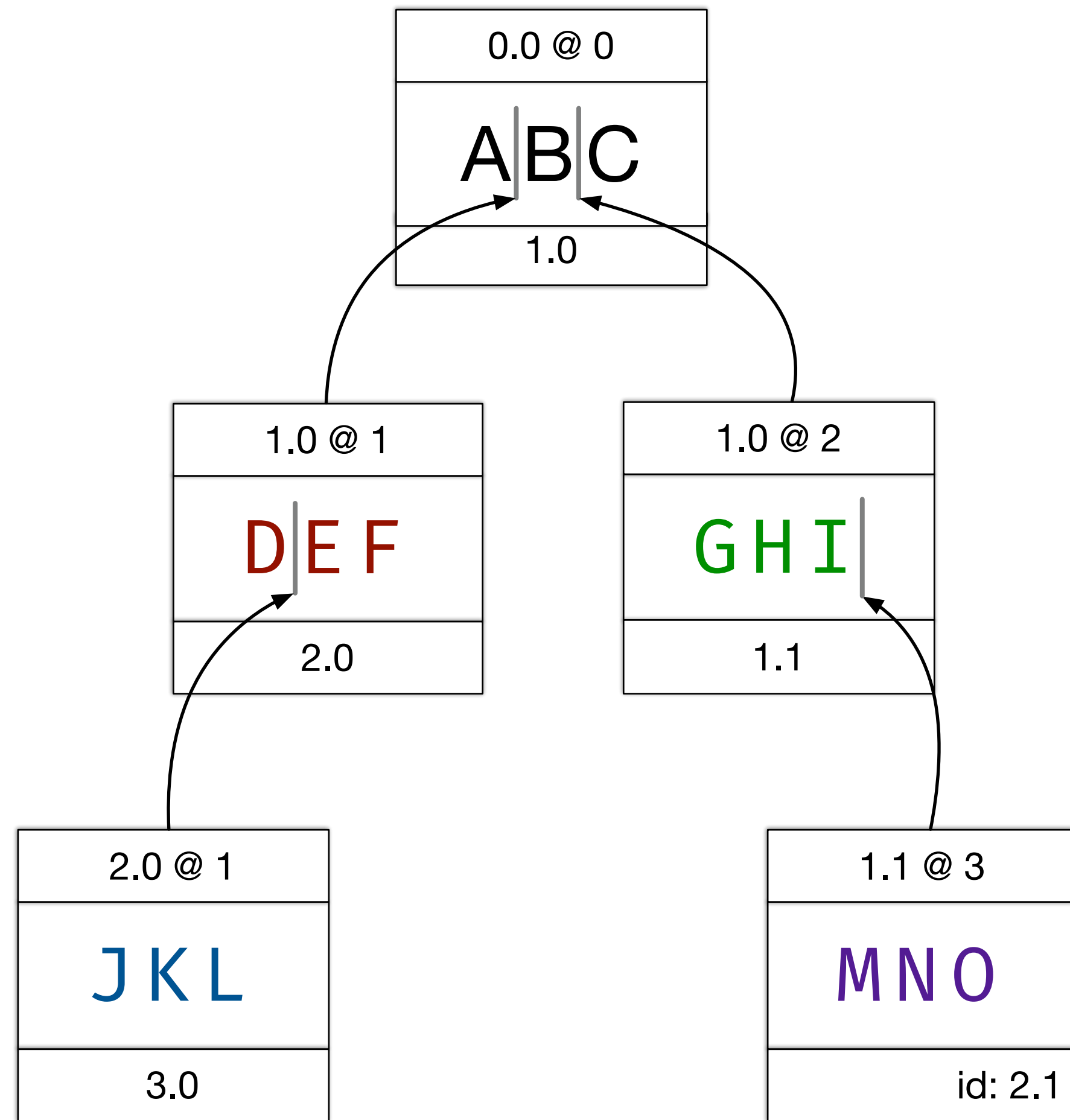
# Site 2



ADJKEFBGHIC

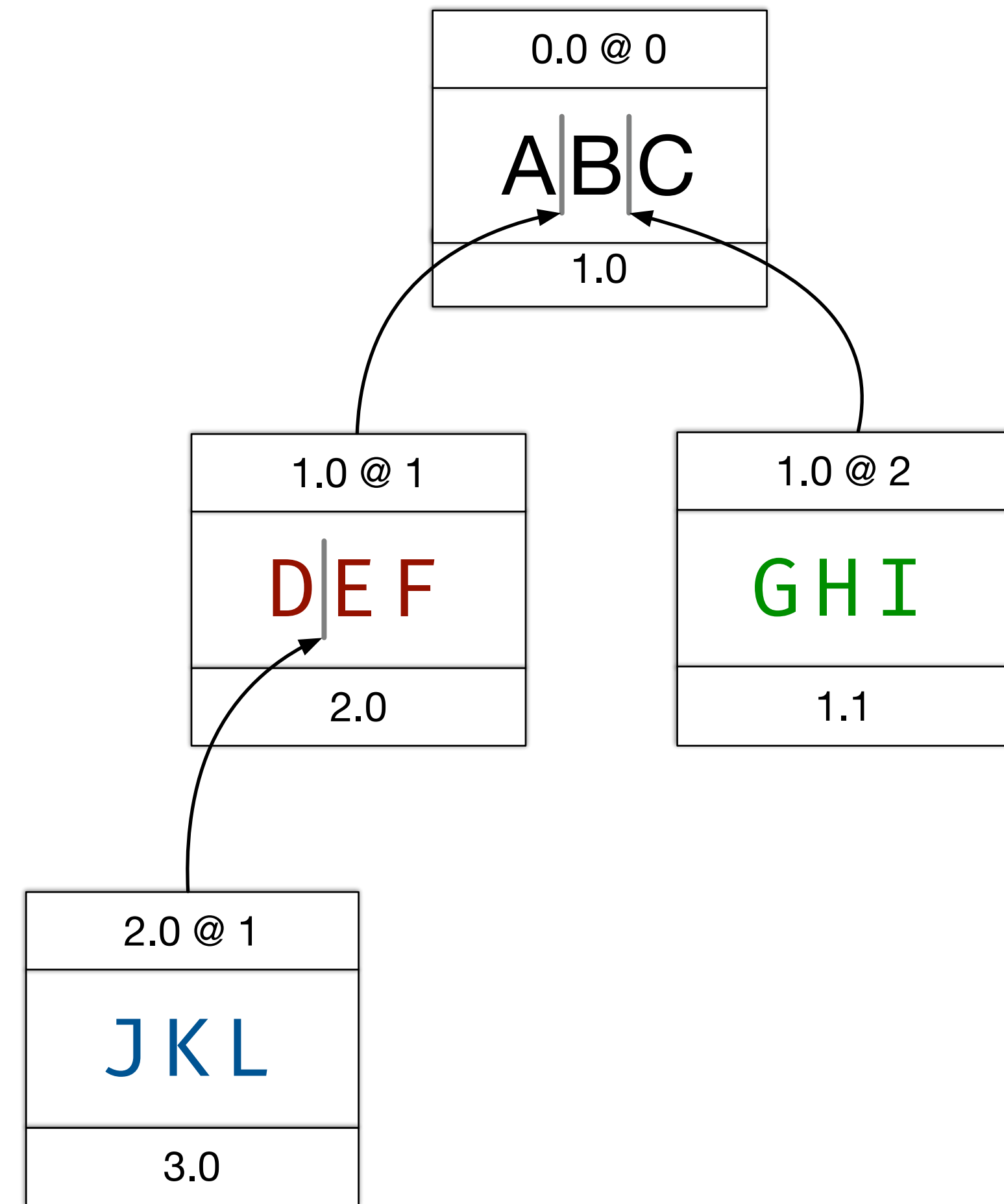


# Site 1



A D J K L E F B G H I C M N O

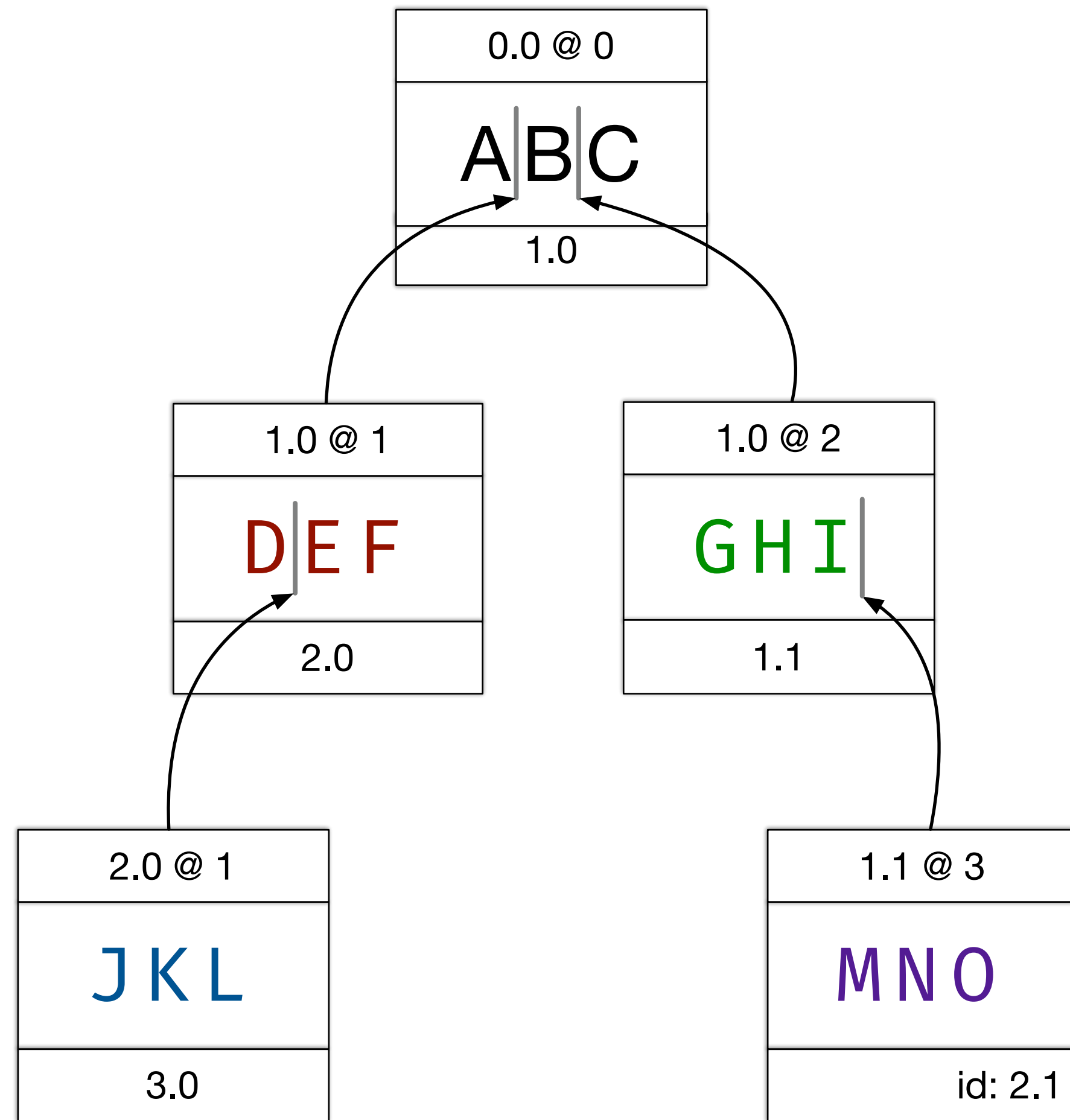
# Site 2



A D J K L E F B G H I C

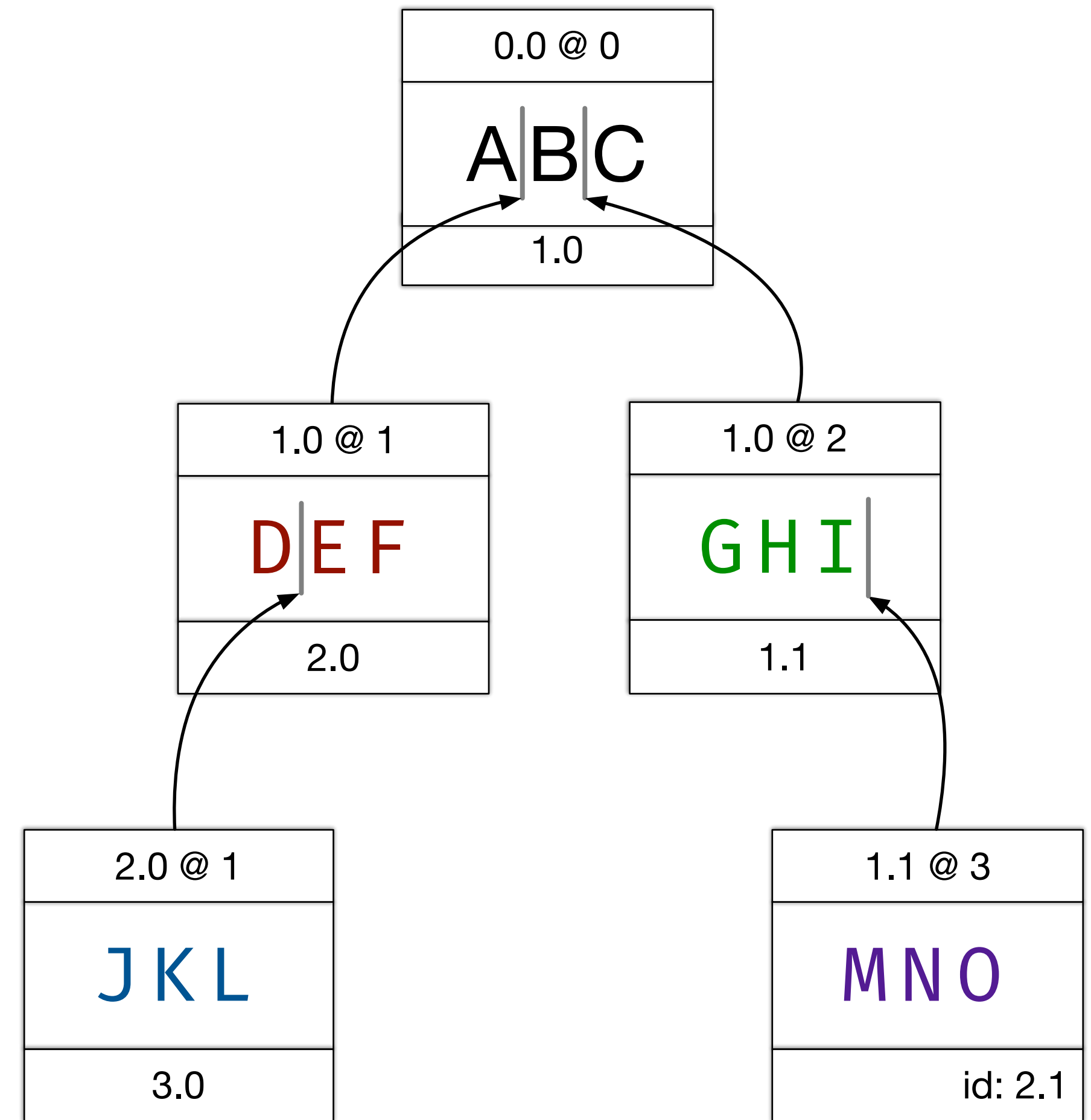


# Site 1



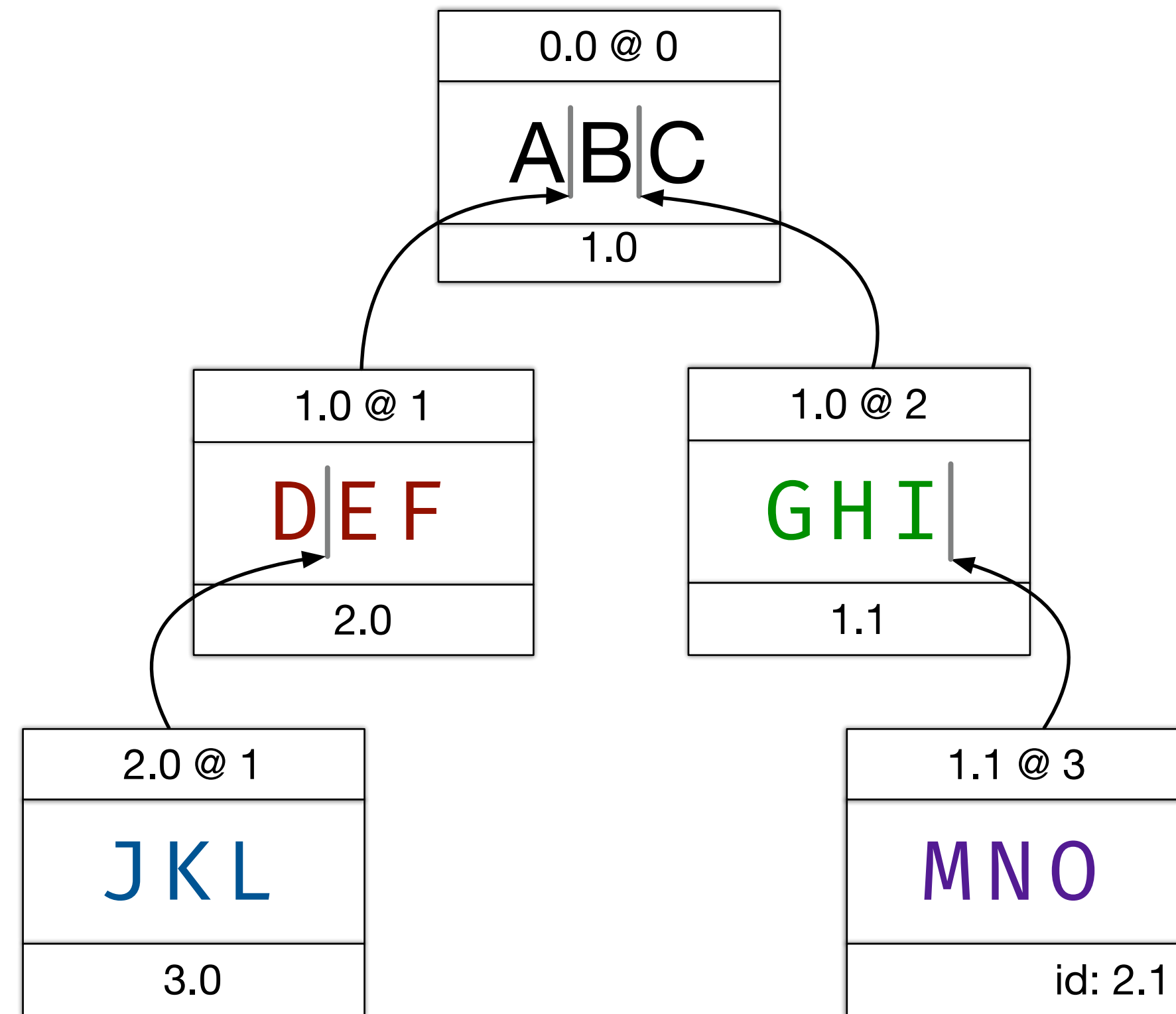
A D J K L E F B G H I C M N O

# Site 2



A D J K L E F B G H I C M N O





## Fragment Sequence:

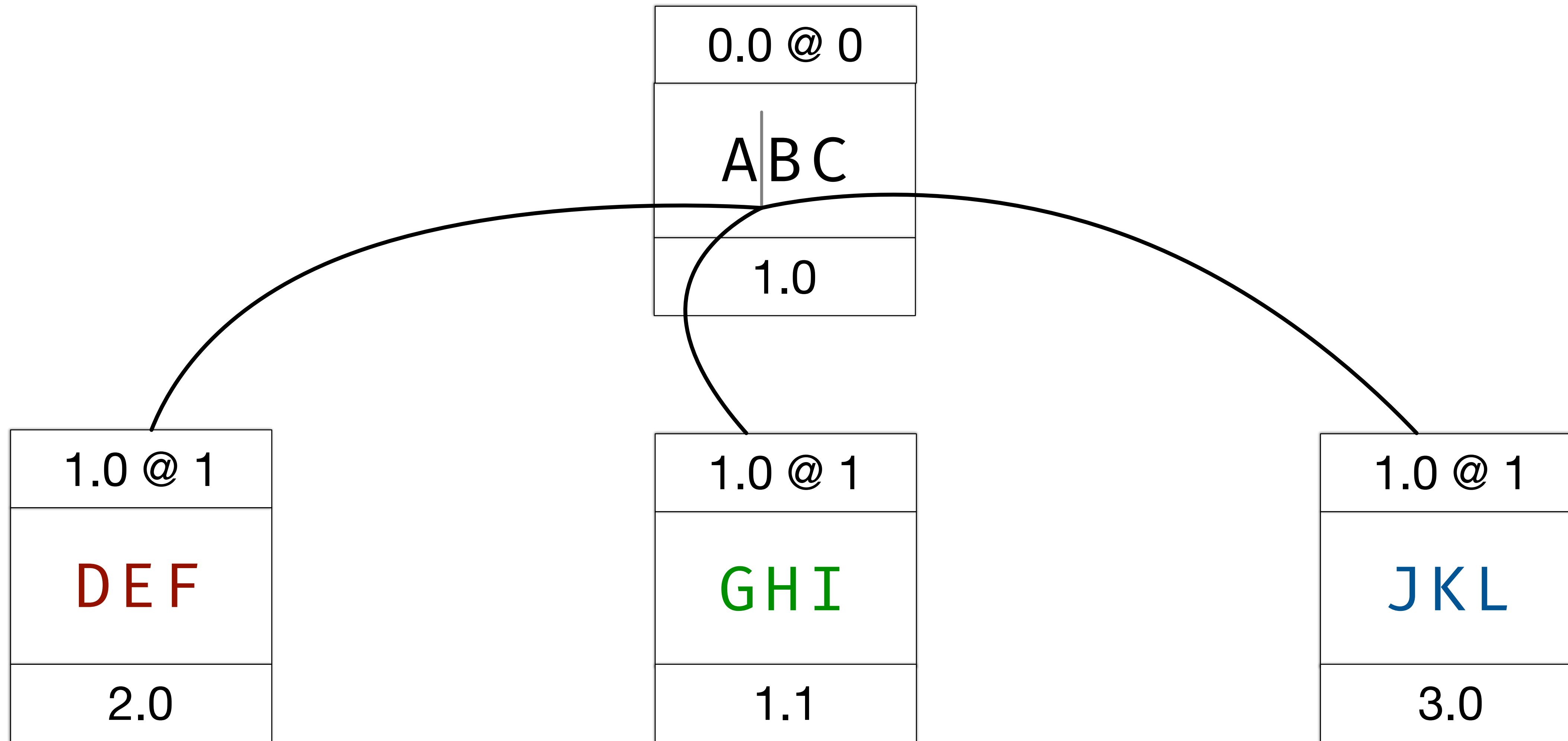
1.0 @ 0	2.0 @ 0	3.0 @ 0	1.0 @ 2	1.0 @ 1	1.1 @ 0	1.0 @ 2	1.1 @ 0
A	D	JKL	EF	B	GHI	C	MNO



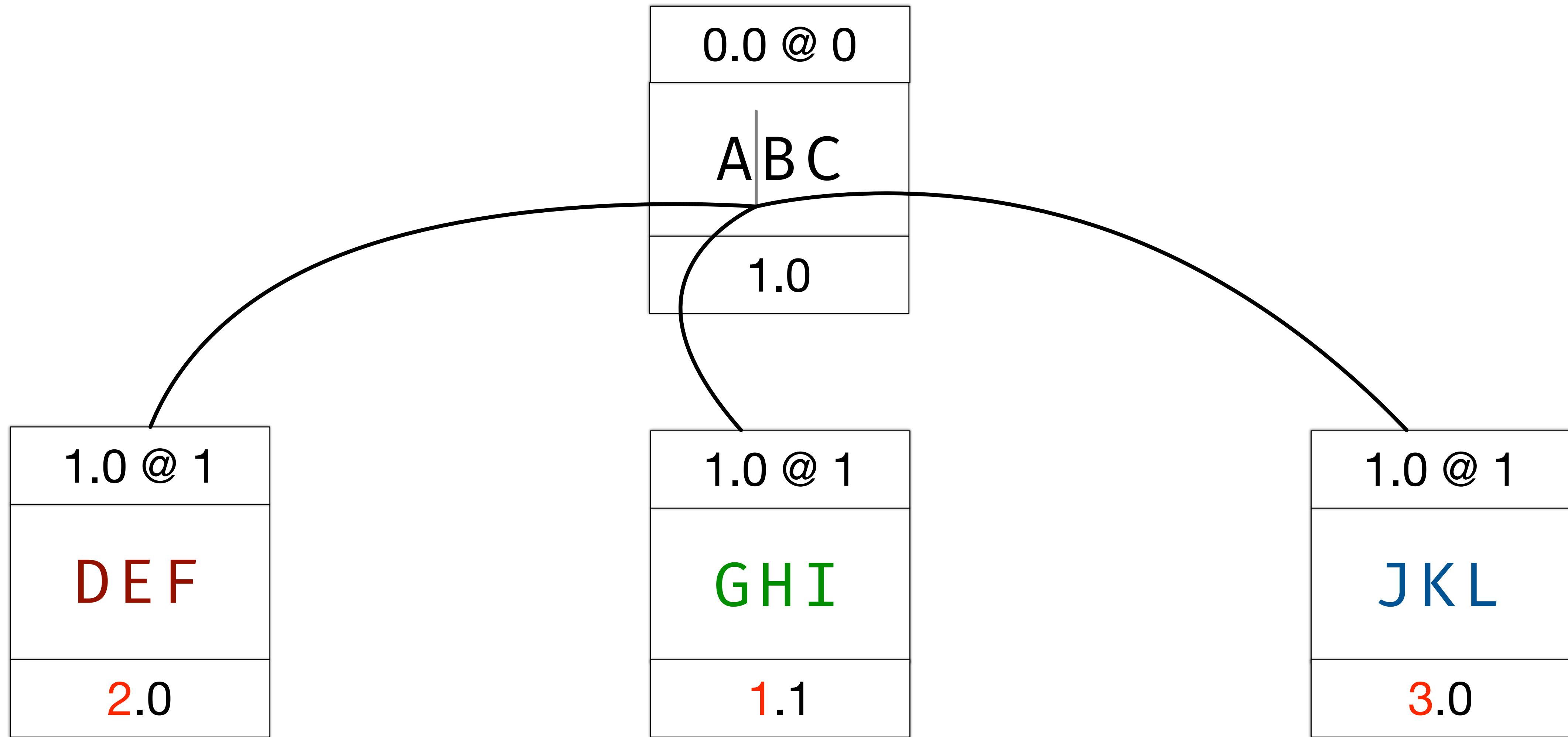
# Dealing With Ties





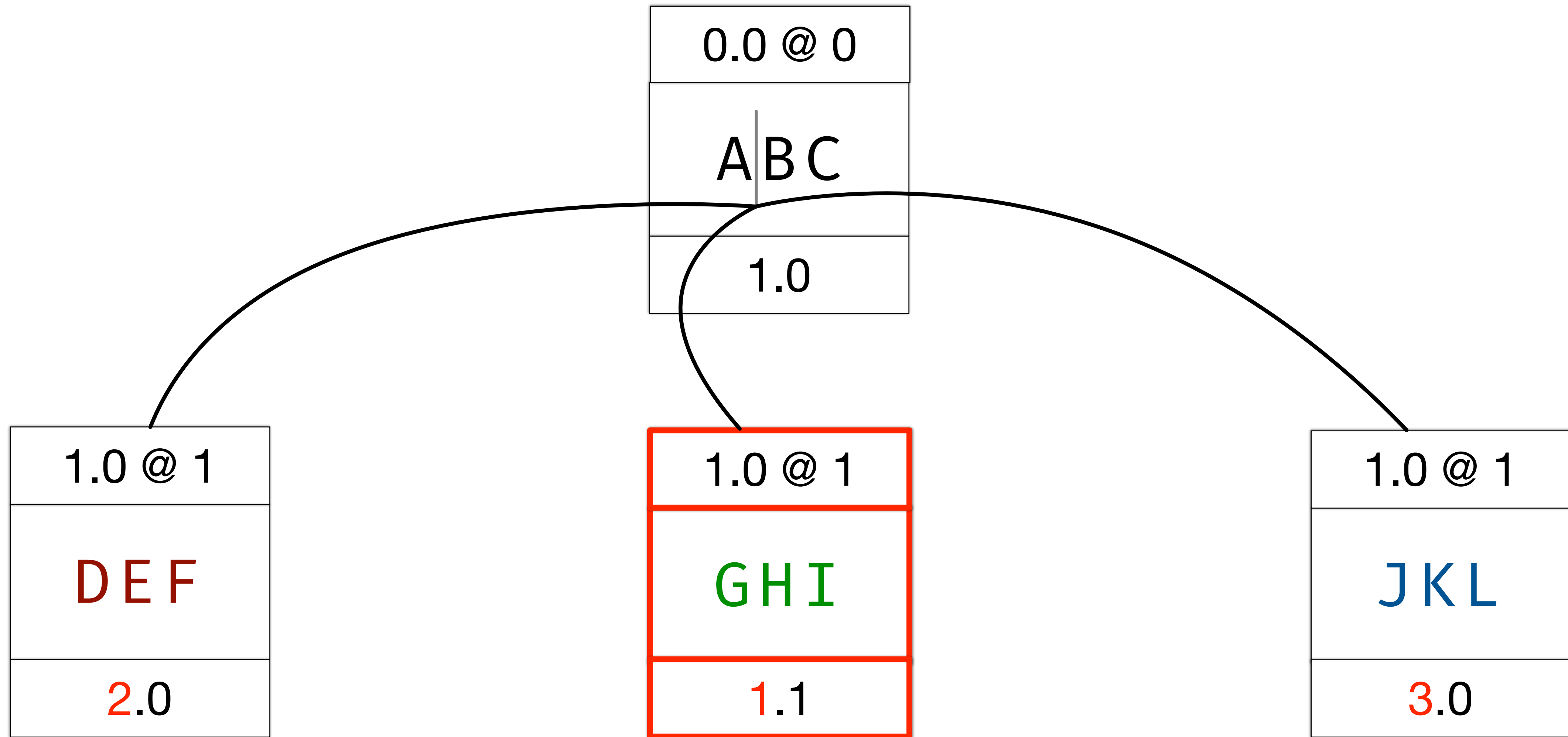


ABC

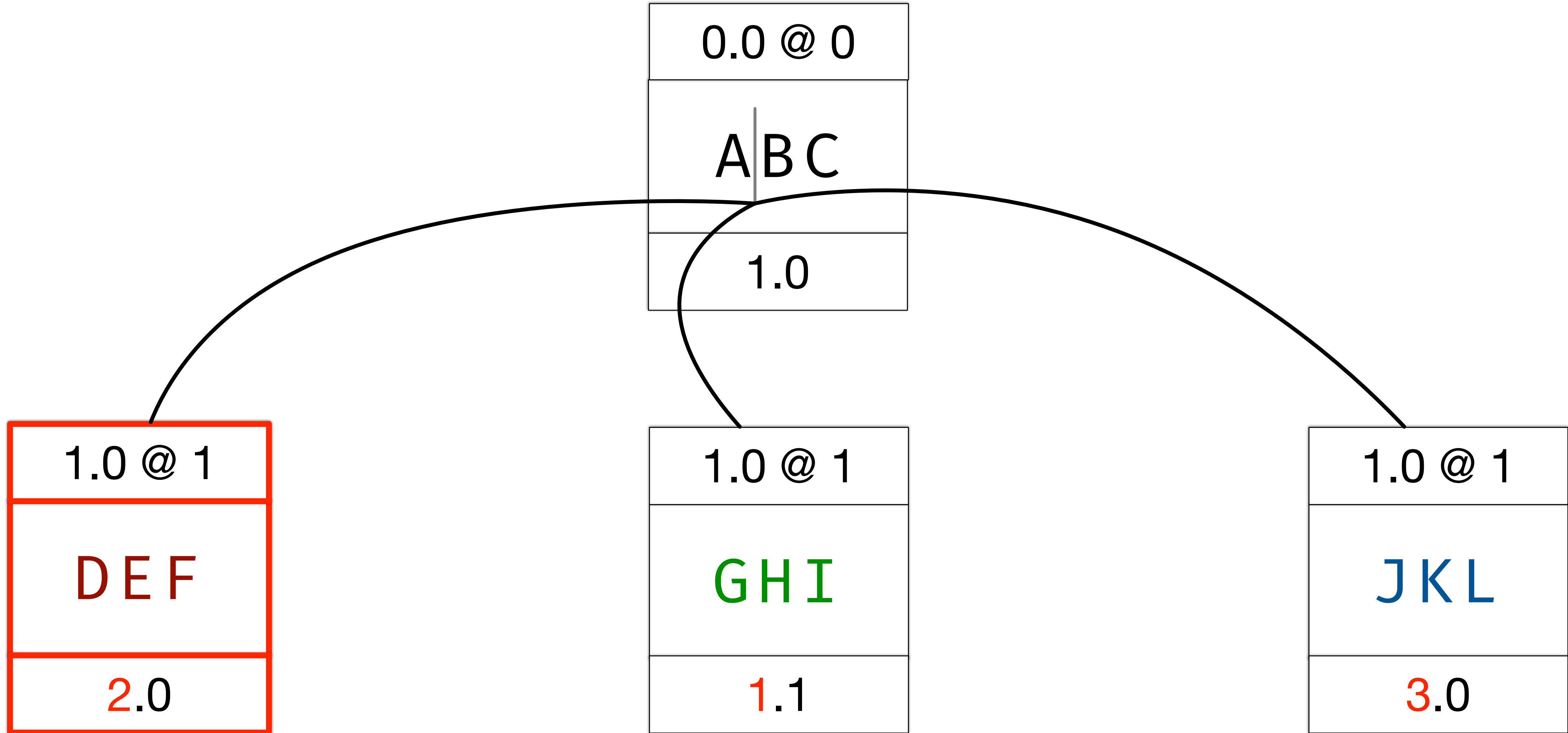


ABC



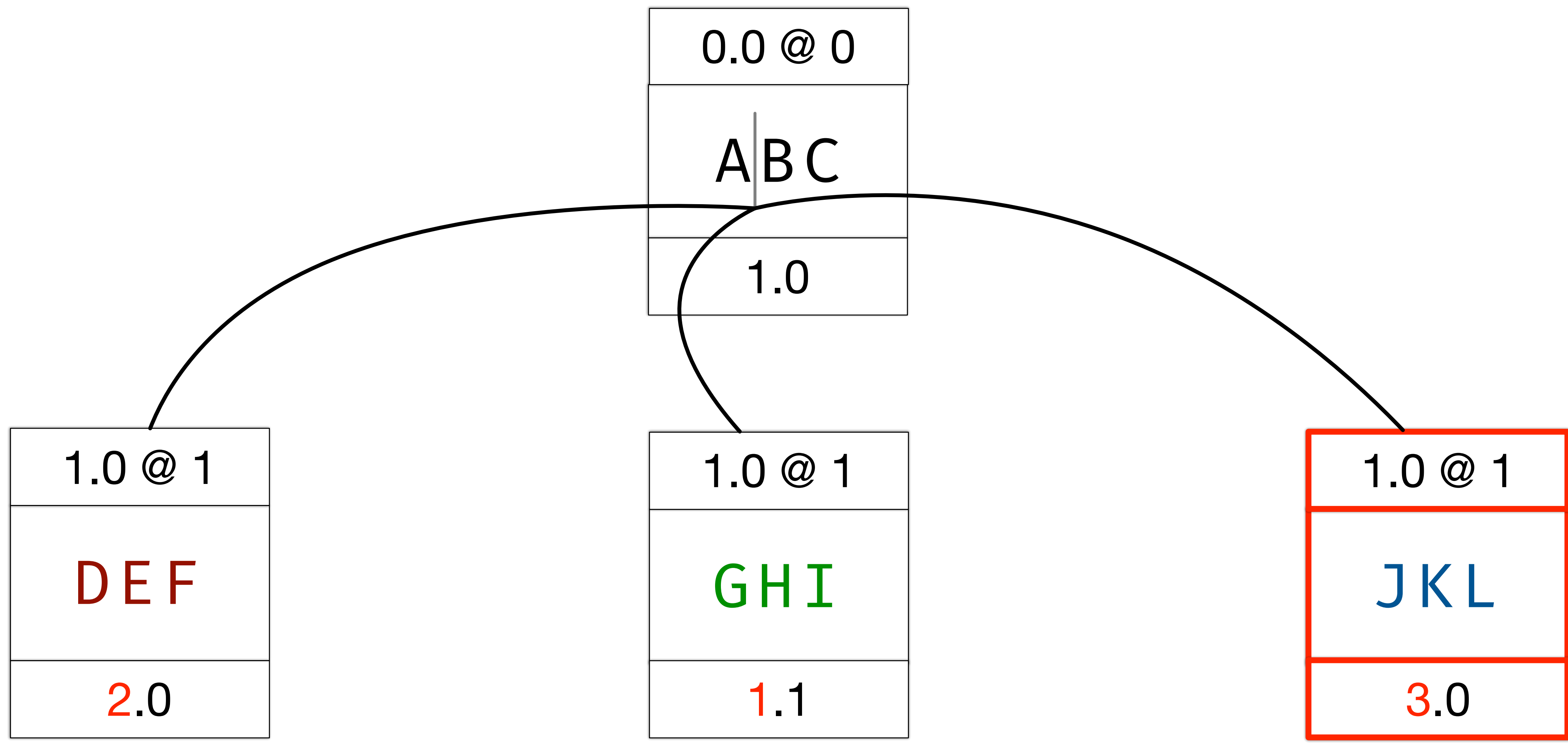


AGHIBC



AGHIDEFBC





AGHIDEFJKLBC

0.0 @ 0
A B C
1.0

1.0 @ 1
DEF
2.0

ADEFBC

---

GHI
3.0

A|DEFBC



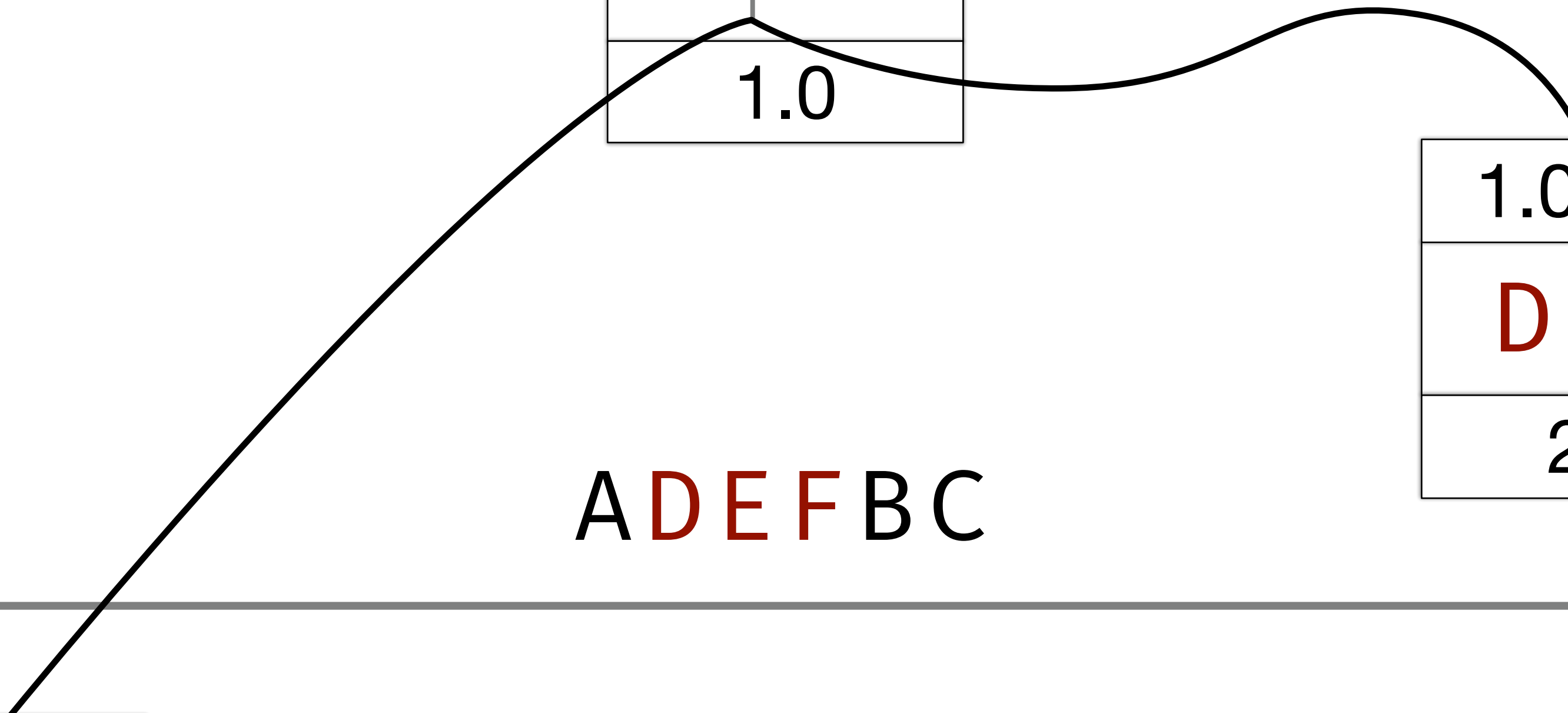
0.0 @ 0
A B C
1.0

1.0 @ 1
DEF
2.0

ADEFBC

1.0 @ 1
GHI
3.0

A|DEFBC





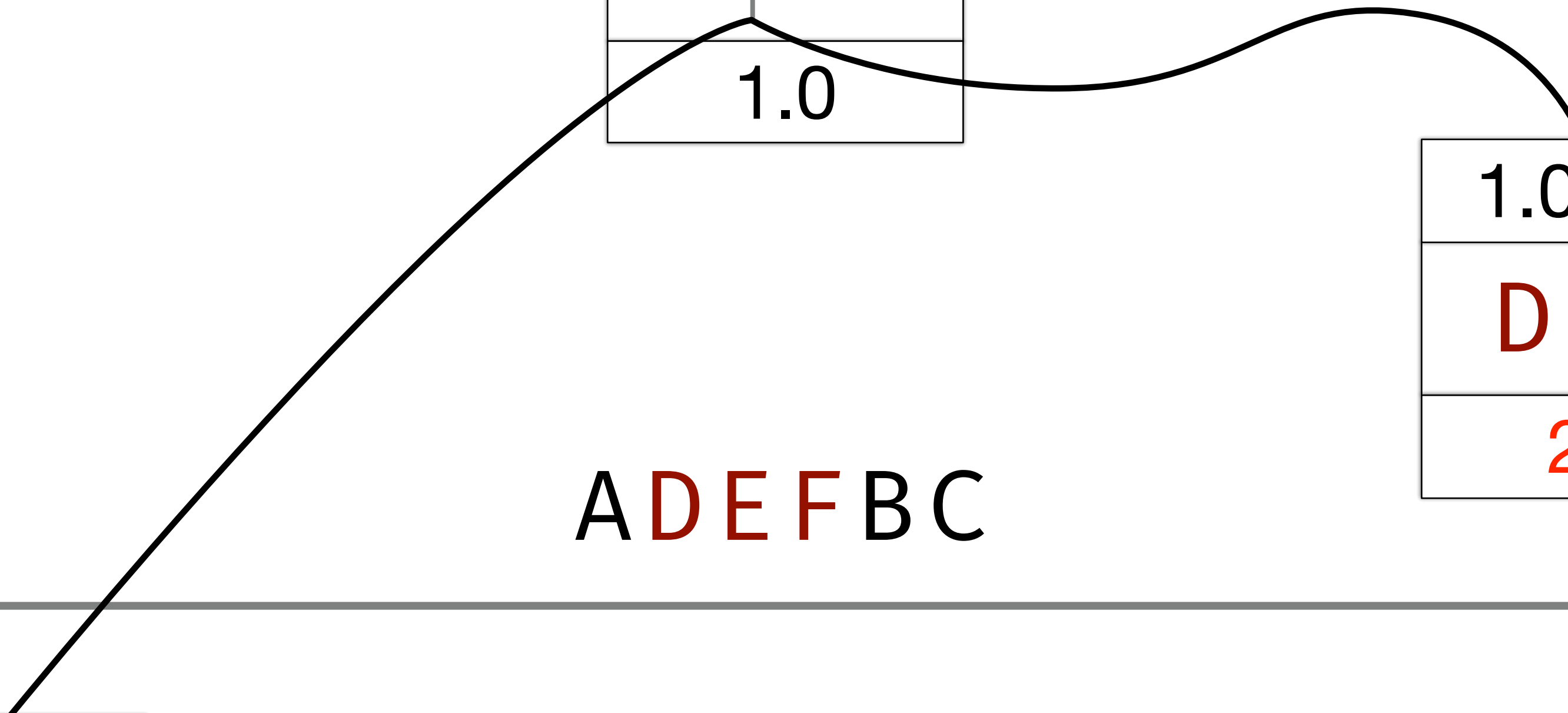
0.0 @ 0
A B C
1.0

1.0 @ 1
DEF
2.0

ADEFBC

1.0 @ 1
GHI
3.0

A|DEFGHIBC





0.0 @ 0
A B C
1.0

1.0 @ 1
D E F
2.0

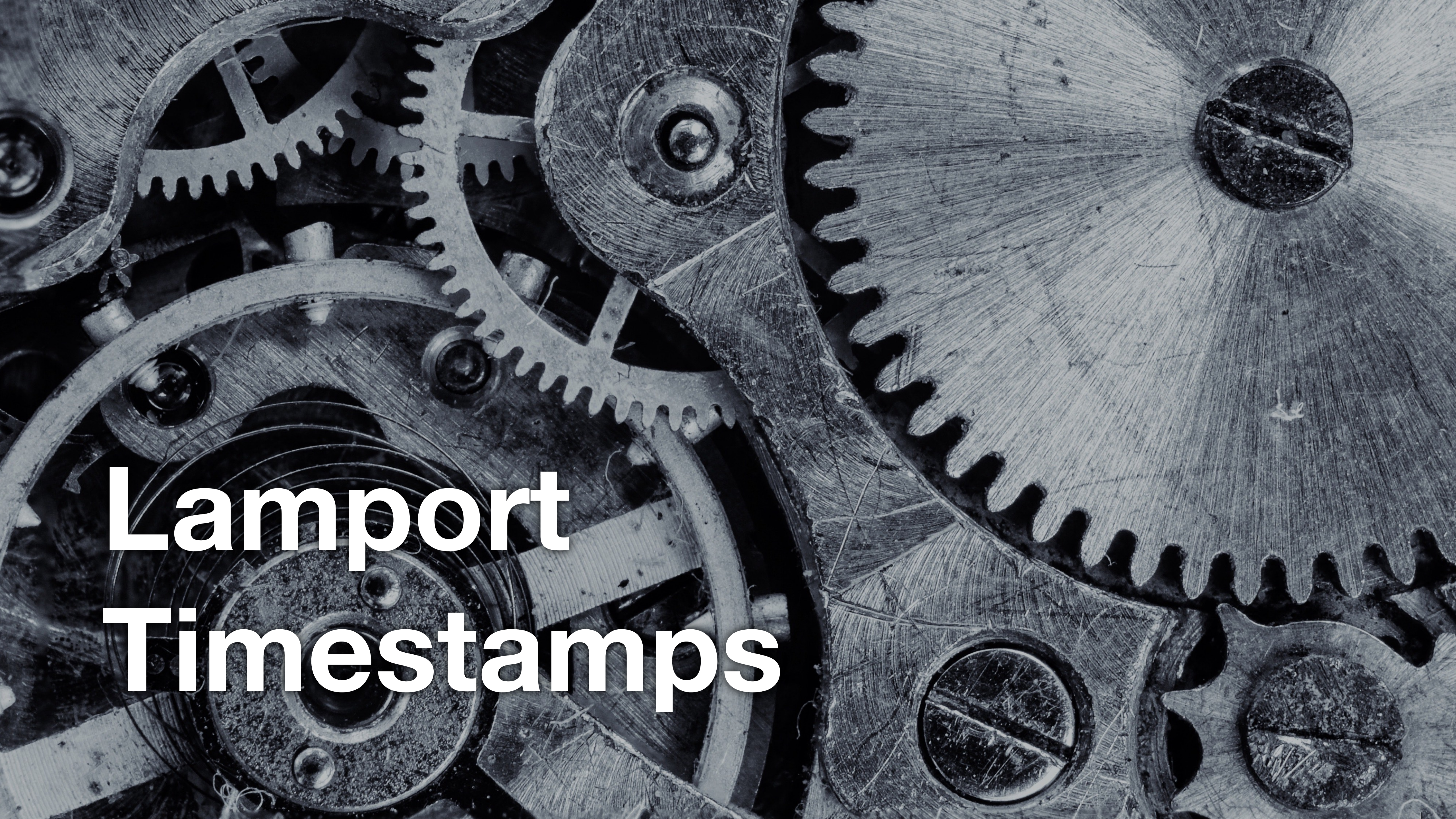
ADEFBC

2.0 @ 0
GHI
3.0

AGHIDEFBC

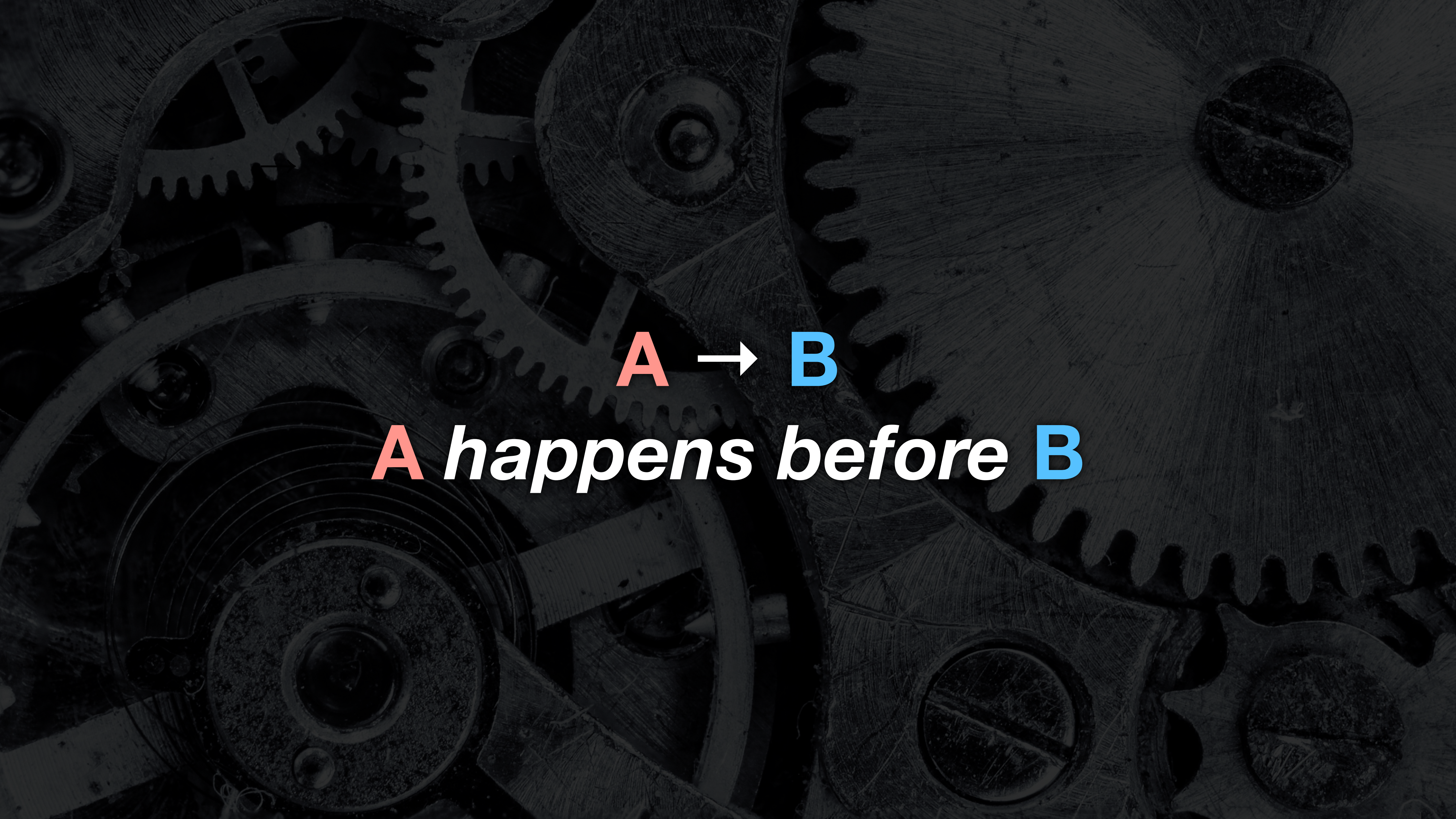






# Lamport Timestamps

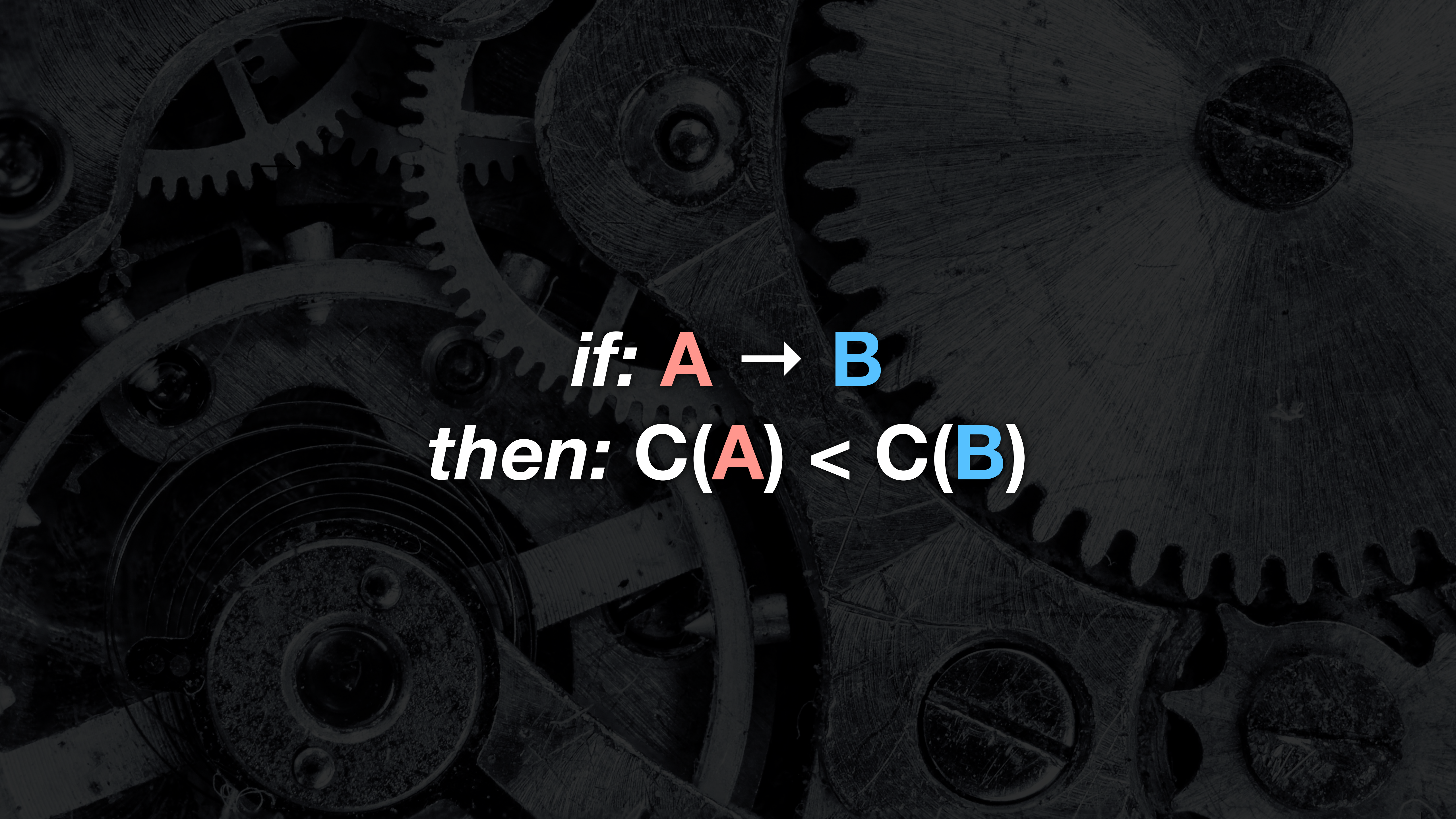




**A** → **B**

**A** *happens before* **B**





*if:* **A**  $\rightarrow$  **B**  
*then:* **C(A)**  $<$  **C(B)**



## Sending:

```
clock += 1;
```

```
let timestamp = clock;
```

```
send(message, clock);
```

## Receiving:

```
let (message, timestamp) = receive();
```

```
clock = max(clock, timestamp) + 1;
```



0.0 @ 0
A B C
1.0

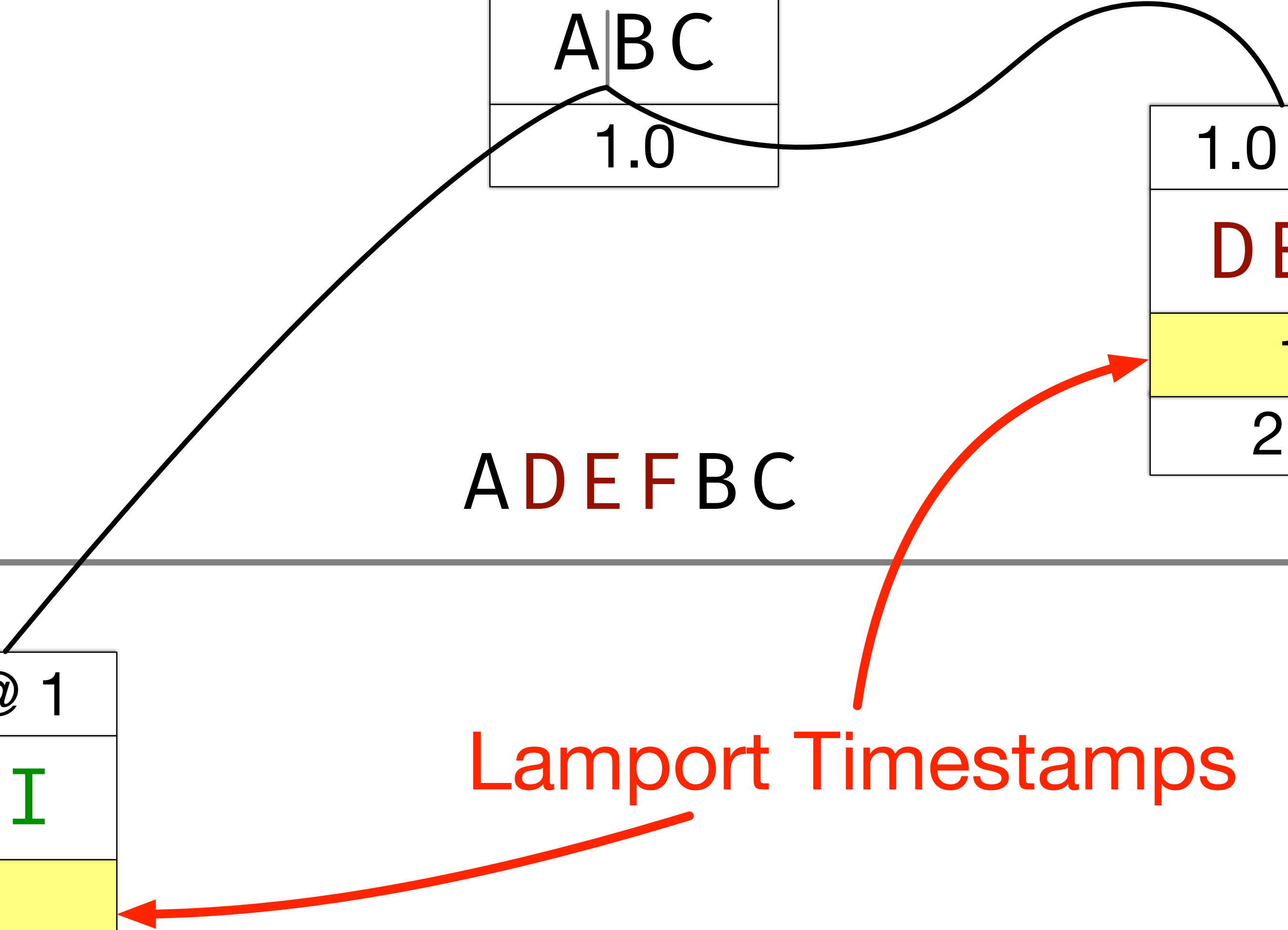
1.0 @ 1
DEF
1
2.0

ADEFBC

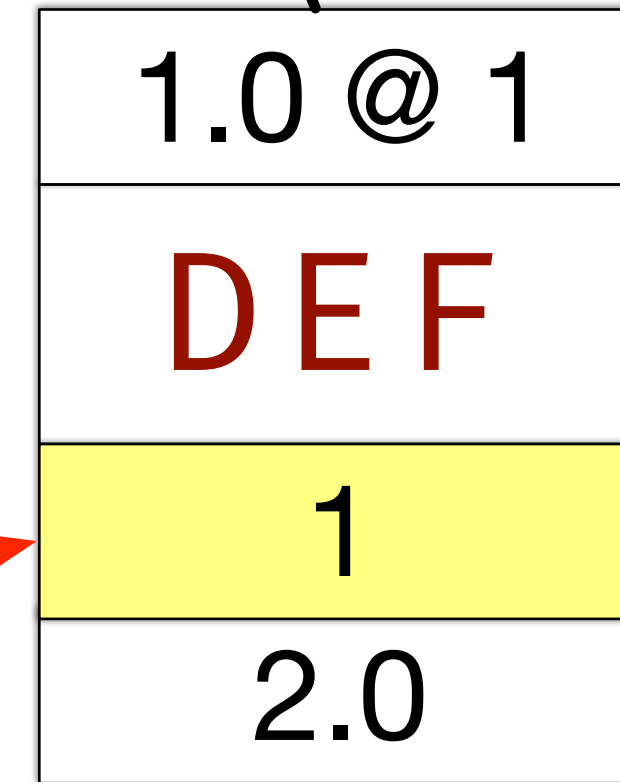
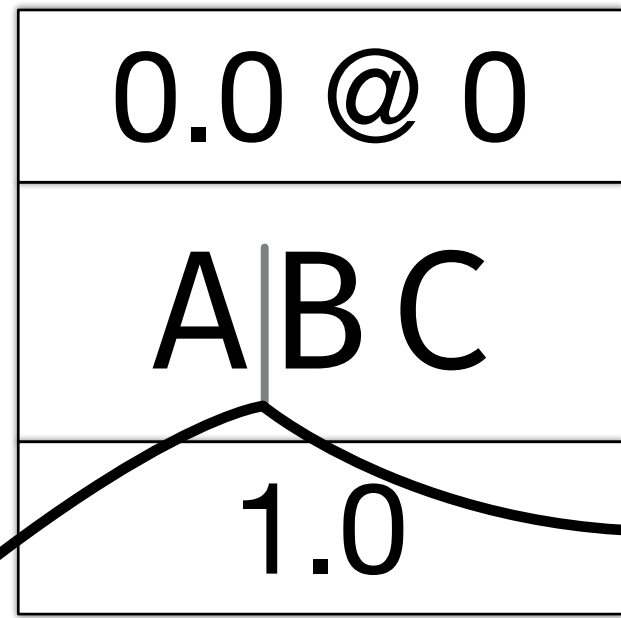
1.0 @ 1
GHI
2
3.0

A|DEFBC

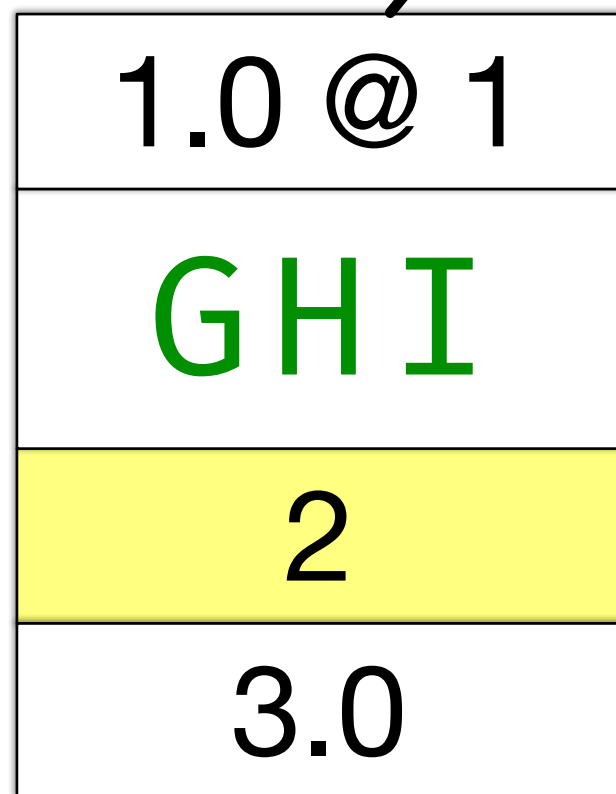
Lamport Timestamps





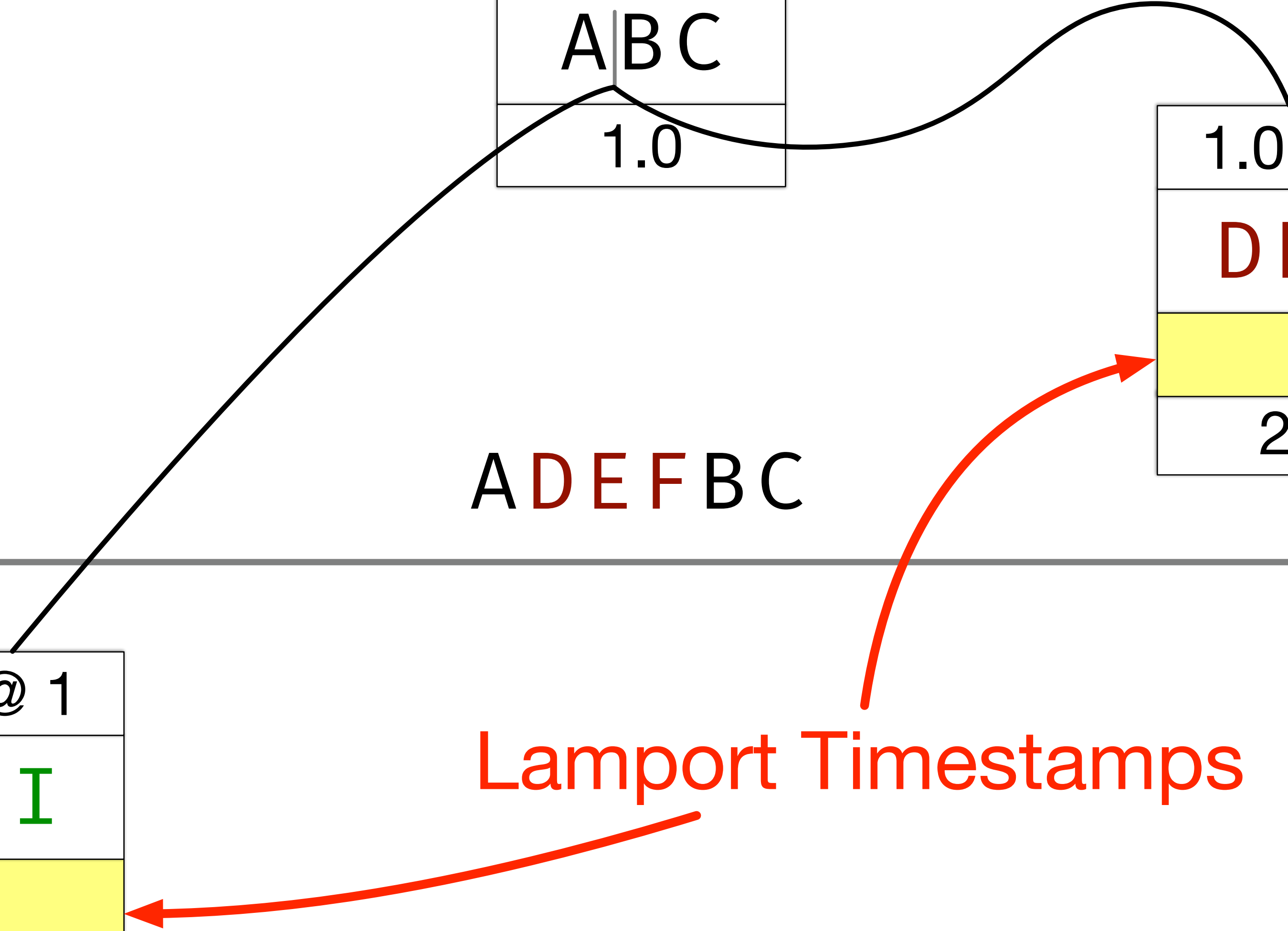


ADEFBC



AGHIDEFBC

Lamport Timestamps







**Deletions**



1.0 @ 0	2.0 @ 0	3.0 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1
A	DEFG	JKLM	HI	MNO	BC



1.0 @ 0	2.0 @ 0	3.0 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1
A	D E F G	J K L	H I	M N O	B C



1.0 @ 0	2.0 @ 0	3.0 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1
A	D E F G	J K L	H I	M N O	B C

2.0 @ 1  
start

1.0 @ 2  
end



1.0 @ 0	2.0 @ 0	3.0 @ 0	1.2 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1
A	DEFG	JKLM	PQRS	HI	MNO	BC

2.0 @ 1  
start

1.0 @ 2  
end



1.0 @ 0	2.0 @ 0	3.0 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1	
A	D	EFG	JKL	HI	MNO	BC

{ 1: 1, 2: 0, 3: 0 }

max sequence numbers in range



1.0 @ 0	2.0 @ 0	3.0 @ 0	1.2 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1	
A	D	EFG	JKL	PQRS	HI	MNO	BC



{ 1: 1, 2: 0, 3: 0 }

max sequence numbers in range



# Deleted fragments are *“tombstoned”*

1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 4	1.1 @ 0	1.0 @ 1	1.0 @ 2
A	D	EFG	JKL	PQRS	HI	MNO	B	C



2.1



2.1



2.1



2.1



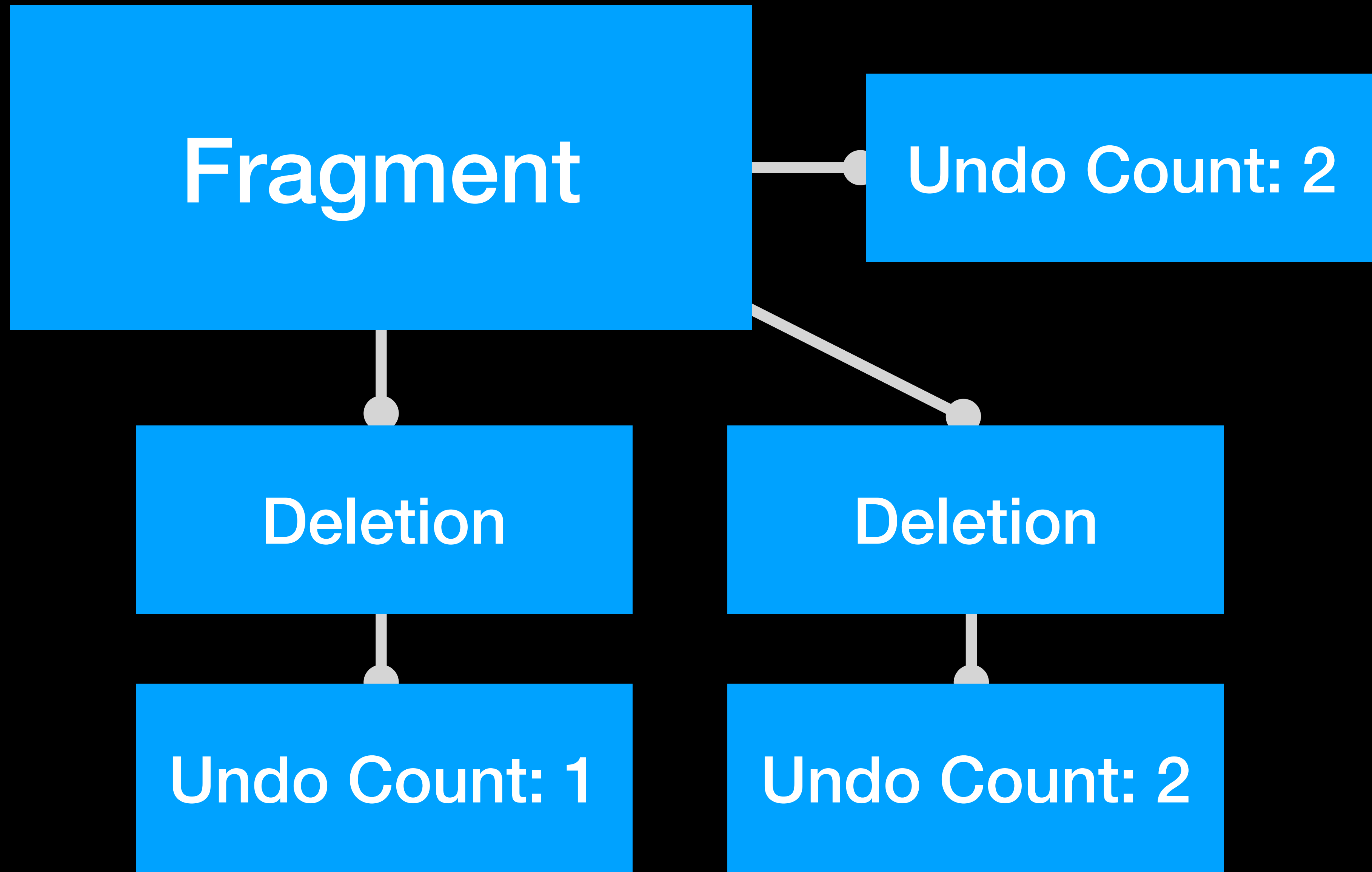
2.1



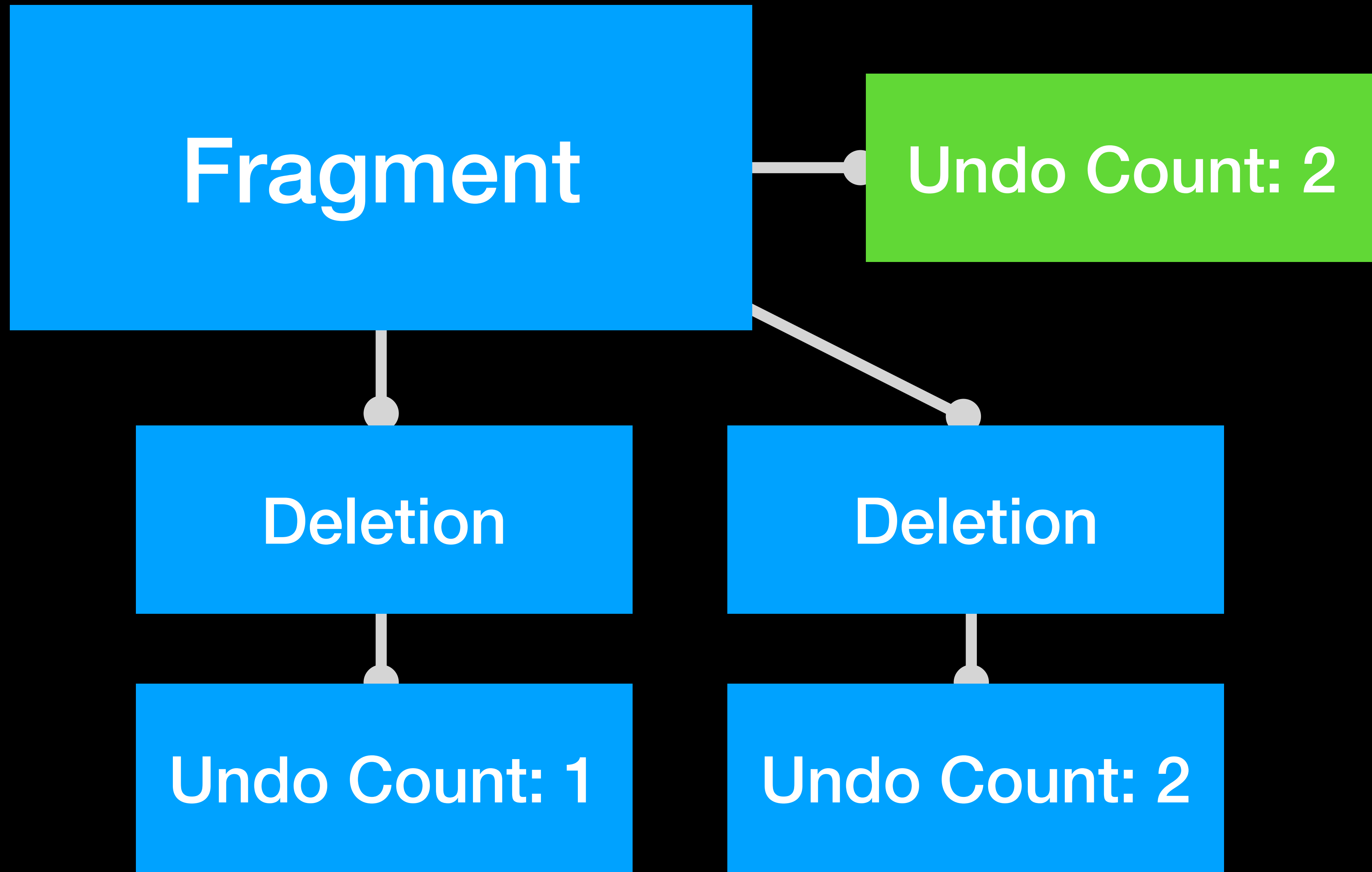
# Undo and Redo



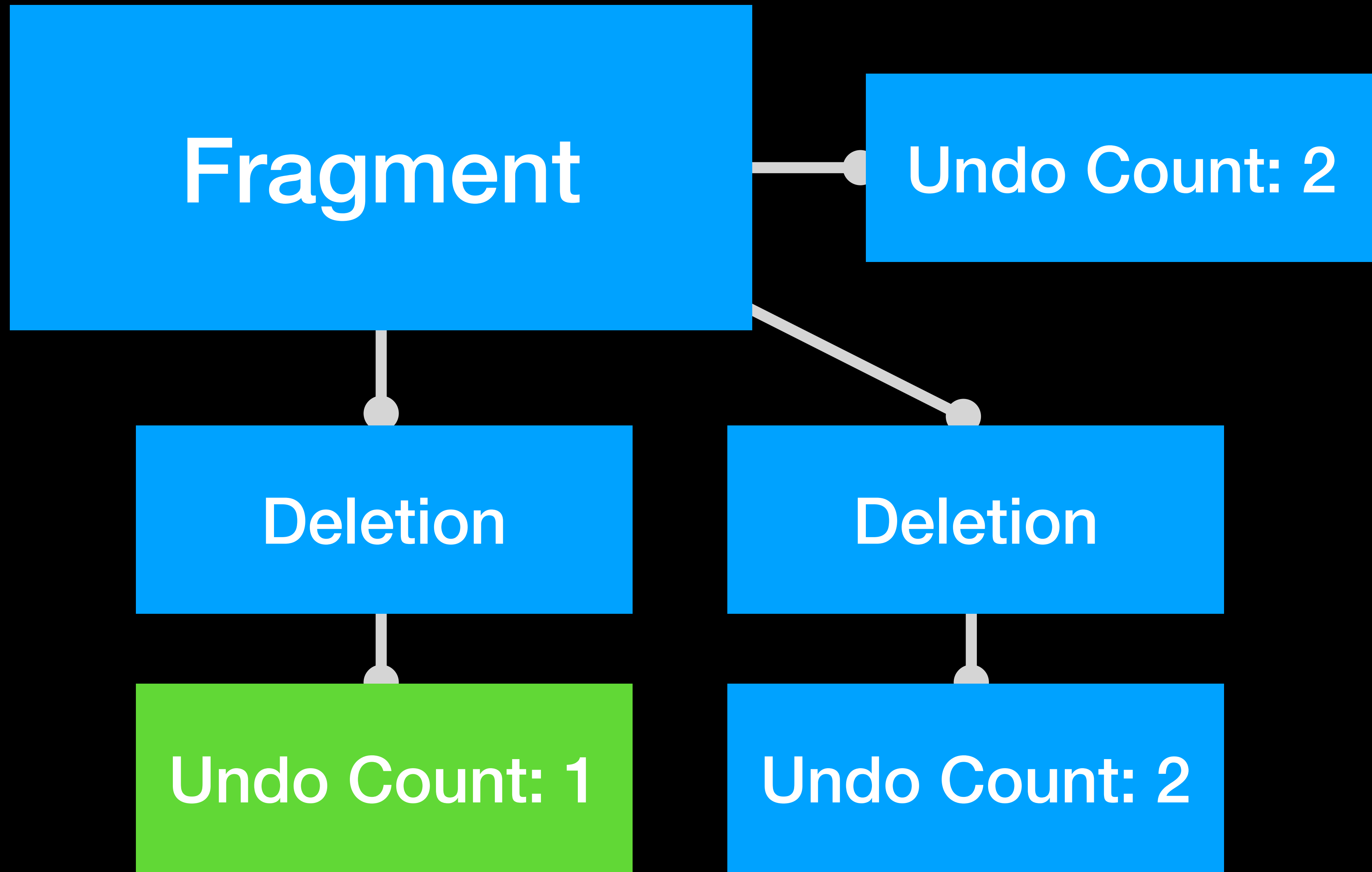




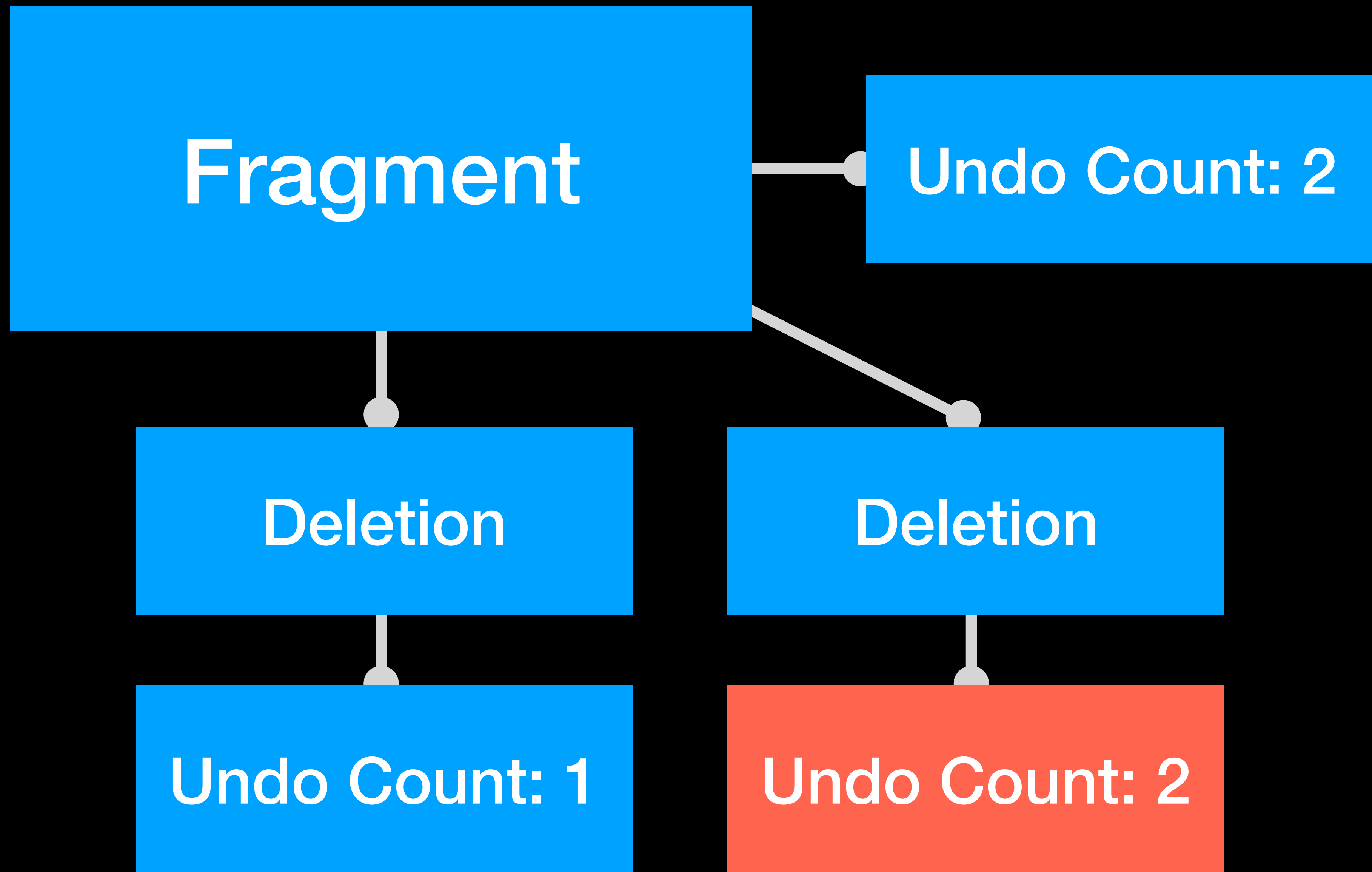




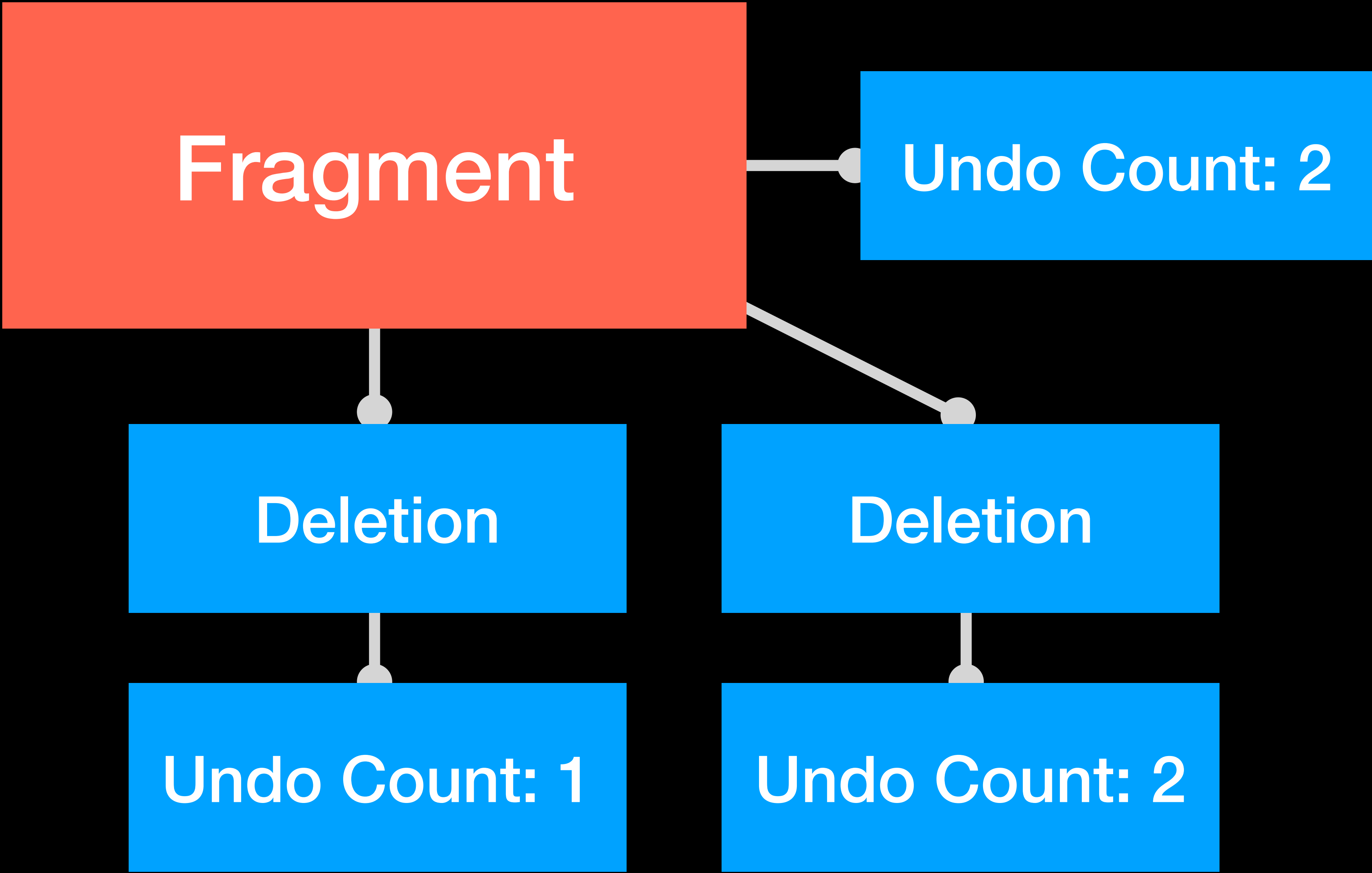














The background is an abstract, textured composition. It features a large, irregular shape on the right side, filled with a mix of purple, red, and brown tones, suggesting a marbled or layered effect. The rest of the background is a lighter, warm palette of beige, tan, and light brown, with a fine, grainy texture. The overall appearance is that of a high-quality, artistic background.

# Efficiently Locating Fragments



2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

Insert "X" at 12



0

2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

Insert "X" at 12



2  
↓

2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

Insert "X" at 12



2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

2

Insert "X" at 12



2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

4

Insert "X" at 12



2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

7  
↓

Insert "X" at 12



2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

11  
↓

Insert "X" at 12



2	0	2	3	4	2	3	0	1
AB	D	EF	JKL	PQRS	GH	MNO	I	C
1.0 @ 0	2.0 @ 0	2.0 @ 1	3.0 @ 0	1.2 @ 0	2.0 @ 3	1.1 @ 0	2.0 @ 5	1.0 @ 2

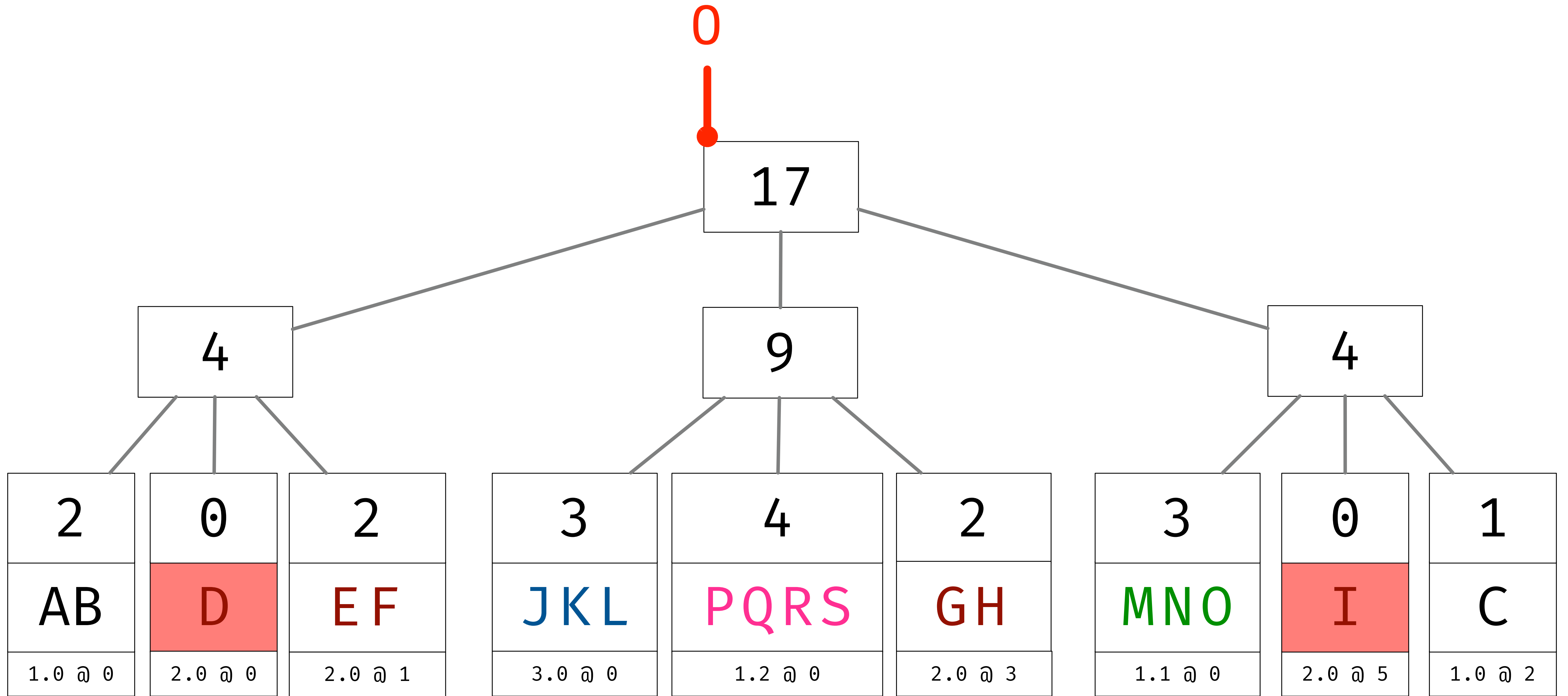
11



*Local:* Insert "X" at 12

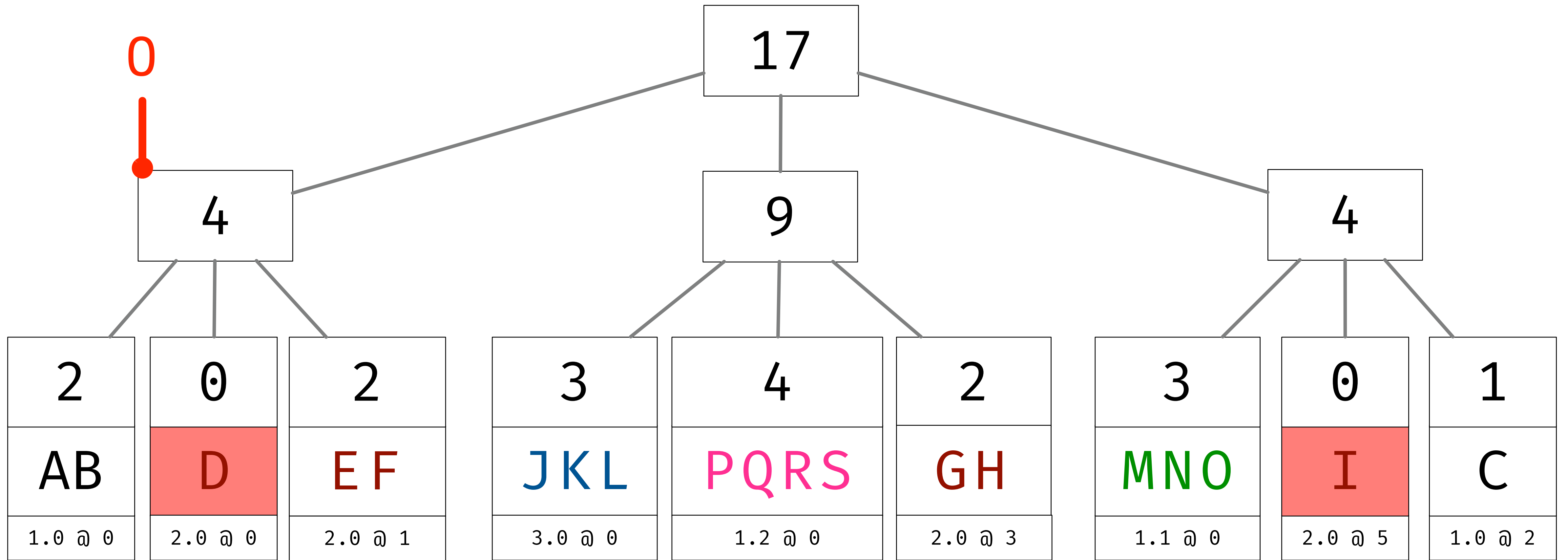
*Remote:* Insert "X" at 2.0 @ 4





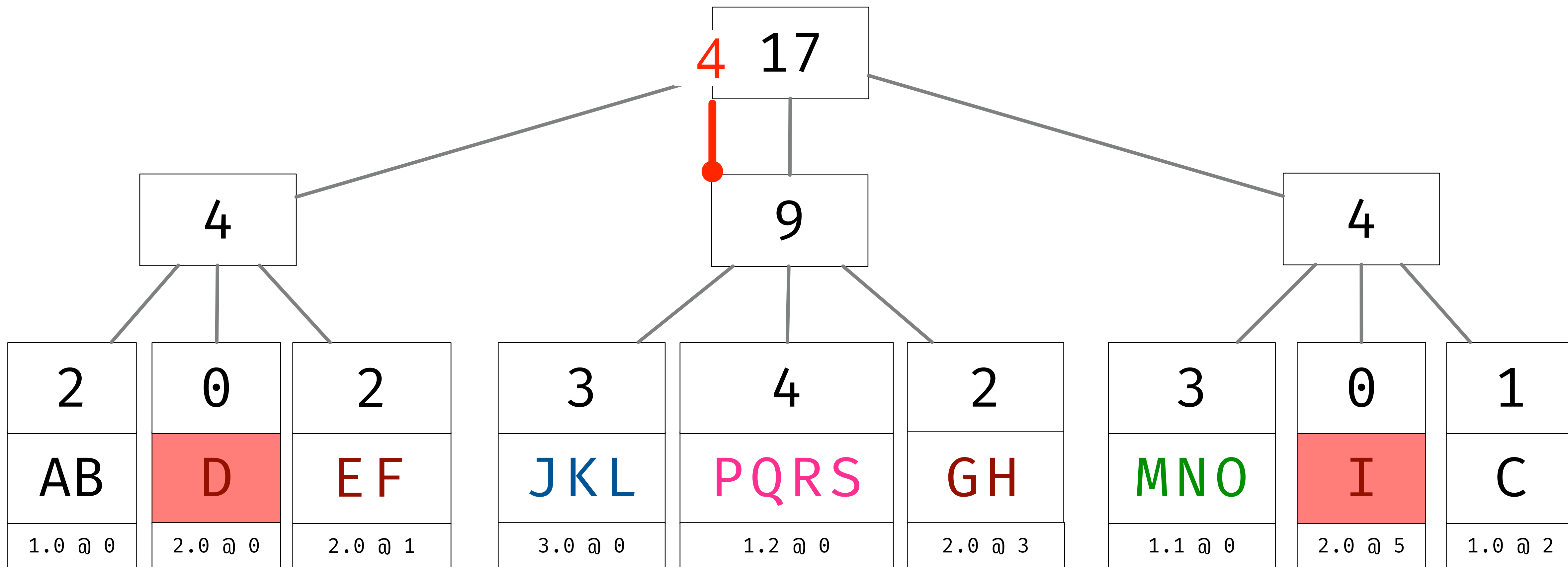
Insert "X" at 12





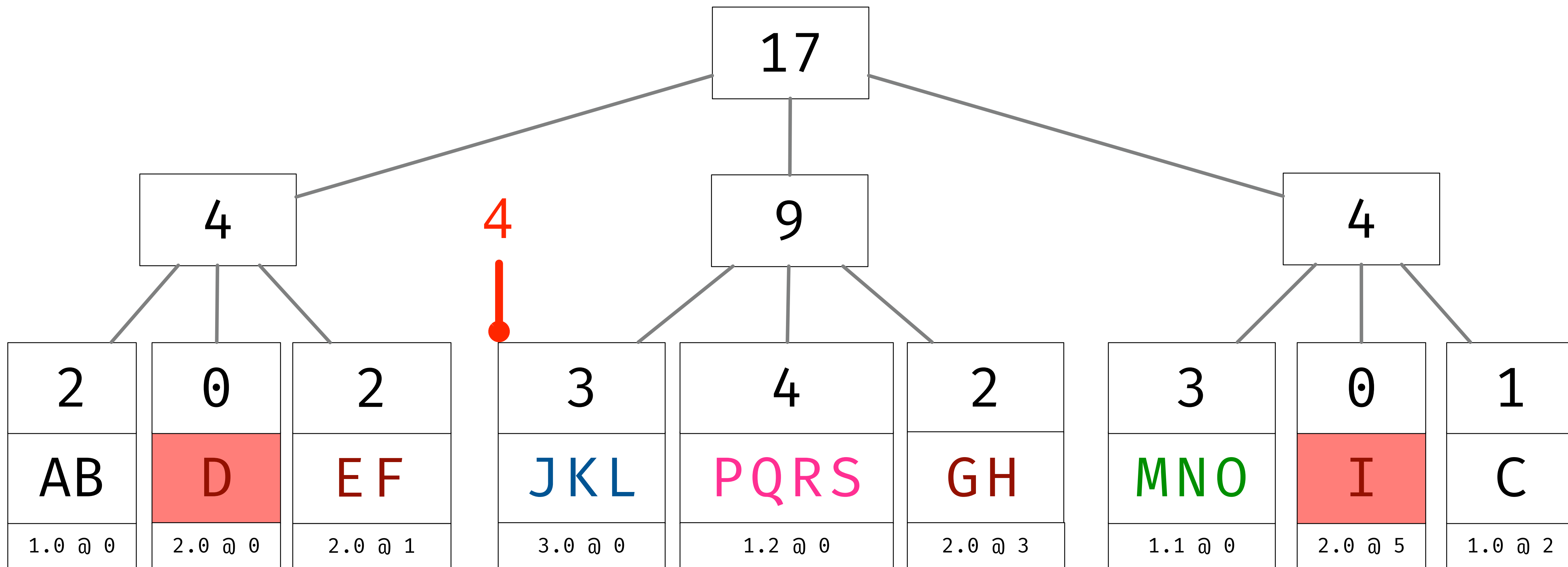
Insert "X" at 12





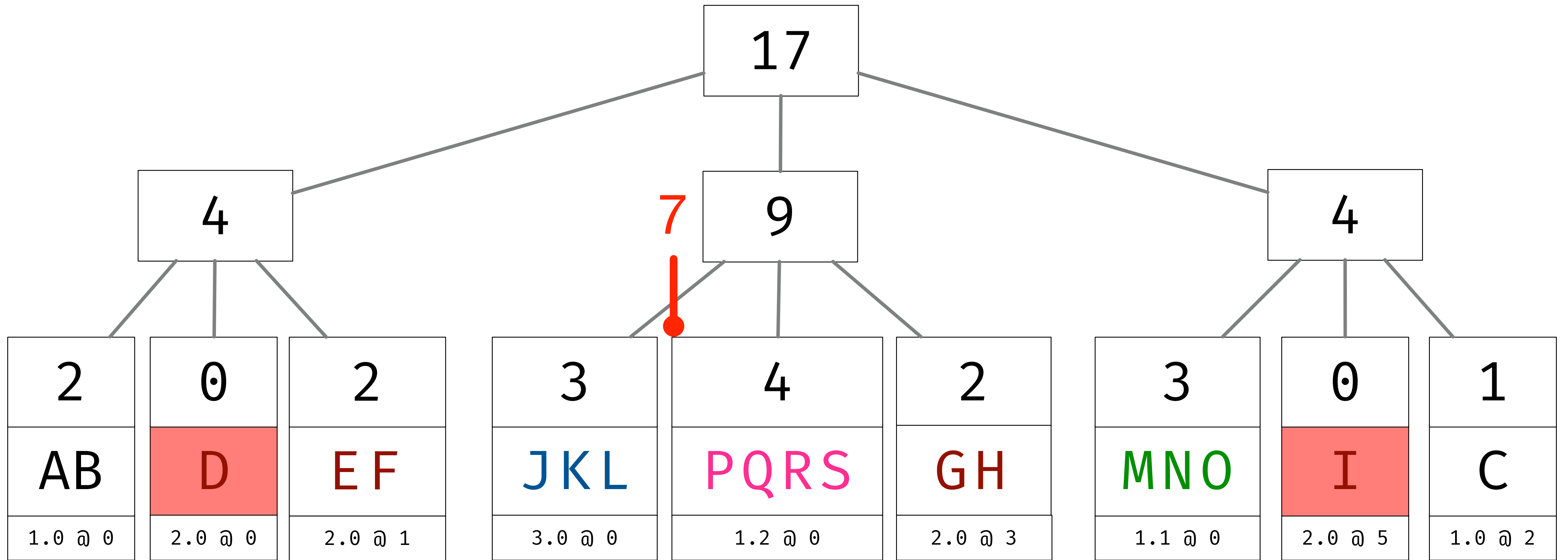
Insert "X" at 12





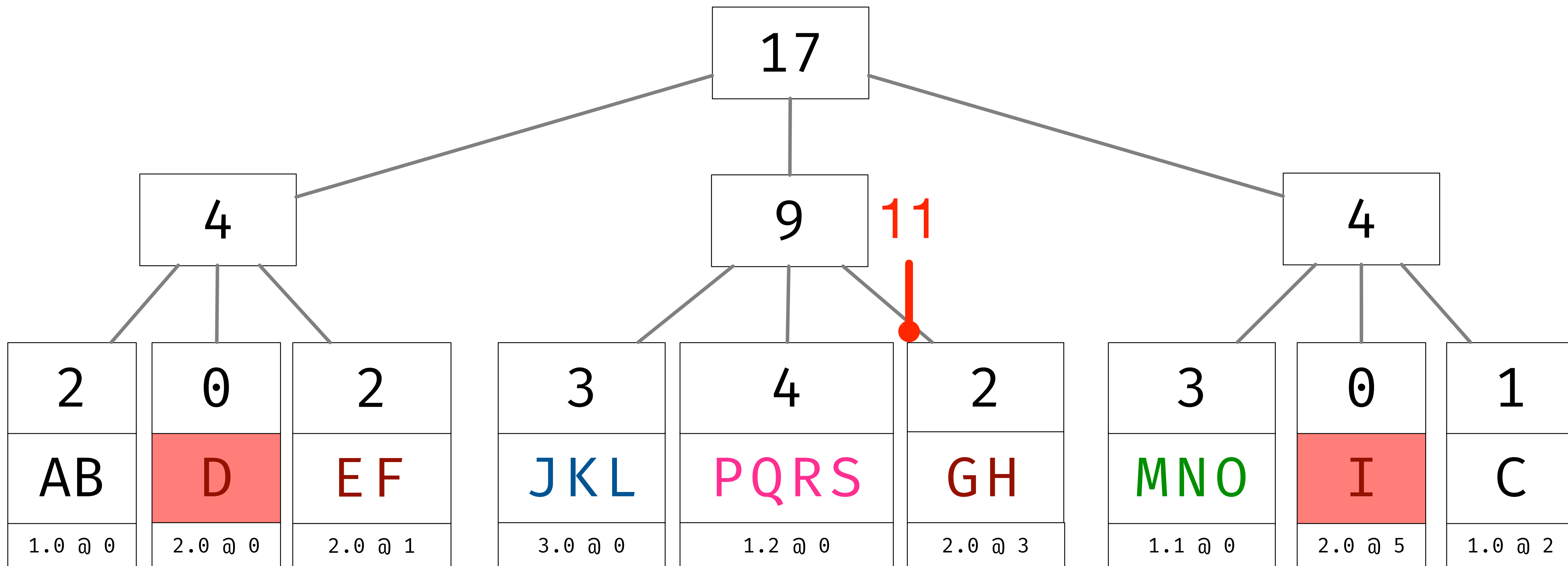
Insert "X" at 12





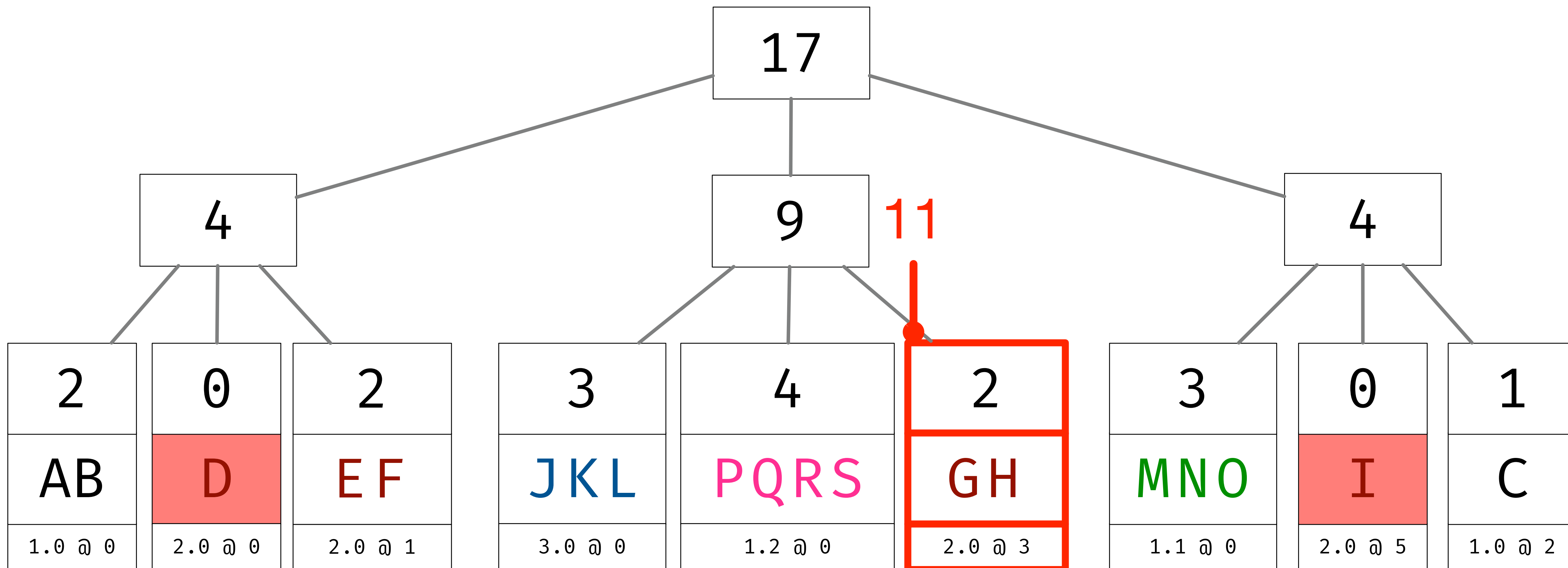
Insert "X" at 12





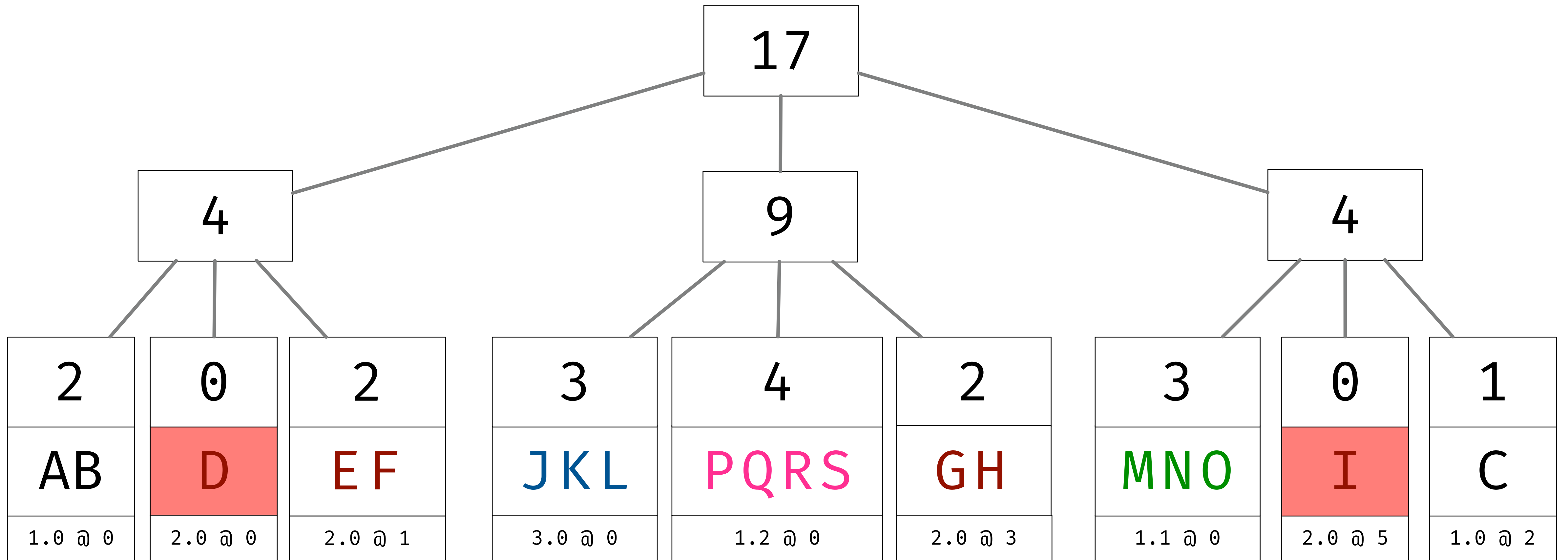
Insert "X" at 12





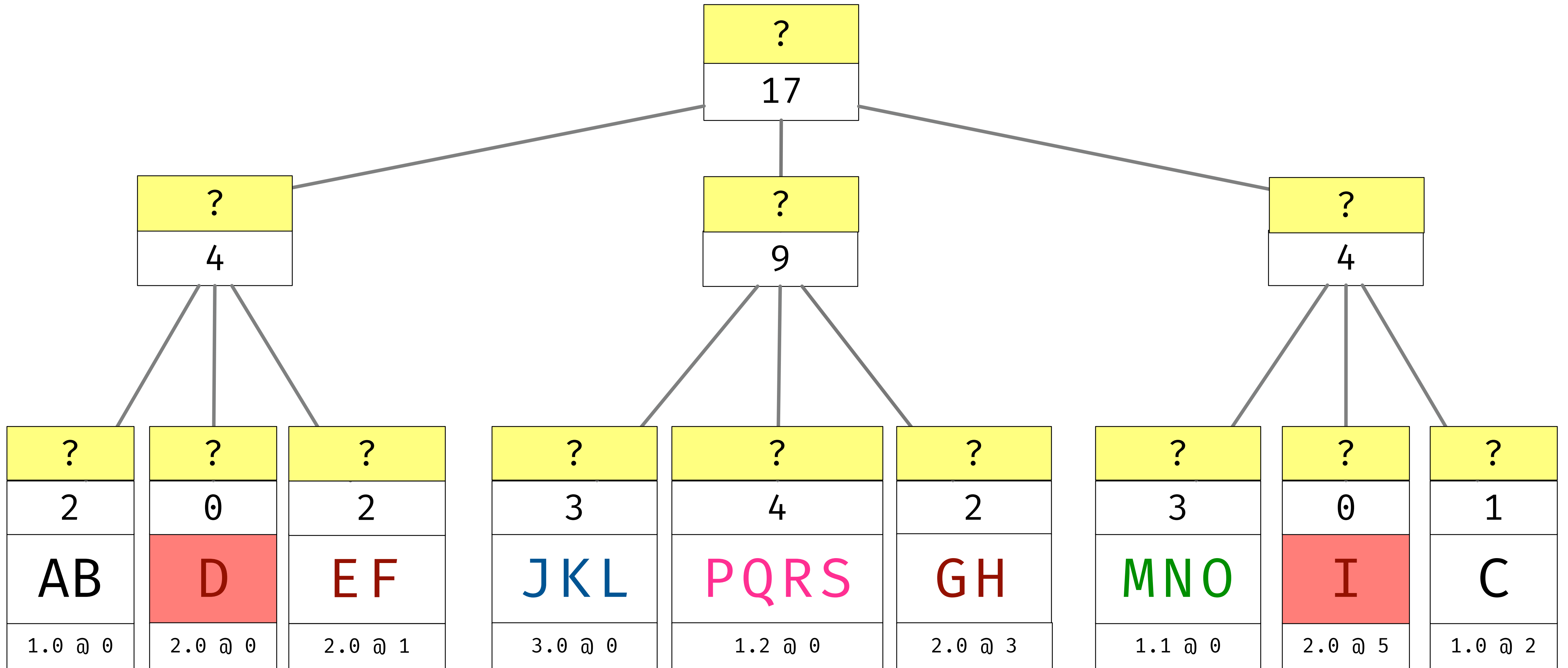
Insert "X" at 2.0 @ 4





Insert "X" at 2.0 @ 4





Insert "X" at 2.0 @ 4



# Fragment Identifiers

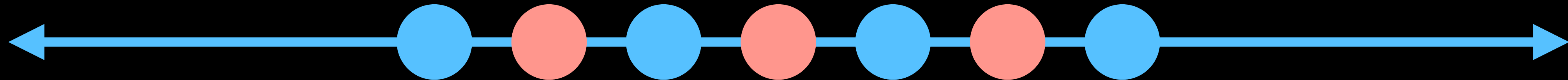
Totally-Ordered





# Fragment Identifiers

Totally-Ordered



Dense



# Integers?

1 < 2 ✓

1 < ? < 2 ✗



# Floats?

$$1.1 < 1.2$$



$$10^{-308} < ? < 2 \times 10^{-308}$$





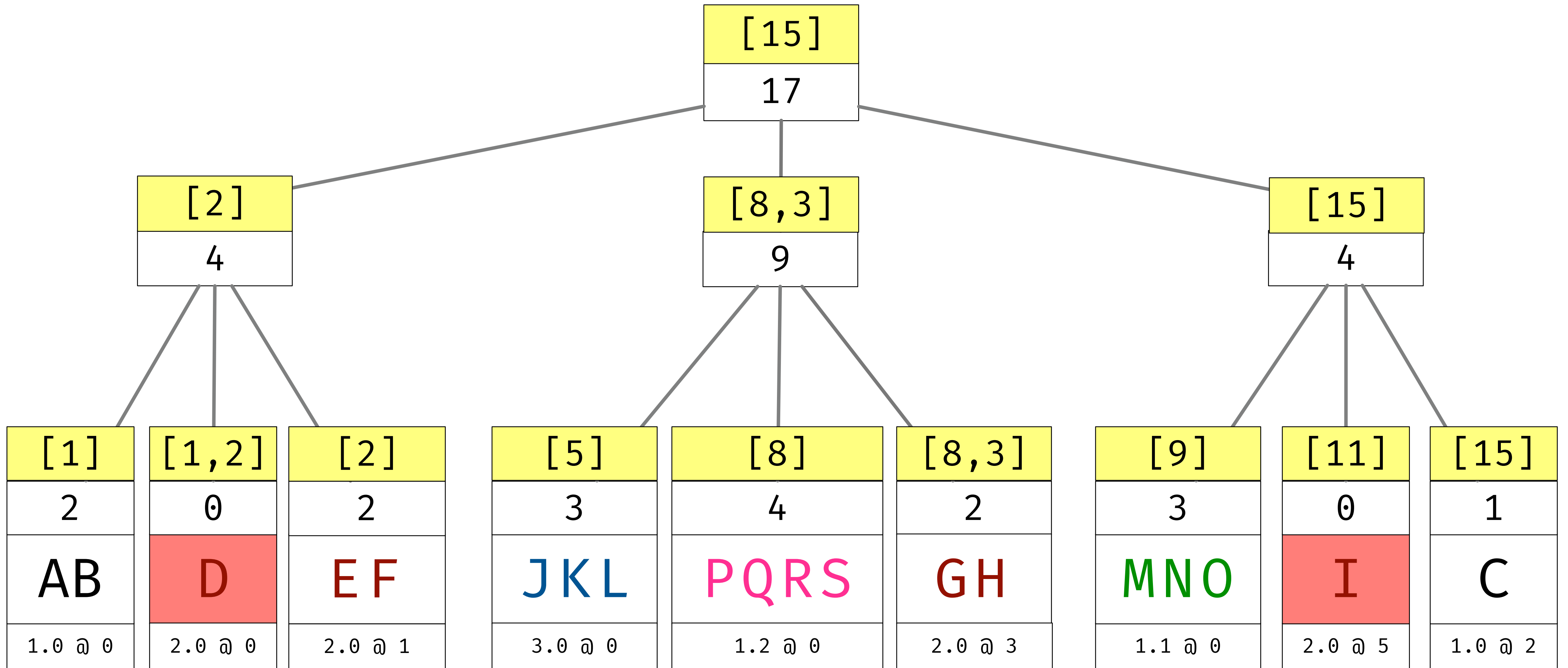
# Strings

$A < B$



$A < AB < B$





Insert "X" at 2.0 @ 4



DEFGHI

2.0 @ 0

<b>DEFGHI</b>
2.0 @ 0

<b>DEFGH</b>	<b>I</b>
2.0 @ 0	2.0 @ 5



<b>DEFGHI</b>
2.0 @ 0

<b>DEFGH</b>	<b>I</b>
2.0 @ 0	2.0 @ 5

<b>D</b>	<b>EFGH</b>	<b>I</b>
2.0 @ 0	2.0 @ 1	2.0 @ 5

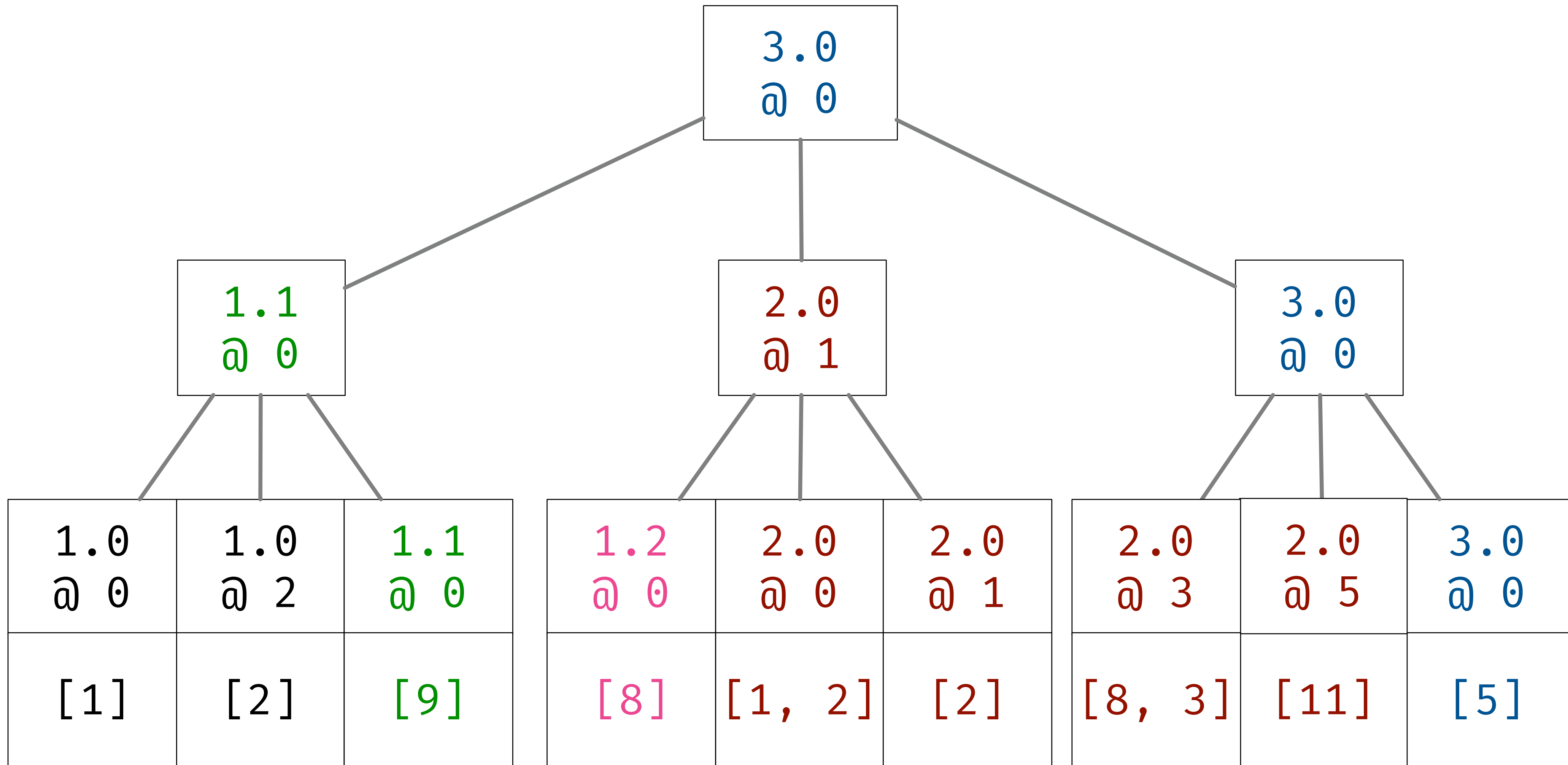
<b>DEFGHI</b>
2.0 @ 0

<b>DEFGH</b>	<b>I</b>
2.0 @ 0	2.0 @ 5

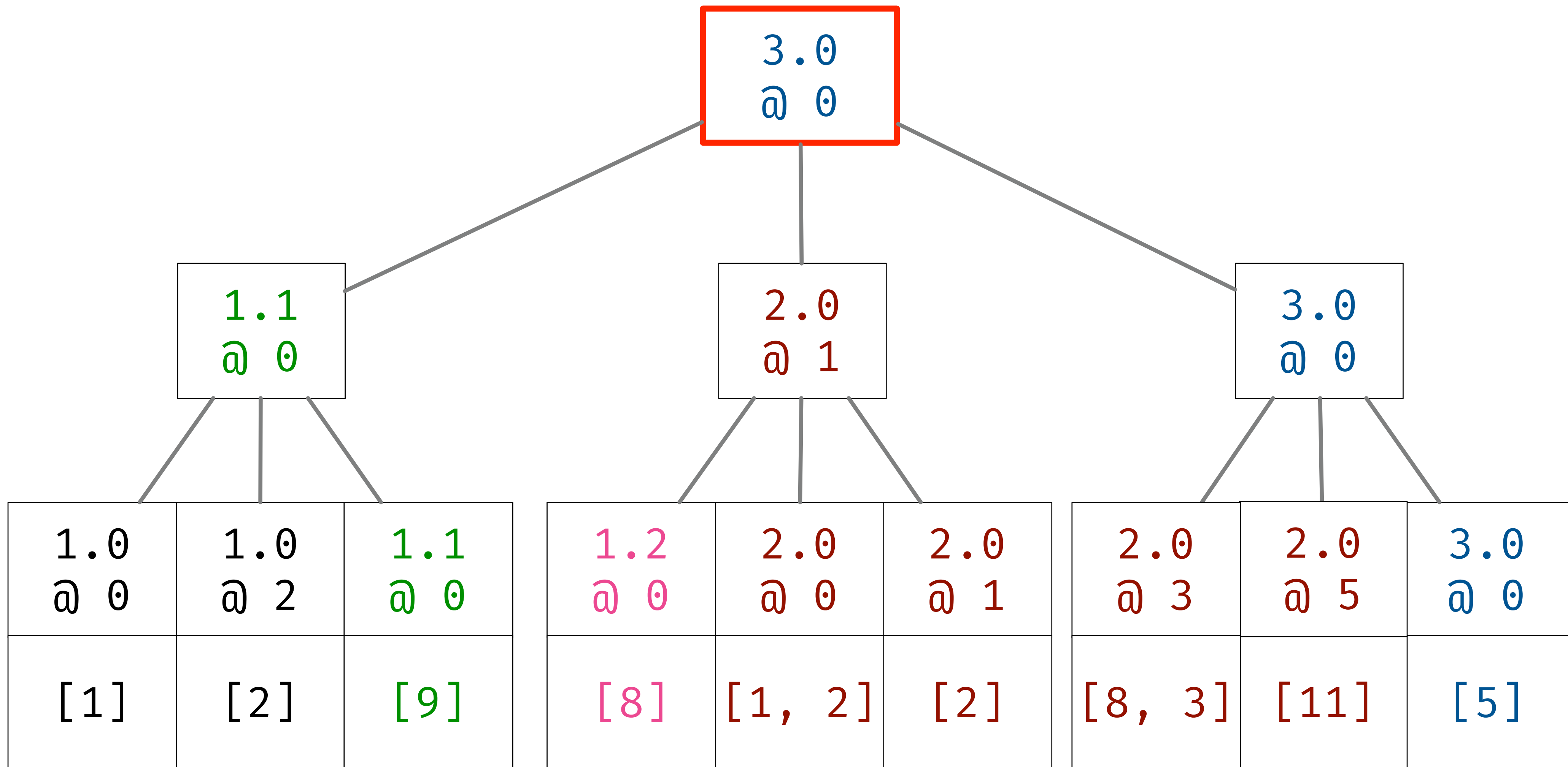
<b>D</b>	<b>EFGH</b>	<b>I</b>
2.0 @ 0	2.0 @ 1	2.0 @ 5

<b>D</b>	<b>EF</b>	<b>GH</b>	<b>I</b>
2.0 @ 0	2.0 @ 1	2.0 @ 3	2.0 @ 5



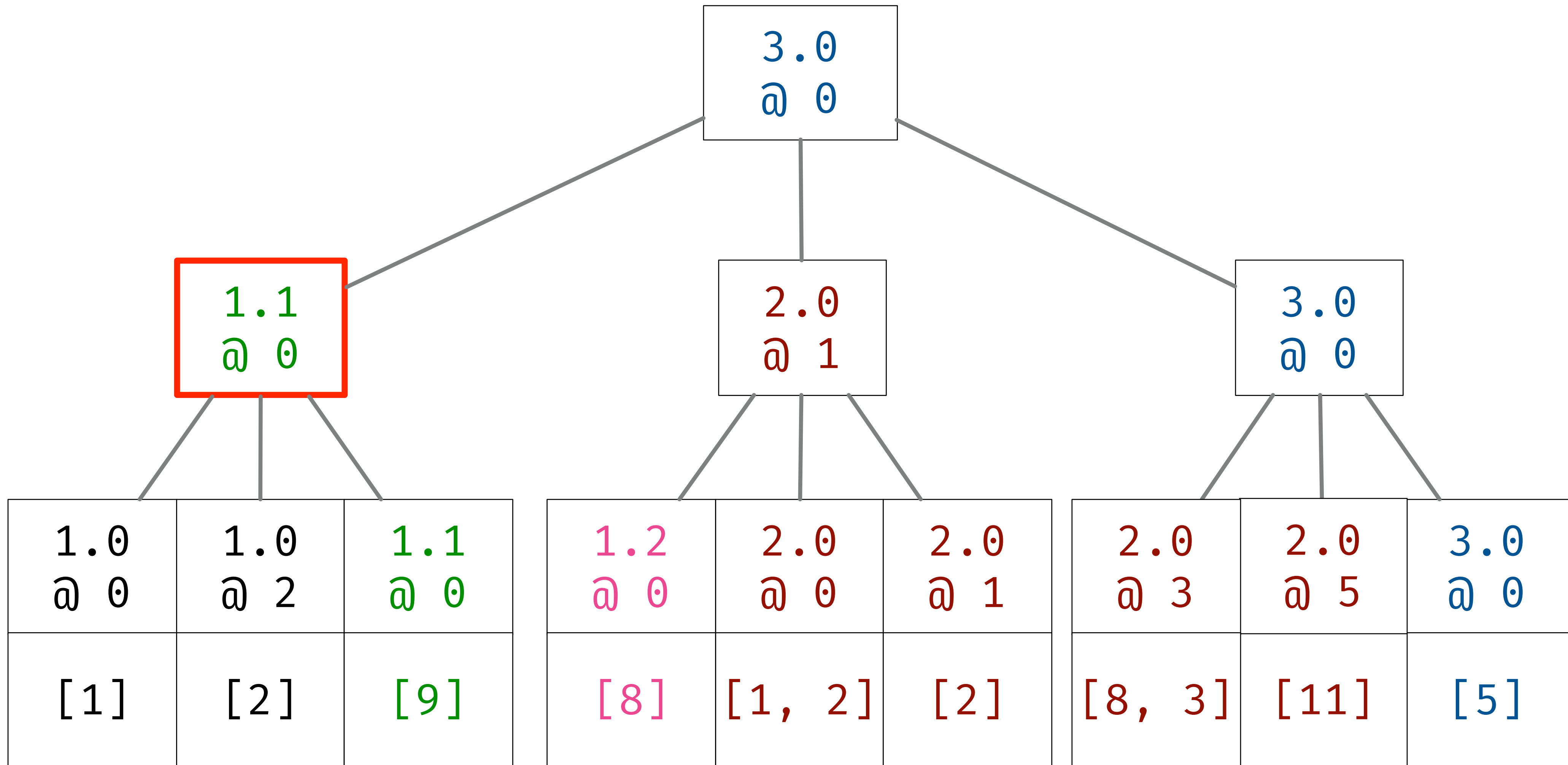


Insertion Split Tree

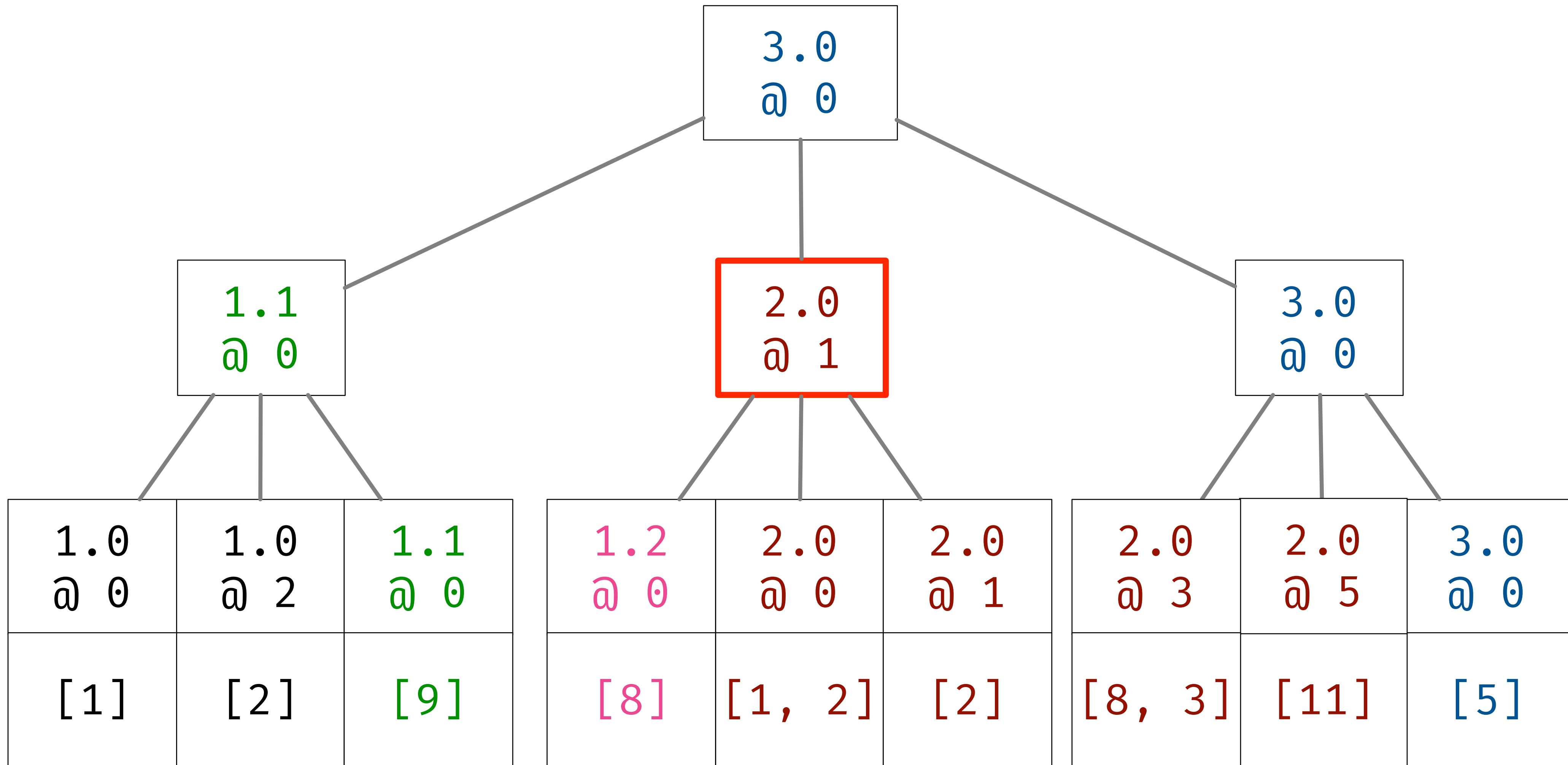


Insert "X" at 2.0 @ 4



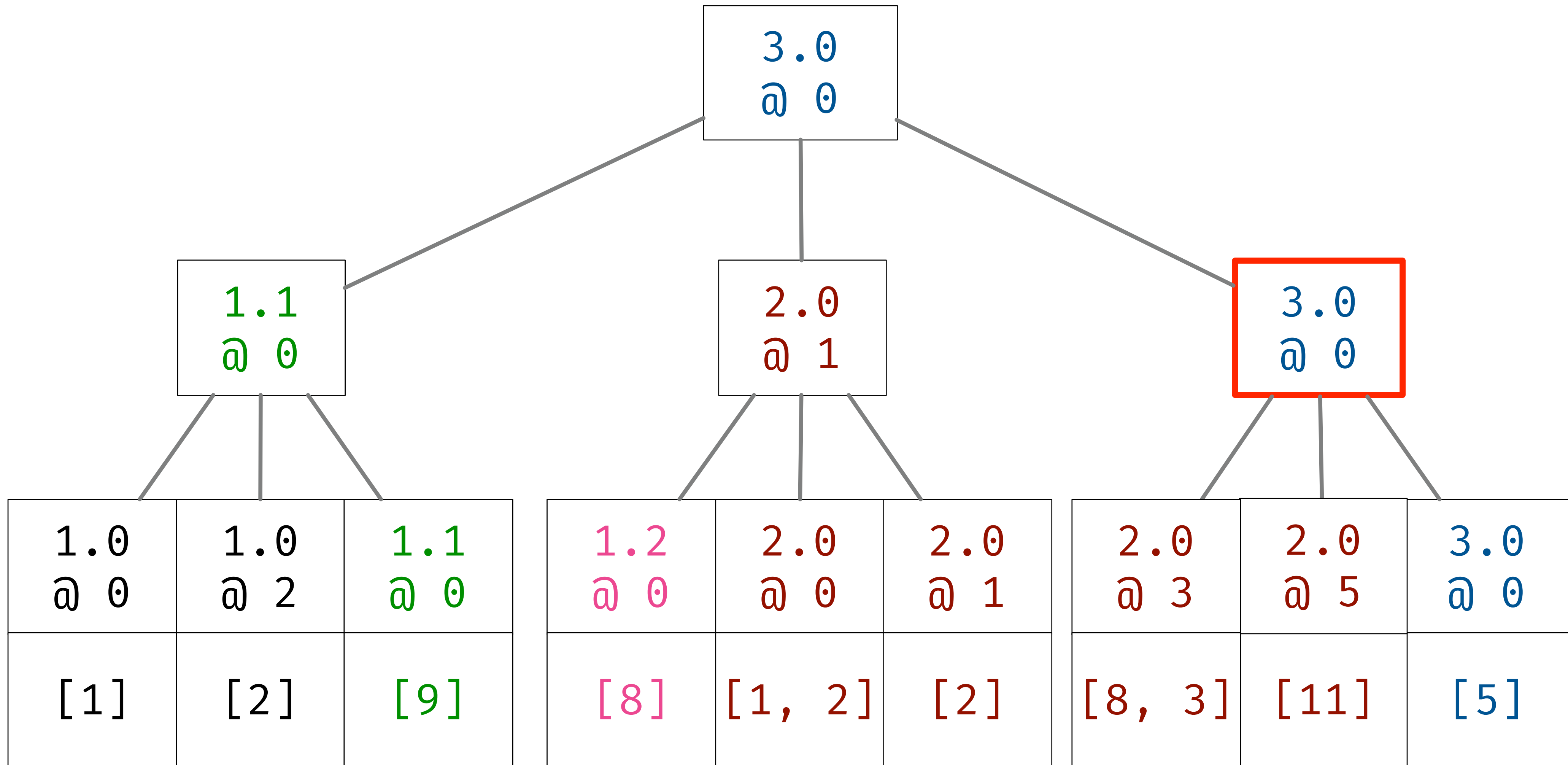


Insert "X" at 2.0 @ 4

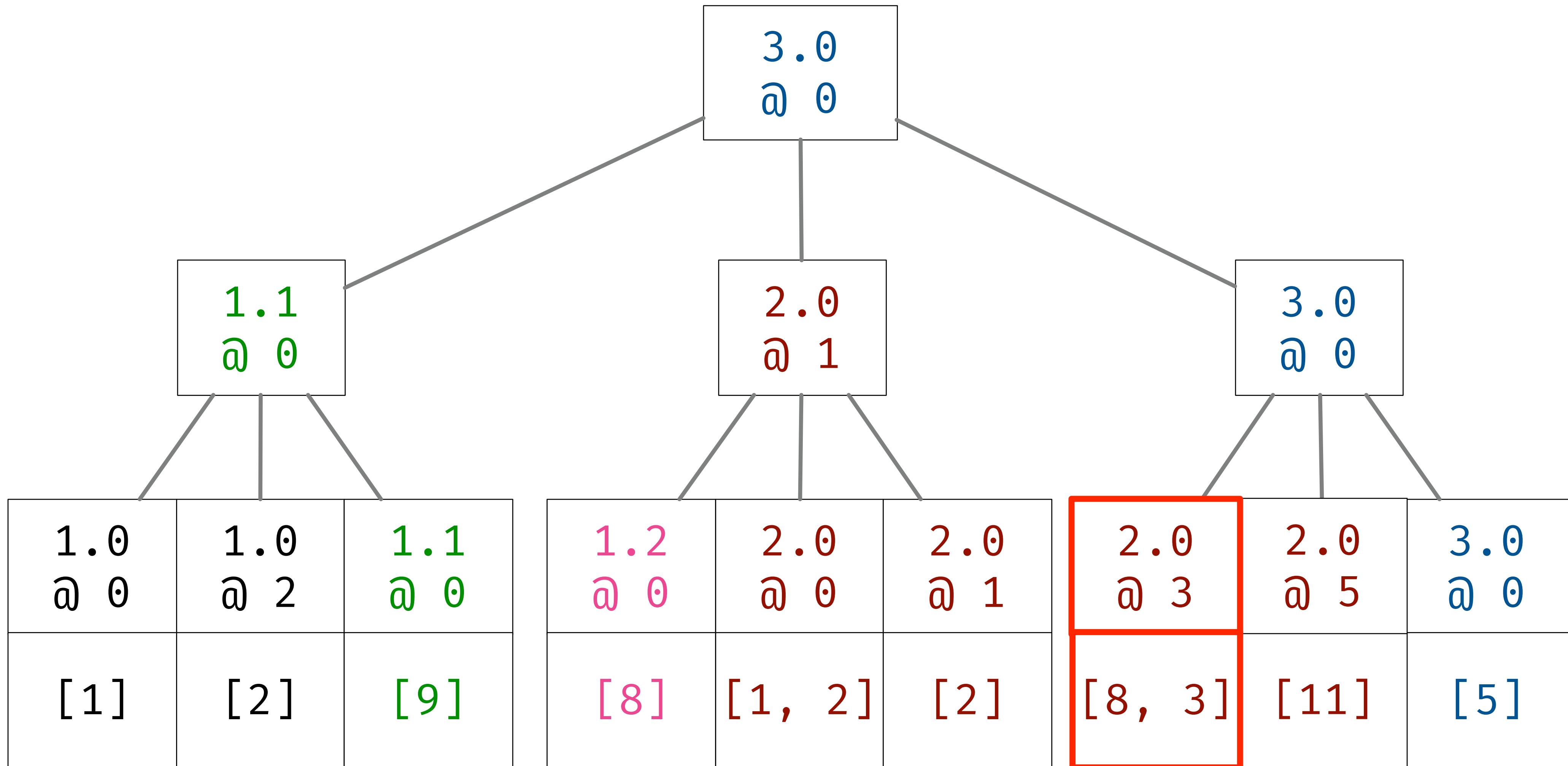


Insert "X" at 2.0 @ 4



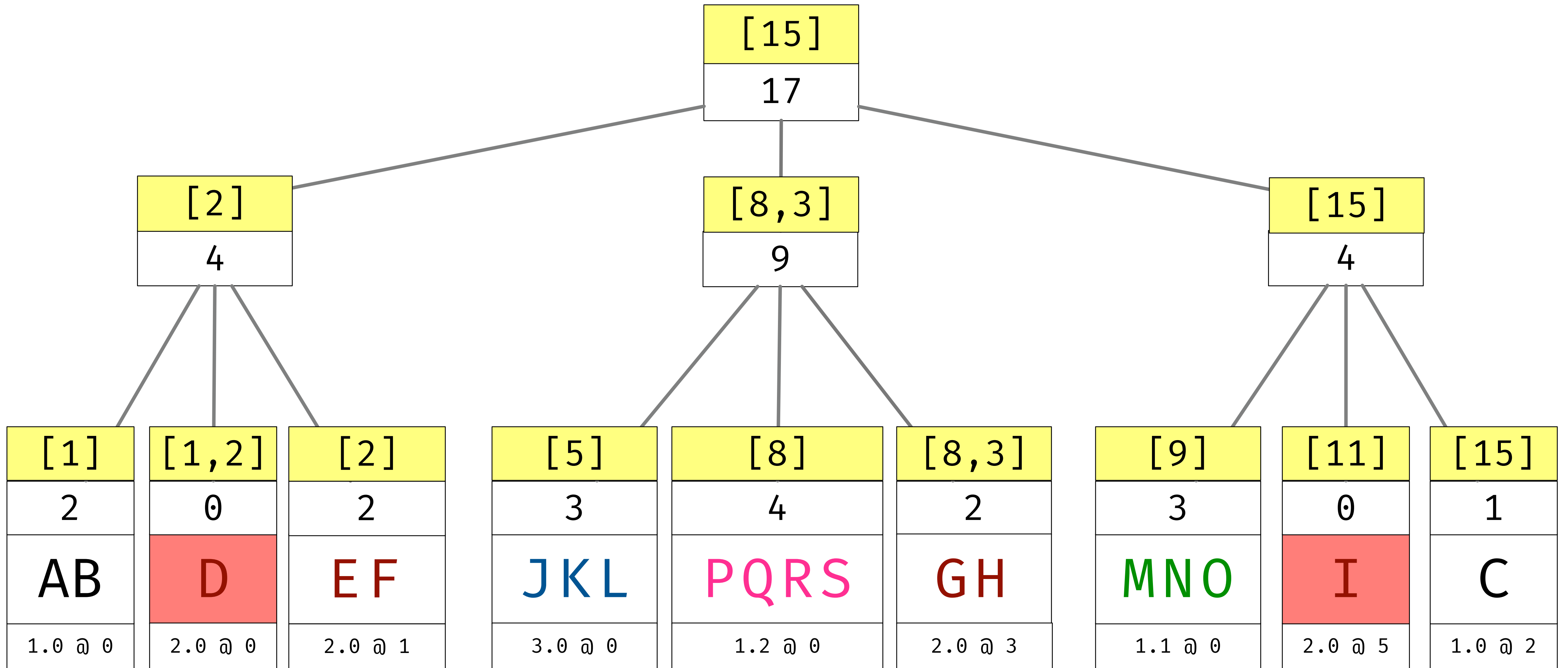


Insert "X" at 2.0 @ 4

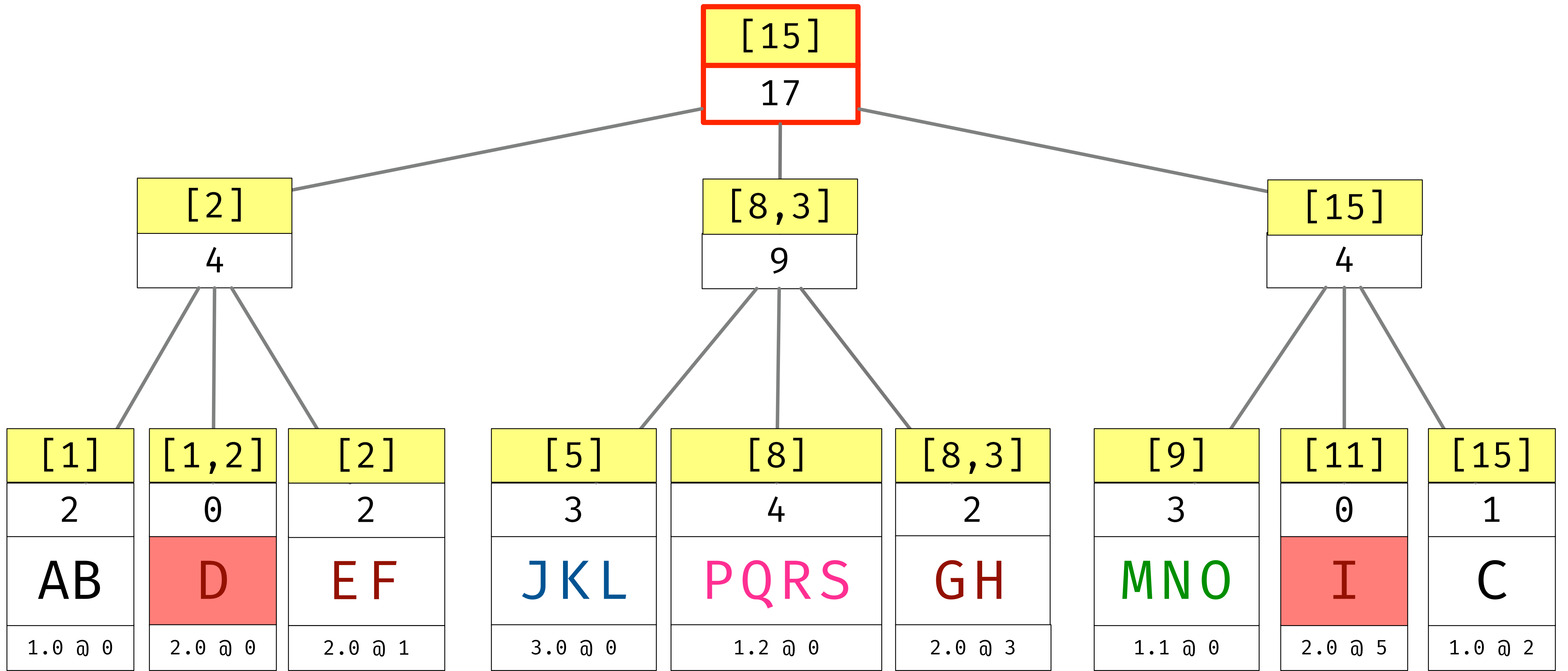


Insert "X" at [8, 3] @ 1



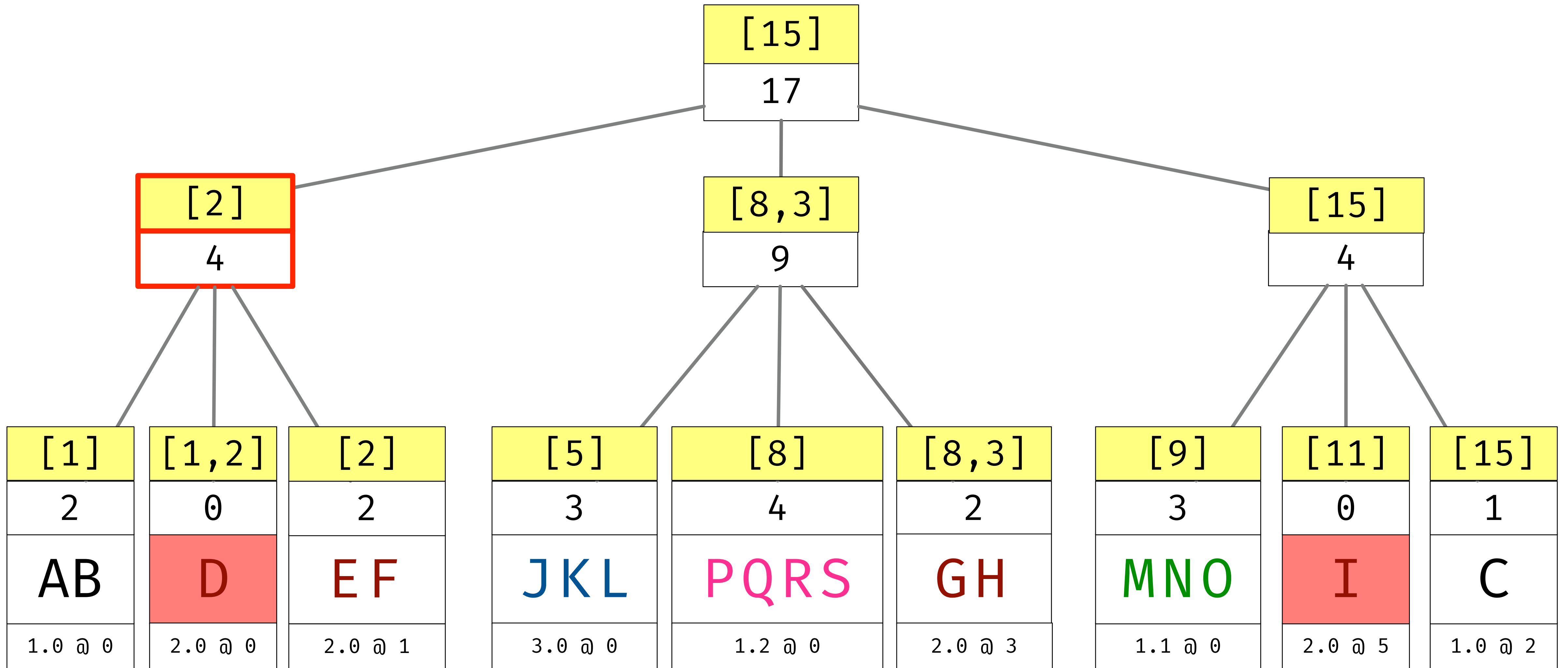


Insert "X" at [8, 3] @ 1

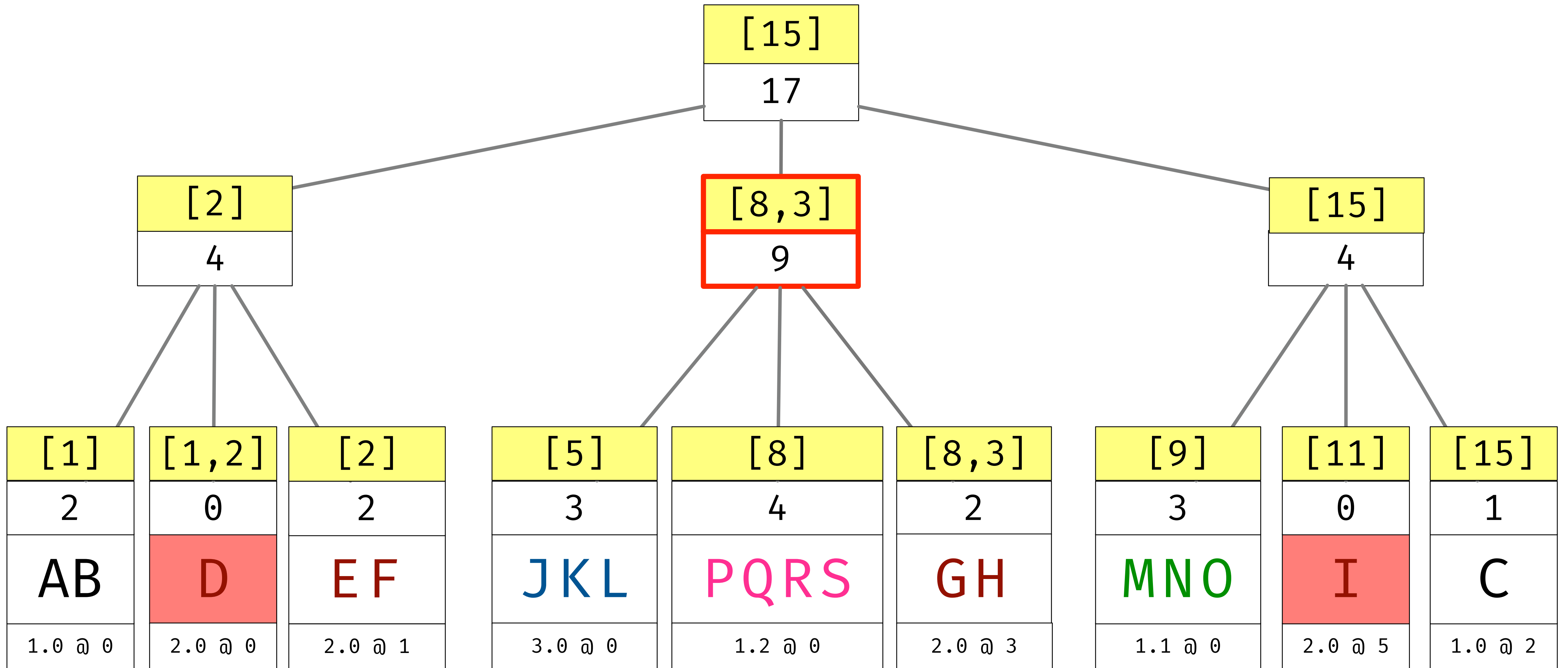


Insert "X" at [8, 3] @ 1



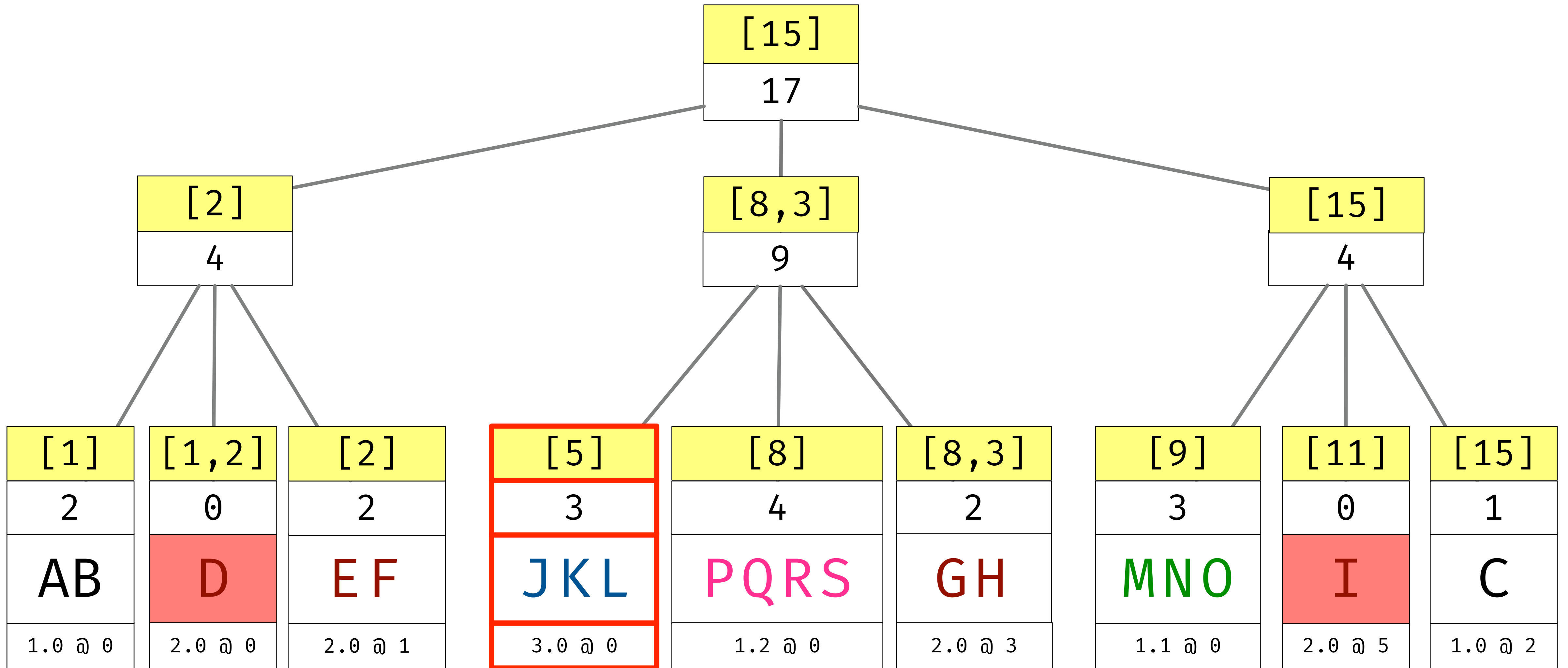


Insert "X" at [8, 3] @ 1

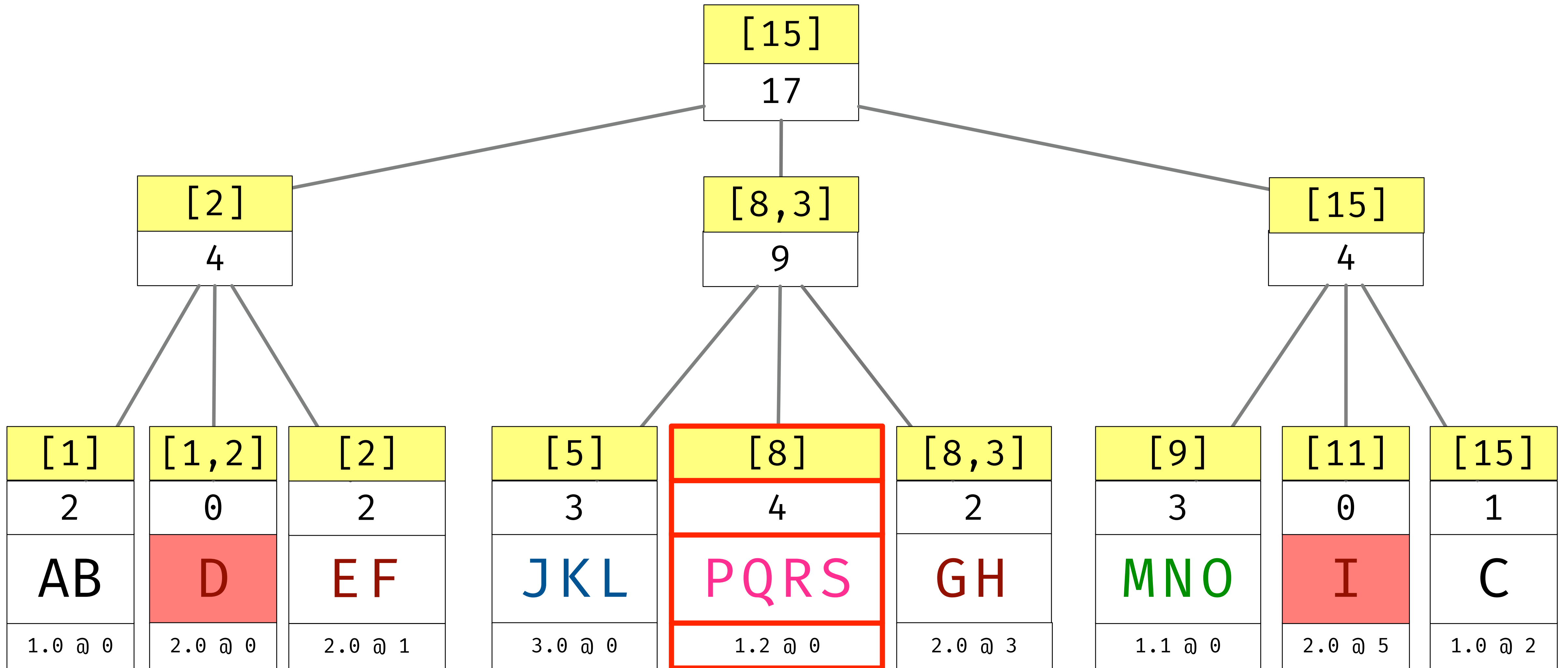


Insert "X" at [8, 3] @ 1



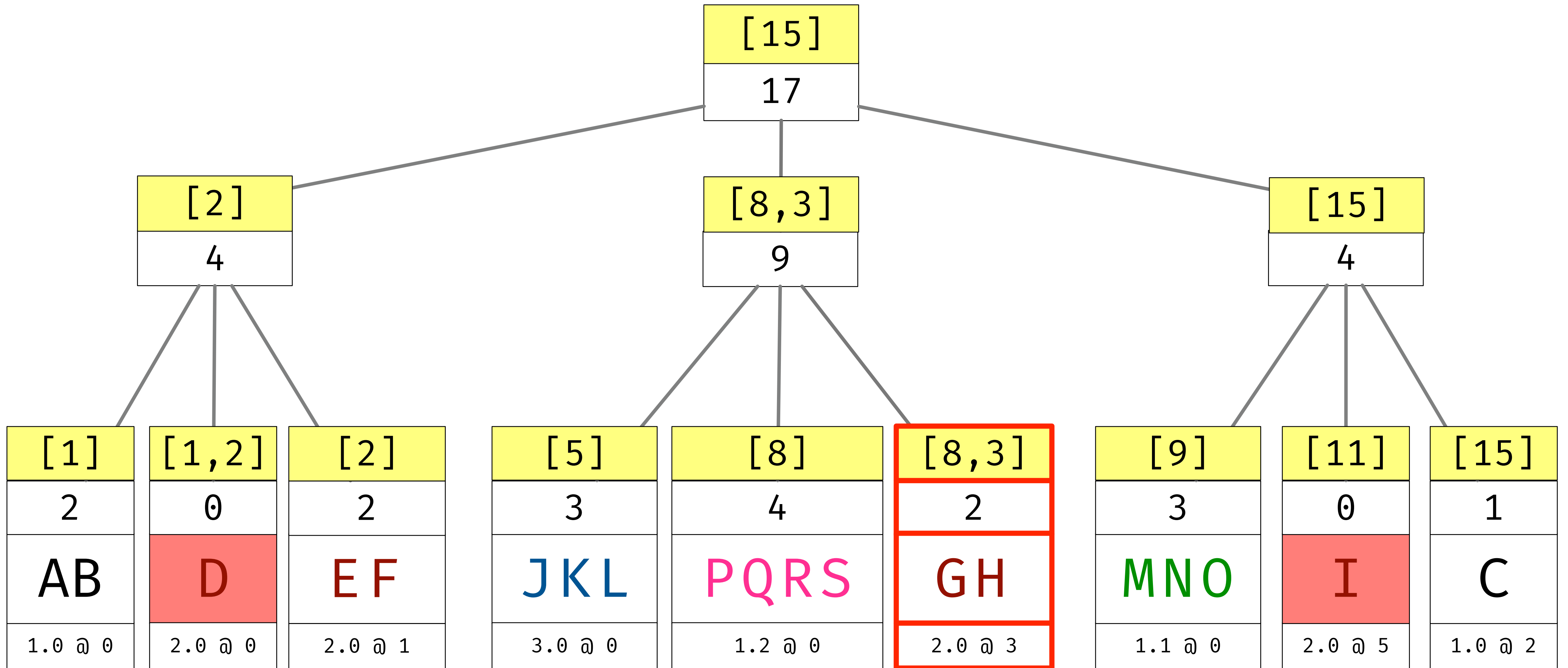


Insert "X" at [8, 3] @ 1

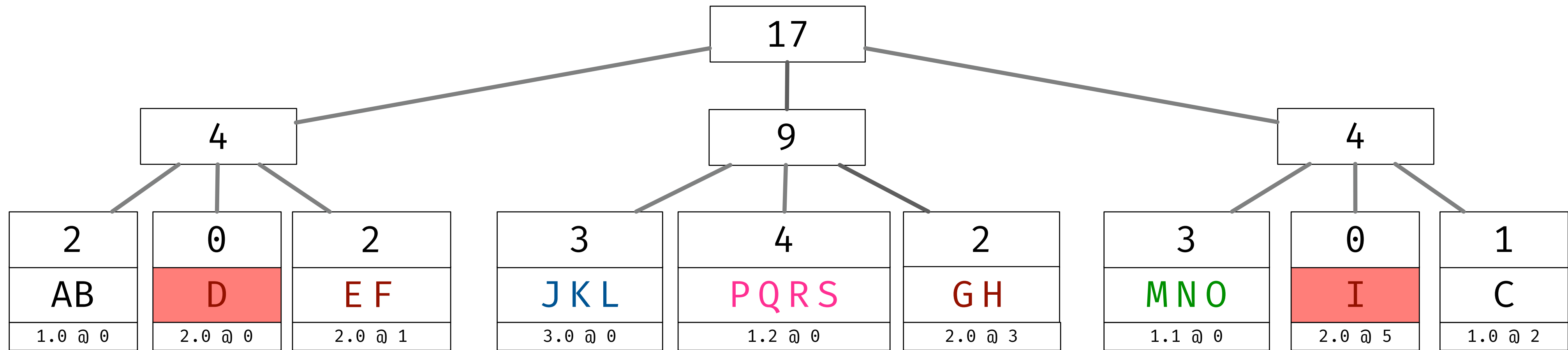


Insert "X" at [8, 3] @ 1



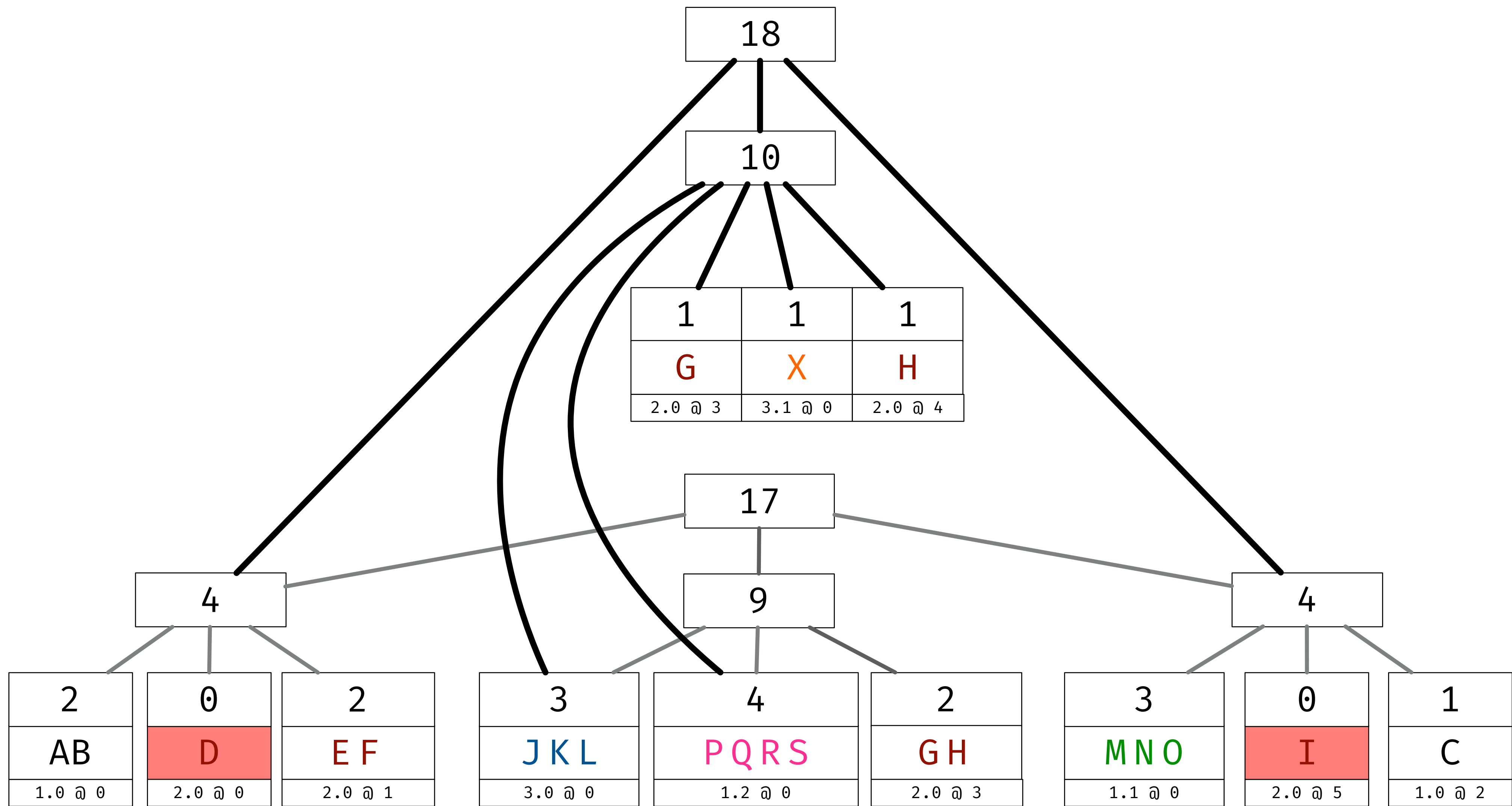


Insert "X" at [8, 3] @ 1



Insert "X" at 2.0 @ 4





Insert "X" at 2.0 @ 4

# Foreground Thread

Buffer (v1)

# Background Thread



**Foreground Thread**

**Background Thread**



# Foreground Thread

# Background Thread

Buffer (v1)



Snapshot (v1)

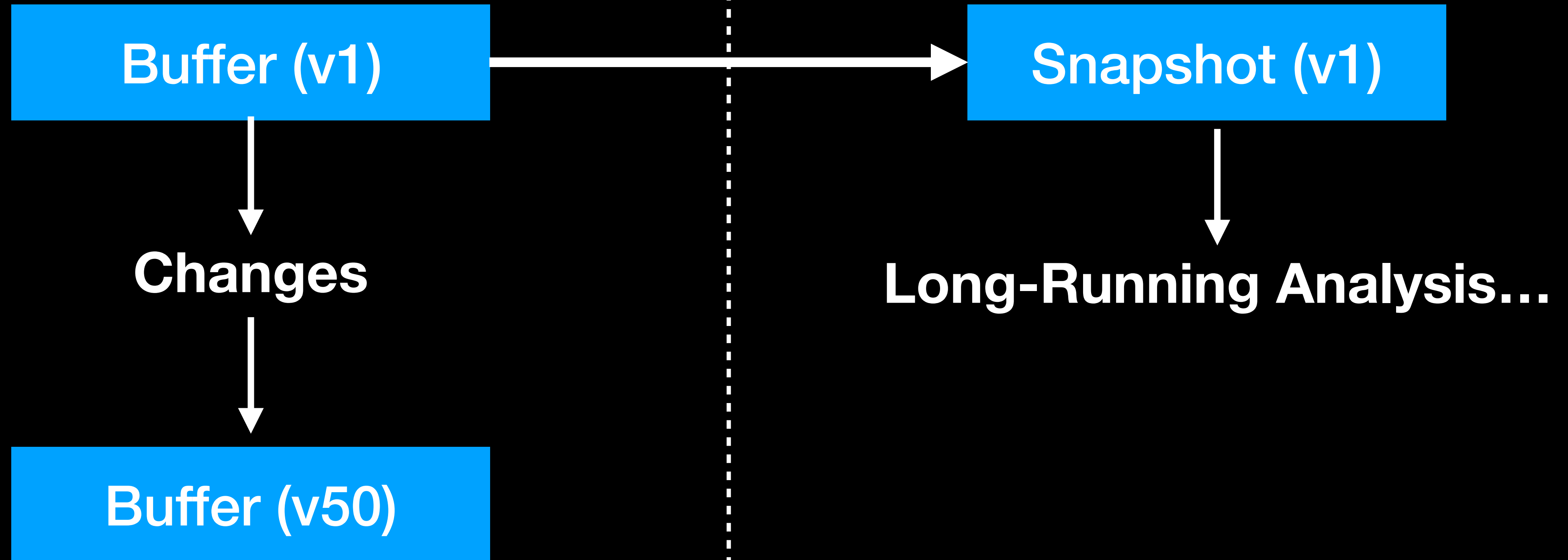


Long-Running Analysis...



# Foreground Thread

# Background Thread



# Foreground Thread

Buffer (v1)



Changes



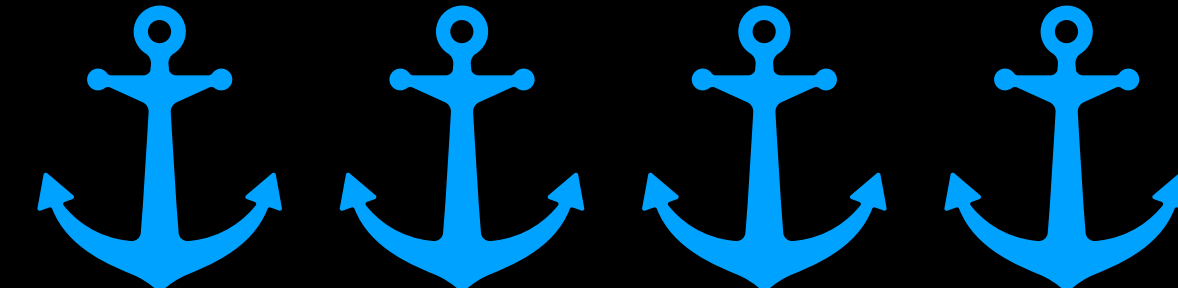
Buffer (v50)

# Background Thread

Snapshot (v1)



Long-Running Analysis...



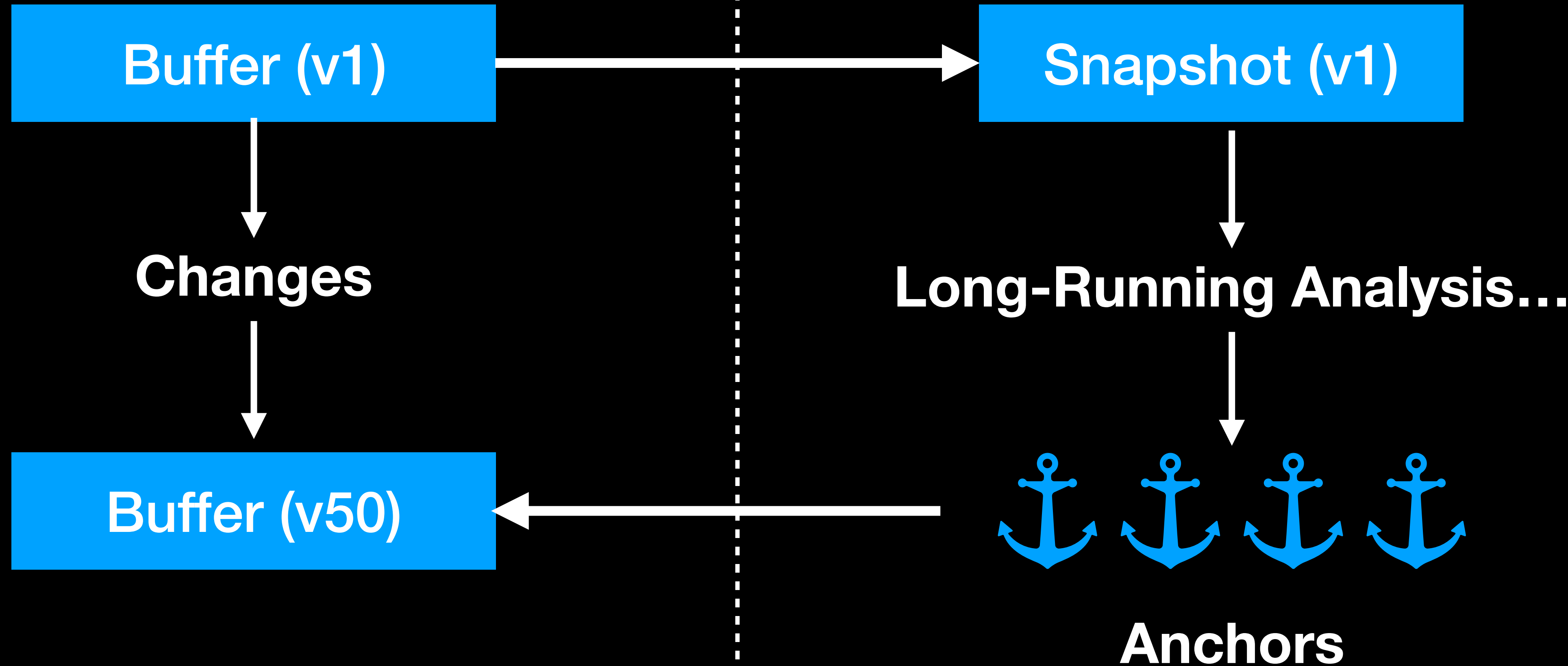
Anchors





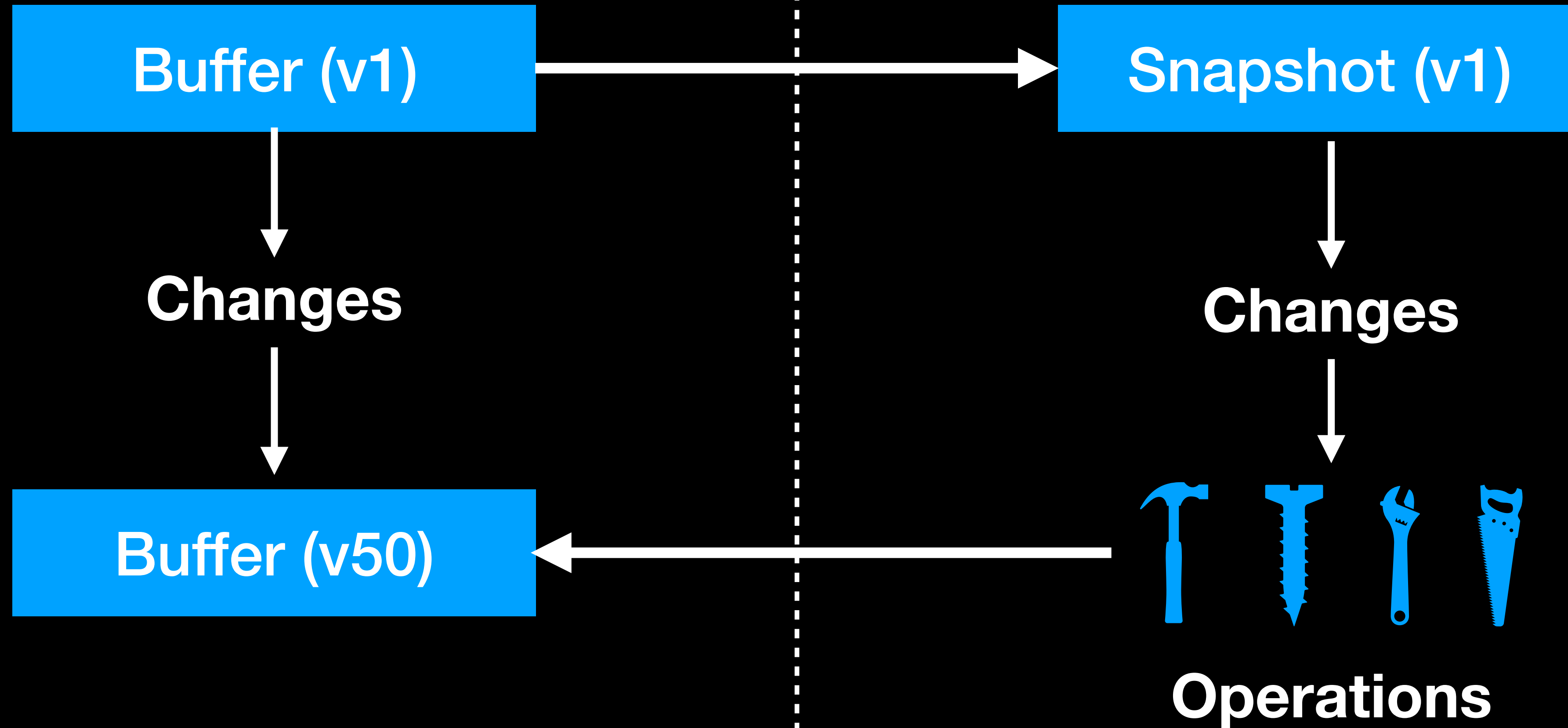
# Foreground Thread

# Background Thread



# Foreground Thread

# Background Thread

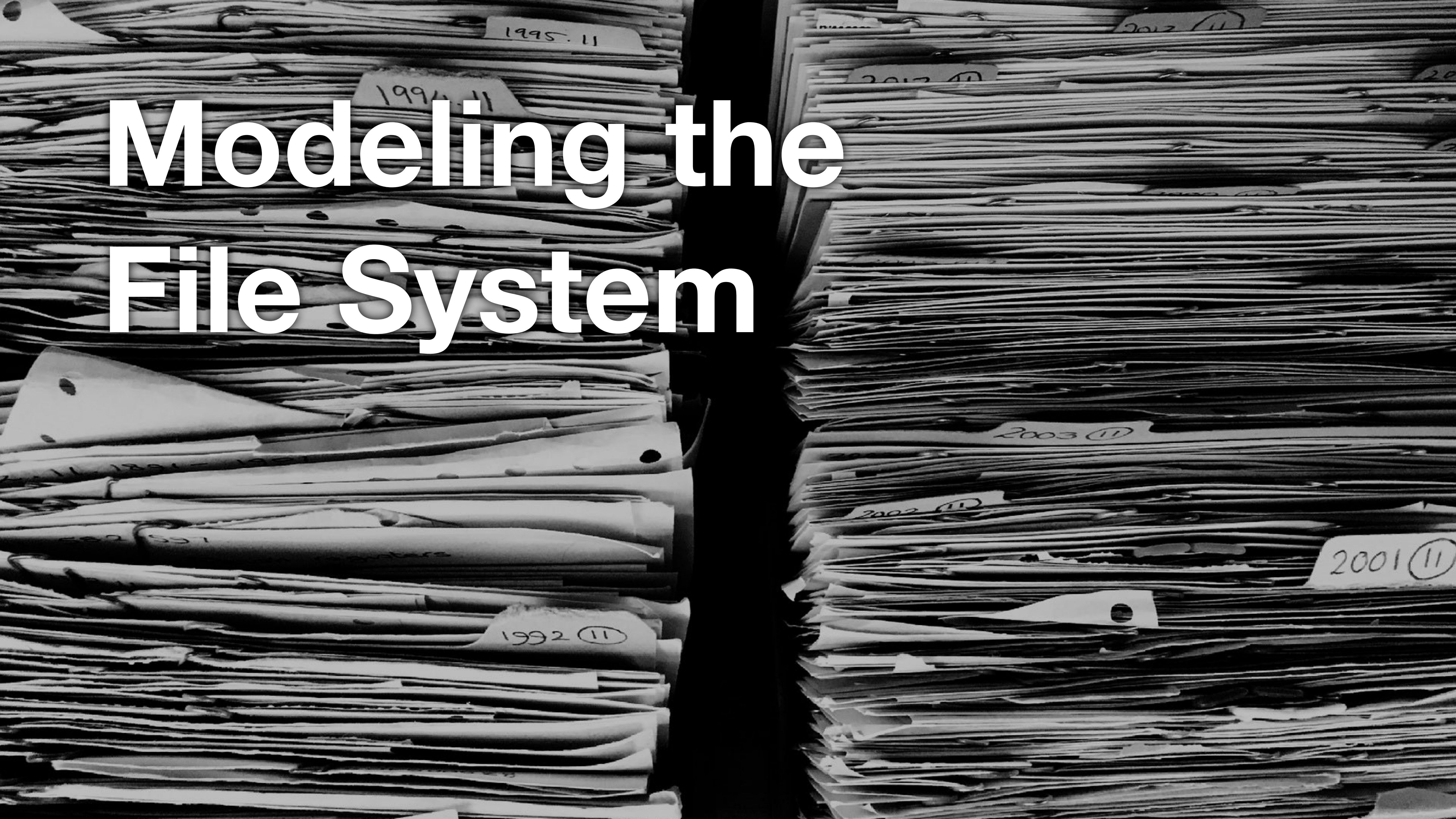




```
enum Tree<T: Item> {  
    Resident(Arc<Node<T>>),  
    NonResident(NodeId),  
}
```







# Modeling the File System

1995.11

1994.11

2012 (11)

2012 (11)

2003 (11)

2002 (11)

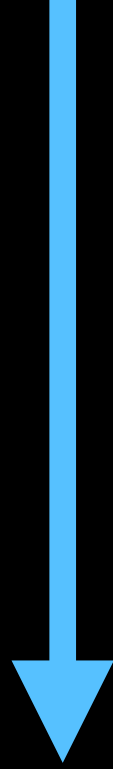
2001 (11)

1992 (11)



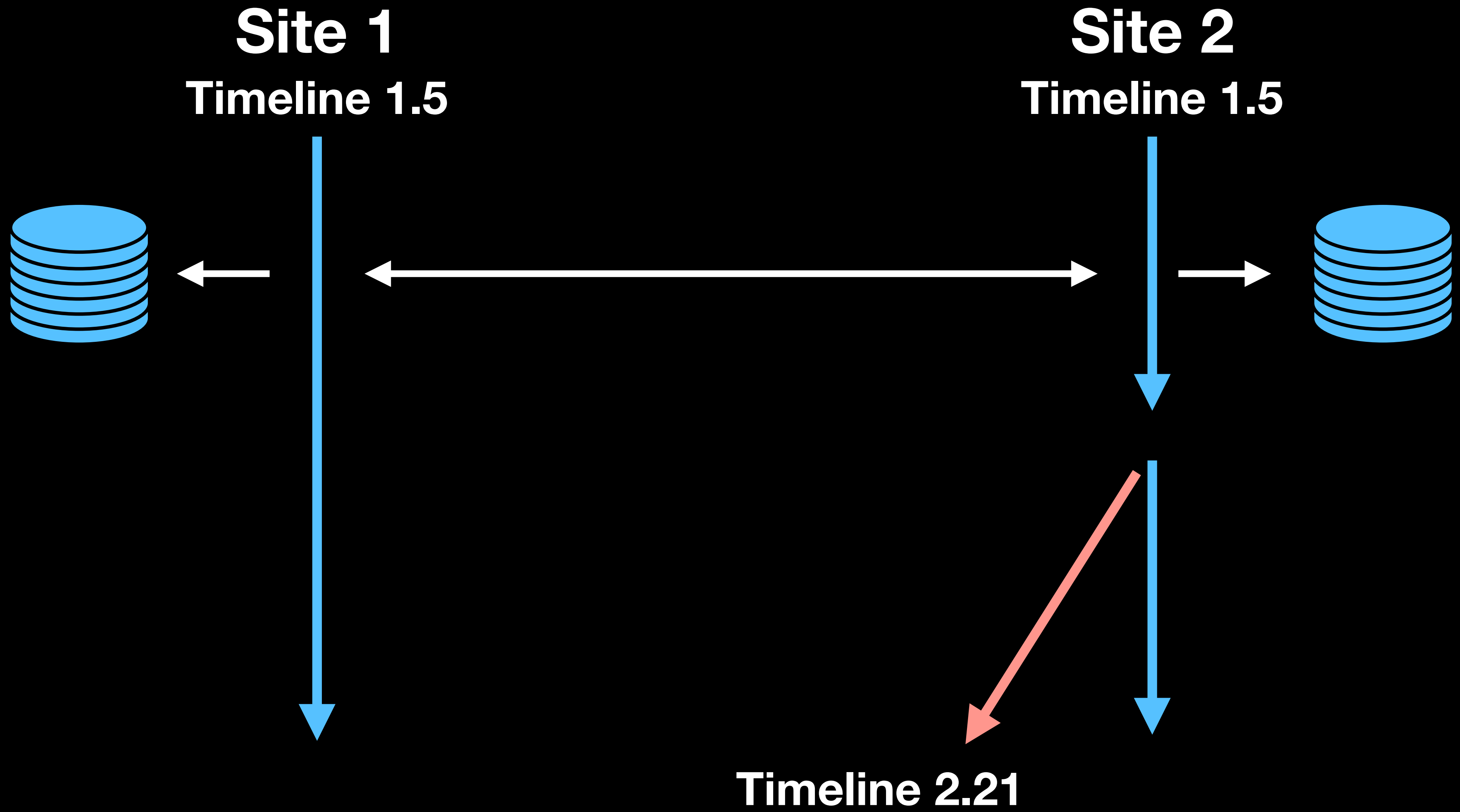
**Site 1**

**Timeline 1.5**

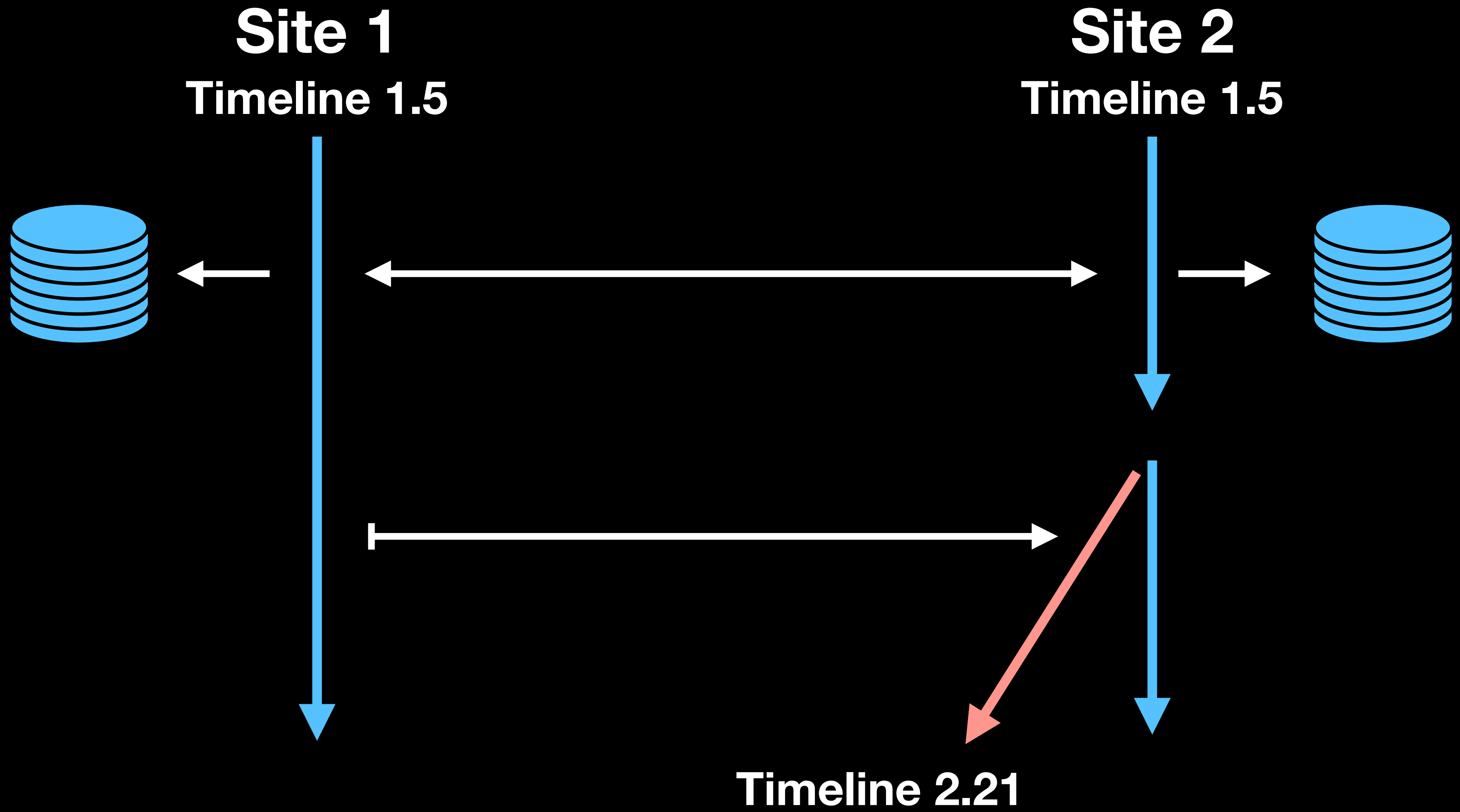






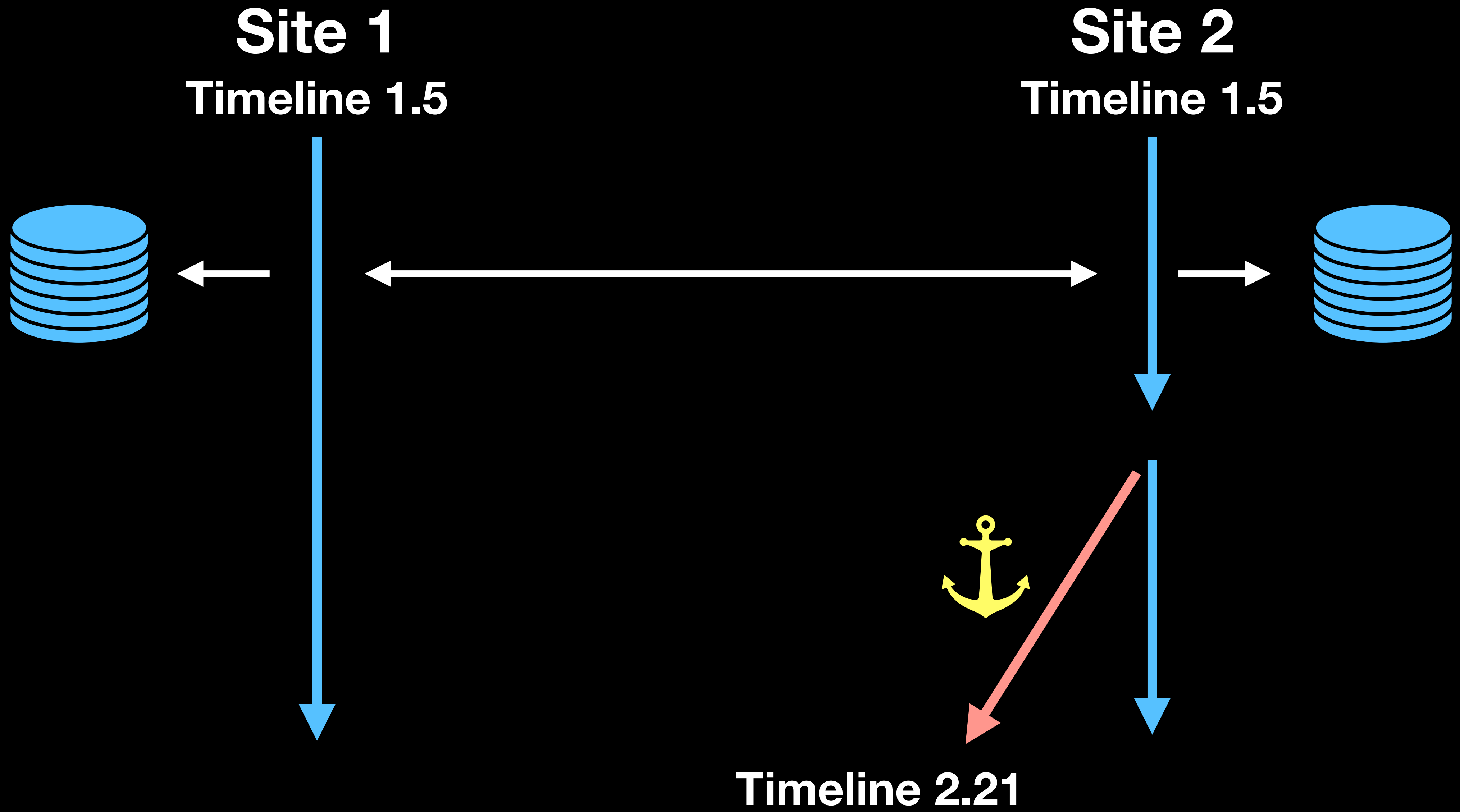
















<https://github.com/atom/eon>