

Introduction to

# Databases with SQL

Optimizing

**IMDb**

200,000+ ratings

400,000+ movies

1,400,000+ stars

Person	
INTEGER	id
TEXT	name
NUMERIC	birth



stars



Movie	
INTEGER	id
TEXT	title
NUMERIC	year



has



Rating	
INTEGER	id
REAL	rating
INTEGER	votes

# people

id	name
158	Tom Hanks
5562	Owen Wilson
68338	Kristen Bell
...	...

# stars

person_id	movie_id
158	114709
5562	317219
68338	2294629
...	...

# movies

id	title
114709	Toy Story
317219	Cars
2294629	Frozen
...	...

# people

id	name
158	Tom Hanks
5562	Owen Wilson
68338	Kristen Bell
...	...

# stars

person_id	movie_id
158	114709
5562	317219
68338	2294629
...	...

# movies

id	title
114709	Toy Story
317219	Cars
2294629	Frozen
...	...

# movies

id	title
114709	Toy Story
3606752	Cars 3
2294629	Frozen
317219	Cars
910970	WALL·E
382932	Ratatouille
2948372	Soul
8097030	Turning Red





# movies

id	title
114709	Toy Story
3606752	Cars 3
2294629	Frozen
317219	Cars
910970	WALL·E
382932	Ratatouille
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# movies

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910970	WALL·E
382932	Ratatouille
2948372	Soul
8097030	Turning Red

# Index

A structure used to speed up the retrieval of rows from a table

```
CREATE INDEX name
```

```
CREATE INDEX name  
ON table (column0, ...);
```



EXPLAIN QUERY PLAN

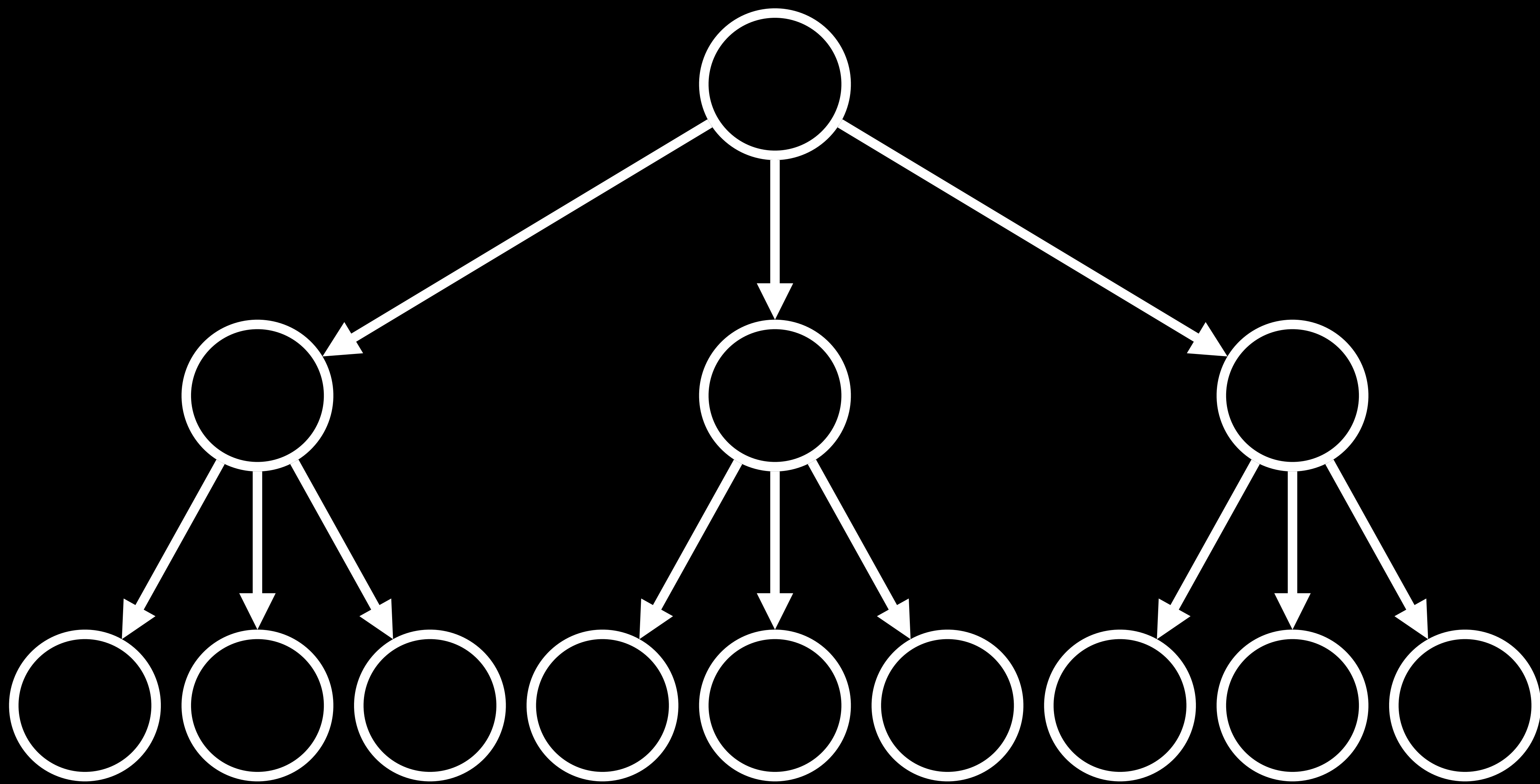
SELECT ...;

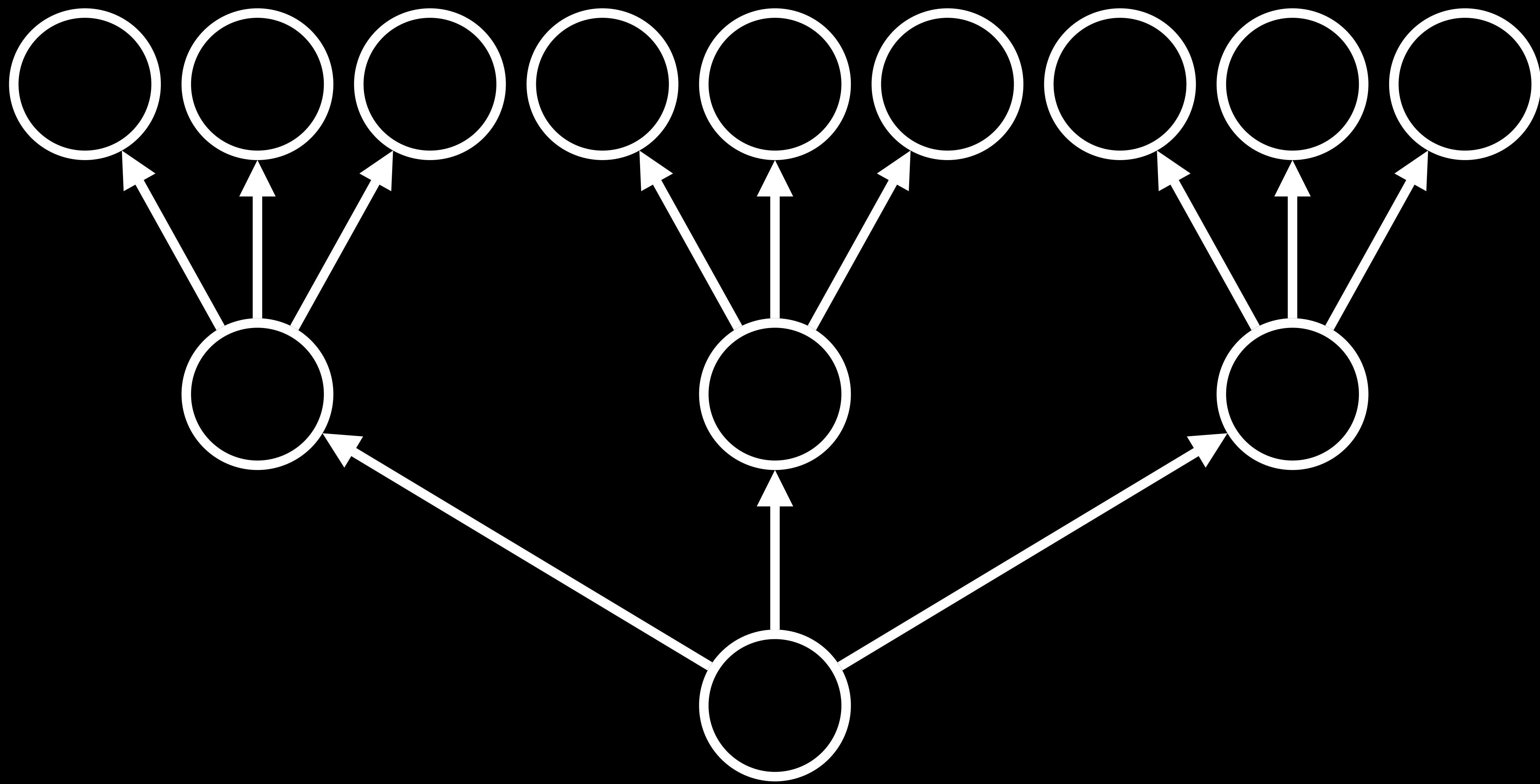
# Covering Index

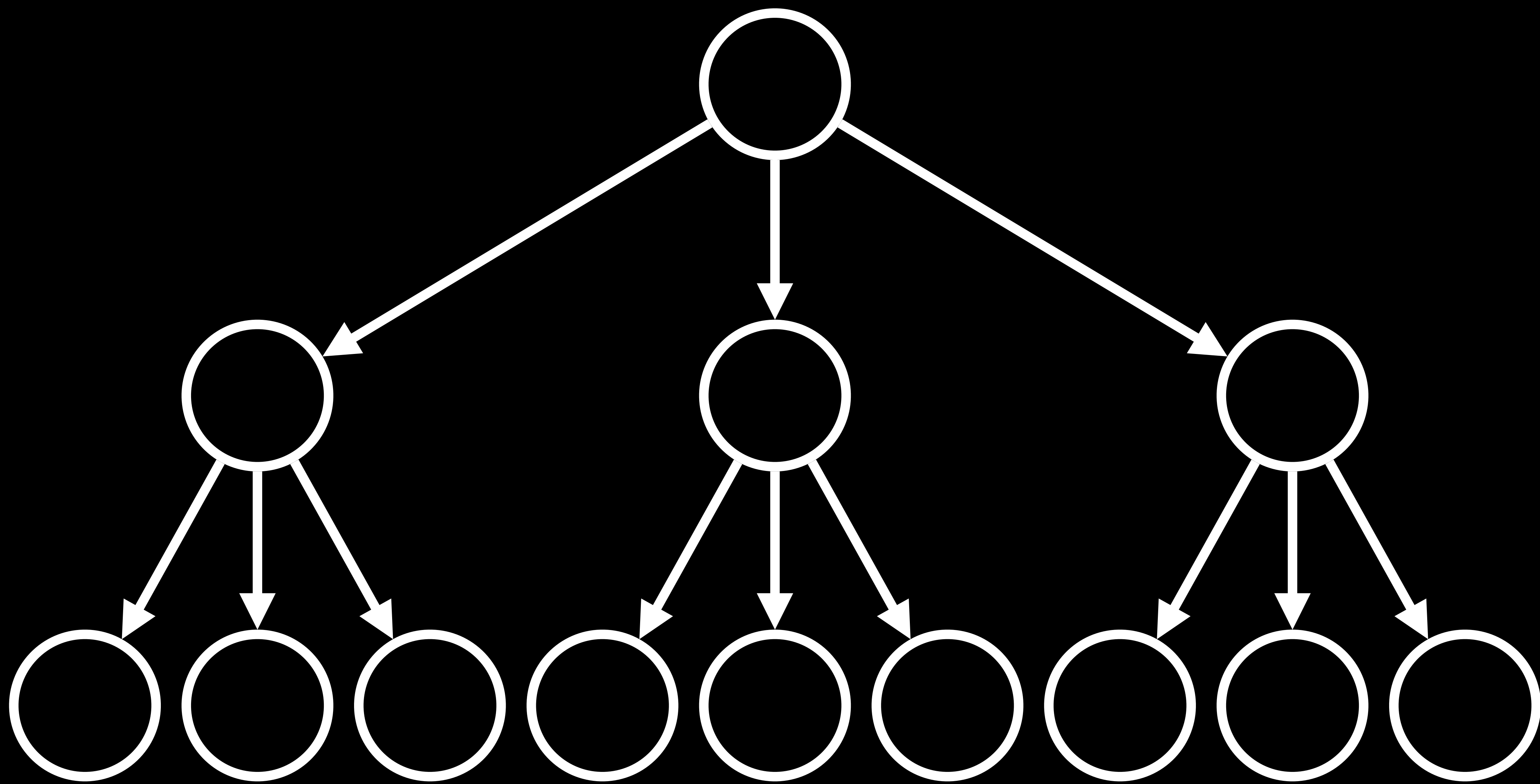
An index in which queried data can be retrieved from the index itself

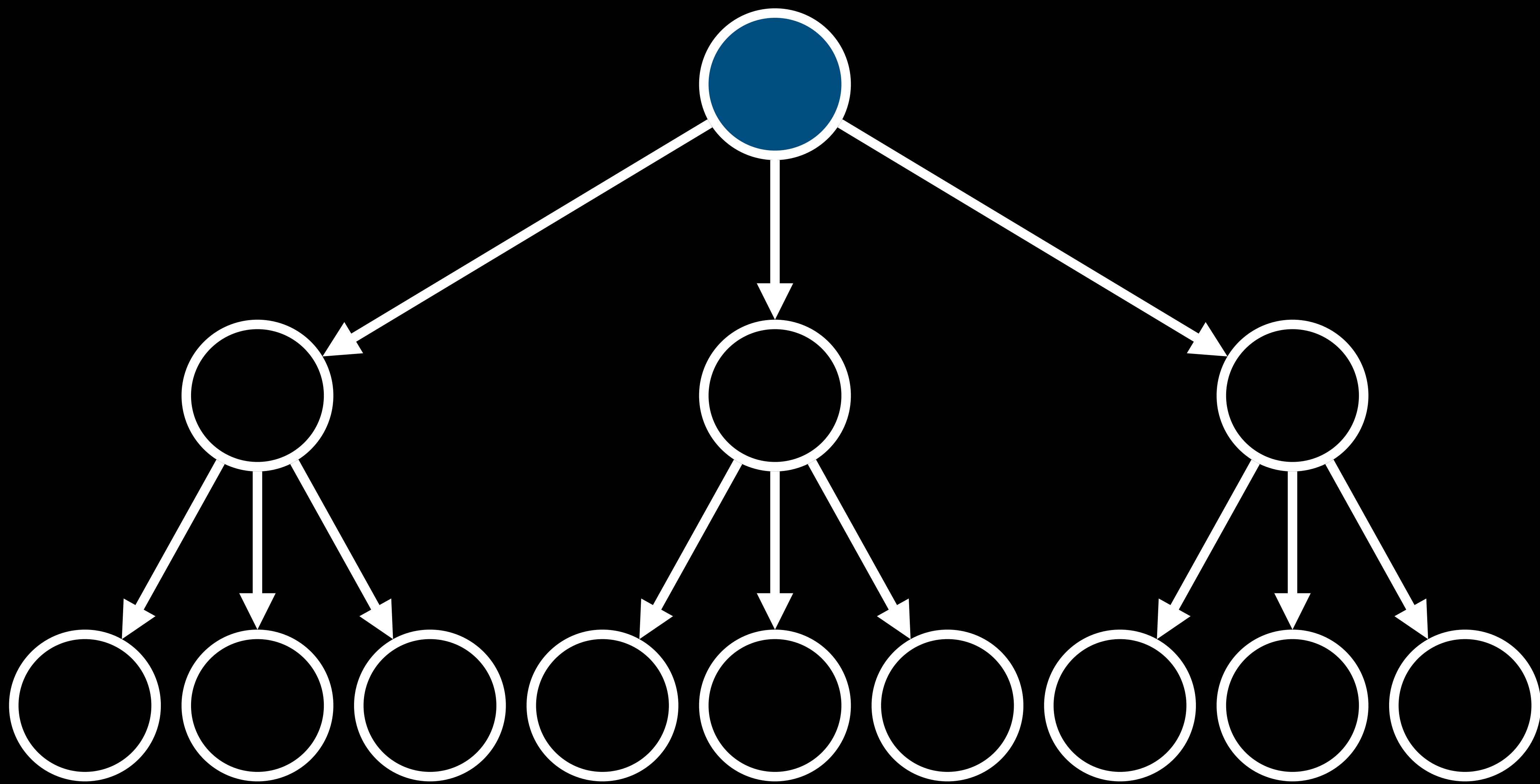
# B-Tree

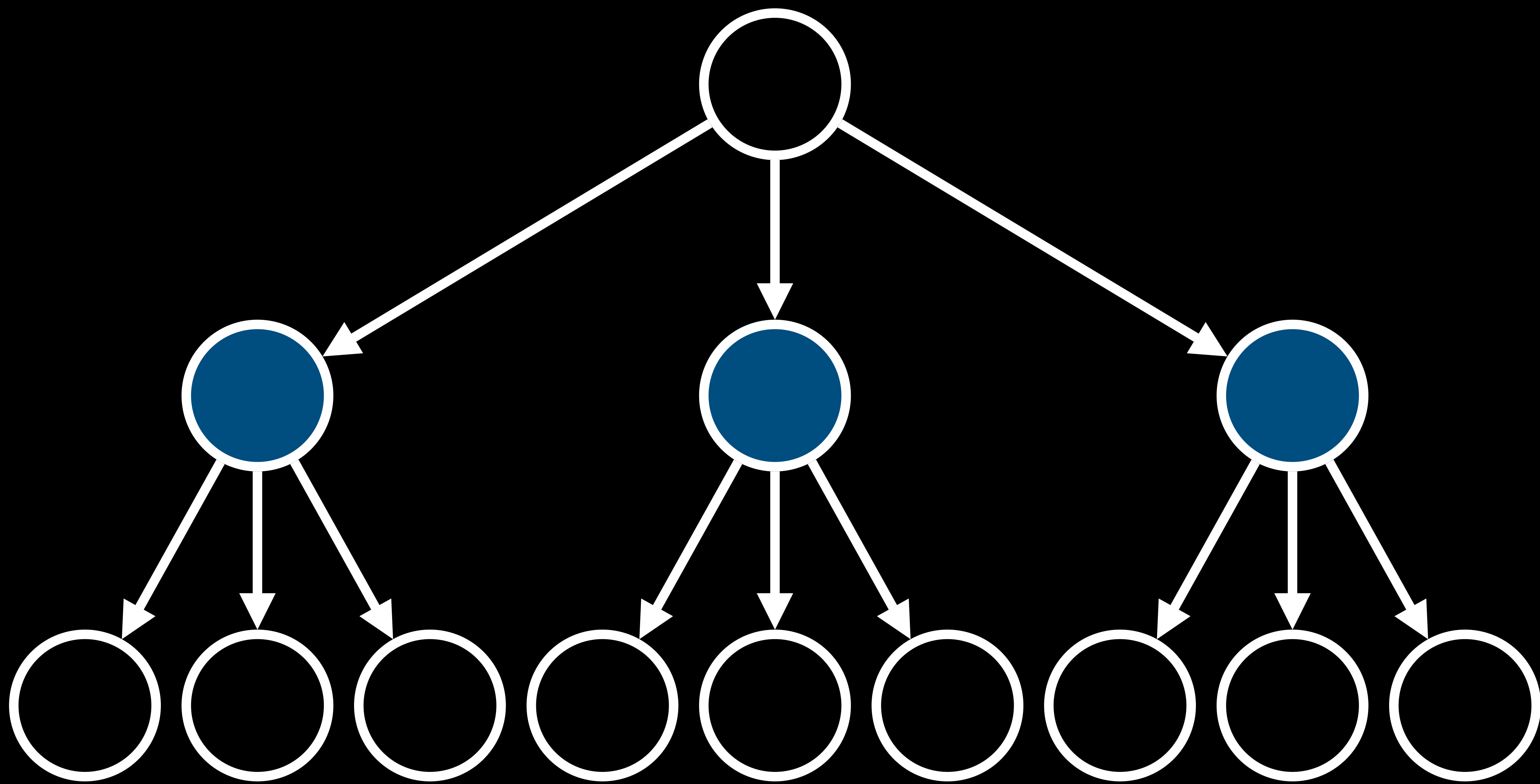
A balanced tree structure commonly used to create an index



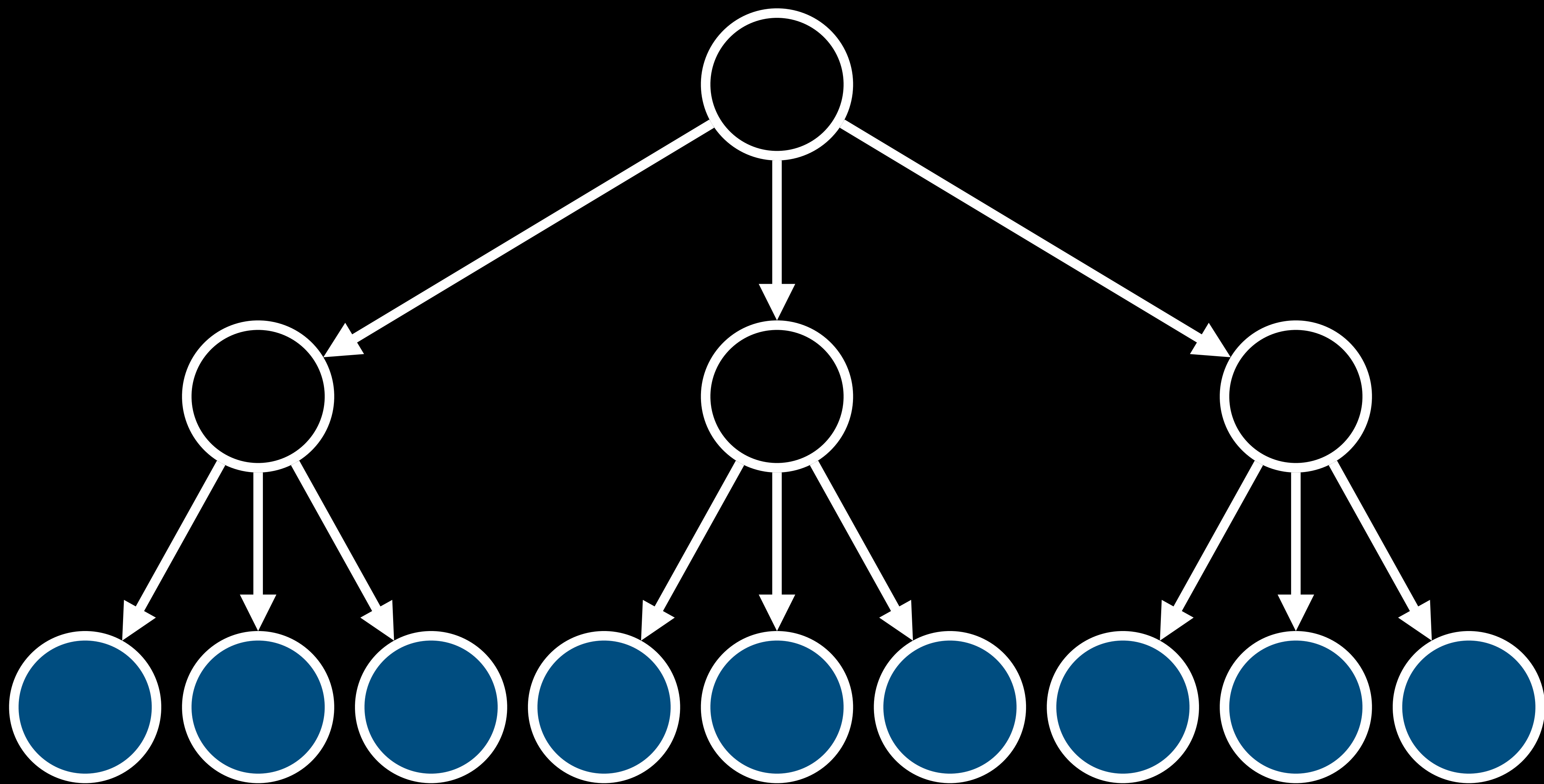












id	title
114709	Toy Story
3606752	Cars 3
2294629	Frozen
317219	Cars
910970	WALL·E
382932	Ratatouille
2948372	Soul
8097030	Turning Red
12801262	Luca

id	title
114709	Cars
3606752	Cars 3
2294629	Frozen
317219	Luca
910970	Ratatouille
382932	Soul
2948372	Toy Story
8097030	Turning Red
12801262	WALL·E

id	title
114709	Cars
3606752	Cars 3
2294629	Frozen
317219	Luca
910970	Ratatouille
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8097030	Turning Red
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id	title
114709	Toy Story
3606752	Cars 3
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317219	Cars
910970	WALL·E
382932	Ratatouille
2948372	Soul
8097030	Turning Red
12801262	Luca

title
Toy Story
Cars 3
Frozen
Cars
WALL·E
Ratatouille
Soul
Turning Red
Luca

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca



Cars

Cars 3

Frozen

Luca

Ratatouille

Soul

Toy Story

Turning Red

WALL·E

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

Cars

Cars 3

Frozen

Luca

Ratatouille

Soul

Toy Story

Turning Red

WALL·E

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

Cars

Cars 3

Frozen

Luca

Ratatouille

Soul

Toy Story

Turning Red

WALL·E

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

Cars

Cars 3

Frozen

Luca

Ratatouille

Soul

Toy Story

Turning Red

WALL·E

**title**

Toy Story

Cars 3

Frozen

Cars

WALL·E

Ratatouille

Soul

Turning Red

Luca

Cars
Cars 3
Frozen
Luca
Ratatouille
Soul
Toy Story
Turning Red
WALL·E

4

2

3

9

6

7

1

8

5

title
Toy Story
Cars 3
Frozen
Cars
WALL·E
Ratatouille
Soul
Turning Red
Luca

1

2

3

4

5

6

7

8

9

Cars
Cars 3
Frozen
Luca
Ratatouille
Soul
Toy Story
Turning Red
WALL·E

4

2

3

9

6

7

1

8

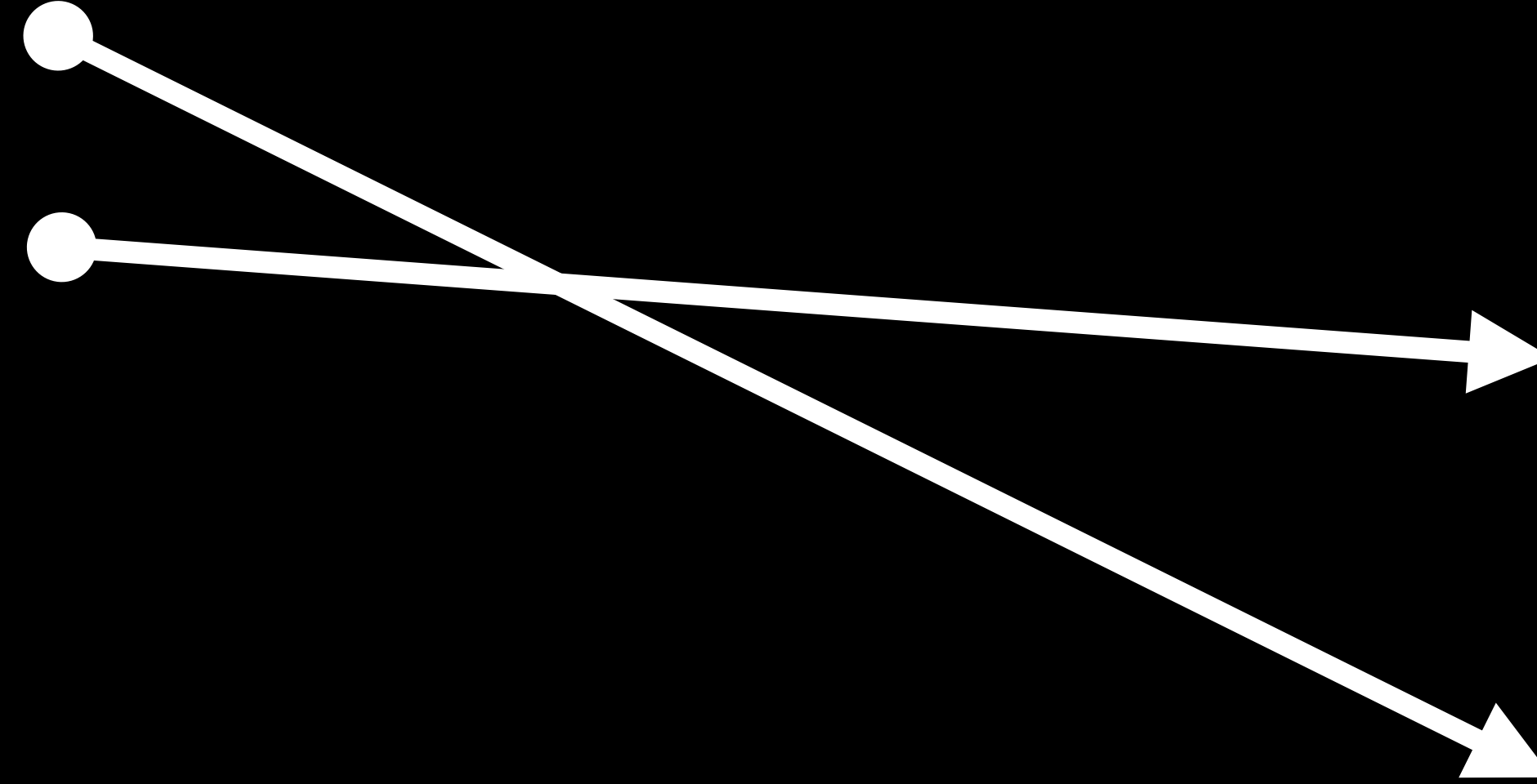
5



title	
1	Toy Story
2	Cars 3
3	Frozen
4	Cars
5	WALL·E
6	Ratatouille
7	Soul
8	Turning Red
9	Luca

Cars
Cars 3
Frozen
Luca
Ratatouille
Soul
Toy Story
Turning Red
WALL·E

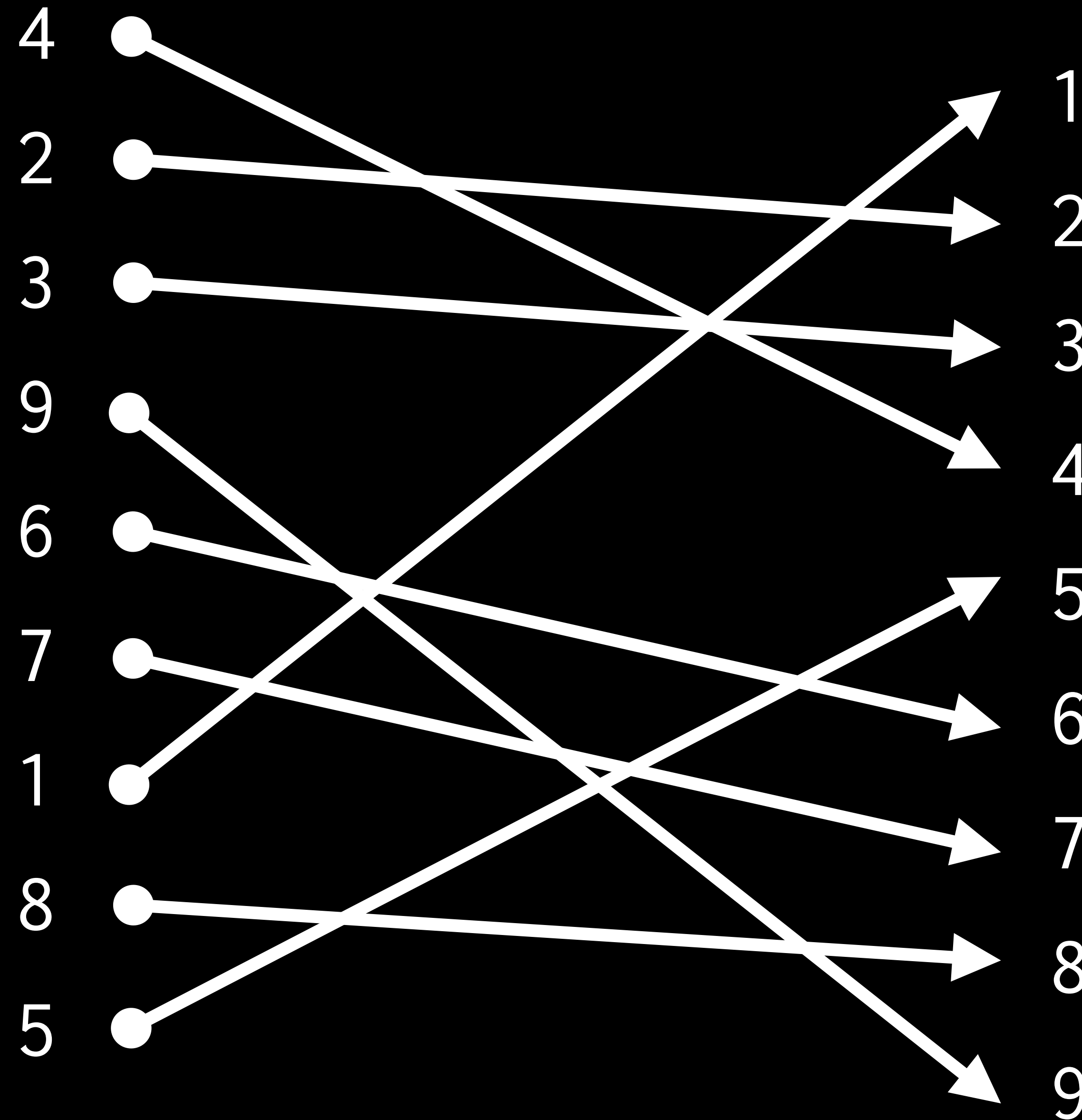
4  
2  
3  
9  
6  
7  
1  
8  
5



1  
2  
3  
4  
5  
6  
7  
8  
9

title
Toy Story
Cars 3
Frozen
Cars
WALL·E
Ratatouille
Soul
Turning Red
Luca

Cars
Cars 3
Frozen
Luca
Ratatouille
Soul
Toy Story
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title
Toy Story
Cars 3
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Turning Red
Luca



Cars	4
Cars 3	2
Frozen	3
Luca	9
Ratatouille	6
Soul	7
Toy Story	1
Turning Red	8
WALL·E	5

Cars	4
Cars 3	2
Frozen	3
Luca	9
Ratatouille	6
Soul	7
Toy Story	1
Turning Red	8
WALL·E	5

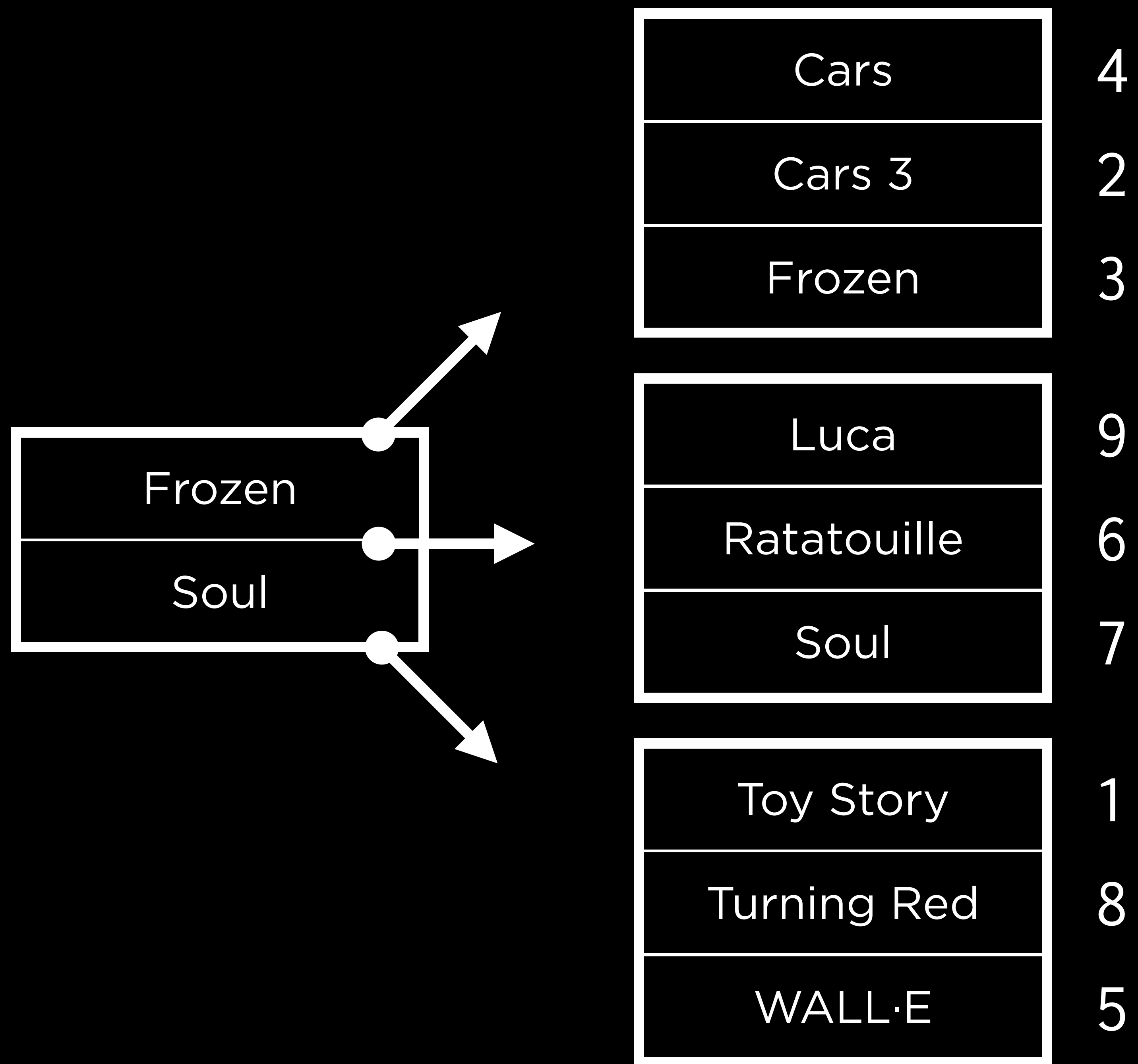
Cars	4
Cars 3	2
Frozen	3
Luca	9
Ratatouille	6
Soul	7
Toy Story	1
Turning Red	8
WALL·E	5

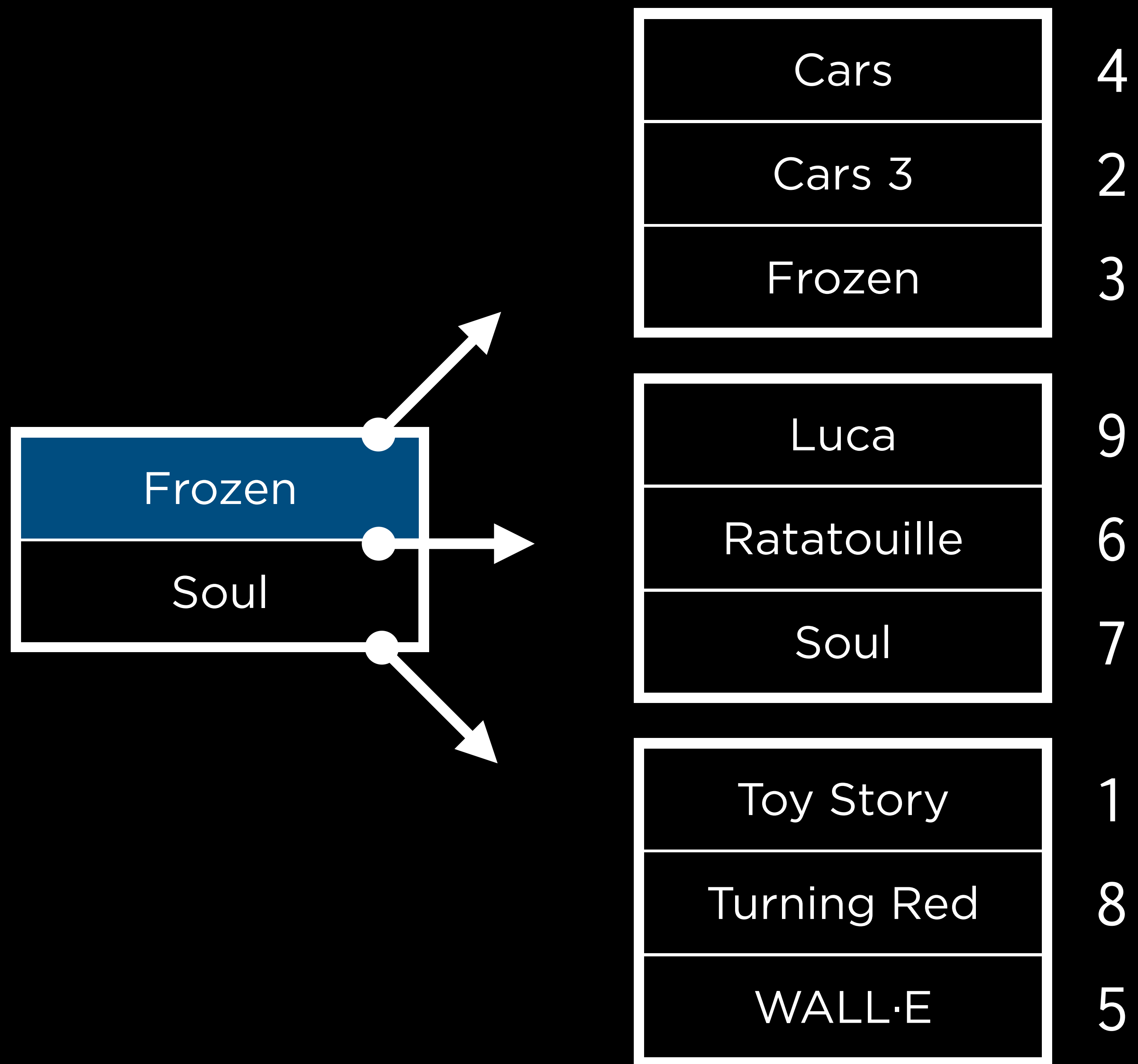
Cars	4
Cars 3	2
Frozen	3
Luca	9
Ratatouille	6
Soul	7
Toy Story	1
Turning Red	8
WALL·E	5

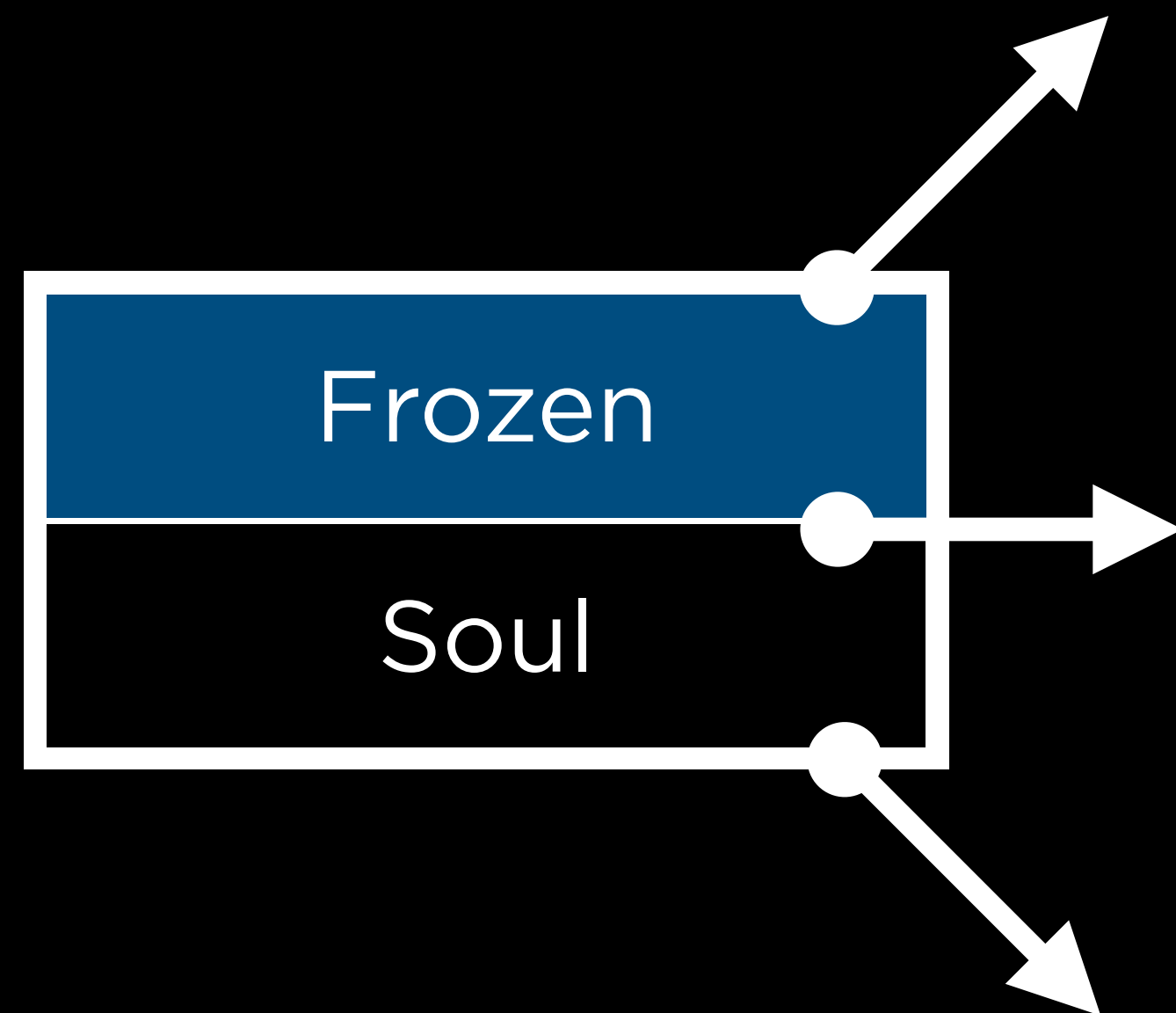
Cars	4
Cars 3	2
Frozen	3

Luca	9
Ratatouille	6
Soul	7

Toy Story	1
Turning Red	8
WALL·E	5





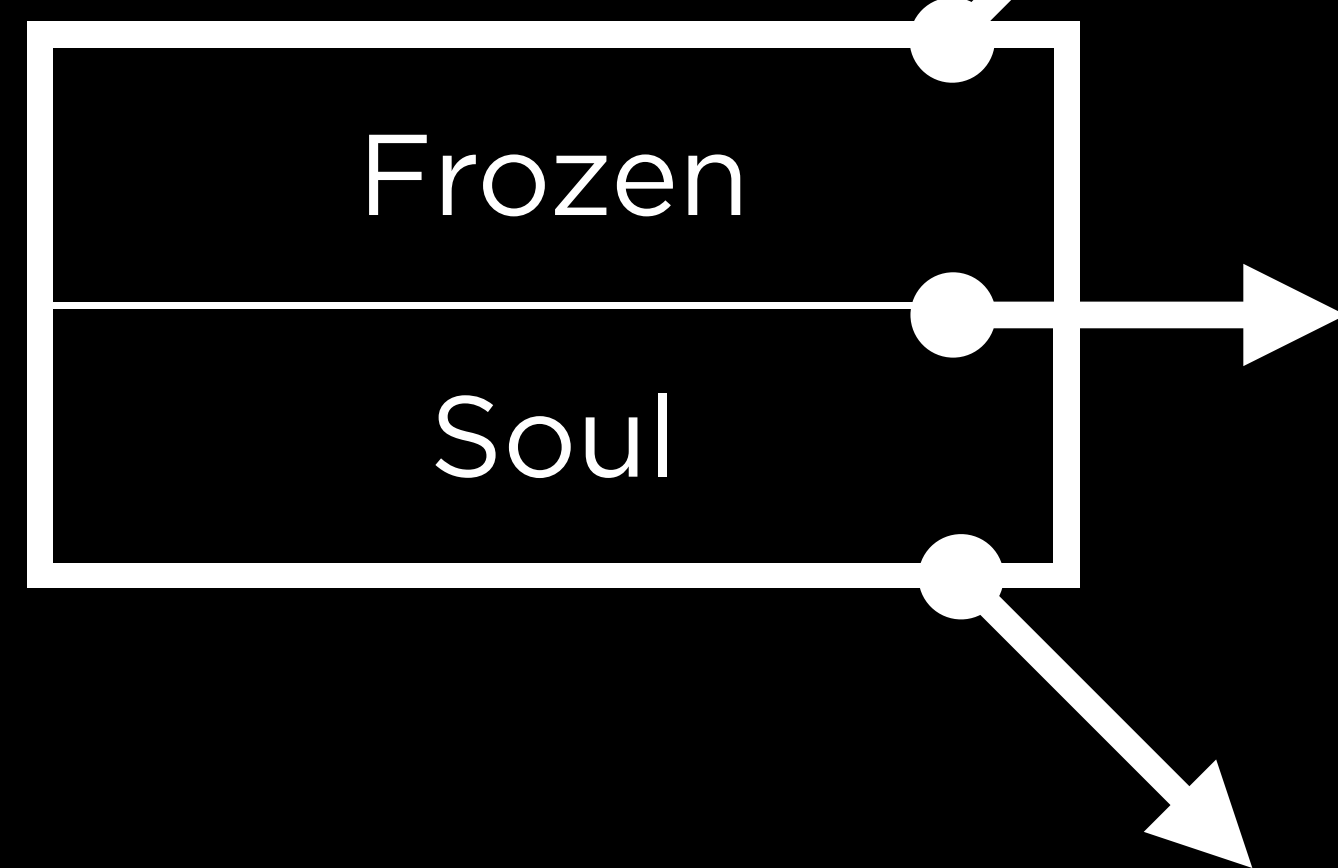


Cars	4
Cars 3	2
Frozen	3

Luca	9
Ratatouille	6
Soul	7

Toy Story	1
Turning Red	8
WALL·E	5

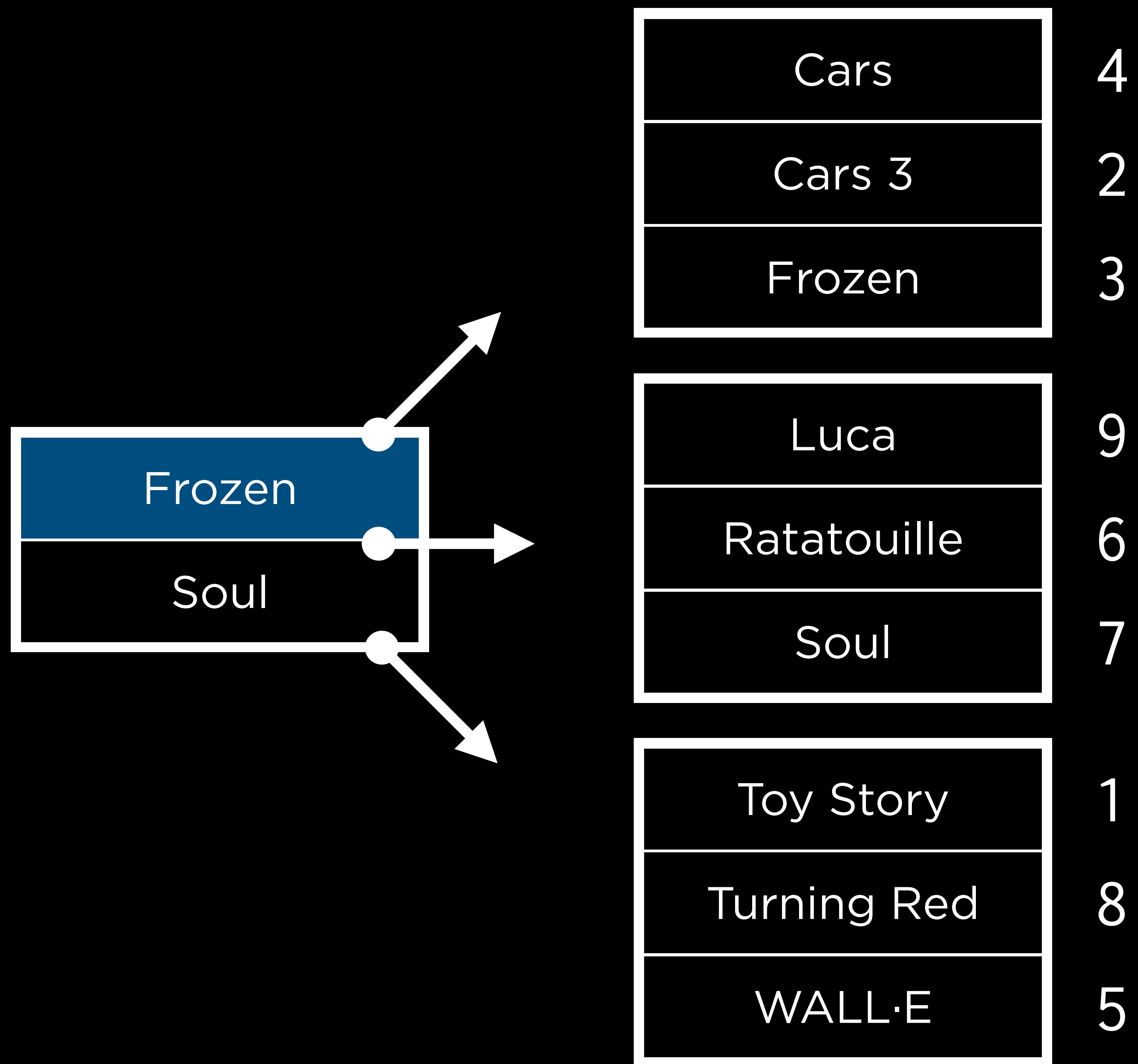


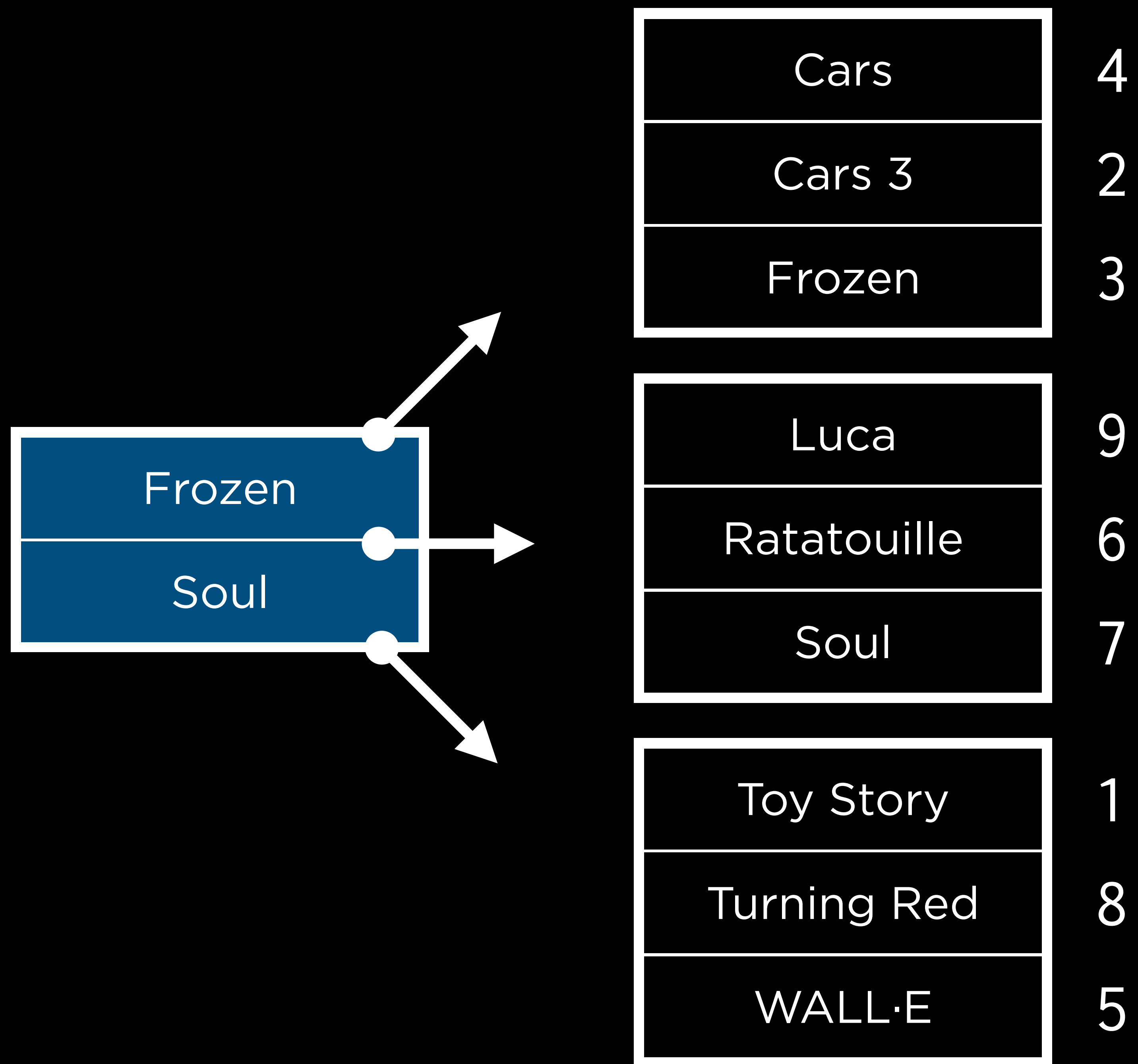


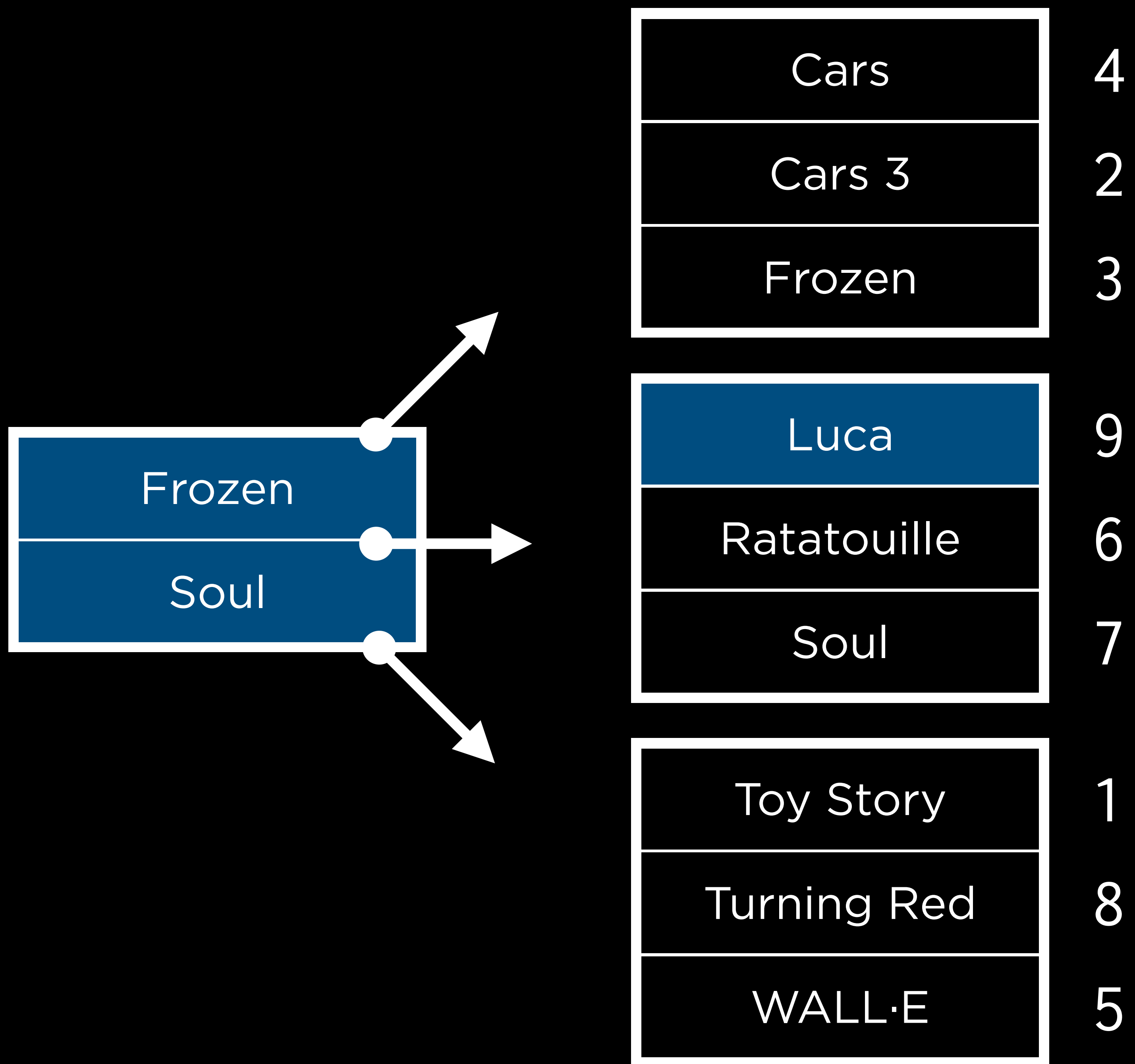
Cars	4
Cars 3	2
Frozen	3

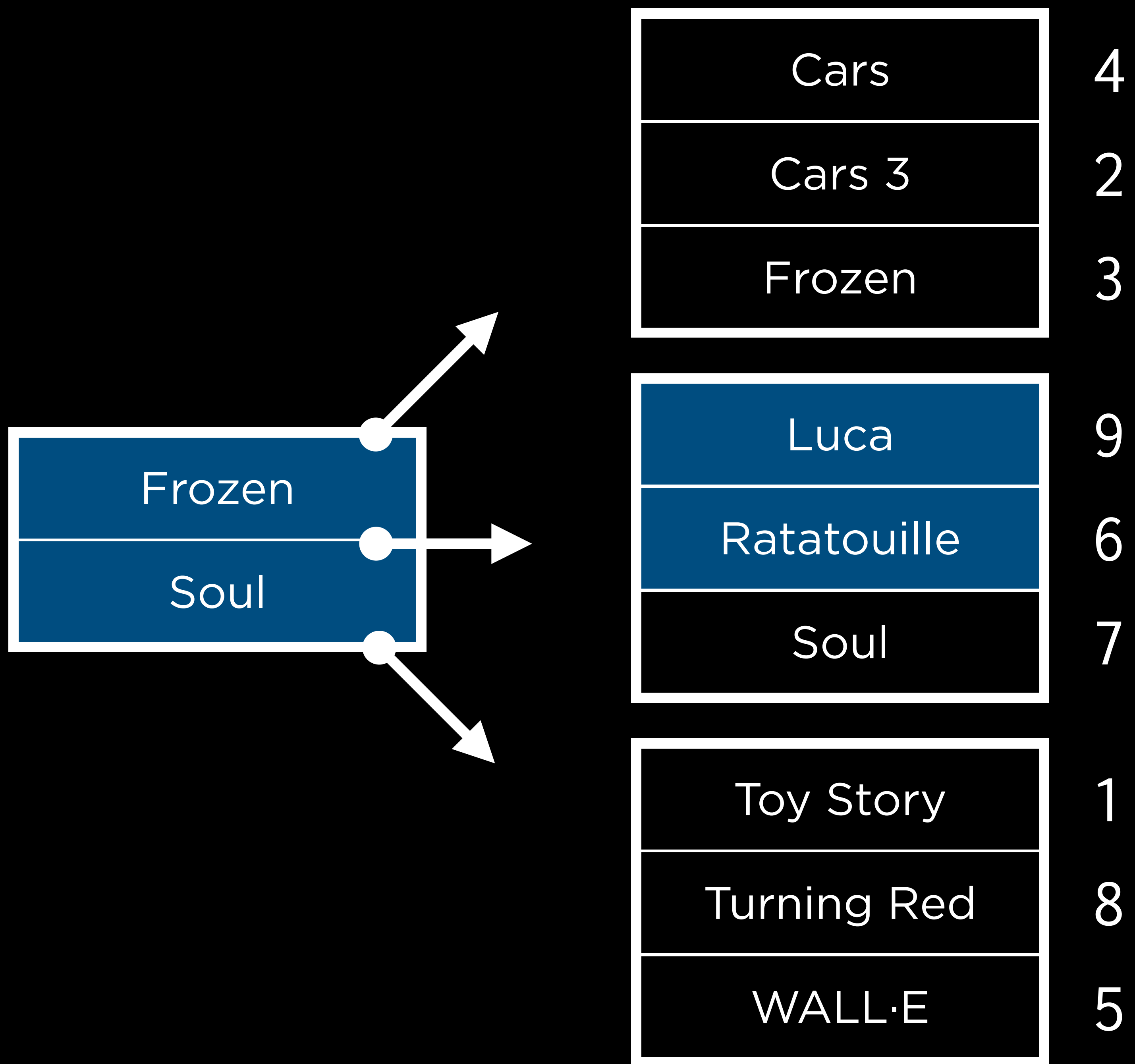
Luca	9
Ratatouille	6
Soul	7

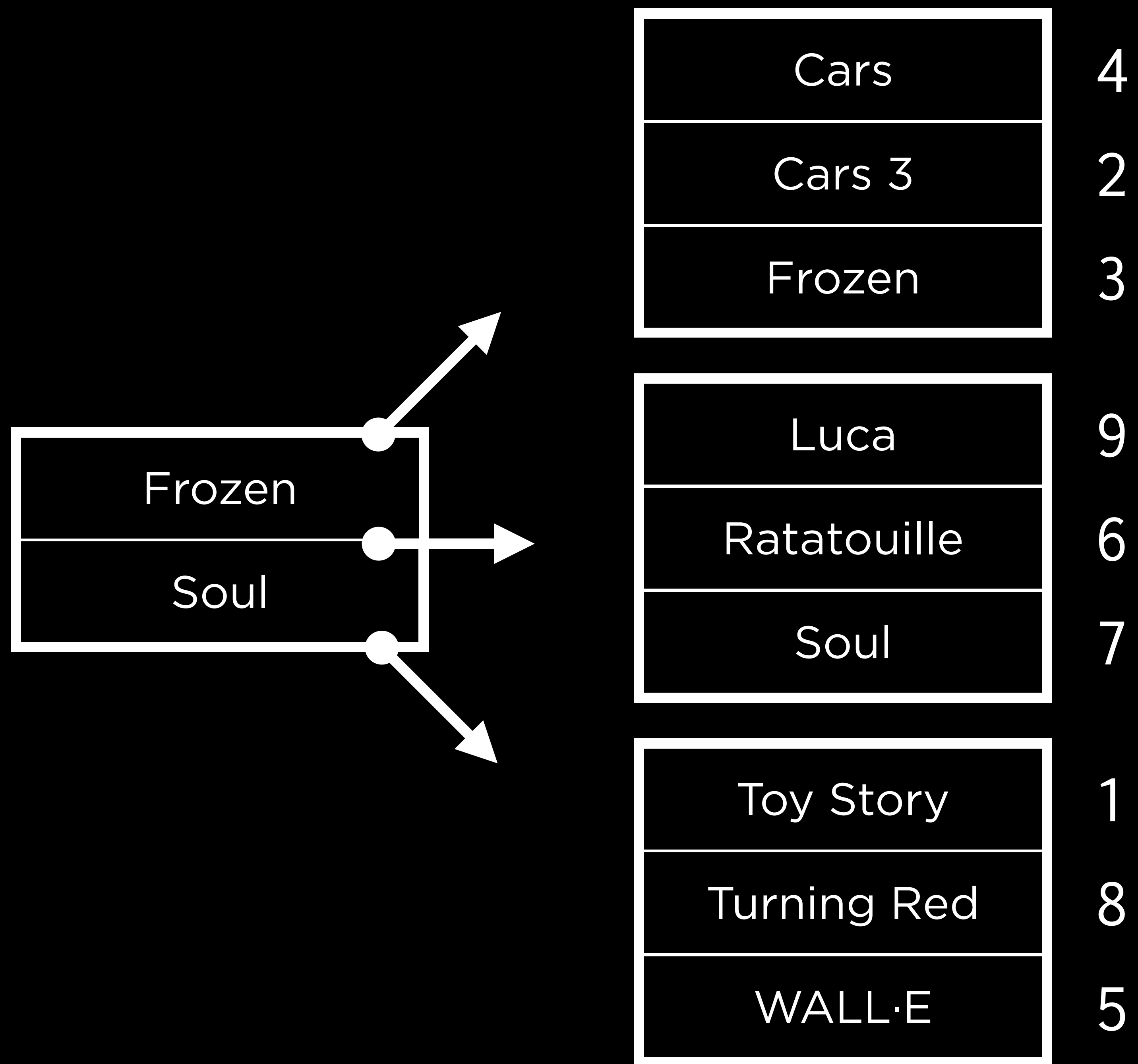
Toy Story	1
Turning Red	8
WALL·E	5

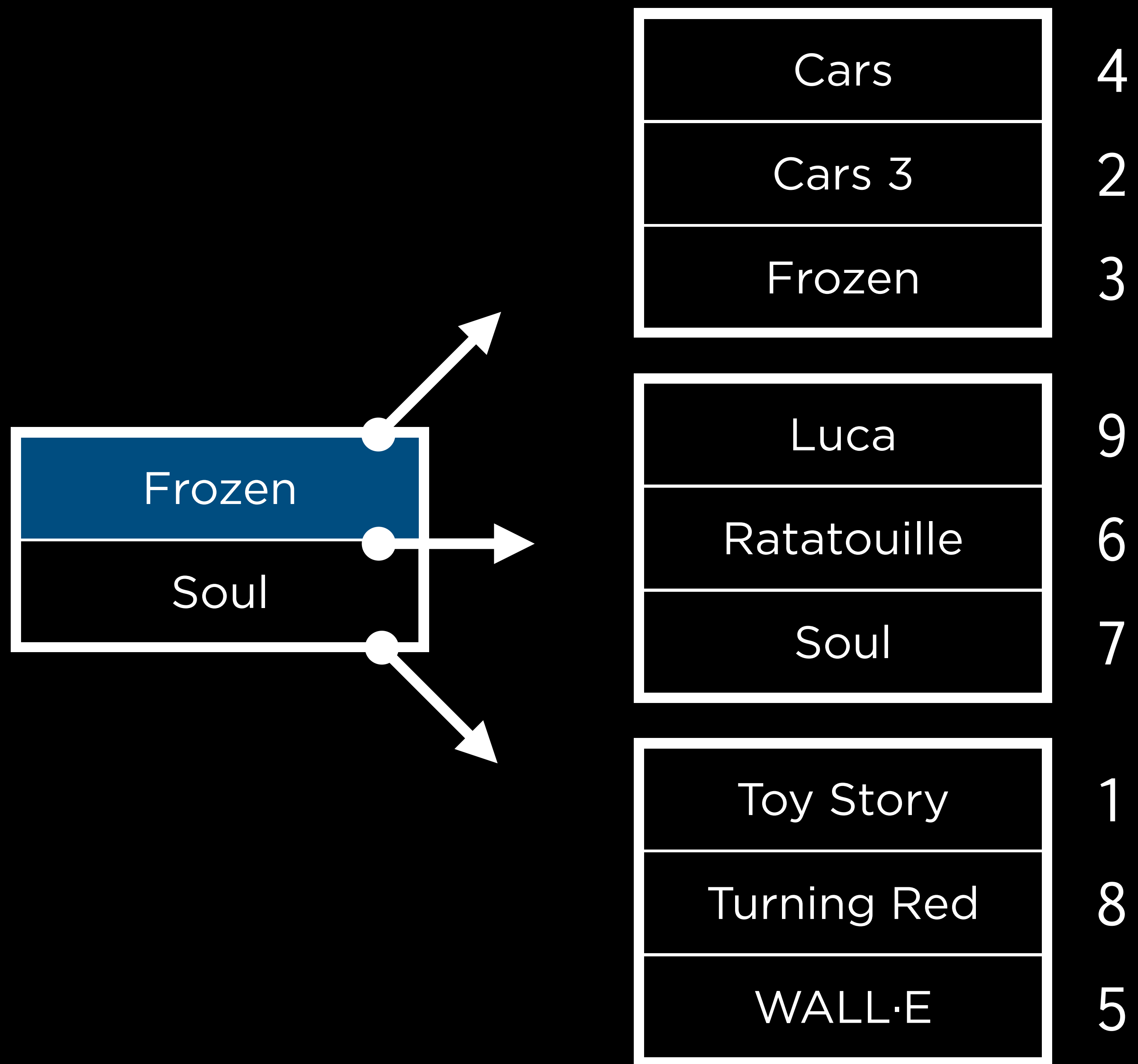


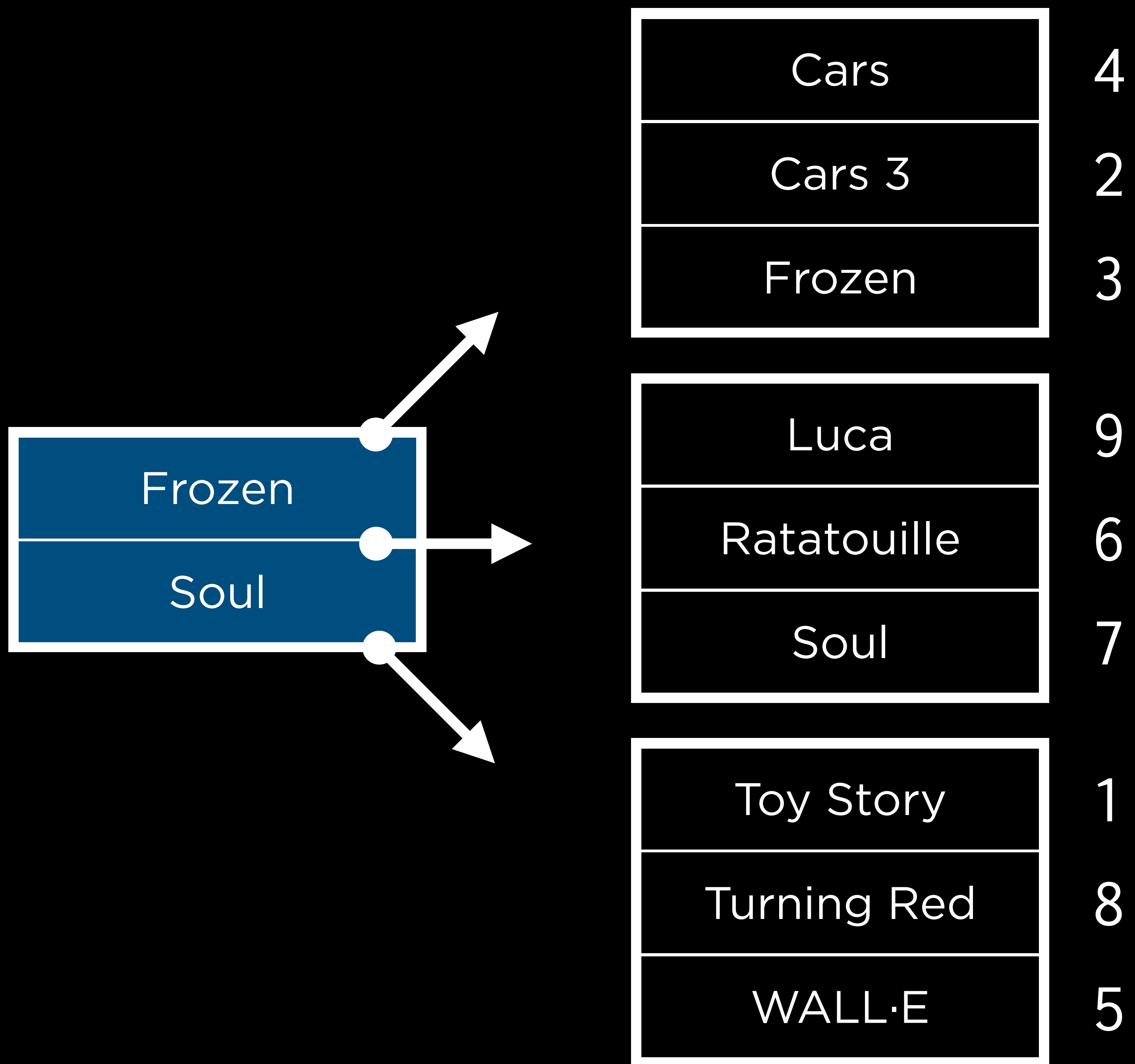




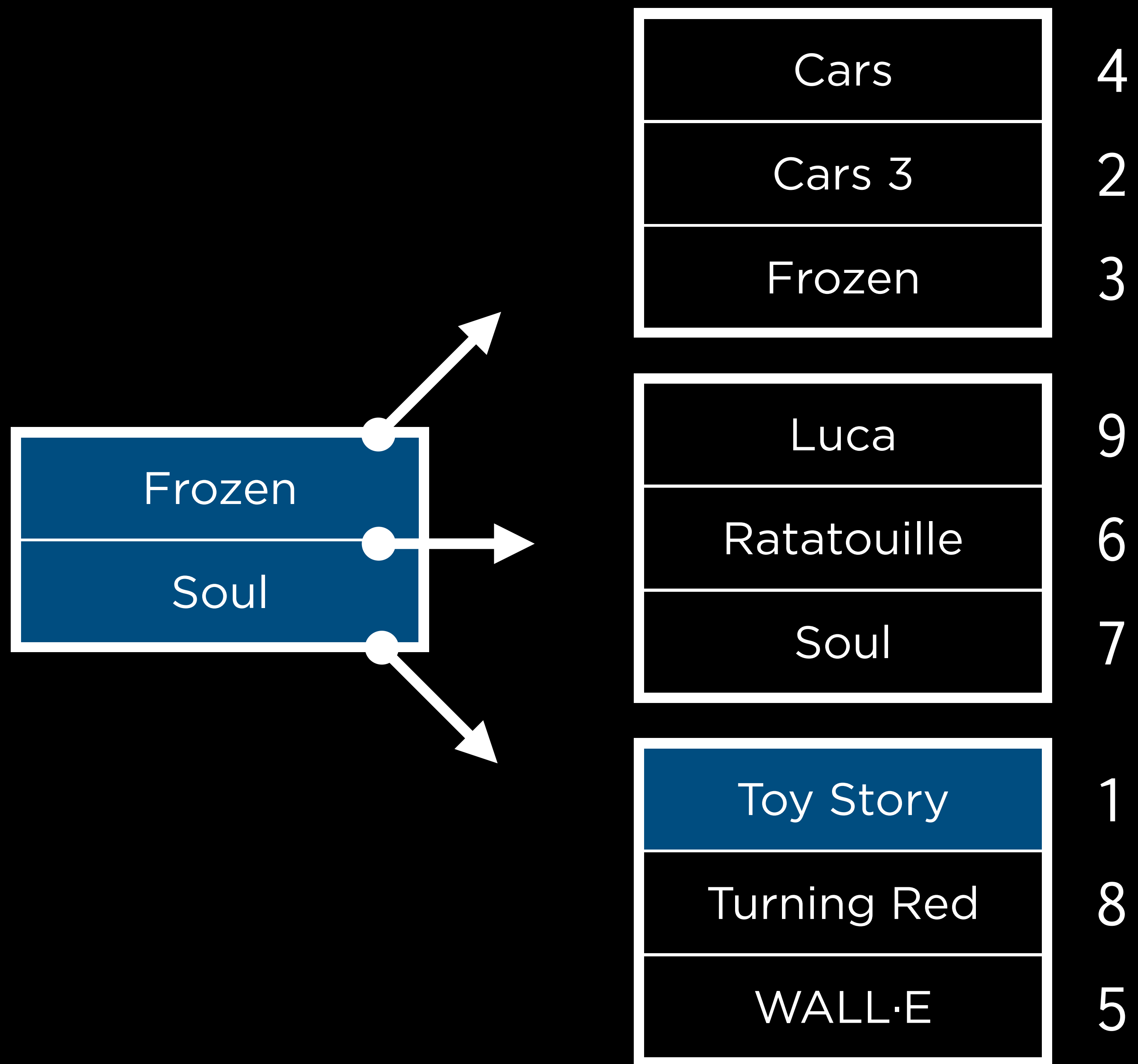


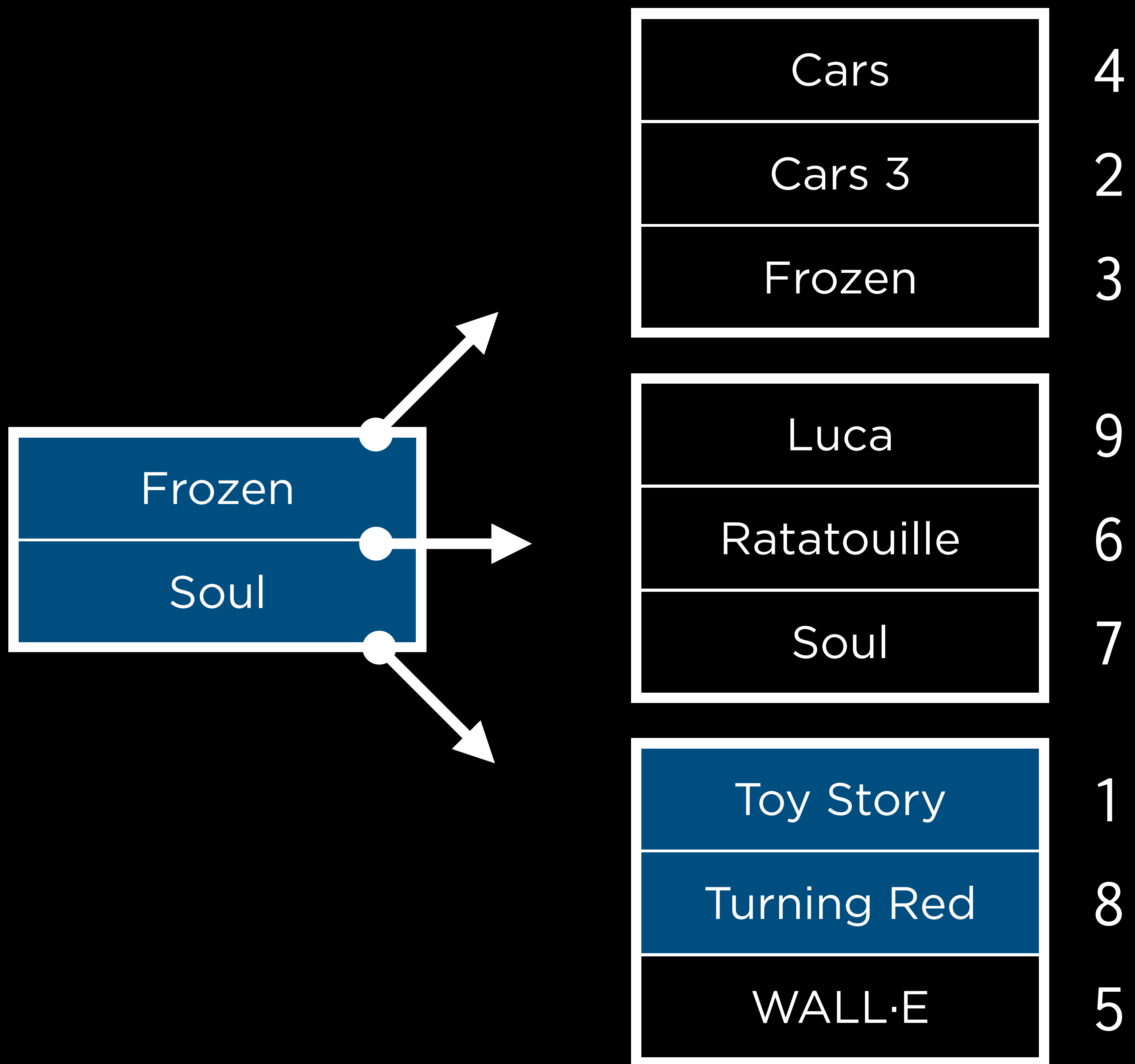


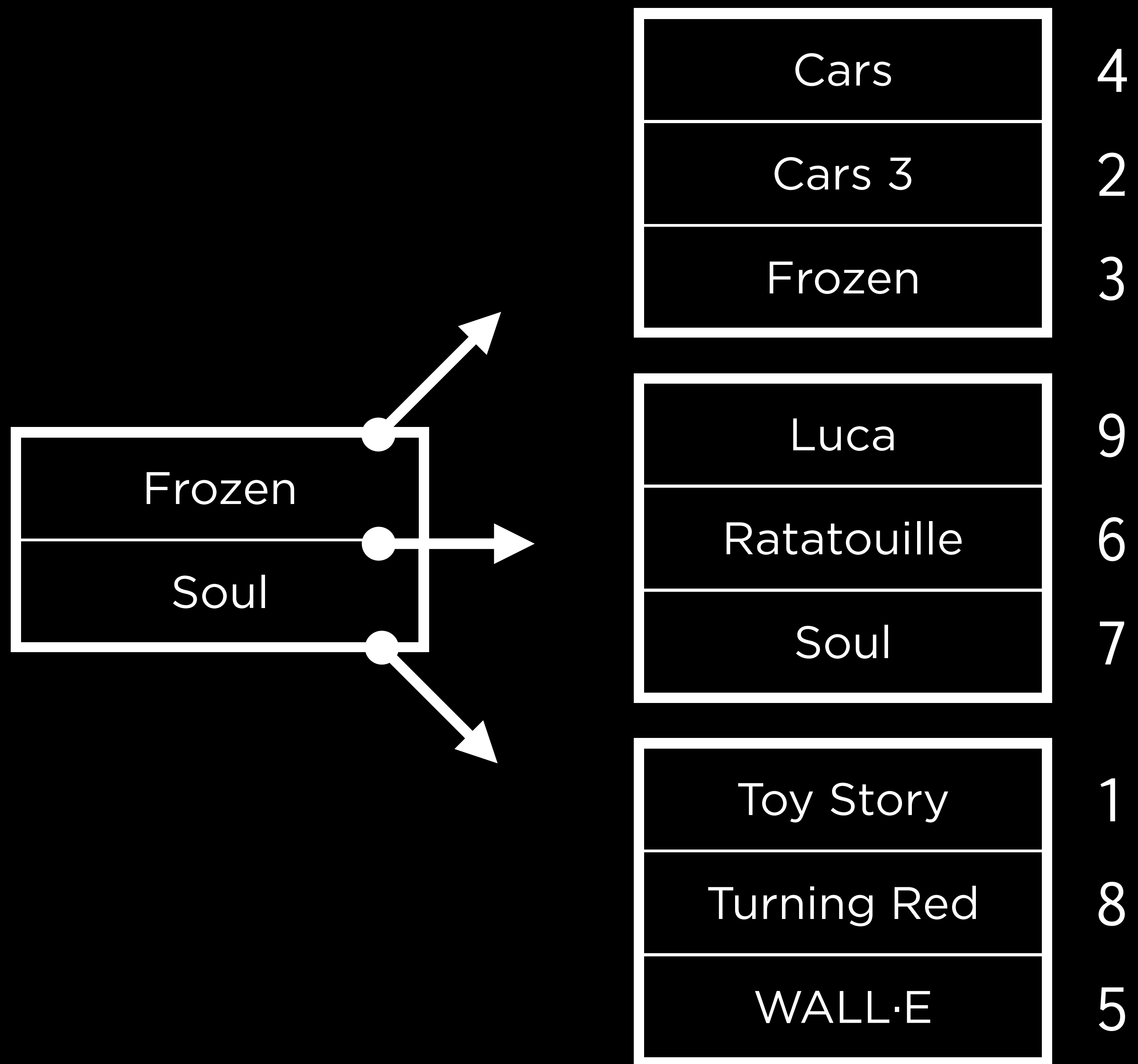


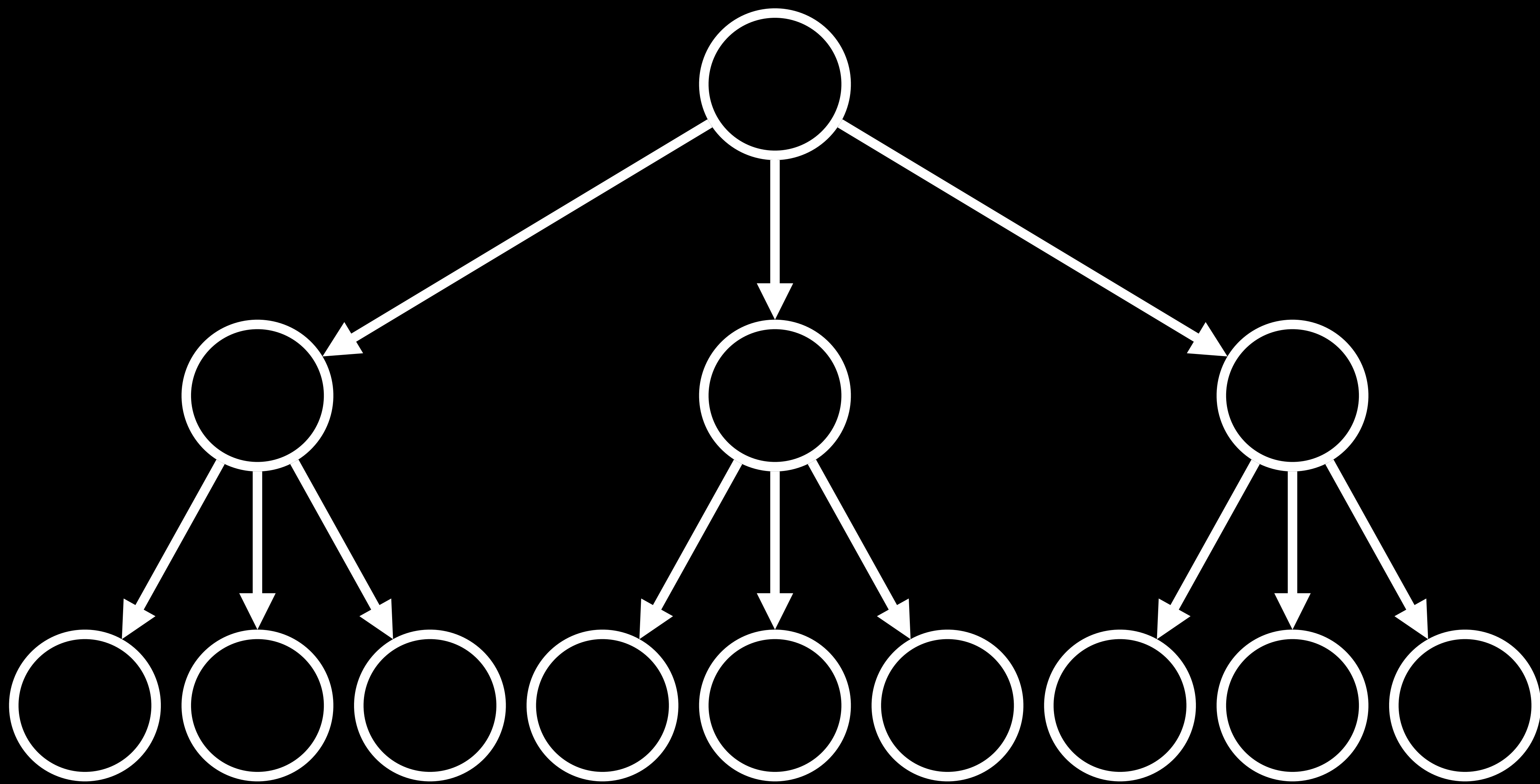












# Partial Index

An index that includes only a subset of rows from a table

```
CREATE INDEX name  
ON table (column0, ...)  
WHERE condition;
```

**Vacuum**

# Concurrency

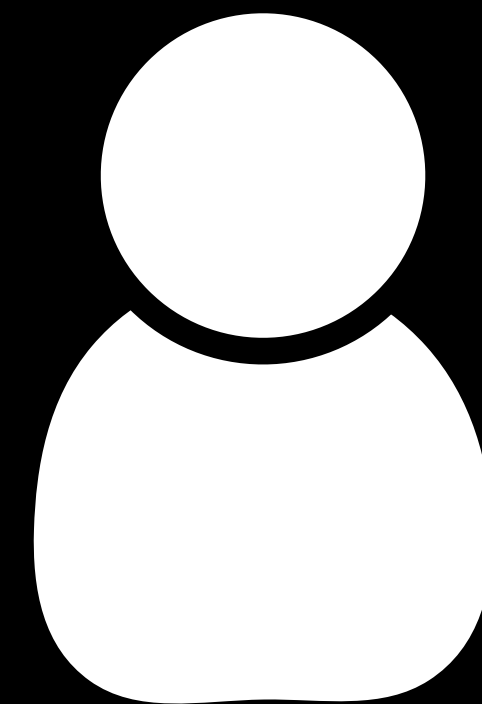


# accounts

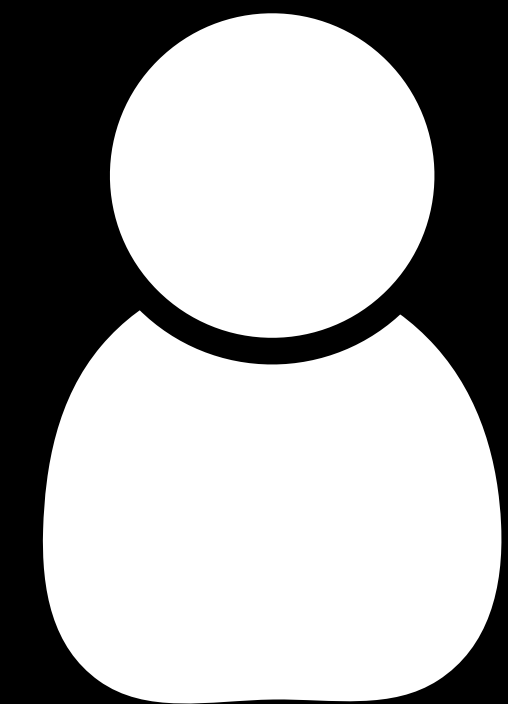
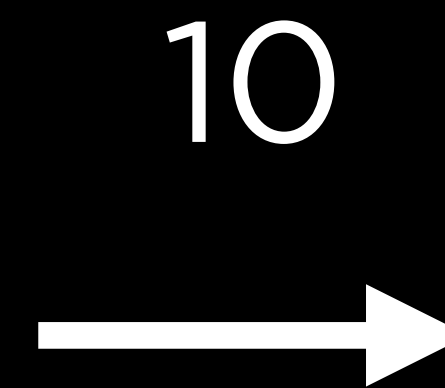
id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30

# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



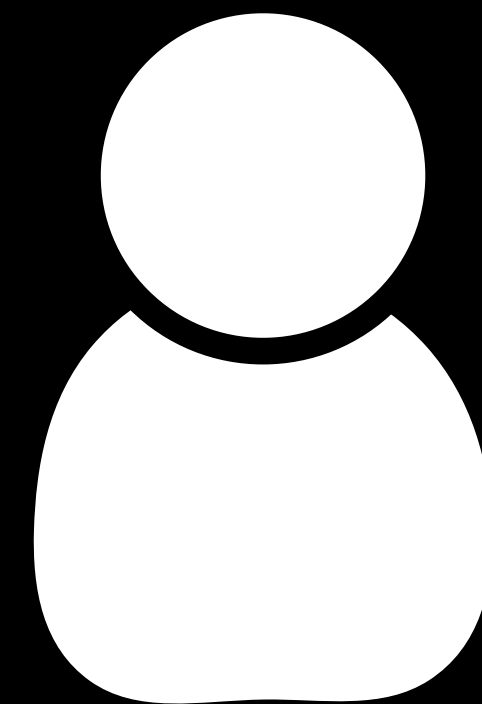
**Alice**



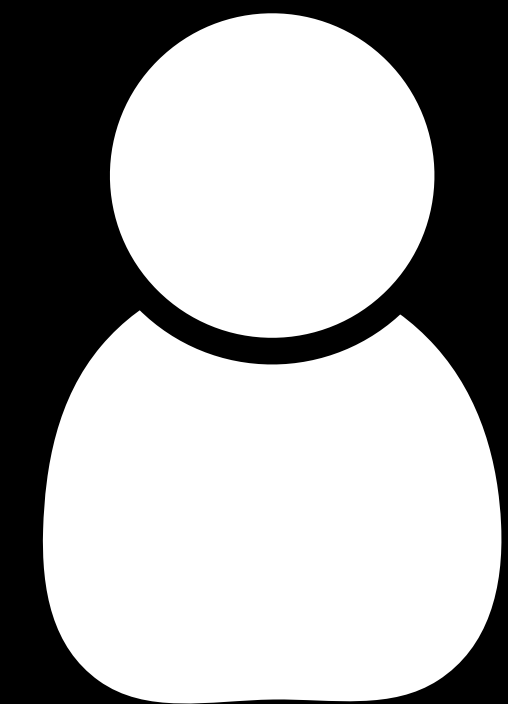
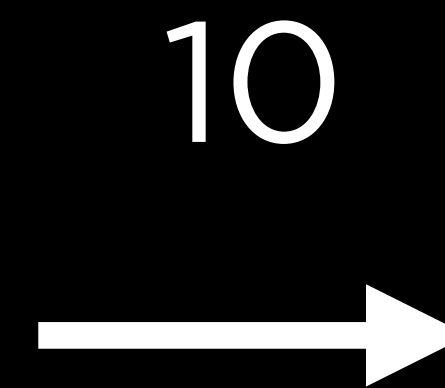
**Bob**

# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



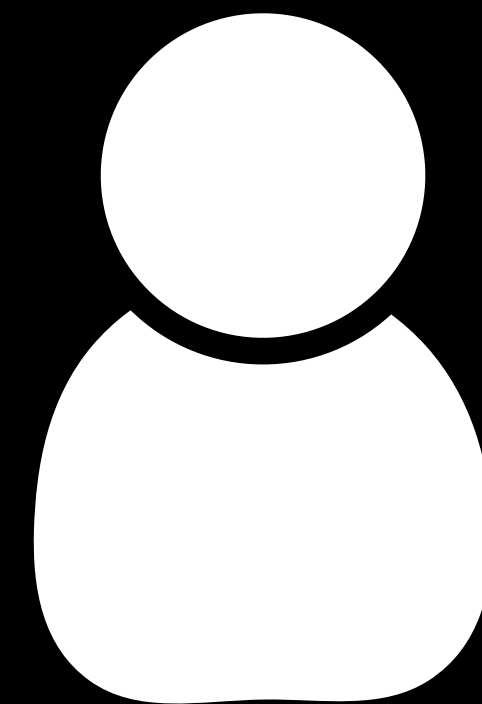
Alice



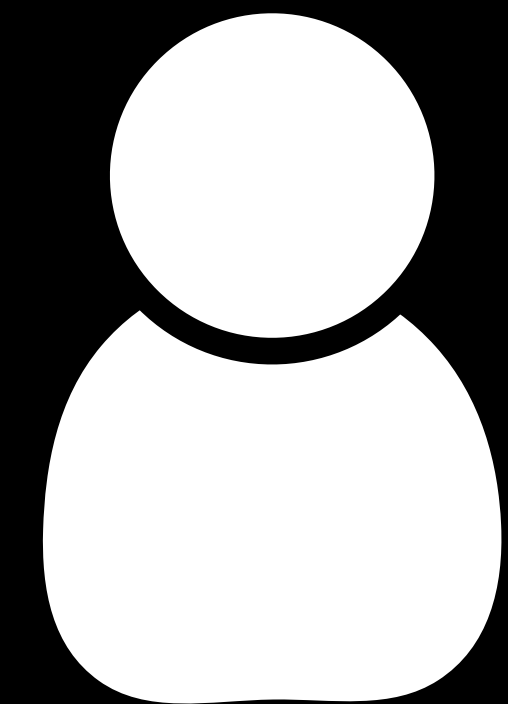
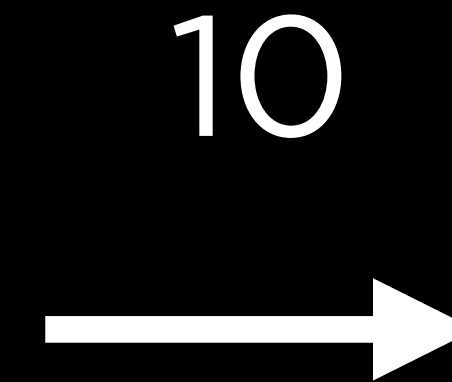
Bob

# accounts

id	name	balance
1	Alice	10
2	Bob	30
3	Charlie	30



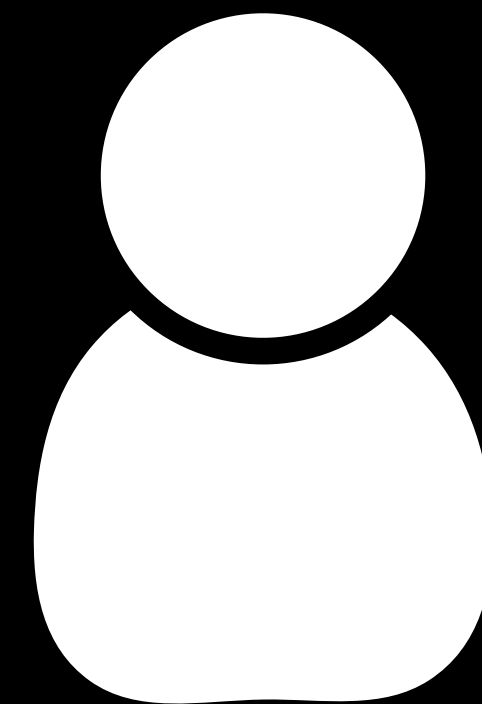
Alice



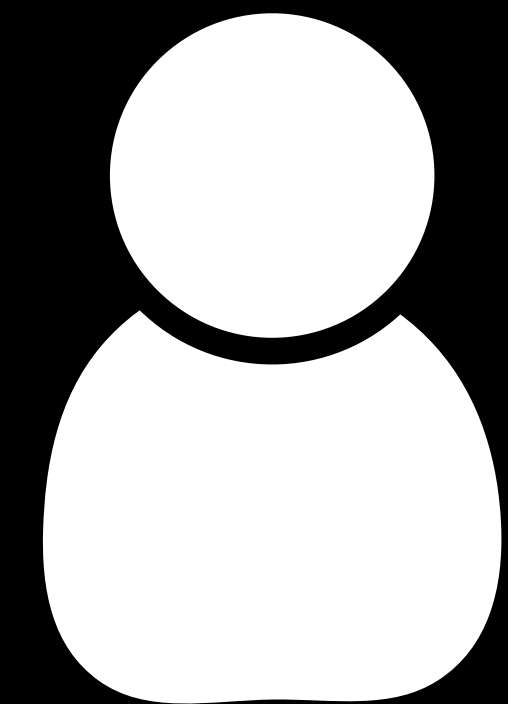
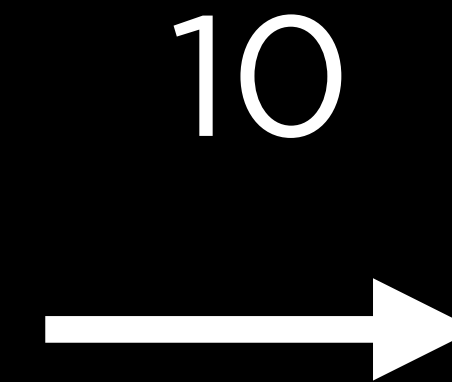
Bob

# accounts

id	name	balance
1	Alice	10
2	Bob	30
3	Charlie	30



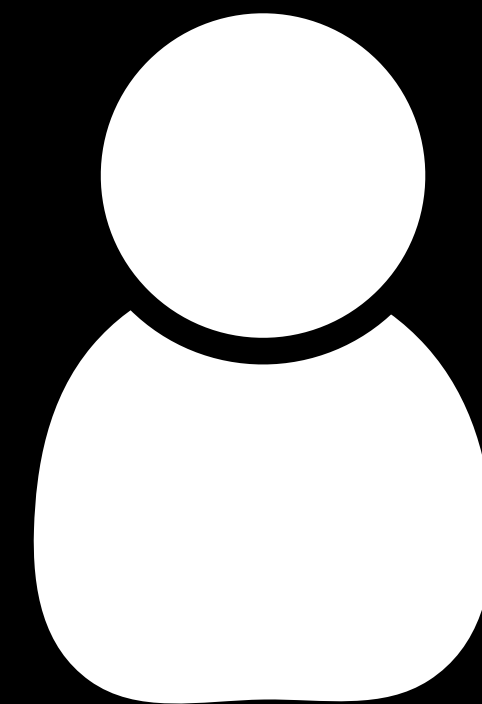
Alice



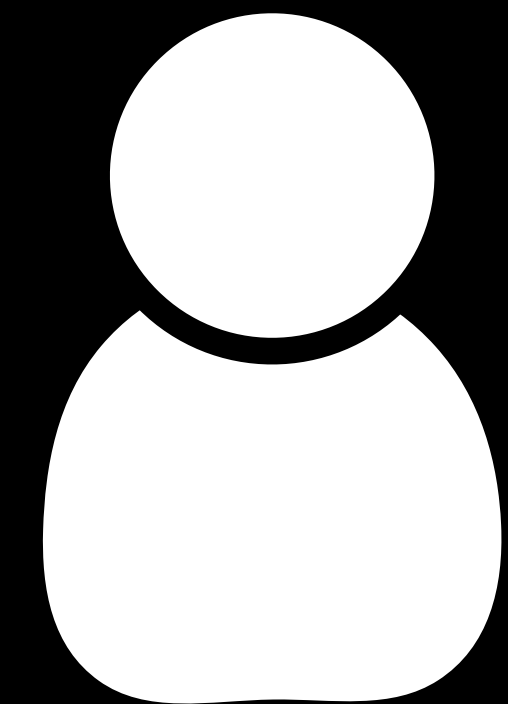
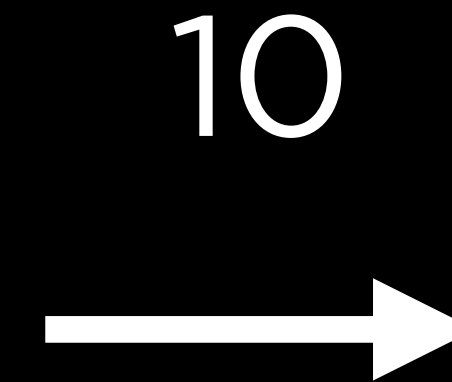
Bob

# accounts

id	name	balance
1	Alice	0
2	Bob	30
3	Charlie	30



**Alice**



**Bob**

# accounts

id	name	balance
1	Alice	0
2	Bob	30
3	Charlie	30

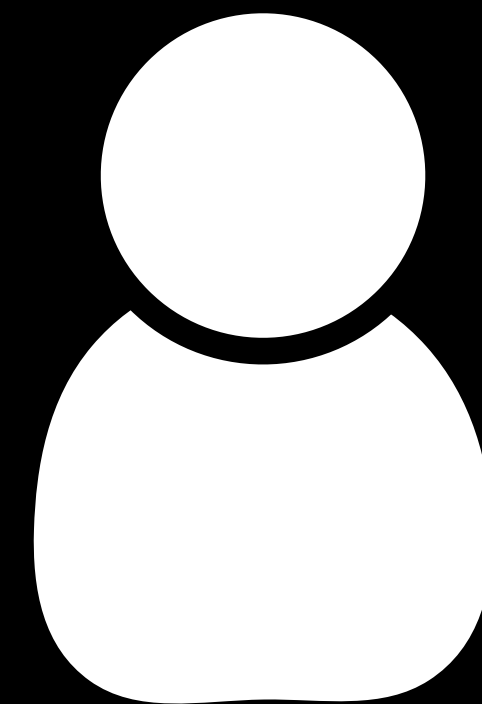
# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30

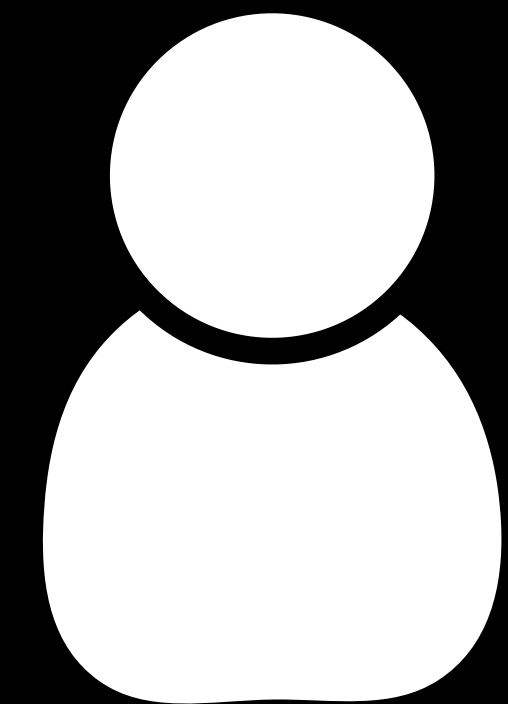
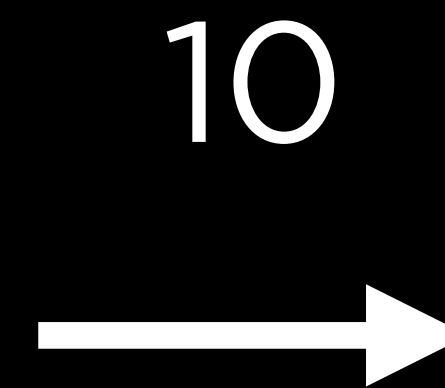


# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



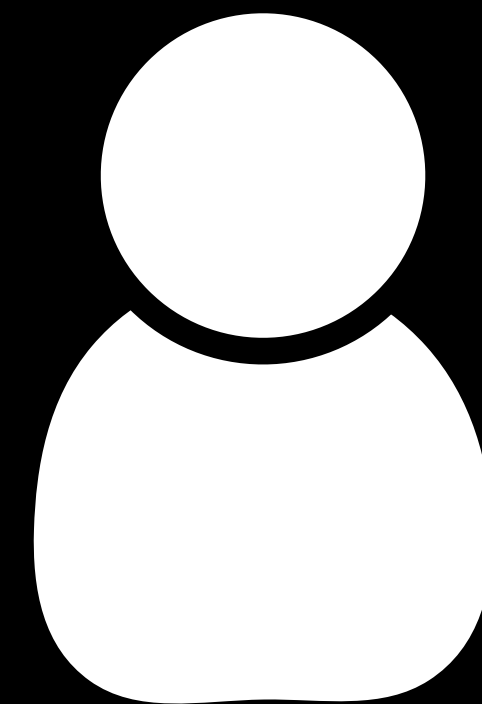
**Alice**



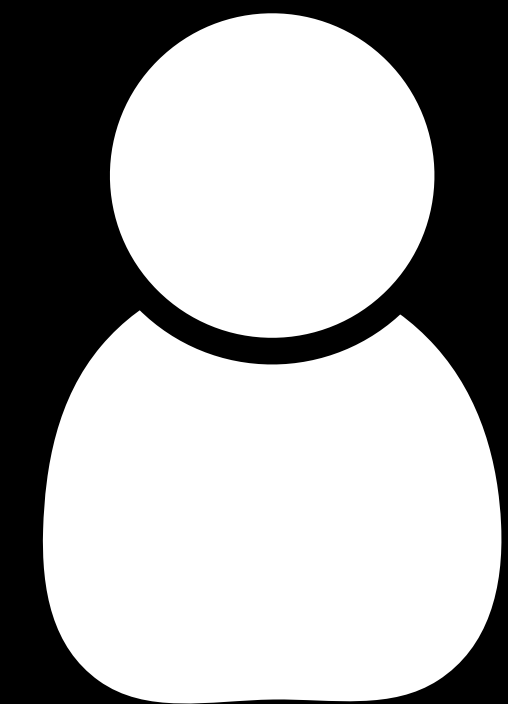
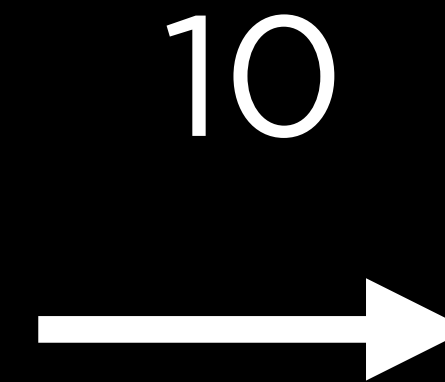
**Bob**

# accounts

id	name	balance
1	Alice	0
2	Bob	30
3	Charlie	30



**Alice**



**Bob**

# Transaction

A unit of work in a database

ACID

Atomicity

Consistency

Isolation

Durability

```
BEGIN TRANSACTION;
```

```
BEGIN TRANSACTION;
```

```
...
```

```
BEGIN TRANSACTION;
```

```
...
```

```
COMMIT;
```

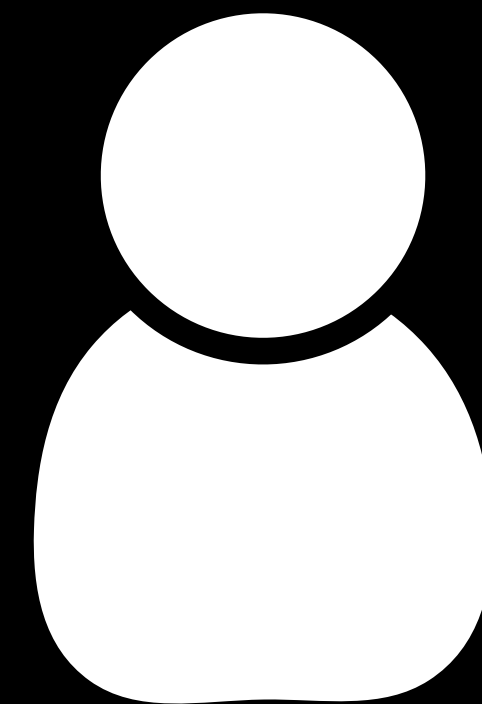


# accounts

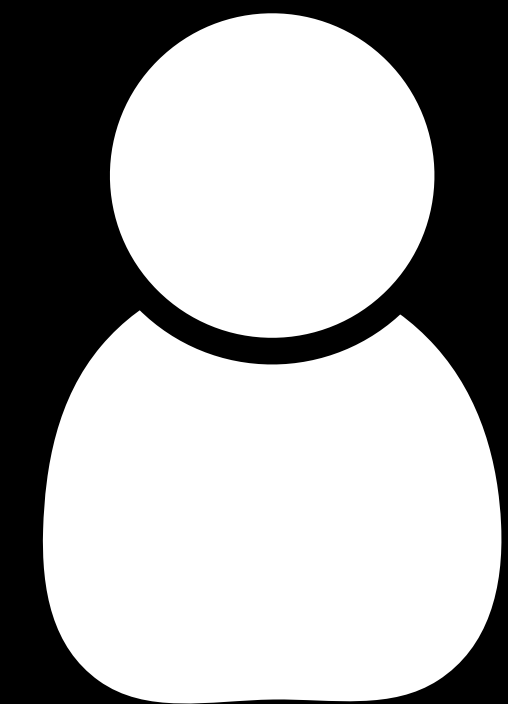
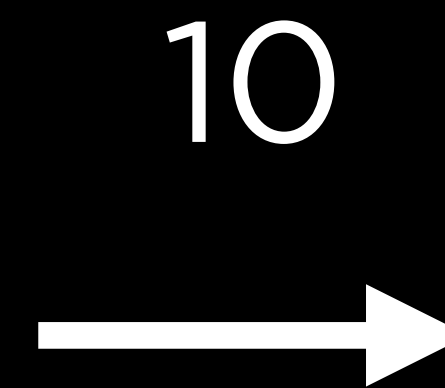
id	name	balance
1	Alice	0
2	Bob	30
3	Charlie	30

# accounts

id	name	balance
1	Alice	0
2	Bob	30
3	Charlie	30



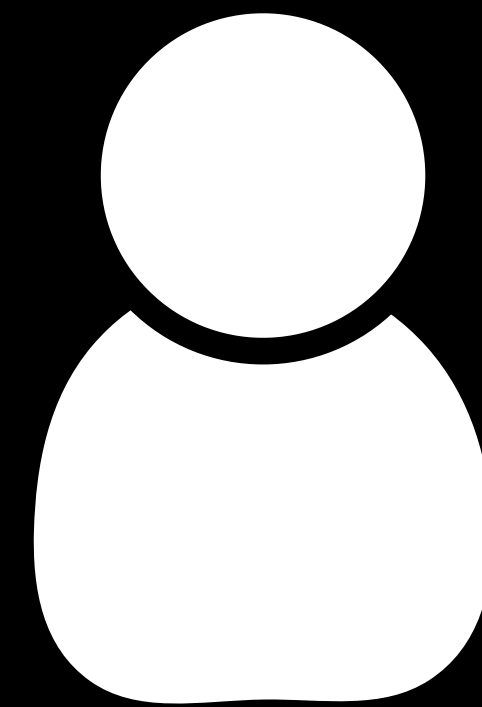
**Alice**



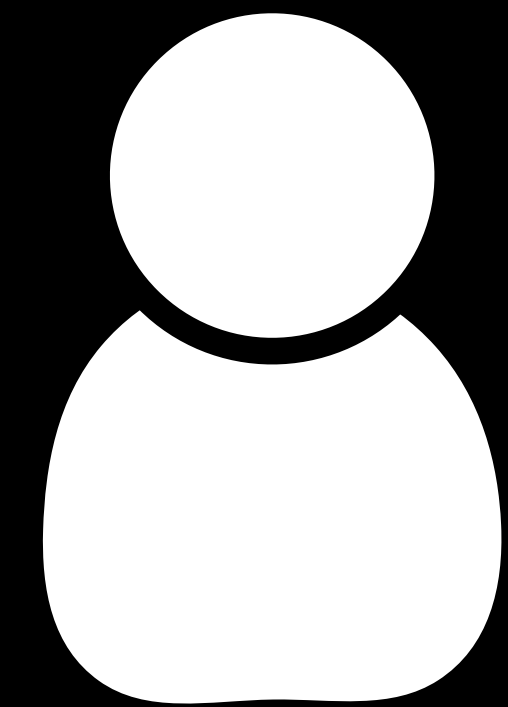
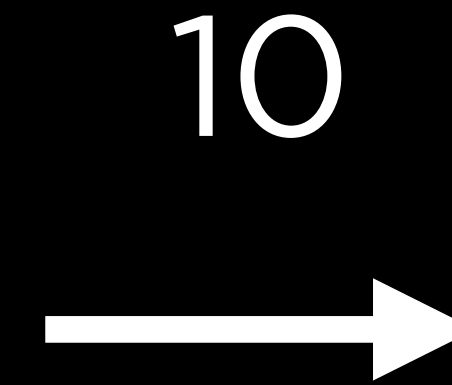
**Bob**

# accounts

id	name	balance
1	Alice	-10
2	Bob	40
3	Charlie	30



Alice



Bob

# accounts

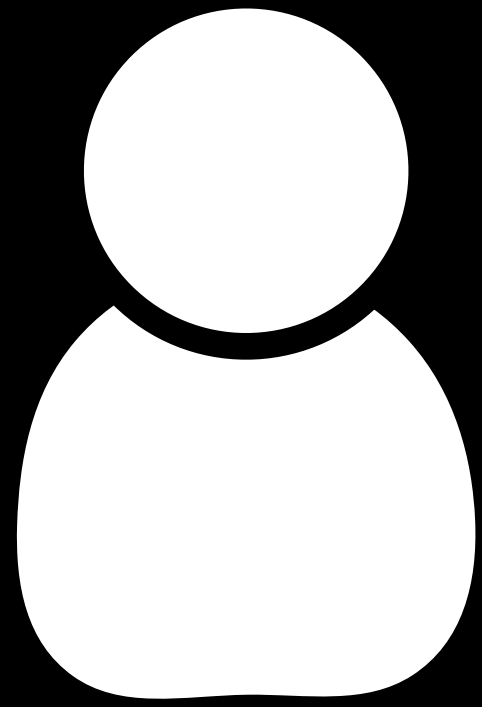
id	name	balance
1	Alice	0
2	Bob	30
3	Charlie	30

```
BEGIN TRANSACTION;
```

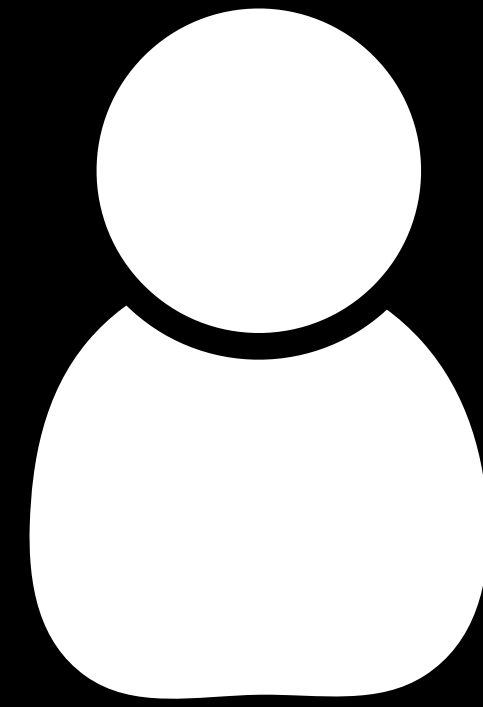
```
...
```

```
ROLLBACK;
```

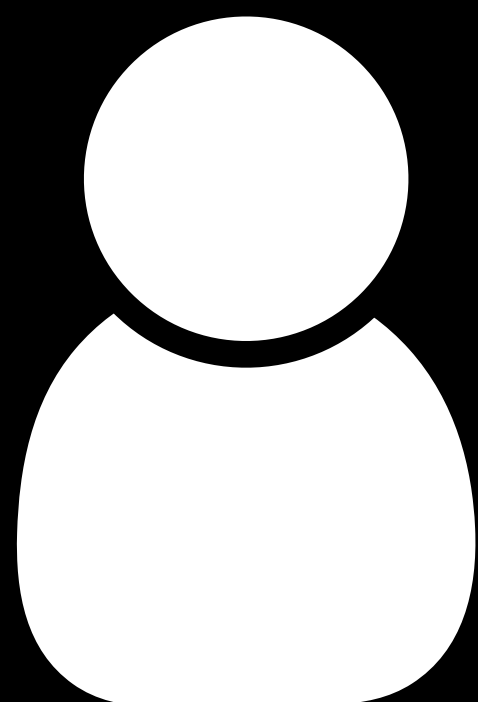
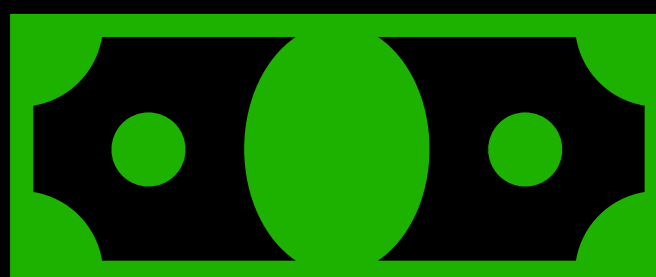
# Race Conditions



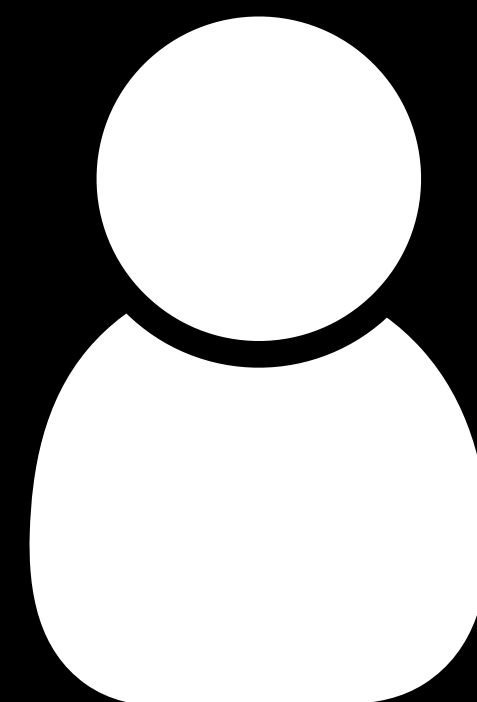
**Charlie**



**Alice**



Charlie



Alice





Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
+\$30 to Alice		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
	Charlie's balance: \$30	
+\$30 to Alice		
-\$30 from Charlie		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
	Charlie's balance: \$30	
+\$30 to Alice		
	+\$30 to Alice	
-\$30 from Charlie		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
	Charlie's balance: \$30	
+\$30 to Alice		
	+\$30 to Alice	
-\$30 from Charlie		
	-\$30 from Charlie	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
	Charlie's balance: \$30	
+\$30 to Alice		
	+\$30 to Alice	
-\$30 from Charlie		
	-\$30 from Charlie	
	CHECK constraint failed	



Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
	Charlie's balance: \$30	
+\$30 to Alice		
	+\$30 to Alice	
		Alice's balance: \$60
-\$30 from Charlie		
	-\$30 from Charlie	
	CHECK constraint failed	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Charlie's balance: \$30		
	Charlie's balance: \$30	
+\$30 to Alice		
	+\$30 to Alice	
		Alice's balance: \$60
		Withdraw \$60
-\$30 from Charlie		
	-\$30 from Charlie	
	CHECK constraint failed	



Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		





Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		
Commit		
	Begin transaction	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		
Commit		
	Begin transaction	
	Charlie's balance: \$0	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		
Commit		
	Begin transaction	
	Charlie's balance: \$0	
	+\$30 to Alice	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		
Commit		
	Begin transaction	
	Charlie's balance: \$0	
	+\$30 to Alice	
	-\$30 from Charlie	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		
Commit		
	Begin transaction	
	Charlie's balance: \$0	
	+\$30 to Alice	
	-\$30 from Charlie	
	Rollback	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
Begin transaction		
Charlie's balance: \$30		
+\$30 to Alice		
-\$30 from Charlie		
Commit		
	Begin transaction	
	Charlie's balance: \$0	
	+\$30 to Alice	
	-\$30 from Charlie	
	Rollback	

Transfer \$30 to Alice	Transfer \$30 to Alice	Withdraw \$60
		Begin transaction
		Alice's balance: \$60
		Withdraw \$60
		Commit

**Locks**



UNLOCKED

SHARED

EXCLUSIVE

...

# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30

UNLOCKED

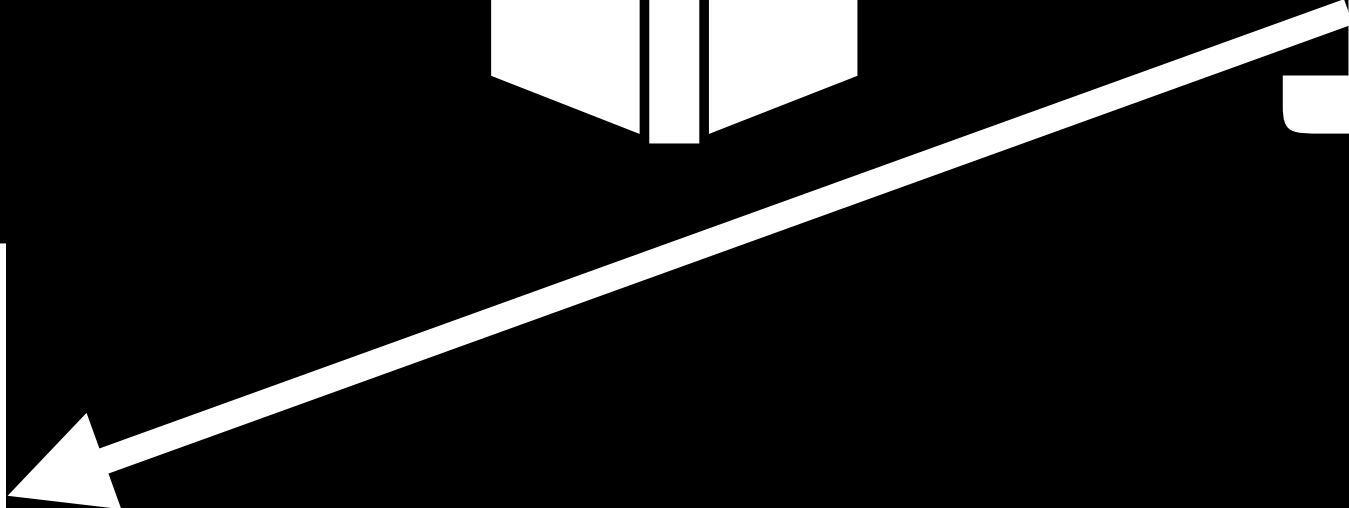
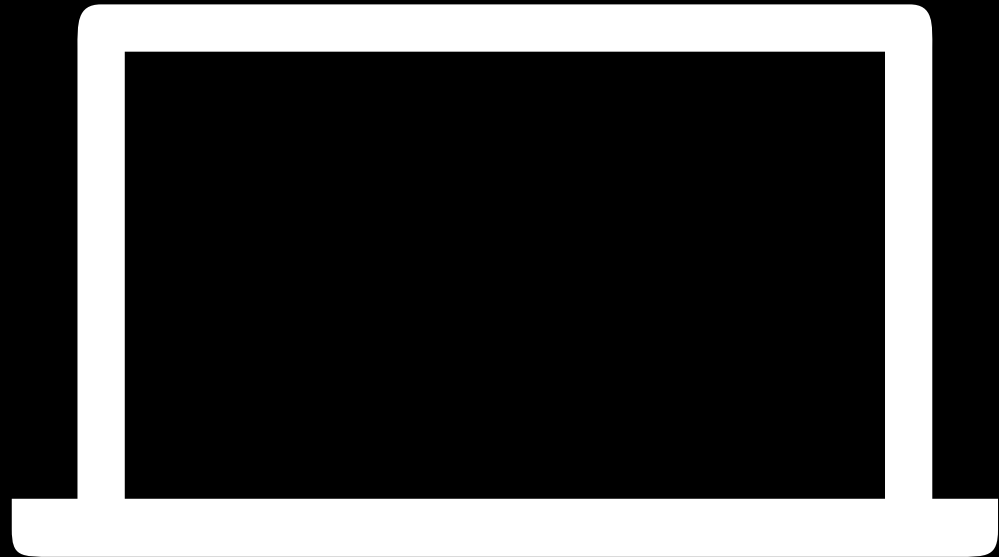


**accounts**

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



**SHARED**

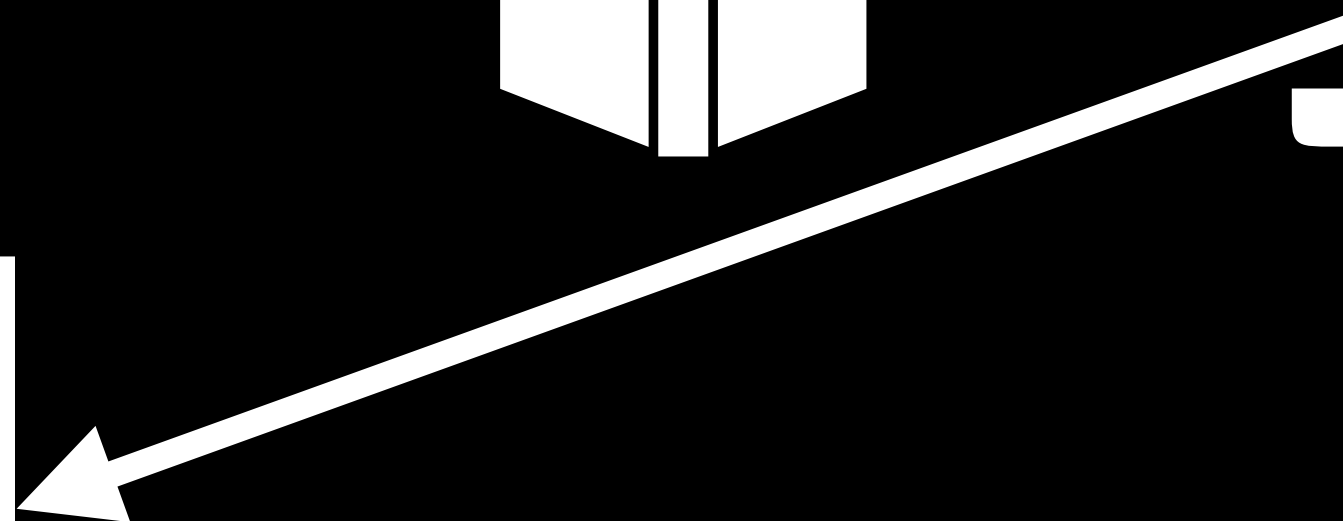


# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



SHARED



SHARED

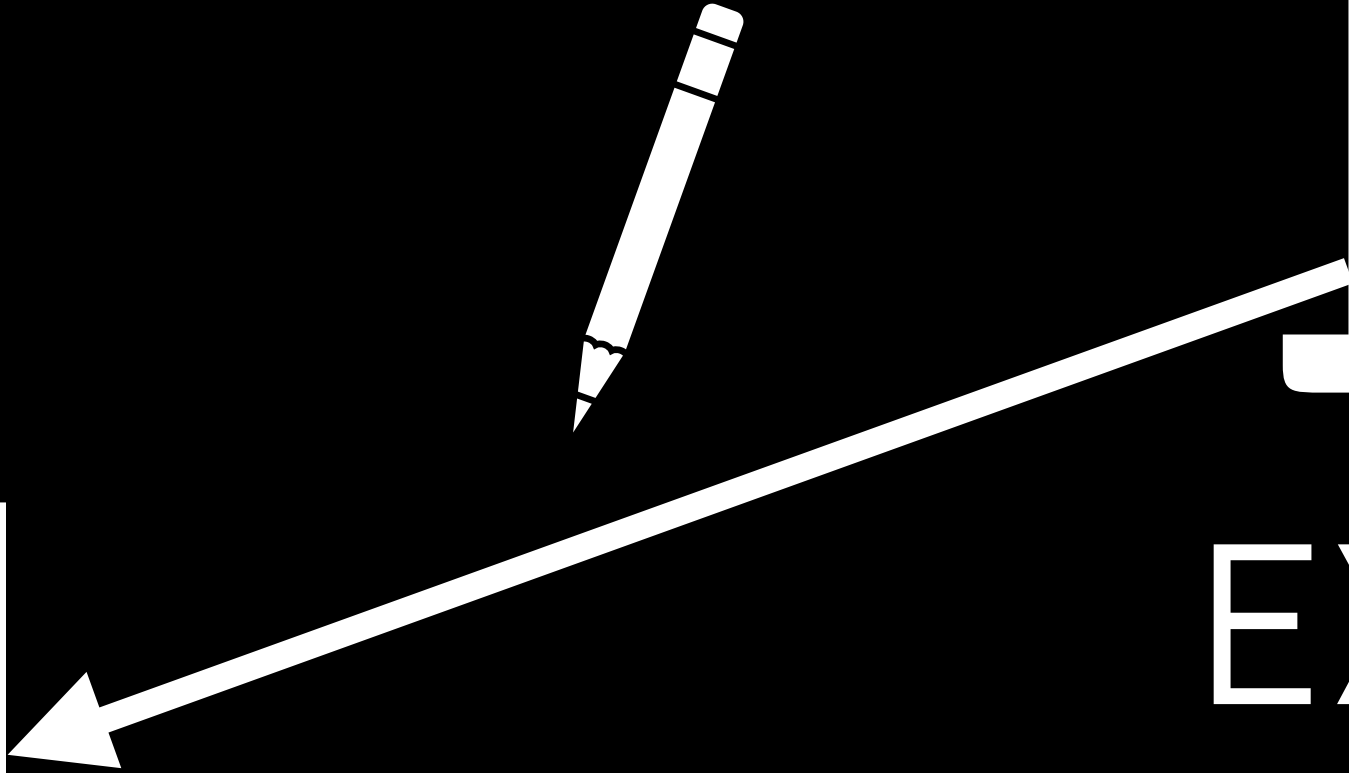
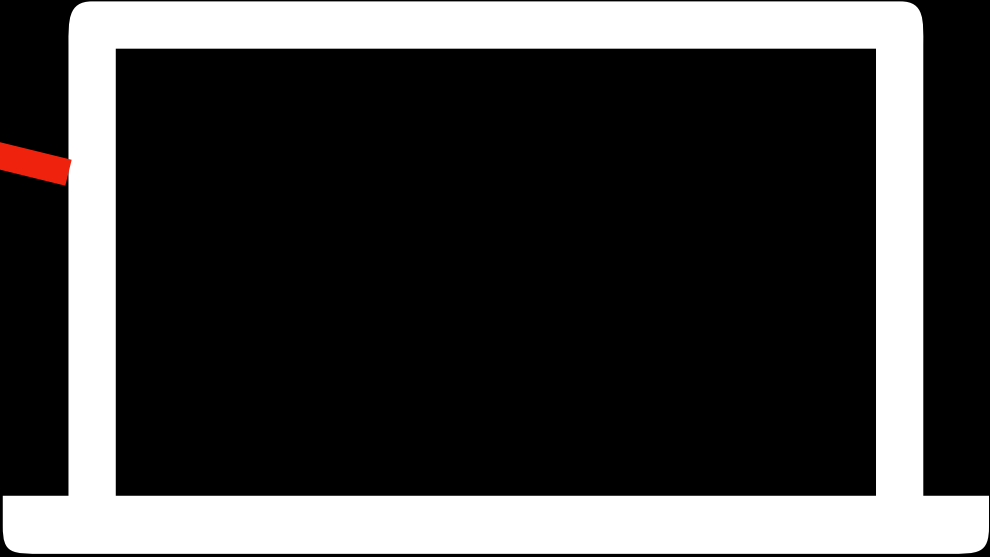


# accounts

id	name	balance
1	Alice	10
2	Bob	20
3	Charlie	30



EXCLUSIVE



Introduction to

# Databases with SQL

Optimizing