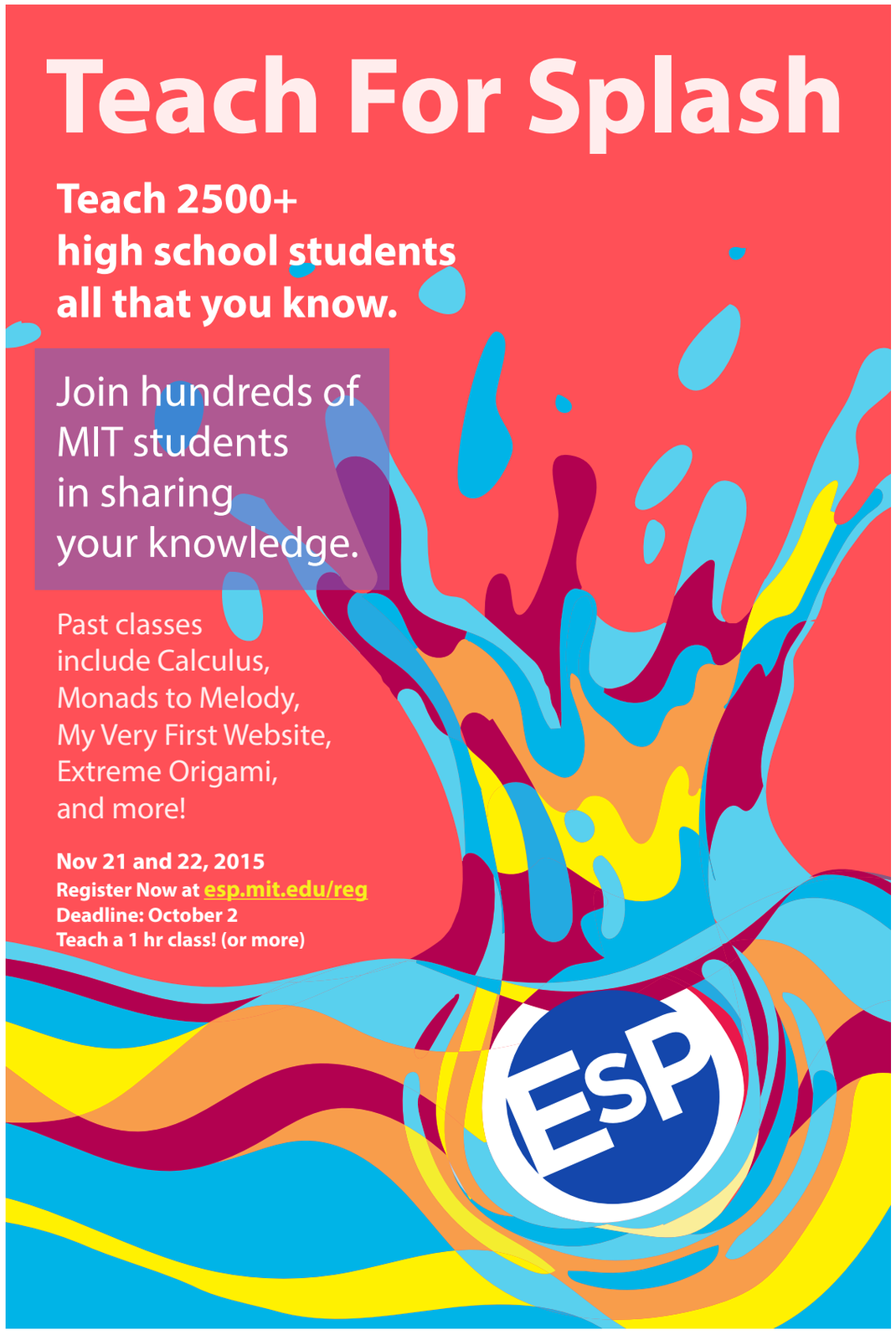
# A Compiler Optimization for Automatic Database Result Caching

Ziv Scully (CMU)
Adam Chlipala (MIT)

POPL'17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Teach a 1 hr class! (or more)
ESP


## M11038: A Battle of Combinatorics Full!

Difficulty: **

Teachers: Luis Herrera Arias

Come and learn about counting things you didn't know you could count. We'll play fun games and learn the secrets of gambling.

**Meeting Time**
Section 1: Sun 9:05am--11:55am

**Grades**
10 - 12

**Enrollment**
Section 1: **Full!** (max 12)

## M11106: Counting Beyond Infinity Full!

Difficulty: ****

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## M11128: Calculate Pi with Trains!

Difficulty: ***

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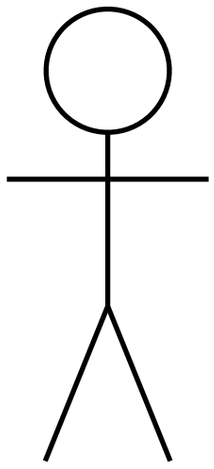

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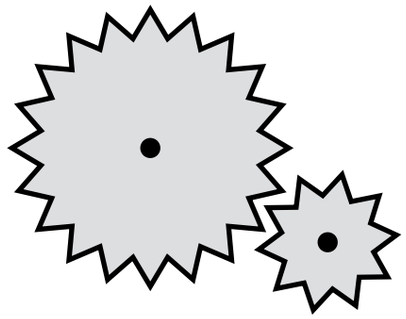
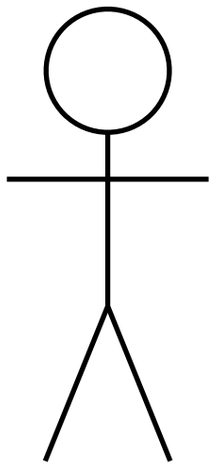


Request logic

Database

| *id* | *title* | *max_size* | *size* |
|---|---|---|---|
| 11038 | "A Battle of Combinatorics" | 12 | 12 |
| 11106 | "Counting Beyond Infinity" | 40 | 40 |
| 11128 | "Calculate Pi With Trains!" | 55 | 54 |



show catalog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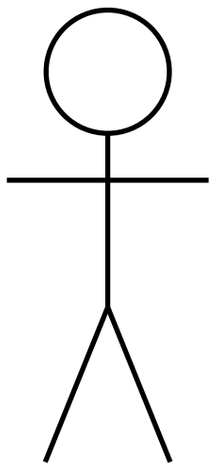

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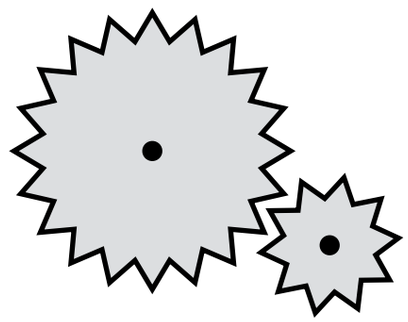

Request logic

query

SELECT *id*, *title* WHERE TRUE

Database

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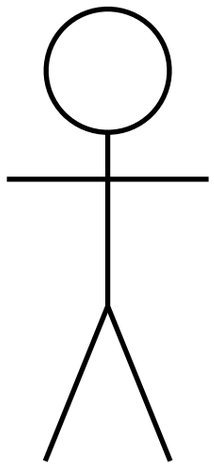

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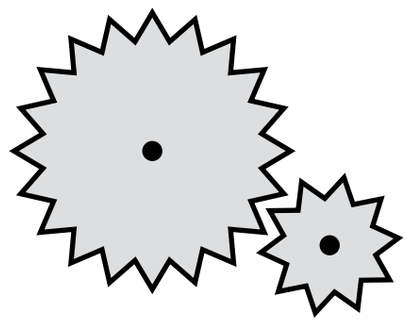

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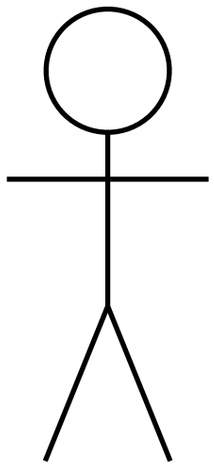

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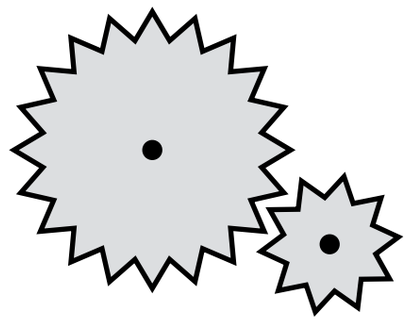

Web Server

Request logic

query

SELECT *max_size*, *size*
WHERE *id* = 11128

Database

| *id* | *title* | *max_size* | *size* |
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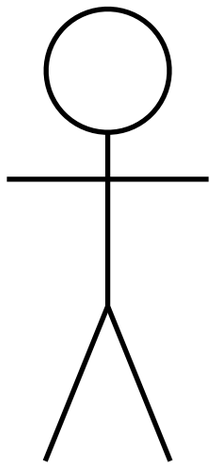
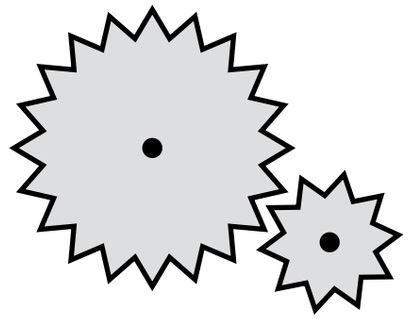


register 11128



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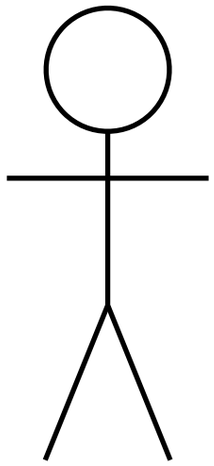

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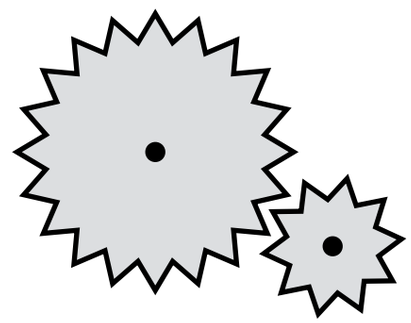

Request logic

update

UPDATE *size* = *size* + 1
WHERE *id* = 11128

Database

| *id* | *title* | *max_size* | *size* |
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**Deadline: Octo**
**Teach a 1 hr cla**

## S9802: How to make a Tesla Coil

Difficulty: ***

Teachers: peter Krogen

Ever wonder how a Tesla coil works? Interested in how you can make 10'+ sparks, and how those sparks can play music? Want to build your very own Tesla coil? Then this class is for you! We'll begin with a quick lecture on how a Tesla Coil works, from the bottom up. We'll then provide you with kits to build solid-state Tesla Coils that can make music, and we'll be there to assist you in building and debugging. The end product is a shoe box sized Tesla coil, capable of generating sparks and playing music.

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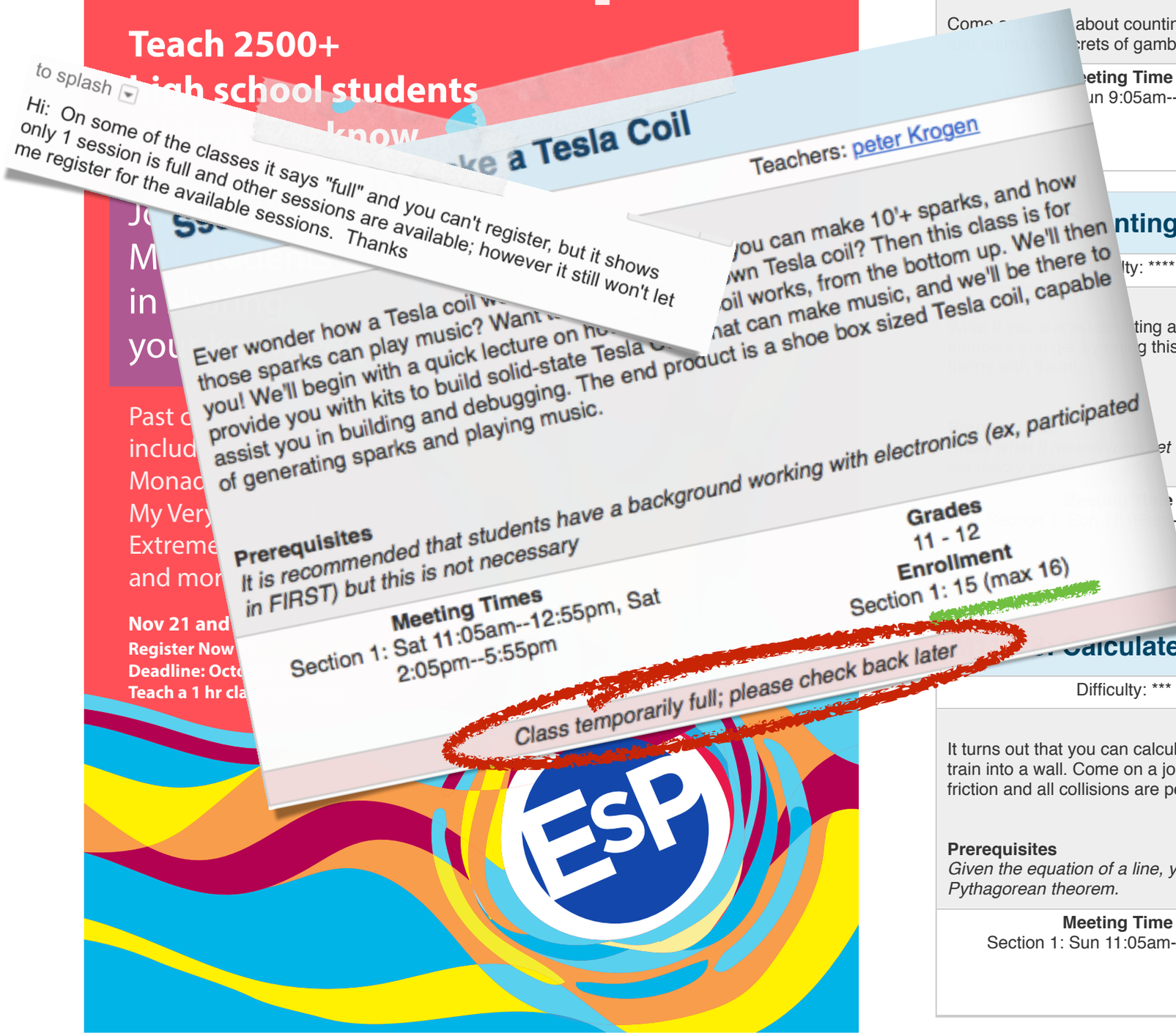


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Teachers: Luis Herrera Arias

## A10204: Math-y Beading

Difficulty: **

Teachers: Vivian Wang

Beads are pretty, but polyhedra are prettier. We'll learn to make buckyballs (a.k.a. truncated icosahedra for math folks or C60 for chem folks) out of beads and string. By the end of the class, you'll have your own shiny geometric trinket to keep! Depending on time and interest, we might learn to make other geometric things...A fractal dodecahedron? Polyhedral carbon nanotori? The possibilities are (almost) endless.

**Prerequisites**
*We'll be working with seed beads (which are pretty small), so a little finger dexterity and a lot of patience will go a long way!*

**Meeting Times**
Section 1: Sat 3:05pm--4:55pm
Section 2: Sun 10:05am--11:55am

**Grades**
9 - 12
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Section 2: **Full!** (max 10)

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to ESP

I have having trouble with changing classes, in that despite the enrollment number on the class being less than the max, it does not allow me to sing up because "class is temporarily full," I have removed my classes that I did have the period, and this class is only available in a single section (its A9946).

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Teachers: Luis Herrera Arias

Teachers: Vivian Wang

*are pretty, but polyhedra are prettier. We'll learn to make buckyballs (a.k.a. truncated icosahedra for math folks or C60 for chem folks) out of beads and string. By the end of the class, you'll have your own shiny geometric trinket to keep! Depending on time and interest, we might learn to make other geometric things...A fractal dodecahedron? Polyhedral carbon nanotori? The possibilities are (almost) endless.*

**Prerequisites**
*We'll be working with seed beads (which are pretty small), so a little finger dexterity and a lot of patience will go a long way!*

**Meeting Times**
Section 1: Sat 3:05pm--4:55pm
Section 2: Sun 10:05am--11:55am

**Grades**
9 - 12
**Enrollment**
Section 1: 9 (max 10)
Section 2: **Full!** (max 10)

*Class temporarily full; please check back later*

## Calculate Pi with Trains!

Difficulty: ***

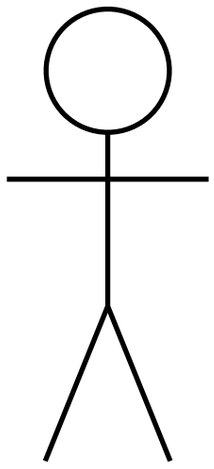
Teachers: Ziv Scully

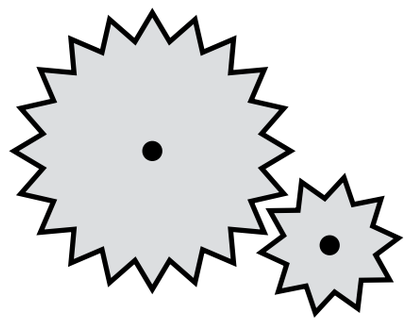
It turns out that you can calculate pi to very high accuracy by bouncing a small train and a big train into a wall. Come on a journey through Extra-Nice Physics Land (where there's no friction and all collisions are perfectly elastic) to see how it works!

**Prerequisites**
*Given the equation of a line, you should know how to find its slope. We'll also use the Pythagorean theorem.*

**Meeting Time**
Section 1: Sun 11:05am--11:55am

**Grades**
9 - 12
**Enrollment**
Section 1: 54 (max 55)





Web Server

Request logic

Database

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| 11106 | "Counting Beyond Infinity" | 40 | 40 |
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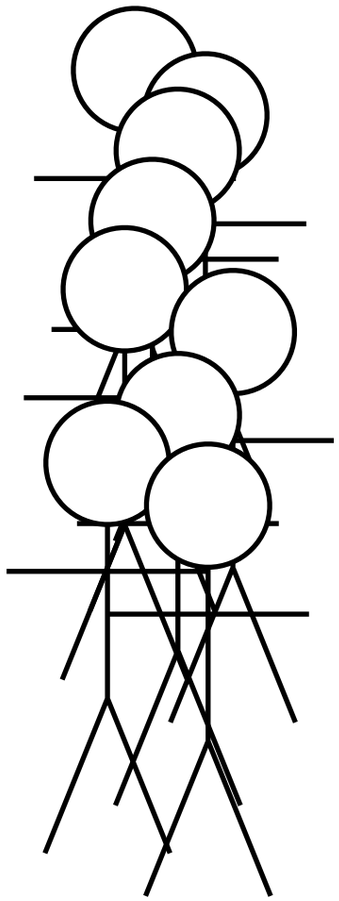

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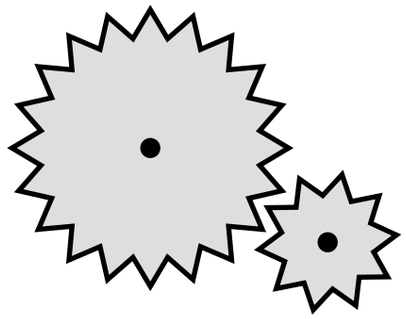

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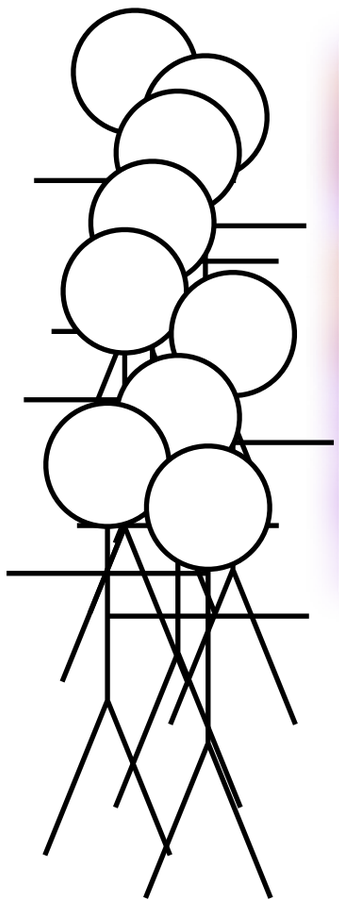

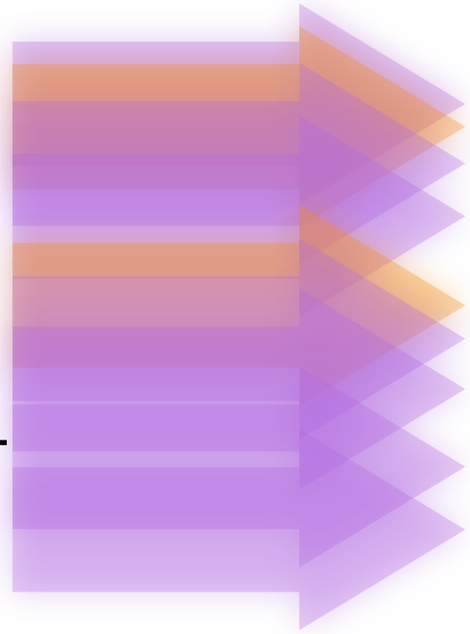

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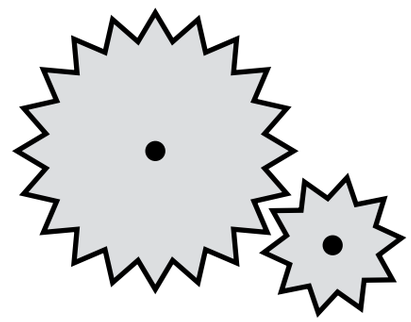

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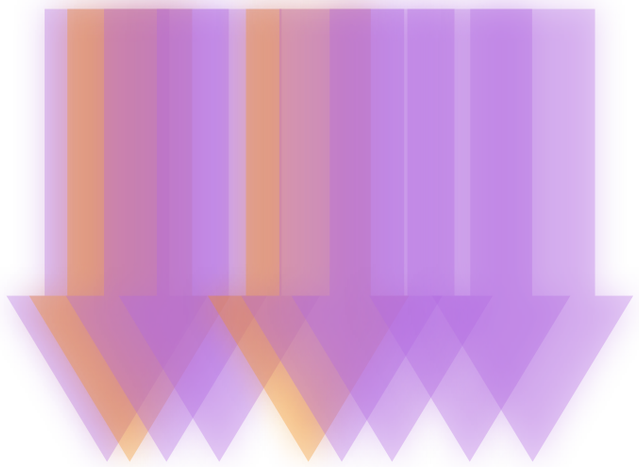

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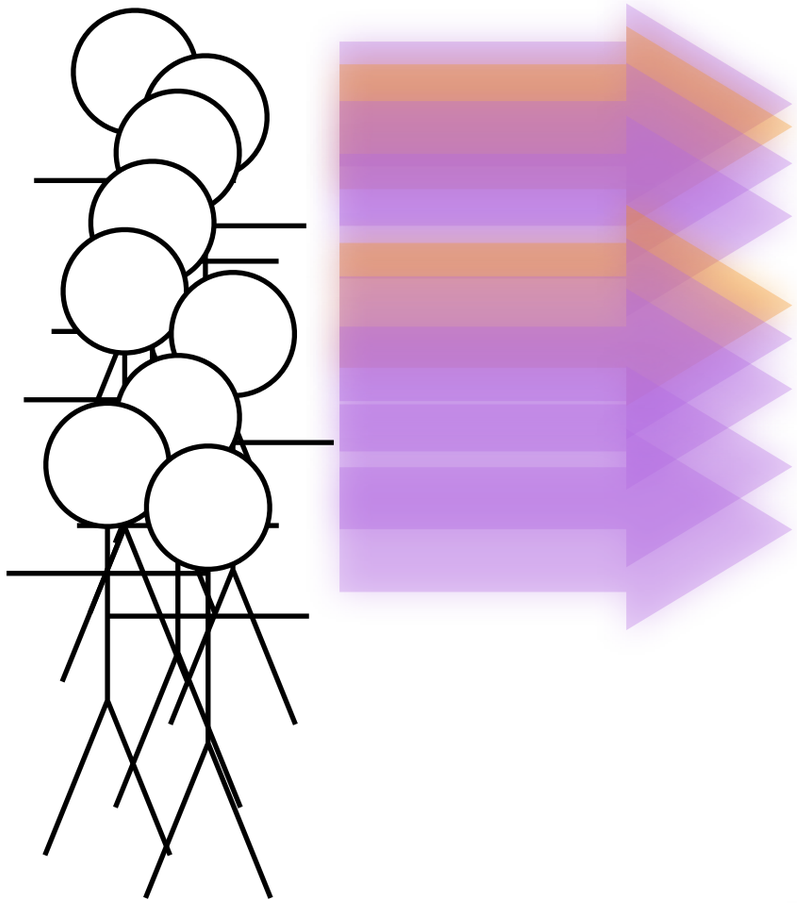
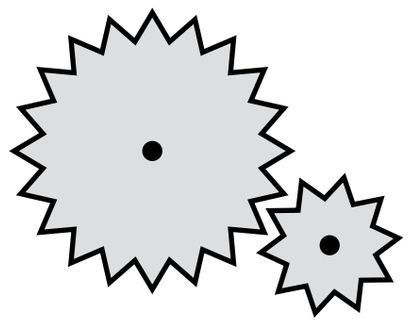




## Web Server



Request logic

Size cache

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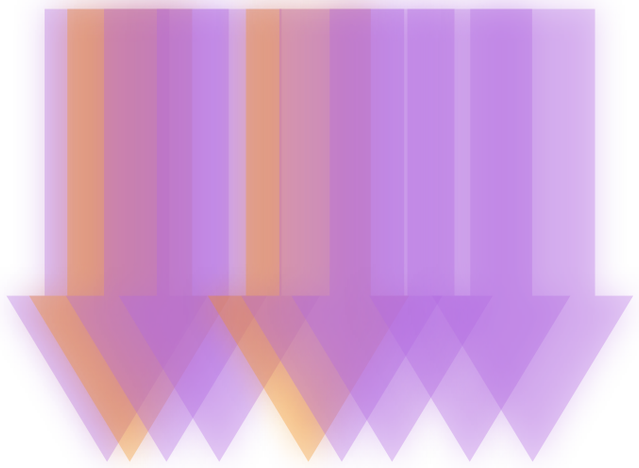

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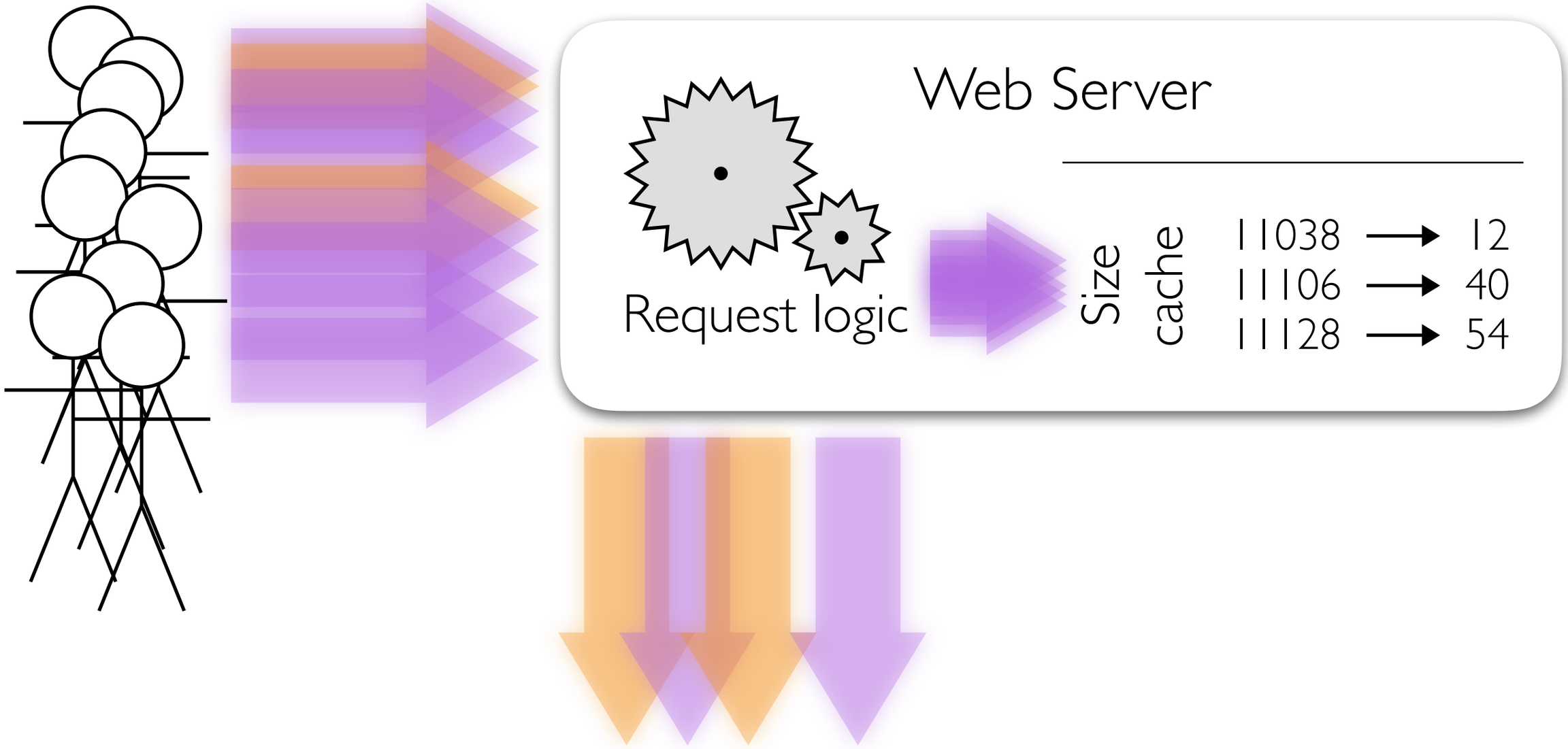


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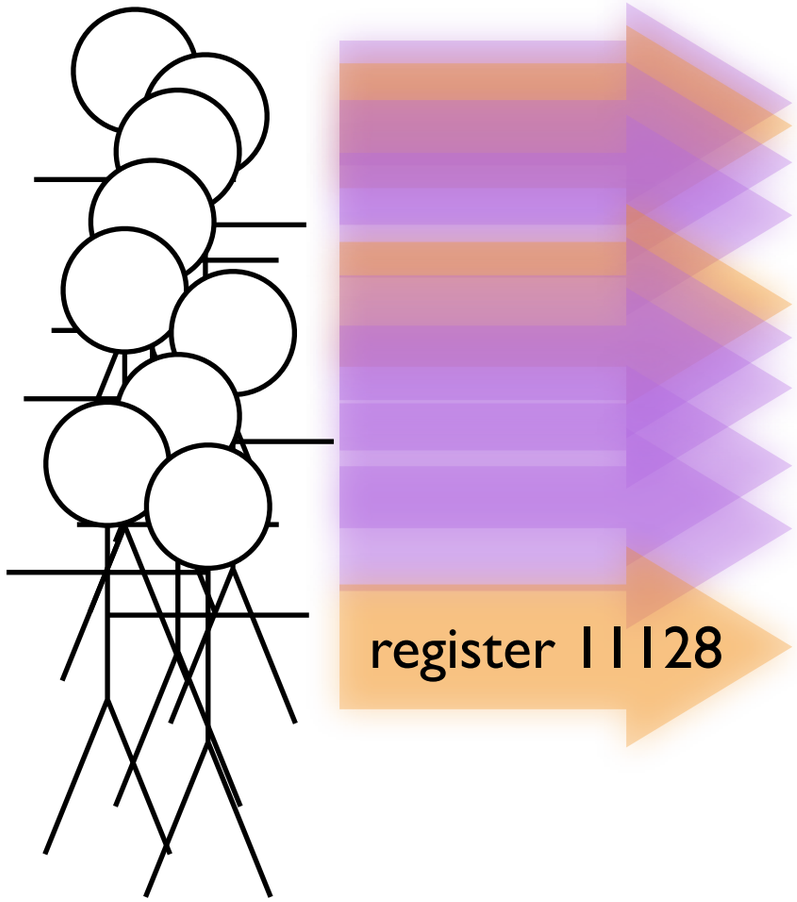

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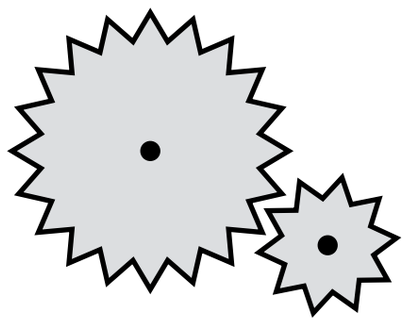
Web Server



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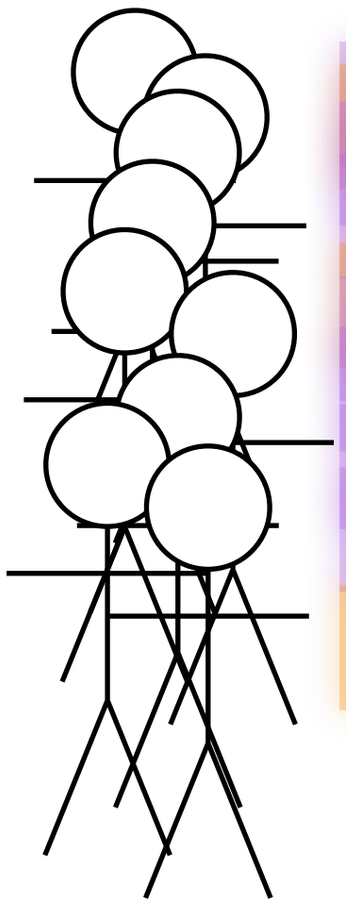

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Web Server

Request logic

Size cache

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update

UPDATE *size* = *size* + 1
WHERE *id* = 11128

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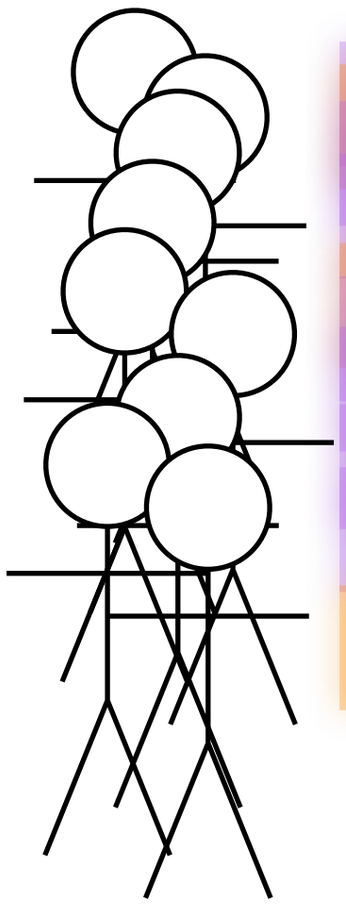

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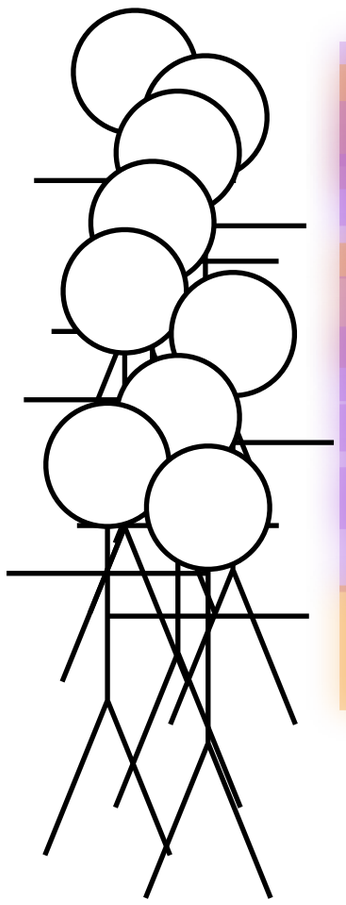

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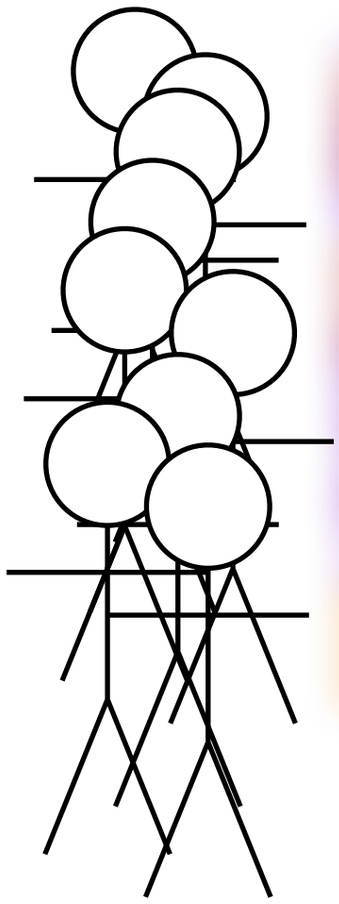

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SQL analysis

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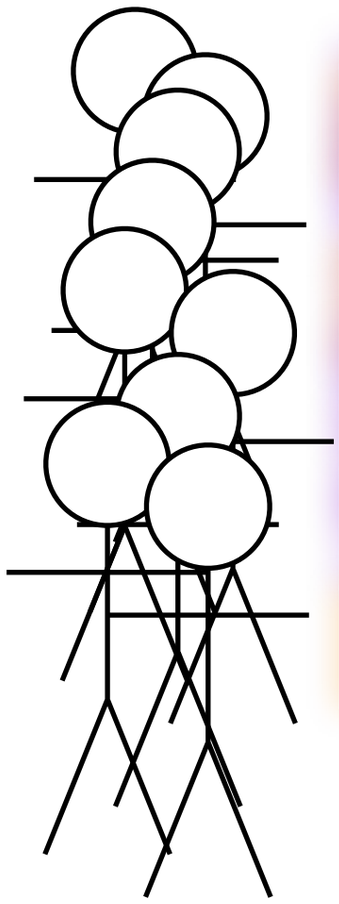

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Cache data structure

register 11128

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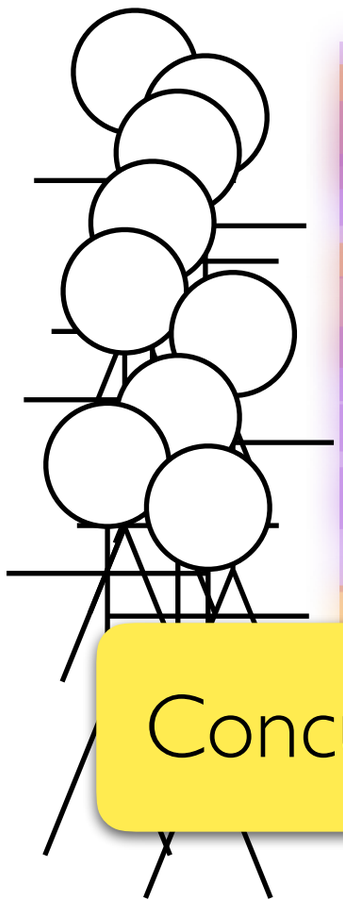

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# Approaches to Caching

| | Caching | Automatic | Flexible |
|---|---|---|---|
| No caching | ✗ | ✓ | ✓ |
| Manual instrumentation | ✓ | ✗ | ✓ |
| Library (e.g. ORM) | ✓ | ✓ | ✗ |

# Approaches to Caching

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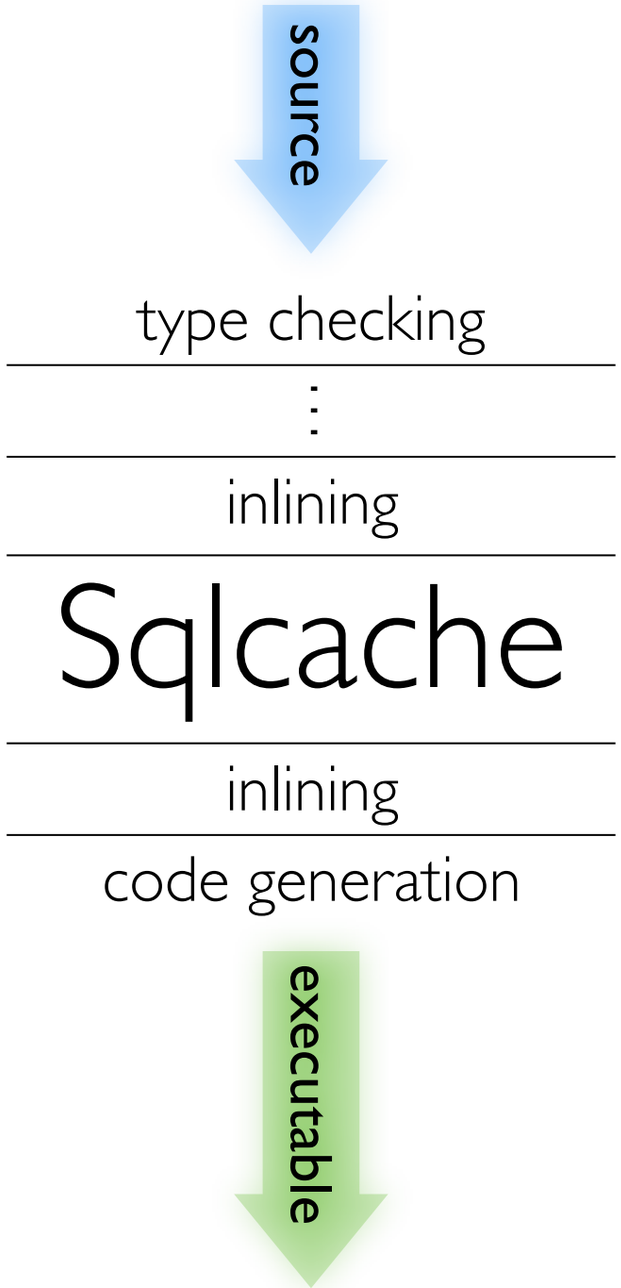
| Library (e.g. ORM) | ✓ | ✓ | ✗ |
| Compiler optimization | ✓ | ✓ | ✓ |

# Sqlcache

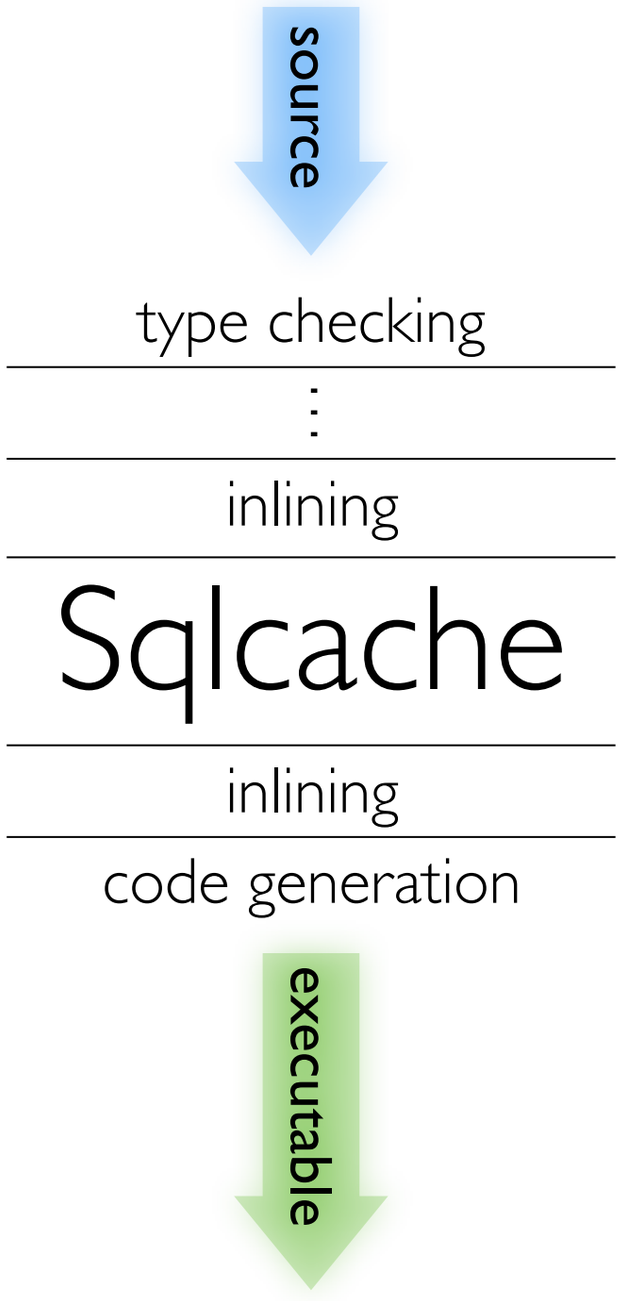
a compiler optimization for caching in the

Ur/Web programming language

# Ur/Web compiler



# Ur/Web compiler




Program instrumentation

SQL analysis

Cache data structure

Concurrency control

*all automatically*

for single-server applications

# Ur/Web Example

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table drawings : {Shape : int, Fill : int}

fun shapesOfFill x =
    gallery <- queryX1 (SELECT Shape FROM drawings
                        WHERE drawings.Fill = {[x]})
                       (fn shape => (* draw it *));
    return <xml>Behold: shapes! {gallery}</xml>

fun addDrawing y z =
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cache invalidations

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cached region

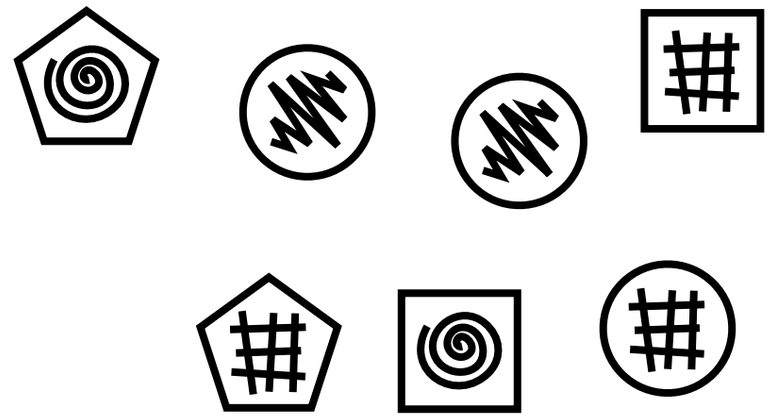
cache invalidations

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`

Cache

Database



INSERT (*shape*, *fill*) = (`y`, `z`)

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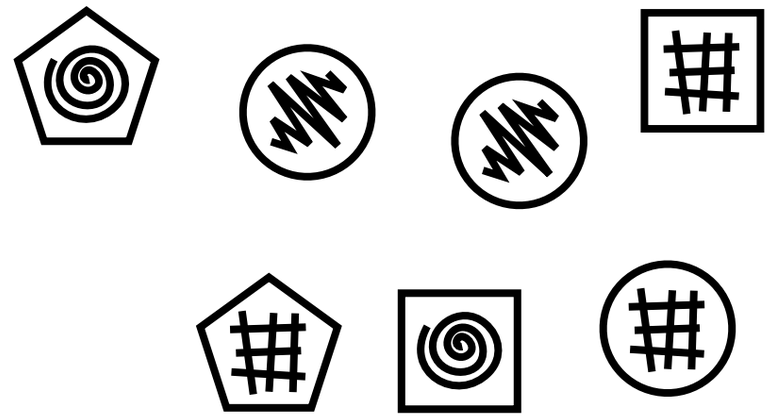
Cache

$\mathbf{x}$ =

Database



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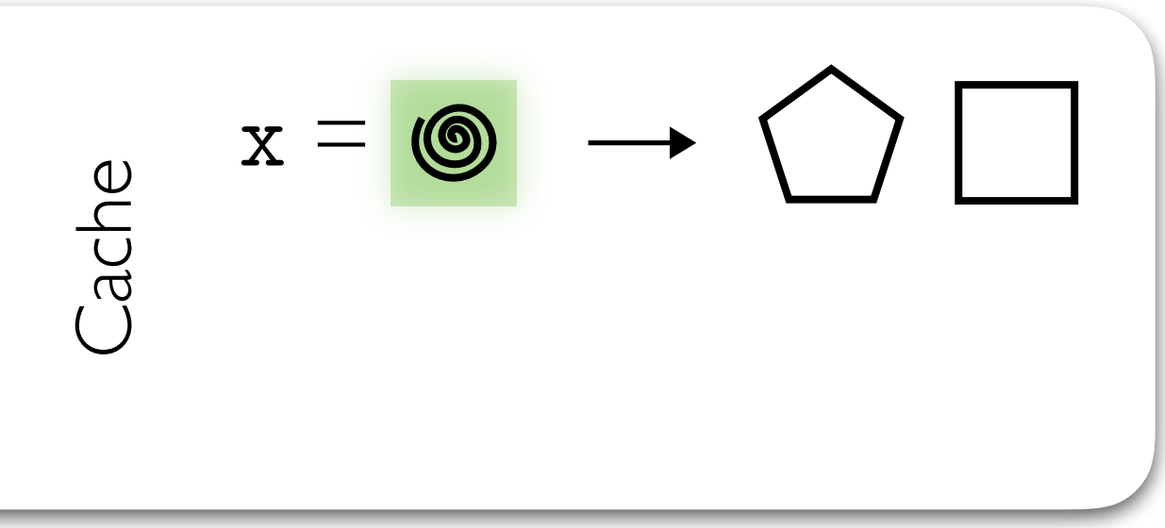


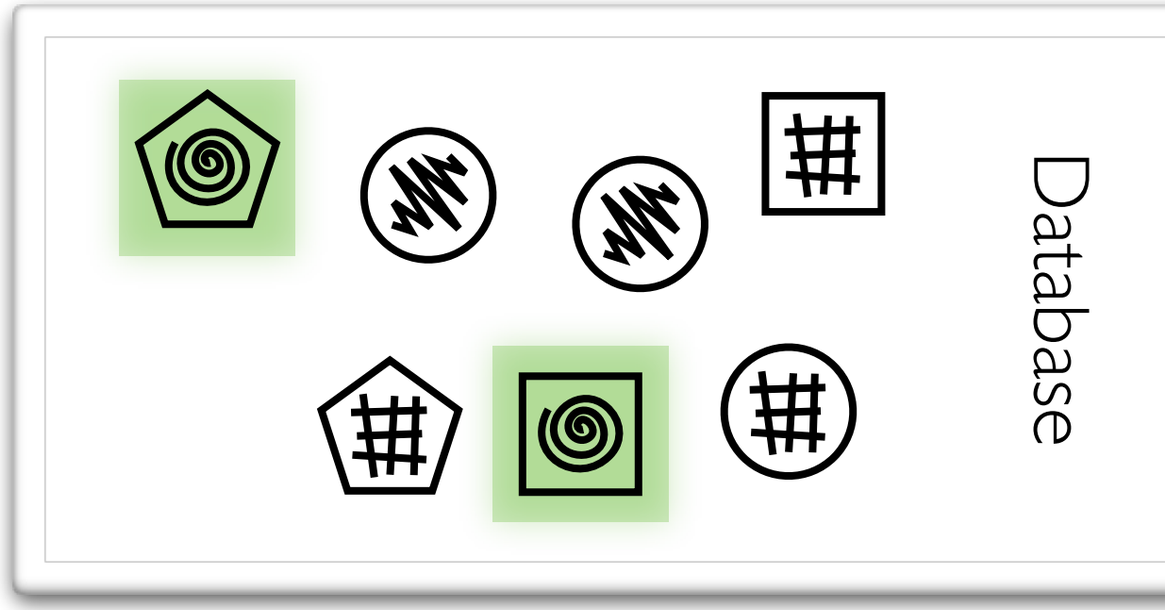


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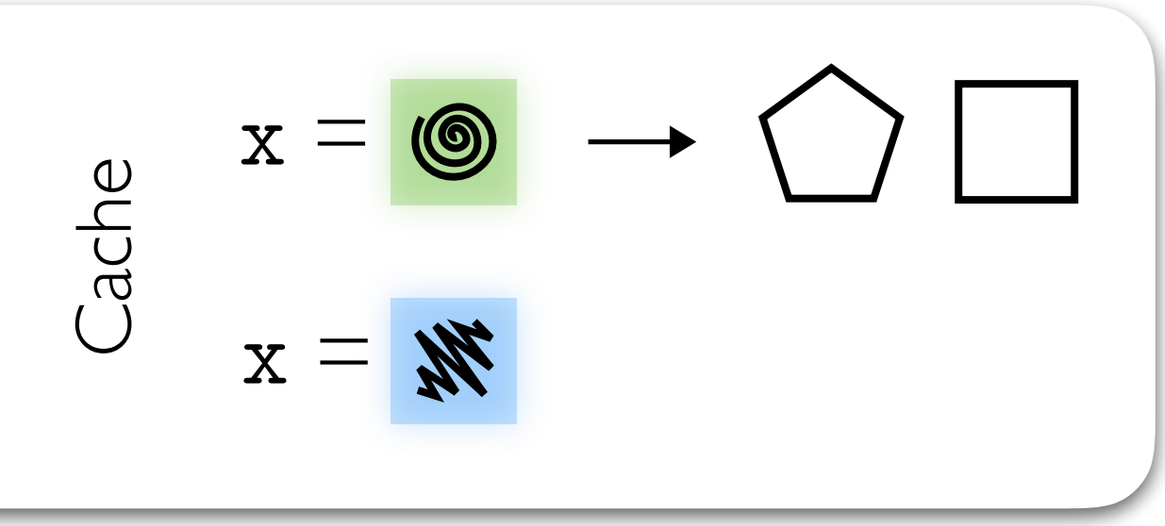


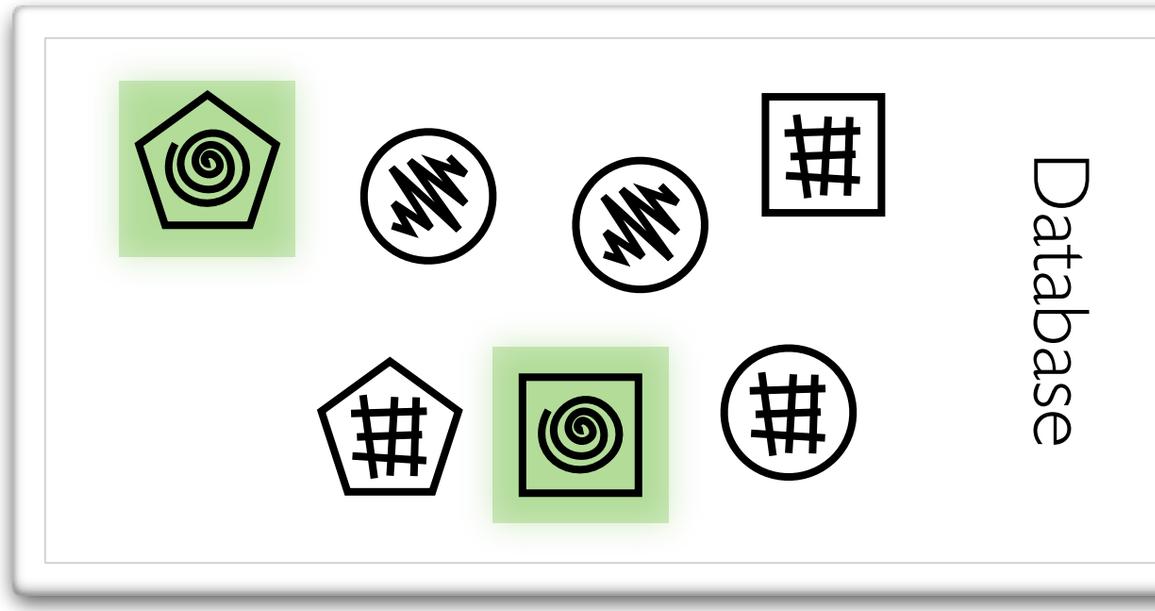


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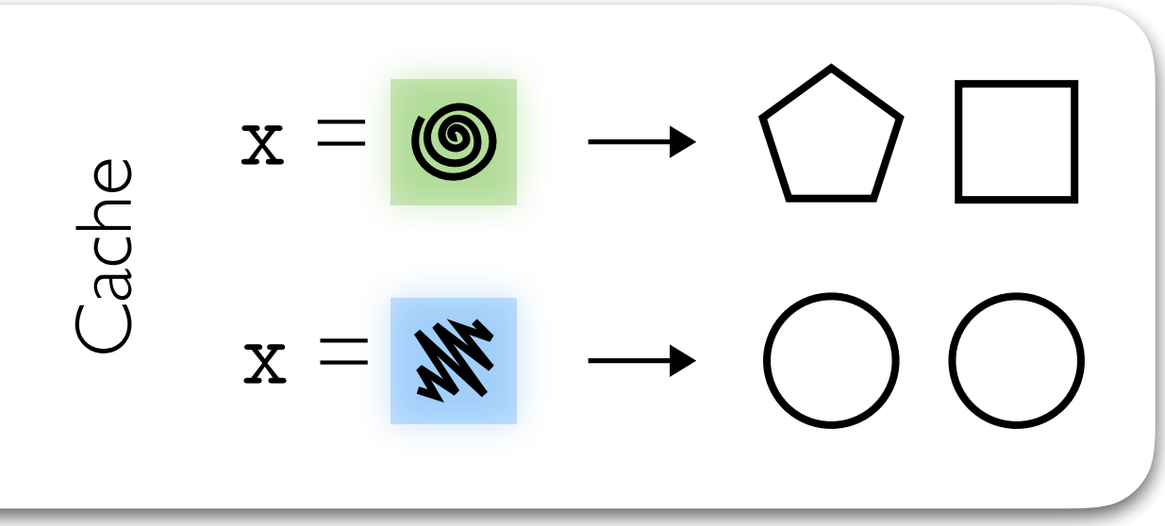


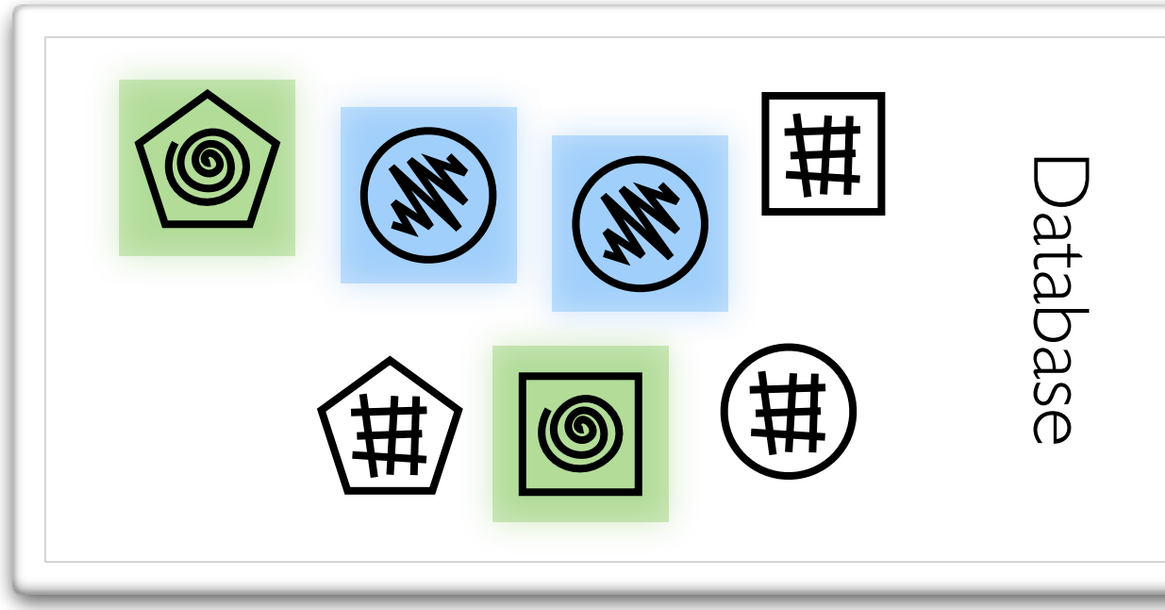


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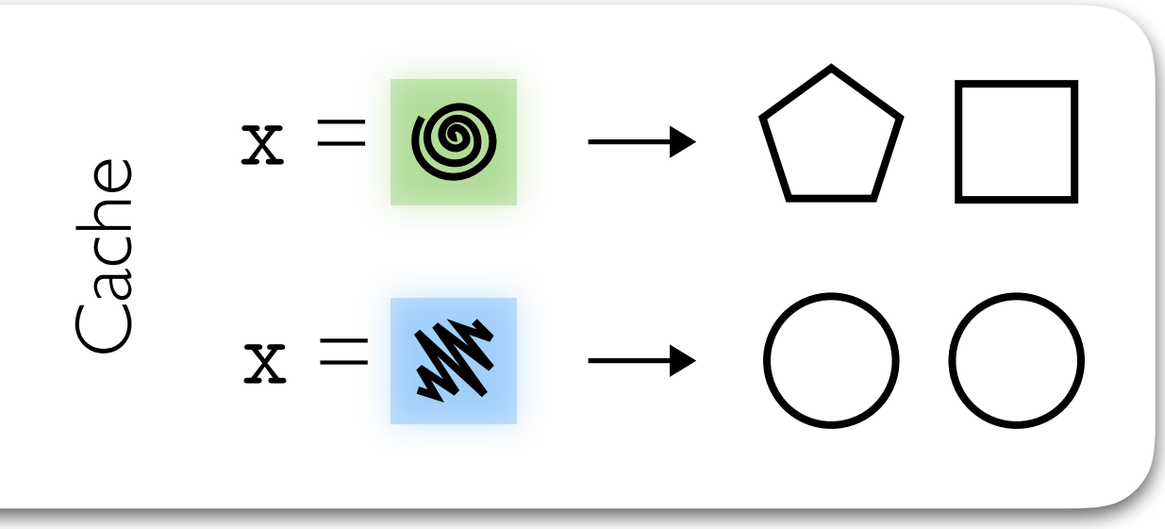


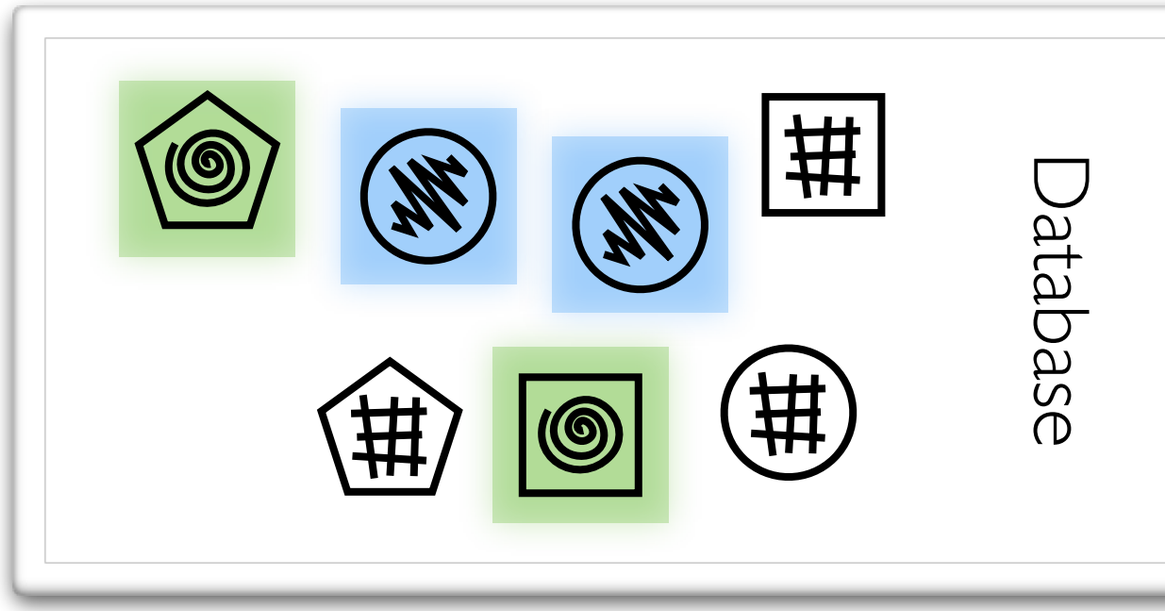


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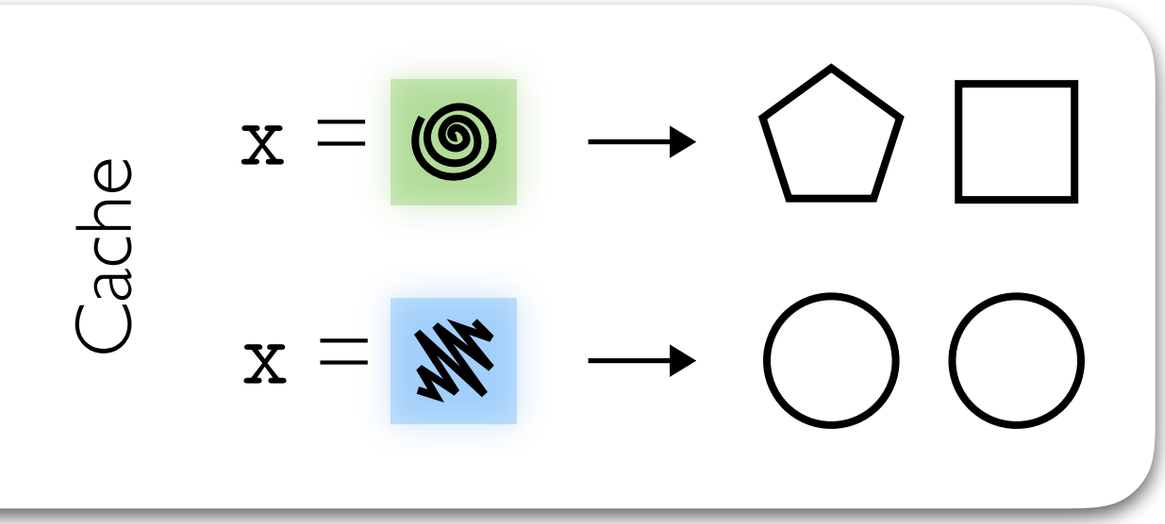


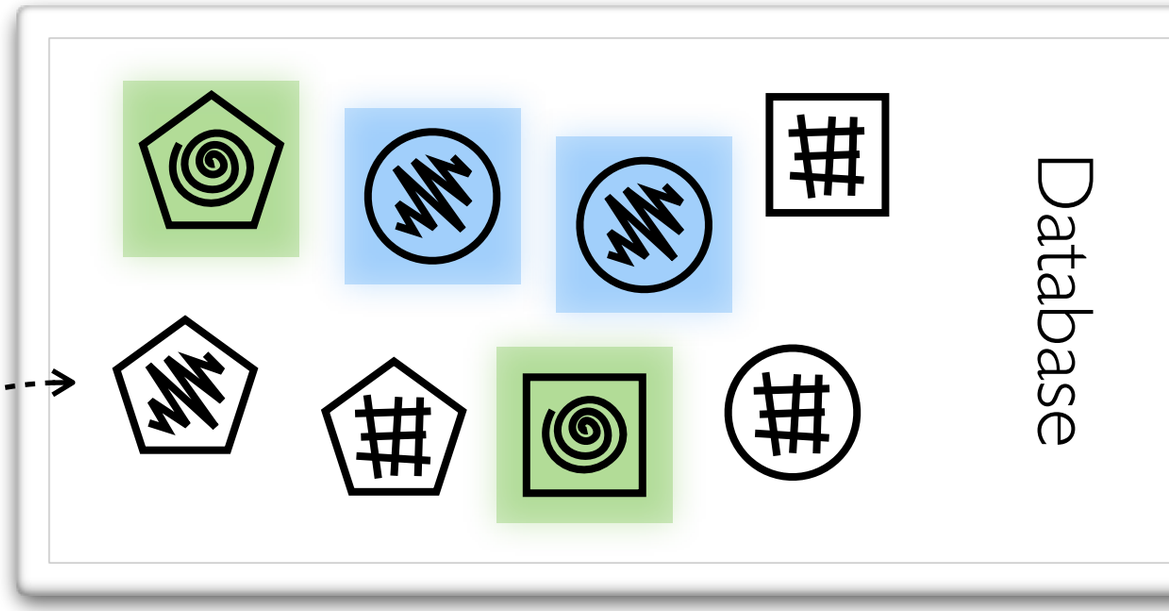


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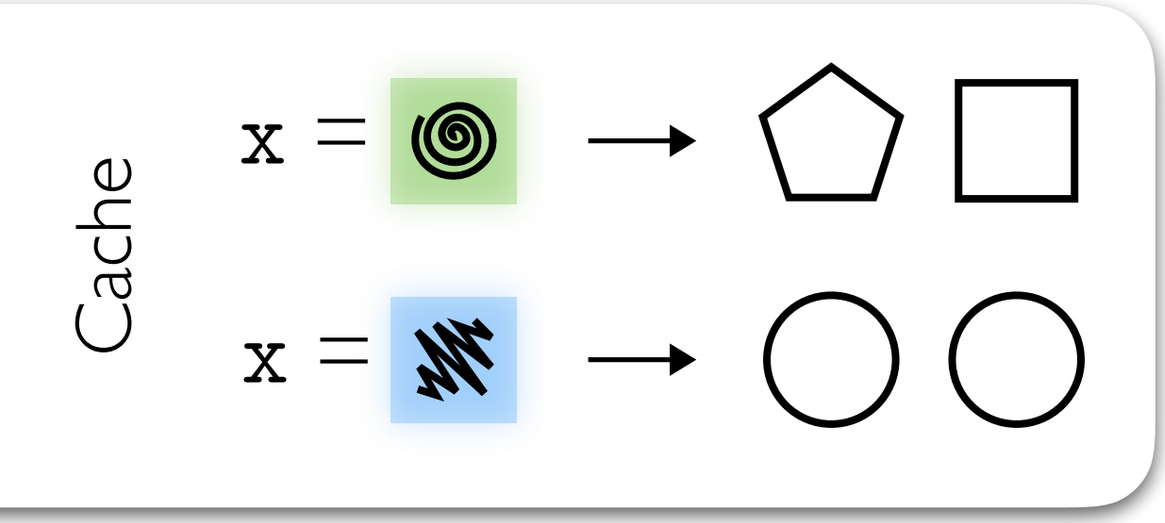
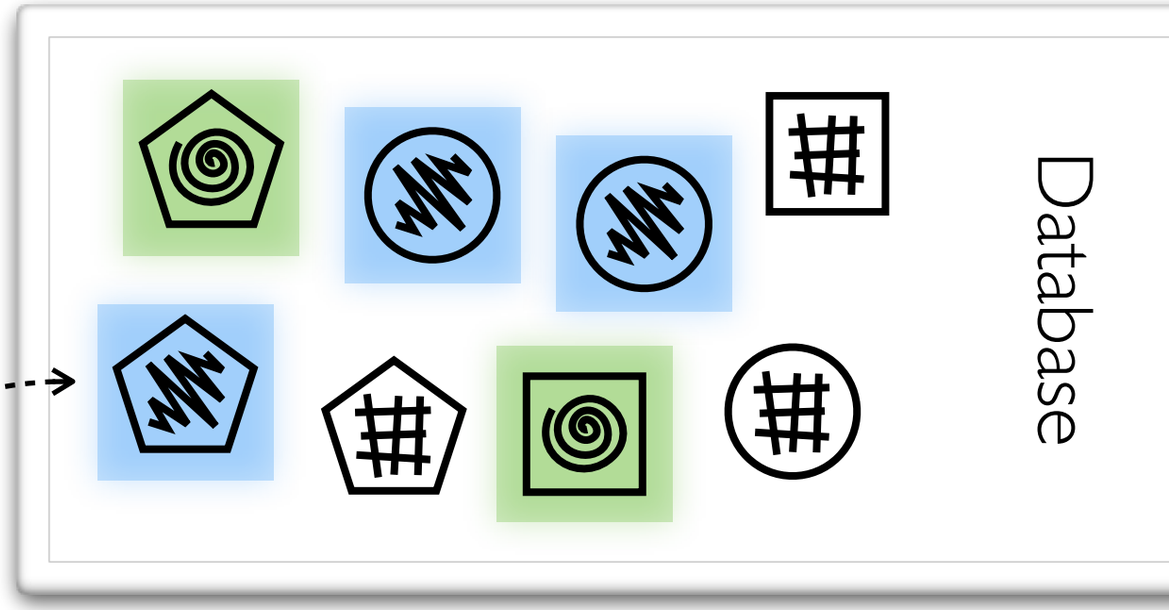
# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`



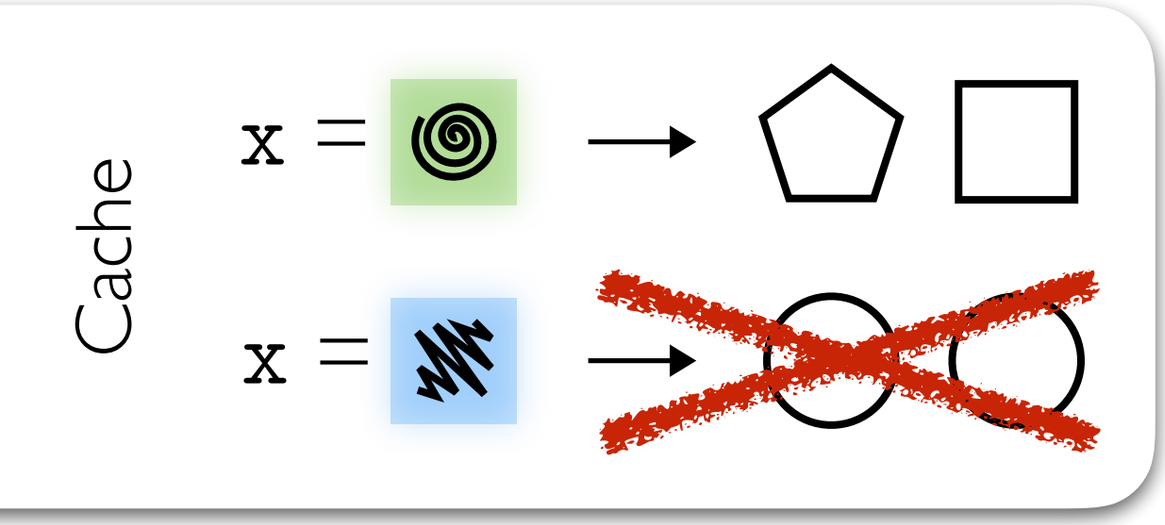



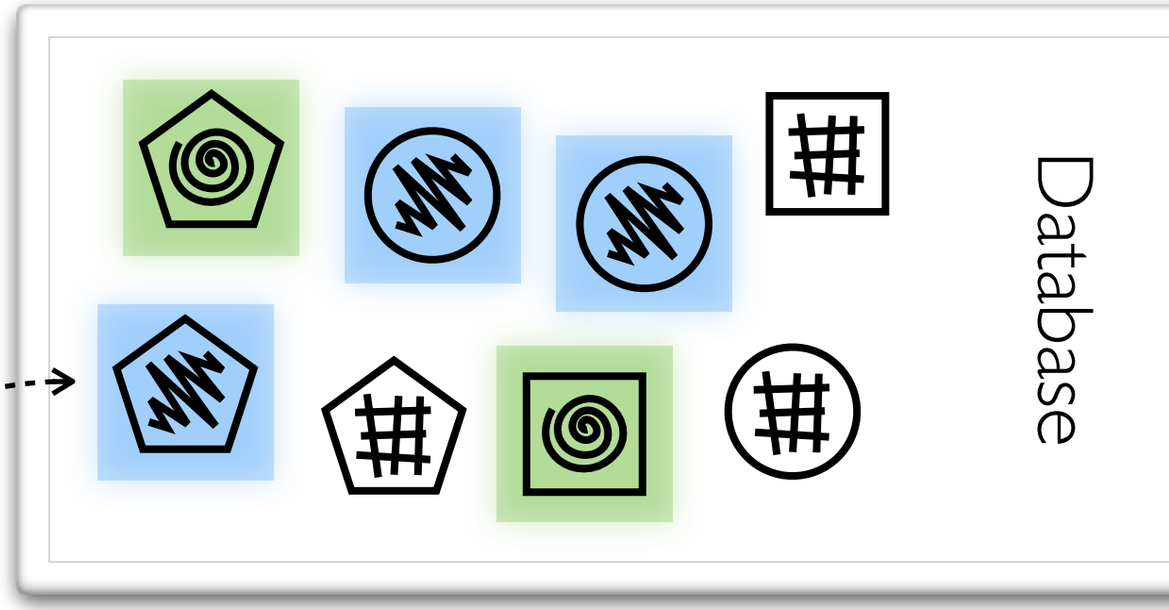

INSERT (*shape*, *fill*) = (`y`, `z`)

(`y`, `z`) =

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`



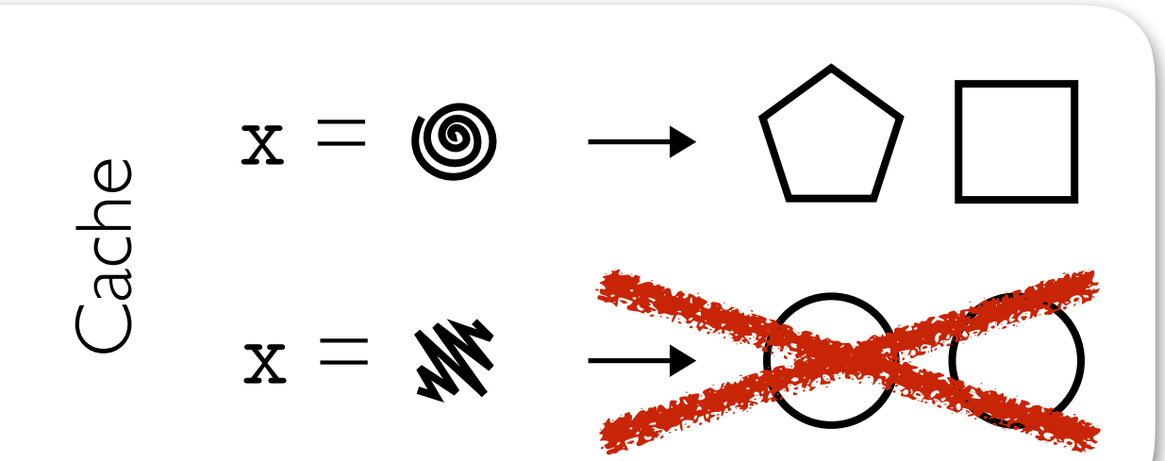



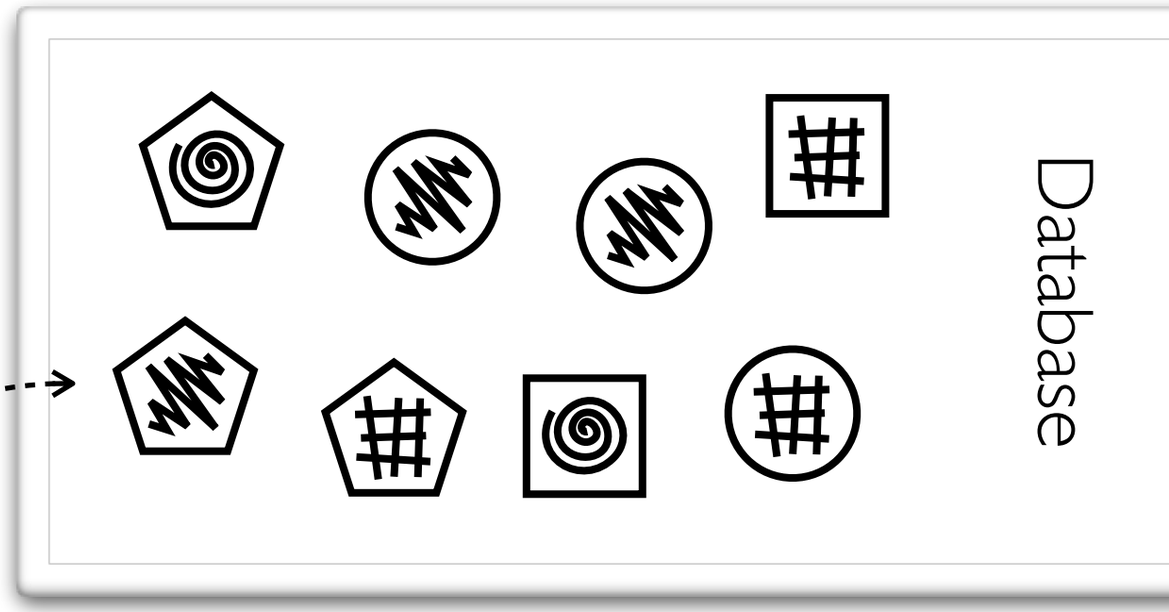

INSERT (*shape*, *fill*) = (`y`, `z`)

(`y`, `z`) =

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`



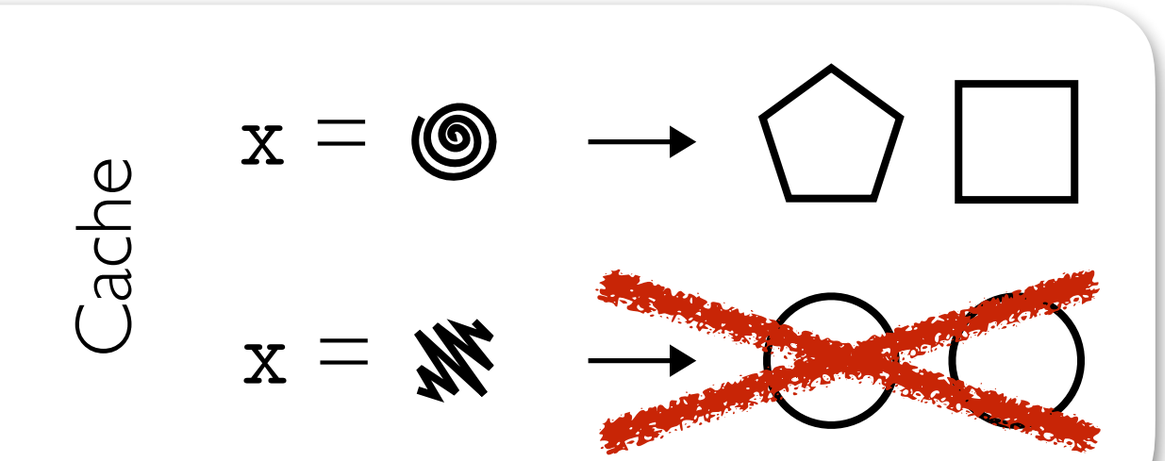



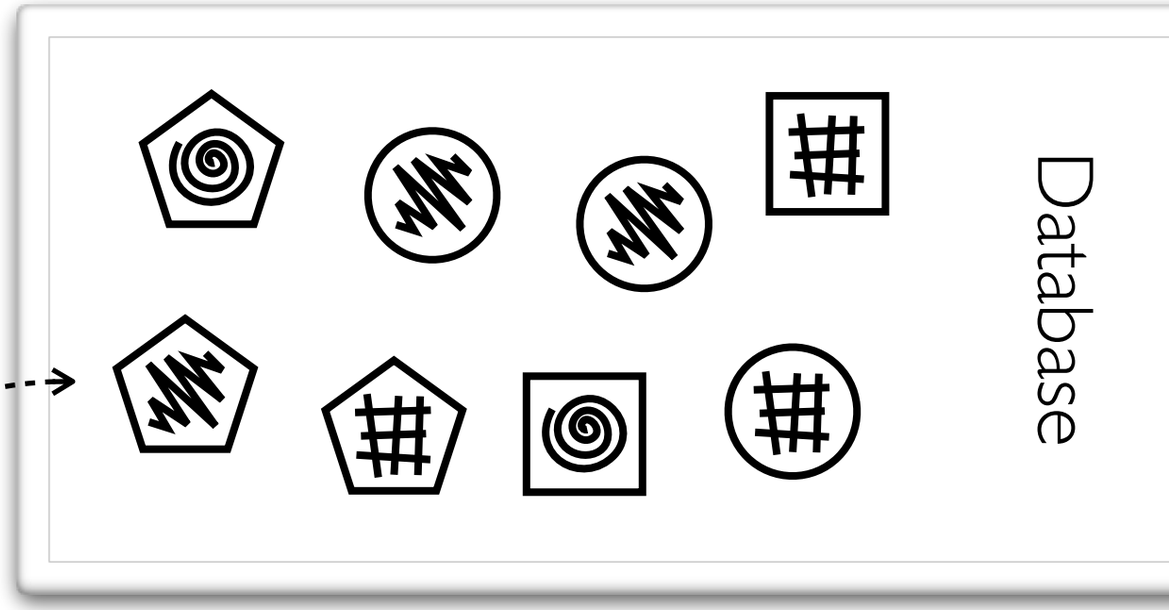

INSERT (*shape*, *fill*) = (`y`, `z`)

(`y`, `z`) =

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = $\mathbf{x}$




INSERT (*shape*, *fill*) = ($\mathbf{y}$, $\mathbf{z}$)

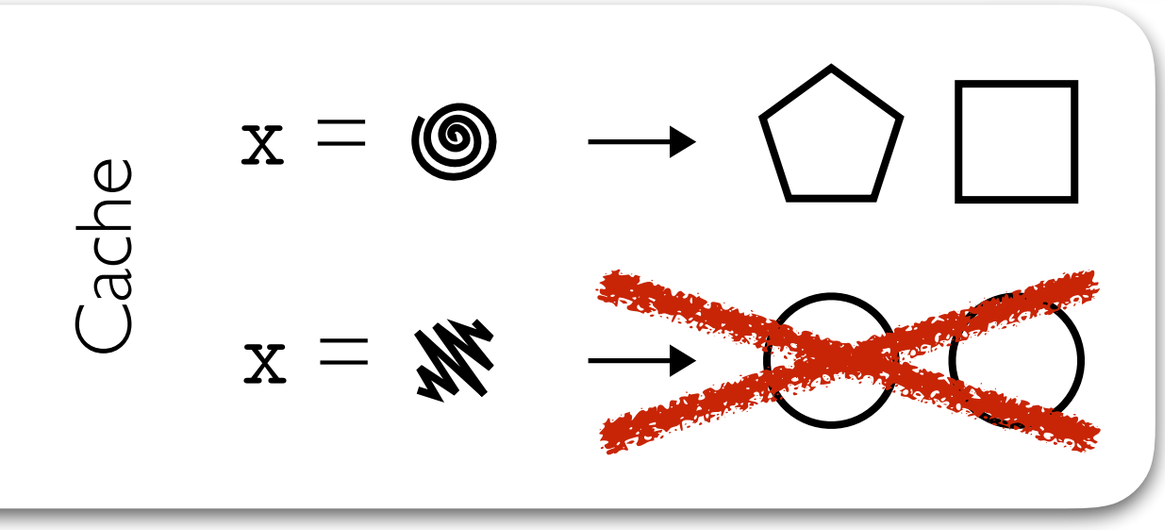
($\mathbf{y}$, $\mathbf{z}$) =

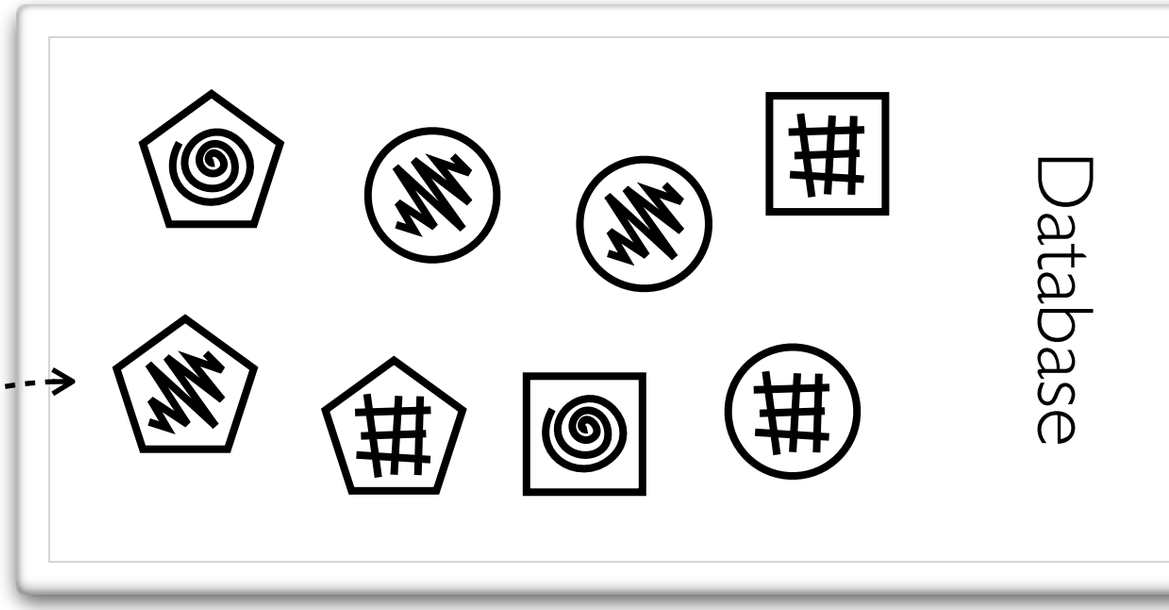
**Invalidation formula:**

$\exists$ (*shape*, *fill*).
*fill* = $\mathbf{x}$ $\wedge$ *shape* = $\mathbf{y}$ $\wedge$ *fill* = $\mathbf{z}$

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`




INSERT (*shape*, *fill*) = (`y`, `z`)

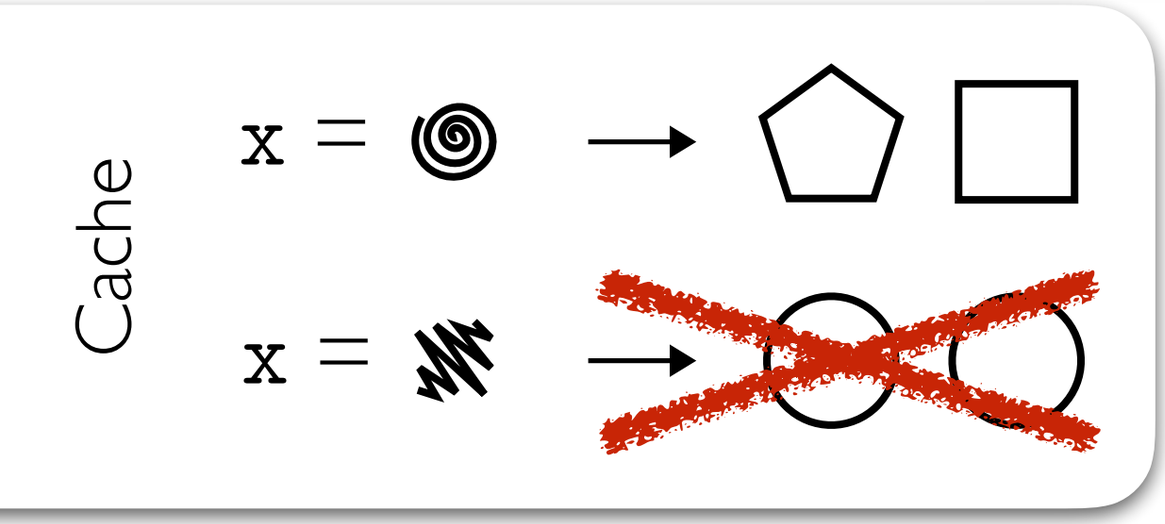
(`y`, `z`) =

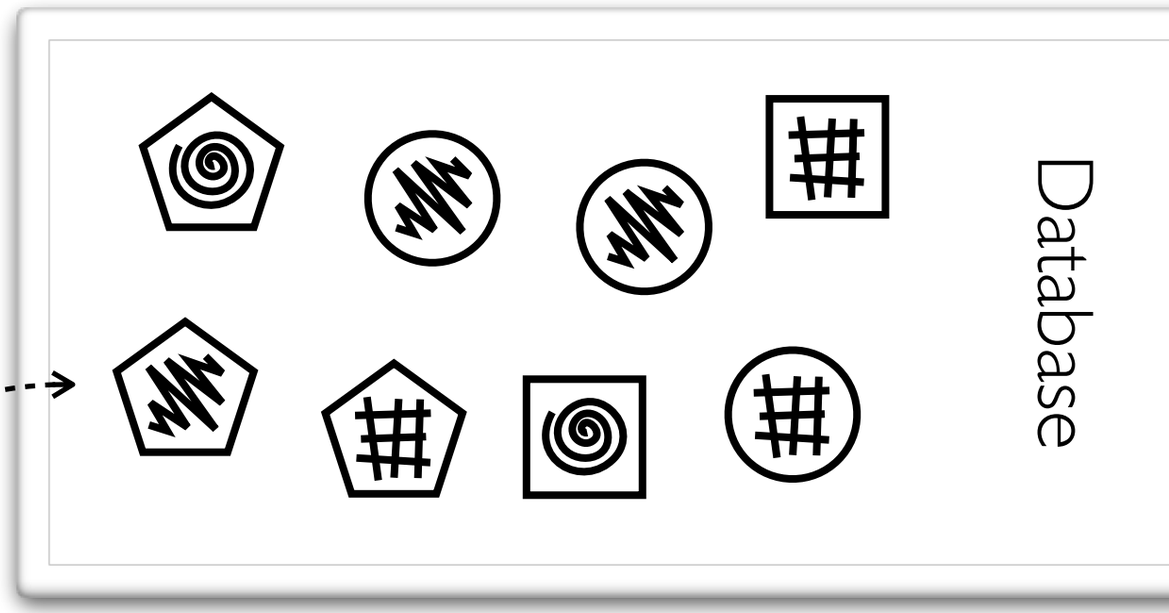
**Invalidation formula:**

∃ (*shape*, *fill*).
*fill* = `x` ∧ *shape* = `y` ∧ *fill* = `z`

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`




INSERT (*shape*, *fill*) = (`y`, `z`)

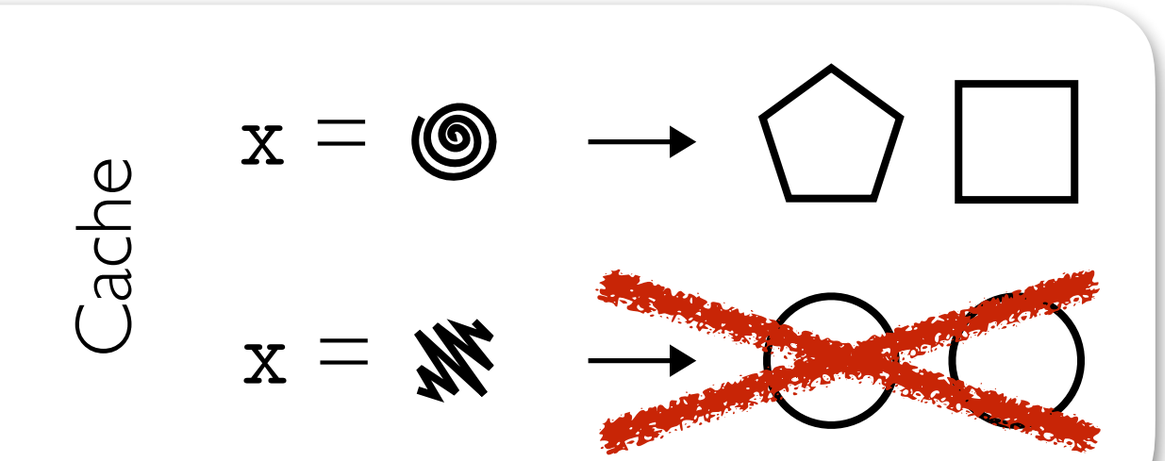
(`y`, `z`) =

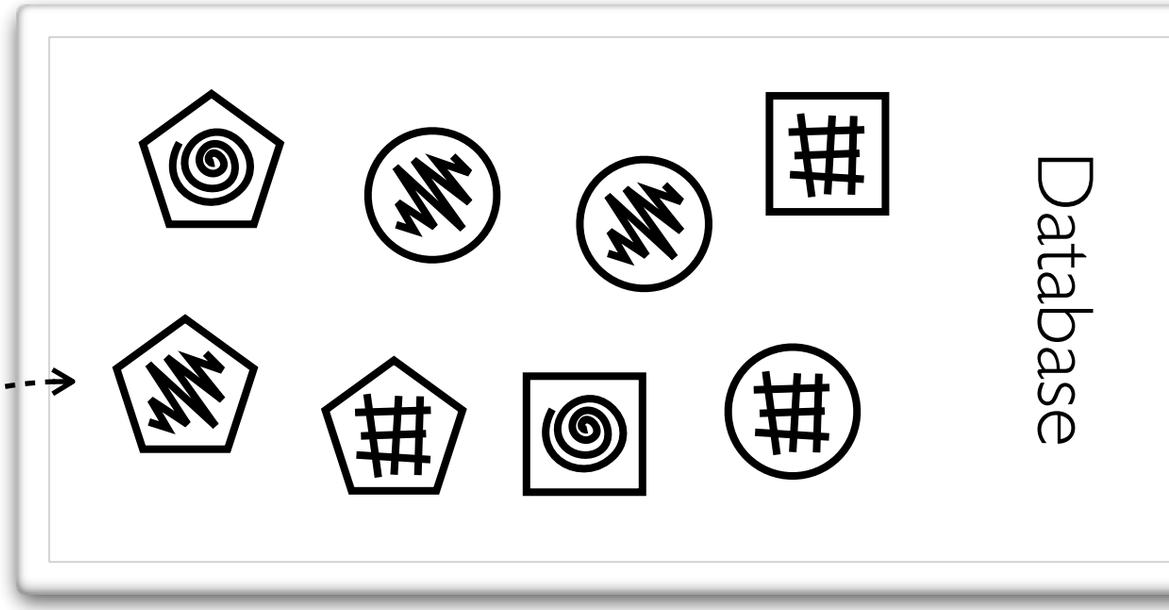
**Invalidation formula:**

∃ (*shape*, *fill*).
*fill* = `x` ∧ *shape* = `y` ∧ *fill* = `z`

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = $\mathbf{x}$




INSERT (*shape*, *fill*) = ($\mathbf{y}$, $\mathbf{z}$)

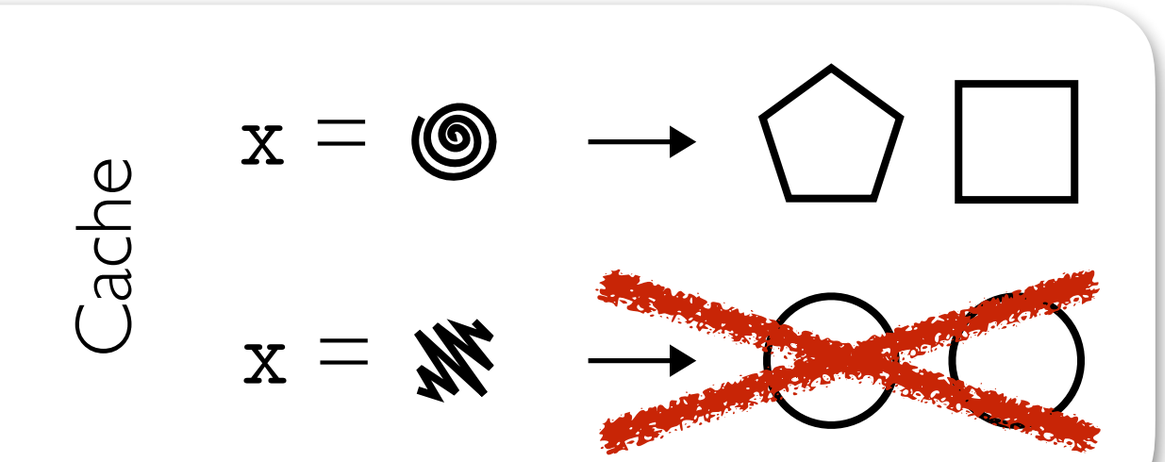
($\mathbf{y}$, $\mathbf{z}$) =

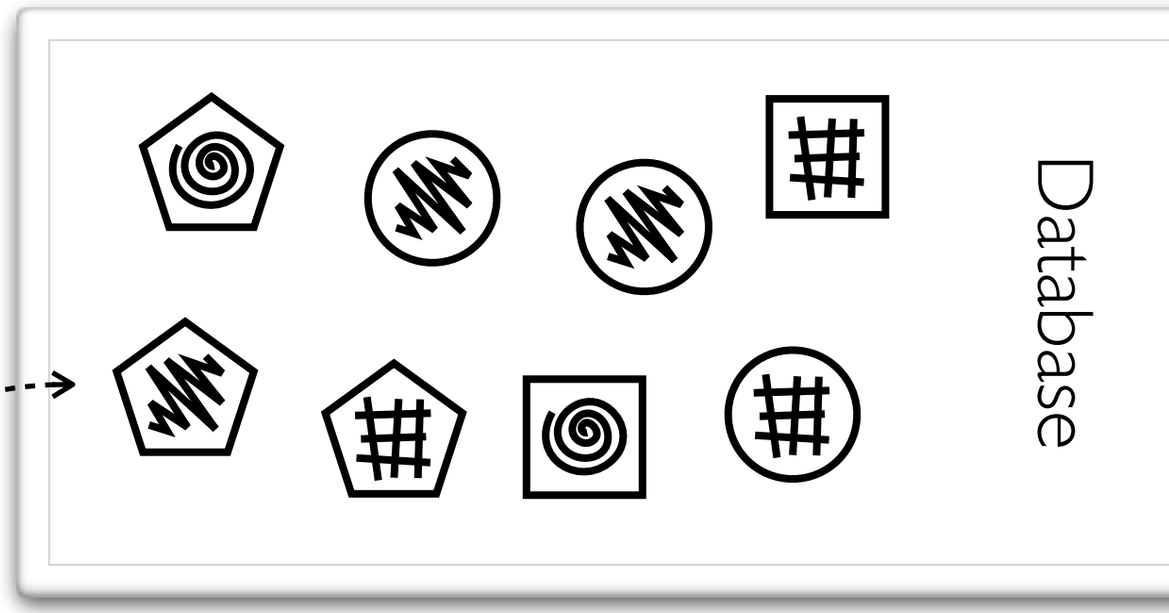
**Invalidation formula:**

$\exists$ (*shape*, *fill*).
*fill* = $\mathbf{x}$ $\wedge$ *shape* = $\mathbf{y}$ $\wedge$ *fill* = $\mathbf{z}$

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = $\mathbf{x}$




INSERT (*shape*, *fill*) = ($\mathbf{y}$, $\mathbf{z}$)

($\mathbf{y}$, $\mathbf{z}$) =

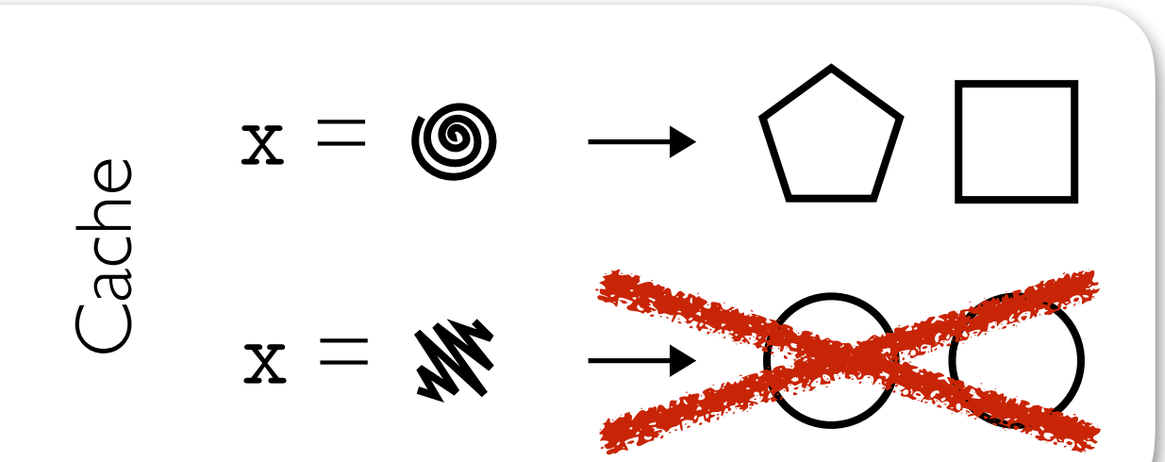
**Invalidation formula:**

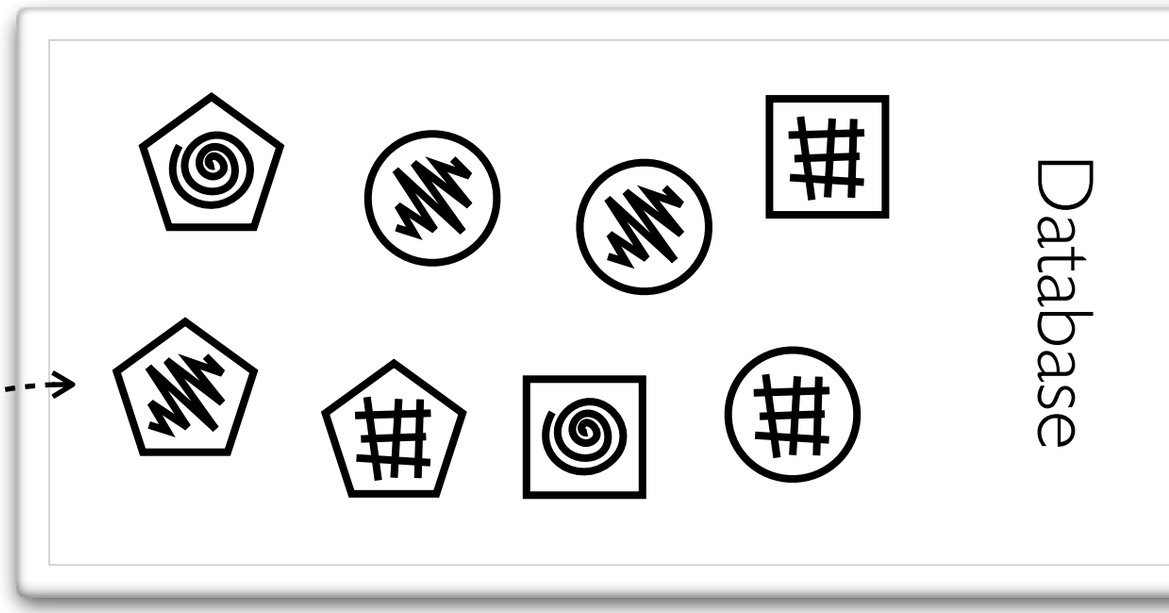
$\exists$ (*shape*, *fill*).
*fill* = $\mathbf{x}$ $\wedge$ *shape* = $\mathbf{y}$ $\wedge$ *fill* = $\mathbf{z}$

$\Longrightarrow$ $\mathbf{x} = \mathbf{z}$

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`




INSERT (*shape*, *fill*) = (`y`, `z`)

(`y`, `z`) =

**Invalidation formula:**

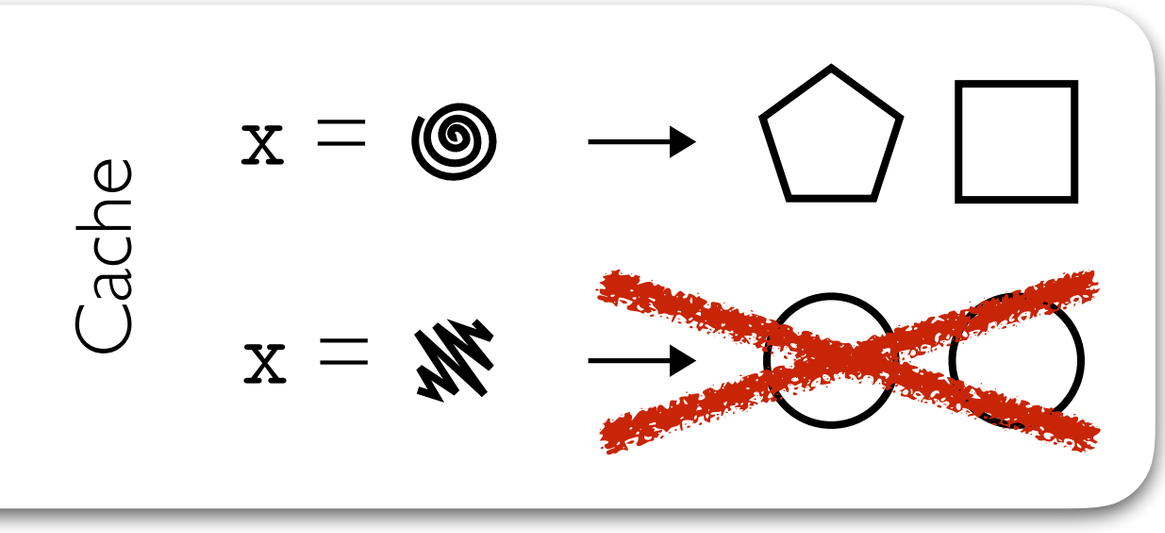
$\exists$ (*shape*, *fill*).
*fill* = `x` $\wedge$ *shape* = `y` $\wedge$ *fill* = `z`

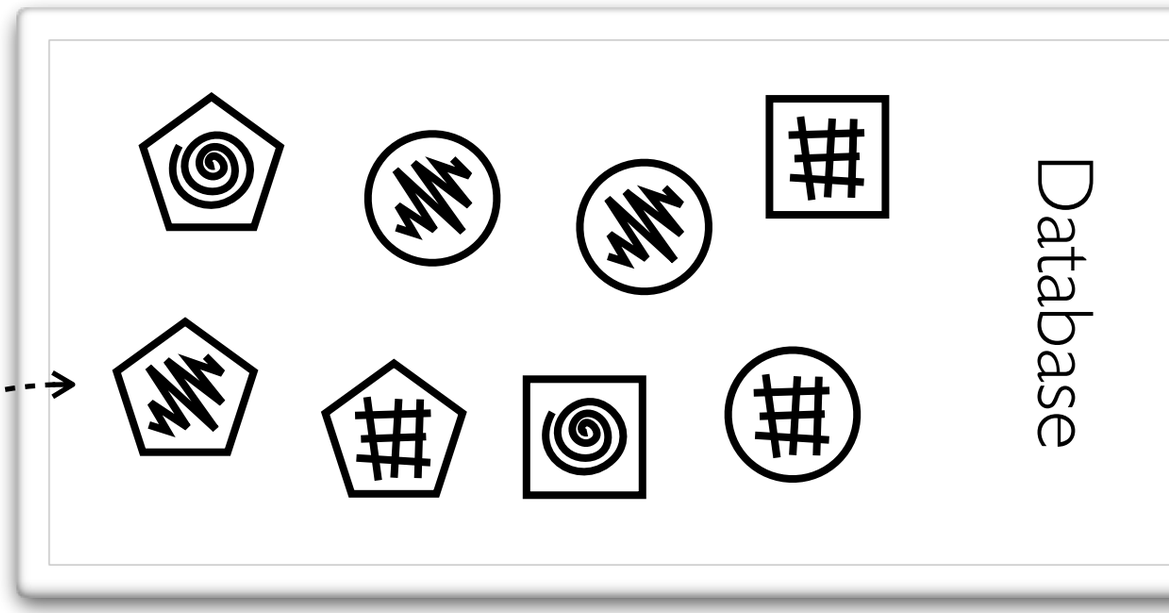
$\Rightarrow$ `x` = `z`

cache key

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`




INSERT (*shape*, *fill*) = (`y`, `z`)

(`y`, `z`) =

**Invalidation formula:**

$$\exists\ (shape, fill).\ fill = \mathtt{x} \wedge shape = \mathtt{y} \wedge fill = \mathtt{z}$$

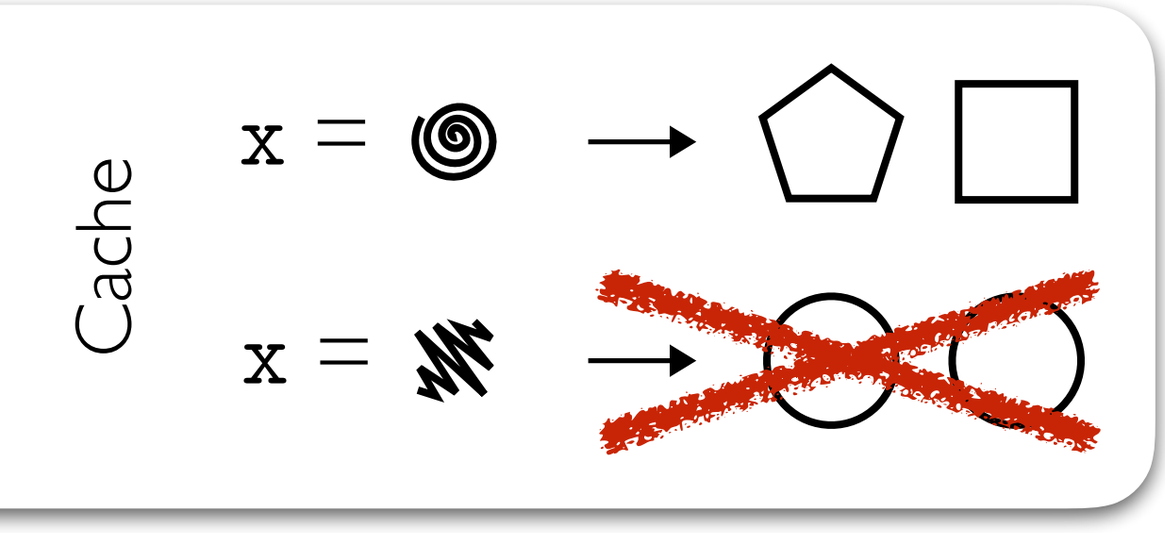
$$\Longrightarrow \mathtt{x} = \mathtt{z}$$

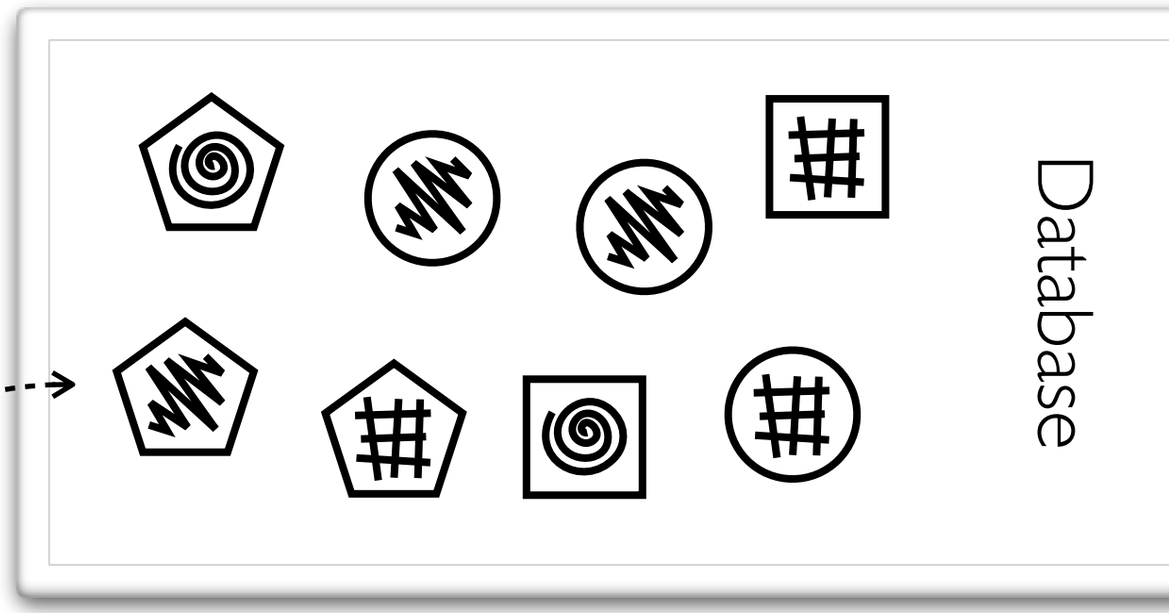
cache key

known during update

# Invalidation for INSERT

SELECT *shape* WHERE *fill* = `x`




INSERT (*shape*, *fill*) = (`y`, `z`)

(`y`, `z`) =

**Invalidation formula:**

∃ (*shape*, *fill*).
*fill* = `x` ∧ *shape* = `y` ∧ *fill* = `z`

⟹ `x` = `z`

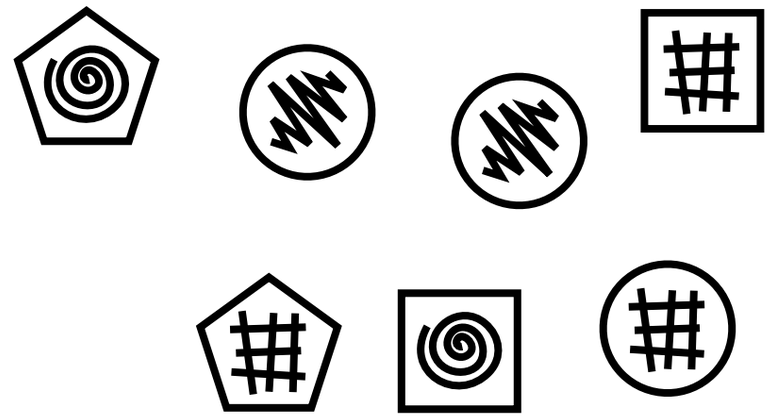
inval(`z`);

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`

Cache

Database



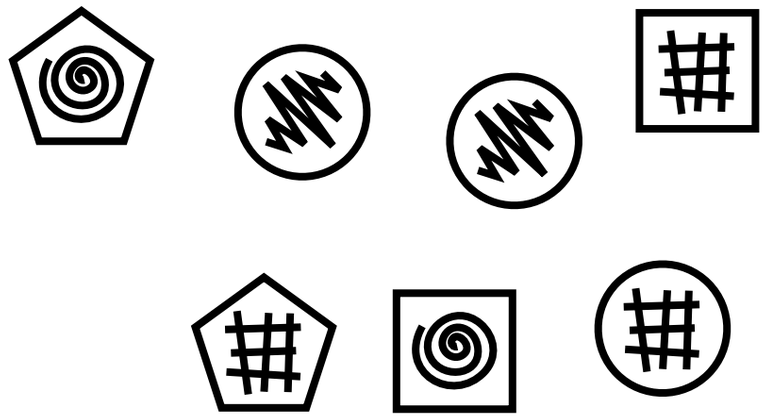
UPDATE *fill* = `y` WHERE *fill* = `z`

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`

Cache

`x` =

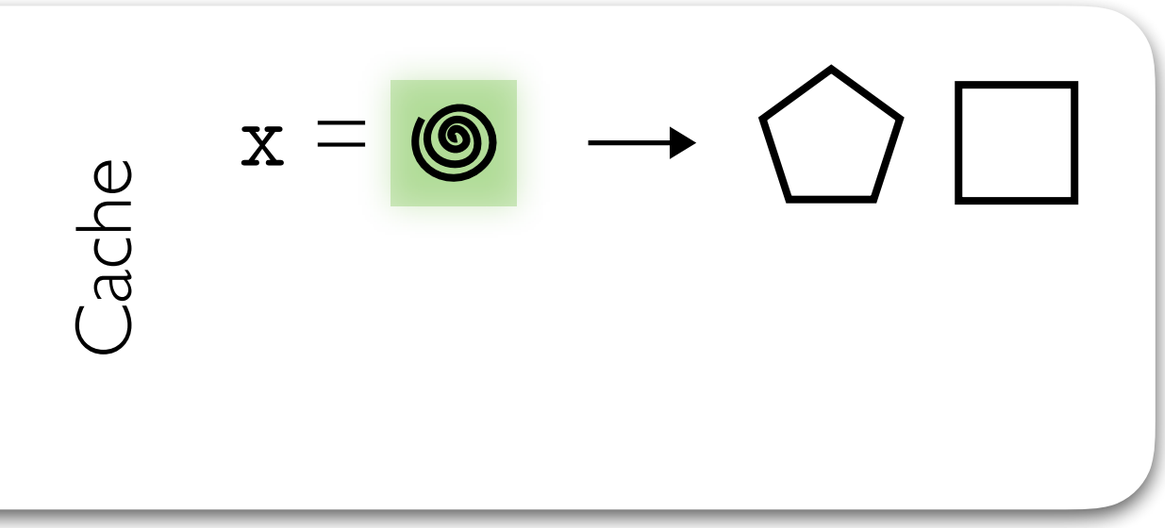


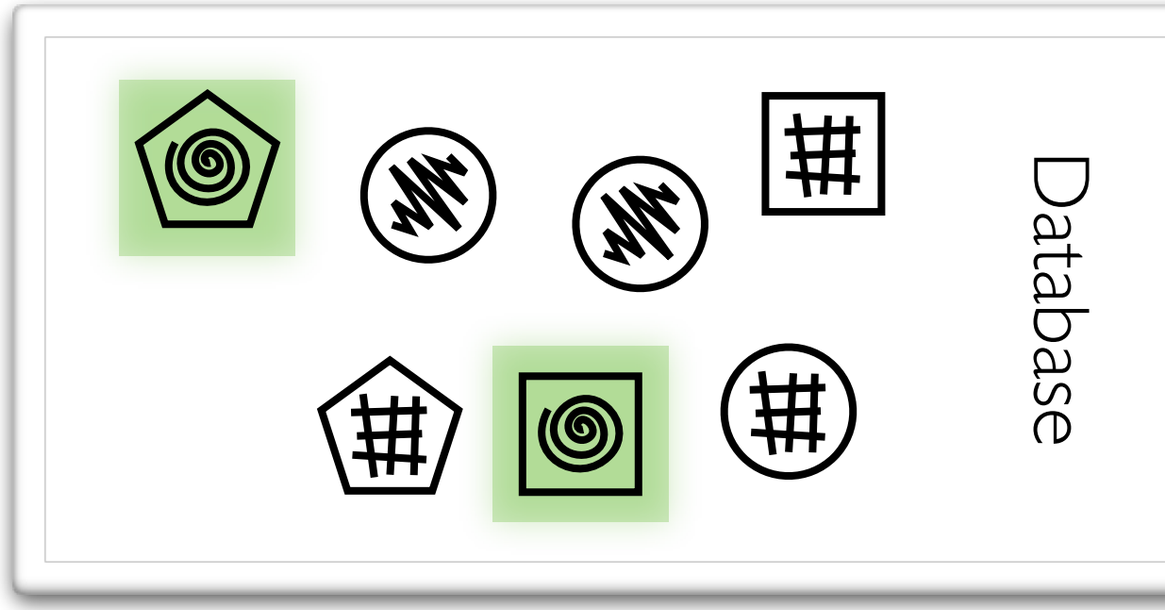
Database

UPDATE *fill* = `y` WHERE *fill* = `z`

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`

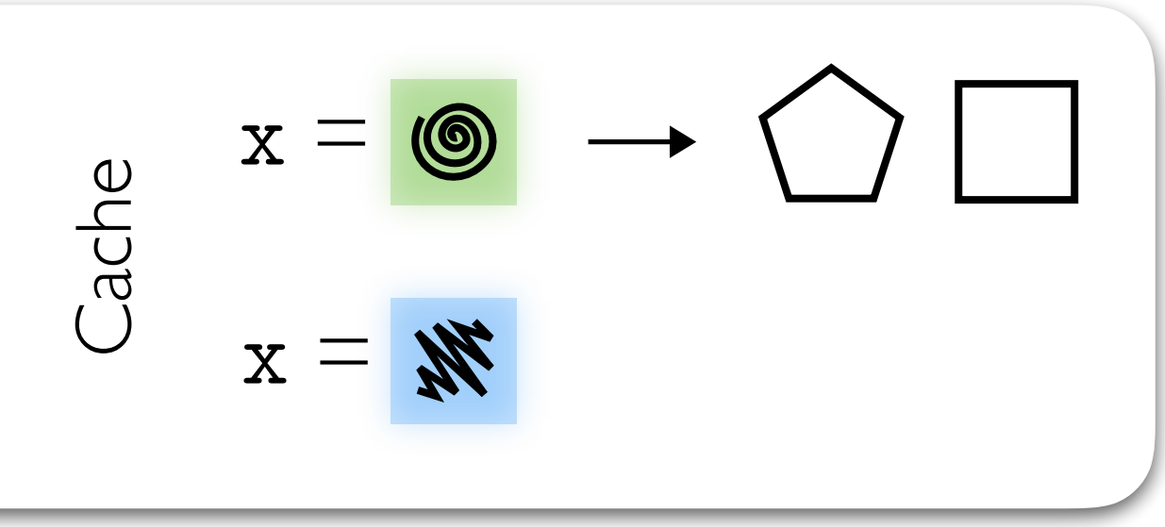


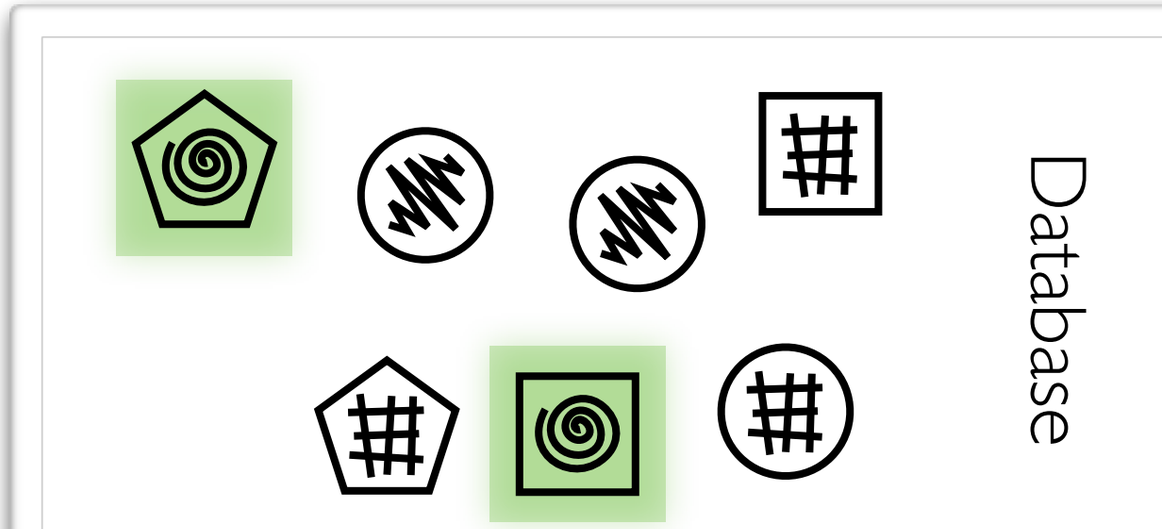




UPDATE *fill* = **y** WHERE *fill* = **z**

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`

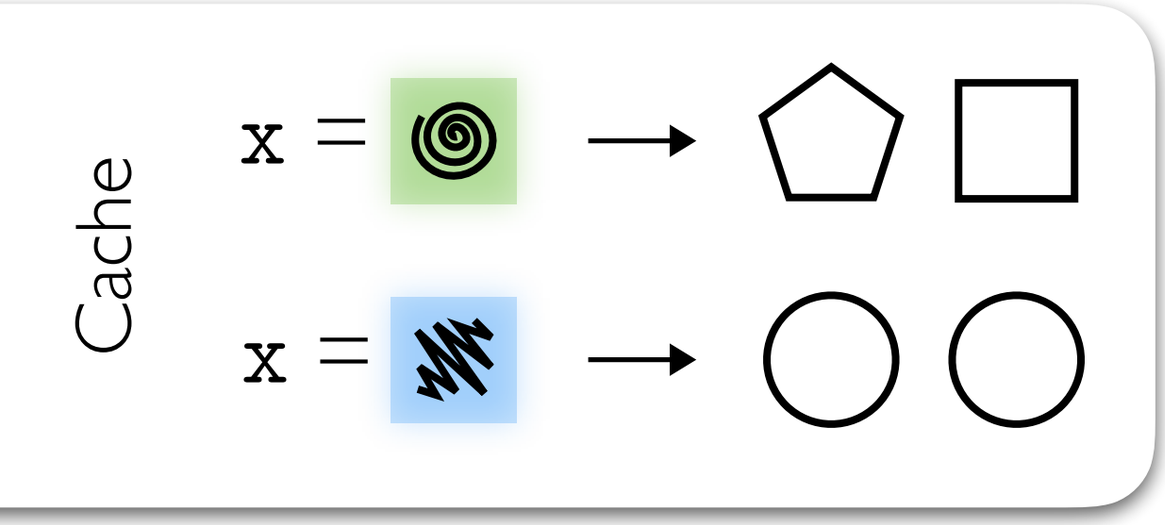


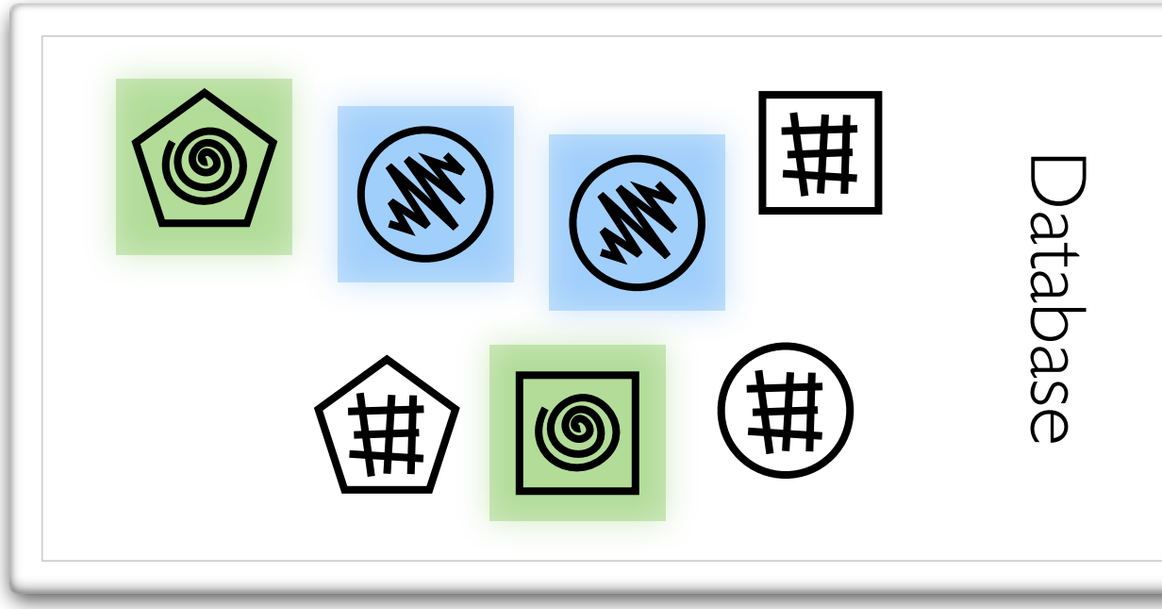




UPDATE *fill* = `y` WHERE *fill* = `z`

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`

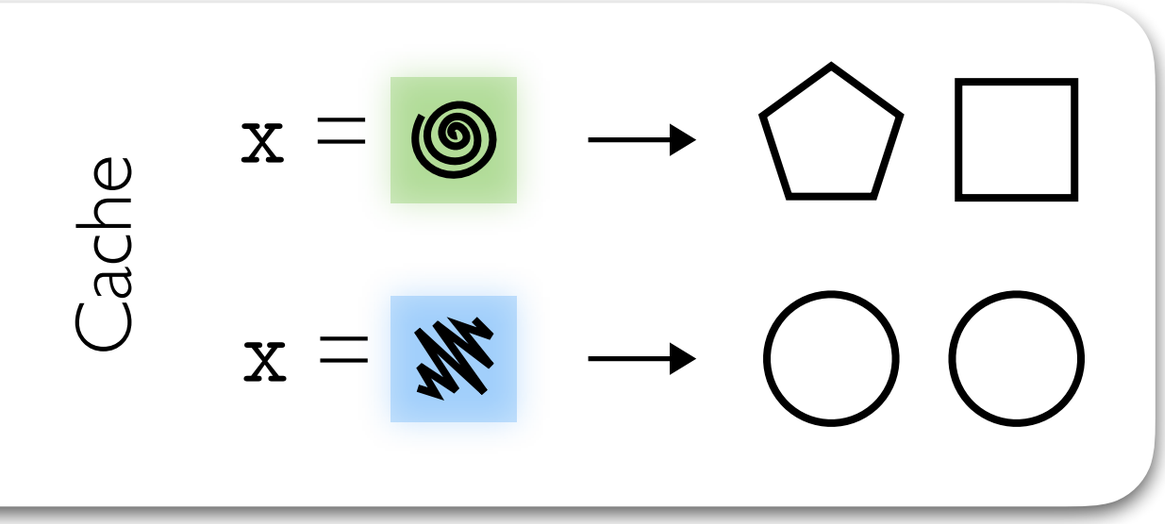


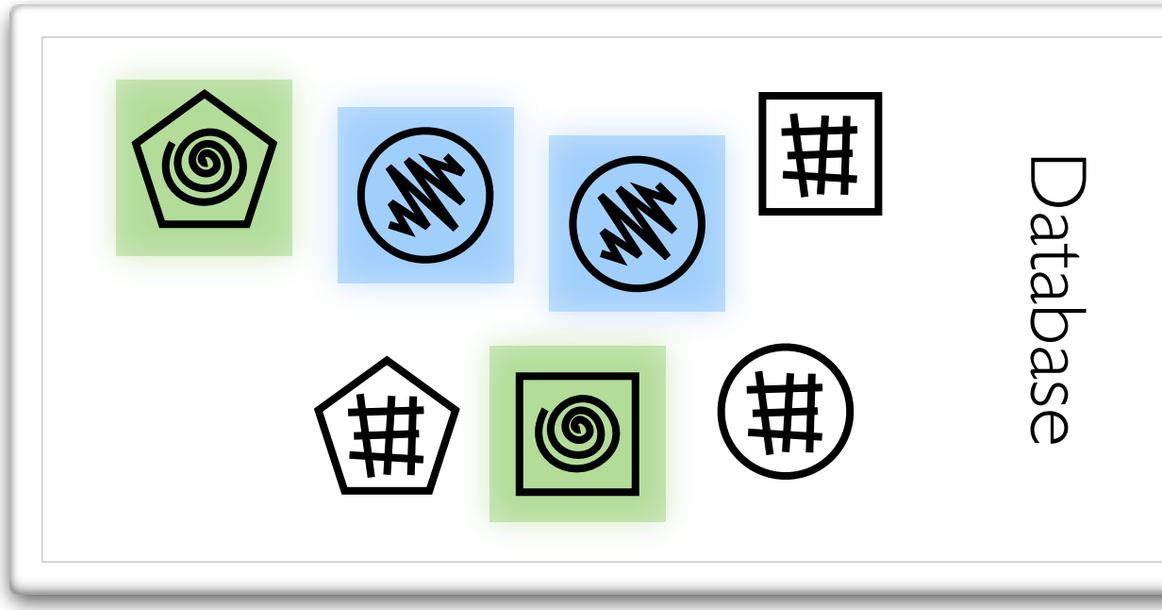




UPDATE *fill* = `y` WHERE *fill* = `z`

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`



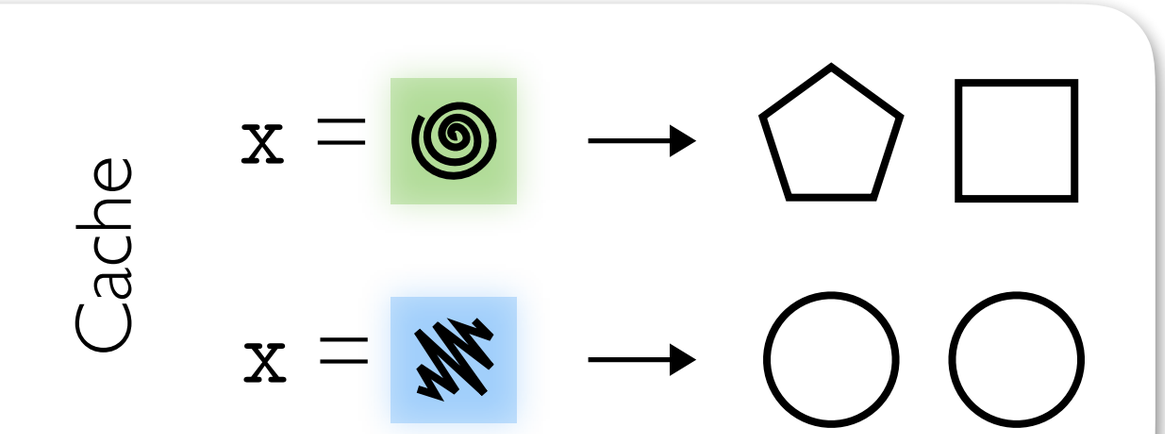



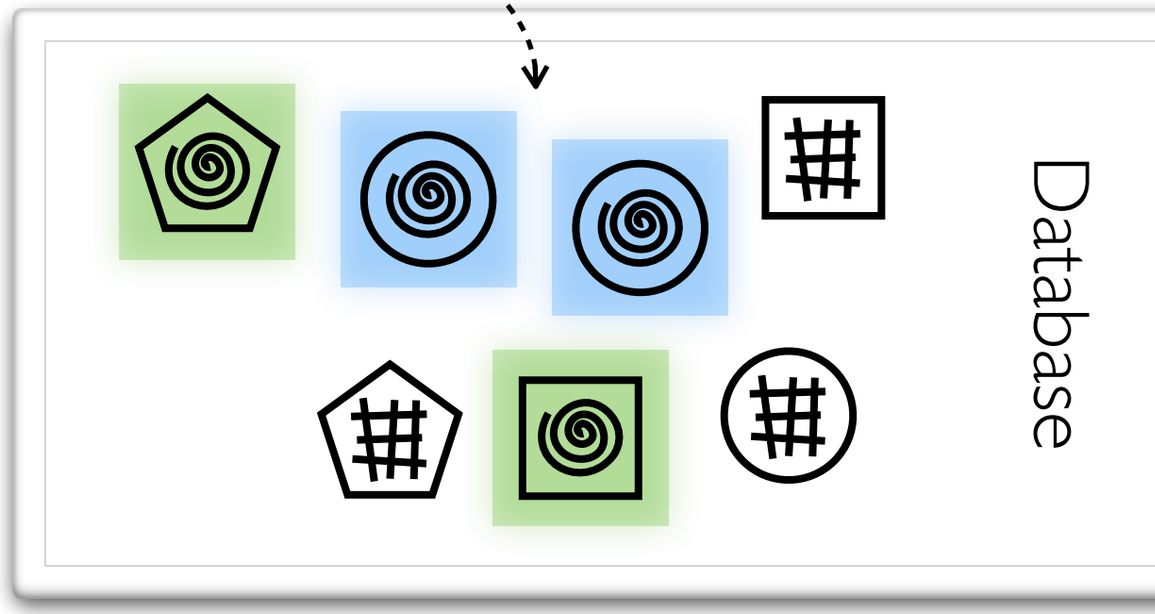

UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`



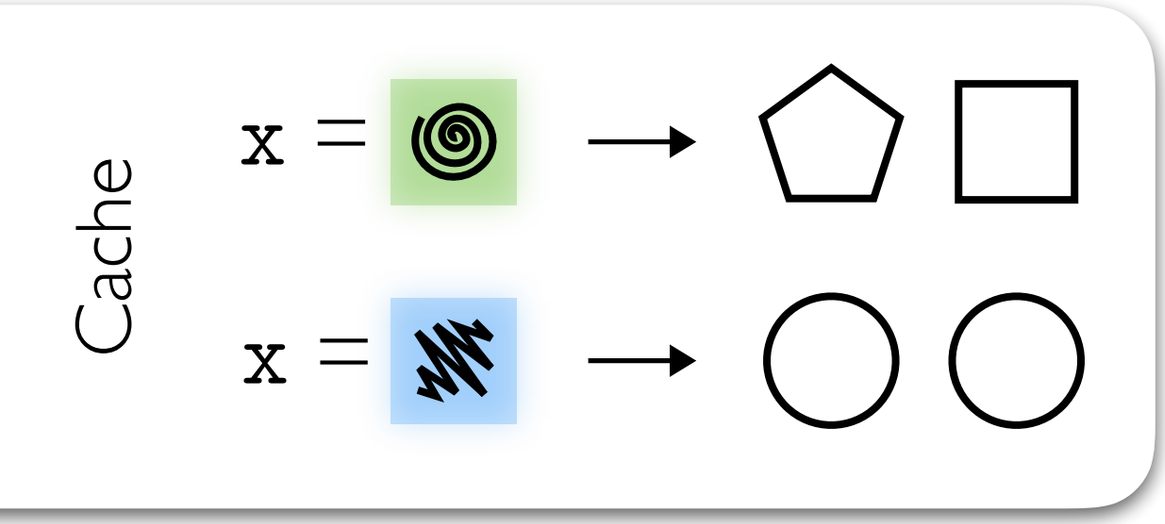



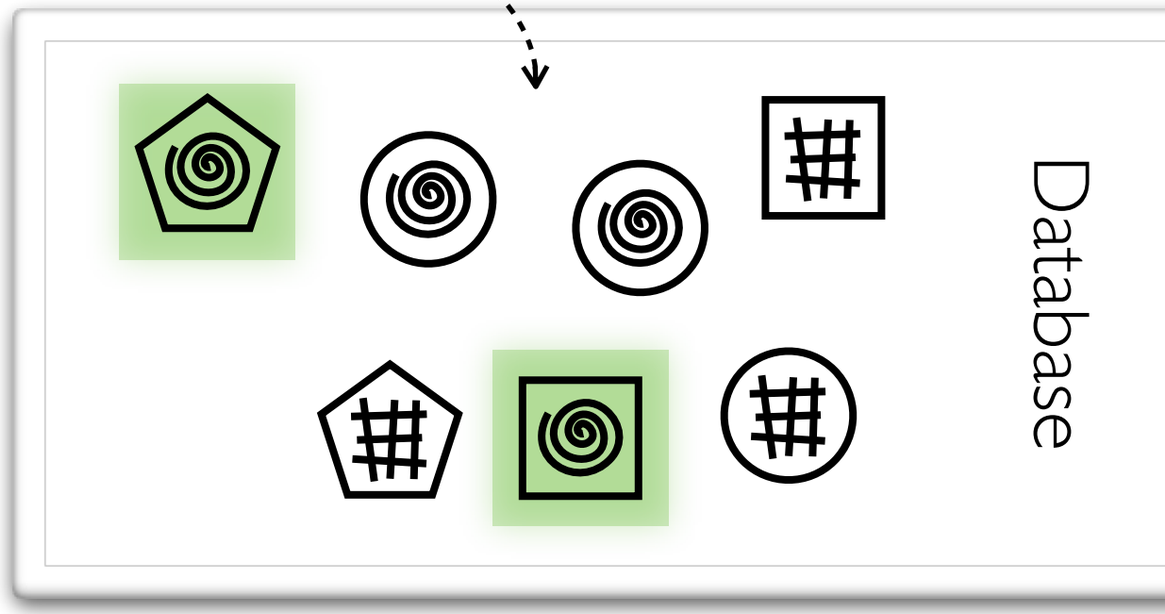

UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`



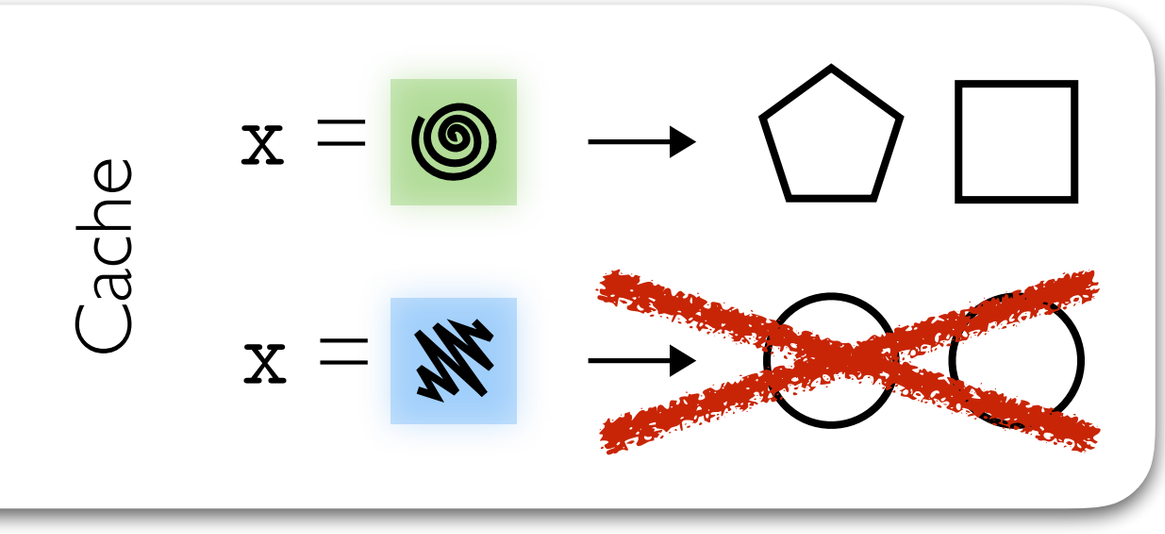



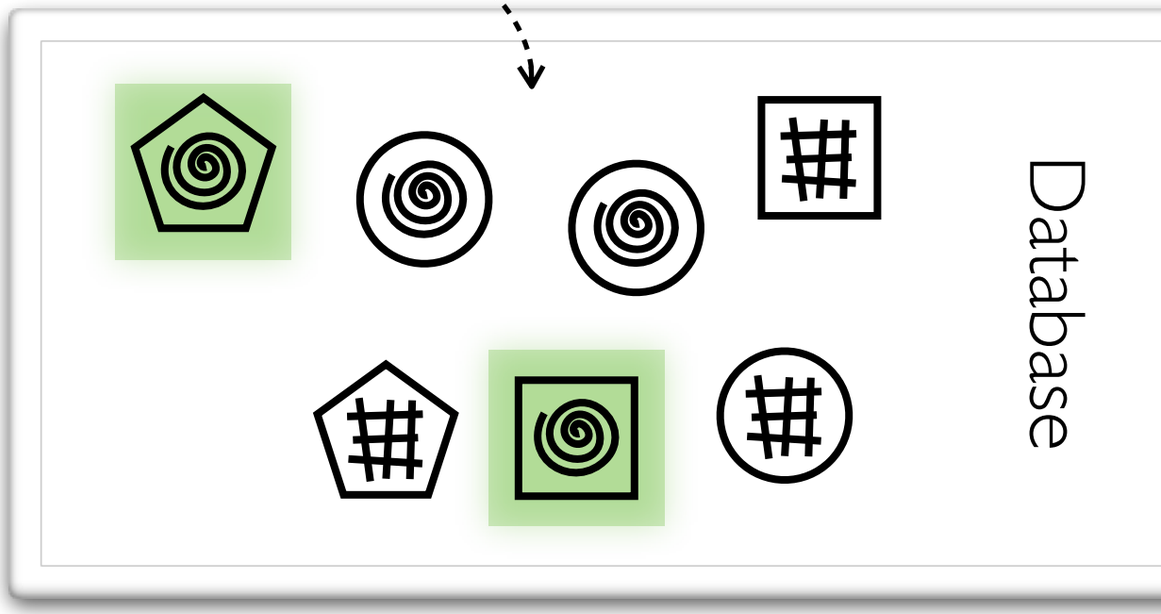

UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`



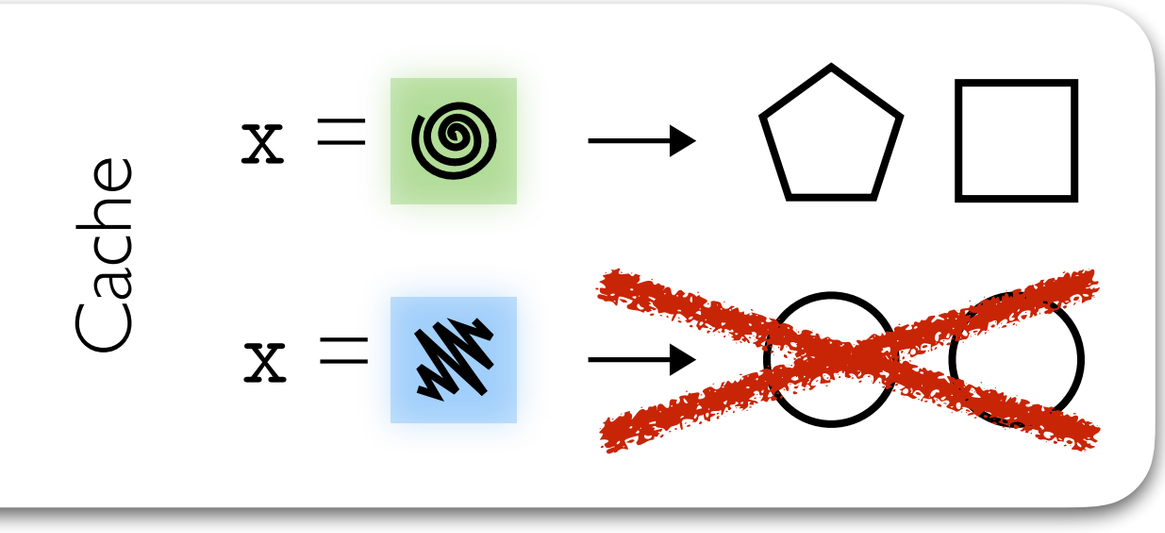



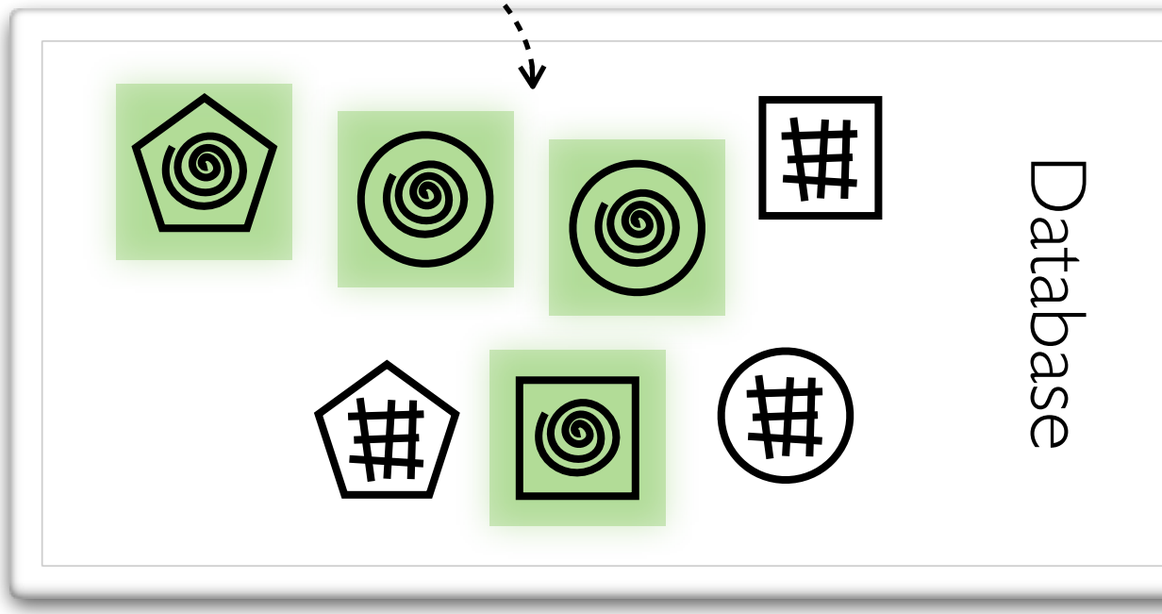

UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`



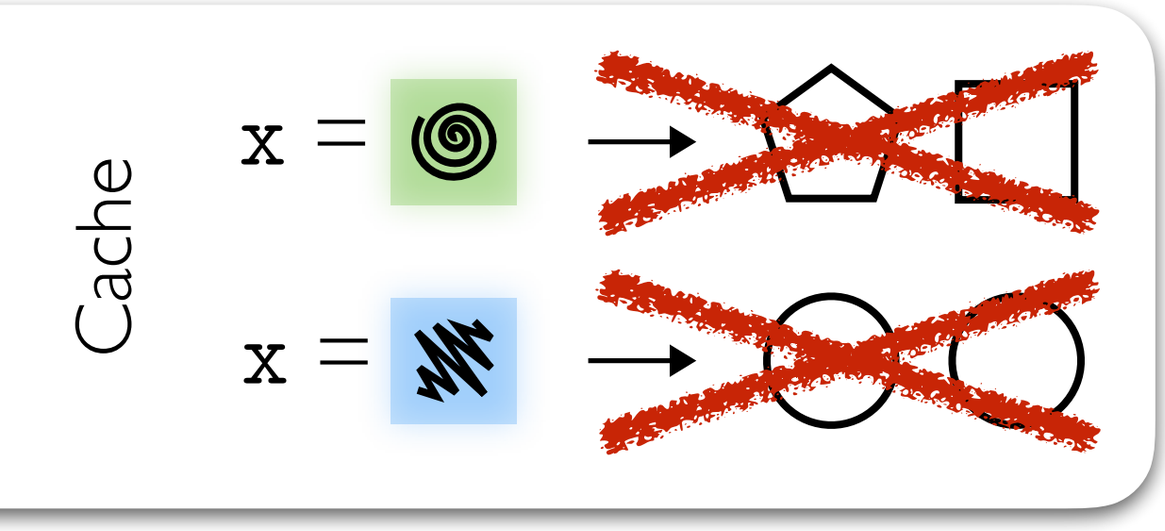



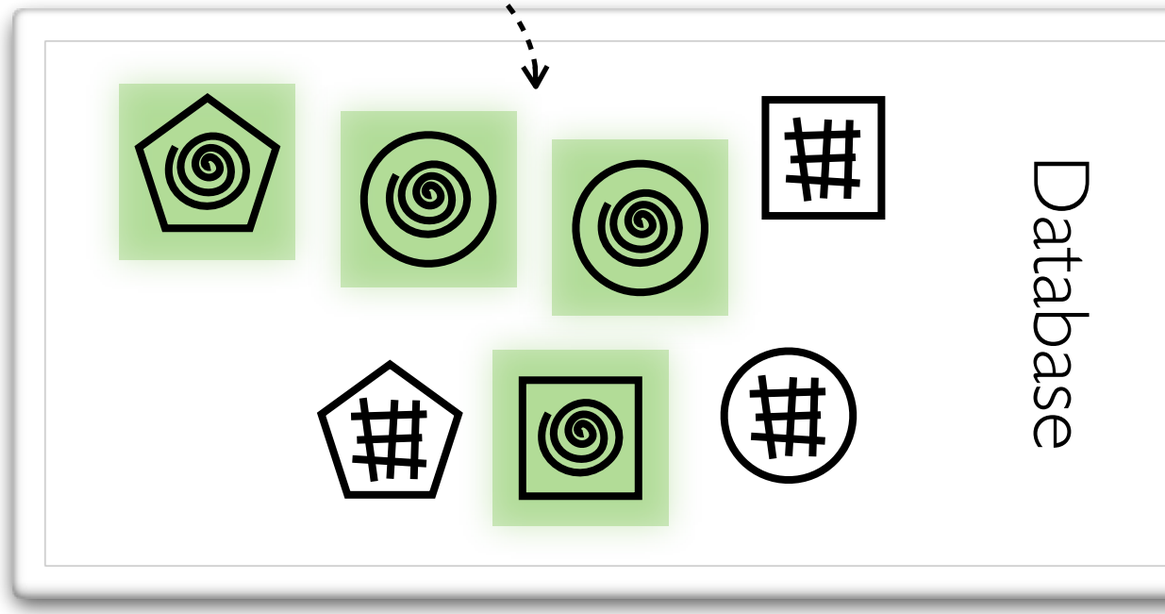

UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`



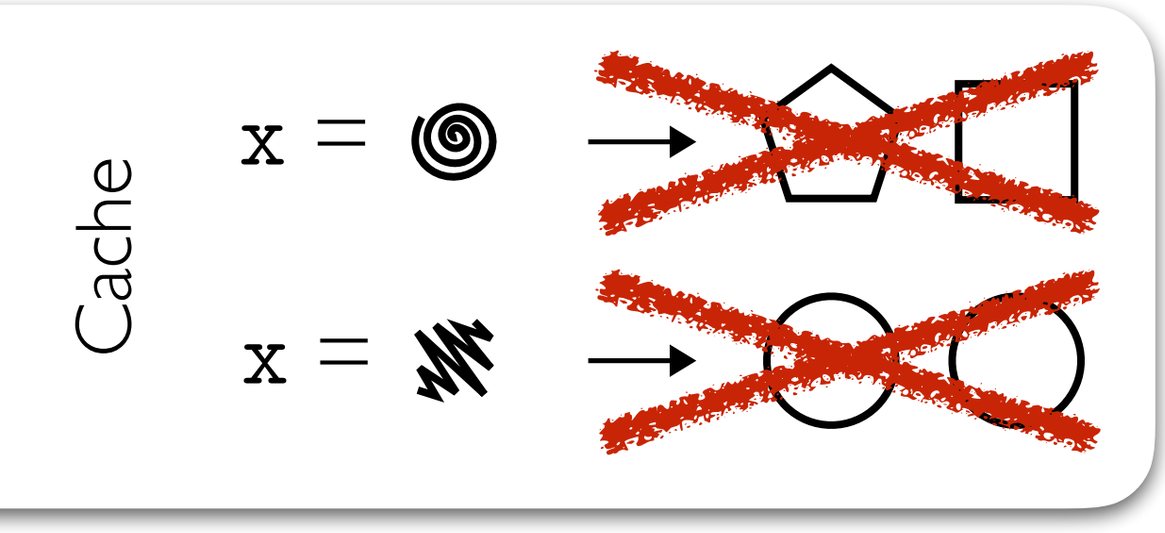



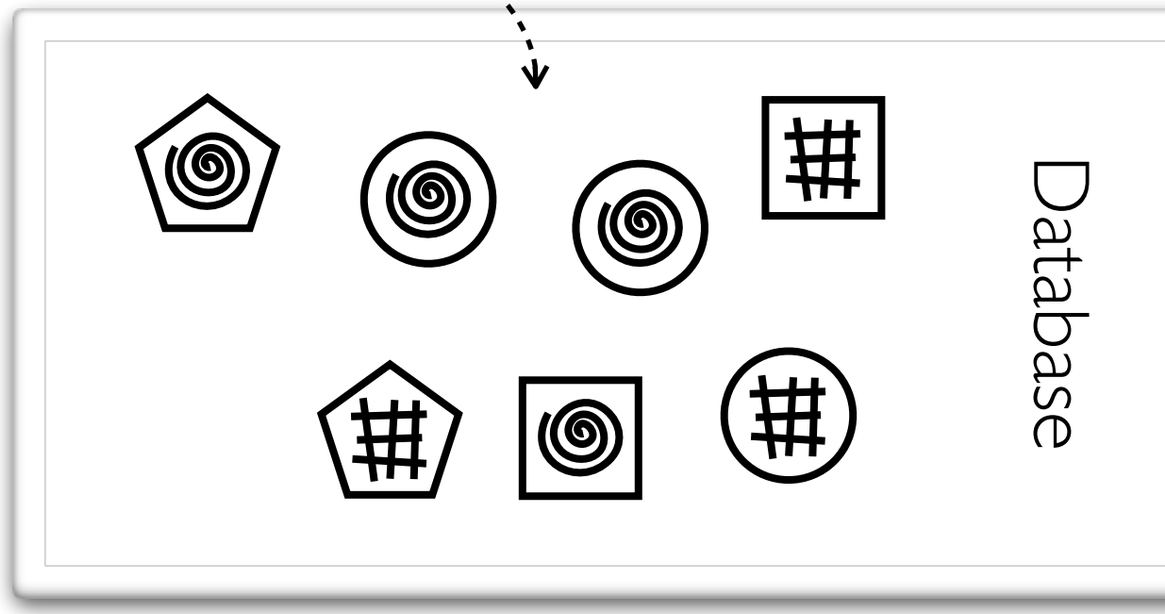

UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`




UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`

Cache

`x` =

`x` =

Database

UPDATE *fill* = `y` WHERE *fill* = `z`

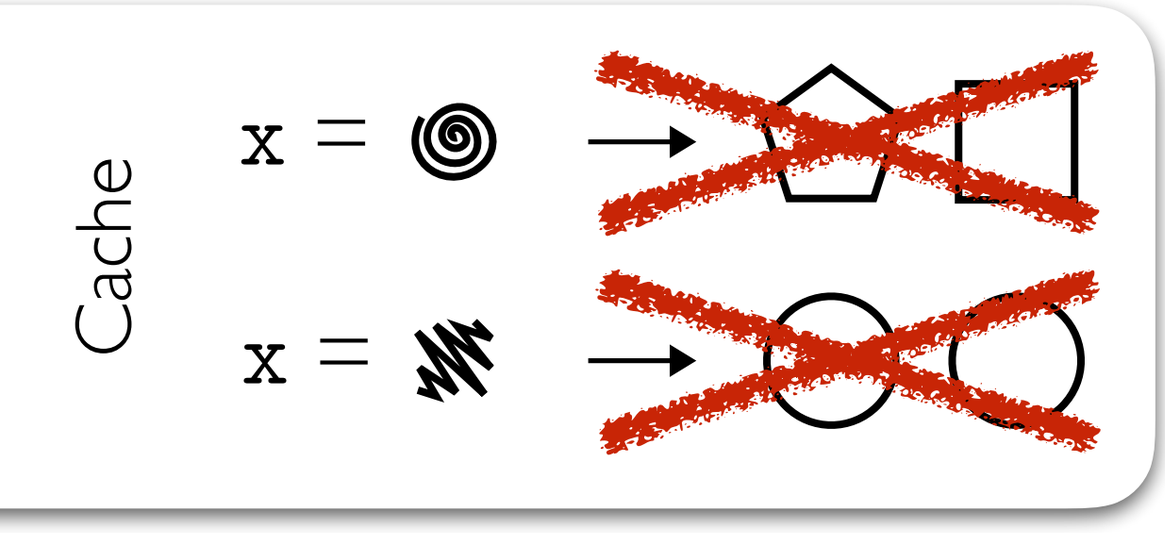
`y` = `z` =

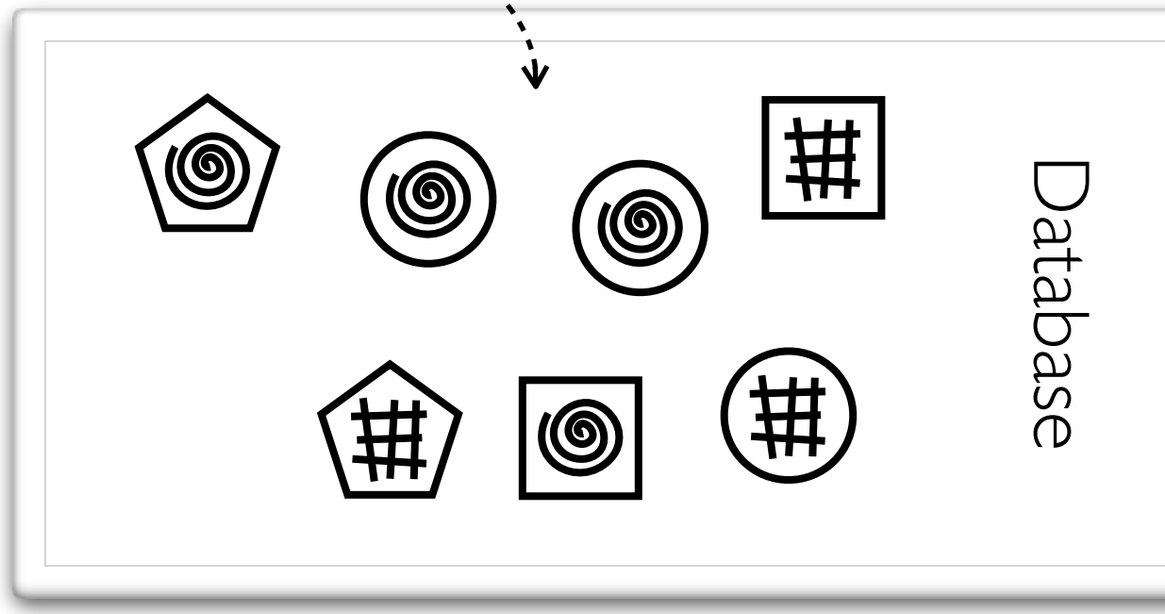
**Invalidation formula:**

$\exists$ (*shape*, *fill*), (*shape*', *fill*').
(*fill* = `x` $\vee$ *fill*' = `x`)
$\wedge$ (*fill*' = `y` $\wedge$ *fill* = `z`)

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`




UPDATE *fill* = `y` WHERE *fill* = `z`

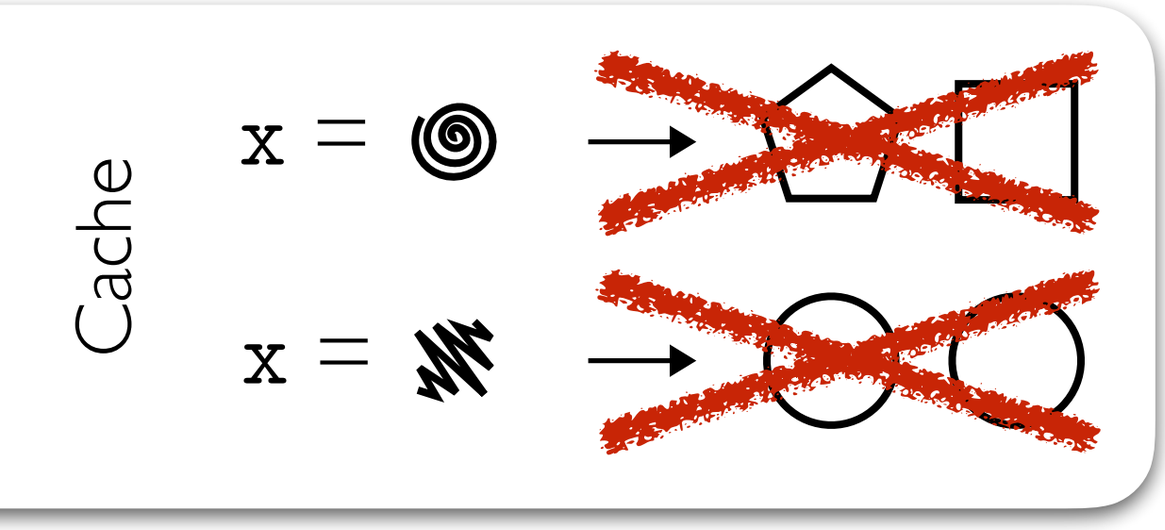
`y` = `z` =

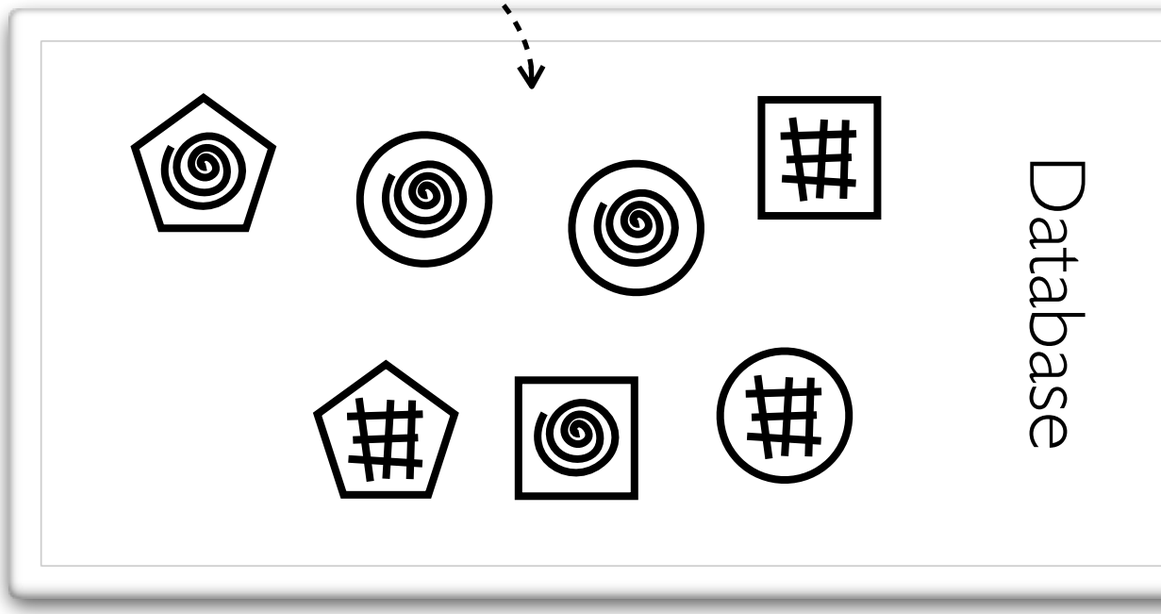
**Invalidation formula:**

$$\exists\ (shape, fill), (shape', fill').\ (fill = \mathtt{x} \vee fill' = \mathtt{x}) \wedge (fill' = \mathtt{y} \wedge fill = \mathtt{z}) \Longrightarrow \mathtt{x} = \mathtt{y} \vee \mathtt{x} = \mathtt{z}$$

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = x




UPDATE *fill* = y WHERE *fill* = z

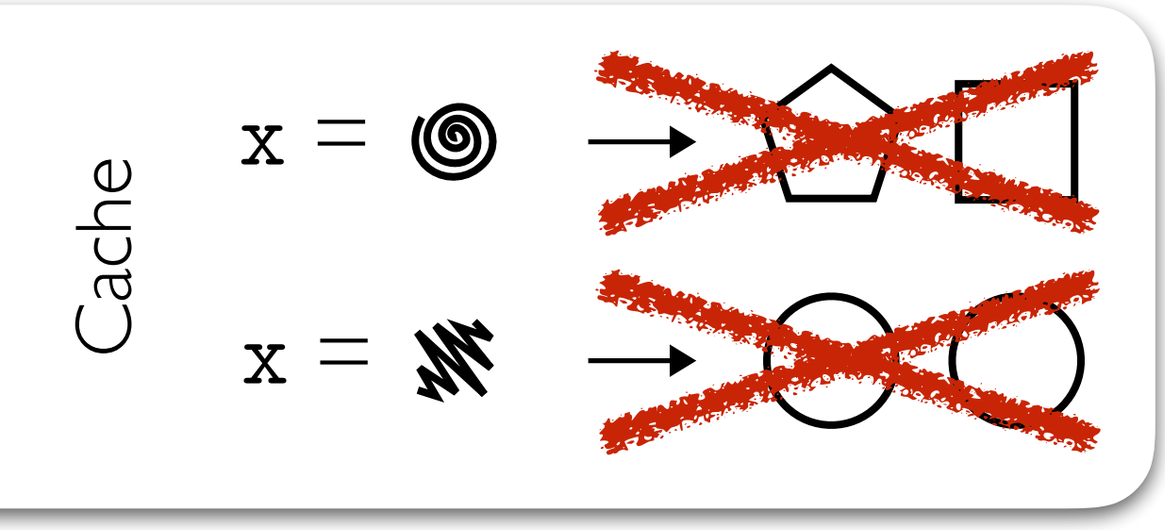
y = z =

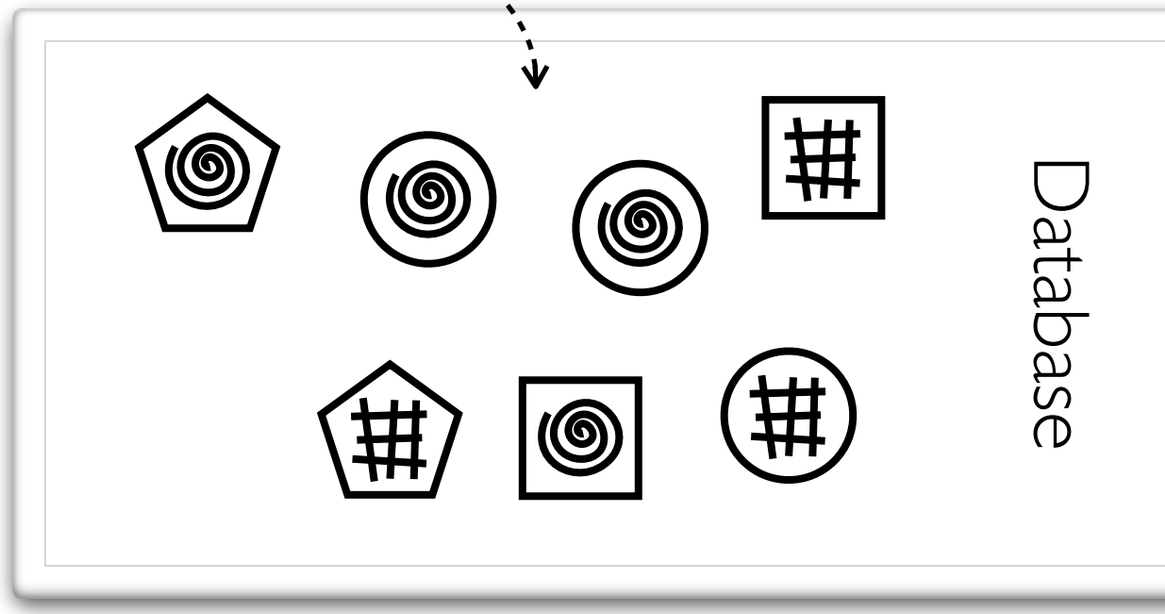
**Invalidation formula:**

$$\exists\ (shape, fill), (shape', fill').\ (fill = x \vee fill' = x) \wedge (fill' = y \wedge fill = z) \Longrightarrow x = y \vee x = z$$

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`




UPDATE *fill* = `y` WHERE *fill* = `z`

`y` = `z` =

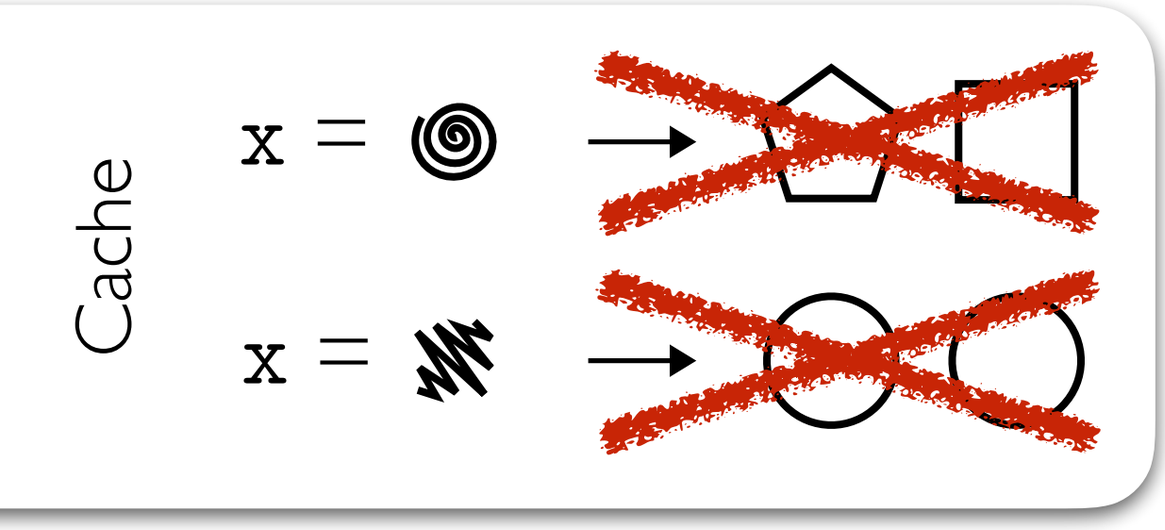
**Invalidation formula:**

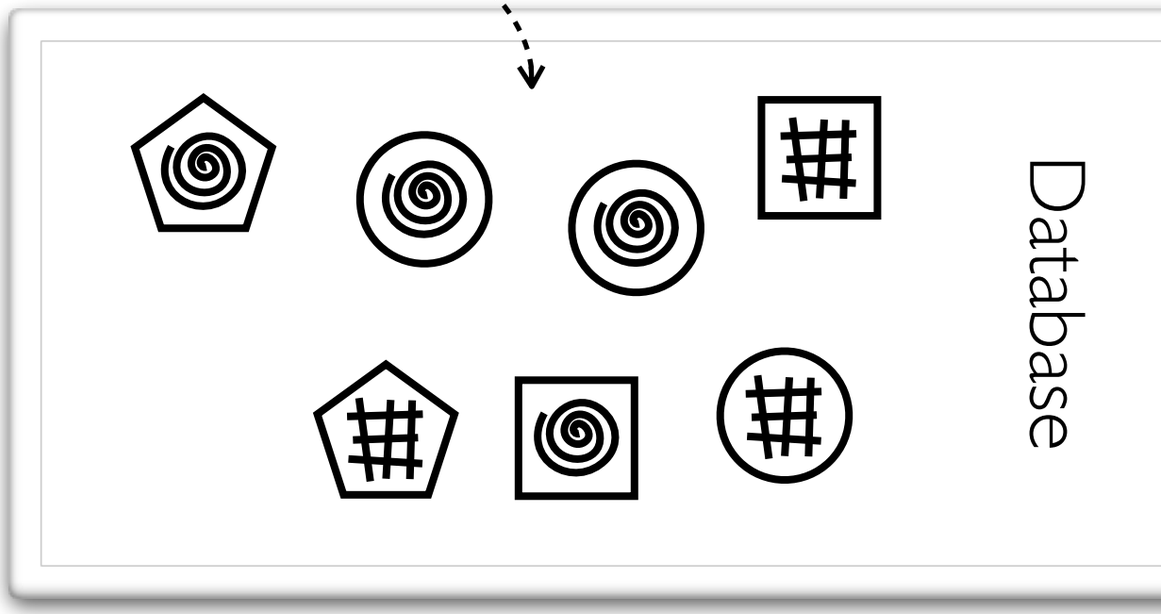
$$\exists\ (shape, fill), (shape', fill').\ (fill = \mathtt{x} \vee fill' = \mathtt{x}) \wedge (fill' = \mathtt{y} \wedge fill = \mathtt{z})$$

$$\Longrightarrow \mathtt{x} = \mathtt{y} \vee \mathtt{x} = \mathtt{z}$$

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = x




UPDATE *fill* = y WHERE *fill* = z

y = z =

**Invalidation formula:**

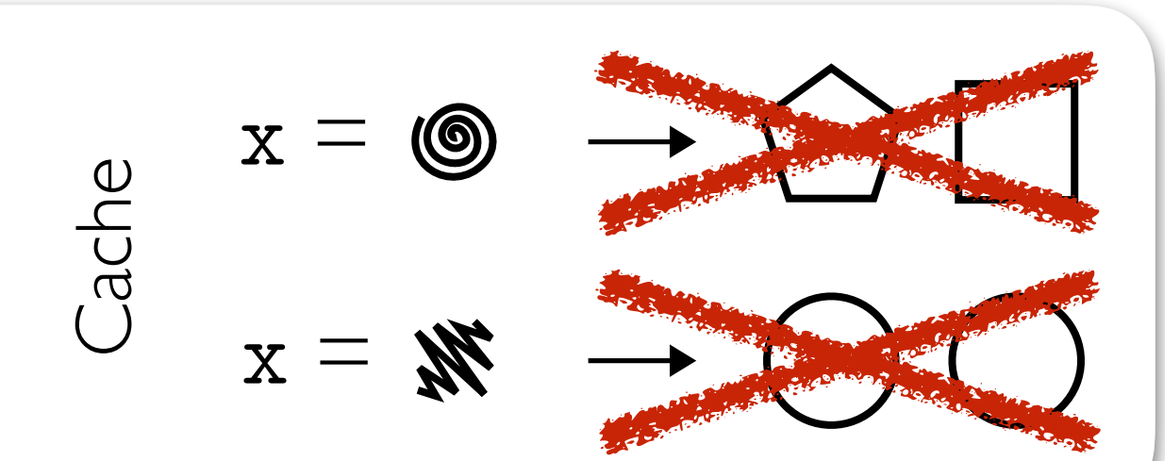
$$\exists\ (shape, fill), (shape', fill').\ (fill = x \vee fill' = x) \wedge (fill' = y \wedge fill = z)$$

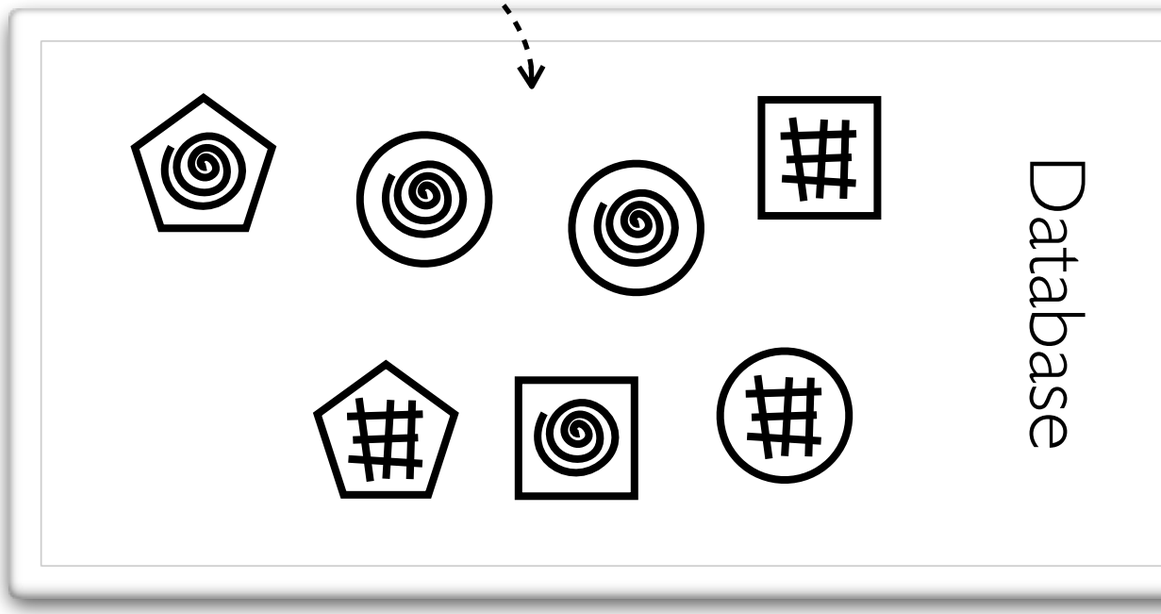
$$\Longrightarrow x = y \vee x = z$$

inval(y); inval(z);

# Invalidation for UPDATE

SELECT *shape* WHERE *fill* = `x`




UPDATE *fill* = `y` WHERE *fill* = `z`

(*fill* = `x` ∧ *fill*' ≠ `x`) ∨ (*fill* ≠ `x` ∧ *fill*' = `x`)
∨ (*fill* = `x` ∧ *fill*' = `x` ∧ *shape* ≠ *shape*')

**Invalidation formula:**

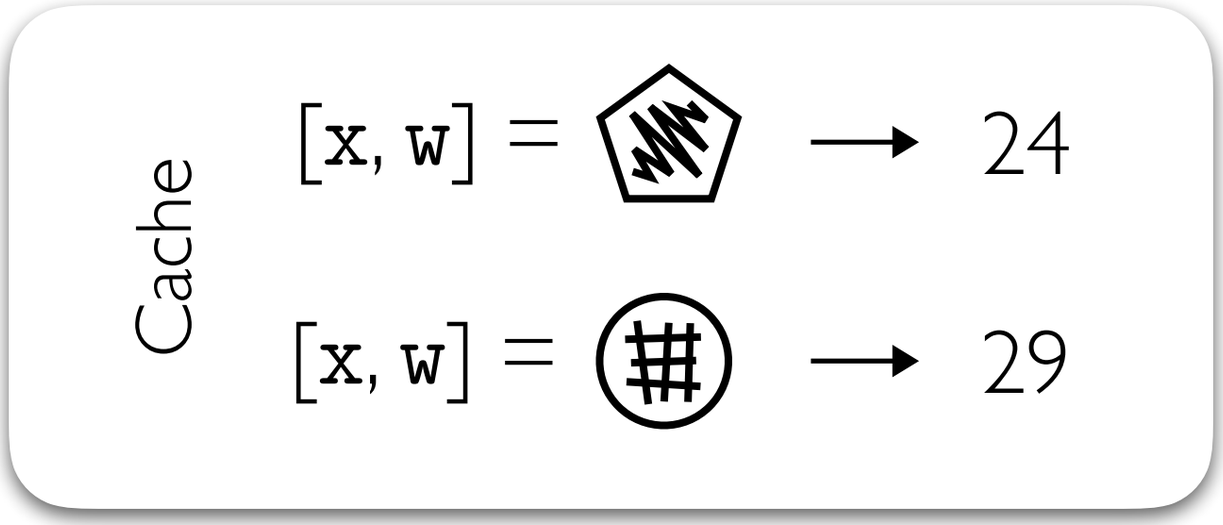
∃ (*shape*, *fill*), (*shape*', *fill*').
(*fill* = `x` ∨ *fill*' = `x`)
∧ (*fill*' = `y` ∧ *fill* = `z`)

⟹ `x` = `y` ∨ `x` = `z`

inval(`y`); inval(`z`);

# Compound Cache Keys

SELECT COUNT(*) WHERE *fill* = `x` ∧ *shape* = `w`



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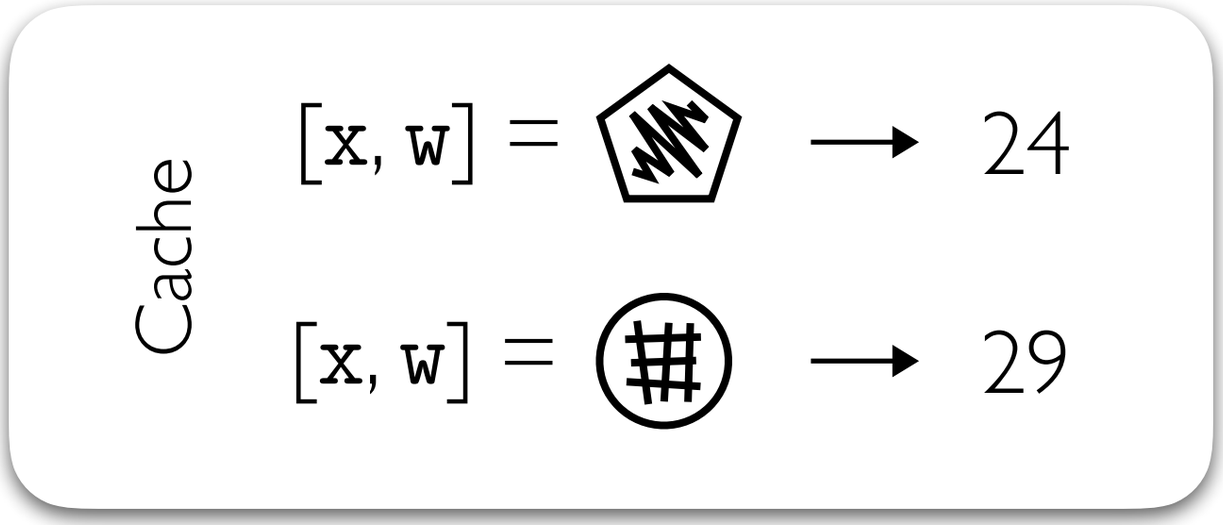


INSERT (*shape*, *fill*) = (`y`, `z`)  UPDATE *fill* = `y` WHERE *fill* = `z`

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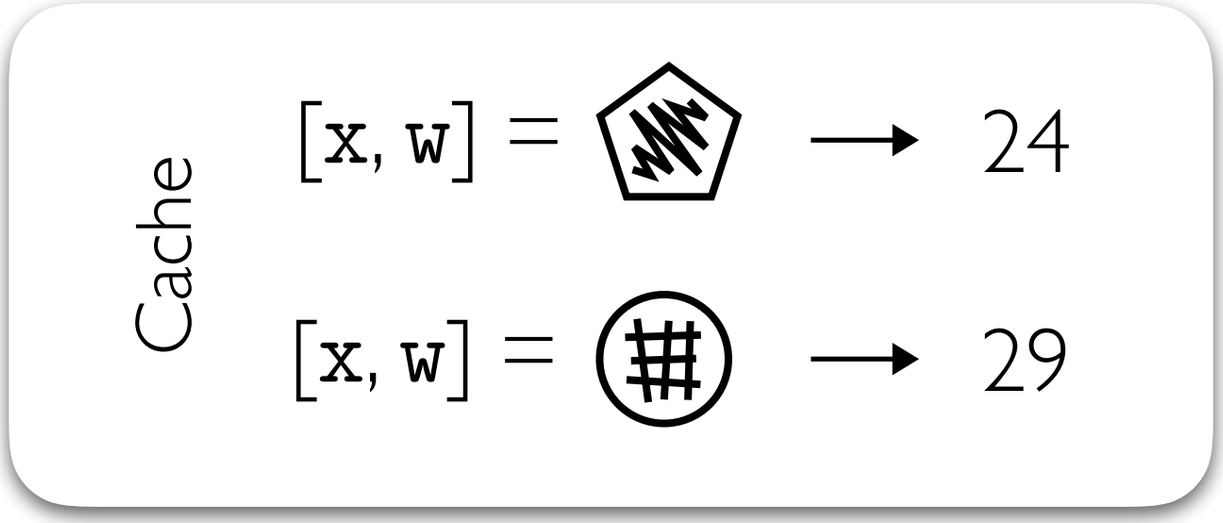
SELECT COUNT(*) WHERE *fill* = `x` ∧ *shape* = `w`




INSERT (*shape*, *fill*) = (`y`, `z`)

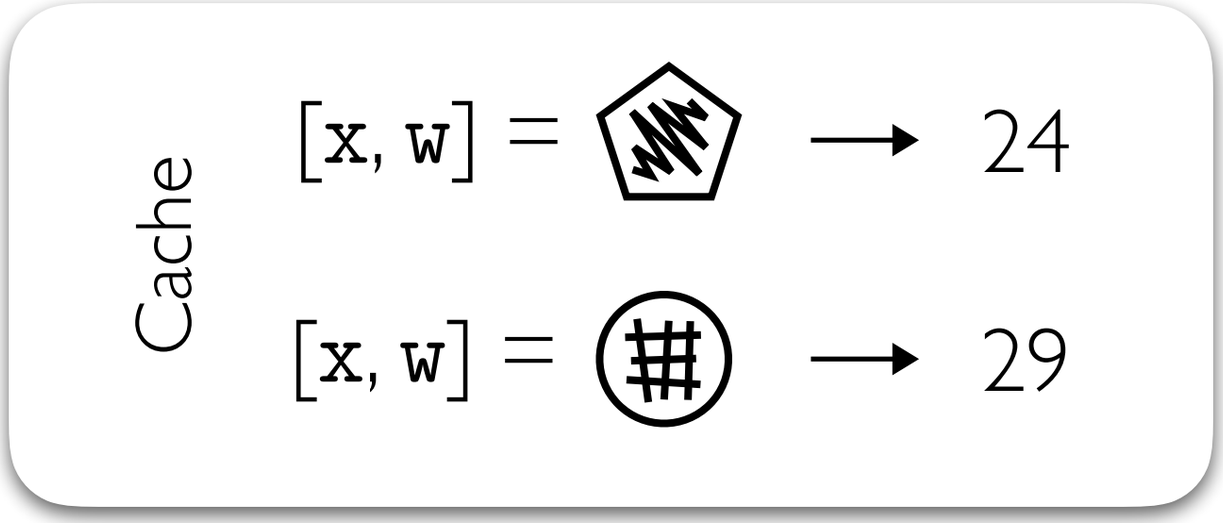
UPDATE *fill* = `y` WHERE *fill* = `z`

$\Longrightarrow$ `x` = `z` ∧ `w` = `y`

inval([`z`, `y`]);

# Compound Cache Keys

SELECT COUNT(*) WHERE *fill* = `x` ∧ *shape* = `w`

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inval([`y`, *]); inval([`z`, *]);

# Cache Data Structure

SELECT COUNT(*) WHERE *fill* = `x` ∧ *shape* = `w`

UPDATE *fill* = `y` WHERE *fill* = `z`
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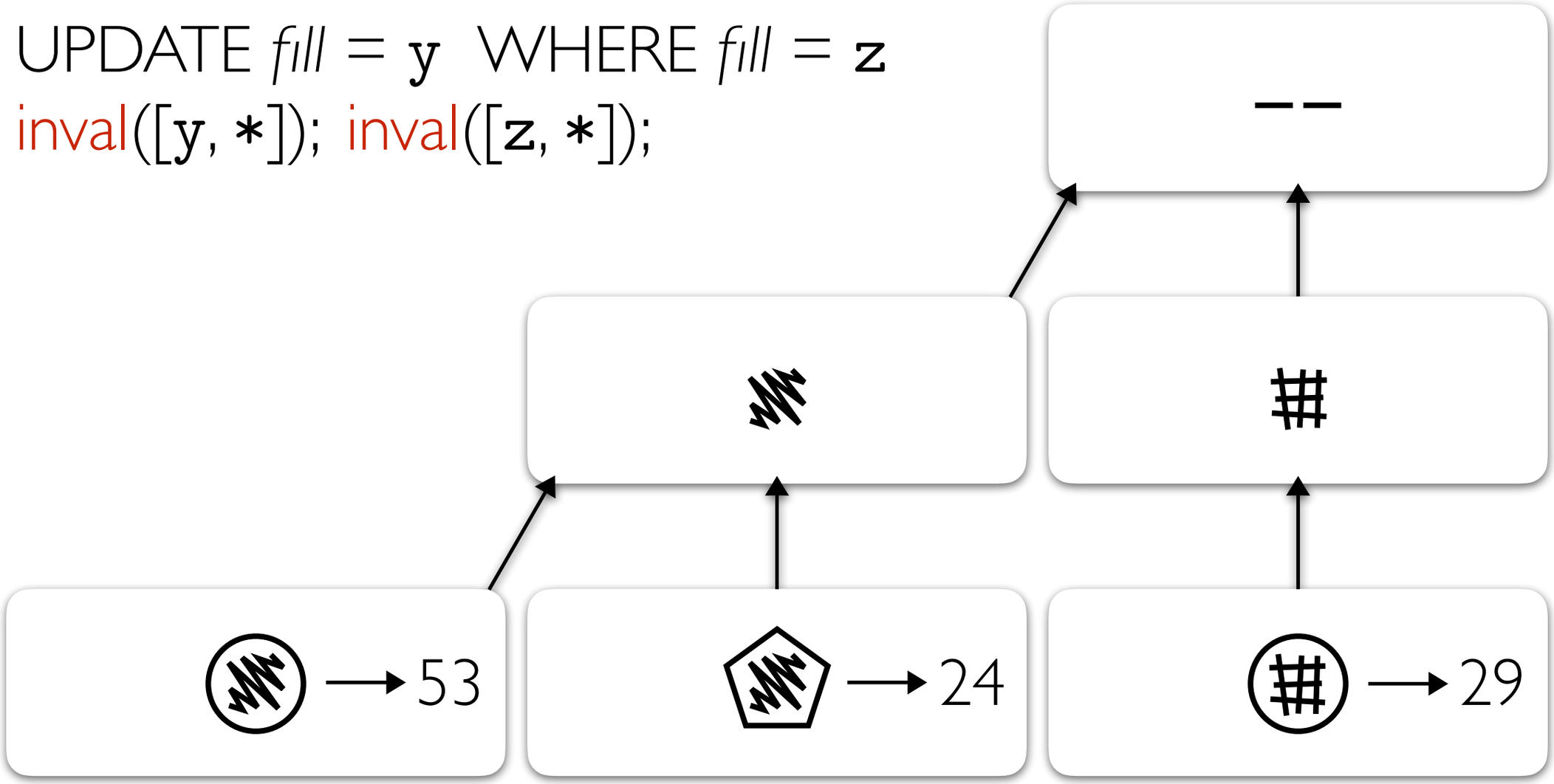

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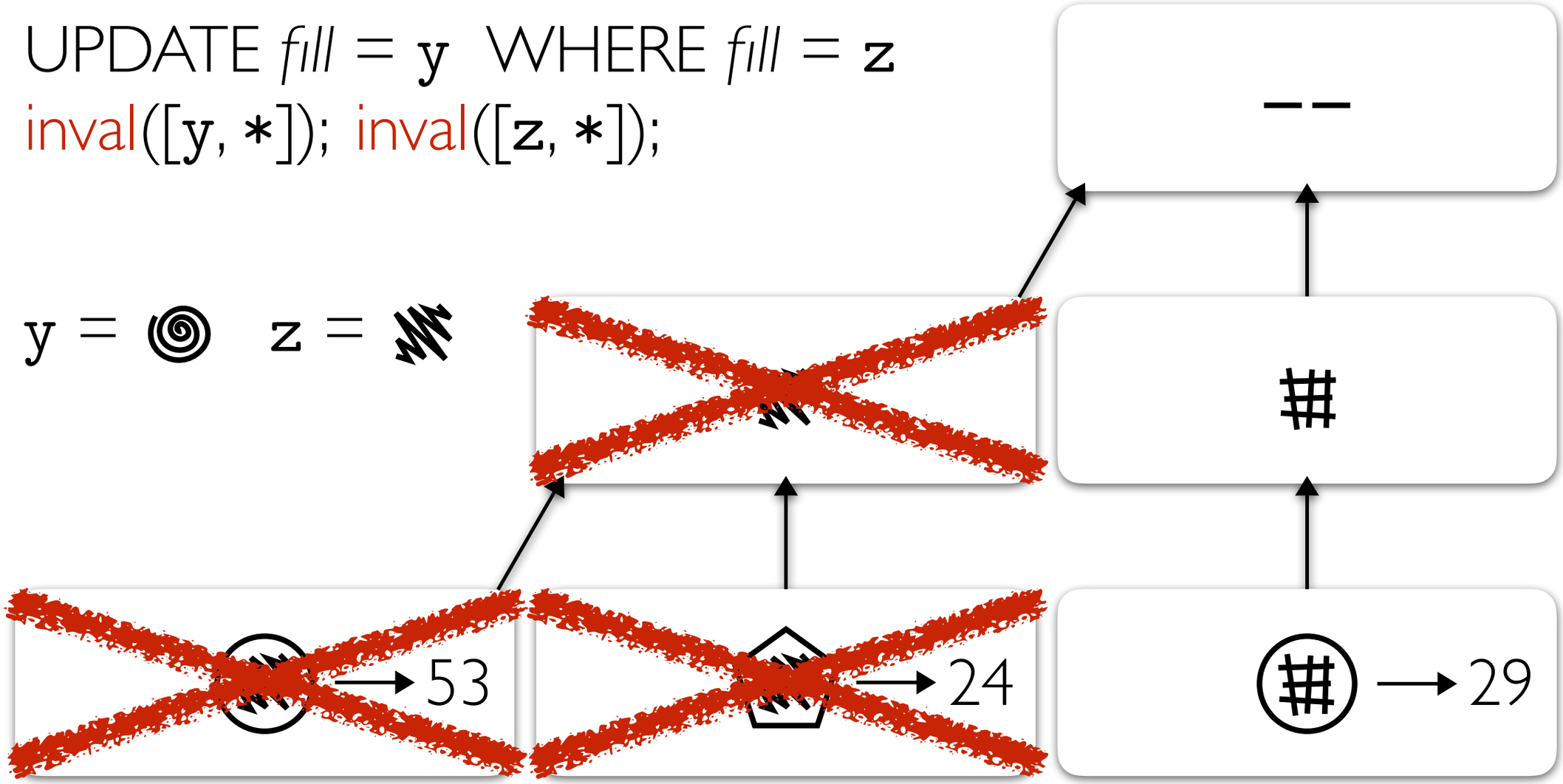

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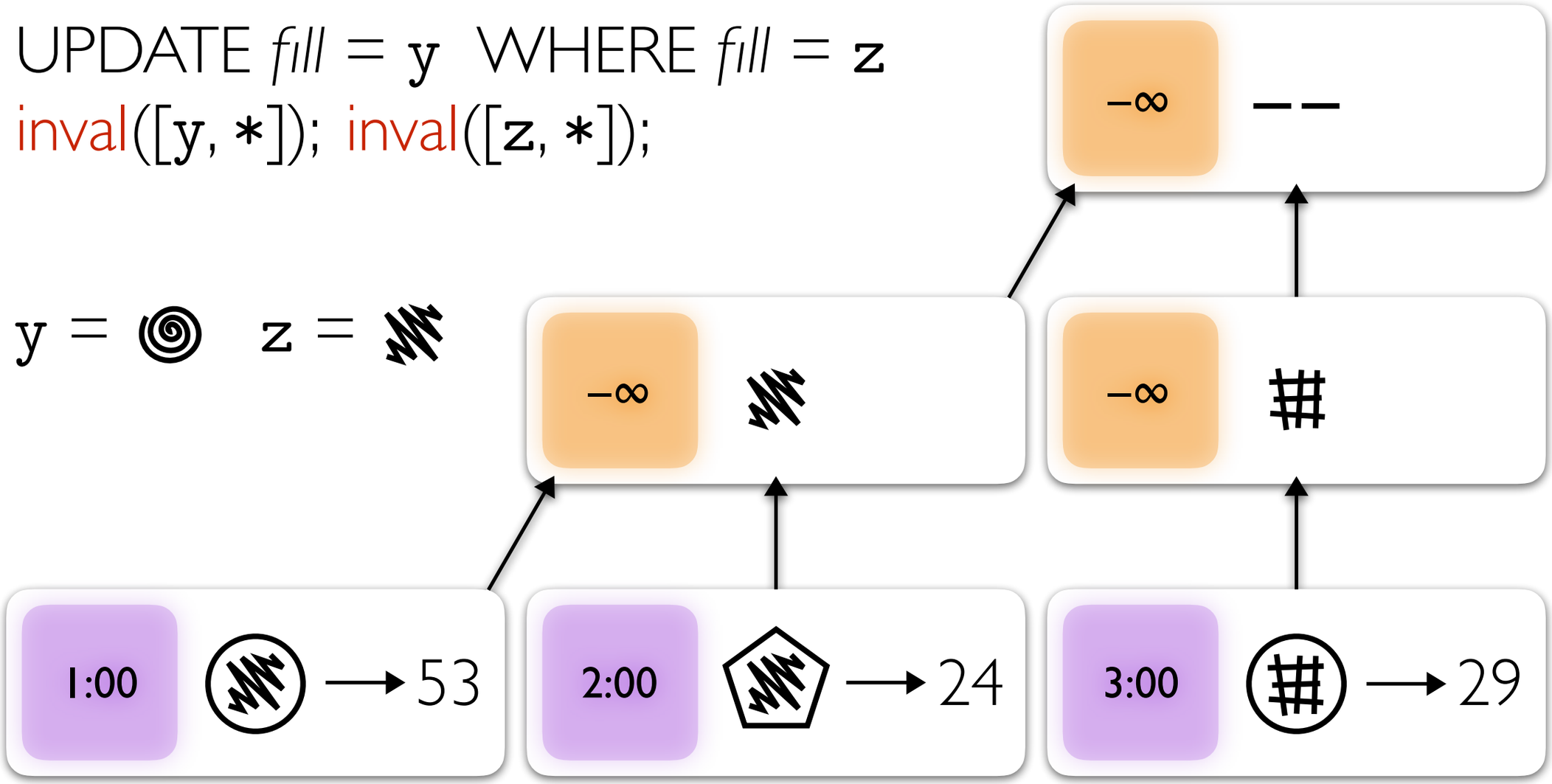

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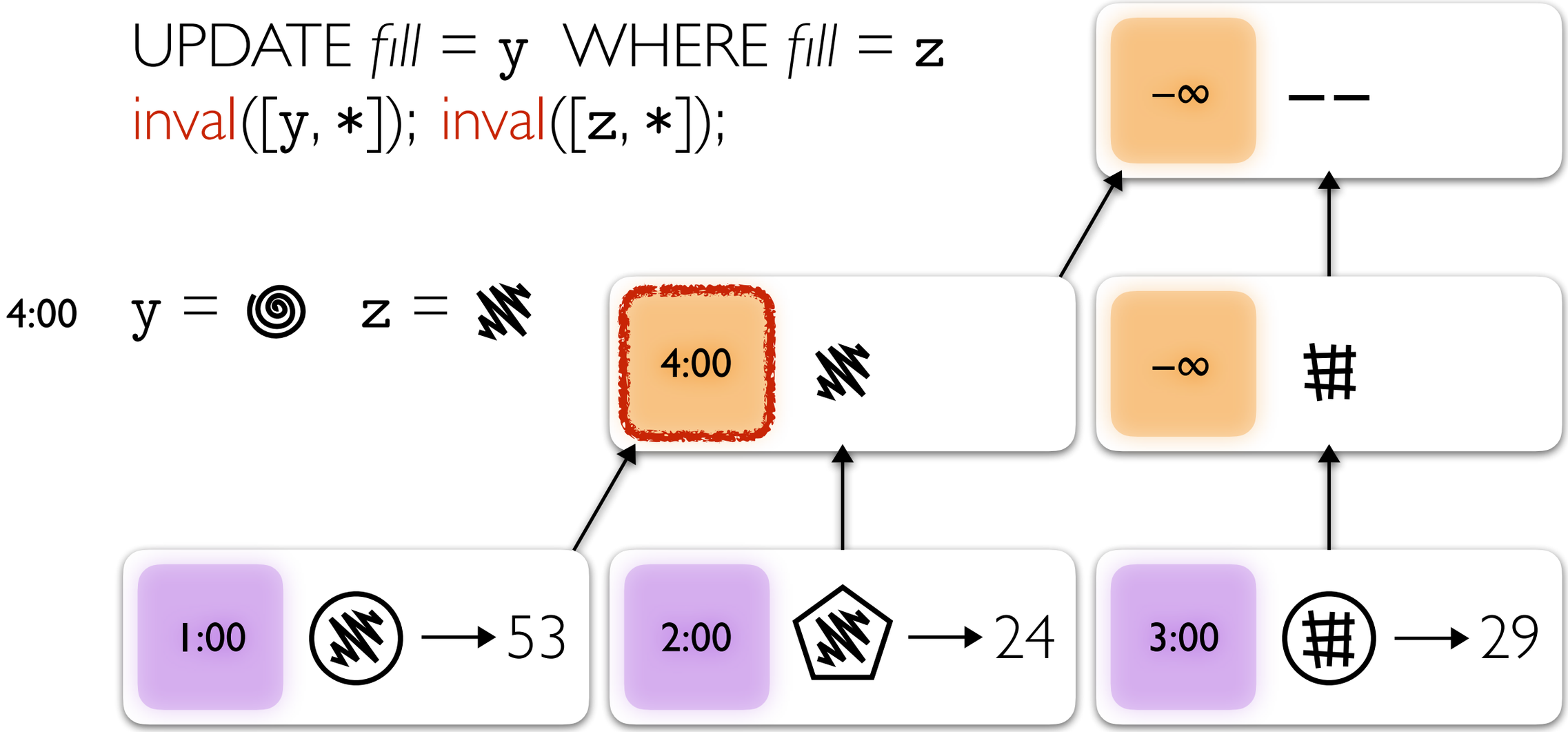

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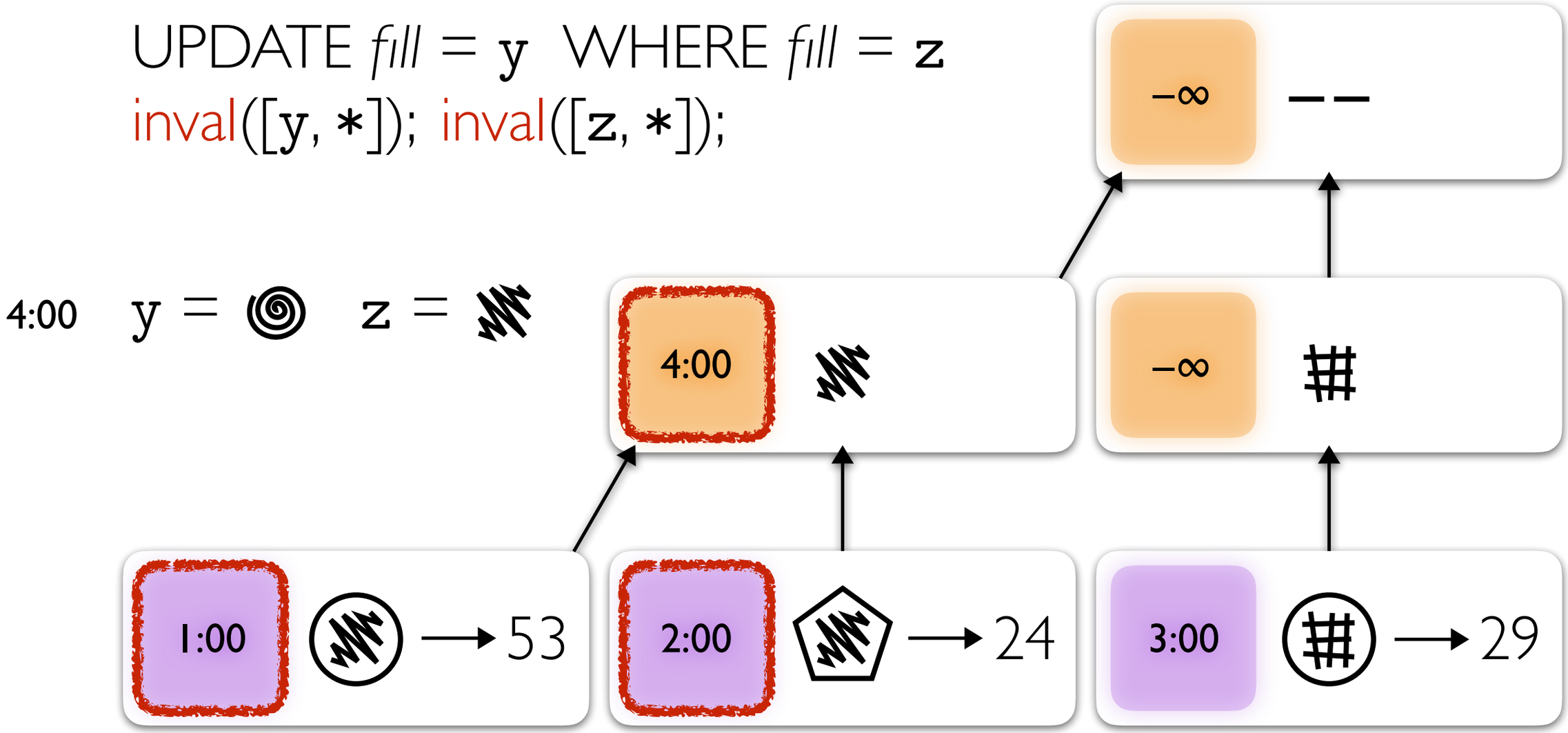

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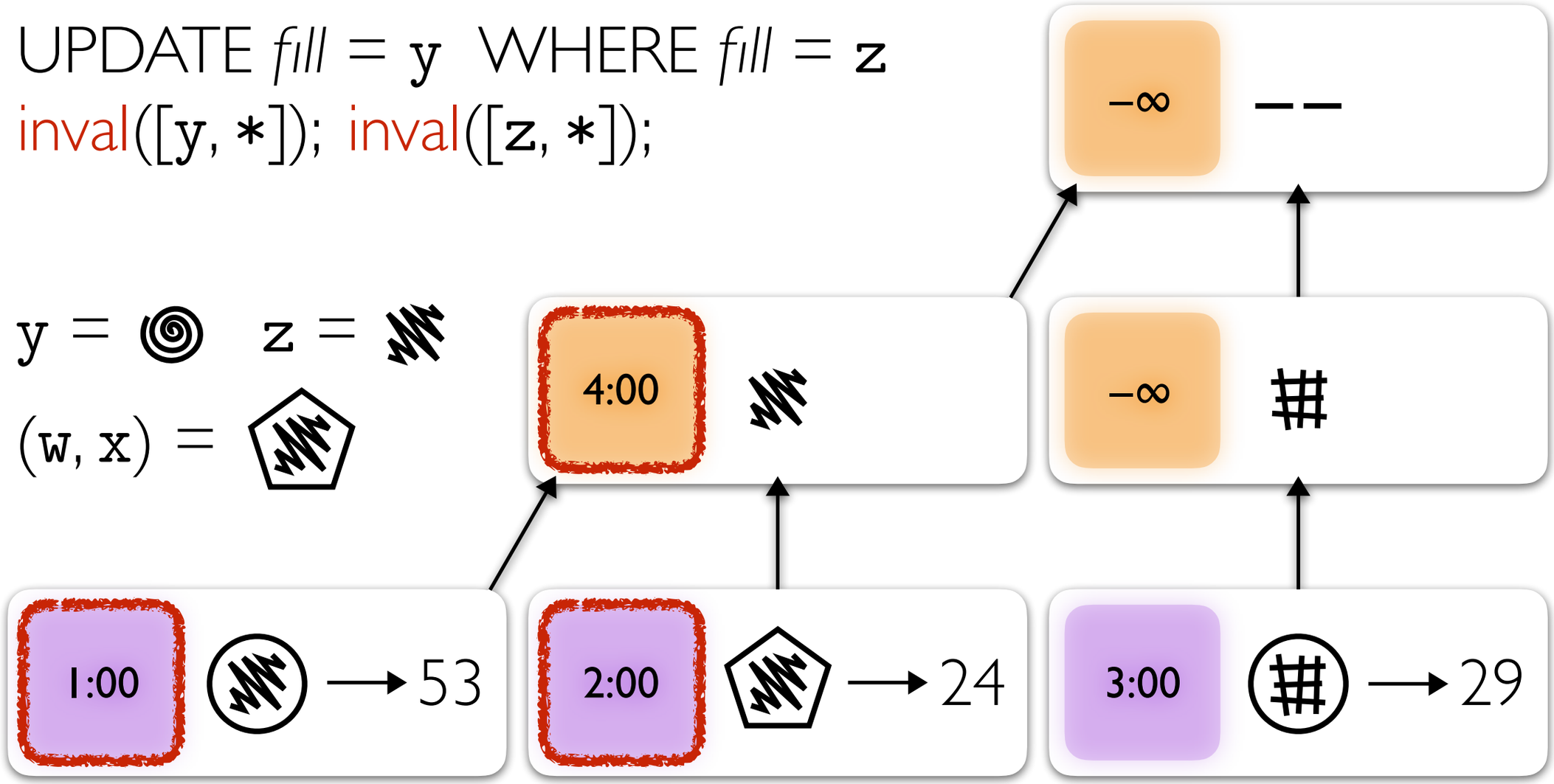

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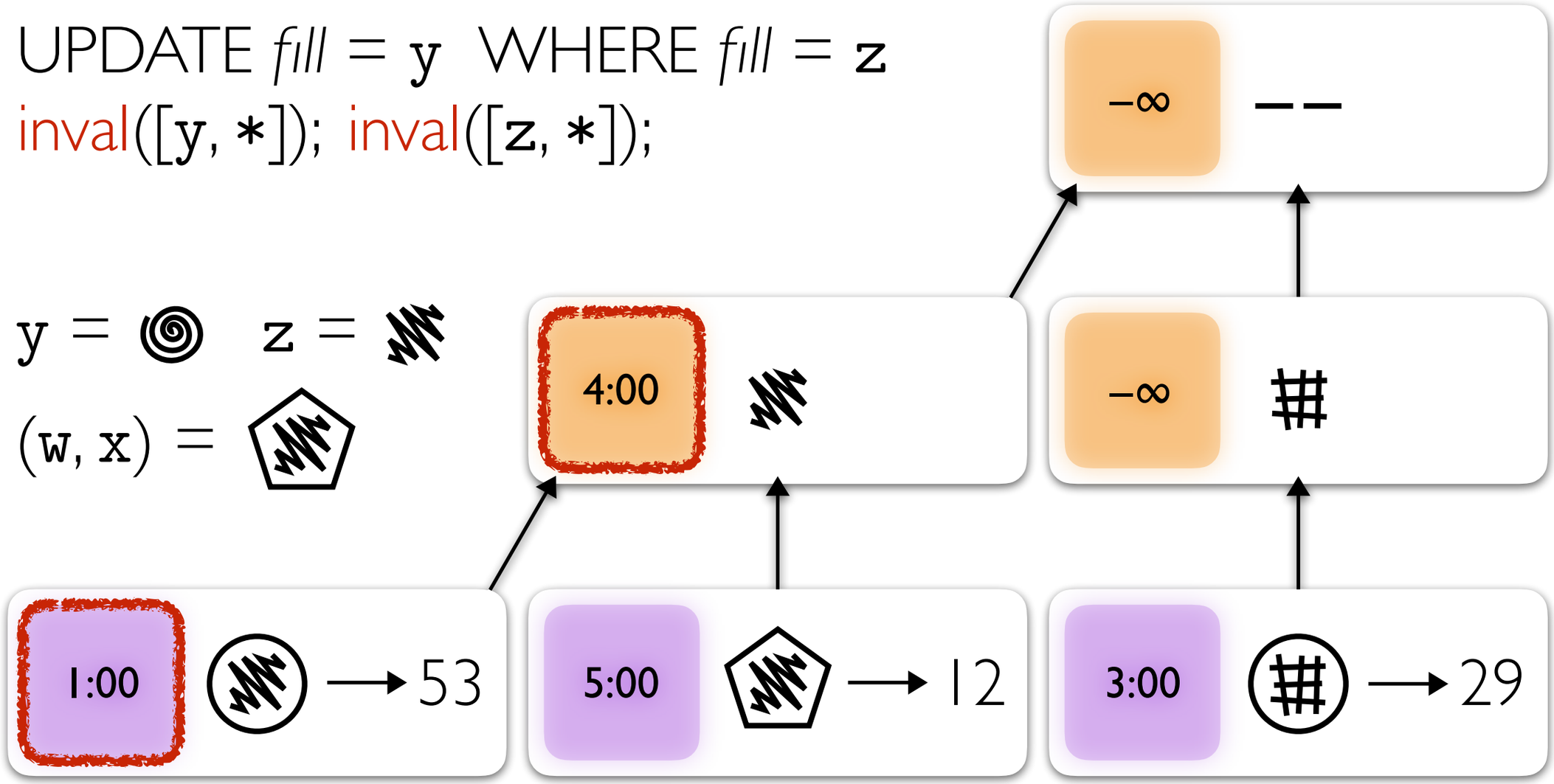

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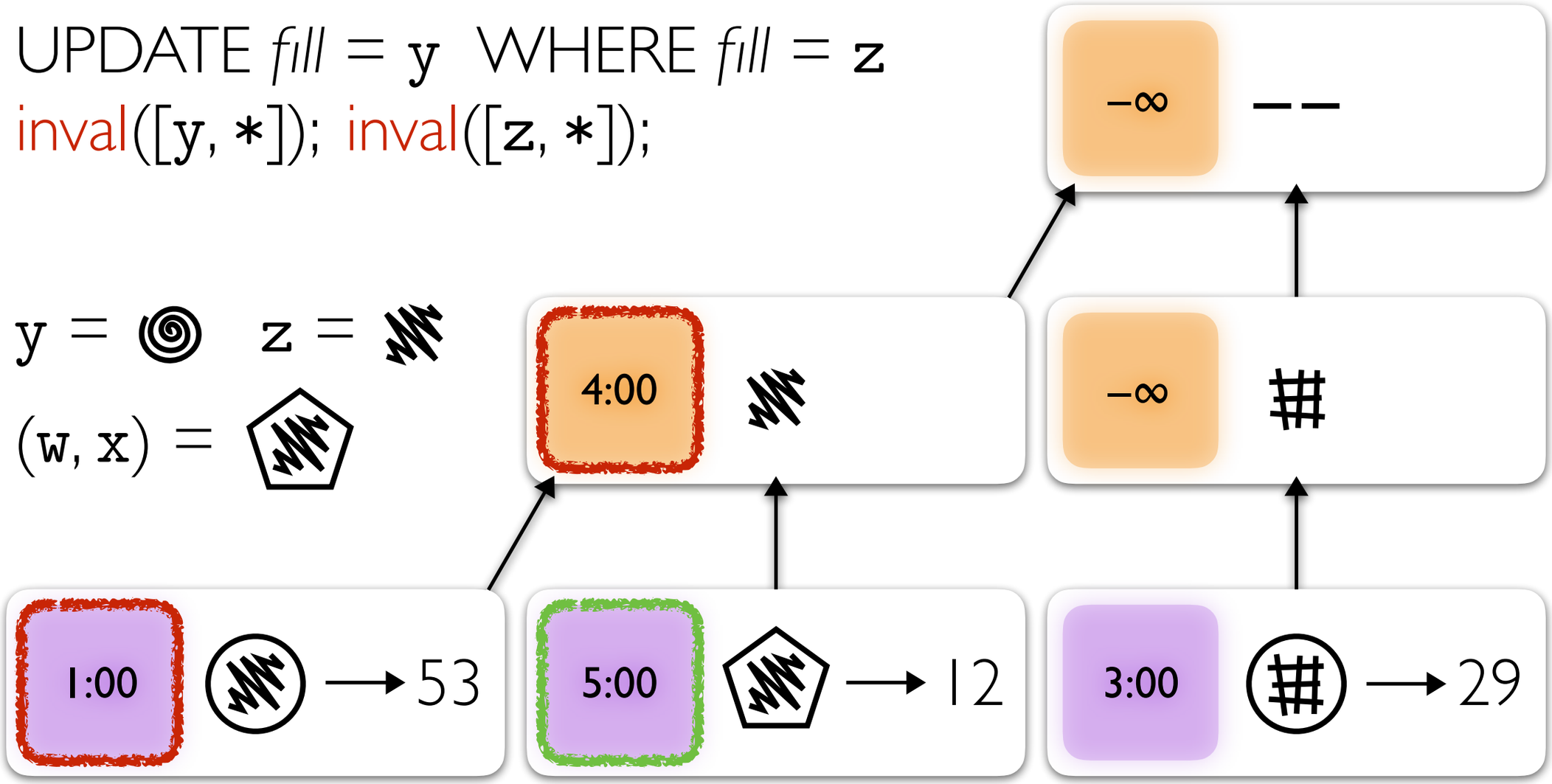

Program instrumentation

SQL analysis

Cache data structure

Concurrency control

Program instrumentation

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talked

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talked

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Consolidate cached expressions, but avoid introducing new keys.

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Two global locks per cache: "data" lock and "transaction" lock.

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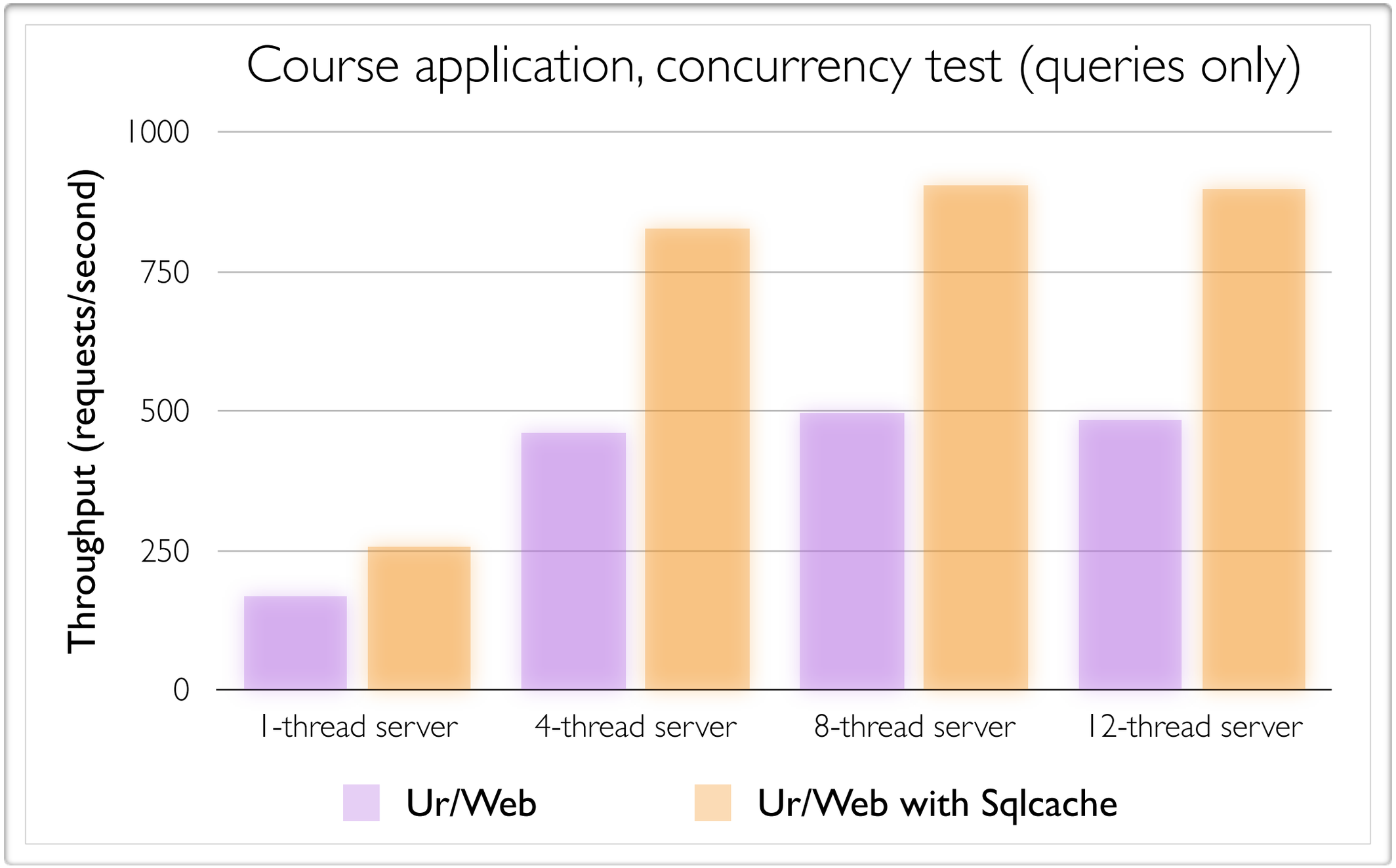
Two global locks per cache: "data" lock and "transaction" lock.

Runtime monitoring

Deactivate caches with low hit rate to reduce serialization.

# Performance Evaluation



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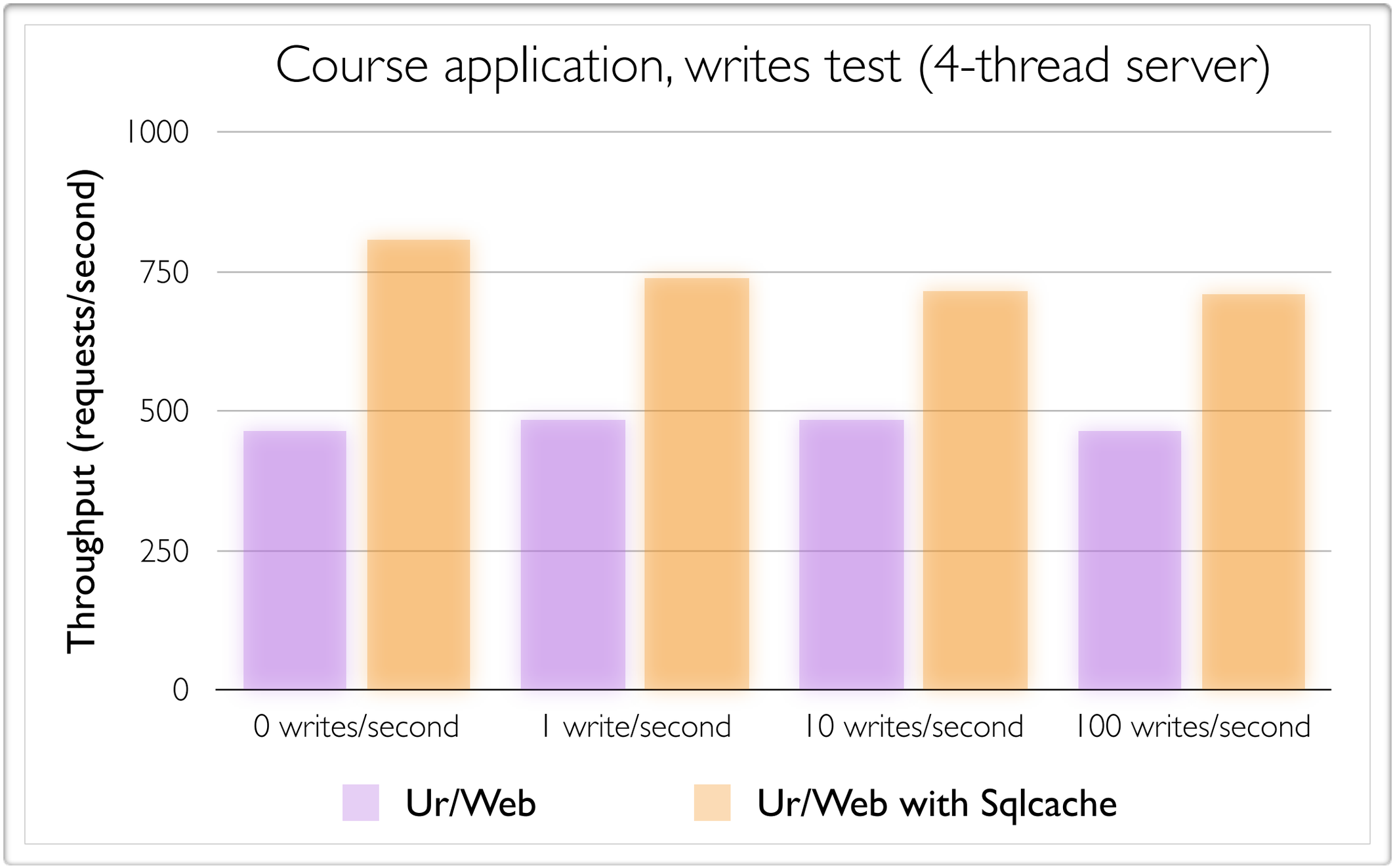


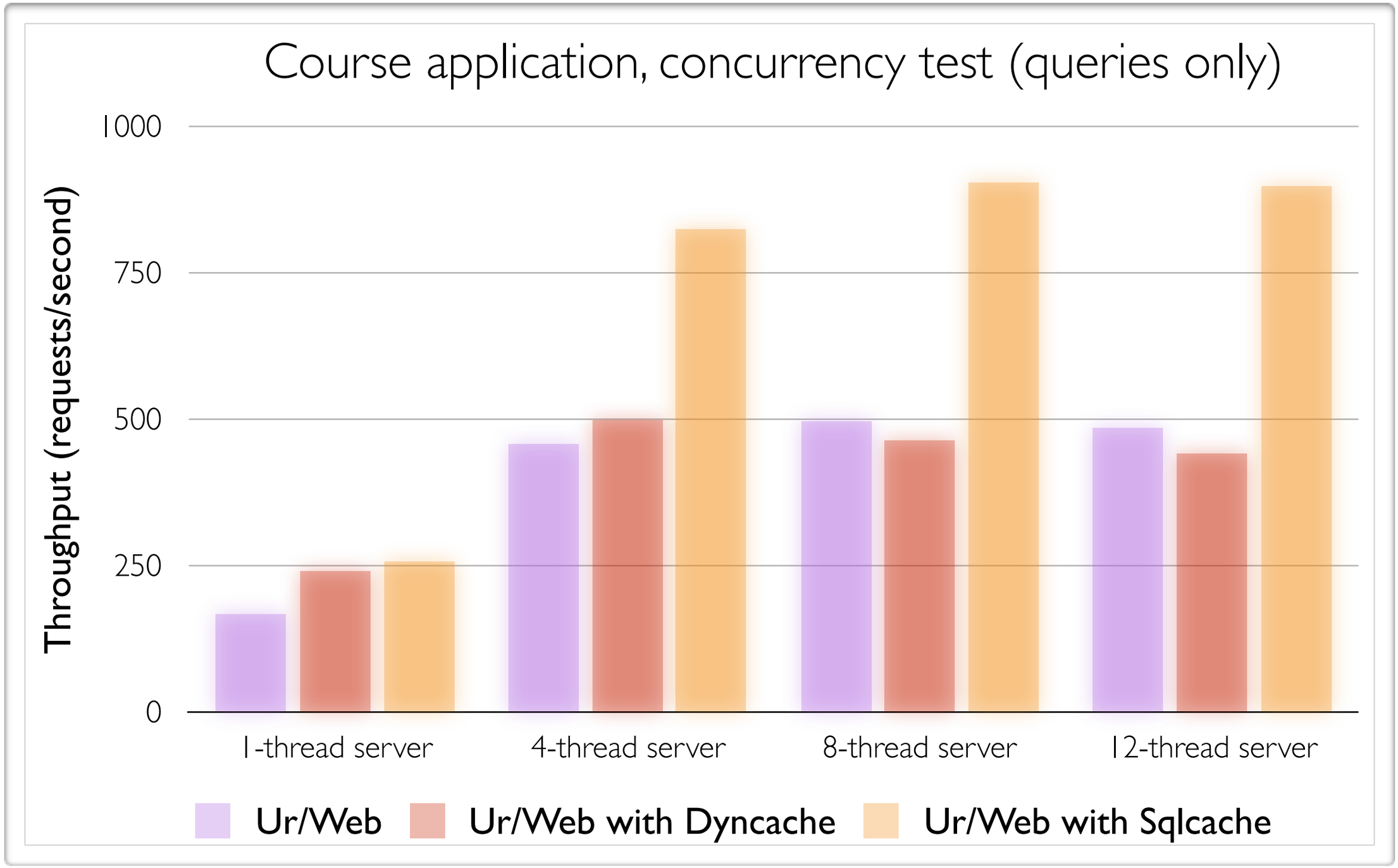
# Sqlcache

caching as a compiler optimization

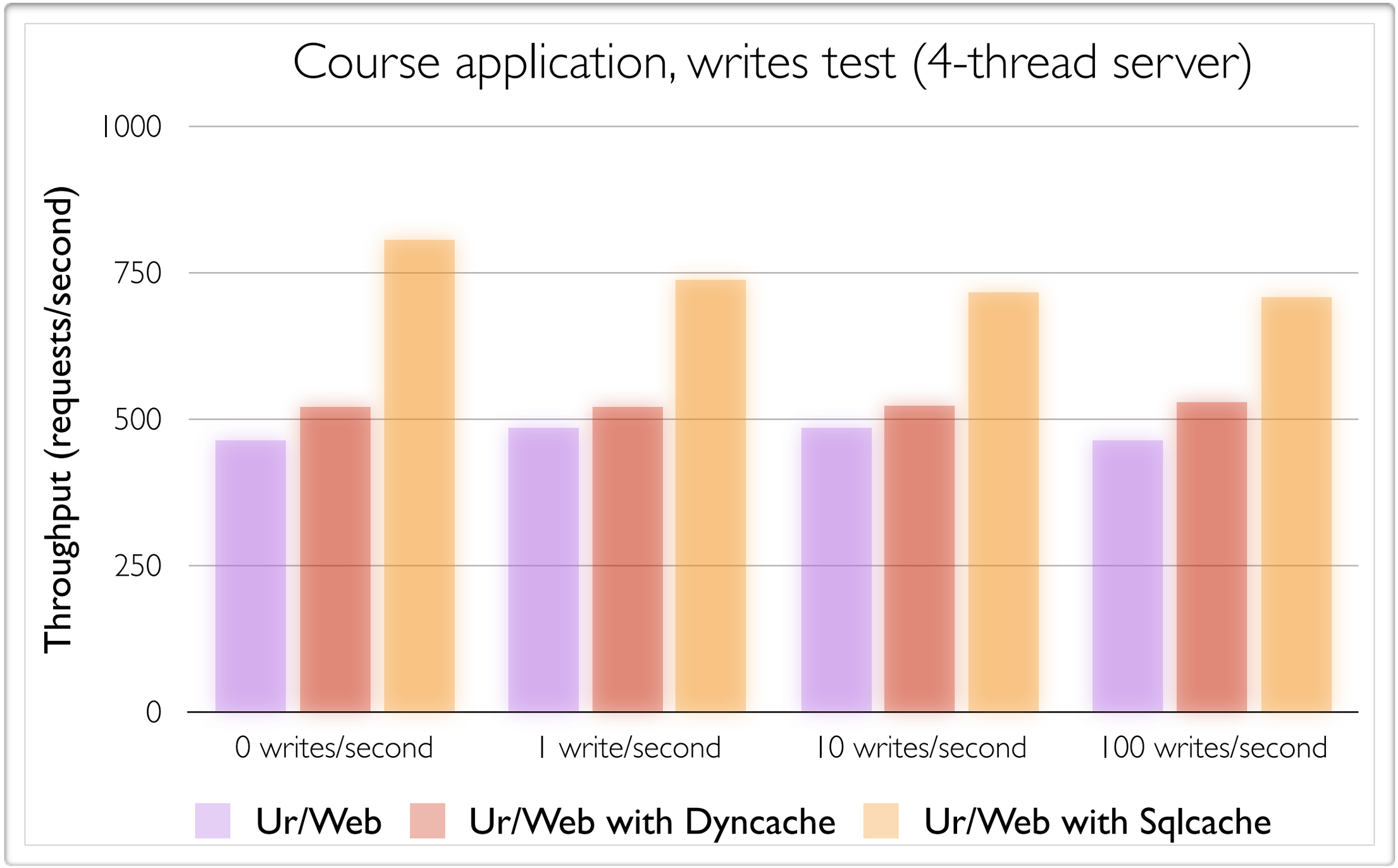
`https://github.com/urweb/urweb`

# Good question!

# Sqlcache vs. Dyncache



# Sqlcache vs. Dyncache



# Supported SQL

logic, equalities

all flavors of JOIN

nested queries: FROM

arithmetic, inequalities

COUNT, SUM

LIMIT, ORDER BY, GROUP BY

CURRENT_TIMESTAMP

nested queries: SELECT, WHERE

cascading triggers

# Related Work

## Updating materialized views

Blakely et al. (1986)

## TxCache

Ports et al. (2010)

## Sync Kit

Benson et al. (2010)

# Why Ur/Web?

```
table drawings : {Shape : int, Fill : int}

fun shapesOfFill x =
    gallery <- queryX1 (SELECT Shape FROM drawings
                        WHERE drawings.Fill = {[x]})
                       (fn shape => (* draw it *));
    return <xml>Behold: shapes! {gallery}</xml>

fun addDrawing y z =
    dml (INSERT INTO drawings (Shape, Fill)
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fun replaceFill y z =
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    return <xml>Fill replaced!</xml>
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First-class SQL

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Controlled side effects

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Controlled side effects

Lots of inlining

First-class SQL