Caching in Mobile Apps

COS 316: Principles of Computer System Design

Lecture 10

10/6/2022 | Murali Ramanujam | muralisr.com

Outline

- Use of caches
- Libraries in mobile apps
- Cache performance in mobile apps
  - Reasons for suboptimal caching
  - Improving cache performance
- Caching more things
  - Computations?

What are caches useful for?

Reusing prior content to improve performance

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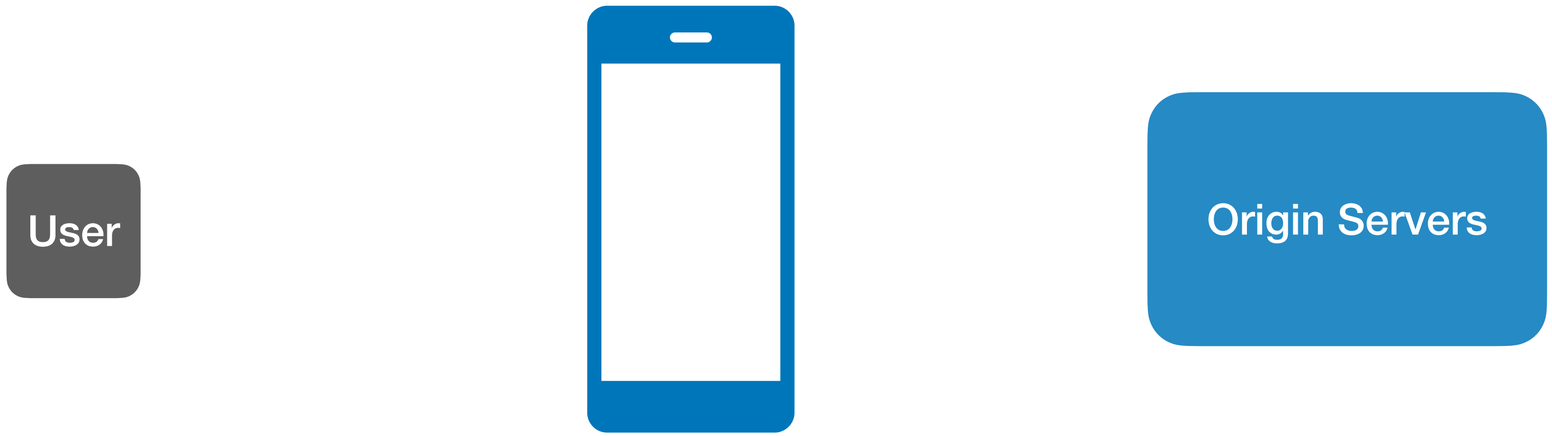
Reusing prior content to improve performance

- CPU memory
- Databases
- CDNs
- Browsers
- And even mobile apps

Interacting with mobile apps

Apps are similar to web browsers



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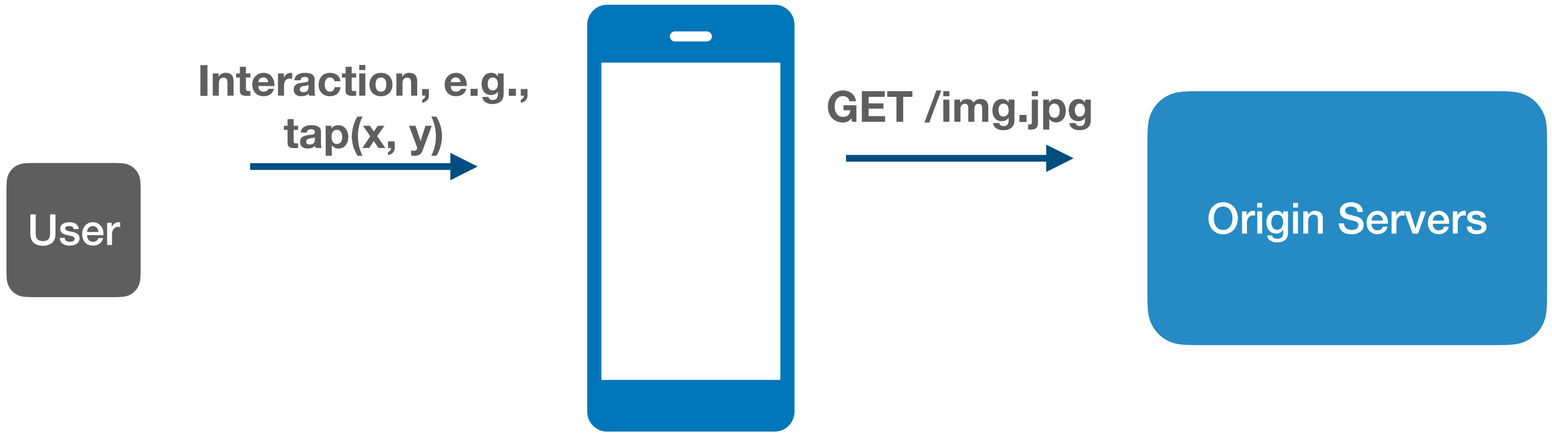

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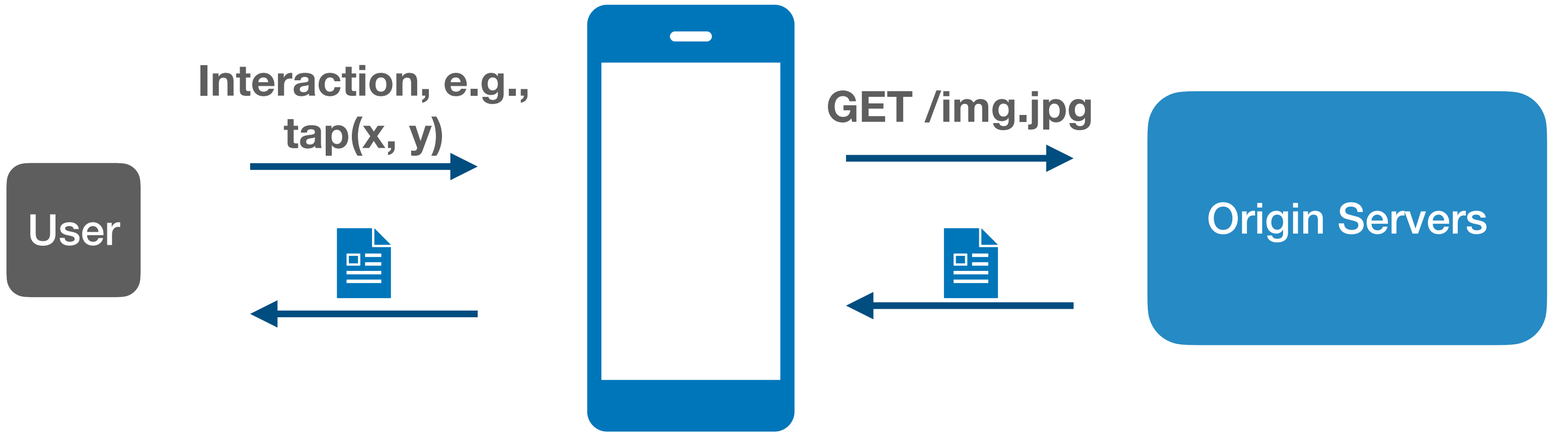

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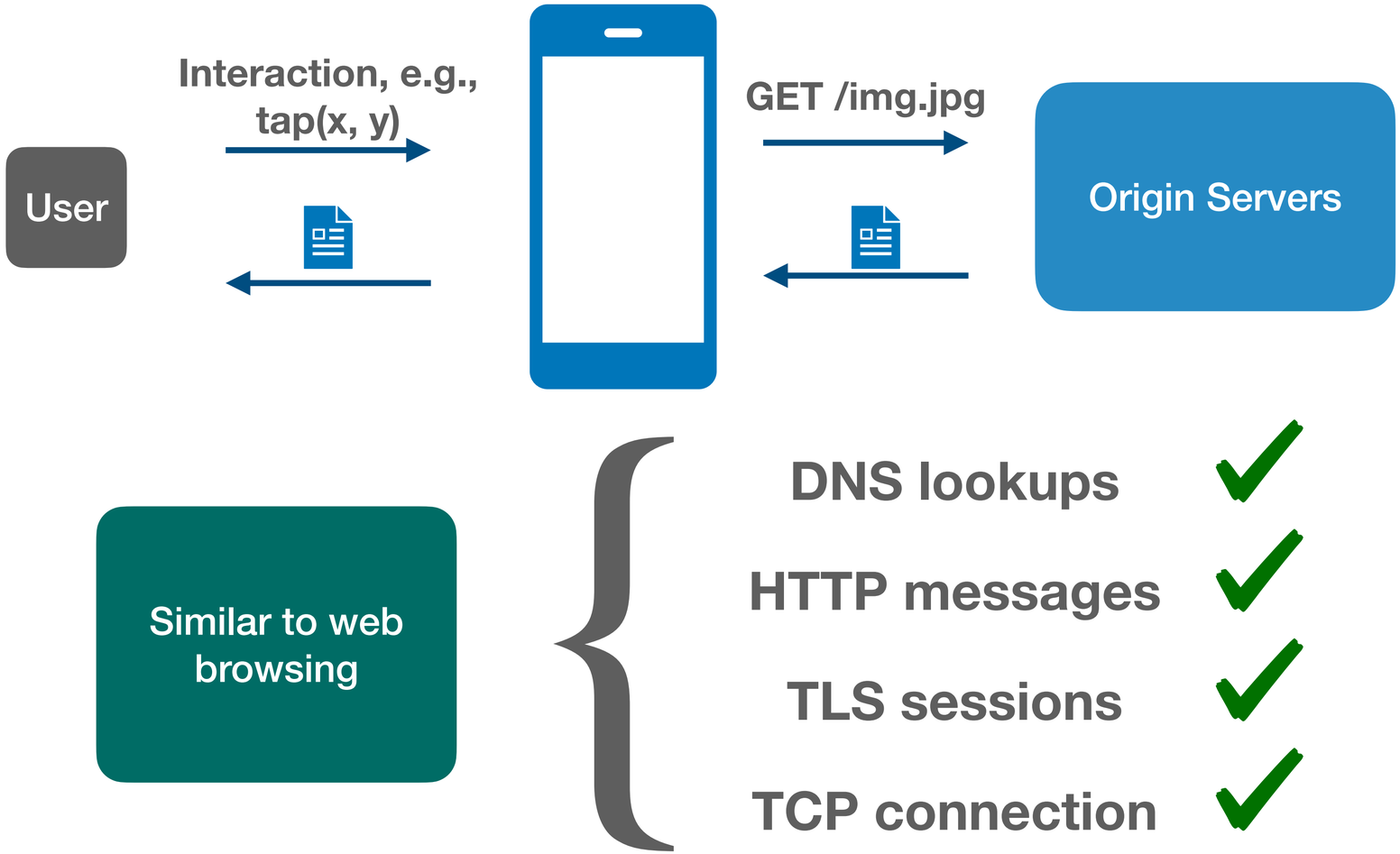

Client side caches for apps

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  - Similar to browsers

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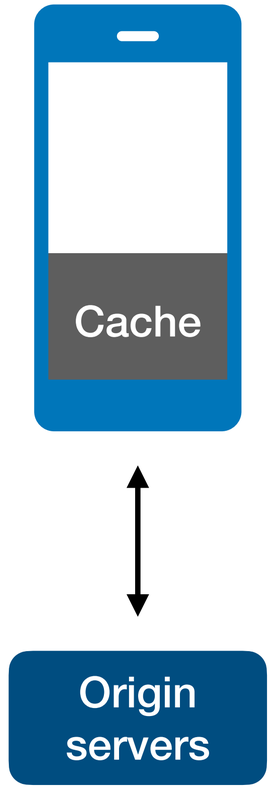
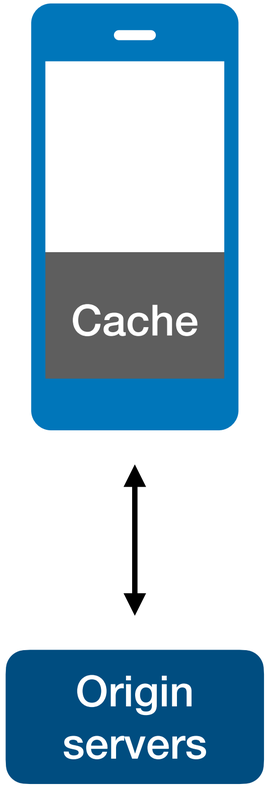


Client side caches for apps

- Apps incorporate web caches
  - Similar to browsers
- Caching libraries
  - OkHttp
  - Ion
  - Picasso
  - .. and more



Caching libraries

- HTTP request/response handling
  - Generate appropriate request headers
  - Parse and handle response headers
- Cache consistency
- Caching algorithm
  - LRU, LFU, etc.

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How do these caching libraries perform today?

State of cache performance today

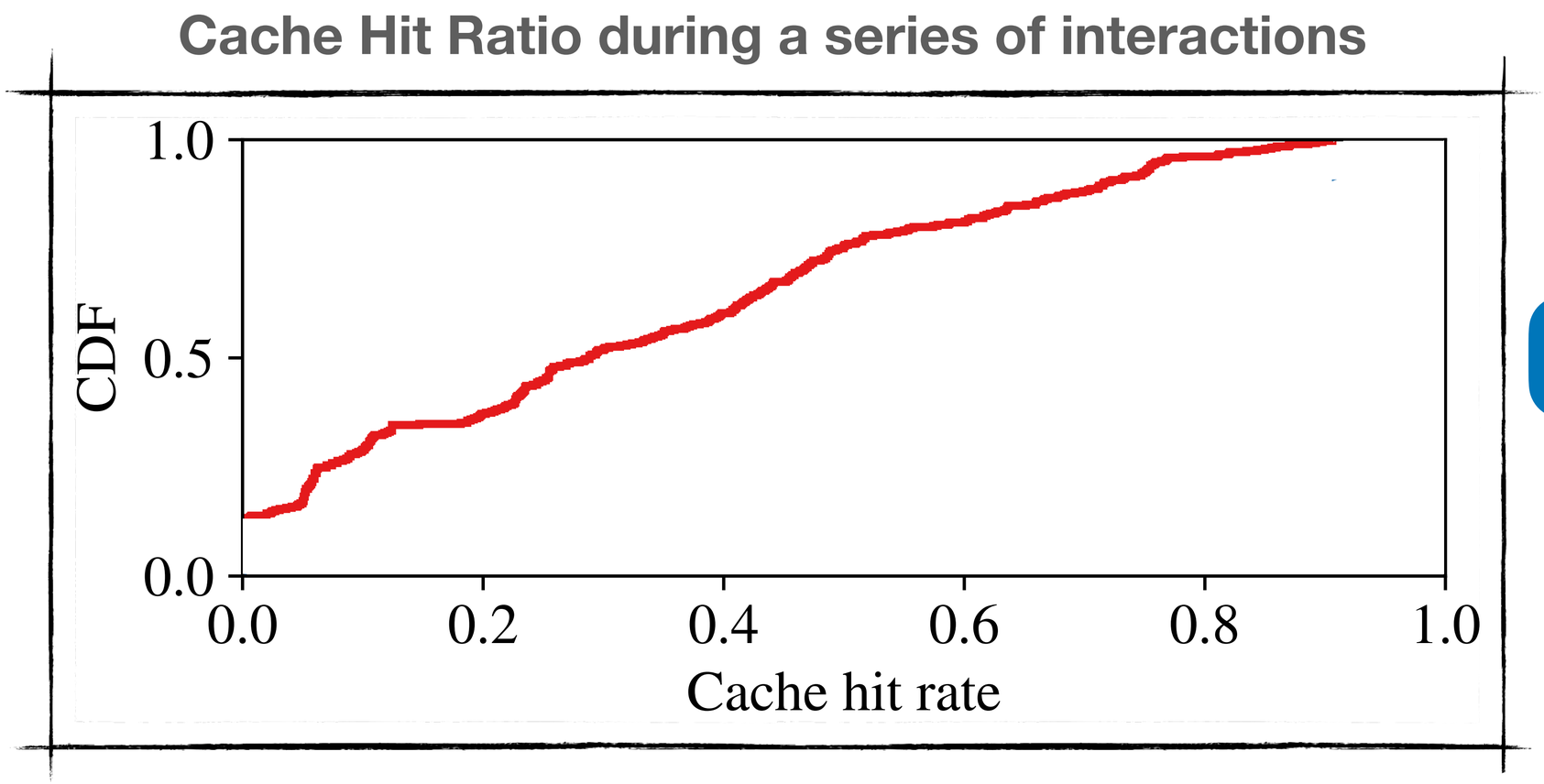
Cache Hit Ratio during a series of interactions

State of cache performance today

Cache Hit Ratio during a series of interactions

Subsequent series of interactions

State of cache performance today



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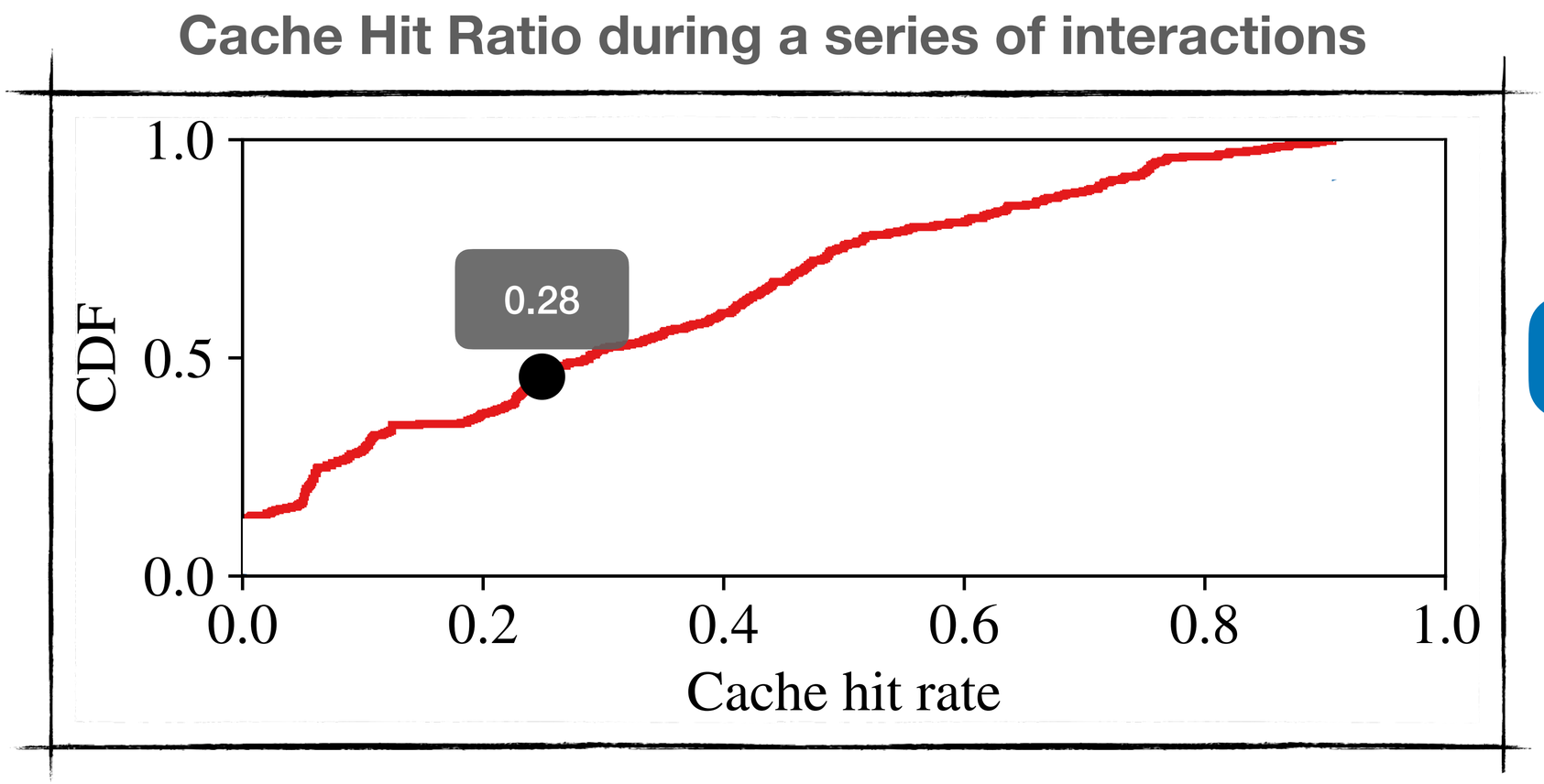

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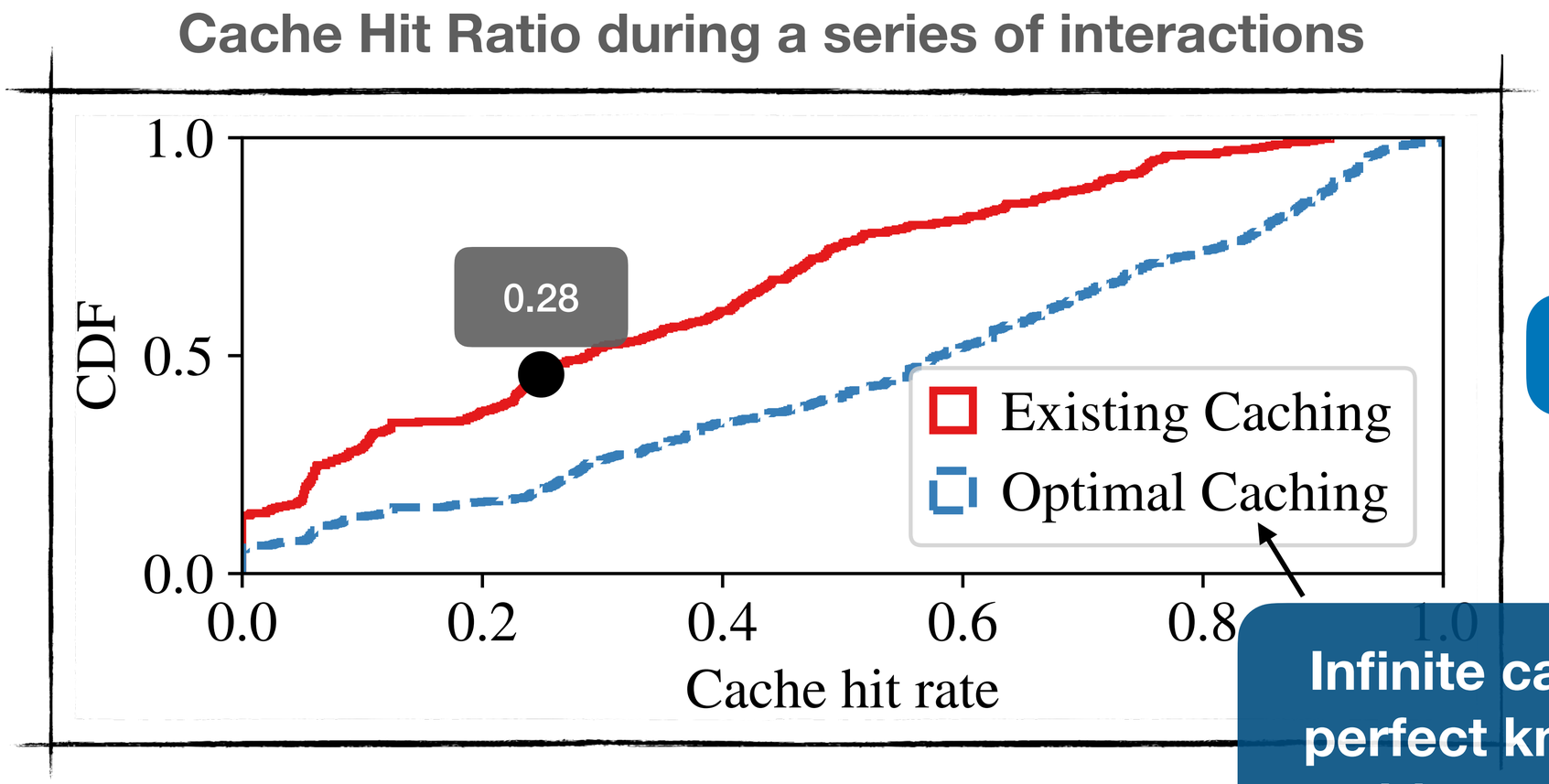

Subsequent series of interactions

Infinite capacity and perfect knowledge of object expirations

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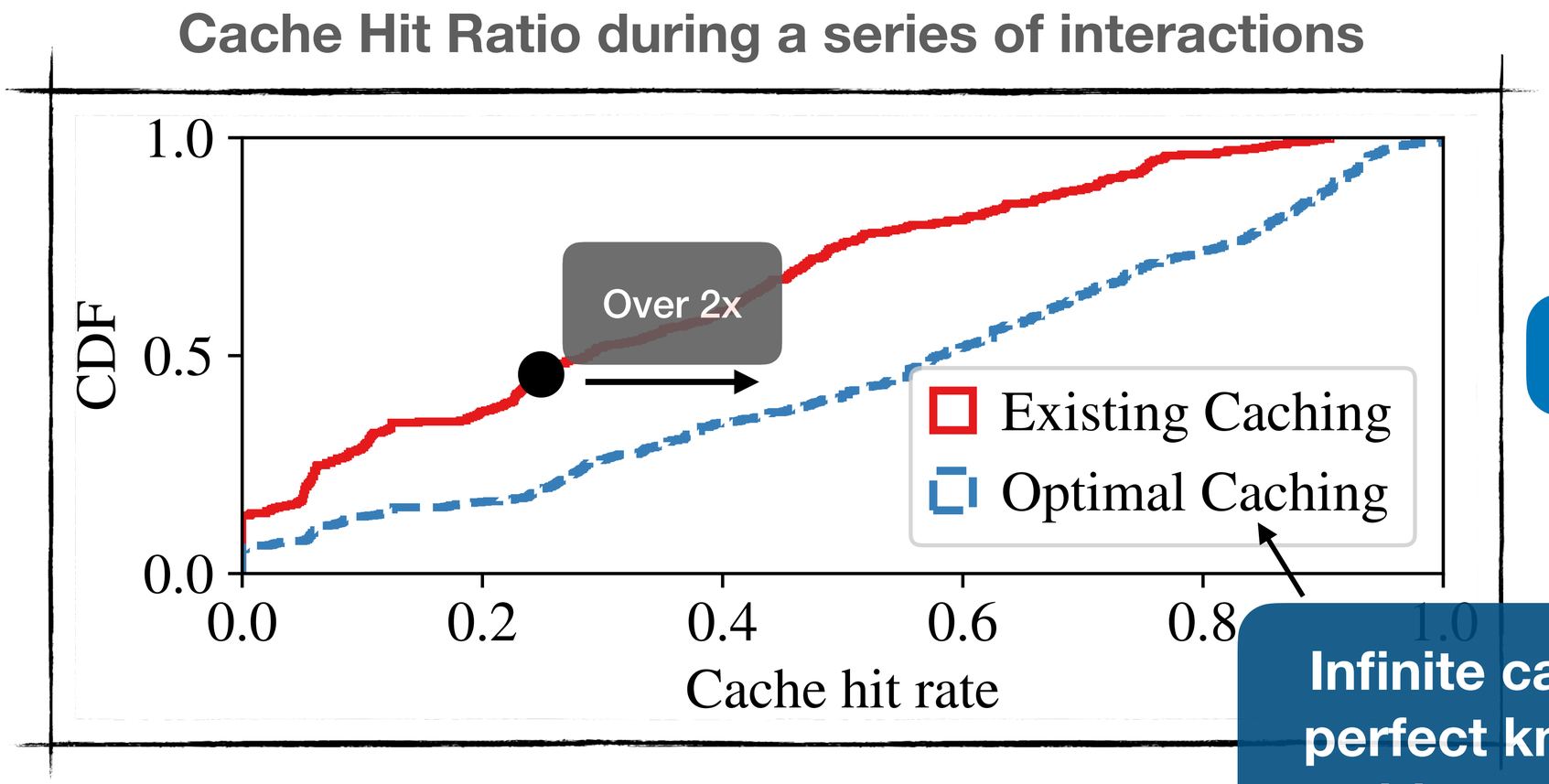

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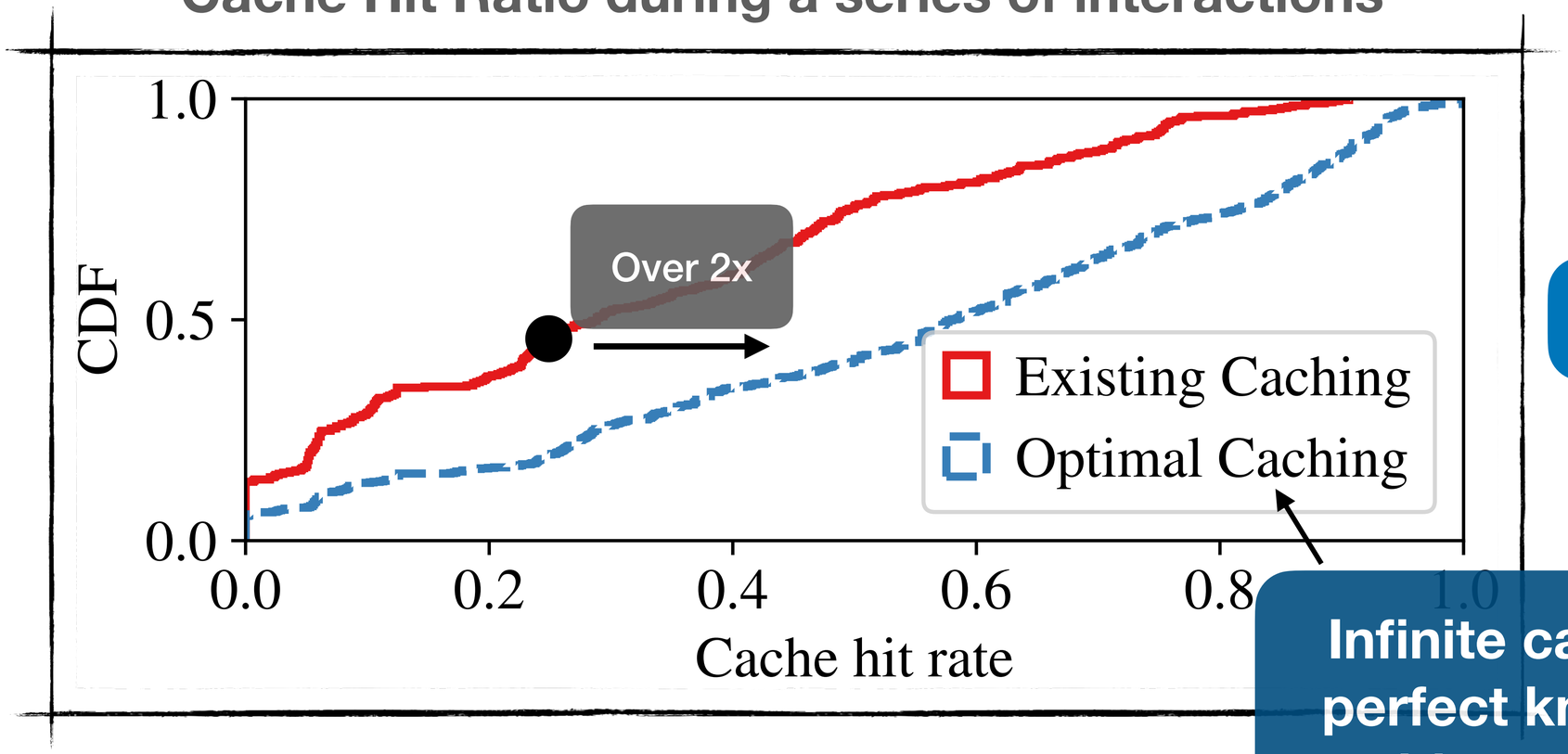


Subsequent series of interactions

Infinite capacity and perfect knowledge of object expirations

Current caching is suboptimal

App responsiveness

App responsiveness

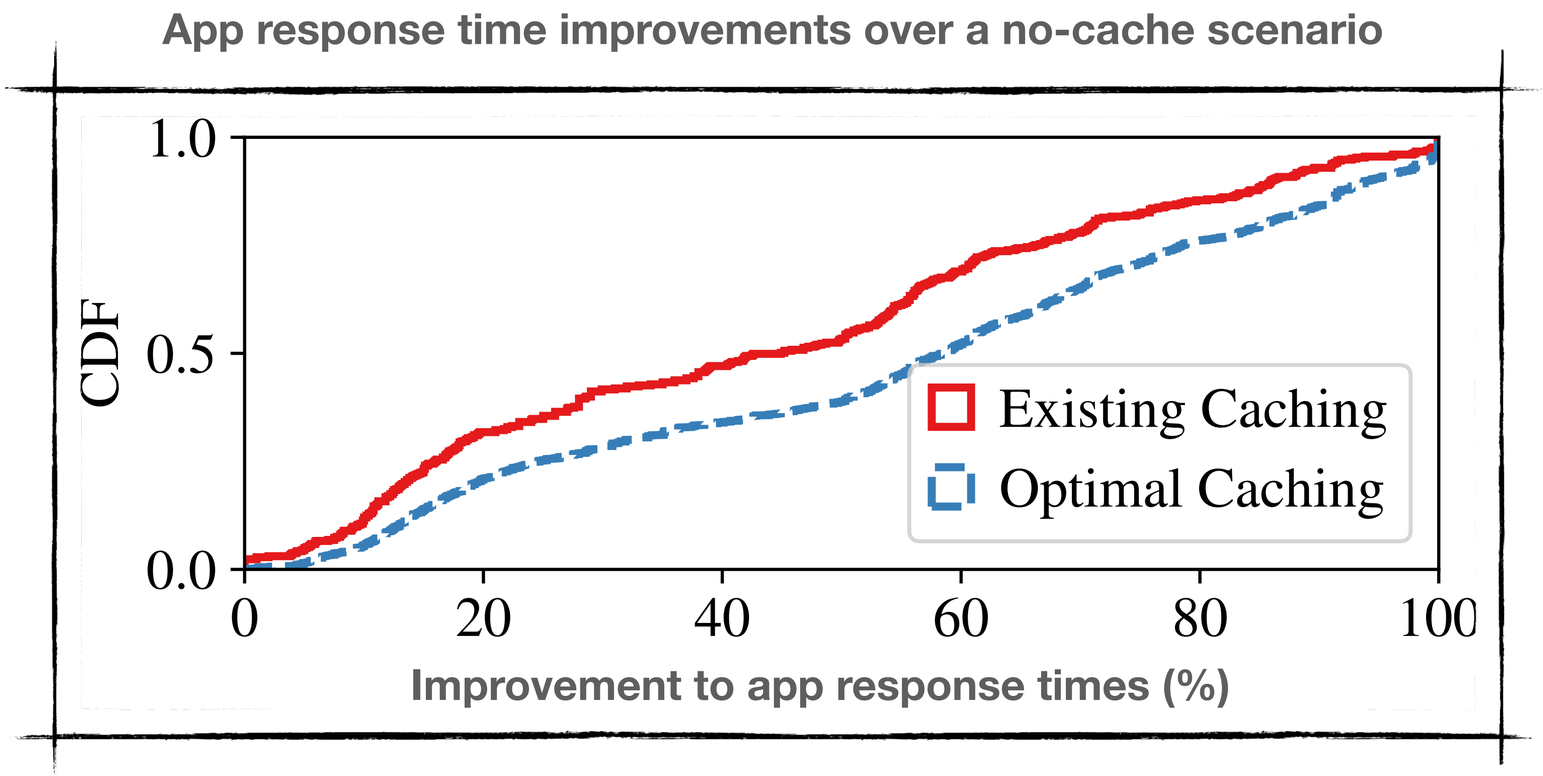
How does cache hit rate affect responsiveness?

Subsequent series of interactions

Optimal version has infinite capacity, perfect expiration

App responsiveness

How does cache hit rate affect responsiveness?



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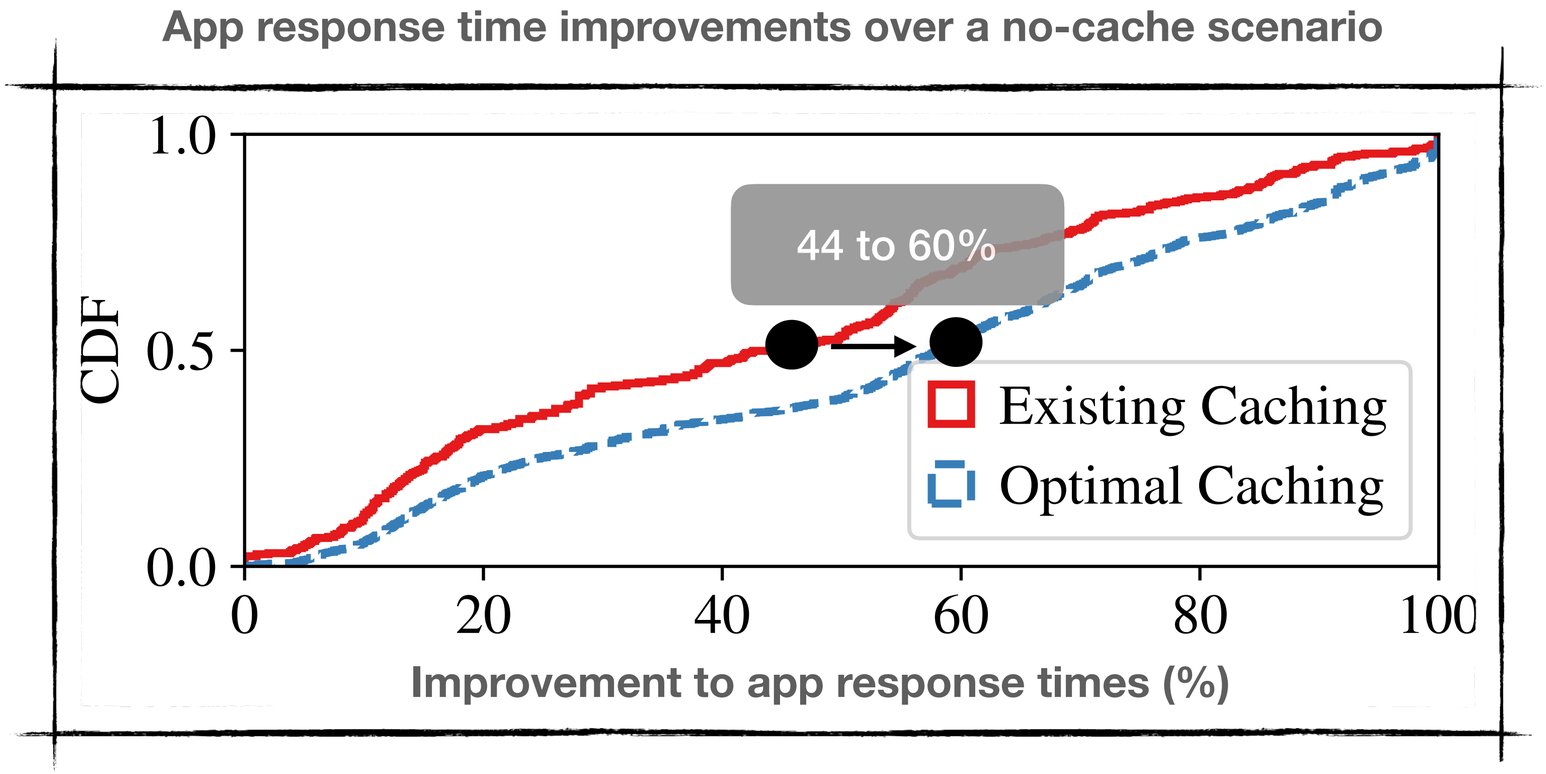

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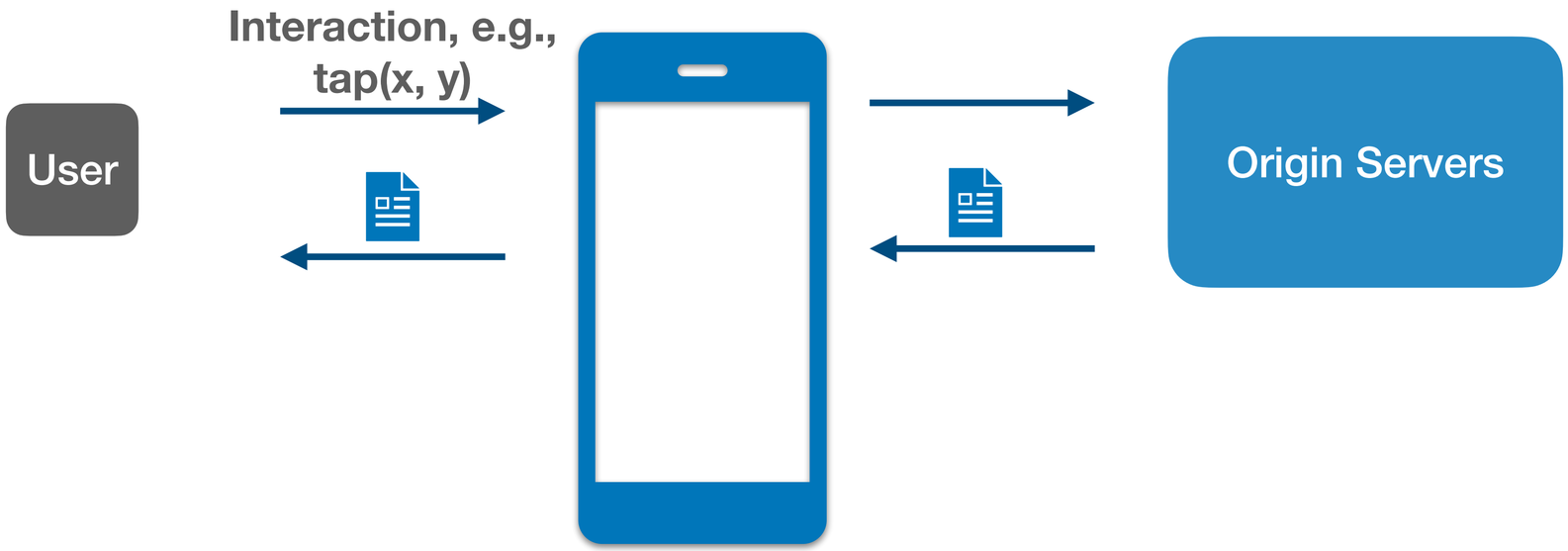
Cache performance

Why isn’t cache hit rate optimal?



Cache performance

From last lecture

HTTP Response Header for Cache Control

- Whether to cache
  - no store: no cache should store it
- Who should cache
  - private: only a private cache (e.g., browser)
  - public: any cache, including shared ones
- How long to cache
  - max-age=N: for N seconds
  - must-revalidate: check with the server (don't return stale item)

Cache-Control: public, max-age=86400, must-revalidate

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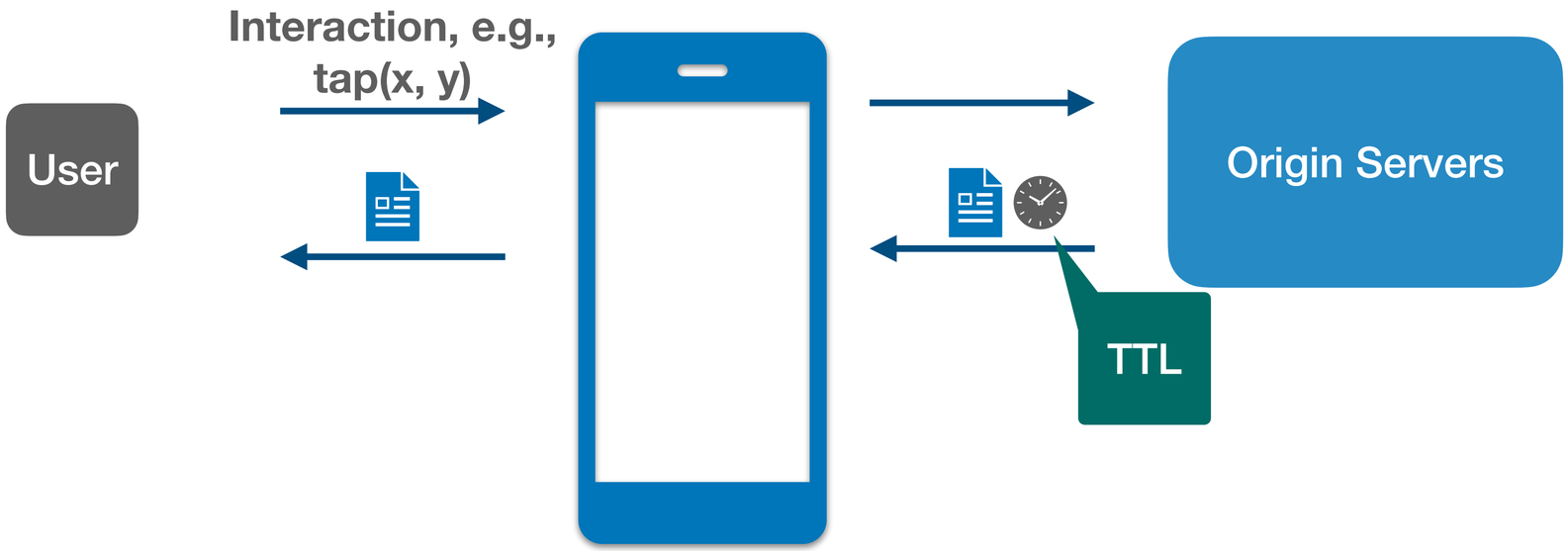

TTL: Time to Live

Cache performance

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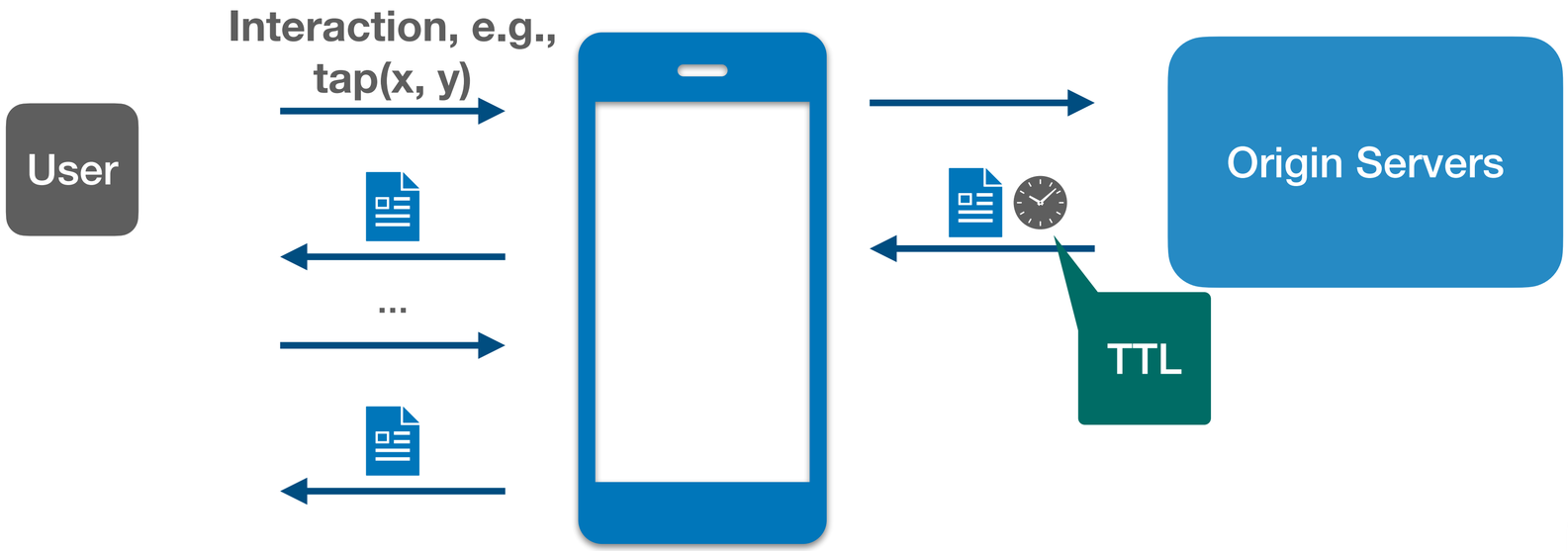

TTL: Time to Live

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Repeatedly fetch asset every second

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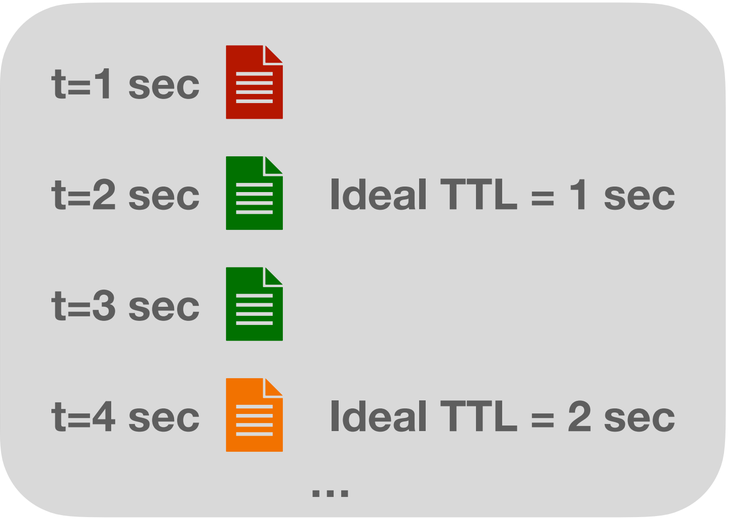

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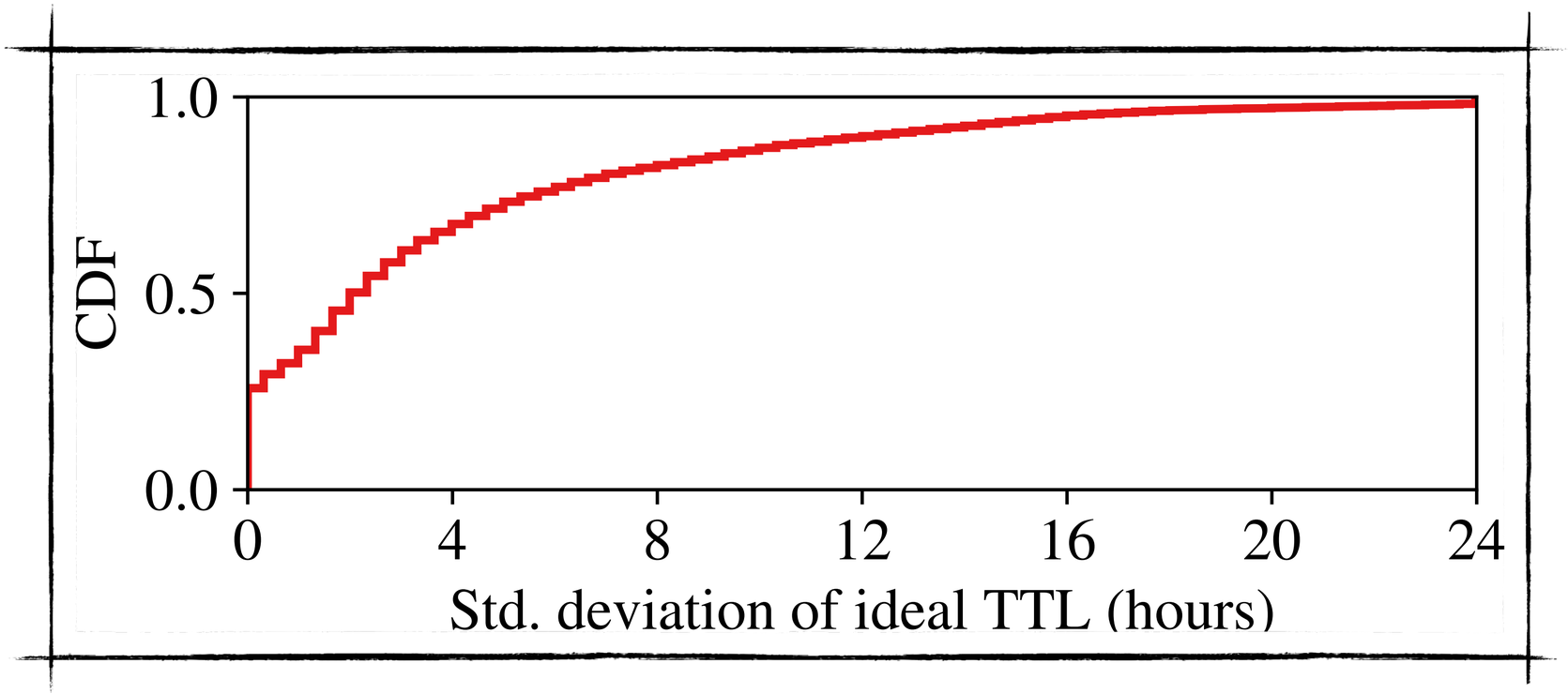
Let’s plot the std. dev.

Caching correctly is difficult

Variations in ideal TTL



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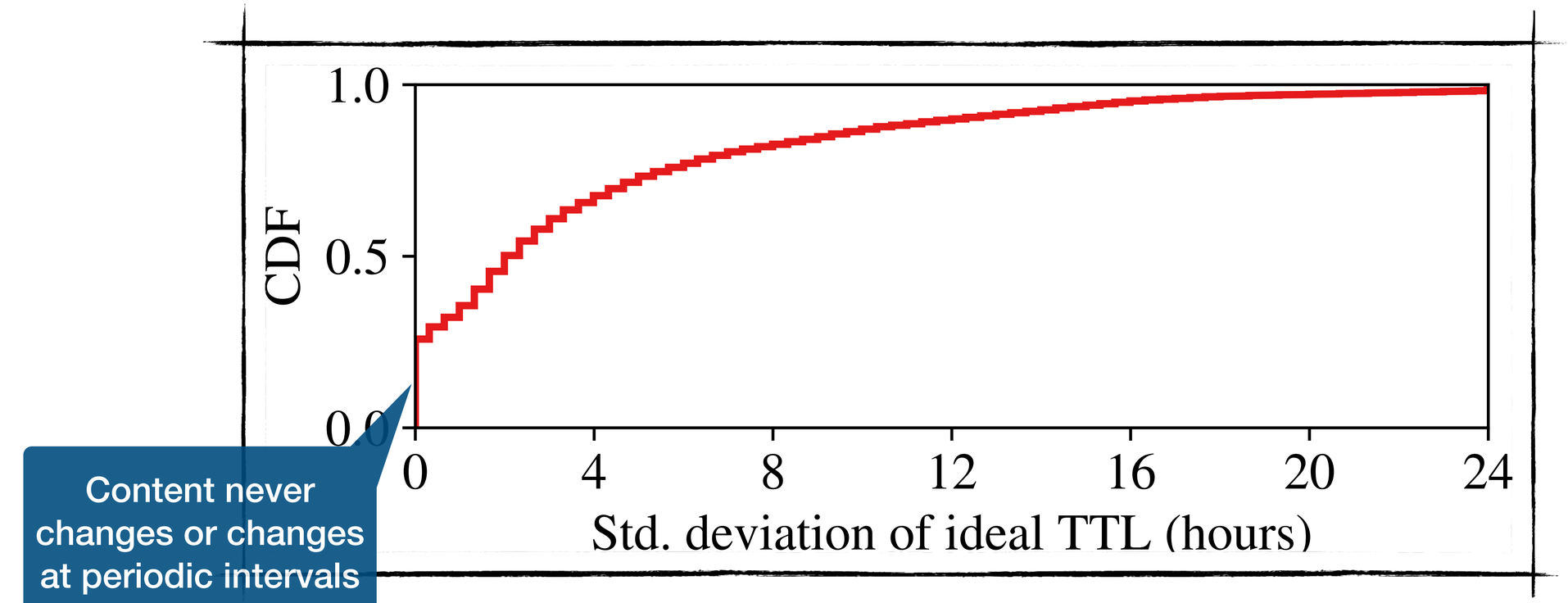
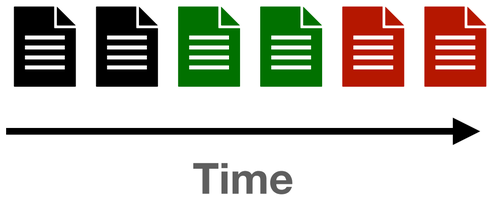


Content never changes or changes at periodic intervals



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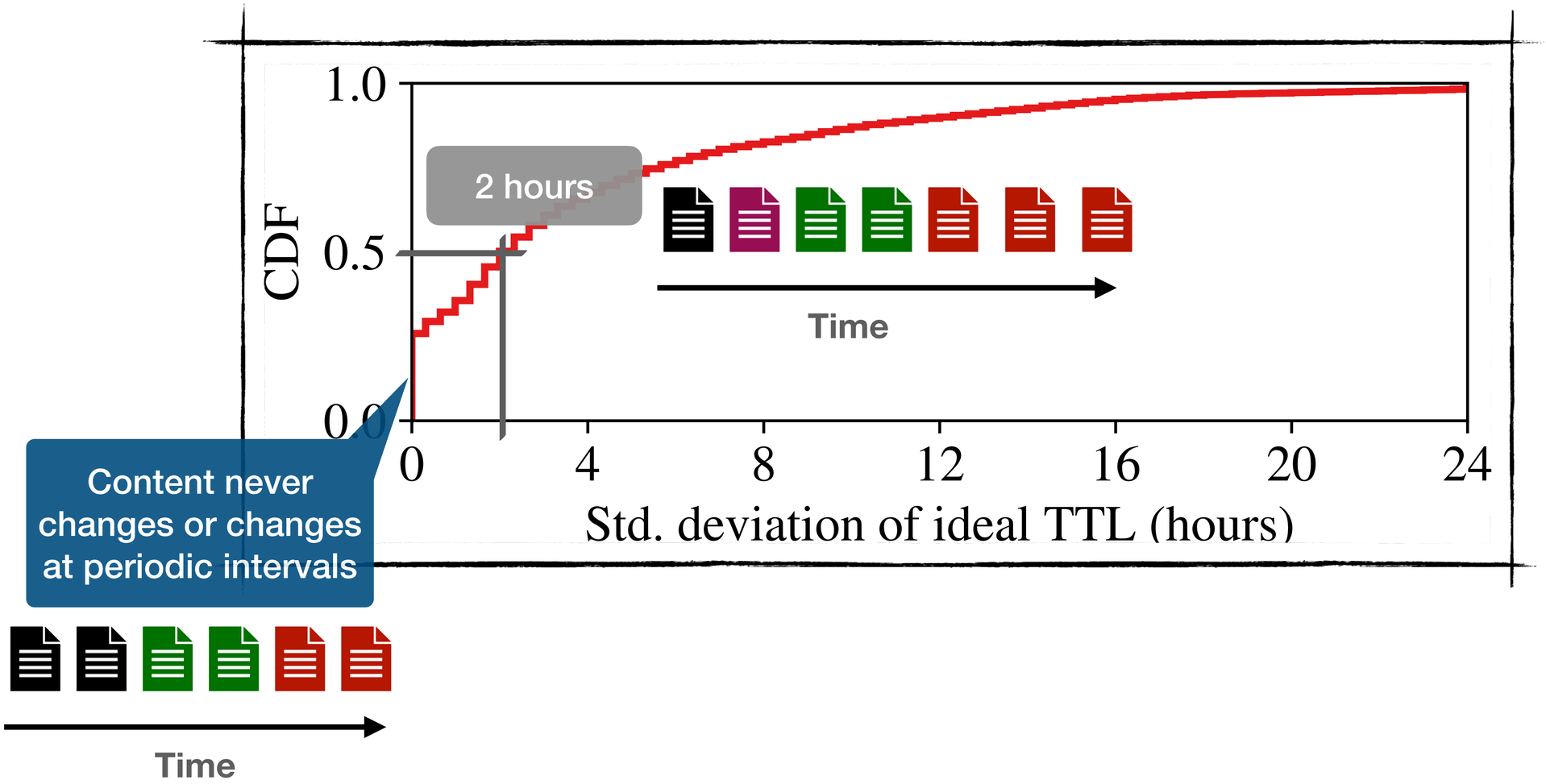

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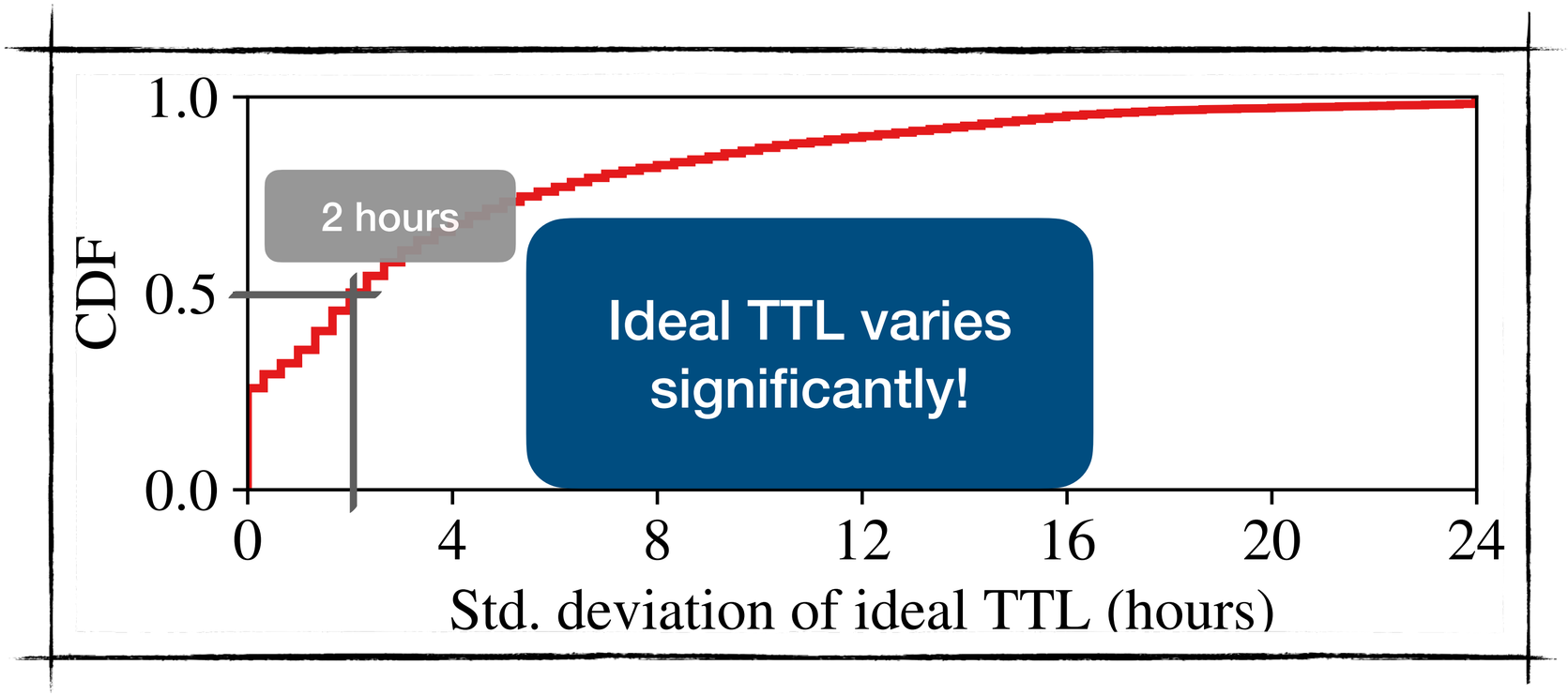

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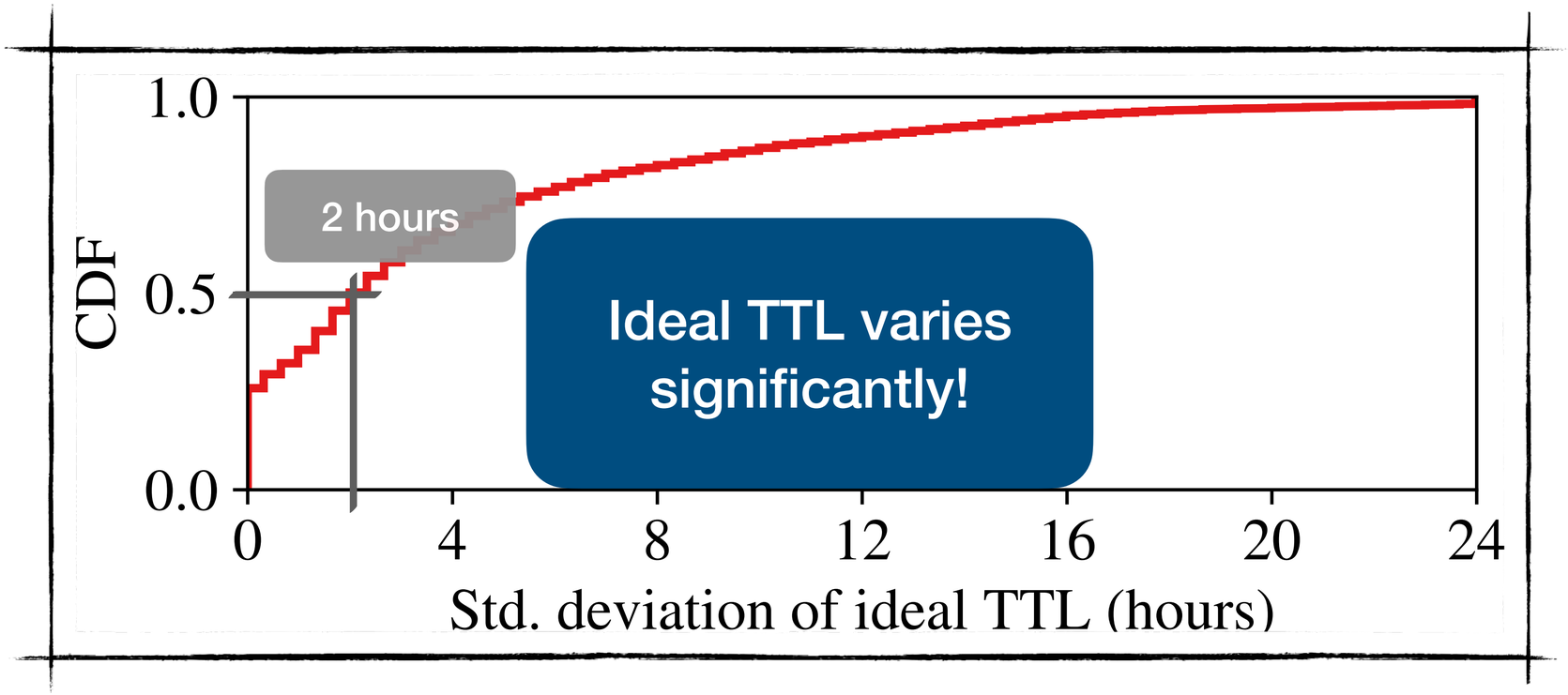

High TTLs → good cache performance → stale content

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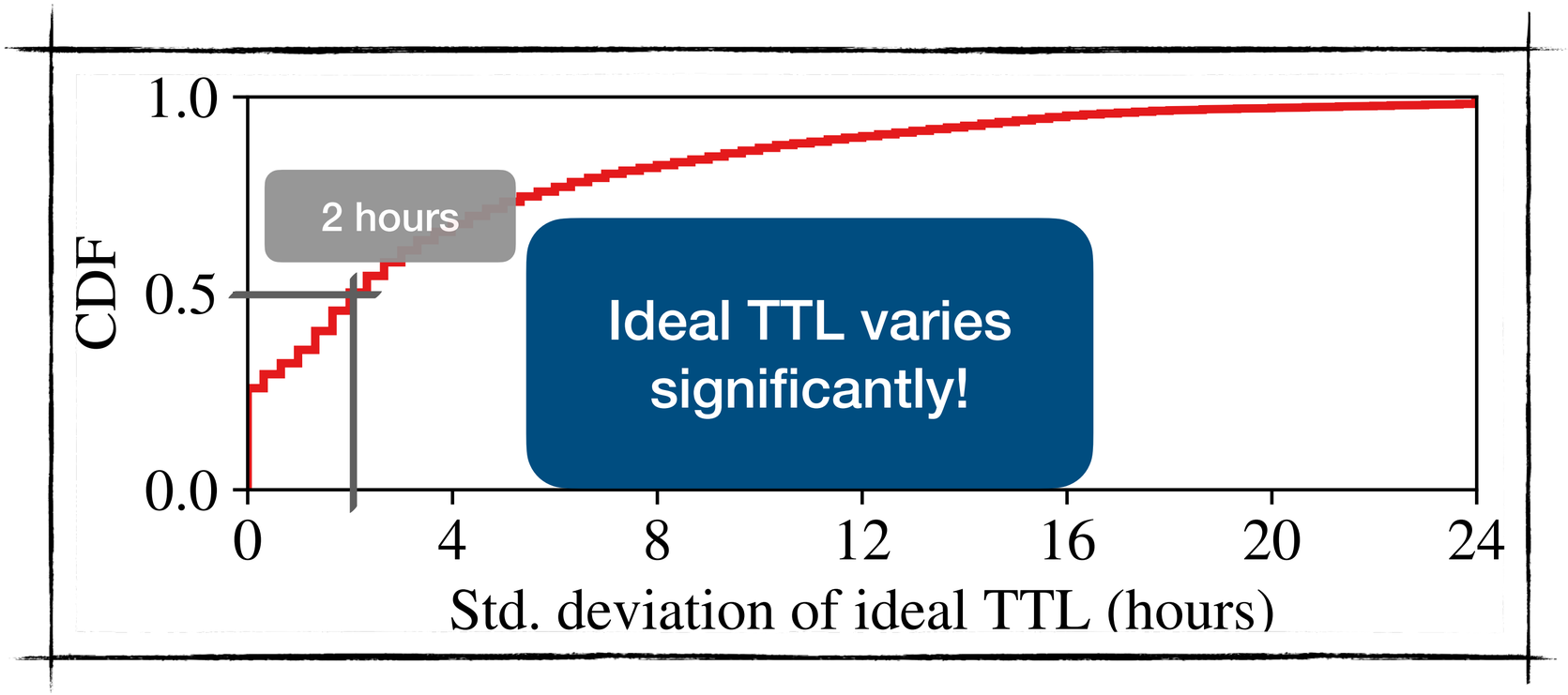

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Low TTLs → fresh content → poor cache performance

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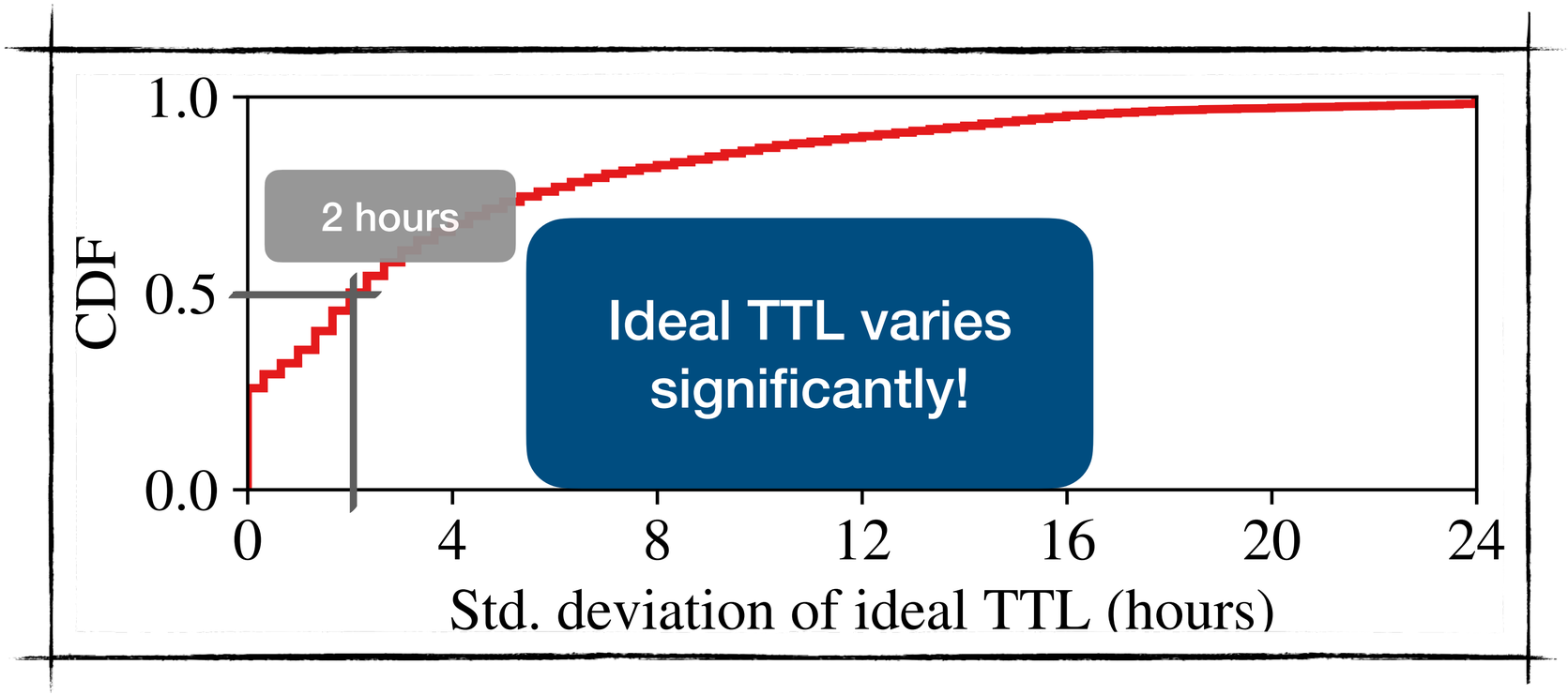

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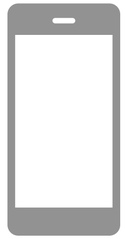
Making caching better

Anatomy of an app interaction



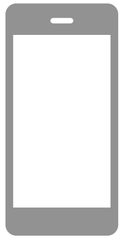
Origin server

Making caching better

Anatomy of an app interaction

Task: Loading a news article

Actions by user after opening app



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Tap on “Entertainment News” category

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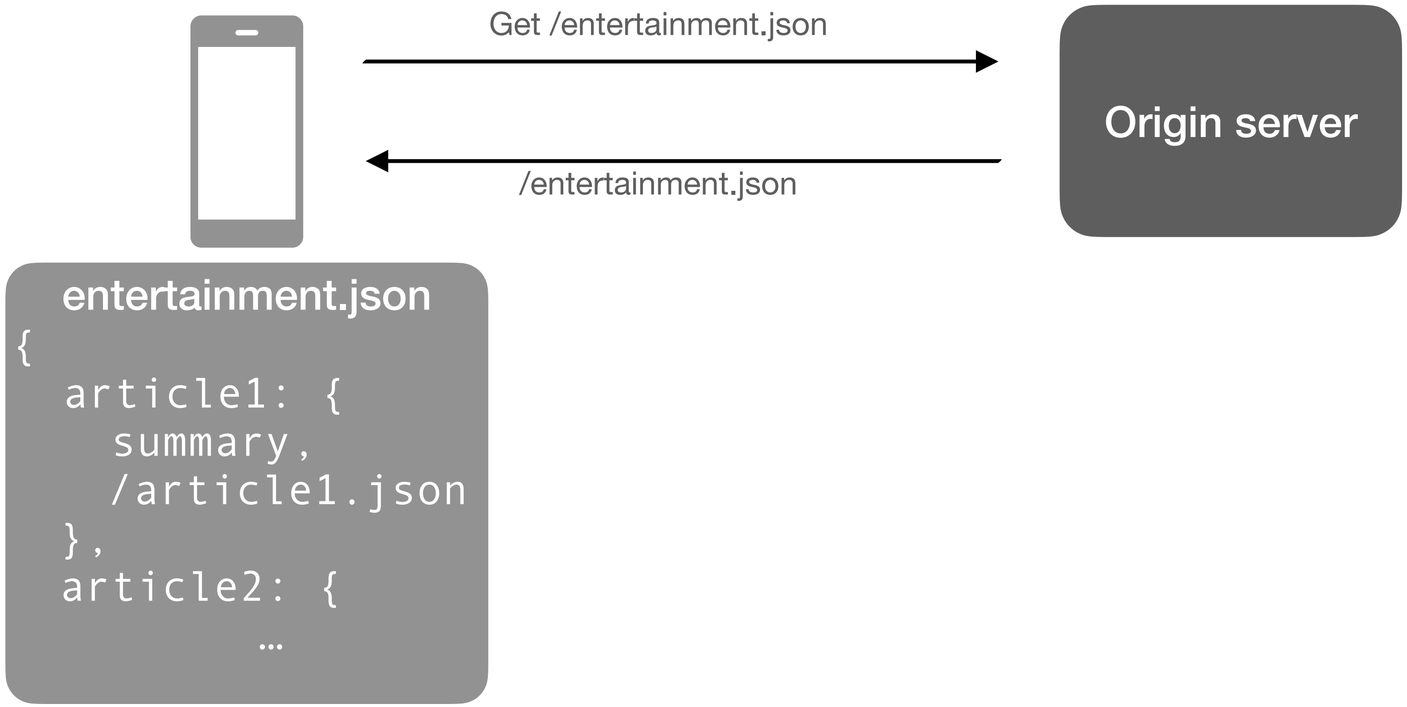

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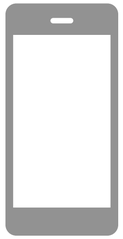

entertainment.json

```
{
  article1: {
    summary,
    /article1.json
  },
  article2: {
          …
```

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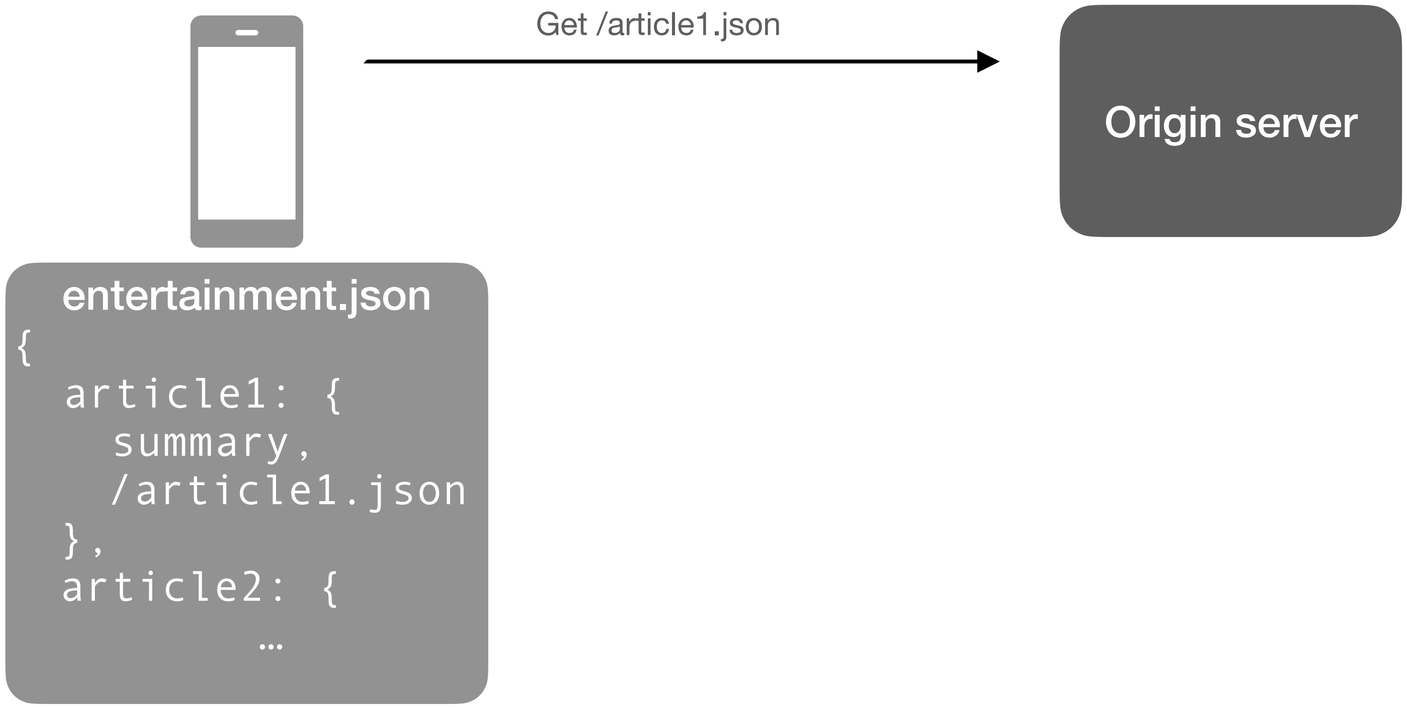

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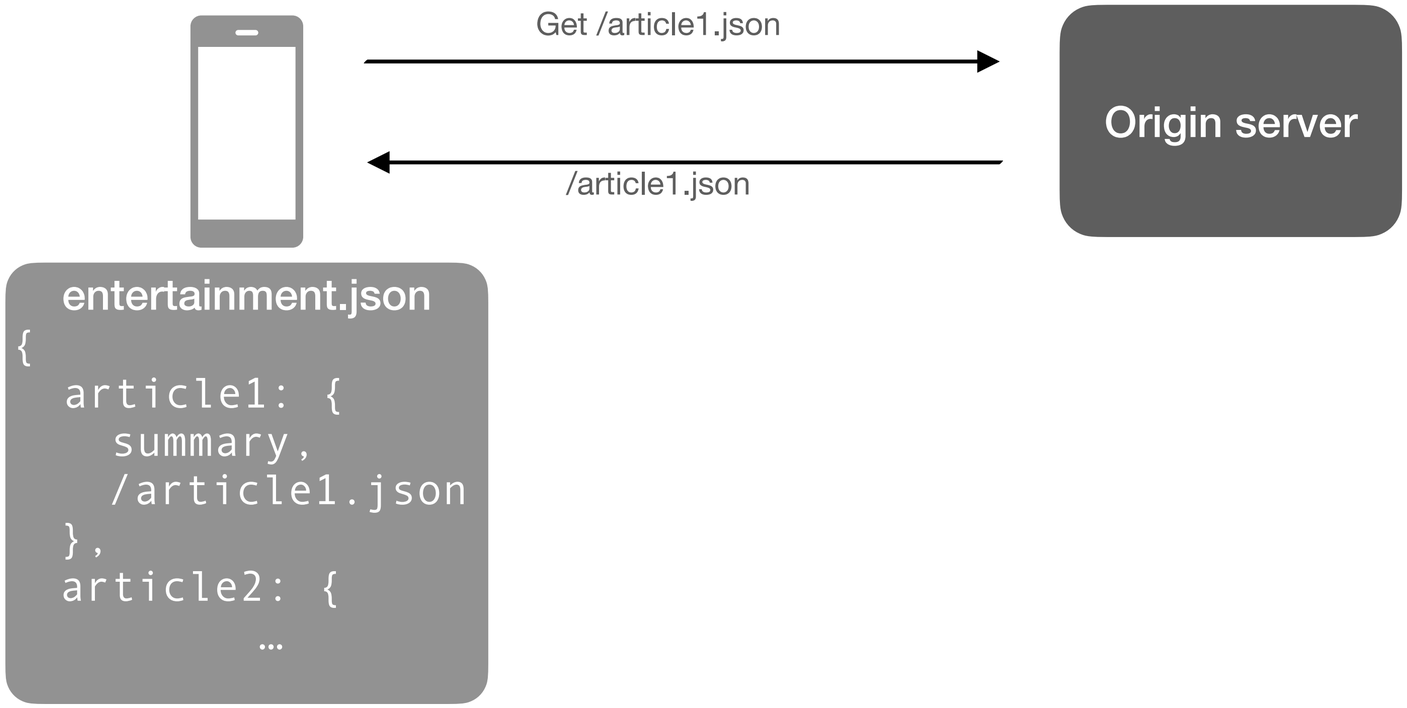

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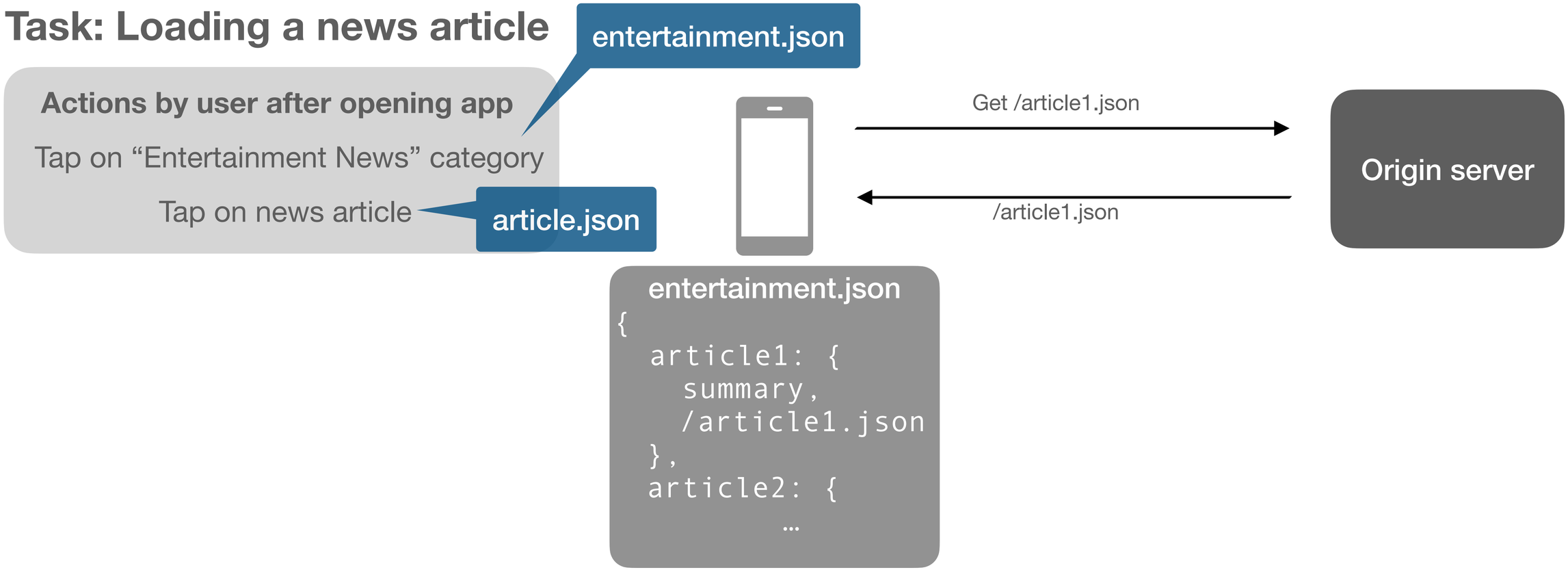

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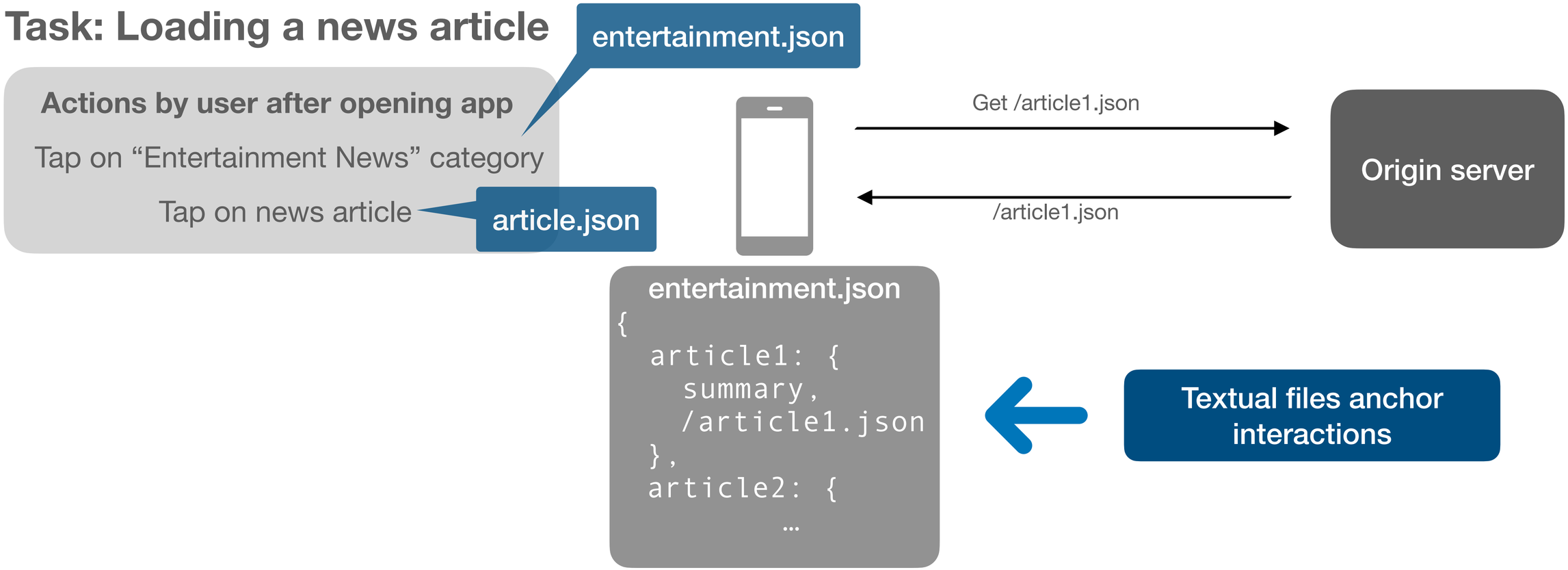

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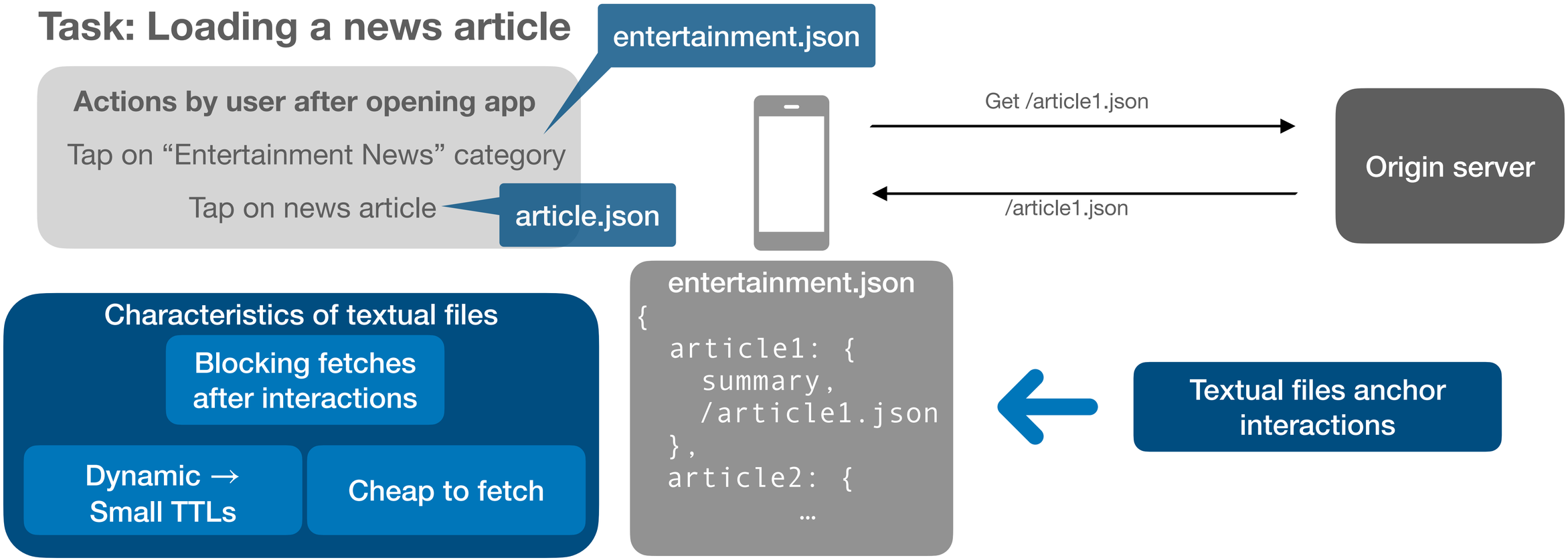

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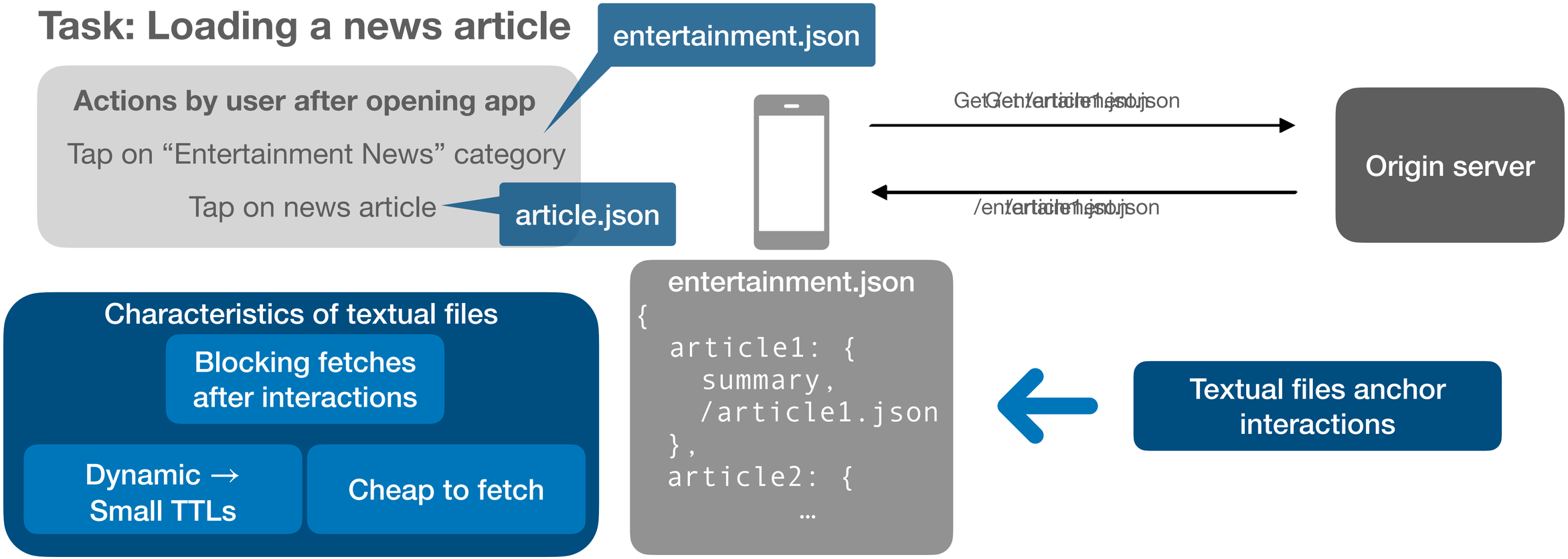

Making caching better

Insights about textual files

Blocking fetches after interactions

Dynamic → Small TTLs

Cheap to fetch

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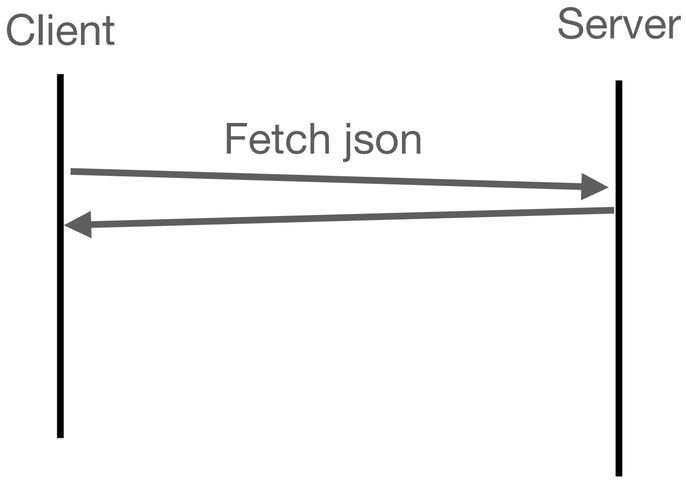

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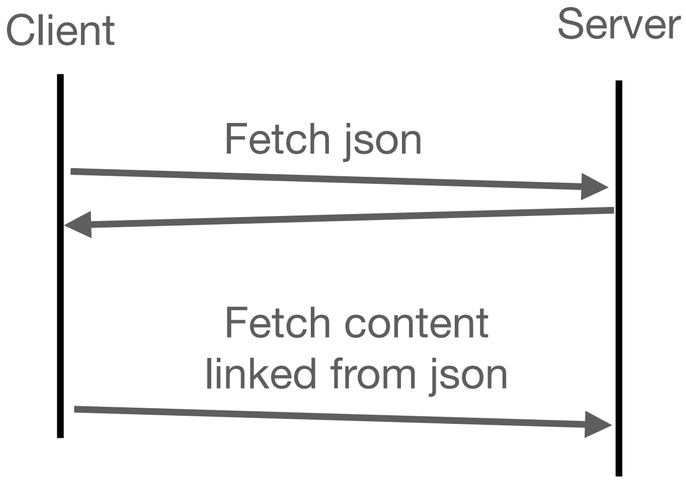

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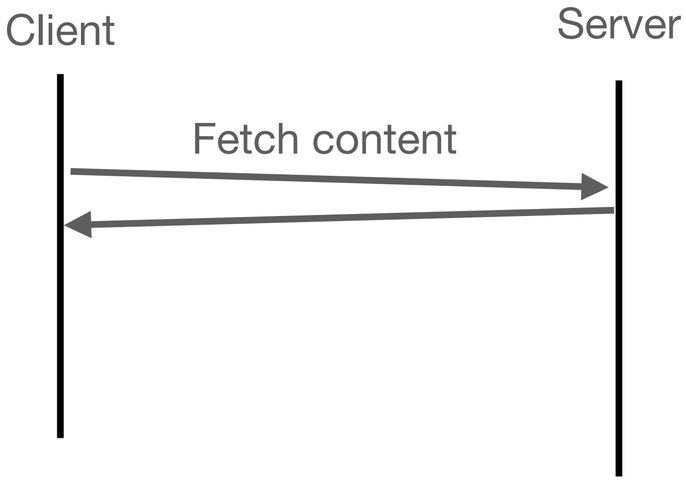

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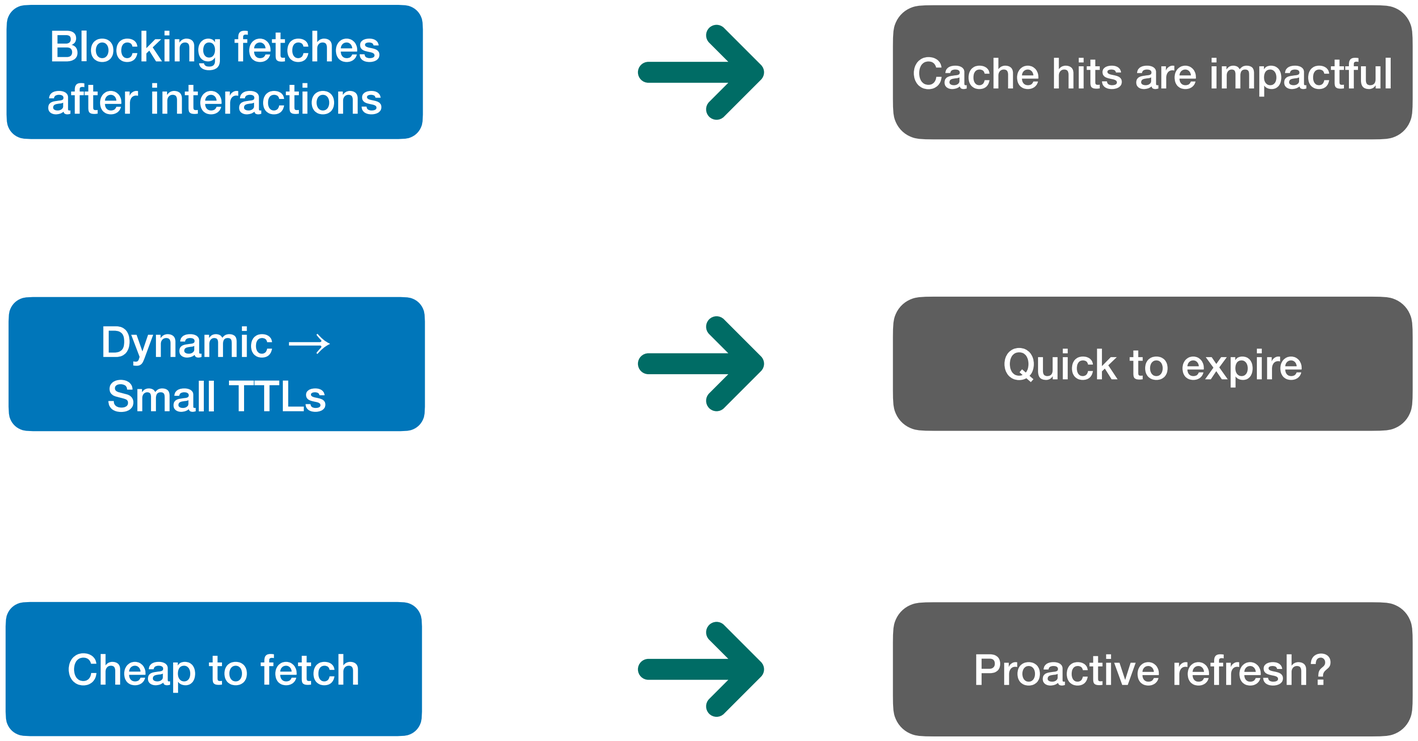
Blocking fetches after interactions → Cache hits are impactful

Dynamic → Small TTLs → Quick to expire

Cheap to fetch

Making caching better

Insights about textual files



Making caching better

Insights about textual files

Blocking fetches after interactions → Cache hits are impactful

Dynamic → Small TTLs → Quick to expire

Cheap to fetch → Proactive refresh?

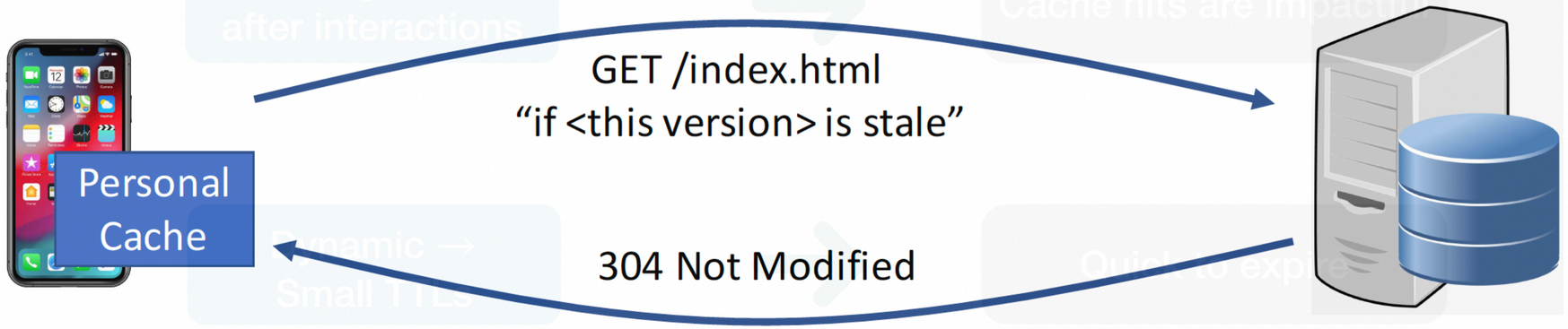
Conditional GET

Making caching better

Insights about textual files

From last lecture

Cache Validation: Client Checks Freshness



How do they identify the “version”?

- Timestamp
  - When the item was modified by the server
  - E.g., Last-Modified: Wed, 21 Oct 2015 07:28:00 GMT
- Version number
  - Entity tag provided by the server
  - E.g., ETag: "33a64df551425fcc55e4d42a148795d9f25f89d4"

Conditional GET

Making caching better

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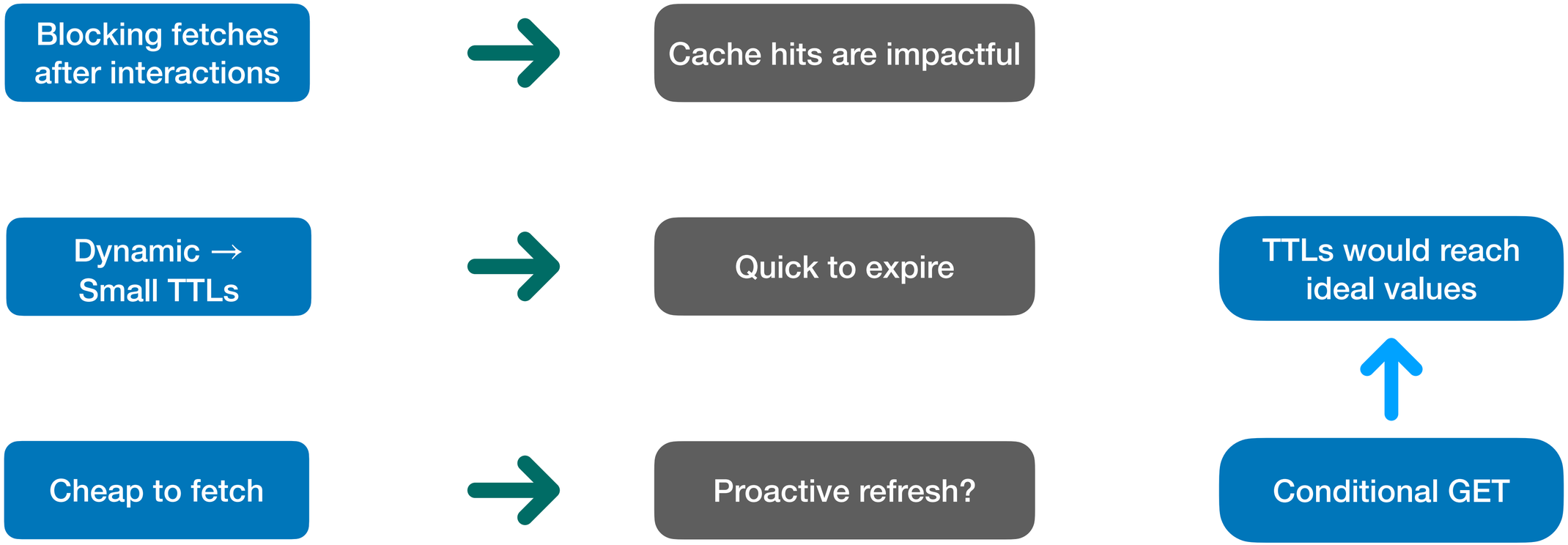

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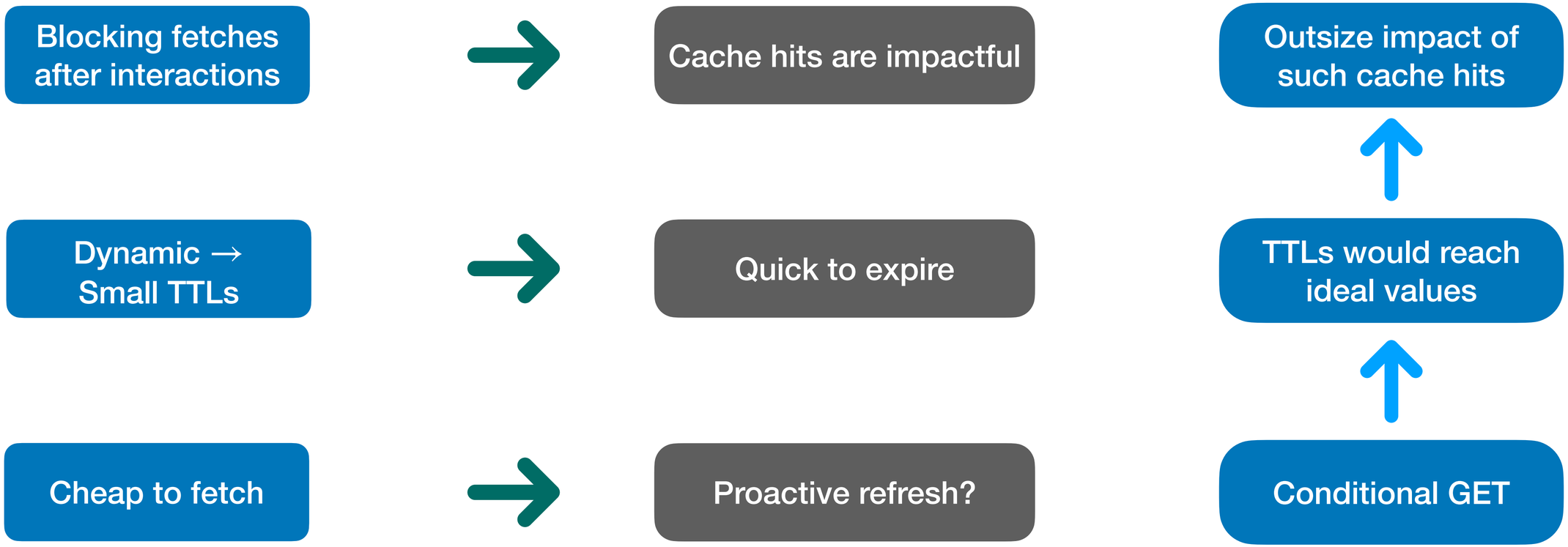

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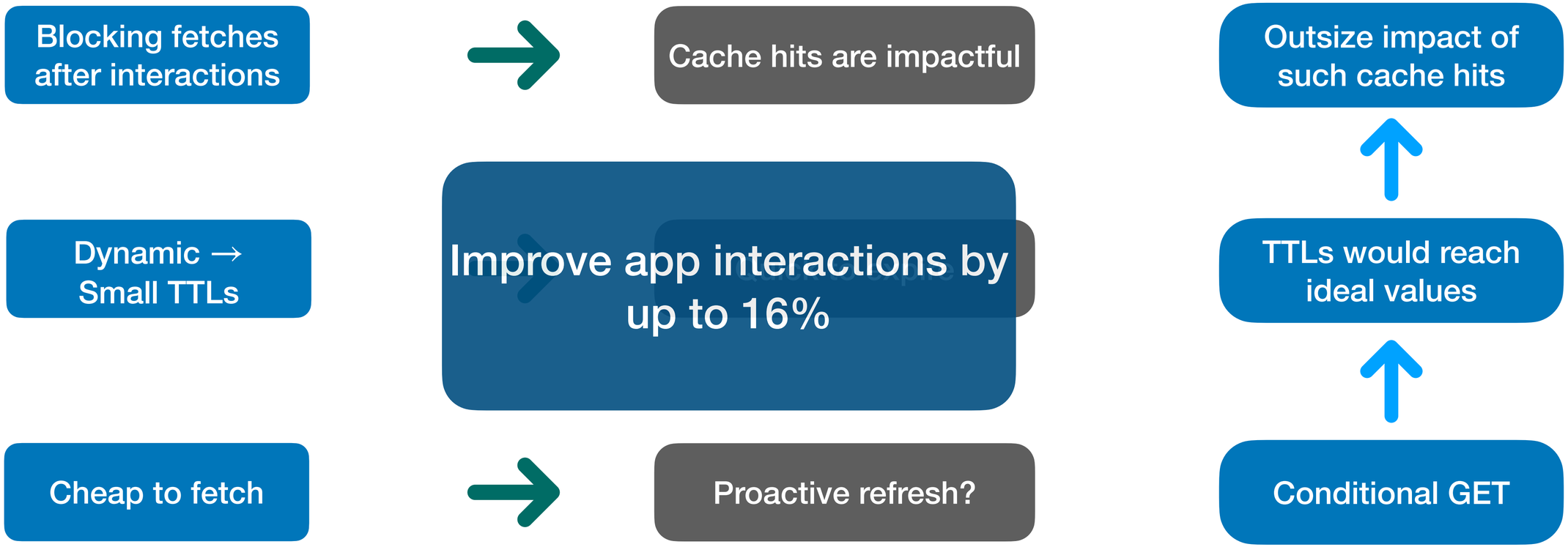

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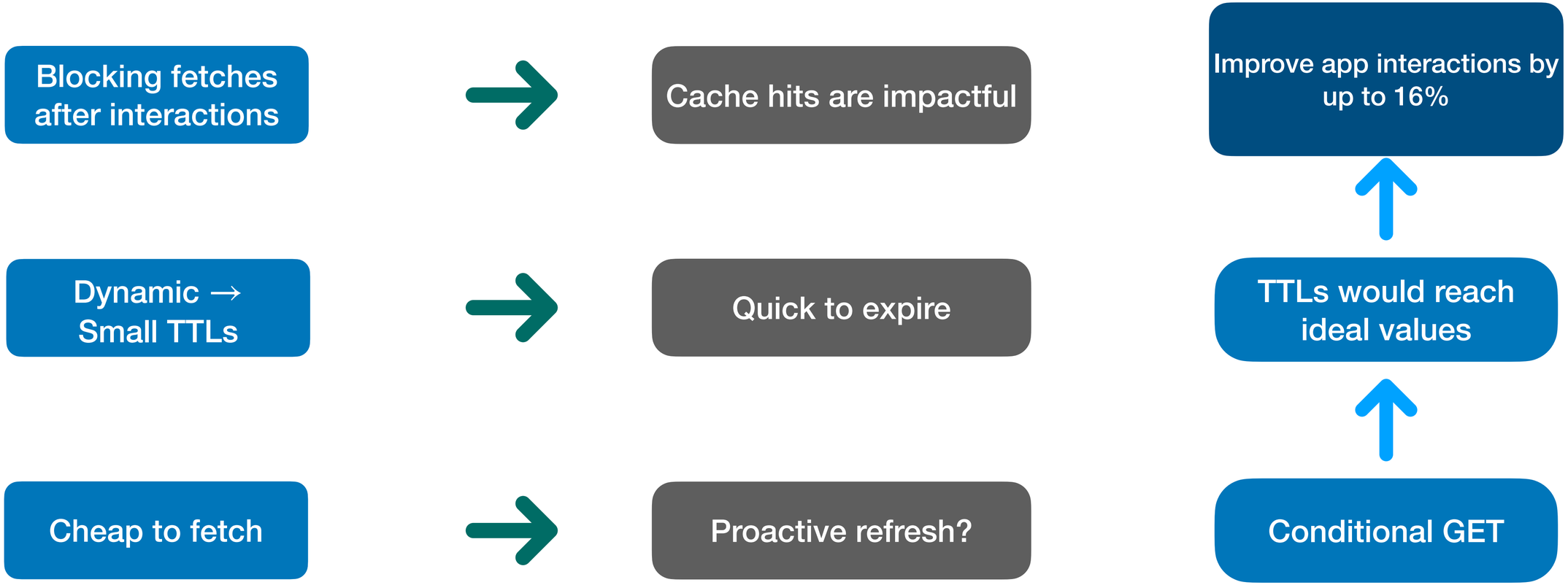
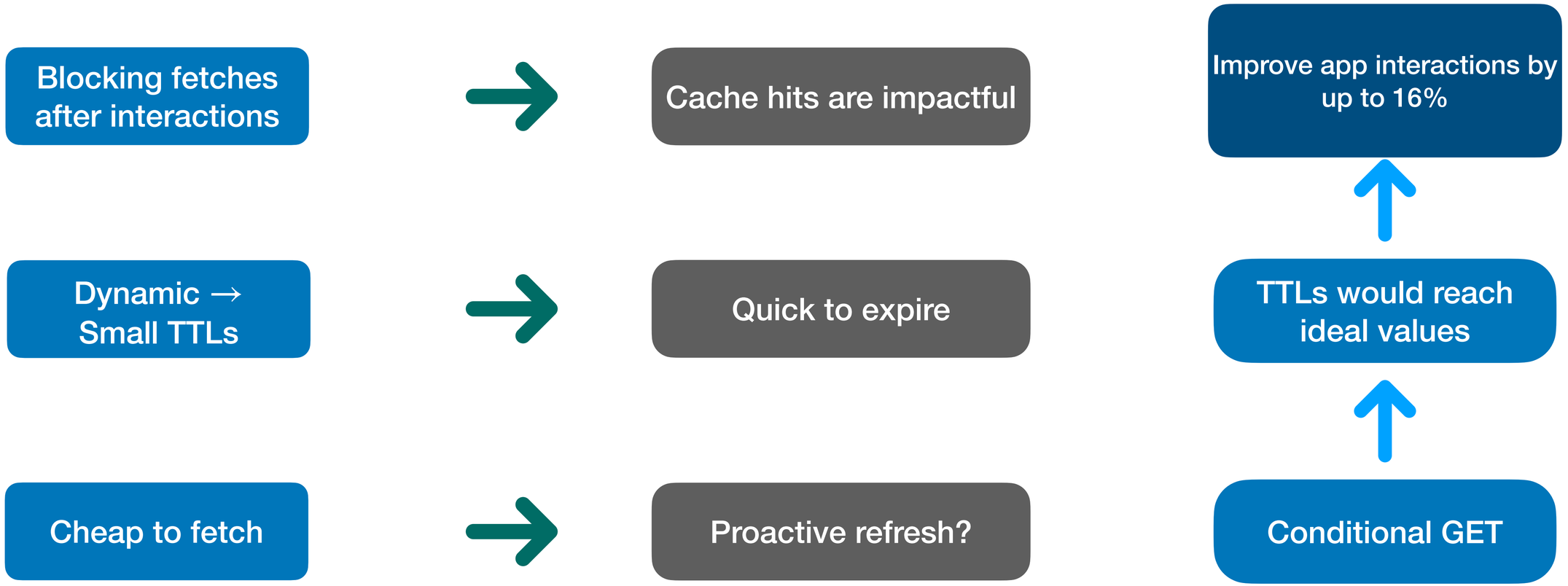


What about other assets in the cache, like images?

Making caching better

Insights about textual files



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HEAD requests

A different way of caching

Why wait to observe requests?

Caches don’t help first (cold) loads

A different way of caching

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Caches don't help first (cold) loads

From last lecture

Client Machine (e.g., Browser)

Advantages

- Very low latency
- Preserves access bandwidth
- Available when disconnected

Disadvantages

- Low hit rate due to "cold" misses
- Many cache consistency checks
- Incomplete logs at the server

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Personal Cache

A different way of caching

Why wait to observe requests?

Caches don’t help first (cold) loads

aka “*pre*fetching”

Could we “warm” the cache?

A different way of caching

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Near-instantaneous response to users

A different way of caching

Why wait to observe requests?

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Near-instantaneous response to users

But what would the user want?

Prefetching correctly is difficult

Load content in the background at periodic intervals
Avoid network fetches during interactions

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4 of top 50
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Coupling of speedups and overheads

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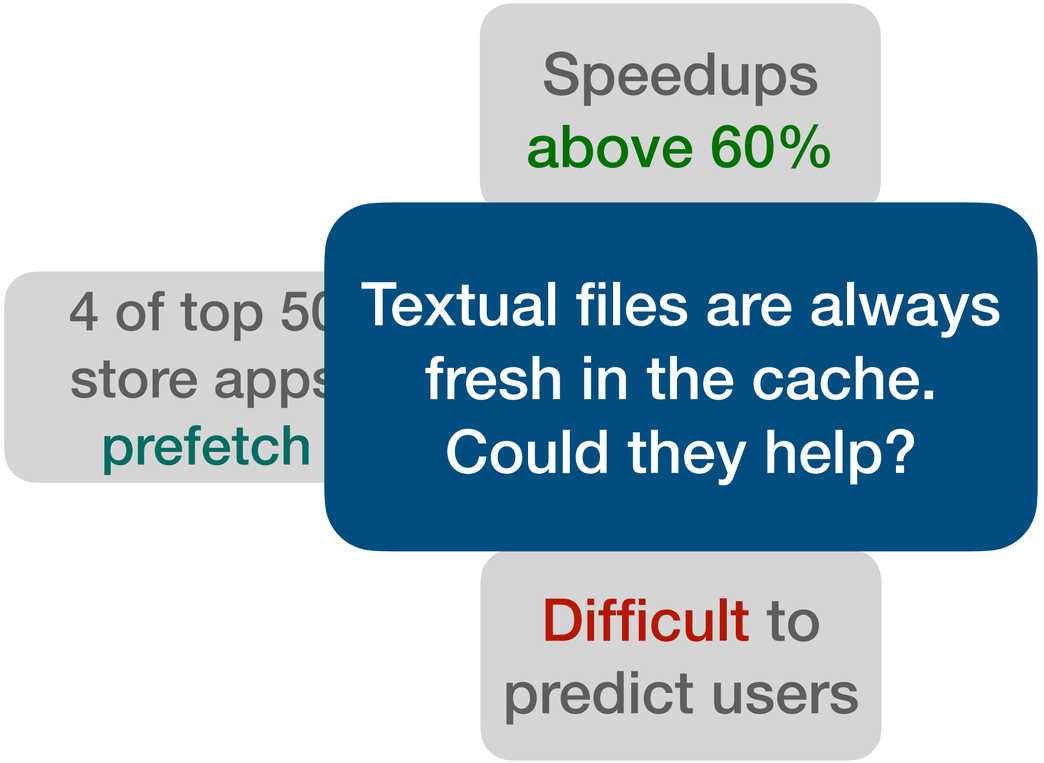

Coupling of speedups and overheads

Analyzing textual files

Opportunities for prefetching

Analyzing textual files

Opportunities for prefetching

entertainment.json

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{
  article1: {
    summary,
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article1.json

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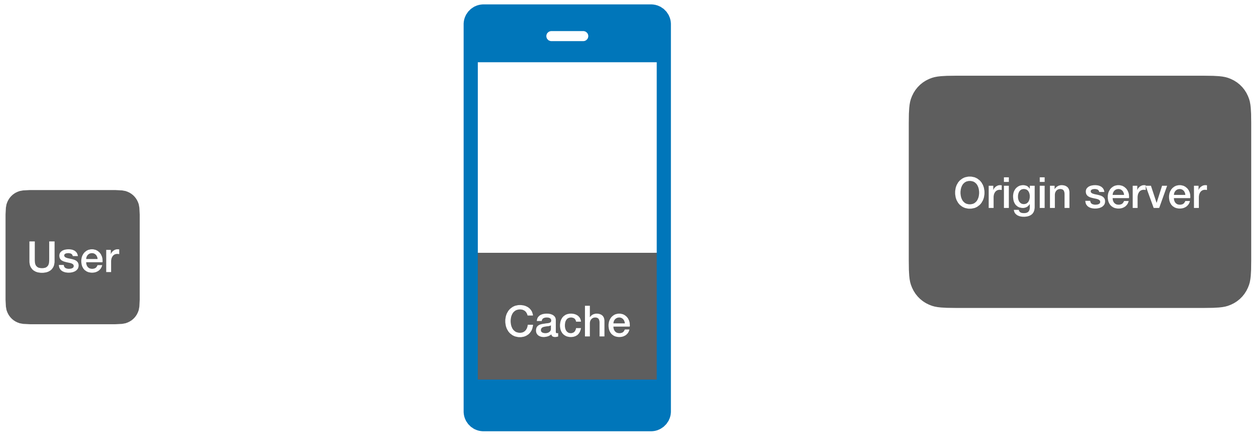
Text files contain pointers to upcoming requests

Just-in-time prefetching



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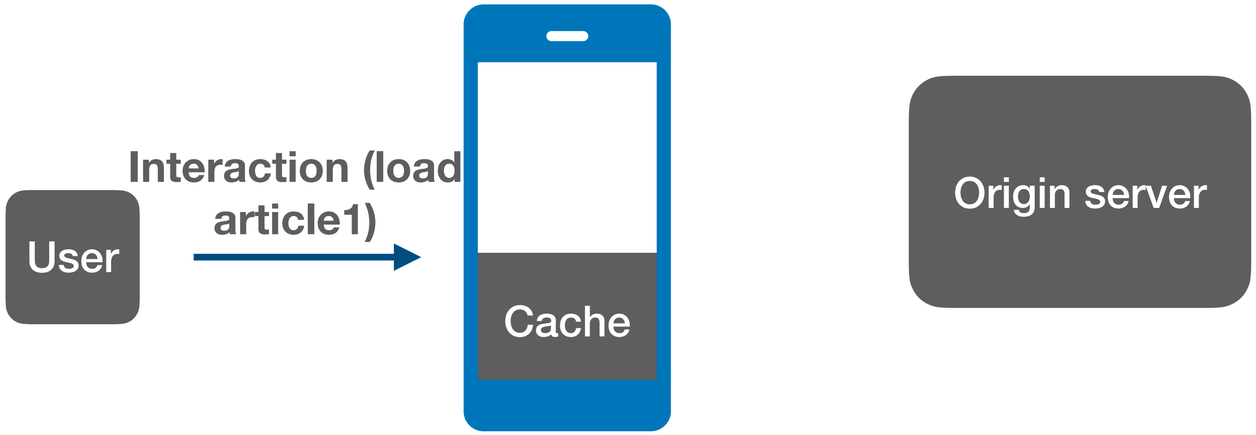

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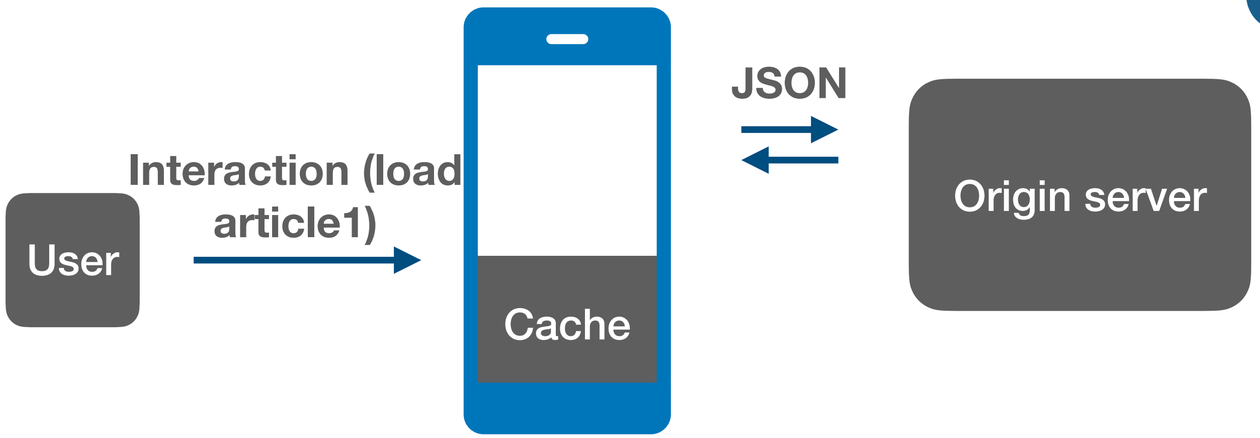

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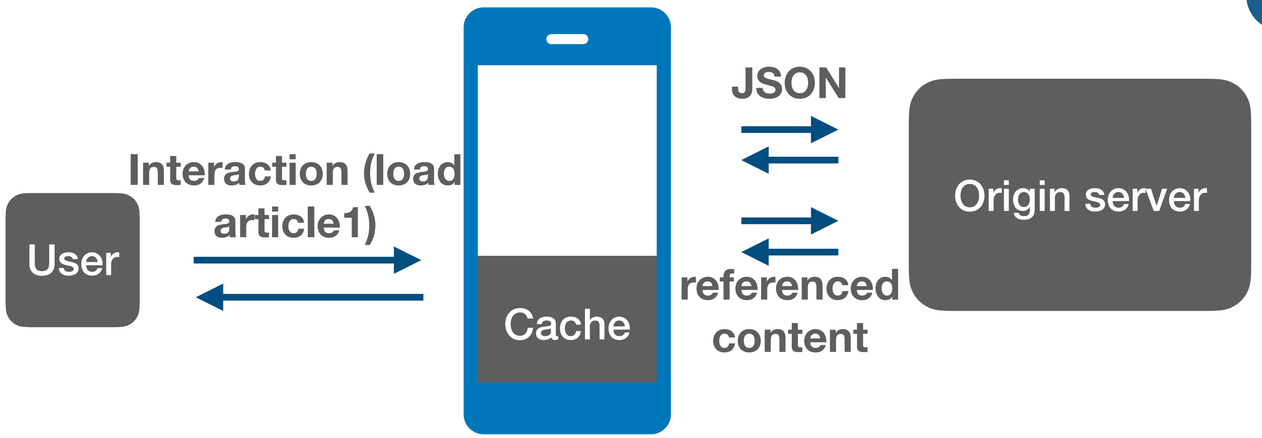

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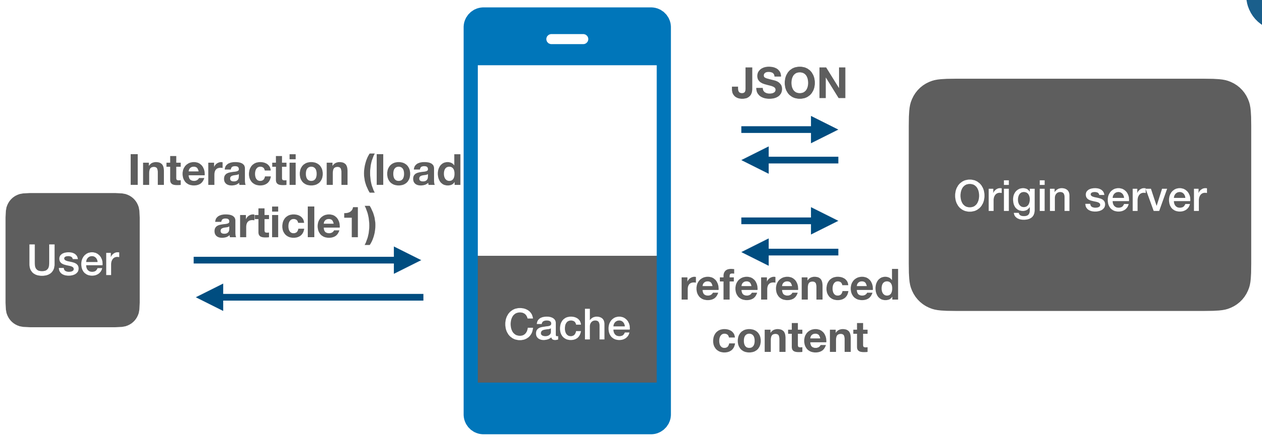

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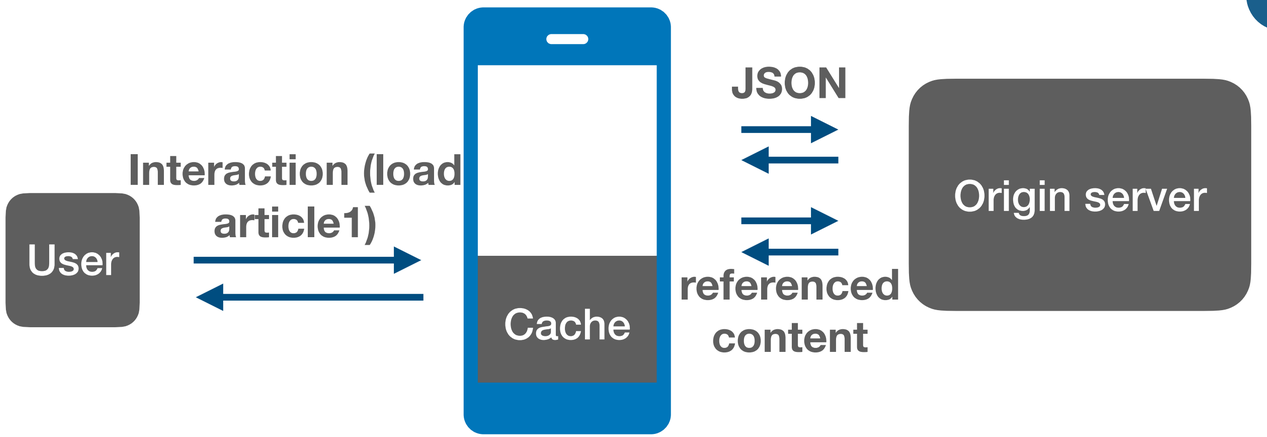

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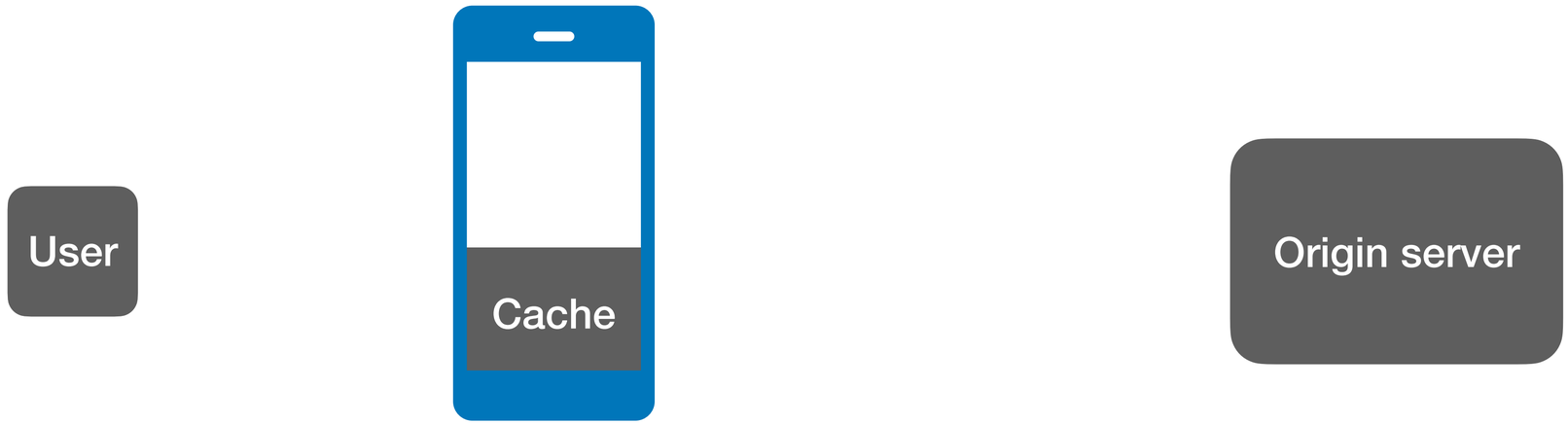

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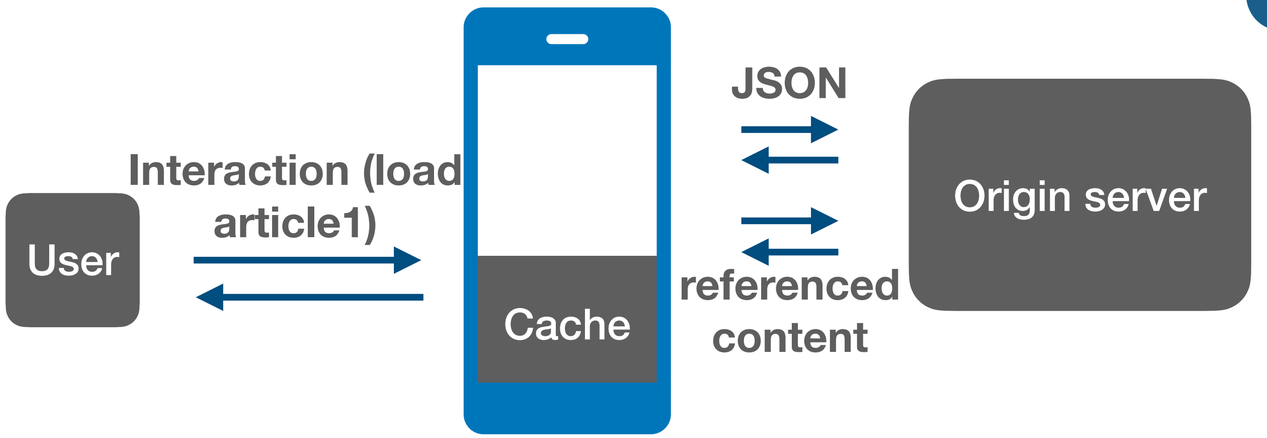

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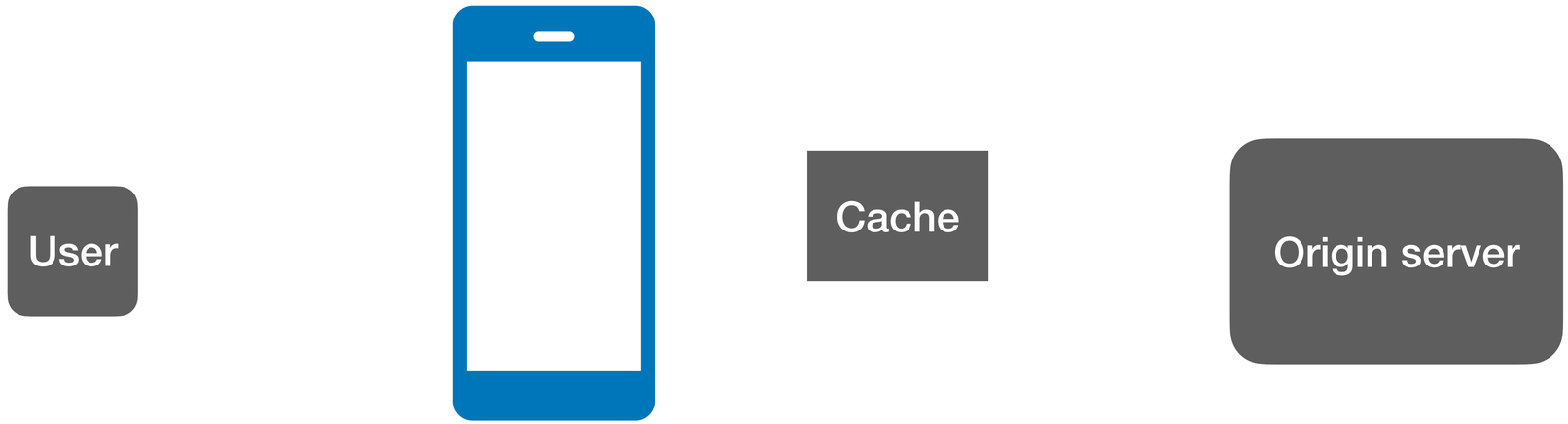

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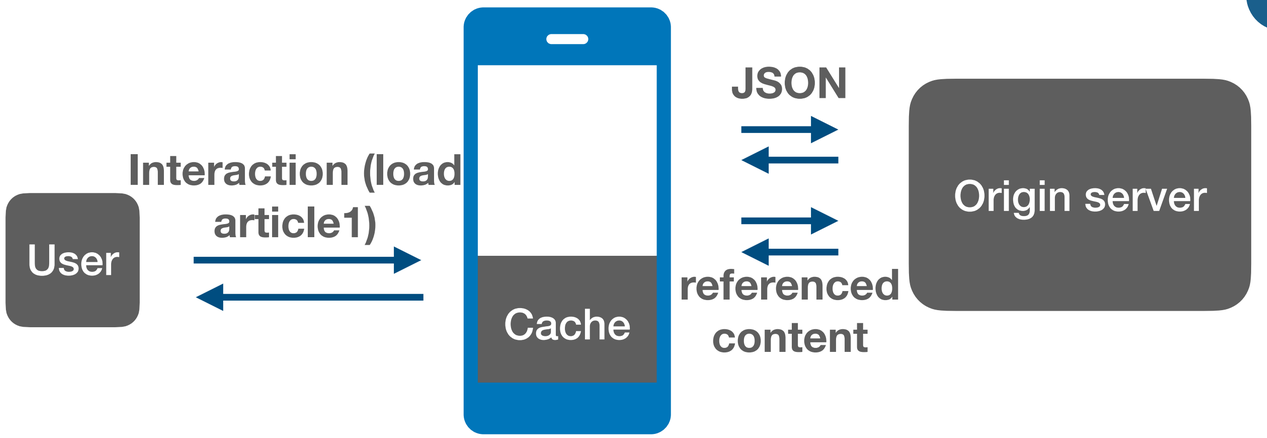

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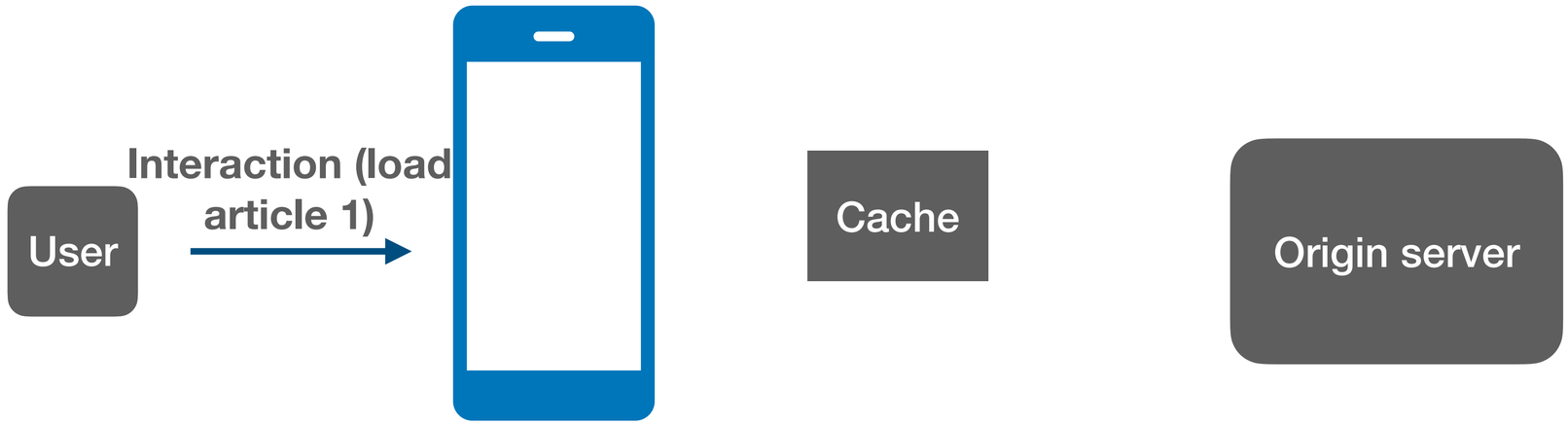

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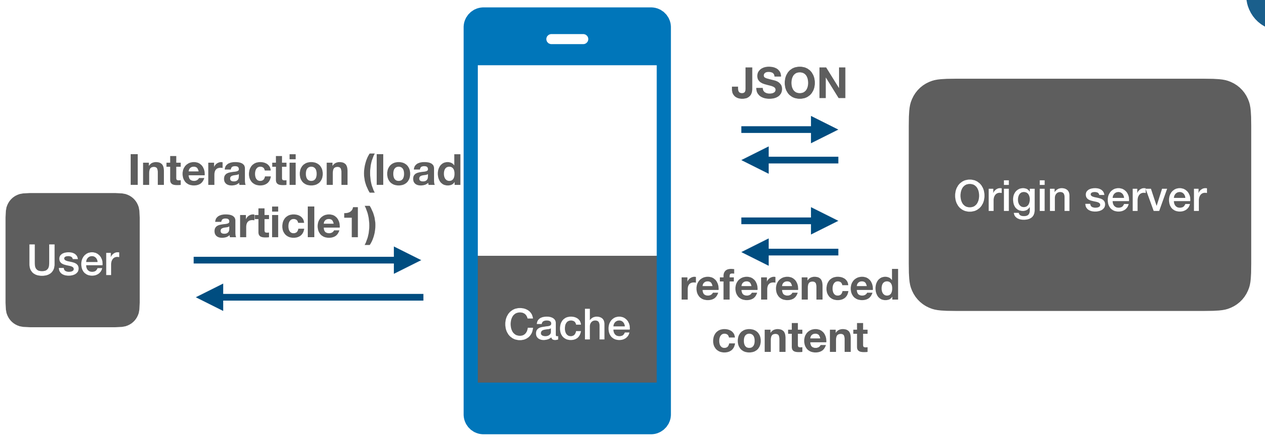

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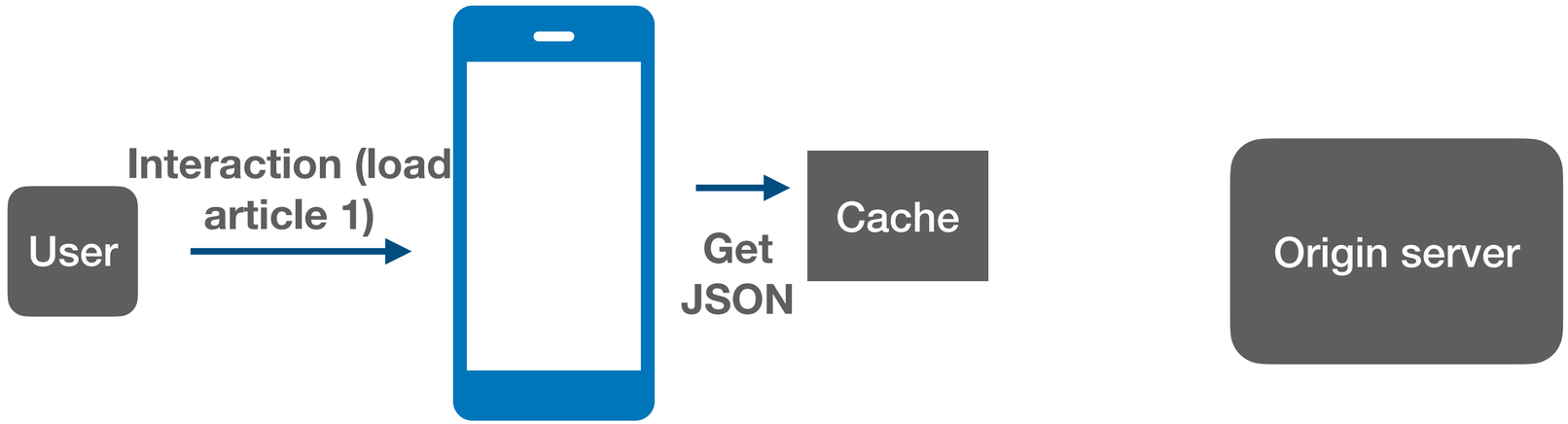

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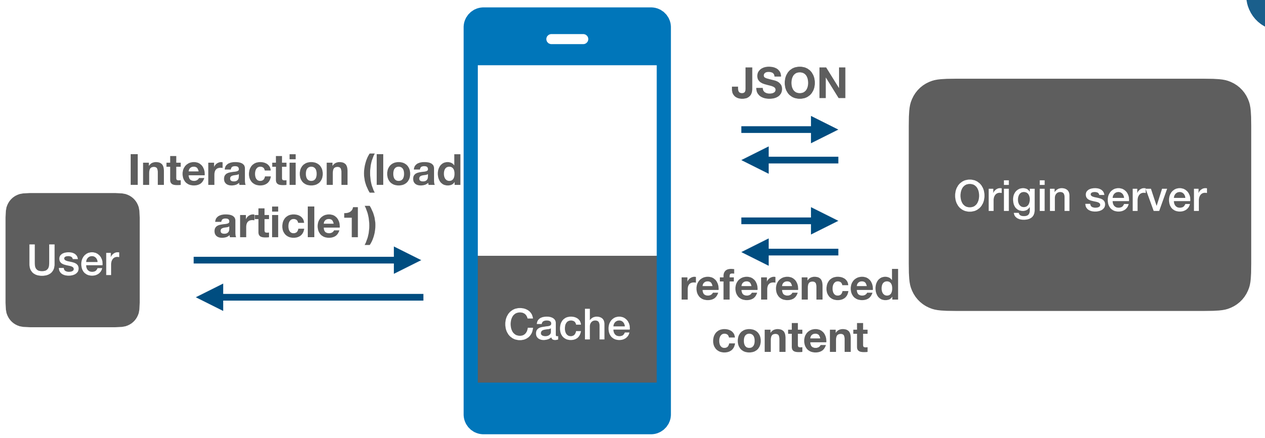

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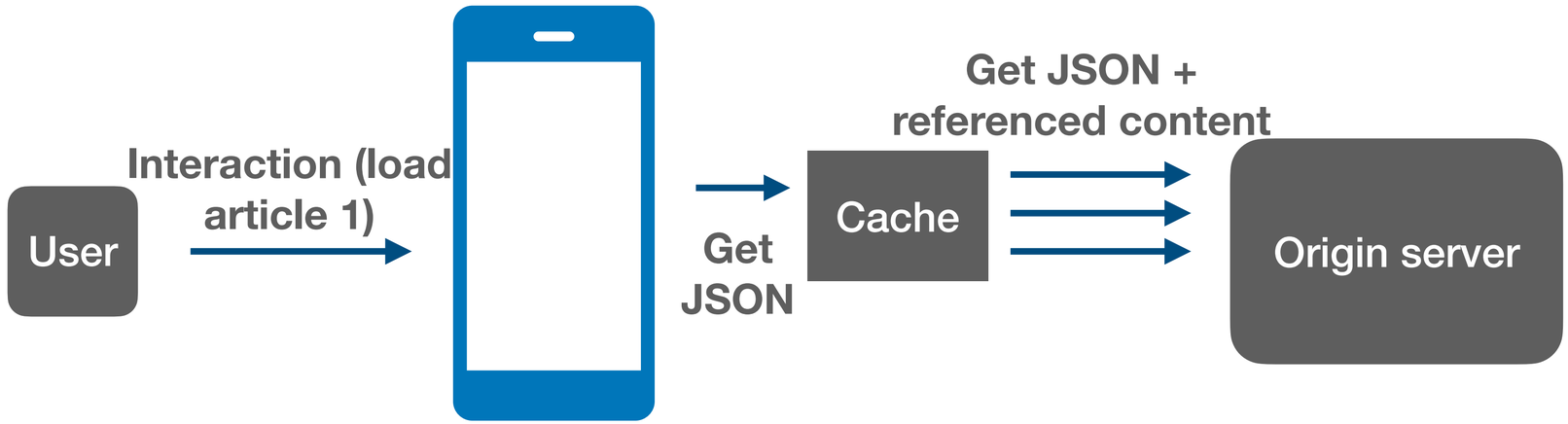

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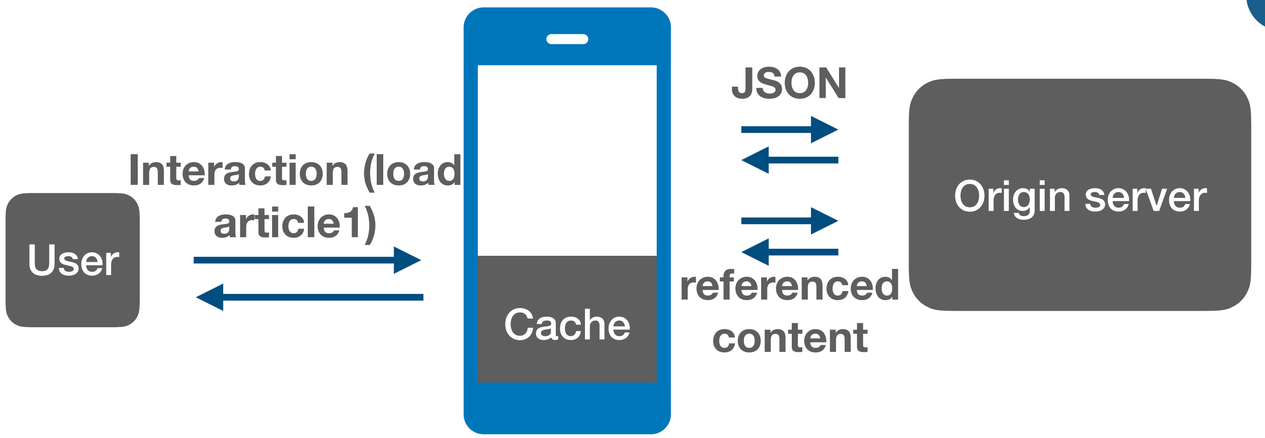

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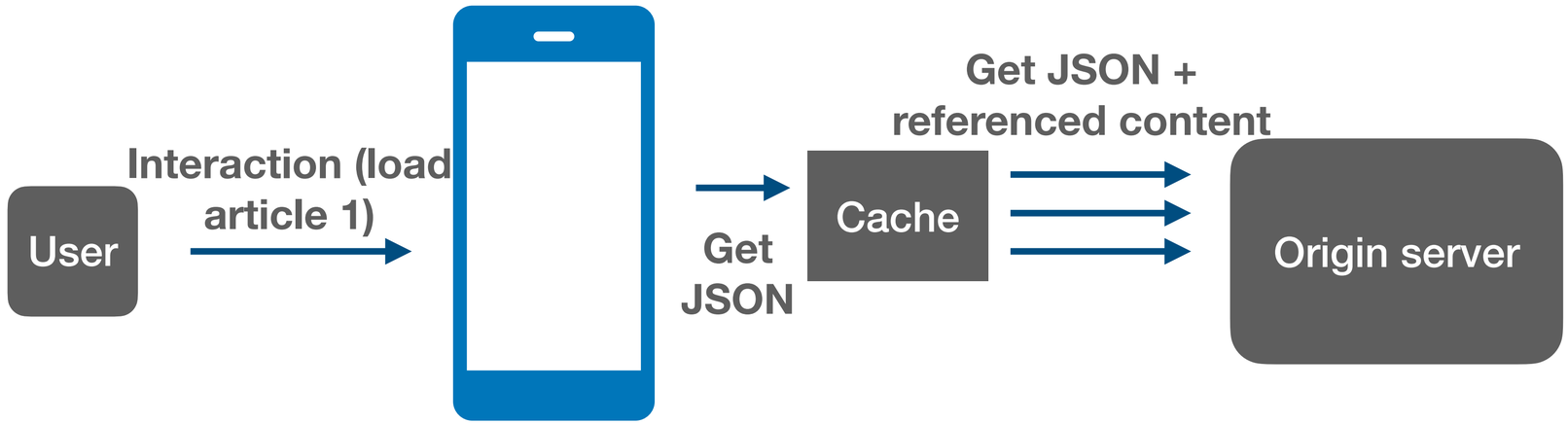

Sidestep the prediction problem

“User requested article1.json so they’ll need the images in it as well”

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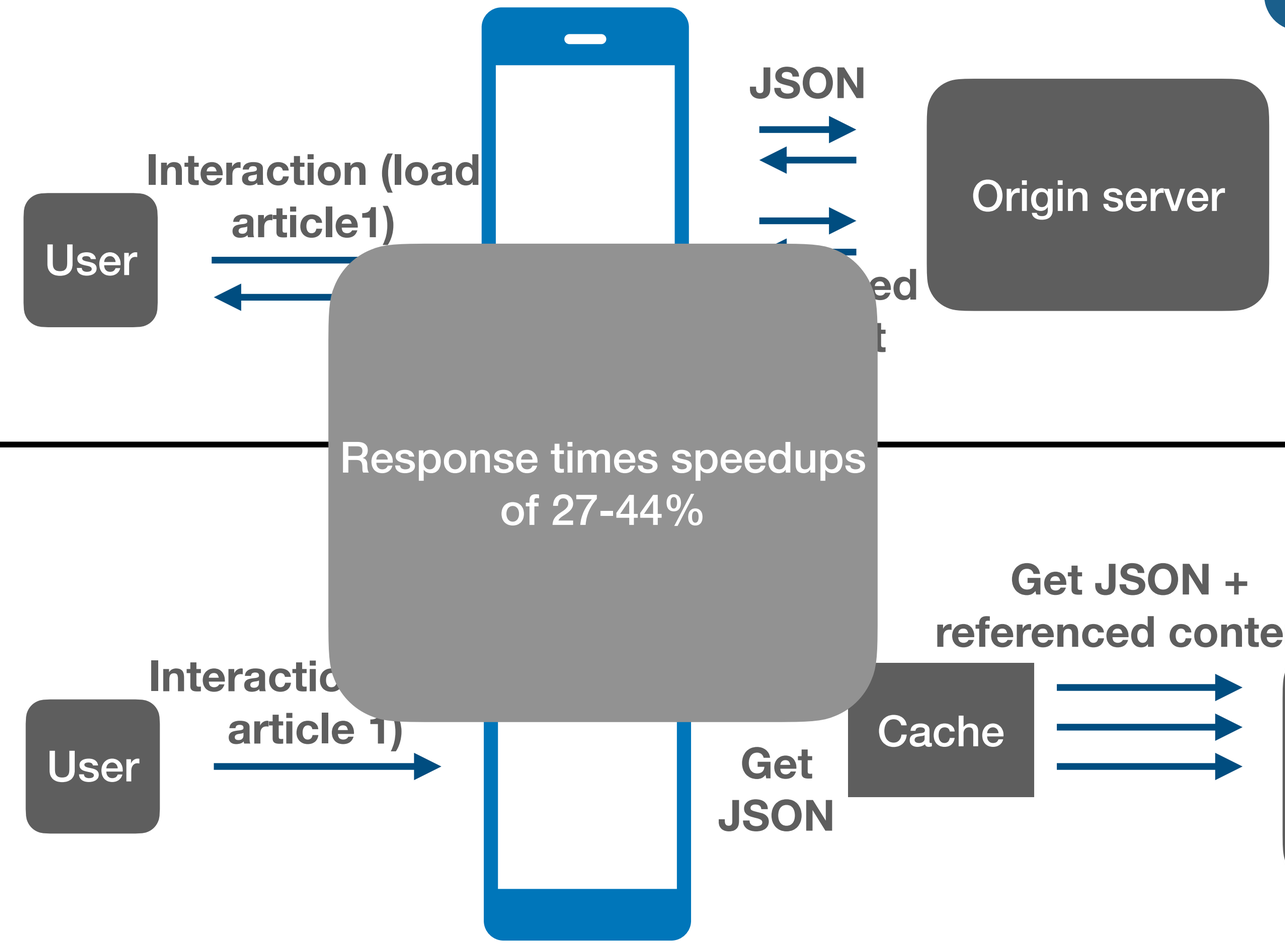

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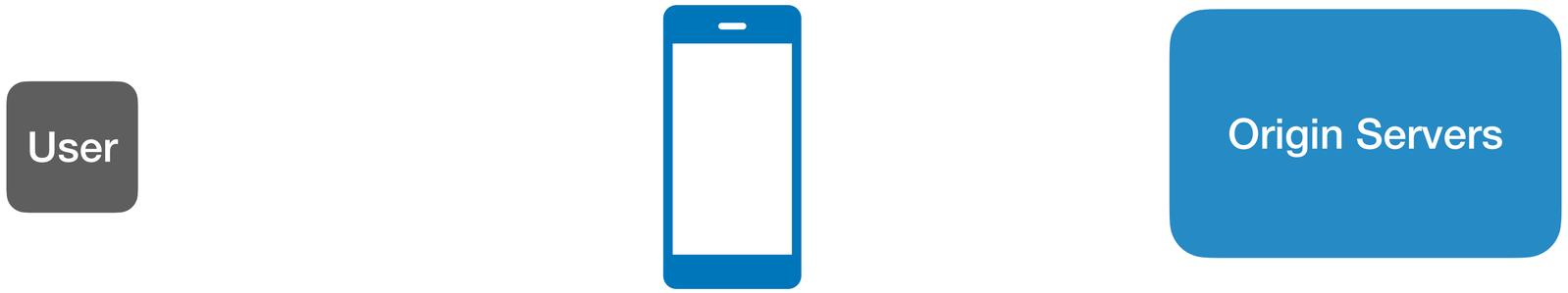

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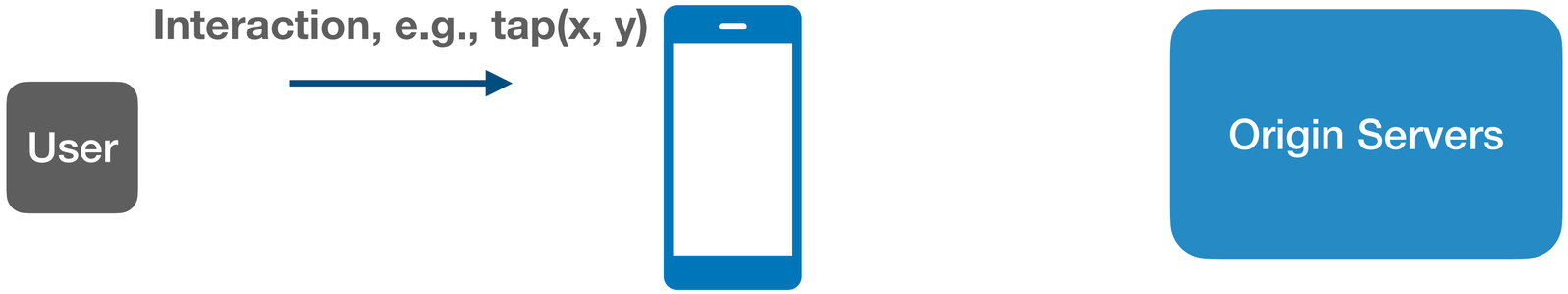

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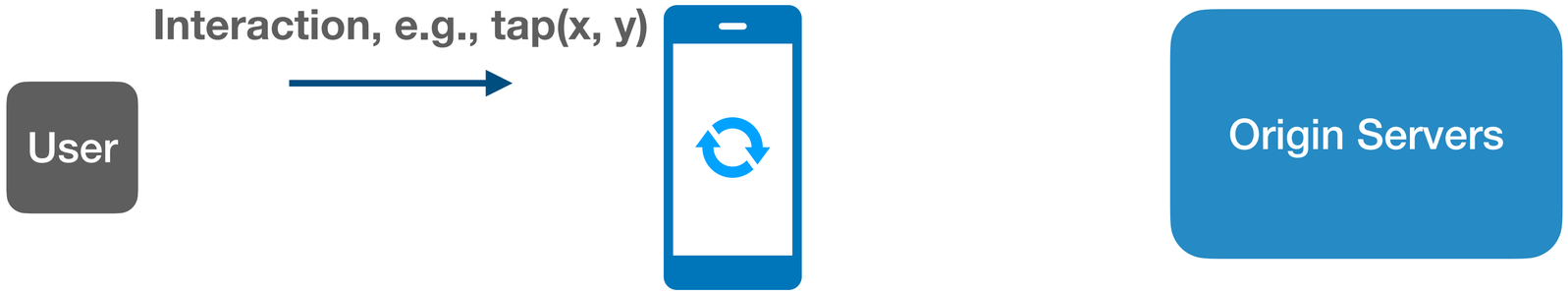

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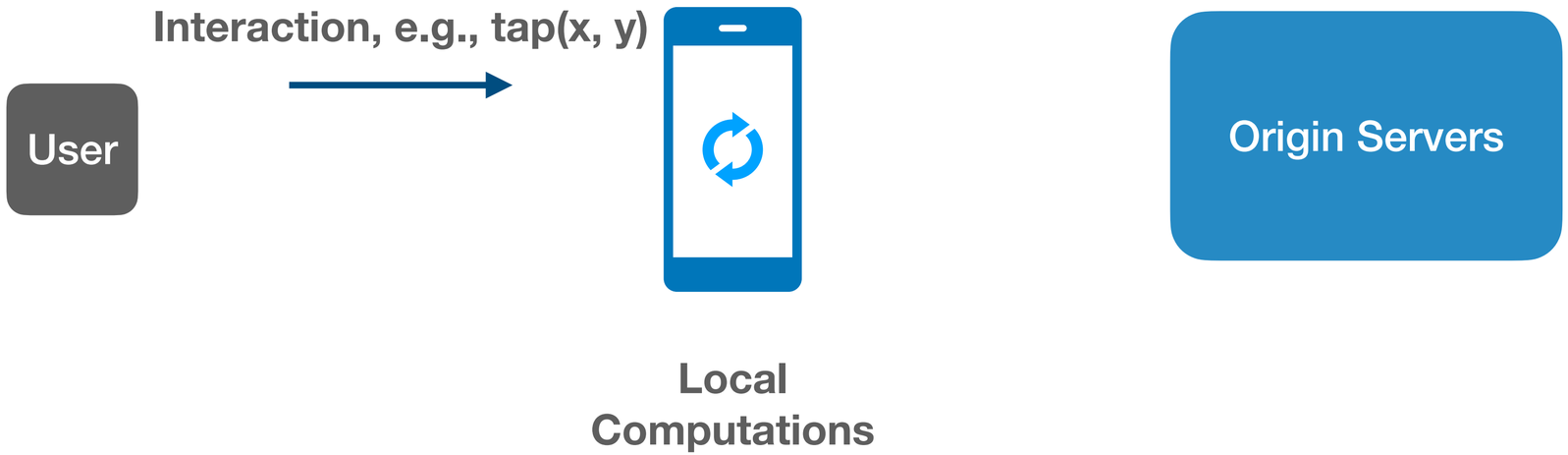

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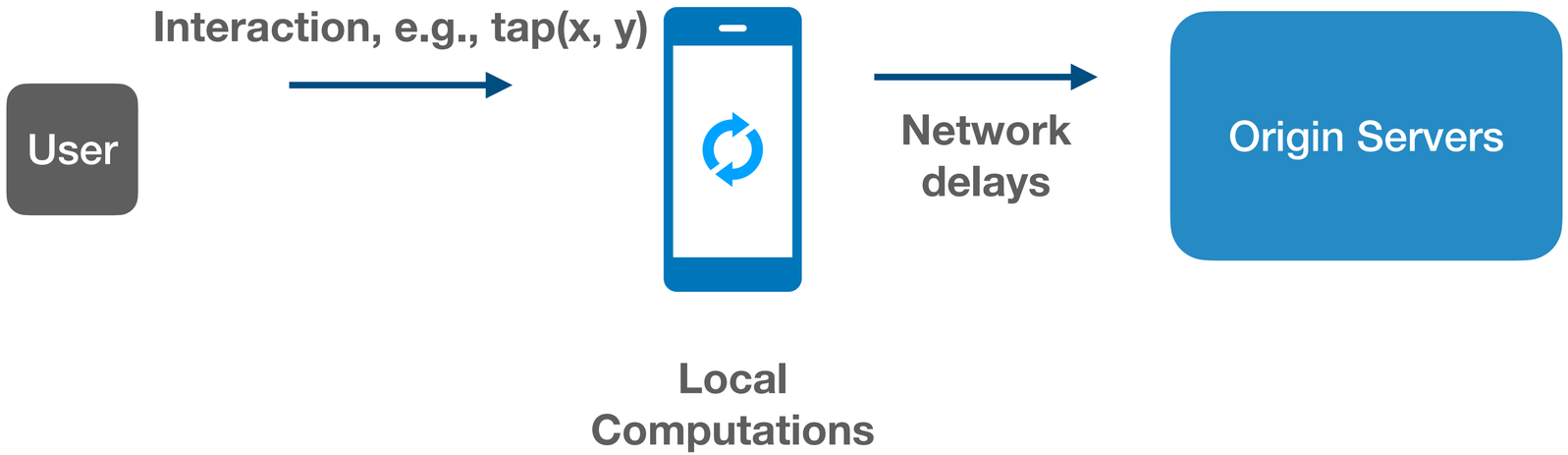

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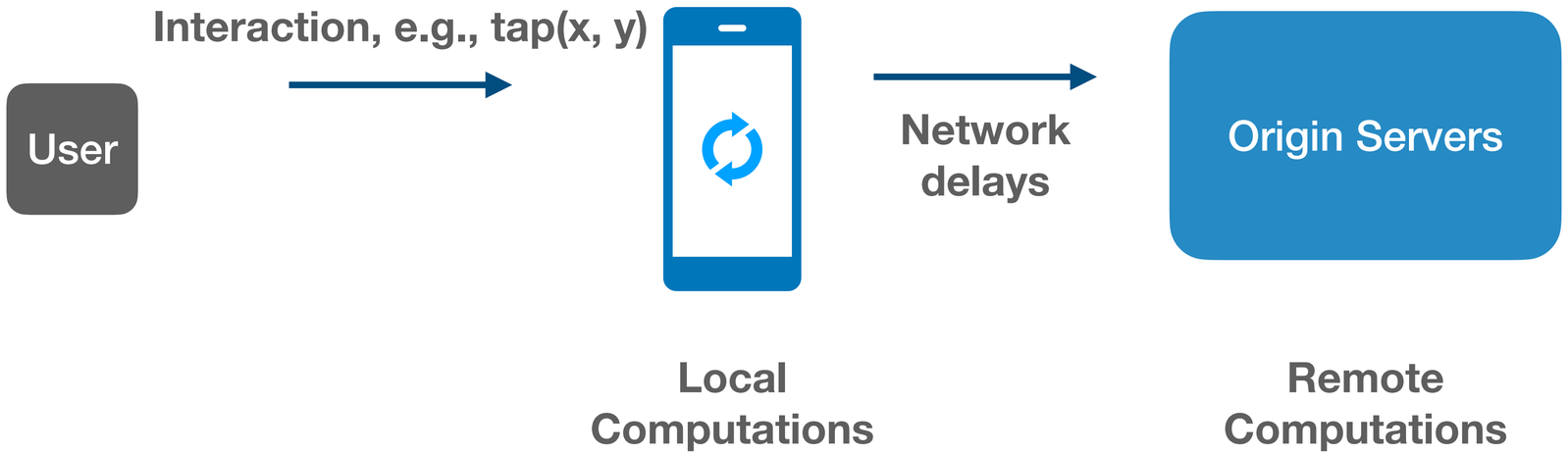

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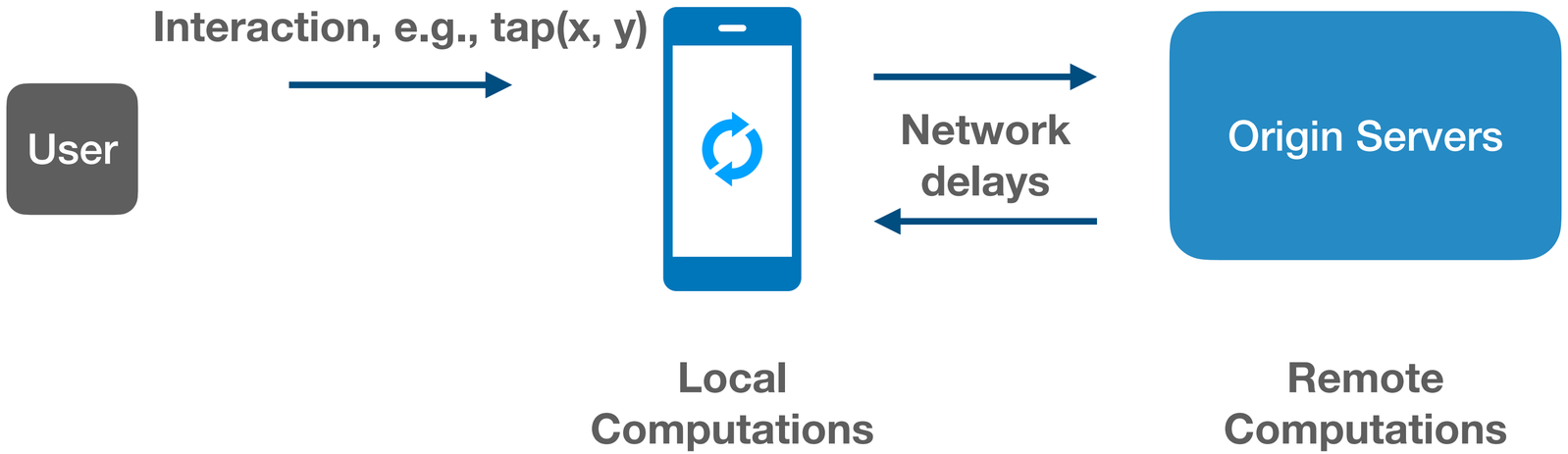

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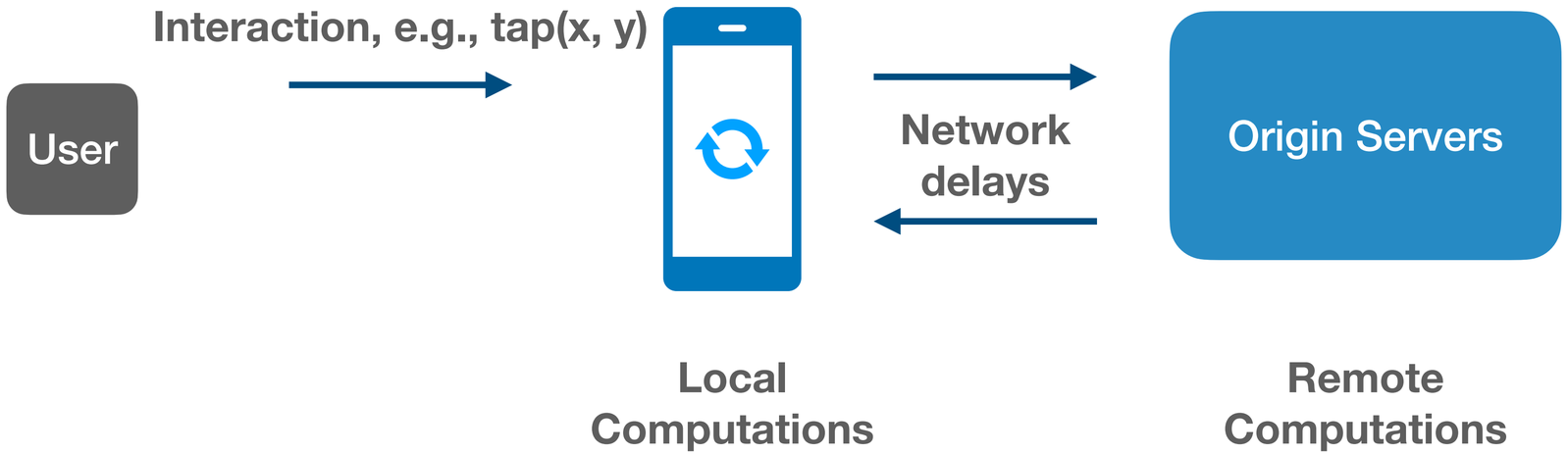

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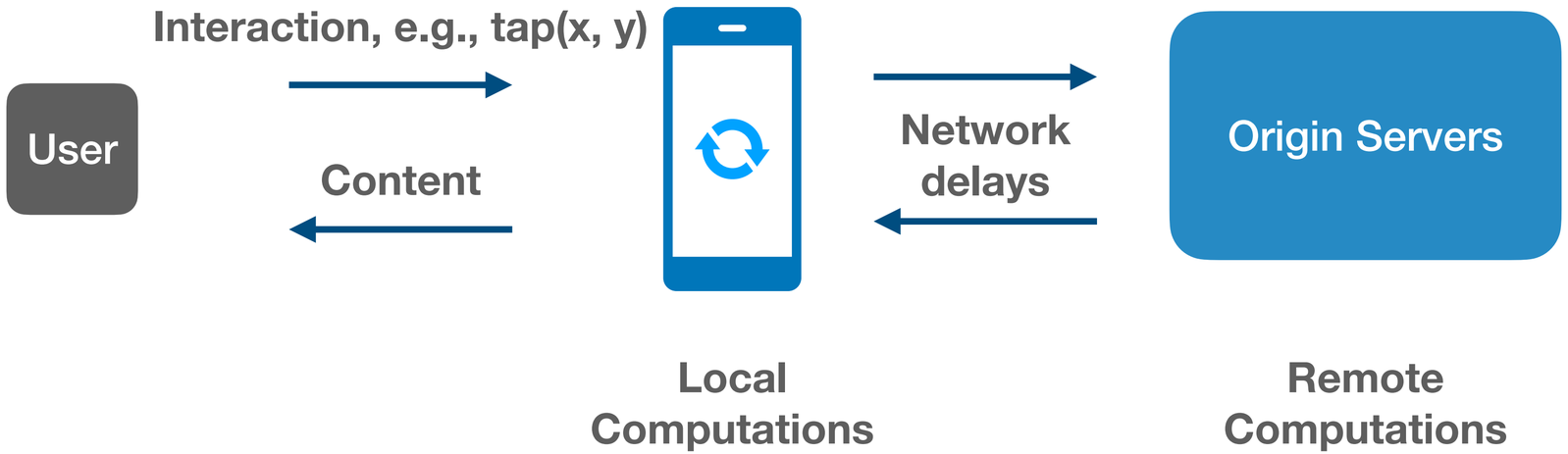

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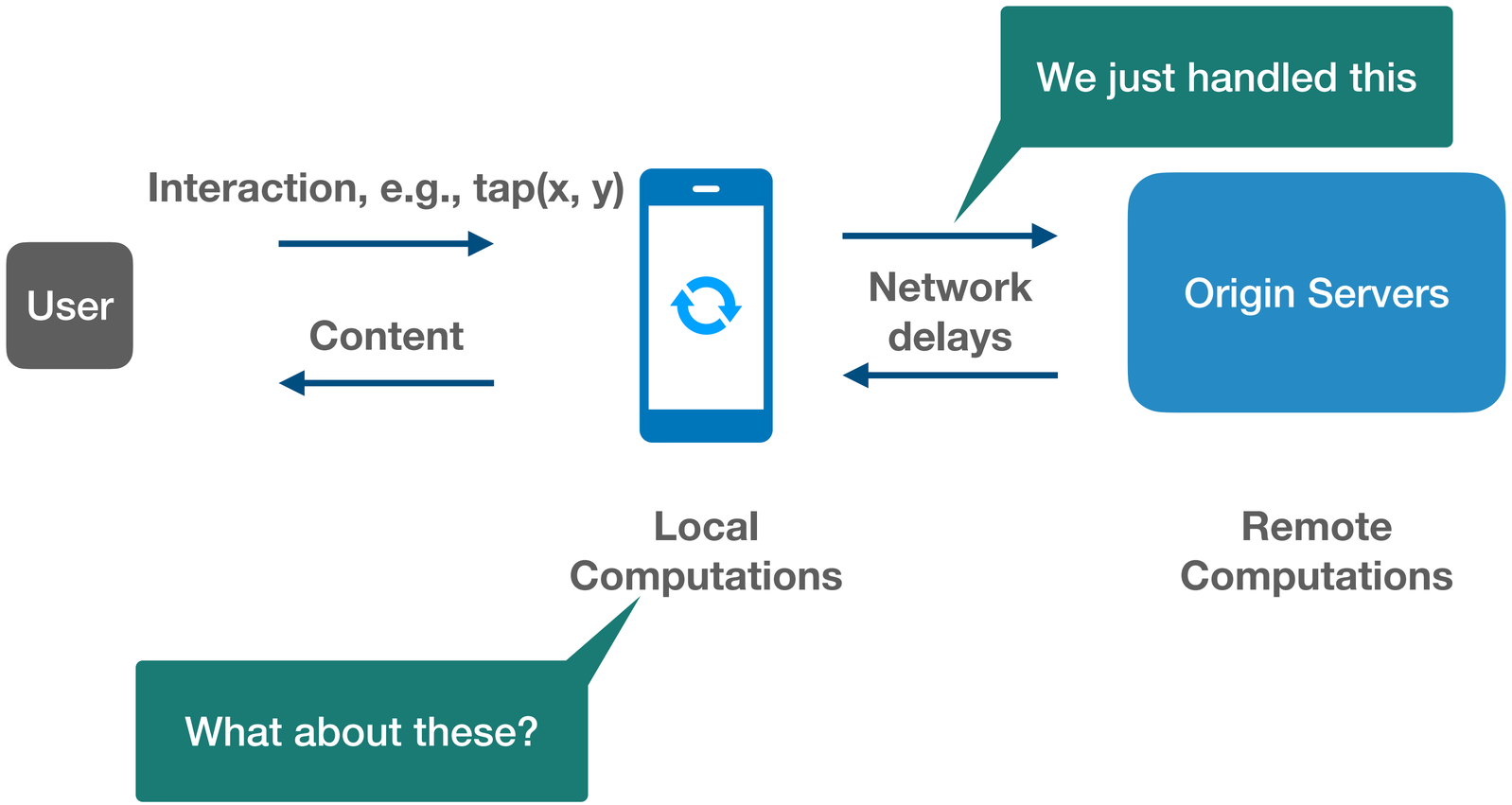

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If read state matches a prior run

Apply prior writes

Potential of memoization

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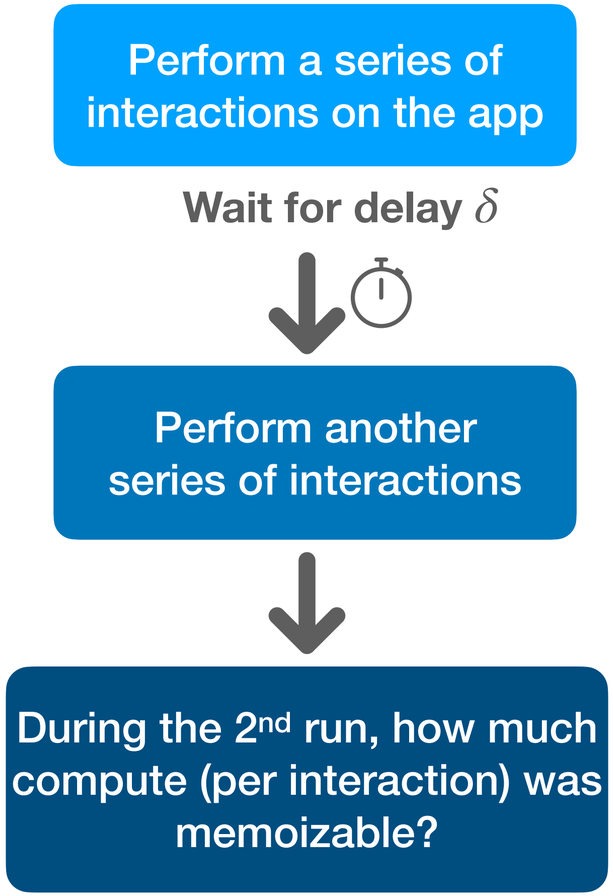

Potential of memoization

Perform a series of interactions on the app

Wait for delay δ

Perform another series of interactions

During the 2nd run, how much compute (per interaction) was memoizable?

Upper bound of memoization benefits with zero overhead

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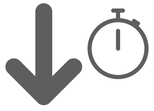

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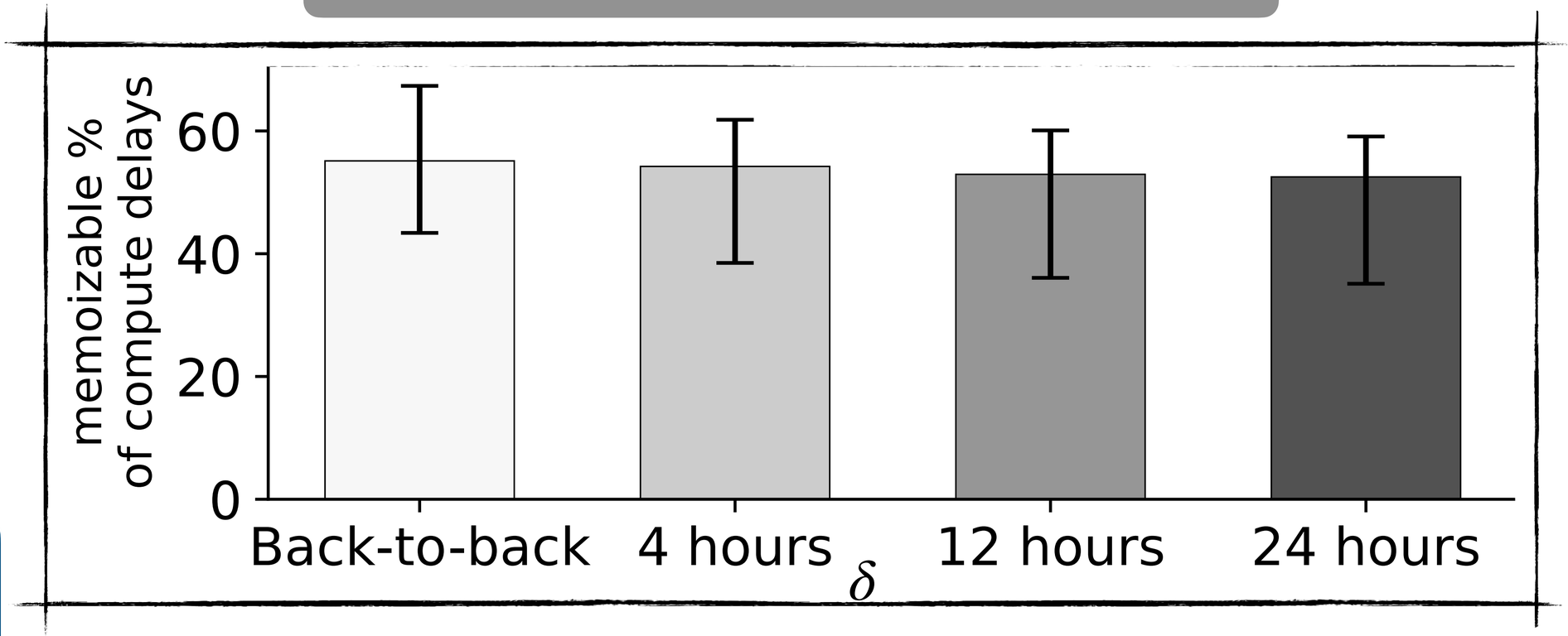

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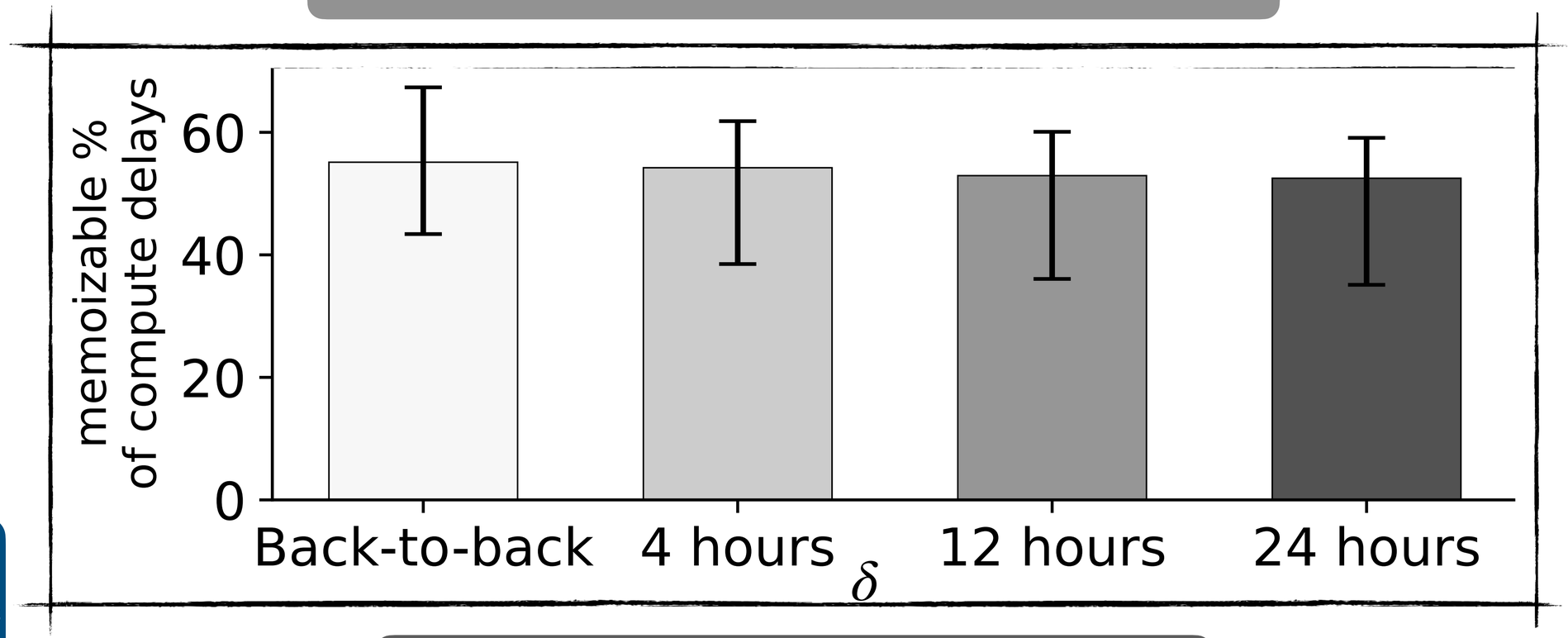
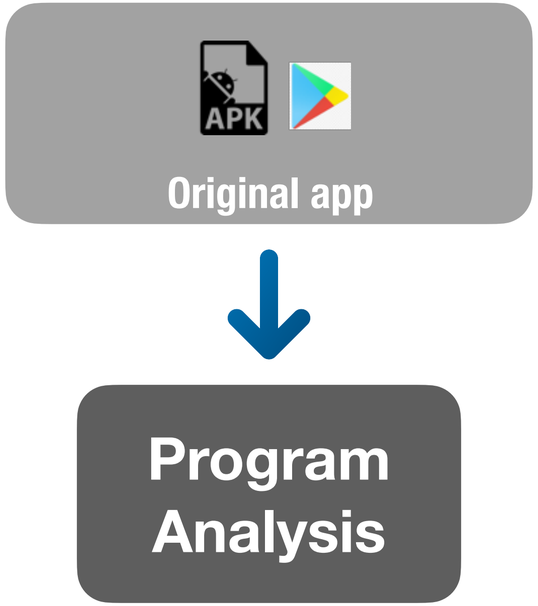
Upper bound of memoization benefits with zero overhead



Benefits persist over time due to stable computations

Implementing memoization

Implementing memoization



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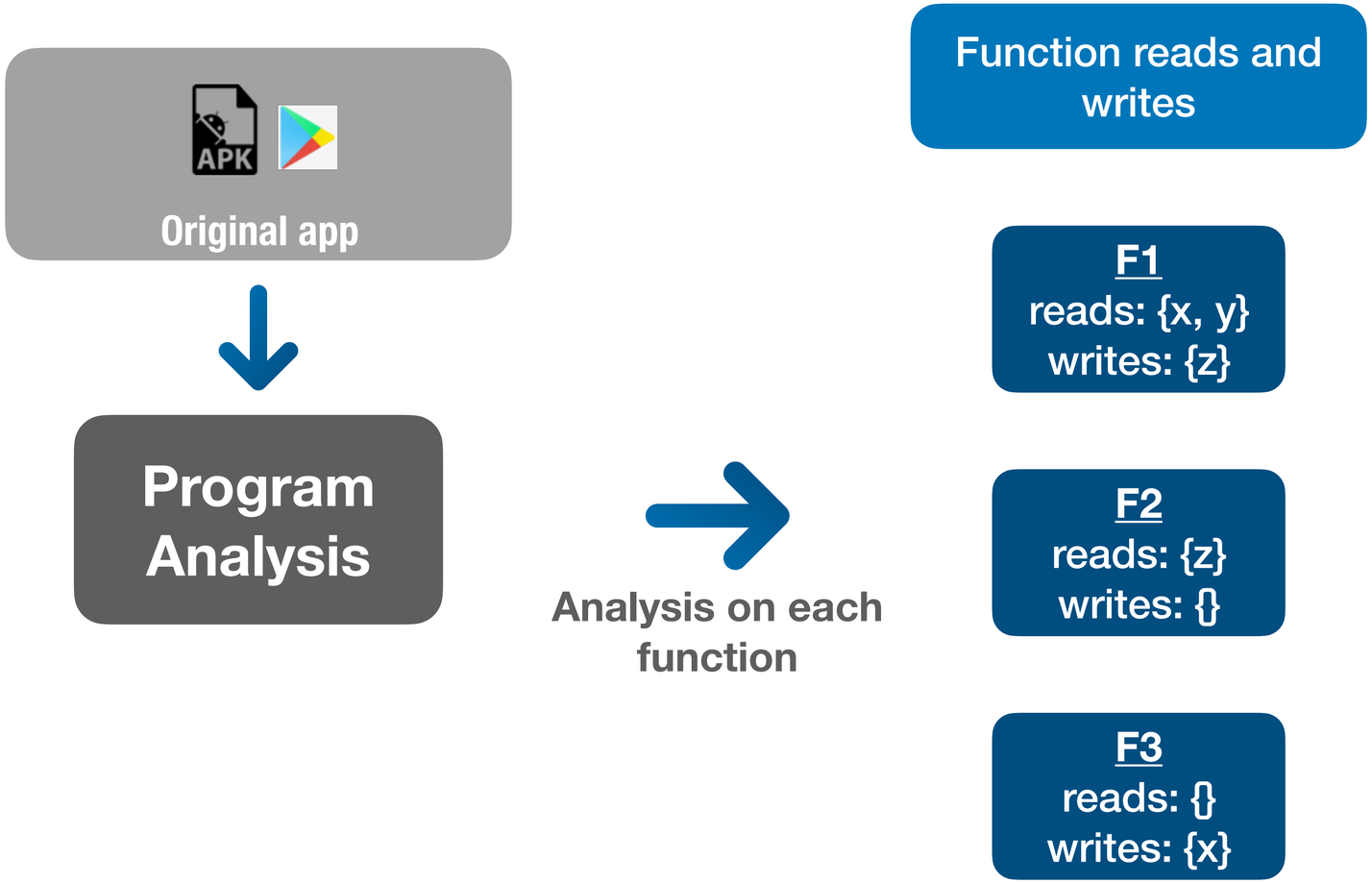

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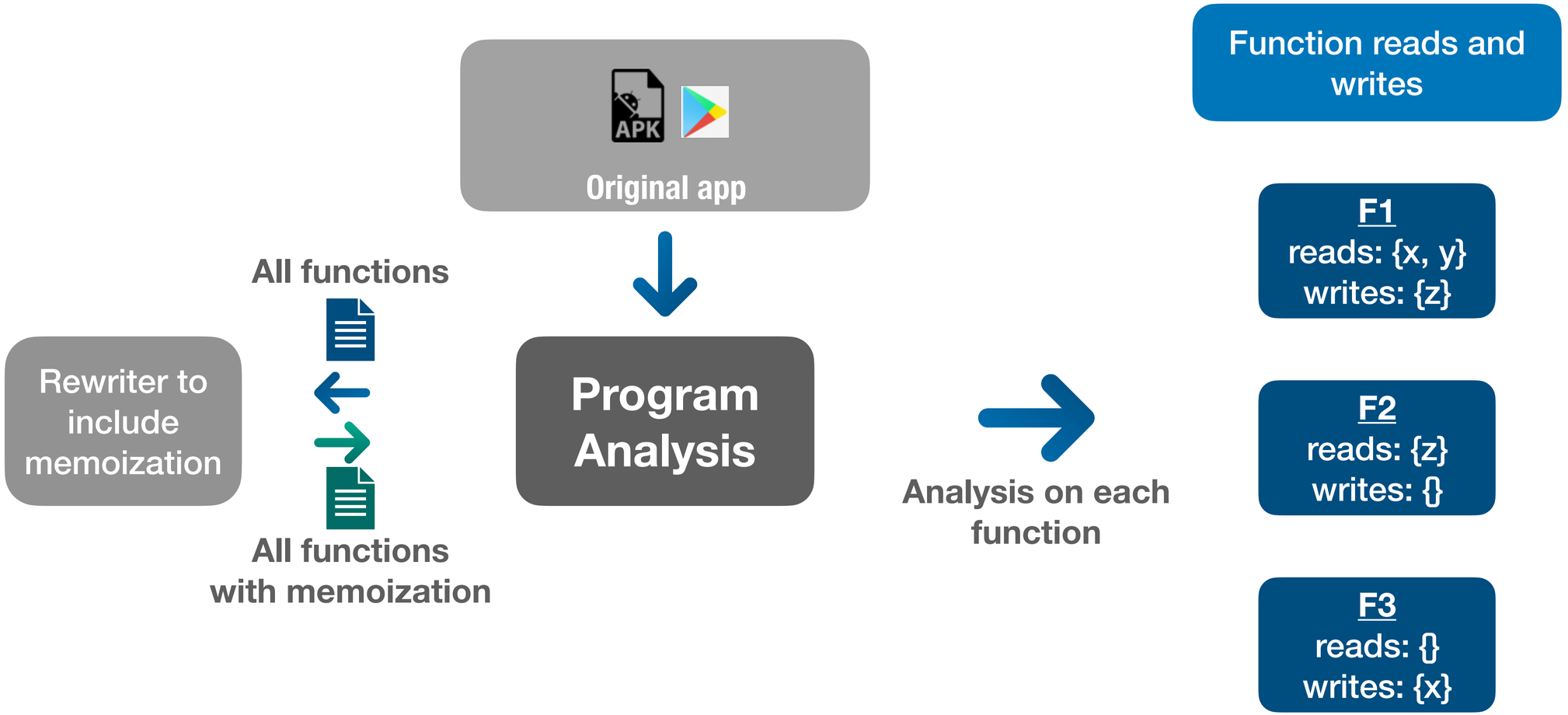

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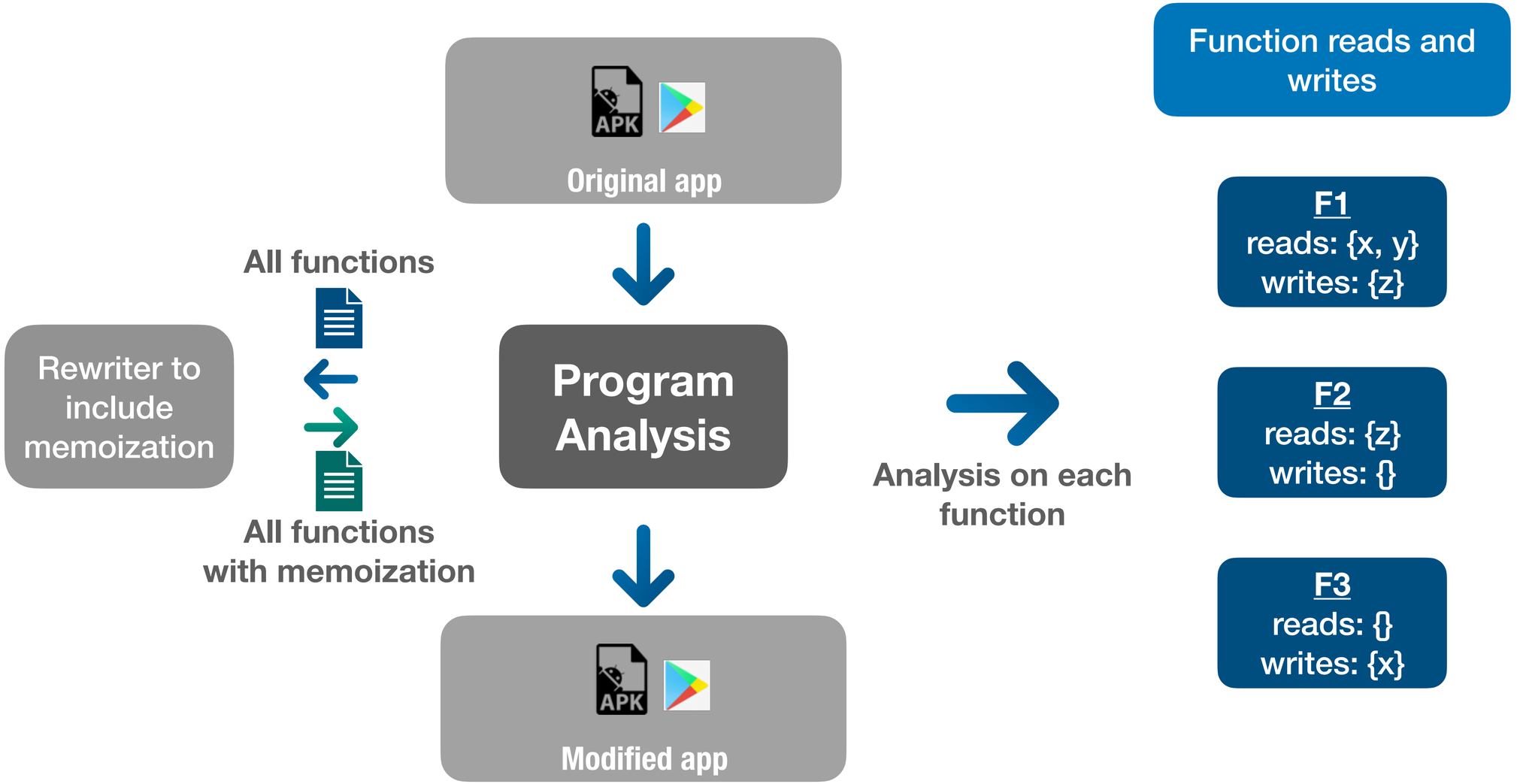

Straightforward memoization

The result

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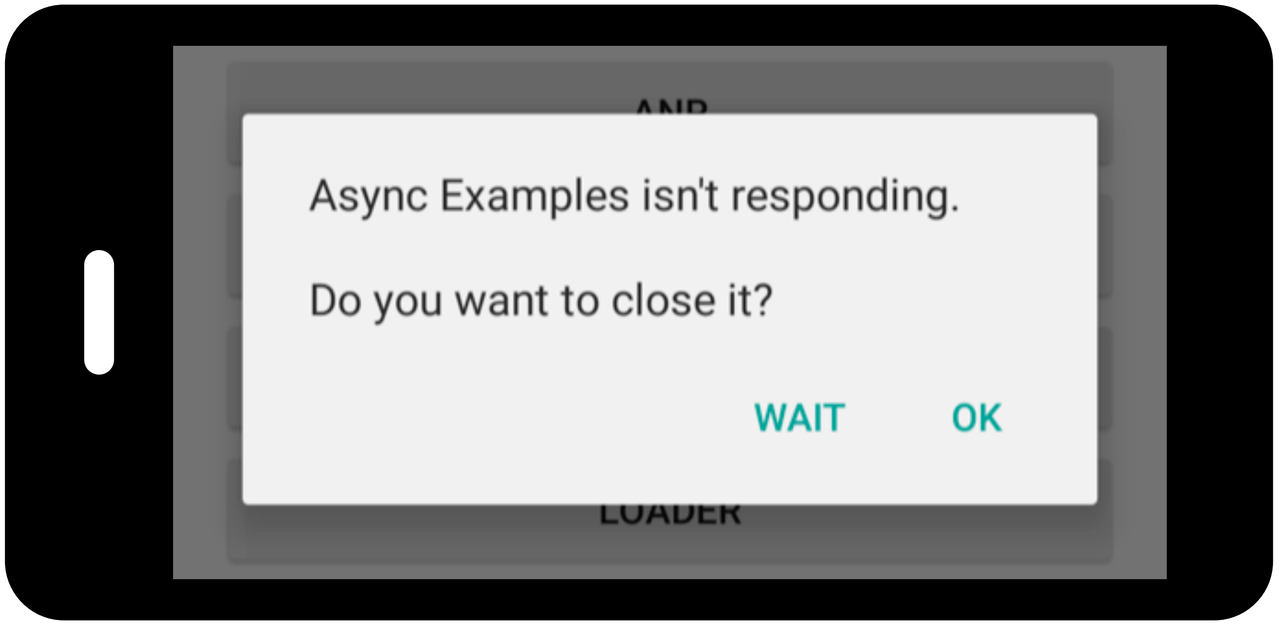

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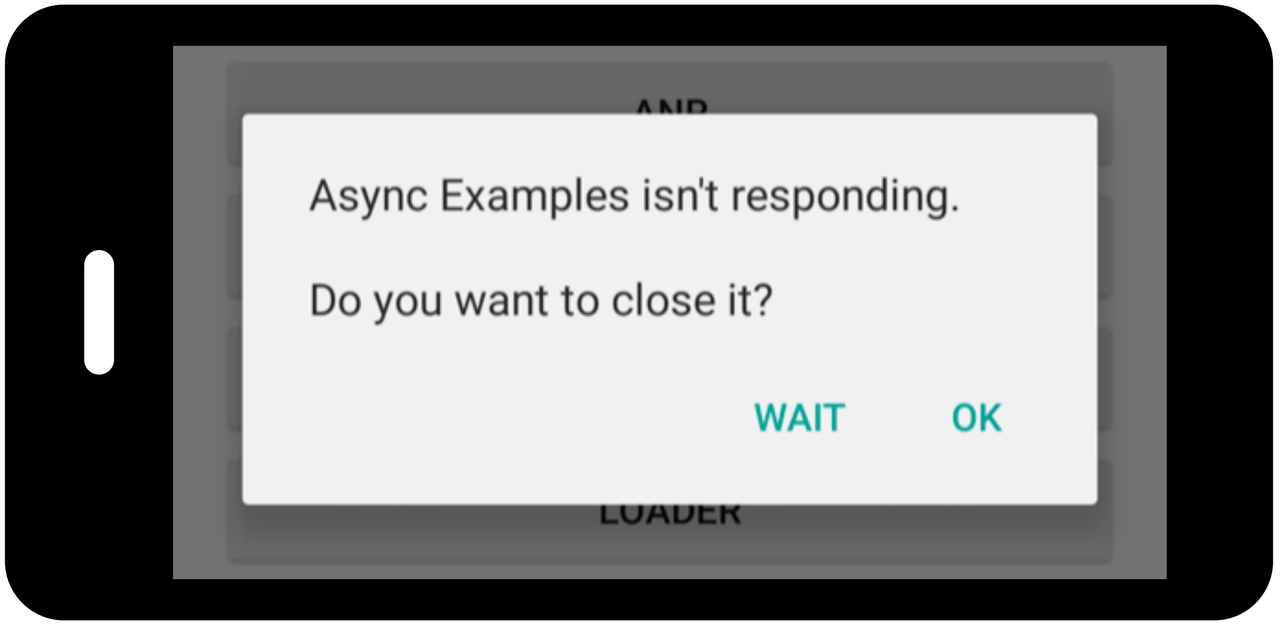

Blocking, expensive, potentially unnecessary cache queries

Challenges with memoization

An experimental result

Challenges with memoization

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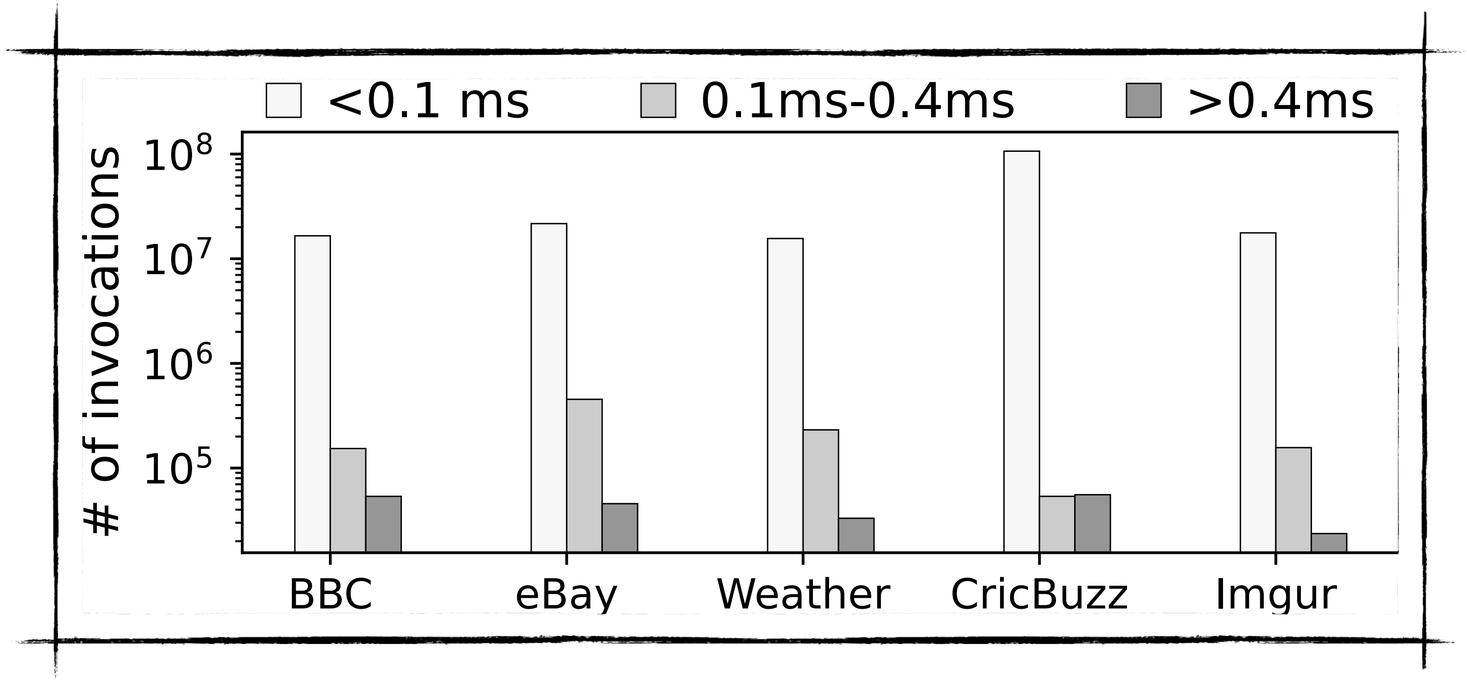
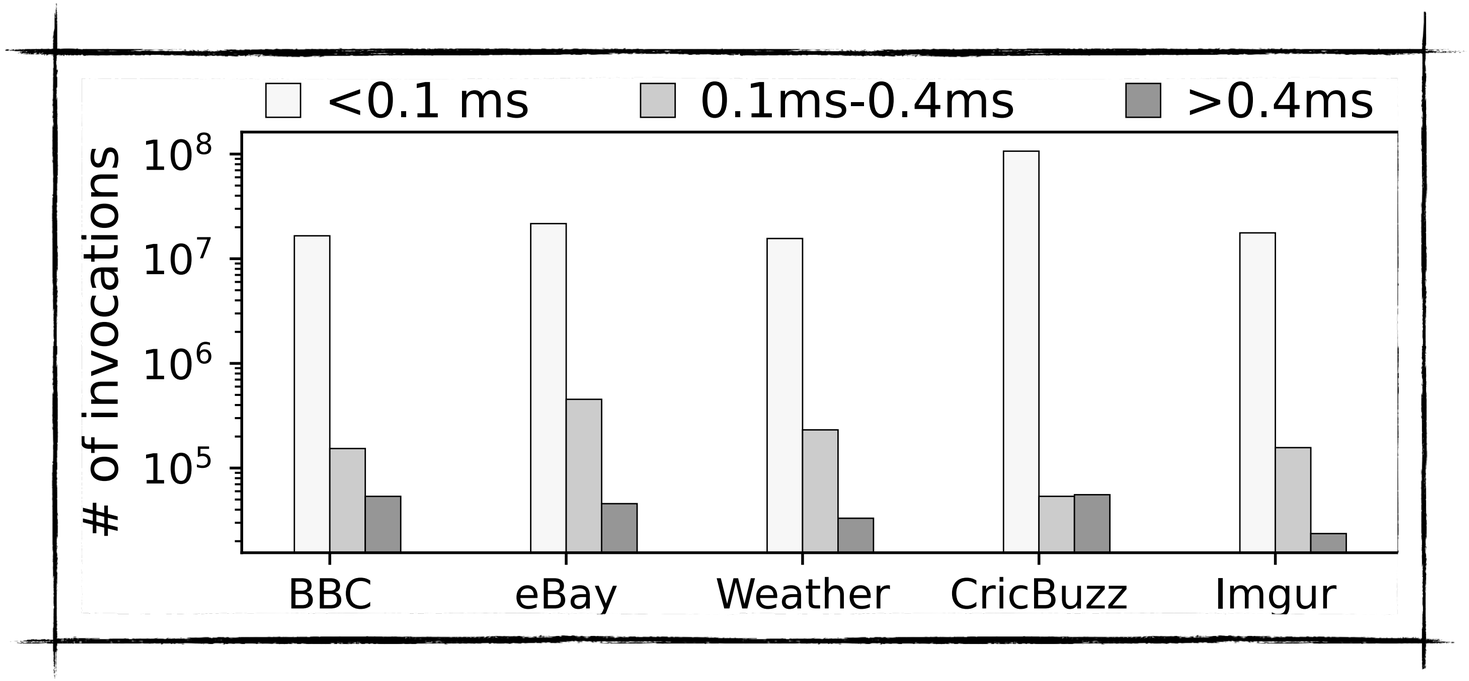


Function invocation runtimes for 5 exemplar apps

Challenges with memoization

An experimental result



Function invocation runtimes for 5 exemplar apps

Large number of invocations → Queries can overwhelm resources

Low function runtimes → Overheads can exceed runtimes

Lookaheads

Making cache lookups fast!

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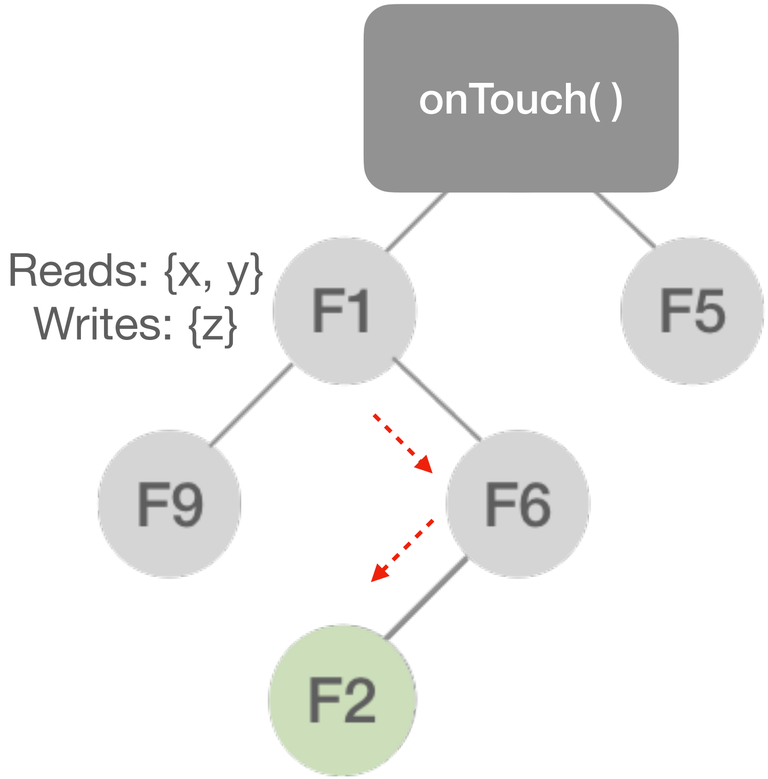

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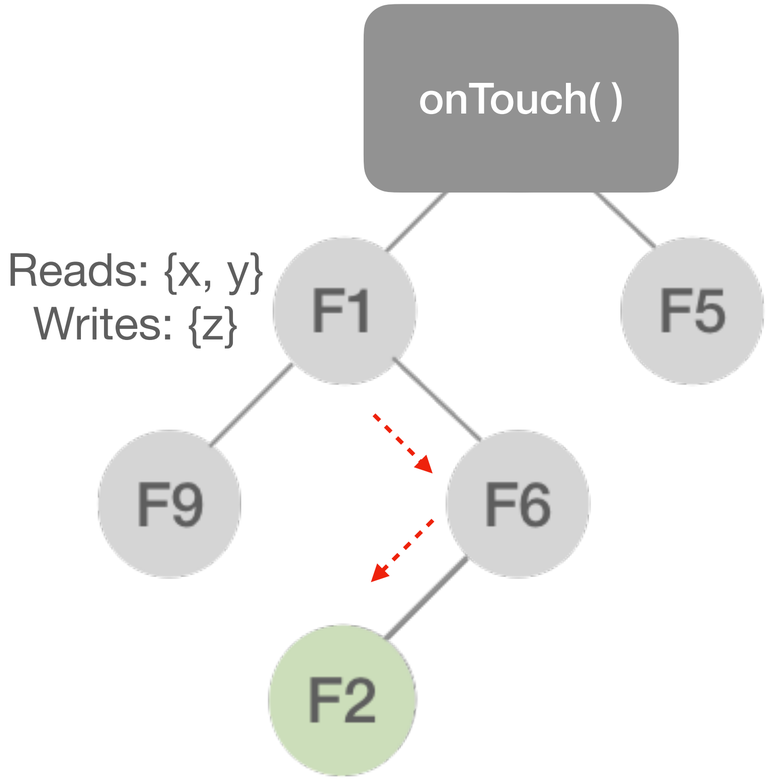

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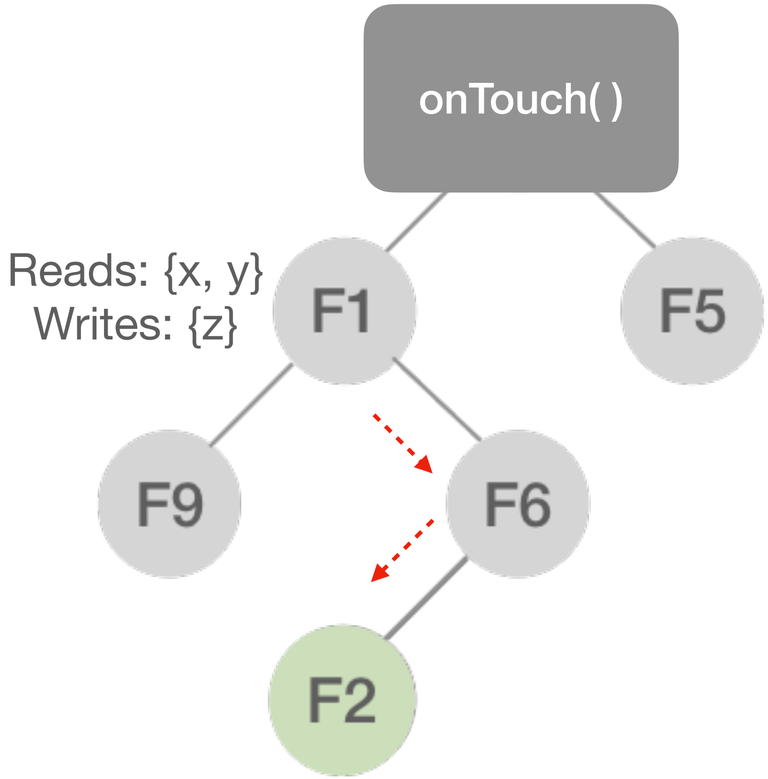

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  - ***Read state of upcoming functions may vary!***

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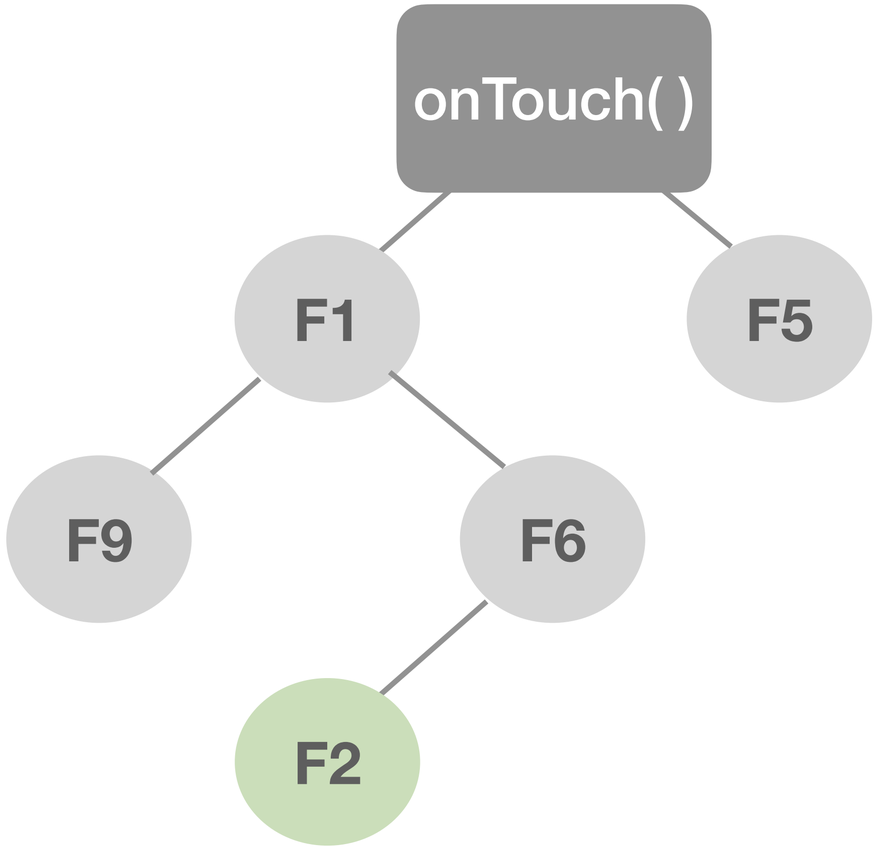

Static callgraph

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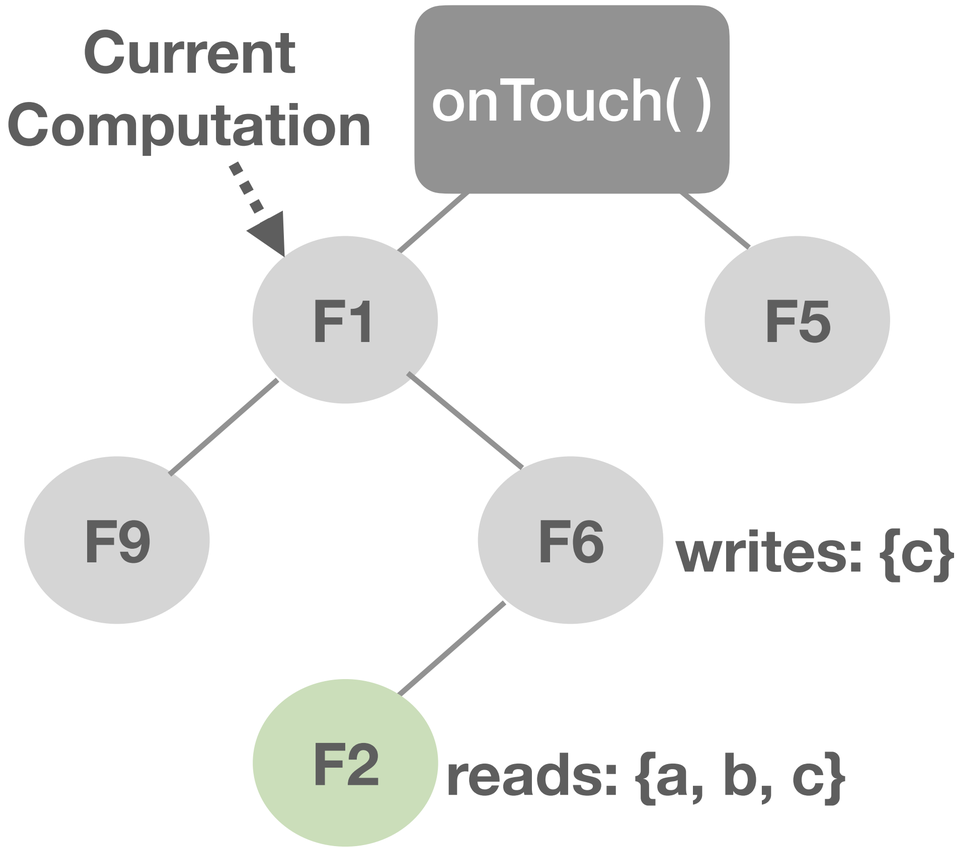

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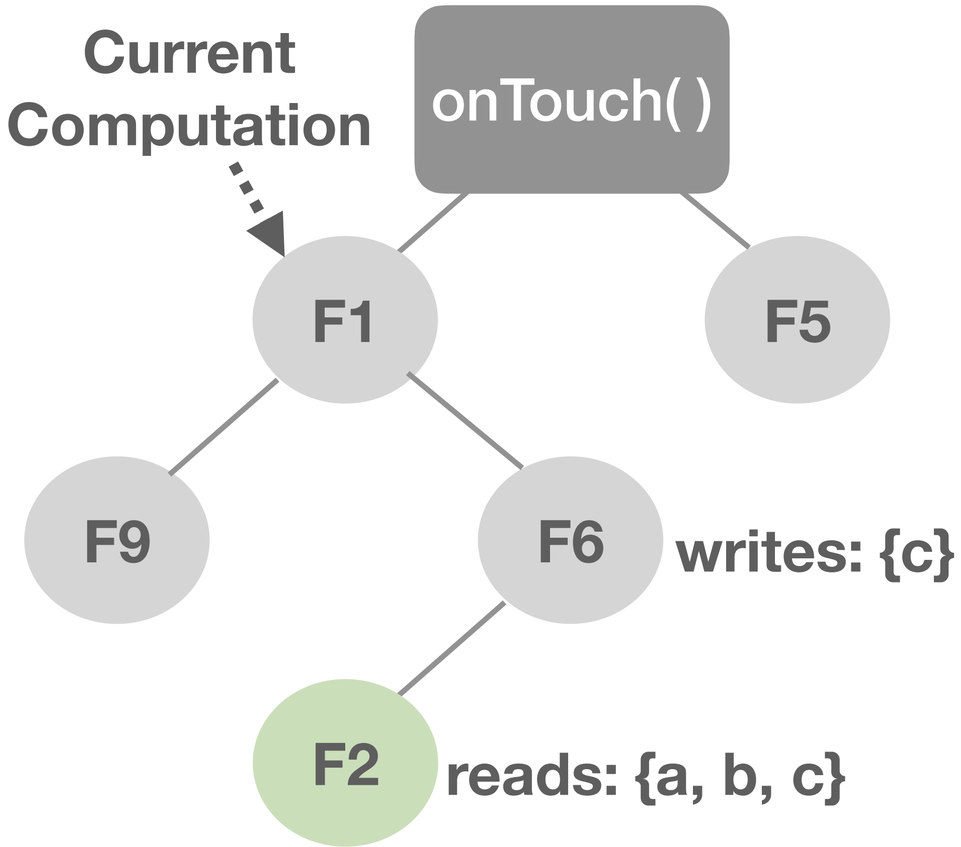

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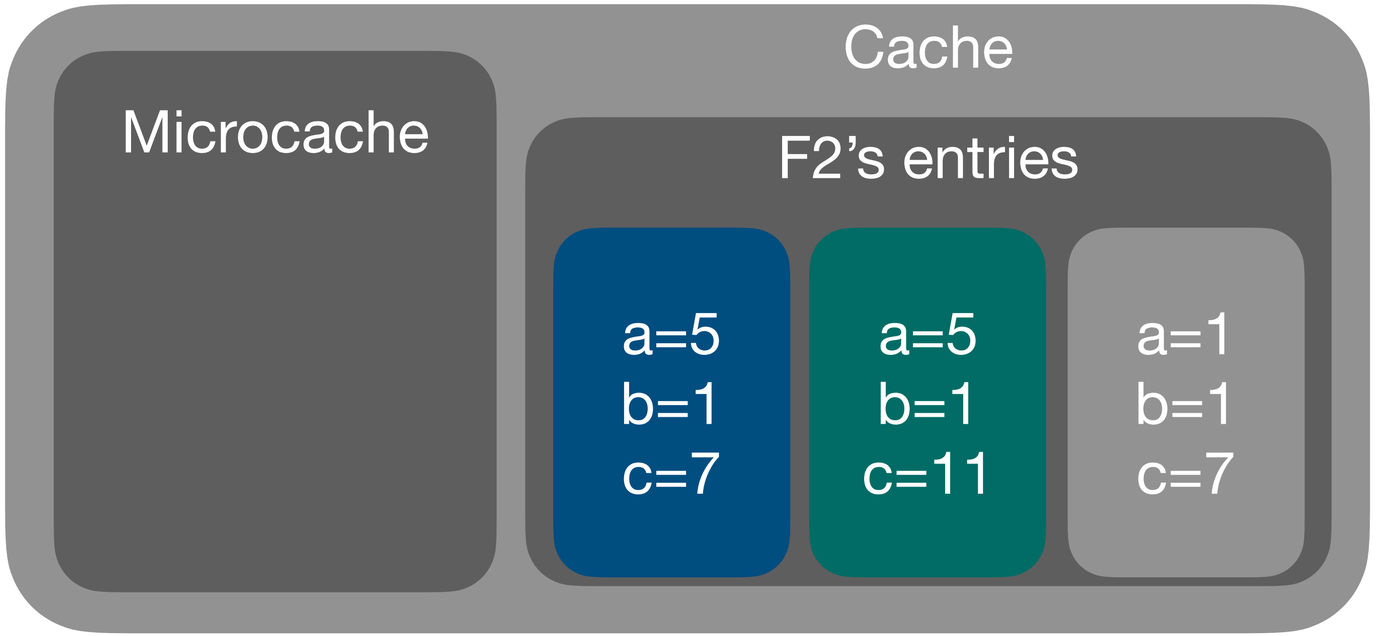

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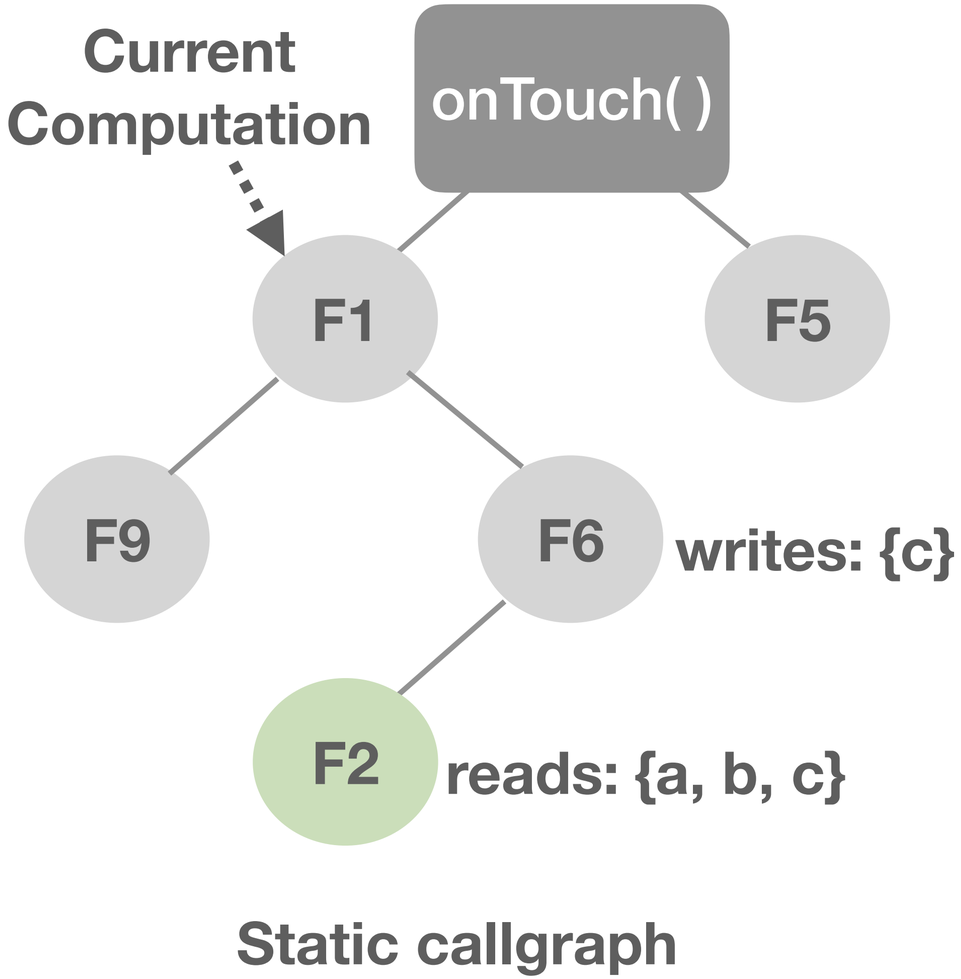

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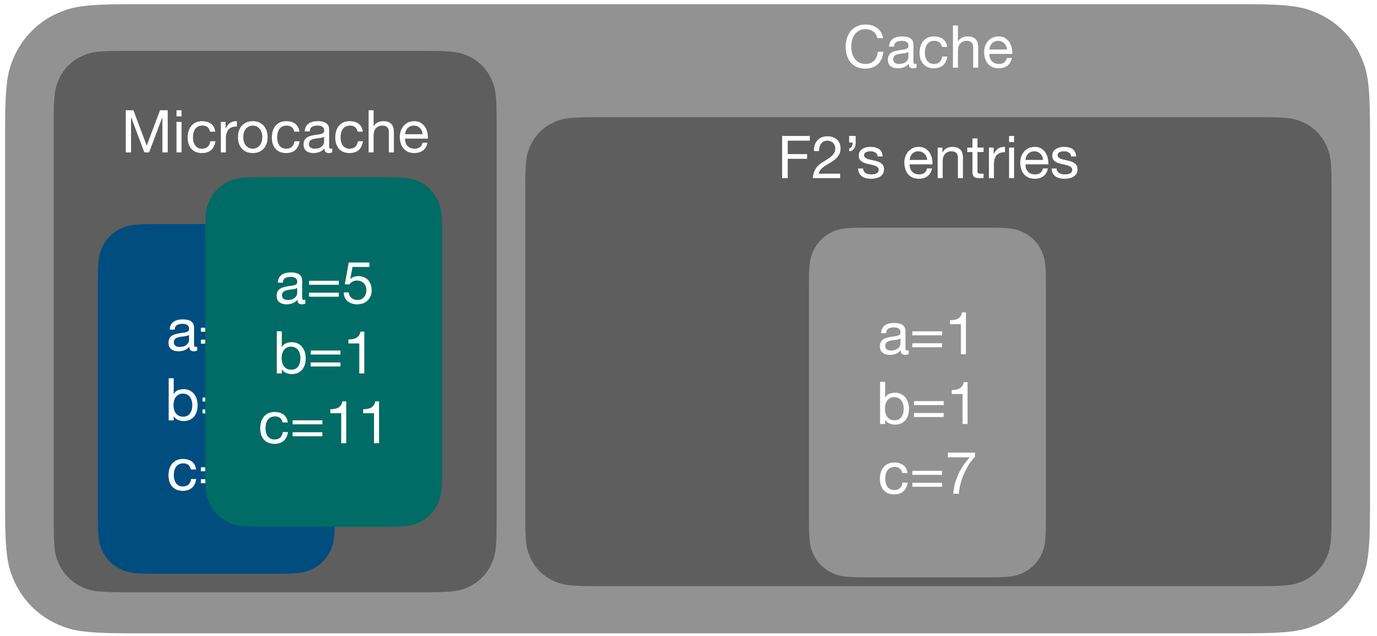

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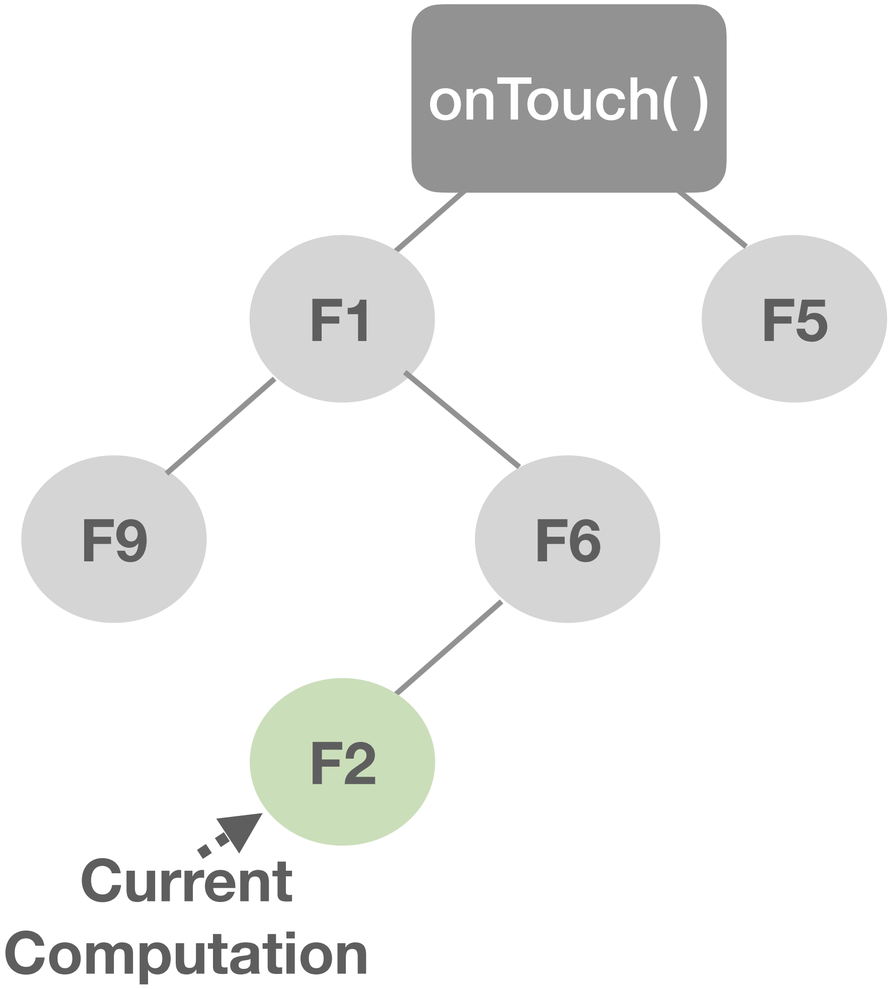

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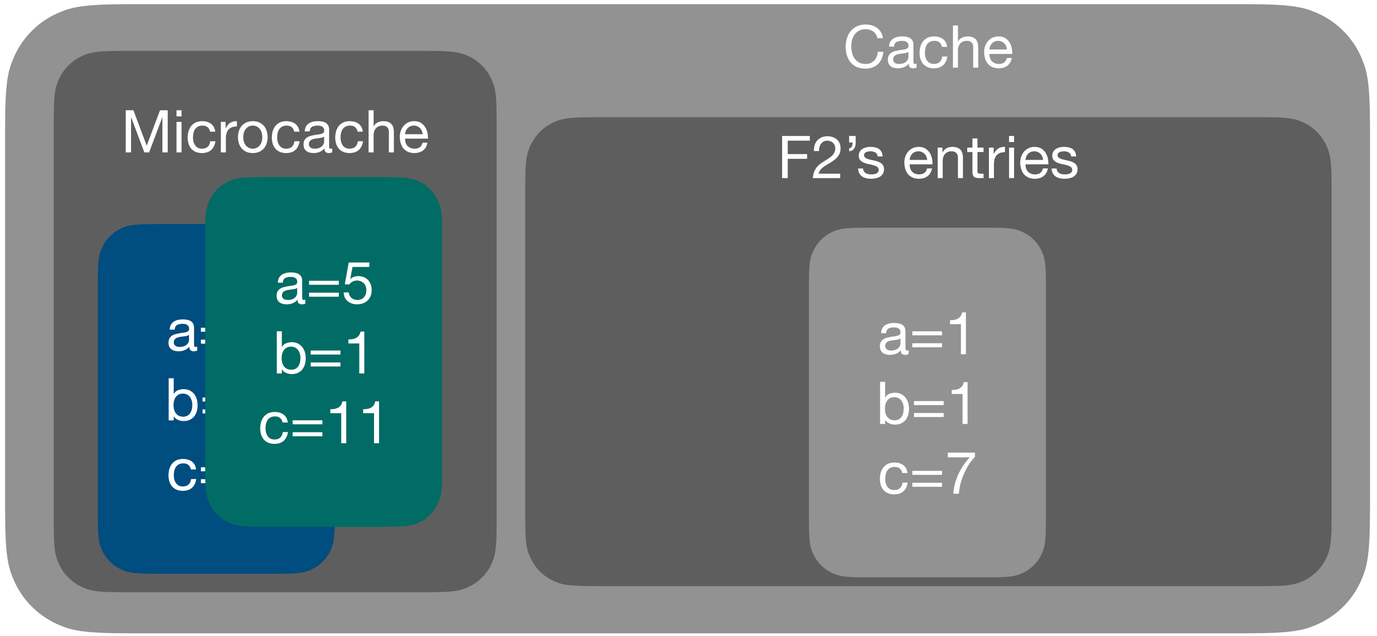

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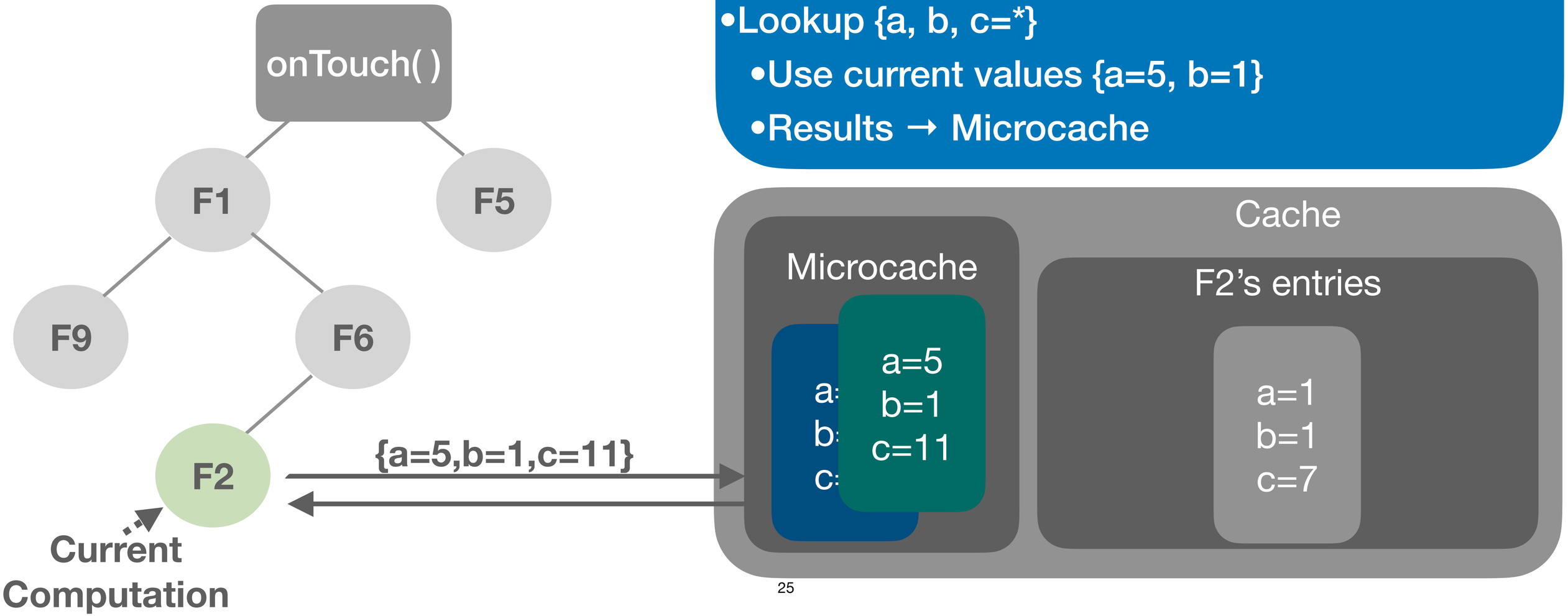

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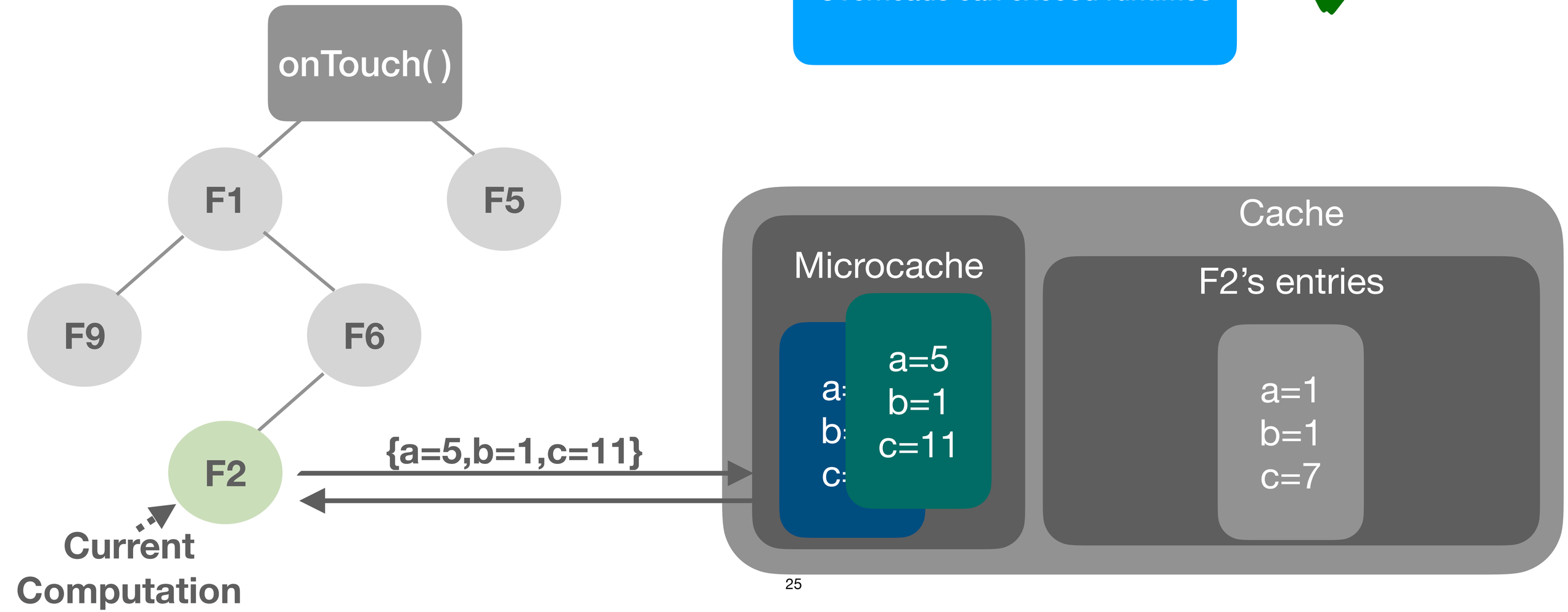

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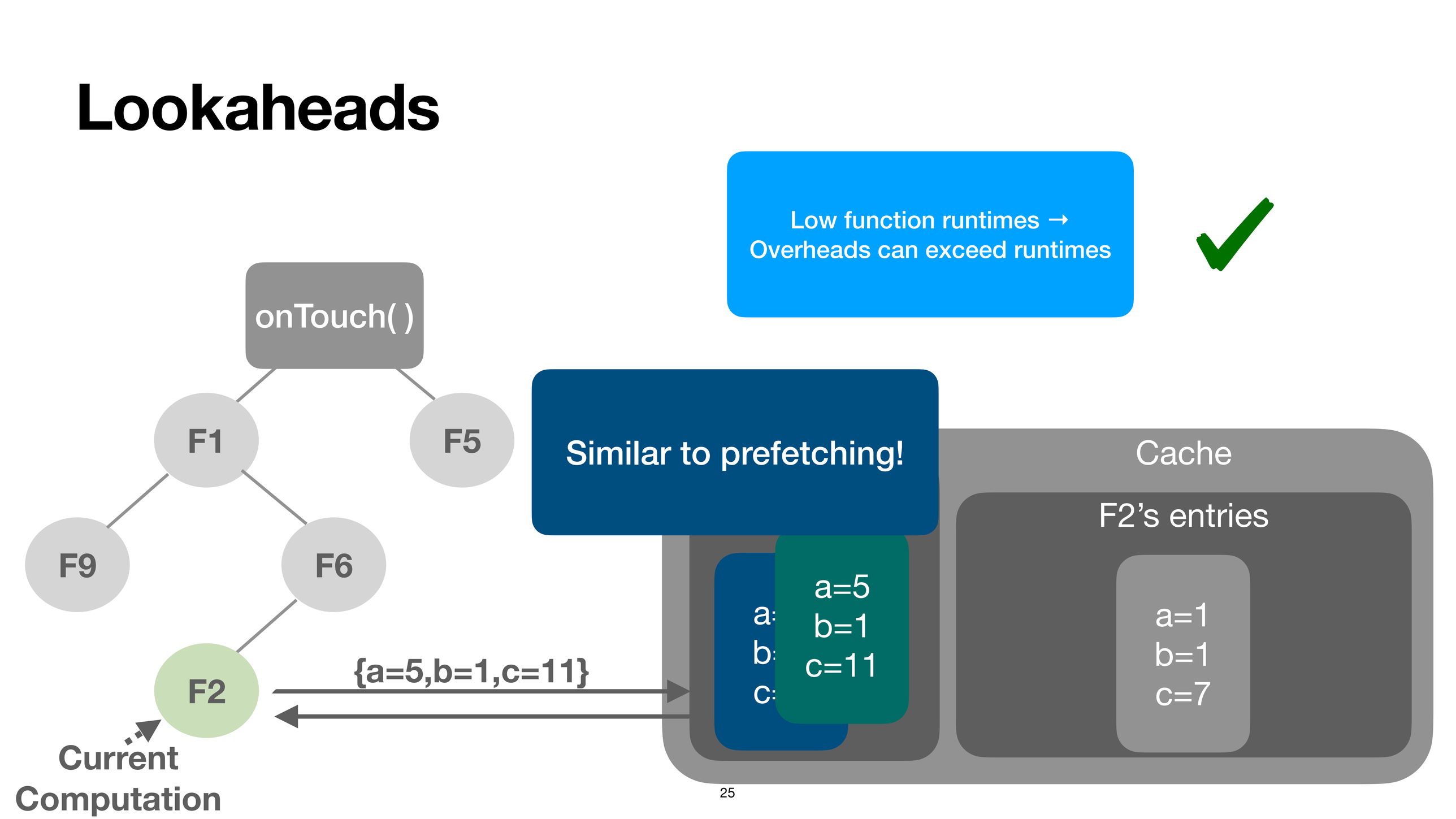

Caching Policies

Caching Policies

Adding to the cache

Removing from the cache

Caching Policies

What functions do we memoize?

Removing from the cache

Caching Policies

What functions do we memoize?

How to evict cache entries?

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Given a function, what fraction of its invocations were memoized?

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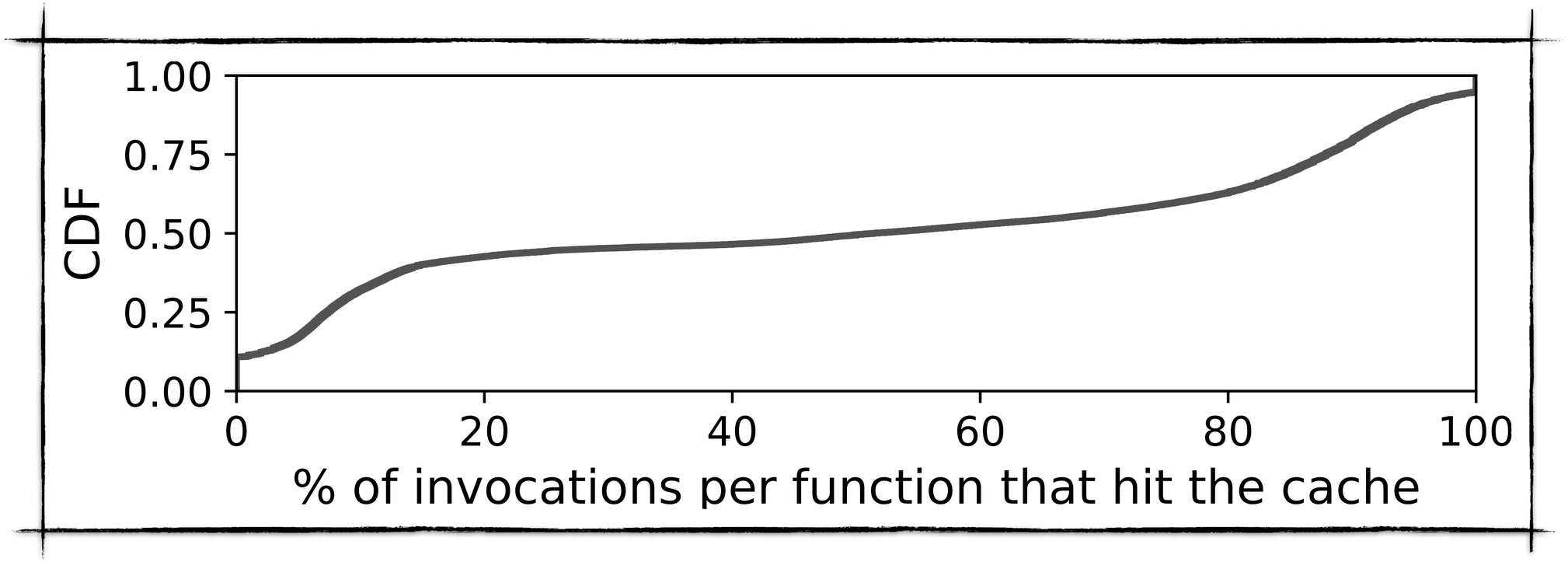

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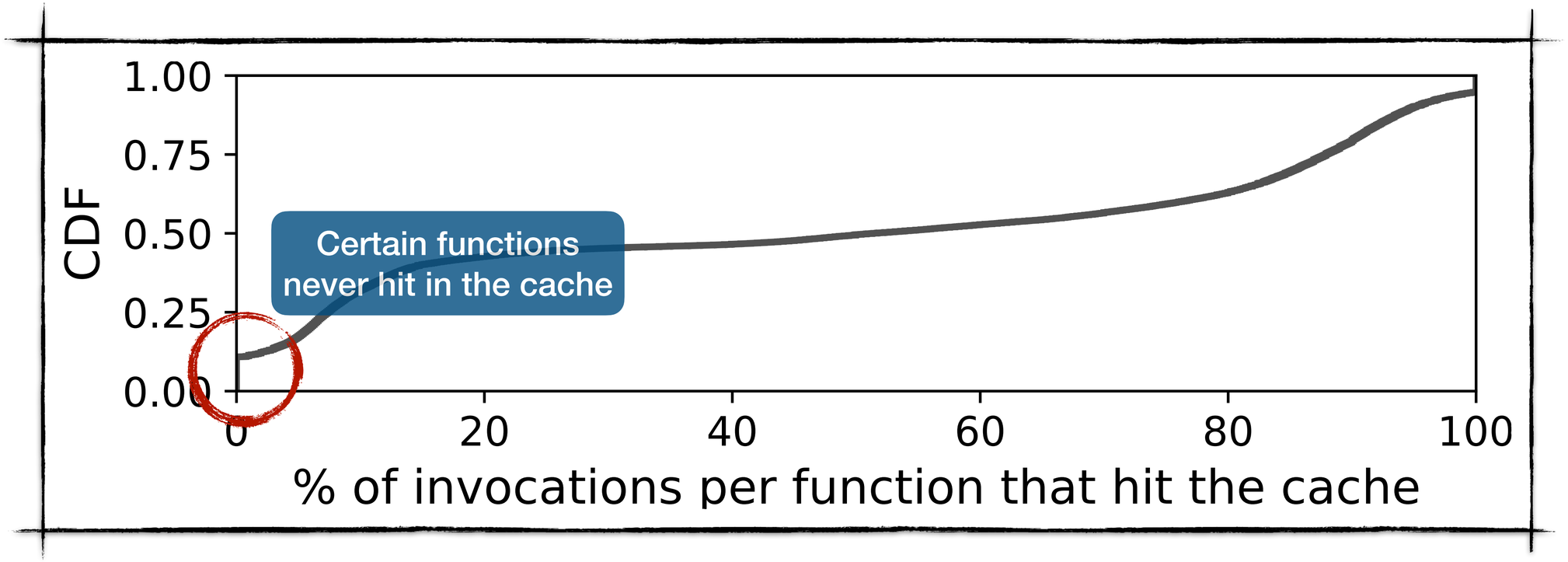

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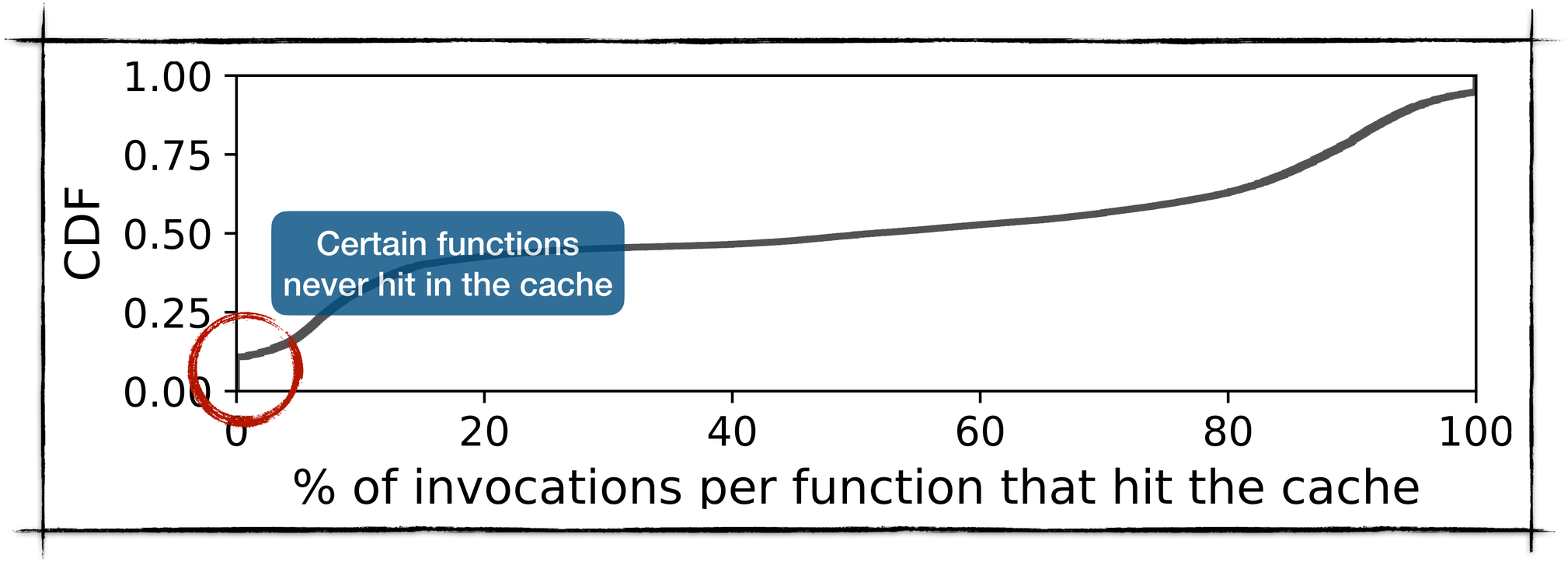

Track hit rate with cache entries: Deactivate low hit-rate functions

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Rank cache entries by utility

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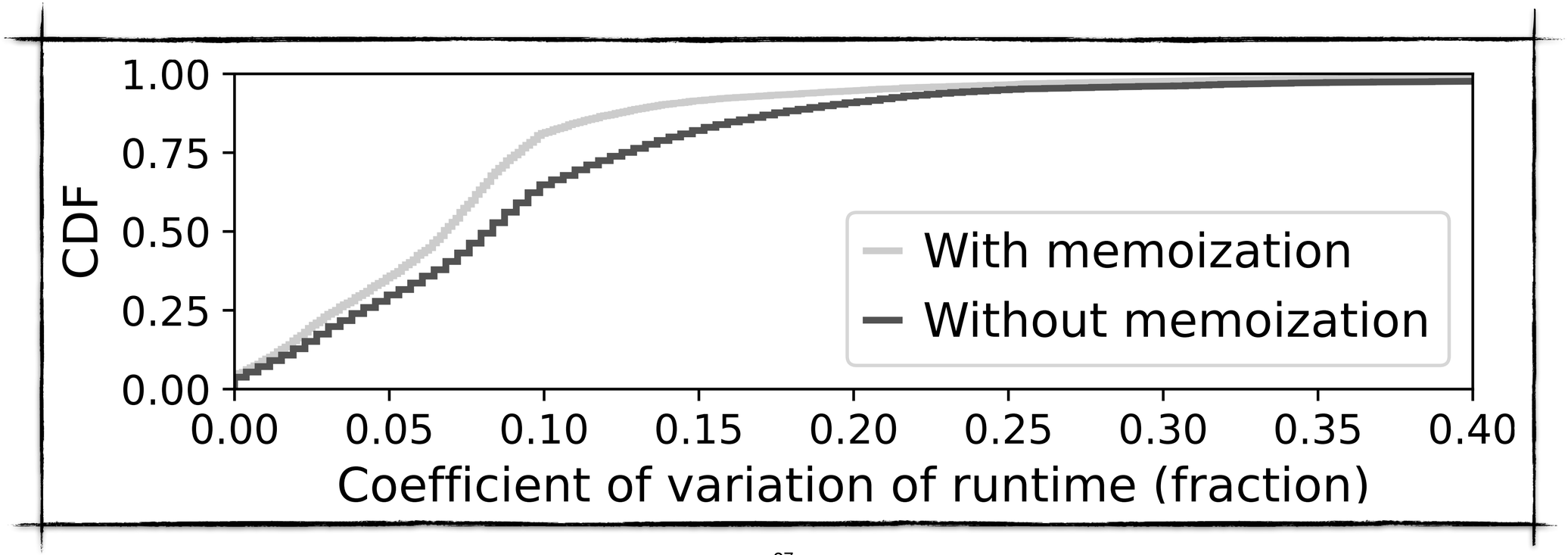

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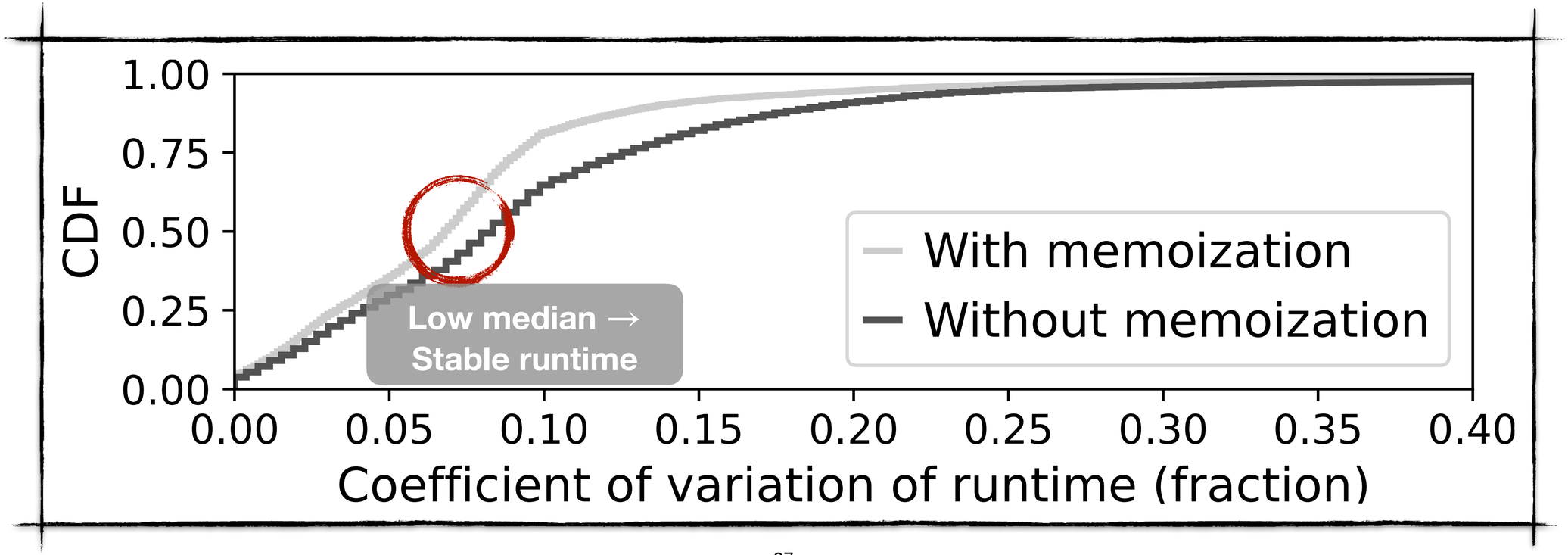


Caching Policies

Annotate cache entries with utility/potential benefits

Rank cache entries by utility

How does the runtime of a particular function vary across its invocations?

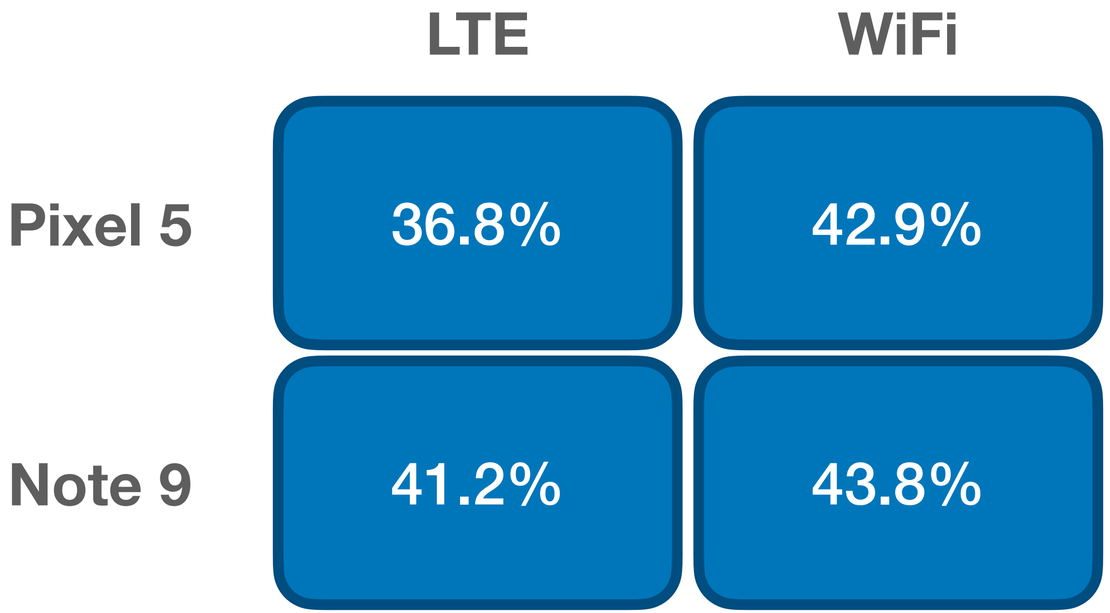
Low median → Stable runtime

Store first runtimes → Diff is the speedup

First memoized and unmemoized invocation

Computation Improvements

Devices: Note 9, Pixel 5. Networks: WiFi, LTE.



Median computation improvements per interaction

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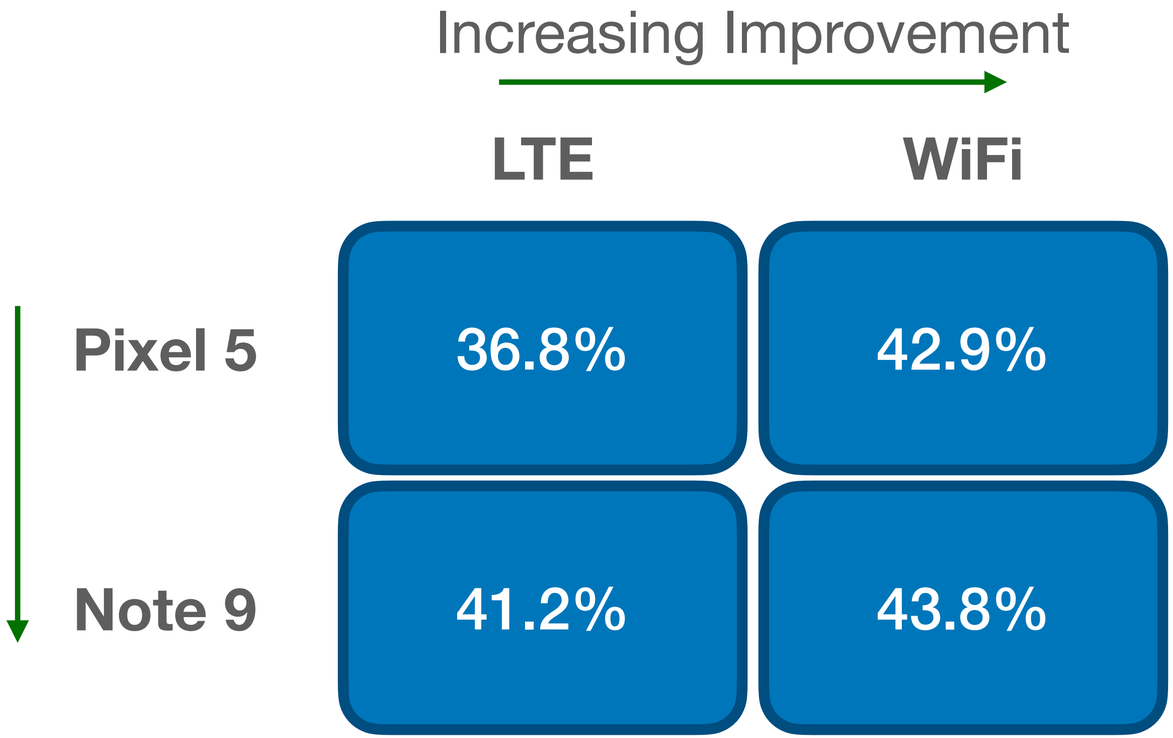
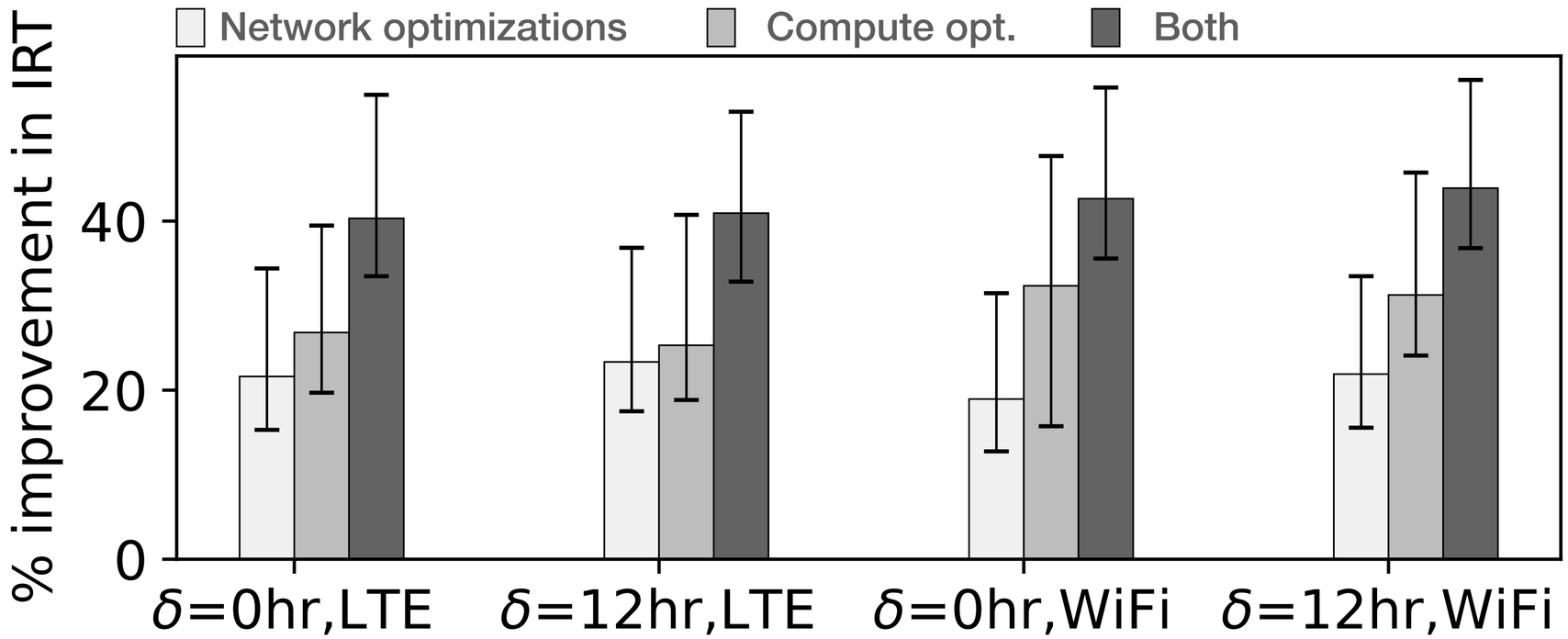


Median computation improvements per interaction

Performance Improvements

With Network and Compute optimizations



Caching in mobile apps

Summary

- Apps could cache content, just like web browsers and CDN. But this potential is not utilized optimally
    - Techniques exist to optimize caching and prefetching
    - For web content:
        - improve TTLs
        - prefetch just-in-time
    - For computations:
        - improve cache lookup time with lookaheads
        - optimized cache entries
        - domain specific caching policies

More content on compute caching (Floo)

Floo: Kinds of local computations

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Compute bottlenecks are critical

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But what are these computations exactly?

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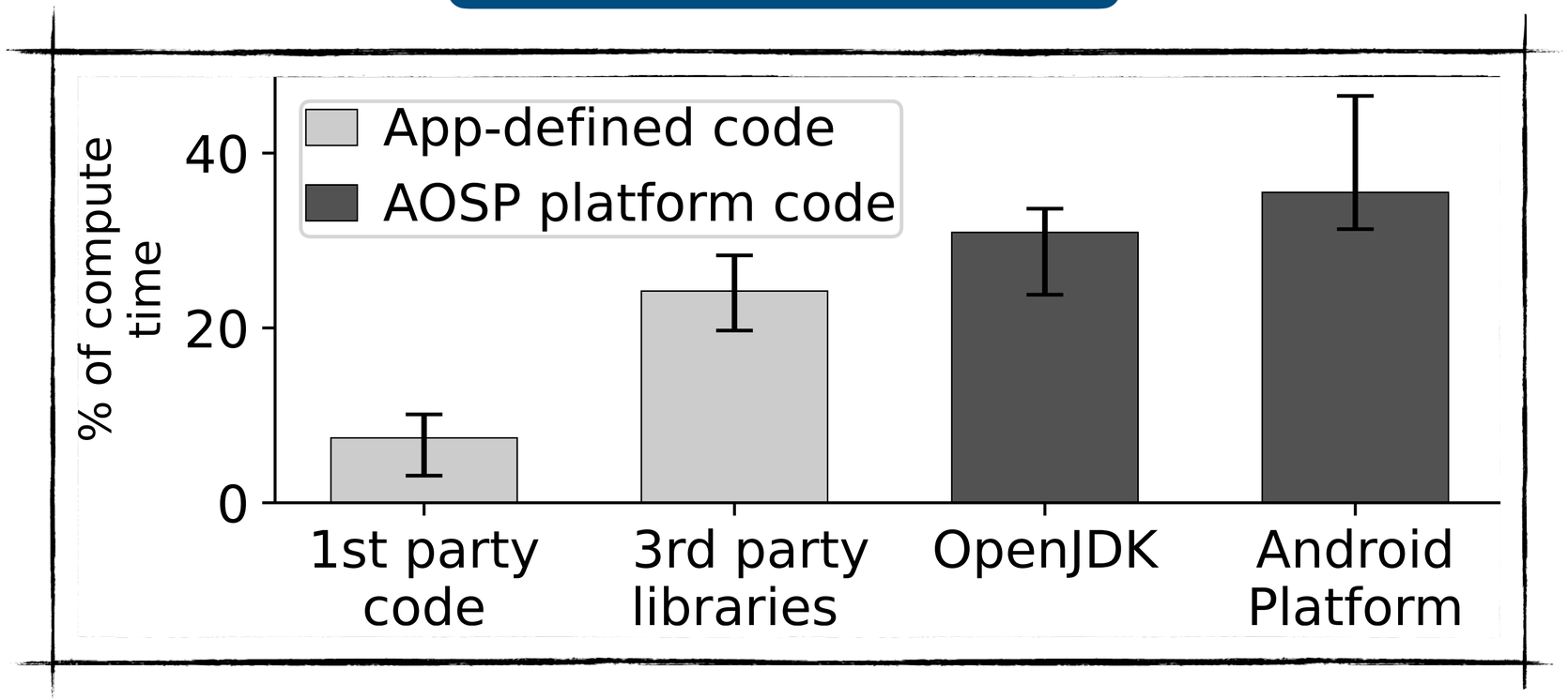

Floo: Kinds of local computations

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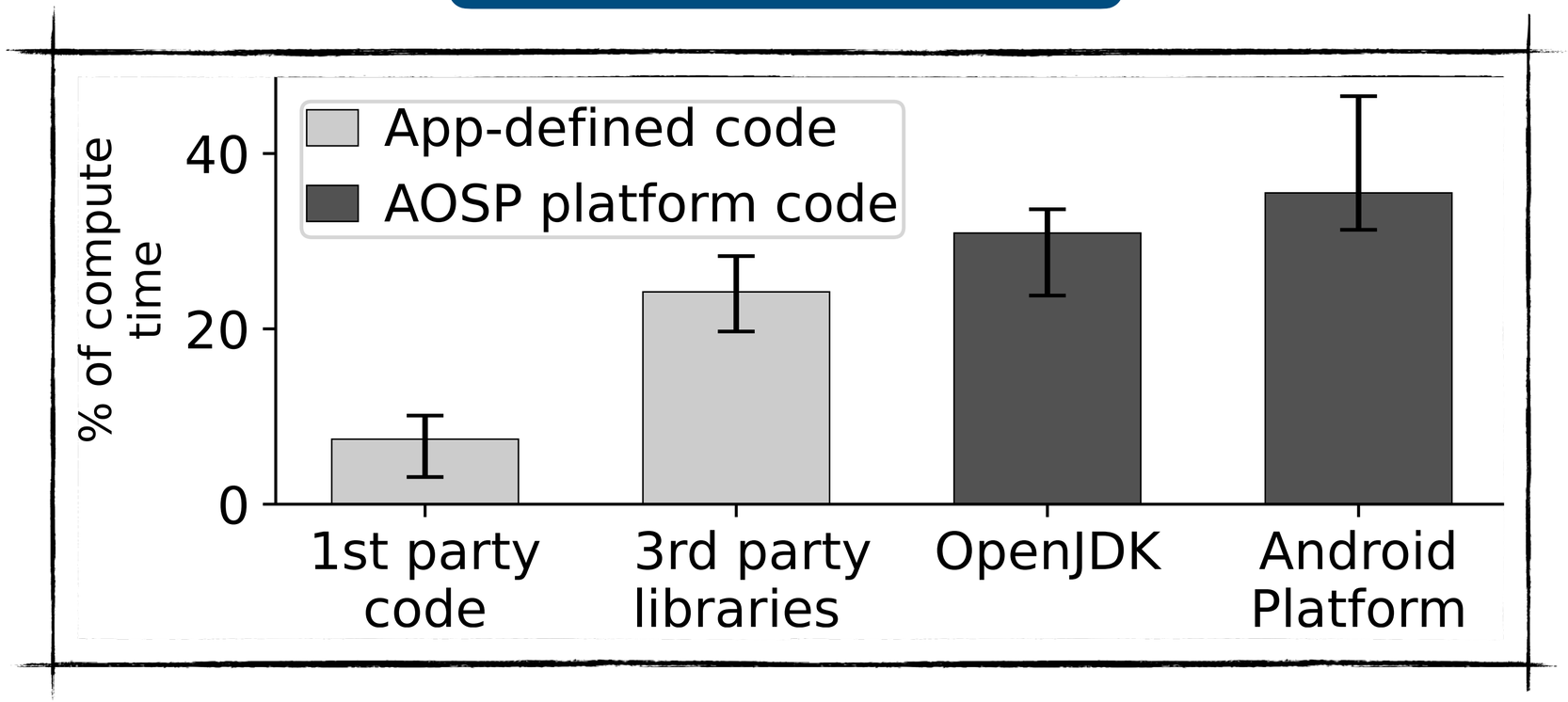

App-defined *and* AOSP functions are substantial

Implementing memoization

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Exclude functions using nondeterministic or native APIs

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Fn f() {
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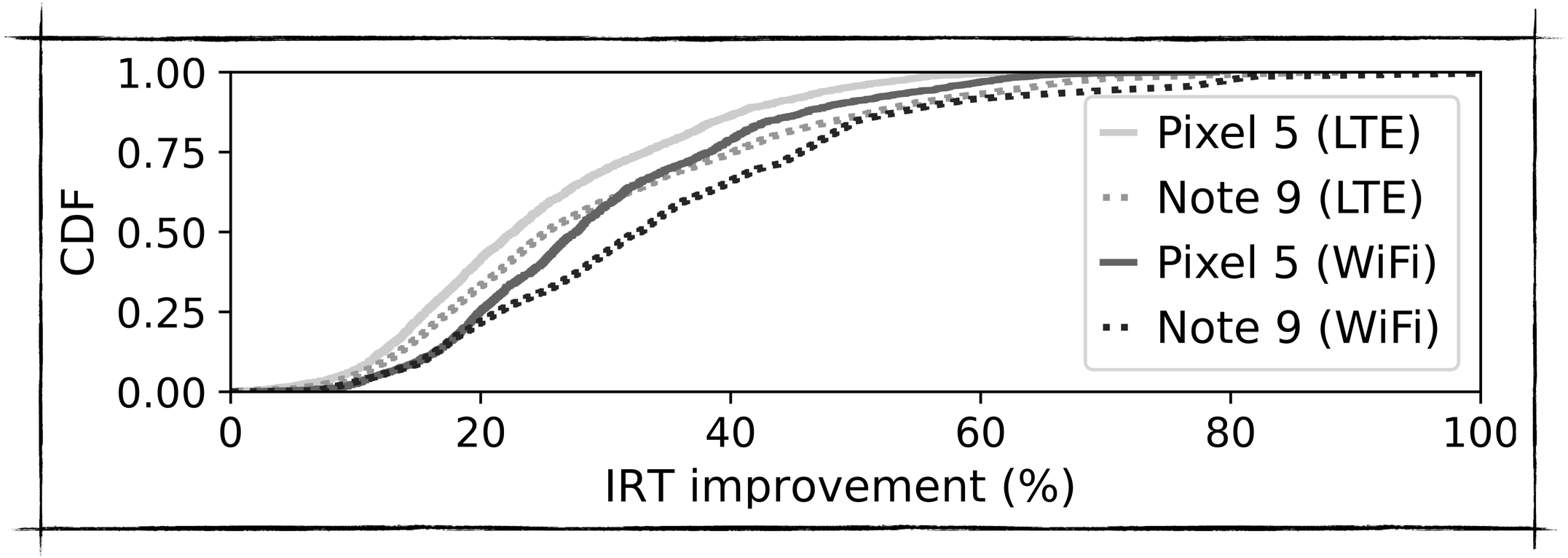
Support for impure functions

Evaluation

Floo - mobile computation caching

- How does Floo **improve the compute** time?
- How does this improvement translate into **responsiveness**?
- How does Floo perform with **fewer device resources**?
- Do Floo's transformations **preserve correct app behavior**?
- What is the **source of Floo's wins**?
- How does Floo compare against **prior work**?
- Does the improvement change based on **user access delays**?
- What are the **typical app characteristics** that enable memoization?

Responsiveness (IRT) Improvements



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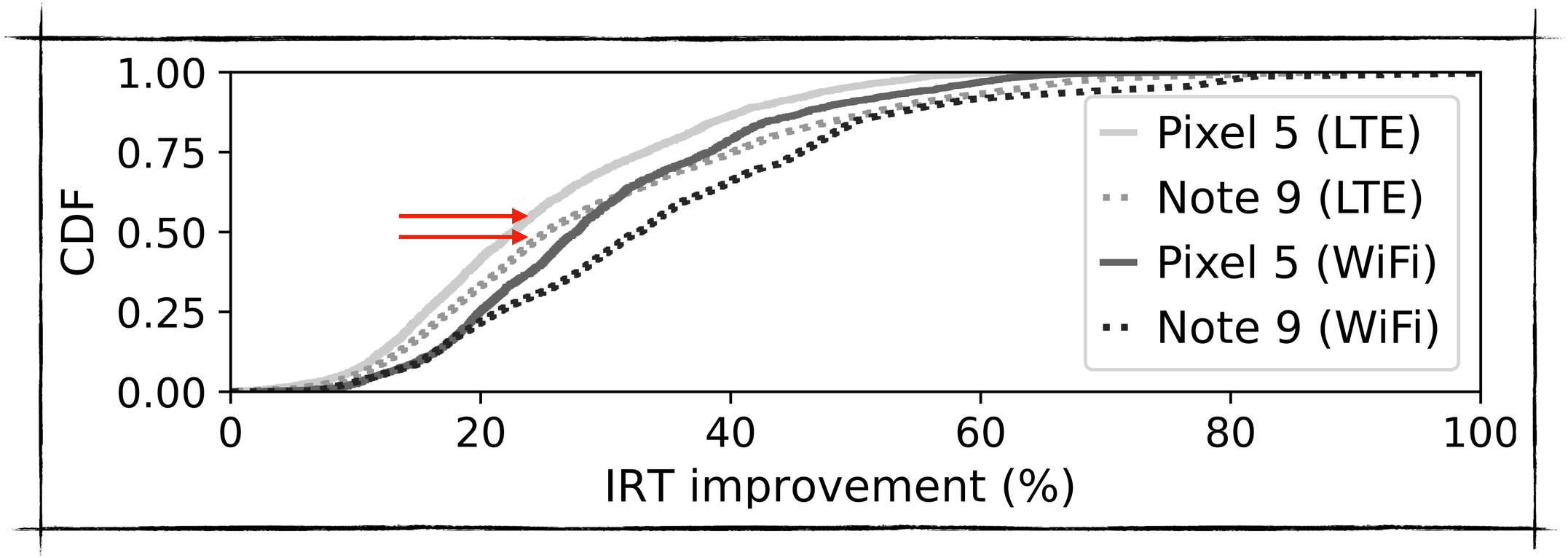

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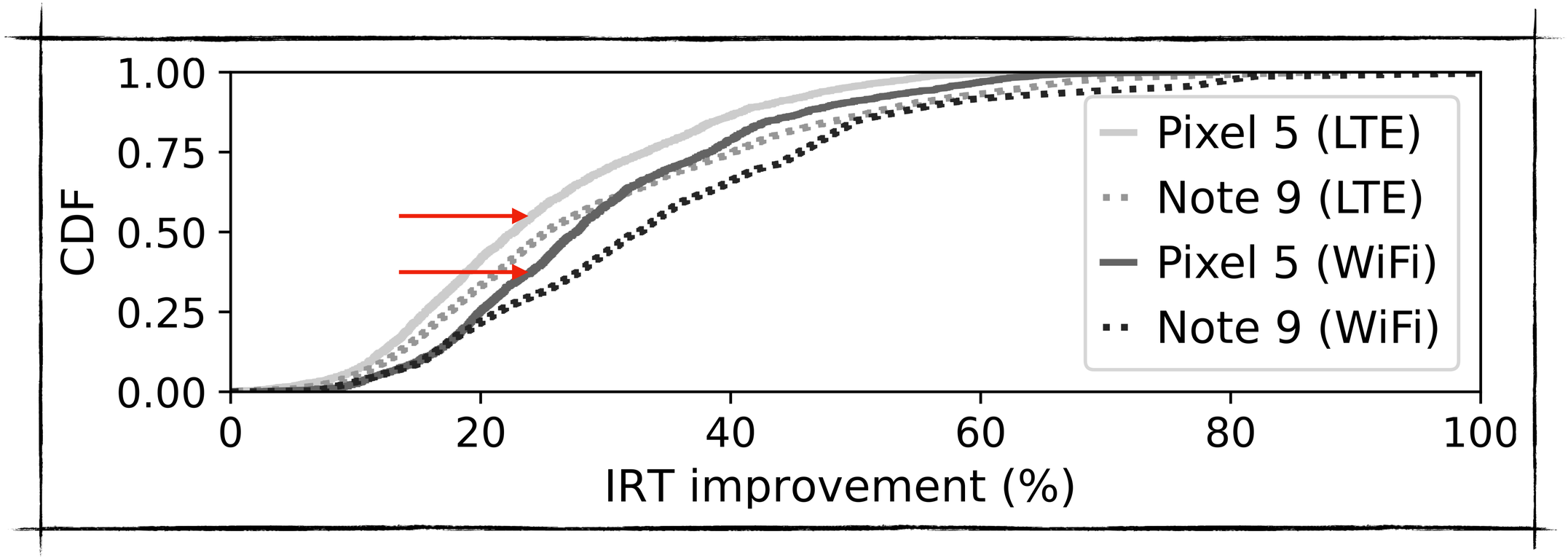

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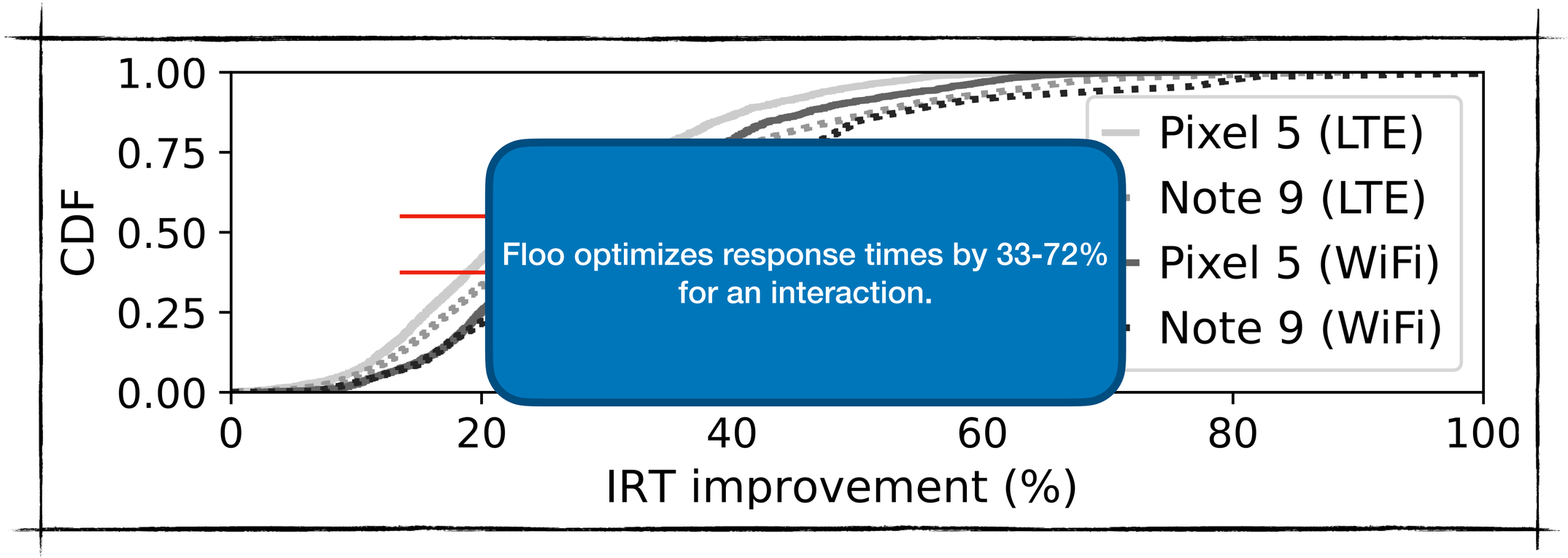
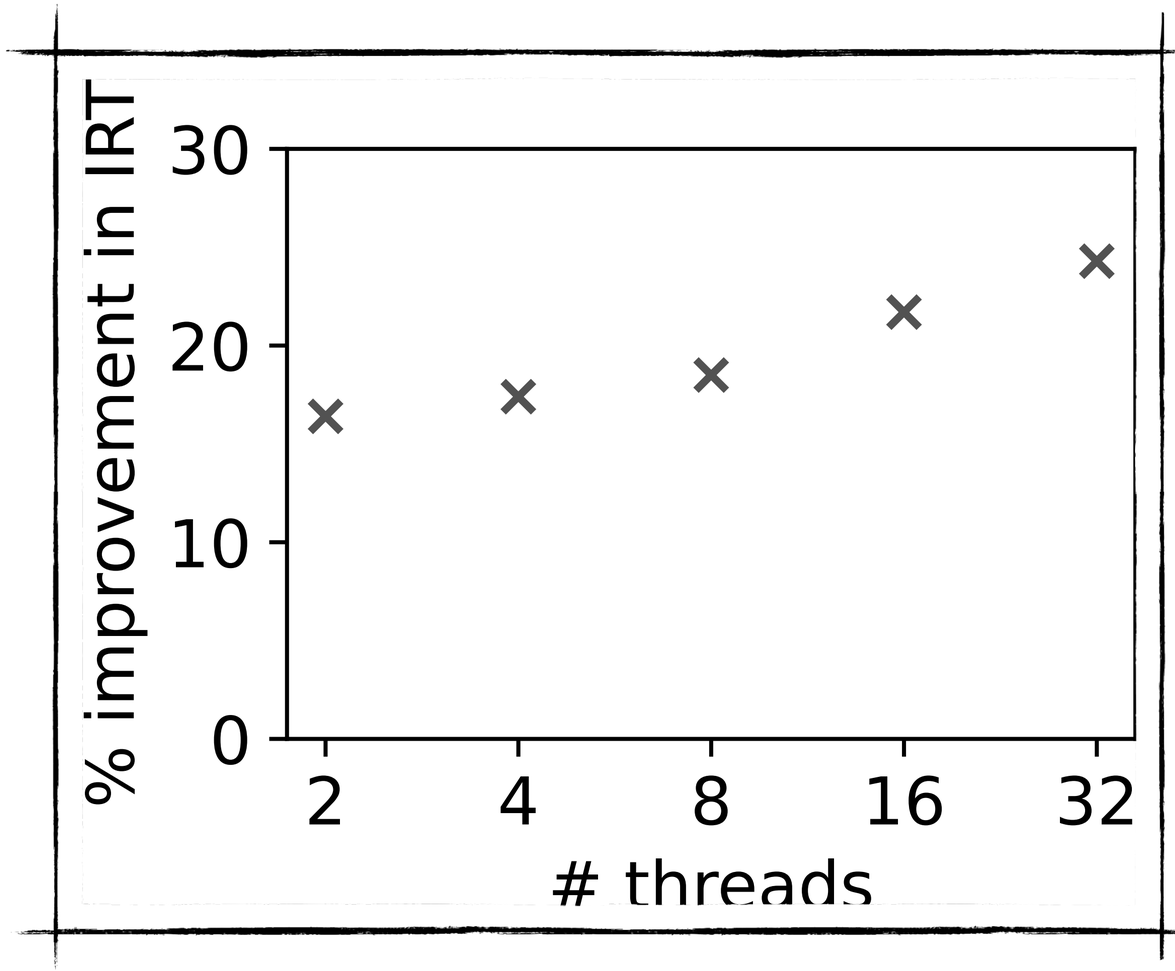
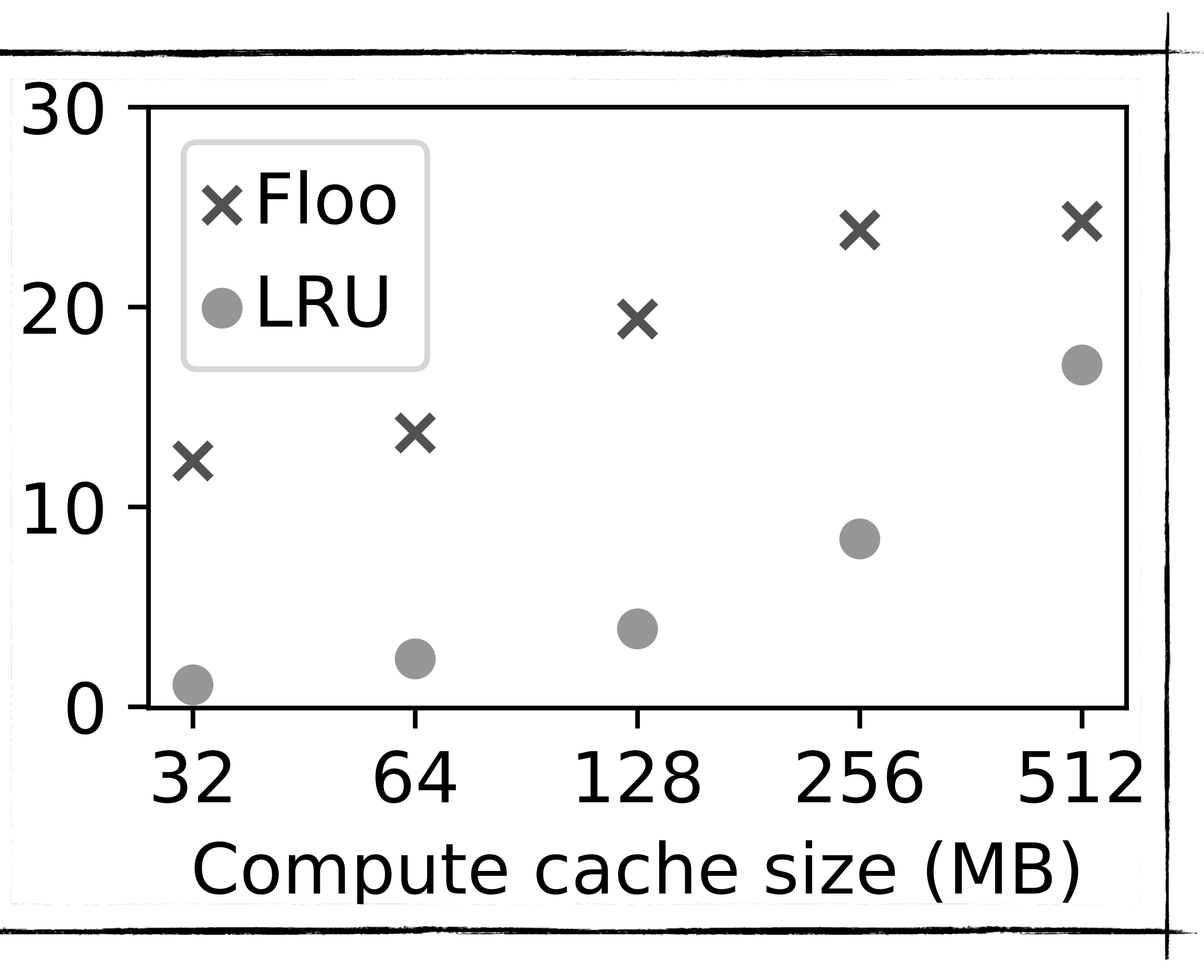


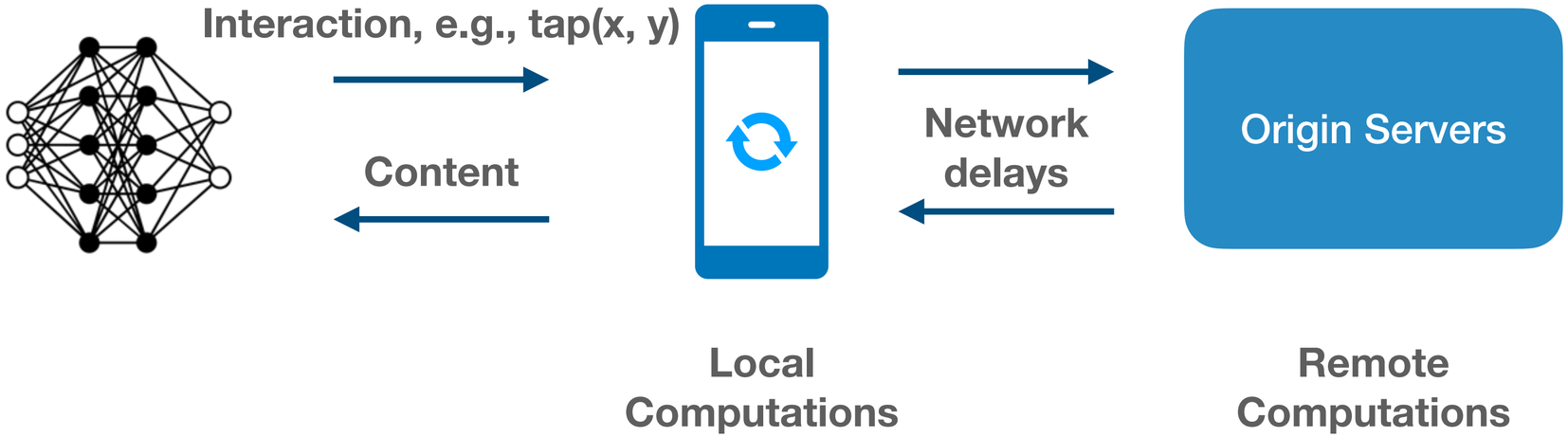
Varying device resources





Correctness

Does Floo preserve developer intent?



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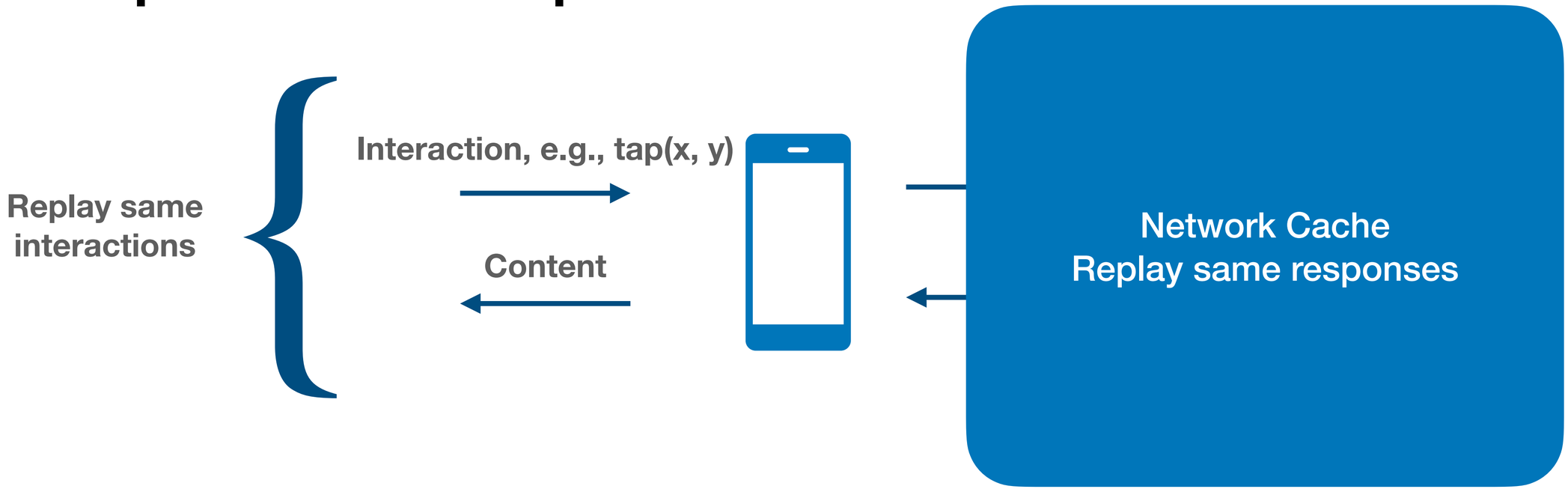

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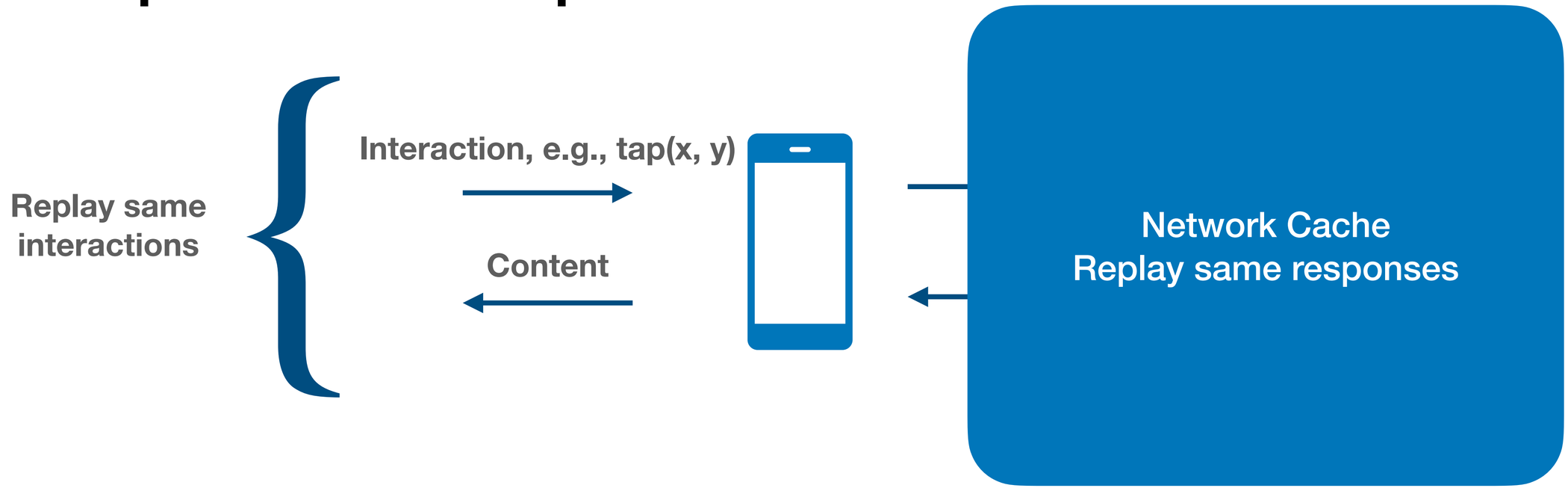

- Same server side content
- Same user interactions
- Single thread to prevent races
- Enforce determinism

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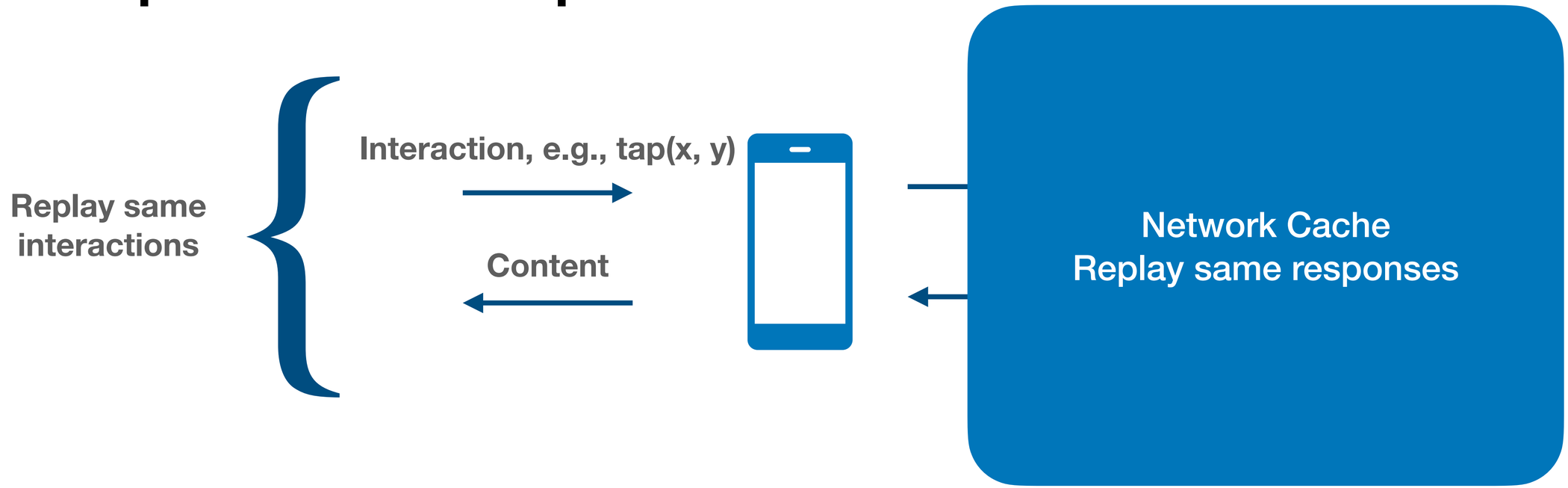

- Same server side content
- Same user interactions
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- Enforce determinism

Compare behavior with and without Floo

Correctness

Does Floo preserve developer intent?

Correctness

Does Floo preserve developer intent?

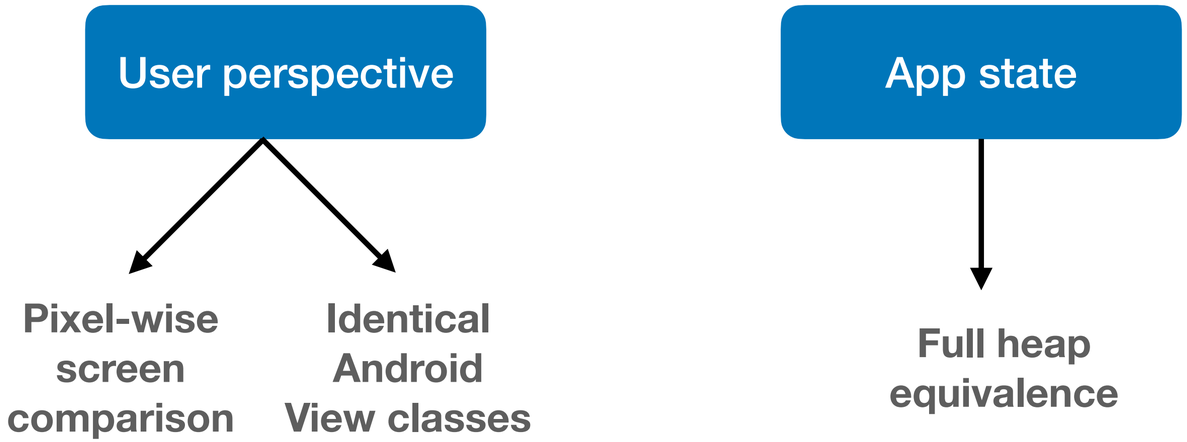
User perspective

App state

Correctness

Does Floo preserve developer intent?

Enforce determinism
Force single thread



Correctness

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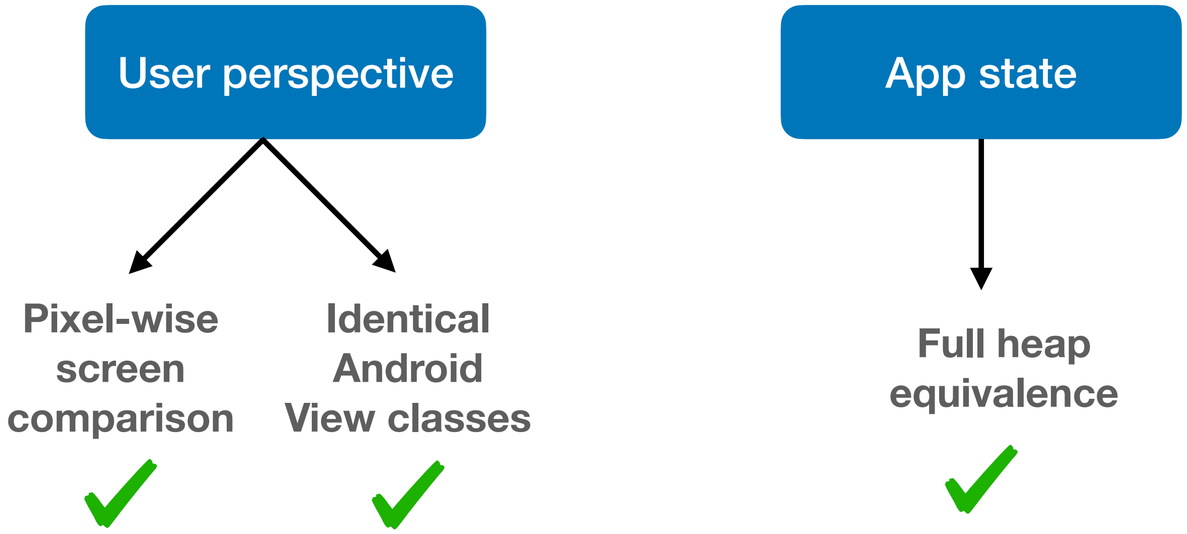

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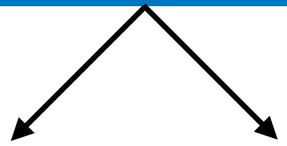


Pixel-wise screen comparison

Identical Android View classes

Match after each interaction

App state

Full heap equivalence

Match after a series of interactions

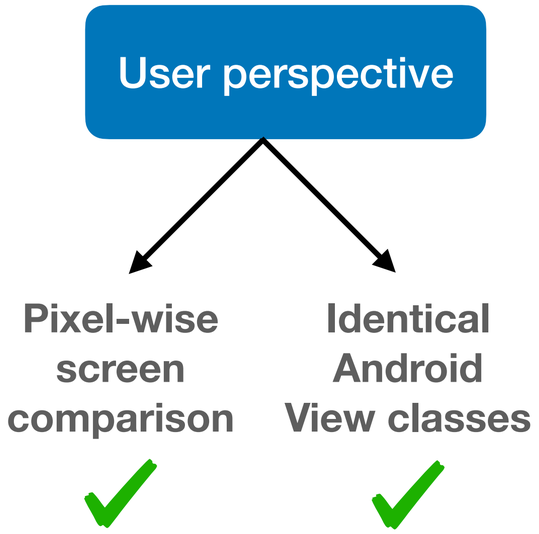
Enforce determinism
Allow multiple threads

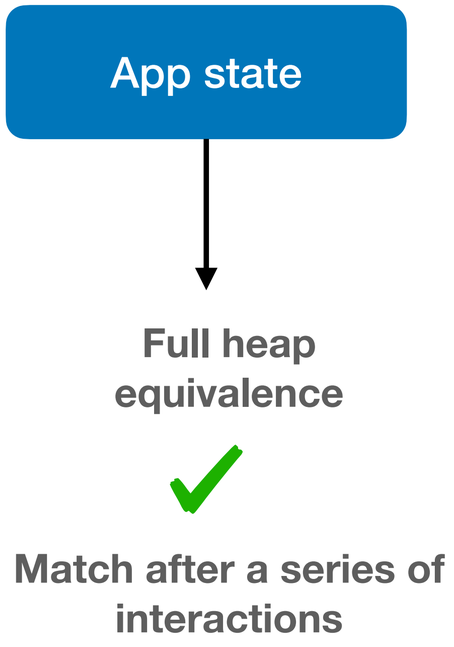
App state

Correctness

Does Floo preserve developer intent?

Enforce determinism
Force single thread





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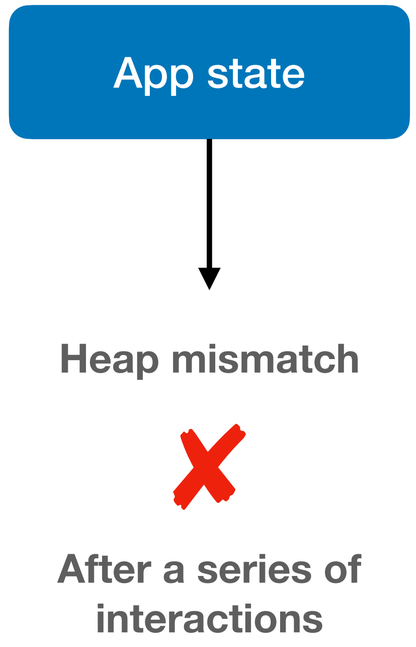


Correctness

Investigating app state mismatches

Correctness

Investigating app state mismatches

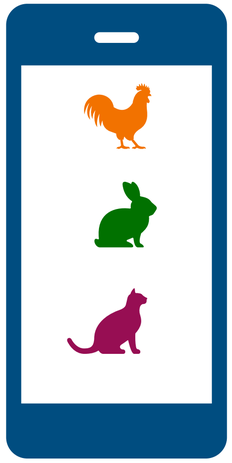
Thread schedule variations

Correctness

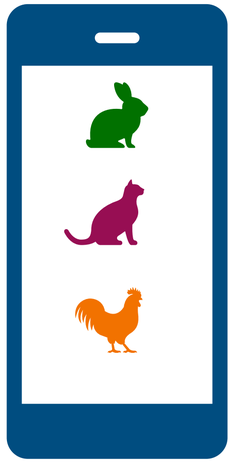
Investigating app state mismatches

Thread schedule variations

Run 1:
Without Floo



Run 2:
With Floo



Heap and potential visual mismatch across two runs

Correctness

Investigating app state mismatches

Thread schedule variations

Undetected synchronizations

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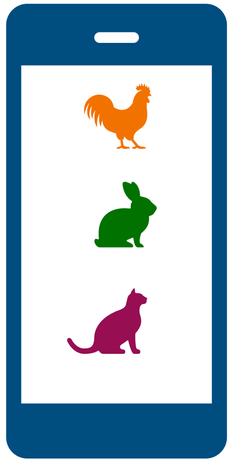
Without Floo



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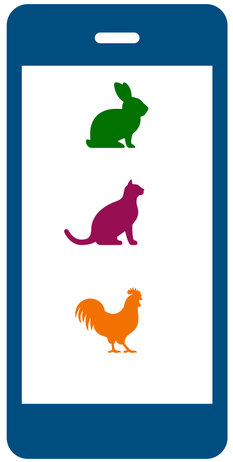

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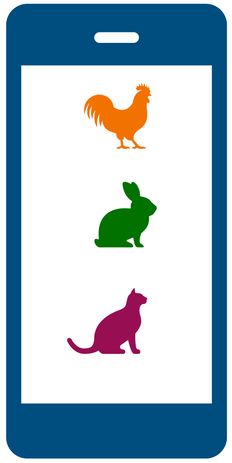

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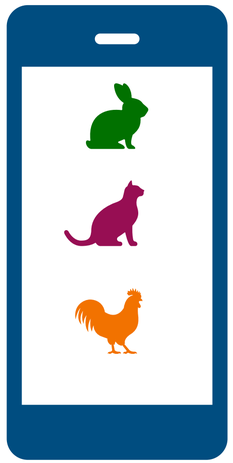

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Undetected synchronizations

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while(!x.contentReady); // busy wait
y = x.contentReady; // y must be true
```

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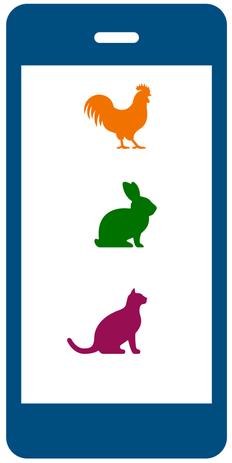

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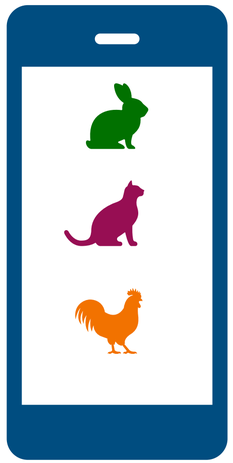

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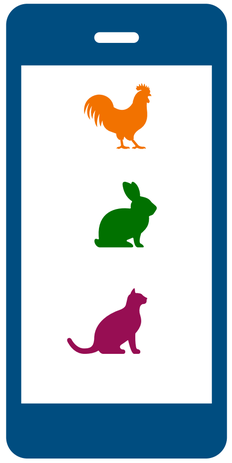

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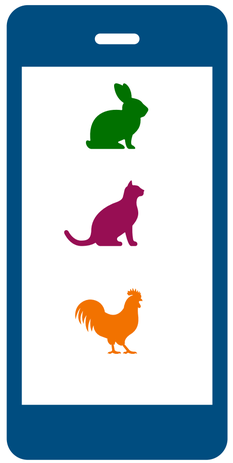

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```
while(!x.contentReady); // busy wait
y = x.contentReady; // y must be true
```

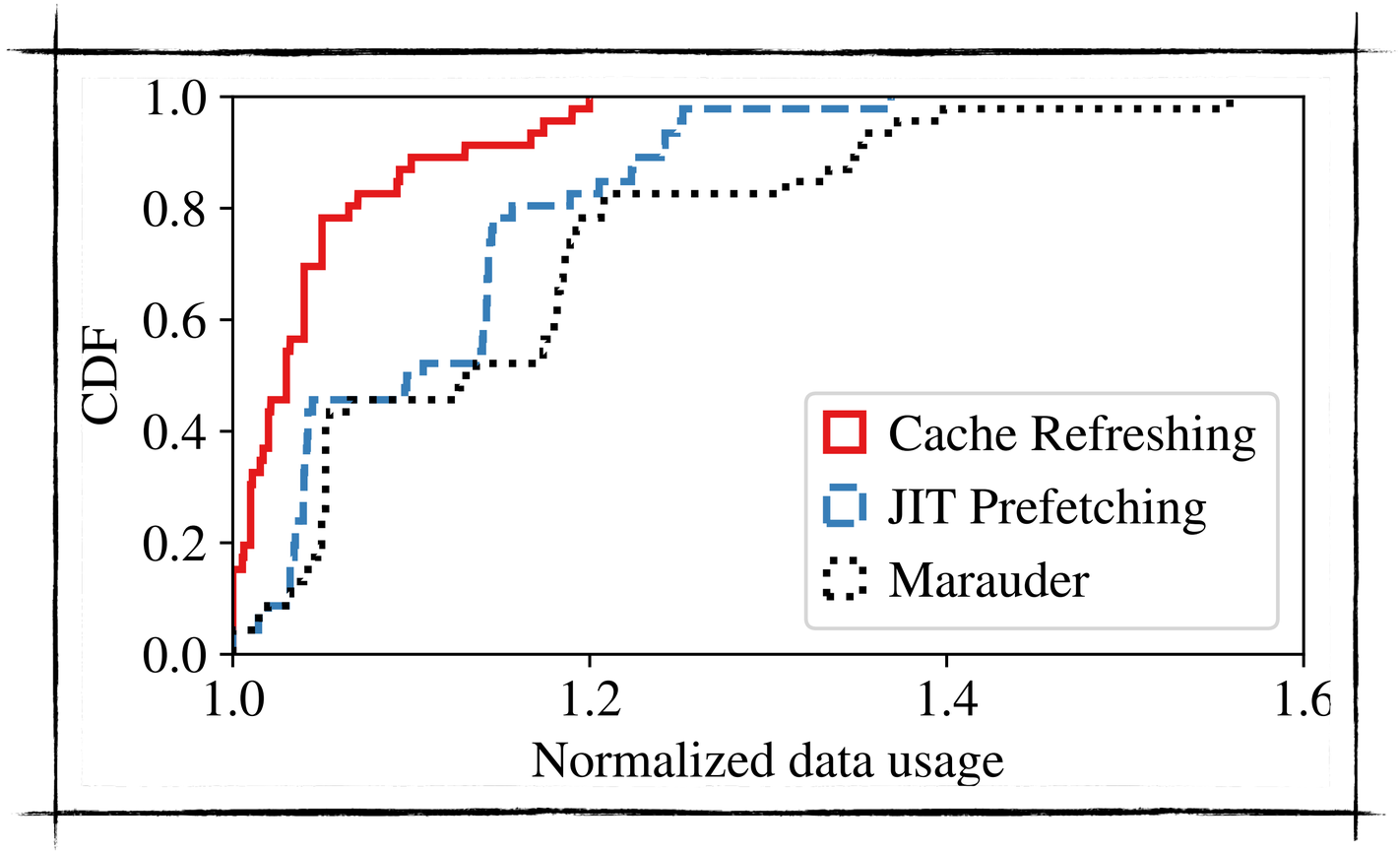
We entered the function with x.contentReady as false and set y to be true

```
if x.contentReady is false
set y=true
```

Incorrect behavior

More content on mobile web caching (Marauder)

Bandwidth overheads



Constituent benefits