On the Analysis of Caches with Pending Interest Tables

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ICN, October 2, 2015

Overview

- Named Data Networking
  - Data names instead of IP addresses
- Data Structures:
  - Content Store
  - Pending Interest Table
  - Forwarding Information Base
- Packets:
  - Interest packet
  - Data packet

Overview

Content Store

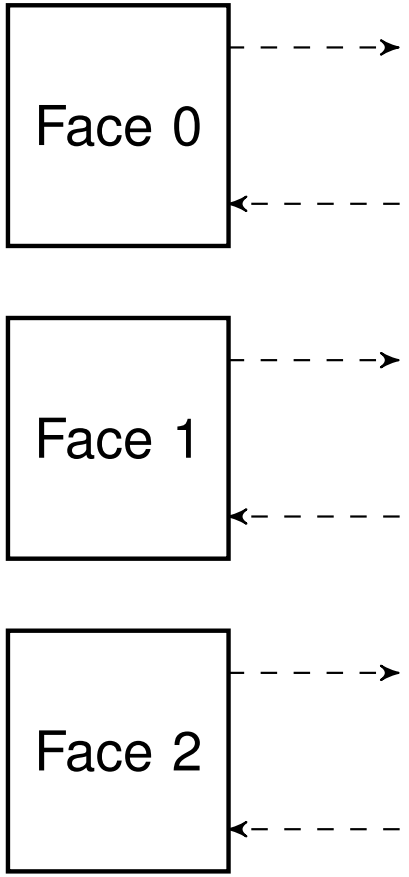
Name	Data

Pending Interest Table

Name	Face

Forwarding Information Base

Prefix	Face
/icn/	1



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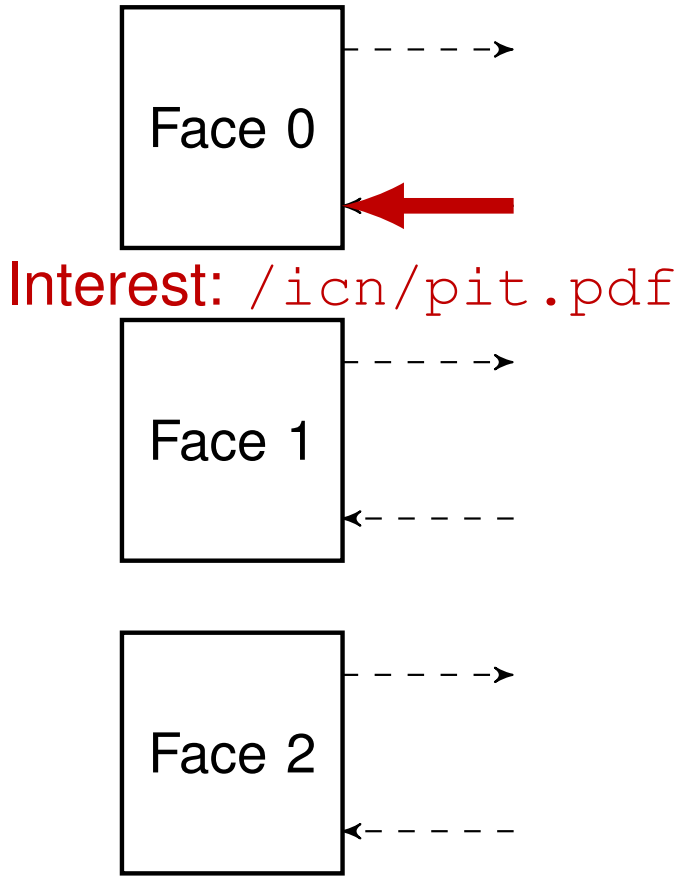

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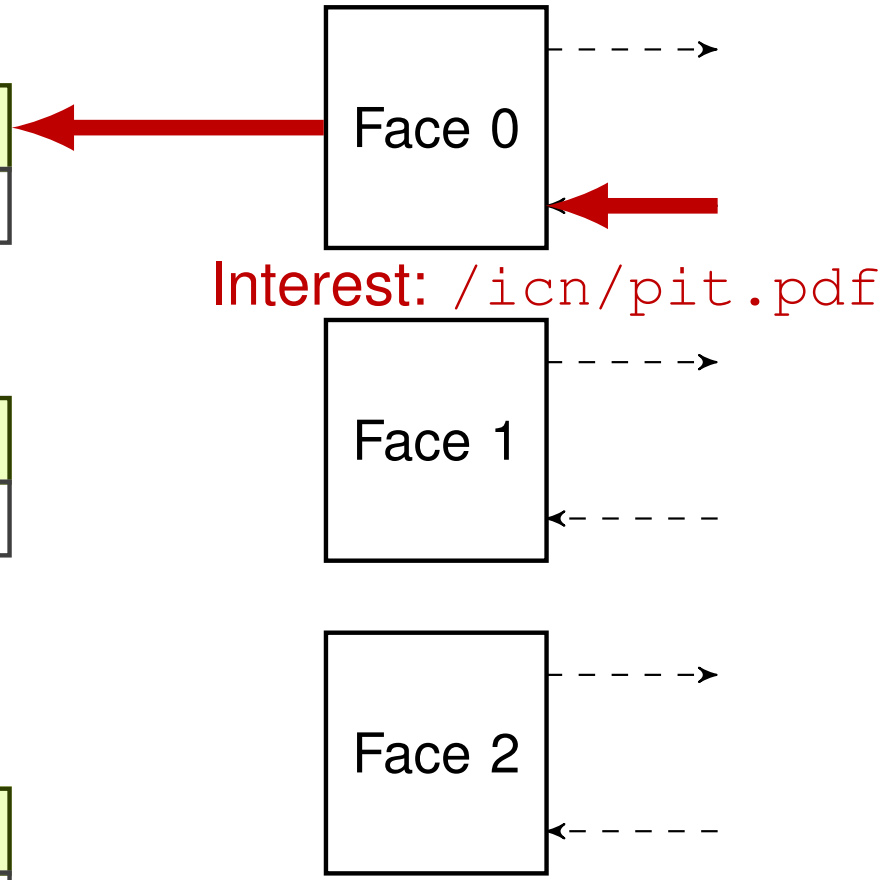

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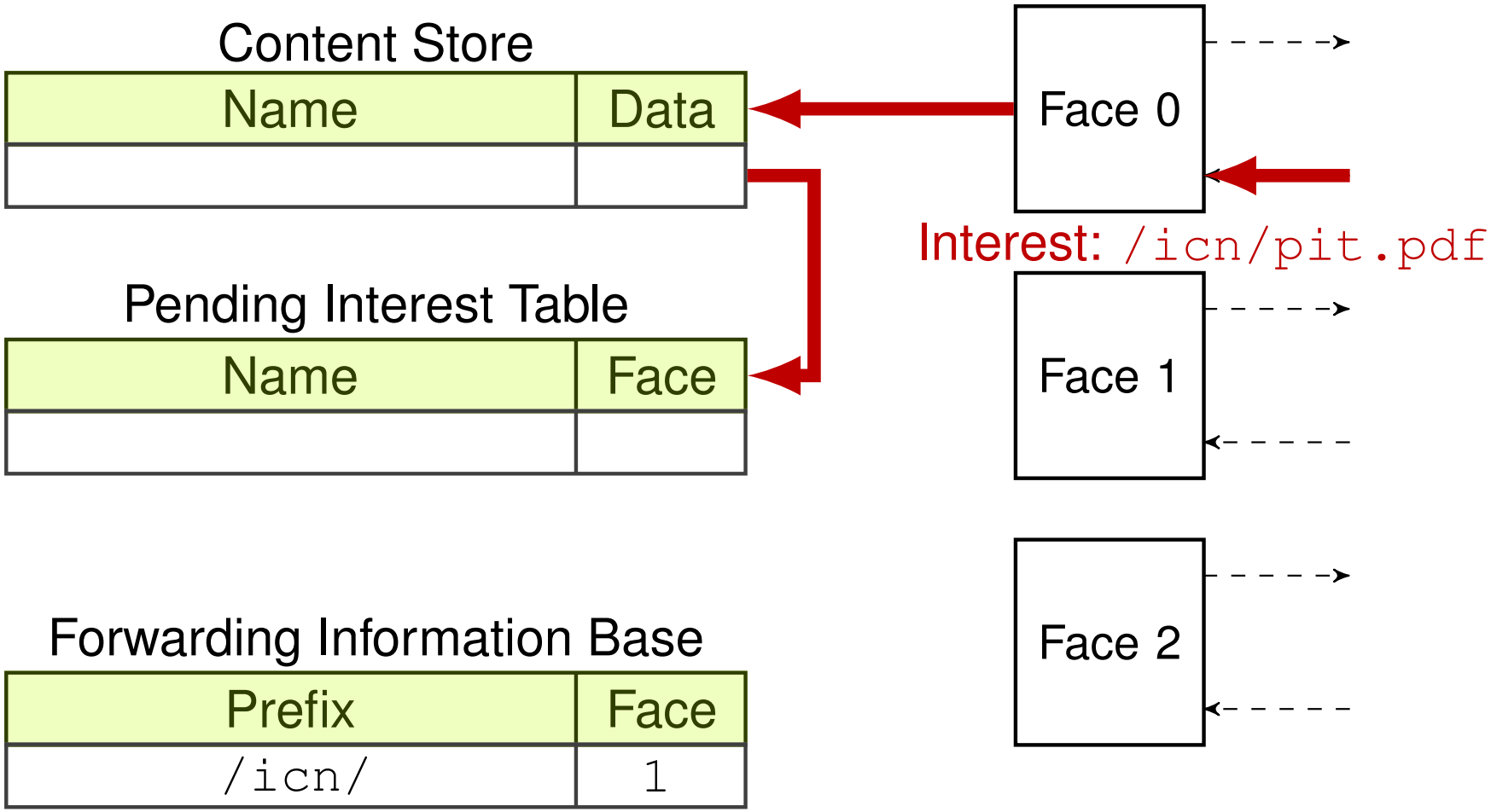
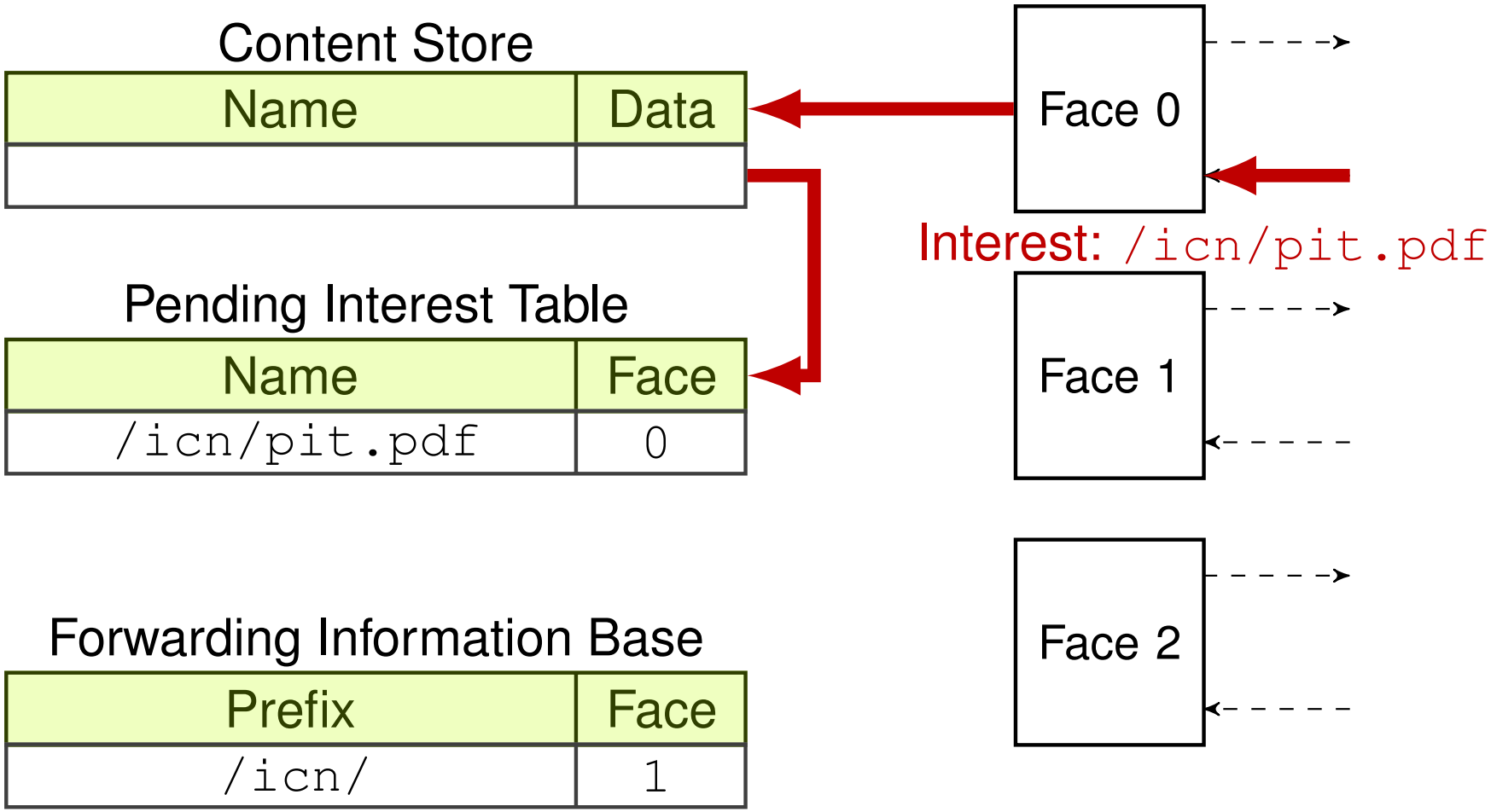

Content Store
Name
Data
Pending Interest Table
Name
Face
Forwarding Information Base
Prefix
Face
/icn/
1
Face 0
Face 1
Face 2
Interest: /icn/pit.pdf

Overview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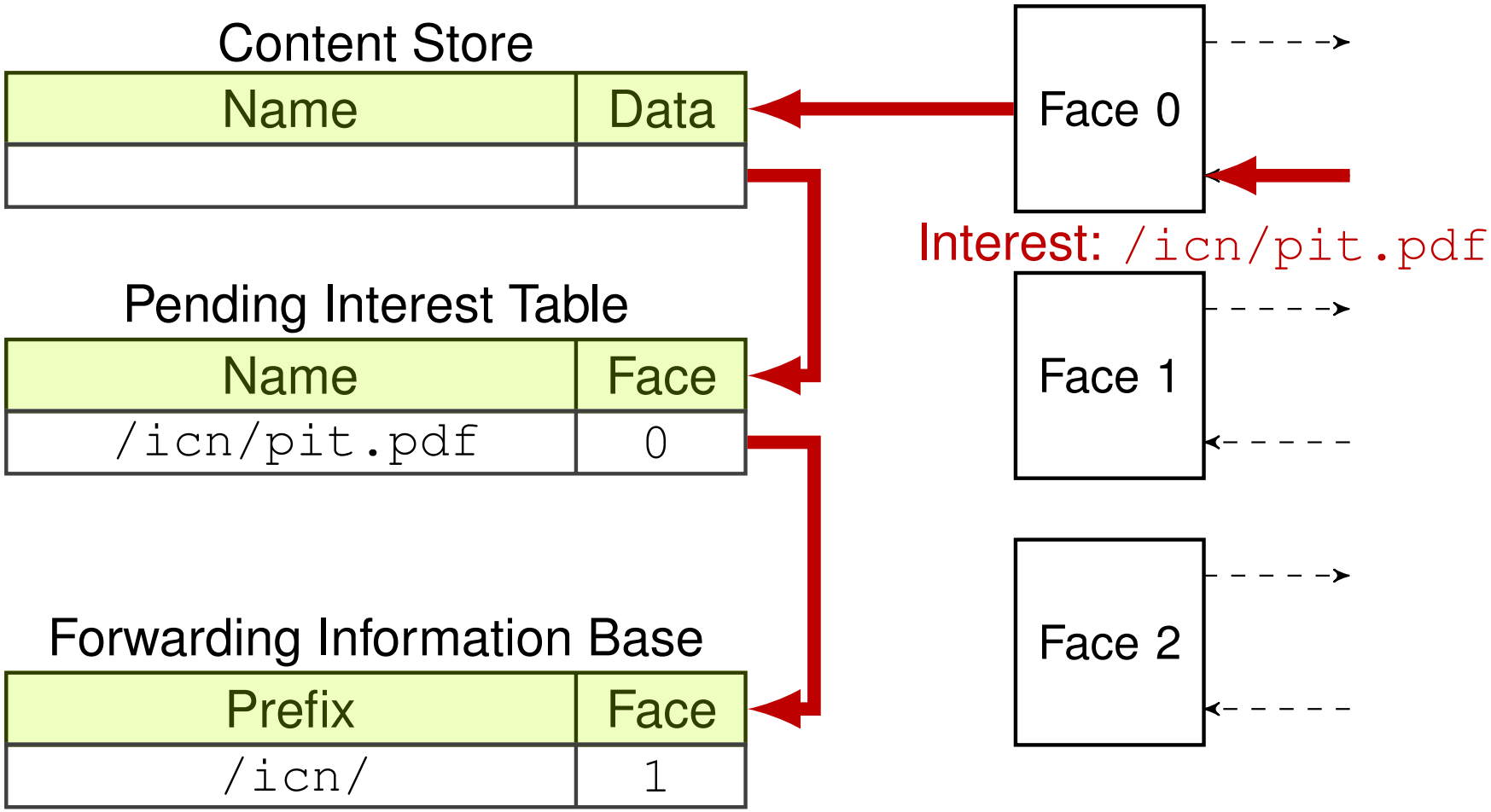
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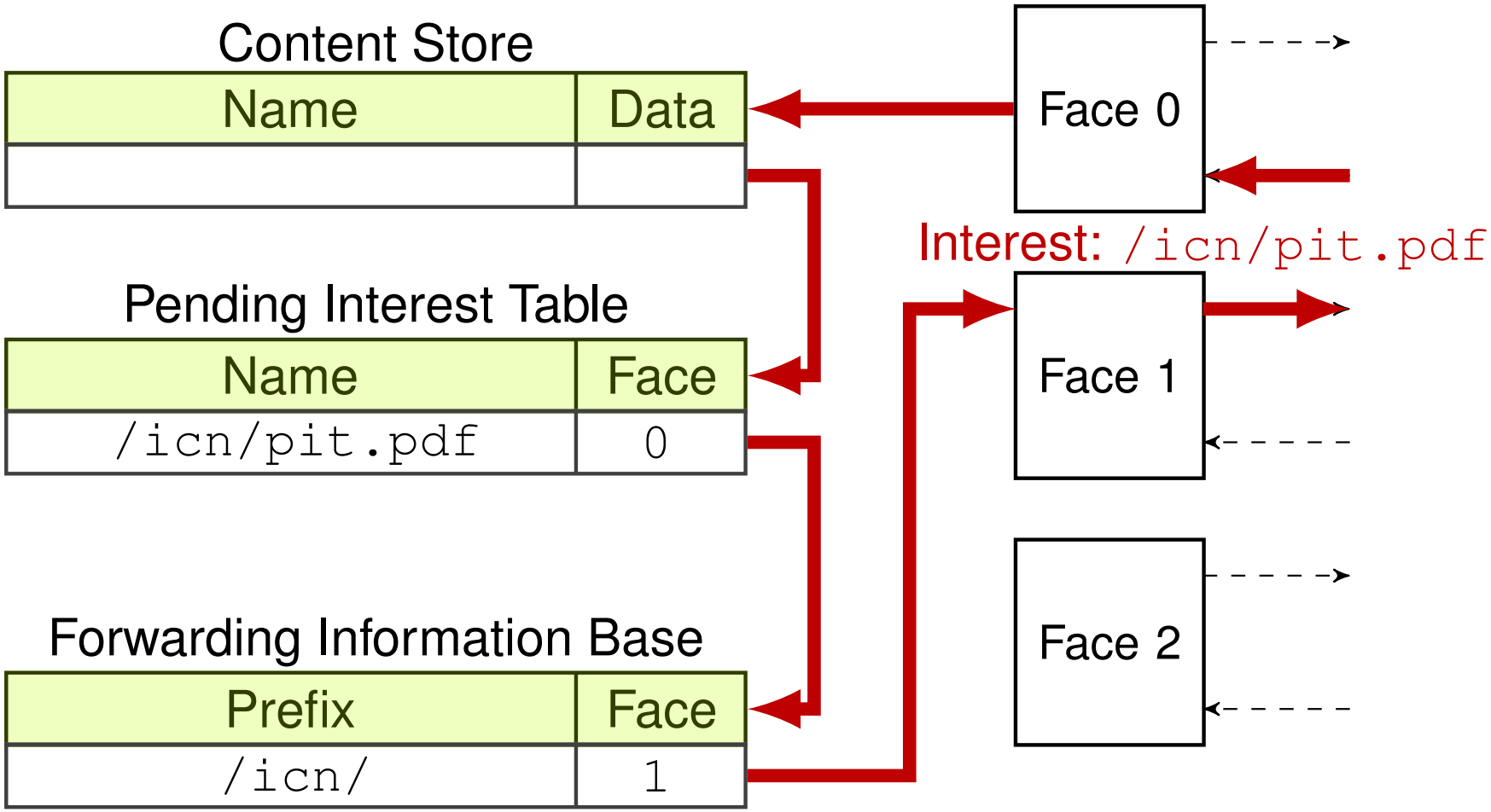
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/icn/pit.pdf	0

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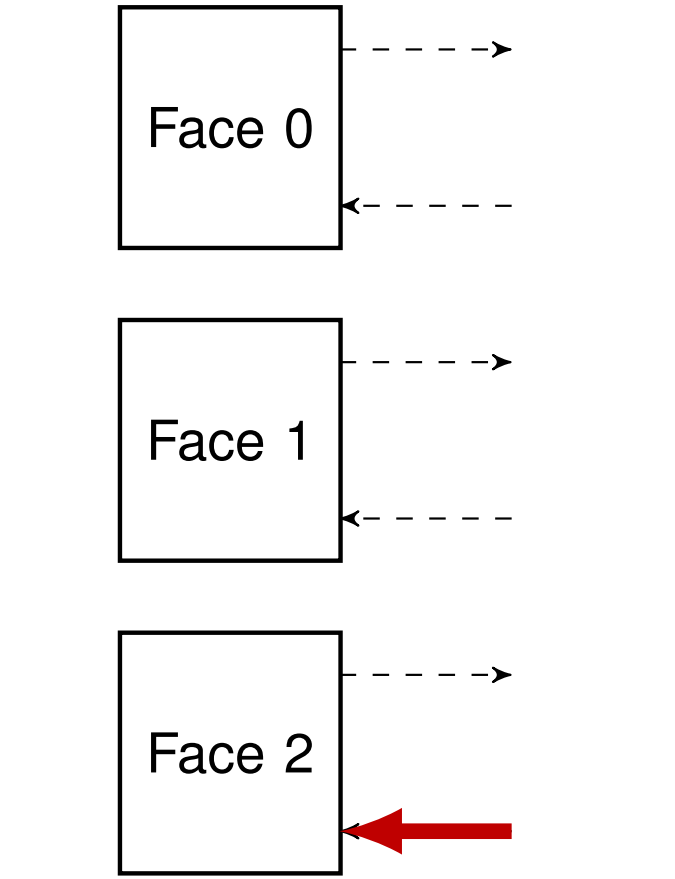

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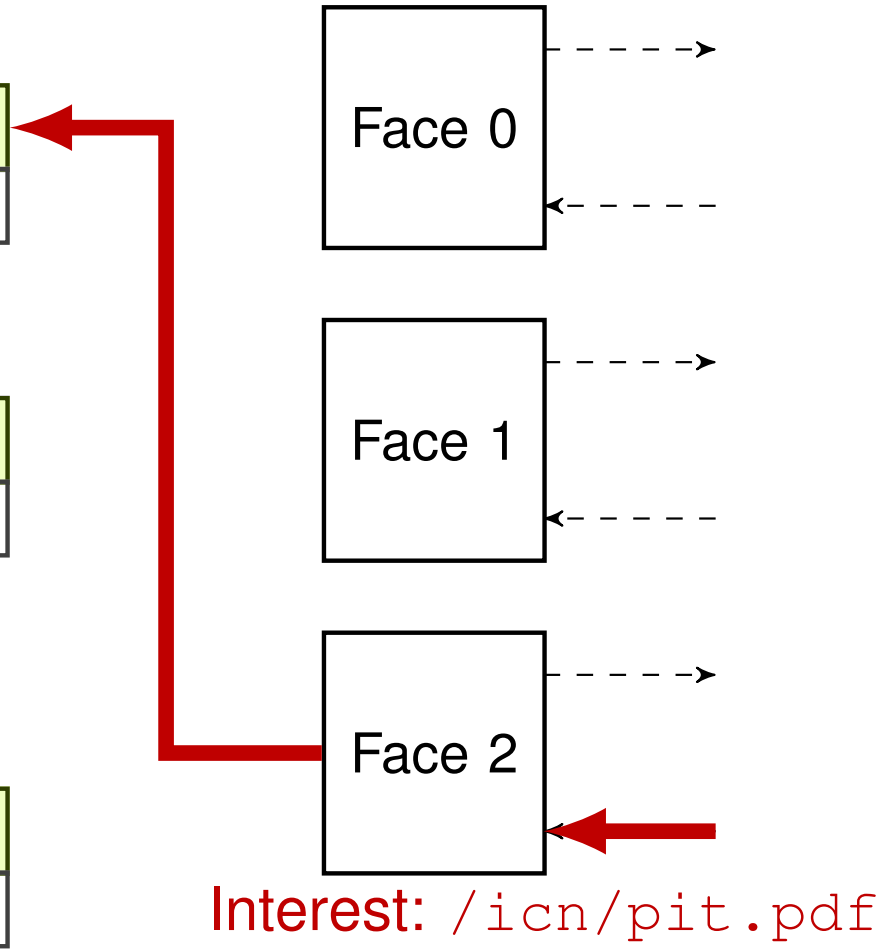

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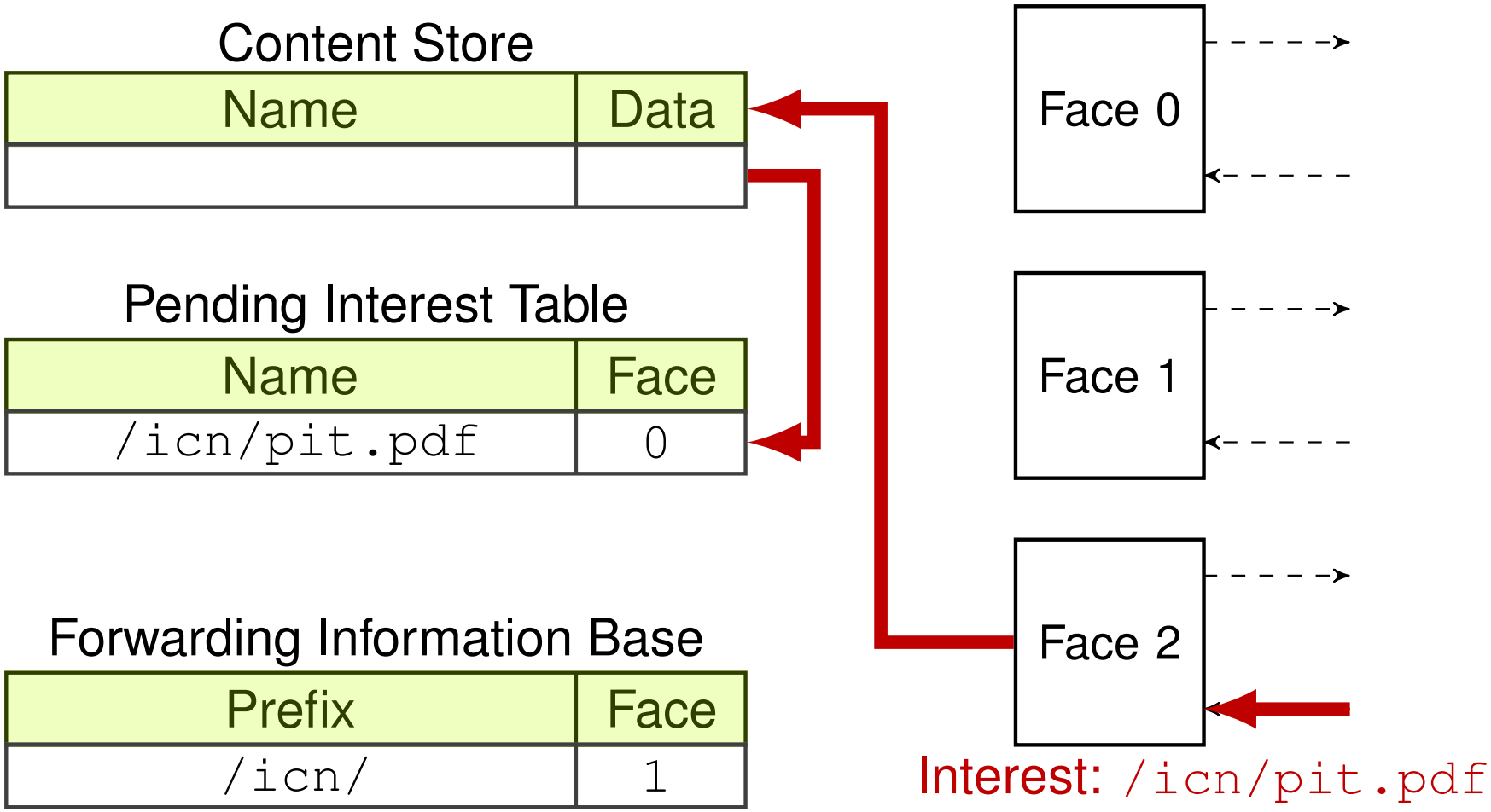
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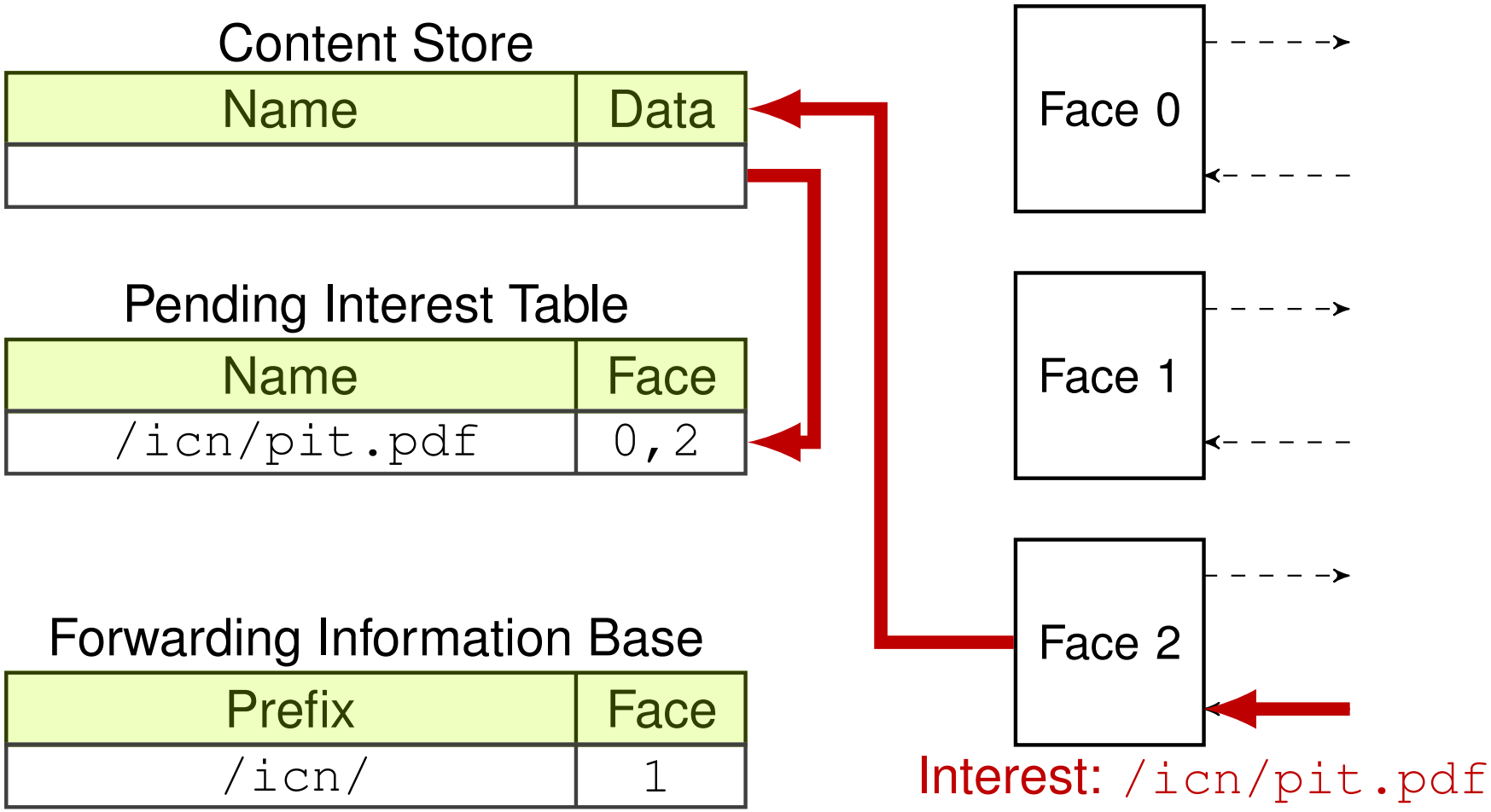
Content Store
Name
Data
Pending Interest Table
Name
Face
/icn/pit.pdf
0,2
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Face
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1
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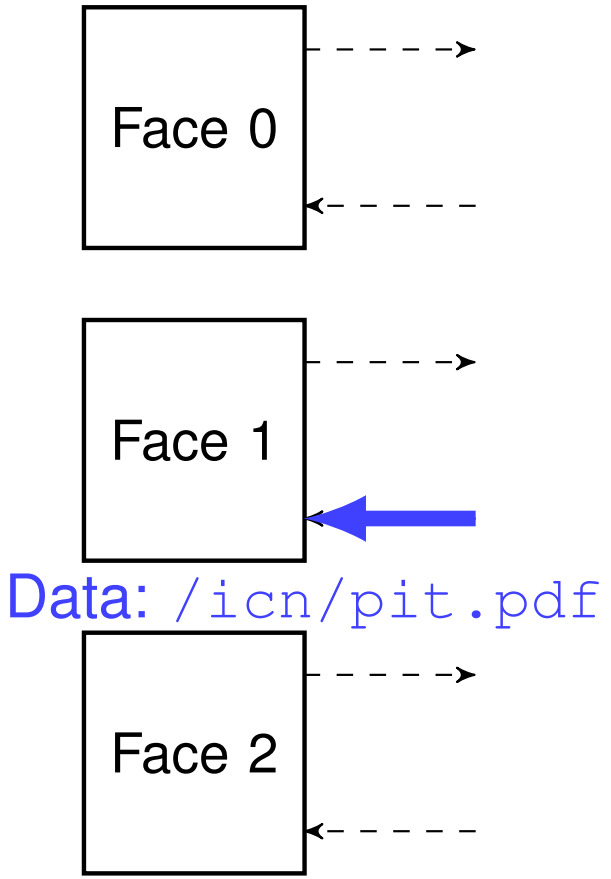

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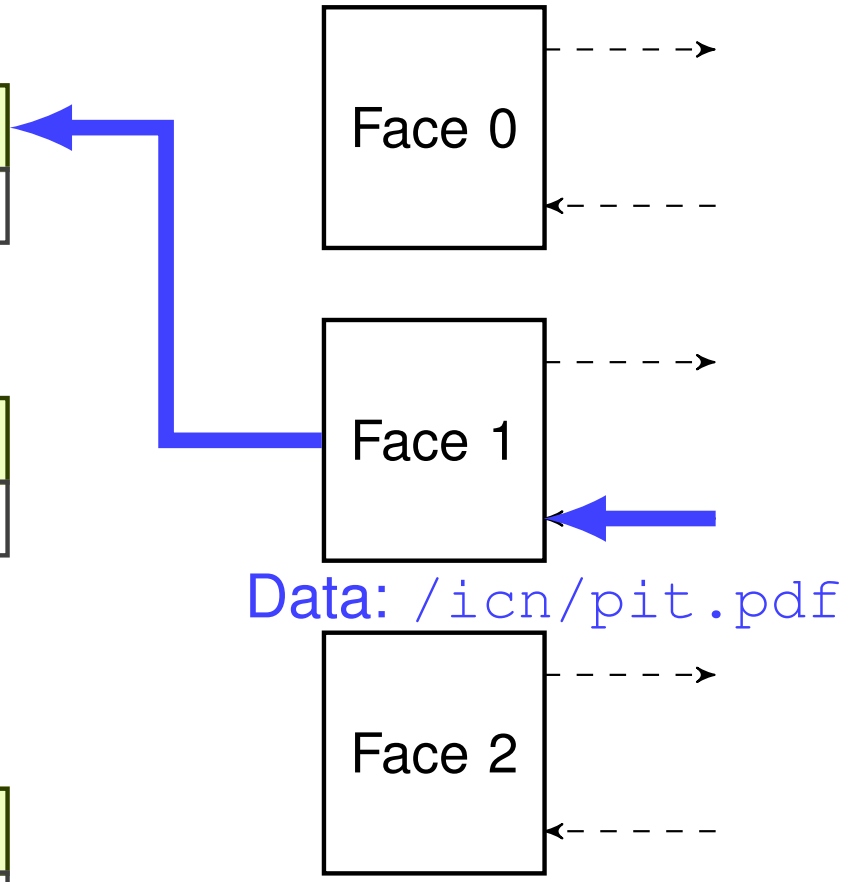

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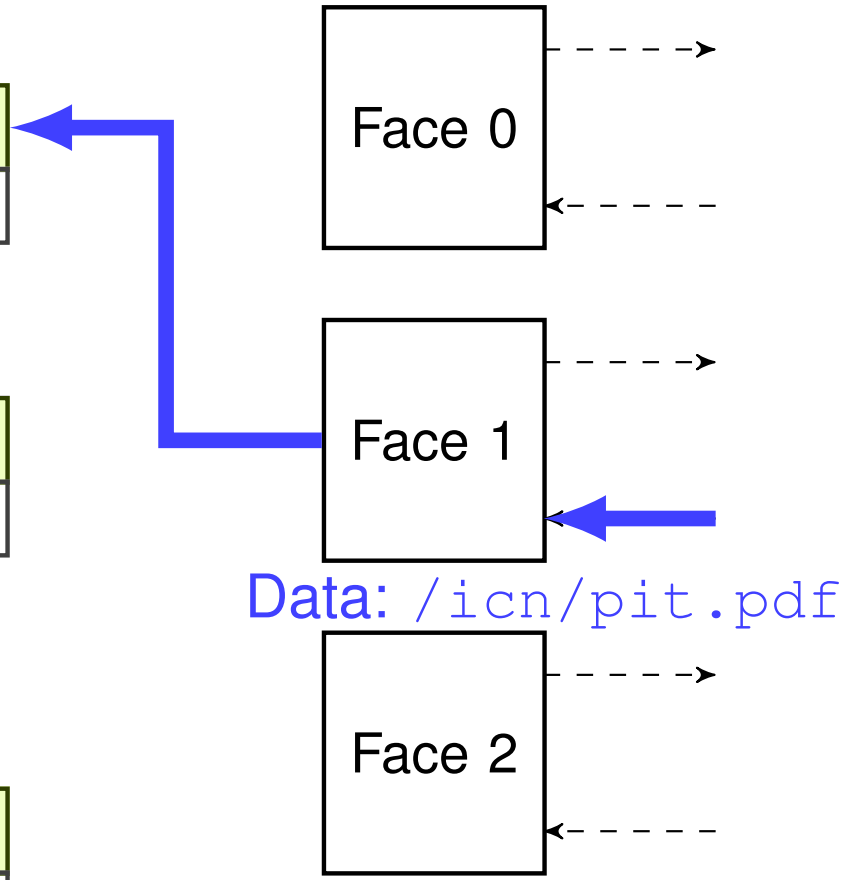

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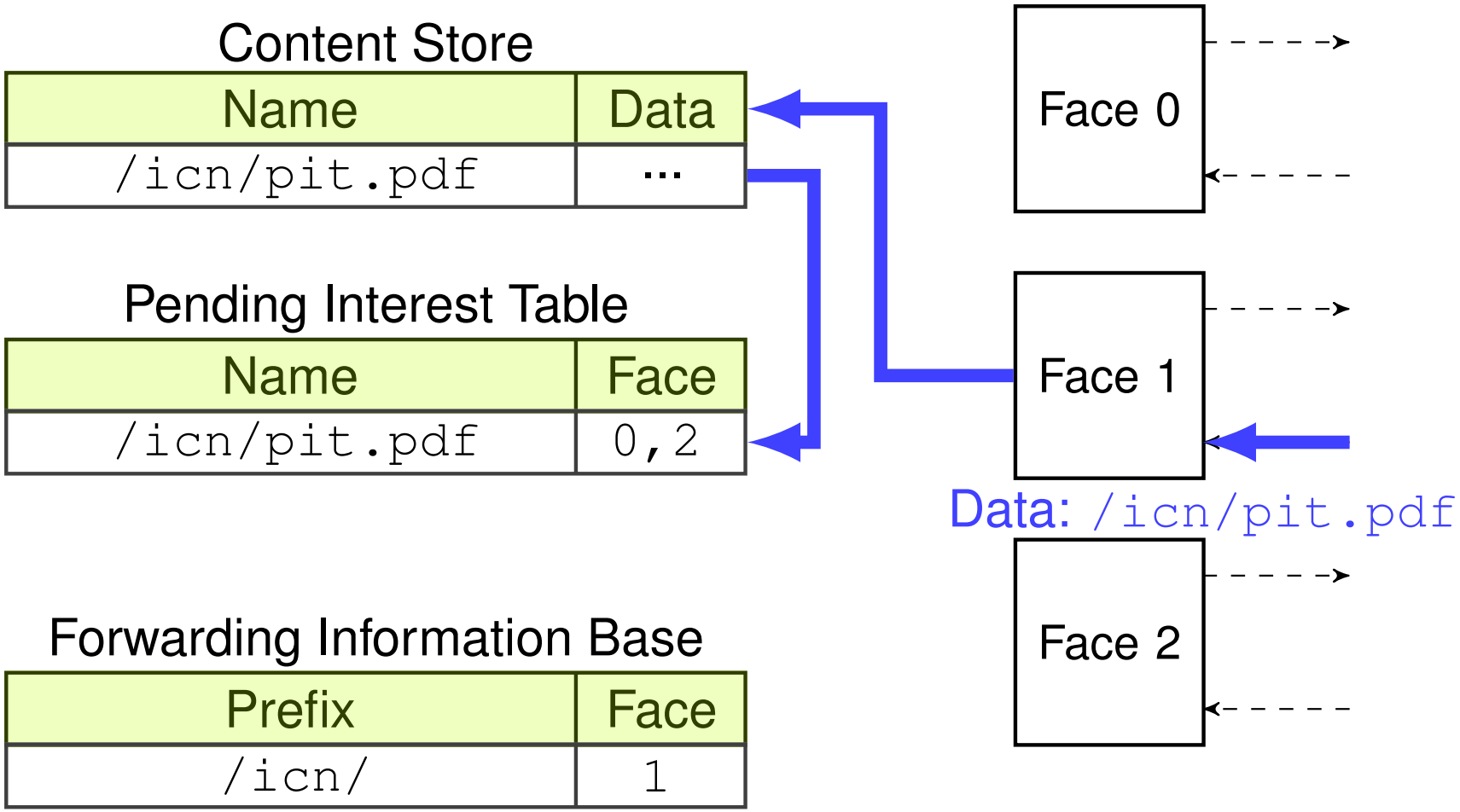
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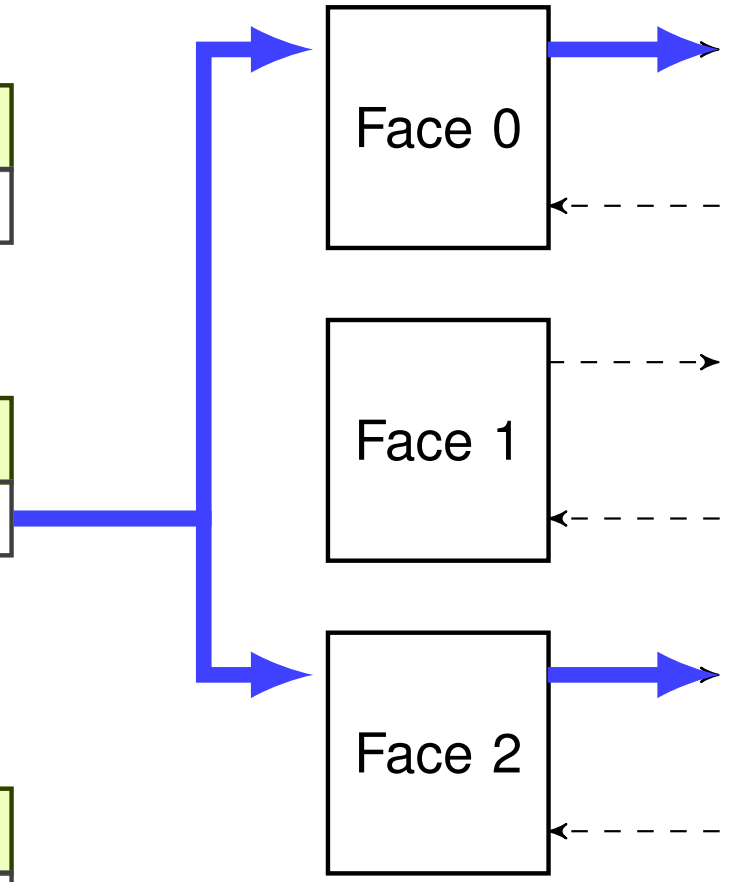

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- Affects cache behavior
  - hit probability
  - response time

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Goal: Analytically model cache with PIT

Outline

- Time-To-Live Caches
- Model and Analysis
- Replacement Based Policies
- Simulation Results

Time-To-Live (TTL) Caches

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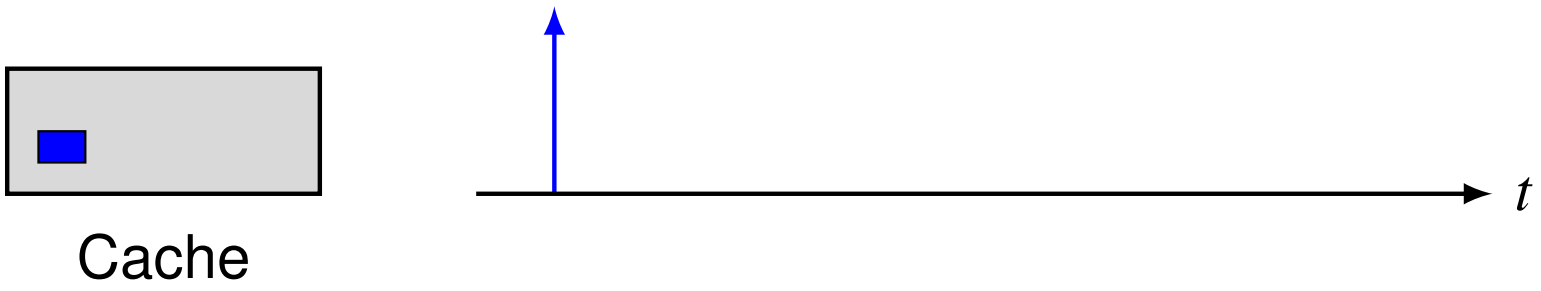

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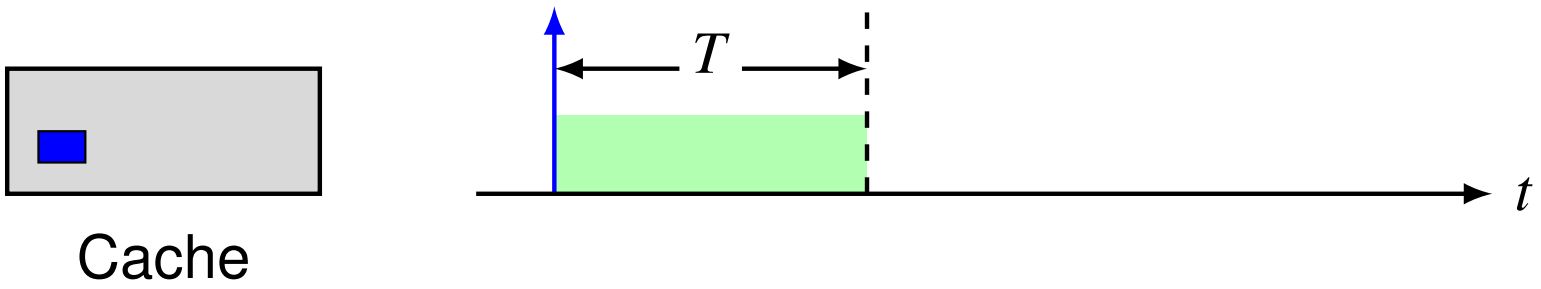

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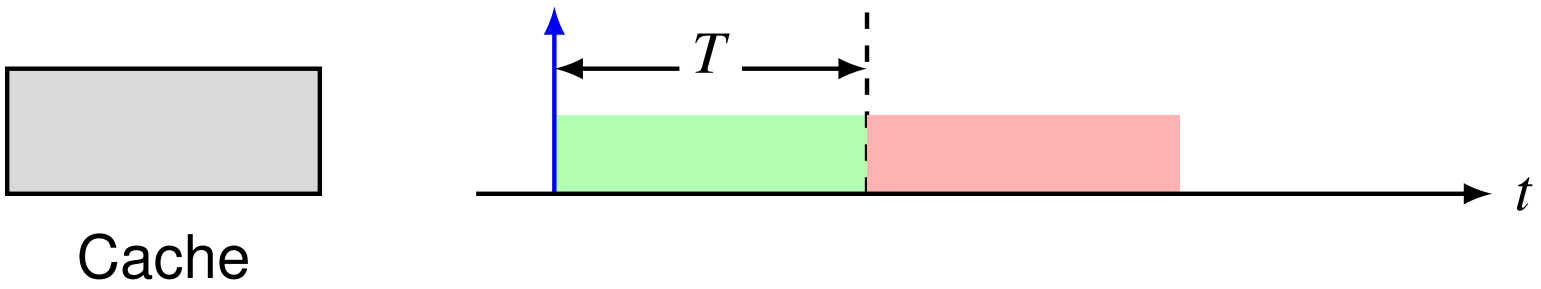

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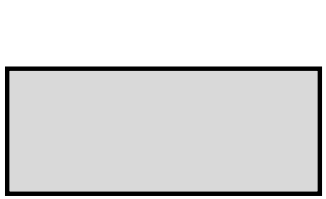

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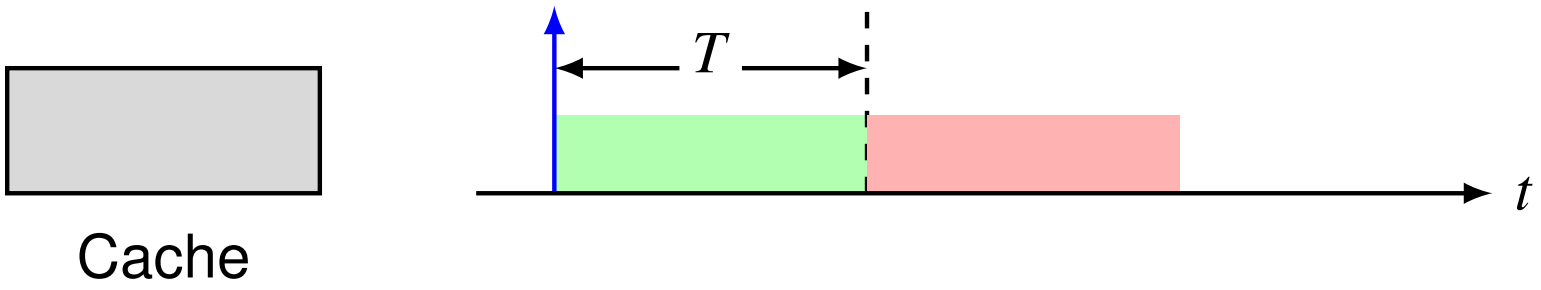

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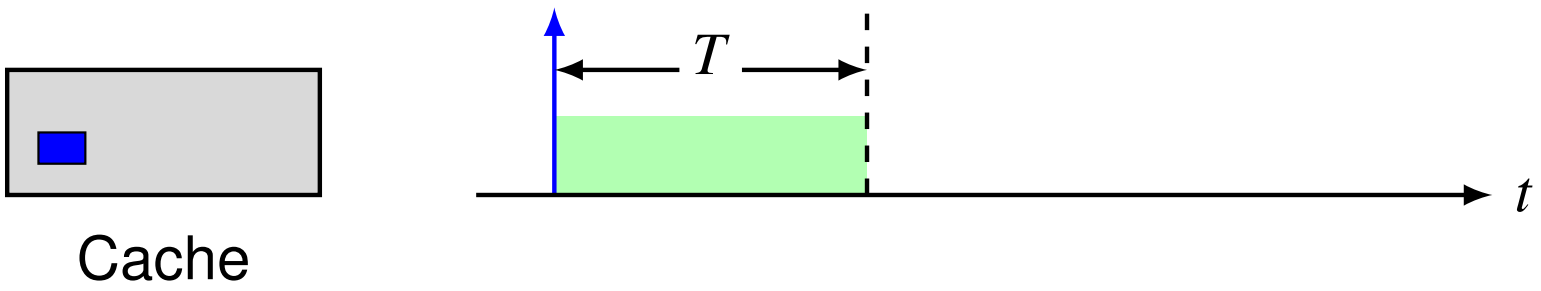

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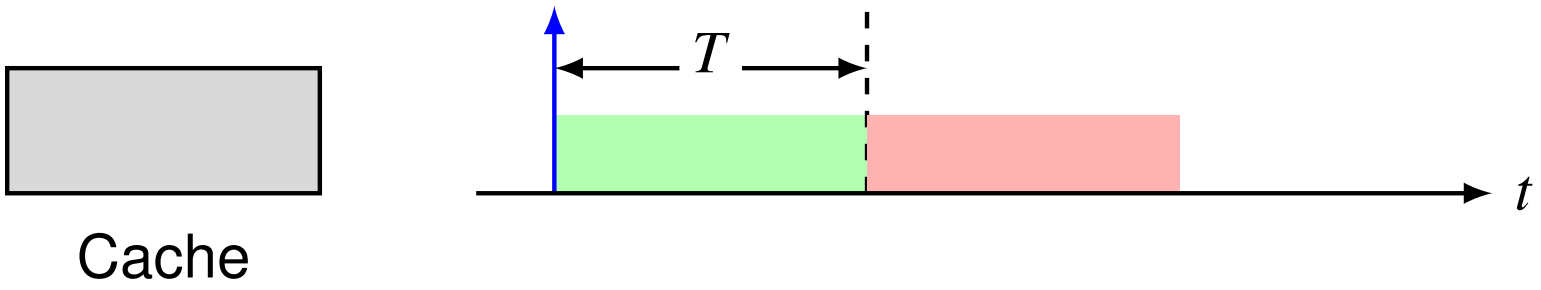

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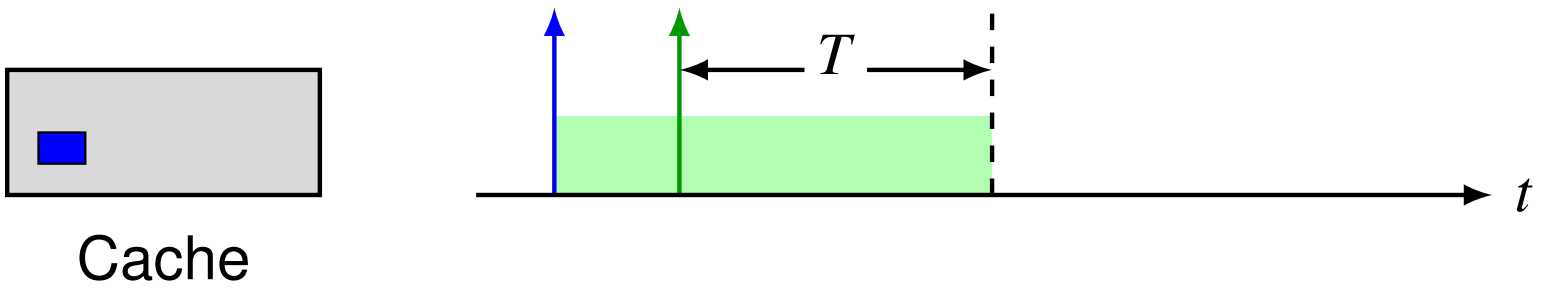

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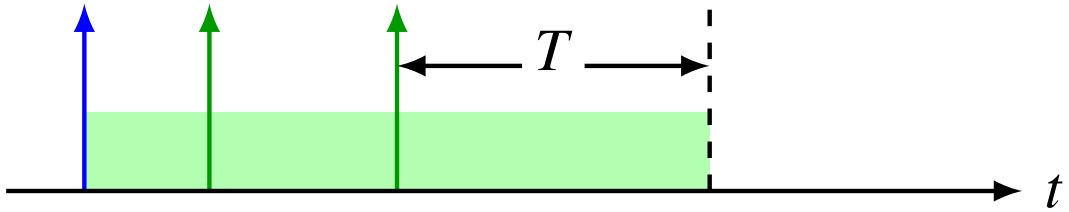

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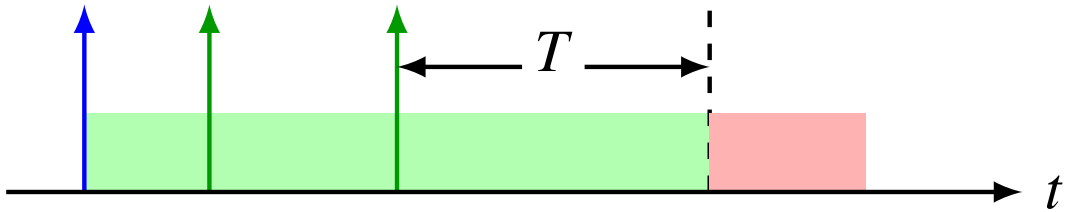
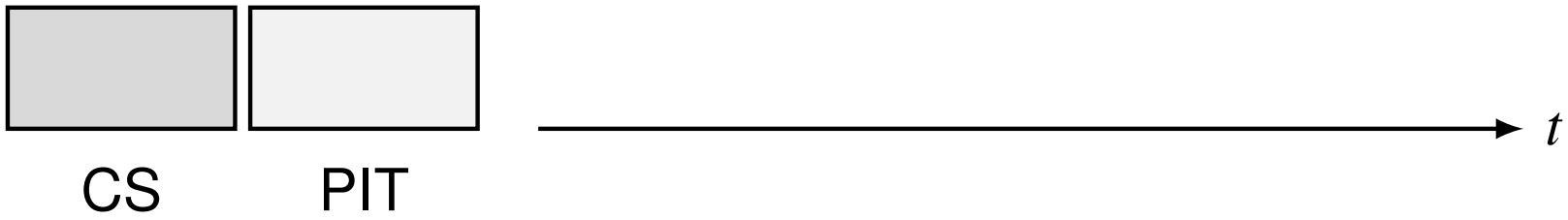


Model

- Requests: renewal arrivals
- Reset TTL cache with PIT



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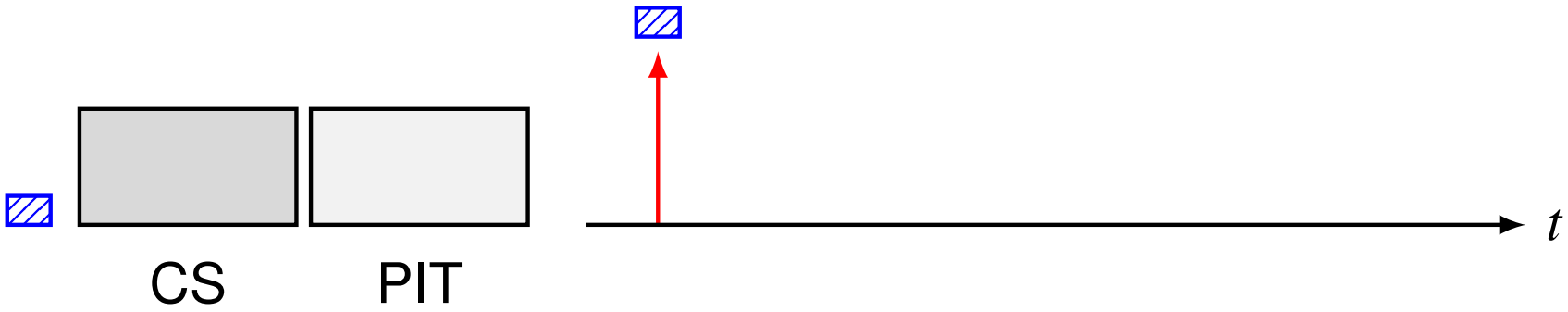

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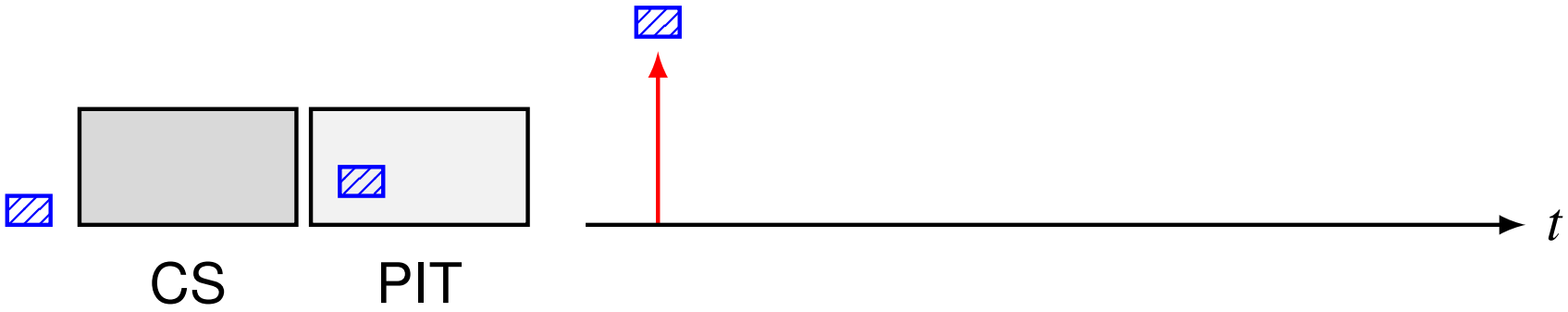

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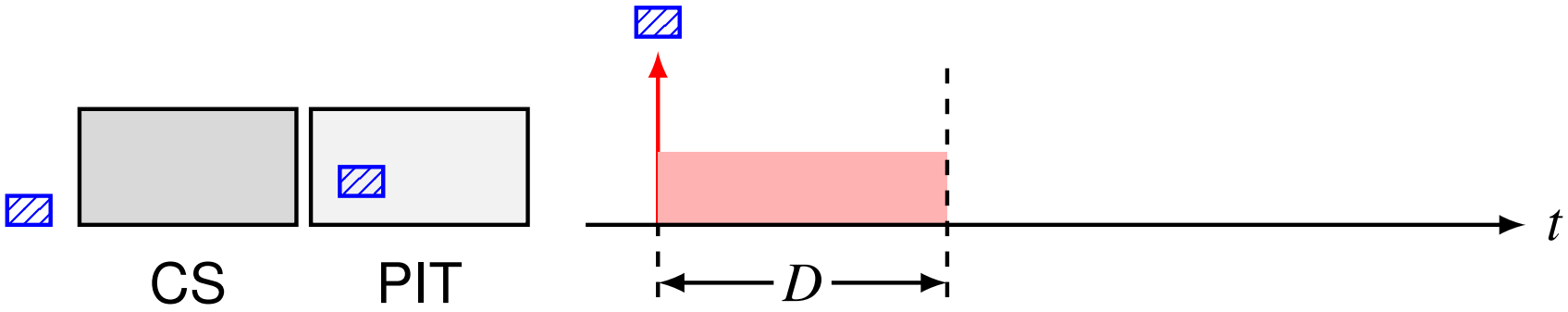

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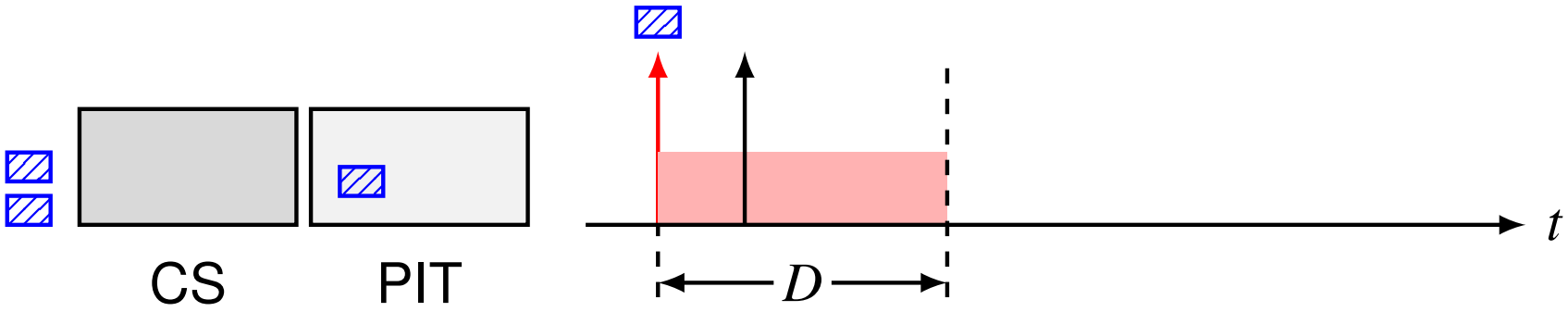

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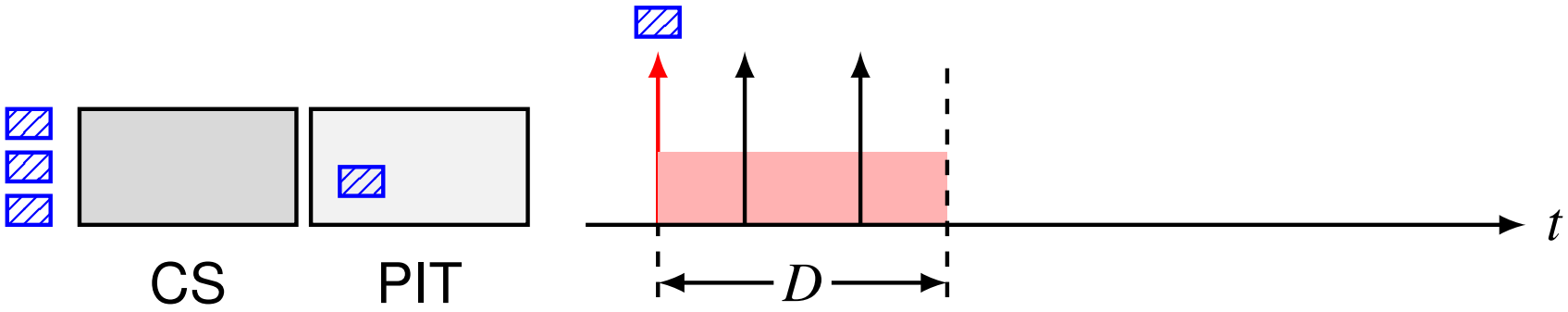

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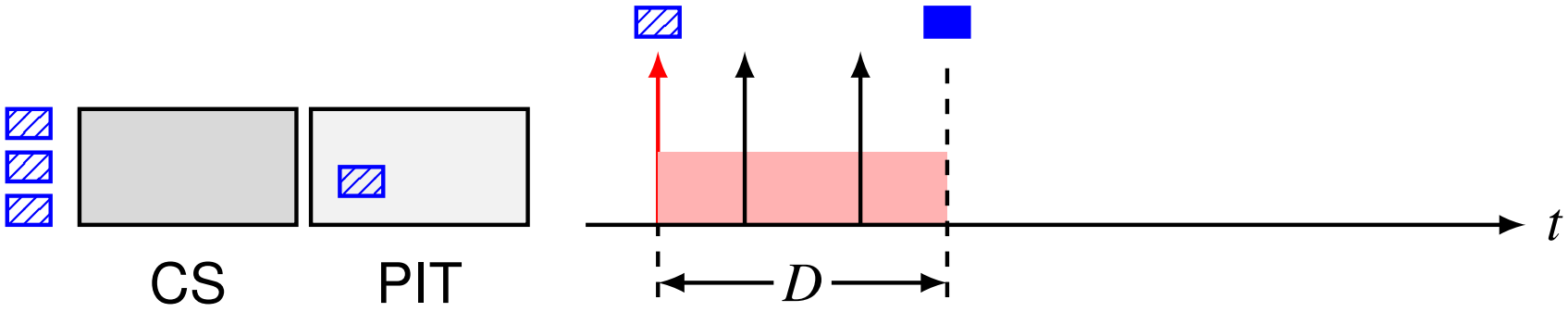

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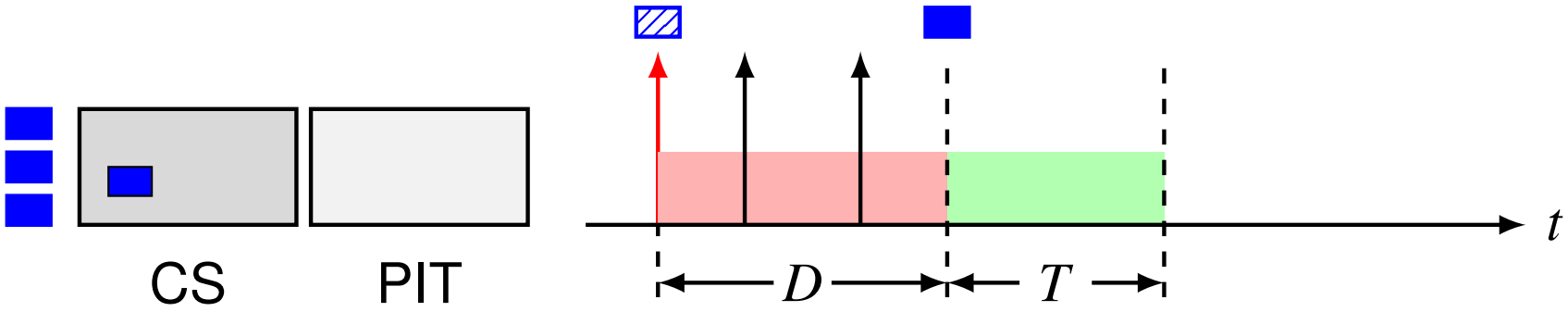

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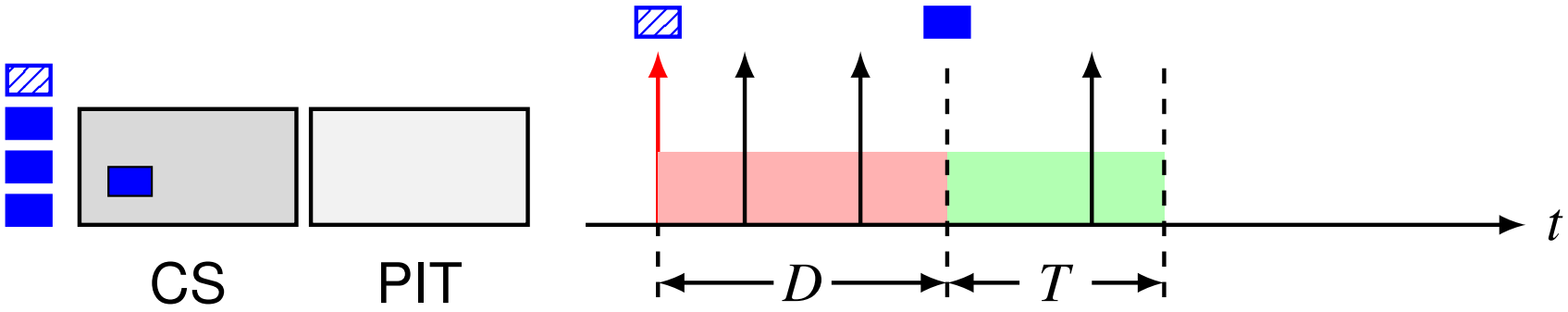

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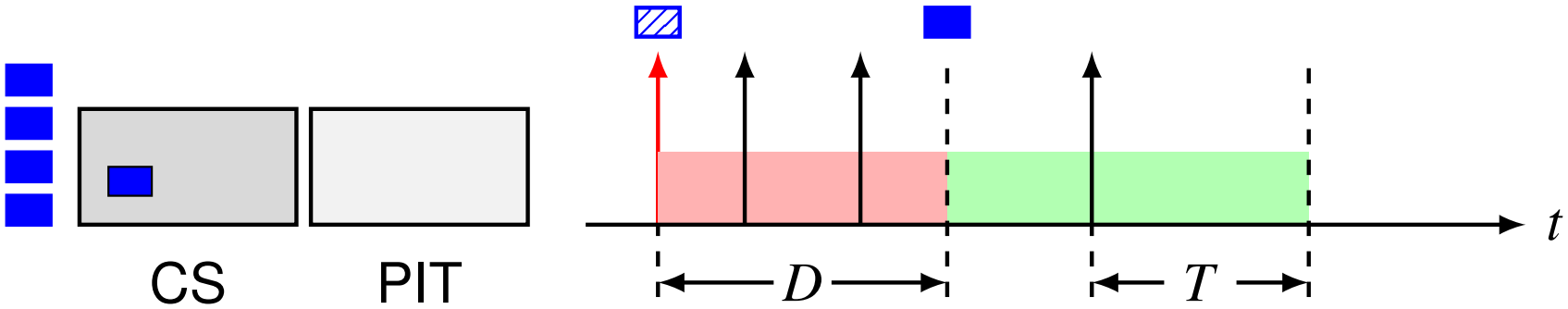

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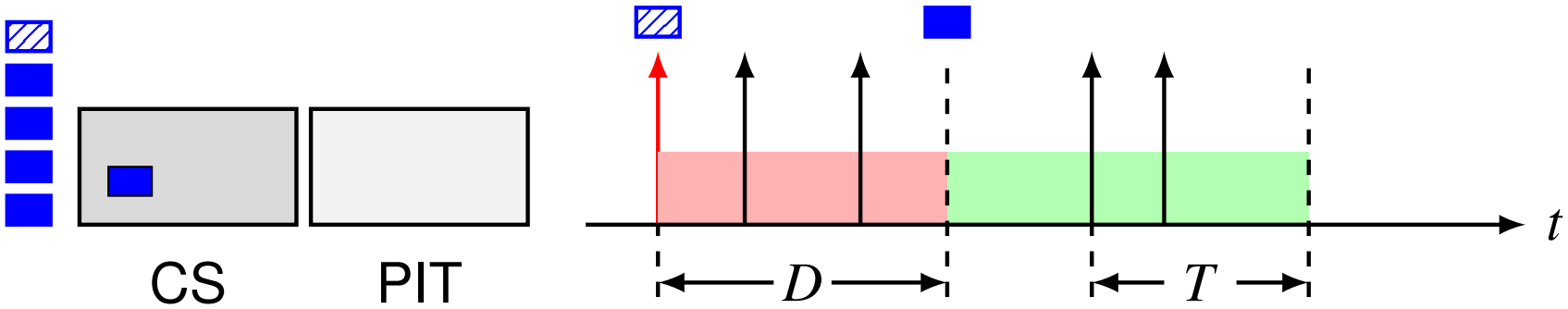

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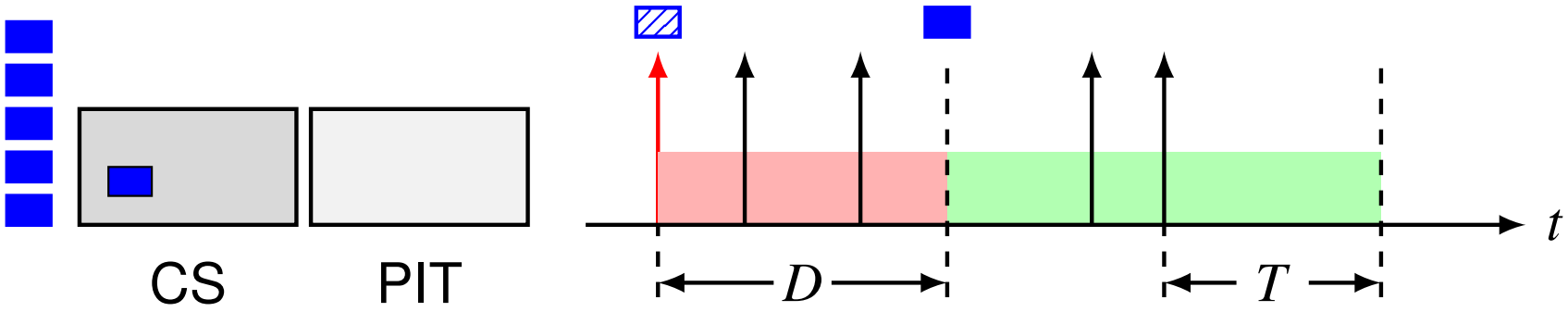

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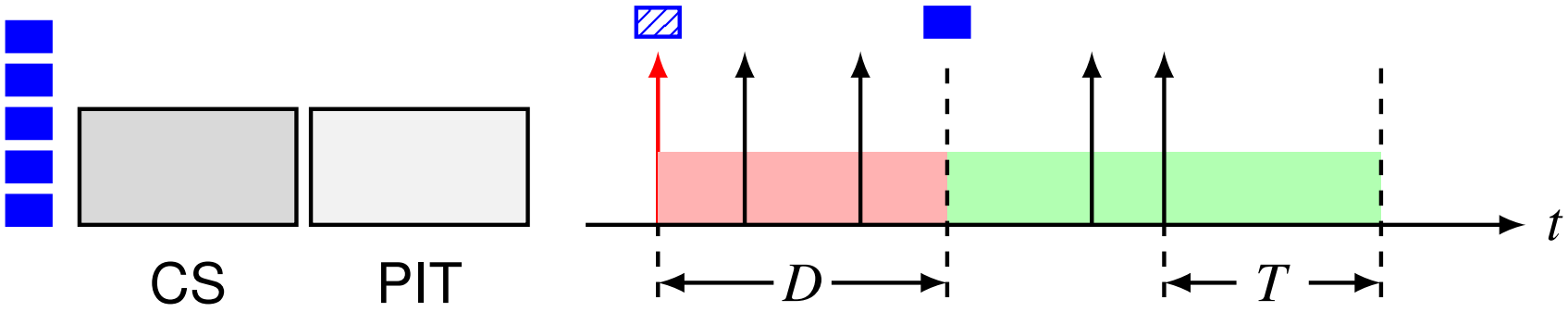

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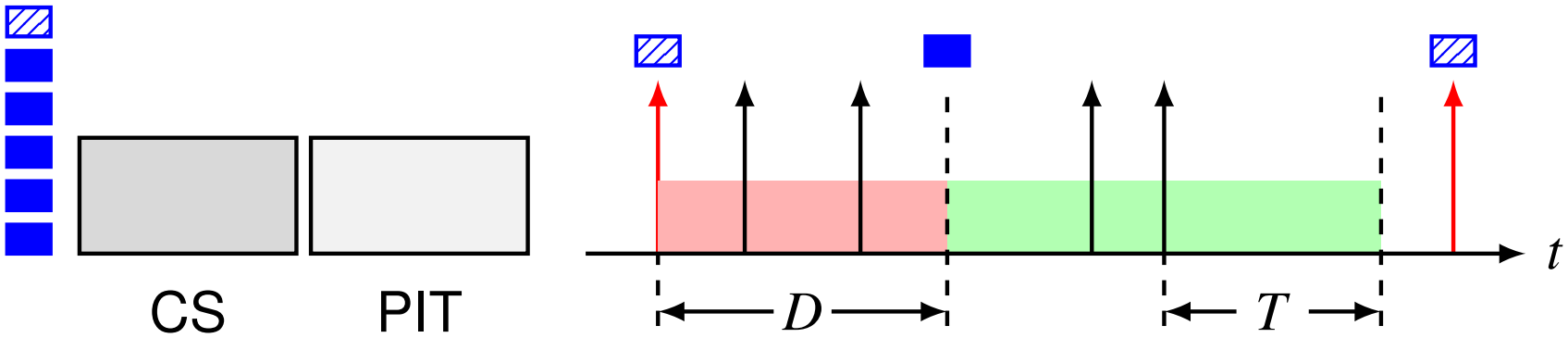
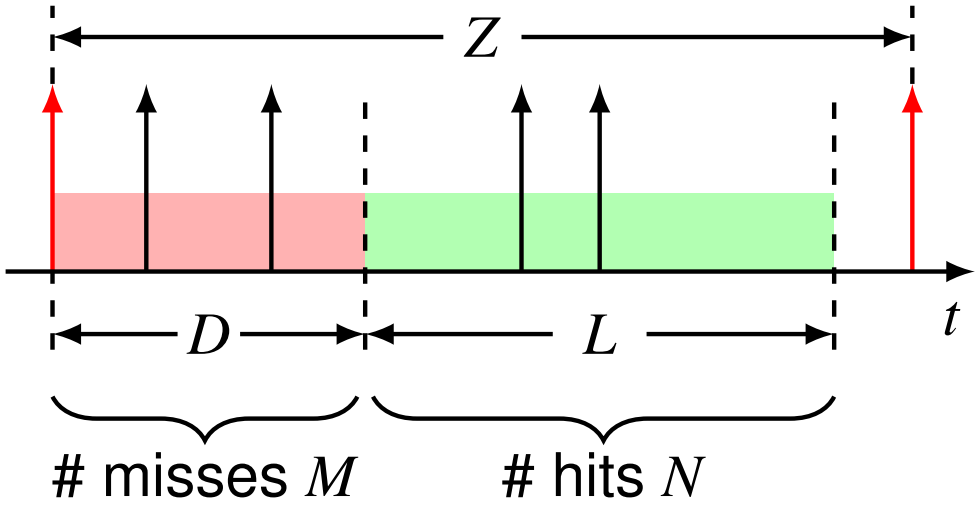


Metrics



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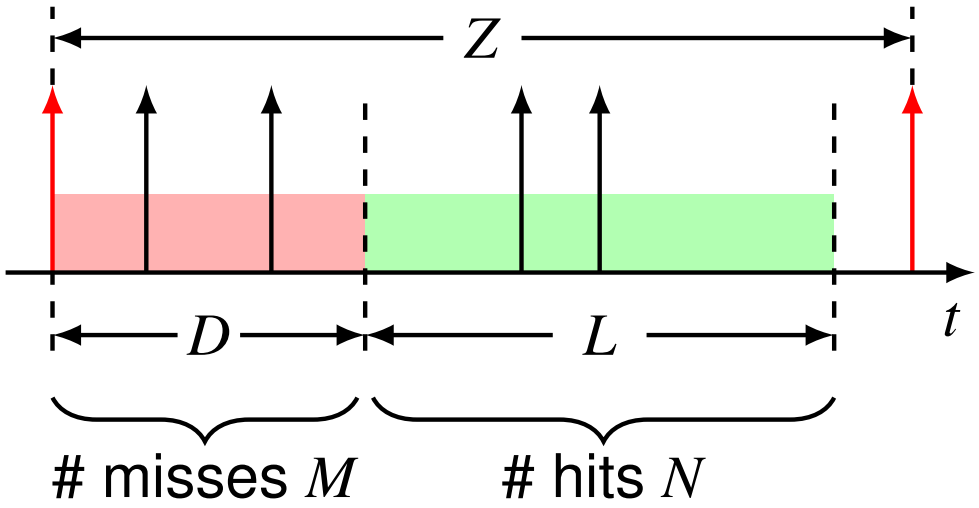
$$h = \frac{\mathbb{E}[N]}{\mathbb{E}[M] + \mathbb{E}[N]}$$



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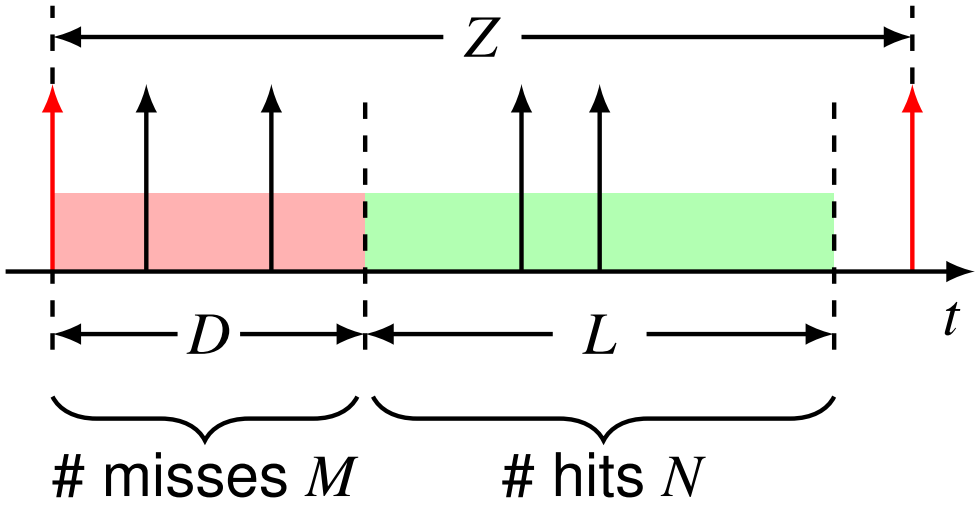
$m(t)$: renewal function
Poisson: $m(t) = \lambda t$



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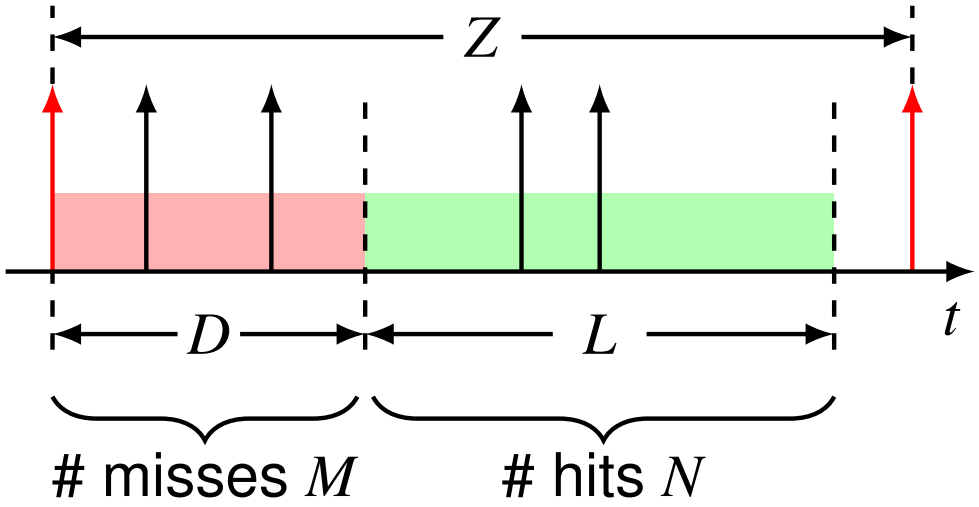


- Cache occupancy prob

$$o = \mathbb{E}[L]/\mathbb{E}[Z]$$

Metrics

- Cache hit prob

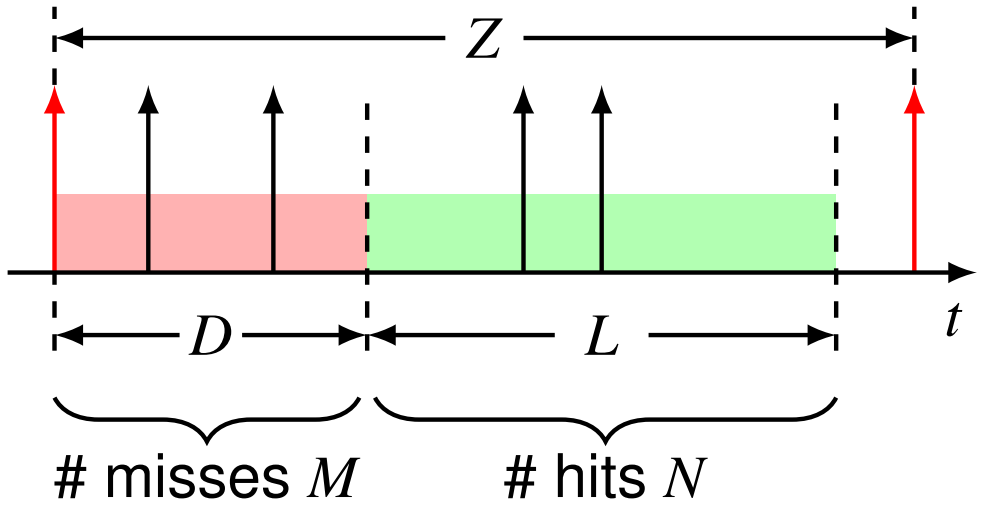
$$h = \frac{\mathbb{E}[N]}{\mathbb{E}[M] + \mathbb{E}[N]}$$

- Cache response time

$$r = \mathbb{E}[w(D)]/(\mathbb{E}[M]+\mathbb{E}[N])$$

$$w(t) = t + \int_0^t (t-x)\mathrm{d}m(x)$$

$m(t)$: renewal function
Poisson: $m(t) = \lambda t$



- Cache occupancy prob

$$o = \mathbb{E}[L]/\mathbb{E}[Z]$$

- PIT occupancy prob

$$p = \mathbb{E}[D]/\mathbb{E}[Z]$$

Replacement Based Policies

Characteristic Time Approximation

- Introduced by Che et al. for LRU policy w/ Poisson arrivals
- Extended to other policies, e.g. FIFO, Random, . . .
- Extended to general request arrival processes
- Characteristic time T solution of

$$\sum_i o_i(T) = C$$

  - o_i – cache occupancy probability of file i
  - C – cache size

LRU Cache with Poisson Arrivals

- Modeled as reset TTL with constant T
- Cache hit/occupancy probability

$$h_i = o_i = \frac{e^{\lambda_i T} - 1}{\lambda_i \mathbb{E}D_i + e^{\lambda_i T}}$$

  - λ_i – arrival rate of requests for file i
  - $\mathbb{E}D_i$ – expected download delay for file i
  - characteristic time T solution of

$$\sum_i \frac{e^{\lambda_i T} - 1}{\lambda_i \mathbb{E}D_i + e^{\lambda_i T}} = C$$

LRU Cache with Poisson Arrivals

- PIT occupancy probability

$$p_i = \frac{\lambda_i \mathbb{E}D_i}{\lambda_i \mathbb{E}D_i + e^{\lambda_i T}}$$

LRU Cache with Poisson Arrivals

- PIT occupancy probability

$$p_i = \frac{\lambda_i \mathbb{E}D_i}{\lambda_i \mathbb{E}D_i + e^{\lambda_i T}}$$

- PIT size

$$S \sim \mathcal{N}\left(\sum_i p_i, \sum_i p_i(1-p_i)\right)$$

LRU Cache with Poisson Arrivals

- PIT occupancy probability

$$p_i = \frac{\lambda_i \mathbb{E}D_i}{\lambda_i \mathbb{E}D_i + e^{\lambda_i T}}$$

- PIT size

$$S \sim \mathcal{N}\left(\sum_i p_i, \sum_i p_i(1-p_i)\right)$$

- Average cache response time

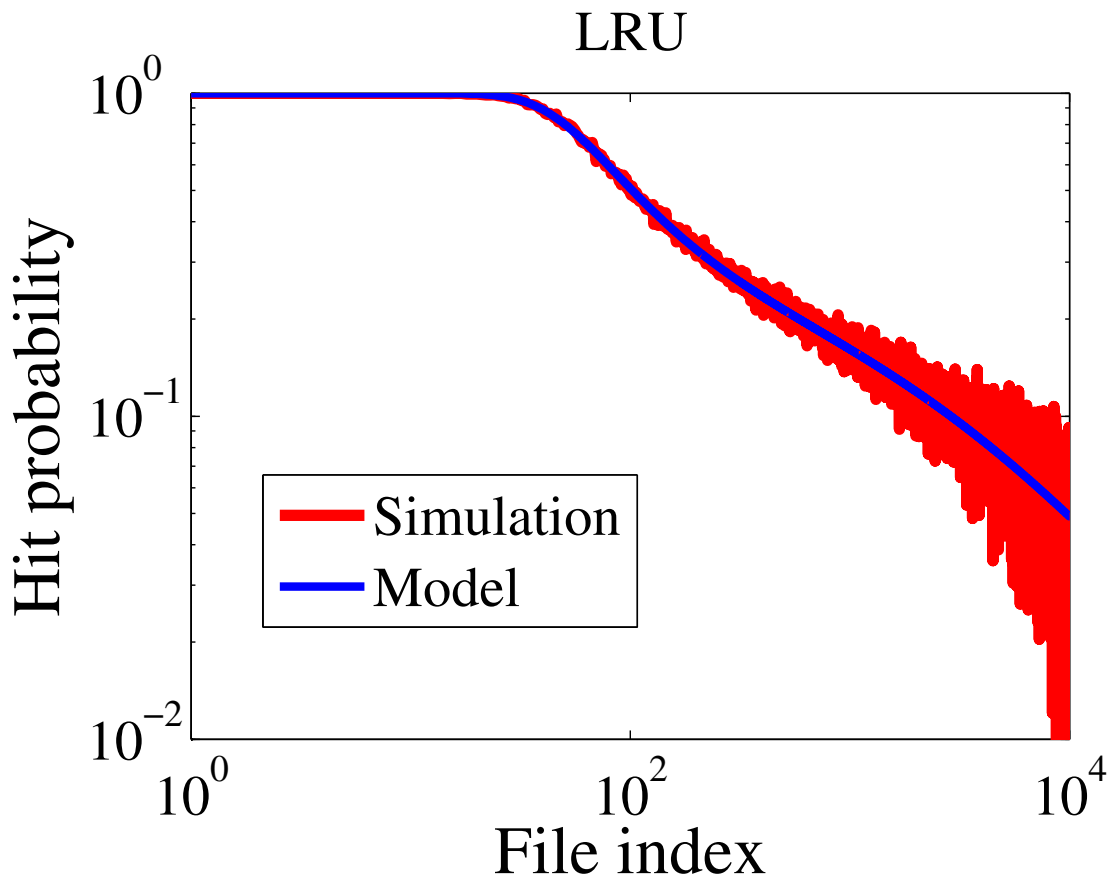
$$r_i = \frac{\mathbb{E}D_i + 0.5\lambda_i \mathbb{E}D_i^2}{\lambda_i \mathbb{E}D_i + e^{\lambda_i T}}$$

Simulation

- Cache size = 10^3
- # different files = 10^4
- Requests: Poisson process w/ rate $\lambda = 10^5$ per second
- File popularity: Zipf distribution, $\lambda_i \propto i^{-0.8}$
- Download delay: 100 ms
- One simulation run: total of 10^7 requests simulated
- Base model:
  - ZDD: Zero-Download Delay

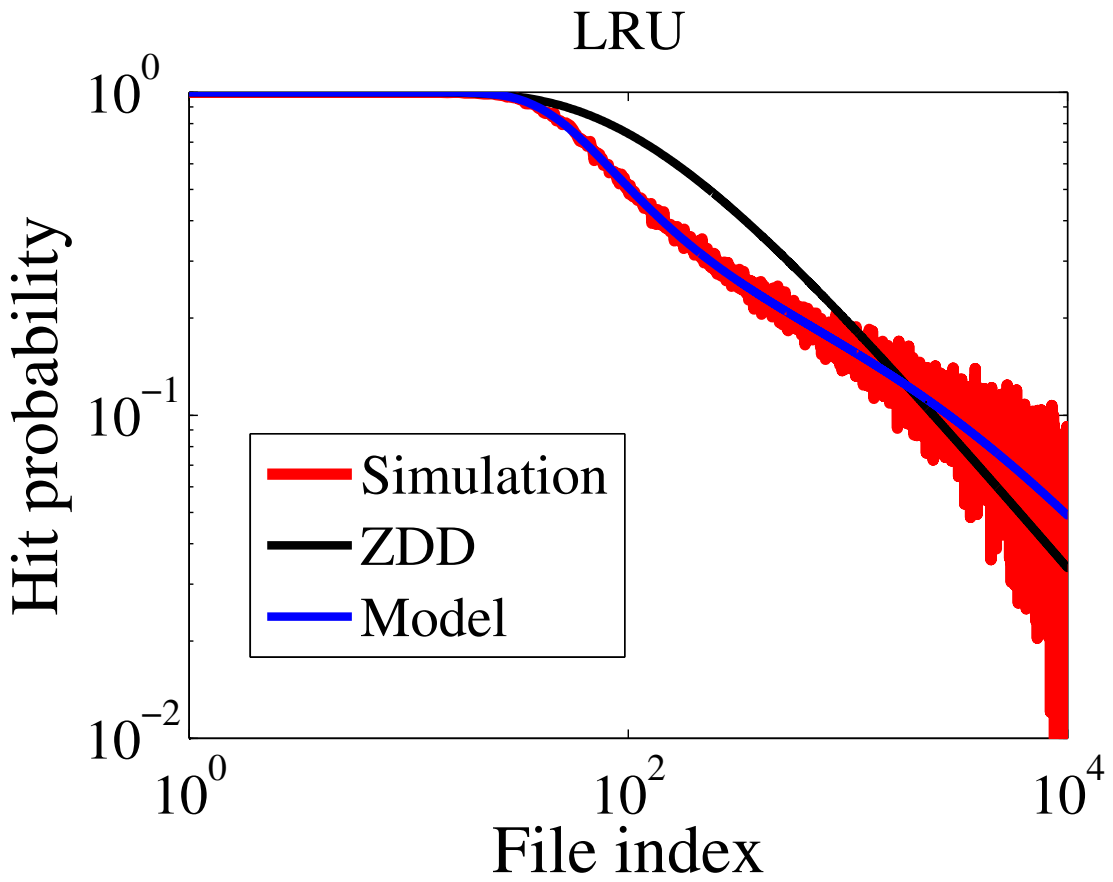
Result – Cache Hit Probability

- Hit probability for individual files ($D = 100$ ms)



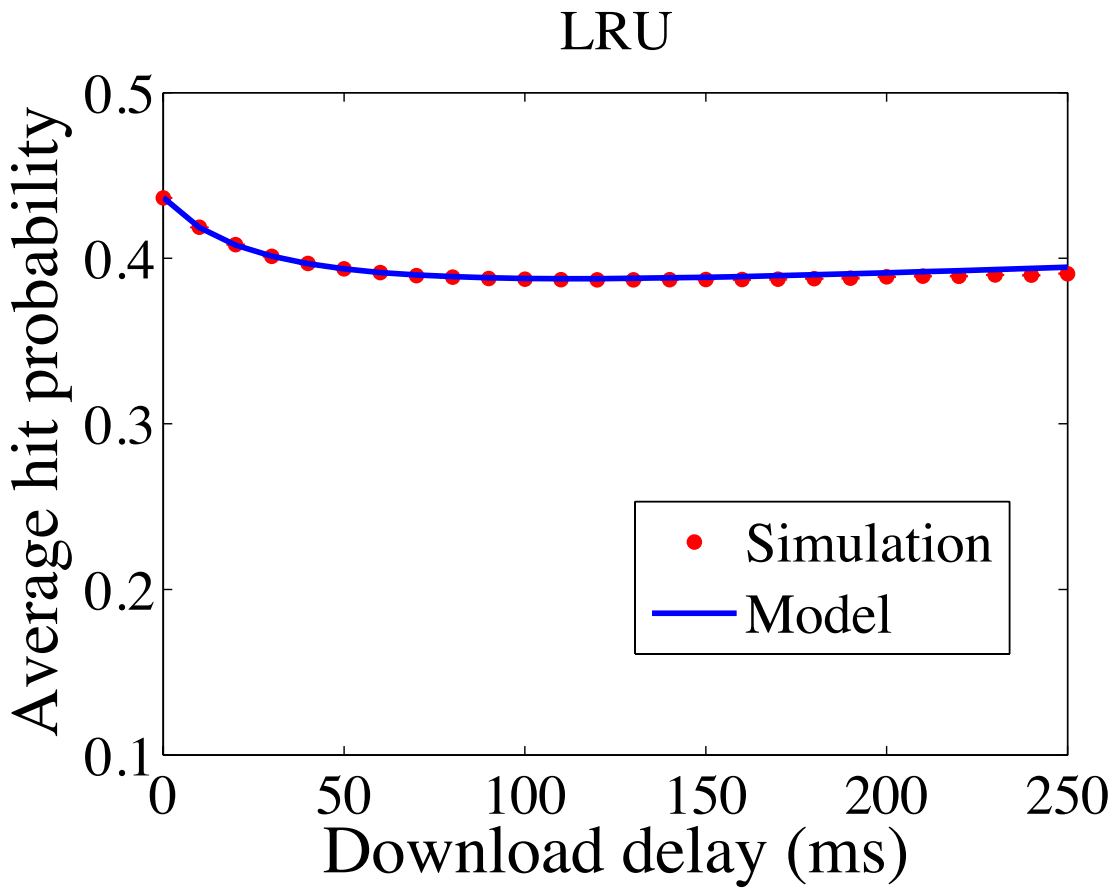
Result – Cache Hit Probability

- Hit probability for individual files ($D = 100$ ms)



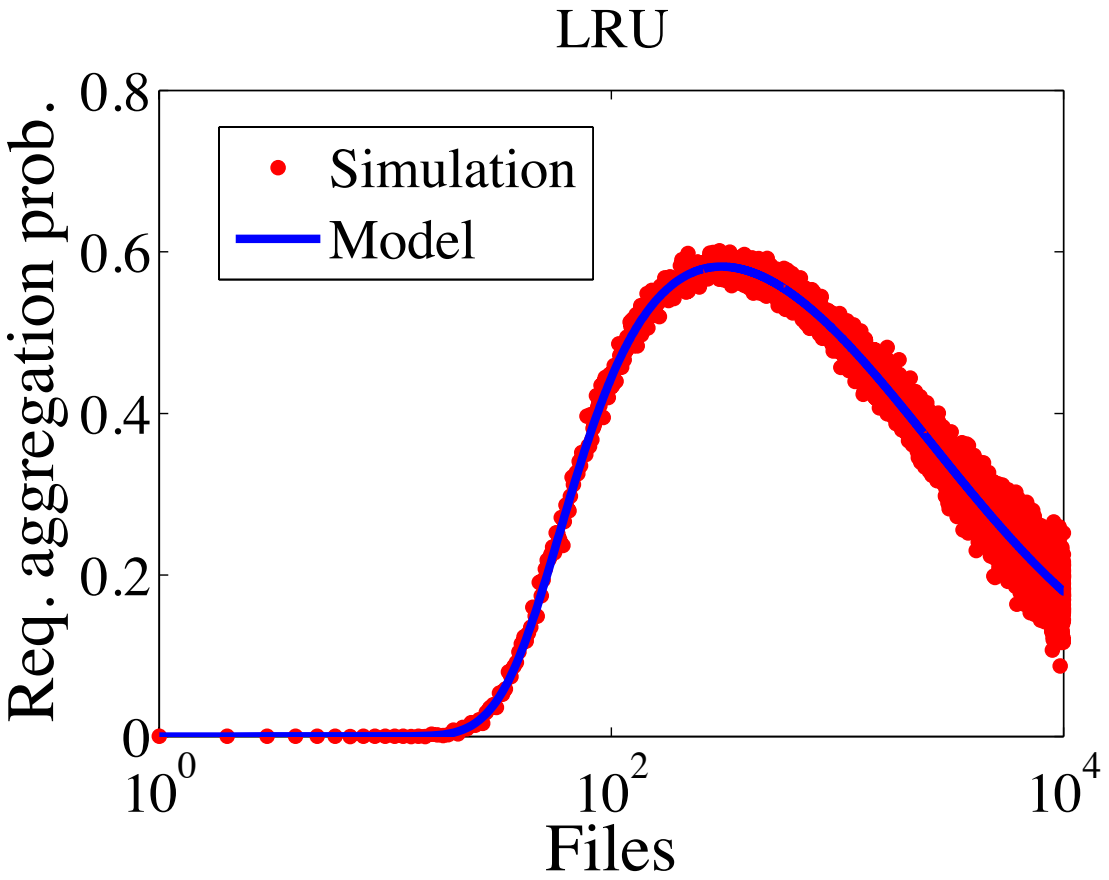
Result – Cache Hit Probability

- Average hit probability vs. download delay



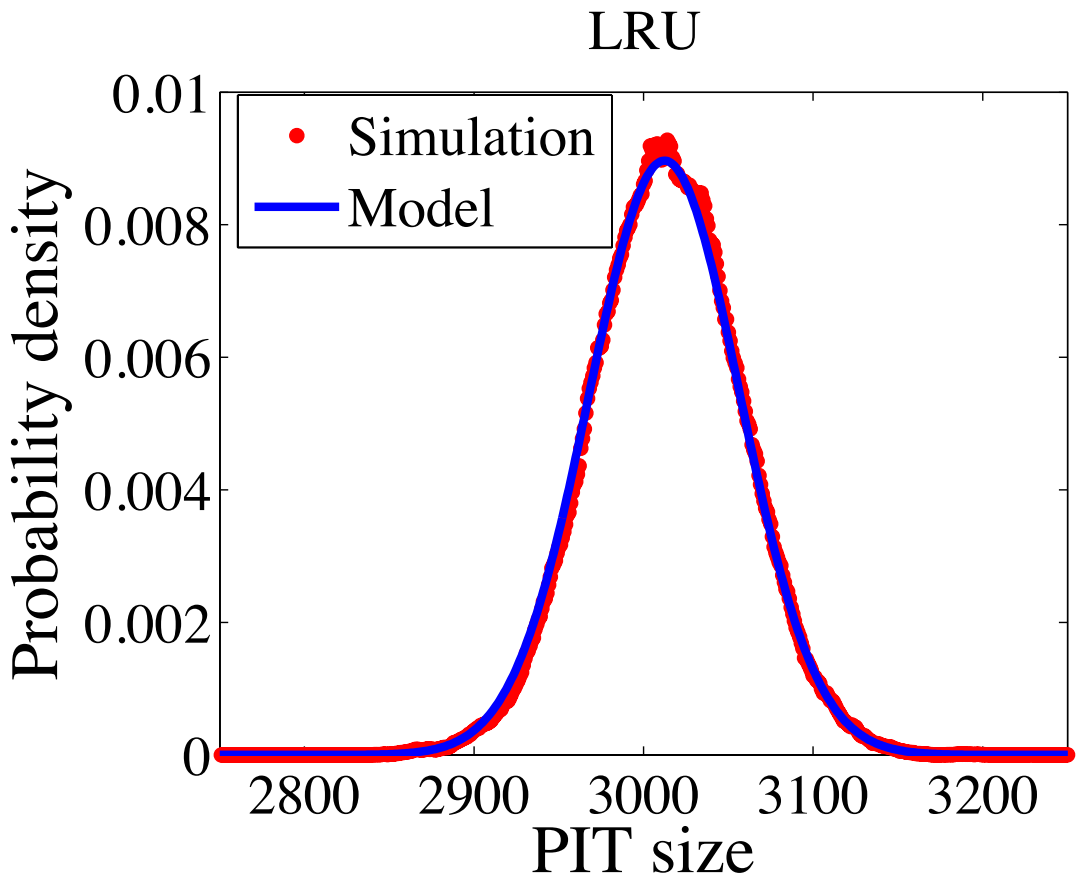
Result – Request Aggregation

- PIT occupancy probability for individual files ($D = 100$ ms)



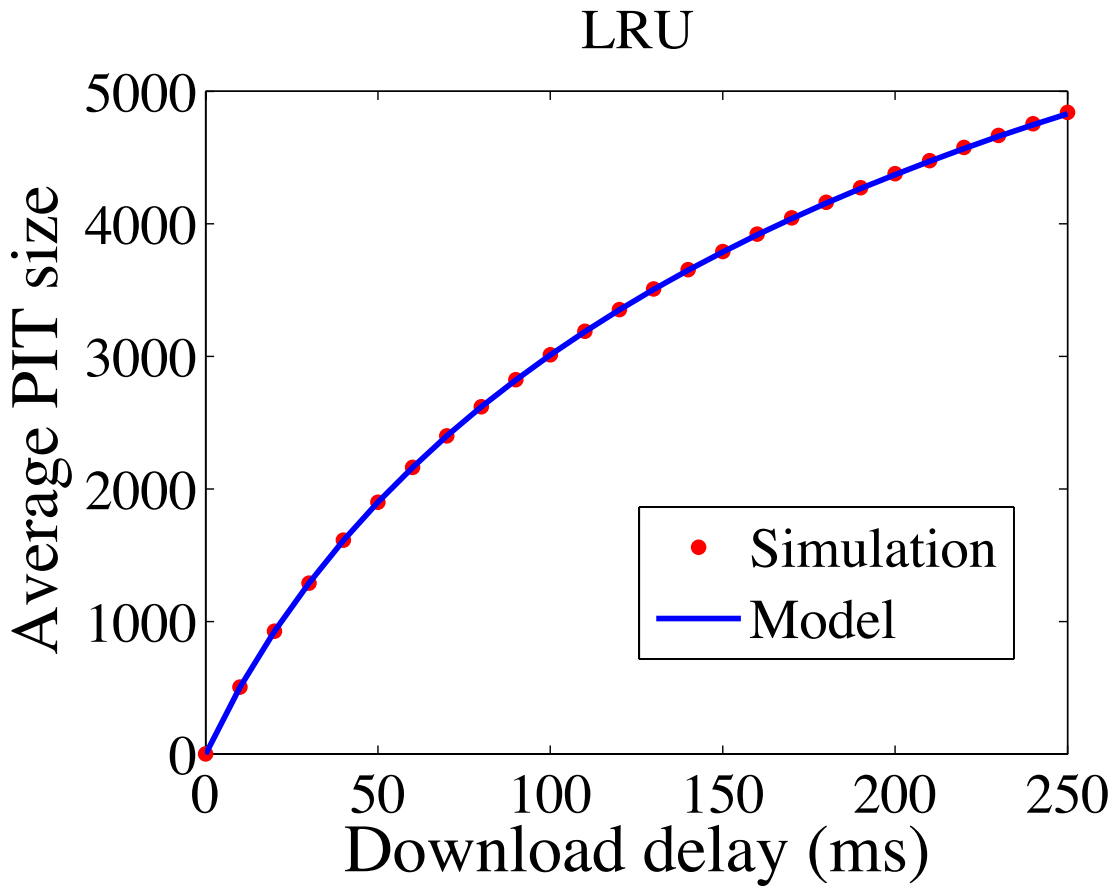
Result – PIT Size

- PIT size distribution



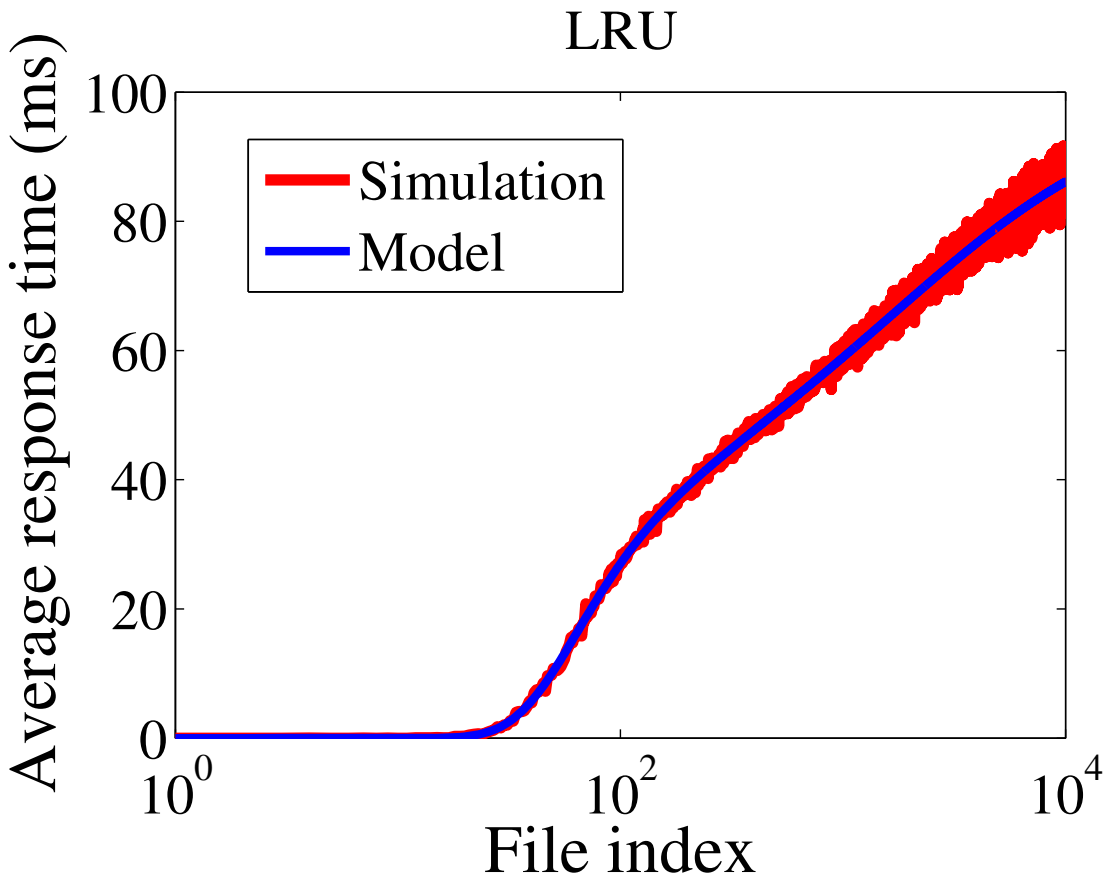
Result – PIT Size

- Average PIT size vs. download delay



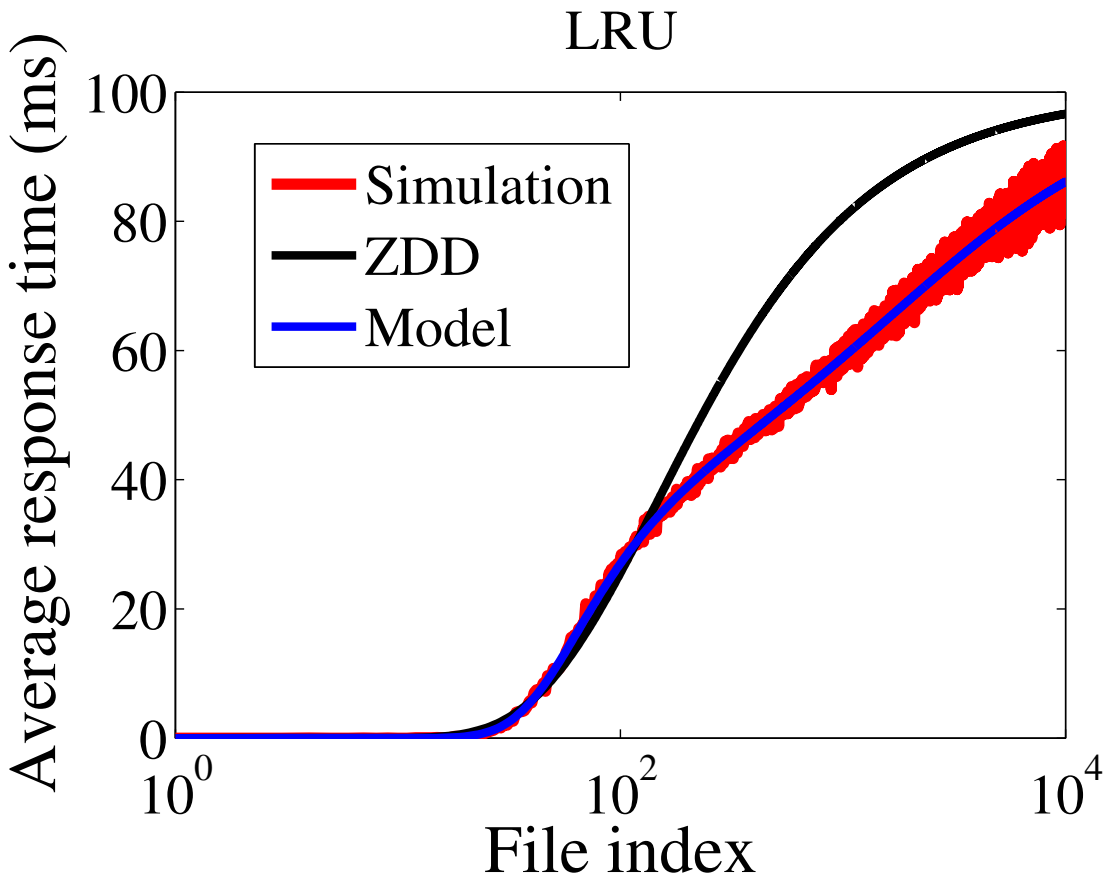
Result – Cache Response Time

- Response time for individual files ($D = 100$ ms)



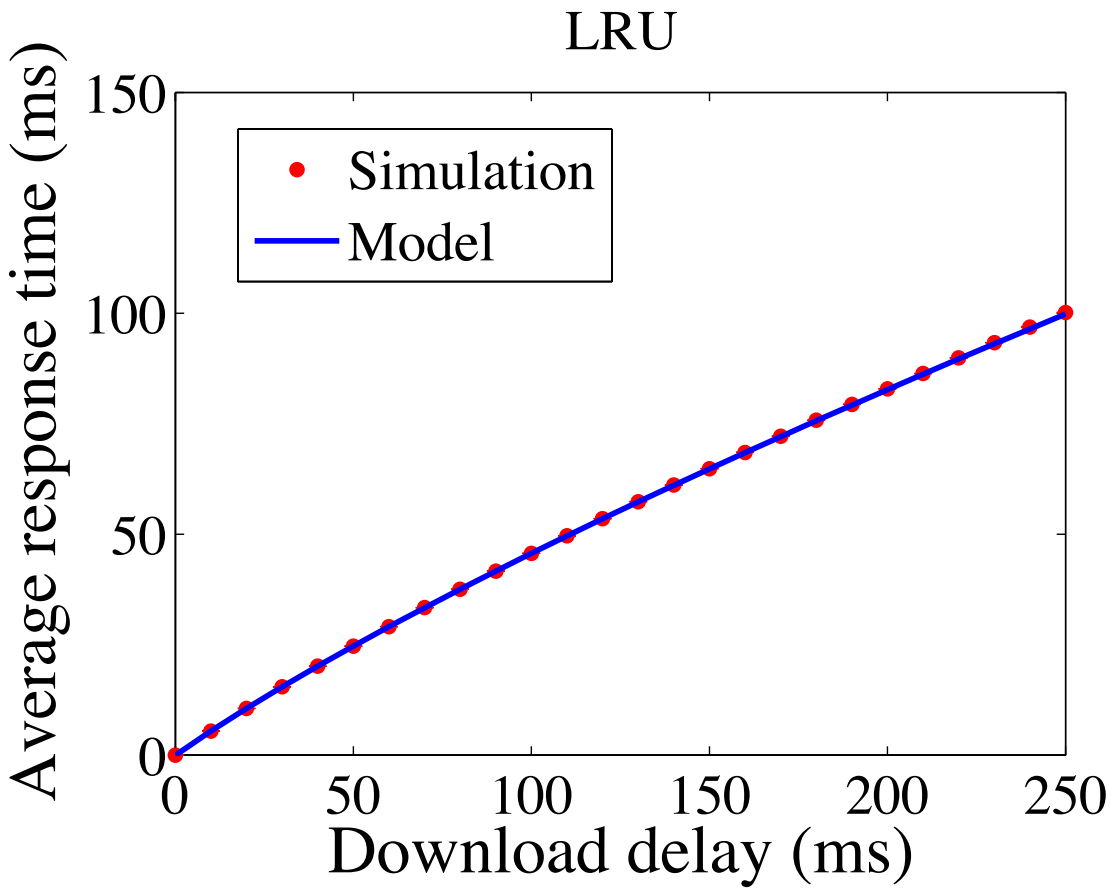
Result – Cache Response Time

- Response time for individual files ($D = 100$ ms)



Result – Cache Response Time

- Average response time vs. download delay

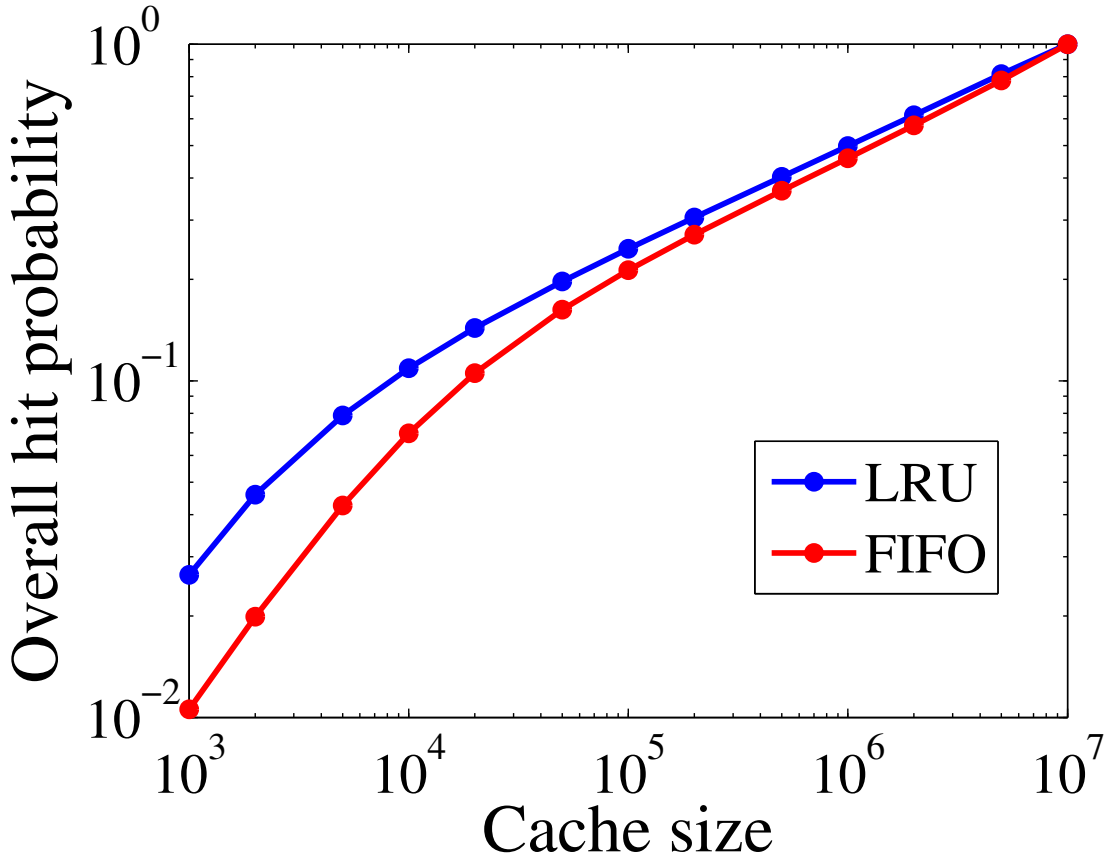


Numerical Results

- Cache size = 10^4
- # different files = 10^7
- Requests: Poisson process w/ rate $\lambda = 10^5$ per second
- File popularity: Zipf distribution, $\lambda_i \propto i^{-0.8}$
- Download delay: 100 ms
- Model only – no simulations

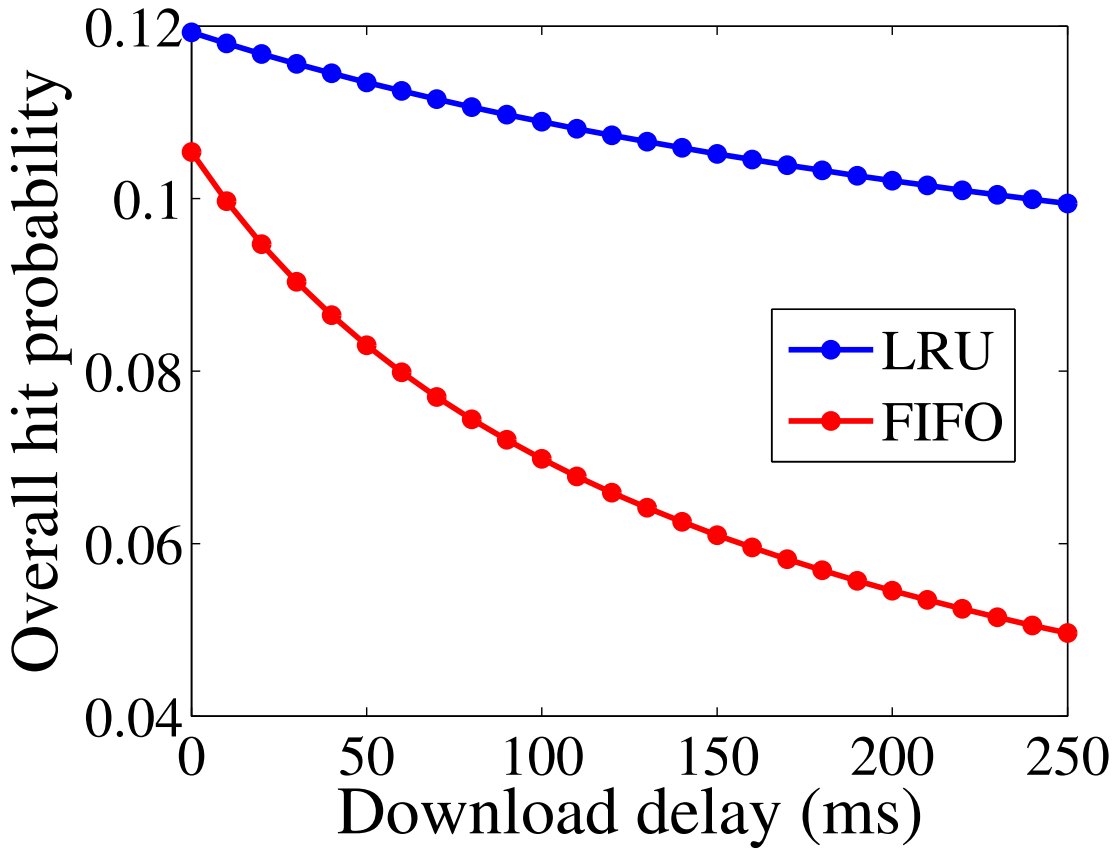
Result – Cache Hit Probability

- Average hit probability vs. cache size



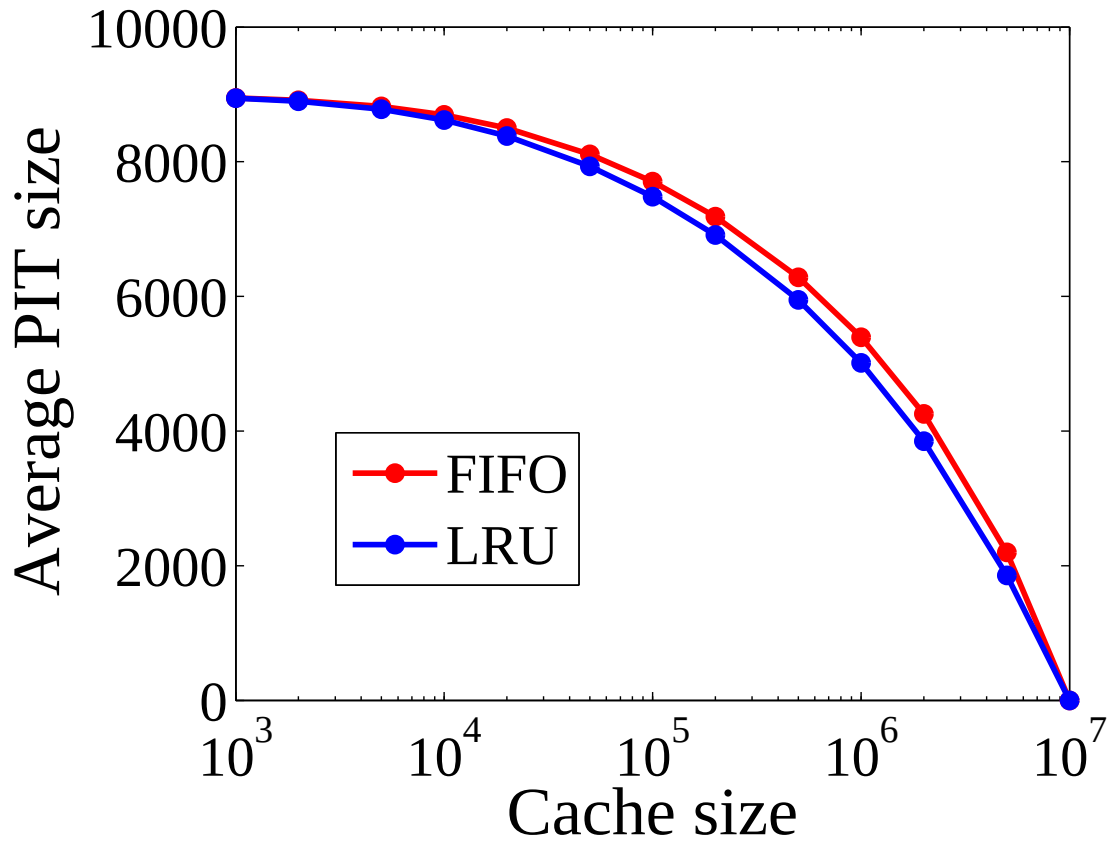
Result – Cache Hit Probability

- Average hit probability vs. download delay



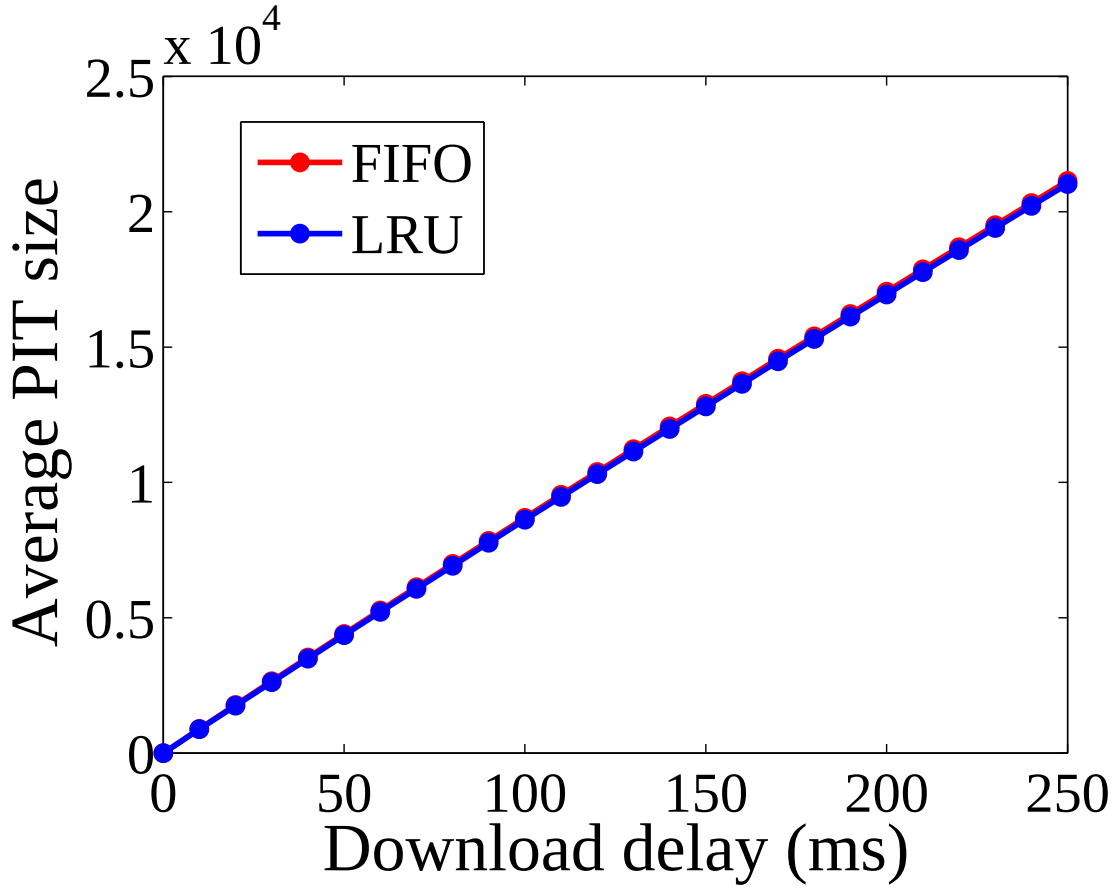
Result – PIT Size

- Average PIT size vs. cache size



Result – PIT Size

- Average PIT size vs. download delay



Summary

- Conclusions:
  - Modeled cache with PIT and non-zero download delay
    - Cache hit probability
    - PIT size
    - Cache response time
  - Analysis based on TTL caches
    - LRU, FIFO and Random
  - Characteristic time holds with positive download delay
- Future Work:
  - Requests arriving for chunks of files (e.g. streaming video)
  - Different scales of download delays