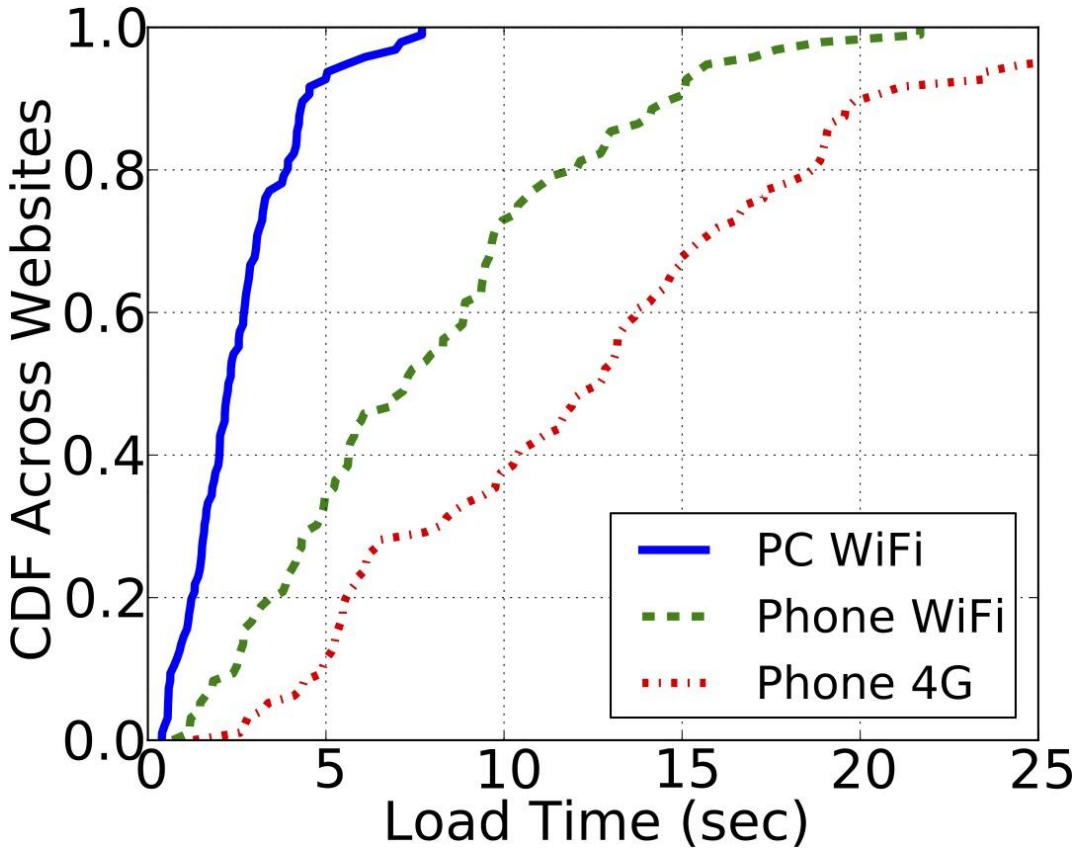
Klotski: Reprioritizing Web Content to Improve User Experience on Mobile Devices

Michael Butkiewicz♕, Daimeng Wang♕,
Zhe Wu♖, Harsha V. Madhyastha♖, Vyas Sekar♘

♕ UC Riverside ♖ University of Michigan ♘ CMU

Motivation: Slow Mobile Web



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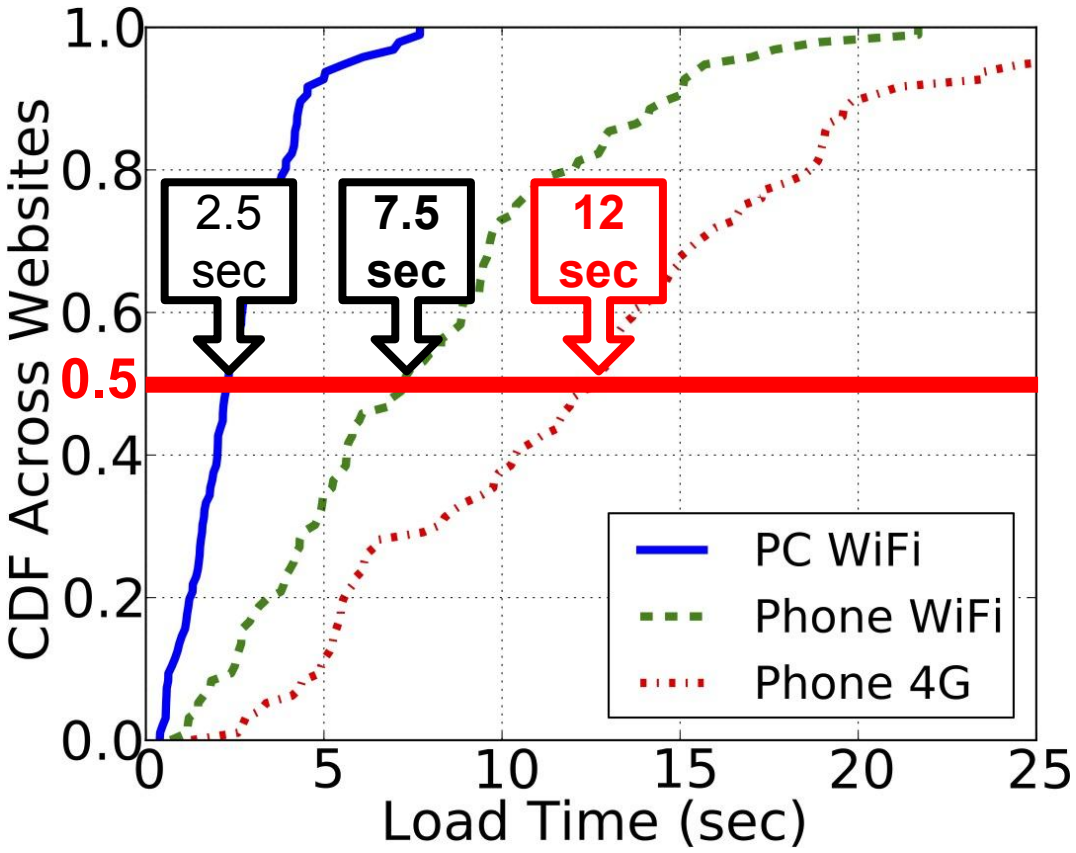

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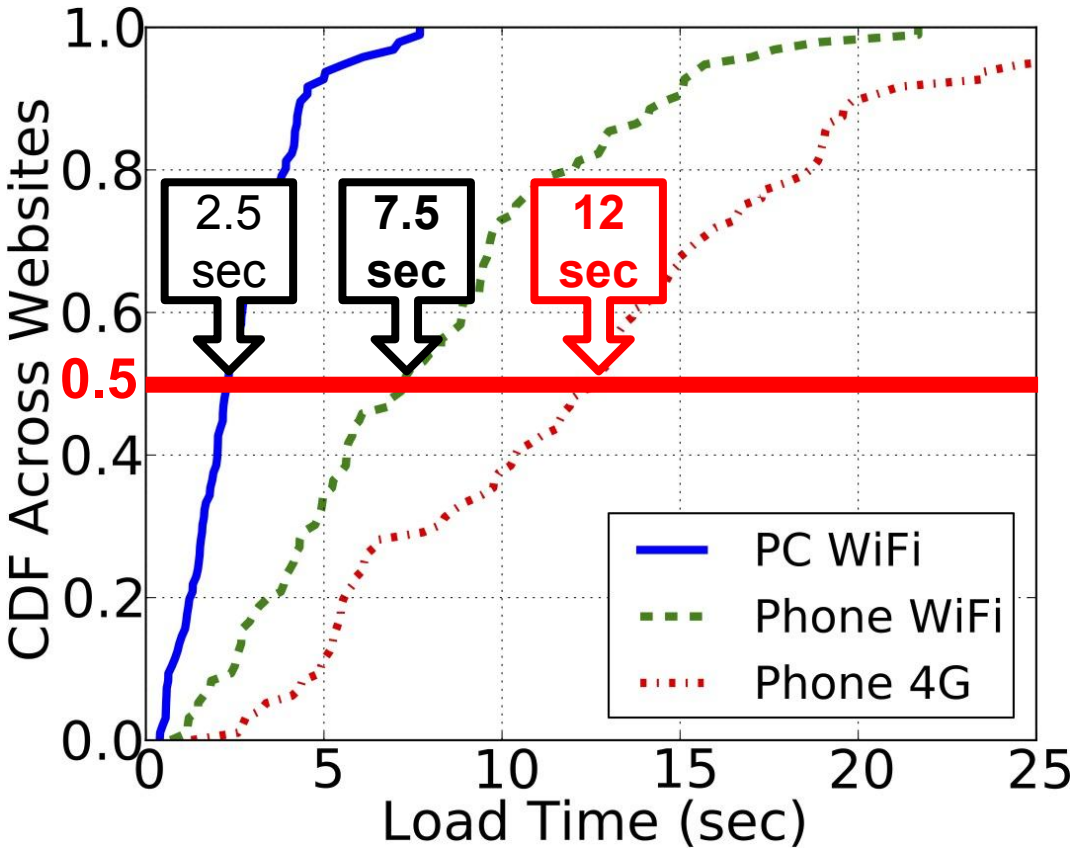

Slow page loads → Less users, Lost business

Wide Range of Existing Solutions

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Compression

Caching

Wide Range of Existing Solutions

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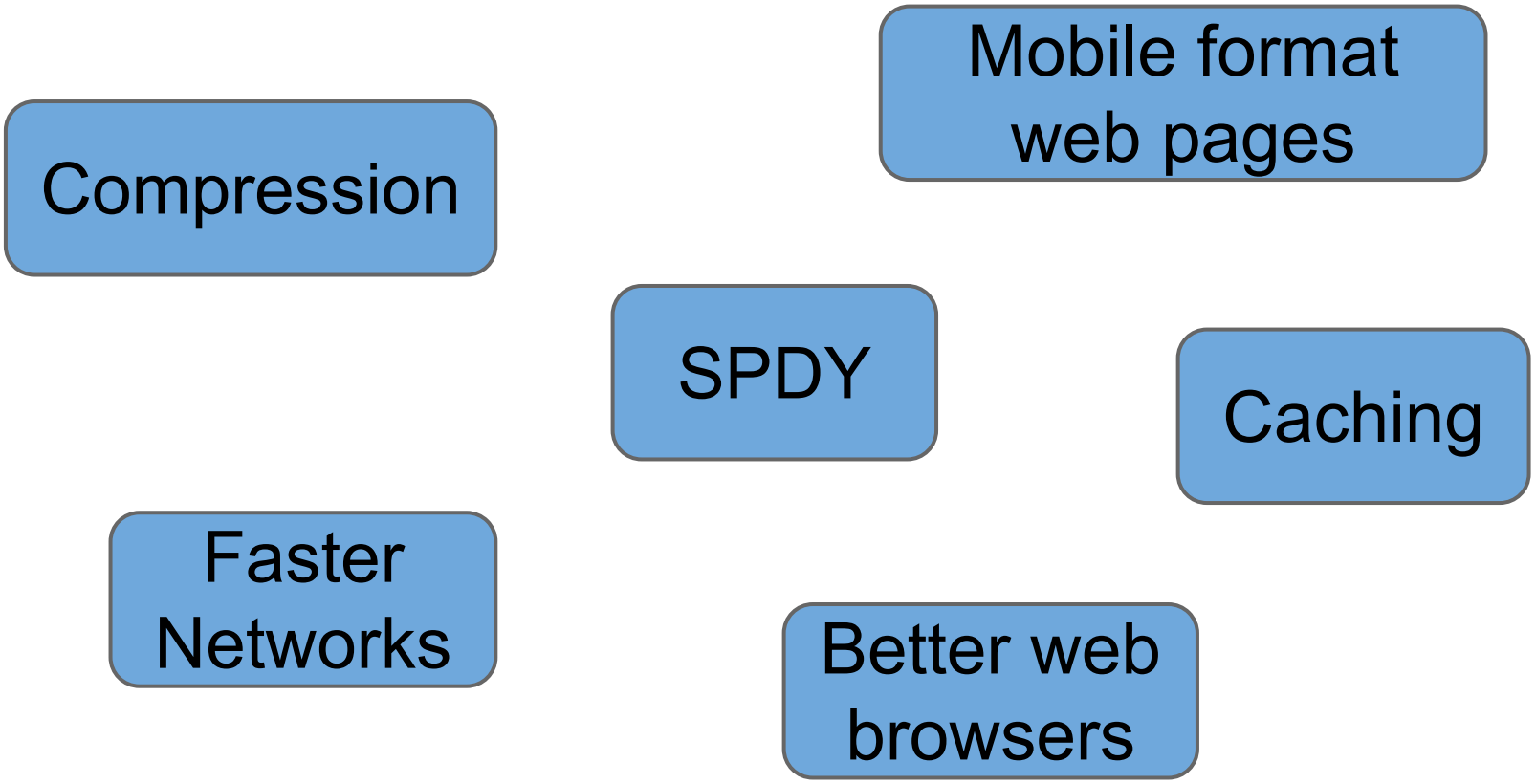
Mobile format web pages

SPDY

Caching

Wide Range of Existing Solutions



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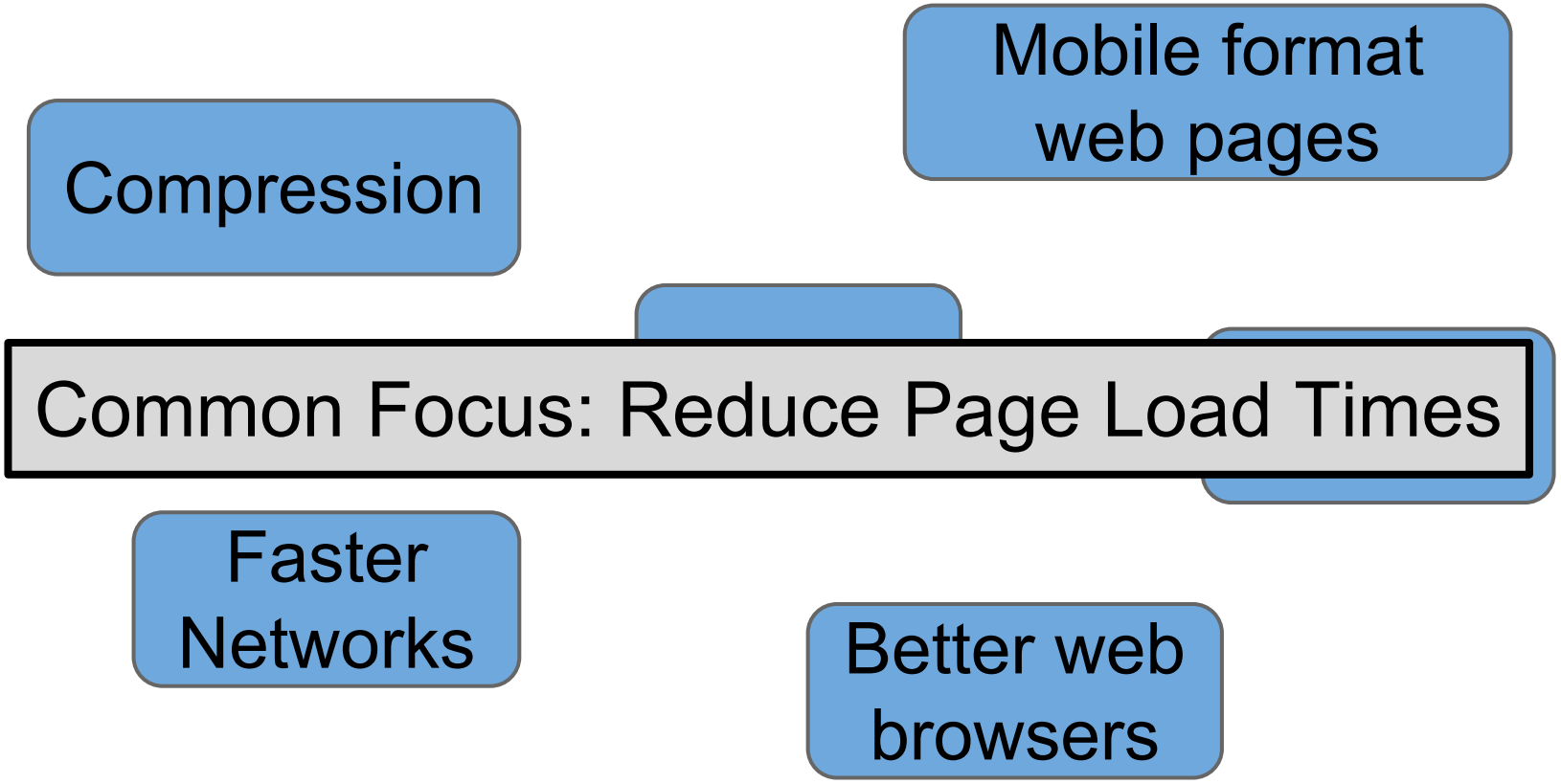
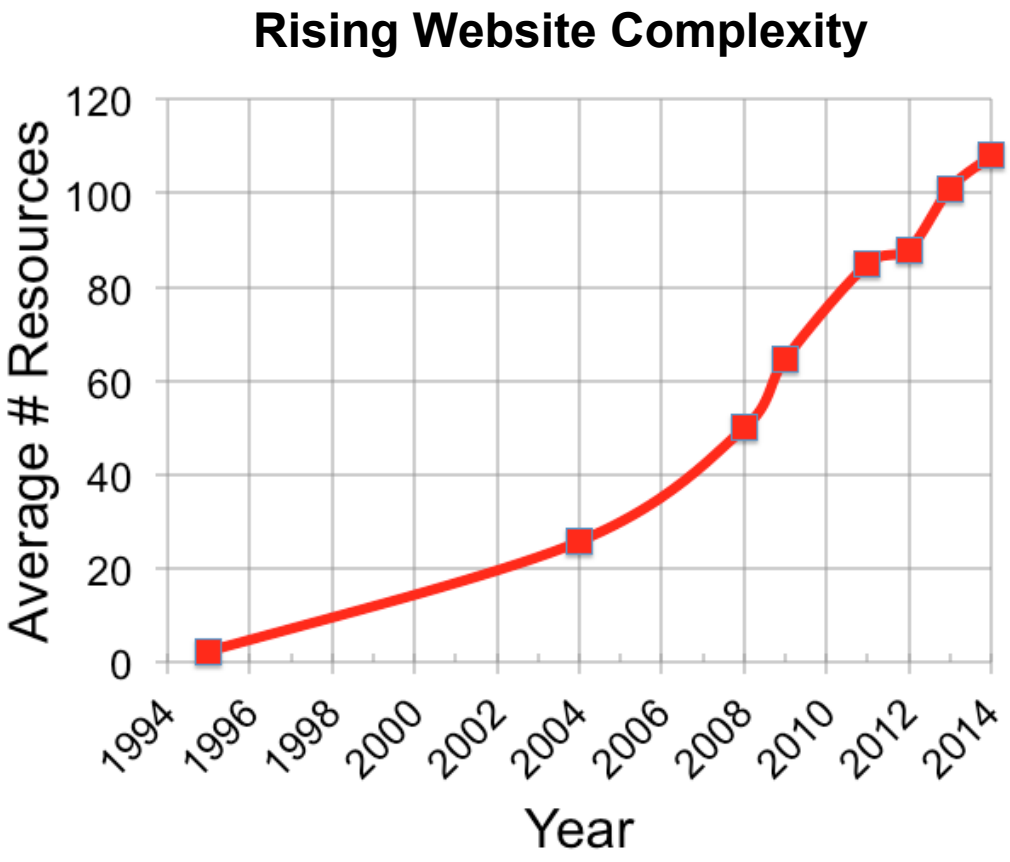
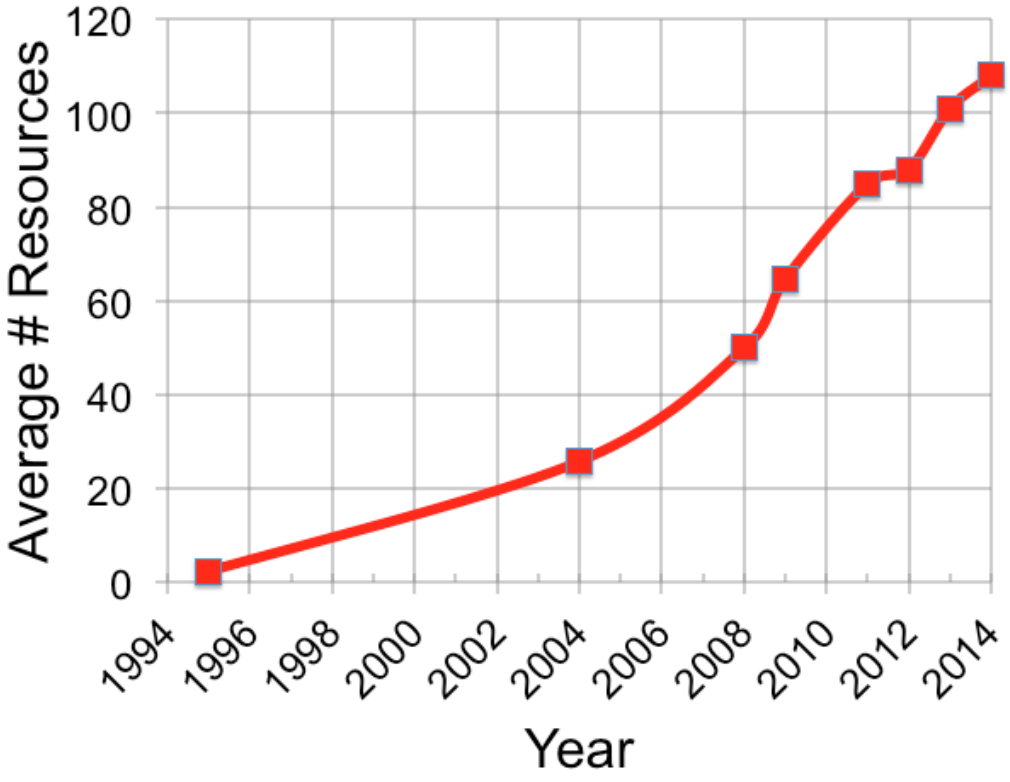


Reducing Load Time is Not Enough

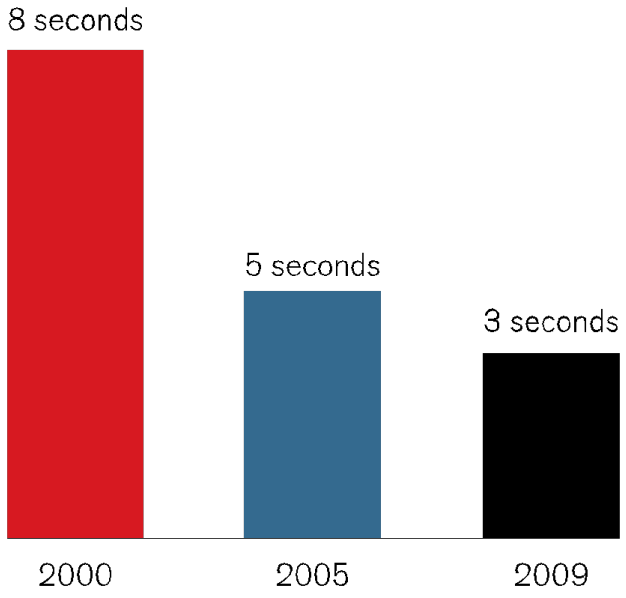


Reducing Load Time is Not Enough

Rising Website Complexity



Falling User Tolerance



Source: Akamai

Our Approach:
Dynamic Reprioritization

- Forseeable Future: High load times norm, not exception

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  How to reduce page load time?

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  - Typical tolerance limit of 2-4 seconds
  - Deliver “high utility” resources within time budget

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- Reformulate the problem:

  ~~How to reduce page load time?~~

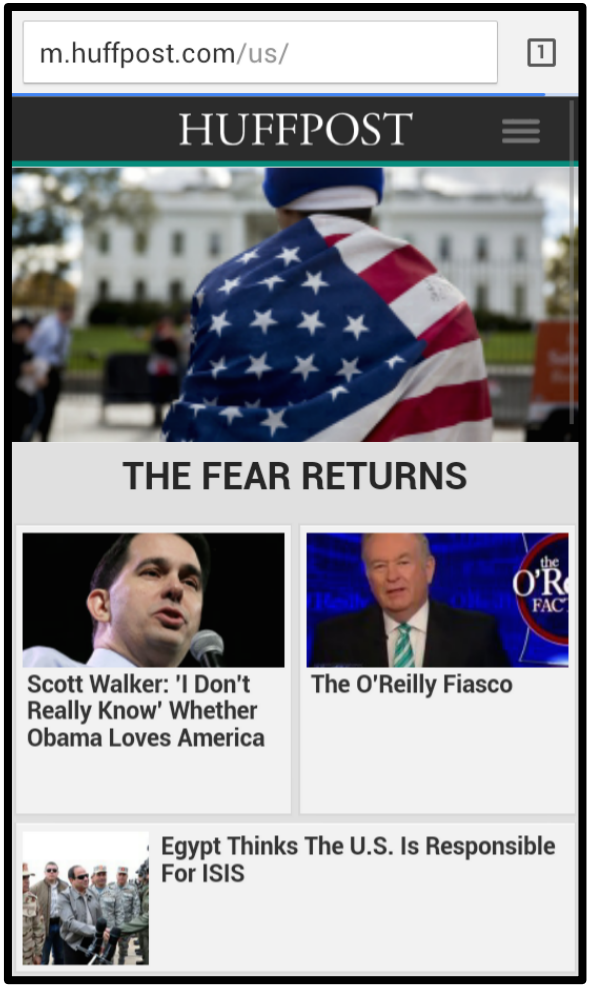
  How to ***Prioritize*** the content most ***important*** to user?

  - Typical tolerance limit of 2-4 seconds
  - Deliver “high utility” resources within time budget
- Our solution: Klotski proxy
  - No modifications to clients and web servers!

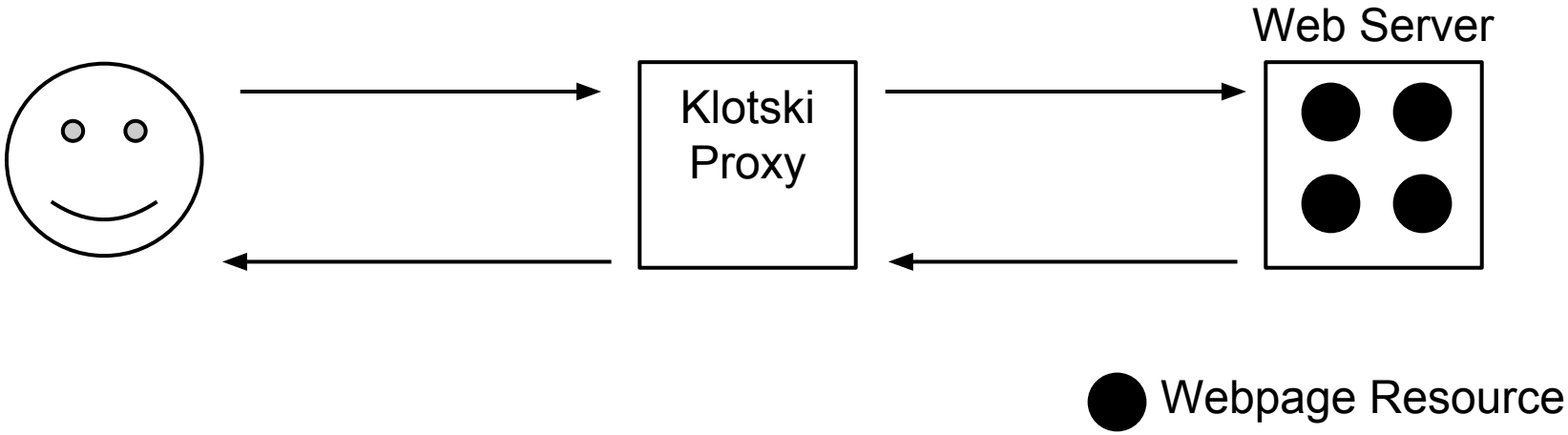
Klotski in Action!

Original Page Load at 3s

Klotski Page Load at 3s



Klotski: Idealized View



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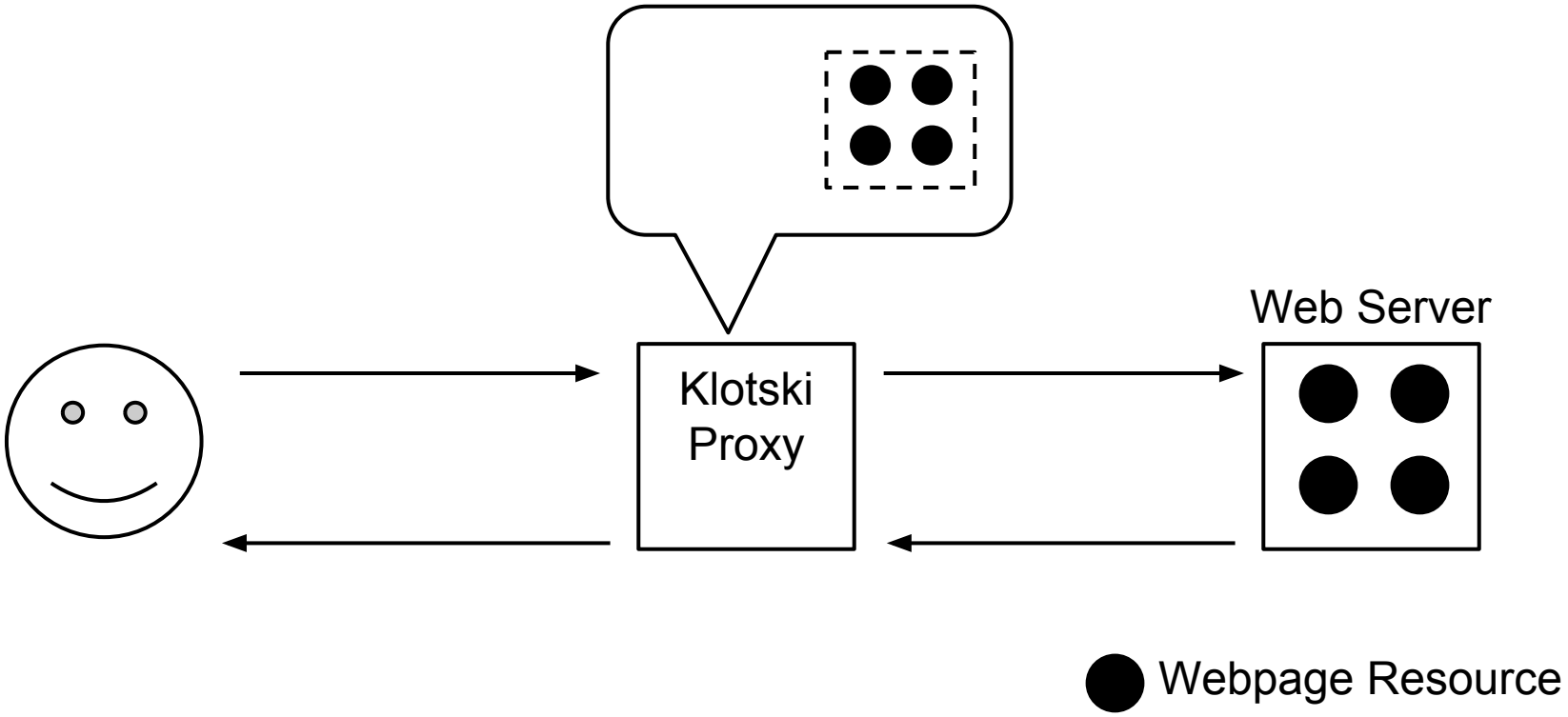

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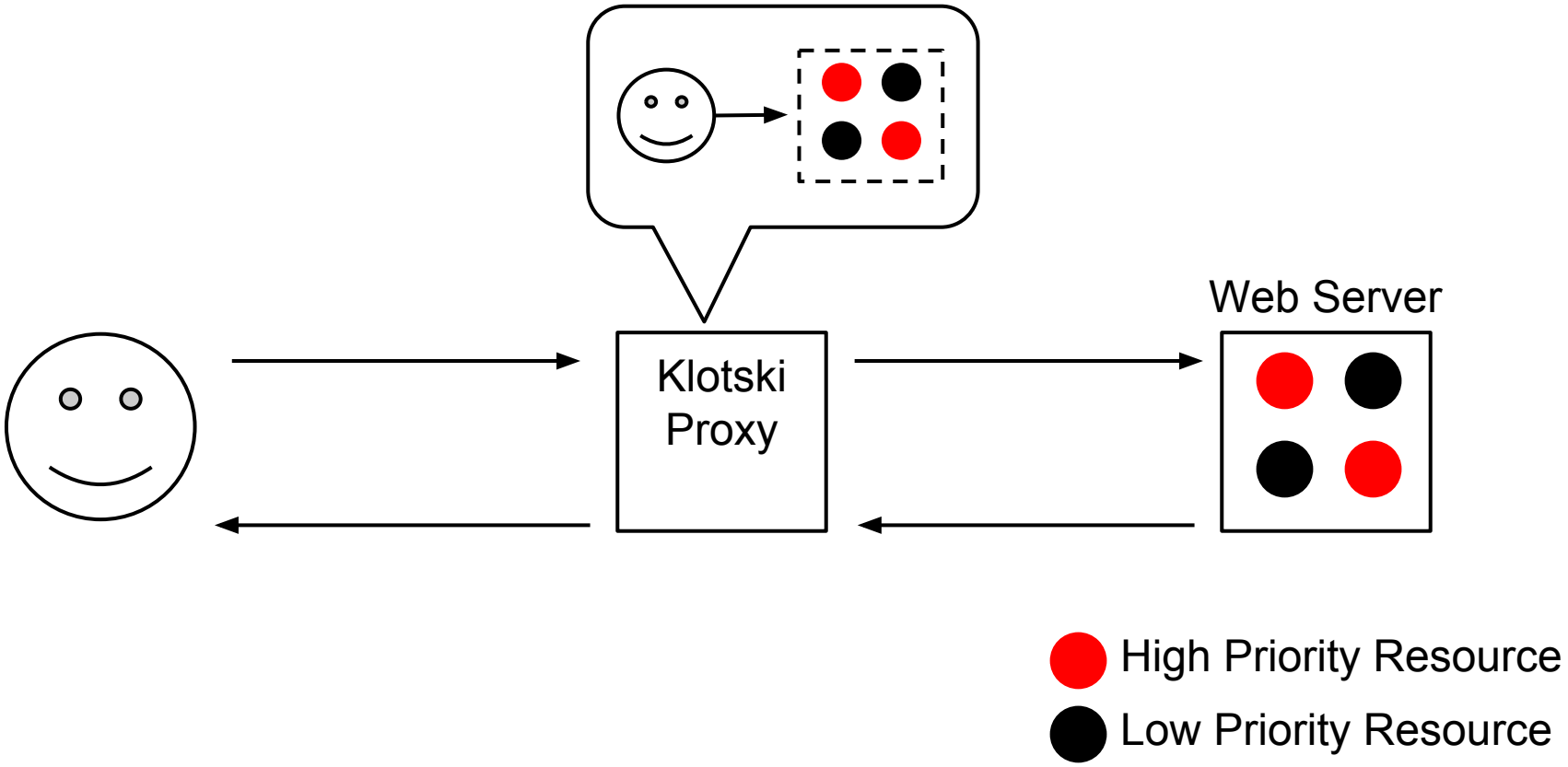

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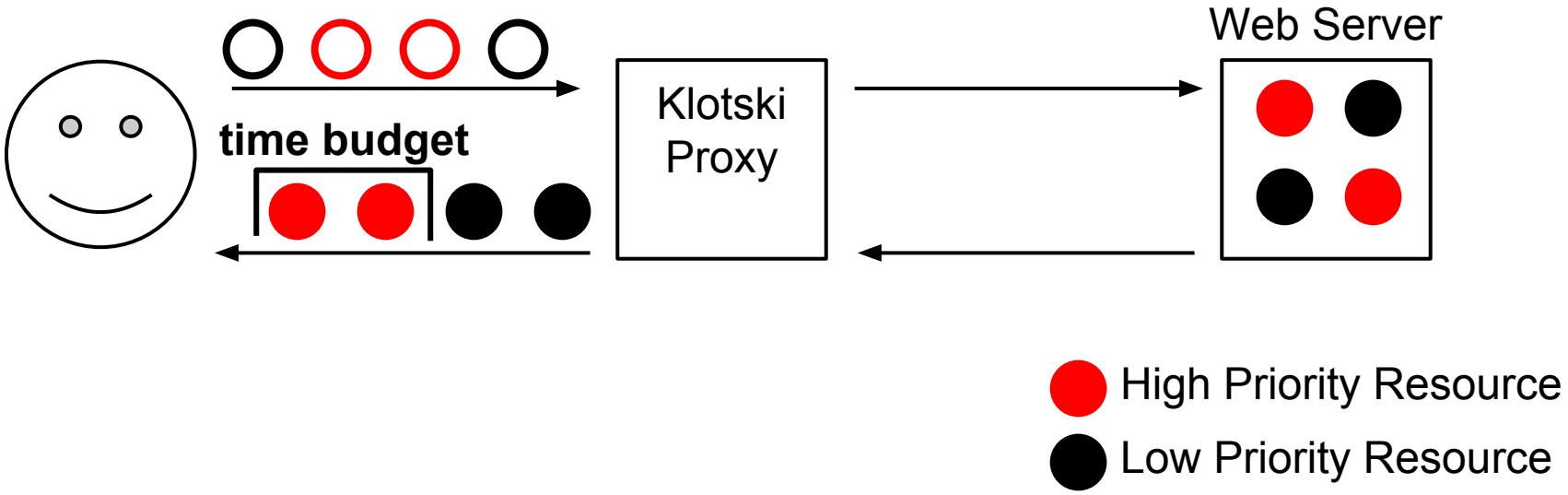
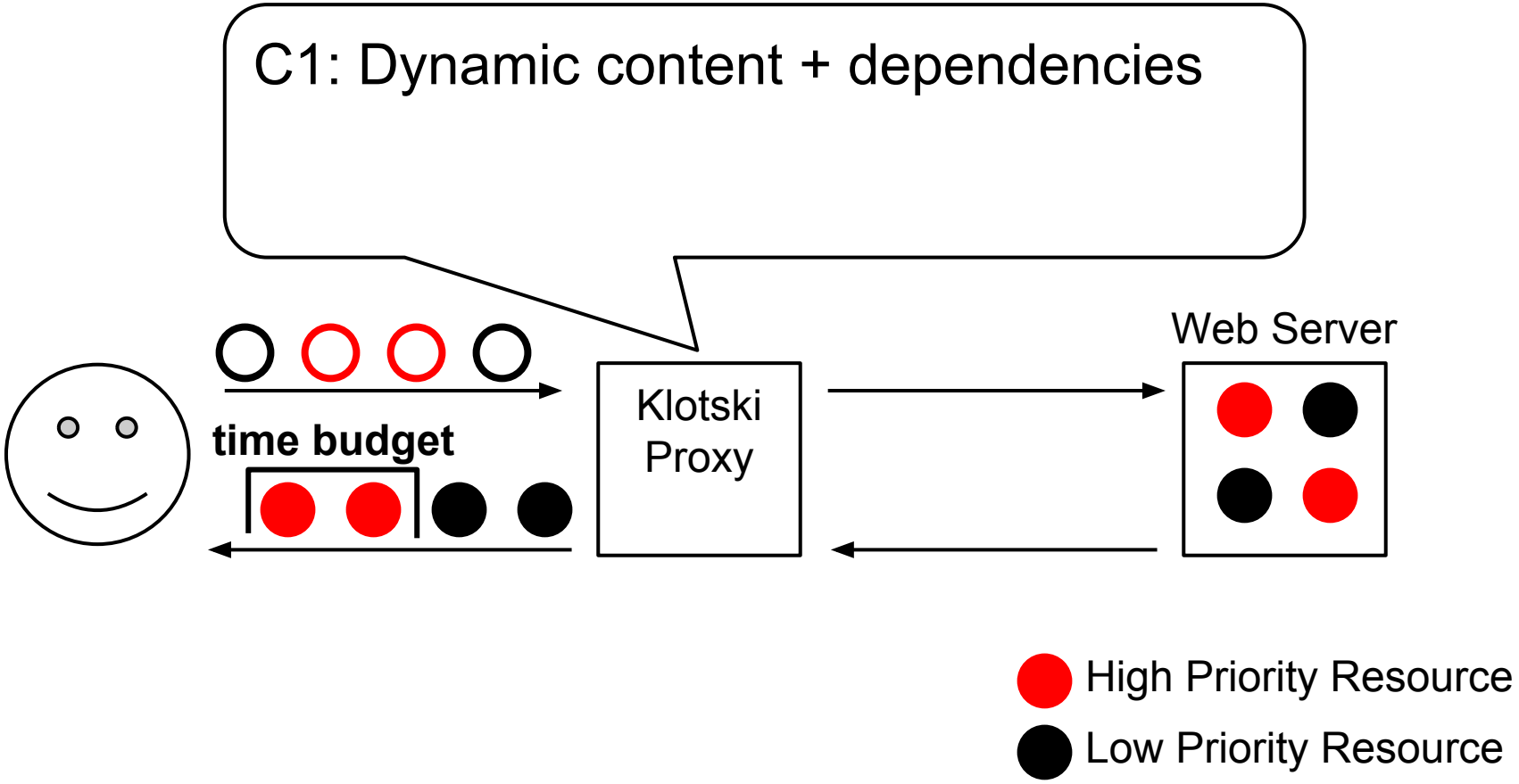


Challenges with Idealized View



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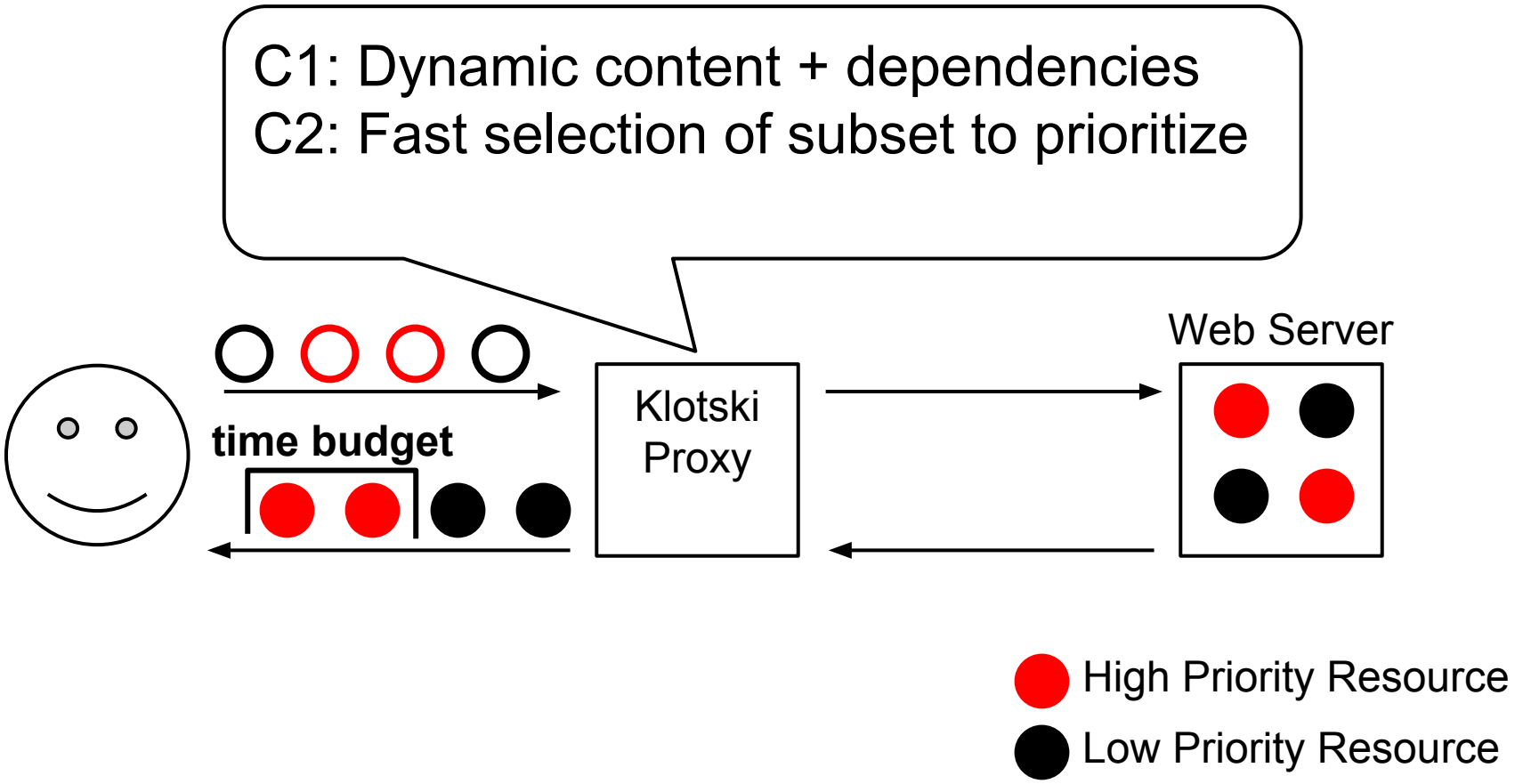

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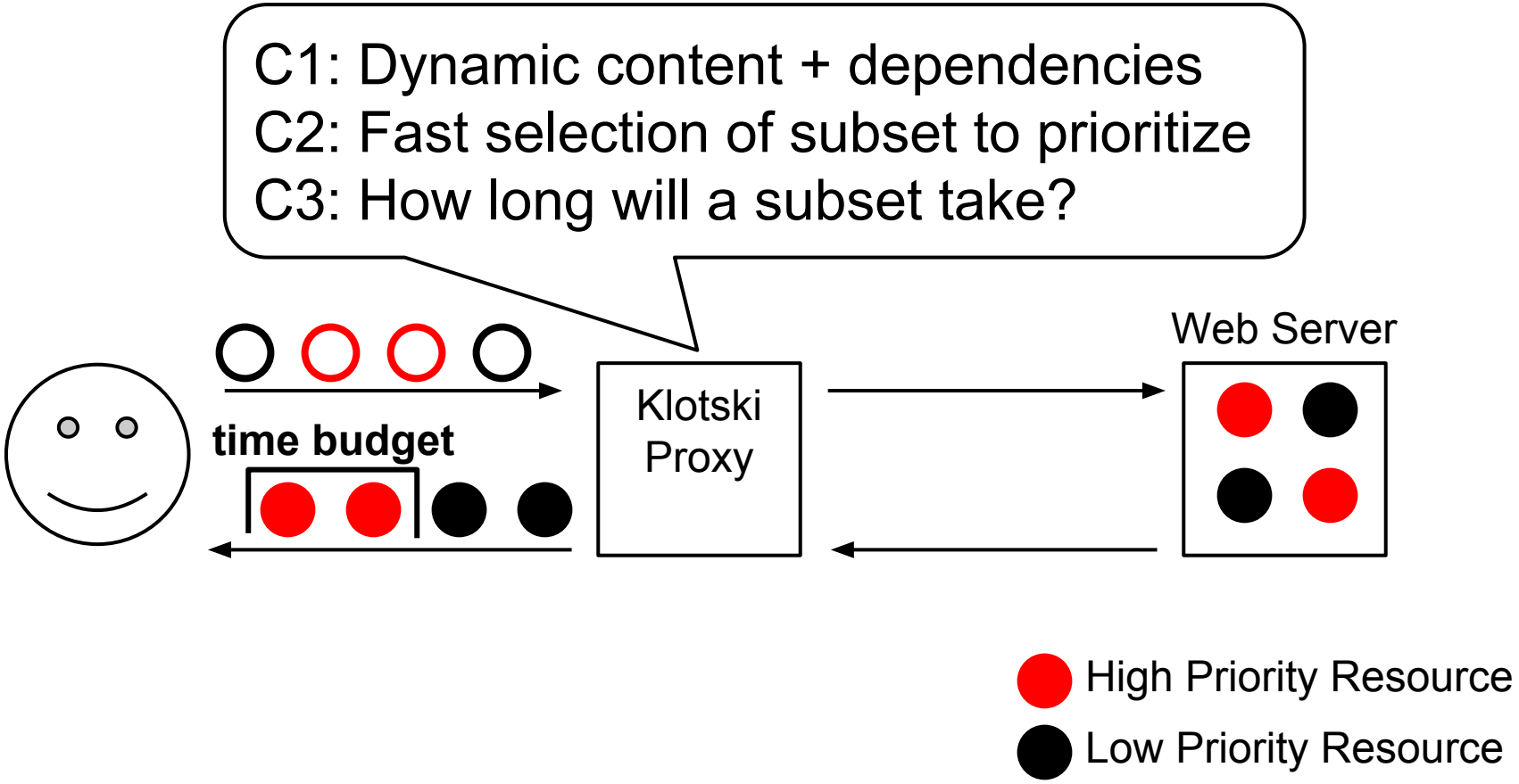
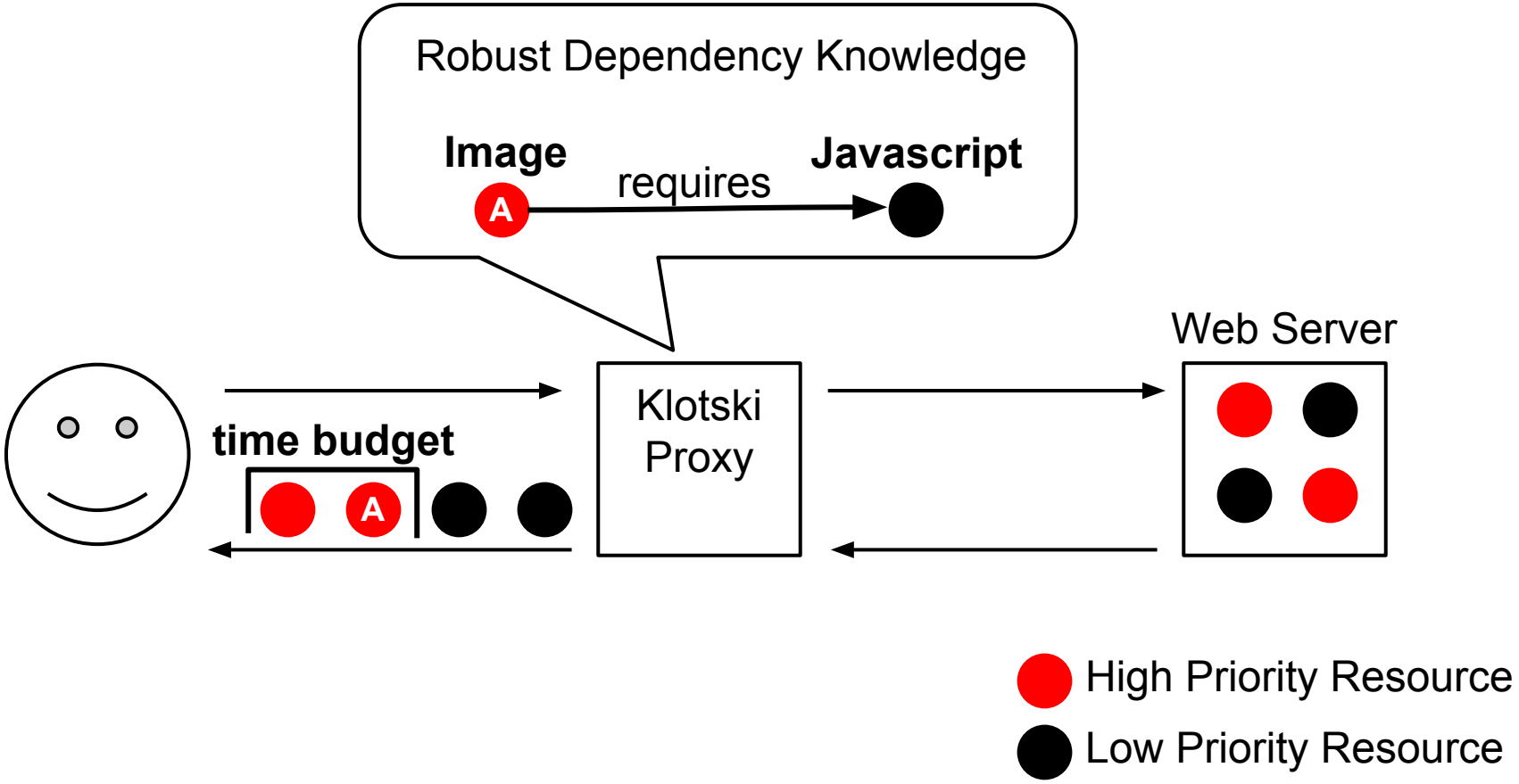
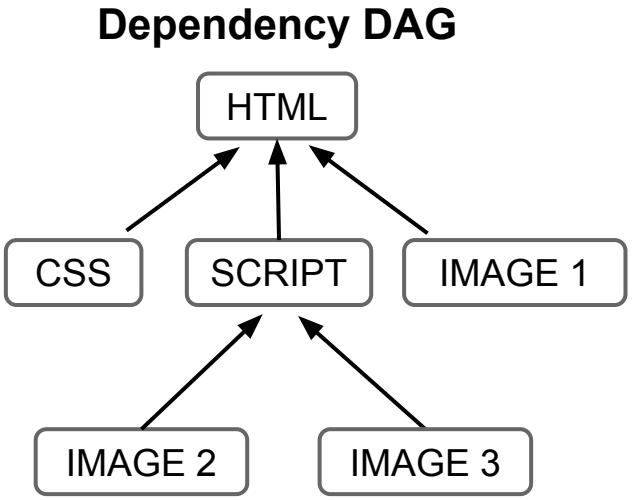


Challenge 1:
Dynamic Content and Dependencies



Intuition: Page structure is stable



- Prior work on static dependencies
  - E.g., WebProphet, WProf

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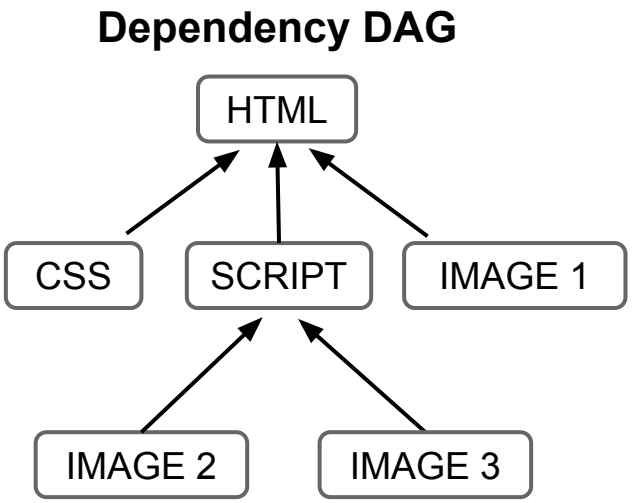

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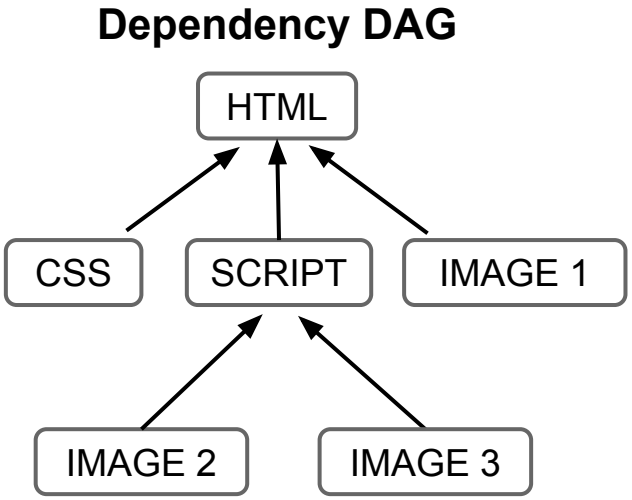
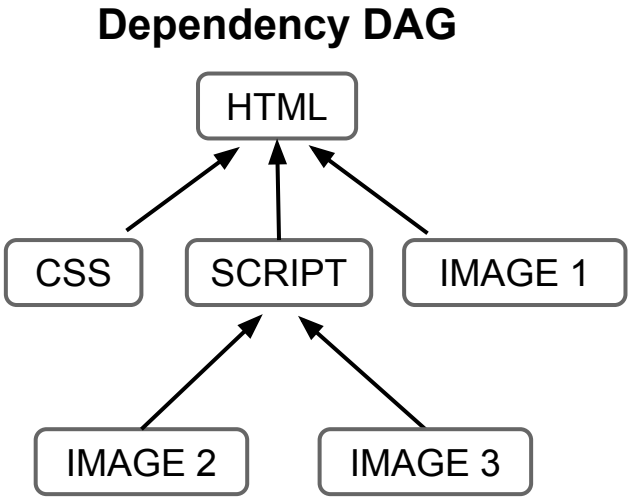


- Prior work on static dependencies
  - E.g., WebProphet, WProf
- Problem: Dependencies not reusable due to dynamic content
- Our observation:
  - Nodes in DAG change
  - DAG structure largely stable

Intuition: Page structure is stable



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- Problem: Dependencies not reusable due to dynamic content
- Our observation:

Load page repeatedly to generate *fingerprint*:

- DAG structure with a URL pattern at every node
- Pattern generalizes URL of dynamic resources

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Learn URL Patterns

- Generalize known prior URLs of a dynamic resource

foo.com/SG39HZ78/a.js
foo.com/SHFS2732/a.js
⟶ foo.com/*/a.js

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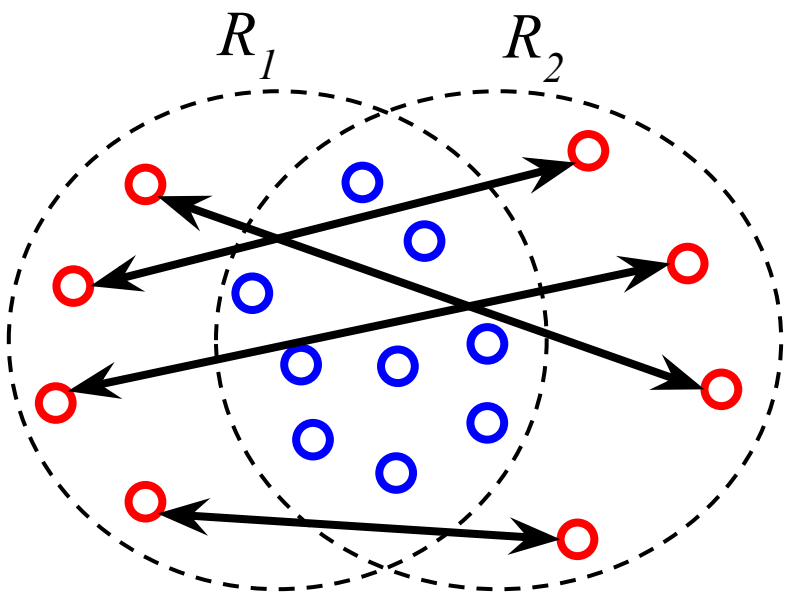
- 3 Cases = 90% of Replacements:
  - Single token in URL changes
  - Only URL argument changes: www.site.org/a.js?FOO=1...
  - CDN node name: {CDN2.bar.com/x.jpg, CDN5.bar.com/x.jpg}

Identify Resource Replacements

- Capture set of prior URLs:
  Track Replacement of Resource
  over multiple page loads

Identify Resource Replacements



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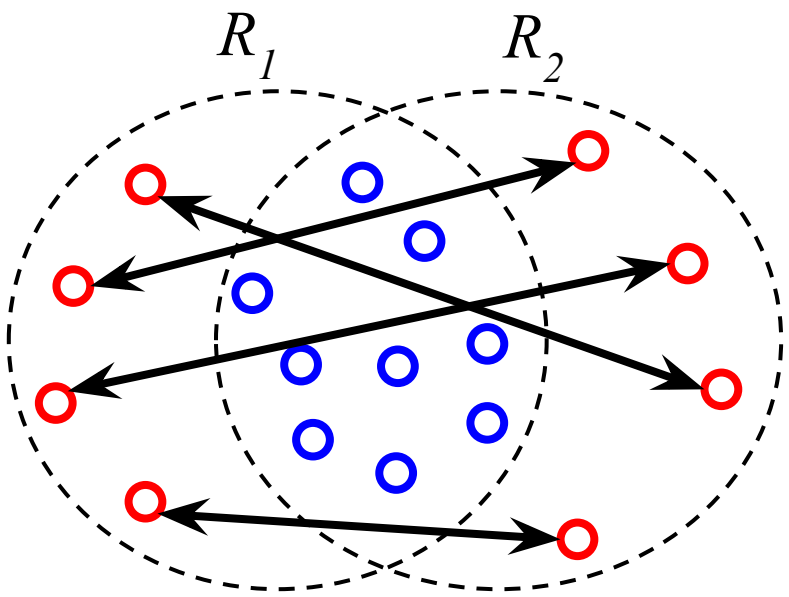

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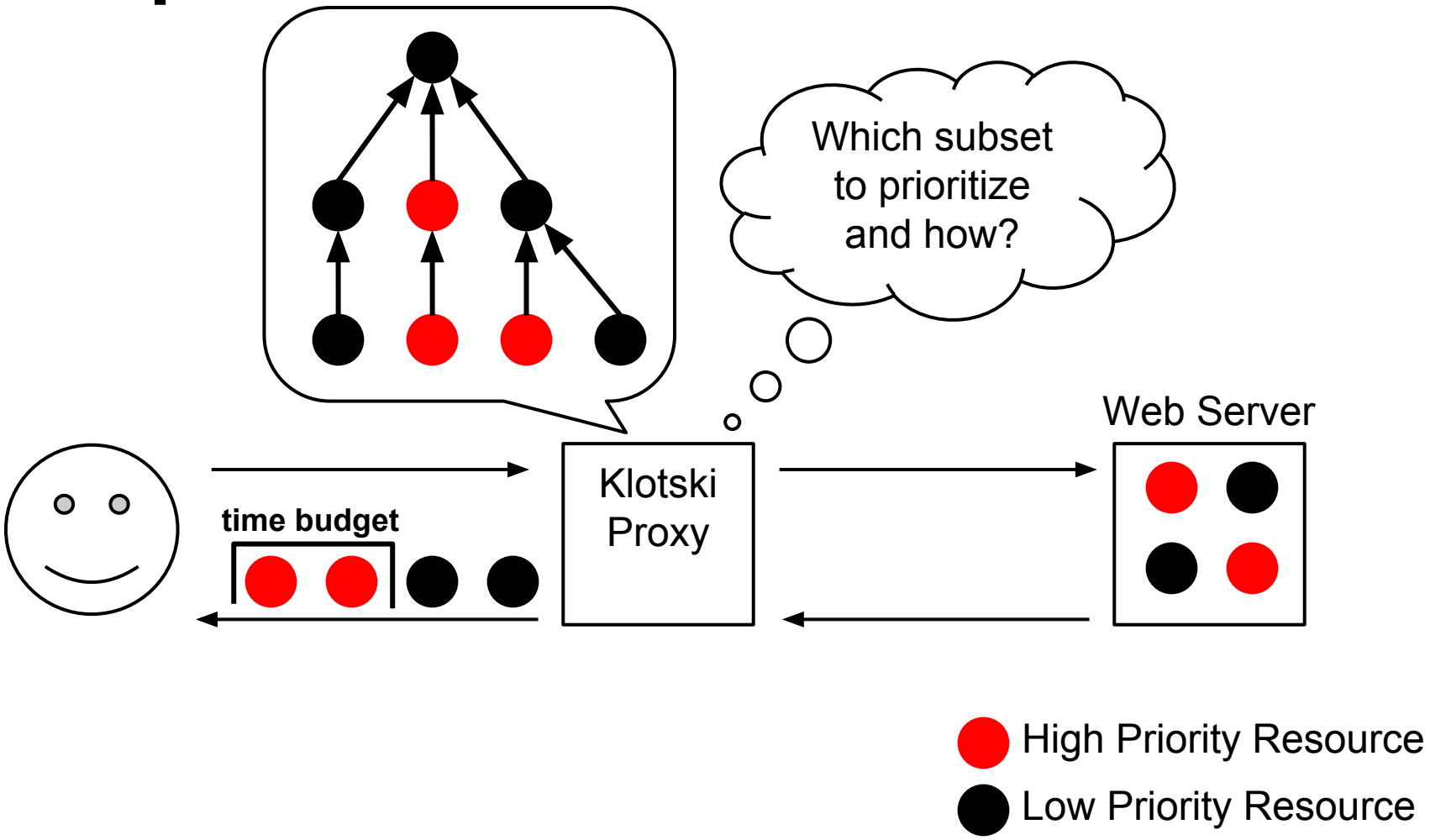
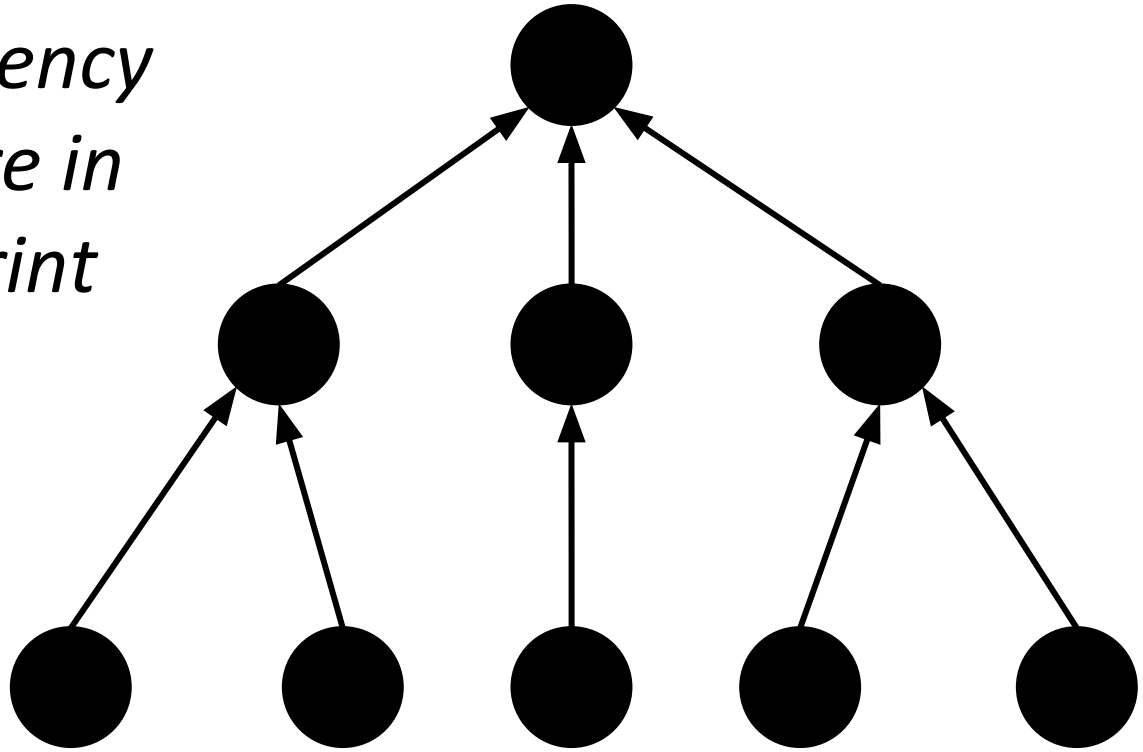
- Combination of techniques:
  - Match position in DAG dependency structure
  - Identical position on screen
  - Identical reference in source

Challenge 2: Optimal Prioritization Schedule



Select Subset of High Utility Resources

Dependency structure in fingerprint



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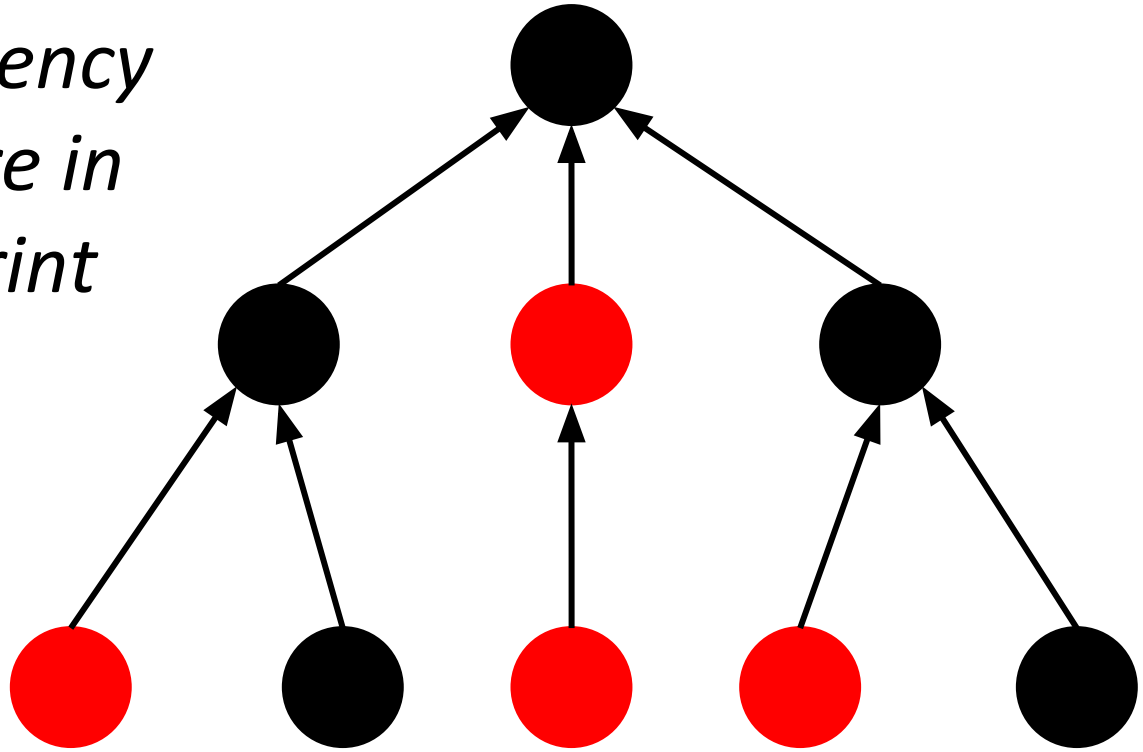

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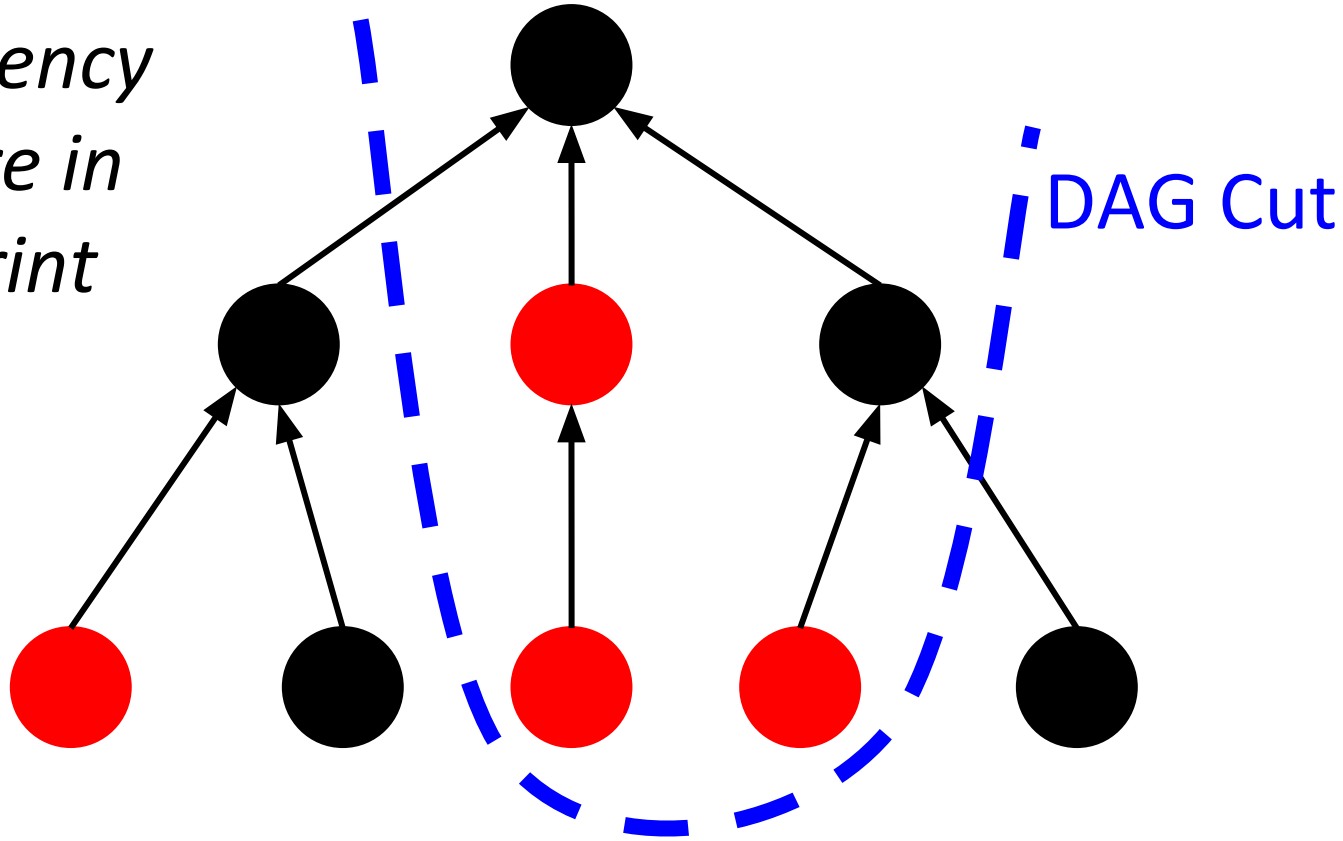


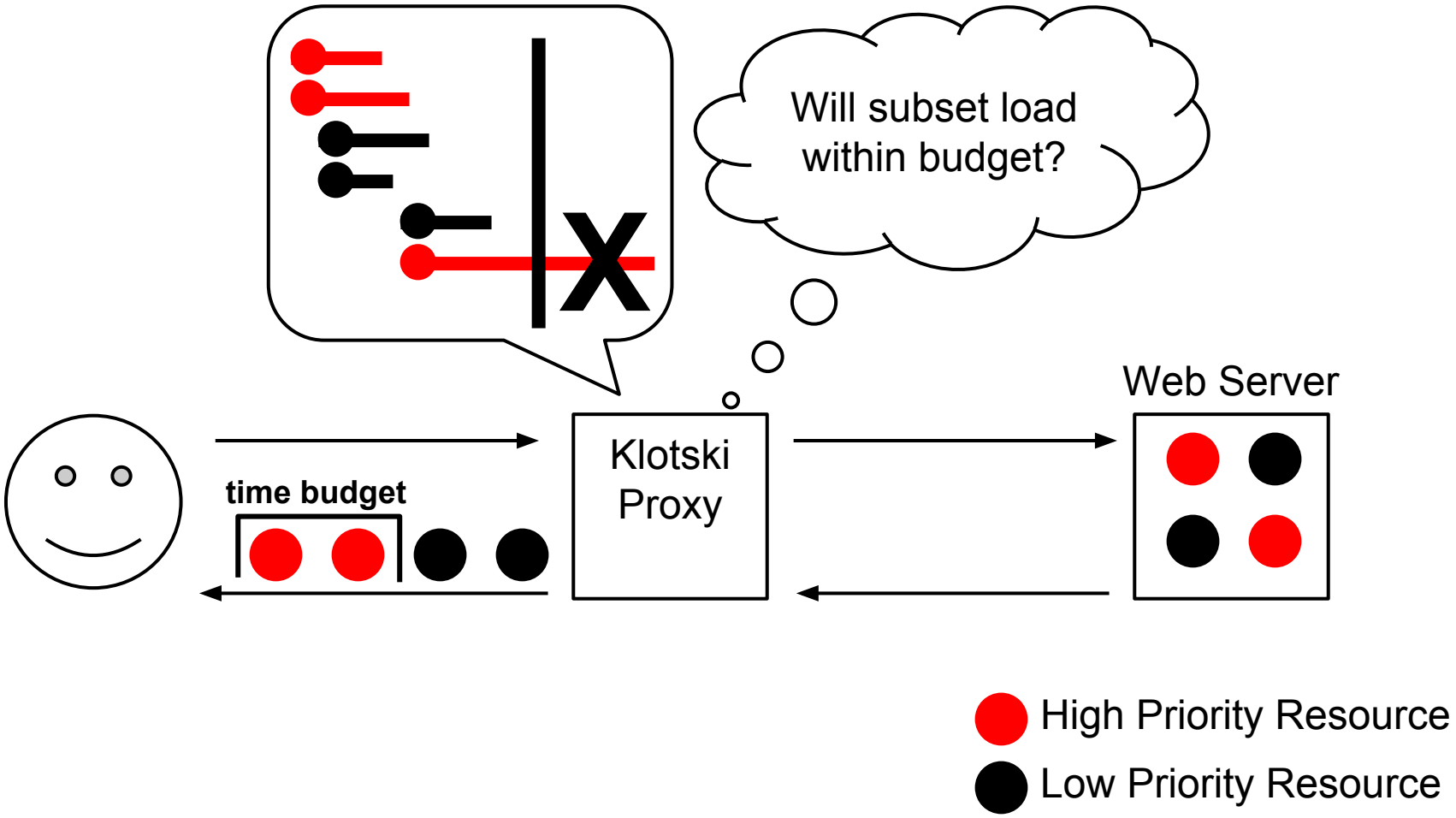
- Reduces to knapsack with dependencies: NP-Hard
- Apply greedy heuristic

Prioritizing High-Utility Resources

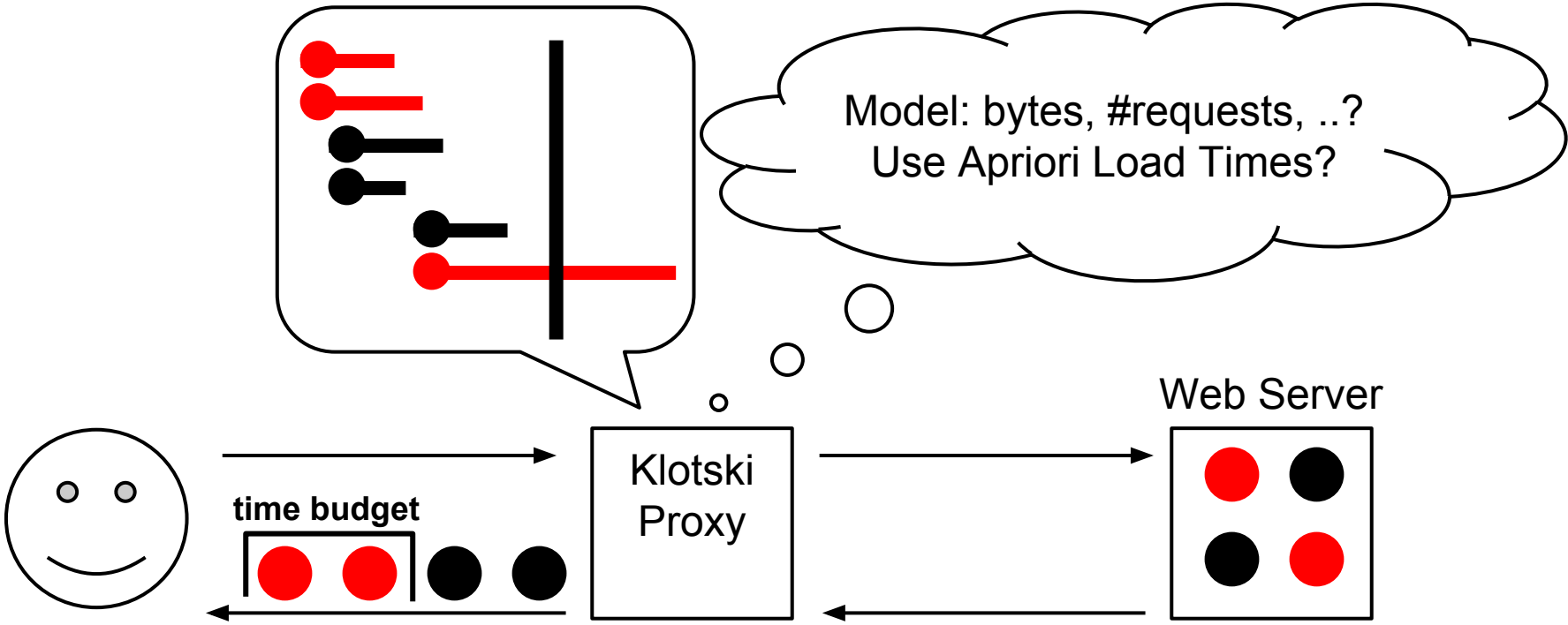
- Static URLs: Use ***SPDY PUSH*** to pre-emptively deliver as soon as main HTML is requested

- Dynamic URLs: Prioritize delivery if ***match with regular expression*** of a selected resource

Challenge 3:
Estimating Load Times in the “Wild”



Seemingly Natural Non-Solutions

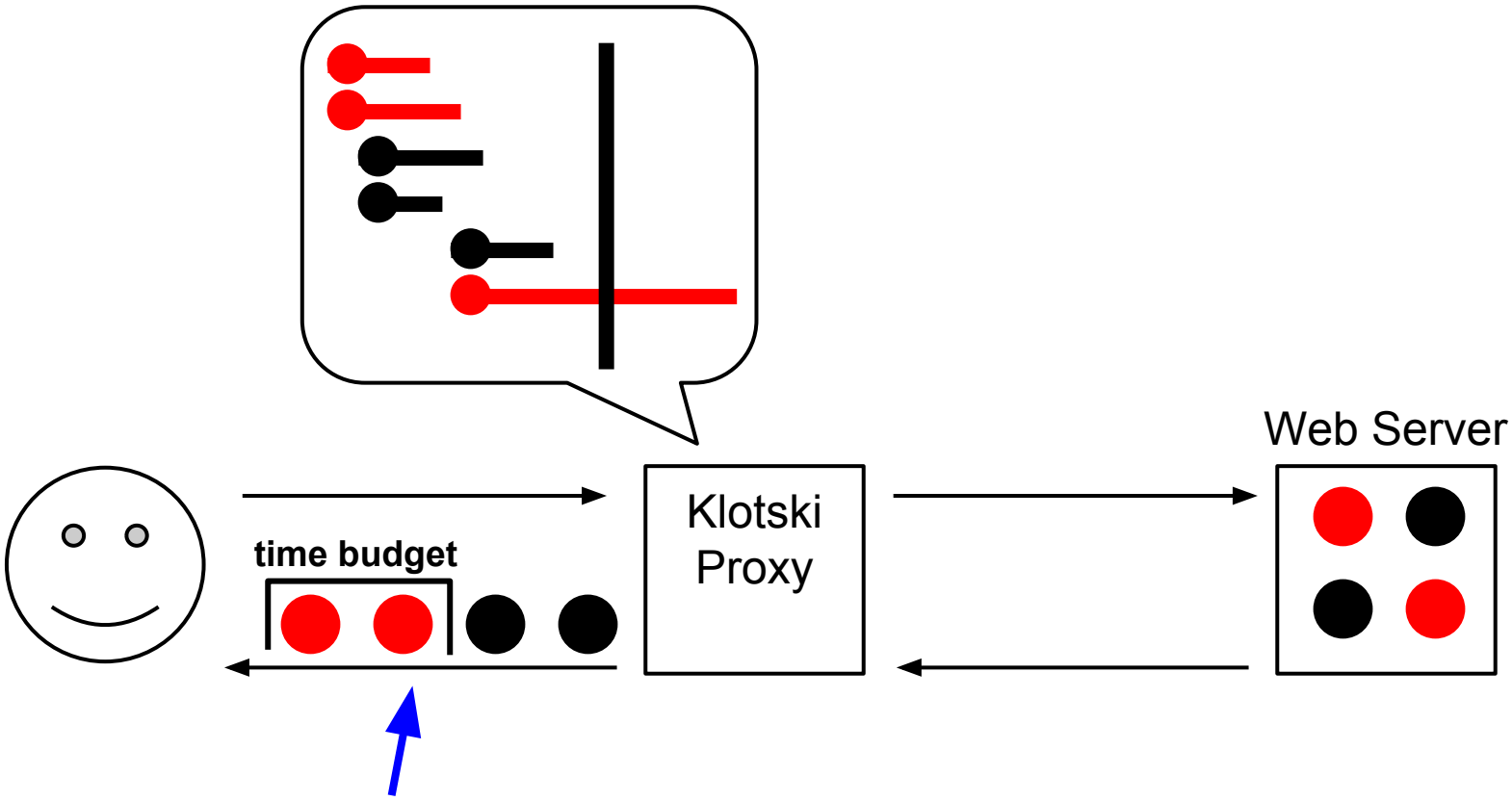


Model: Too simplistic to capture browser effects
Apriori Loads: No longer valid with reprioritization
Cannot capture diversity in client conditions

esource

source

Intuition Behind Klotski Estimator



Bottleneck = Client-Proxy Link (e.g, 4G)

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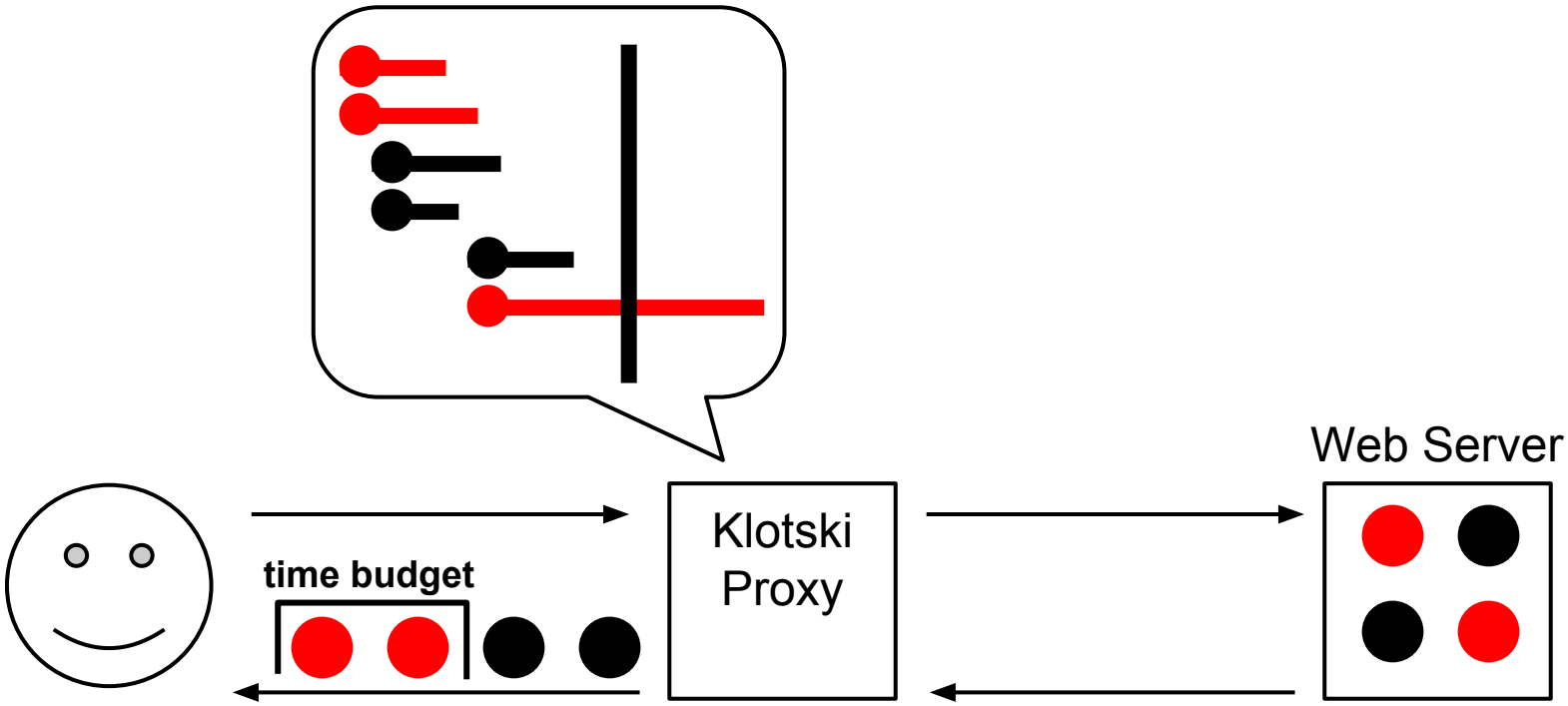
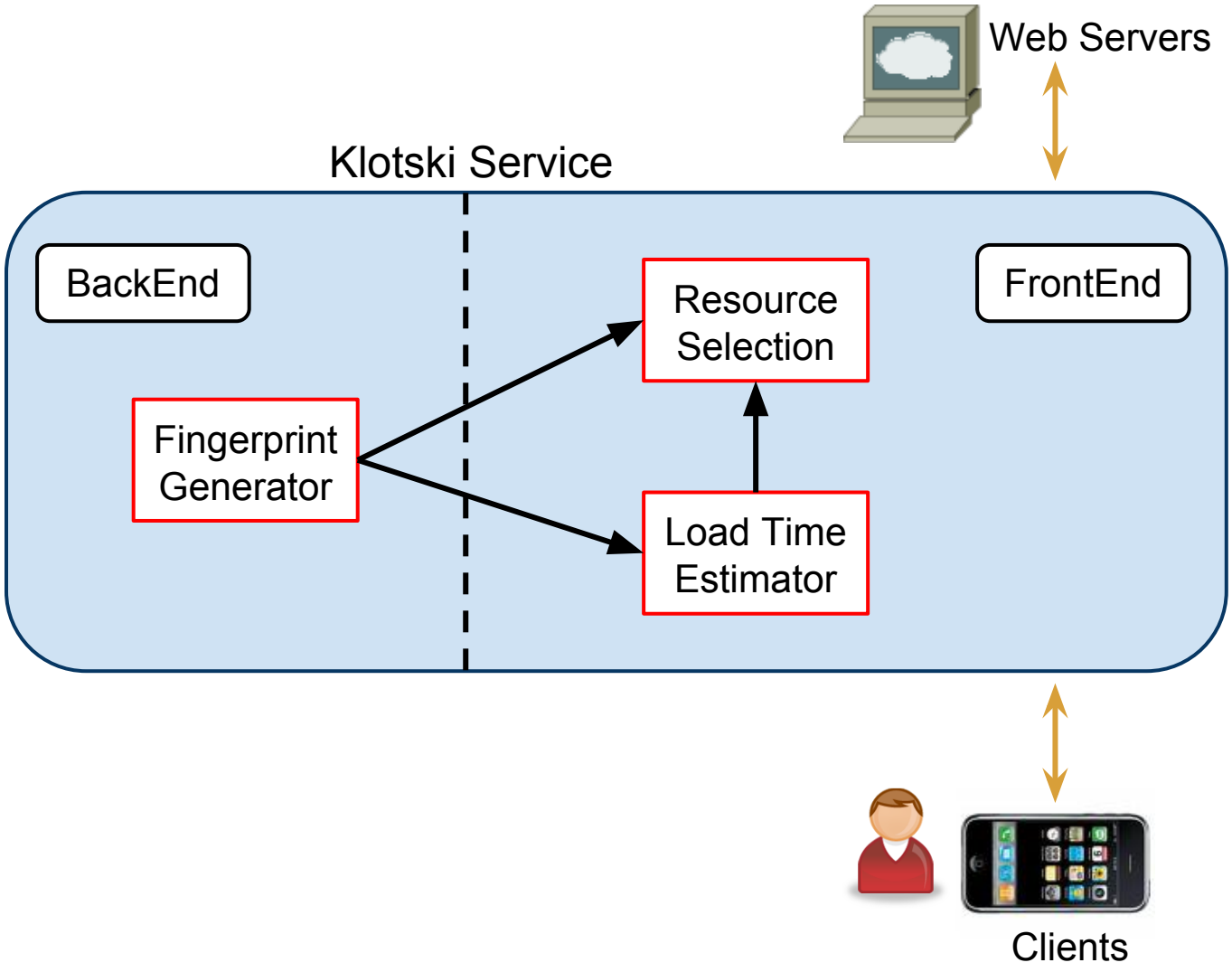


Build Fluid Model Simulation

- Proxy as work conserving scheduler
- Priorities/Dependencies, fairly shared bw for concurrent transfers
- Some subtle issues: PUSH, client processing delays

Klotski: System Architecture



Klotski: Experimental Results

Data Set

Websites

- 50 Random From Alexa Top 200

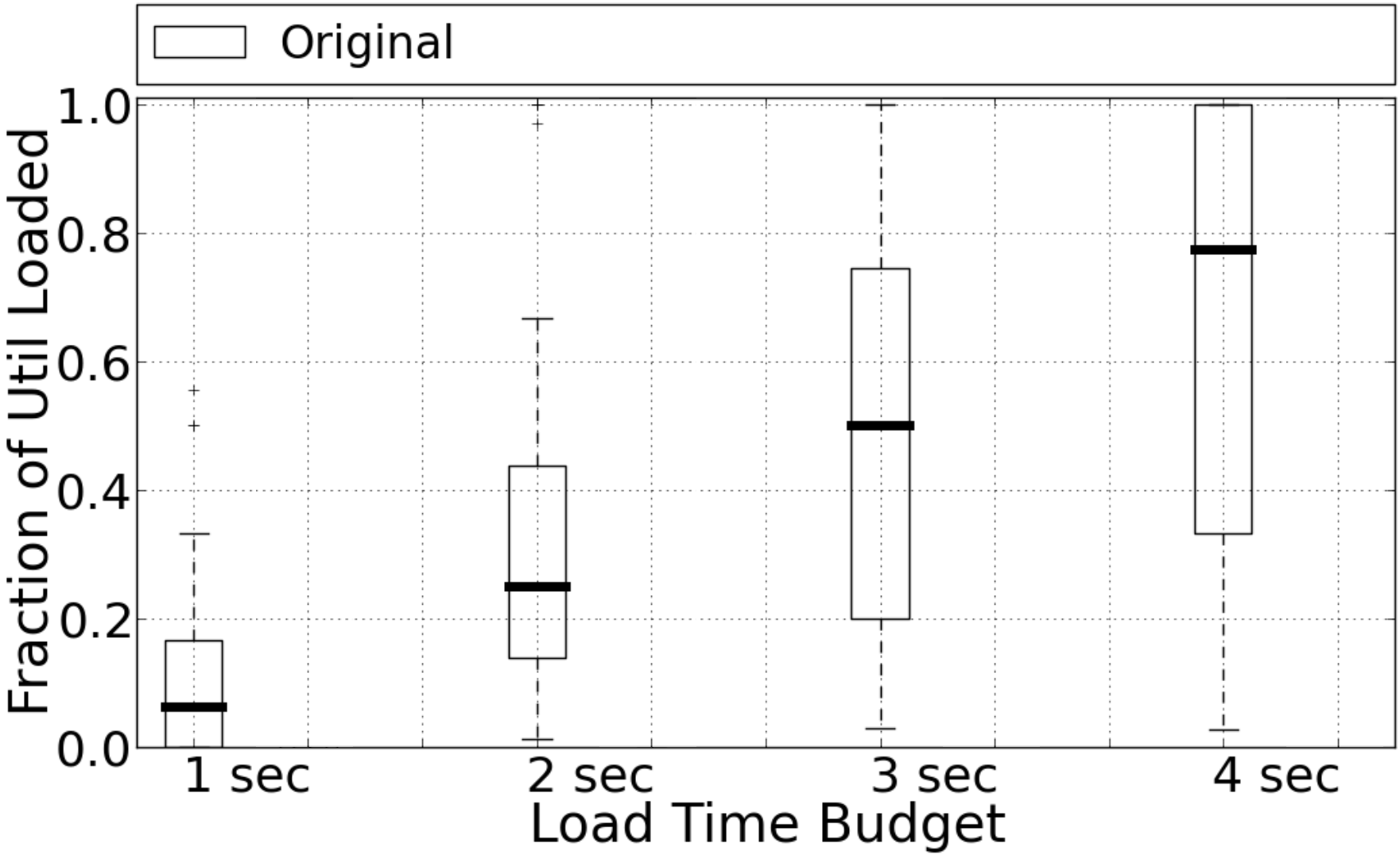
Mobile Device

- Android Smartphone
- 4G Connection
- Google Chrome

Paper Only Results

- Desktop PC + Ethernet
- Smartphone + Full Website
- User study on utility preferences
- Resource churn over time

Klotski Improves User Experience



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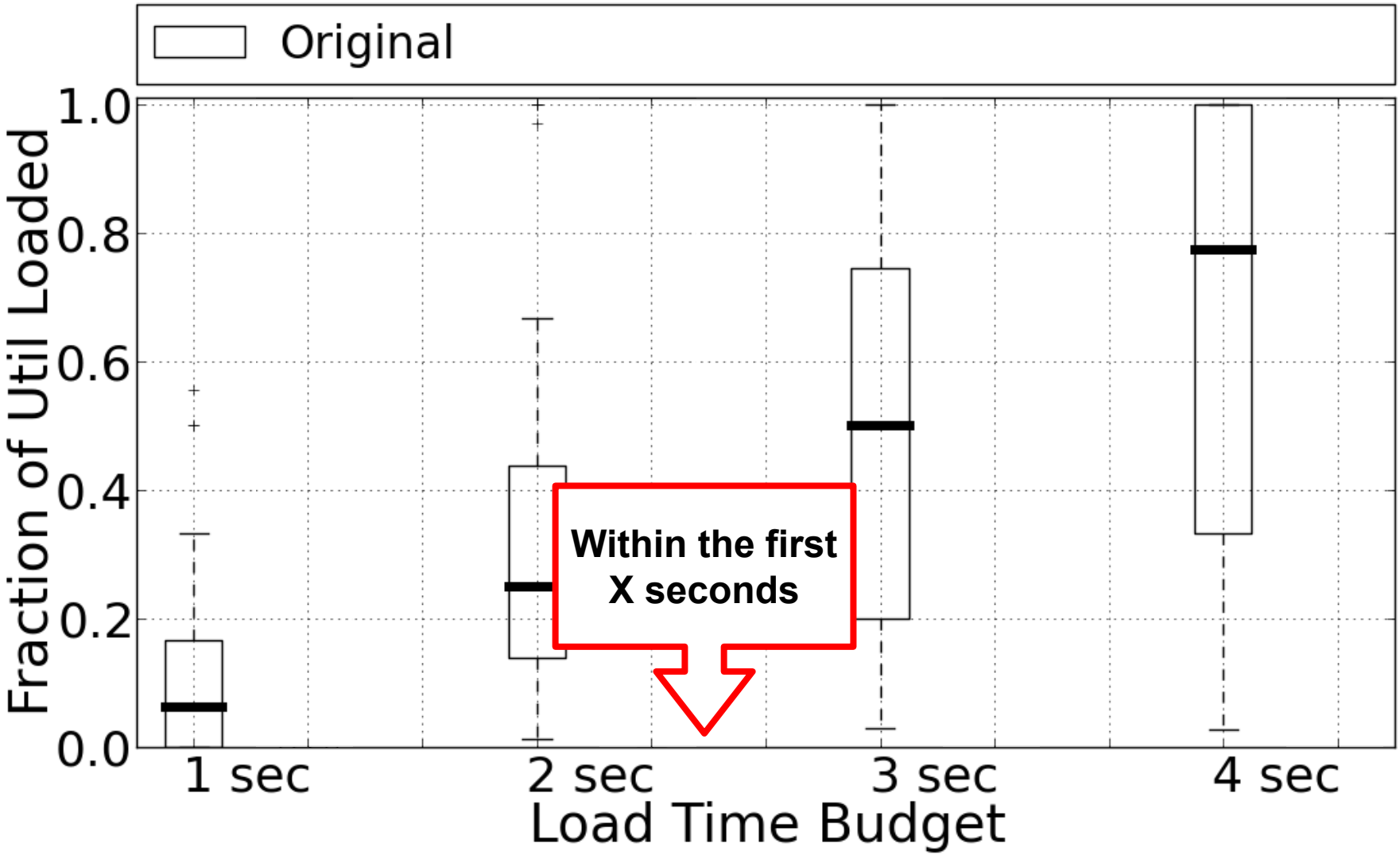

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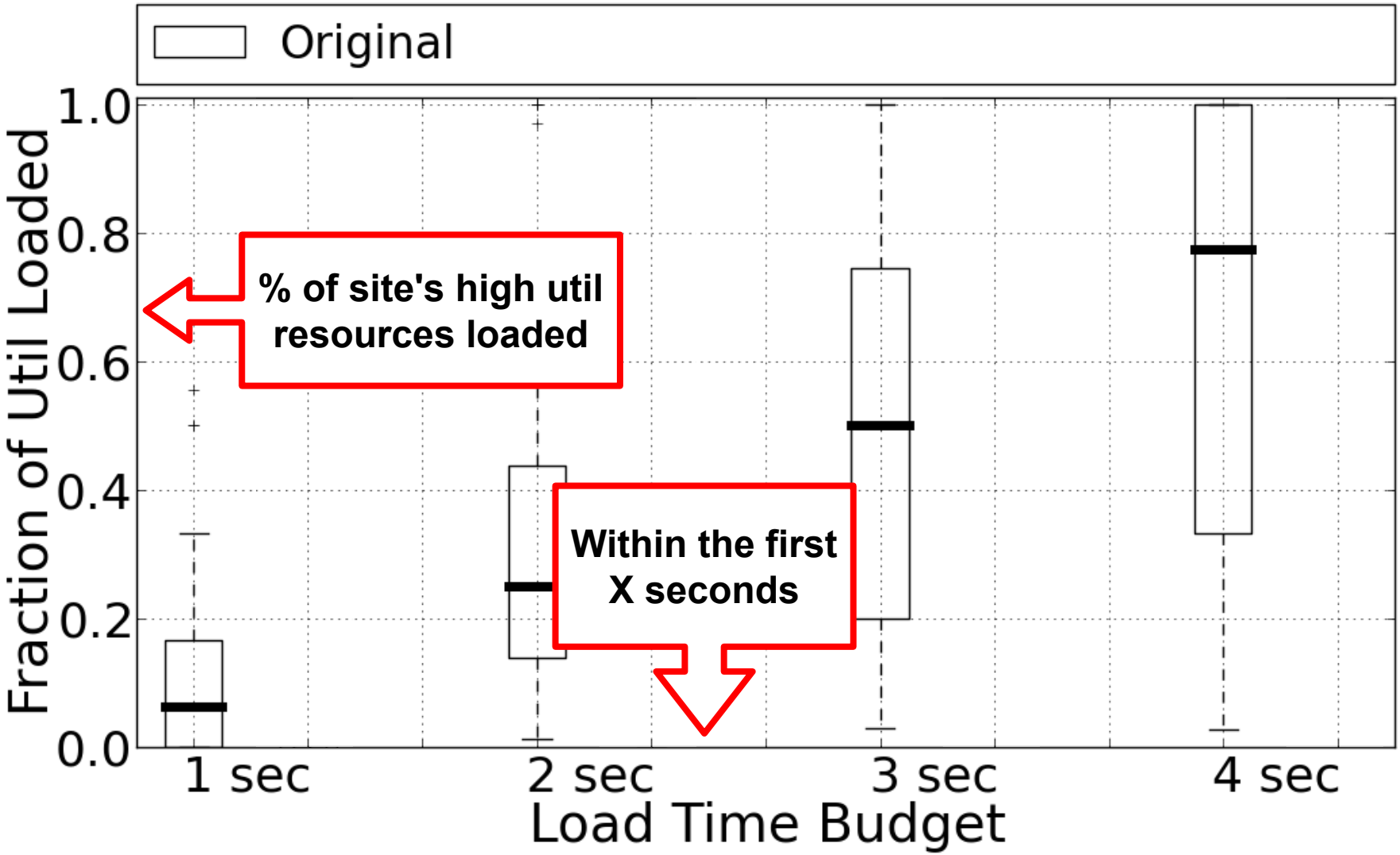

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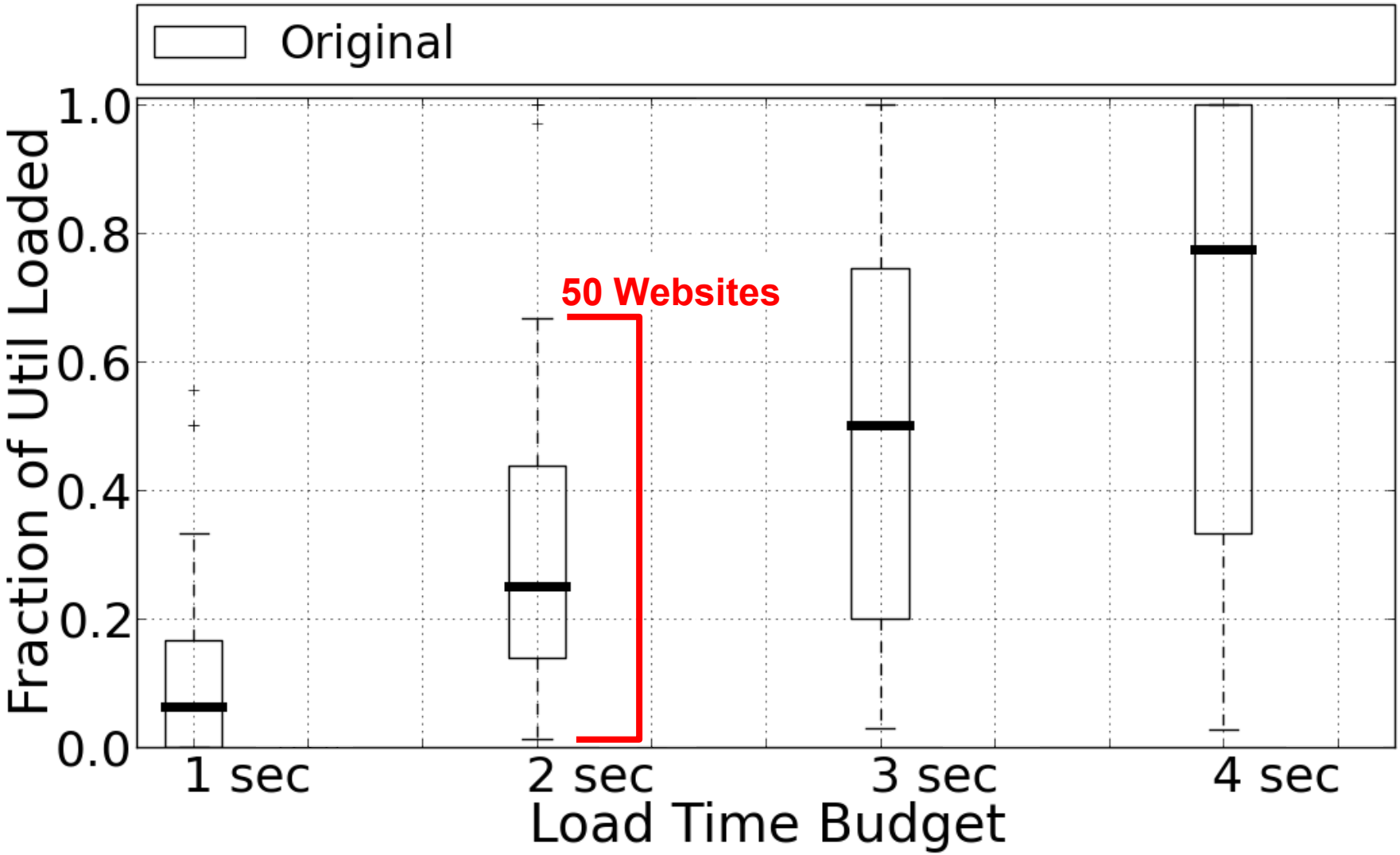

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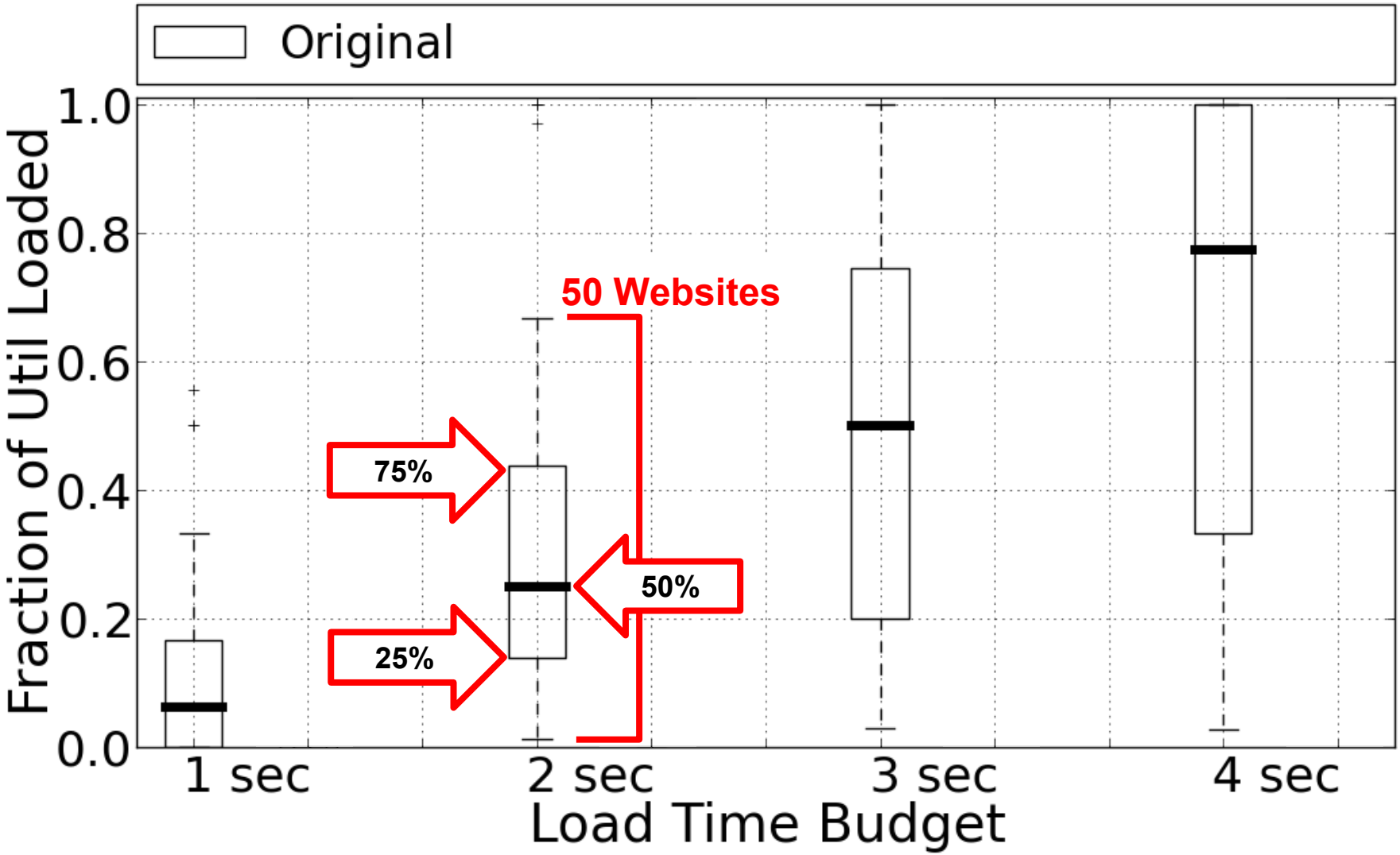

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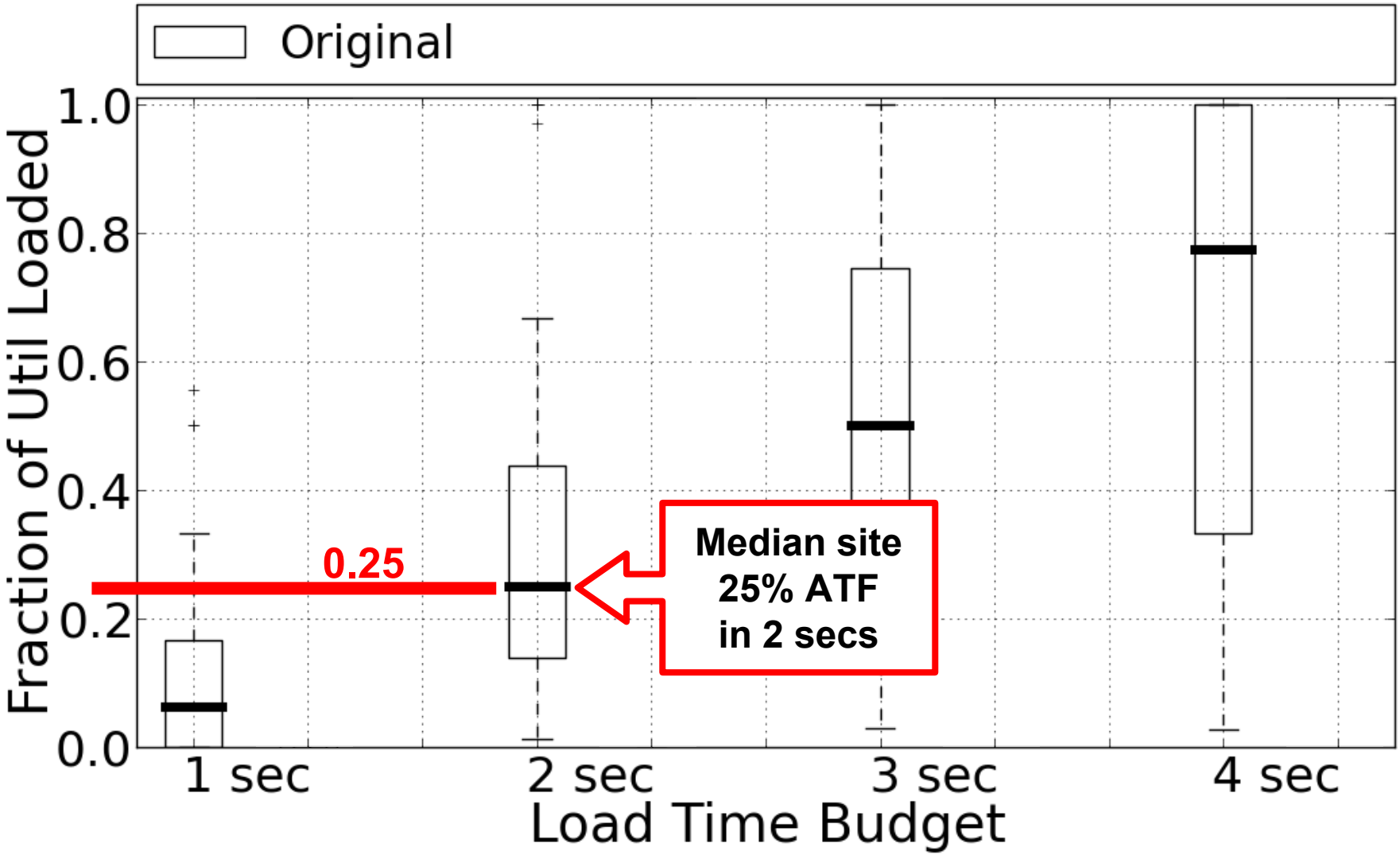

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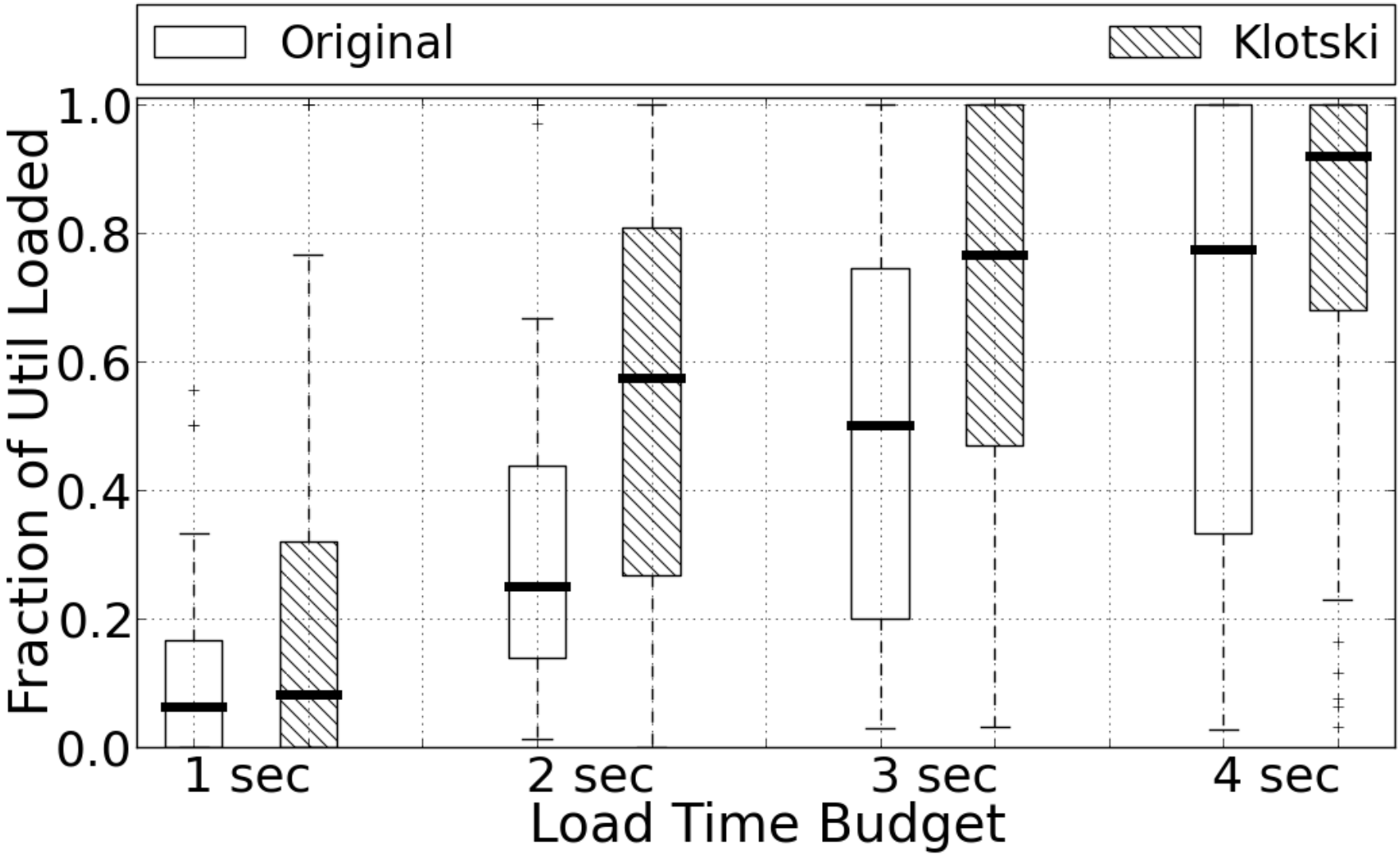

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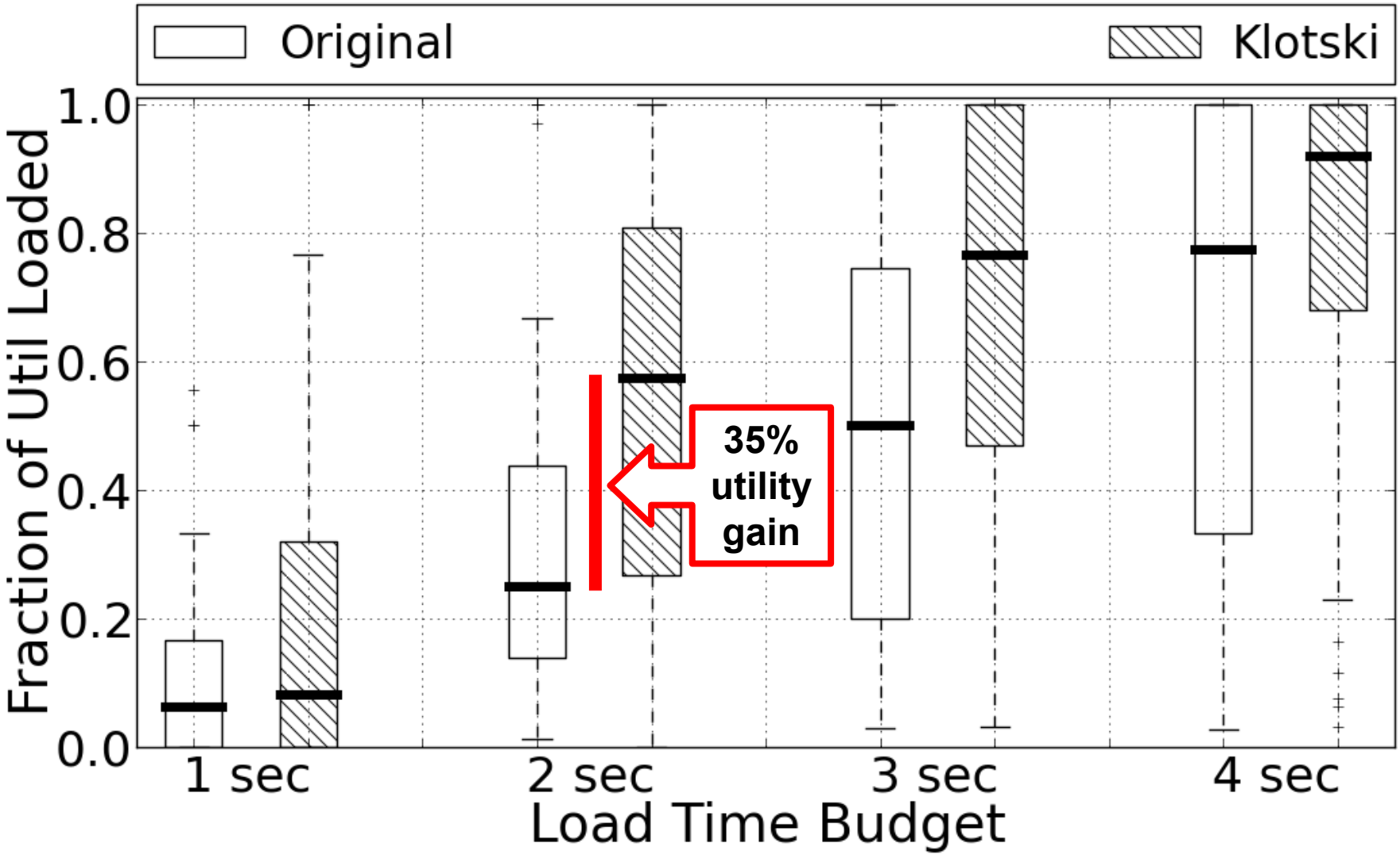

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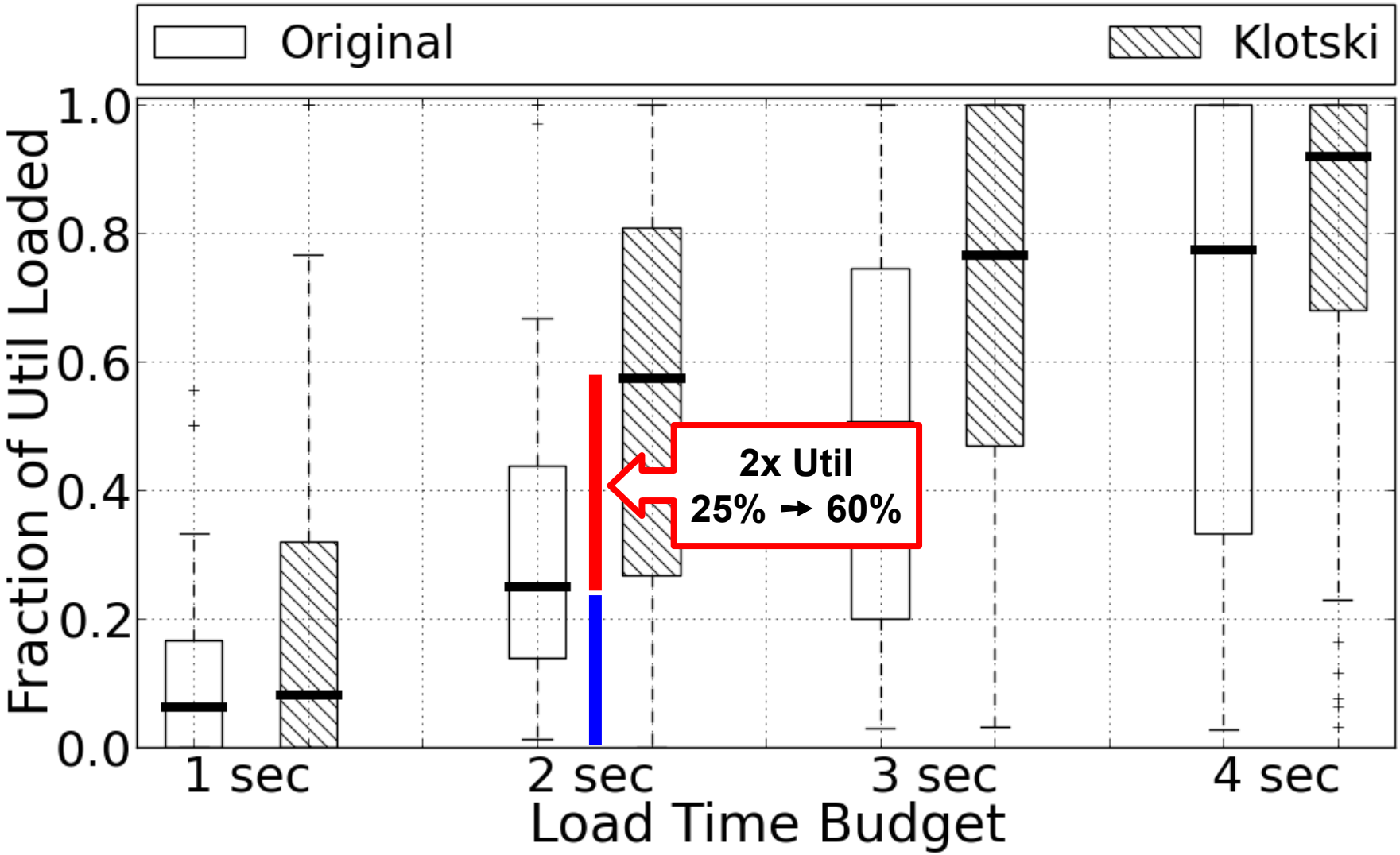
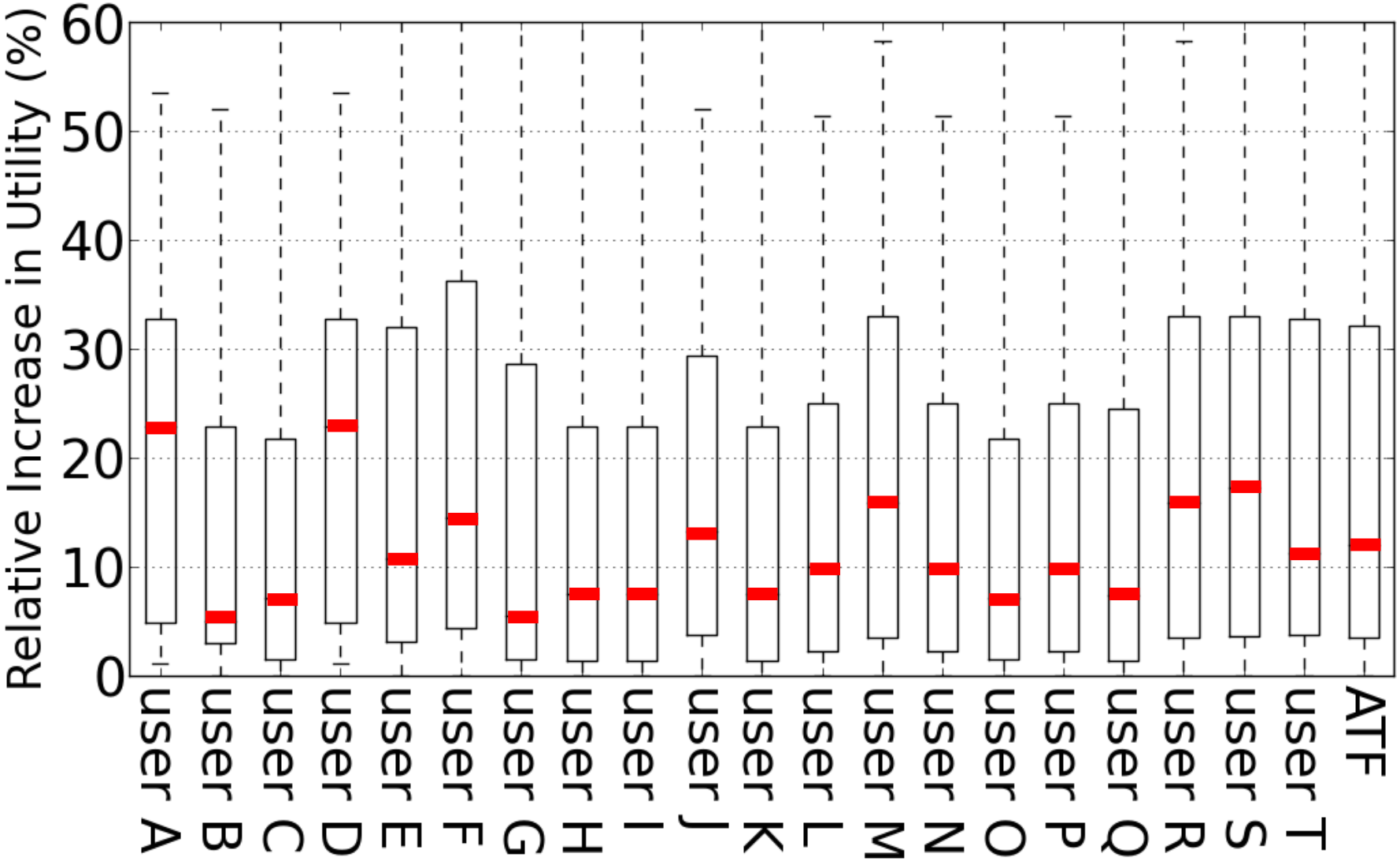


High Utility Gain For Diverse Users



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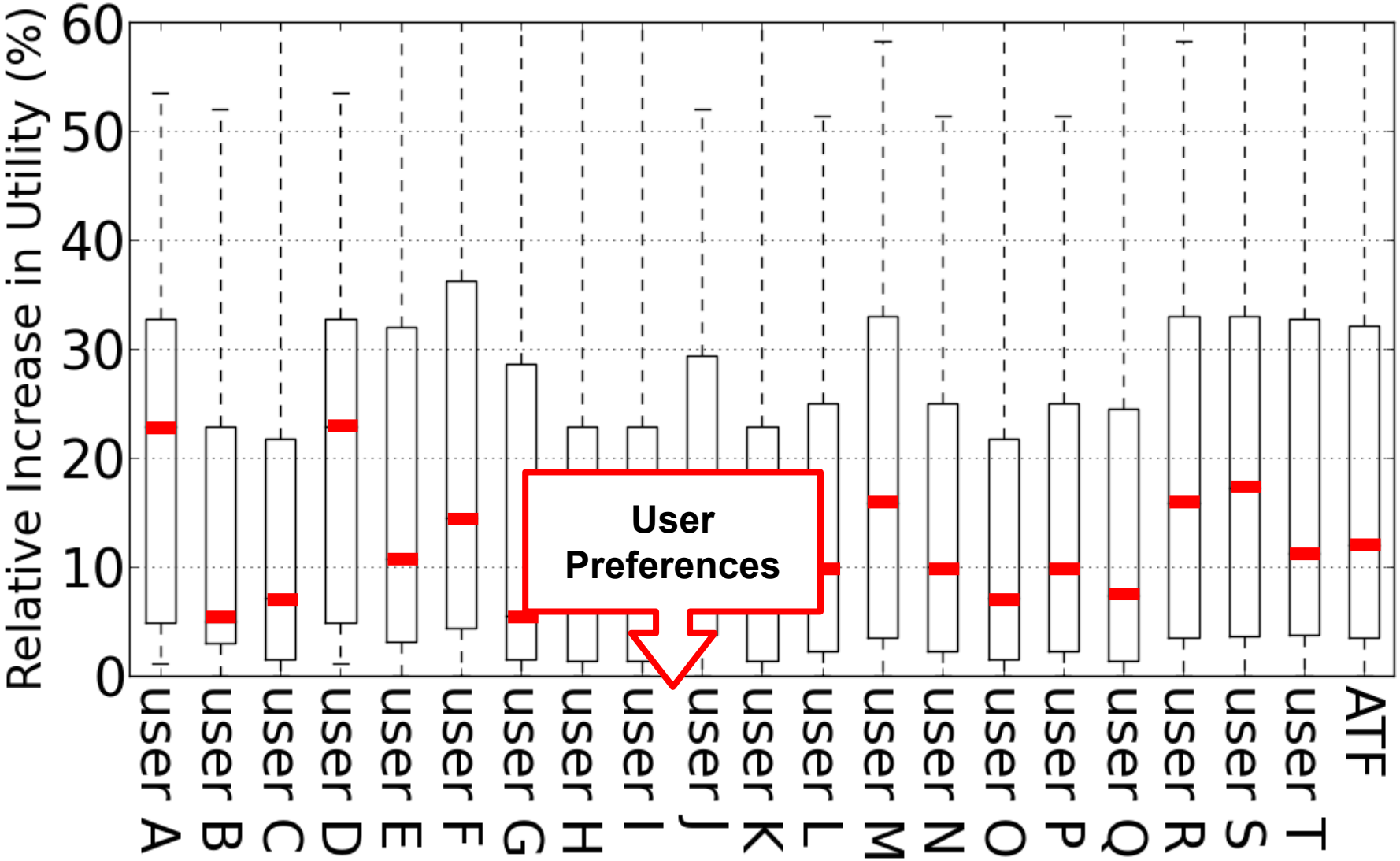

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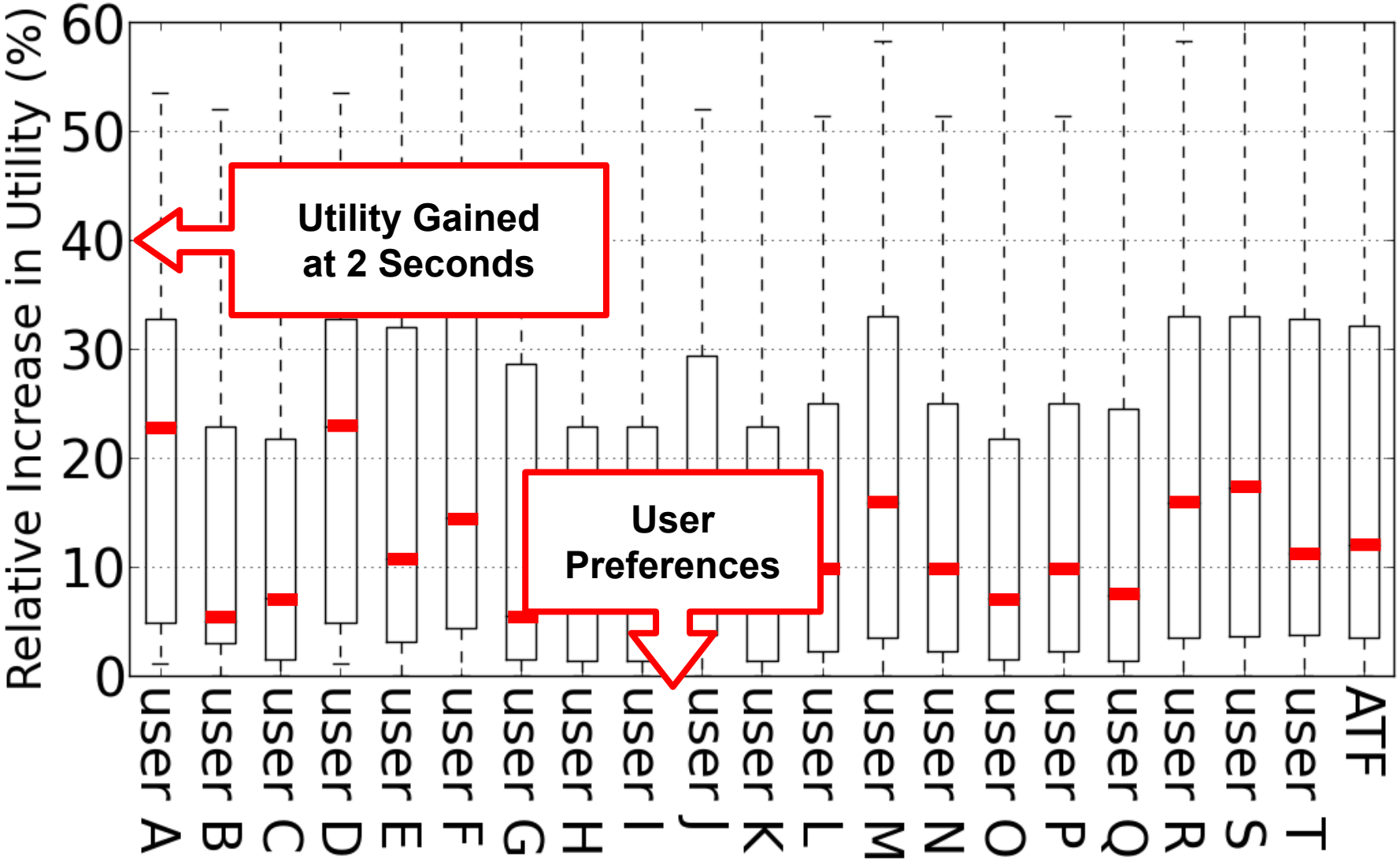

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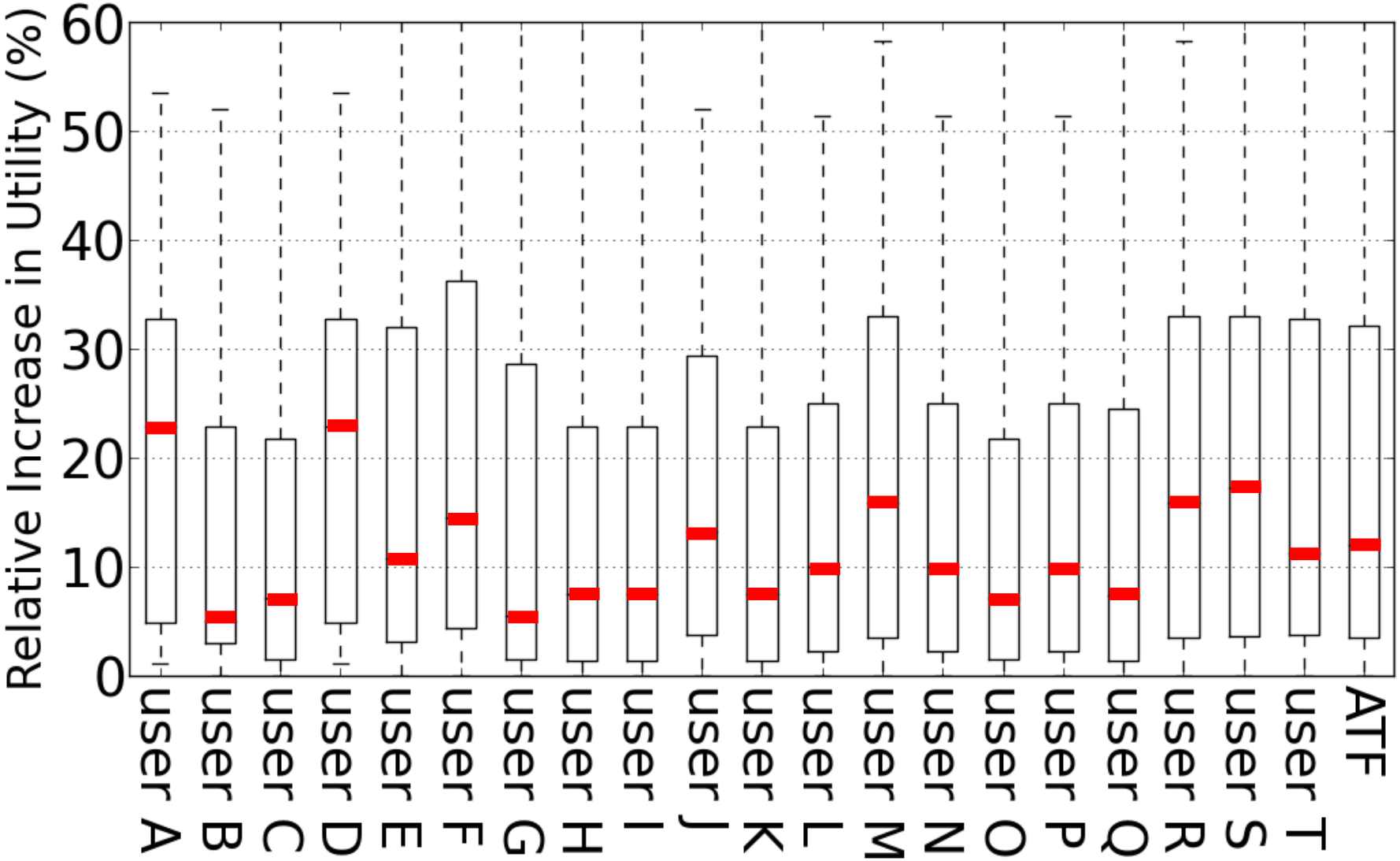

Conclusions

- Mobile web continues to be a pain point
  - Focus on load time alone is likely insufficient
- Instead we focus on dynamic reprioritization
- Key challenges we address:
  - dynamic dependency representation
  - fast resource selection
  - load time estimation
- Klotski greatly improves user experience
  - for diverse preferences