WebCore:

Architectural Support for Mobile Web Browsing

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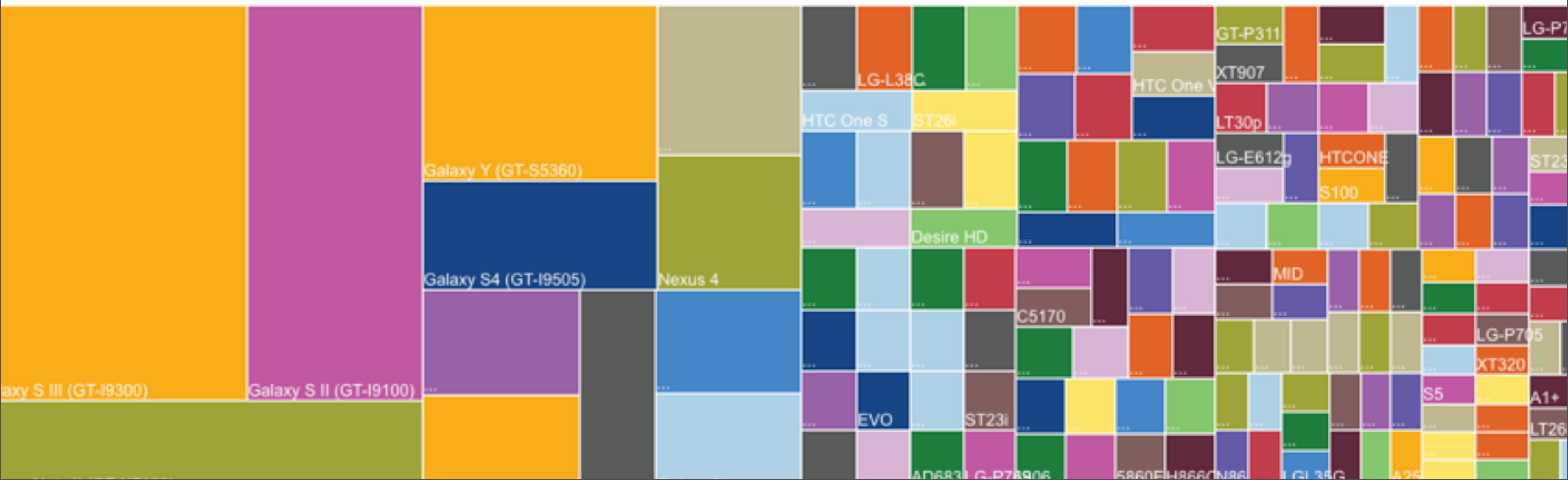
Department of Electrical and Computer Engineering
The University of Texas at Austin

ISCA MainTalk — June 18th, 2014

http2

HTML

CSS


Galaxy Y (GT-S5360)
Galaxy S4 (GT-I9505)
Nexus 4
LG-L38C
HTC One S
ST26i
Desire HD
GT-P311
XT907
LT30p
LG-E612g
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MID
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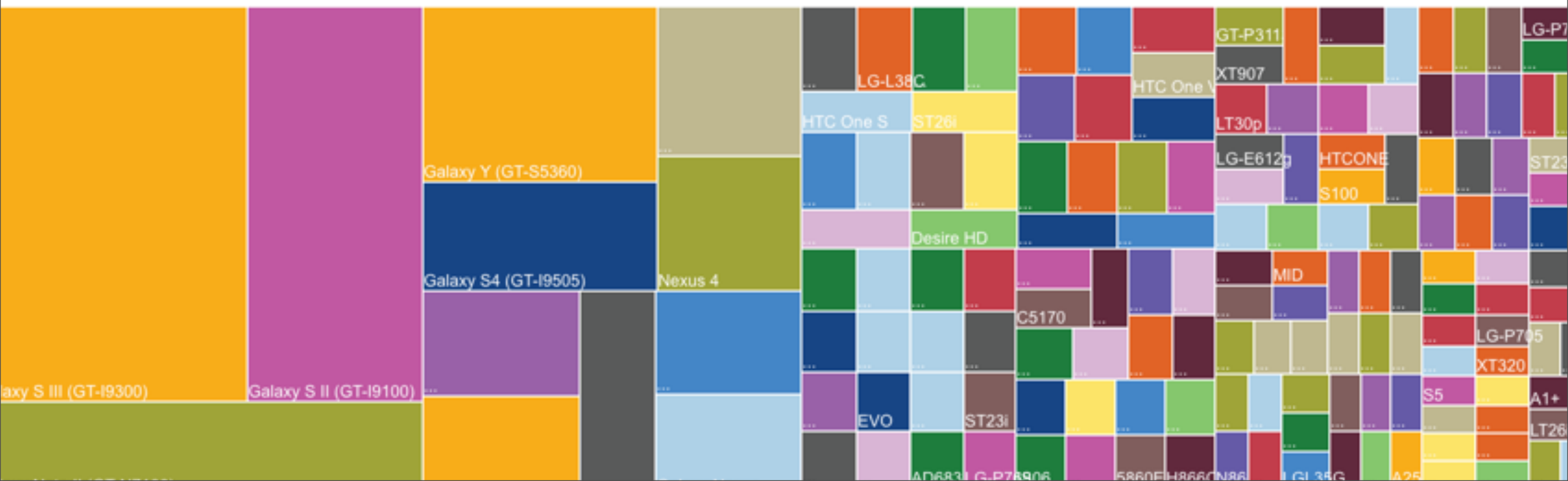
iOS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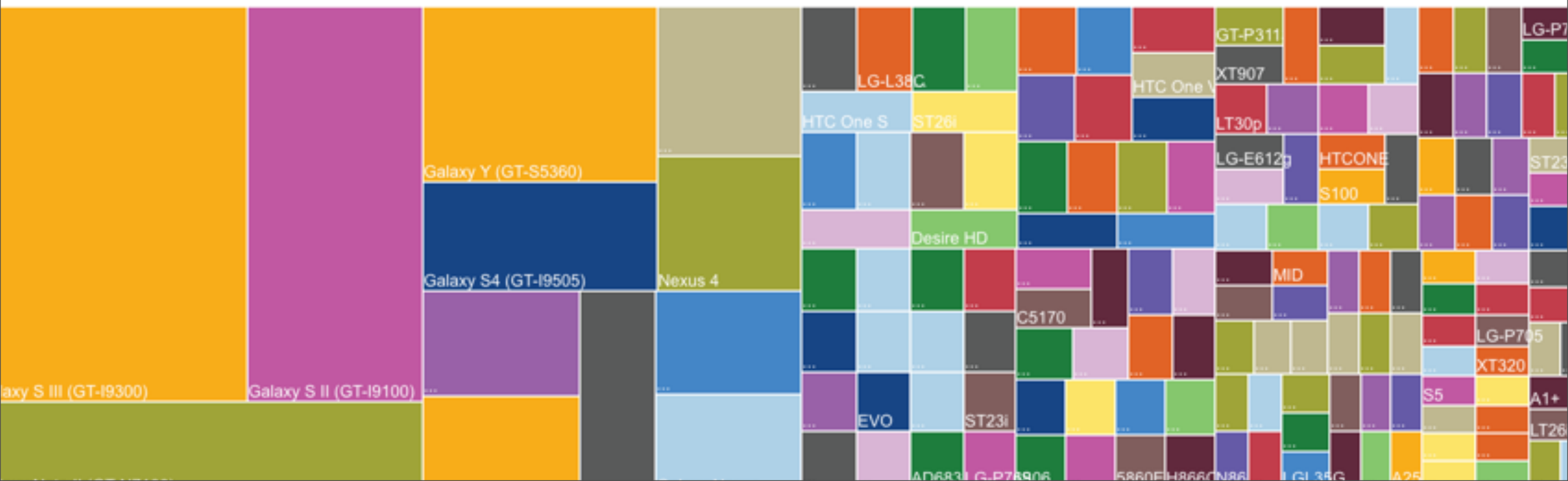
Swift

Java

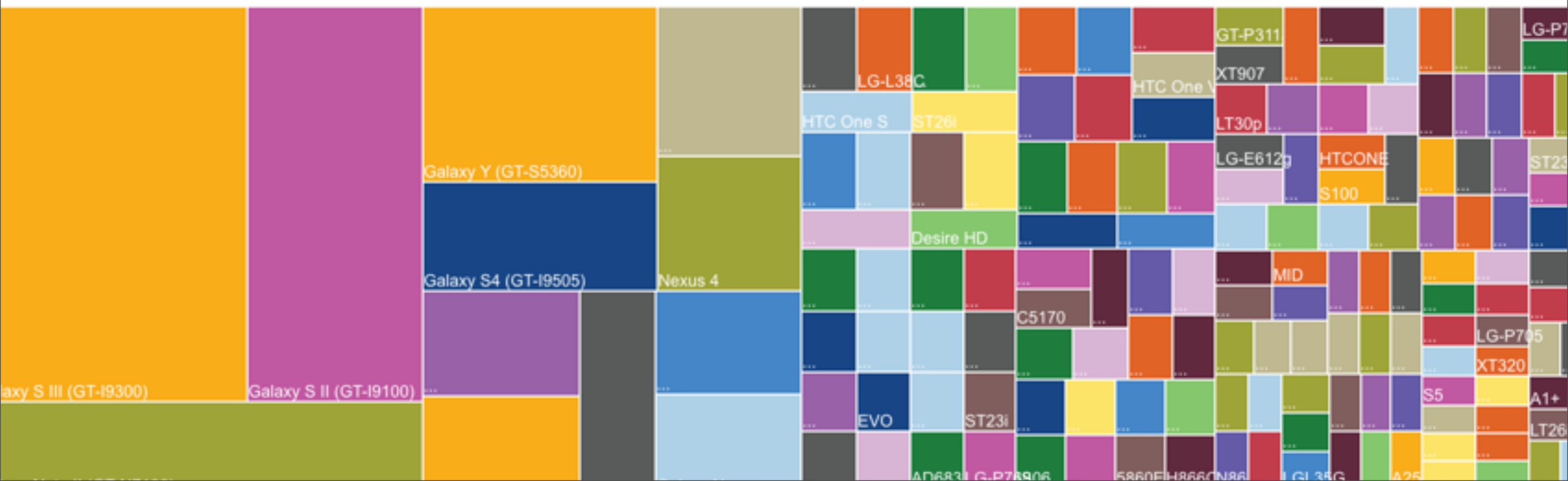
TM

iOS




HTML
CSS
JS


iOS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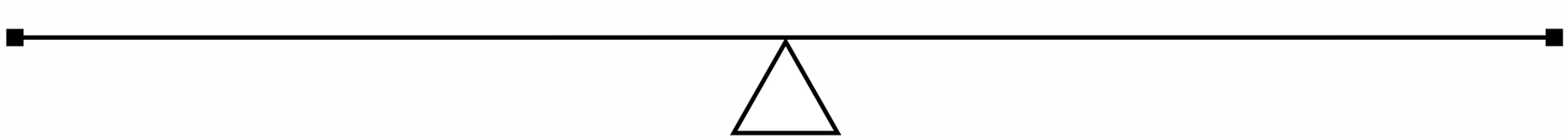
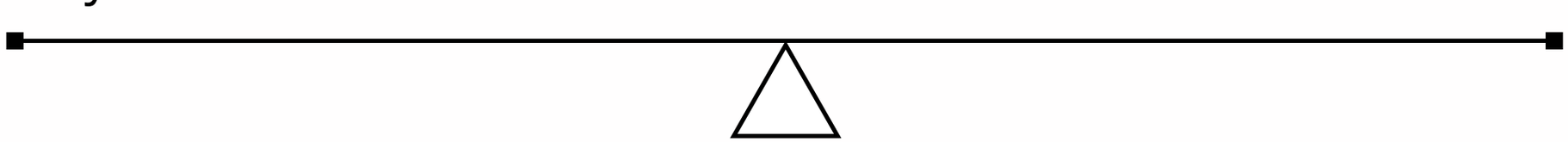
The Fundamental Challenges



The Fundamental Challenges

Achieving High Performance
Demanded by End-User



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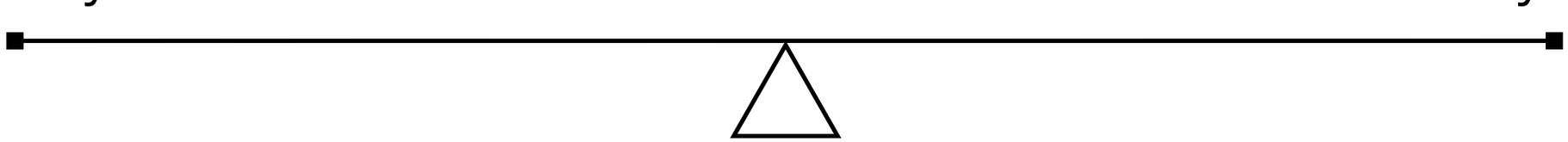
Conserving Energy Due to Limited Battery Capacity



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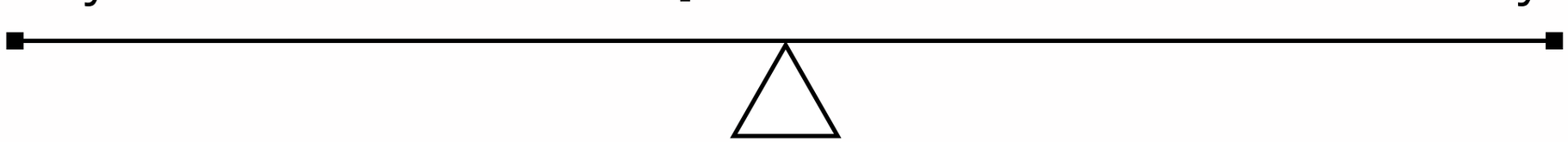
Achieving High Performance Demanded by End-User

Conflicting requirements

Conserving Energy Due to Limited Battery Capacity



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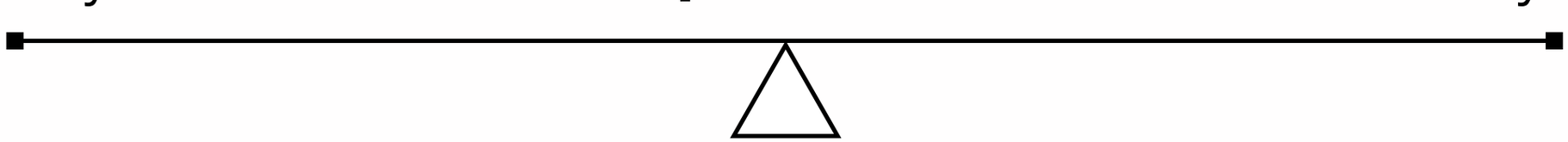

How to achieve high performance with low energy?

The Fundamental Challenges

Achieving High Performance Demanded by End-User

Conflicting requirements

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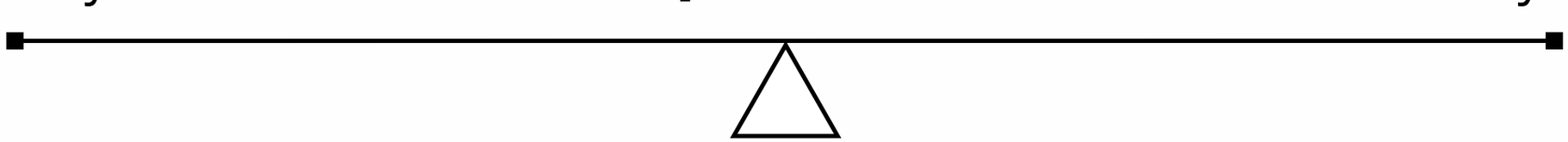

A mobile architecture to achieve high performance with low energy?

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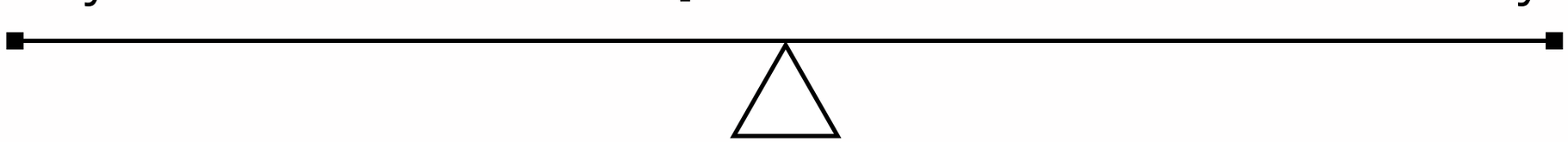
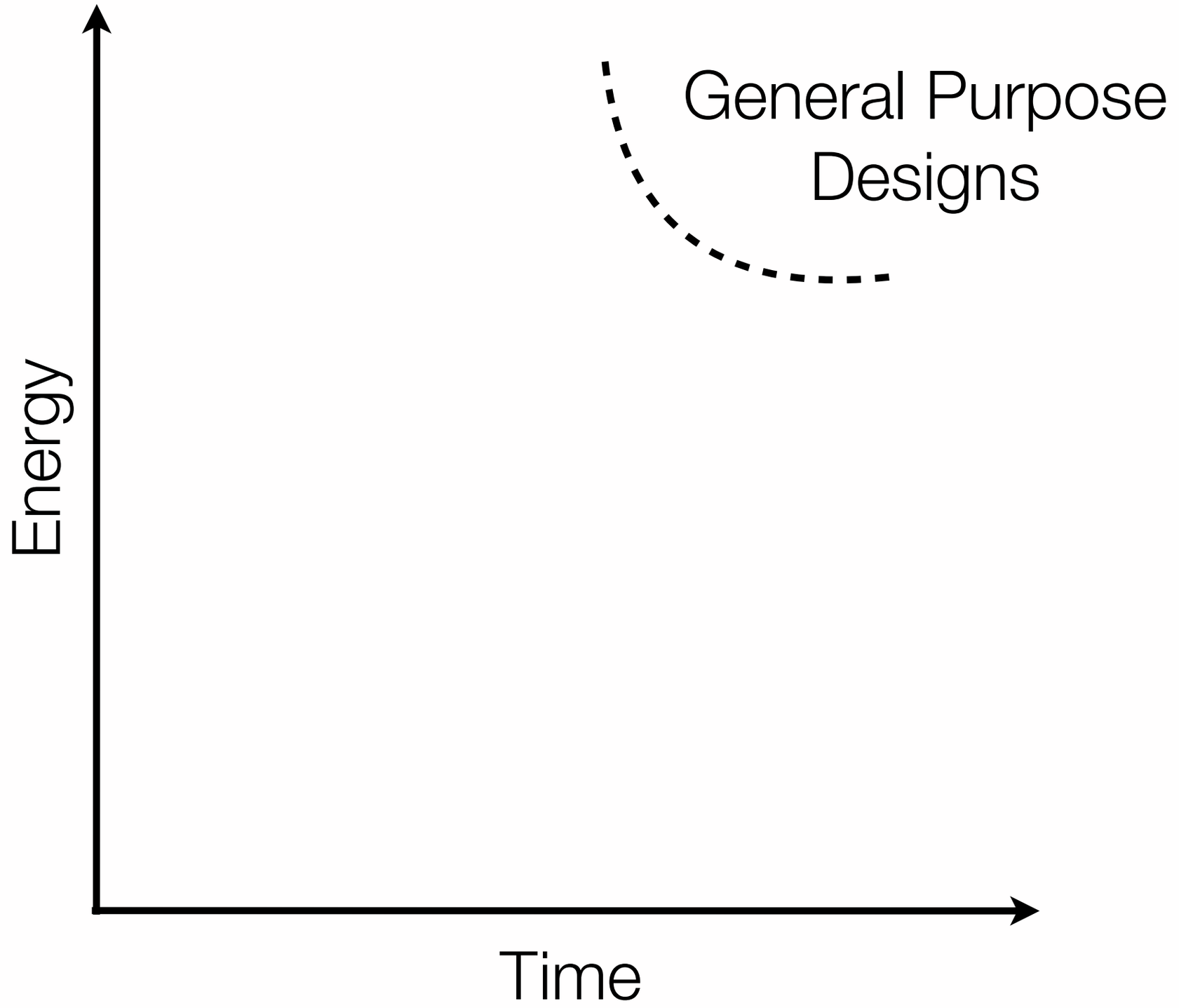


WebCore:

A mobile architecture to achieve high performance with low energy

Executive Summary



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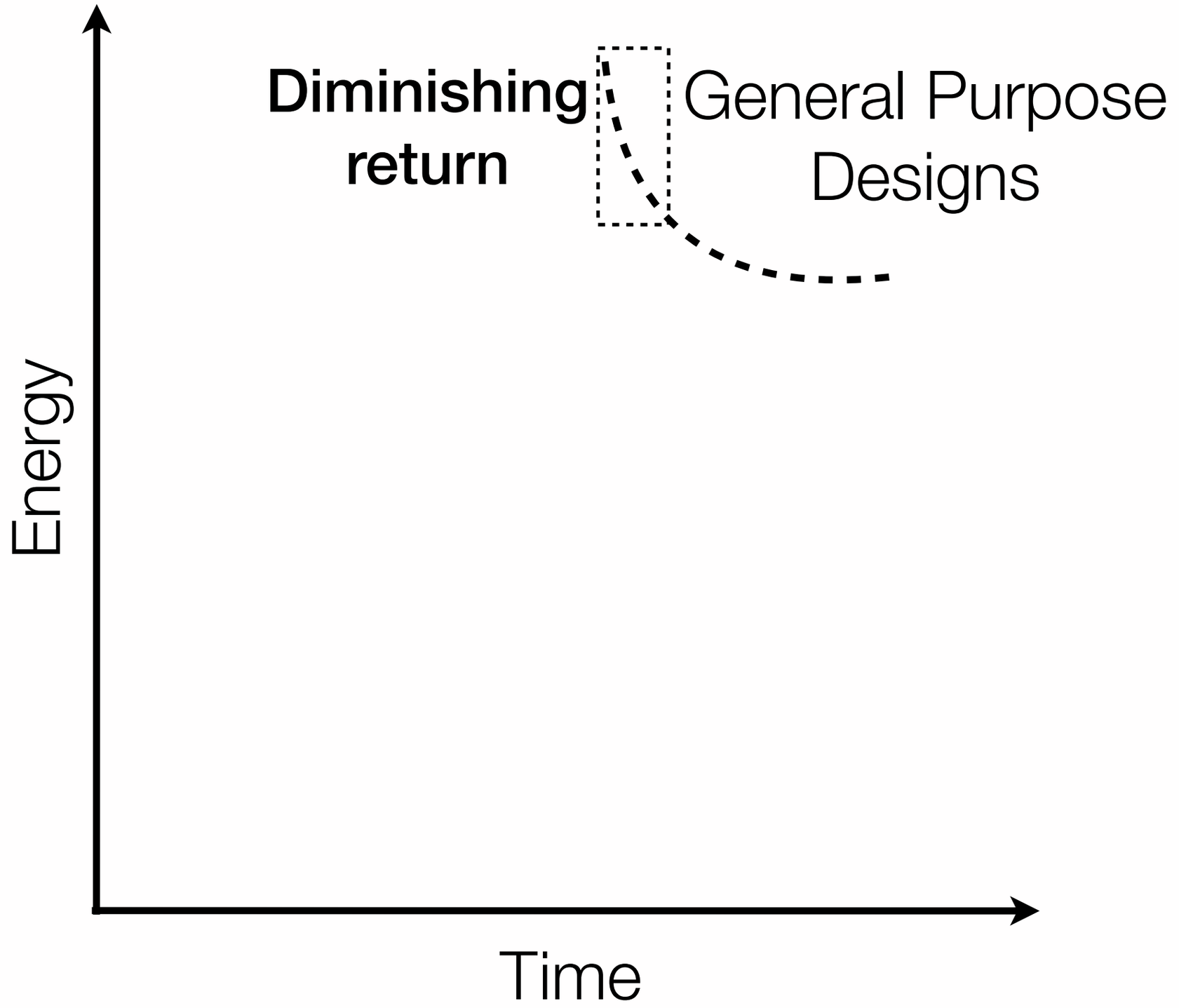

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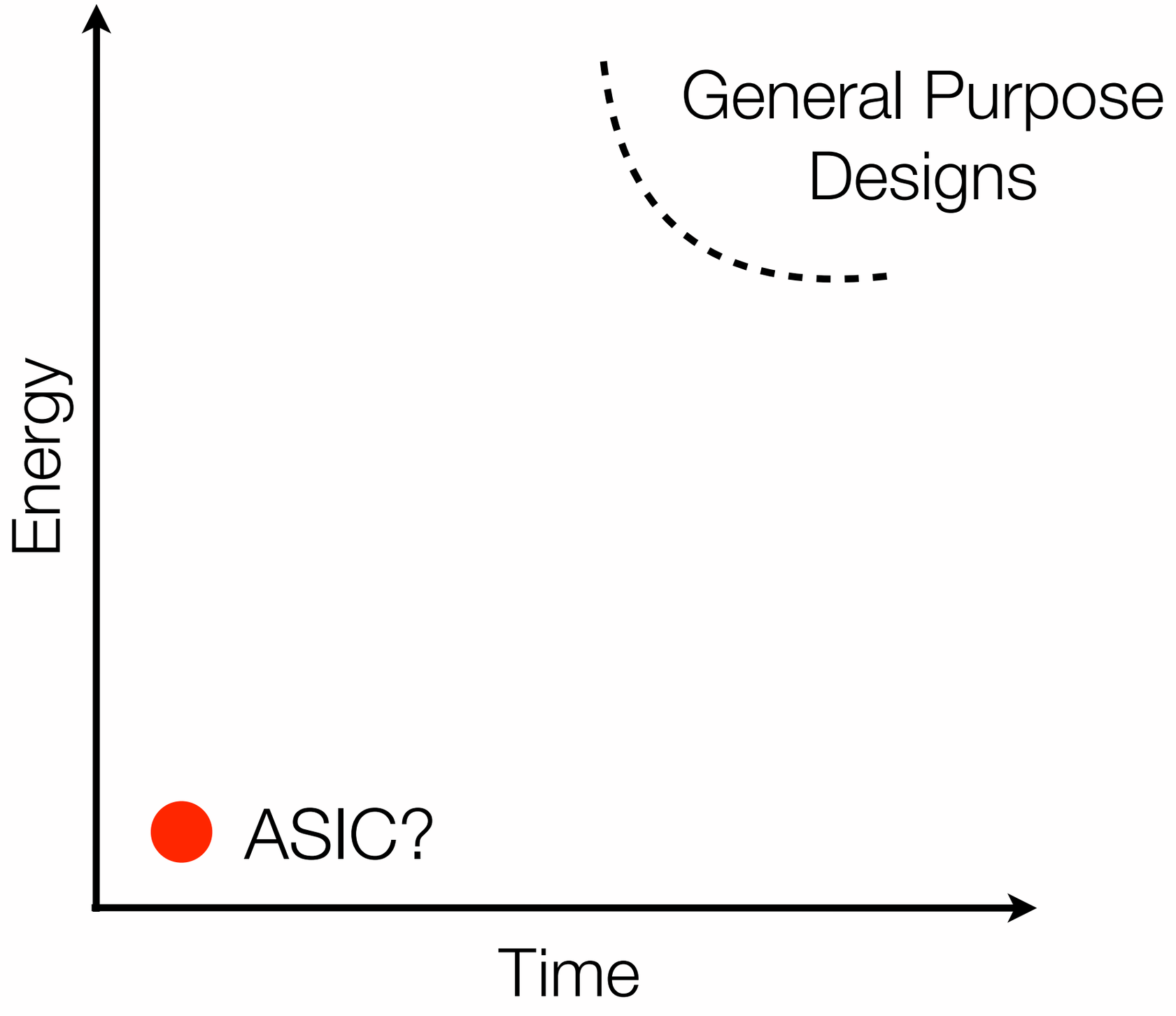

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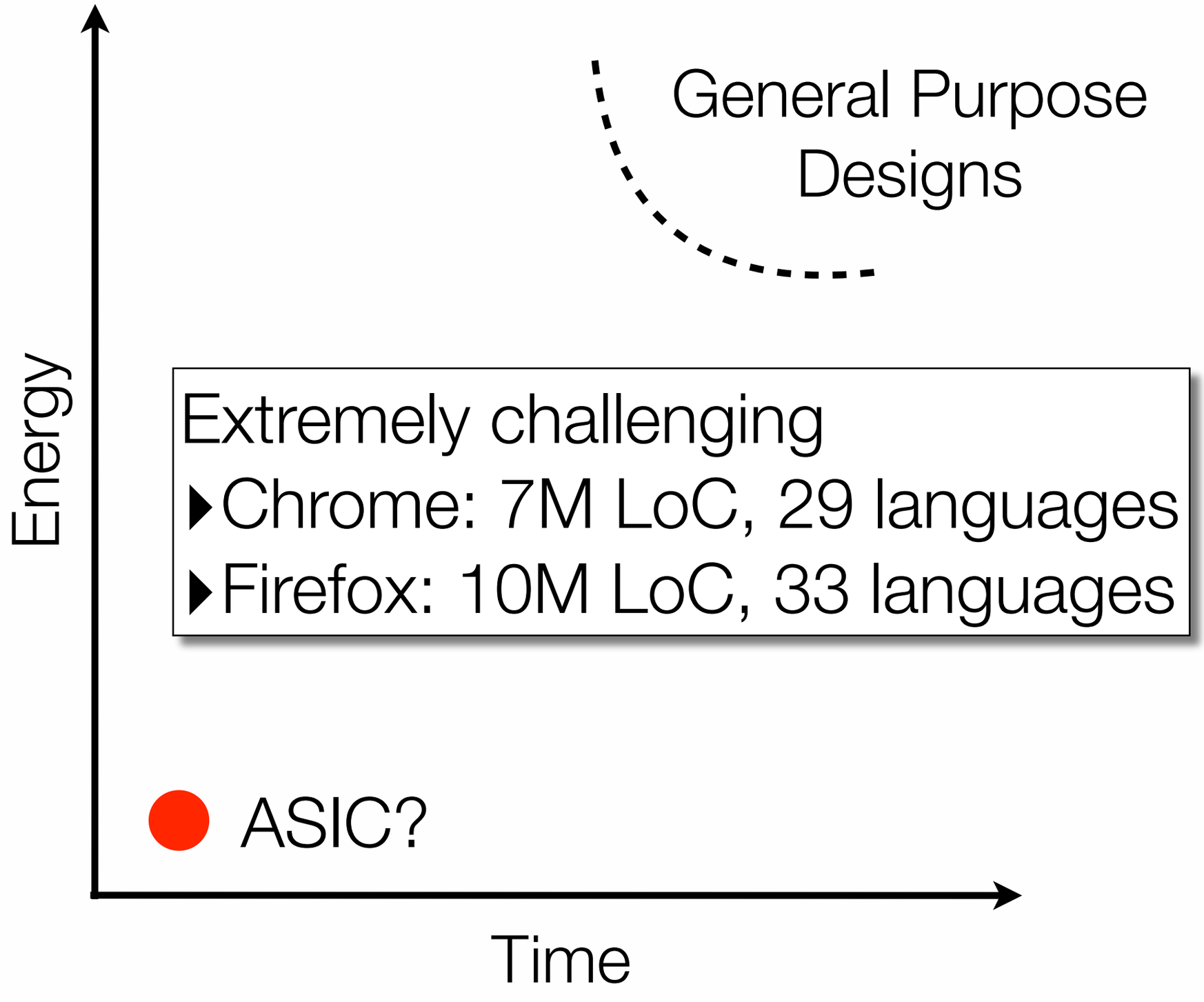

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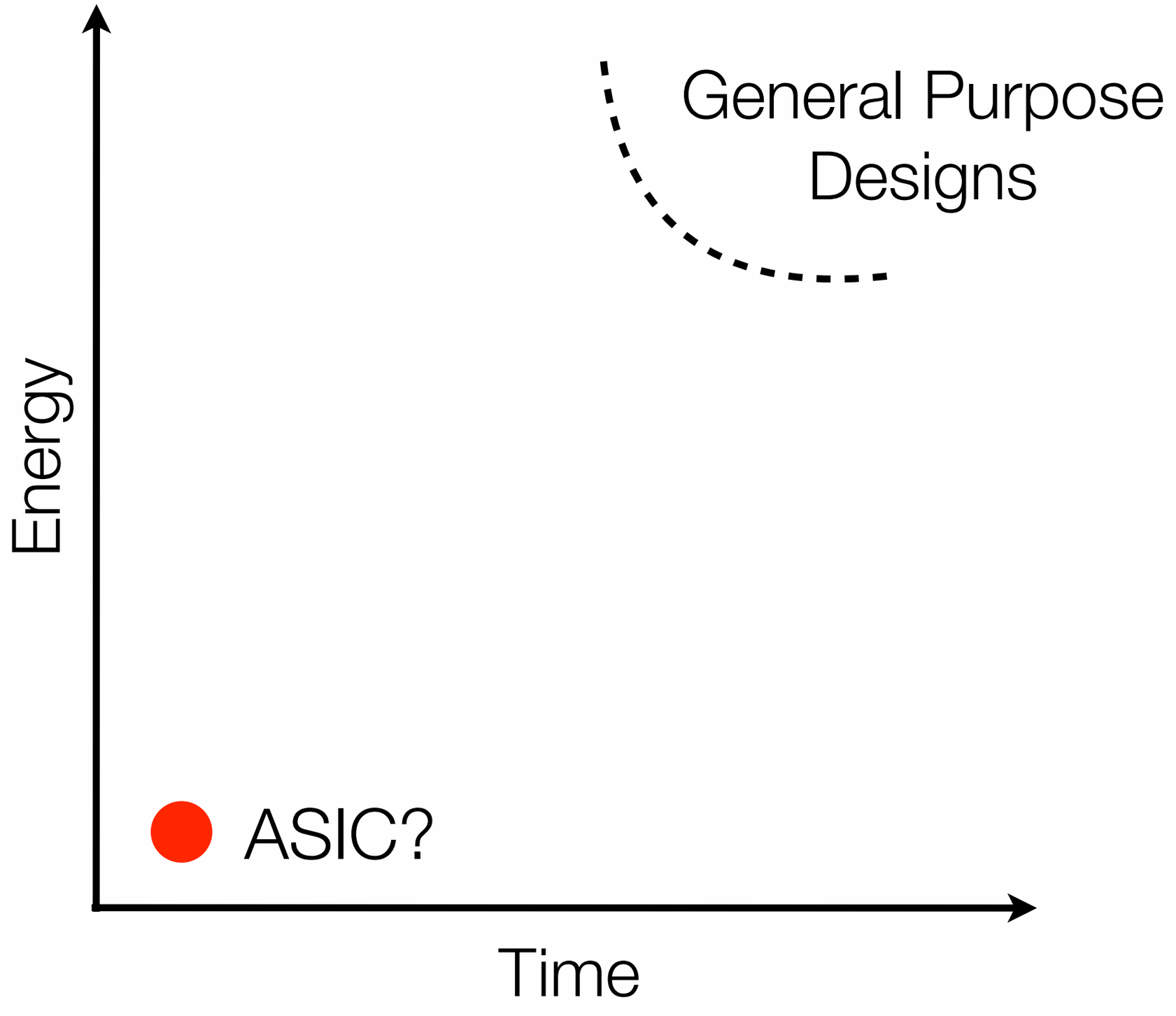

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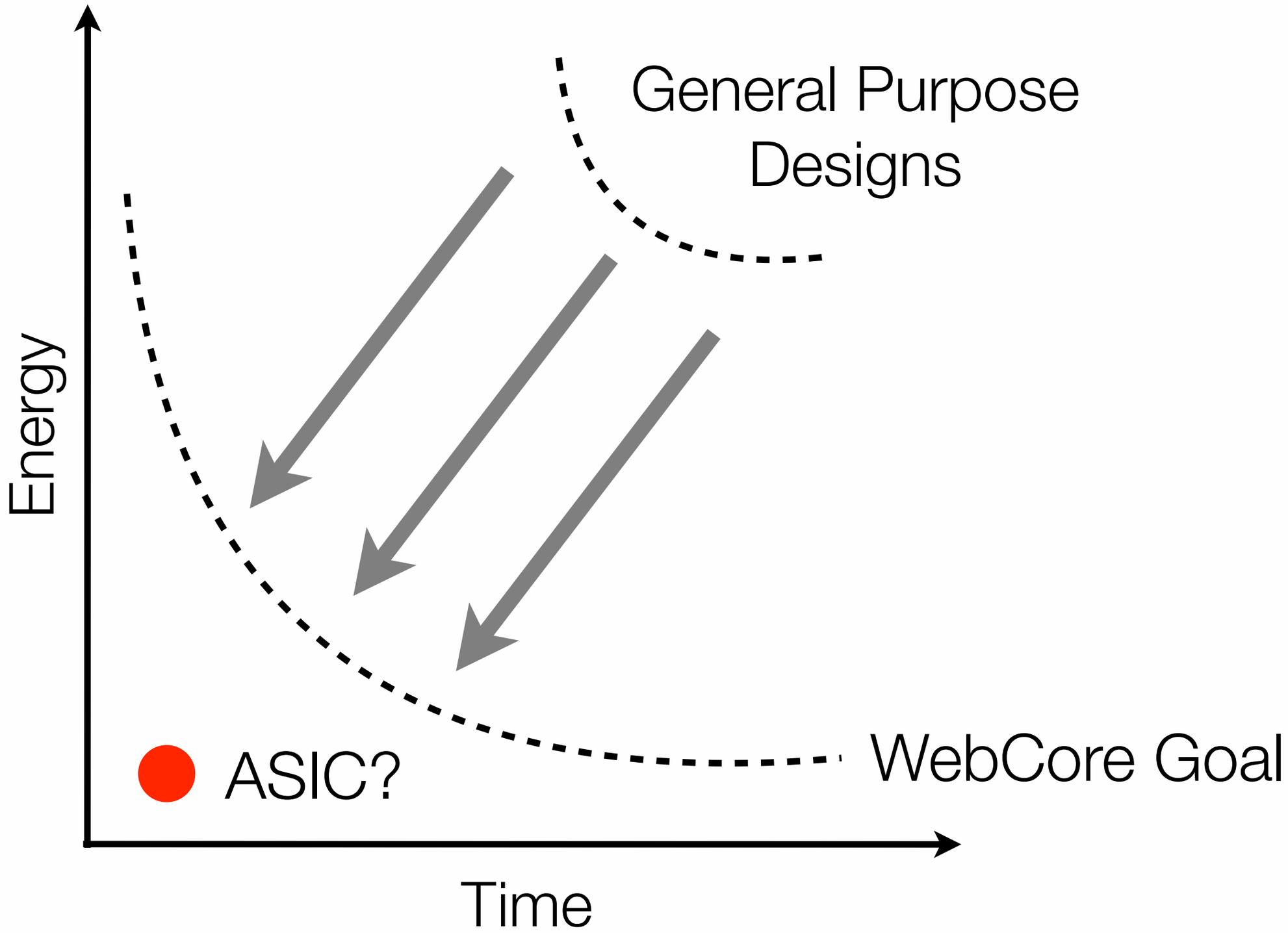

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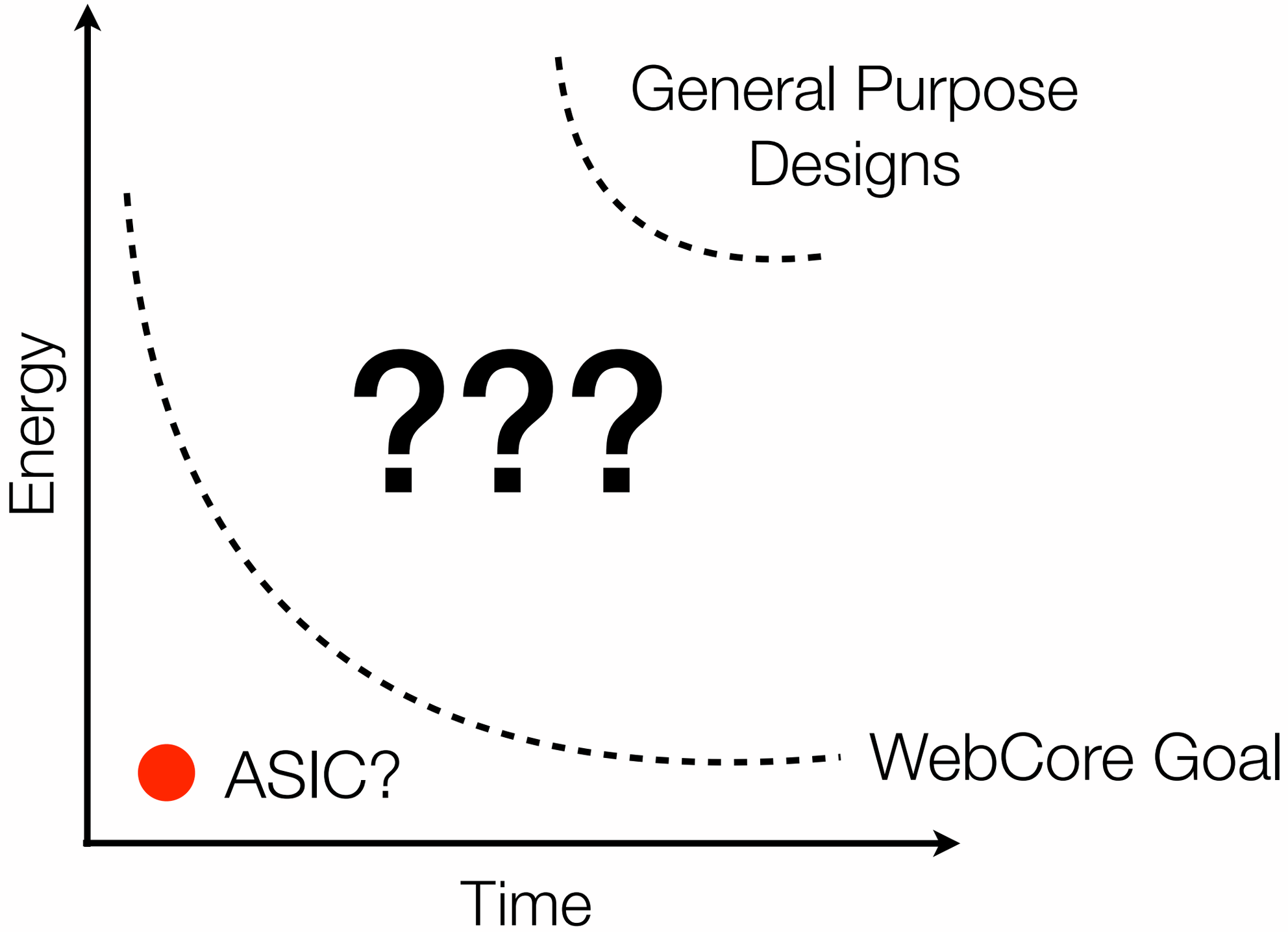

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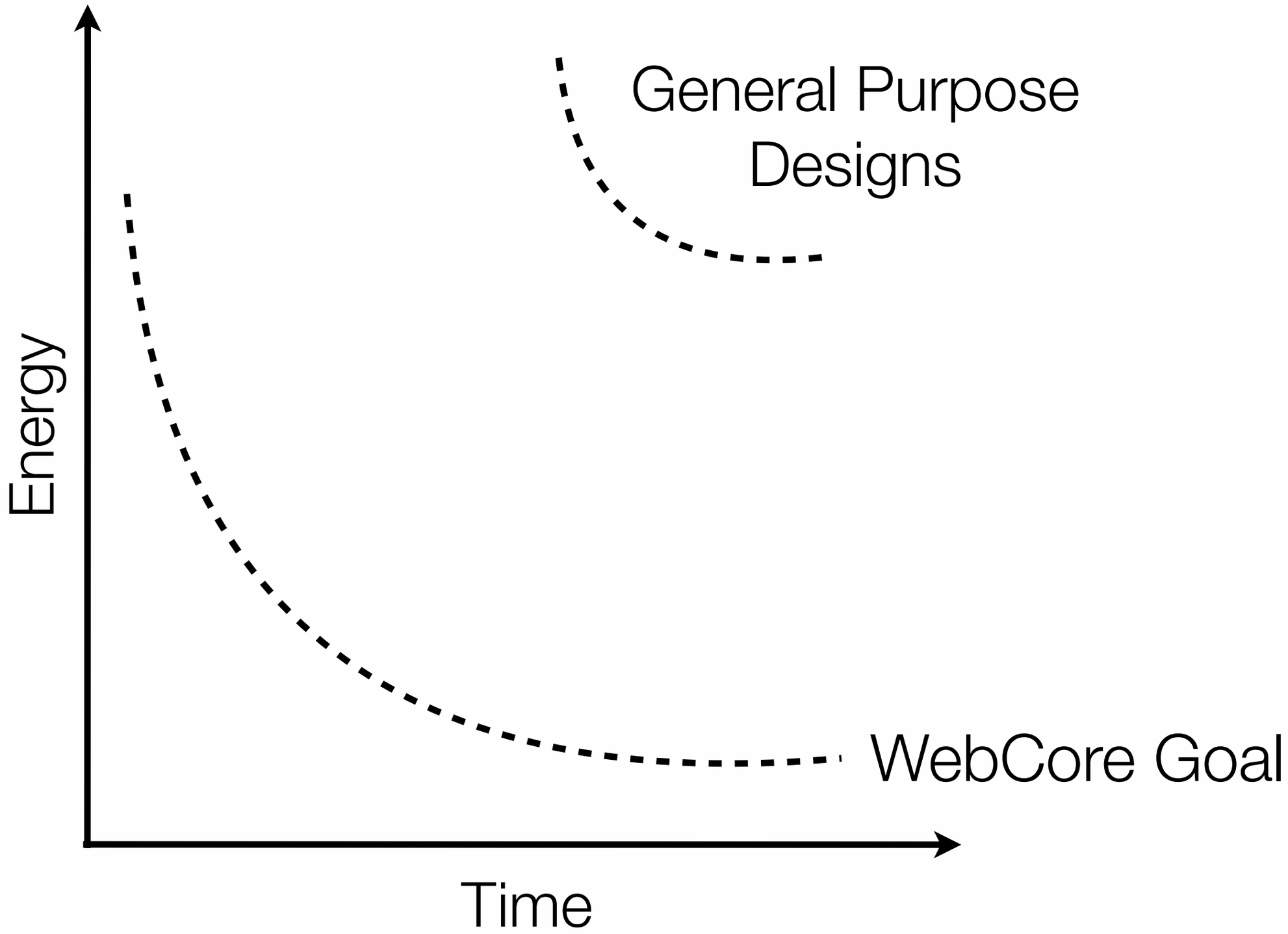

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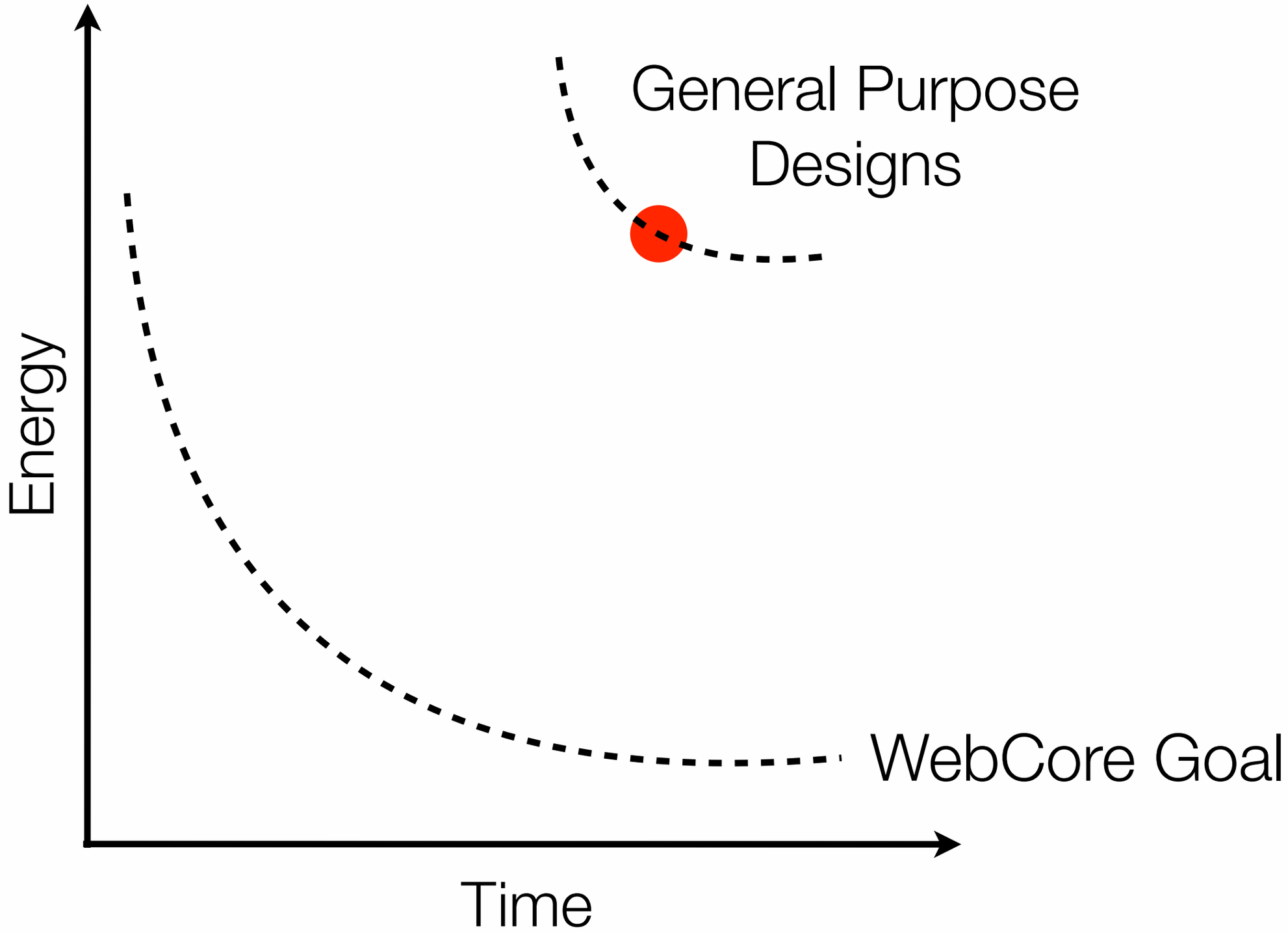

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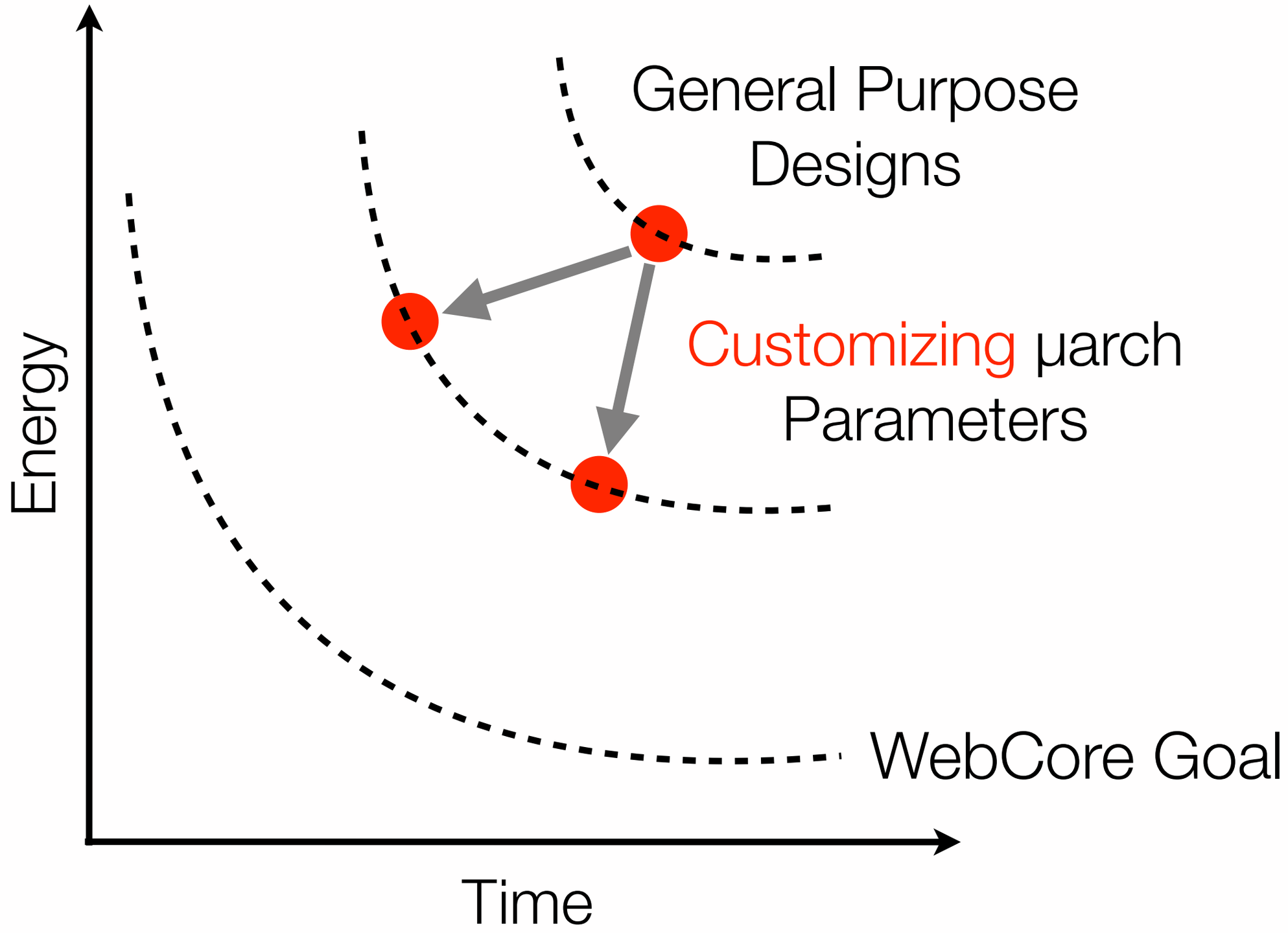

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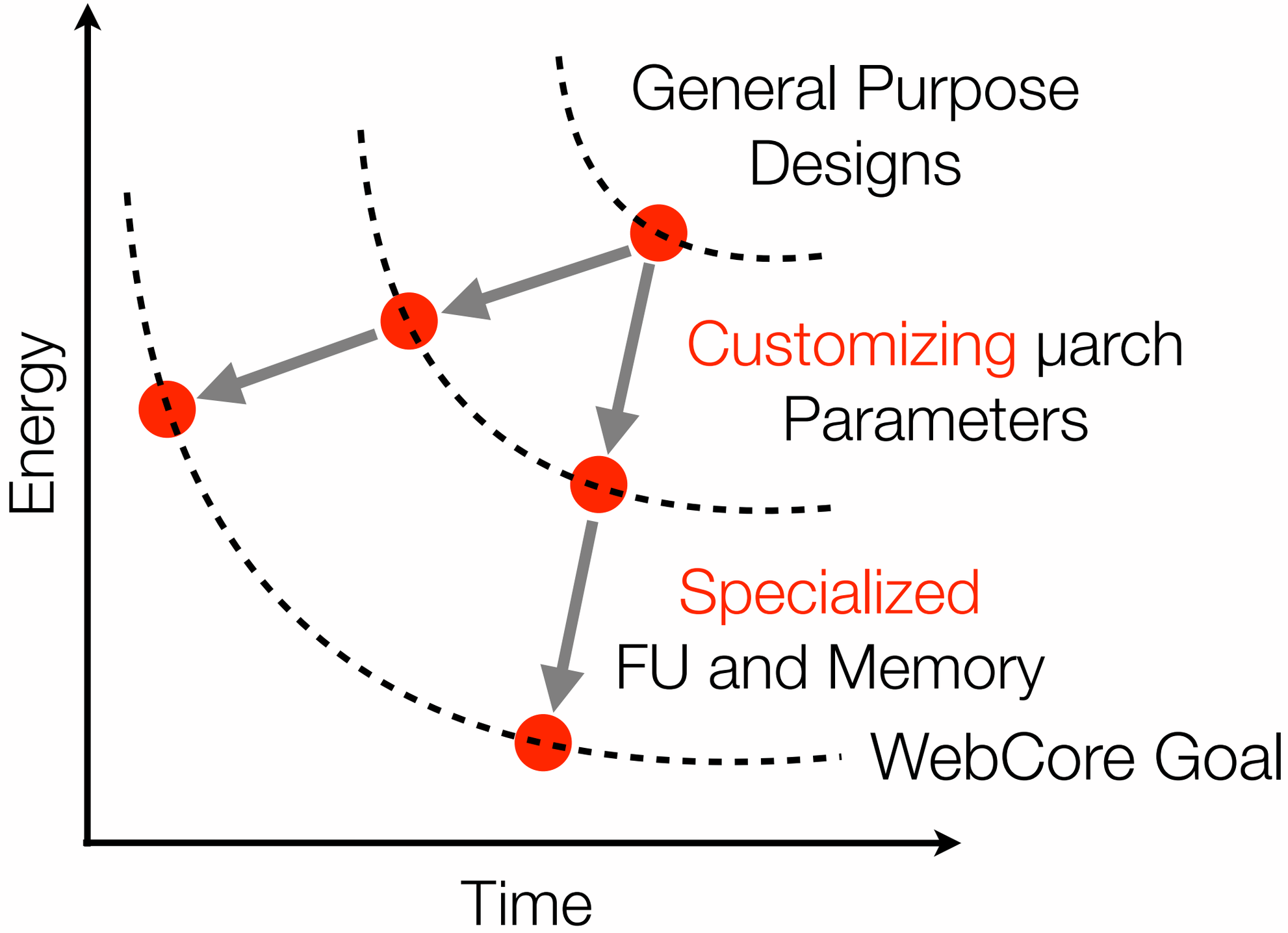

Agenda of Today's Talk

- Motivation of our work: energy-efficiency of the mobile Web

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  - **Customization**
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Customization: Find the Ideal General Purpose Baseline Architecture

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  - Out-of-order (Silvermont, A15) or in-order (Saltwell, A7)?
  - Are existing general purpose mobile designs ideal?
- Exhaustive design space exploration

Customization: Find the Ideal General Purpose Baseline Architecture

- Why customi
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Parameters	Measure
Issue width	count
# Functional units	count
Load queue size	# entries
Store queue size	# entries
Branch prediction size	log_2(#entries)
ROB size	# entries
# Physical registers	# entries
L1 I-cache size	log_2(KB)
L1 I-cache delay	cycles
L1 D-cache size	log_2(KB)
L1 D-cache delay	cycles
L2 cache size	log_2(KB)
L2 cache delay	cycles

Customization: Find the Ideal General Purpose Baseline Architecture

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Parameters	Measure	Range
Issue width	count	1,2,4
# Functional units	count	1::1::4
Load queue size	# entries	4::4::16
Store queue size	# entries	4::4::16
Branch prediction size	log_2(#entries)	1::1::10
ROB size	# entries	8::8::128
# Physical registers	# entries	5::5::140
L1 I-cache size	log_2(KB)	3::1::8
L1 I-cache delay	cycles	1::1::3
L1 D-cache size	log_2(KB)	3::1::8
L1 D-cache delay	cycles	1::1::3
L2 cache size	log_2(KB)	7::1::10
L2 cache delay	cycles	16,32,64

Design Space Exploration (DSE) Setup

- Integrated power (McPAT) and performance x86 full-system simulator (Marss86)
- WebKit engine in the Chromium Web browser

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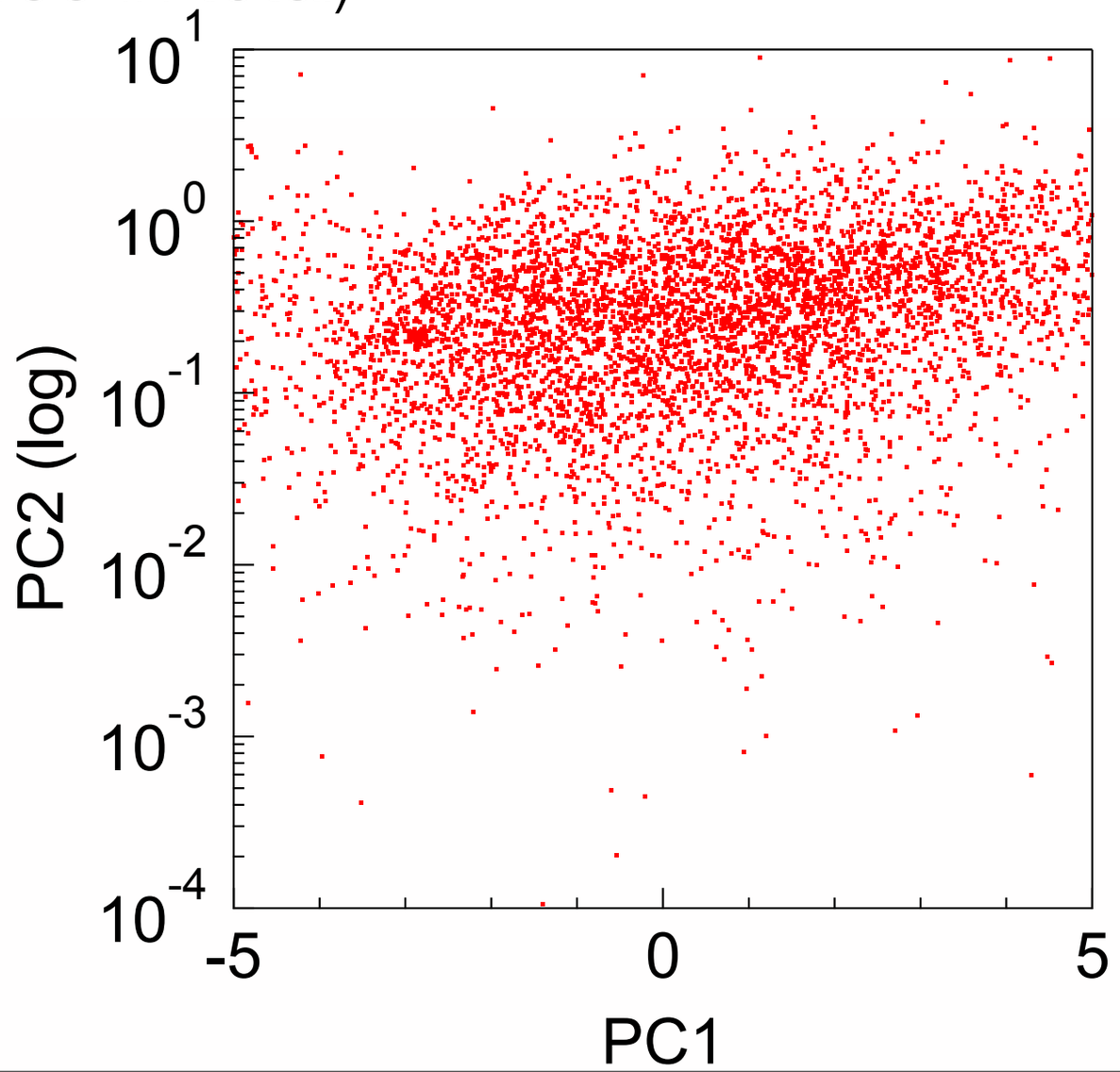

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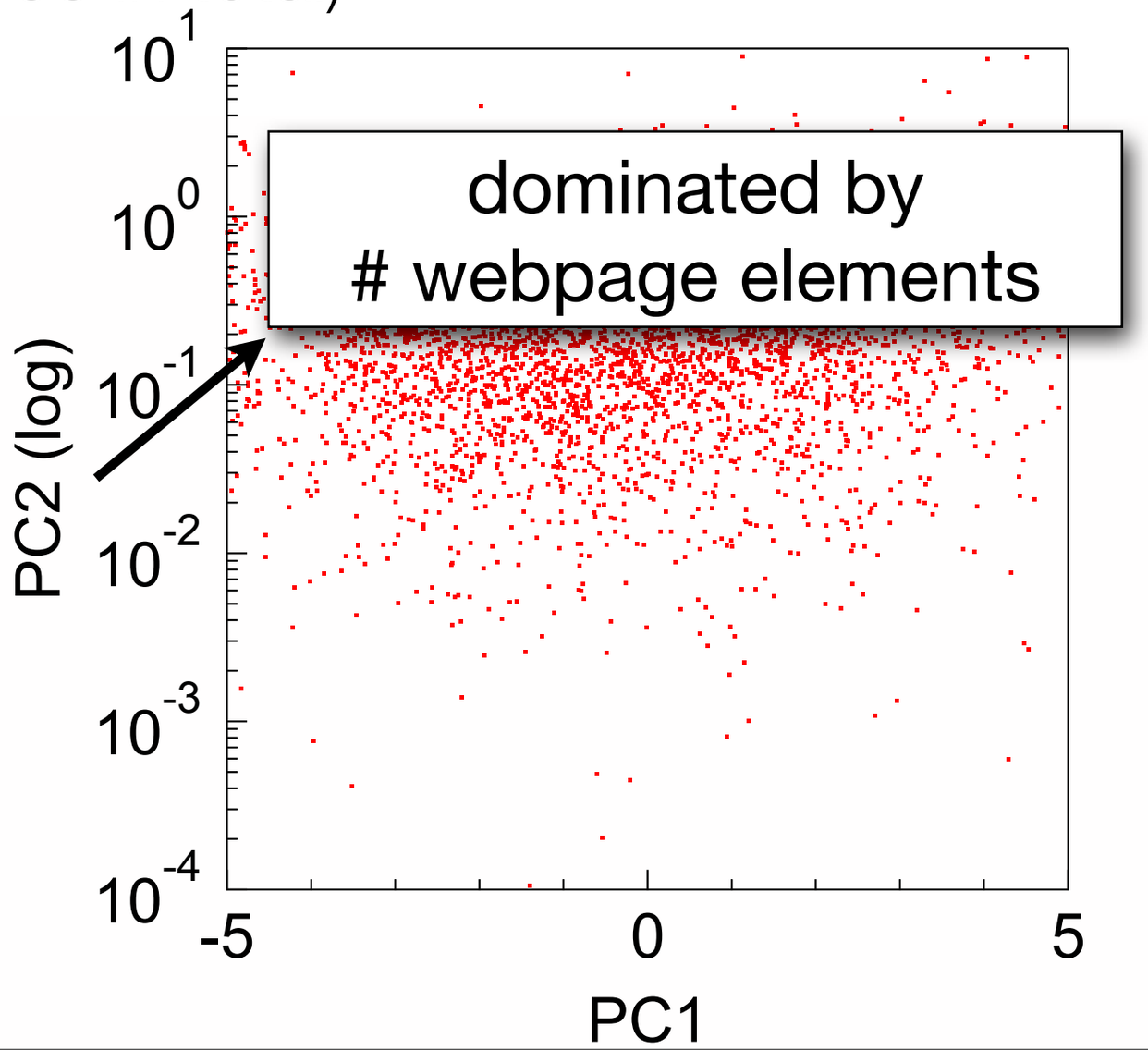

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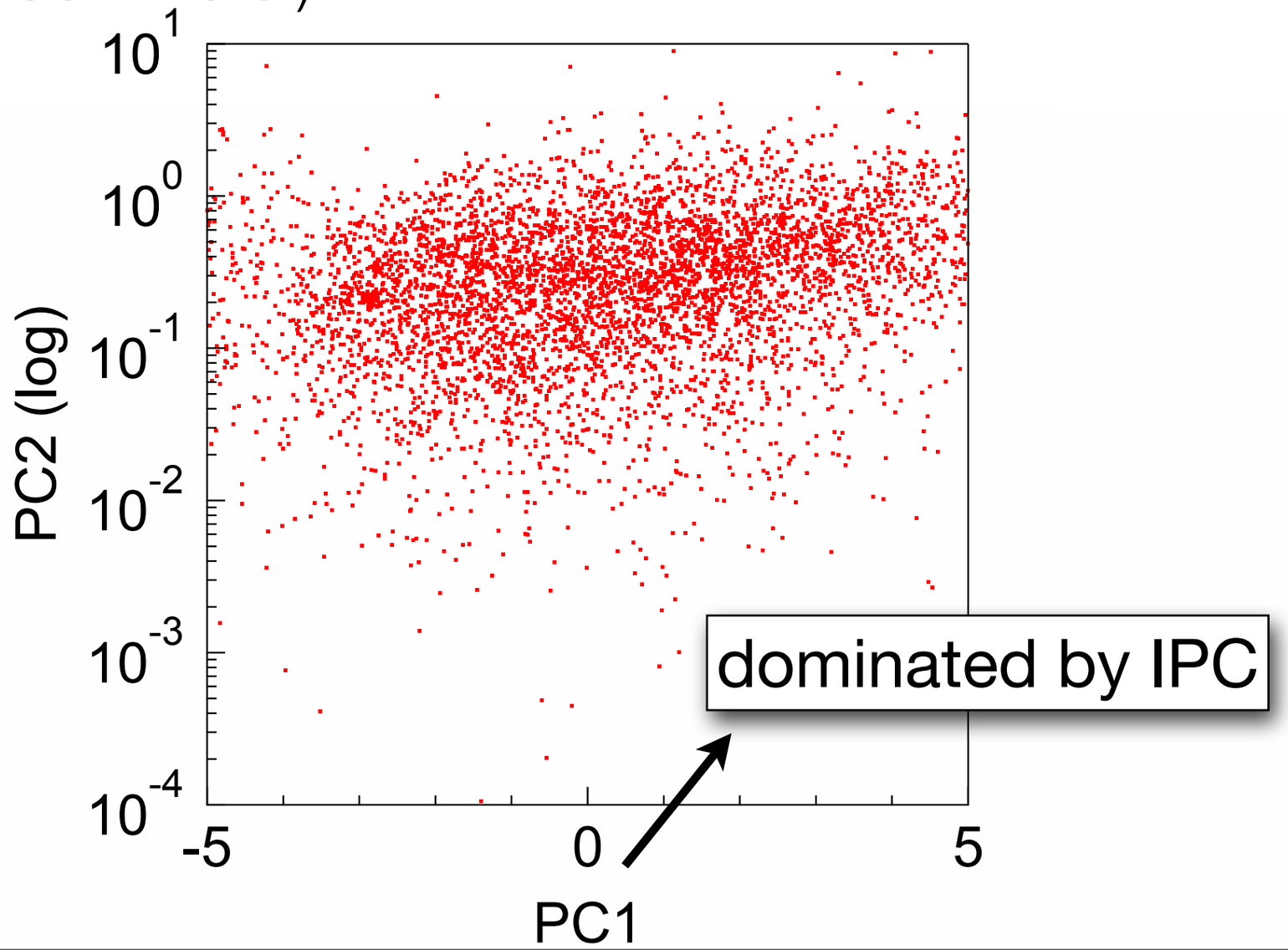

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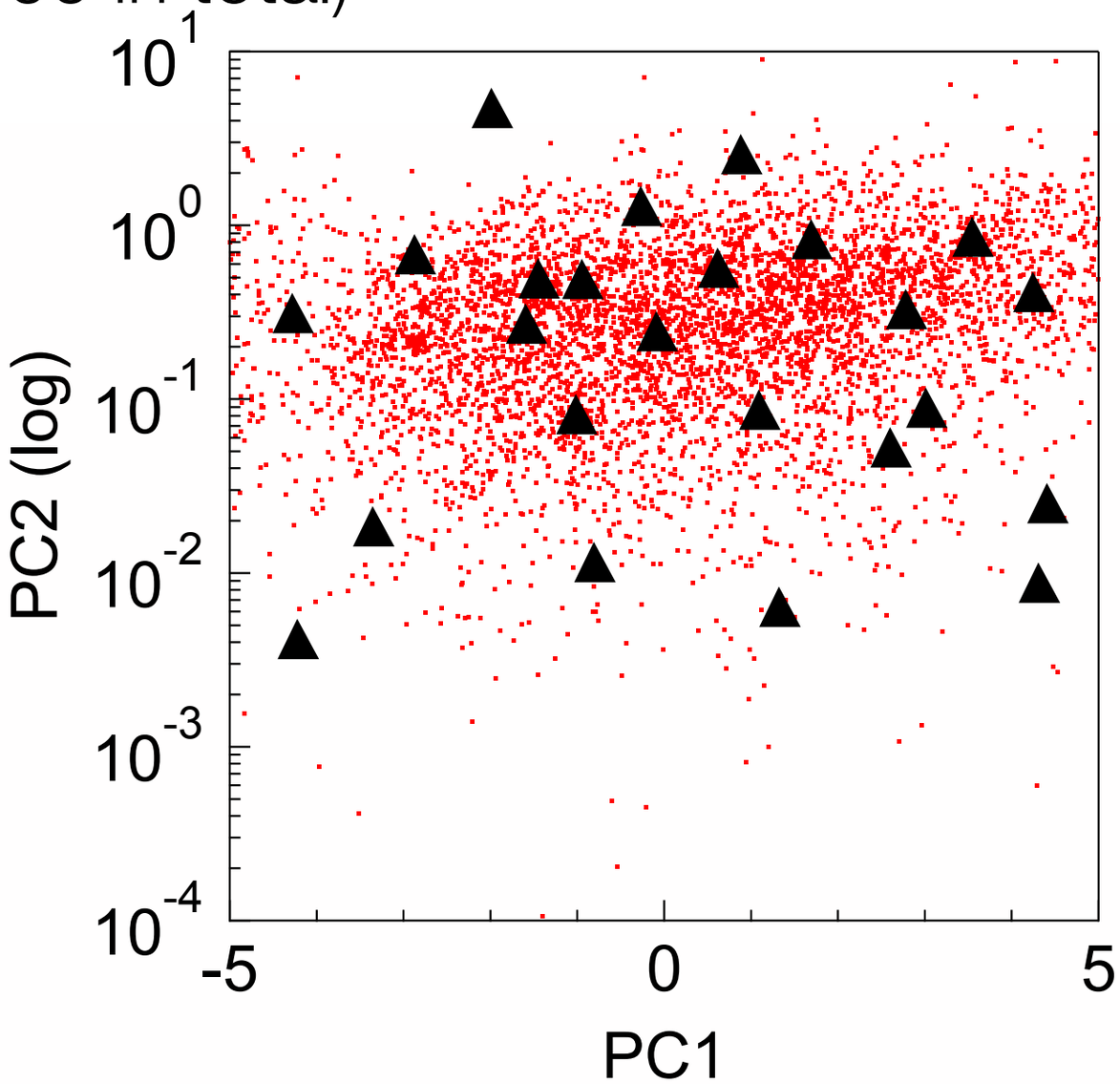
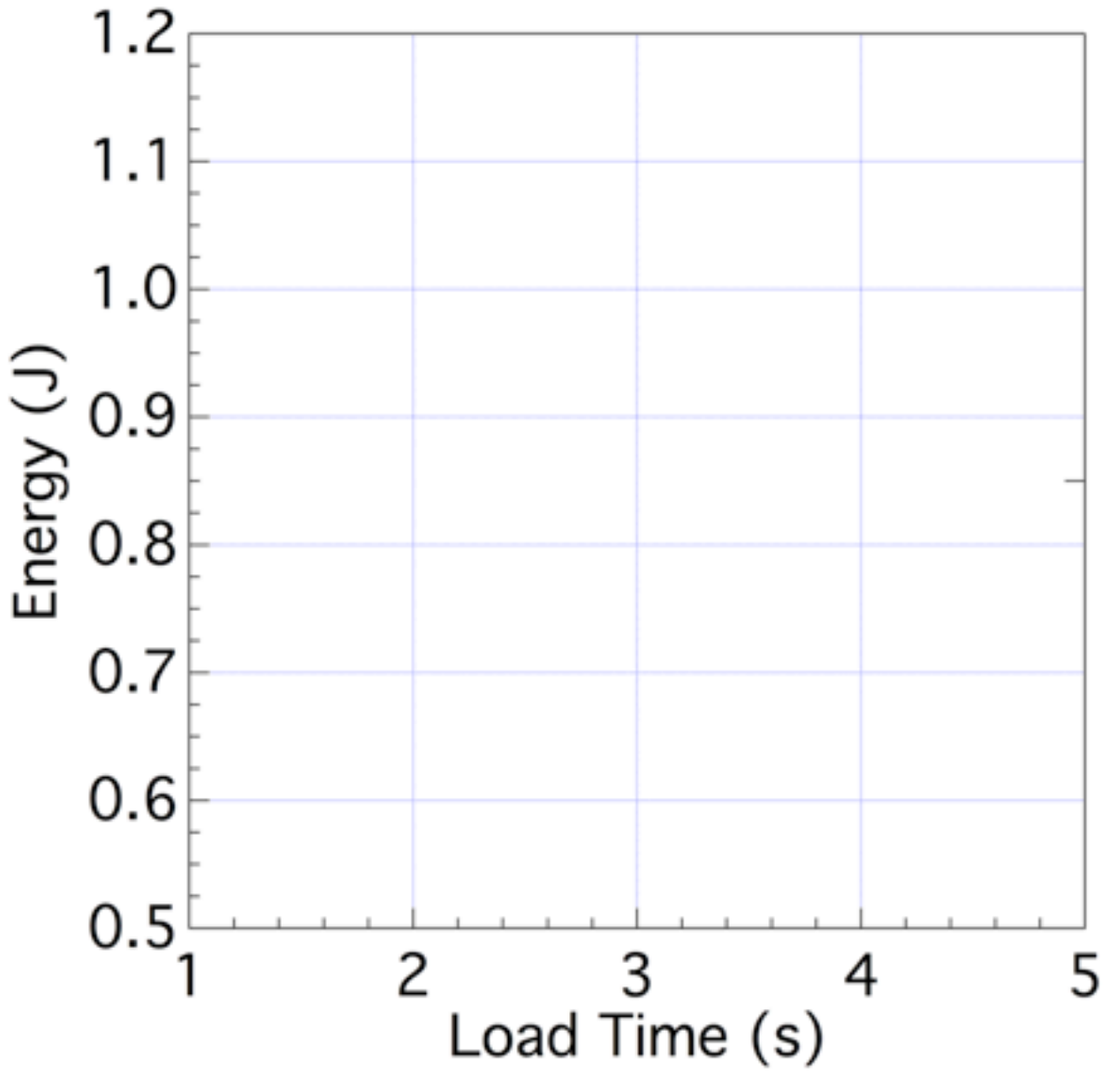


Design Space Exploration (DSE) Findings



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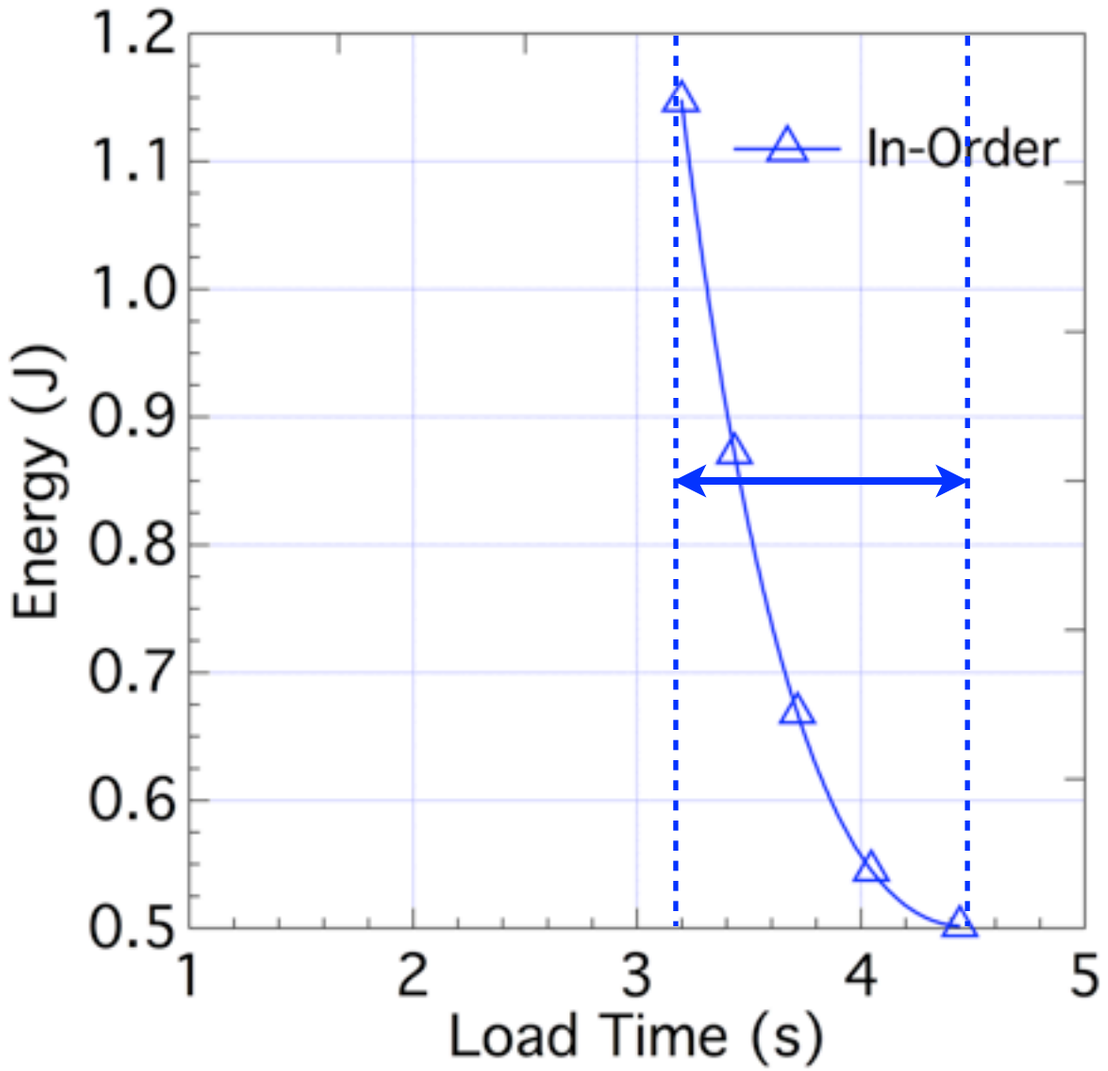

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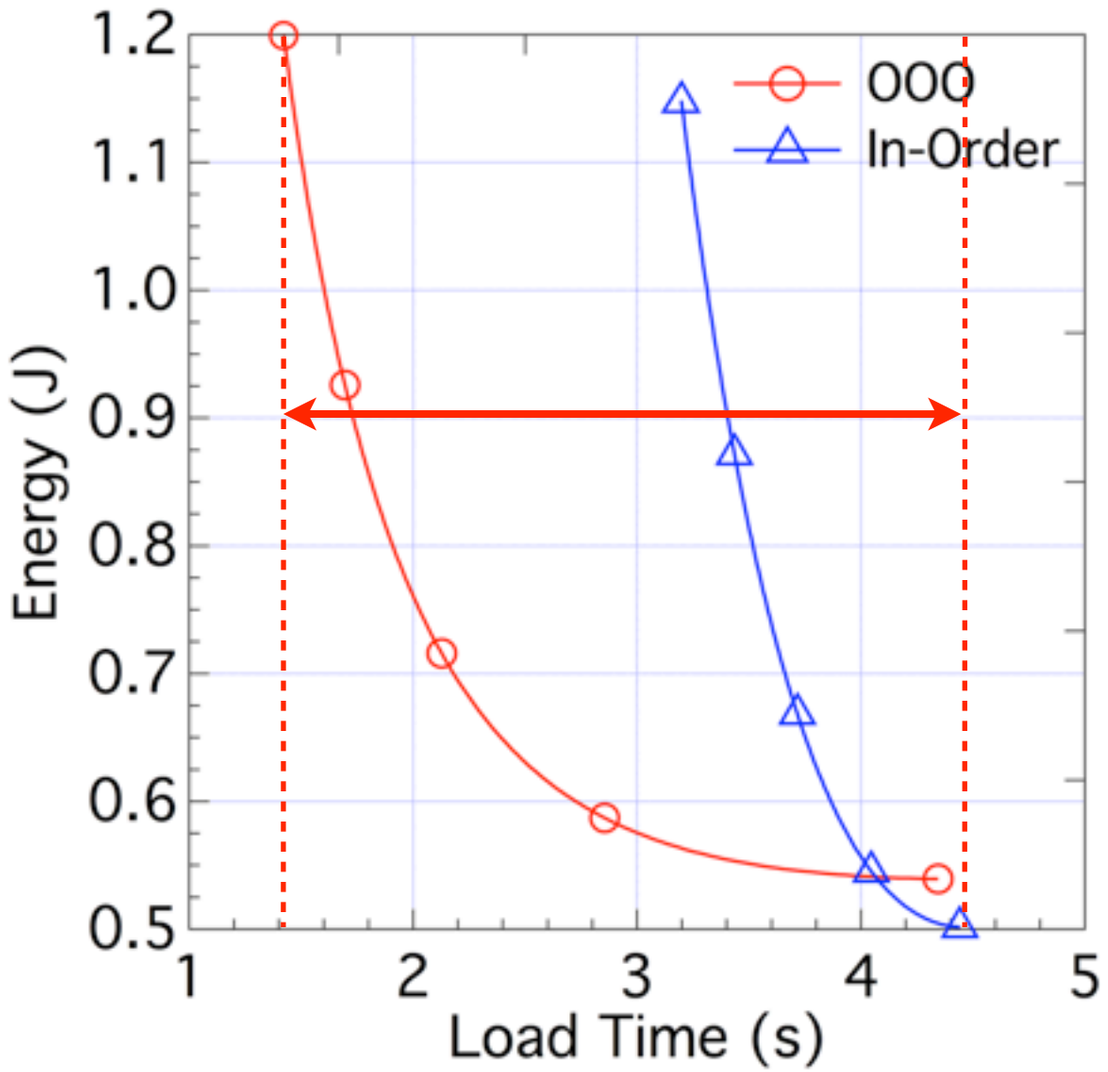
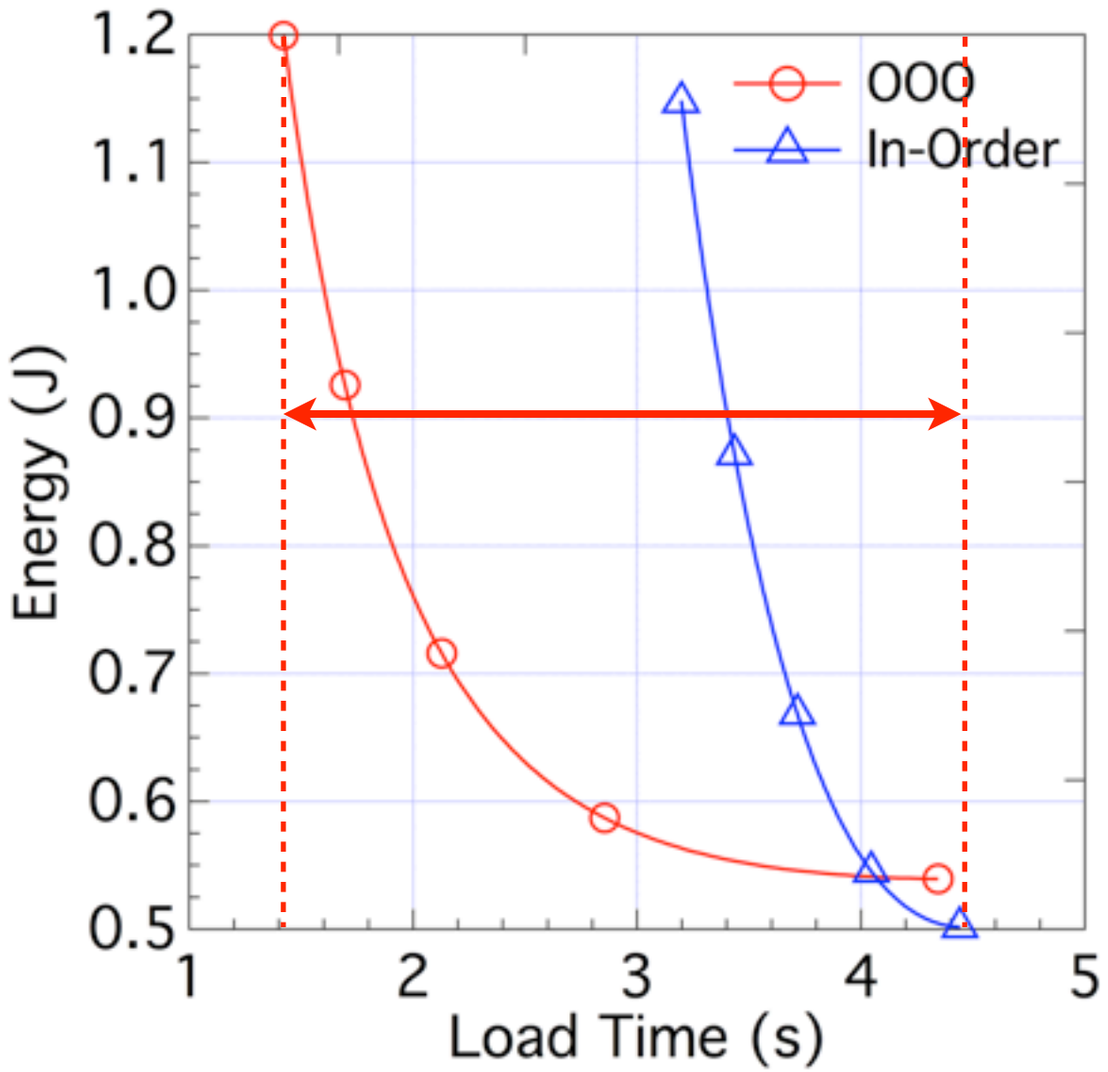


Design Space Exploration (DSE) Findings

- Out-of-order μarchitecture is much more flexible



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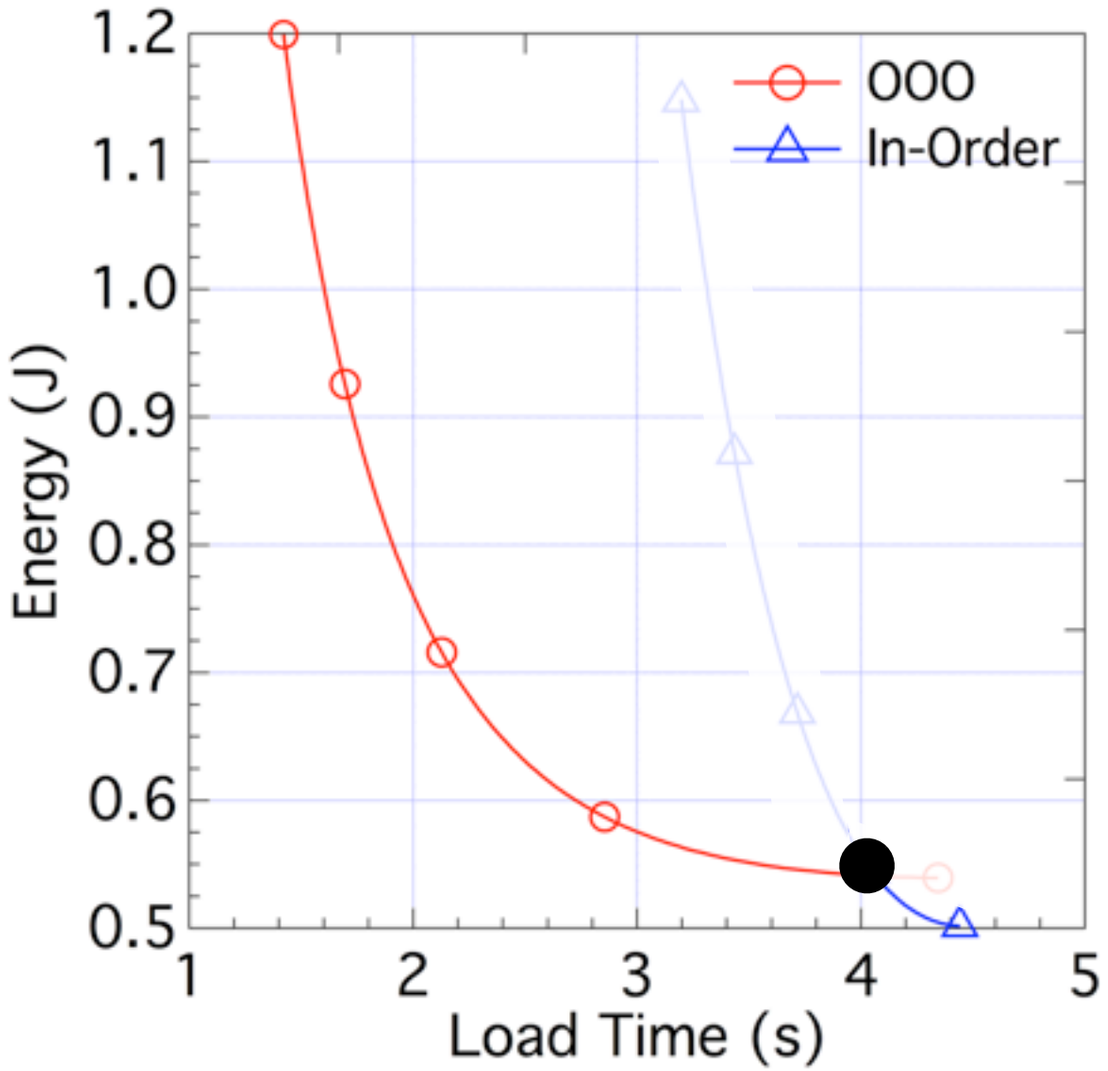
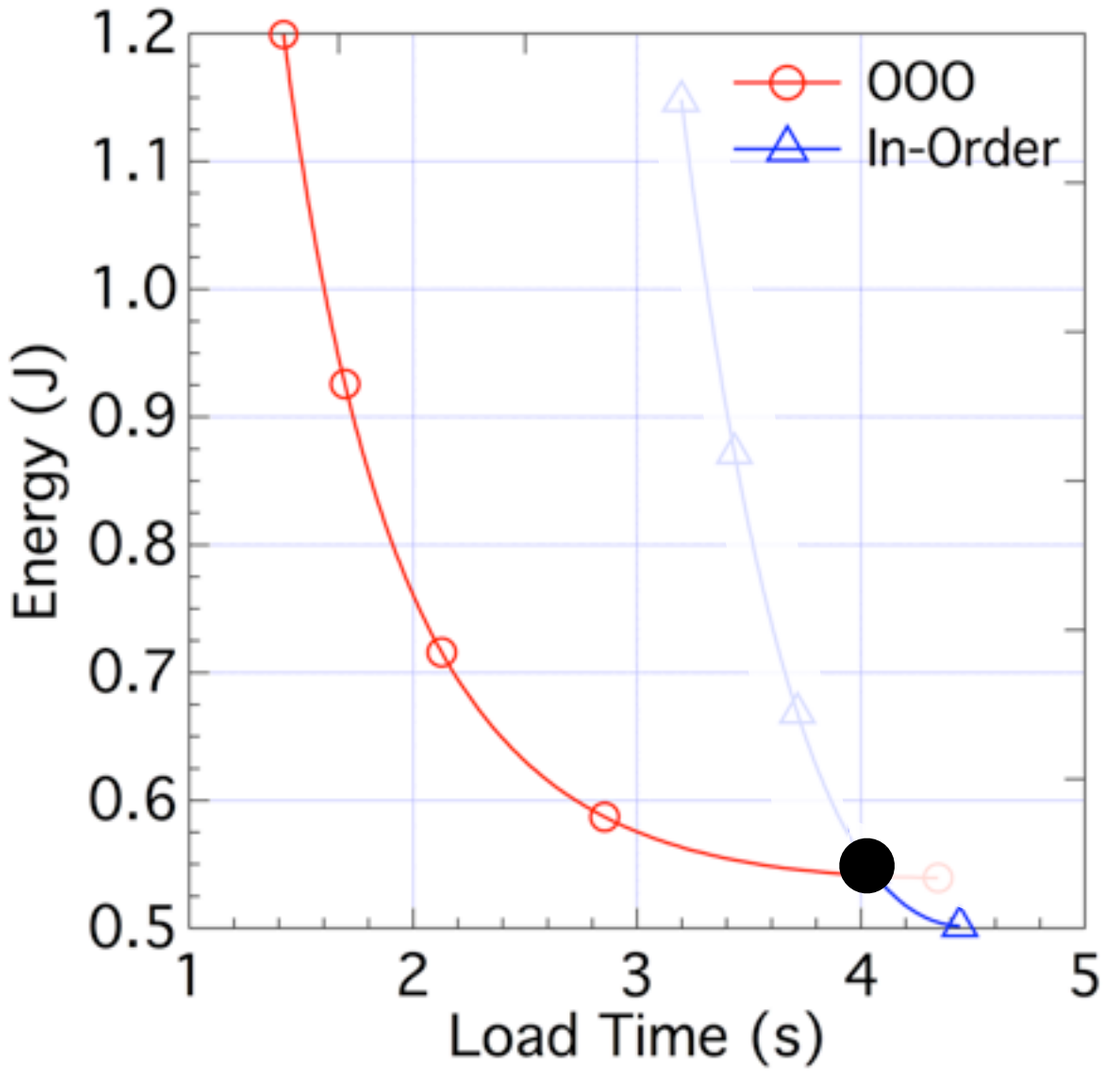


Design Space Exploration (DSE) Findings

- Out-of-order μarchitecture is much more flexible
- In-order cores are acceptable if end-users can tolerate latency



Understand the Difference Using Kernel Knowledge

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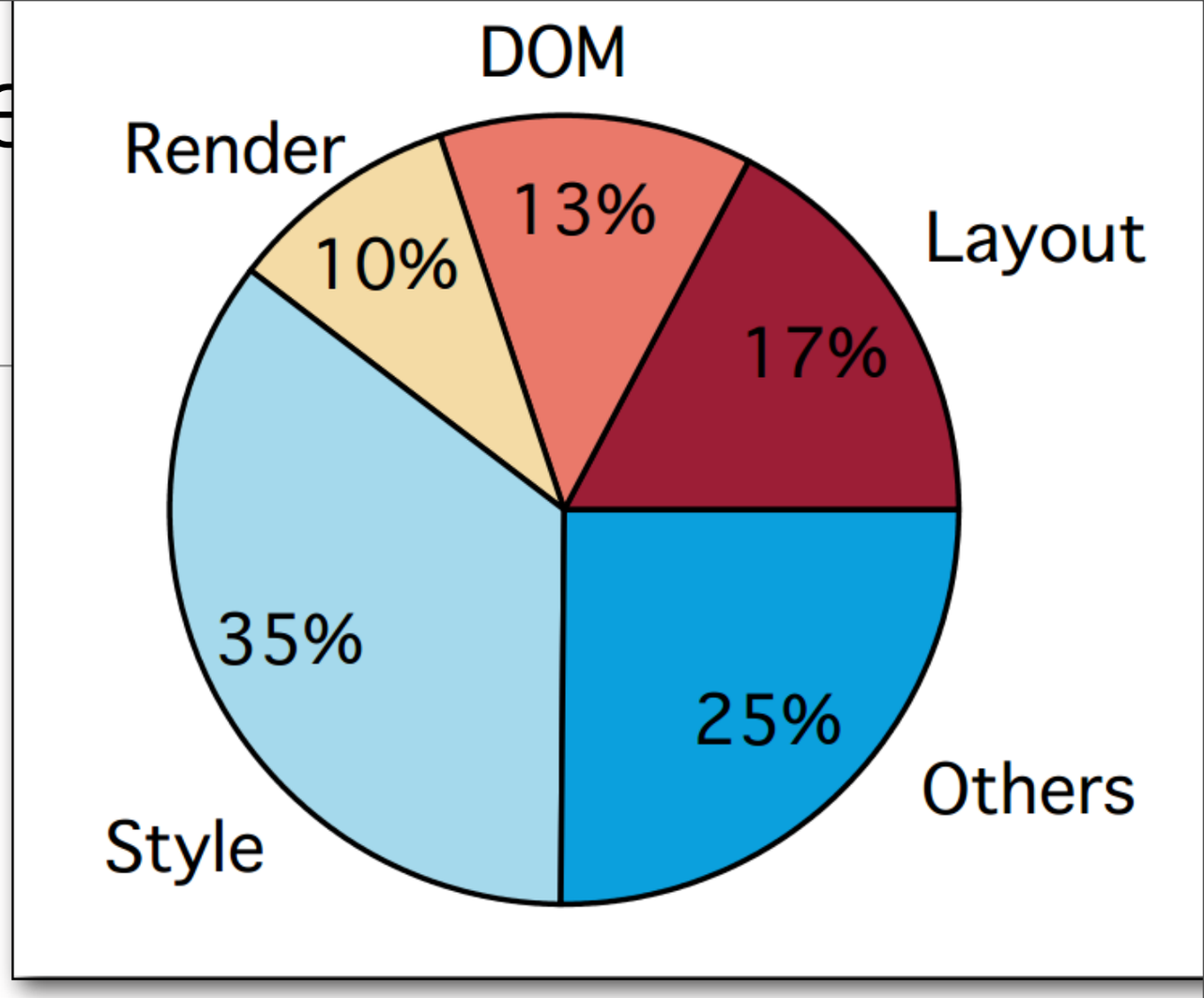
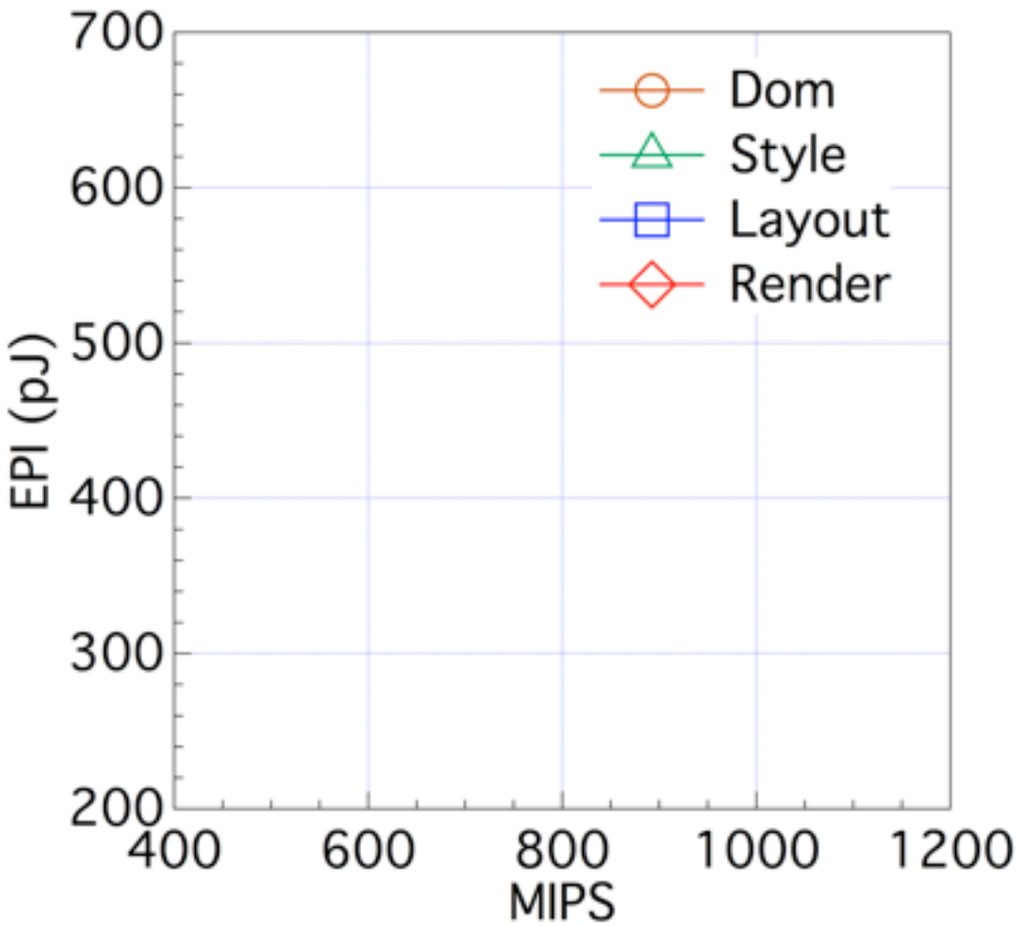


Execution time breakdown

Understand the Difference Using Kernel Knowledge



In-order design

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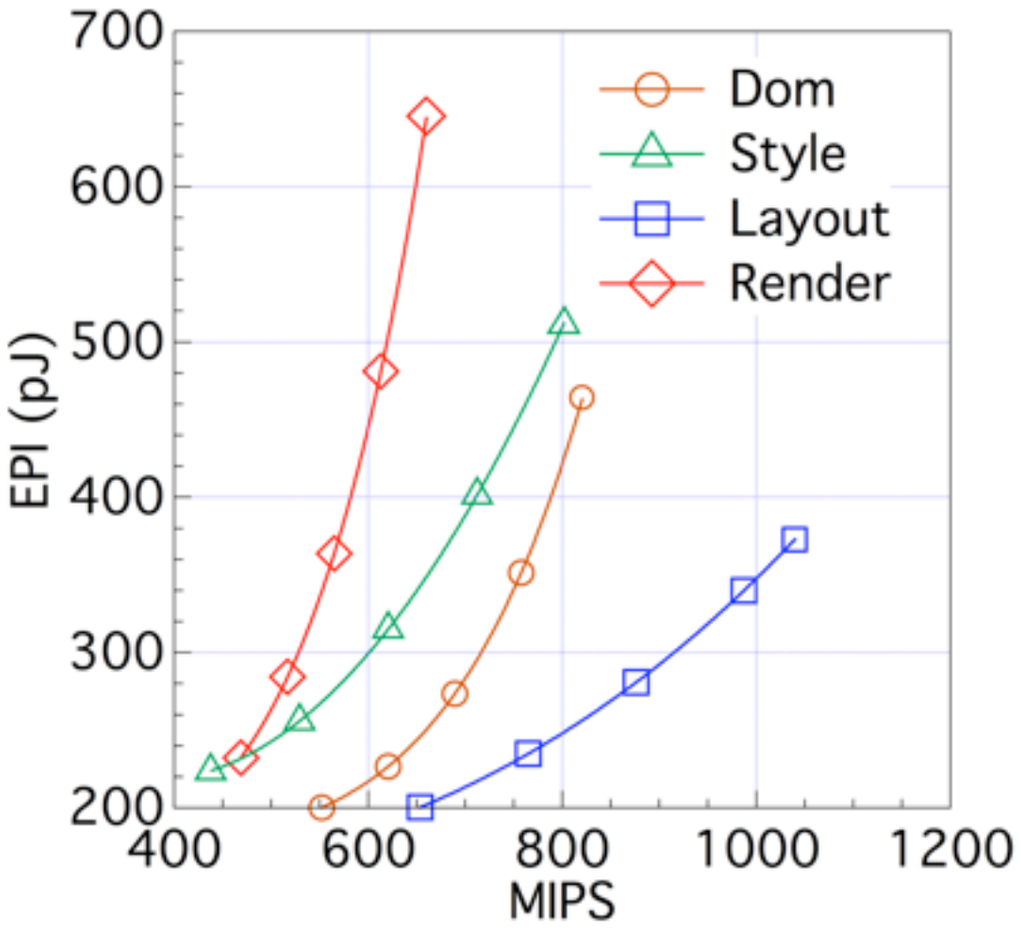

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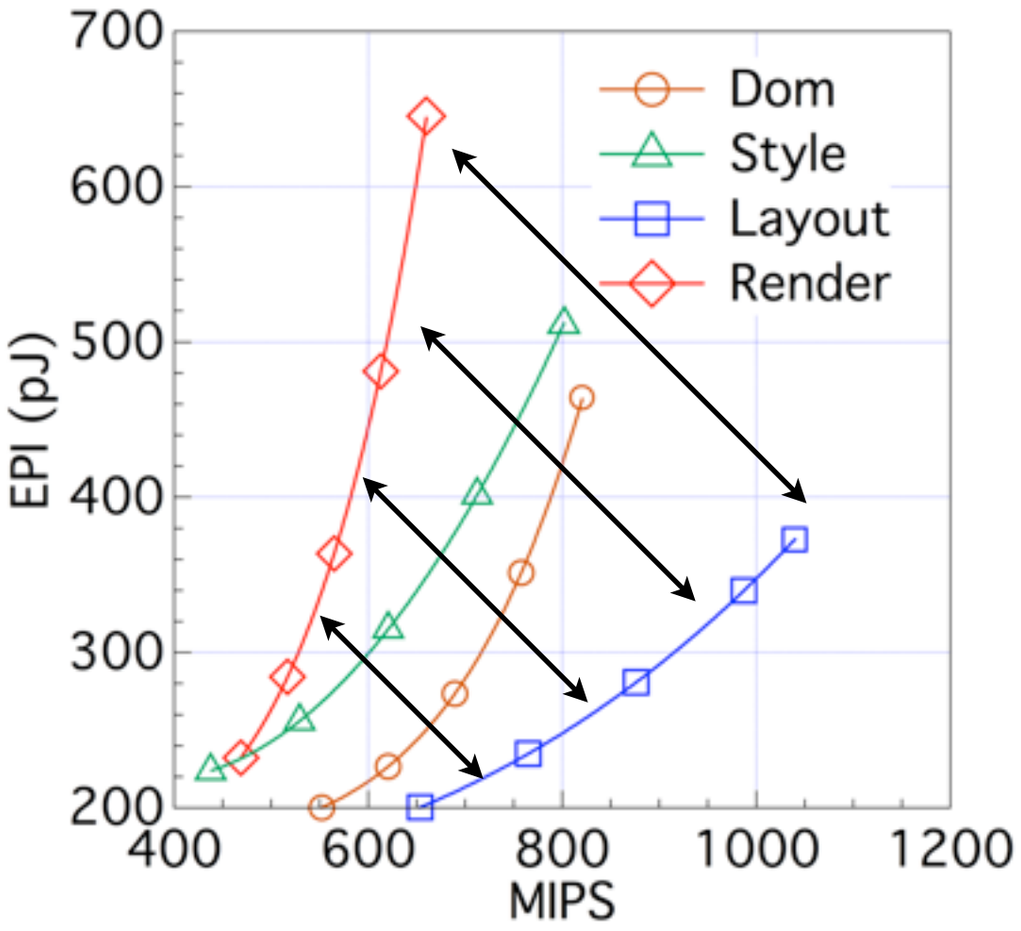
Understand the Difference Using Kernel Knowledge

- In-order designs show strong kernel variance



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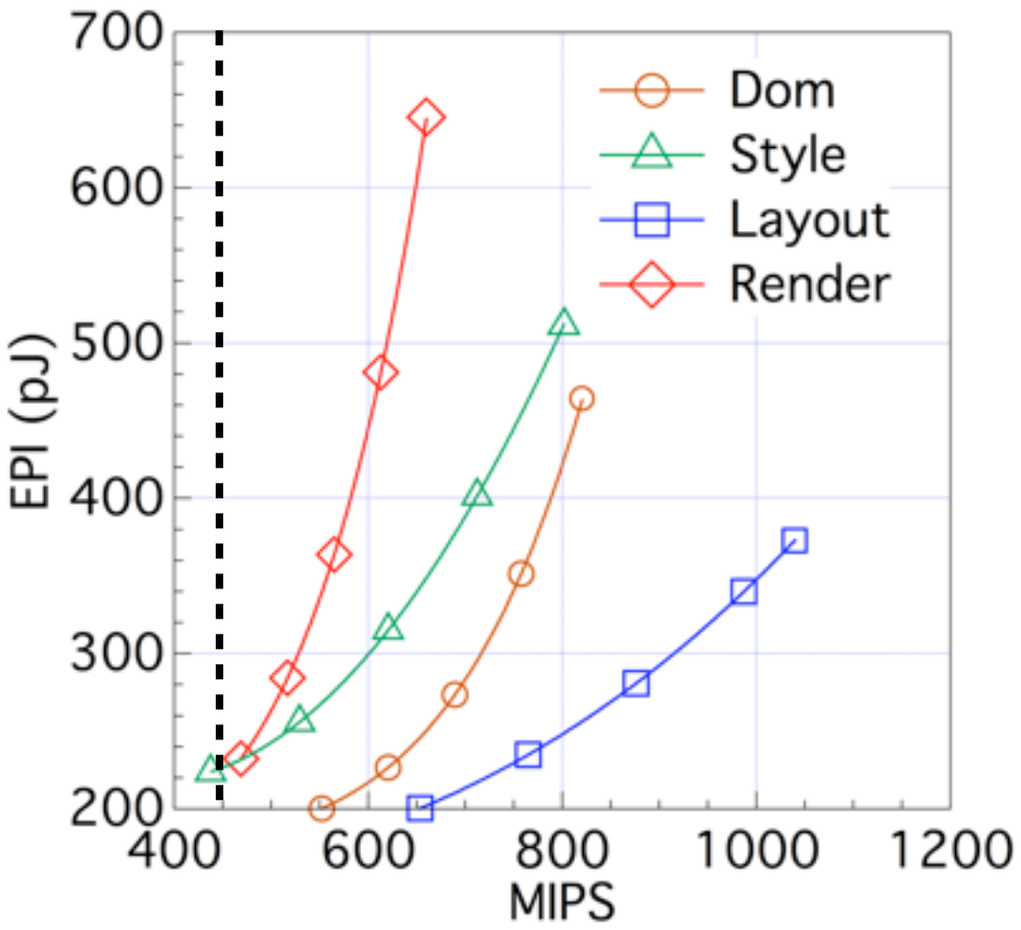

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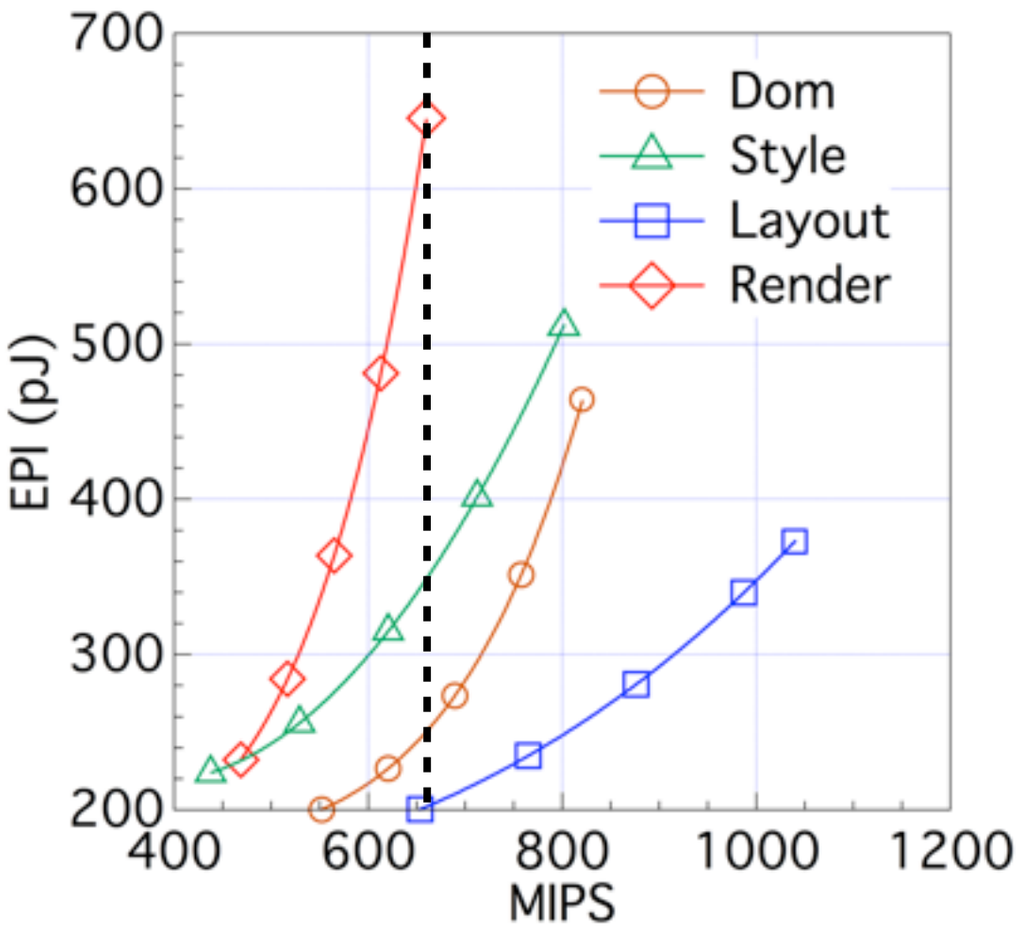

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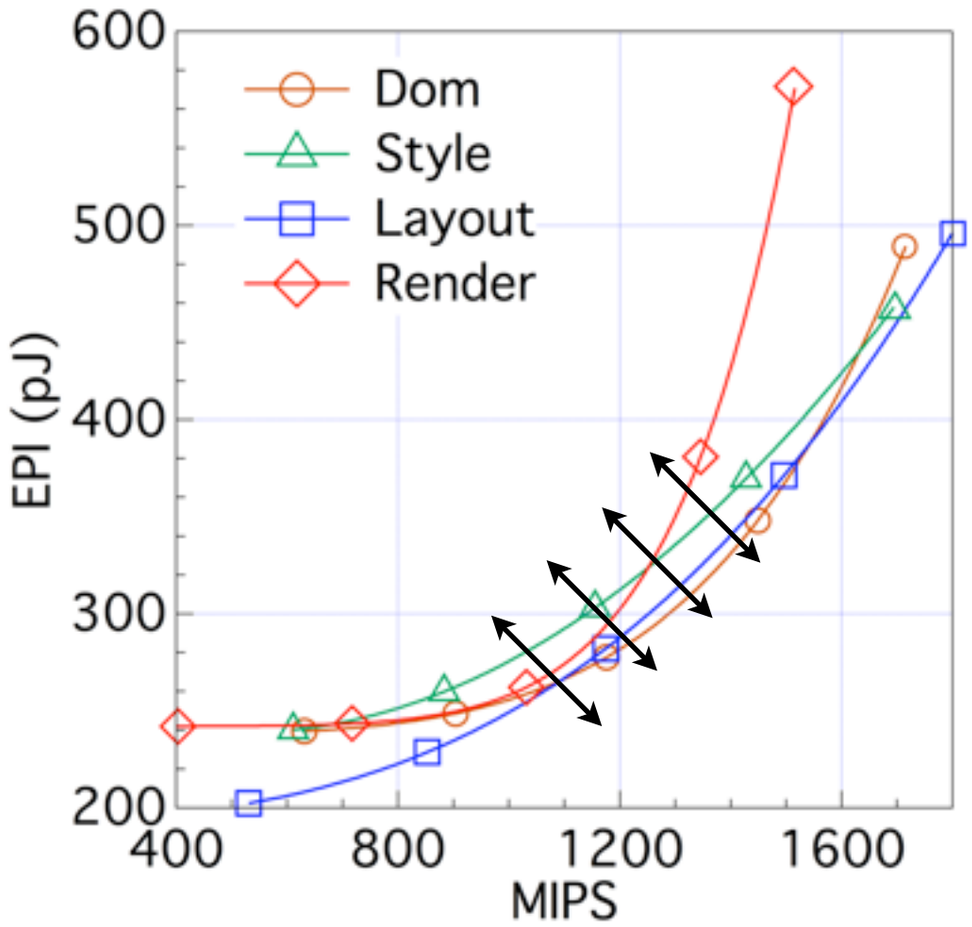
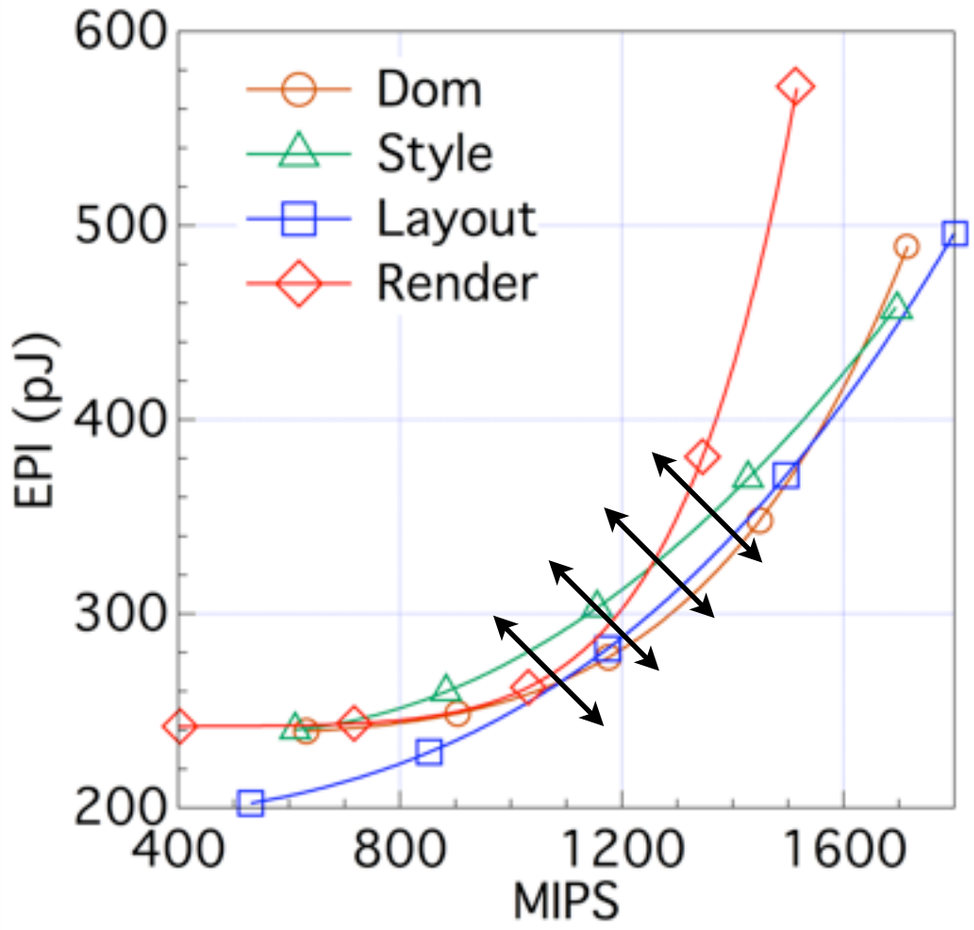


Out-of-order design

Understand the Difference Using Kernel Knowledge

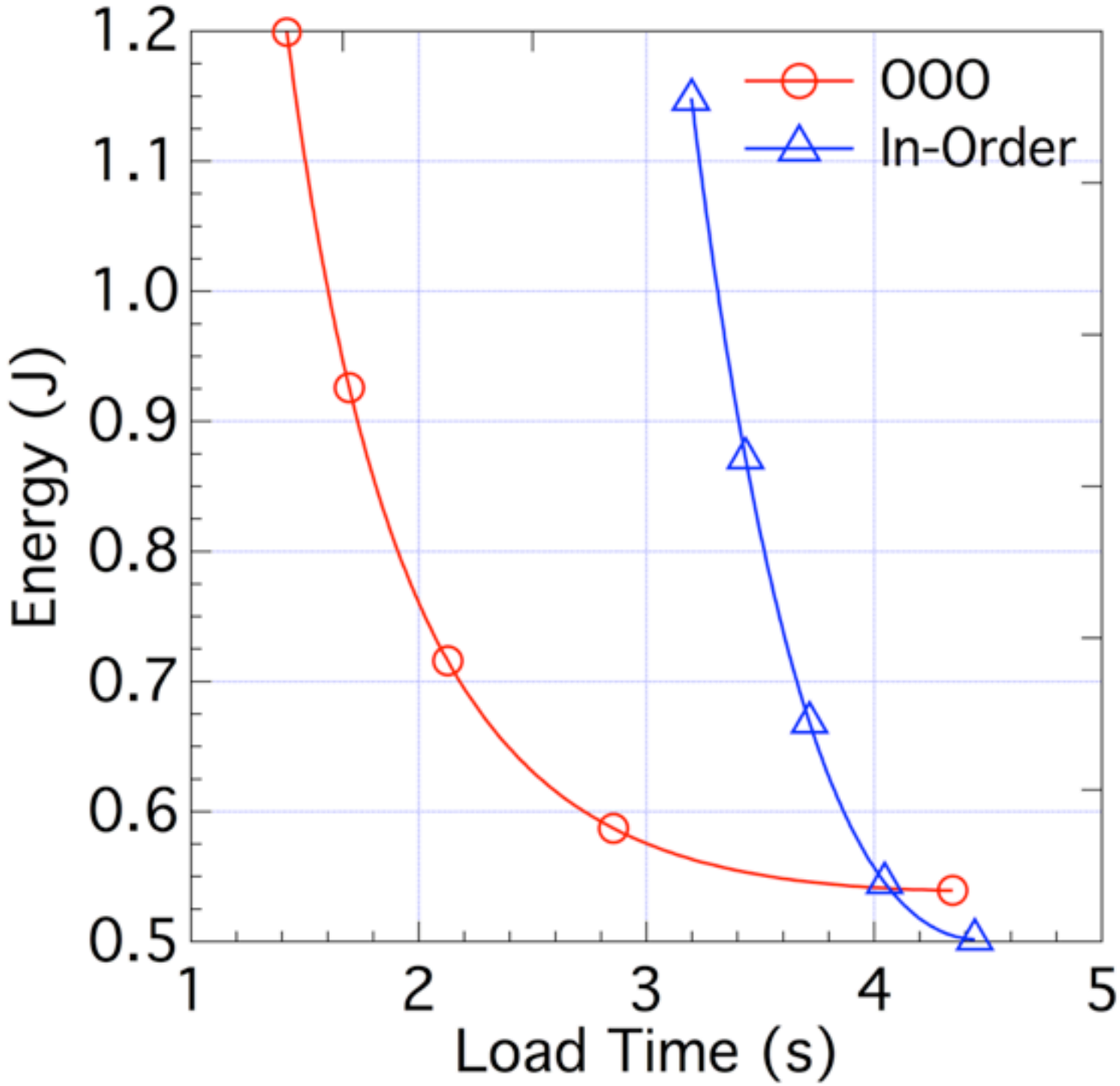
- In-order designs show strong kernel variance
- An Out-of-order design can accommodate kernel variance

In-order design



Out-of-order design

Customization: Identifying Major Sources of Energy Inefficiency



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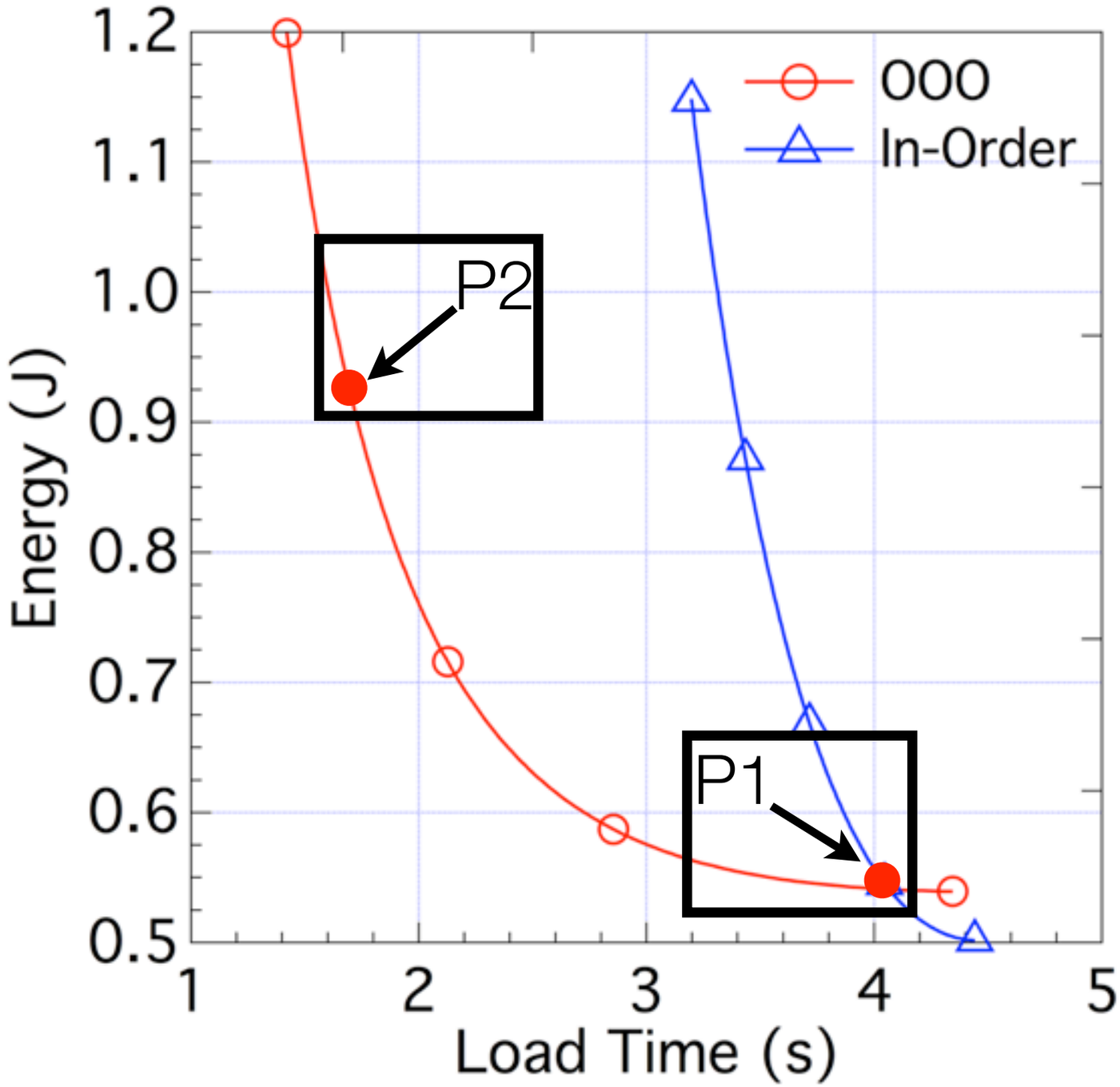

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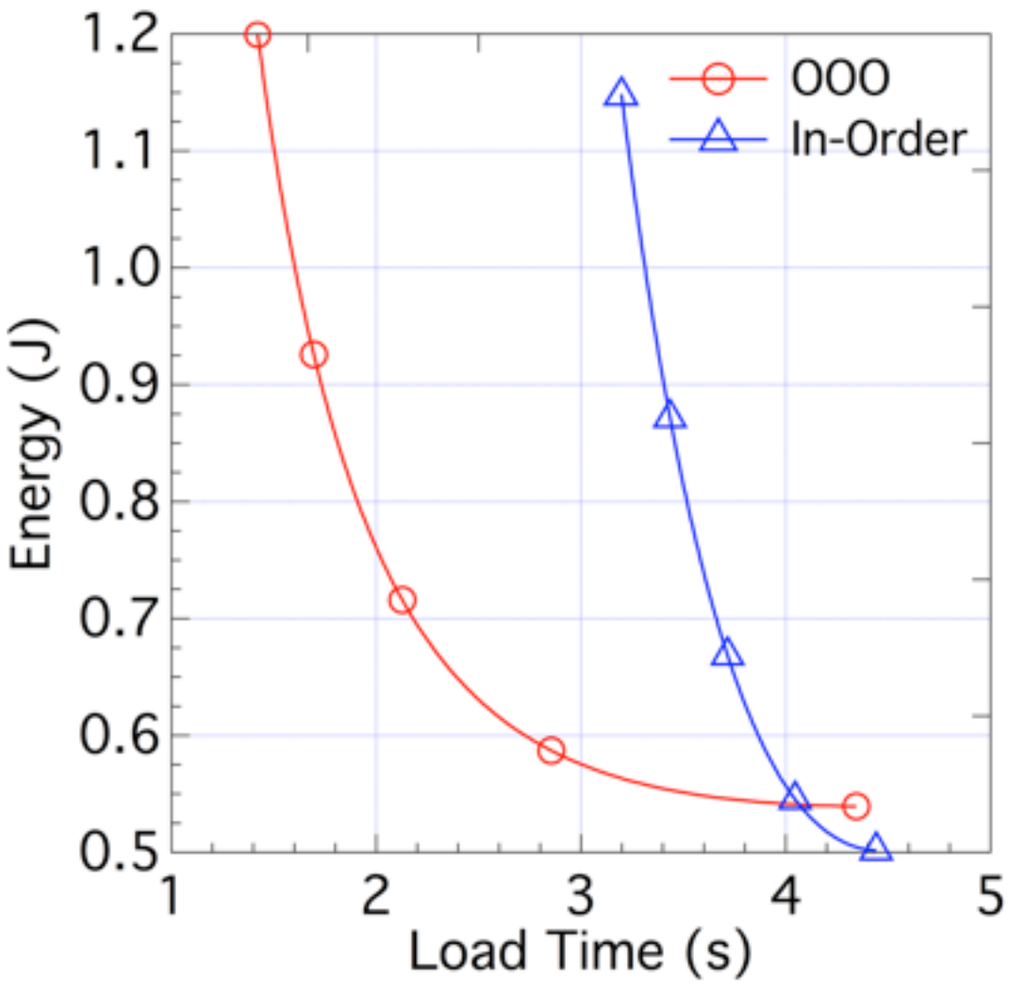
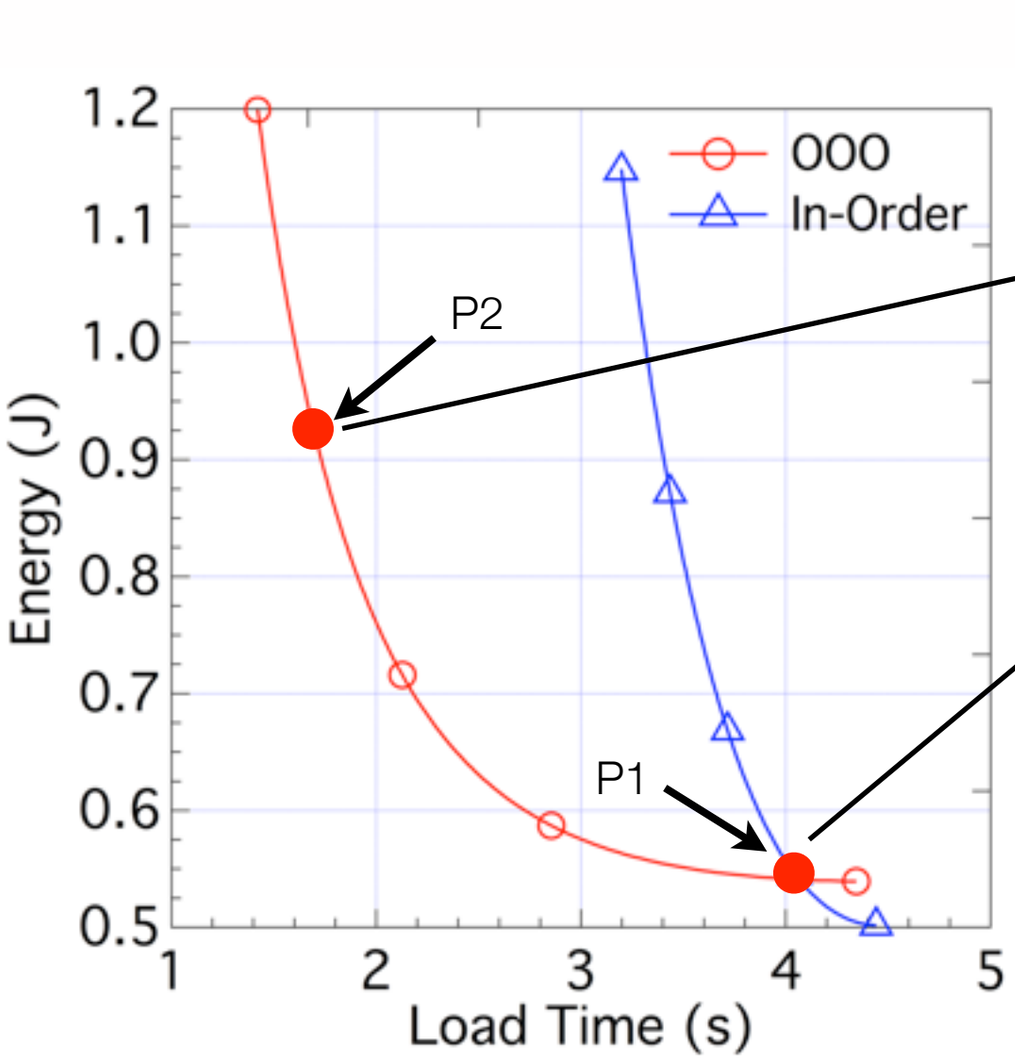


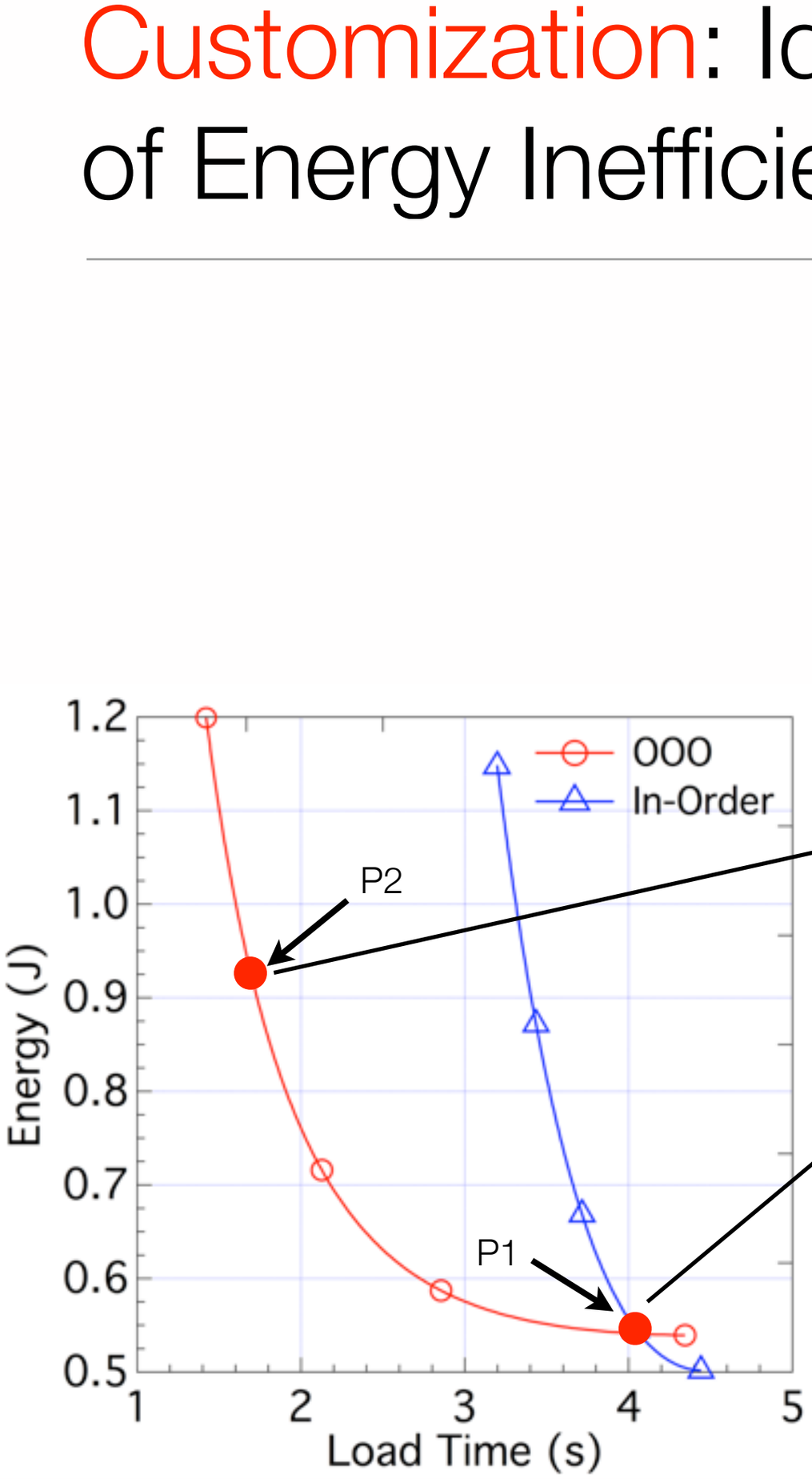
	P1	P2
Issue width	1	3
# Function units	2	3
Load queue size	4	16
Store queue size	4	16
BTB size	1024	128
ROB size	128	128
L1 I-$ size (KB)	64	128
# Physical	128	140
L1 D-$ size (KB)	8	64
L2-$ size (KB)	256	1024

Customization: Identifying Major Sources of Energy Inefficiency



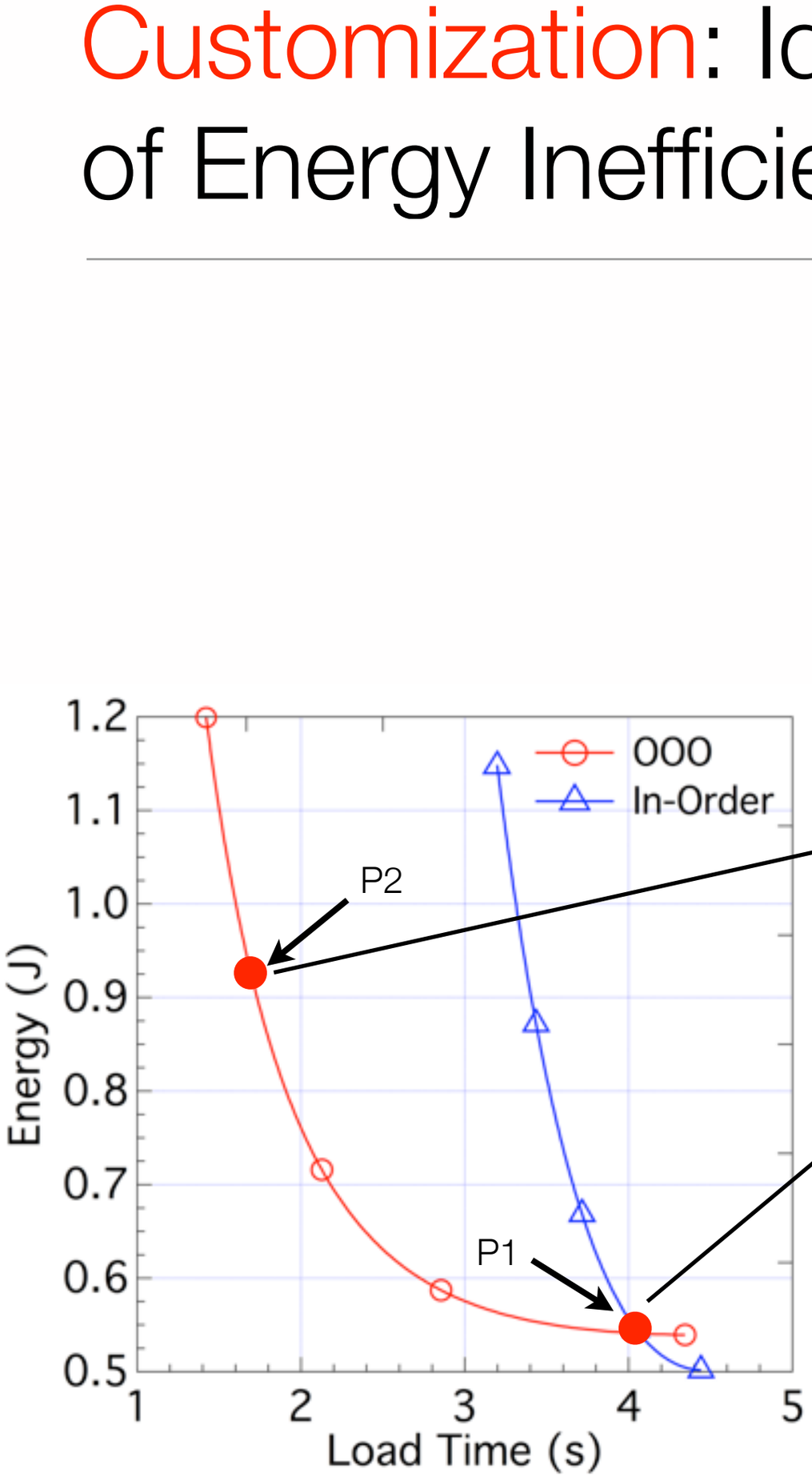
	P1	P2
Issue width	1	3
# Function units	2	3
Load queue size	4	16
Store queue size	4	16
BTB size	1024	128
ROB size	128	128
L1 I-$ size (KB)	64	128
# Physical	128	140
L1 D-$ size (KB)	8	64
L2-$ size (KB)	256	1024

Customization: Identifying Major Sources of Energy Inefficiency



	P1	P2	ARM A15
Issue width	1	3	3
# Function units	2	3	8
Load queue size	4	16	16
Store queue size	4	16	
BTB size	1024	128	256
ROB size	128	128	40+
L1 I-$ size (KB)	64	128	32
# Physical	128	140	?
L1 D-$ size (KB)	8	64	32
L2-$ size (KB)	256	1024	<4096

Customization: Identifying Major Sources of Energy Inefficiency



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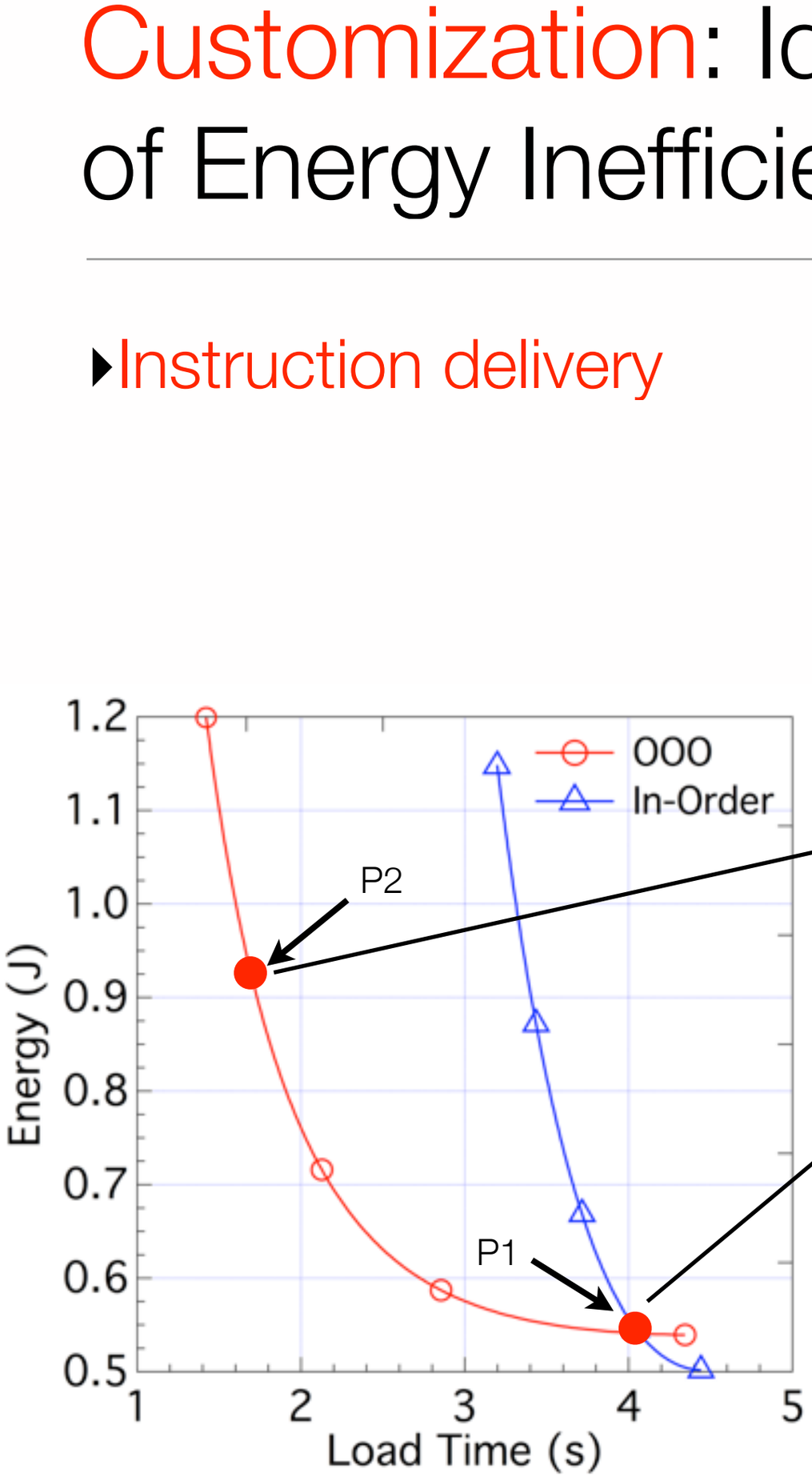
Customization: Identifying Major Sources of Energy Inefficiency

- Instruction delivery



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Customization: Identifying Major Sources of Energy Inefficiency

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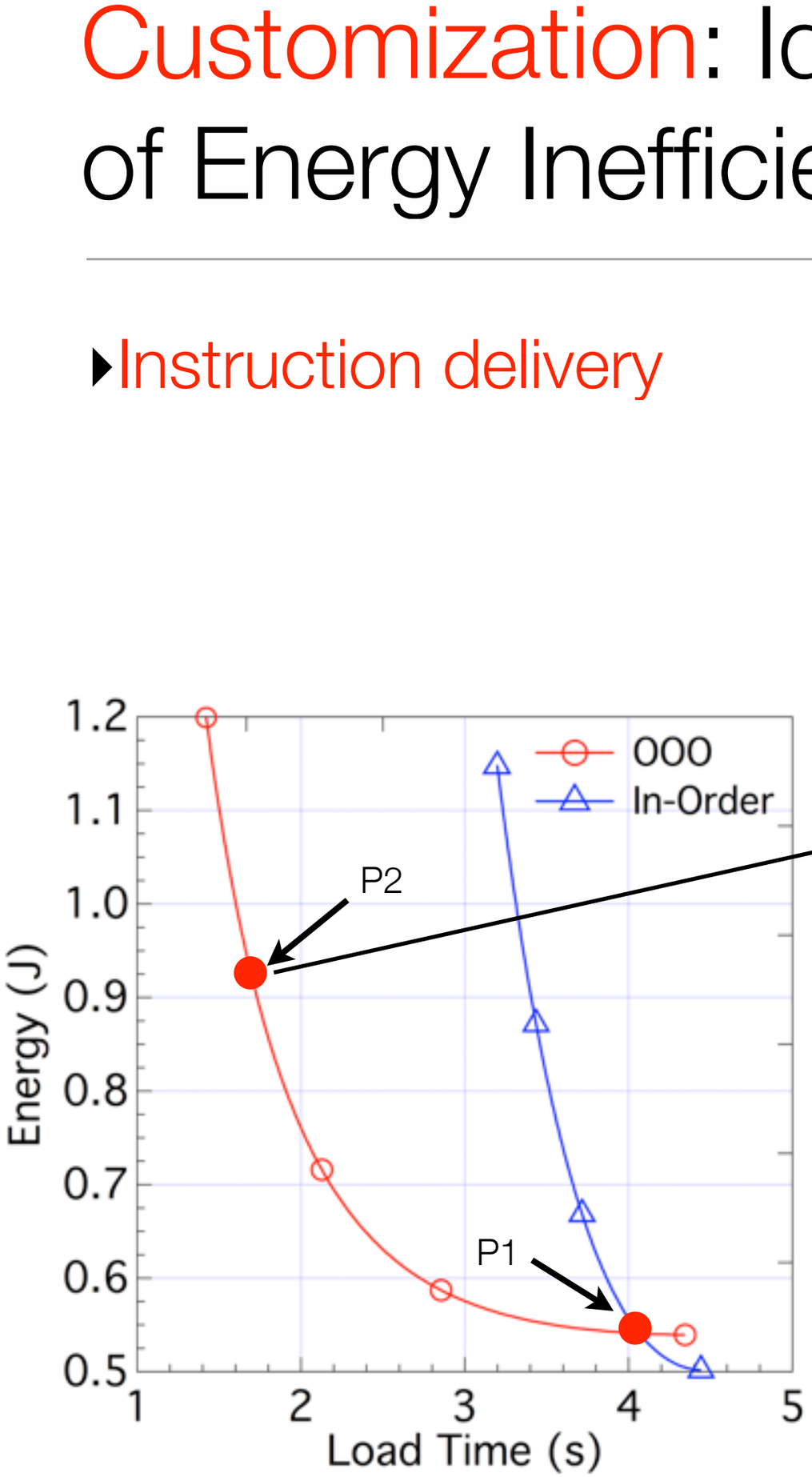

	P1	P2	ARM A15
Issue width	1	3	3
# Function units	2	3	8
Load queue size	4	16	16
Store queue size	4	16	
BTB size	1024	128	256
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L1 D-$ size (KB)	8	64	32
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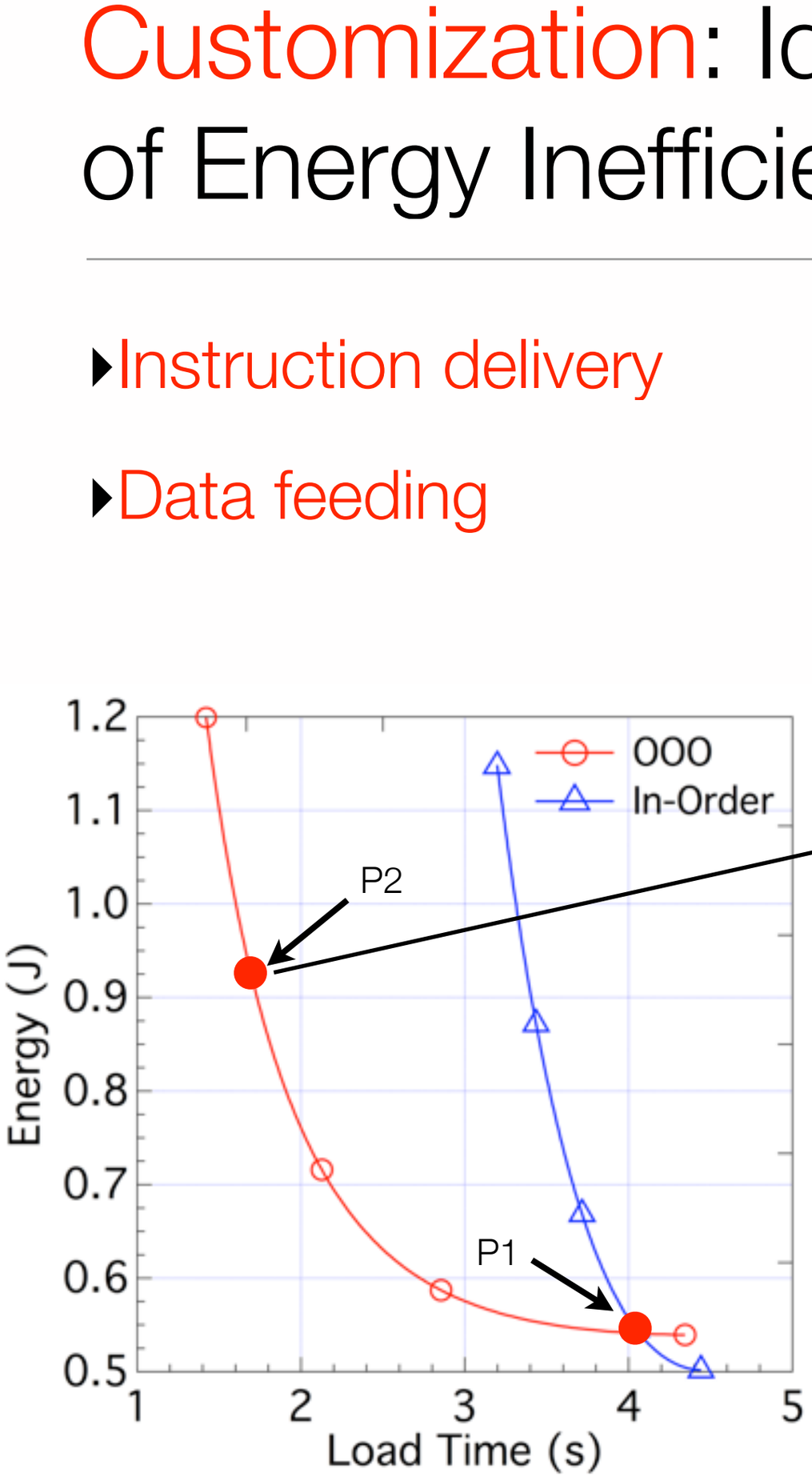
Customization: Identifying Major Sources of Energy Inefficiency

- Instruction delivery
- Data feeding



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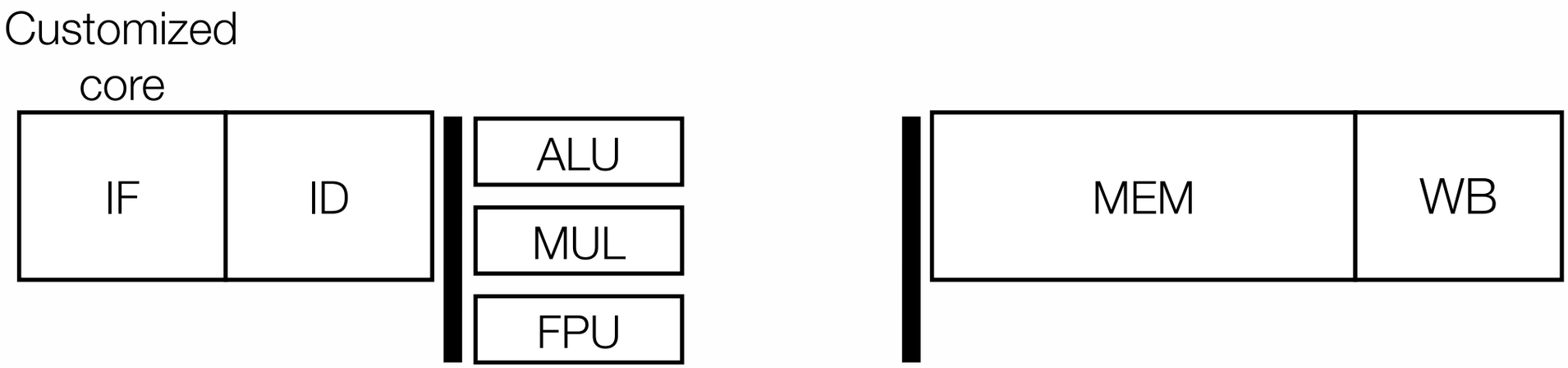
Agenda of Today's Talk

- Motivation of our work: energy-efficiency of the mobile Web
- How does WebCore improve the energy-efficiency?
  - Customization
  - **Specialization**
    - Mitigate instruction delivery: Style resolution unit (SRU)
    - Improving data feeding: Browser engine cache
- Evaluation Results
- Related Work

WebCore Specialization Overview

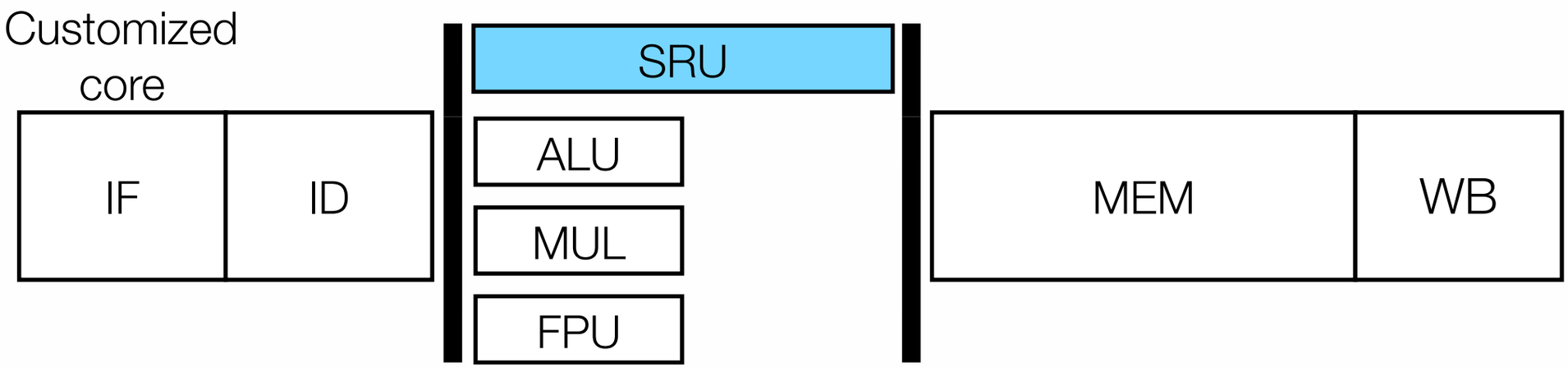
WebCore Specialization Overview

Hardware Layer



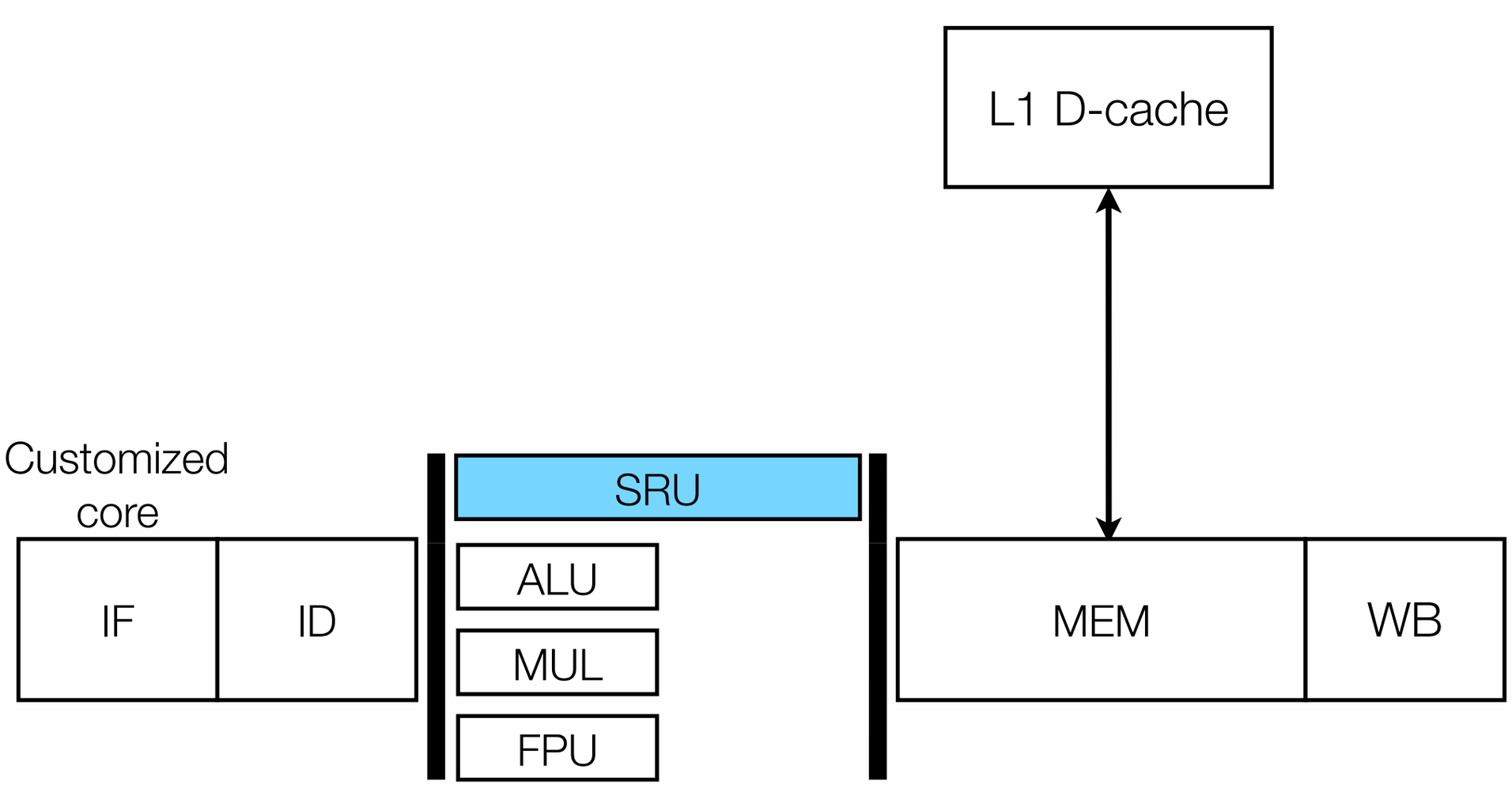
WebCore Specialization Overview

Hardware Layer



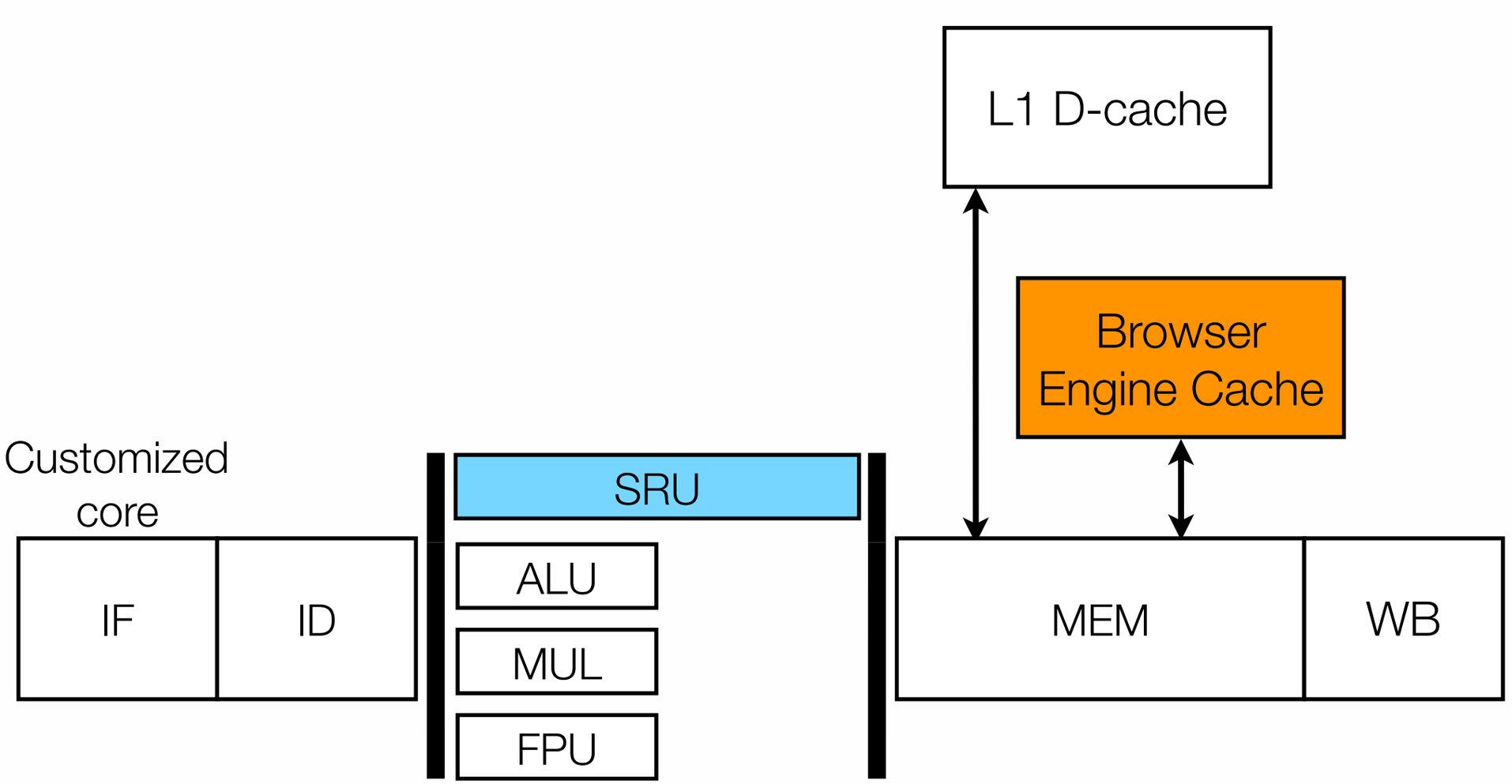
WebCore Specialization Overview

Hardware Layer



WebCore Specialization Overview

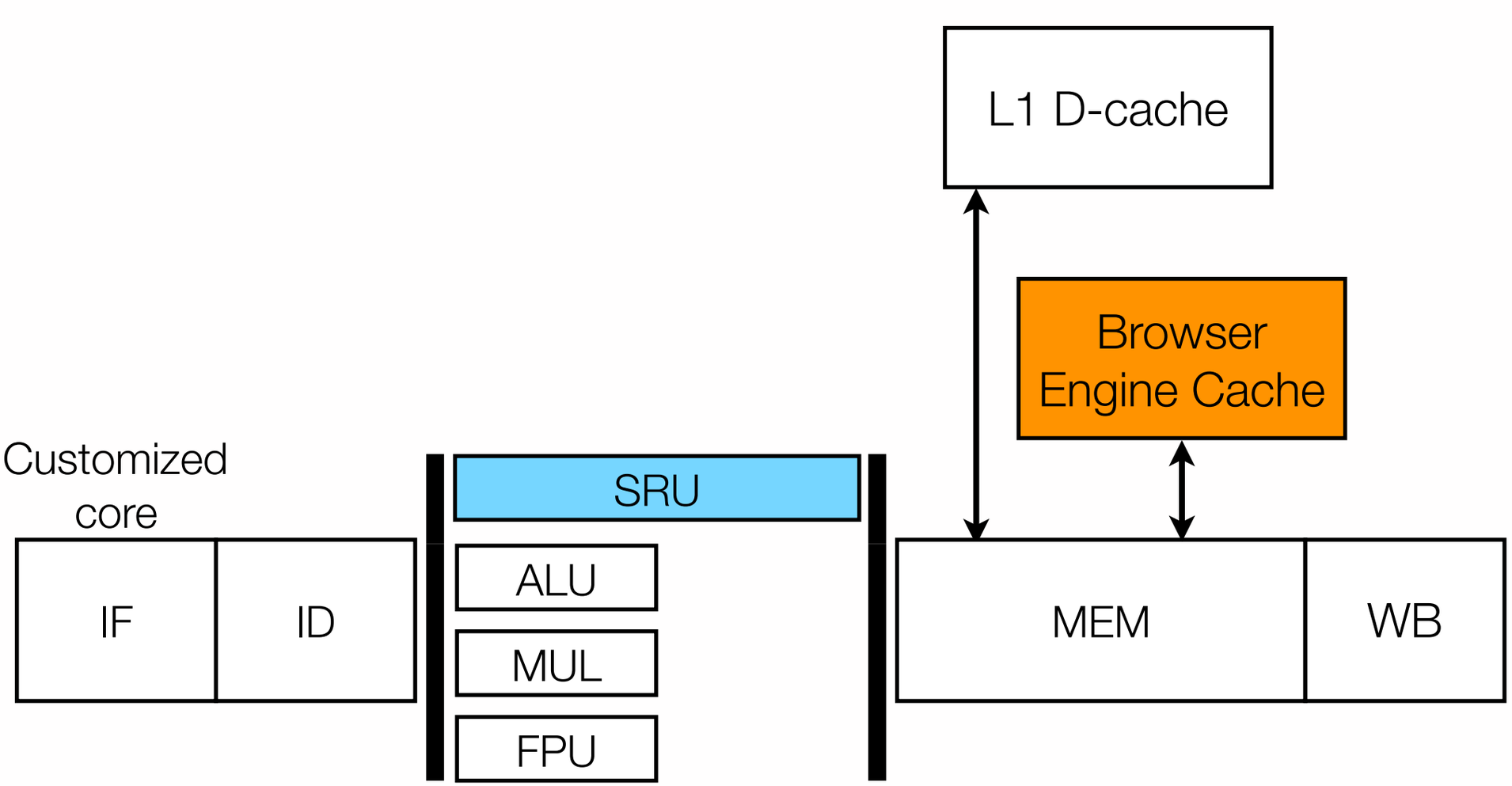
Hardware Layer



WebCore Specialization Overview

API Layer

Hardware Layer

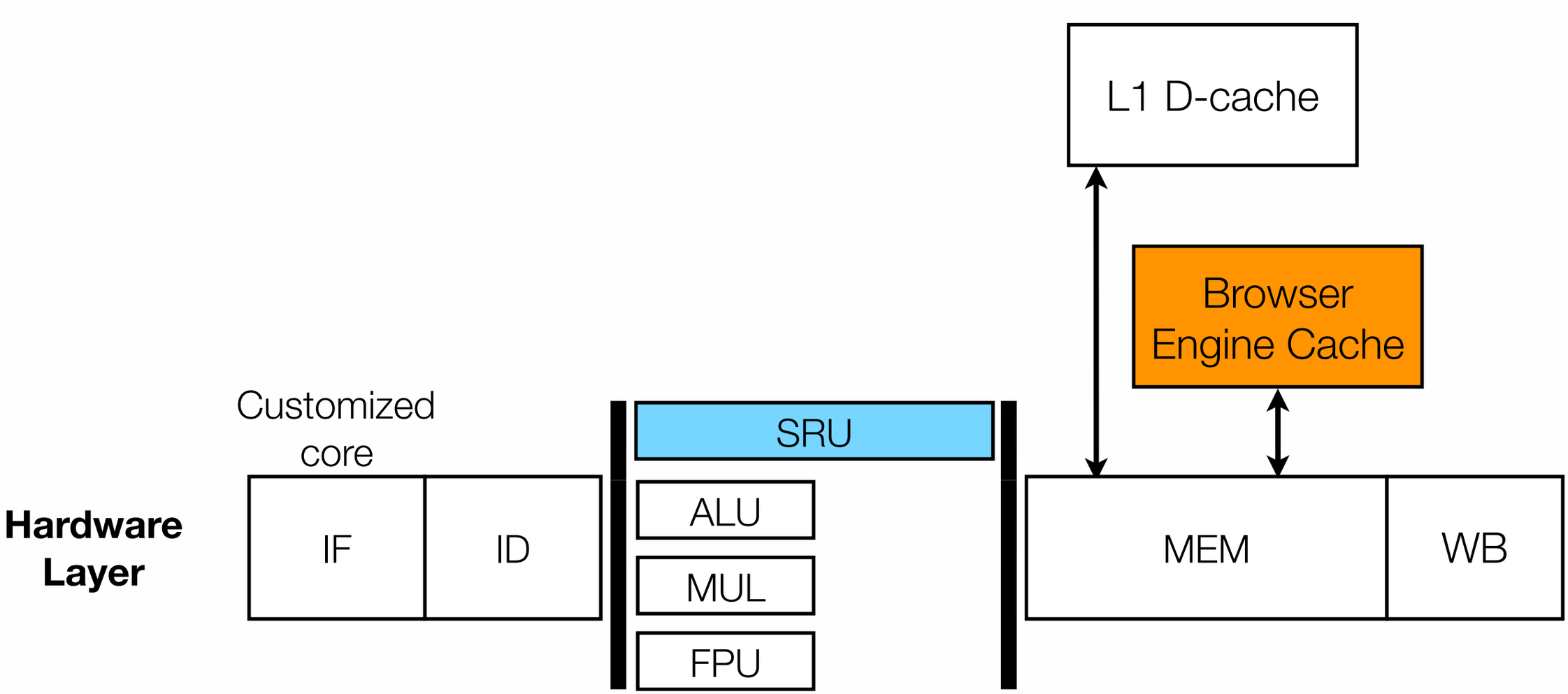


WebCore Specialization Overview

API Layer

```
Style_apply(Id);
```

Hardware Layer

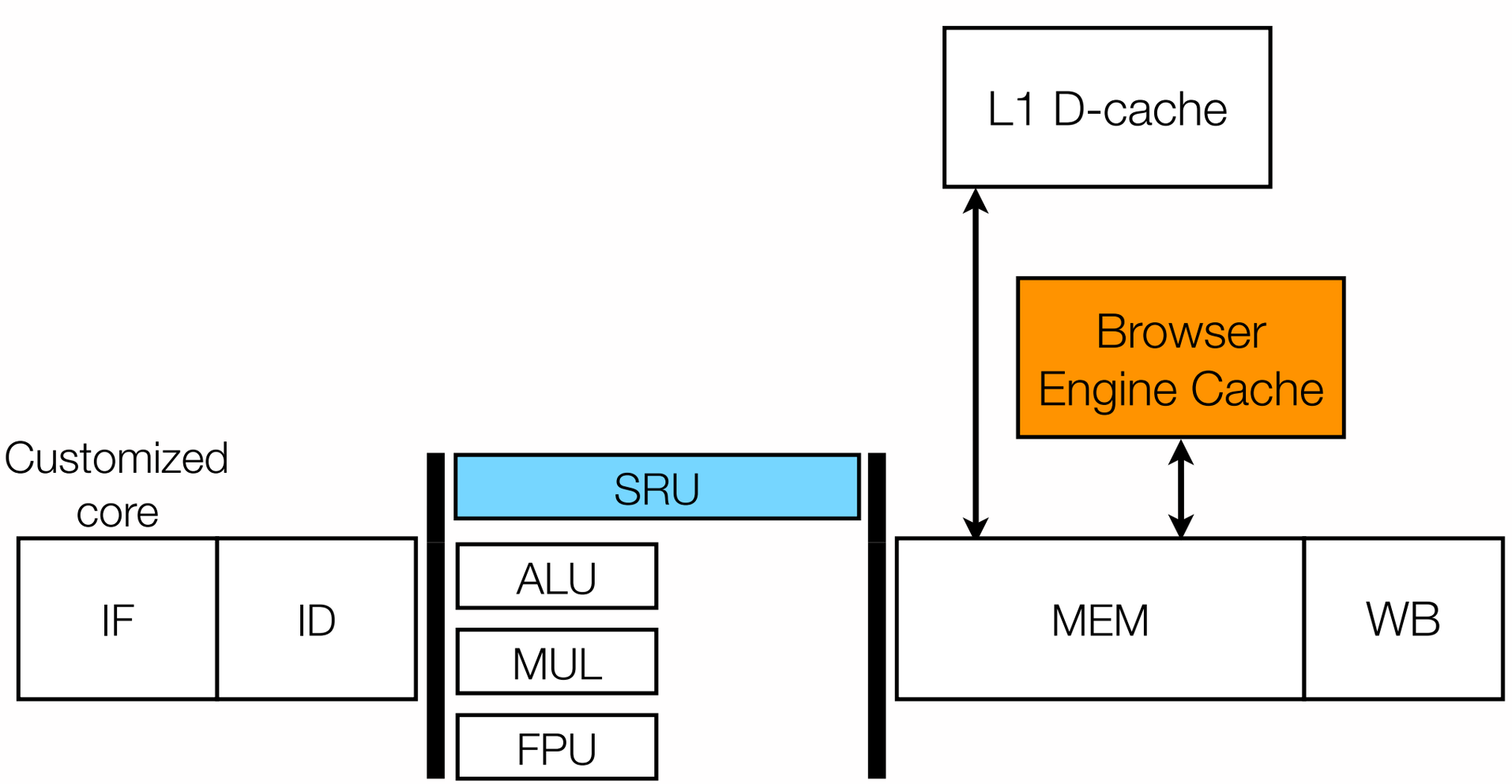


WebCore Specialization Overview

API Layer

```
                                        DOM_LD(Id, &attr);
                                        DOM_ST(Id, &attr);
                    Style_apply(Id);
```

Hardware Layer



WebCore Specialization Overview

API Layer

```
DOM_LD(Id, &attr);
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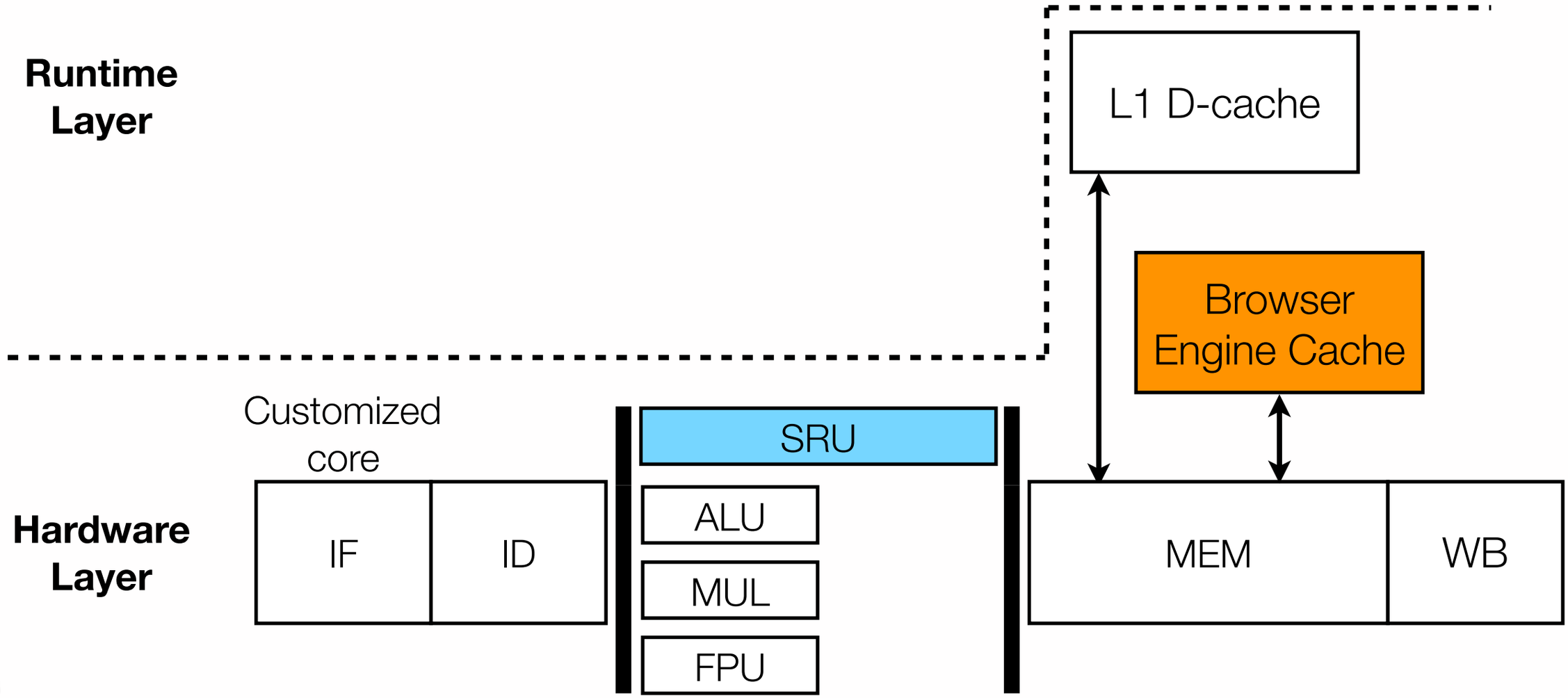
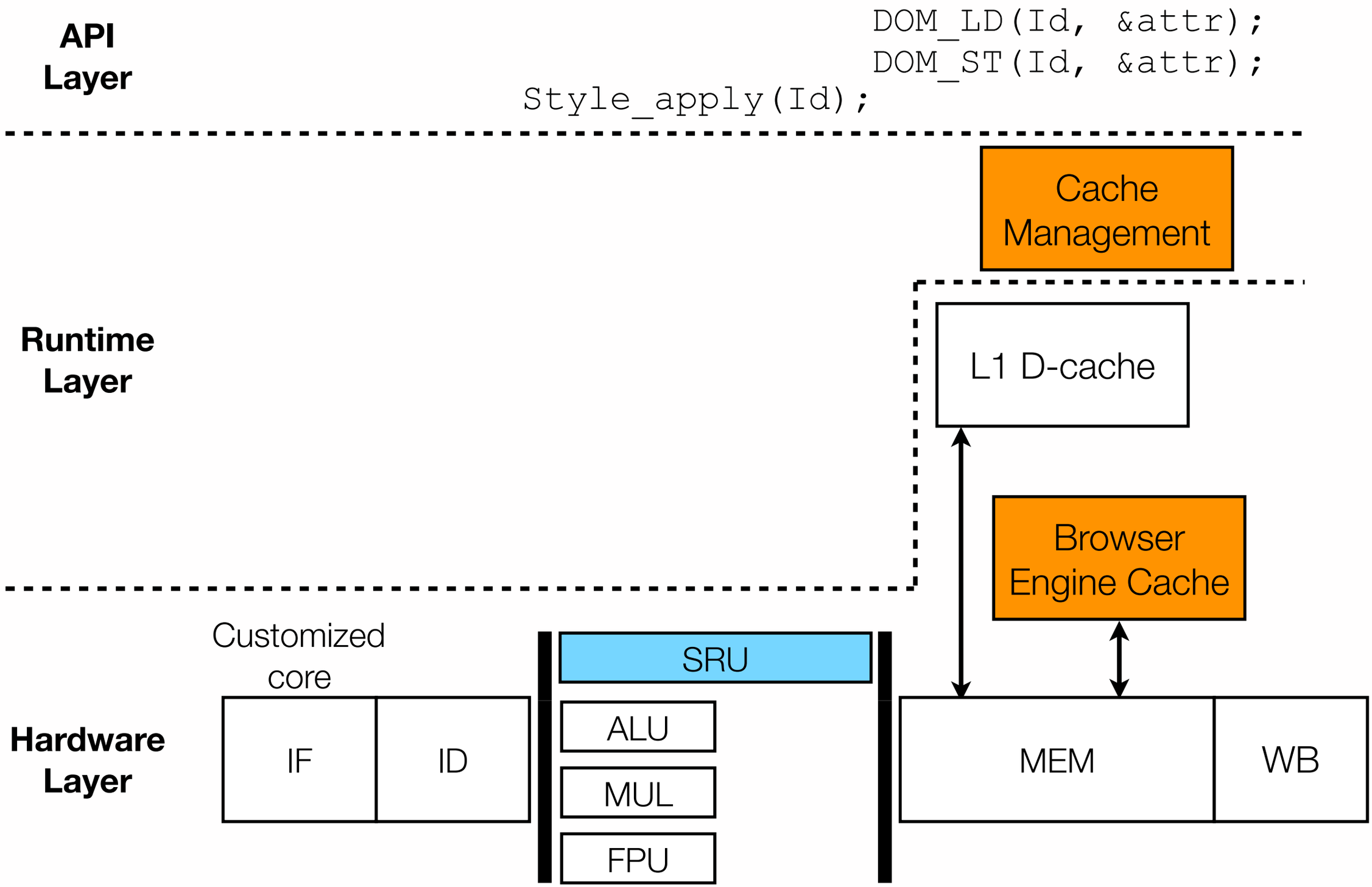
Runtime Layer

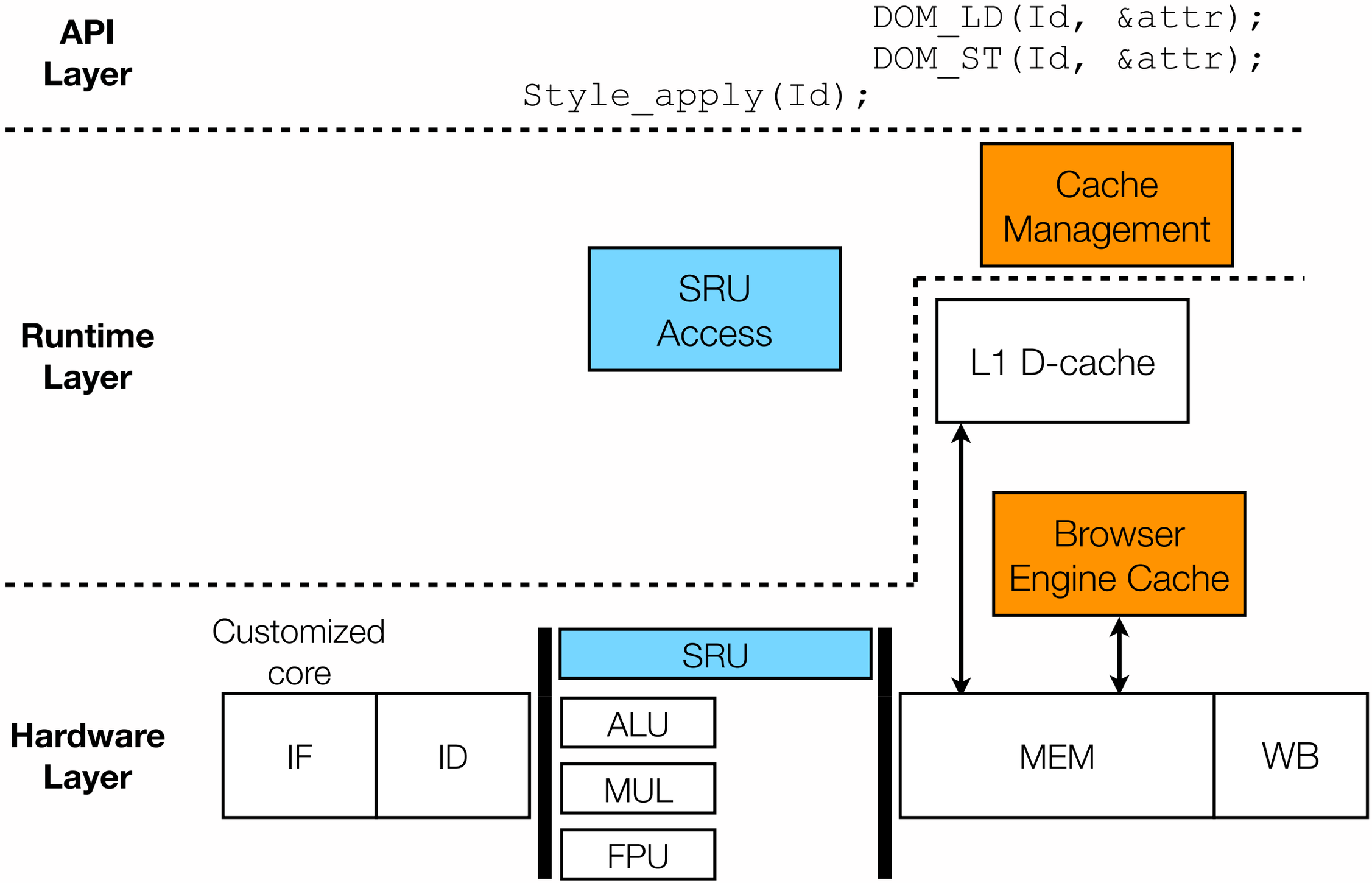


Hardware Layer

WebCore Specialization Overview



WebCore Specialization Overview



WebCore Specialization Overview

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DOM_LD(Id, &attr);
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Runtime Layer

Cache Management

SRU Access

Software Failsafe

L1 D-cache

Browser Engine Cache

Hardware Layer

Customized core

IF | ID

SRU

ALU

MUL

FPU

MEM | WB

Agenda of Today's Talk

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- How does WebCore improve the energy-efficiency?
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  - **Specialization**
    - **Mitigate instruction delivery: Style resolution unit (SRU)**
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Style Resolution Unit

- *Style* kernel is the most critical kernel

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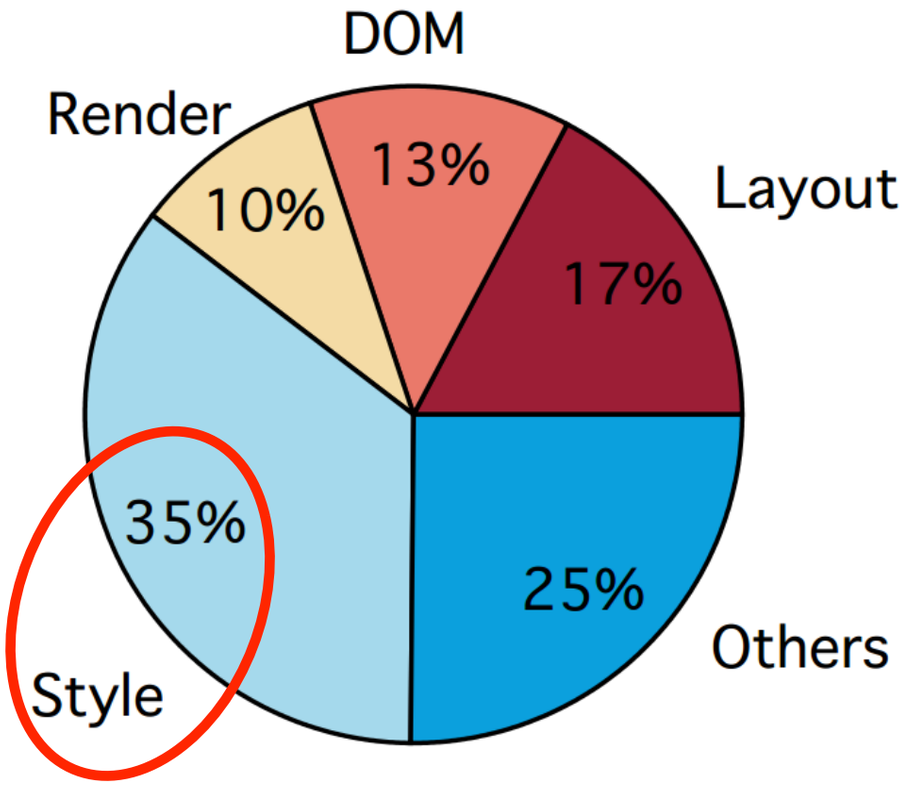
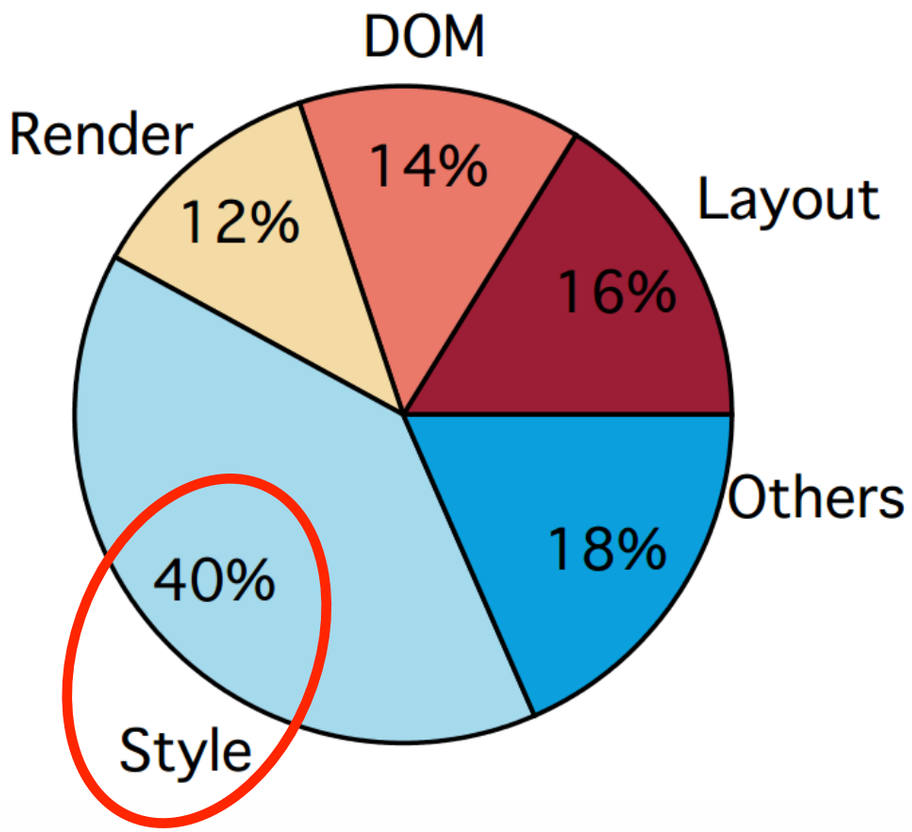


Execution time breakdown



Energy consumption breakdown

Style Resolution Unit

- *Style* kernel is the most critical kernel

```
for (each rule in matchedRules) {
  for (each property in rule) {
    switch (property.id) {
      case Font:
        Style[Font] = Handler(property.value, DOMNode);
        break;
      case N: ...}}}
```

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Rule-level Parallelism (RLP)

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Rule-level Parallelism (RLP)

Property-level Parallelism (PLP)

- Exploiting the parallelism to increase the arithmetic intensity and reduce instruction footprint

Style Resolution Unit (2)

- A running example from www.cnn.com

Style Rules

Rule	**Property** 1		**Property** 2	
	id	value	id	value
1	padding	0	margin	0
2	padding	6 px	width	36 px

Style Resolution Unit (2)

- A running example from www.cnn.com

Style Rules

High priority

Rule	**Property** 1		**Property** 2	
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Style Rules

Final Style Info

High priority

Rule	Property 1		Property 2	
	id	value	id	value
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Property 1		Property 2		Property 3	
id	value	id	value	id	value

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padding	0				

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Style Resolution Unit (2)

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Style Resolution Unit (2)

- Order Matters in RLP
- Order Does **Not** Matter in PLP

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Style Resolution Unit (3)

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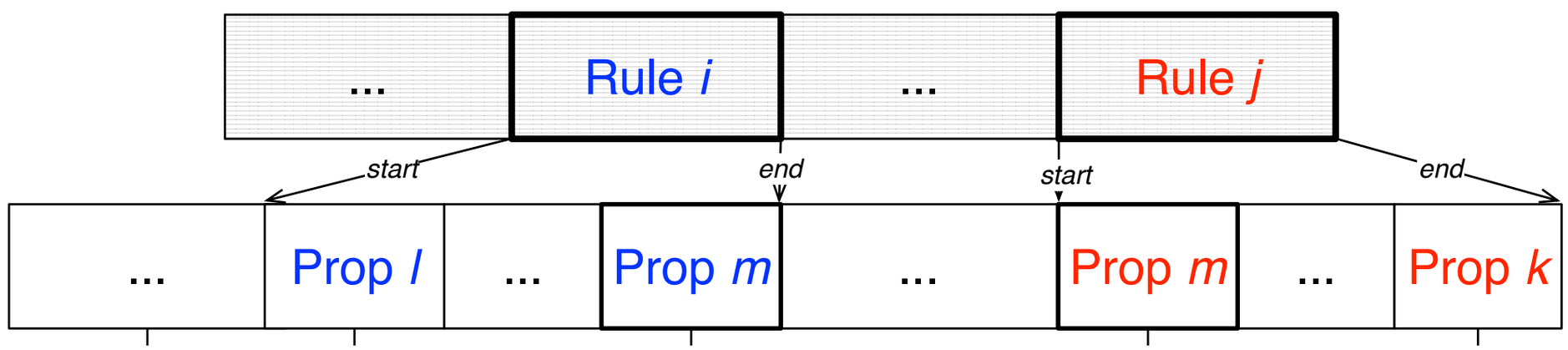
Input Scratchpad Memory



Style Resolution Unit (3)

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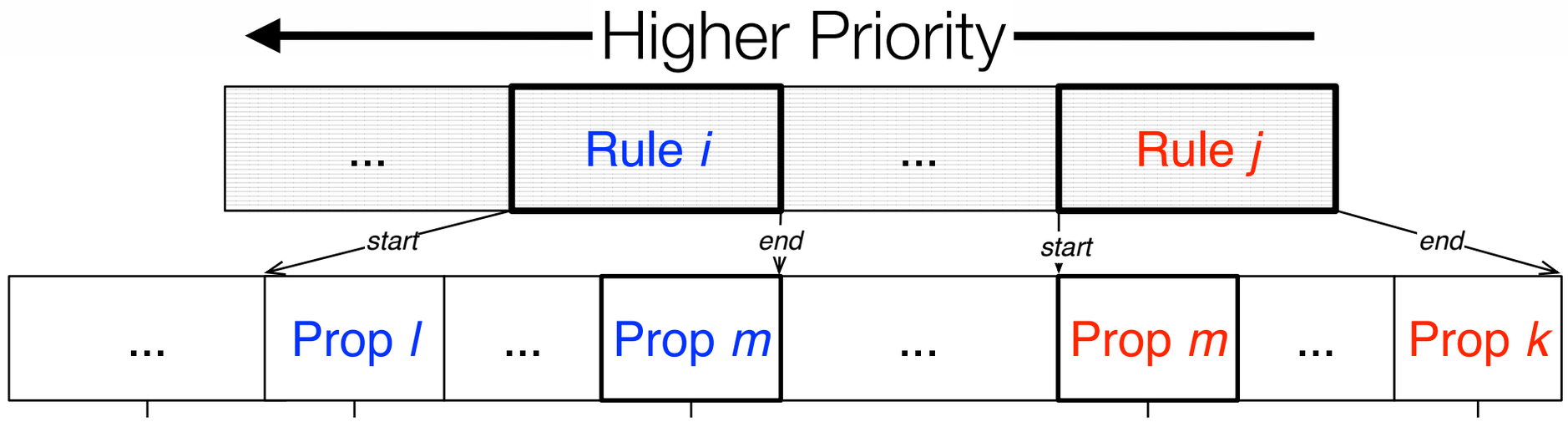
Input Scratchpad Memory



Style Resolution Unit (3)

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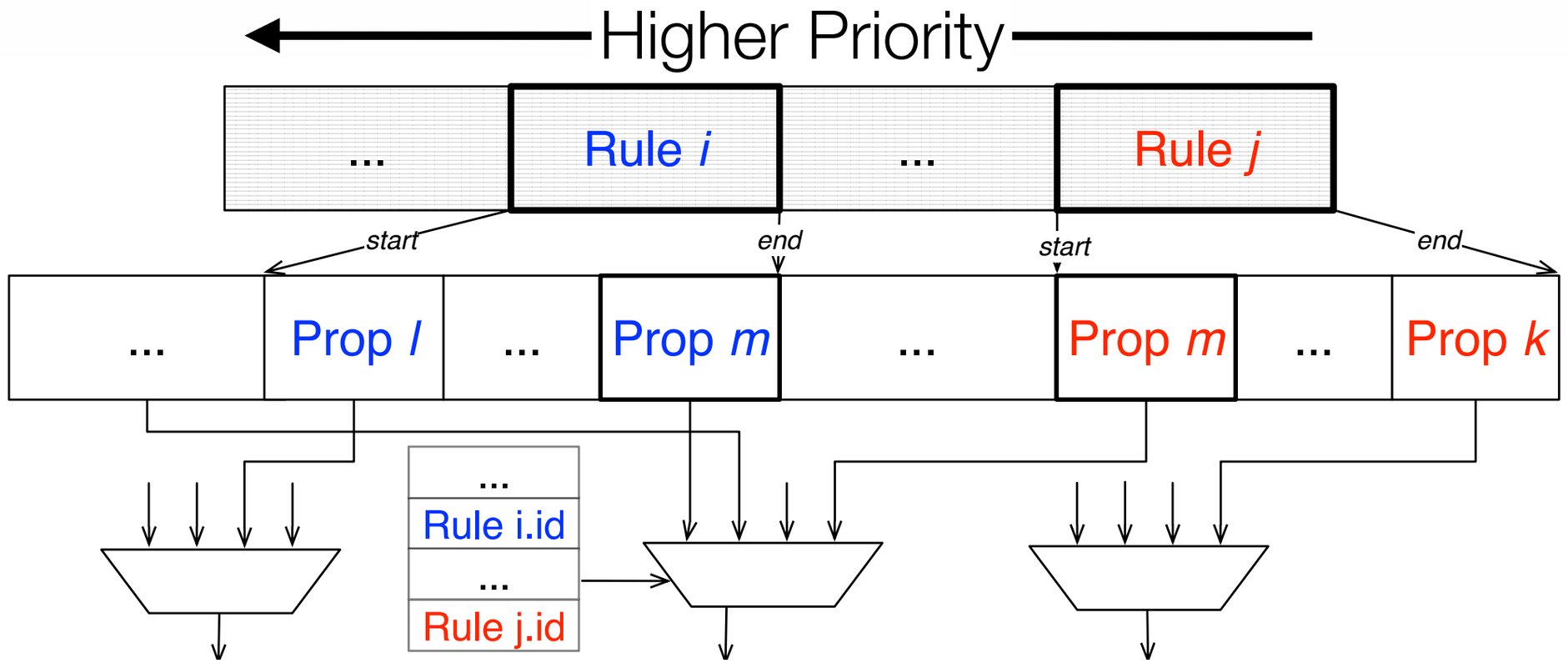
Input Scratchpad Memory

Conflict Resolution



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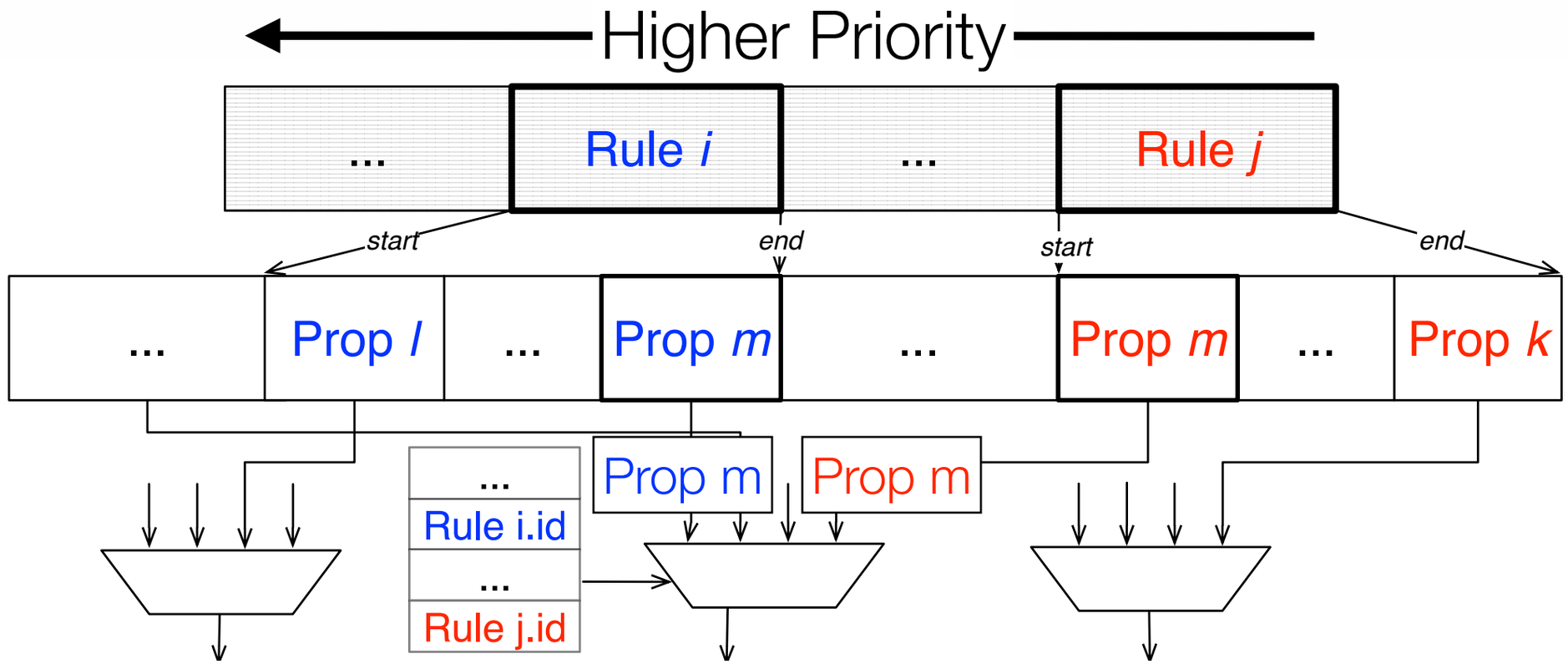
Input Scratchpad Memory

Conflict Resolution



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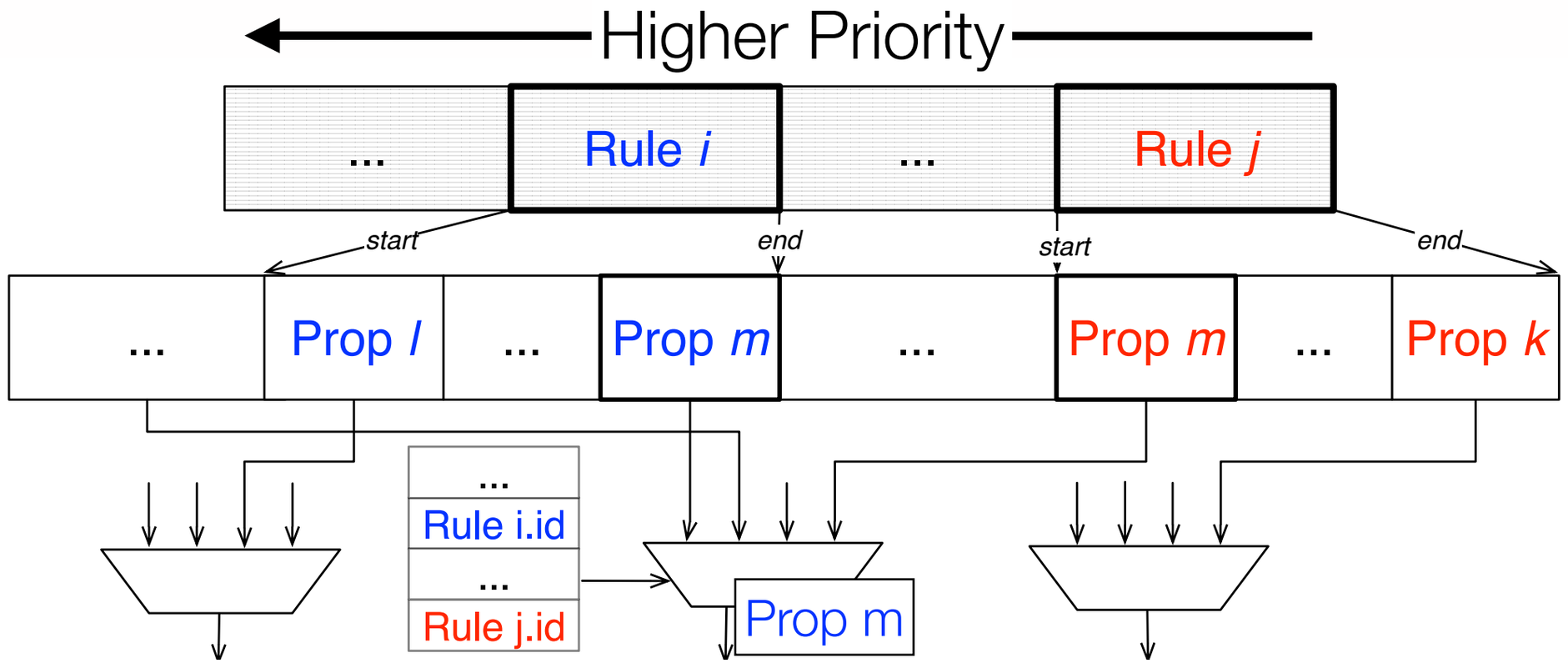

Style Resolution Unit (3)

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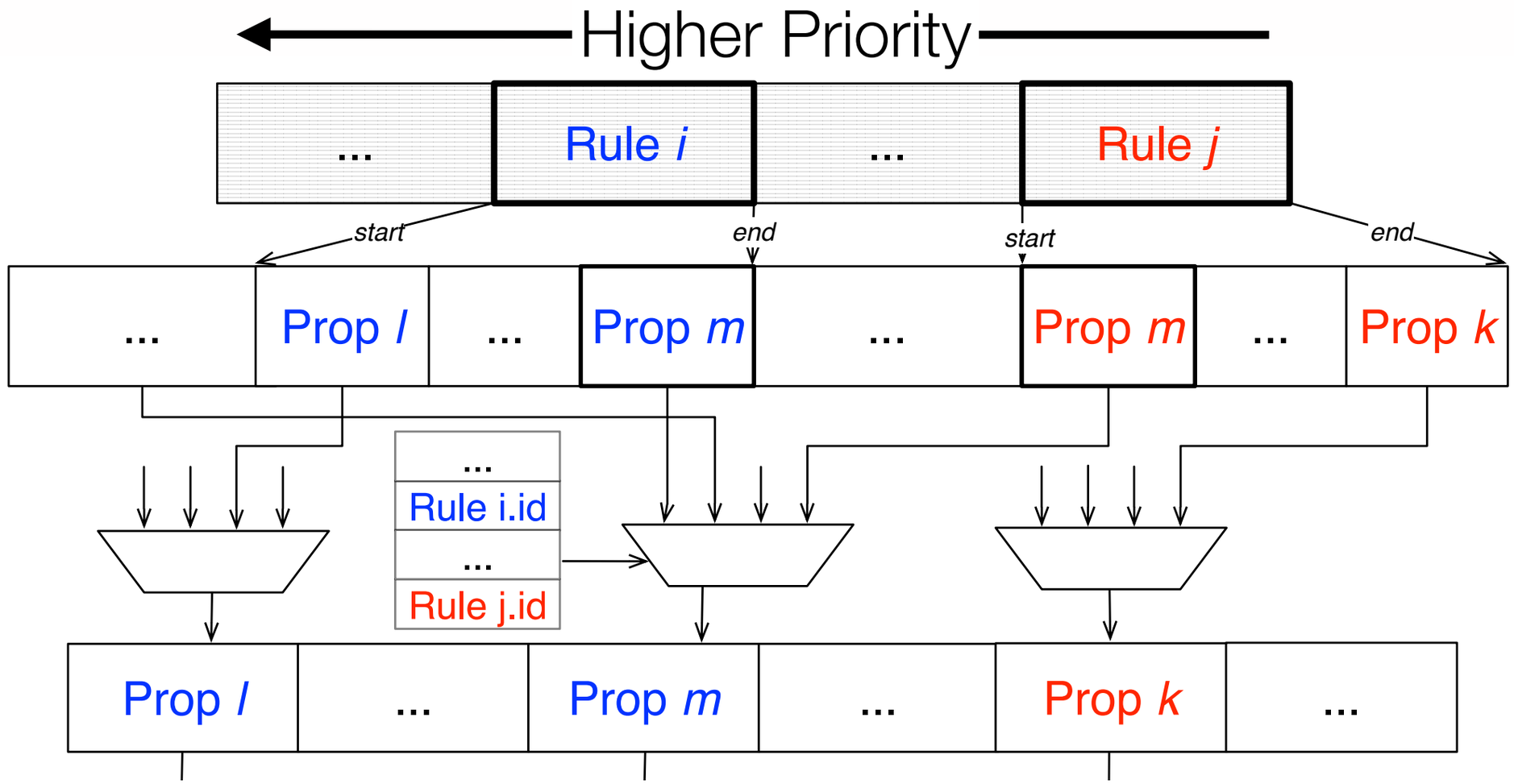
- Order Does **Not** Matter in PLP

Input Scratchpad Memory

Conflict Resolution

Compute Lanes



Style Resolution Unit (3)

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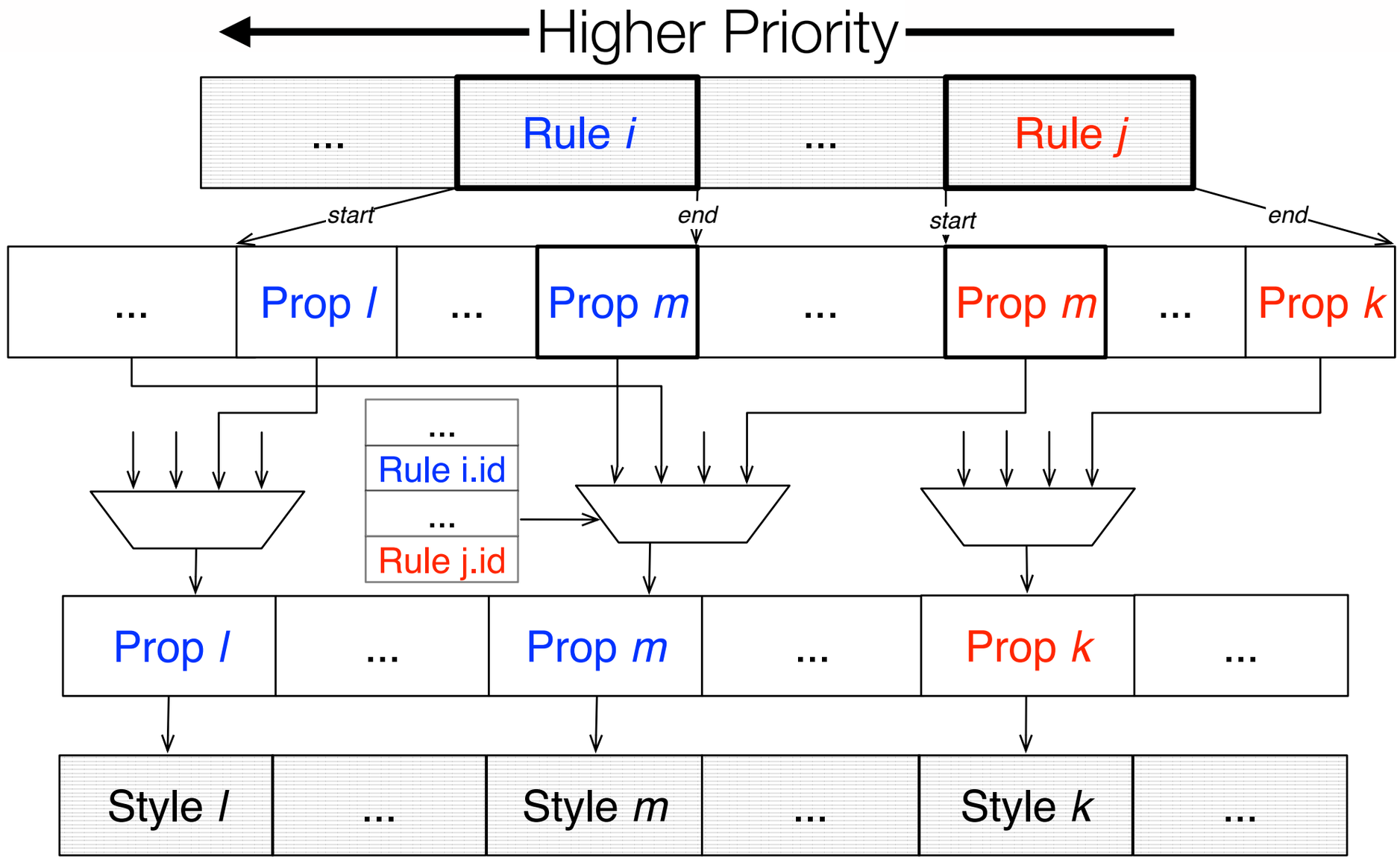
- Order Does **Not** Matter in PLP

Input Scratchpad Memory

Conflict Resolution

Compute Lanes

Output Scratchpad Memory



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Evaluations

- Fully synthesized using Synopsys 28 nm toolchain

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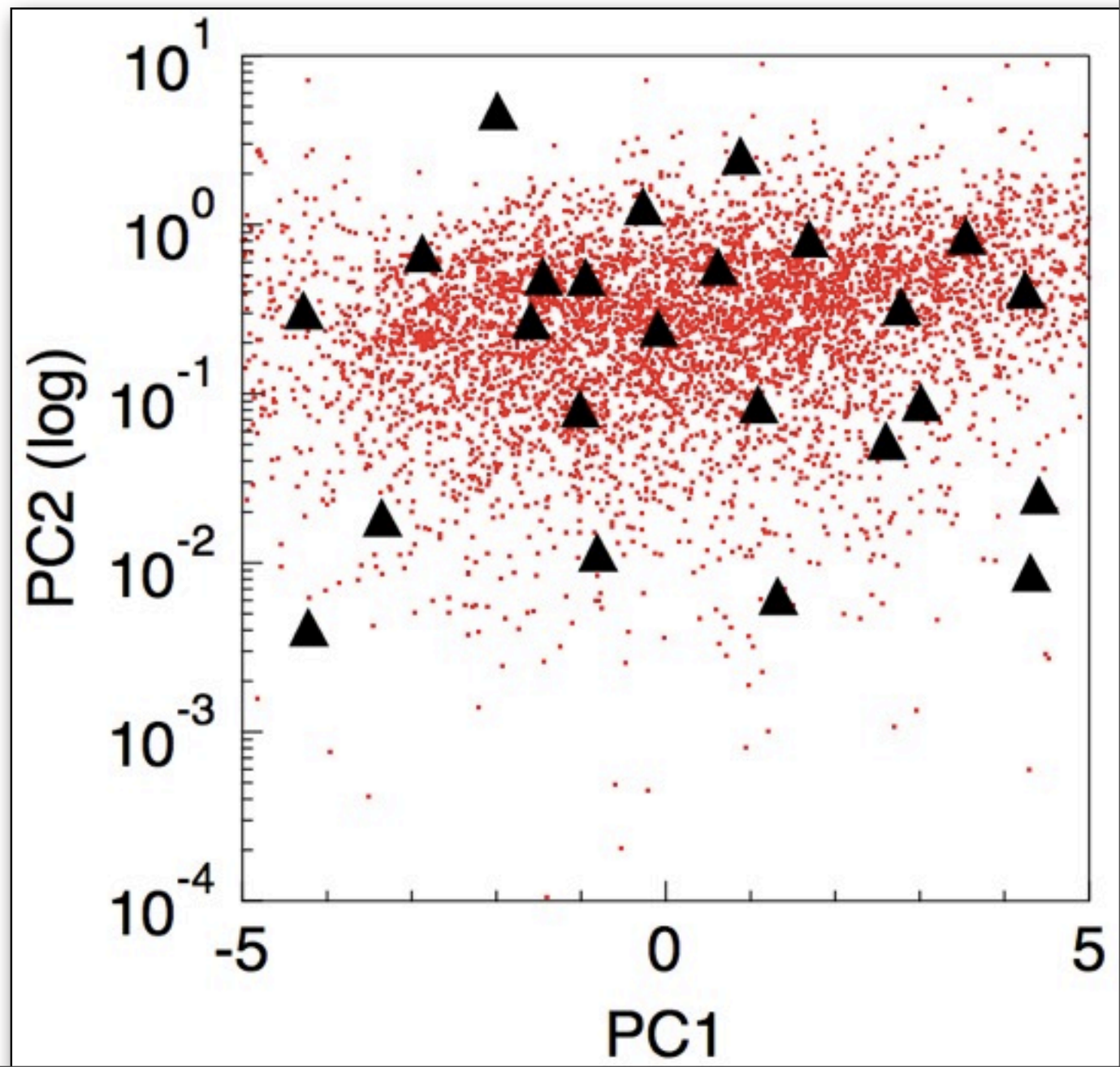
- 24 representative webpages

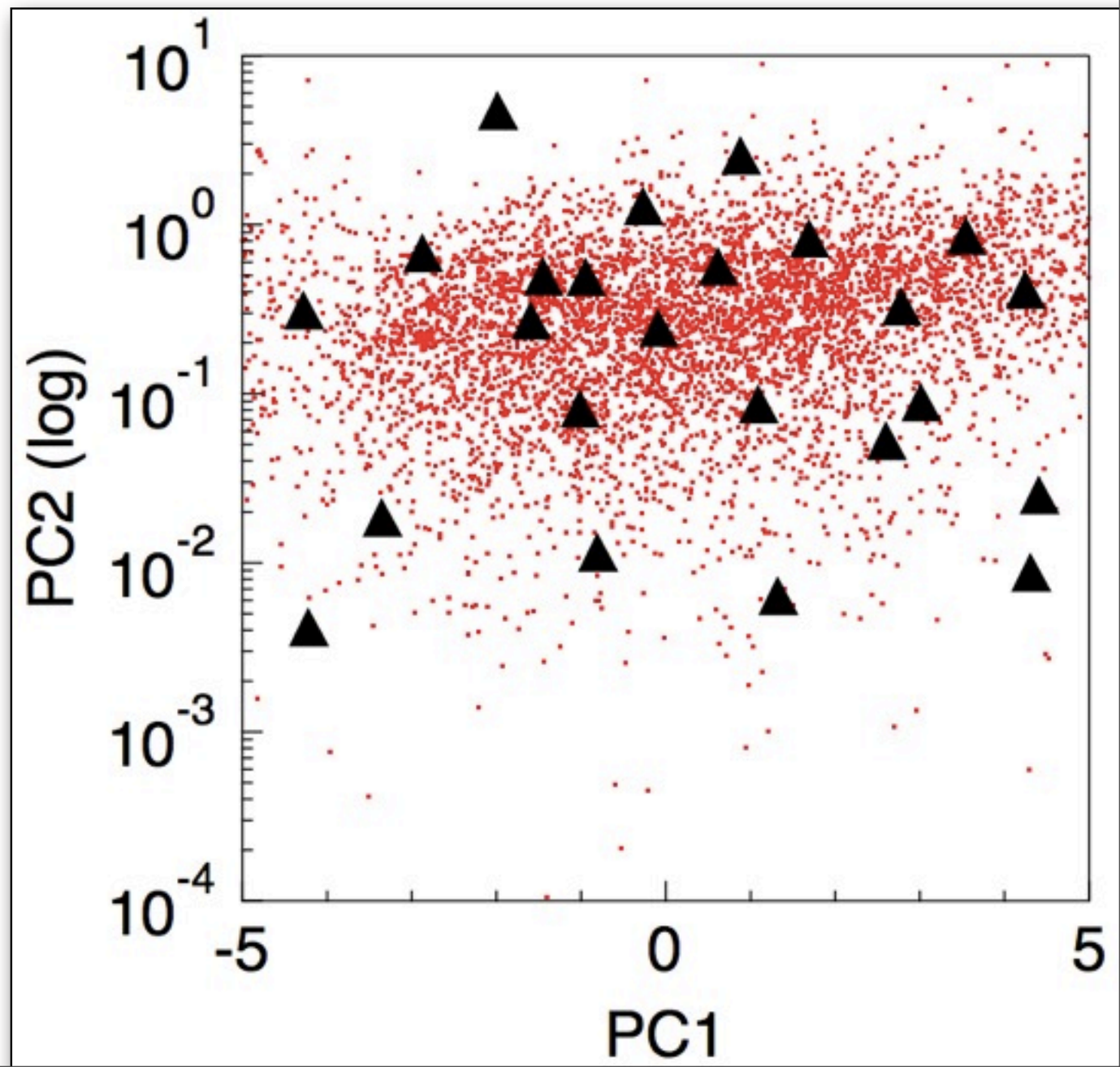


Evaluations

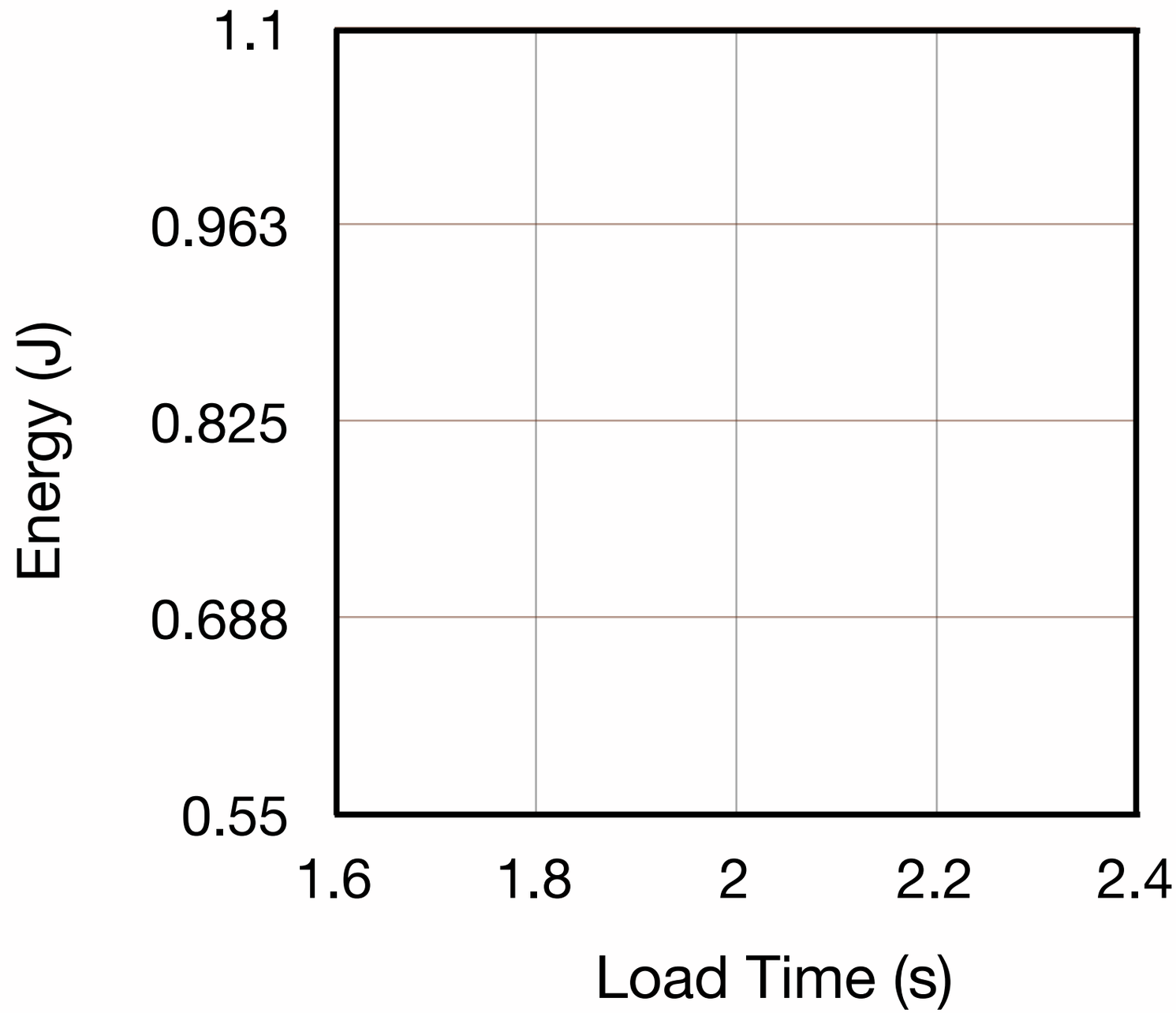
- Fully synthesized using Synopsys 28 nm toolchain
- 24 representative webpages

Desktop and mobile versions

www.amazon.com
www.cnn.com
www.msn.com
www.google.com.hk
www.twitter.com
www.espn.go.com
www.bbc.co.uk
www.slashdot.org
www.youtube.com
www.ebay.com
www.sina.com.cn
www.163.com



Evaluations



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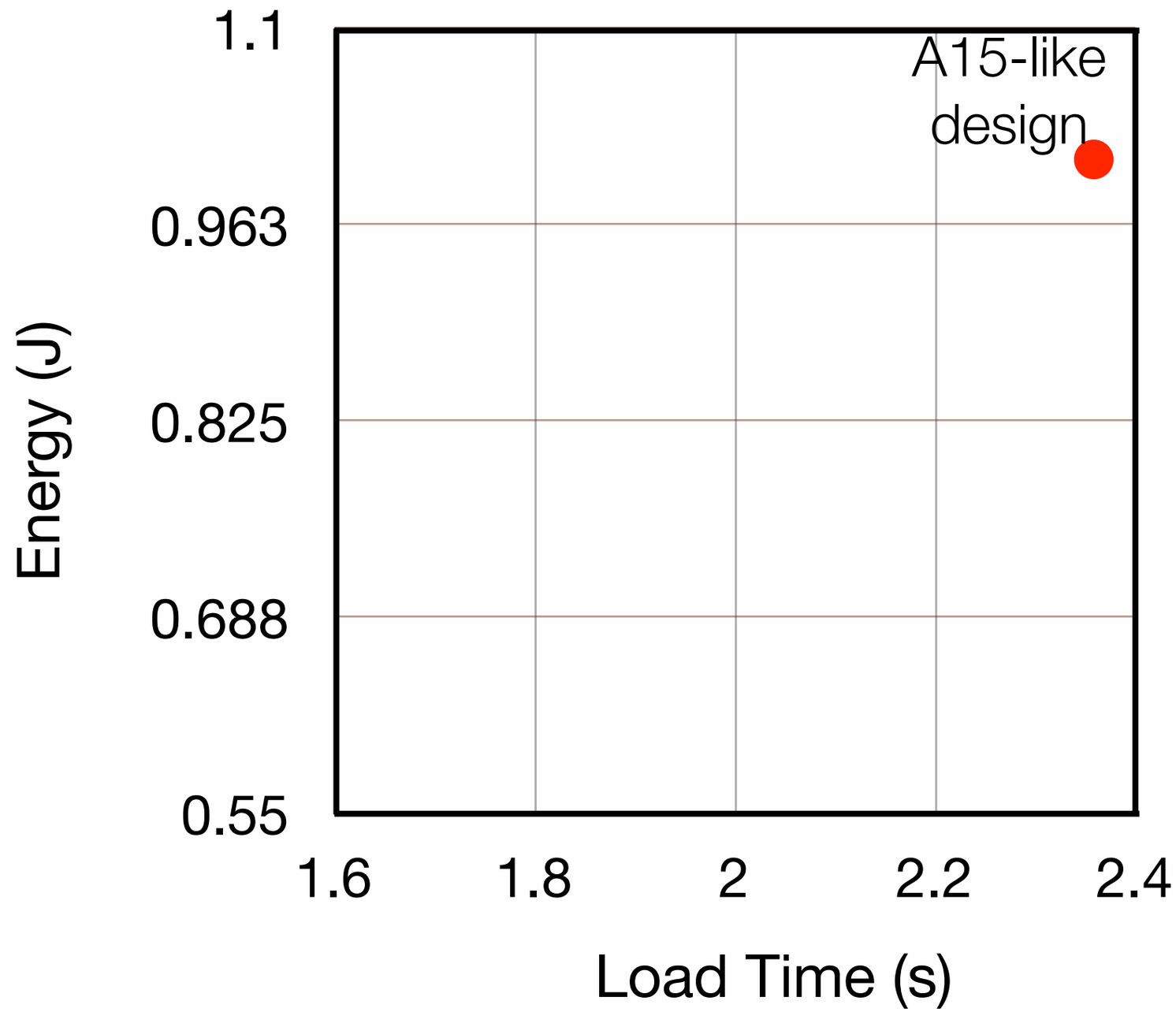

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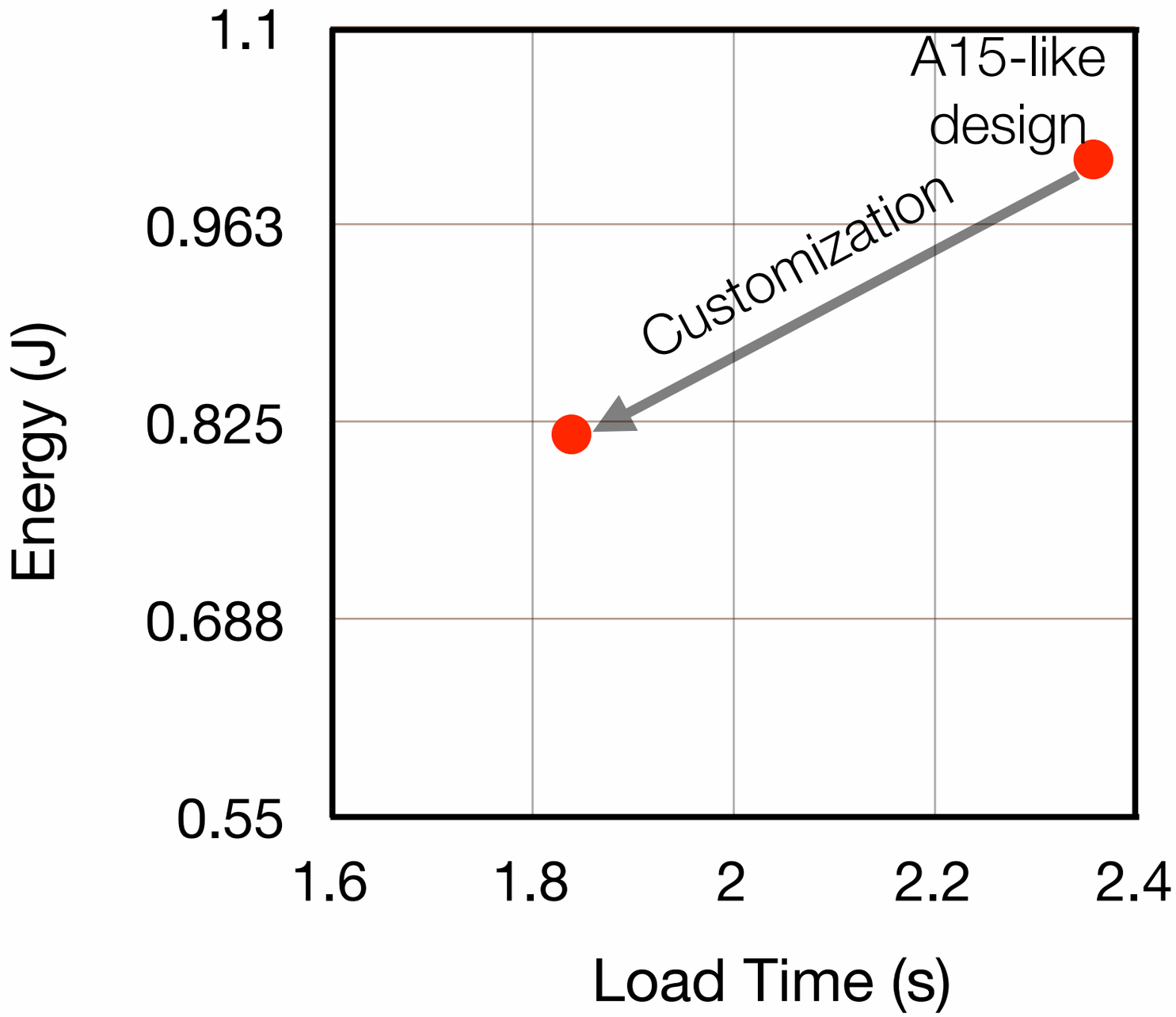

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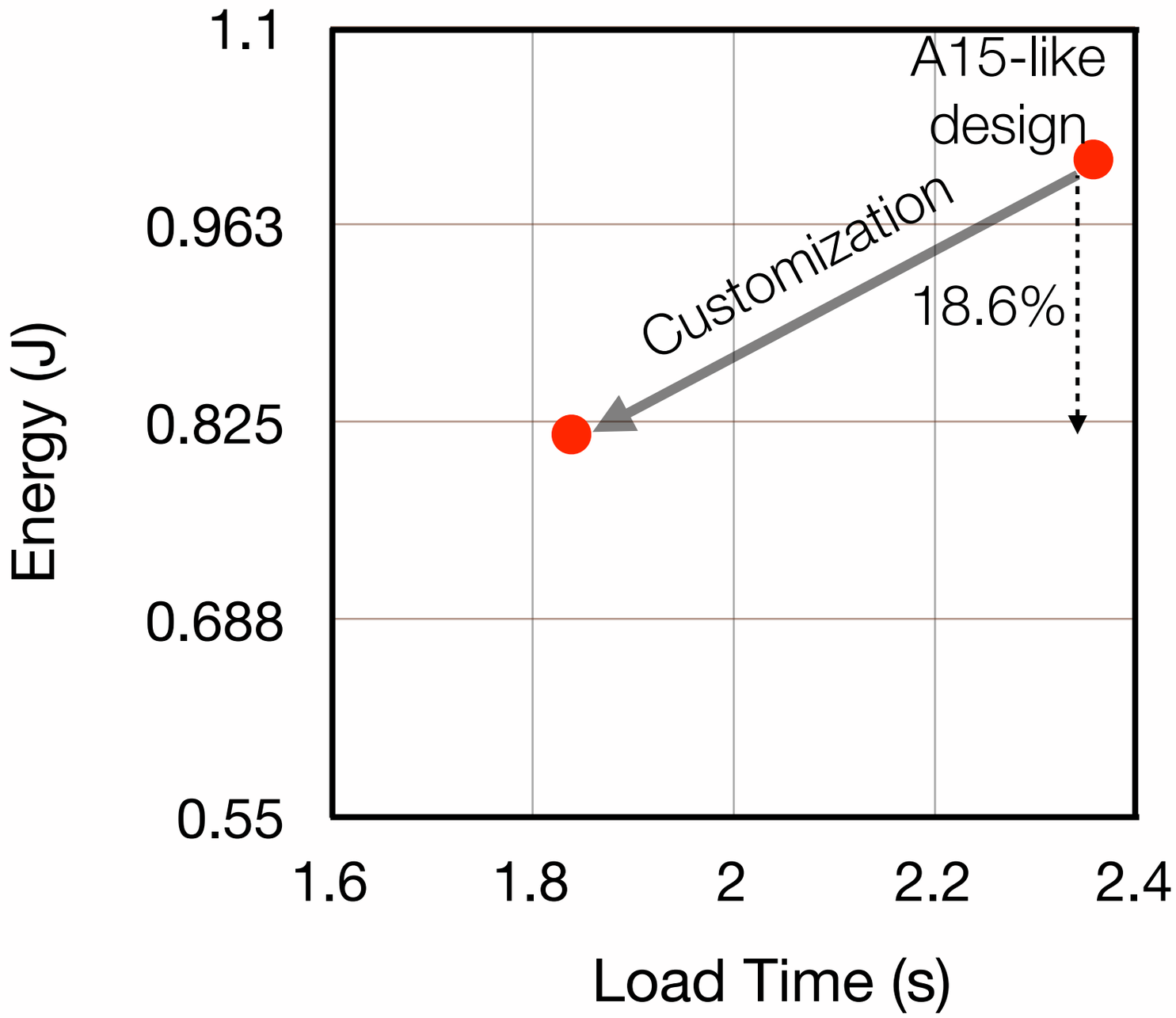

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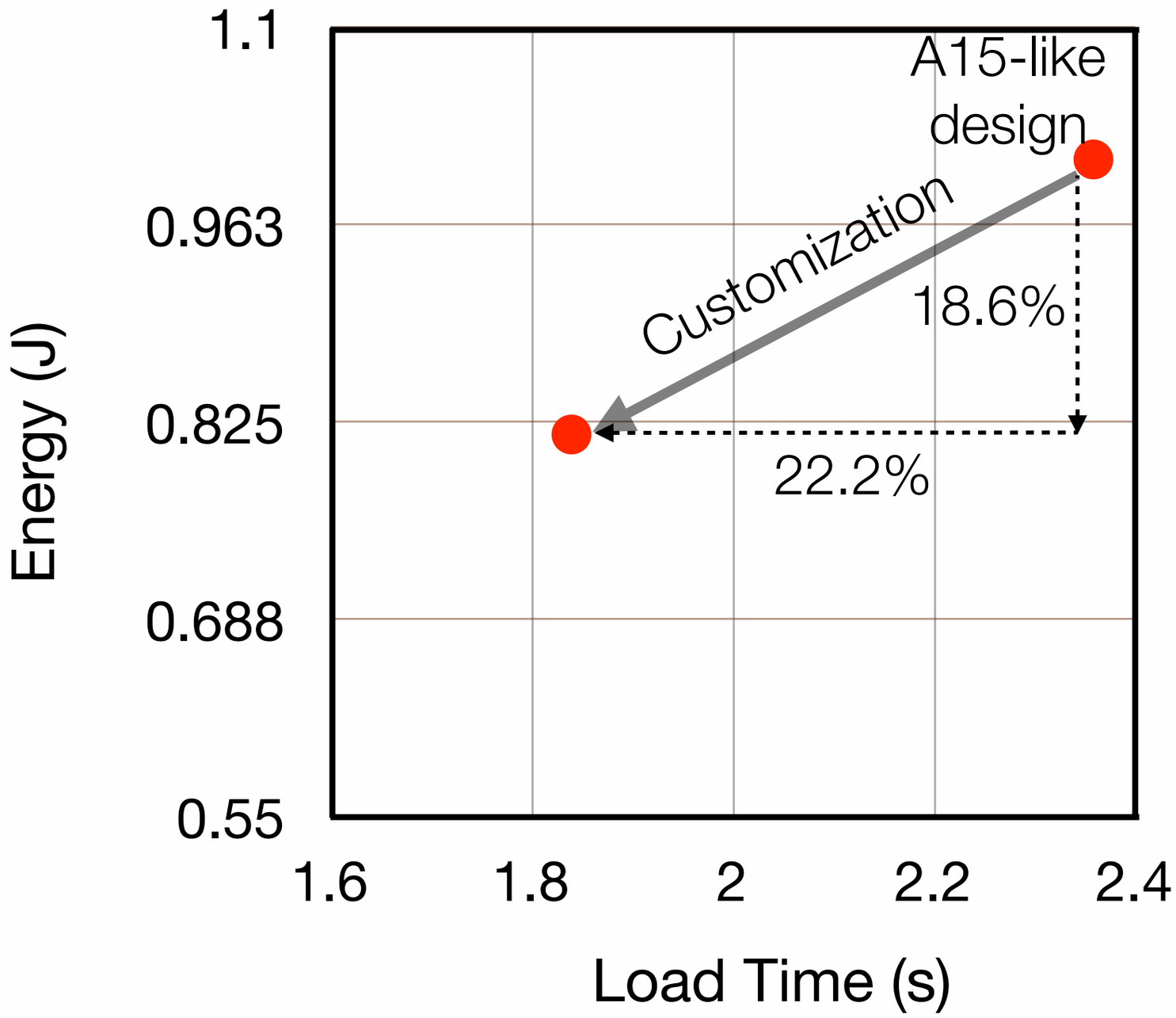

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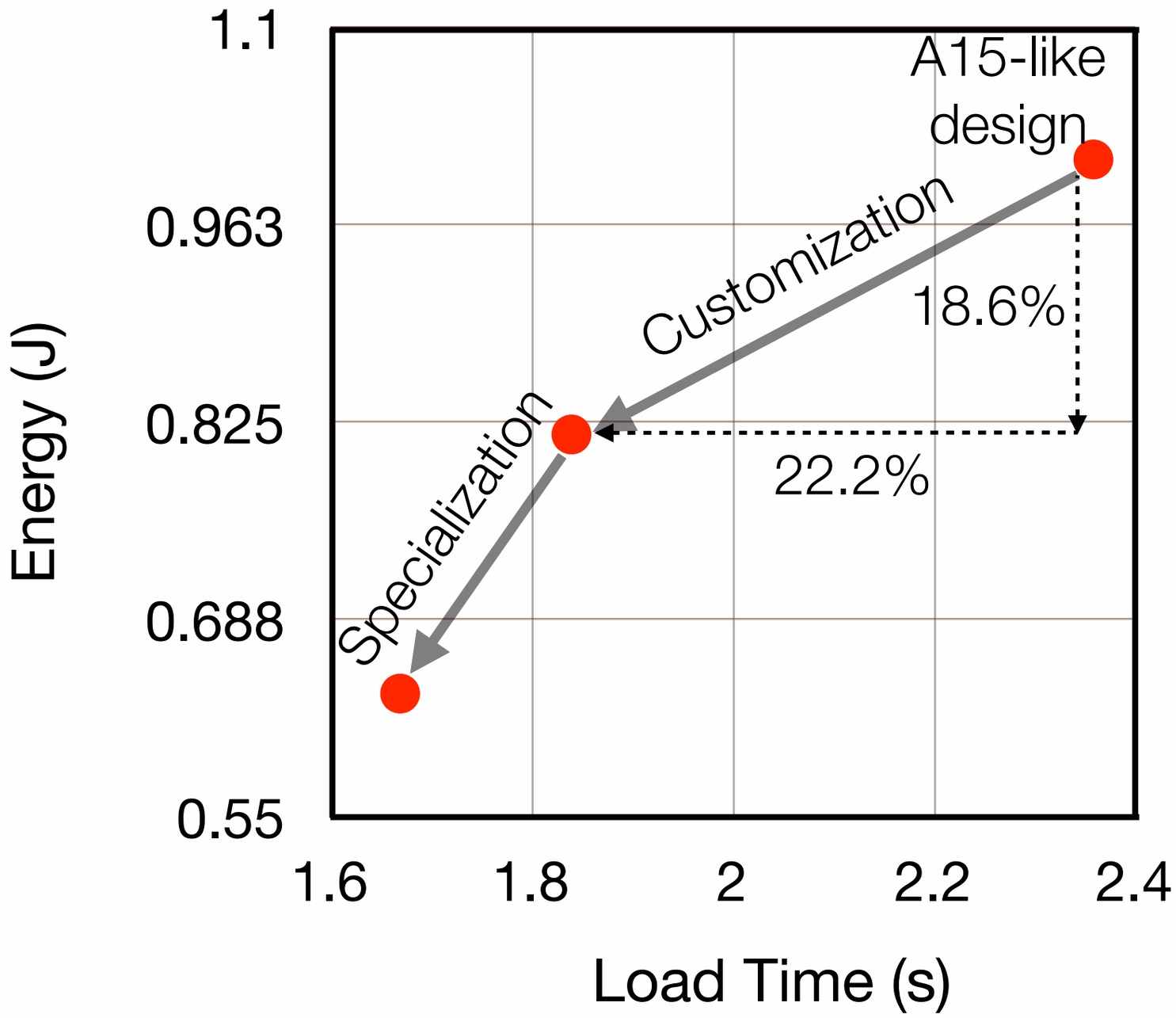
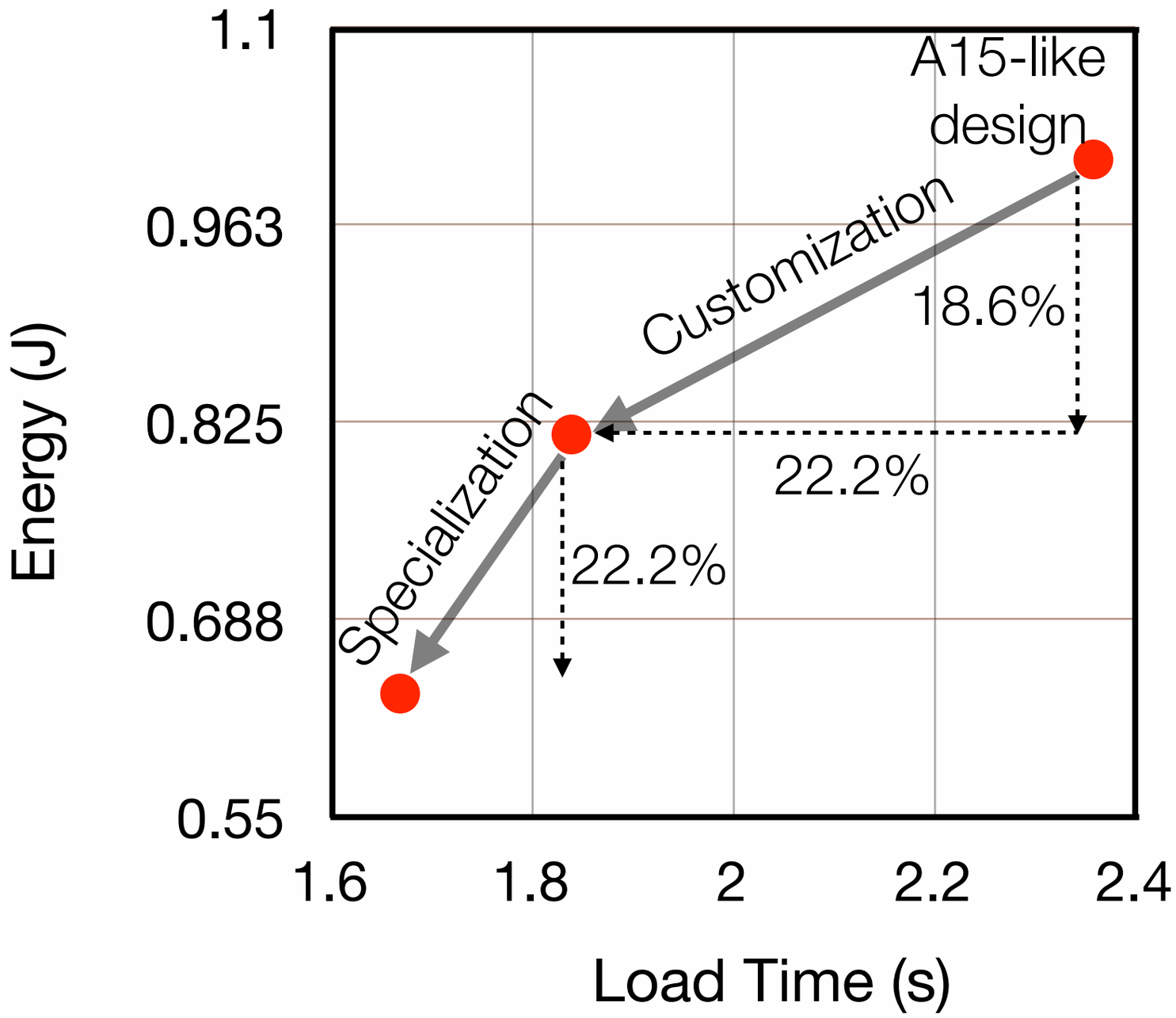
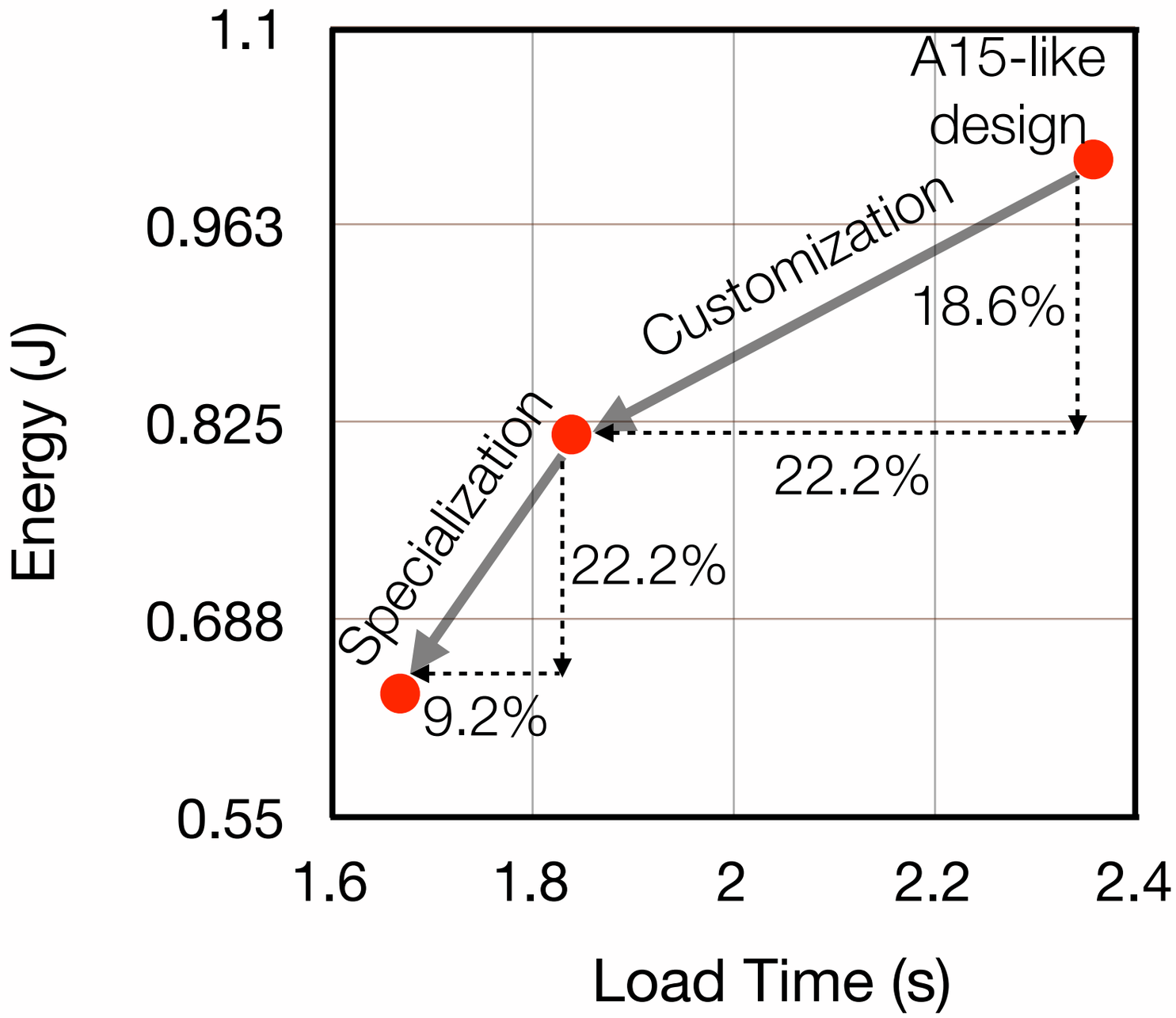


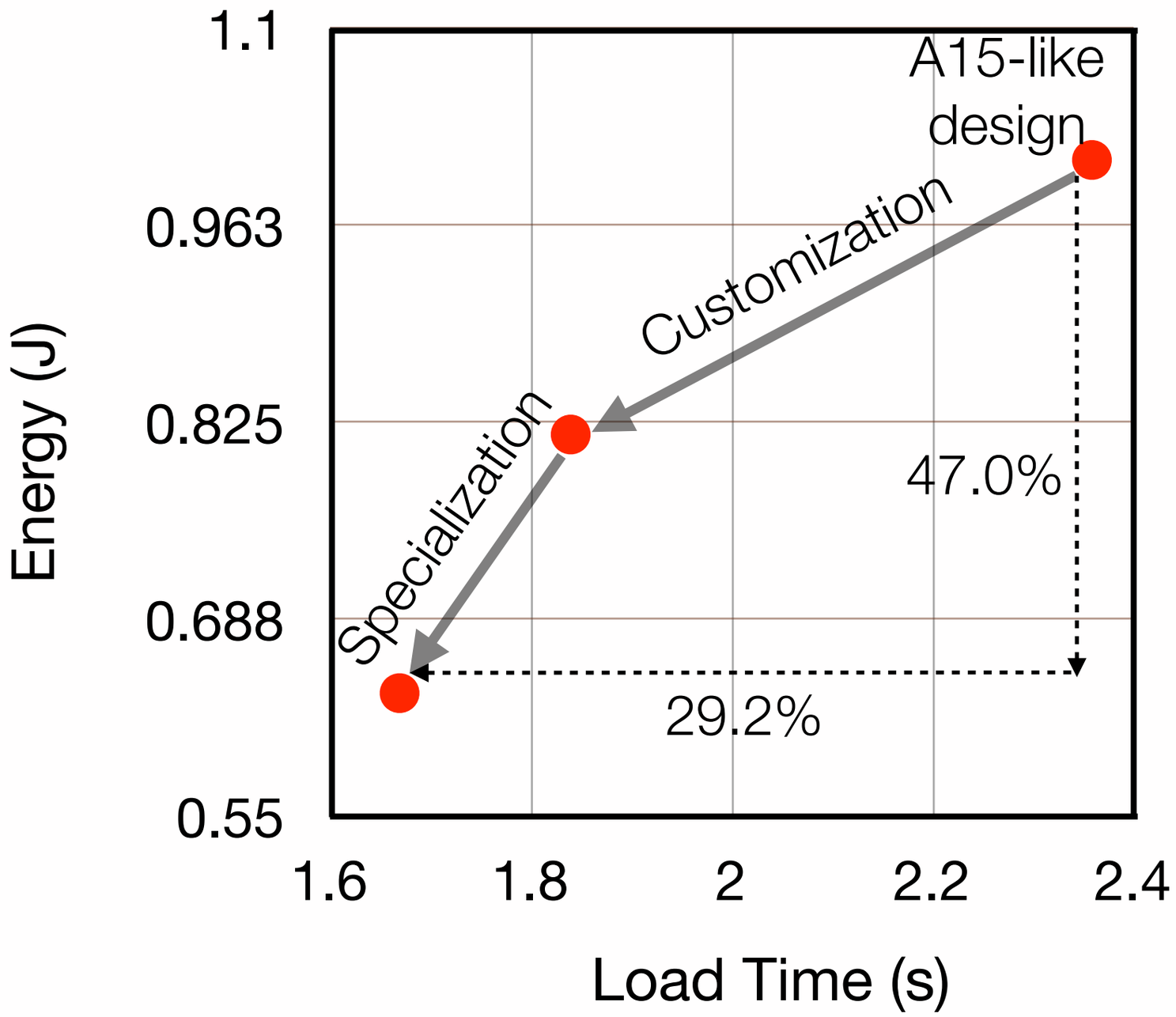
Evaluations



Evaluations

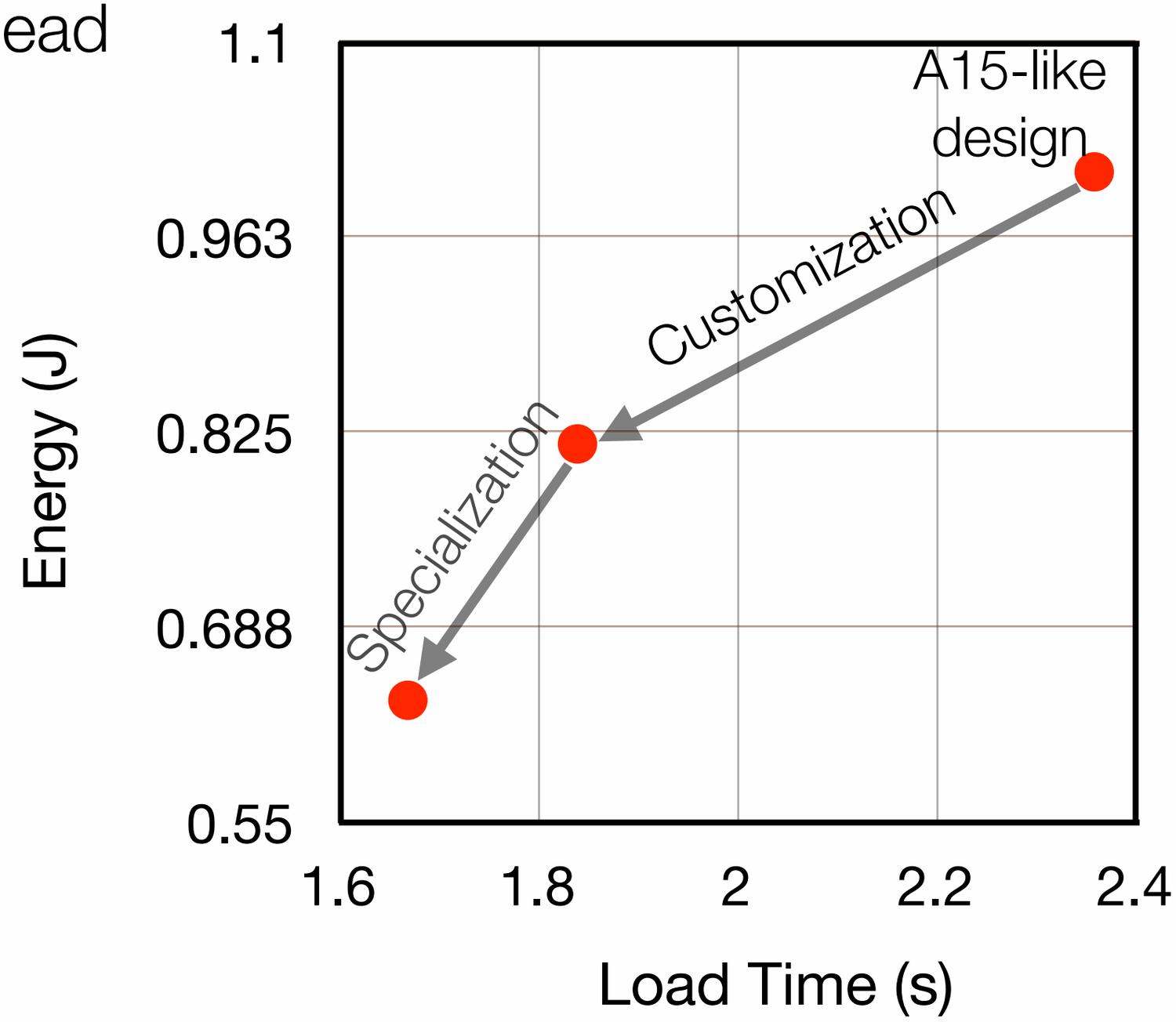


Evaluations



Evaluations

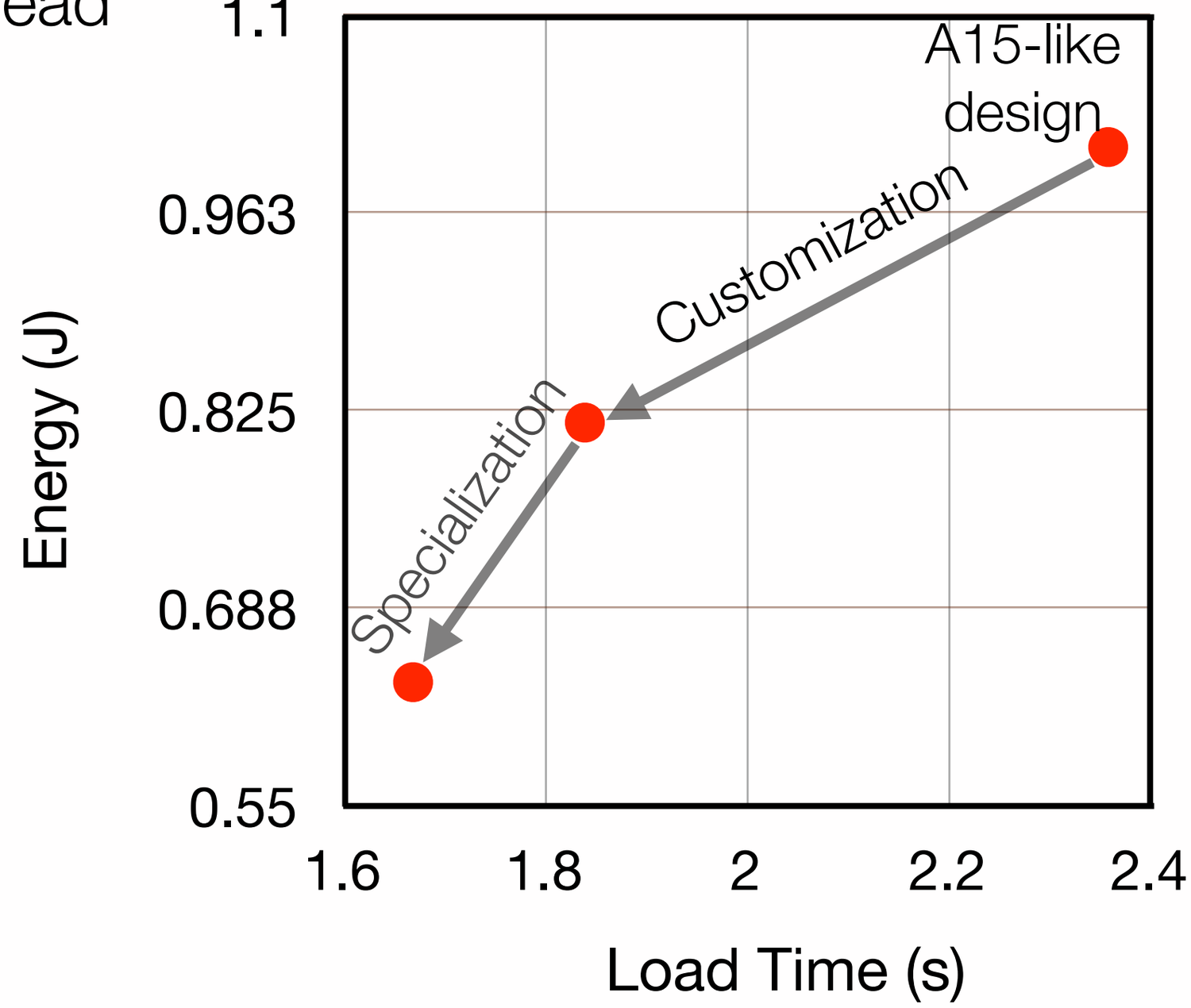
Cost of specialization:
0.59 mm^2 area overhead



Evaluations

Cost of specialization:
0.59 mm^2 area overhead

Better than scaling-up approaches



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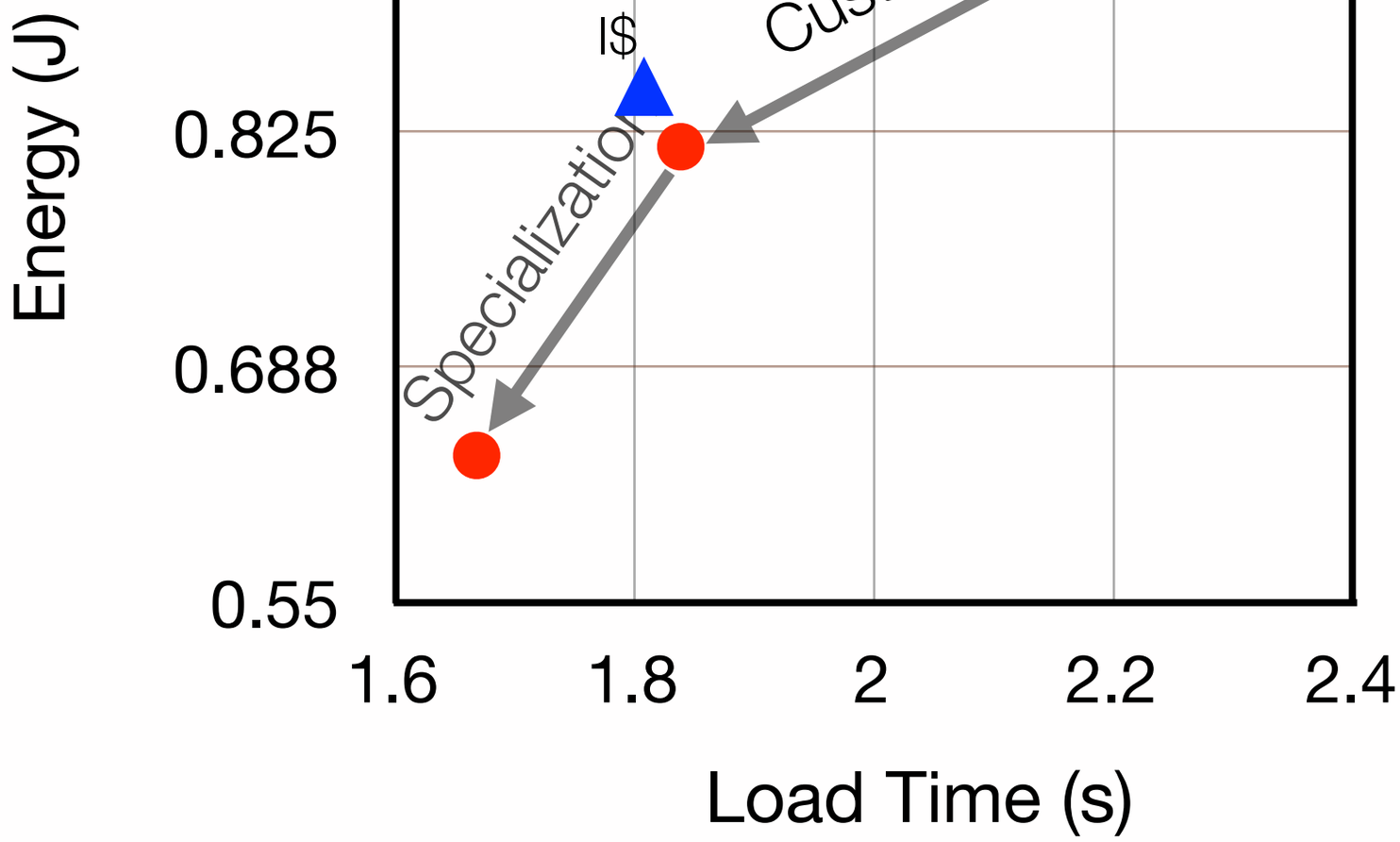

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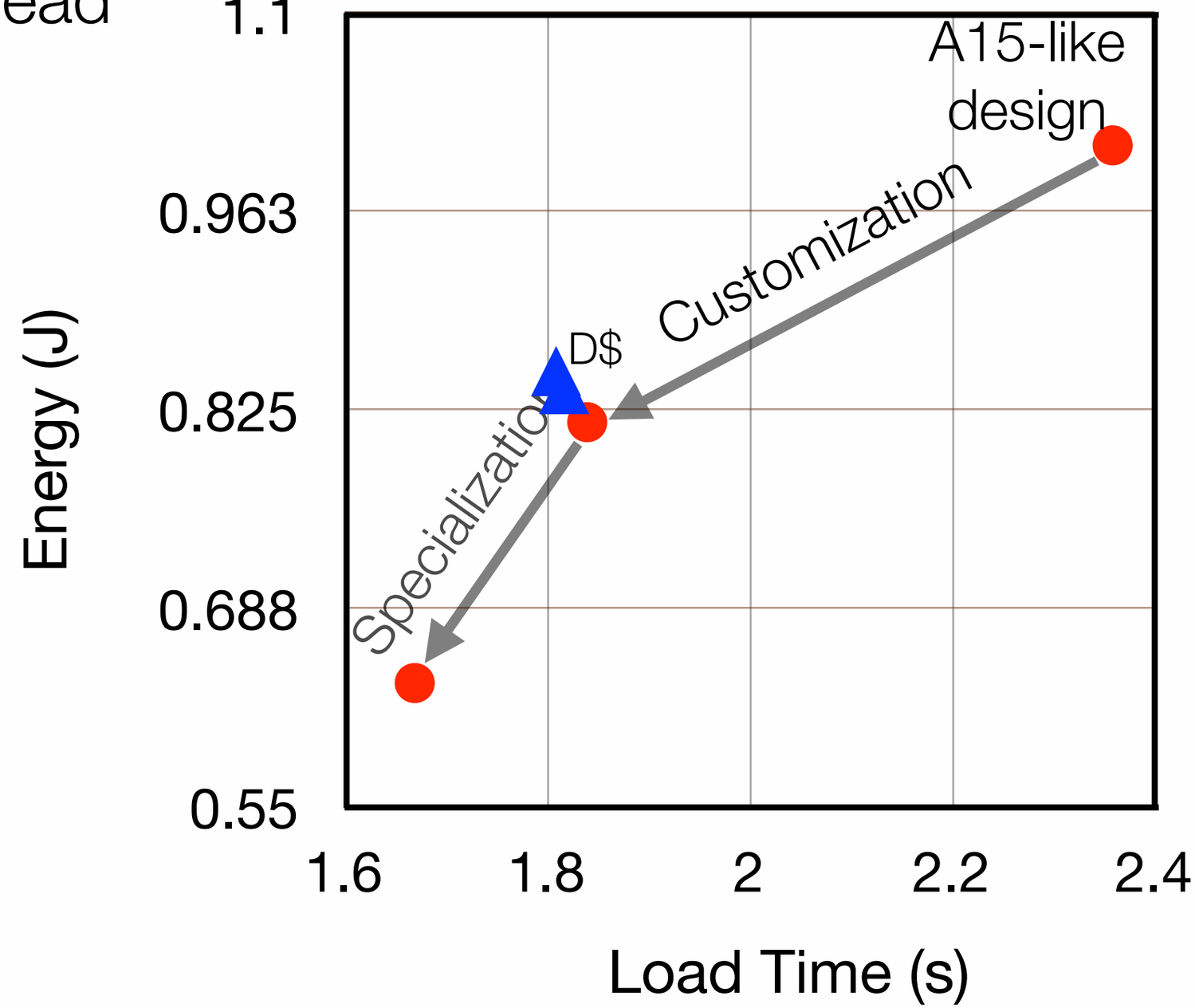

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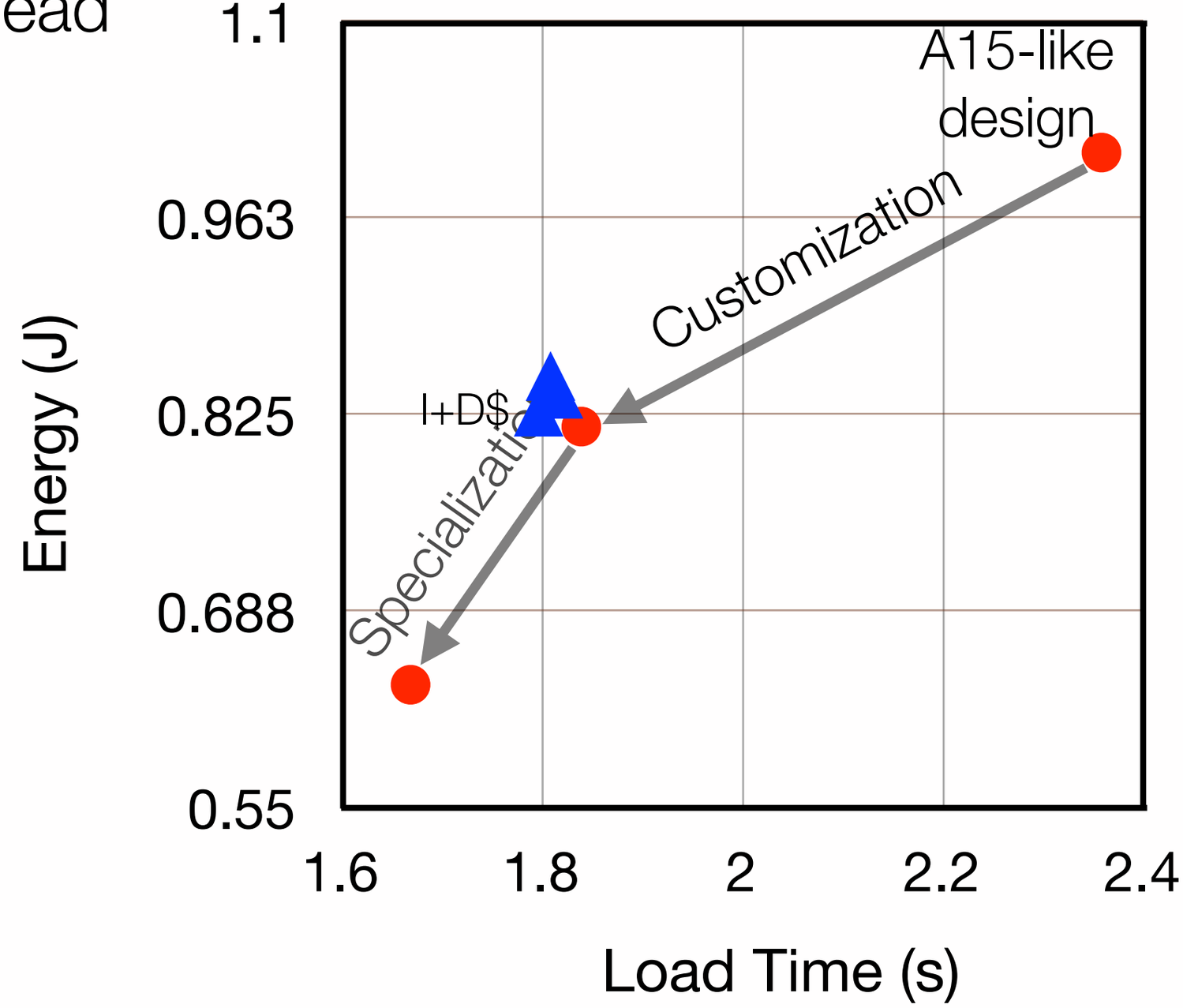
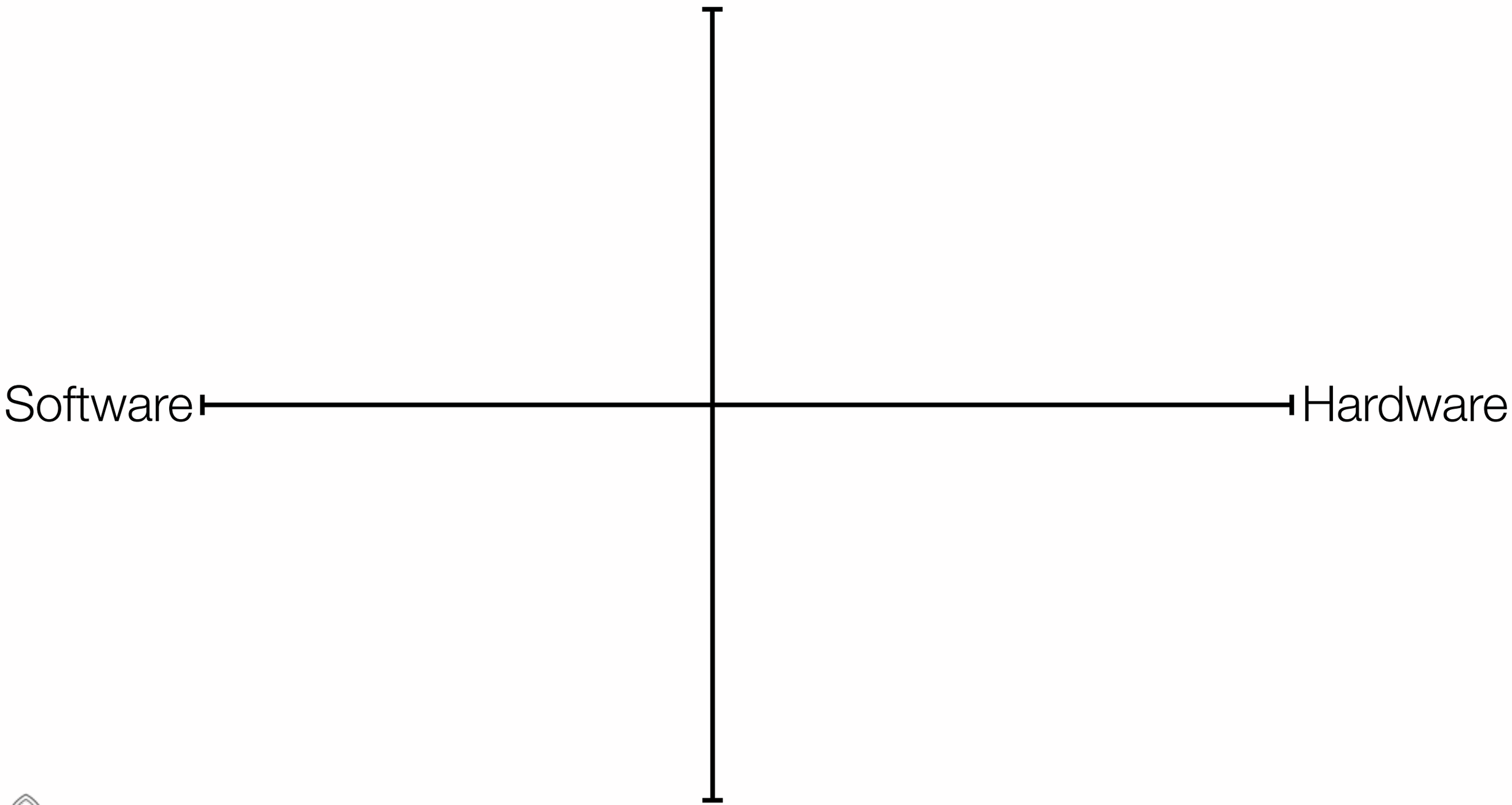
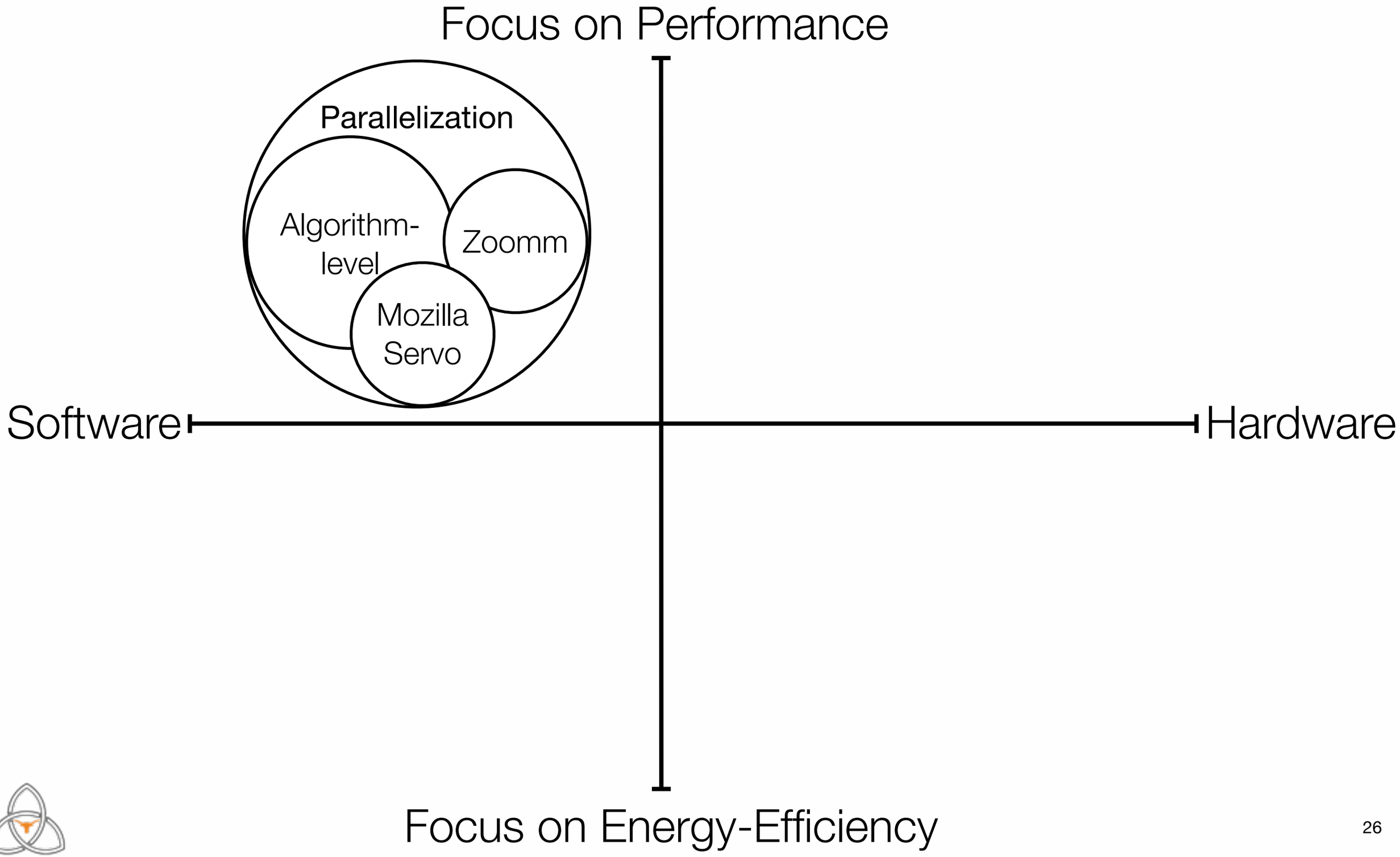


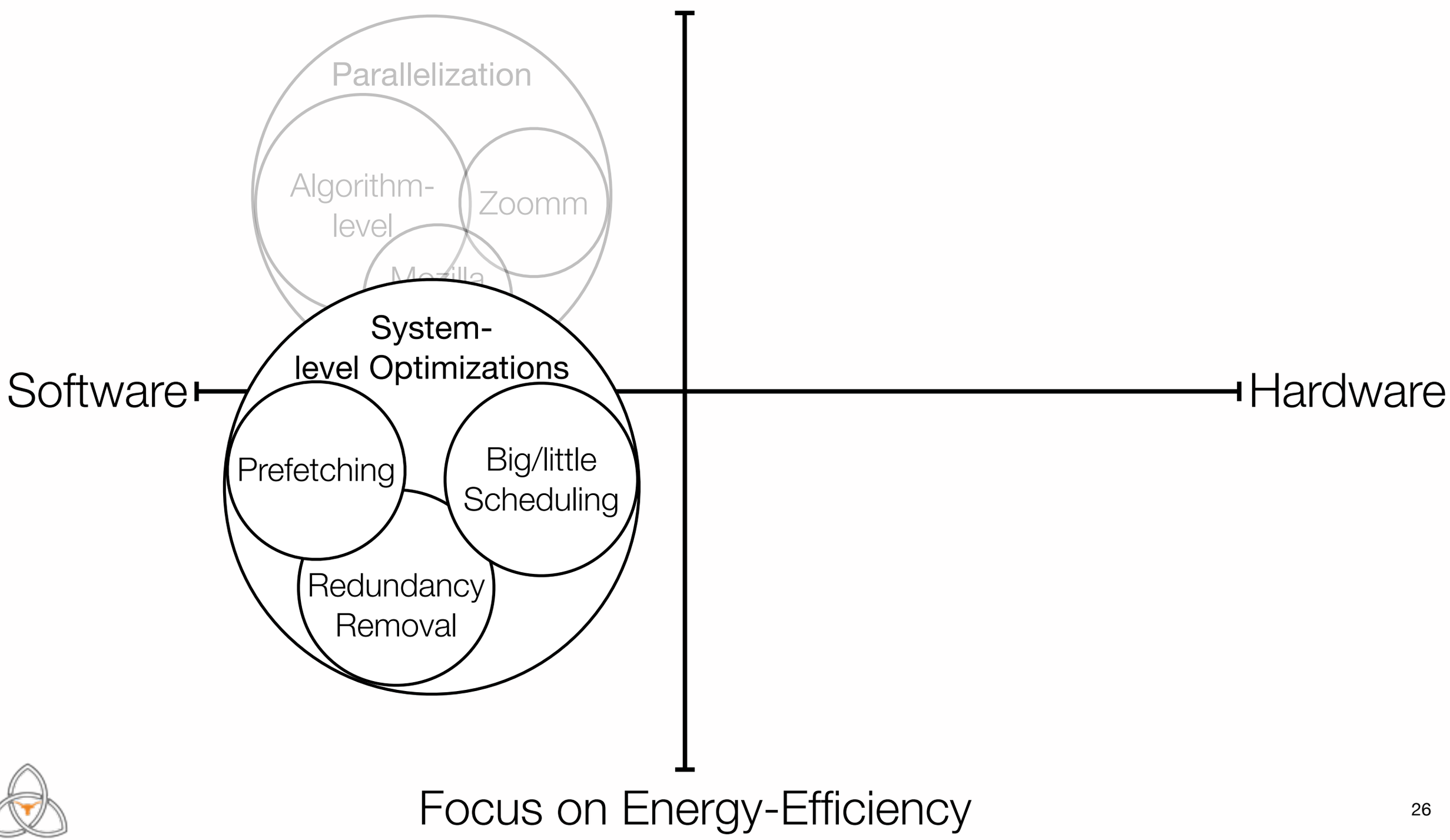
Related Work



Related Work



Related Work



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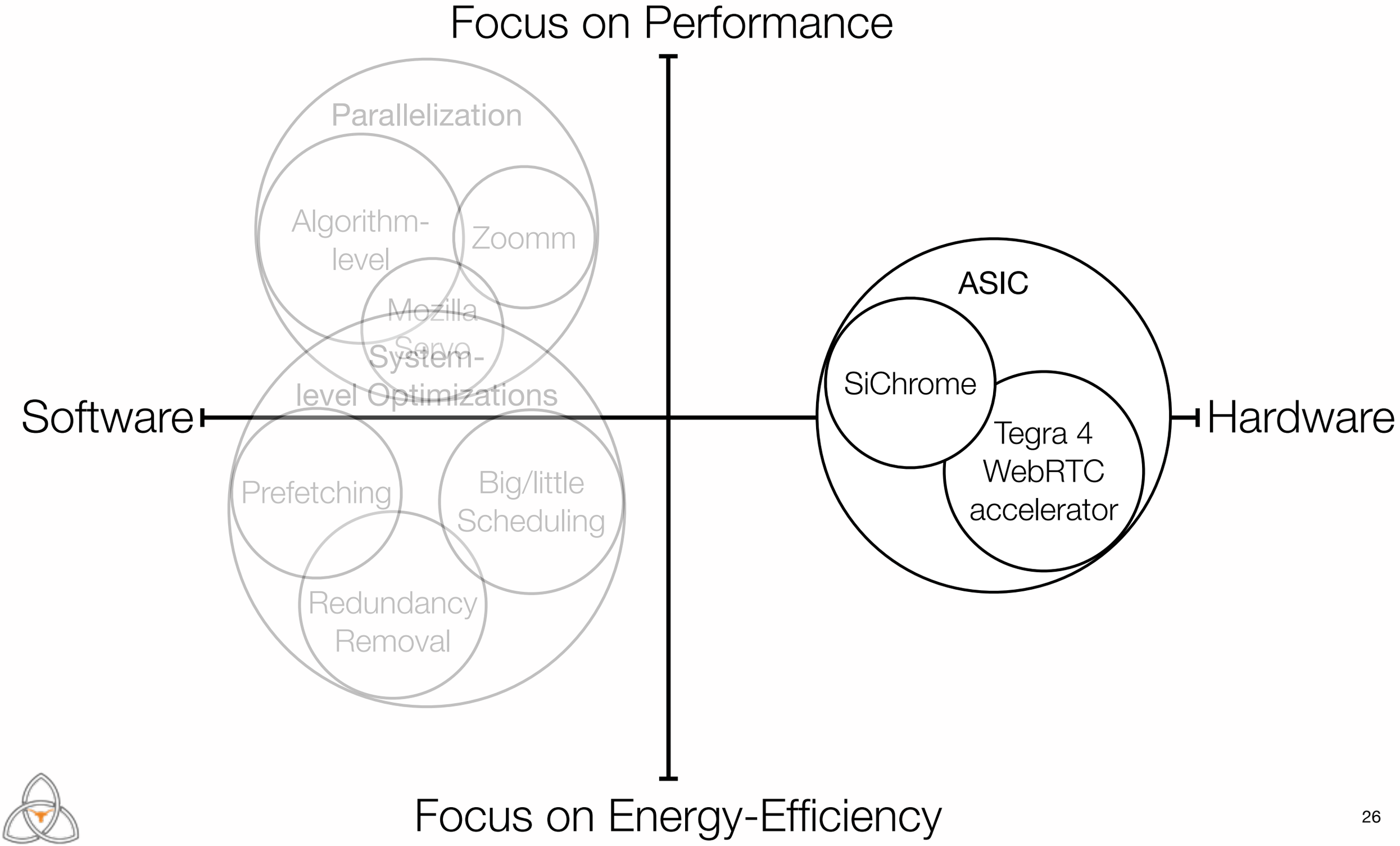

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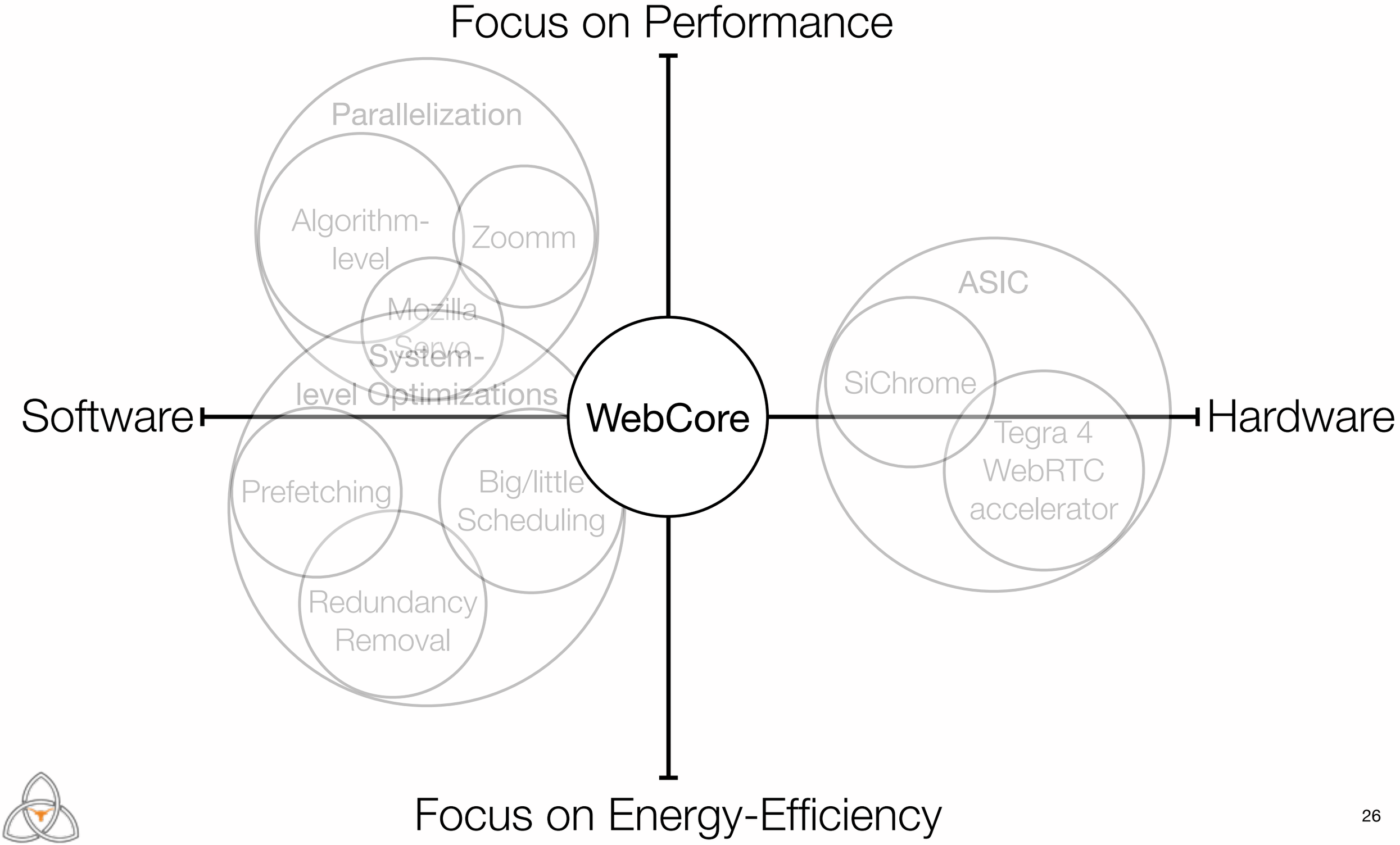
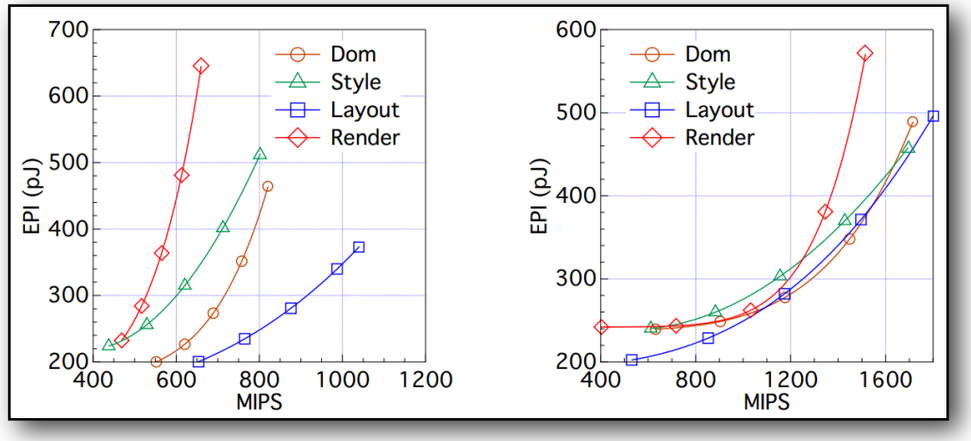
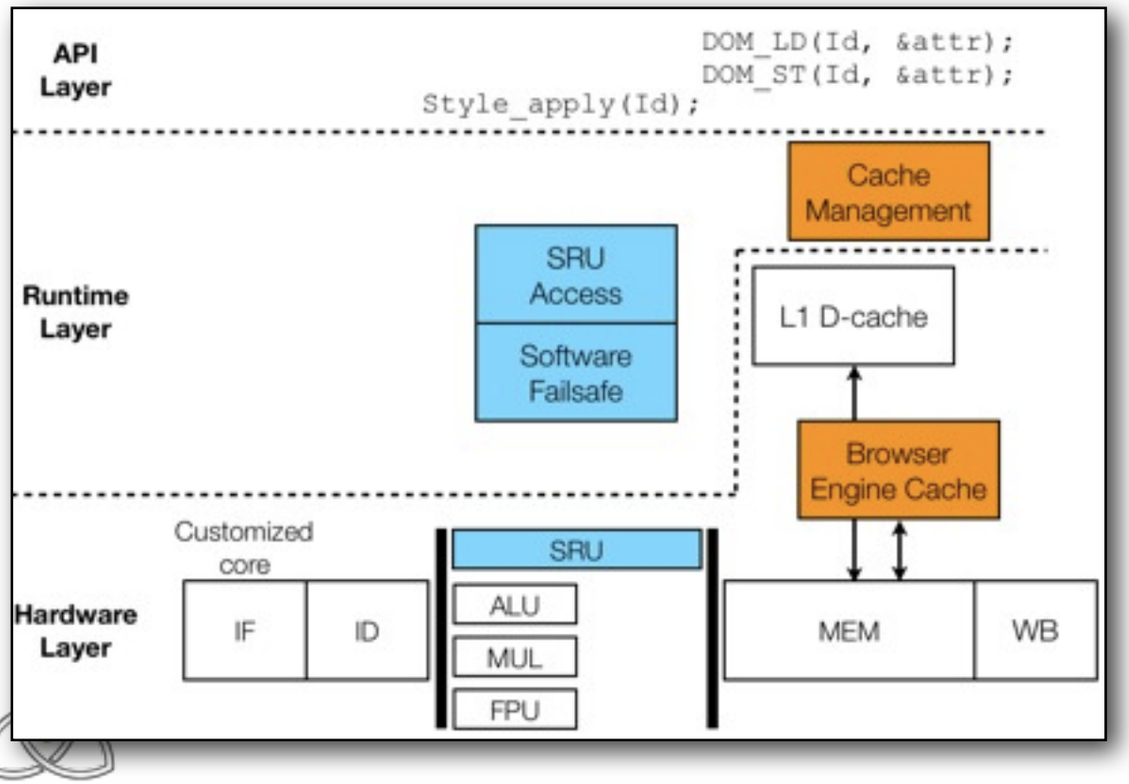


Conclusions

The Web browser has become a general purpose platform that supports a wide range of mobile Web applications



Customization allows us to find the ideal general-purpose baseline architecture



Hardware/software collaborative specialization leverages application knowledge to mitigate inefficiencies in general-purpose architectures

Thank you