Spandex: A Flexible Interface for Efficient Heterogeneous Coherence

Johnathan Alsop*, Matthew D. Sinclair*[†‡], Sarita V. Adve*

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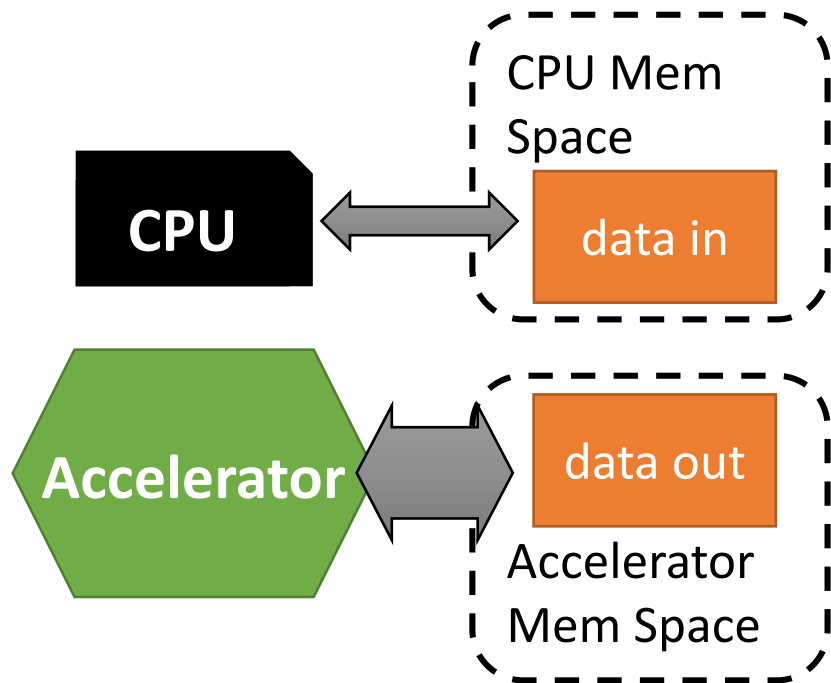
Specialized architectures are increasingly important in all compute domains

Specialization Requires Better Memory Systems

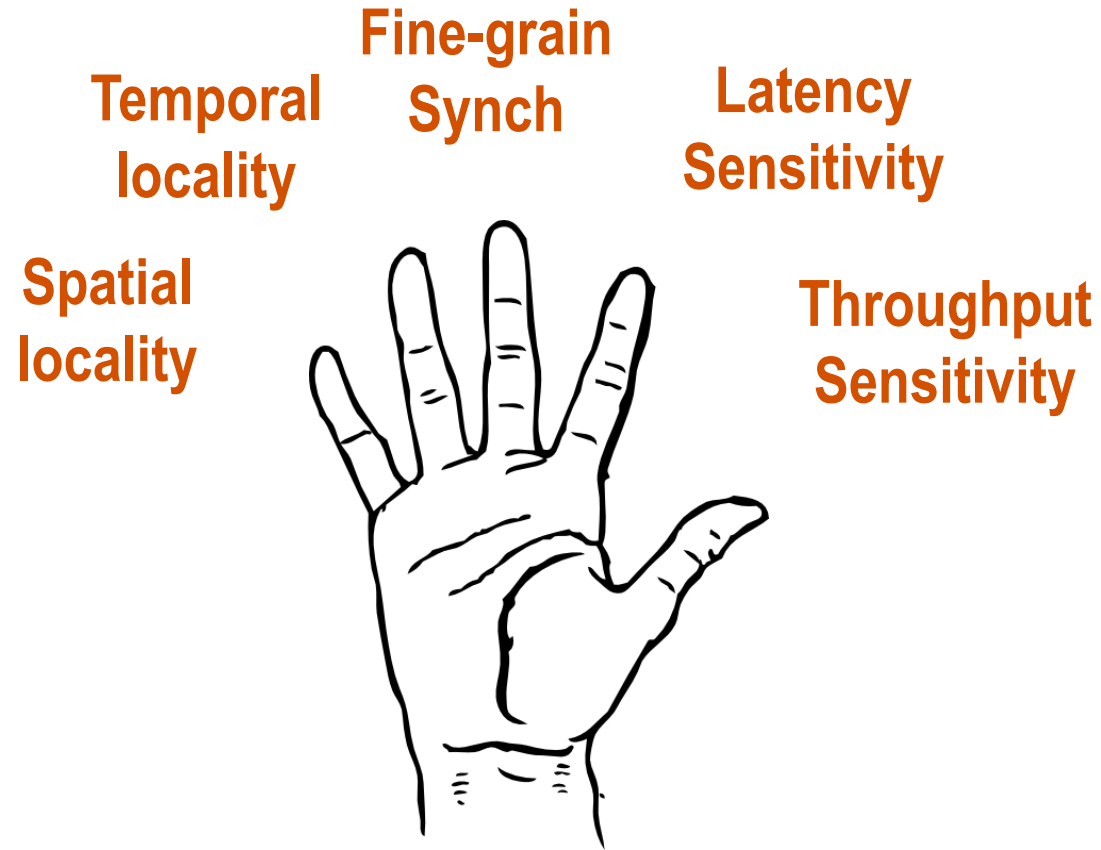**Traditional heterogeneity:**

CPU Mem Space

CPU

data in

Accelerator

data out

Accelerator Mem Space

✖ No fine-grain synchronization
✖ No irregular access patterns
✖ Wasteful data movement

Shared coherent memory:

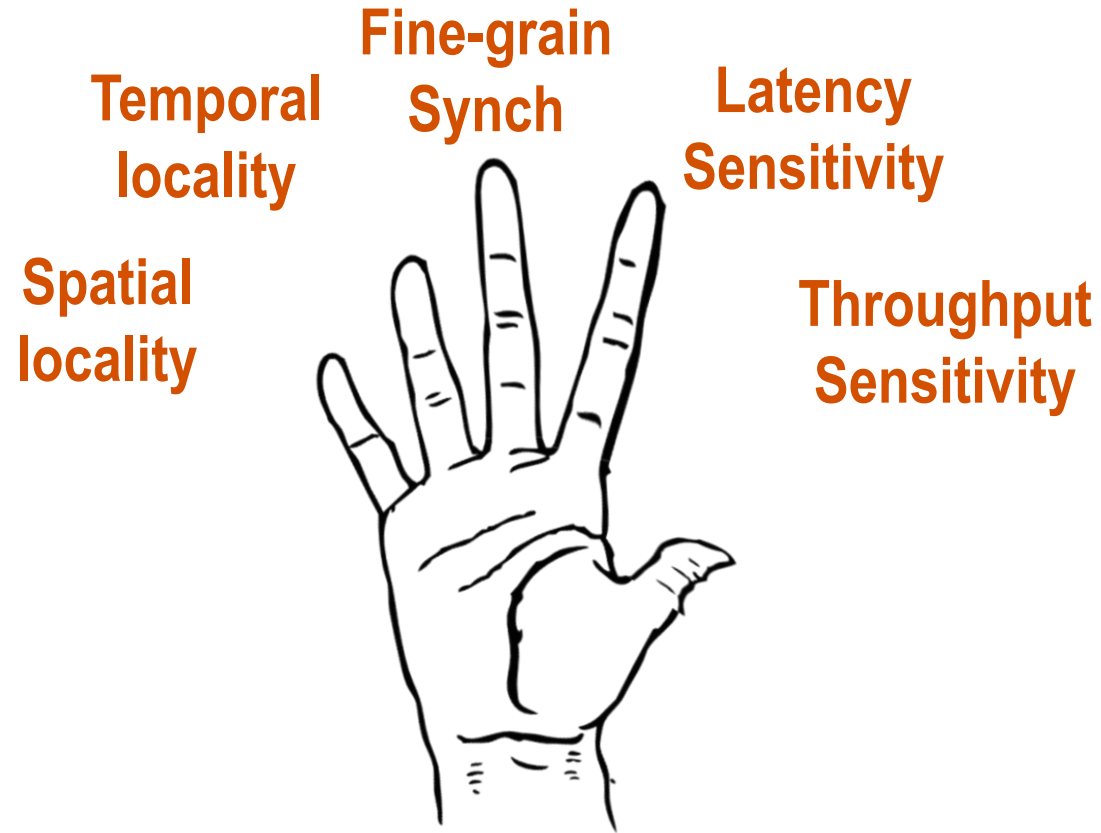Shared Mem Space

CPU

Existing solutions: complex and inflexible

Accelerator
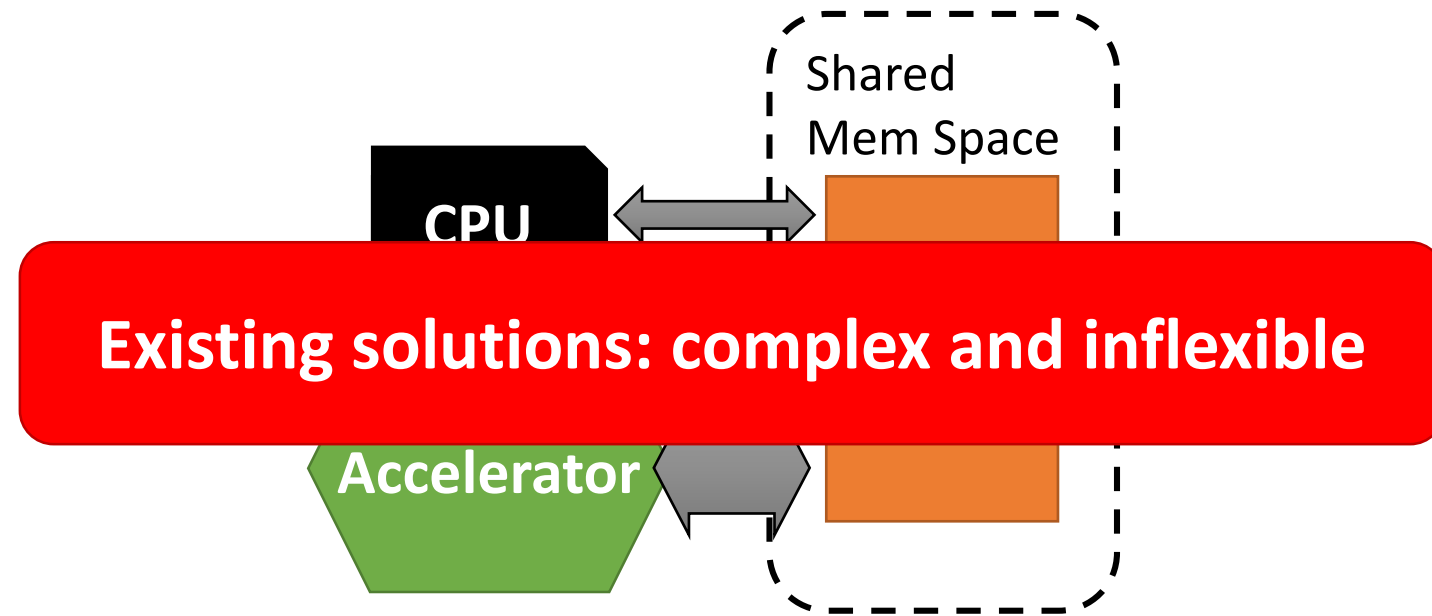
✓ Fine-grain synchronization
✓ Irregular access
✓ Implicit data reuse

Heterogeneous devices have diverse memory demands

Temporal locality

Fine-grain Synch

Latency Sensitivity

Spatial locality

Throughput Sensitivity

Heterogeneous devices have diverse memory demands

Temporal locality

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Throughput Sensitivity

Typical **CPU** workloads:
fine-grain synch, latency sensitive

Heterogeneous devices have diverse memory demands

Fine-grain Synch

Temporal locality

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Spatial locality

Throughput Sensitivity
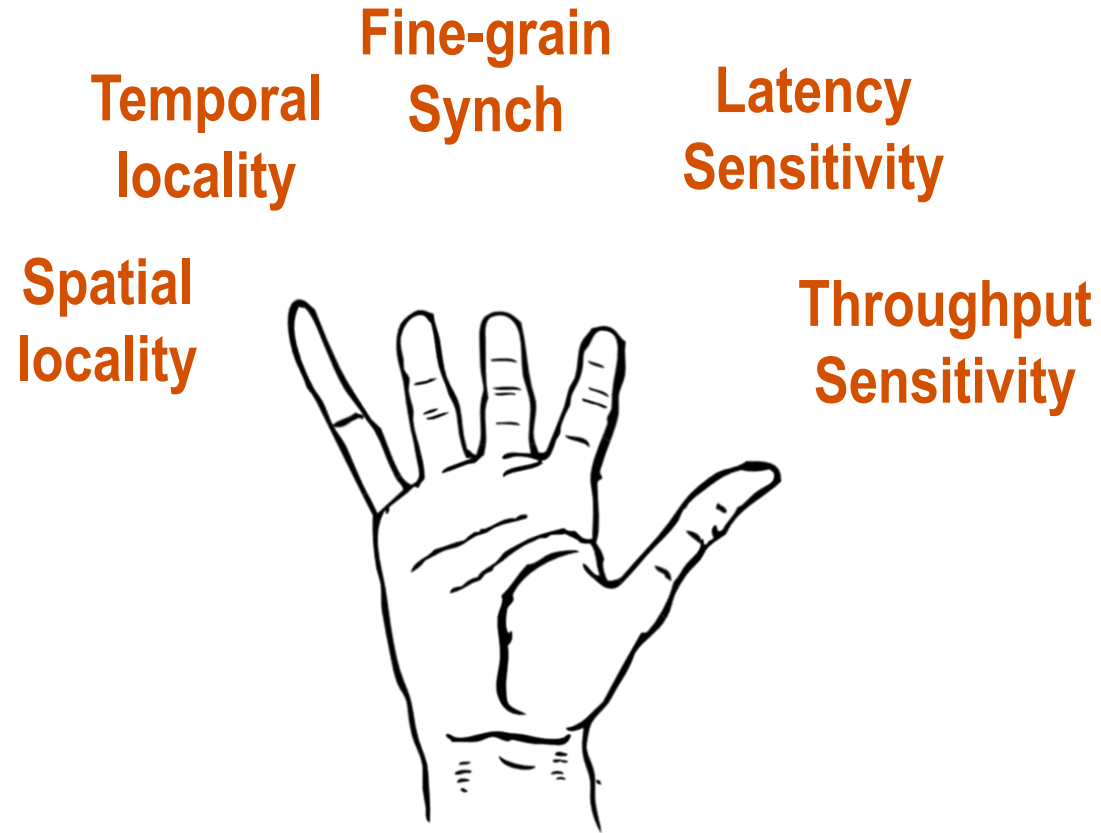
Typical **GPU** workloads:
spatial locality, throughput sensitive

MESI protocol fits CPU workloads

Properties	MESI
Granularity	
Invalidation	
Updates	

Good for:

MESI

CPU

GPUs prefer simpler protocols

Properties	MESI	GPU coherence
Granularity	Line	
Invalidation	Writer-invalidate	
Updates	Ownership	

Good for:

CPU

GPU

DeNovo is a good fit for CPU and GPU

Properties	MESI	GPU coherence	DeNovo
Granularity	Line	Reads: Line Writes: Word	
Invalidation	Writer-invalidate	Self-invalidate	
Updates	Ownership	Write-through	

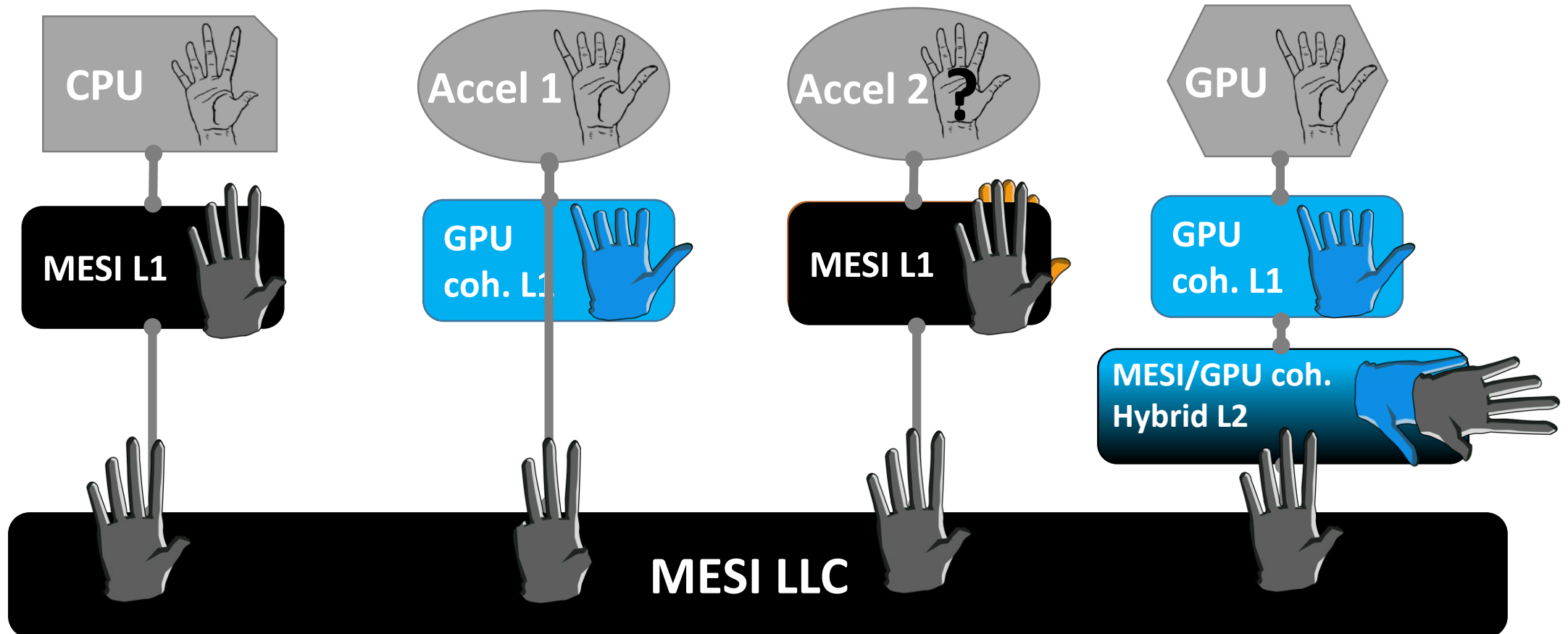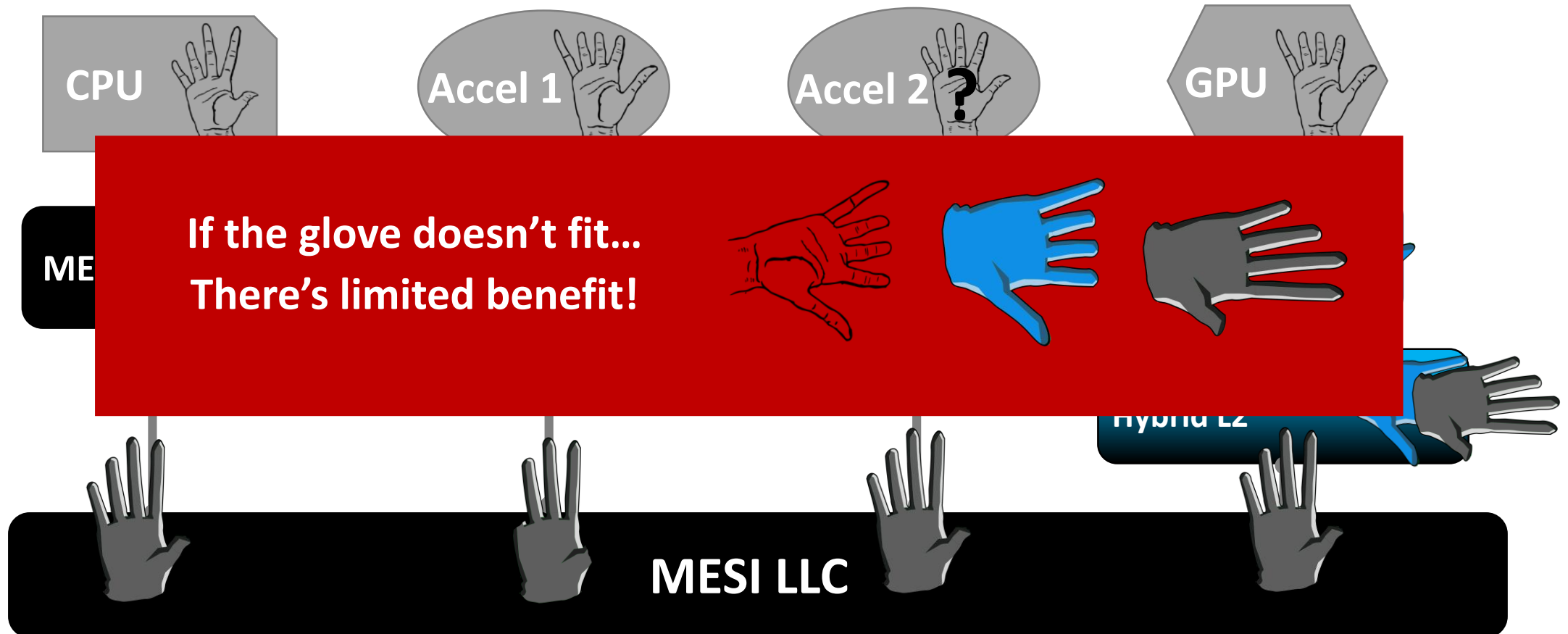**Good for:**

MESI

GPU coh.

DeNovo

CPU　　　　　**GPU**　　　　**CPU or GPU**

Existing Solutions: Inflexible and Inefficient

Examples: ARM ACE, IBM CAPI, AMD APU

Existing Solutions: Inflexible and Inefficient

**If the glove doesn't fit…
There's limited benefit!**

MESI LLC
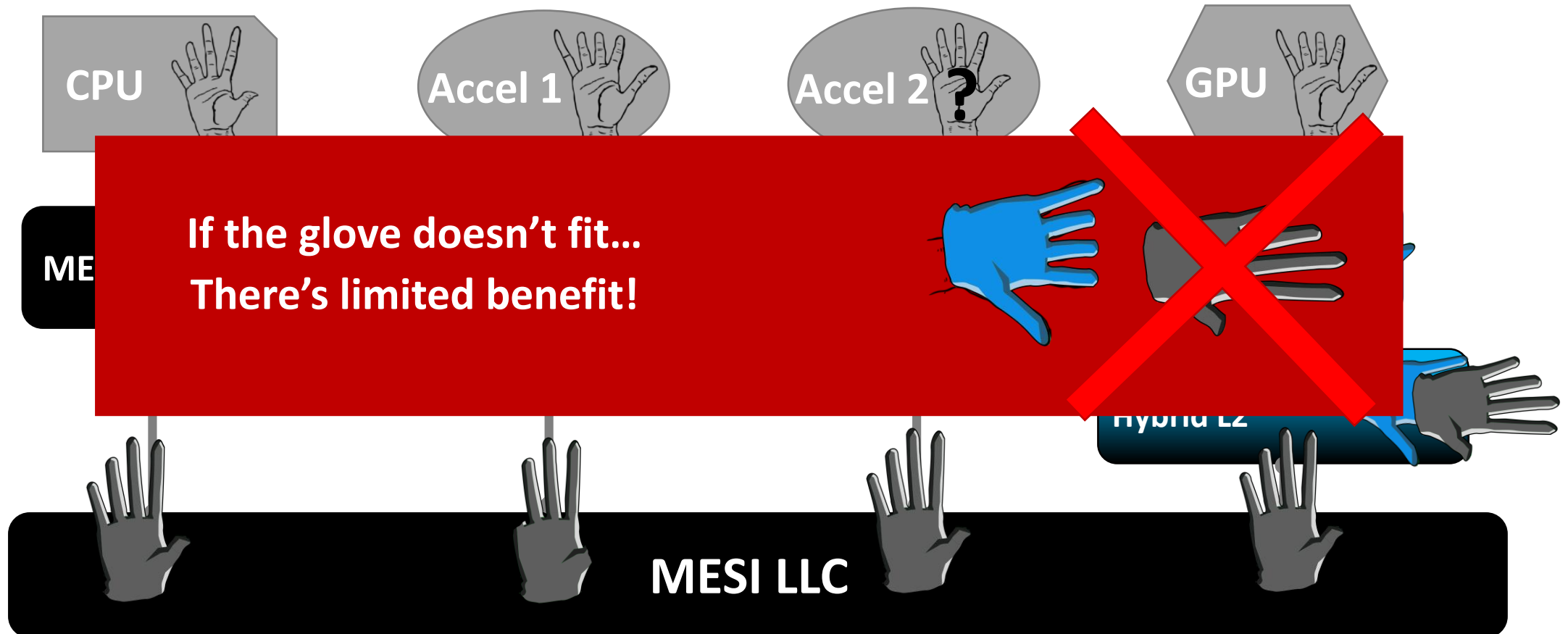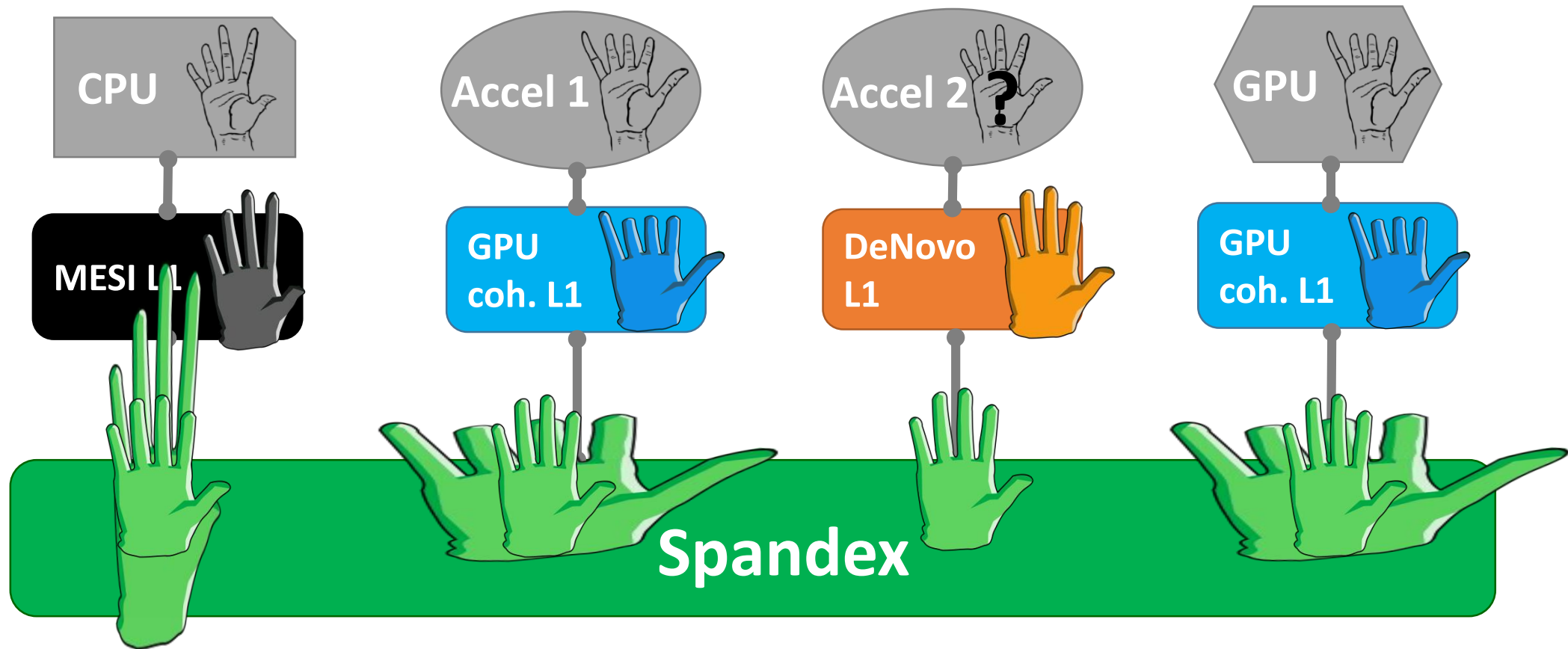
Examples: ARM ACE, IBM CAPI, AMD APU

Existing Solutions: Inflexible and Inefficient

Examples: ARM ACE, IBM CAPI, AMD APU

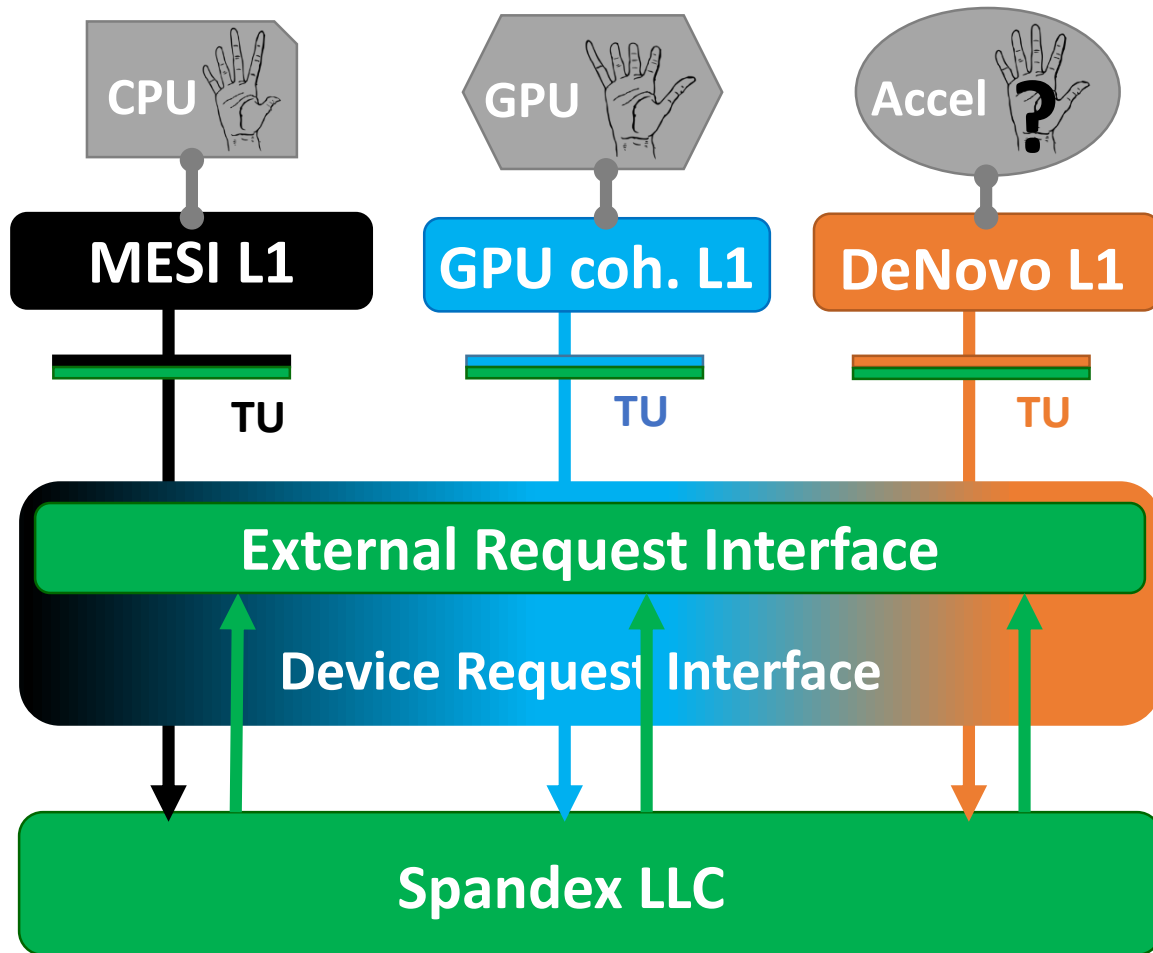# Spandex: Flexible Heterogeneous Coherence Interface

Adapts to exploit individual device's workload attributes

Better performance, lower complexity

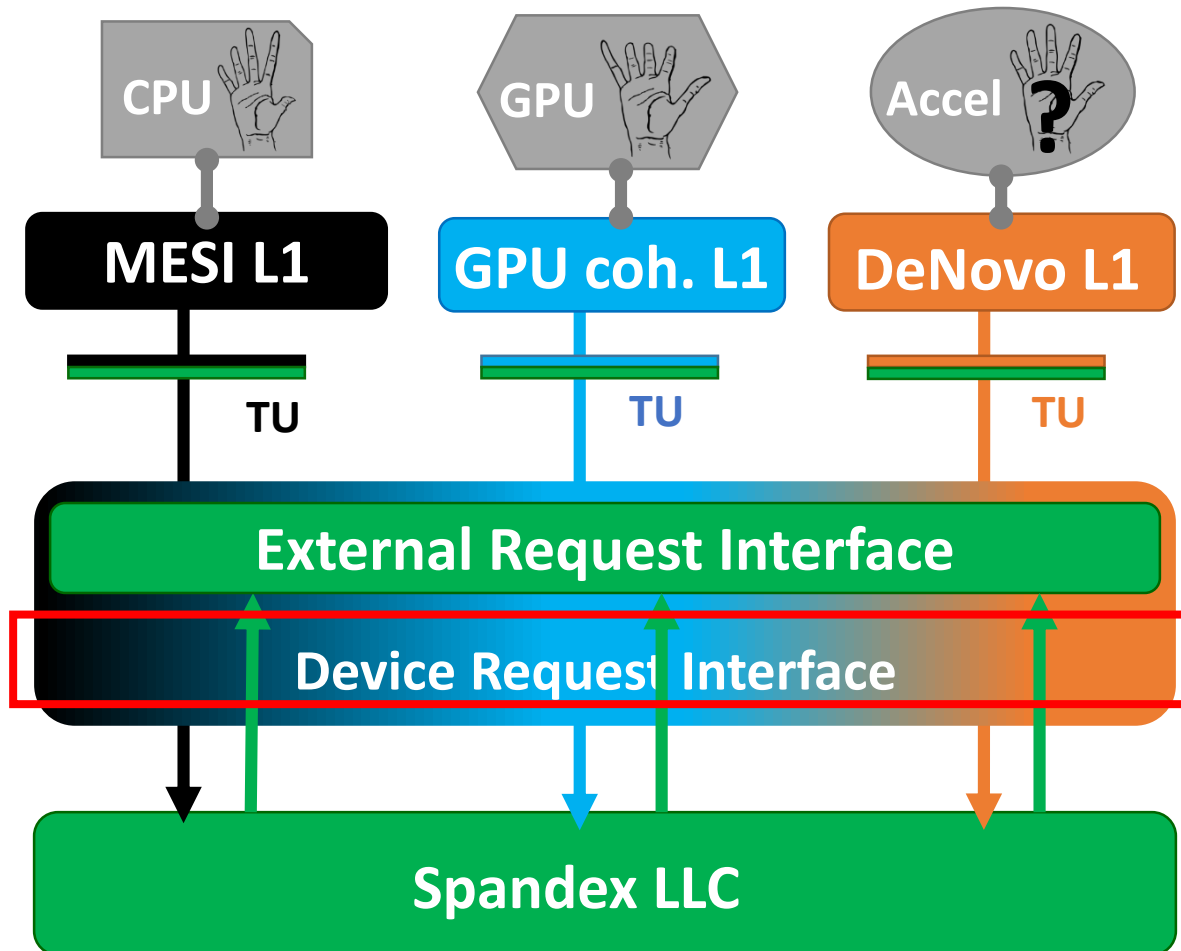⇒ Fits like a glove for any heterogeneous system!

Spandex Overview

Key Components

- Flexible device request interface

- DeNovo-based LLC

- External request interface

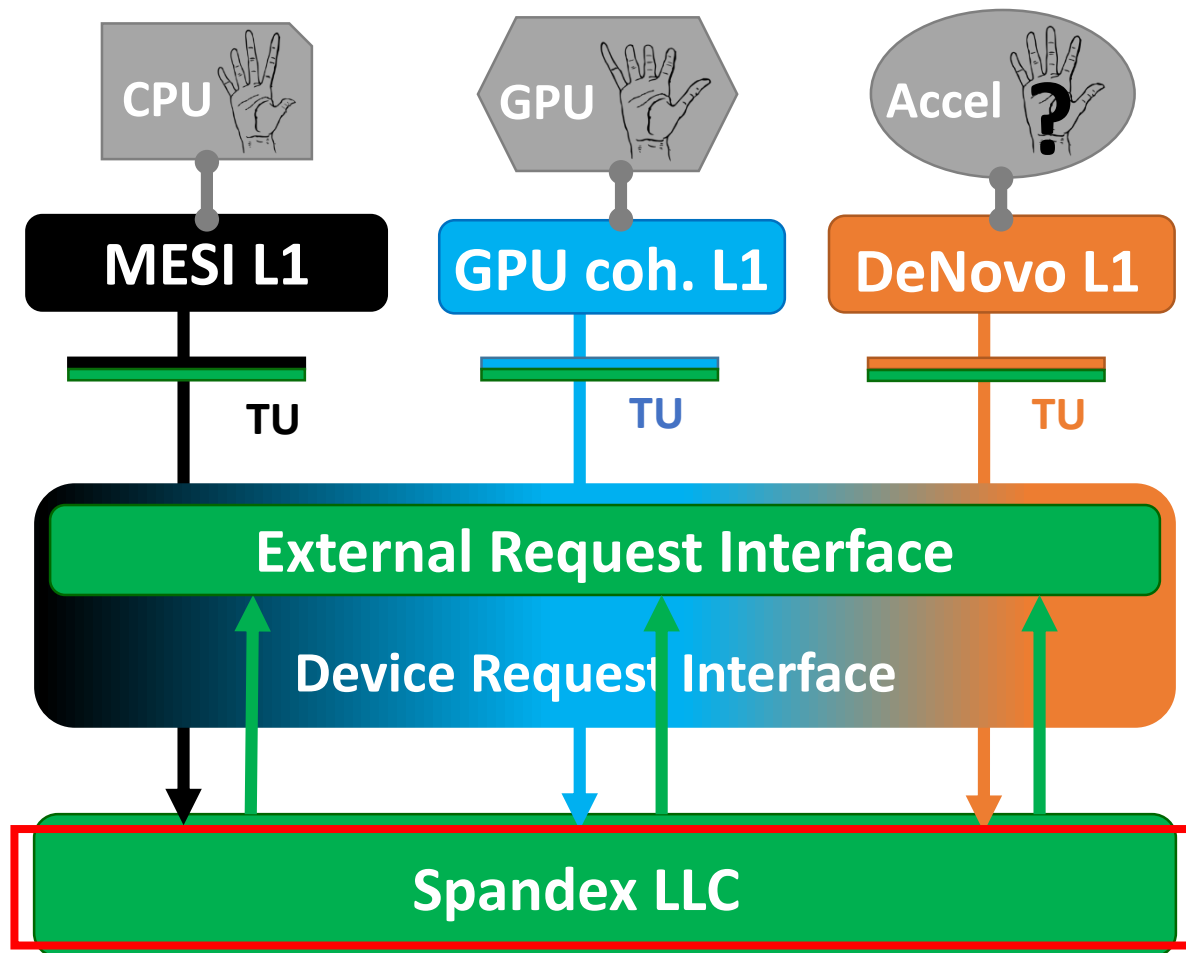Device may need a translation unit (TU)

Spandex Overview

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Device Request Interface

Action	Request	Indicates
Read	ReqV	Self-invalidation
	ReqS	Writer-invalidation

Requests also specify granularity and (optionally) a bitmask
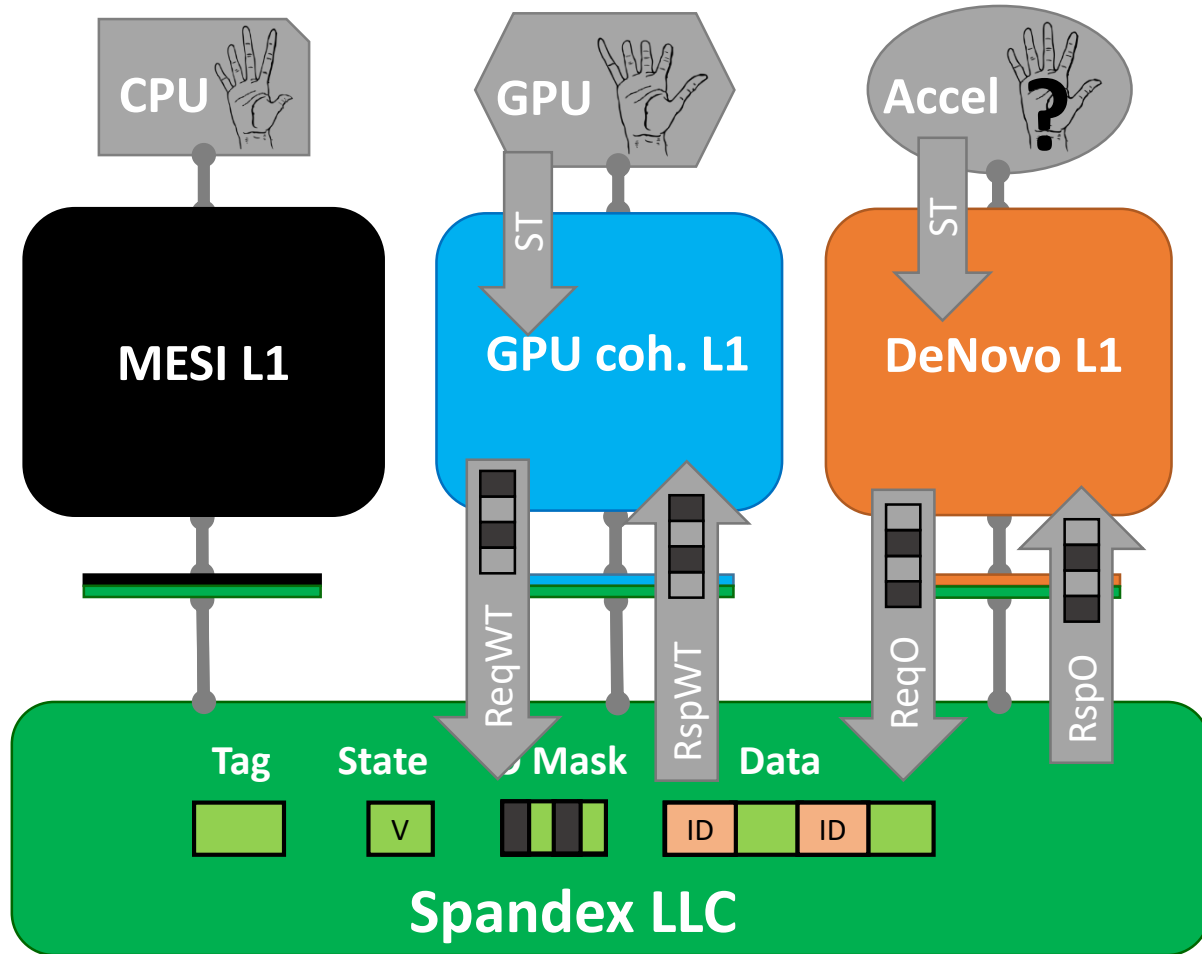
Spandex Overview

Key Components

- Flexible device request interface

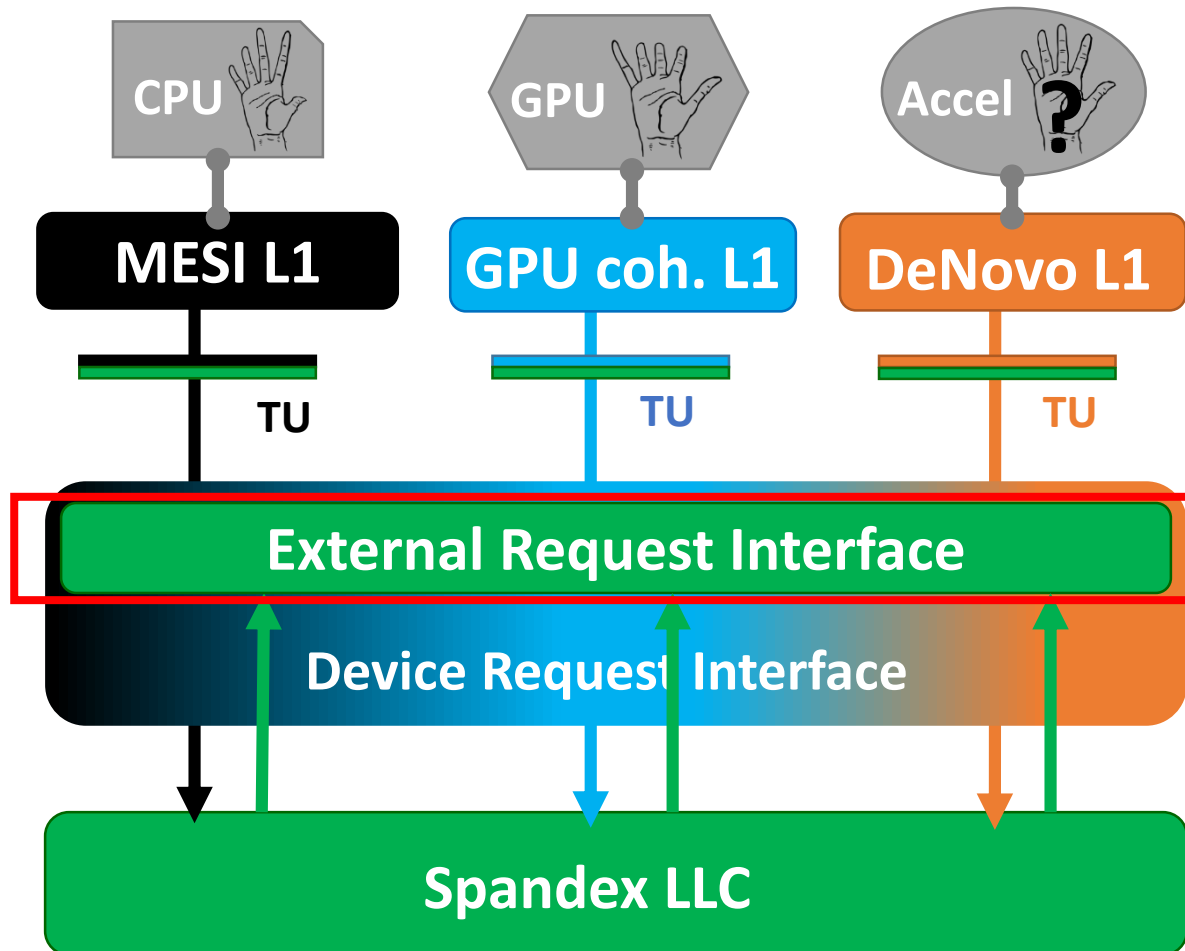- DeNovo-based LLC

- External request interface

Device may need a translation unit (TU)

Spandex LLC

- States: I, V, O, S
- Allocation at line granularity
- Ownership at word granularity
- Data field tracks owner ID
- May generate requests to owner/sharer

✓No false sharing
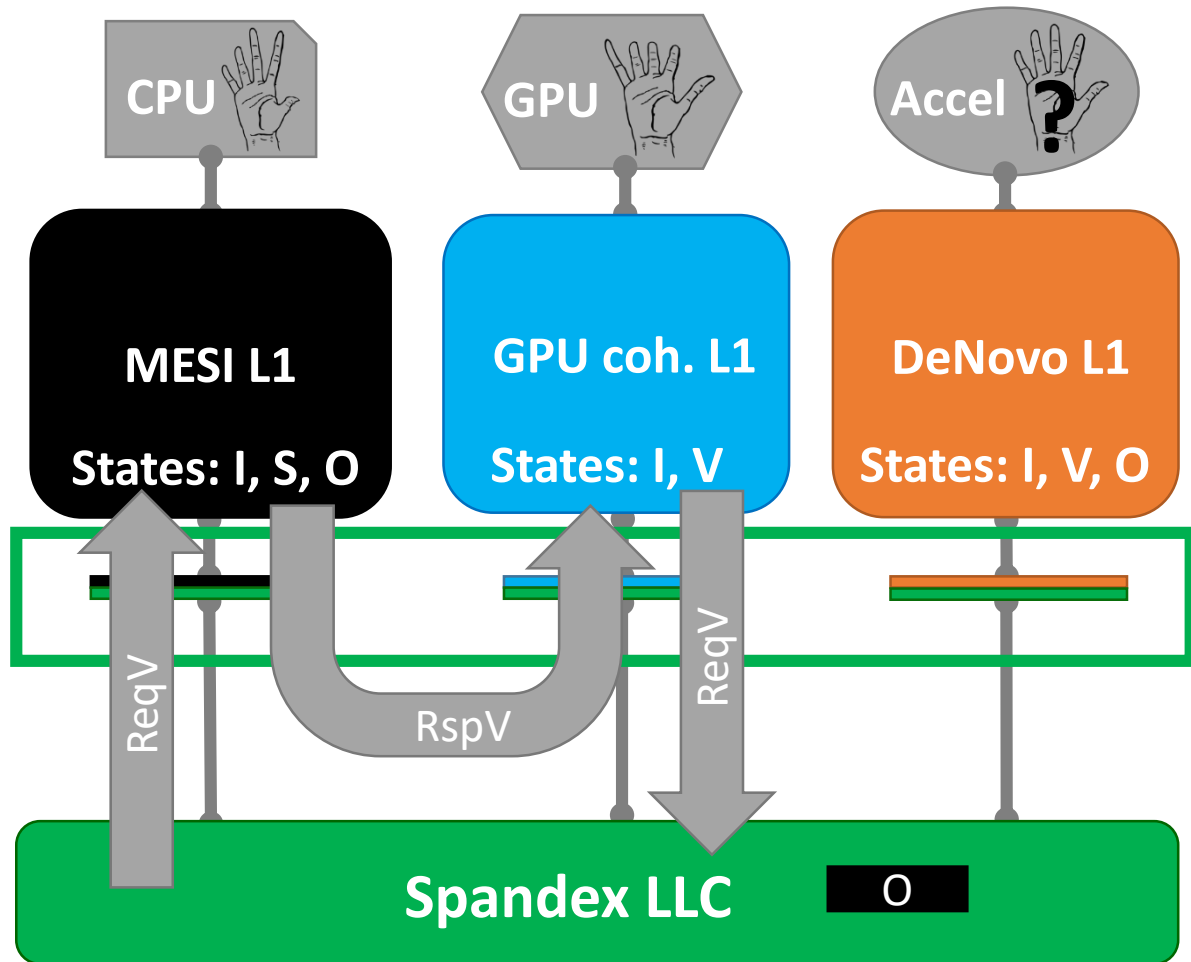✓Non-blocking ownership transfer

Spandex Overview

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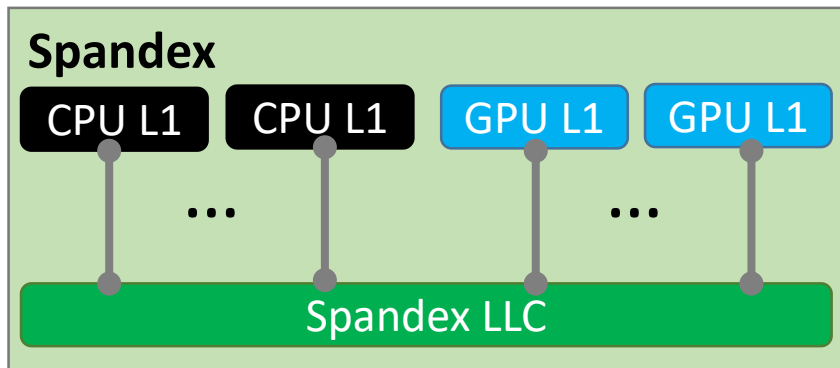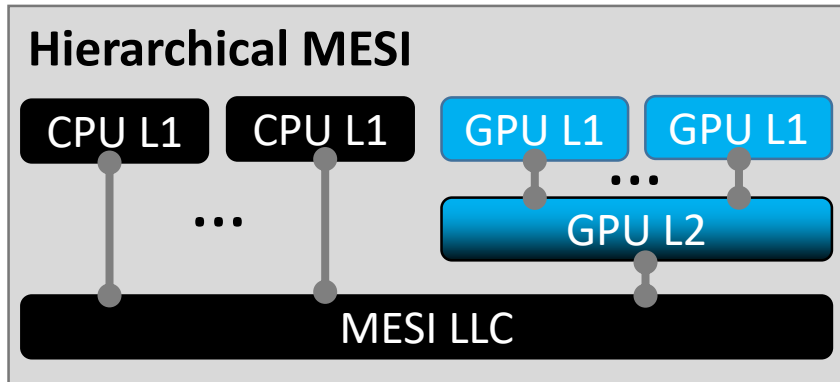Device may need a translation unit (TU)

External Request Interface

External Request	Must handle if supports state
ReqV	O
ReqO	O
ReqO+data	O
RvkO	O
Inv	S
ReqS	S and O

- **Translation Unit** may implement functionality if not supported by device

Evaluation: Configurations

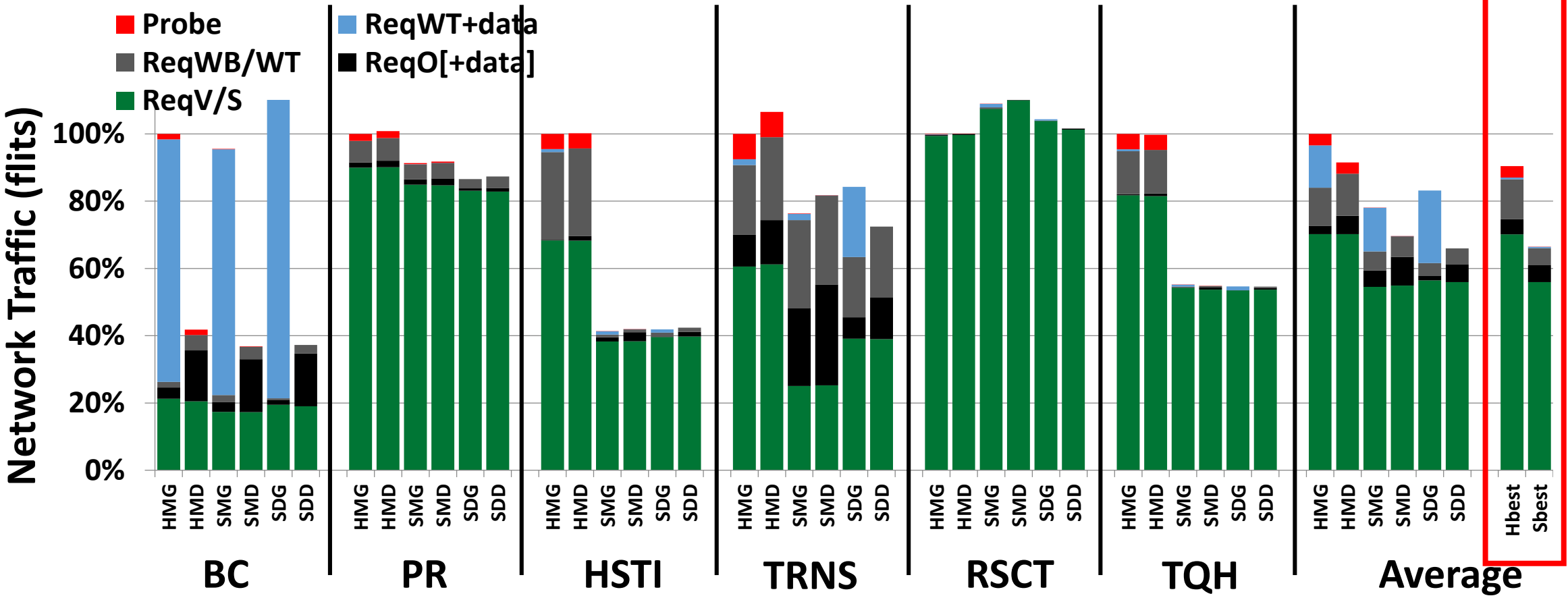| Configuration	LLC protocol	CPU protocol	GPU protocol
HMG	Hierarchical MESI	MESI	GPU coherence
HMD	Hierarchical MESI	MESI	DeNovo

CPU-GPU workloads from **Pannotia** and **Chai** benchmark suites

Evaluation: CPU-GPU Applications
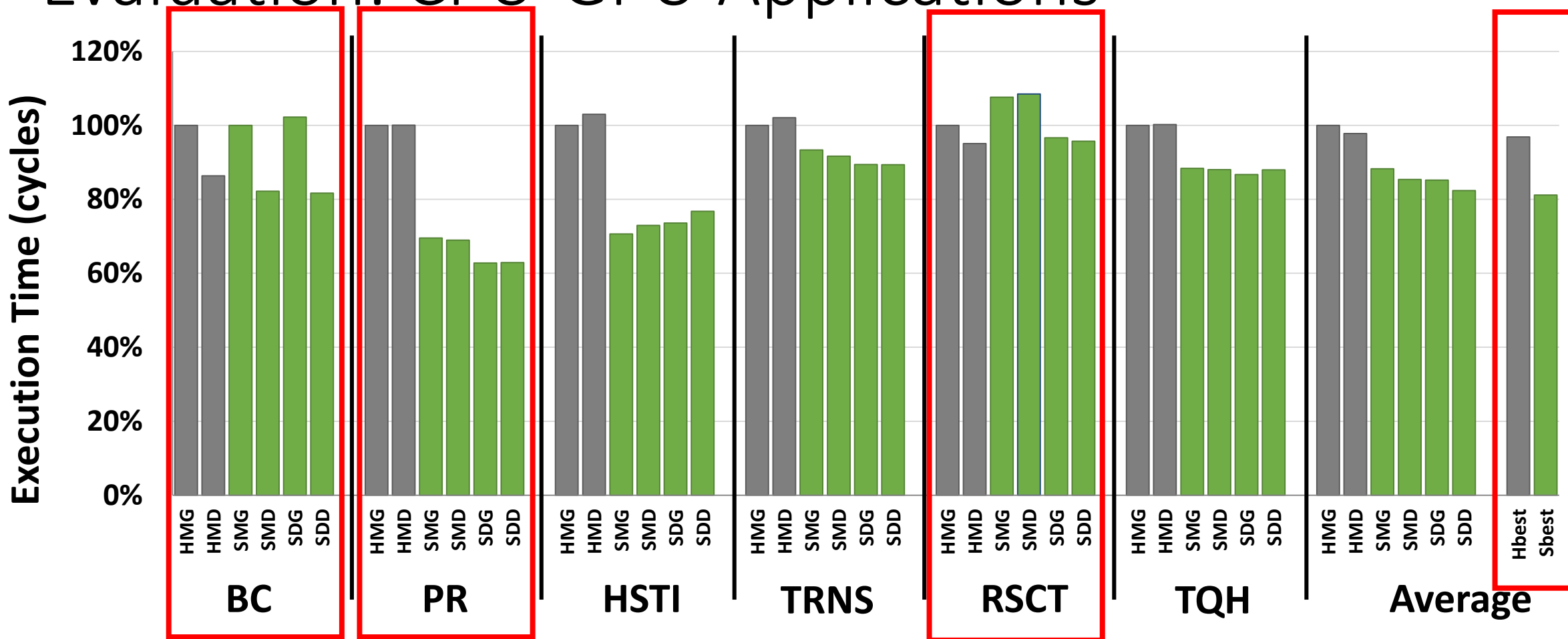

- Different workloads prefer different protocols

- Spandex flexibility ⇒ consistently better execution time (avg 16% lower)

Evaluation: CPU-GPU Applications

Legend: Probe, ReqWB/WT, ReqV/S, ReqWT+data, ReqO[+data]

Y-axis: Network Traffic (flits) — 0%, 20%, 40%, 60%, 80%, 100%

Categories: BC, PR, HSTI, TRNS, RSCT, TQH, Average

Sub-labels: HMG, HMD, SMG, SMD, SDG, SDD (and Hbest, Sbest for Average)

- Spandex flexibility ⇒ consistently better NW traffic (avg 27% lower)

Conclusion and Future Work

⇒ Simple, Flexible, Efficient
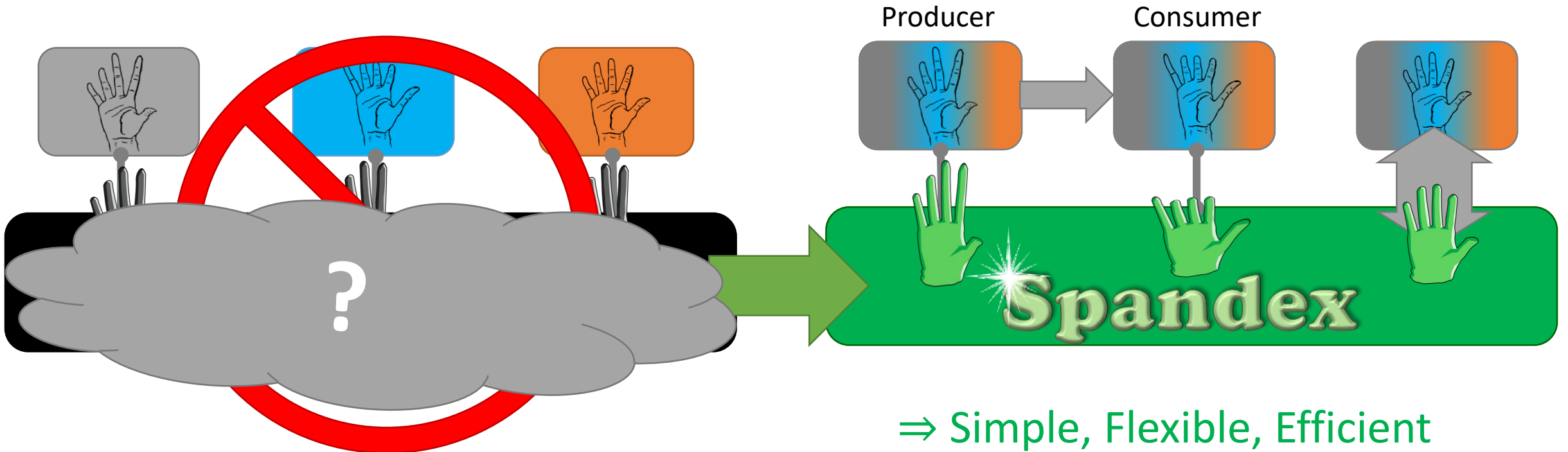
Future Work: exploit SW or HW hints about data access patterns

- Dynamic Spandex request selection
- Producer-consumer forwarding
- Extended granularity flexibility

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