Data Criticality in Network-On-Chip Design

Joshua San Miguel

Natalie Enright Jerger

The Edward S. Rogers Sr. Department
of Electrical & Computer Engineering
UNIVERSITY OF TORONTO

Network-On-Chip Efficiency

Efficiency is the ability to produce results with the least amount of waste.

- Wasted time

  NoC accounts for 30-70% of on-chip data access latency

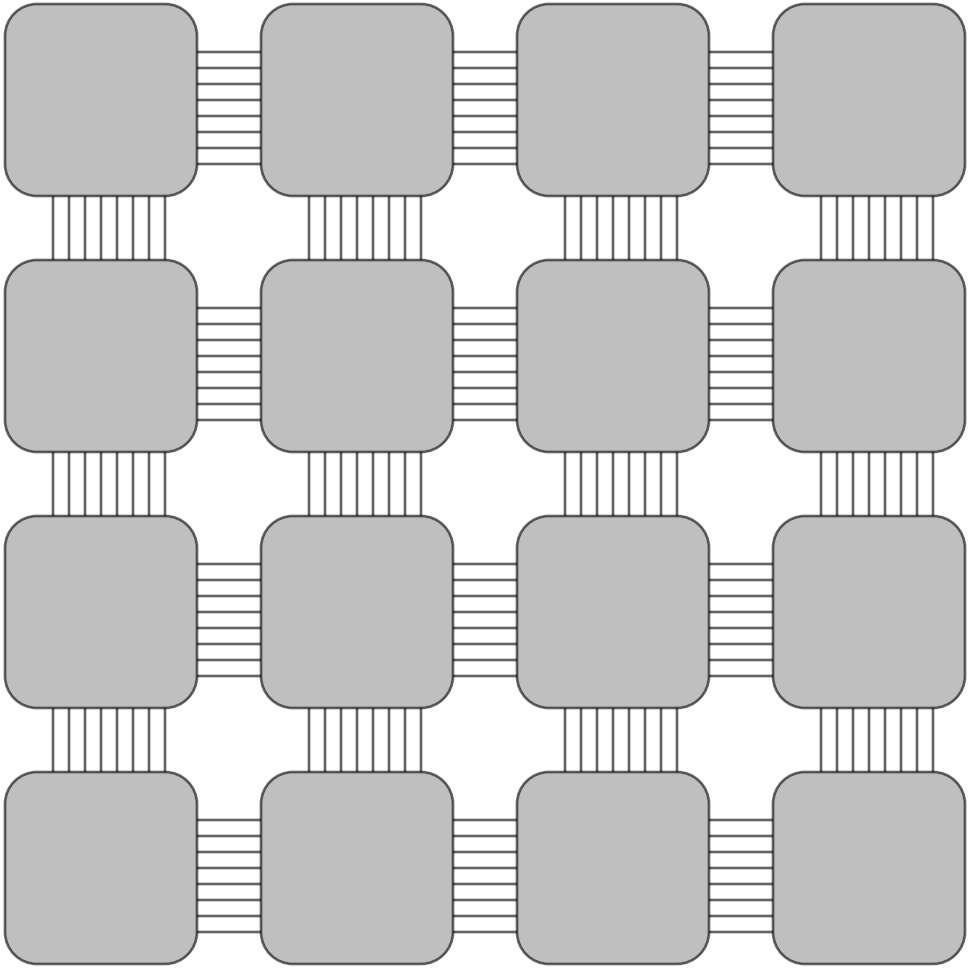
  [Z. Li, HPCA 2009][A. Sharifi, MICRO 2012]

- Wasted energy

  NoC accounts for 20-30% of total chip power

  [J. D. Owens, IEEE Micro 2007][S. R. Vangal, IEEE JSSC 2008]

Network-On-Chip Efficiency



Network-On-Chip Efficiency

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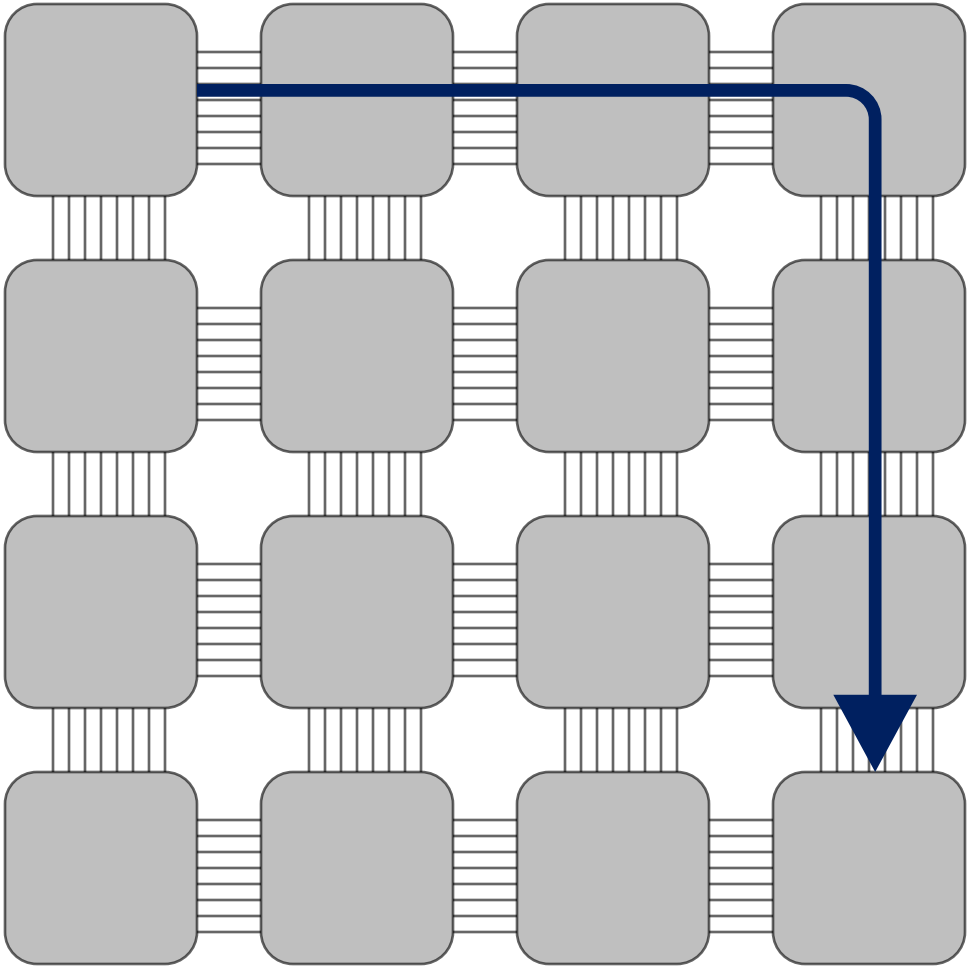

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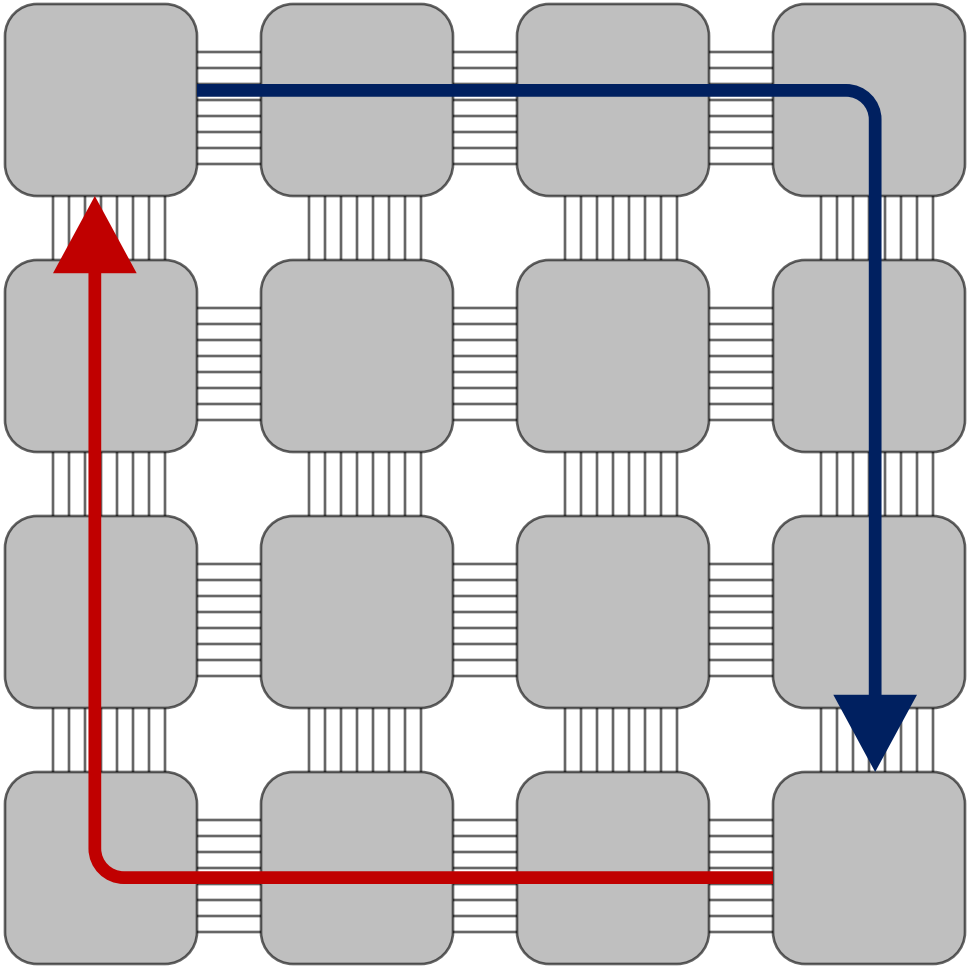
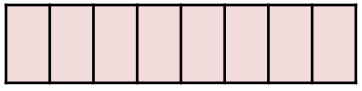


data response



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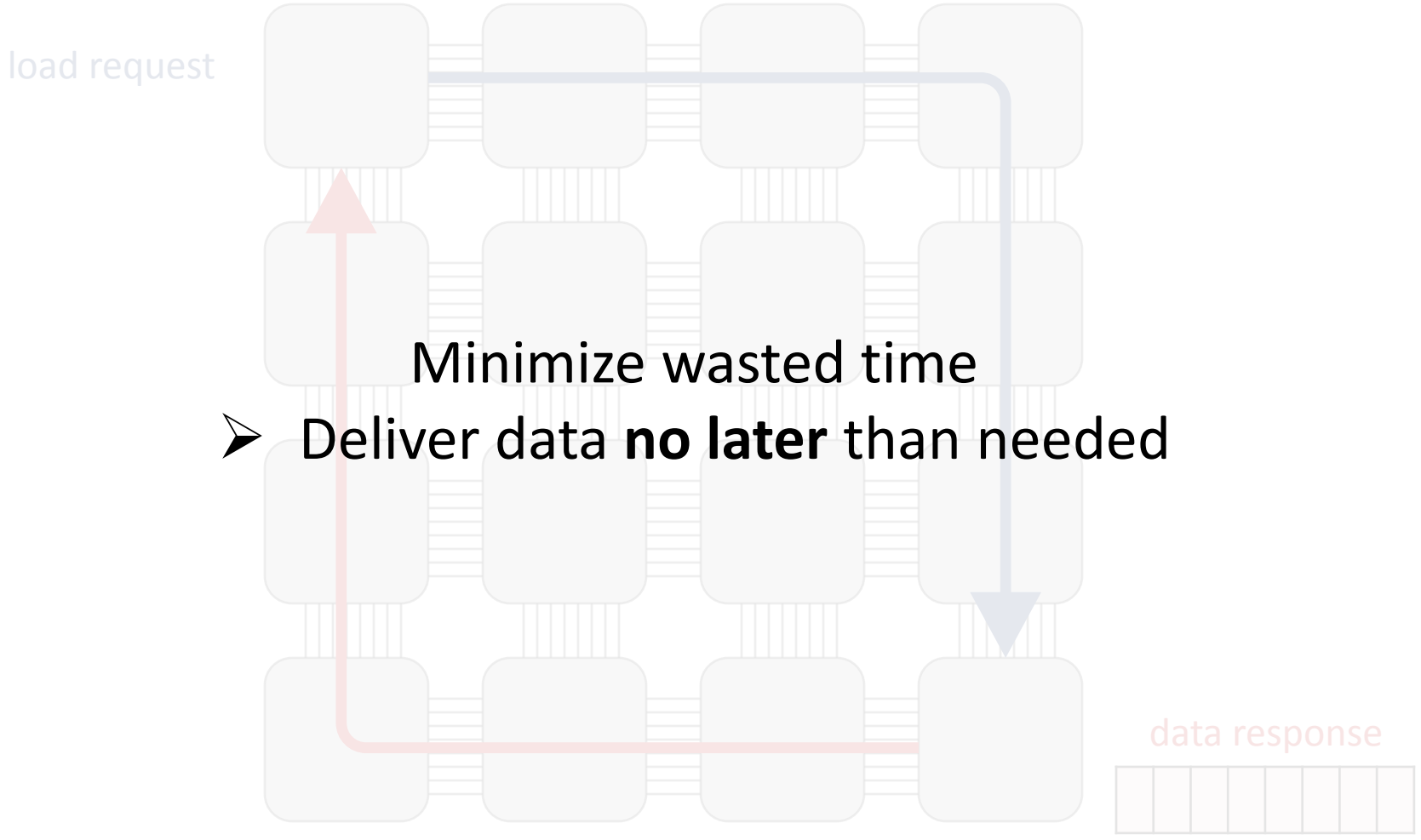

Minimize wasted time

- Deliver data **no later** than needed

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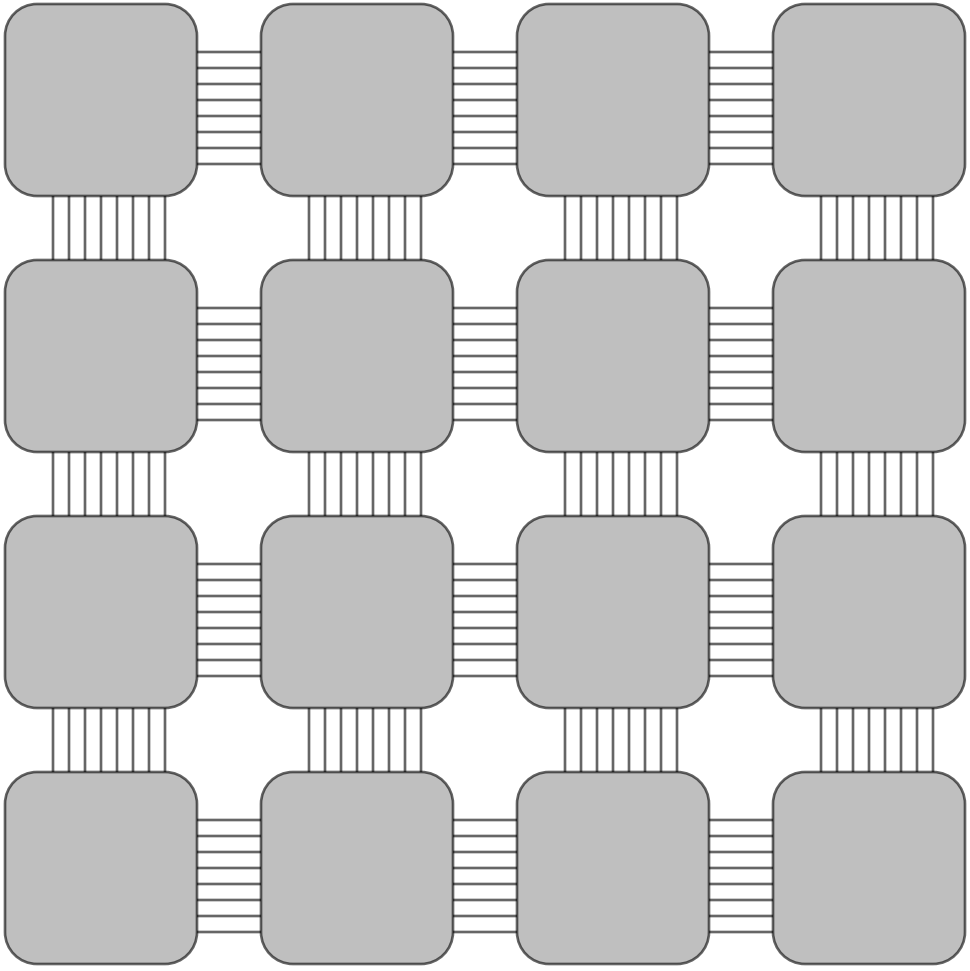

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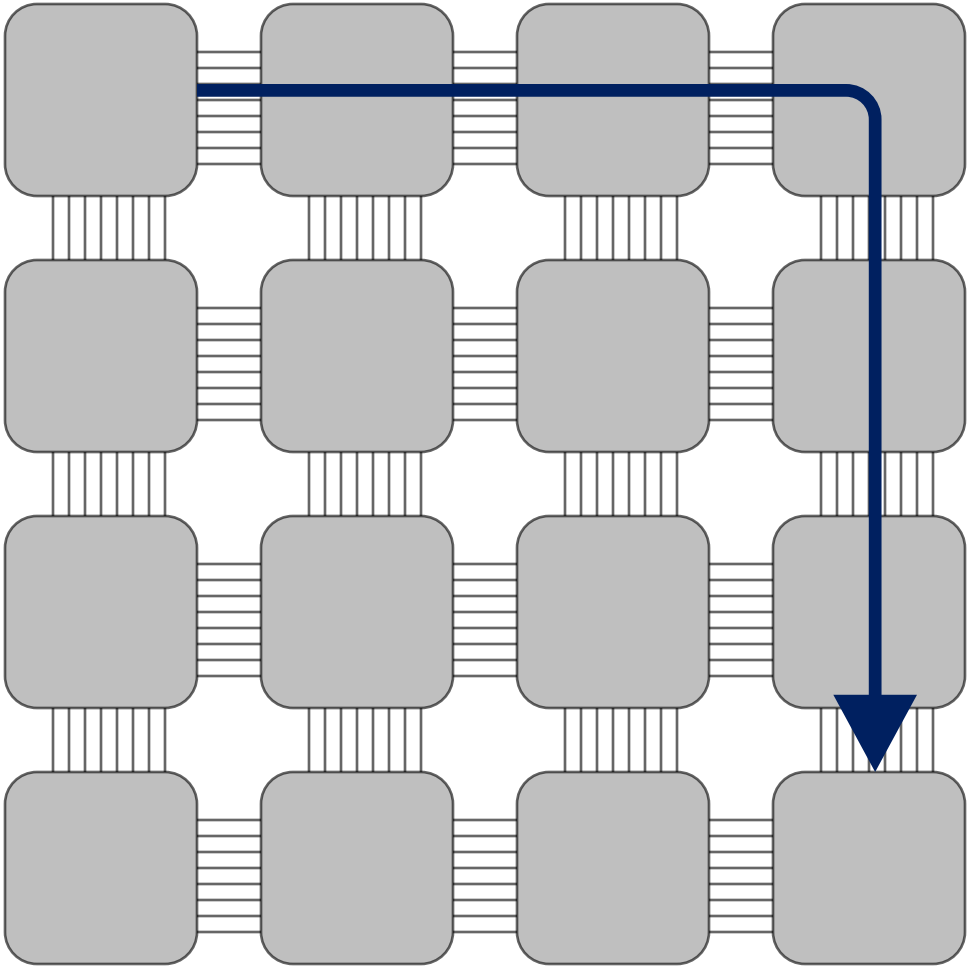

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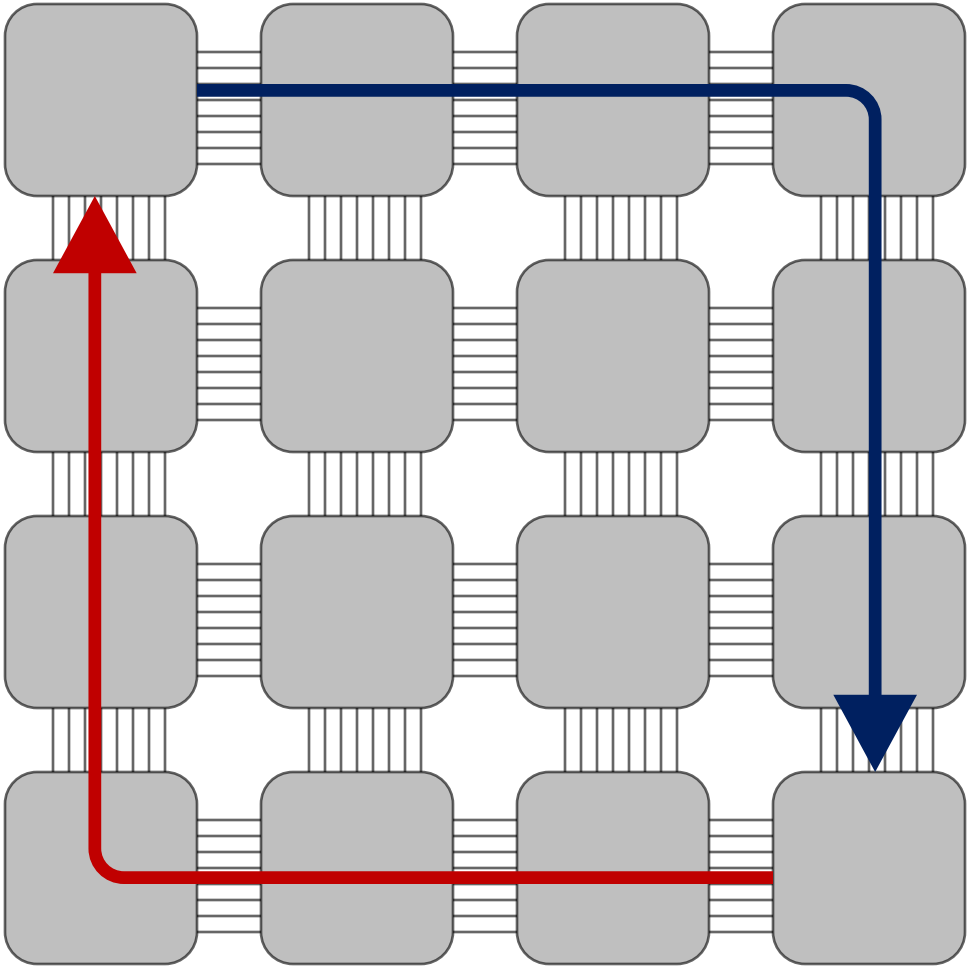

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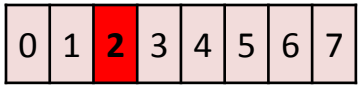

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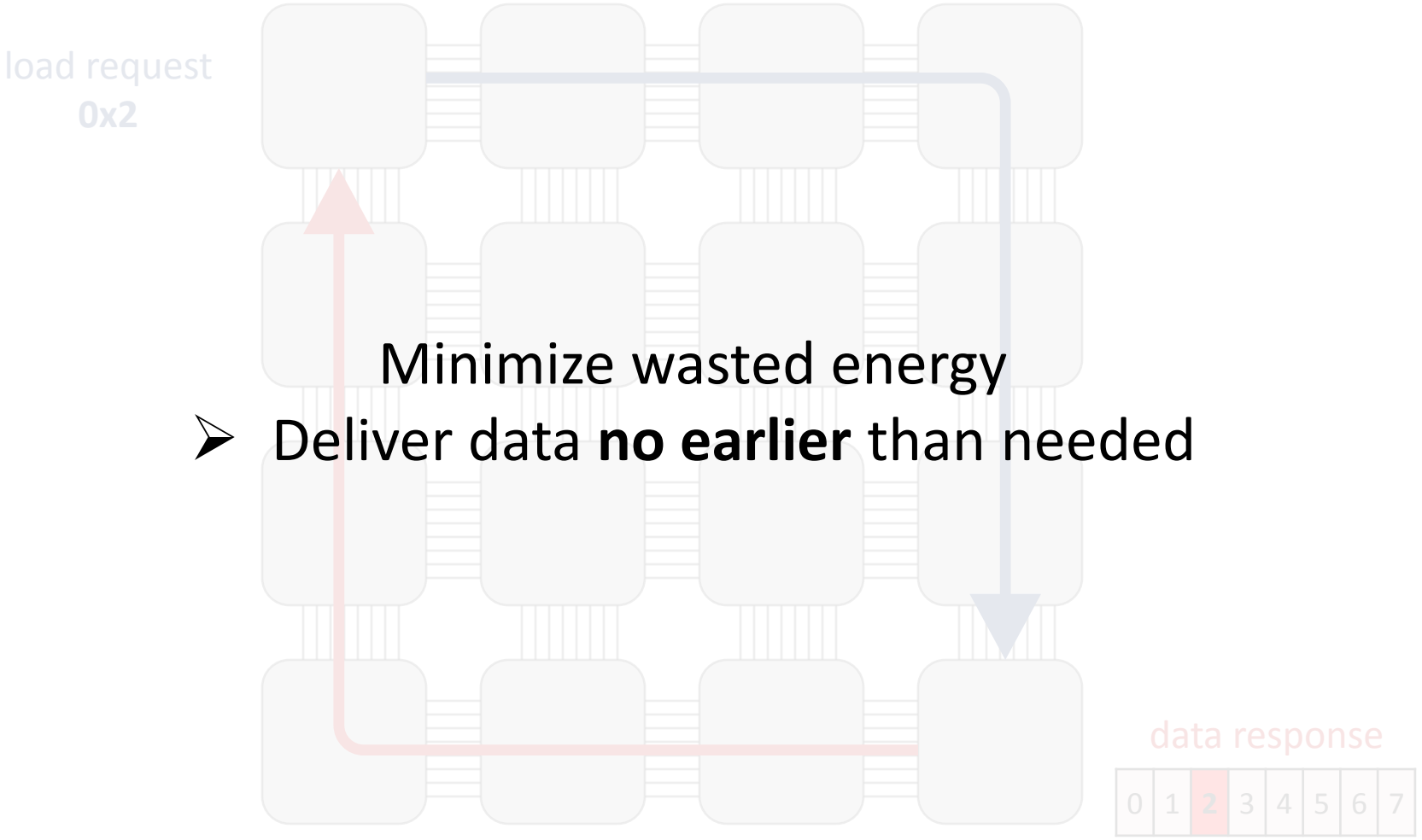

Minimize wasted energy

- Deliver data **no earlier** than needed

Network-On-Chip Efficiency

Why store data in blocks of multiple words?

- Exploit spatial locality in applications
- Avoid large tag arrays in caches
- Improve row buffer utilization in DRAM

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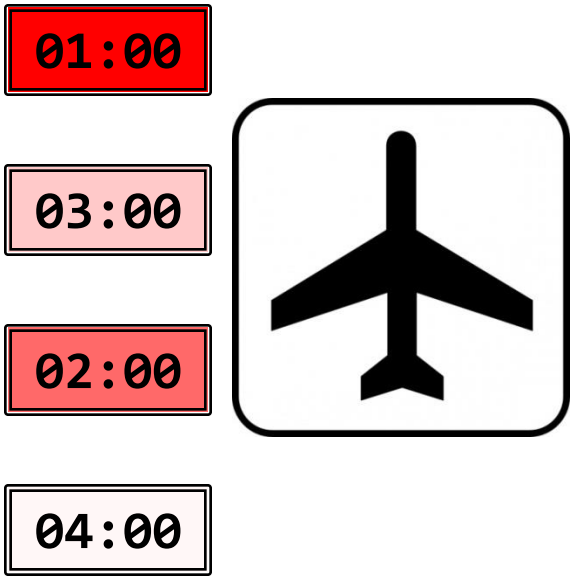
Store data at a coarse granularity, but move data at a fine granularity.

Network-On-Chip Efficiency



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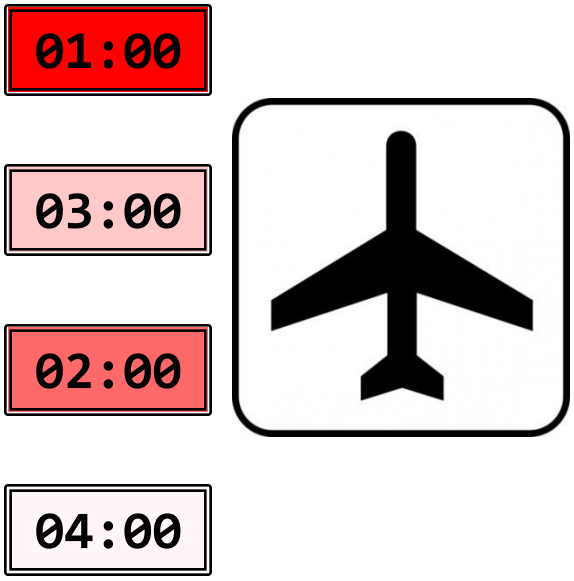

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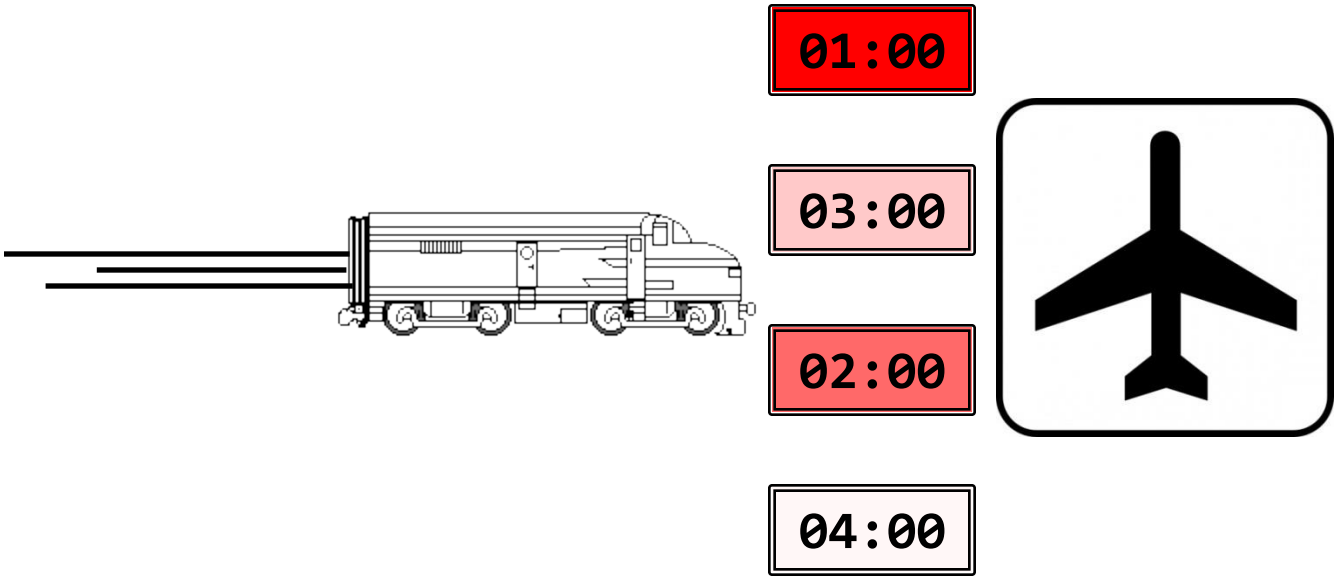
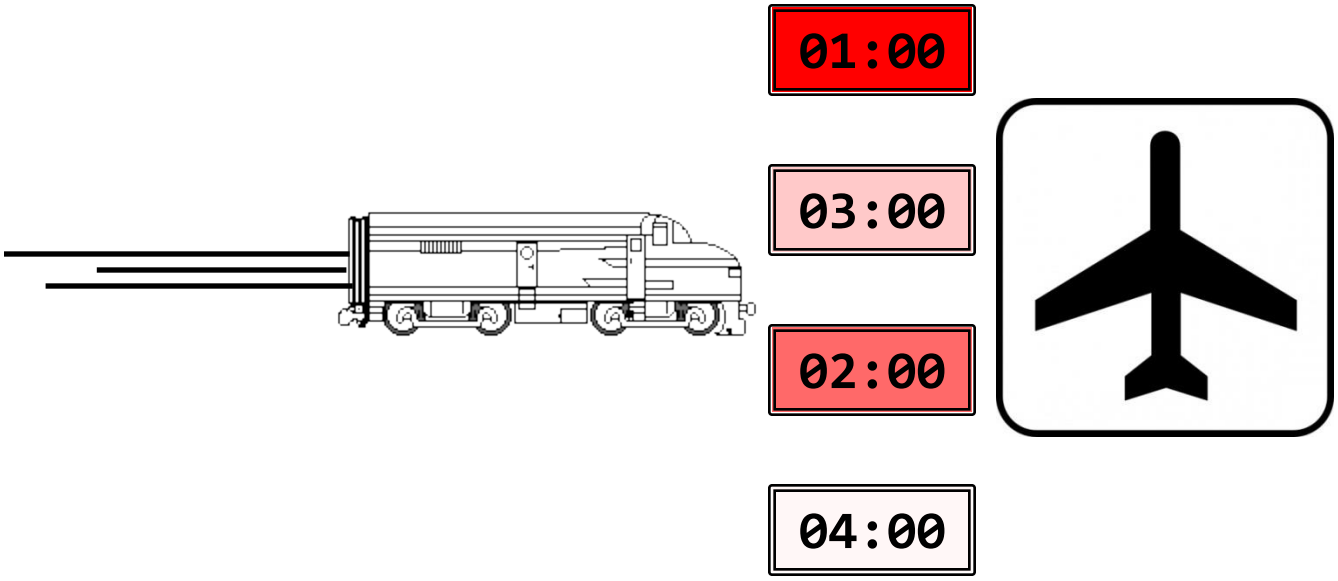


Network-On-Chip Efficiency

Arrive **no later** than needed. But expensive.
Wasted money since some arrive too early.



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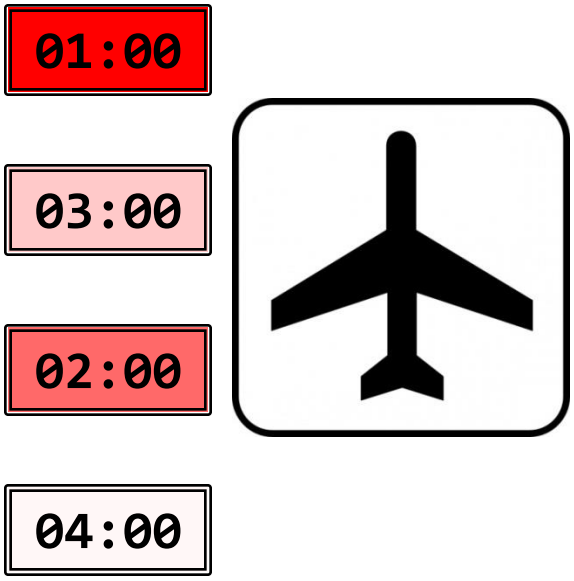

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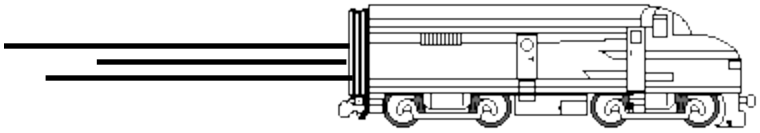

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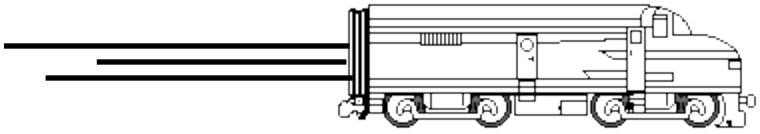

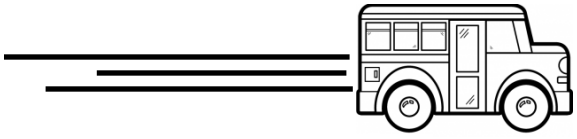

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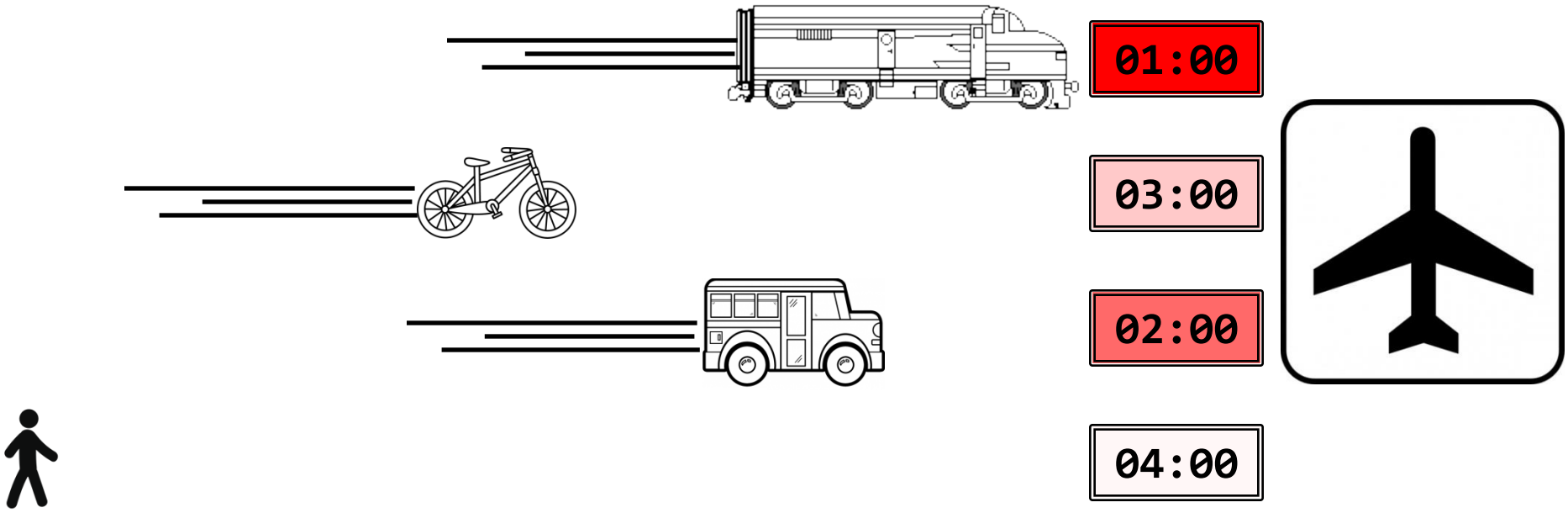

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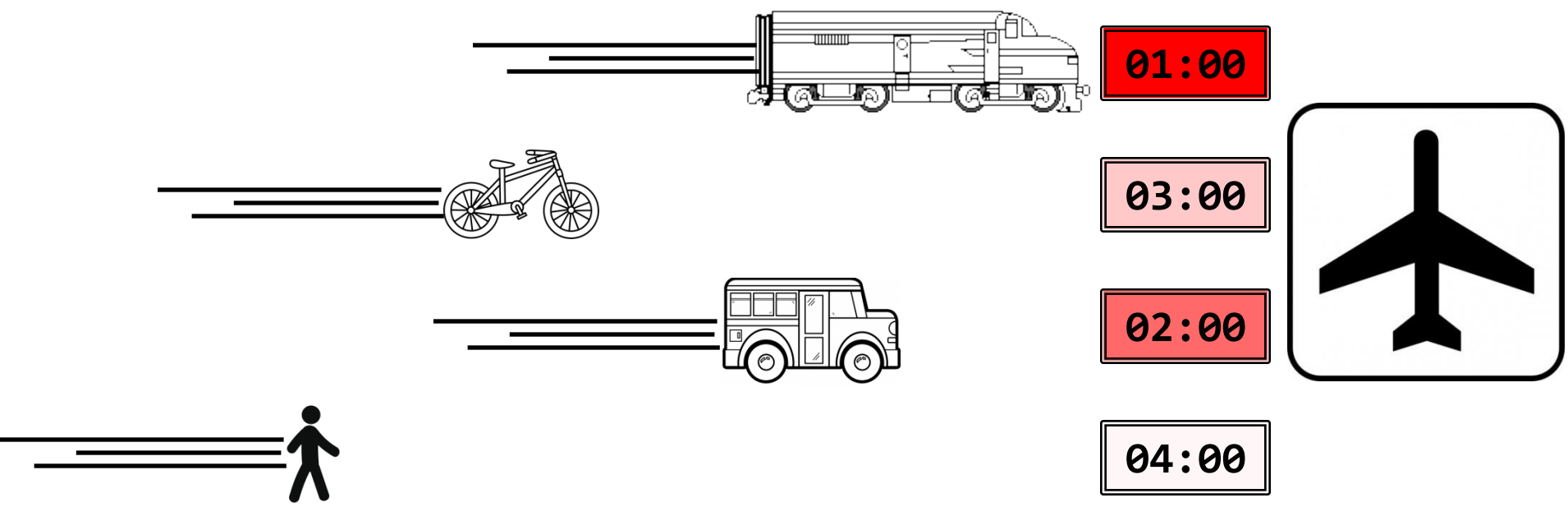
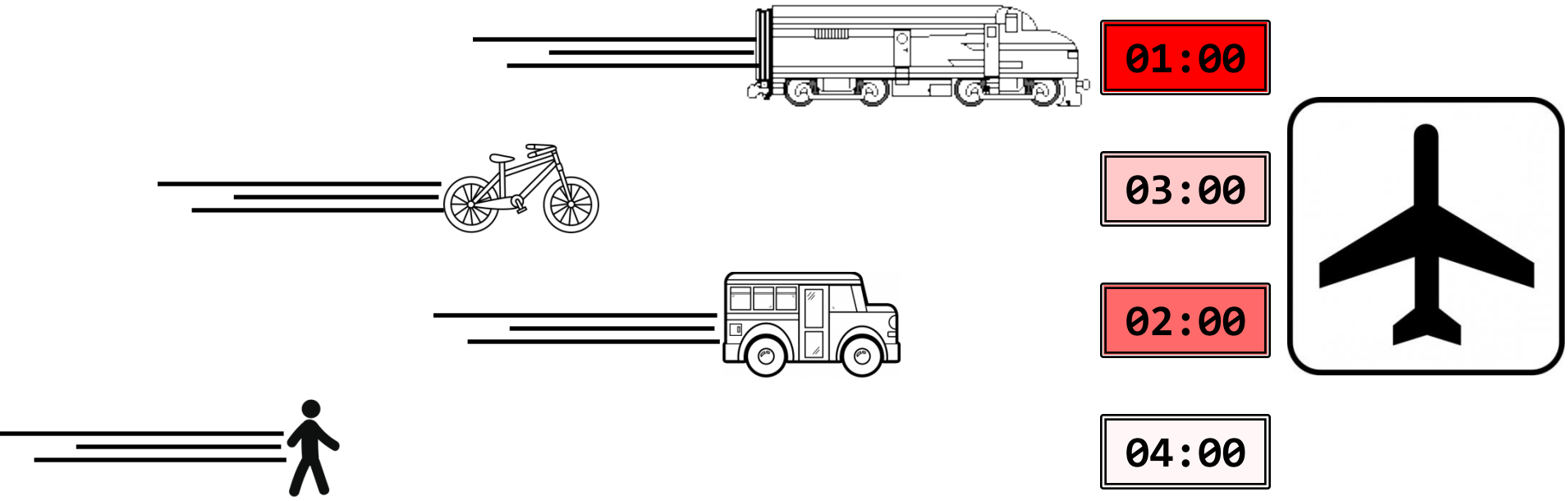


Network-On-Chip Efficiency

Spend just enough money to arrive
both no later and **no earlier** than needed.



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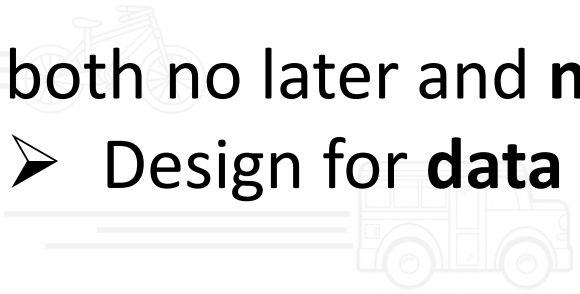

Deliver data both no later and **no earlier** than needed

- Design for **data criticality**

Outline

Defining Criticality

- Data Criticality
- Data Liveness

Measuring Criticality

- Energy Wasted

Addressing Criticality

- NoCNoC

Data Criticality

Data Criticality is the promptness with which an application uses a data word after fetching it from memory.

Critical: used immediately after being fetched.

Non-critical: used some time later after being fetched.

Data Criticality – blackscholes

```
for (i++) {
        ... = BlkSchlsEqEuroNoDiv(sptprice[i]);
}
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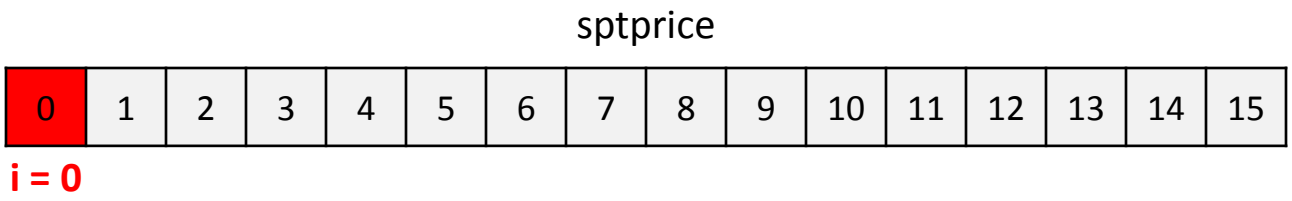

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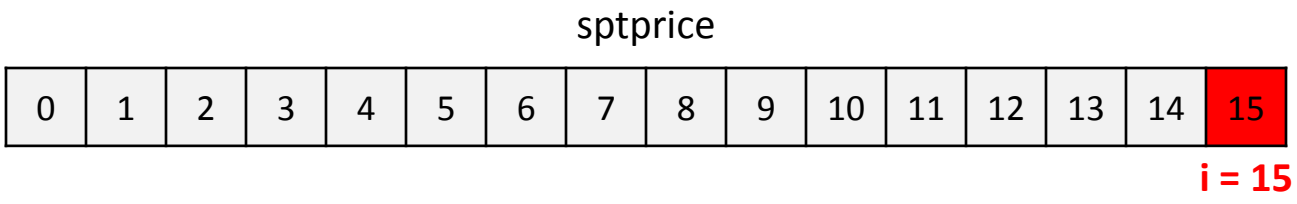

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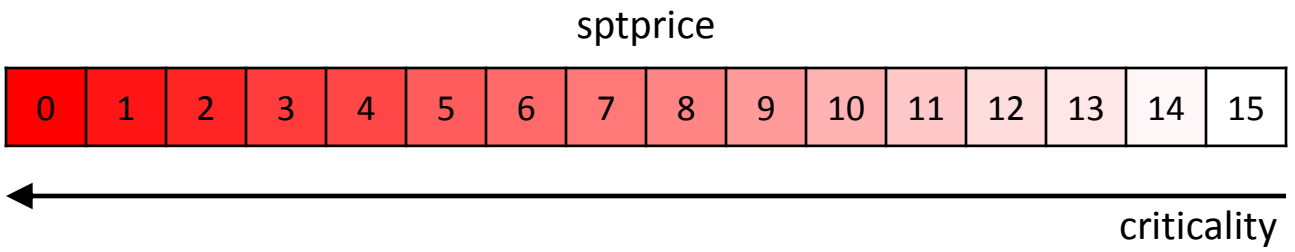


Data Criticality – fluidanimate

```
for (iparNeigh++) {
      if (borderNeigh) {
            pthread_mutex_lock();
            neigh->a[iparNeigh] -= ...;
            pthread_mutex_unlock();
      } else {
            neigh->a[iparNeigh] -= ...;
      }
}
```

Data Criticality

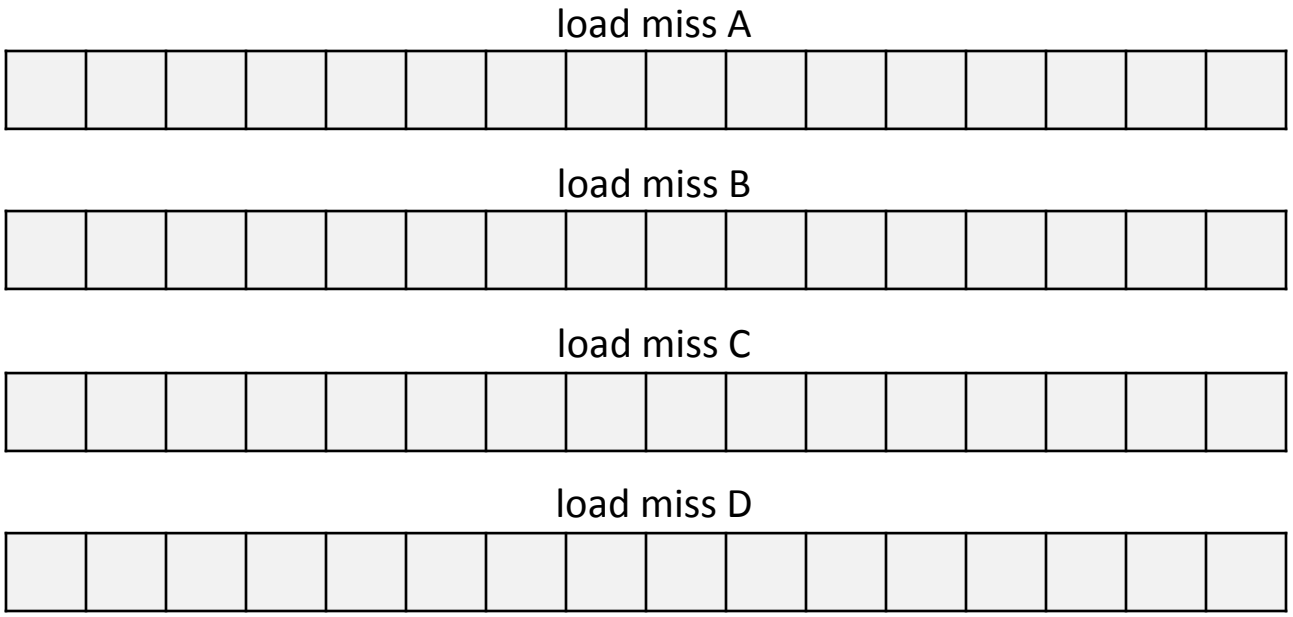
Data criticality is an inherent consequence of spatial locality and is exhibited by most (if not all) real-world applications.

Examples of non-criticality:

- Long-running code between accesses
- Interference due to thread synchronization
- Dependences from other cache misses
- Preemption by the operating system

Data Criticality vs. Instruction Criticality

Instruction (or packet) criticality



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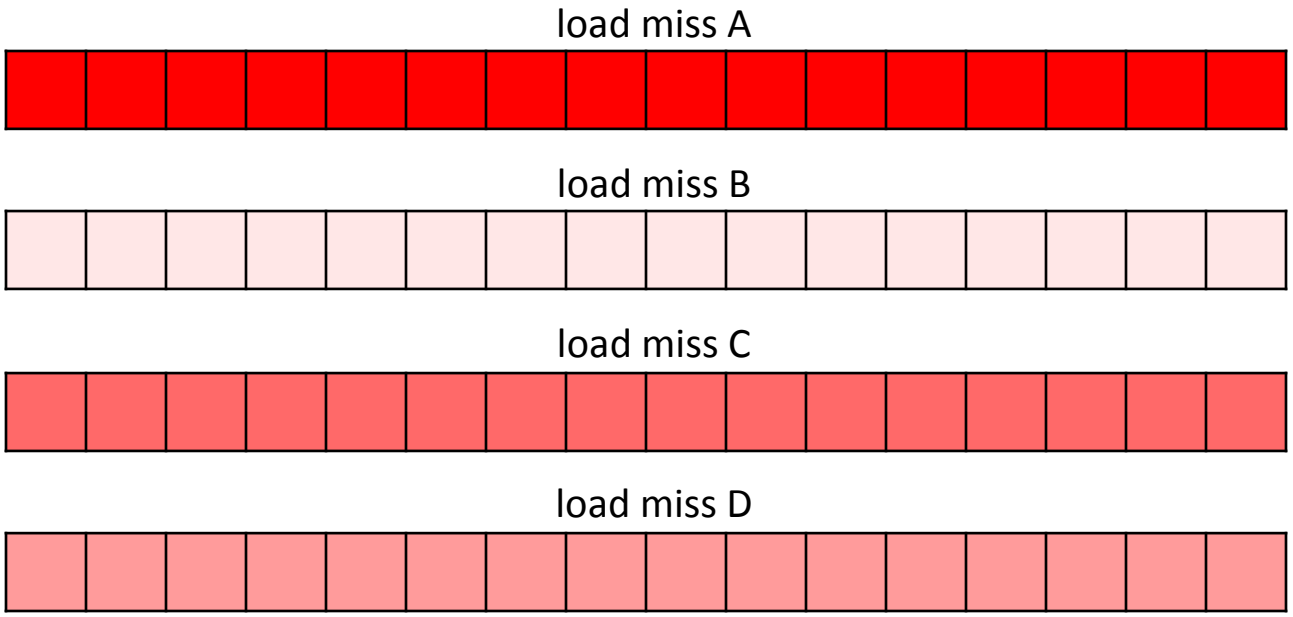

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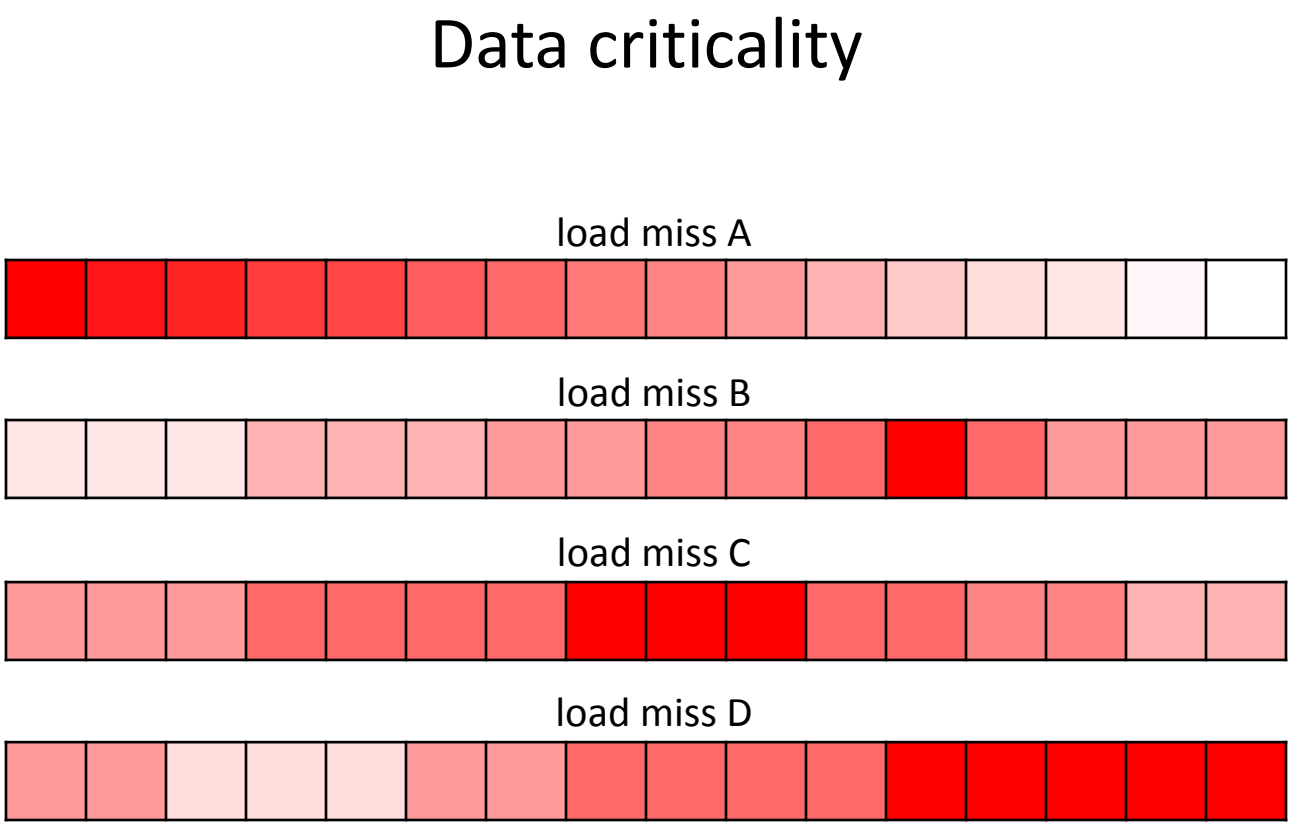

Data Liveness

Data Liveness describes whether or not an application uses a data word at all after fetching it from memory.

Live-on-arrival (live): used at least once during its cache lifetime.

Dead-on-arrival (dead): never used during its cache lifetime.

Data Liveness – fluidanimate

```
for (iz++)
for (iy++)
for (ix++)
for (j++) {
      if (border(ix)) ... = cell->v[j].x;
      if (border(iy)) ... = cell->v[j].y;
      if (border(iz)) ... = cell->v[j].z;
}
```

Data Liveness – fluidanimate

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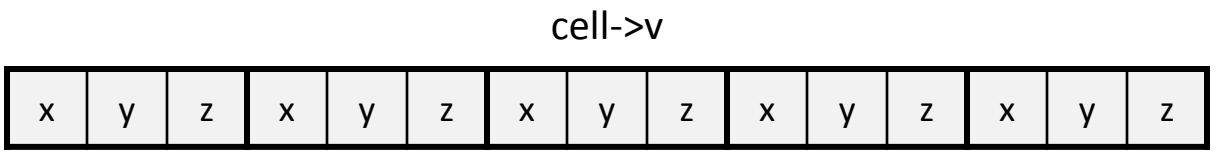

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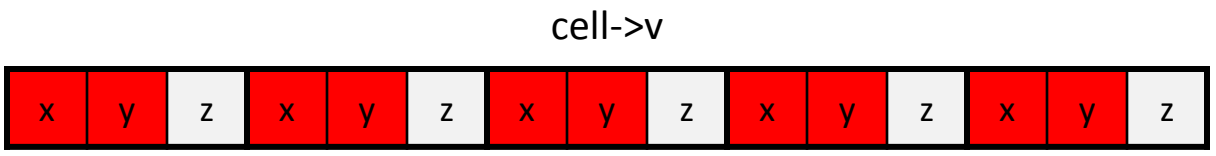

Data Liveness

Data liveness measures the degree of spatial locality in an application.

Examples of dead words:

- Unused members of structs
- Irregular or random access patterns
- Heap fragmentation
- Padding between data elements
- Early evictions due to invalidations, cache pressure or poor replacement policies

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- Data Liveness

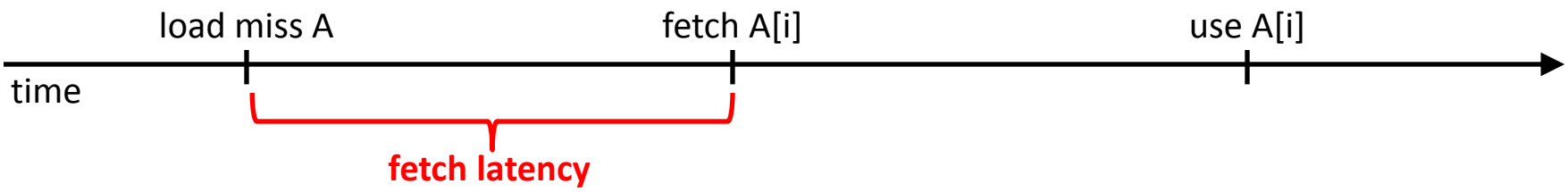
Measuring Criticality

- **Energy Wasted**

Addressing Criticality

- NoCNoC

Measuring Criticality



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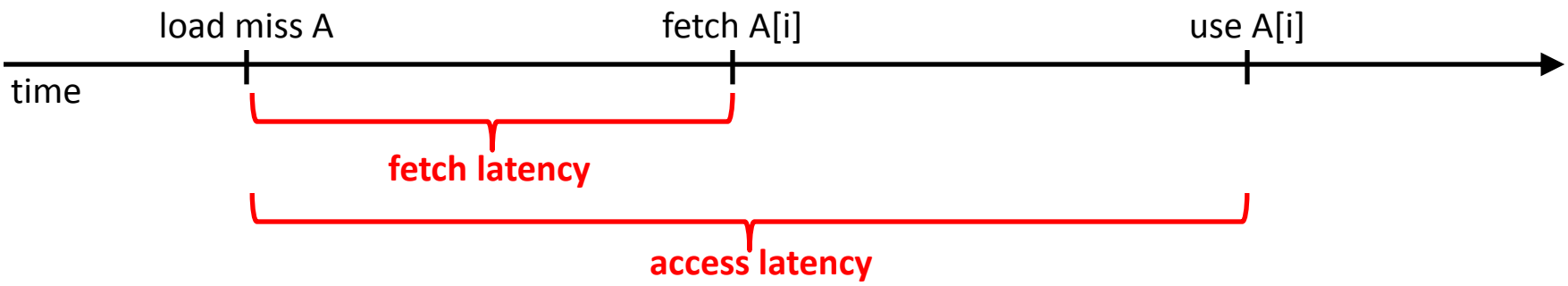

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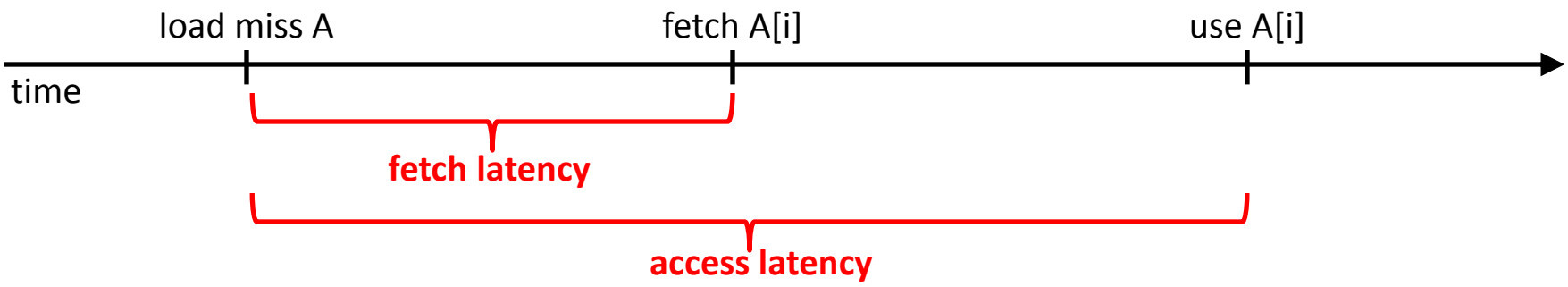


$$non\text{–}criticality = \frac{access\ latency}{fetch\ latency}$$

1x for critical words, >1x for non-critical words

Measuring Criticality

Full-system simulations:

- FeS2, BookSim, DSENT
- 16 2.0 GHz OoO cores
- 64 kB private L1 per core, 16-word cache blocks
- 16 MB shared distributed L2

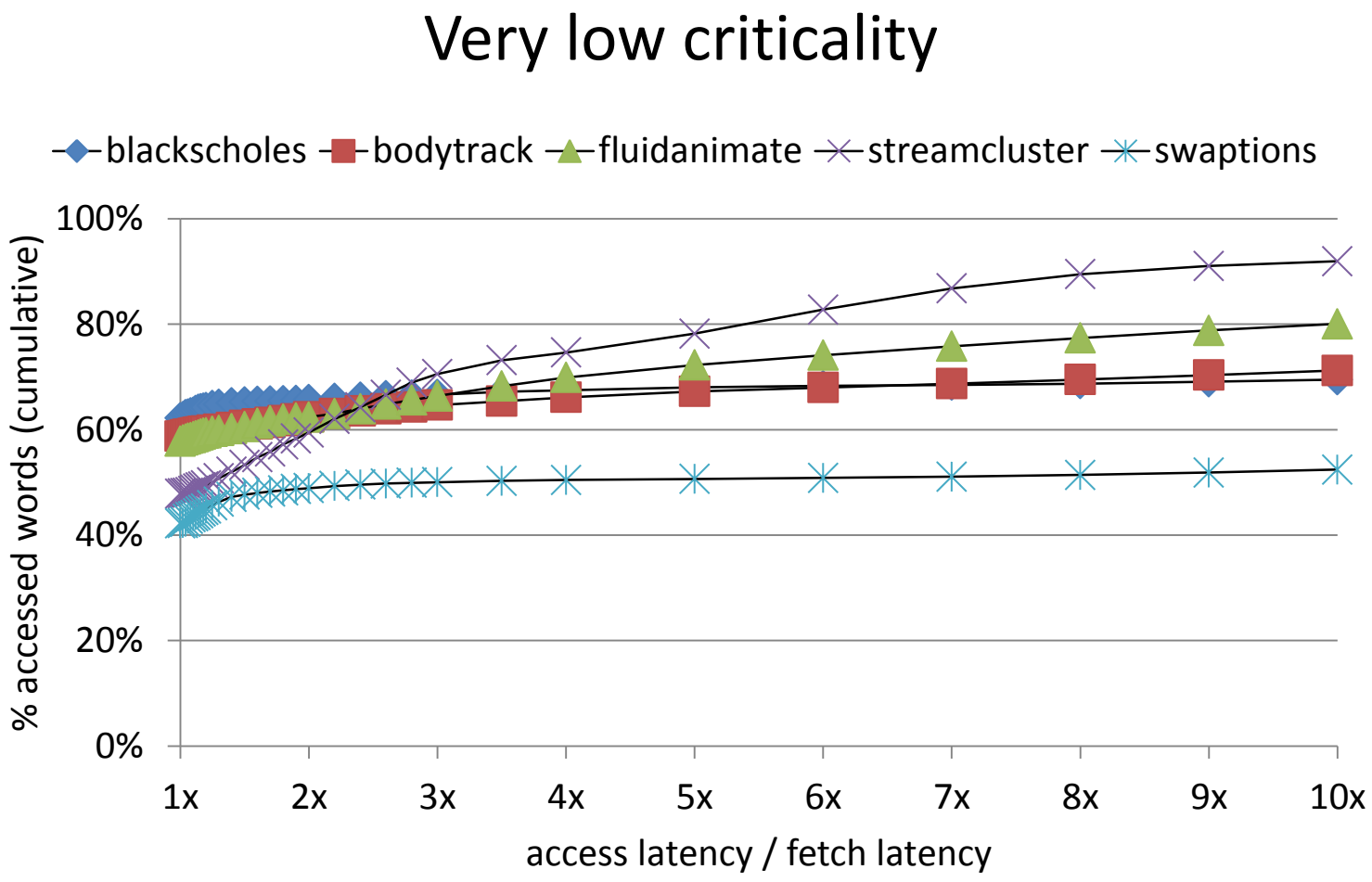
Baseline NoC configuration:

- 4 x 4 mesh, 2.0 GHz, 128-bit channels
- X-Y routing, 3-stage router pipeline, 6 4-flit VCs per port

Applications:

- PARSEC and SPLASH-2

Measuring Criticality



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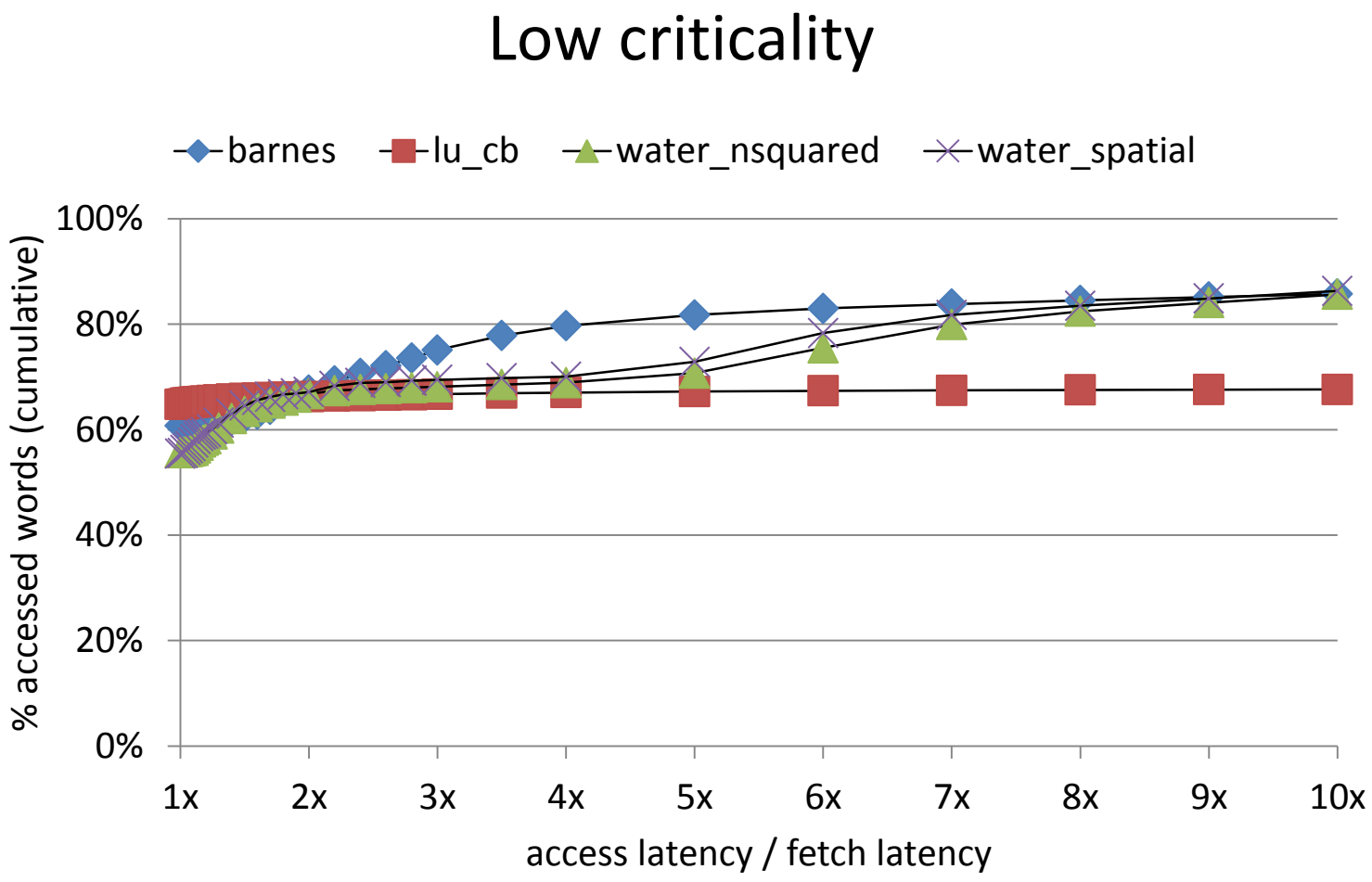

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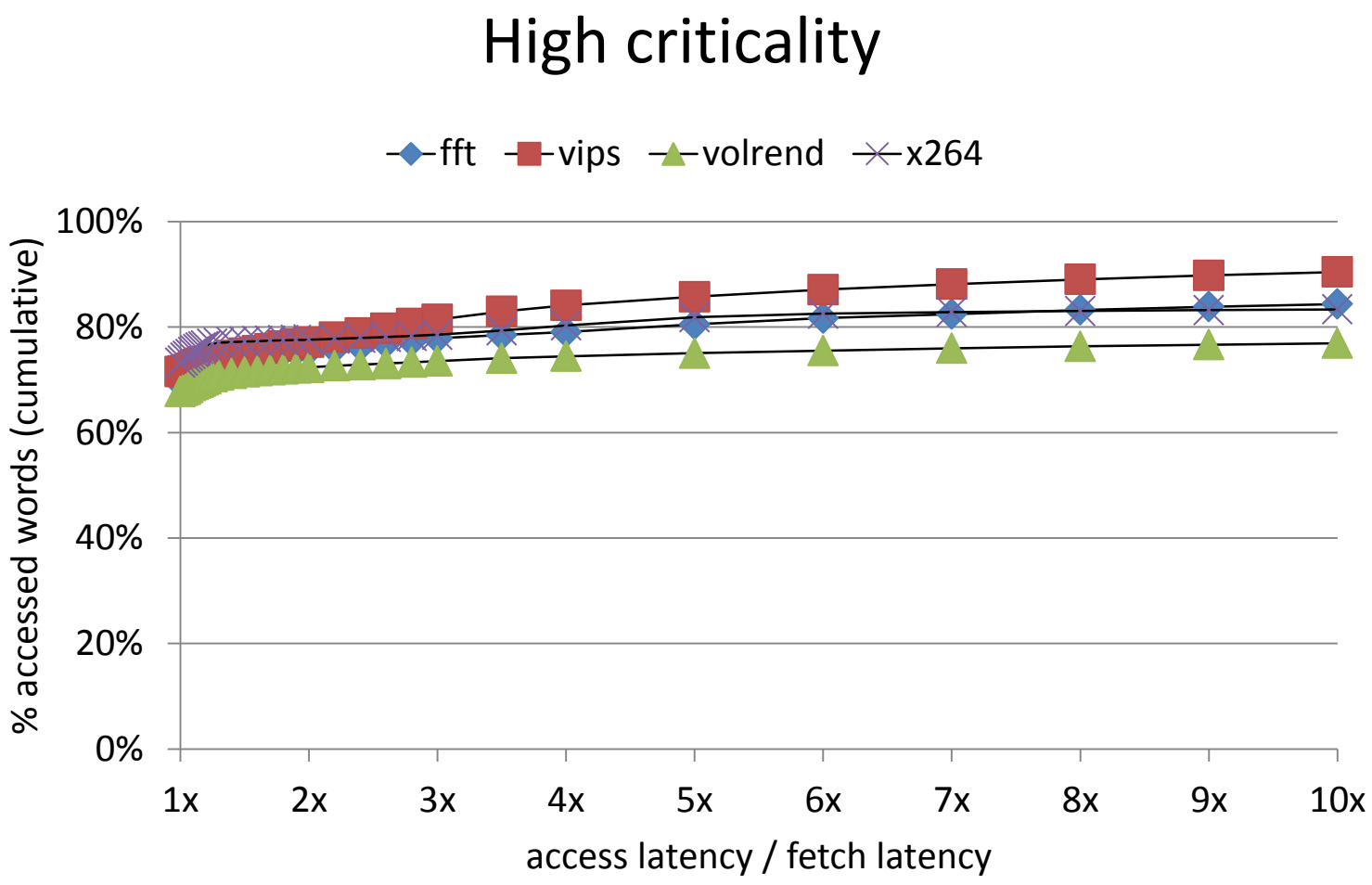

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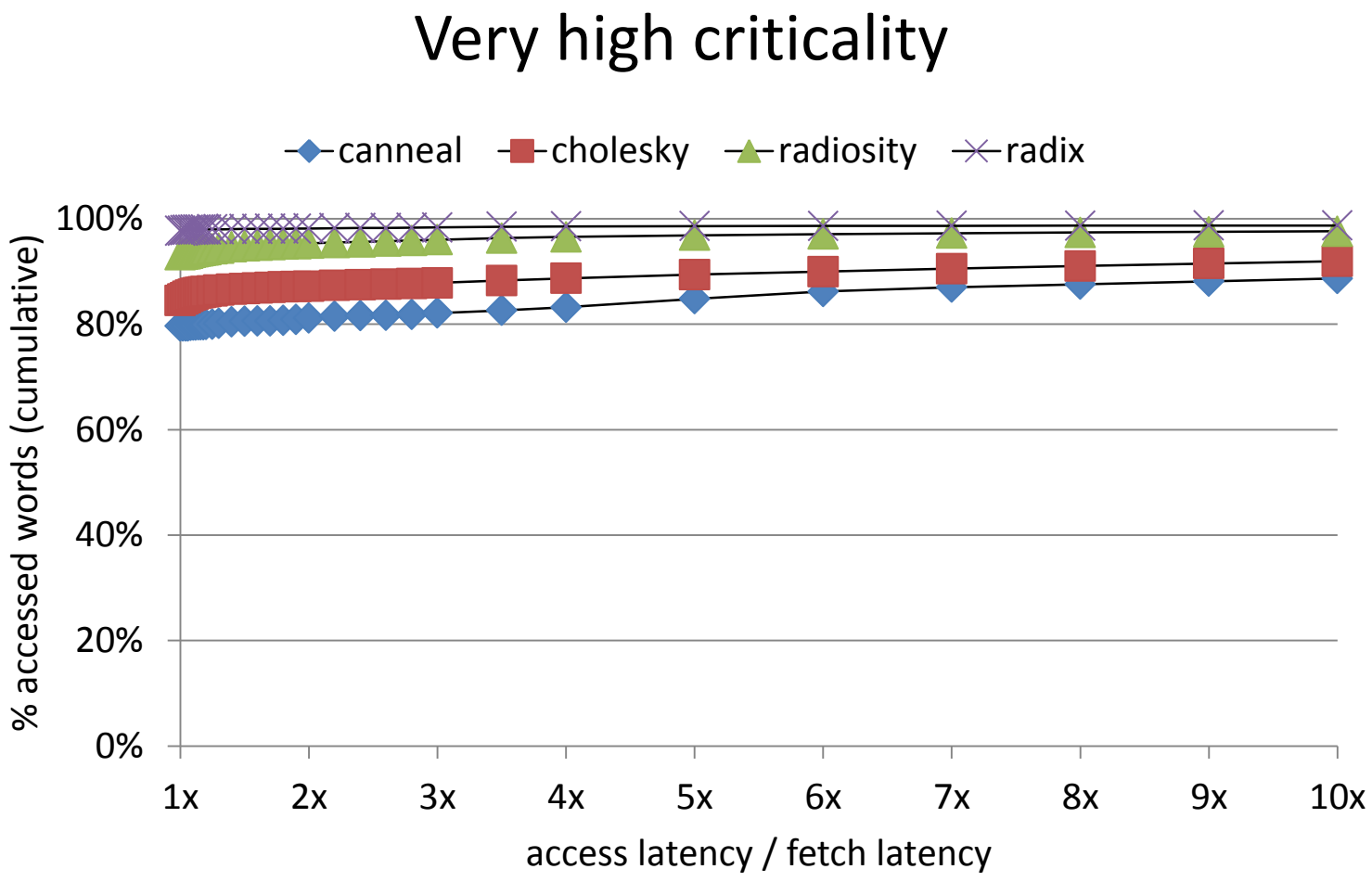

Measuring Criticality – Energy Wasted

Estimate energy wasted due to non-criticality

- Model an ideal NoC where for each word:

$$fetch\ latency \approx access\ latency$$

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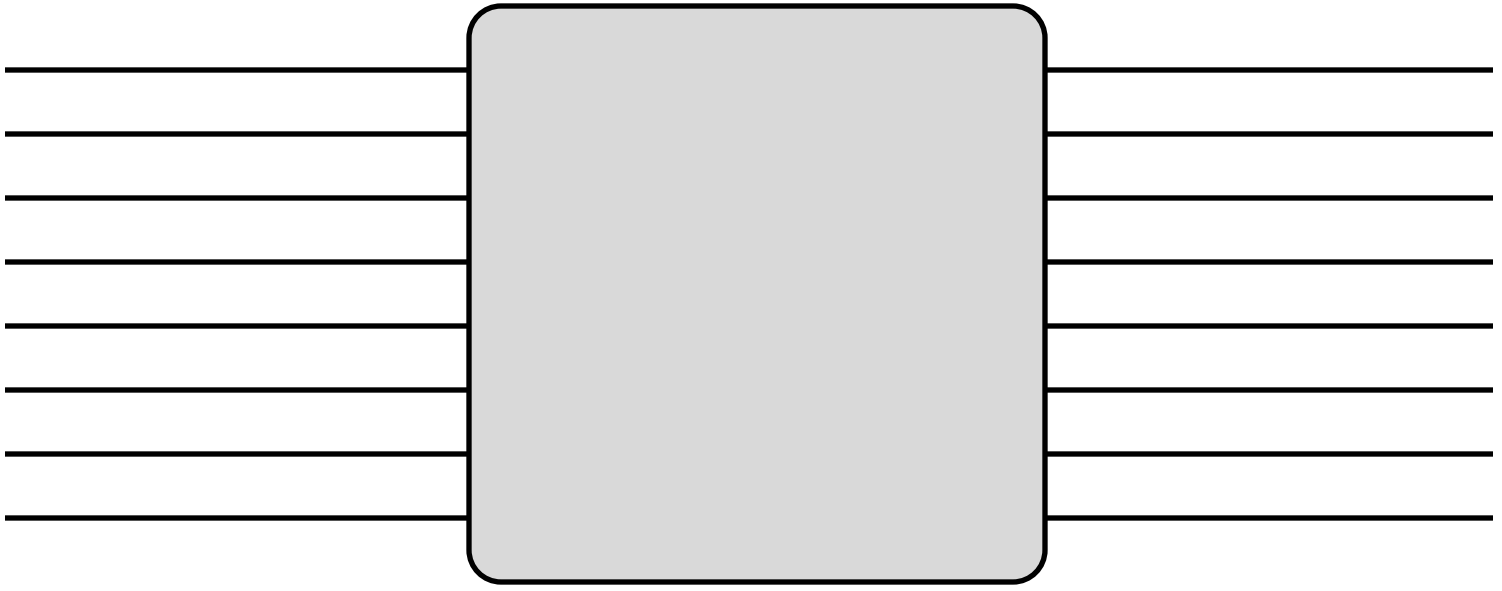

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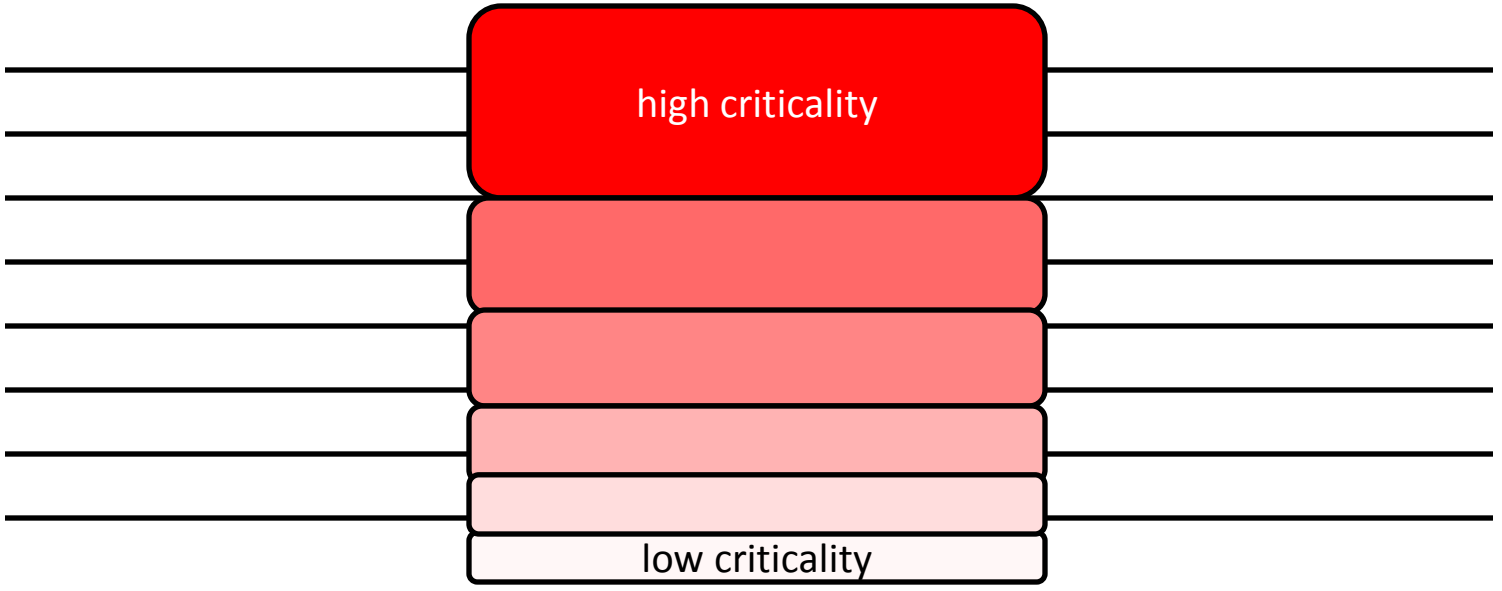
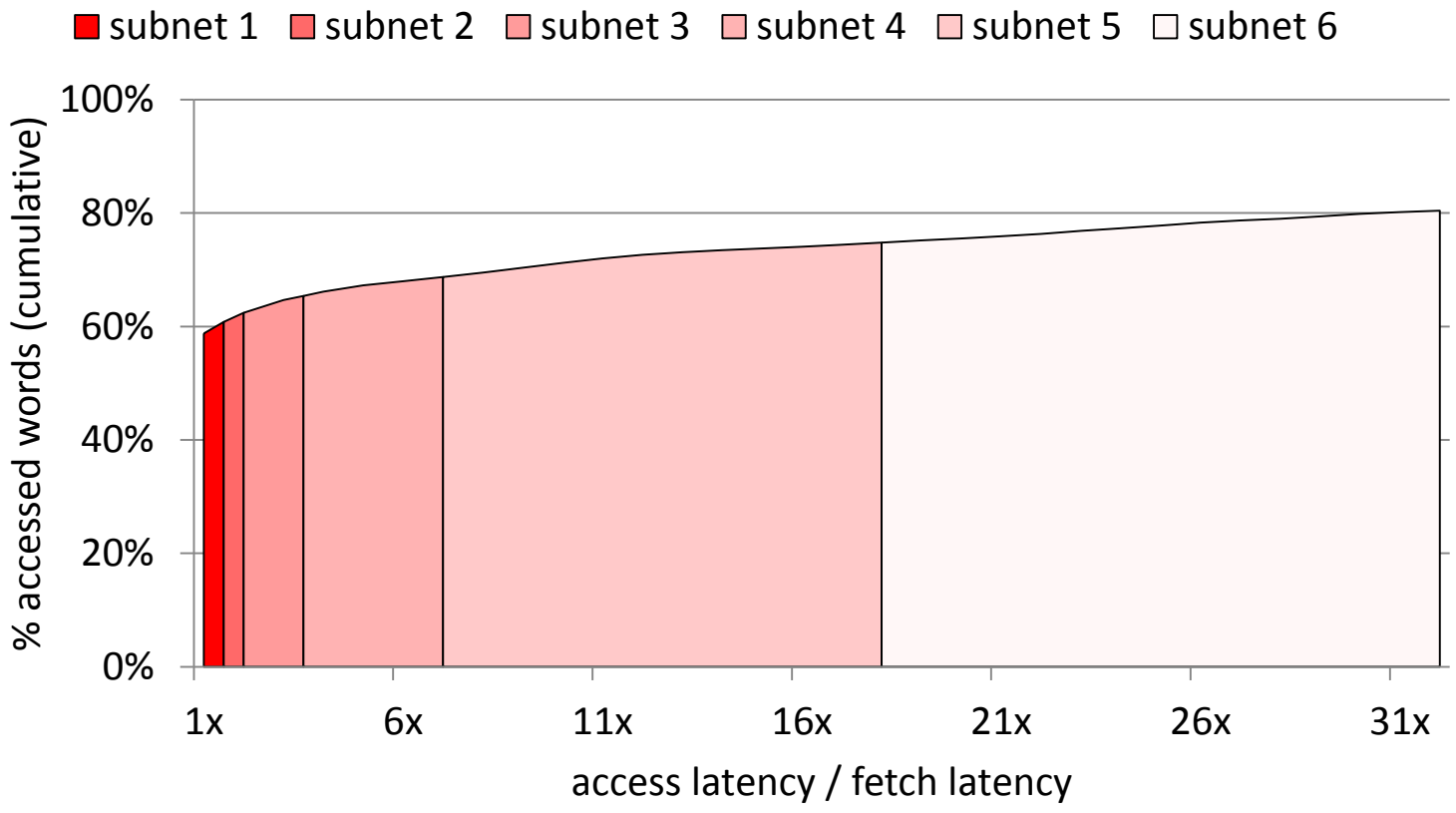


Measuring Criticality – Energy Wasted

e.g., bodytrack:



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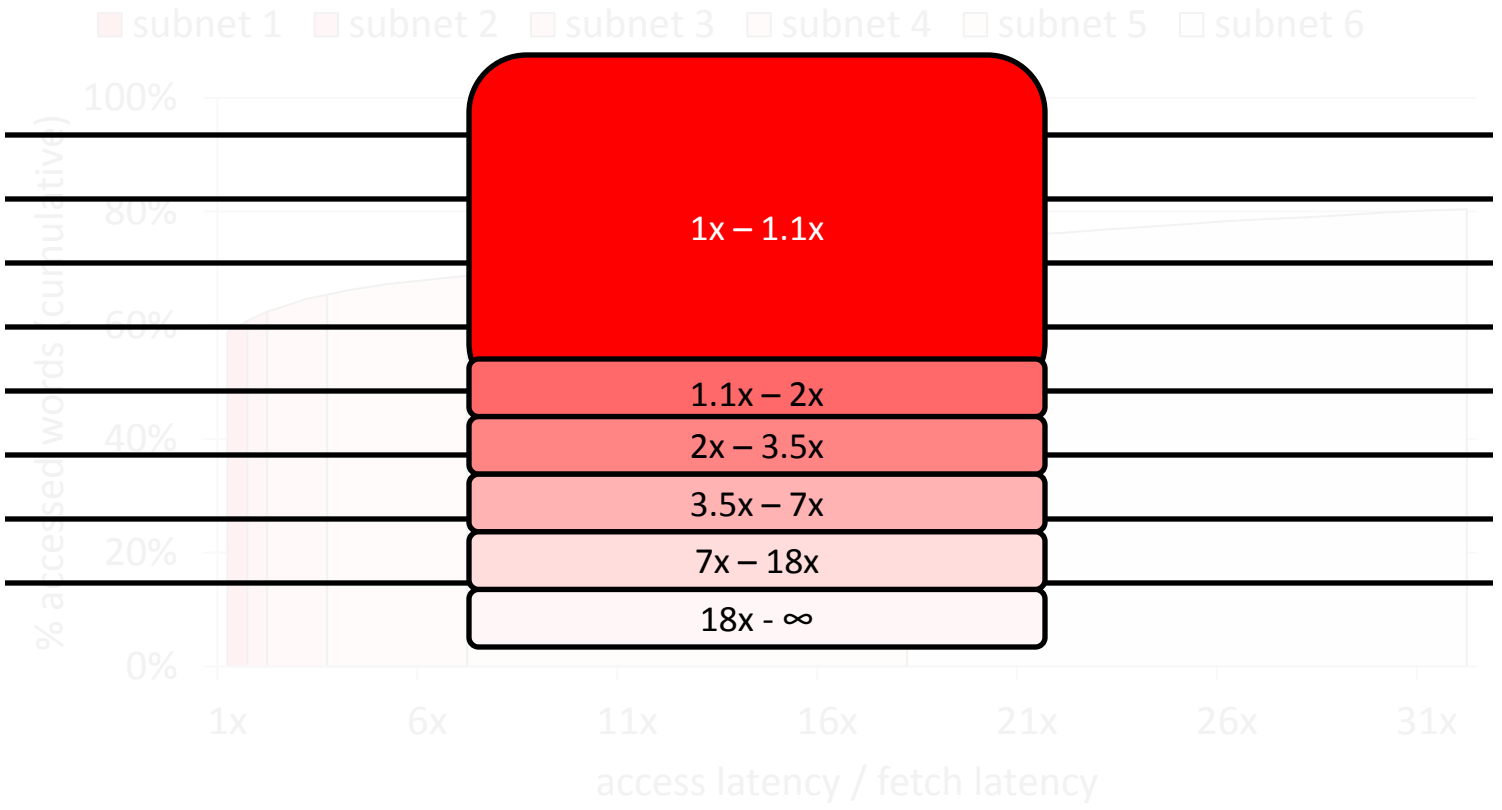

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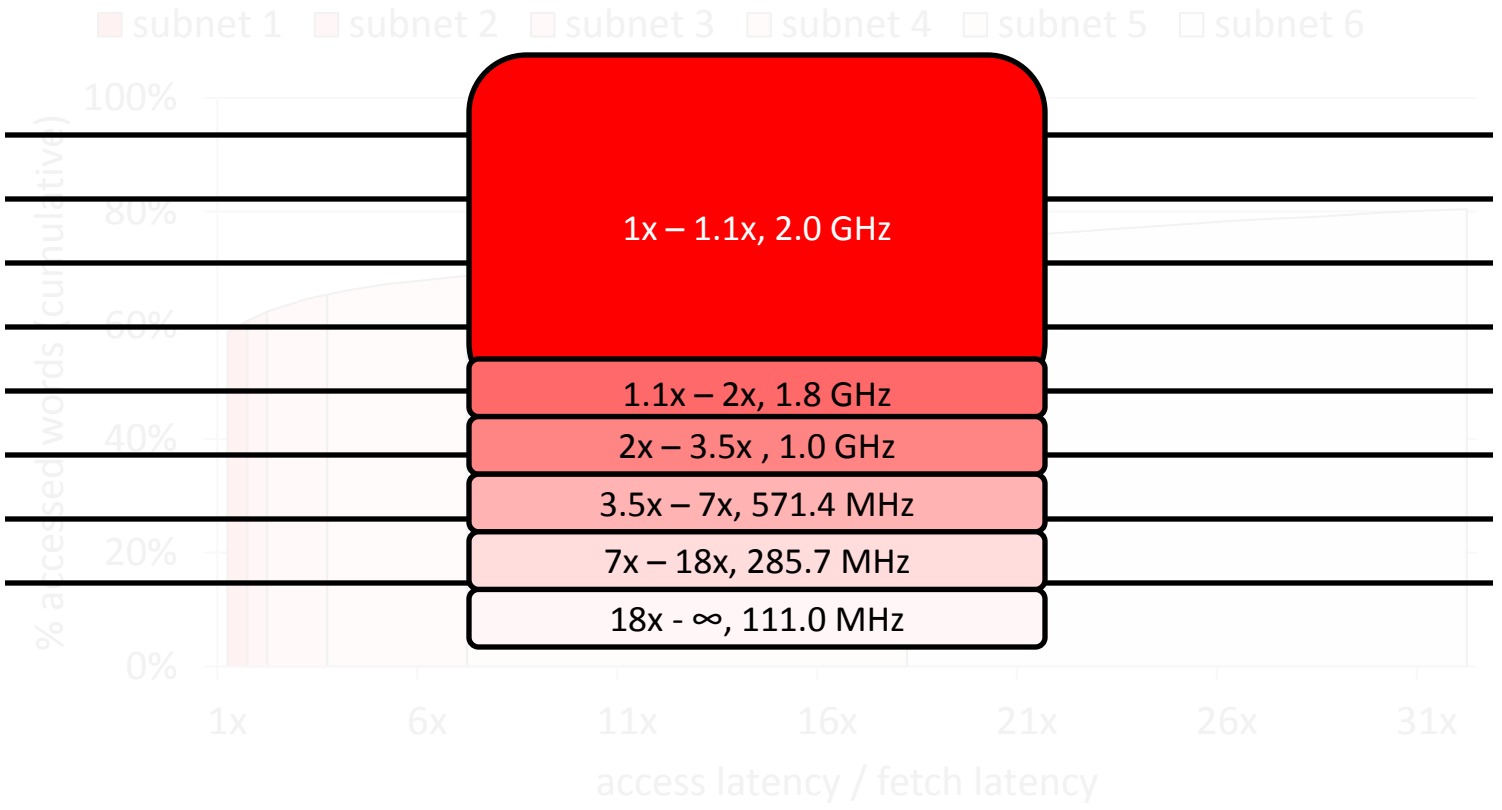

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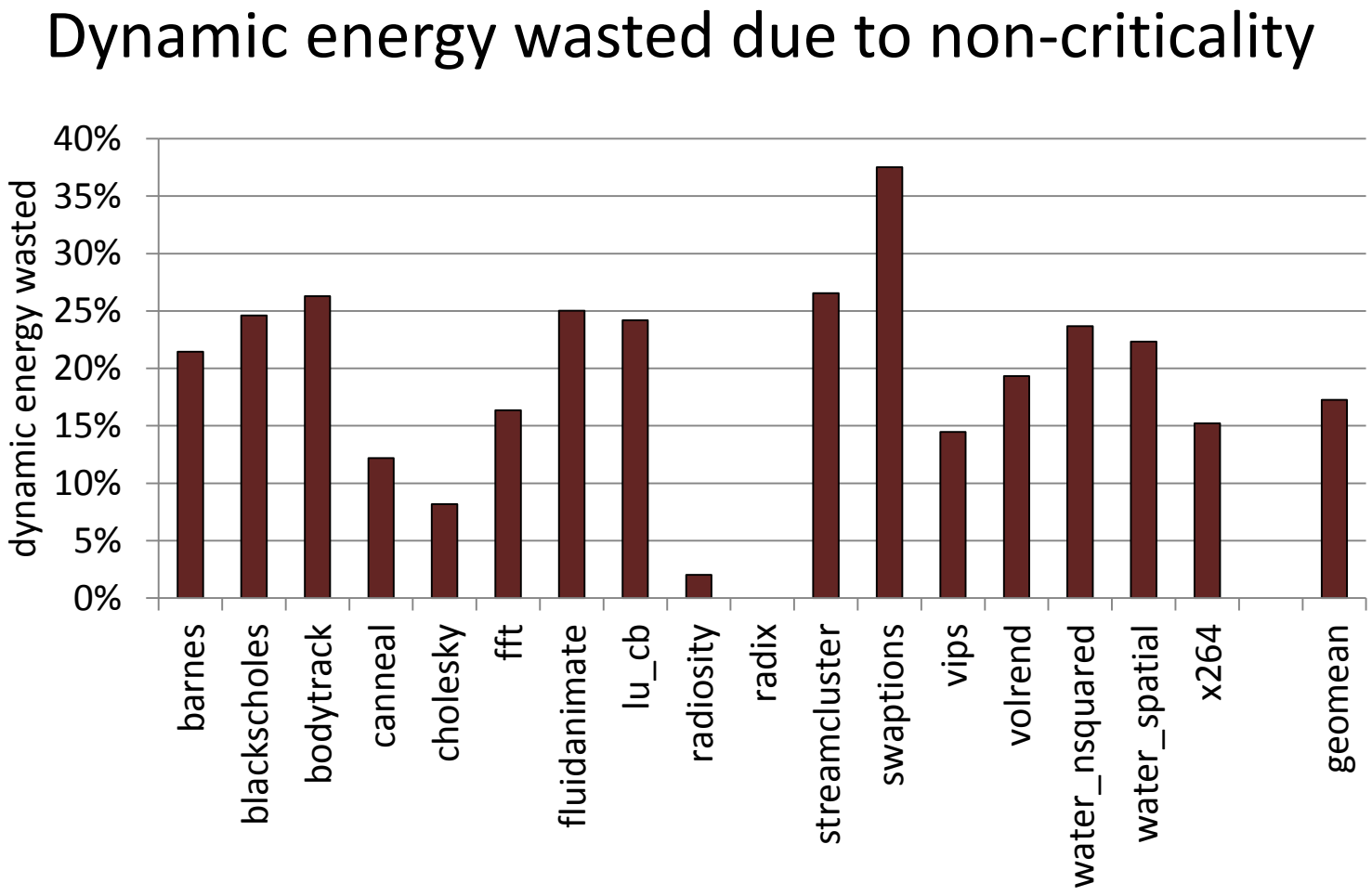

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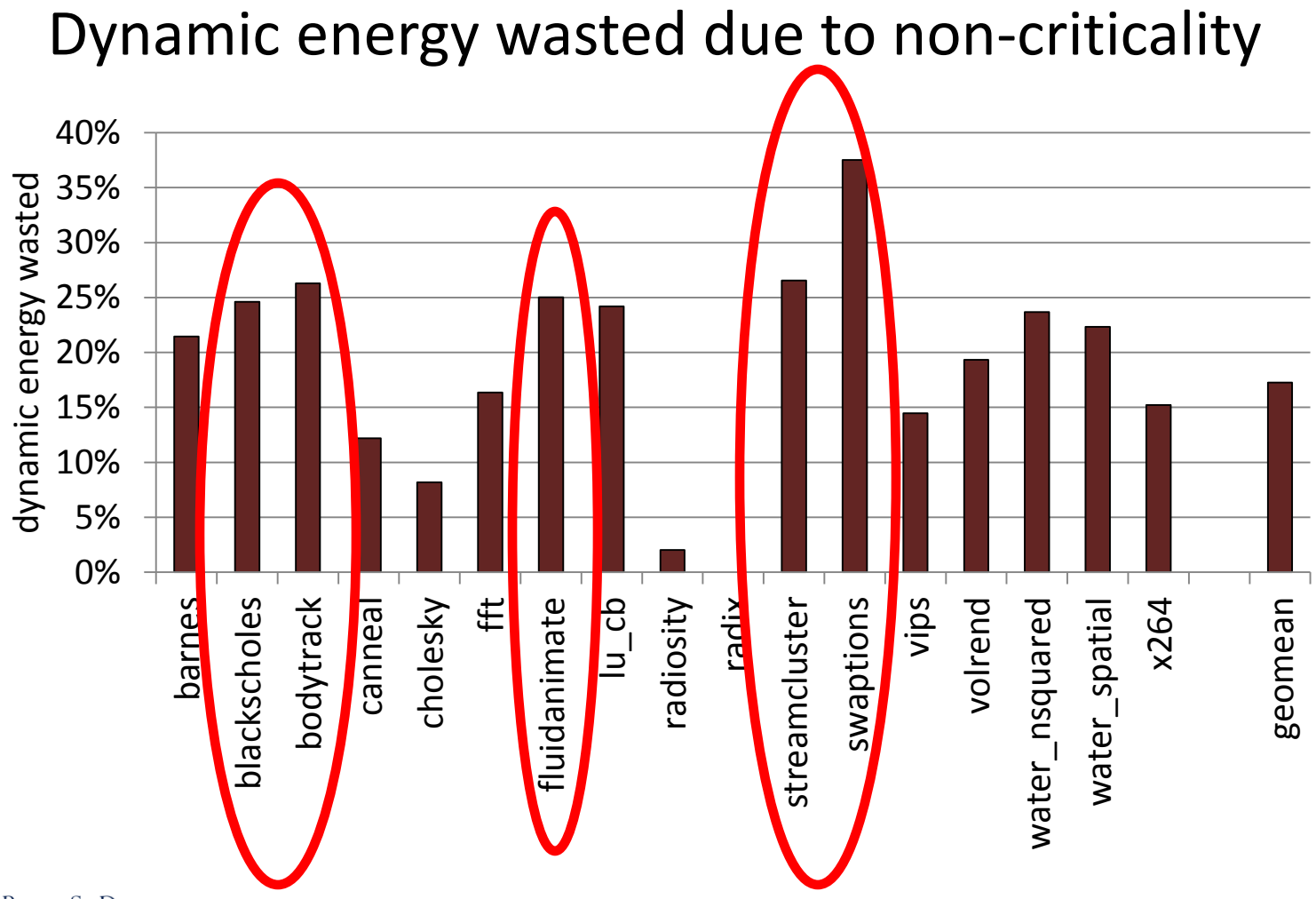

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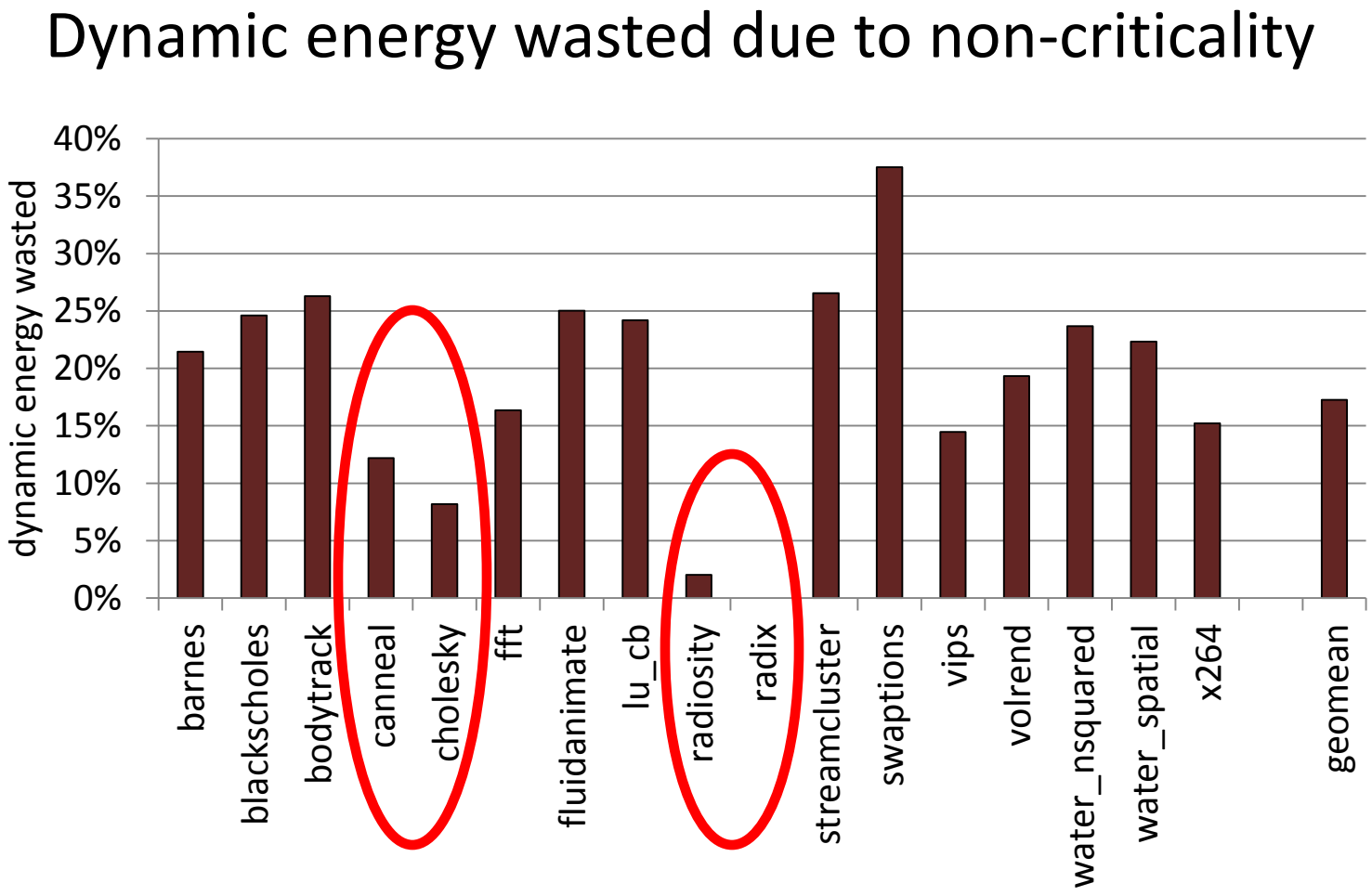

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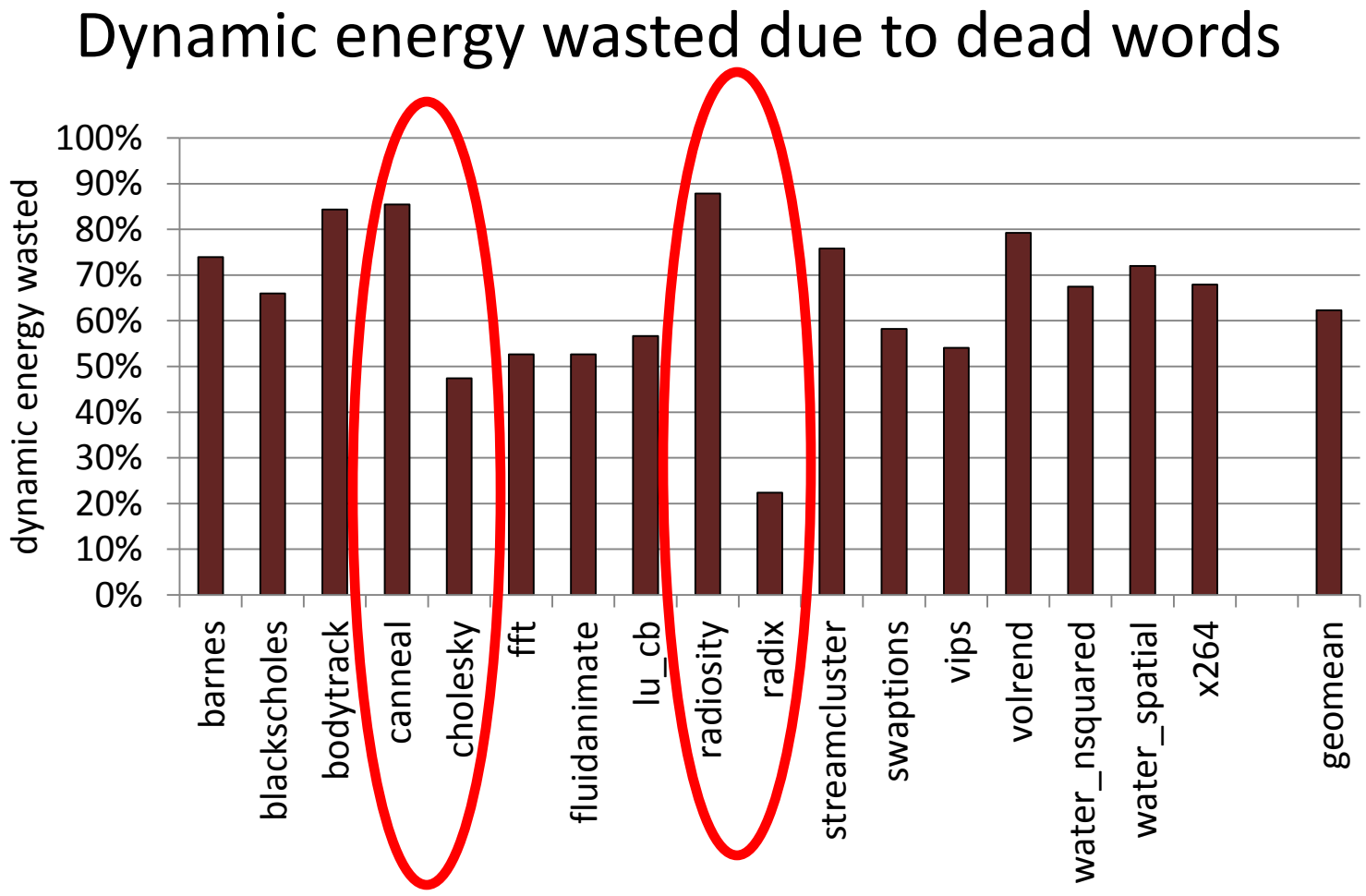
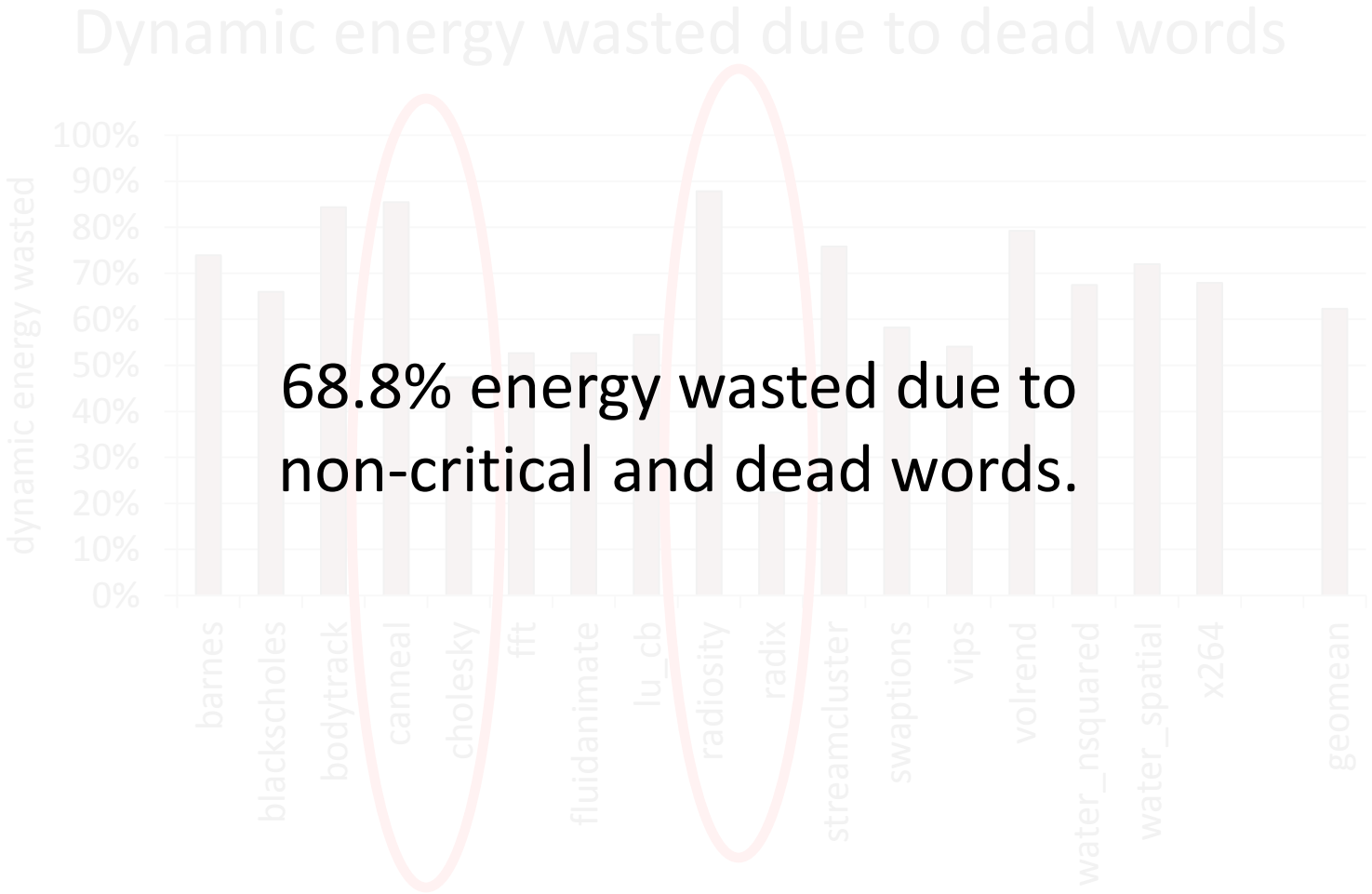


Measuring Criticality – Energy Wasted



68.8% energy wasted due to non-critical and dead words.

Outline

Defining Criticality

- Data Criticality
- Data Liveness

Measuring Criticality

- Energy Wasted

Addressing Criticality

- **NoCNoC**

Addressing Criticality

A criticality-aware NoC design needs to:

1. Predict the criticality of a word prior to fetching it.
2. Separate the fetching of words based on their criticality.
3. Reduce energy consumption in fetching low-criticality words.
4. Eliminate the fetching of dead words.

NoCNoC (Non-Critical NoC)

A proof-of-concept, criticality-aware design

NoCNoC

1. Predict the criticality of a word prior to fetching it.
   - Binary predictor: either critical or non-critical.

NoCNoC

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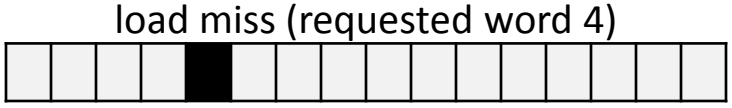

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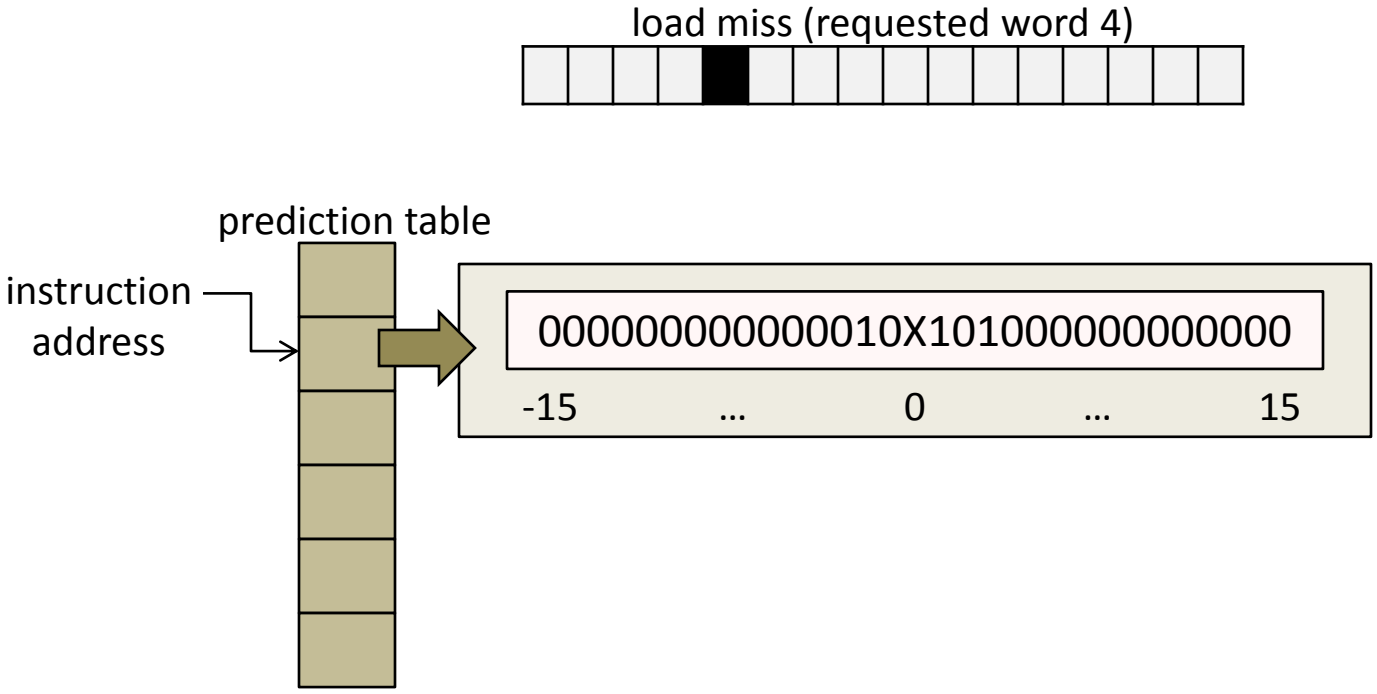

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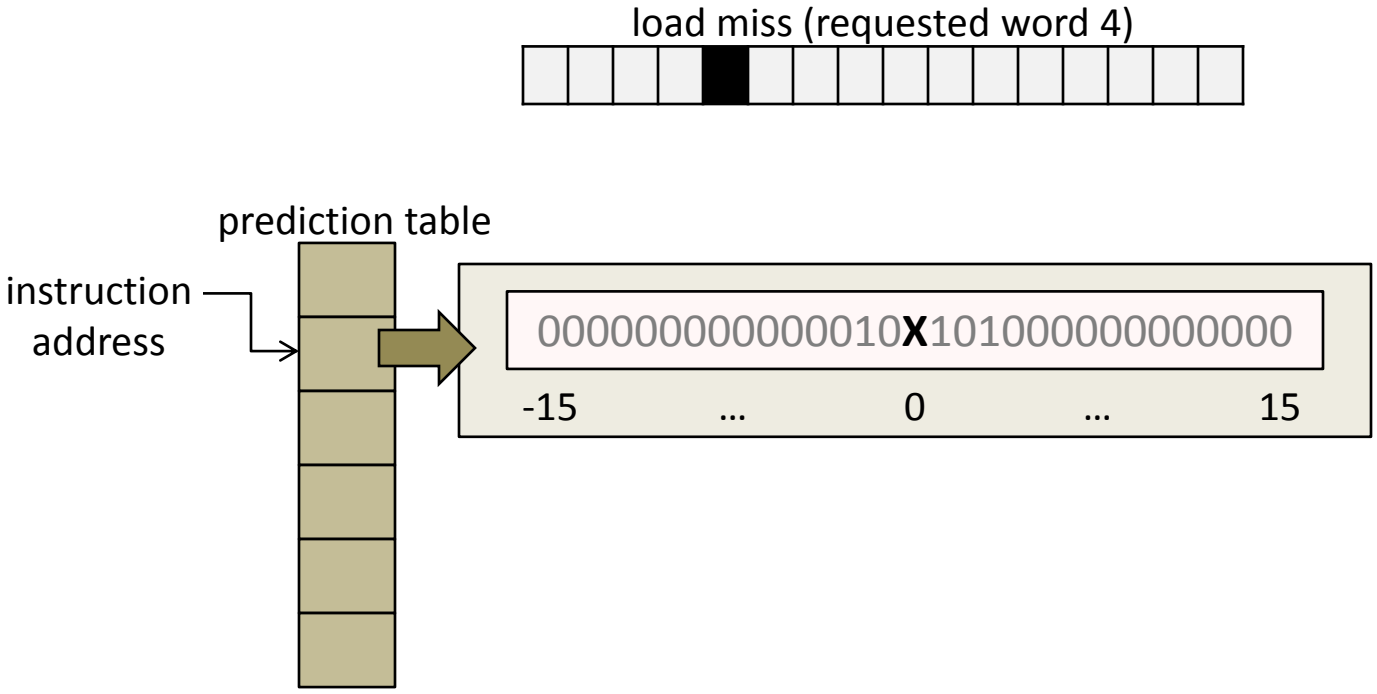

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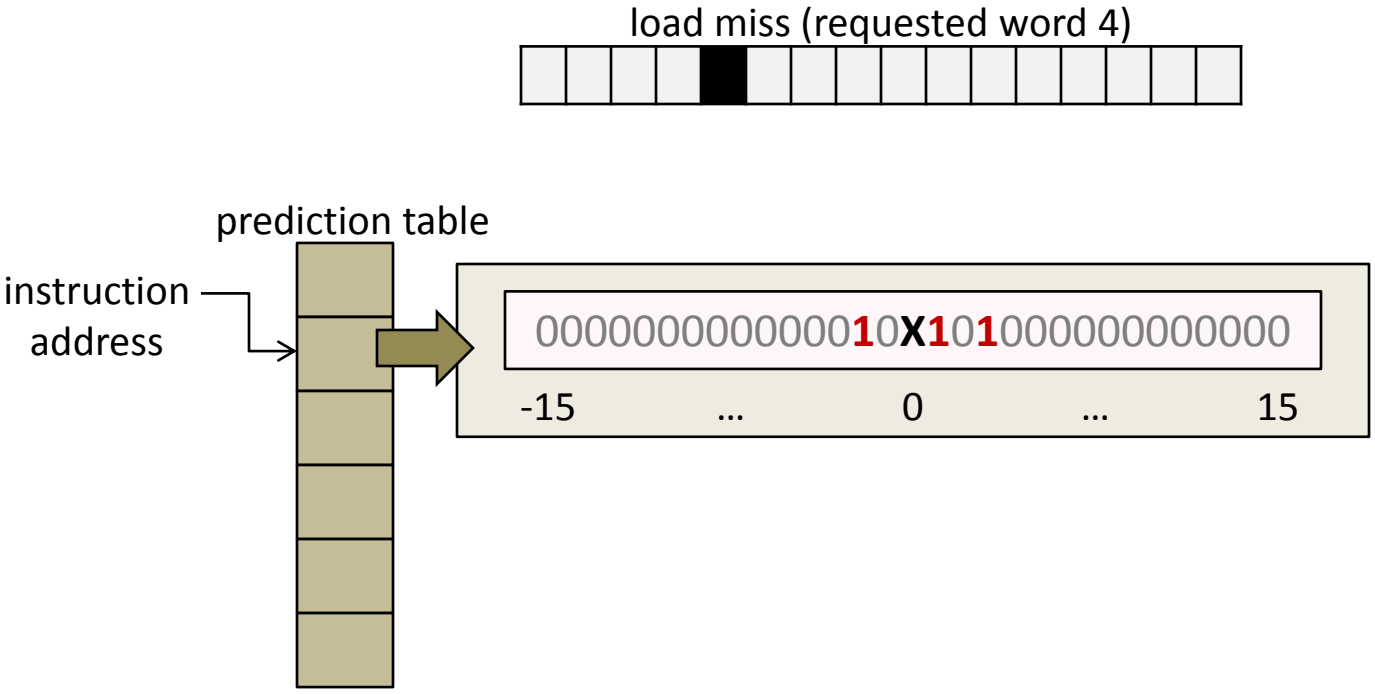

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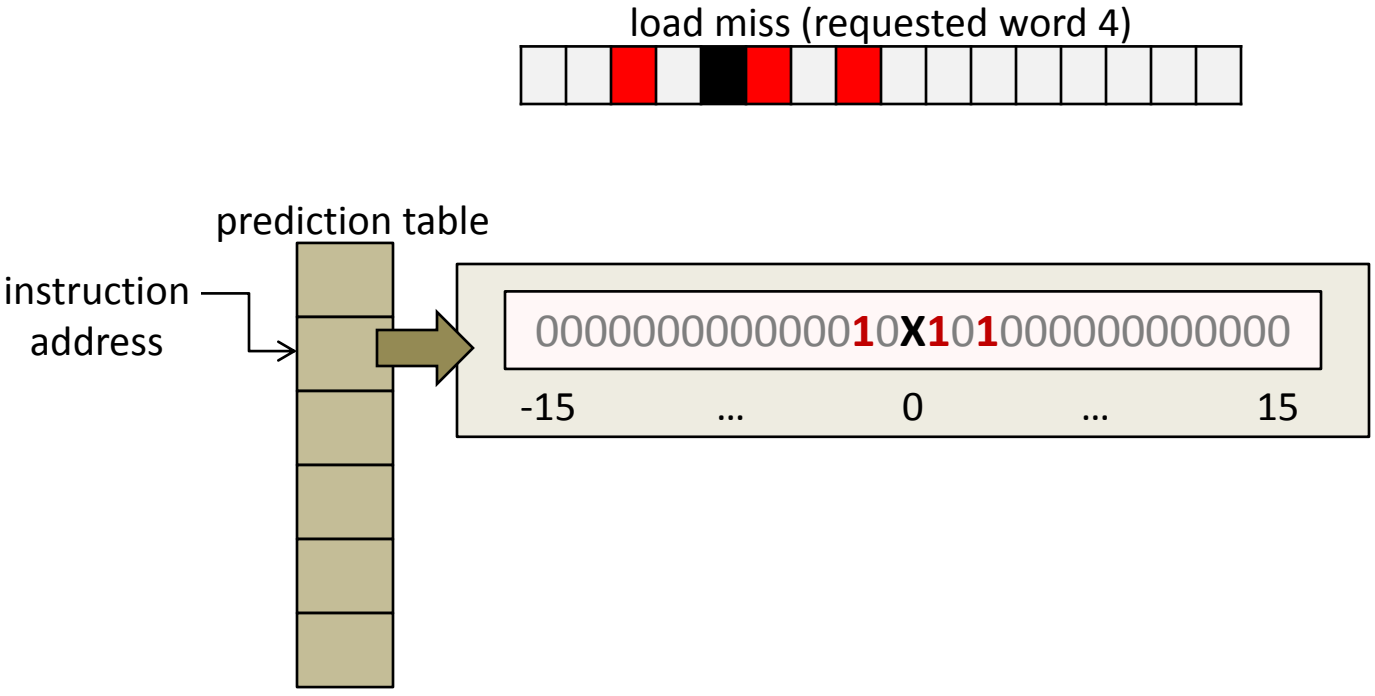

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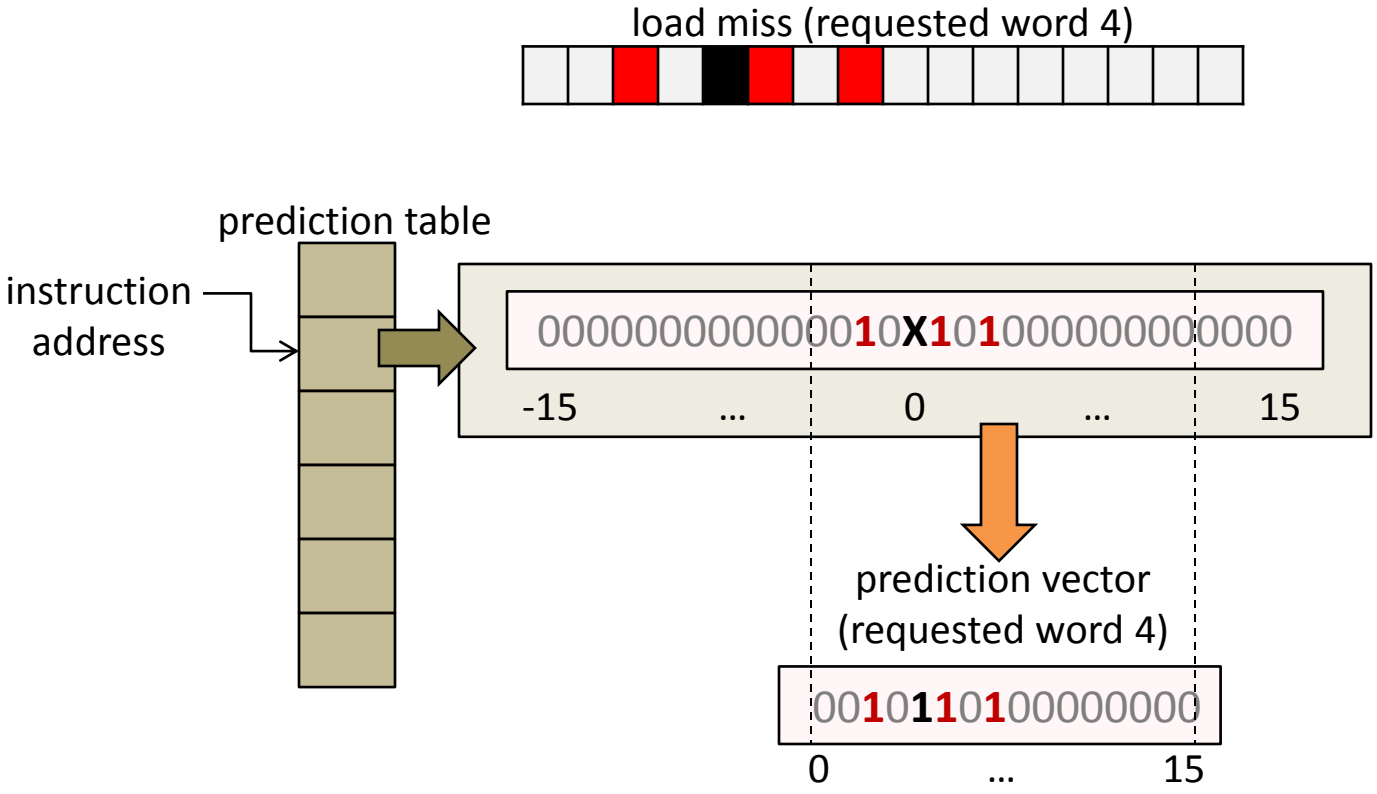

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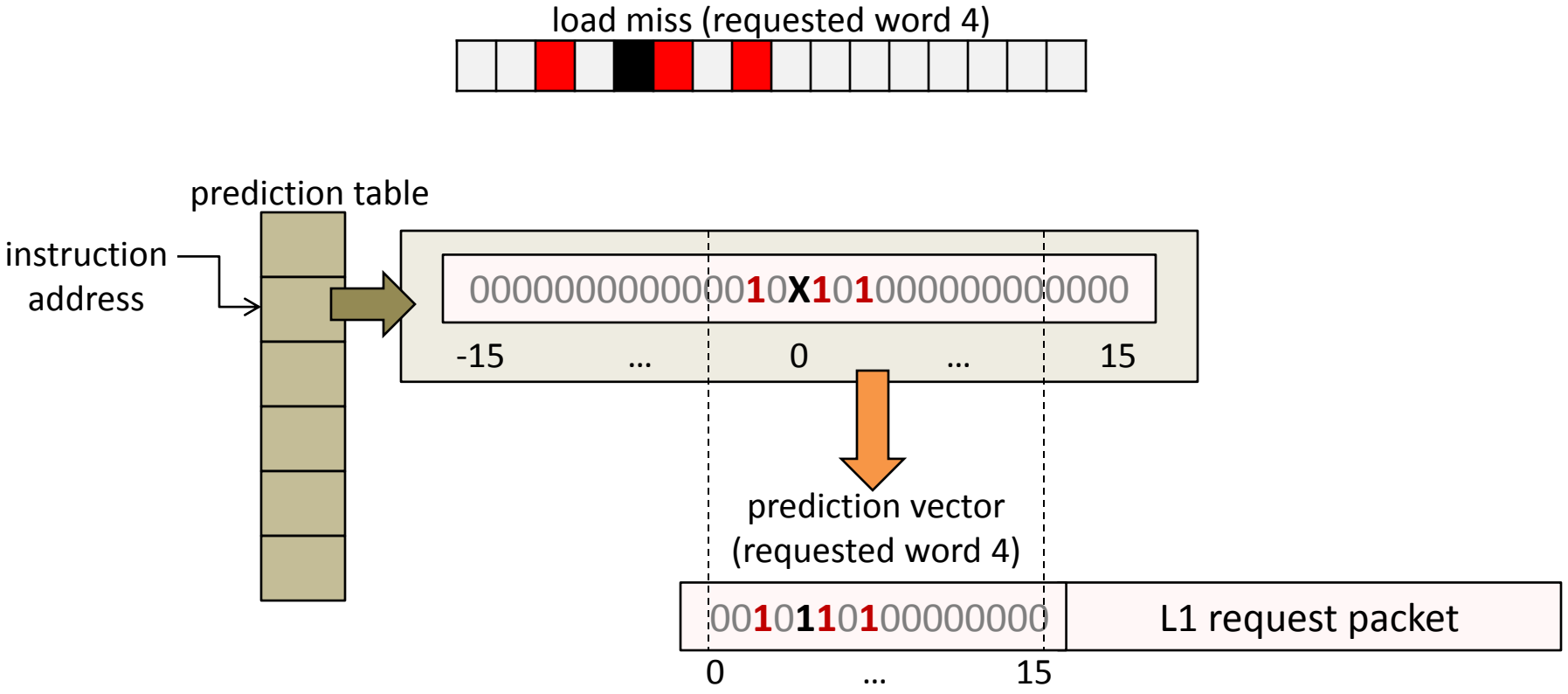

NoCNoC

2. Separate the fetching of words based on their criticality.
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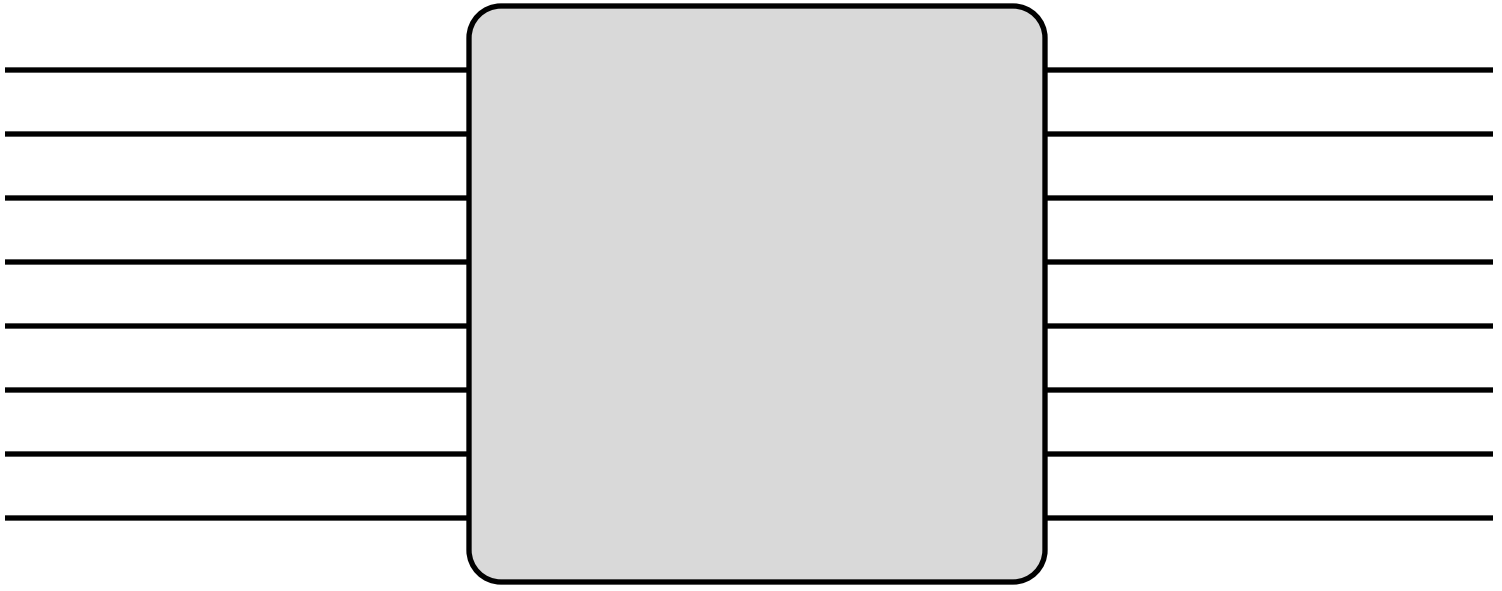

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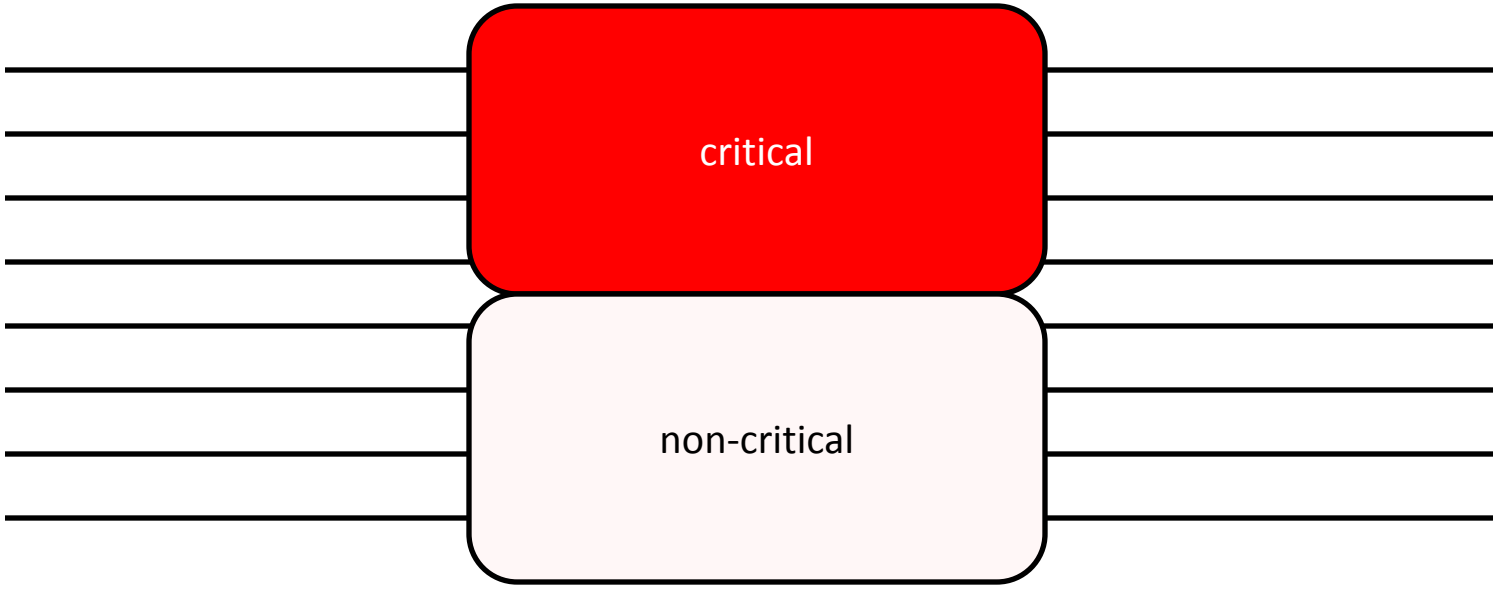

NoCNoC

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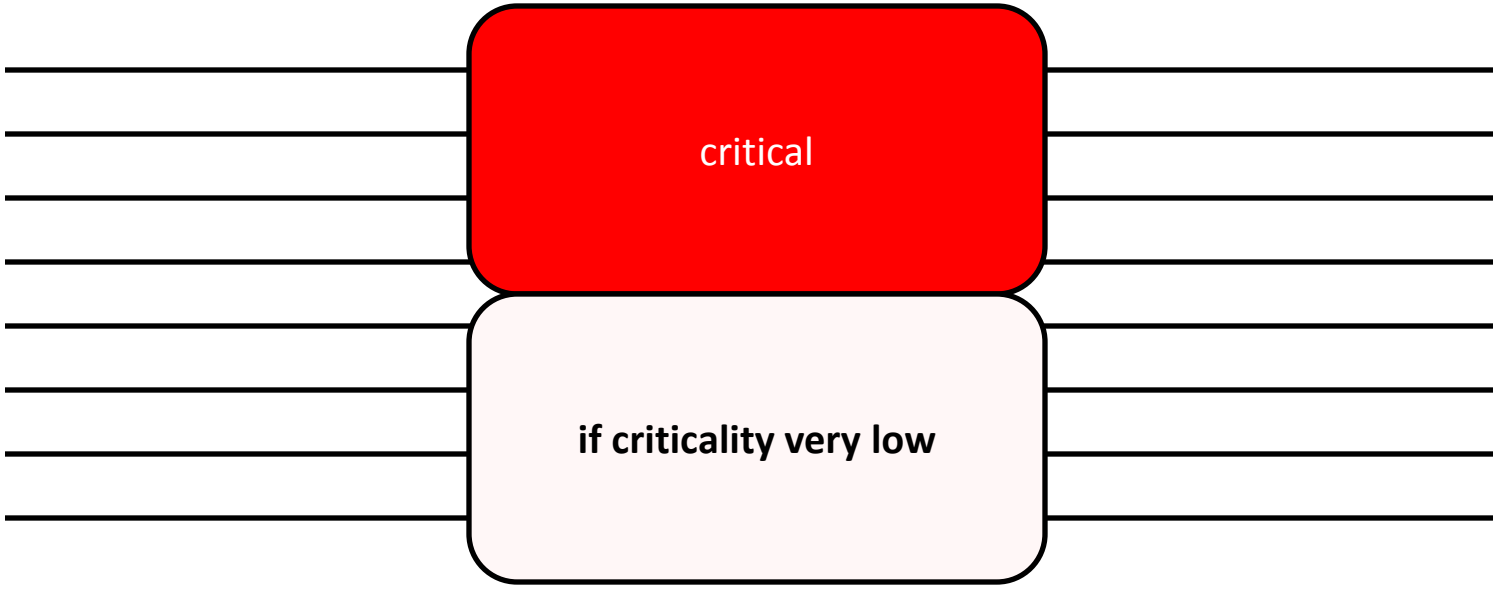

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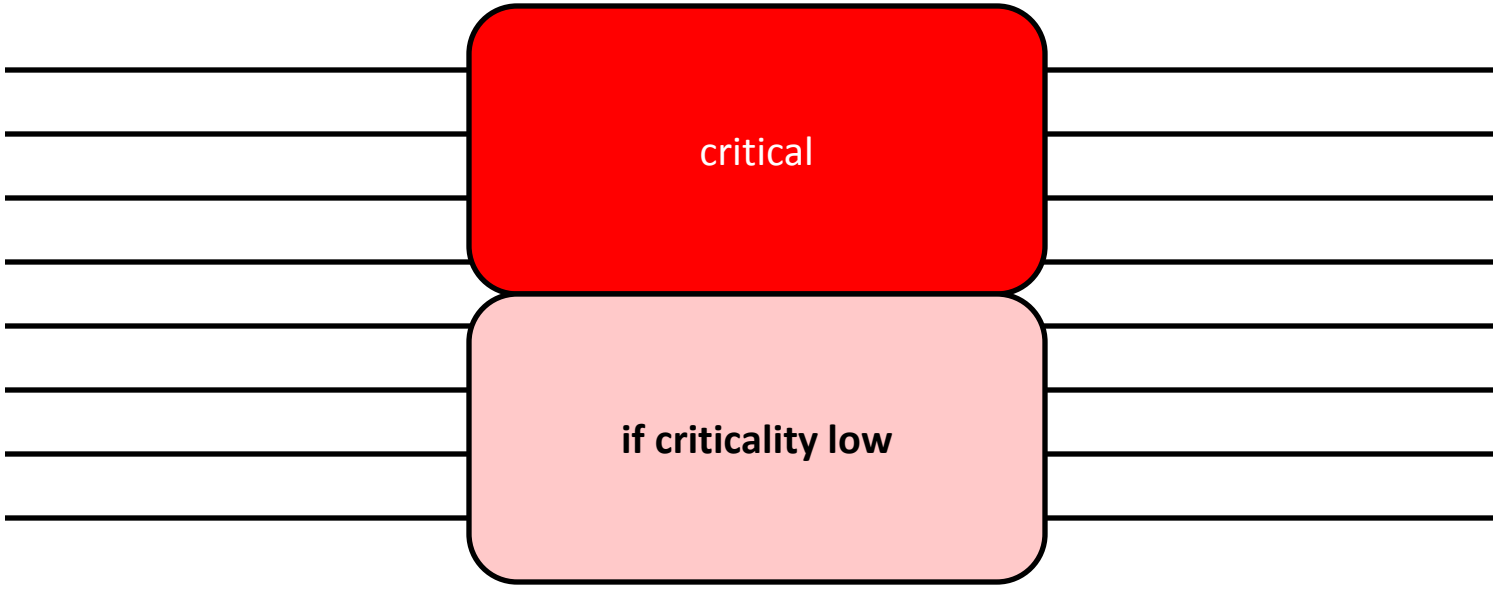

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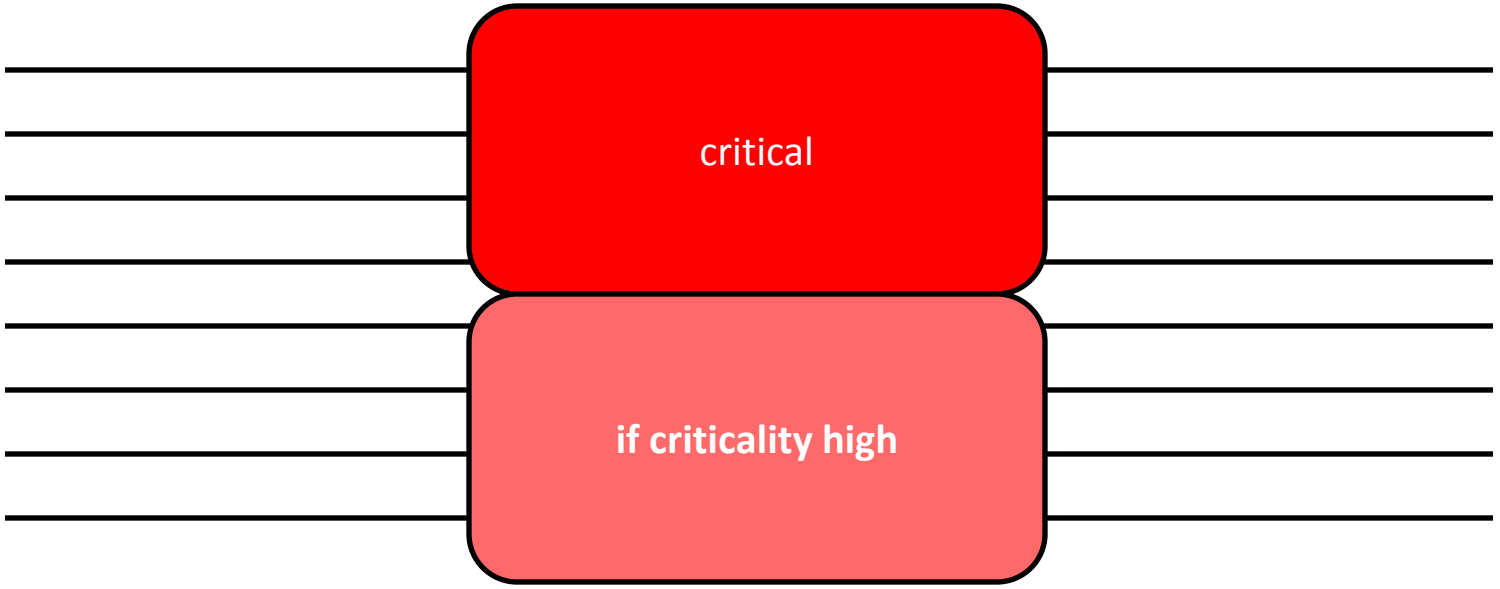

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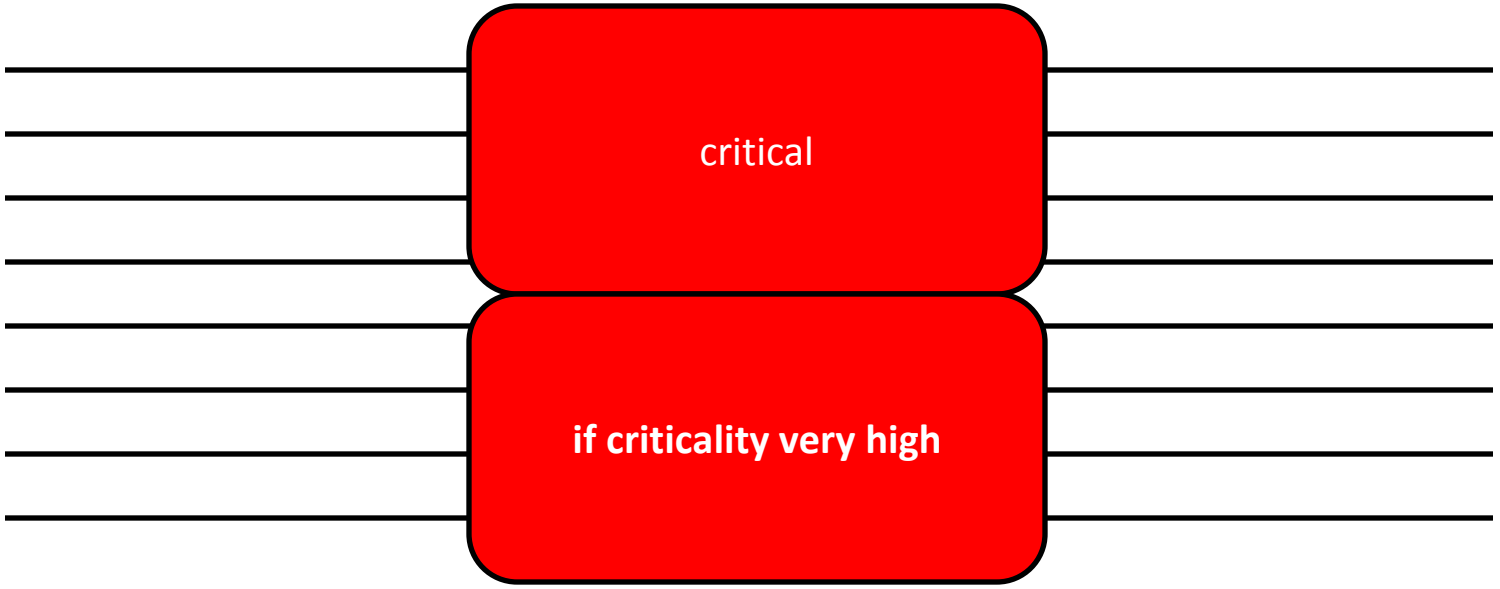

NoCNoC

4. Eliminate the fetching of dead words.
   - Binary predictor: either live or dead.

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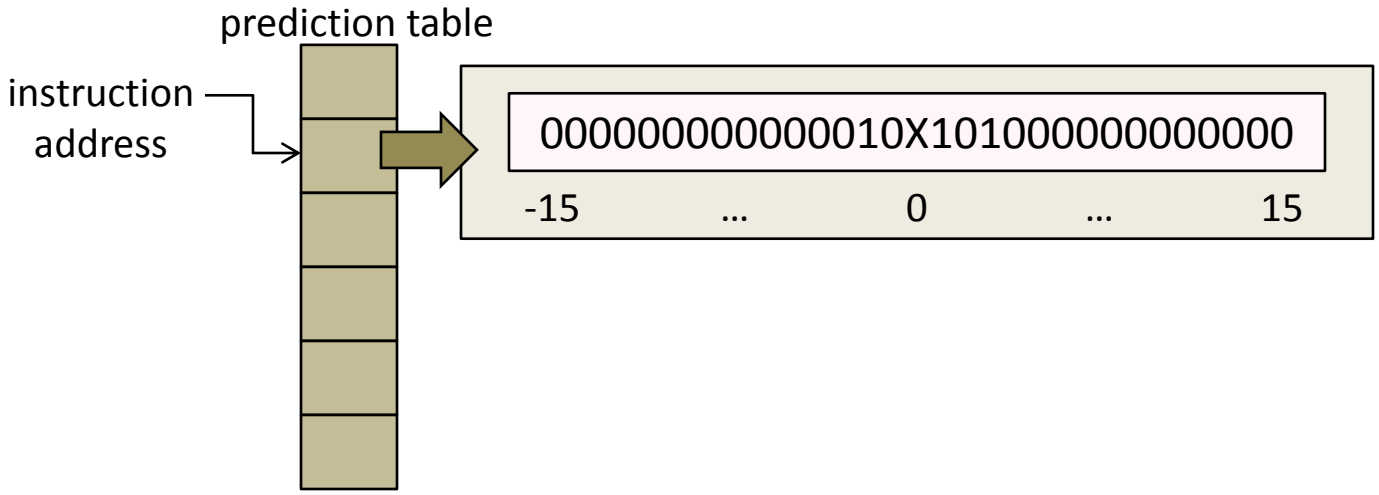
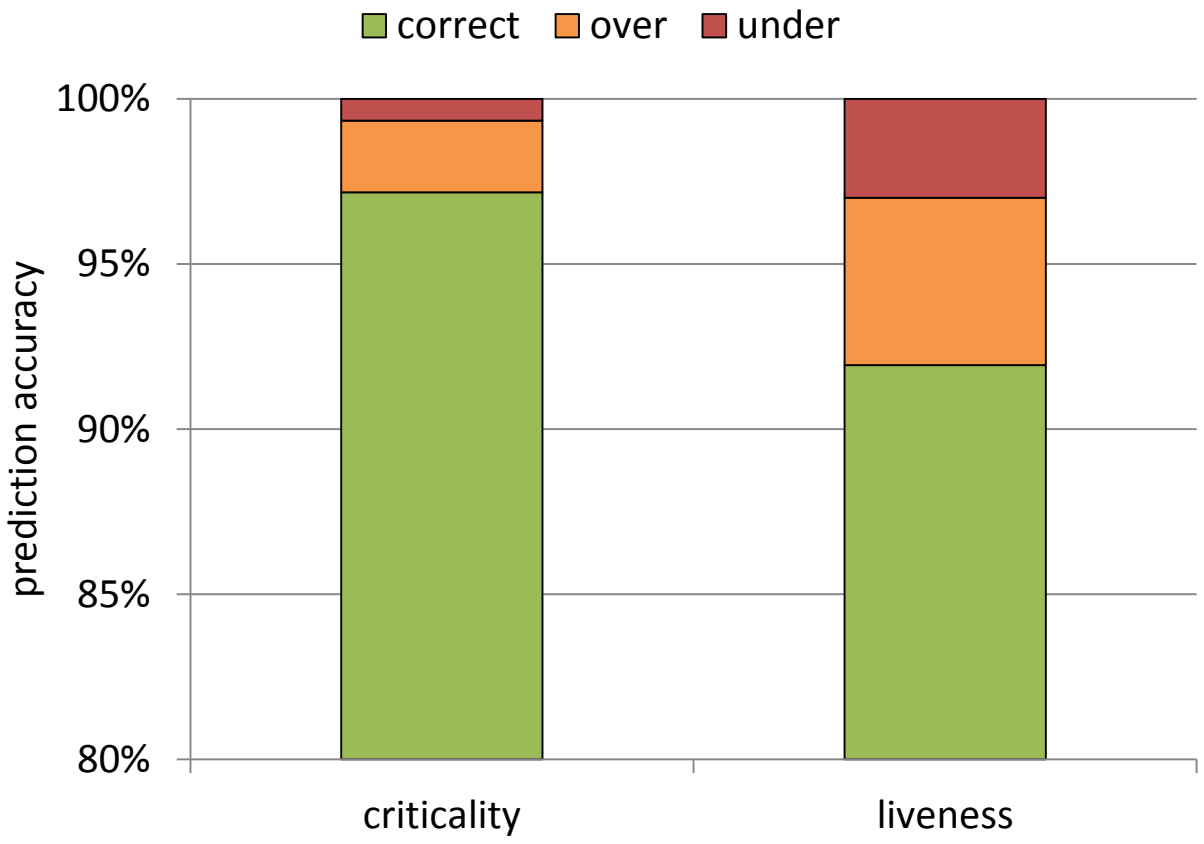


NoCNoC

More details and results in the paper:

- DVFS scheme
- Prediction tables
- Comparison to instruction criticality (Aergia [R. Das, ISCA 2010])

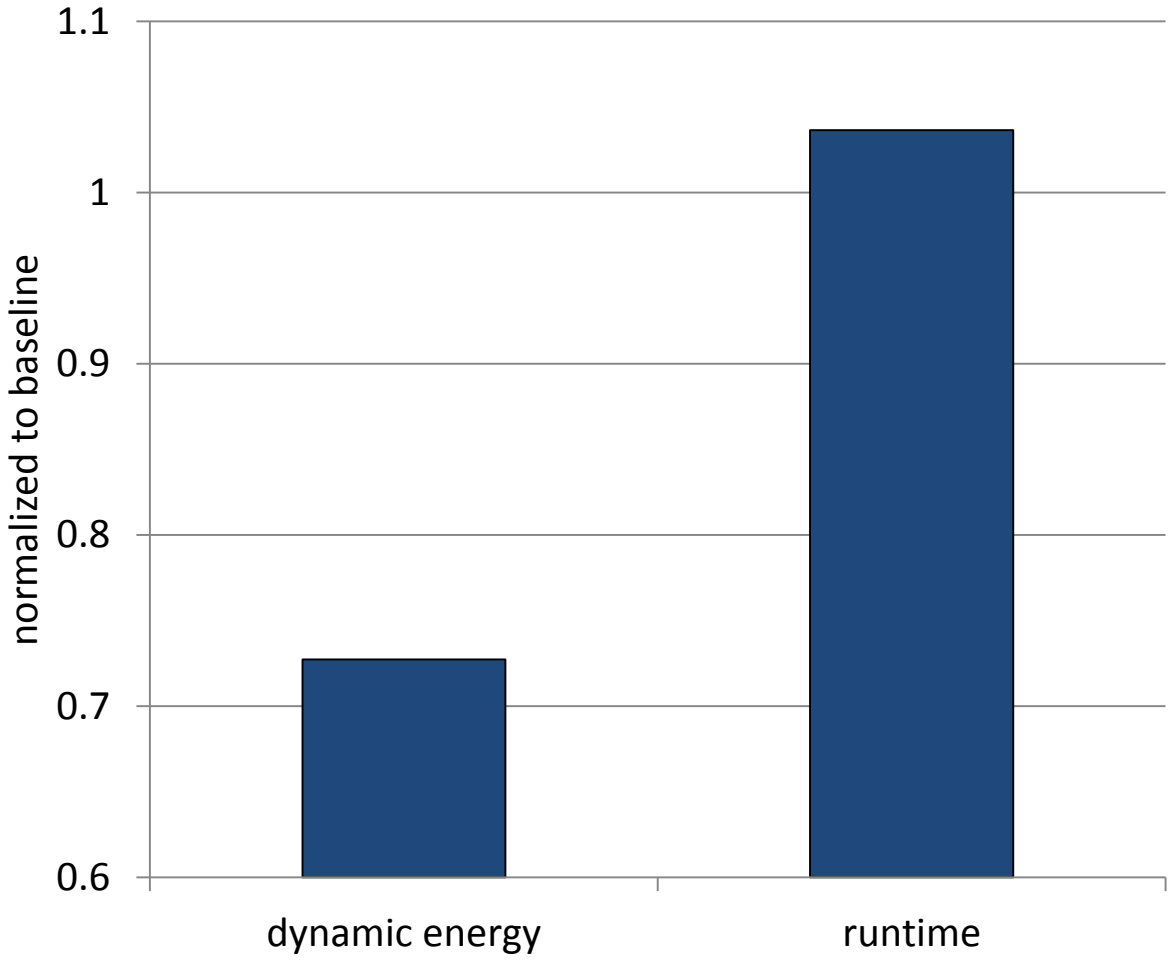
NoCNoC – Prediction Accuracy



NoCNoC – Prediction Accuracy

Outperforms prior liveness predictor (70% accuracy) [H. Kim, NOCS 2011]

NoCNoC – Performance and Energy



Conclusion

Define **Data Criticality**

- Deliver data both no later and **no earlier** than needed.

Measure Criticality

- 68.8% energy wasted due to non-critical and dead words.

Address Criticality

- NoCNoC, a proof-of-concept, criticality-aware design.

Thank you