FAST: Quick Application Launch on Solid-State Drives

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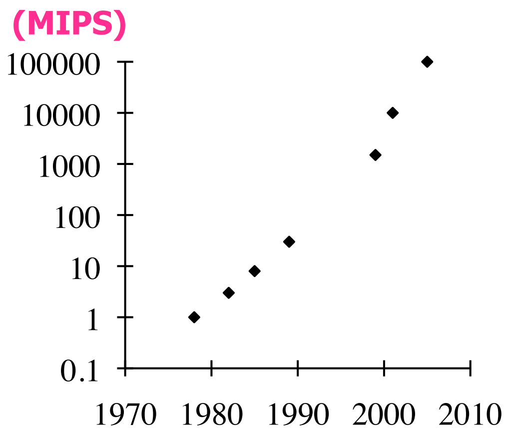
Application Launch Delay

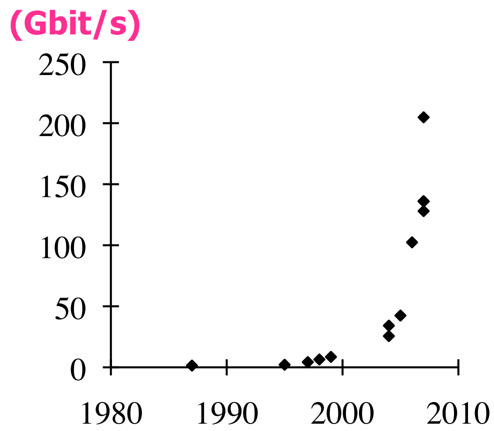
- Elapsed time between two events
  - A user clicks the icon
  - The application becomes responsible
- Important for interactive applications
  - Critically affects user satisfaction

Application Launch Performance

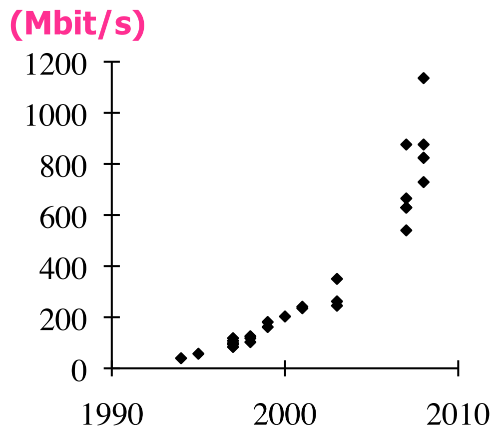
- Moore's law not applicable
  - Faster CPU and larger main memory not helpful
  - HDD seek and rotational latencies do not improve well



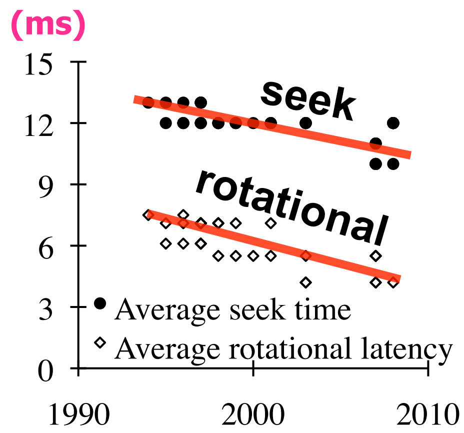
CPU performance



DRAM throughput



HDD throughput



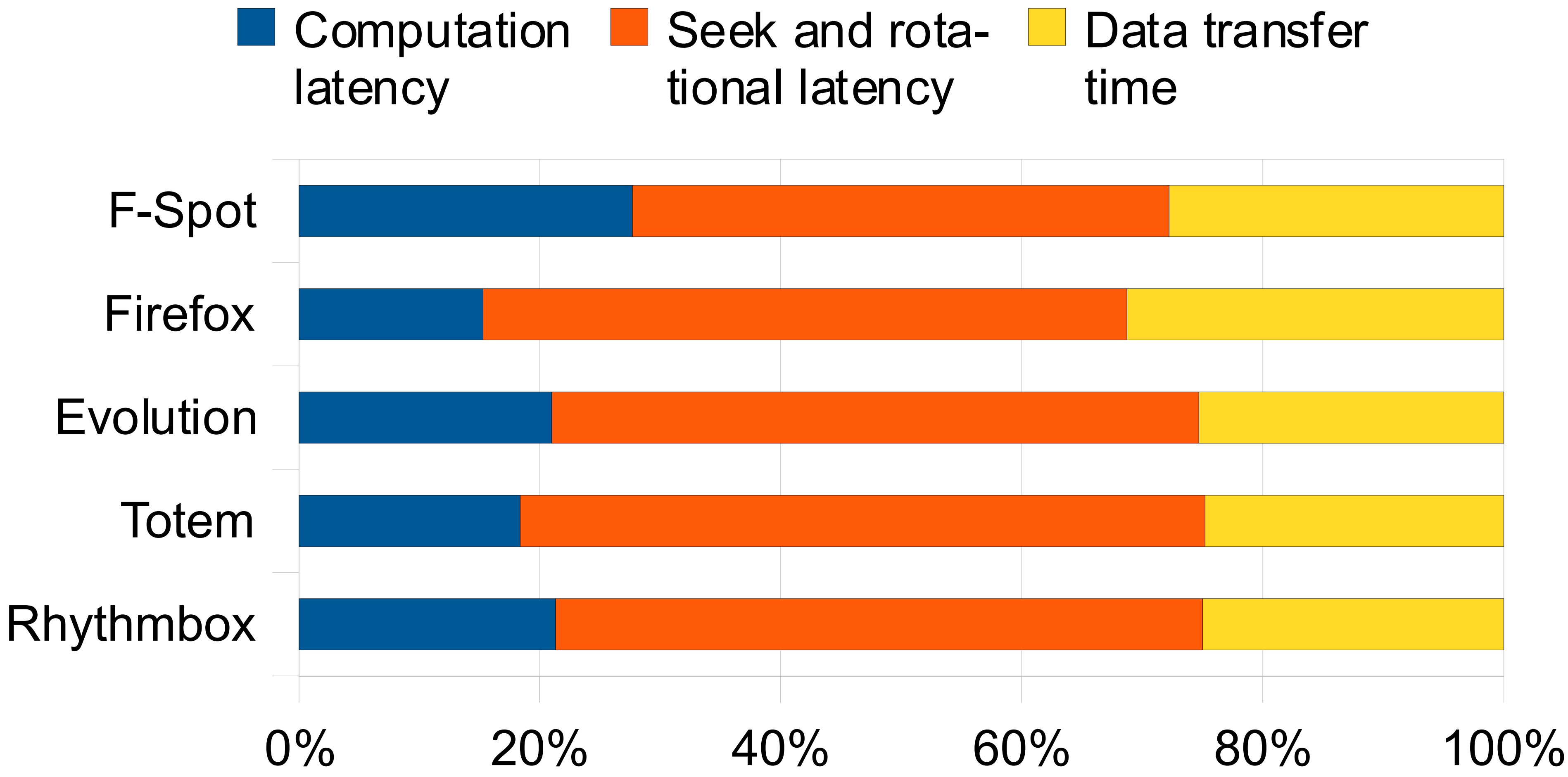
HDD access latency

Exponential improvement

Linear improvement

Application Launch Performance

- Application launch breakdown



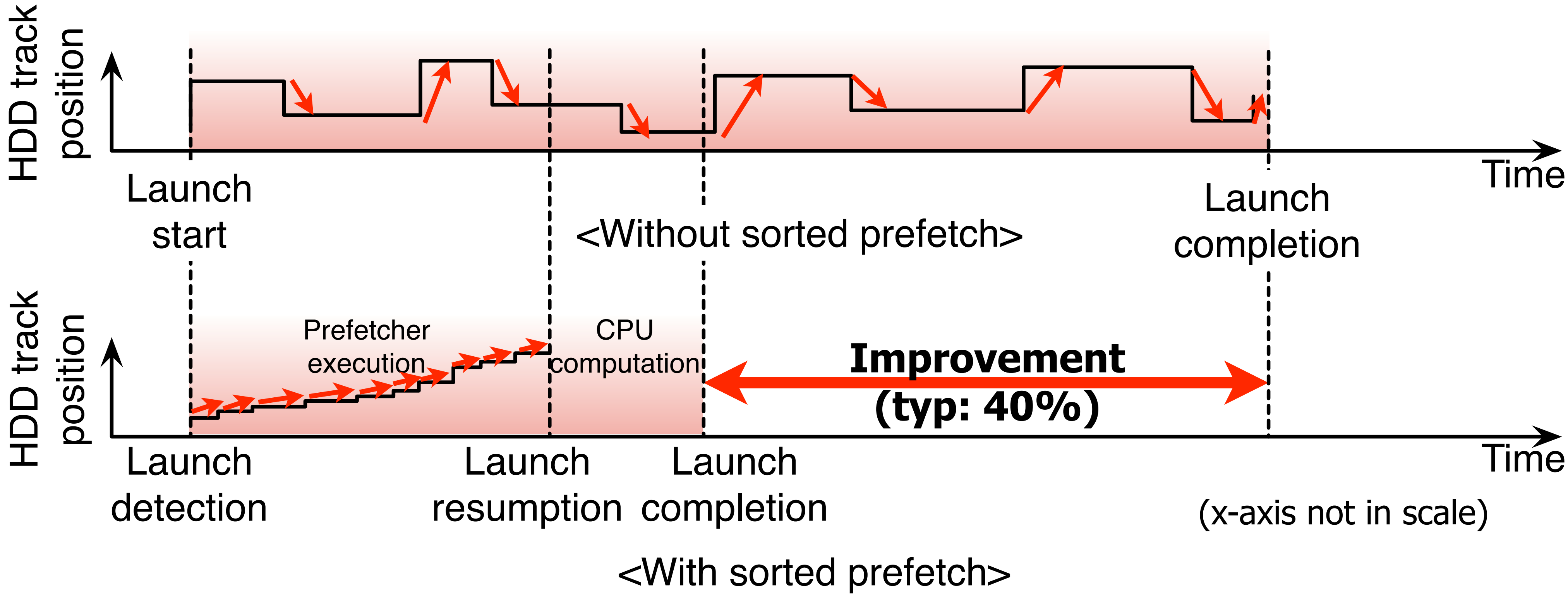
SW-Level Optimization

- Many SW-level schemes deployed in OSes
  - Application defragment, Superfetch, readahead, BootCache, etc.

- Sorted prefetch (ex: Windows prefetch)
  - Obtain the set of accessed blocks for each application
    - Monitor I/O requests during an application launch
  - Pause the target application upon detection of its launch
  - Prefetch the predetermined set of blocks in their LBA order
    - Reduce the total seek distance of the disk head
  - Resume the launch after the prefetch completes

SW-Level Optimization

- How sorted prefetch works



Flash-based SSD

- The single most effective way to eliminate disk head positioning delay
  - Acrobat reader: 4.0s -> 0.8s (84% reduction)
  - Matlab: 16.0s -> 5.1s (68% reduction)
- Characteristics
  - Consist of multiple NAND flash chips
  - No mechanical moving part
  - Uniform access latency (a few 100 microseconds)
- Prices now affordable
  - 80 GB MLC SSD: less than 200$ now

Motivation

- **Question:** Are we satisfied with the app launch on SSD?
  - **Yes** for lightweight applications (e.g., less than **1 sec**)
  - **No** for heavy applications (e.g., more than **5 sec**)
    - Far from ultimate user satisfaction
  - Faster application launch is always good (at least, not bad)

- Needs increase for launch optimization on SSDs
  - Applications are getting **HEAVIER**
    - More blocks to be read
  - SSD random read performance improves slowly
    - Bounded by the single chip performance

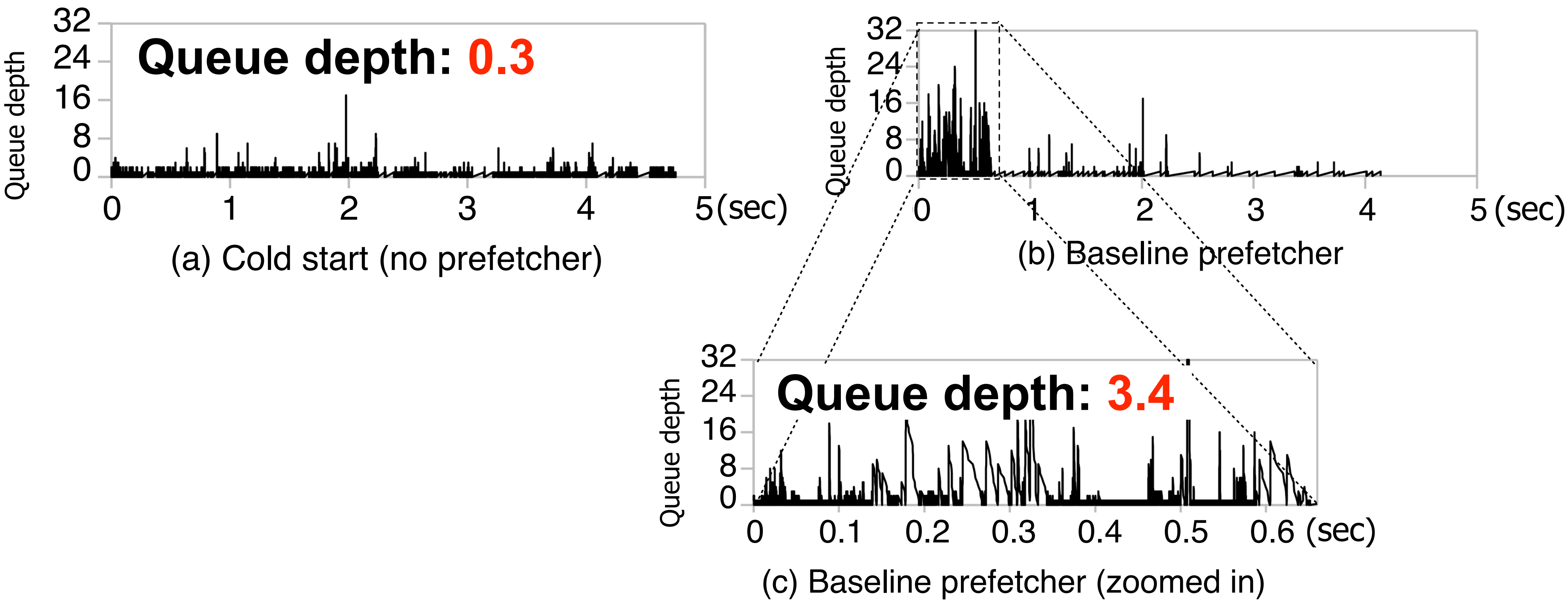
HDD-Aware Optimizers on SSD

- **Question:** Will traditional HDD optimizers work for SSDs?
  - Consensus: they will not be effective on SSDs
  - Rationale: they mostly optimize disk head movement
    - No disk head in SSDs
  - Often recommended not to use on SSDs

- Microsoft Windows 7
  - HDD-aware optimizers disabled upon detection of SSD
    - Windows prefetch, Application defragmentation, Superfetch, Readyboost, etc.

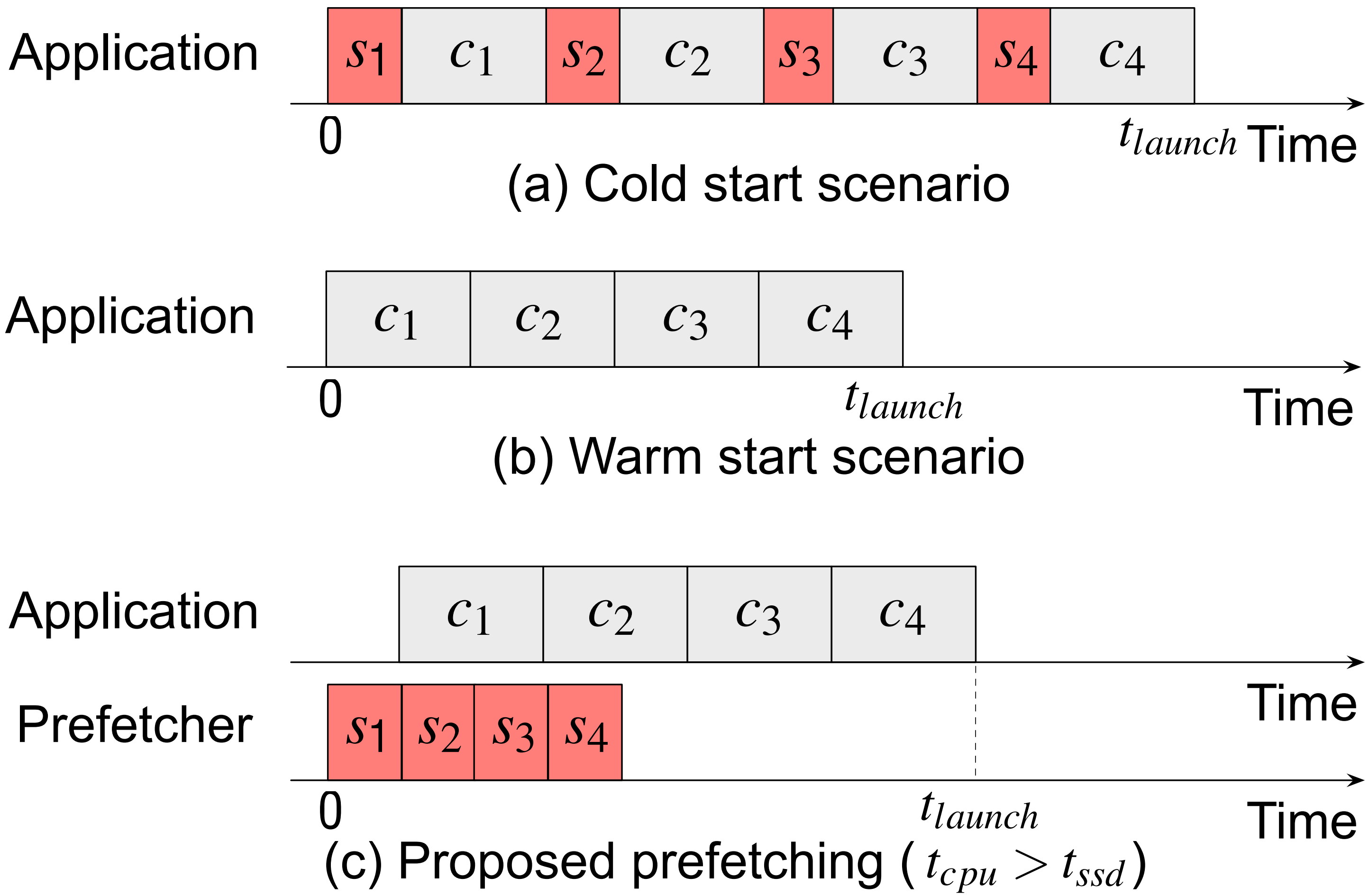
Sorted Prefetch on SSDs

- No benefit from LBA sorting
  - Uniform seek latency of SSD
- Launch performance still improves
  - Increased effective queue depth (0.3->3.4, app: Eclipse)
  - Observed **7**% launch time reduction: better than nothing!



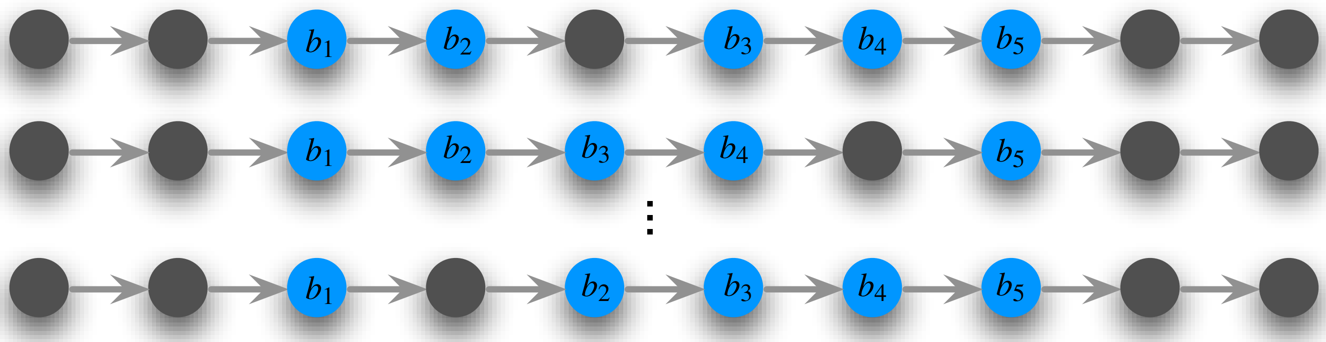
FAST: Fast Application STarter

- Overlap CPU computation with SSD accesses

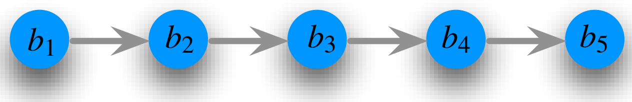


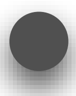
Application Launch Sequence

- **Deterministic** block requests over repeated launches
- Raw block request traces



- Application launch sequence





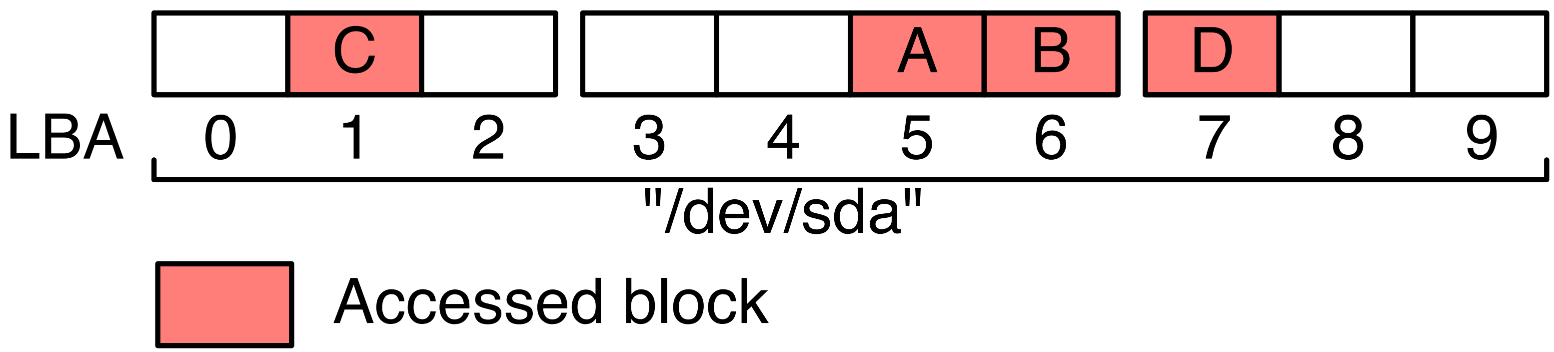
Block requests irrelevant to the application launch

What to Do

- Application launch sequence profiling
  - Using `blktrace` tool
- Prefetcher generation
  - Replay block requests according to the application launch sequence
- Prefetcher execution
  - Simultaneously with the original application
  - By wrapping the system call `exec()`
    - `LD_PRELOAD`

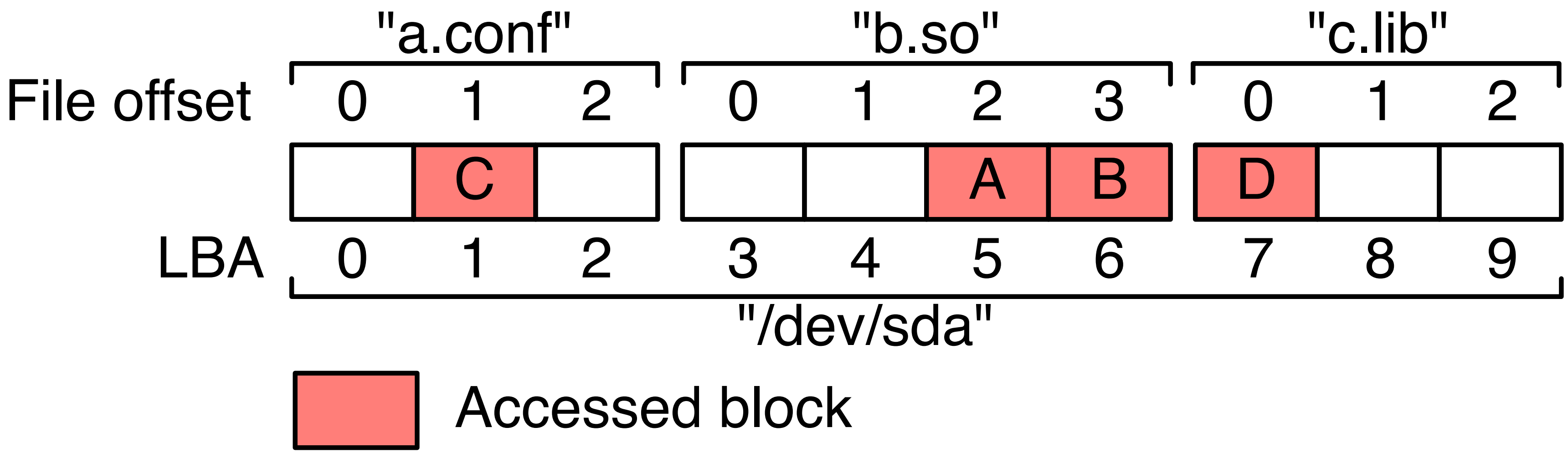
Prefetcher Generation

- Example application launch sequence
  - AB->C->D
- Block-level I/O: (start LBA, size)
  - (5, 2)->(1, 1)->(7, 1) <- obtainable from `blktrace`



Prefetcher Generation

- Example application launch sequence
  - AB->C->D
- Block-level I/O: (start LBA, size)
  - (5, 2)->(1, 1)->(7, 1) <- obtainable from `blktrace`
- File-level I/O: (filename, offset, size)
  - (“b.so”, 2, 2)->(“a.conf”, 1, 1)->(“c.lib”, 0, 1)

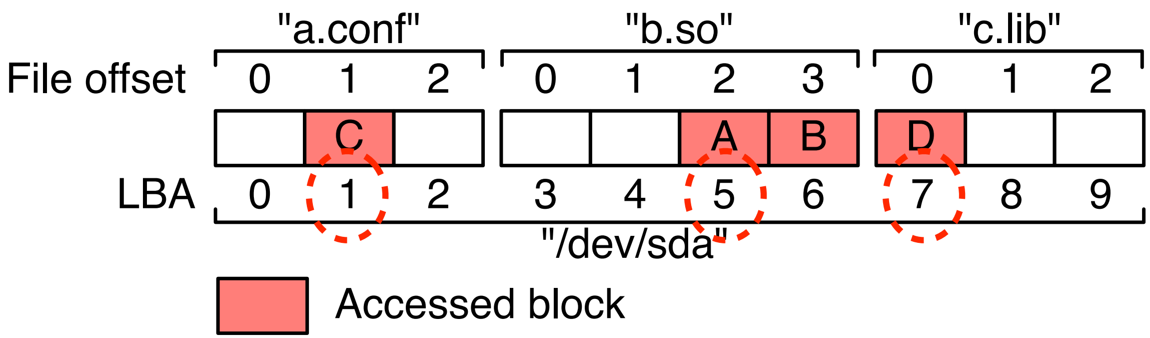


Prefetcher Generation

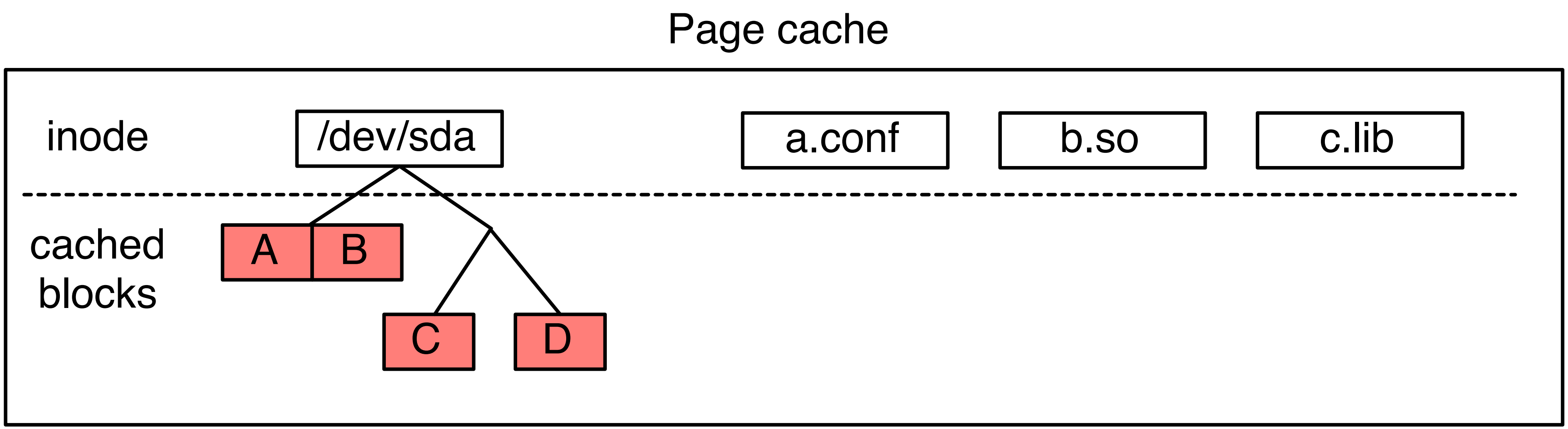
- Block-level I/O replay

```
int main(void) {
  fd = open("/dev/sda",O_RDONLY|O_LARGEFILE);
  posix_fadvise(fd,5*512,2*512,POSIX_FADV_WILLNEED);
  posix_fadvise(fd,1*512,1*512,POSIX_FADV_WILLNEED);
  posix_fadvise(fd,7*512,1*512,POSIX_FADV_WILLNEED);
  return 0;
}
```

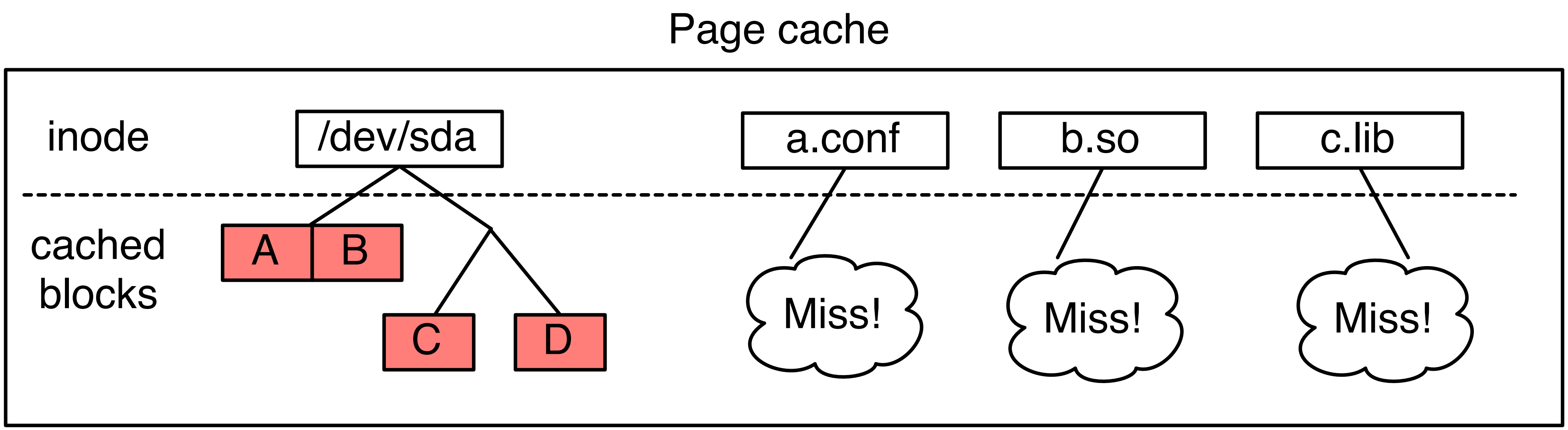
LBA **size**



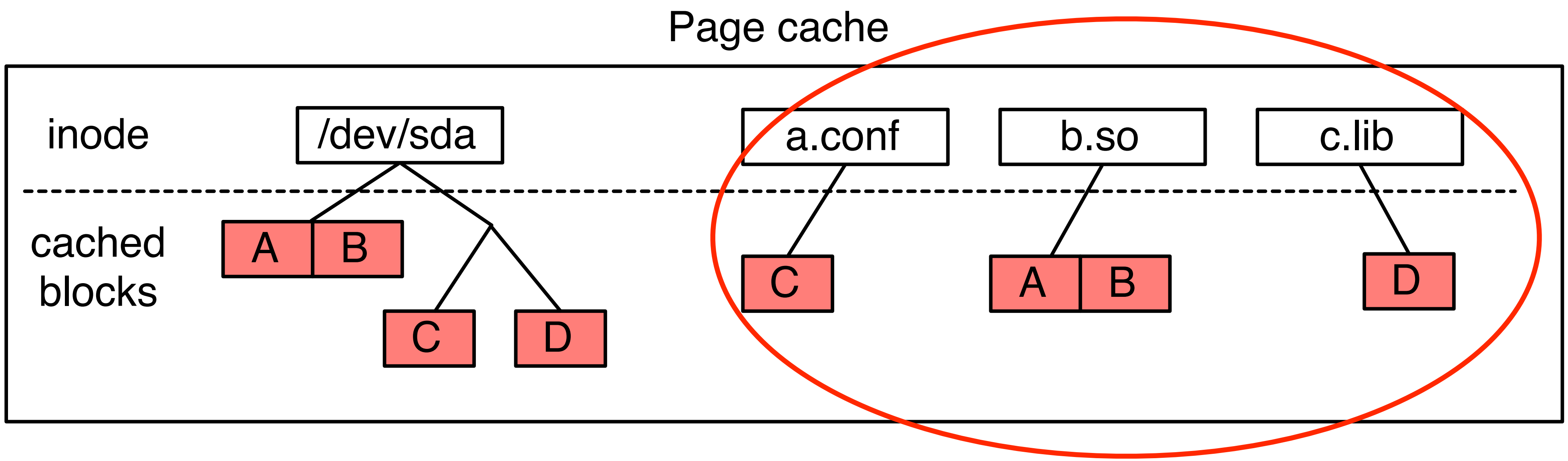
Page Cache Structure



Page Cache Structure



Page Cache Structure



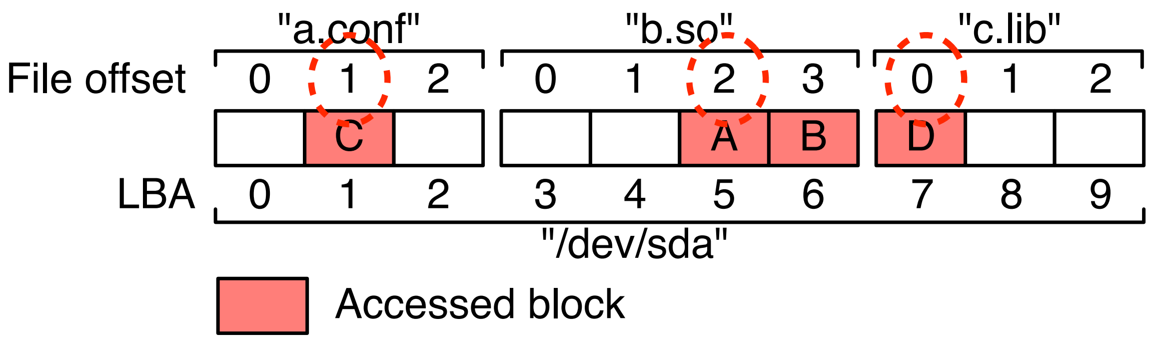
What we need to construct

Prefetcher Generation

- File-level I/O replay

```
int main(void) {
  fd1 = open("b.so",   O_RDONLY);
  posix_fadvise(fd1,2*512,2*512,POSIX_FADV_WILLNEED);
  fd2 = open("a.conf",O_RDONLY);
  posix_fadvise(fd2,1*512,1*512,POSIX_FADV_WILLNEED);
  fd3 = open("c.lib", O_RDONLY);
  posix_fadvise(fd3,0*512,1*512,POSIX_FADV_WILLNEED);
  return 0;
}
```

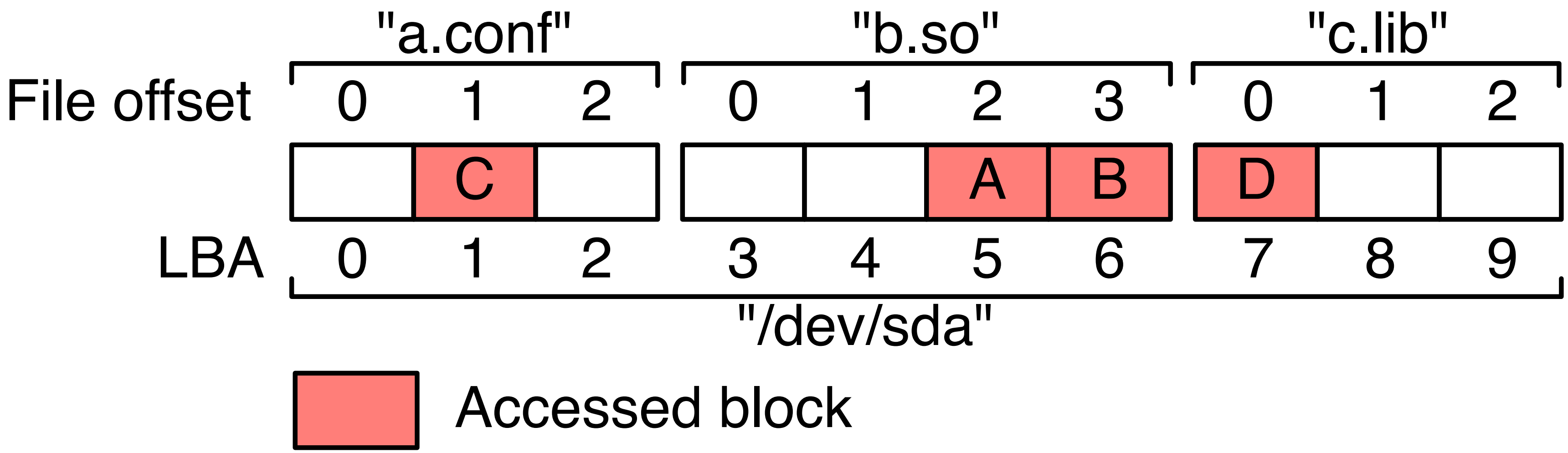
file name   file offset   size



Block-to-File Level I/O Conversion

- LBA-to-inode mapping
  - Not supported by EXT file system

```
(5,2)    →    ("b.so",   2,2)
(1,1)         ("a.conf",1,1)
(7,1)         ("c.lib", 0,1)
```



Block-to-File Level I/O Conversion

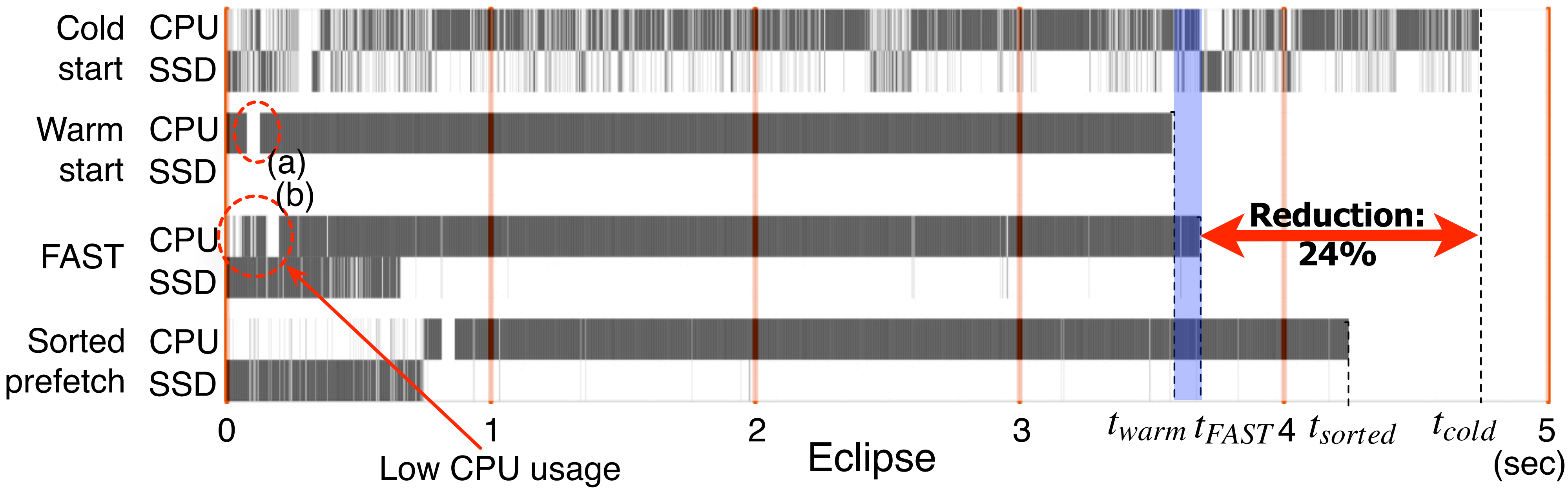
- Inode-to-LBA map for a single file
  - Easy to build
- LBA-to-inode map for the entire file system
  - Millions of files in a file system
  - Frequently changed
  - Only a few 100s of files used by a single application
- Our approach: build a partial map for each application
  - Determine the set of files used for the launch
    - Monitoring system calls using filename as their argument

Application Prefetcher

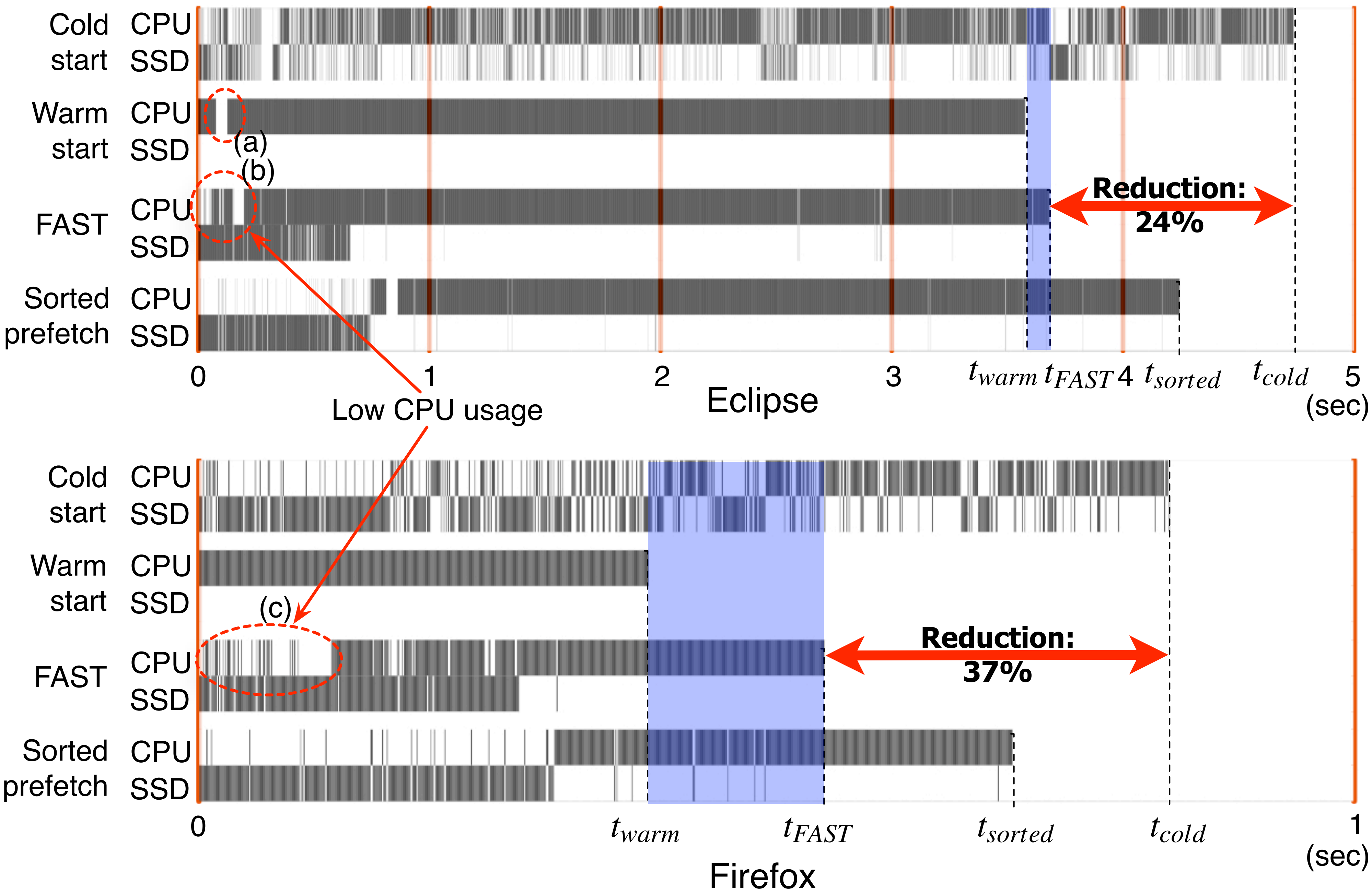
- Automatically generated application prefetcher for Gimp

```
int main(void) {
 ...
 readlink("/etc/fonts/conf.d/90-ttf-arphic-uming-embolden.conf", linkbuf, 256);
 int fd423;
 fd423 = open("/etc/fonts/conf.d/90-ttf-arphic-uming-embolden.conf", O_RDONLY);
 posix_fadvise(fd423, 0, 4096, POSIX_FADV_WILLNEED);
 posix_fadvise(fd351, 286720, 114688, POSIX_FADV_WILLNEED);
 int fd424;
 fd424 = open("/usr/share/fontconfig/conf.avail/90-ttf-arphic-uming-embolden.conf",
O_RDONLY);
 posix_fadvise(fd424, 0, 4096, POSIX_FADV_WILLNEED);
 int fd425;
 fd425 = open("/root/.gnupg/trustdb.gpg", O_RDONLY);
 posix_fadvise(fd425, 0, 4096, POSIX_FADV_WILLNEED);
 dirp = opendir("/var/cache/");
 if(dirp)while(readdir(dirp));
 ...
 return 0;
}
```

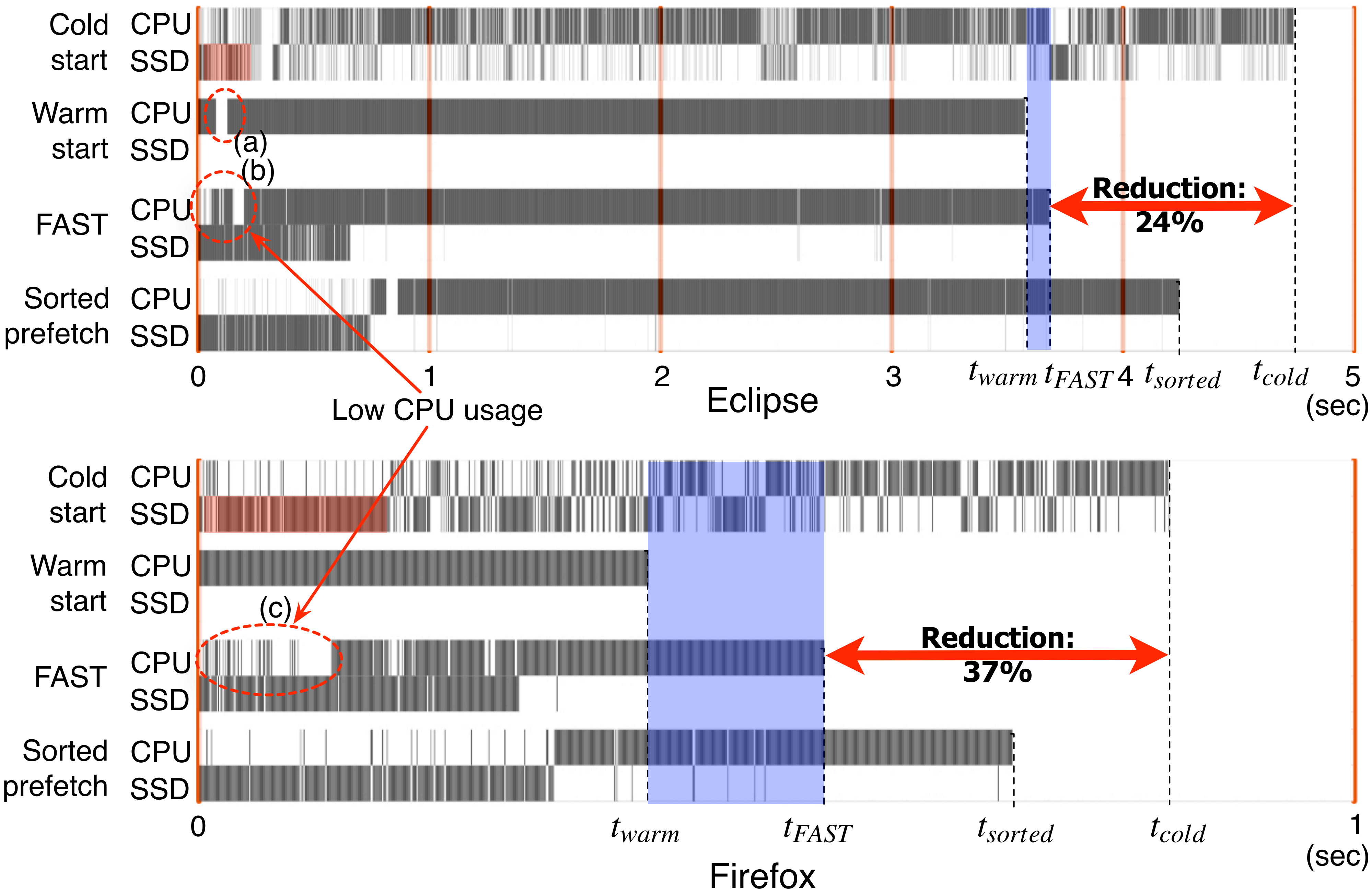
CPU and SSD Usage



CPU and SSD Usage

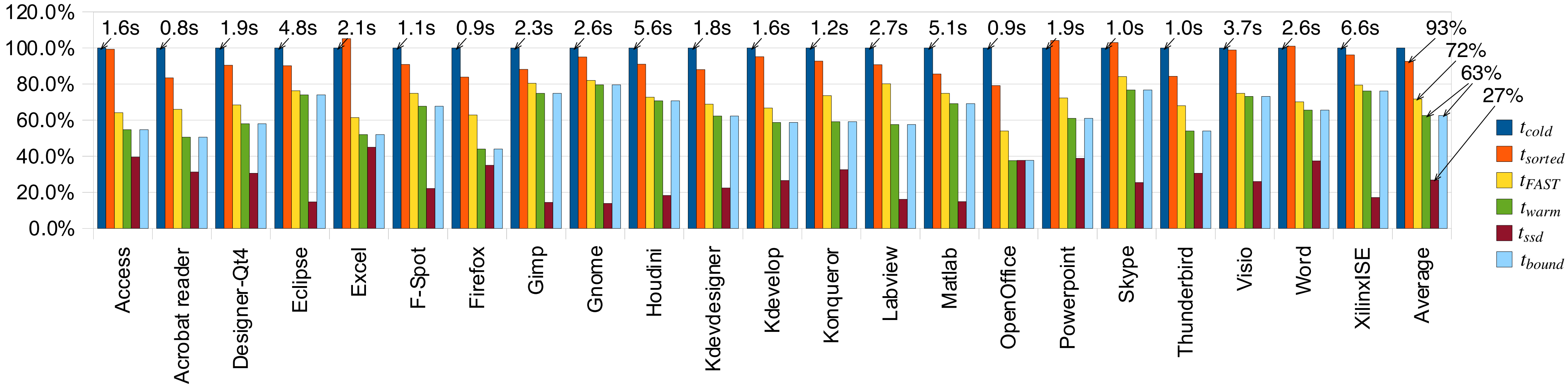


CPU and SSD Usage



Measured Application Launch Time

- Launch time reduction
  - Warm start: 37% (upper bound)
  - Proposed: 28% (min: 16%, max: 46%)
  - Sorted prefetch: 7% (min: -5%, max: 21%)



(Normalized to the cold start time.)

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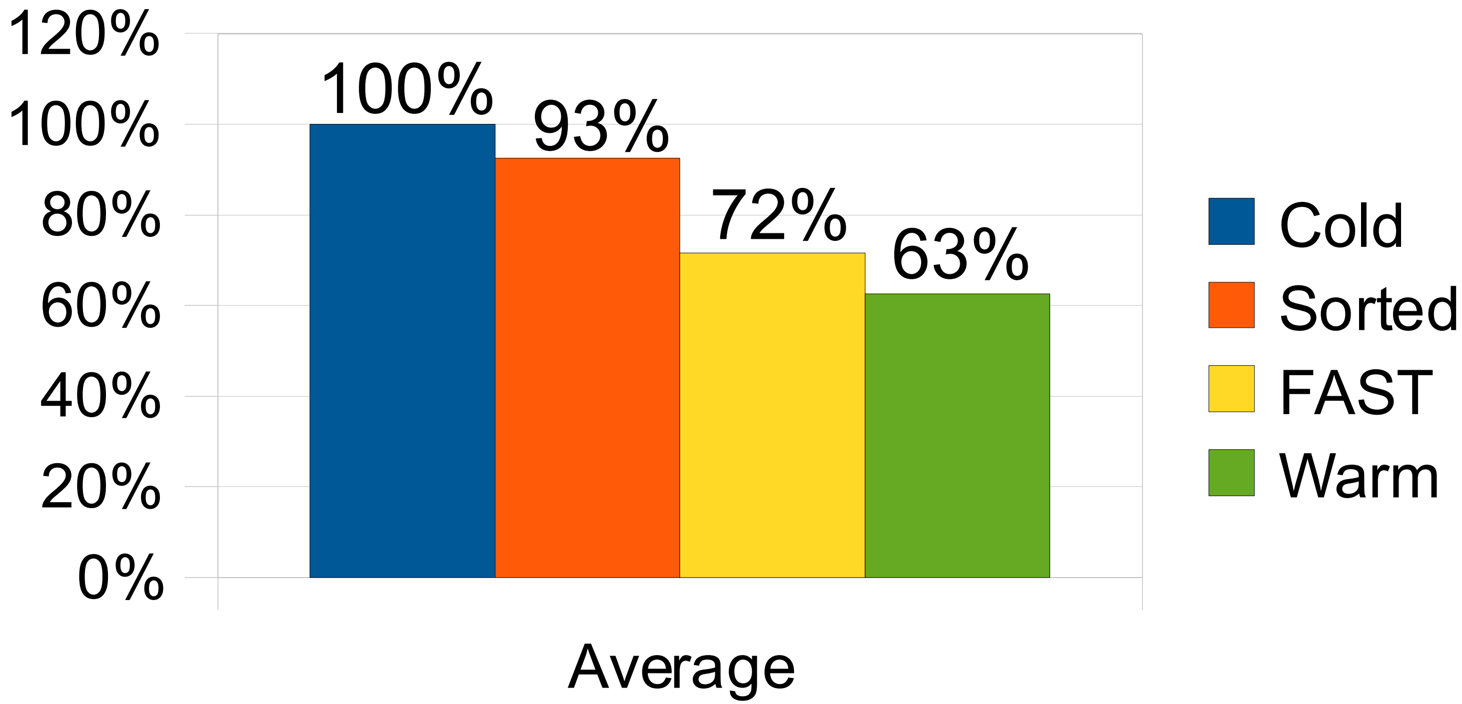


Applicability on Smartphones

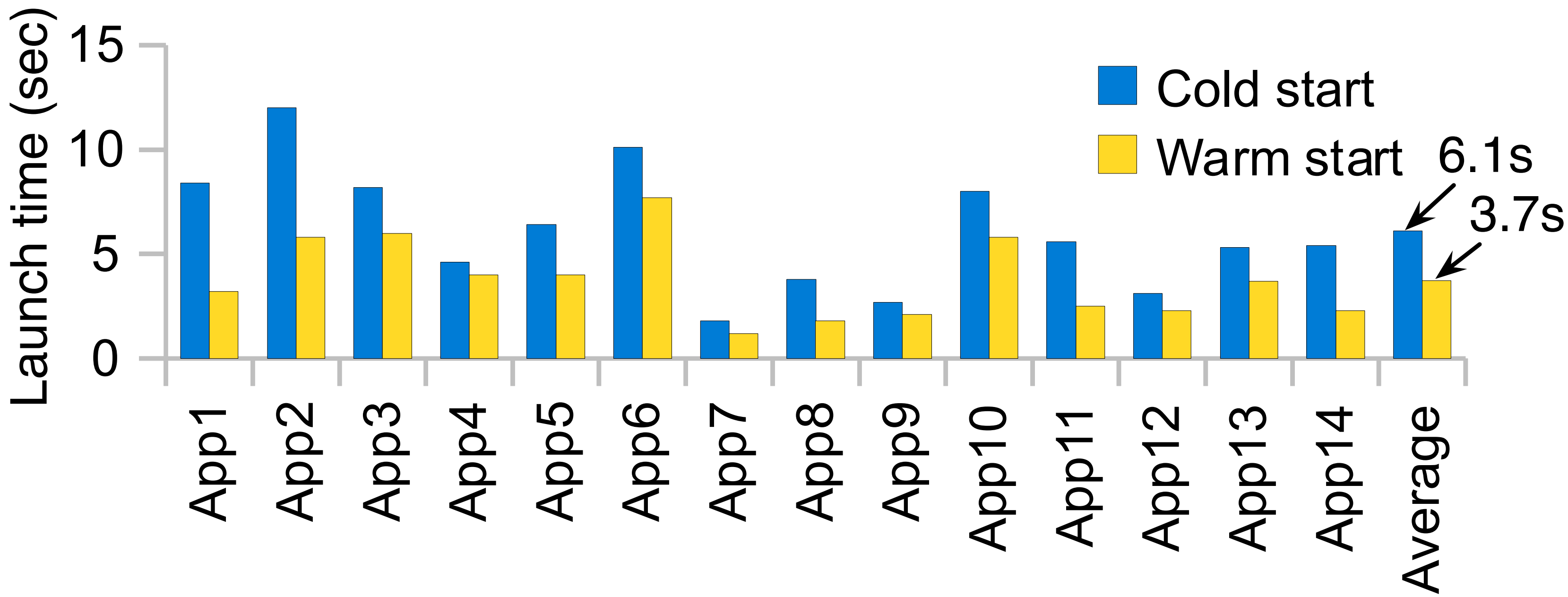
- Similarity to PCs with a SSD
  - Running various applications
    - Application launch performance does matter
  - NAND Flash-based storage
    - The same performance characteristic as SSDs
  - Slightly modified OSes and file systems designed for PCs
    - Easy to port

Applicability on Smartphones

- Further benefits
  - More frequent launches of applications
  - Limited main memory capacity
    - Cold start scenario occurs more often
  - Slower CPU and flash storage speed
    - Relatively longer application launch time

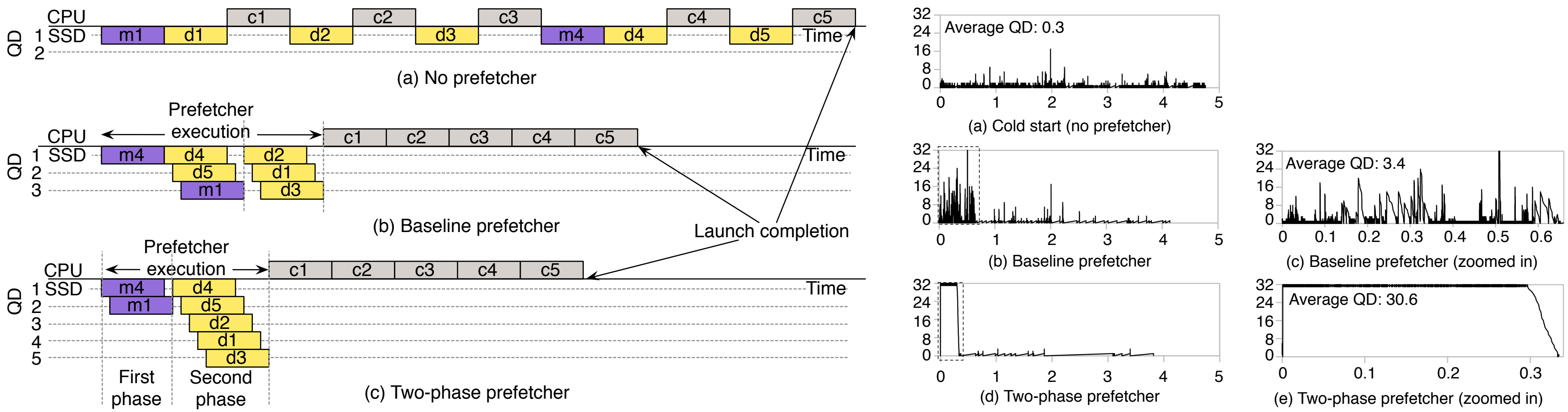
Applicability on Smartphones

- Measured cold & warm start time on iPhone 4
  - Average cold start time: 6.1 seconds
  - Warm start time: 63% of cold start time



Conclusion & Future Work

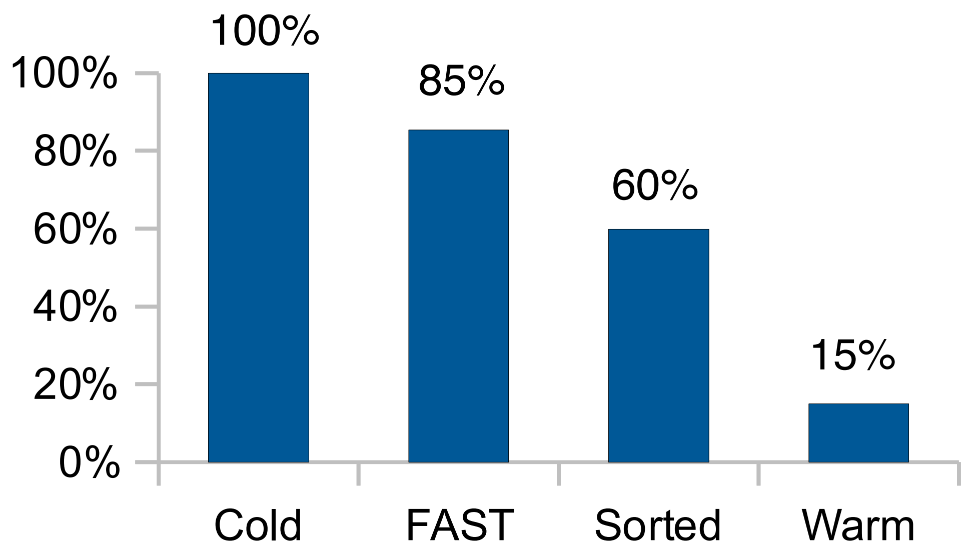
- Introduced an application prefetcher designed for SSDs
- Our ultimate goal
  - **Warm start** performance in the **cold start** scenario
- Further improving FAST by exploiting the SSD parallelism
  - See our poster!



Backup Slides

Applicability on HDDs

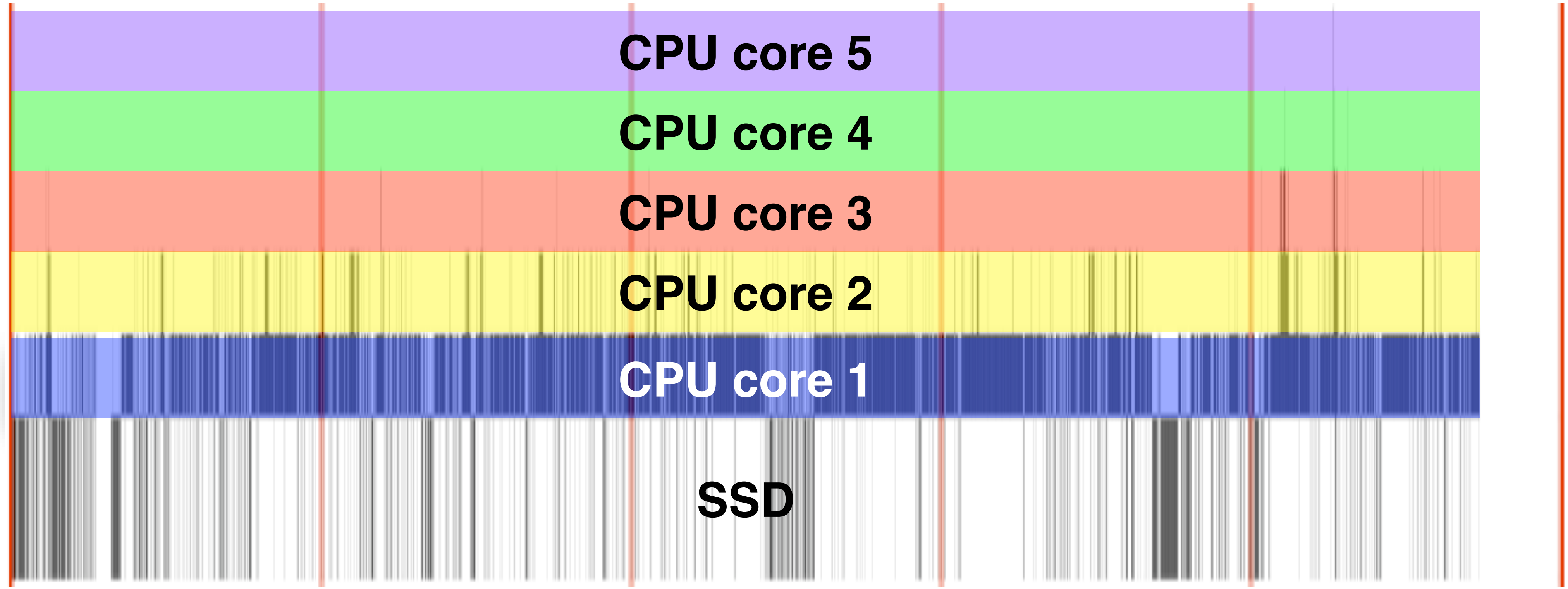
- FAST works as well on HDDs, but ...
  - Application launch on HDDs: I/O bound
  - Little room for overlapping CPU time and HDD access time
  - Launch time reduction: **15%**
- Sorted prefetch performs better
  - Launch time reduction: **40%**



Normalized application launch time on HDD

Determinism on Multi-Core

- We observed determinism even on multi-core CPUs
  - Only one core is active during the most time periods
  - SSD is mostly idle when two or more cores are active



Why not Capturing File I/O?

- Why not simply capture all the file-level I/Os and replay them?
  - Ex) Capture all read() calls using strace
- That's possible, but the problem is...
  - The number of read() calls are extremely large
  - Only few of them will cause page fault, generating a block I/O
  - Replaying all the captured read() calls are inefficient
    - In terms of both prefetcher size and function call overhead
  - Not easy to determine which of them will actually cause page faults
    - May be more complicated than our approach (block-level to file-level I/O conversion)