Concurrency bugs

and tools to find them

CSE 333

James Wilcox

Hi, I'm James

PL/Systems

Ask questions!

Eraser: A Dynamic Data Race Detector for Multithreaded Programs

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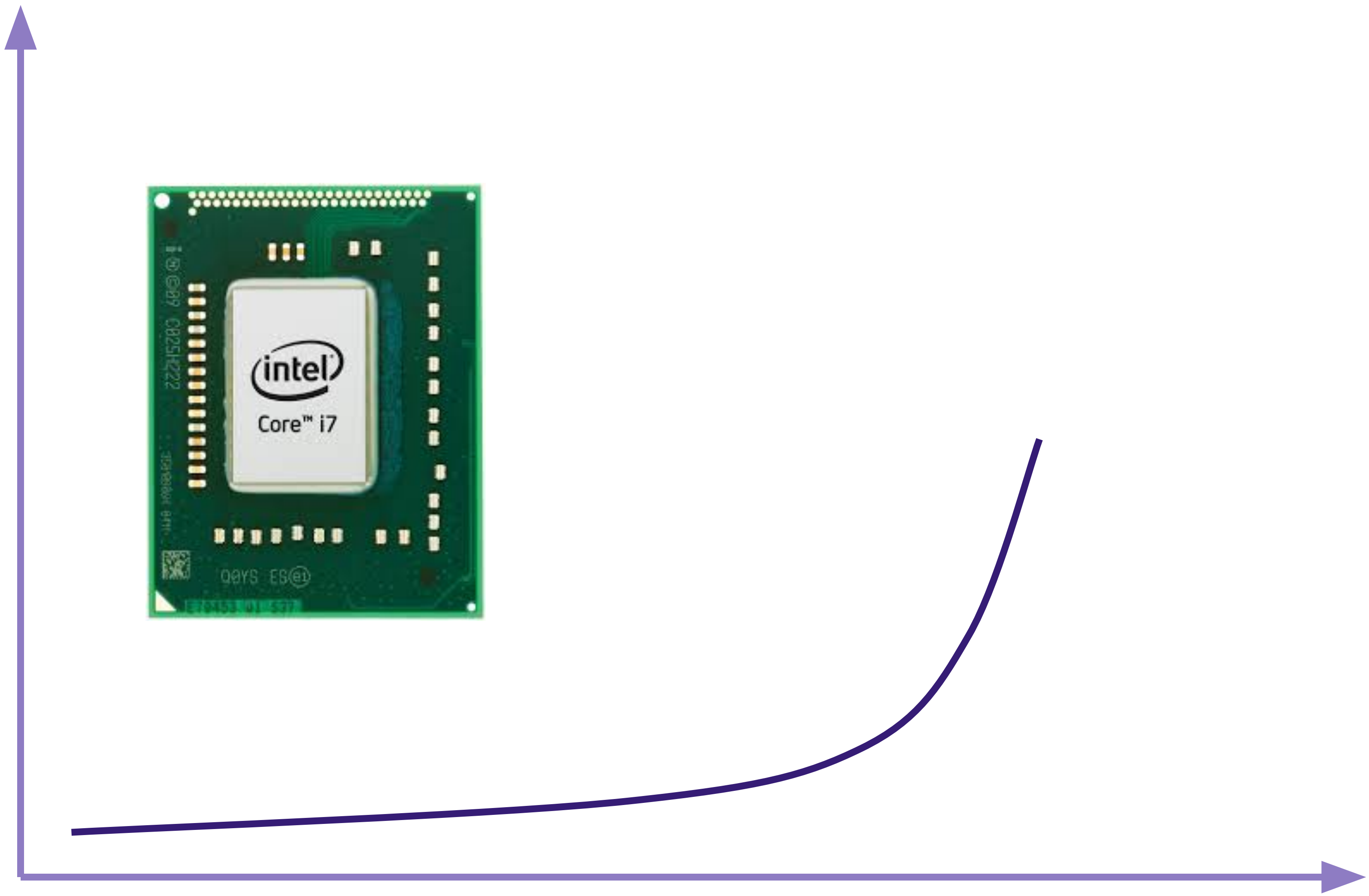
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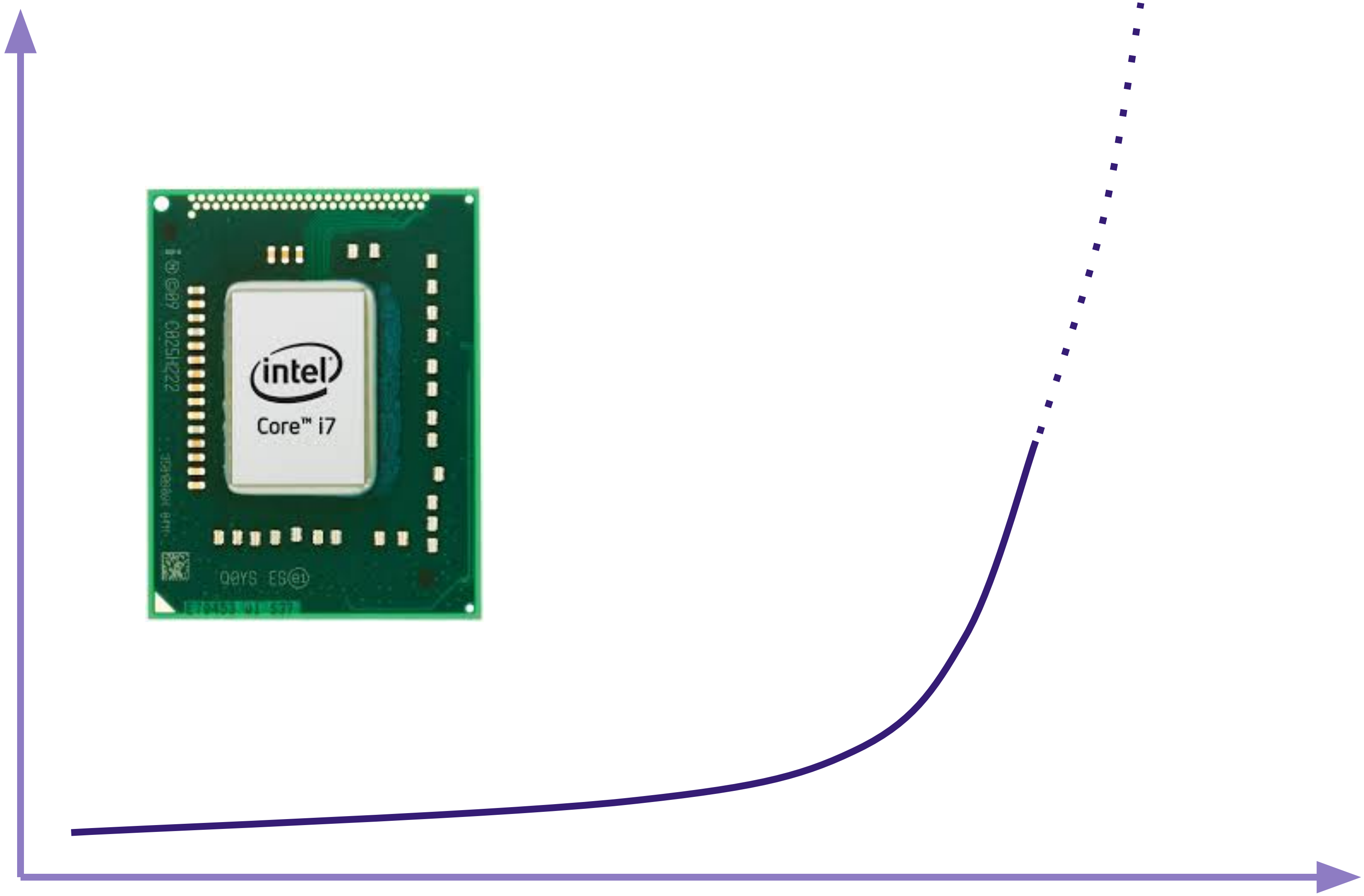
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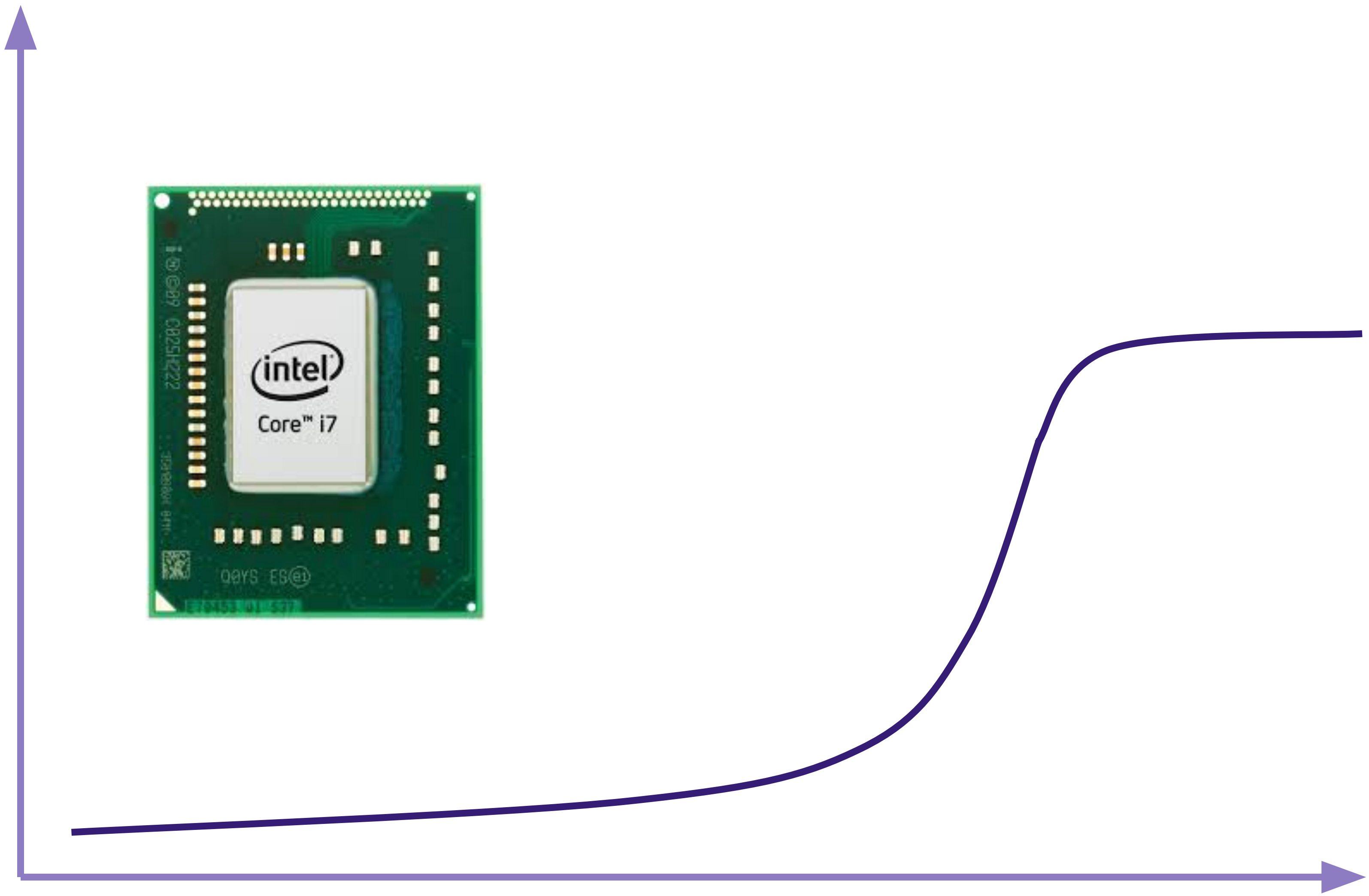
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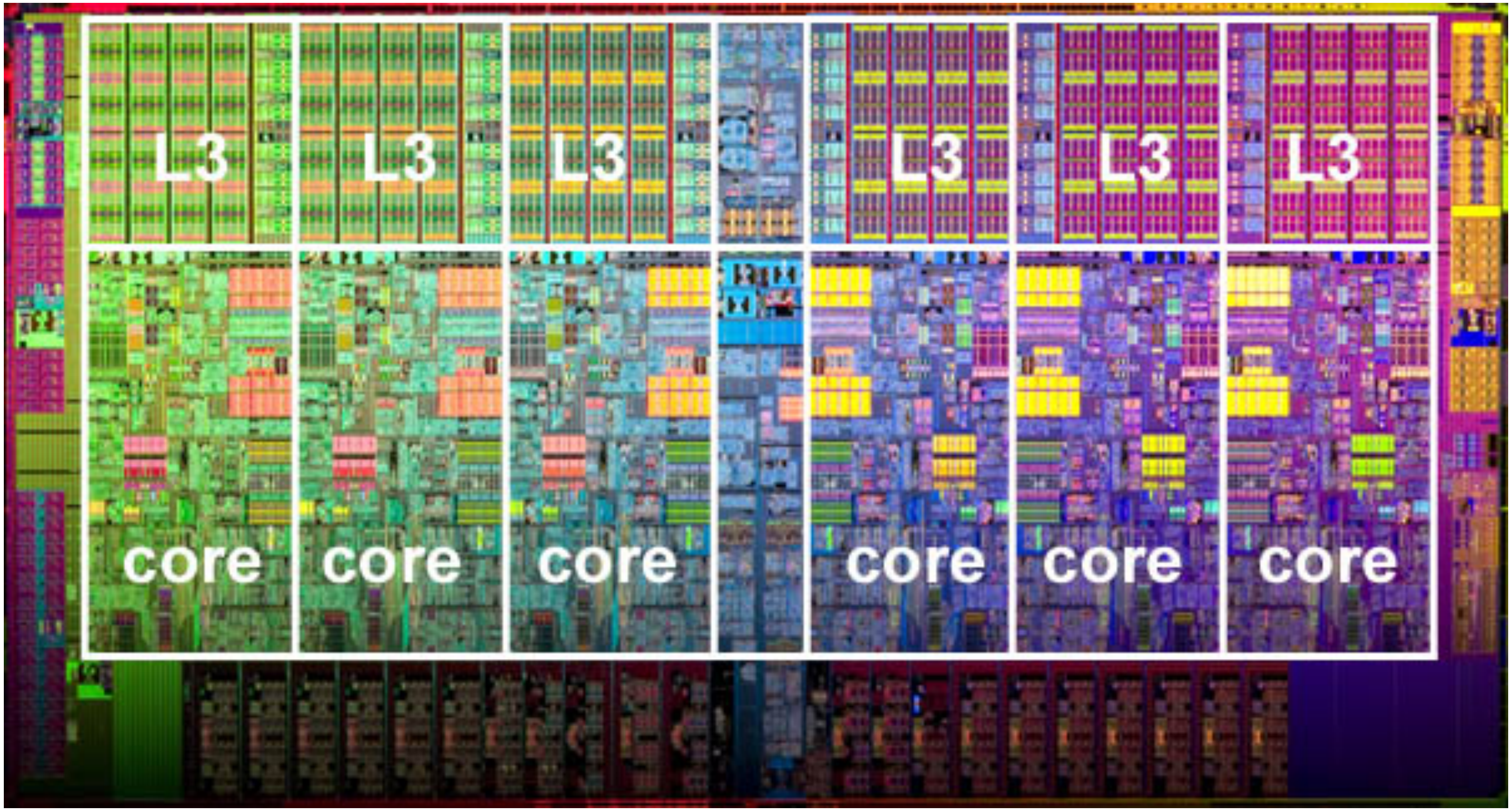
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How multicore programs actually run

Thread 1

```
tmp1 = bal
bal = tmp1 + 10
```

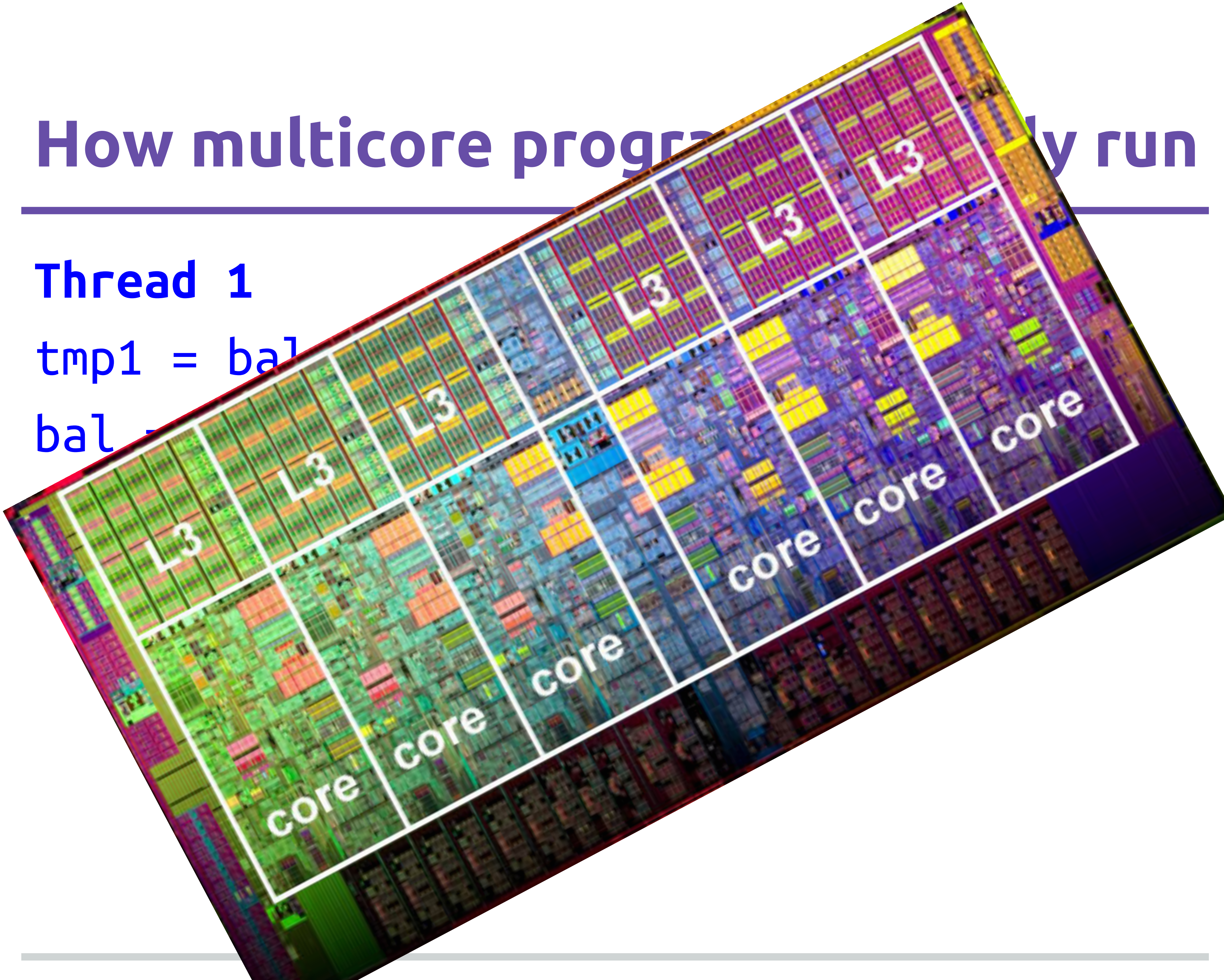
Thread 2

```
tmp2 = bal
bal = tmp2 + 10
```

How multicore progra... ...ly run

Thread 1

```
tmp1 = bal
bal
```



What we probably meant

Thread 1	Thread 2
`tmp1 = bal`	
`bal = tmp1 + 10`	
	`tmp2 = bal`
	`bal = tmp2 + 10`

Interleaving model

The execution behaves as if steps of each thread were interleaved.

Reasoning in Interleaving model

Thread 1	**Thread 2**
`tmp1 = bal`	
`bal = tmp1 + 10`	
	`tmp2 = bal`
	`bal = tmp2 + 10`

Reasoning in Interleaving model

Thread 1 | **Thread 2**

Thread 1	Thread 2
`tmp1 = bal`	
	`tmp2 = bal`
`bal = tmp1 + 10`	
	`bal = tmp2 + 10`

If the program is data race free, then:

The execution behaves as if steps of each thread were interleaved.

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Data races

Two threads access:

the same location

at the same time

at least one of them writes

Happens Before

Lamport 1978. "Time, Clocks, and the Ordering of Events in a Distributed System"

Thread 1	**Thread 2**
`tmp1 = bal`	`tmp2 = bal`
`bal = tmp1 + 10`	`bal = tmp2 + 10`

Thread 1	**Thread 2**
lock m	lock m
tmp1 = bal	tmp2 = bal
bal = tmp1 + 10	bal = tmp2 + 10
unlock m	unlock m

Thread 1

```
lock m
tmp1 = bal
bal = tmp1 + 10
unlock m
```

Thread 2

```
lock m
tmp2 = bal
bal = tmp2 + 10
unlock m
```

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How to find races

Track every memory location

Track happens before

Check every access is ordered

How to find races in practice (Eraser)

Enforce locking discipline

Can be implemented more efficiently

How to find races in practice (Eraser)

Enforce locking discipline

Can be implemented more efficiently

Reports races when no guarding lock
reflects engineering practice

False positives: other sync, “benign” races

Safe languages

segfault -> ArrayOutOfBoundsExceptions

segfault -> NullPointerException

Safe concurrent languages

segfault -> ArrayOutOfBoundsExceptions

segfault -> NullPointerException

data race -> DataRaceException

FTFY

Thread 1	**Thread 2**
`lock m`	`lock m`
`  tmp1 = bal`	`  tmp2 = bal`
`unlock m`	`unlock m`
`lock m`	`lock m`
`  bal = tmp1 + 10`	`  bal = tmp2 + 10`
`unlock m`	`unlock m`

Other ways of finding races

Dynamic

- Efficient HB detectors

Static

- Static lockset
- HB
- Symbolic execution
- Verification

Weak memory models

Ensuring DRF may be prohibitively expensive

Interact directly with hardware memory model

Exposed through, eg, `volatile`

Lock-free data structures/algorithms