High Performance Computing for Engineers

David Thomas

dt10@ic.ac.uk / https://github.com/m8pple

Room 903

https://github.com/HPCE/hpce-2016

High Performance **Computing for Engineers**

- Research
  - Testing communication protocols
  - Evaluating signal-processing filters
  - Simulating analogue and digital designs

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- Products
  - Oil exploration and discovery
  - Mobile-phone apps
  - Financial computing

High Performance *Computing for Engineers*

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  - Throughput
  - Latency
  - Power
  - Design-time
  - Capital and running costs

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  - Design-time
  - Capital and running costs
- Required versus desired performance
  - *Subject to a throughput of X, minimise average power*
  - *Subject to a budget of Y, maximise energy efficiency*
  - *Subject to Z development days, maximise throughput*

What is available to you

- Types of compute device
  - Multi-core CPUs
  - GPUs (Graphics Processing Units)
  - MPPAs (Massively Parallel Processor Arrays)
  - FPGAs (Field Programmable Gate Arrays)

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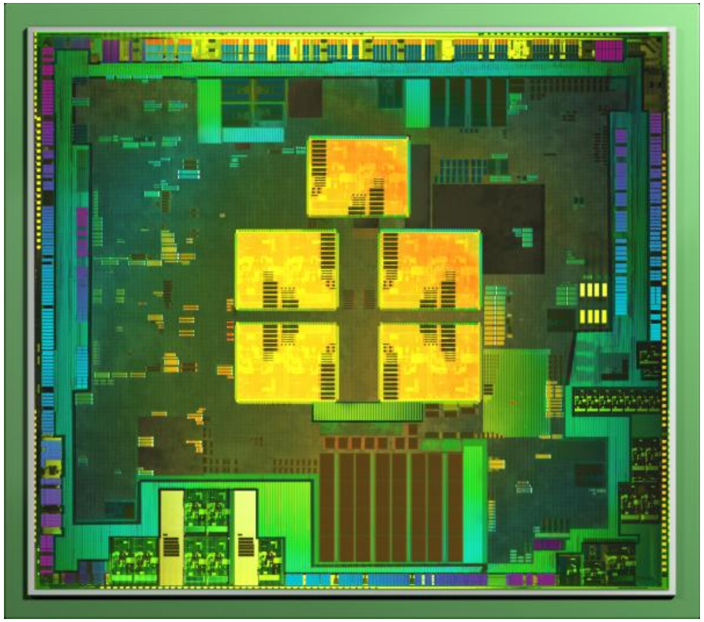
- Types of compute system
  - Embedded Systems
  - Mobile Phones
  - Tablets
  - Laptops
  - Grid computing
  - Cloud computing

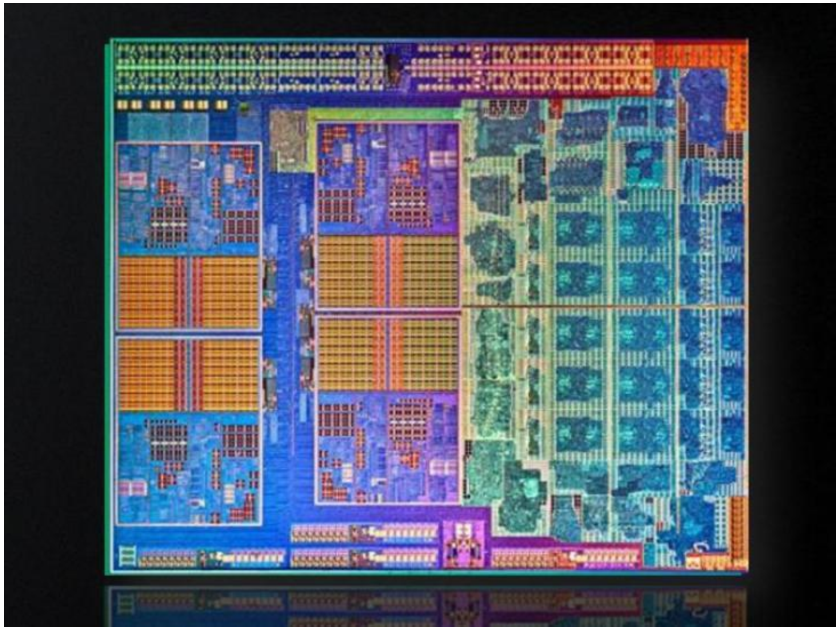
HTC Droid DNA



Snapdragon S4 Pro

- CPU : Quad-core Krait (ARM derivative)
- GPU : Adreno 320 GPU (OpenCL compatible)

Lenovo Thinkpad Edge E525



AMD Fusion A8-3500M

- CPU : Quad-Core 2.4GHz Phenom-II
- GPU : HD 6620G 400MHz (320 cores)

Img:http://laptops-specs.blogspot.com/2011/09/lenovo-thinkpad-edge-e525-specs.html, http://www.techradar.com/images/zoom/amd-llano-965315/index1

Imperial HPC Cluster

- cx1 – cluster of networked machines
  - 1395 nodes (boxes) -> 13558 CPU cores
- cx2 - SGI Altix ICE 8200 EX
  - 456 nodes -> 5272 CPU cores
  - Optimised for MPI (message processing) tasks
- ax4 – one machine: 15TB of RAM + 1280 cores

- Grid-management system
  - Run program on 1000 PCs with one command
  - Available to researchers and undergrads (if they ask nicely)

https://www.imperial.ac.uk/admin-services/ict/self-service/research-support/hpc/
https://wiki.imperial.ac.uk/pages/viewpage.action?title=High+Performance+Computing&spaceKey=HPC

Cloud Computing

- There are now ***big*** commodity cloud providers
  - Amazon Web Services (EC2) : 10x bigger than anyone else
  - Microsoft Azure : 2x bigger than all the rest
  - Google Cloud Platform : public facing cloud is fairly small (?)

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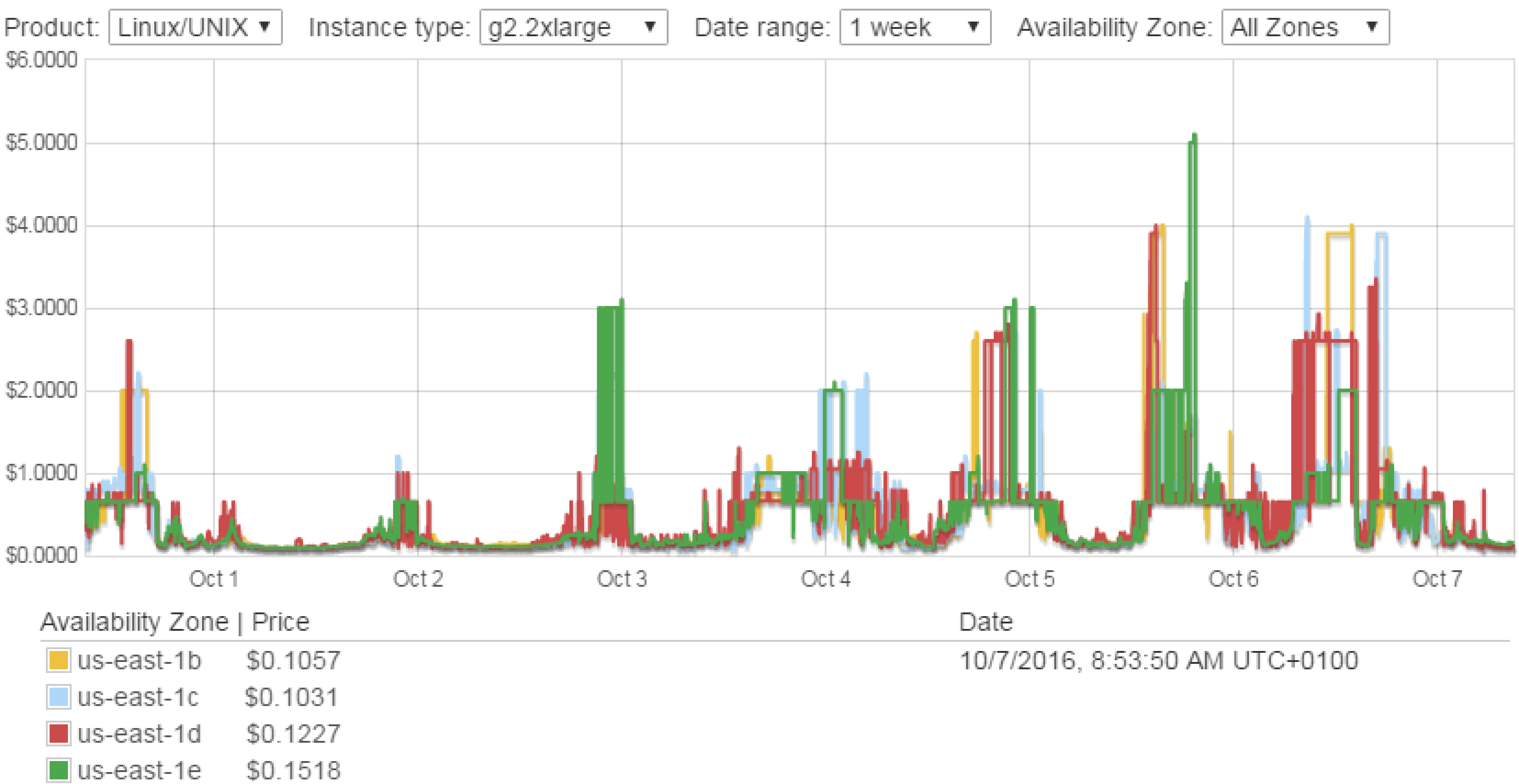
  - On-demand : fixed price for as long as you want
  - Spot-price : price fluctuates according to demand

Pricing can be volatile (and make no sense)



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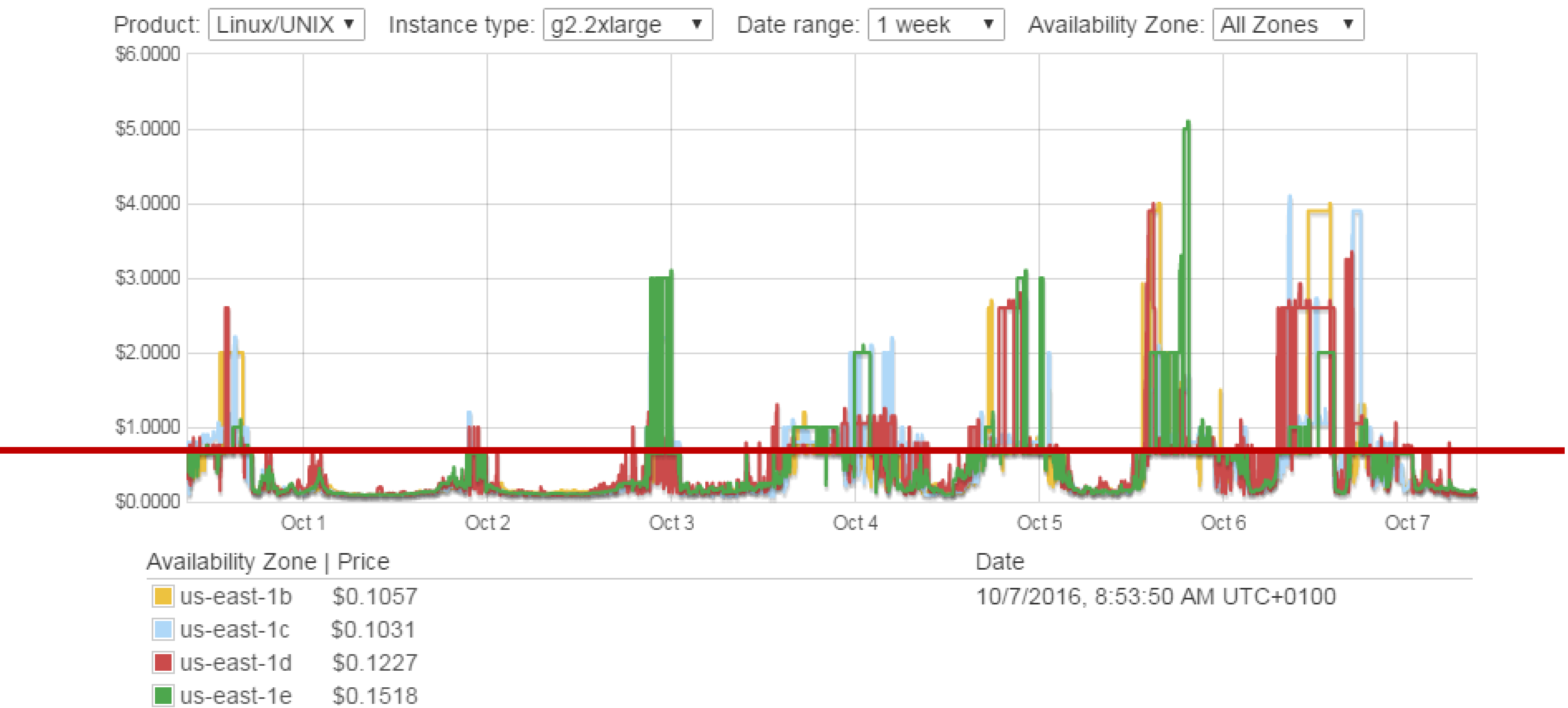
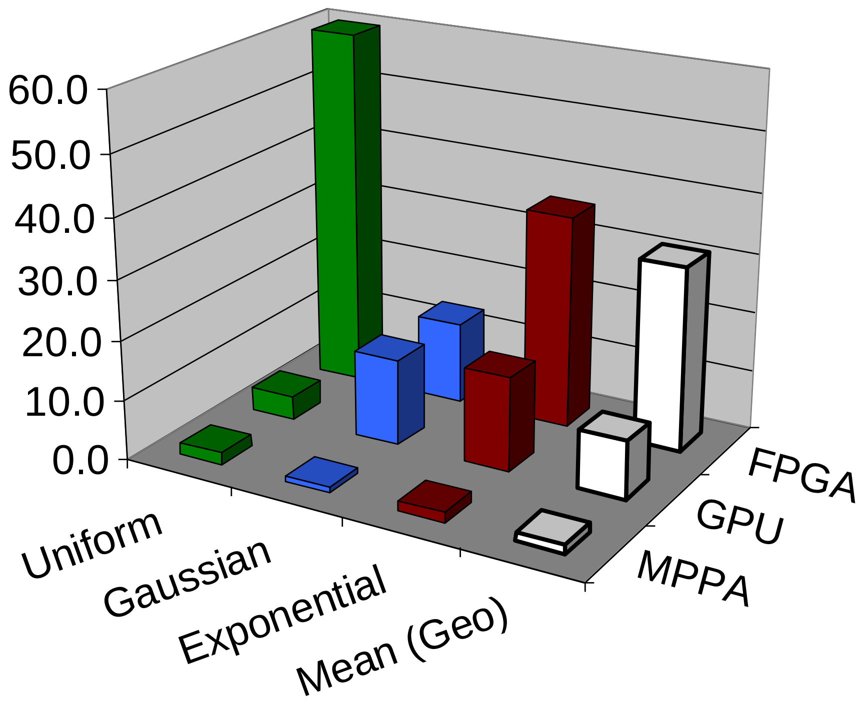
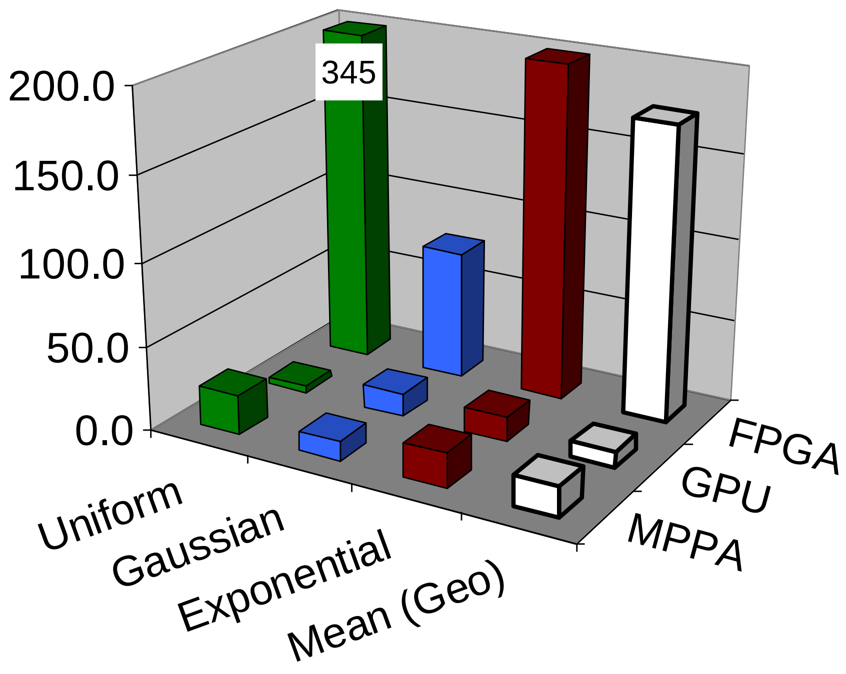


Performance and Efficiency Relative to CPU



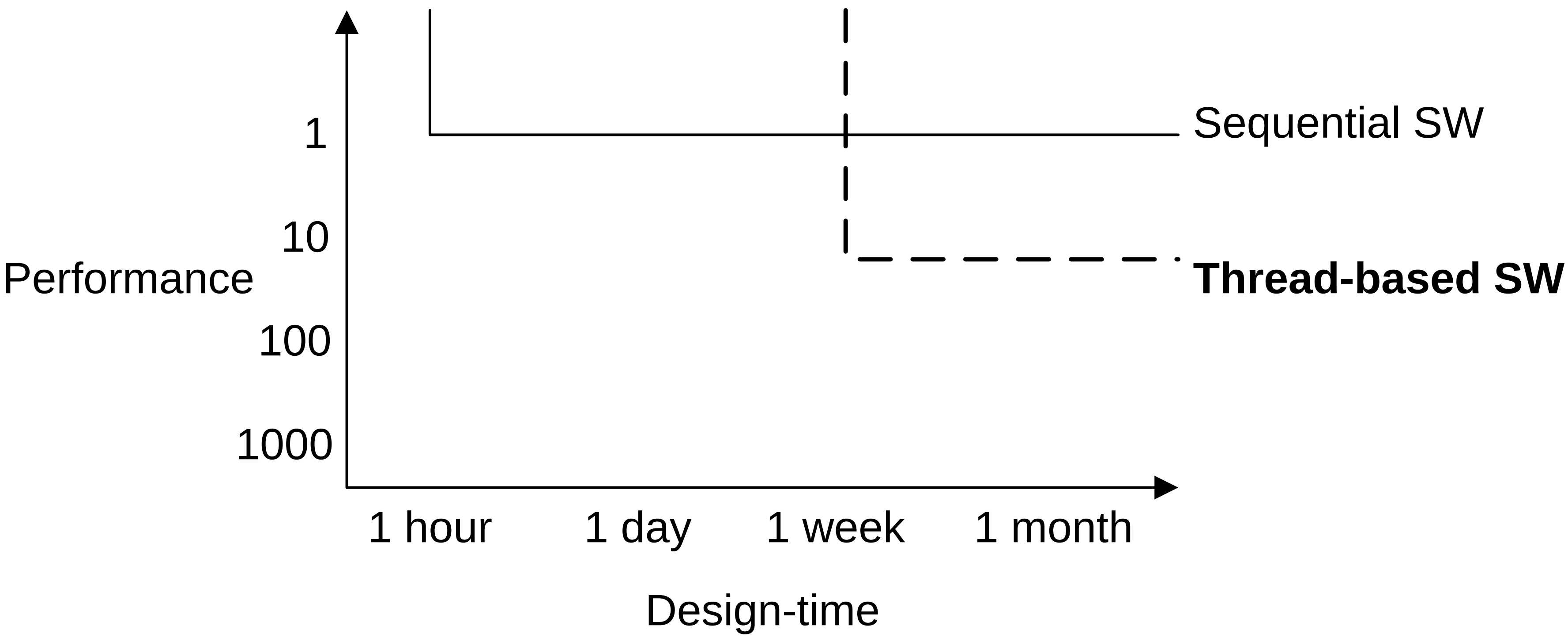
Performance



Power Efficiency

Design tradeoffs

Design tradeoffs



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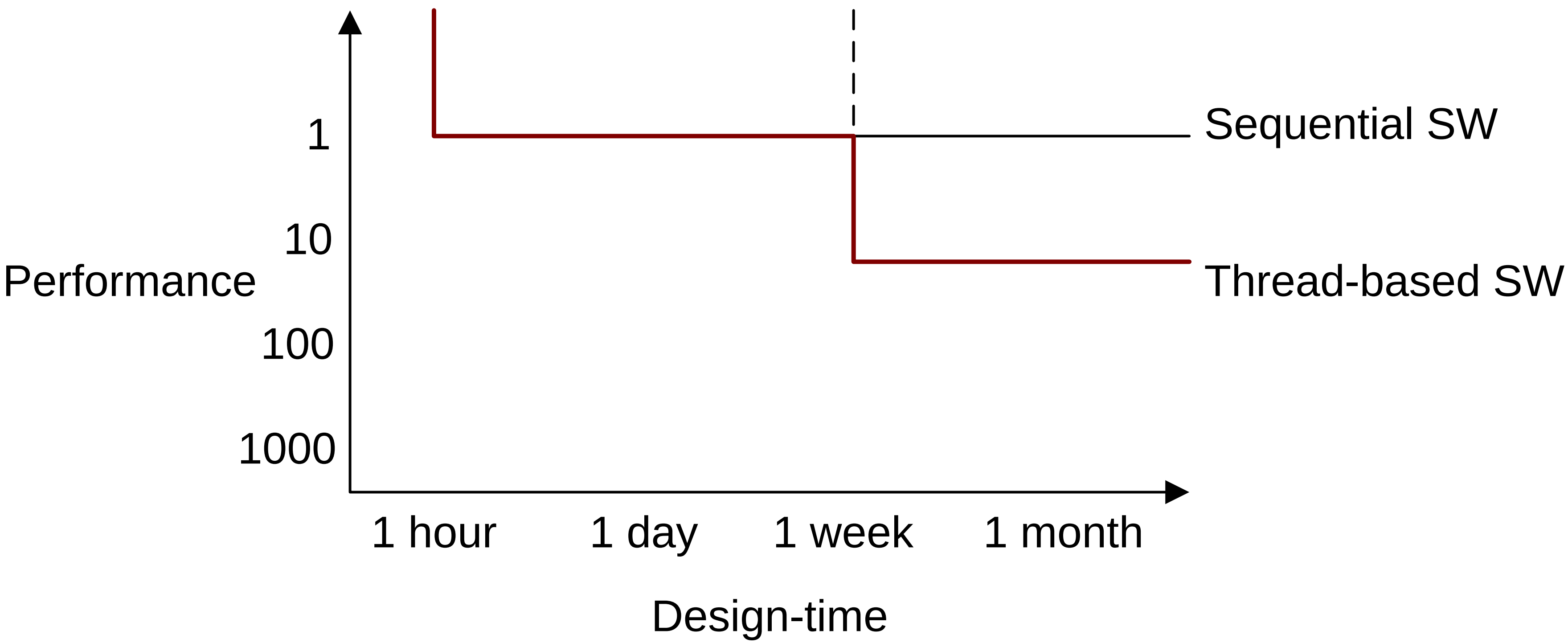

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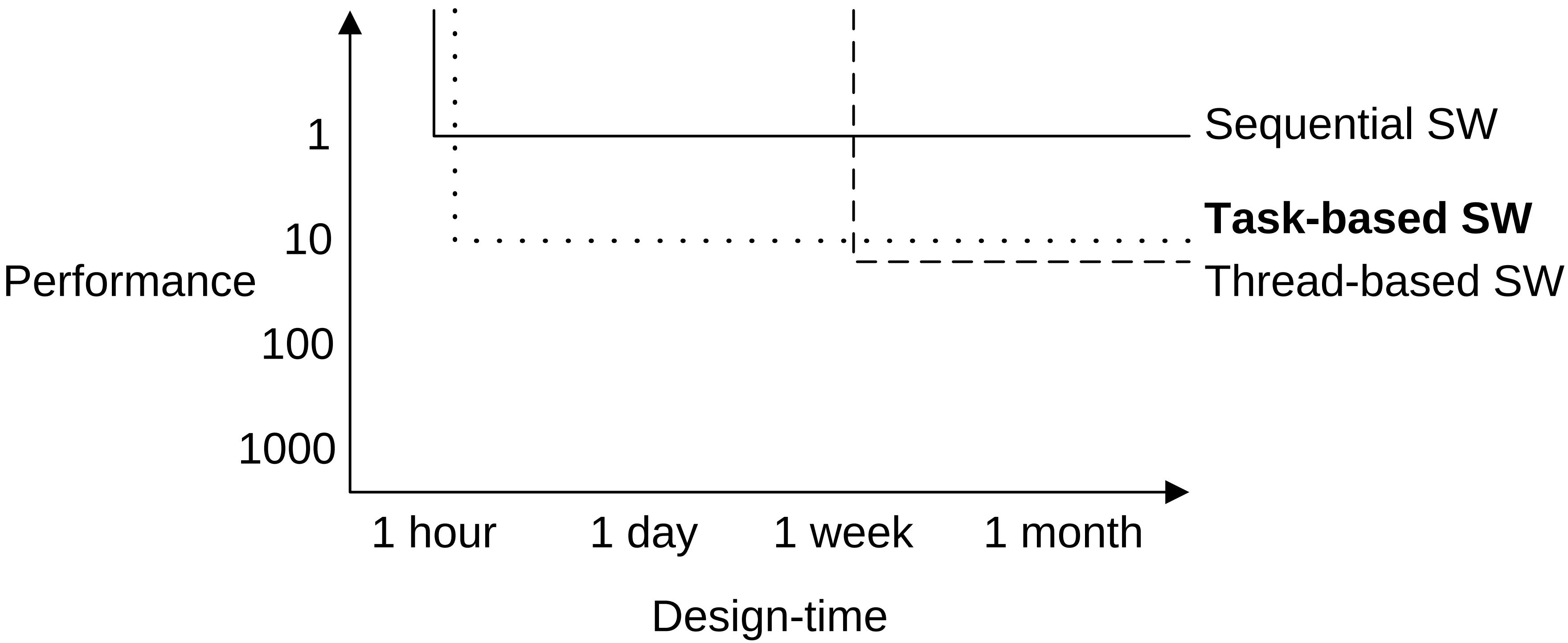


Design tradeoffs

- **Task-based** parallelism vs threads
  - Easy to program (less time coding)
  - Easy to get right (less time testing)
- Many implementations and APIs
  - Intel Threaded Building Blocks (TBB)
  - Microsoft .NET Task Parallel Library
  - OpenCL

ntial SW

ased SW

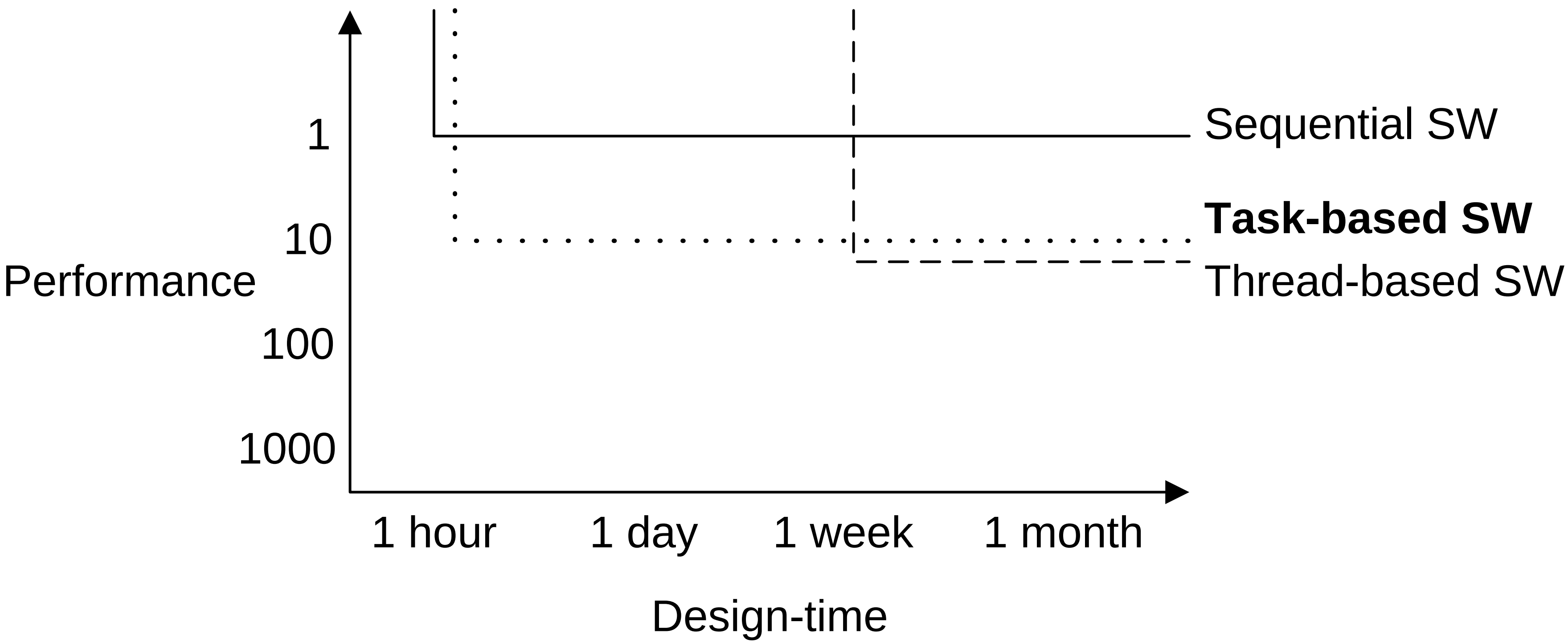
Performance

-based SW

1

Design-time

Design tradeoffs



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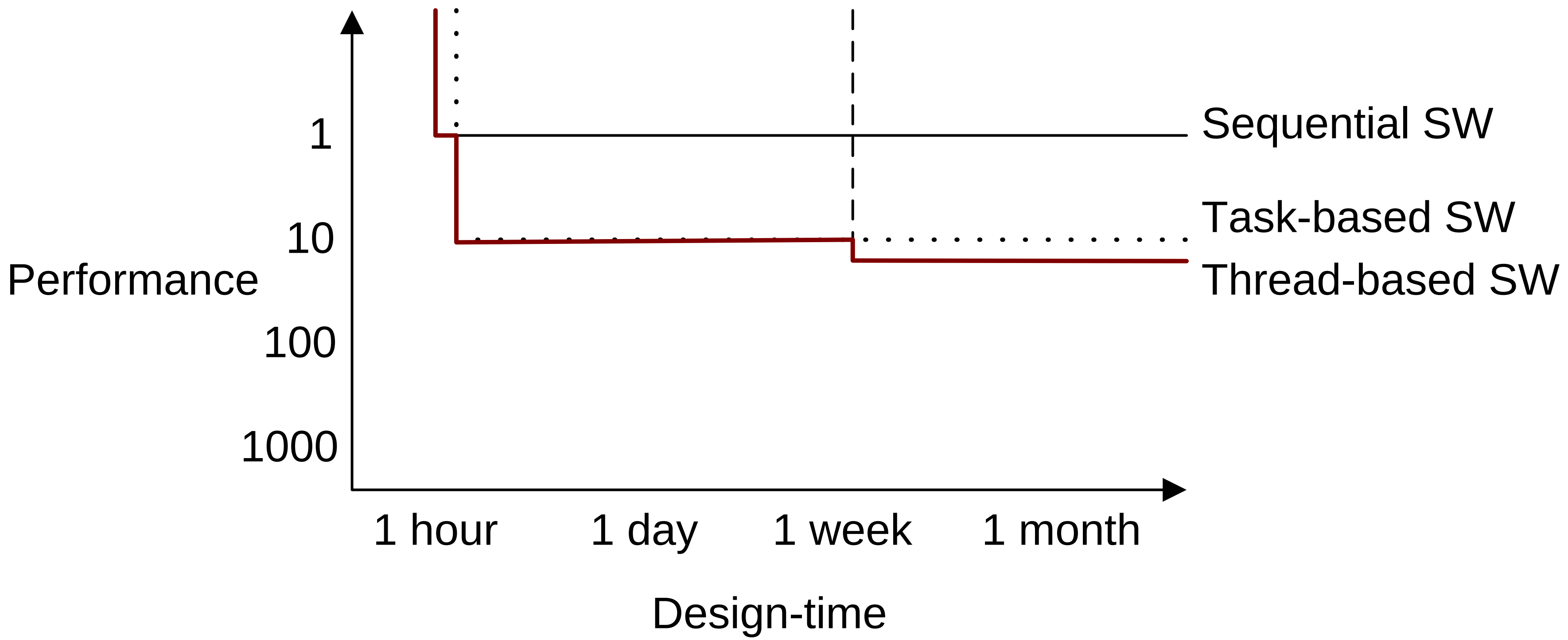
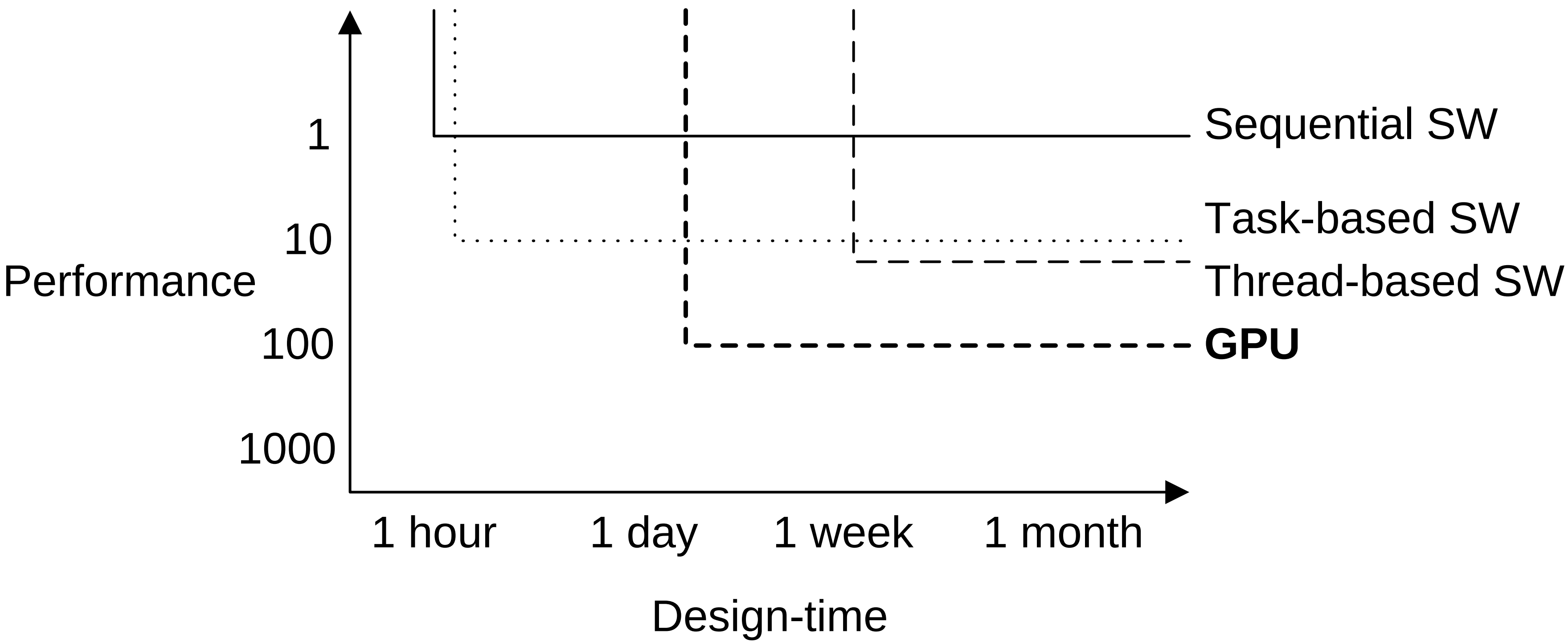
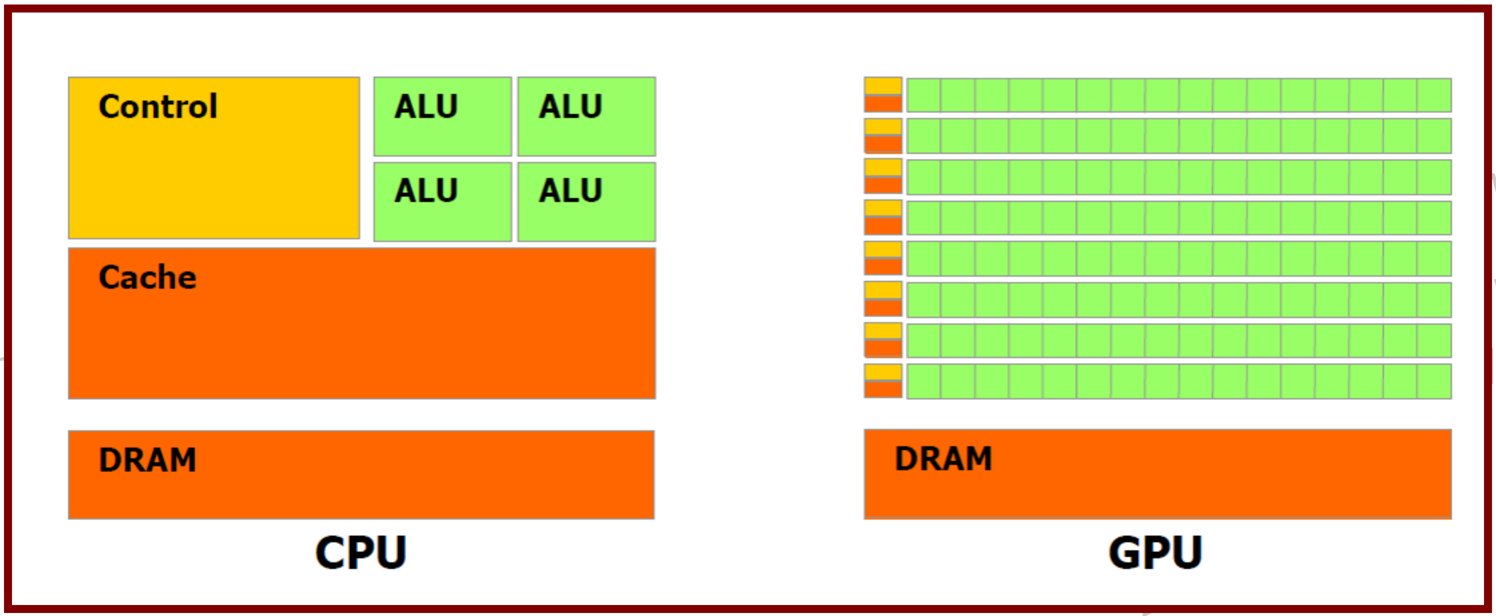


Design tradeoffs



Design tradeoffs

Perform



V

W

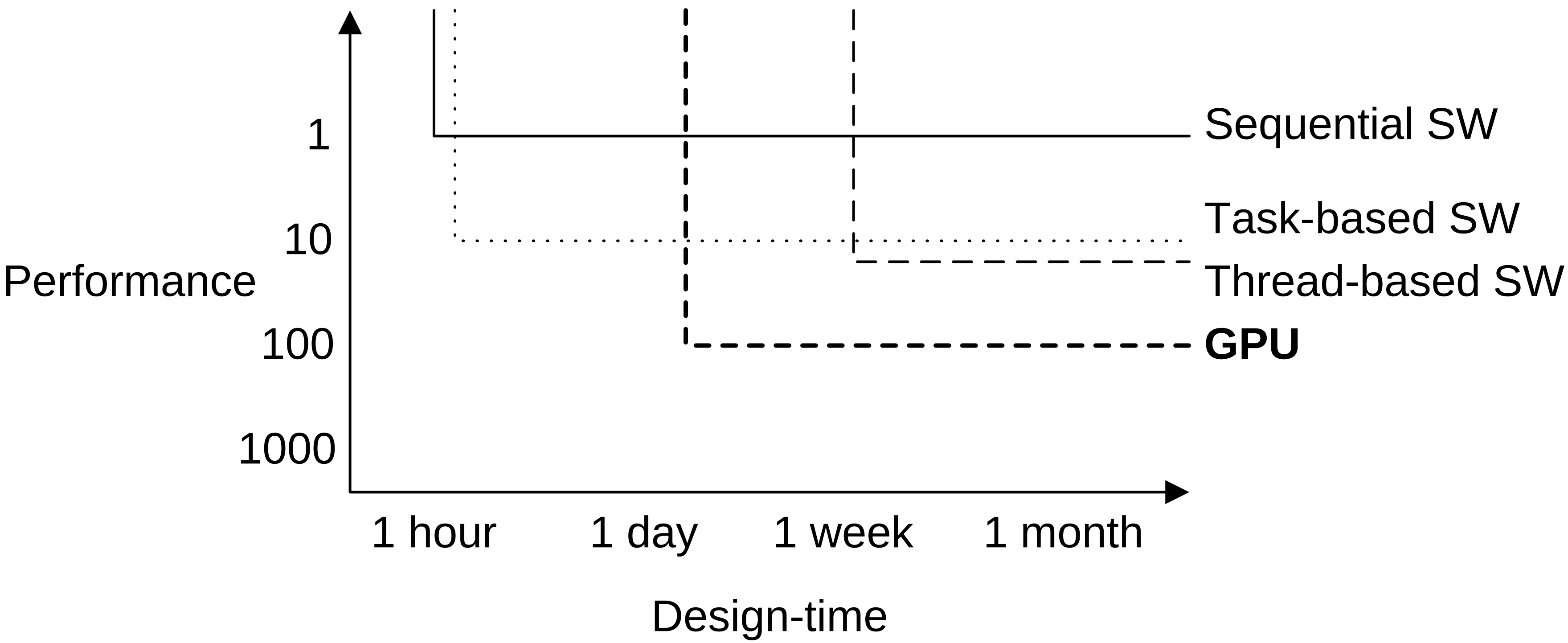
SW

1 hour 1 day 1 week 1 month

Design-time

Src: NVIDIA CUDA Compute Unified Device Architecture, Programmers Guide

Design tradeoffs



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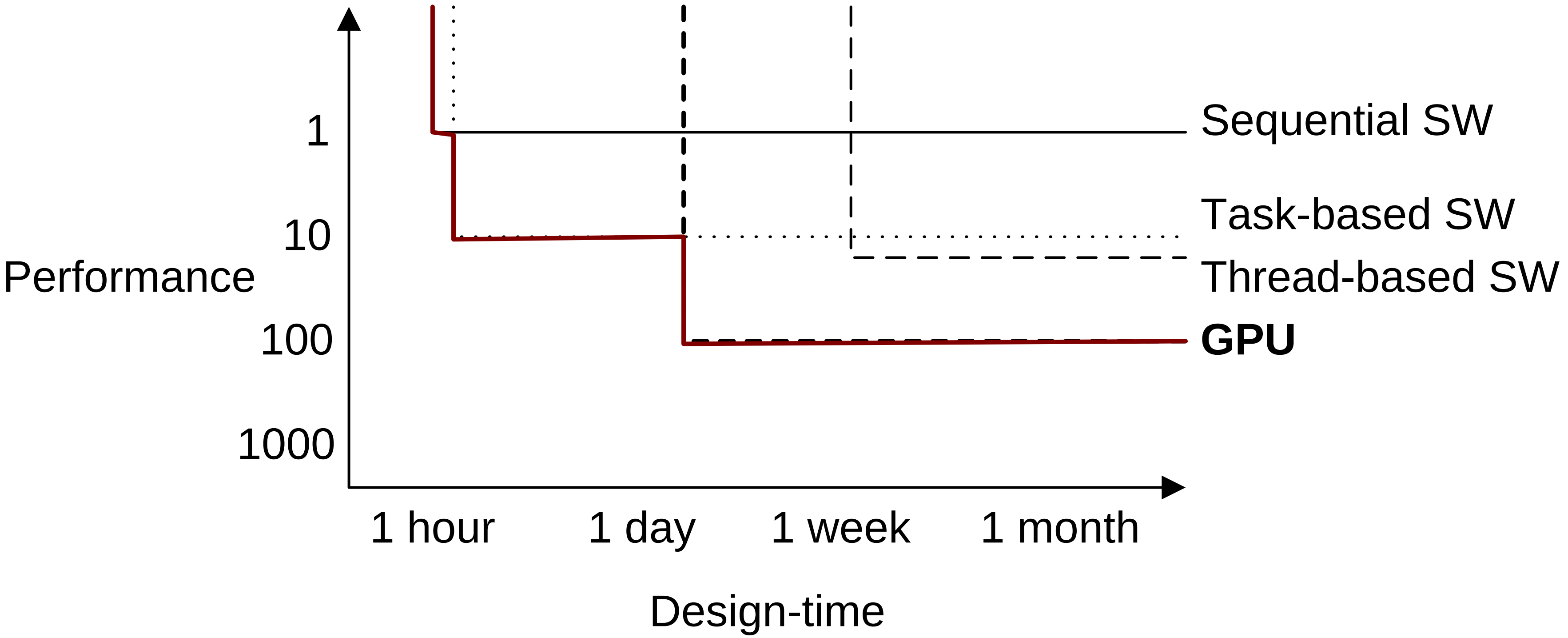

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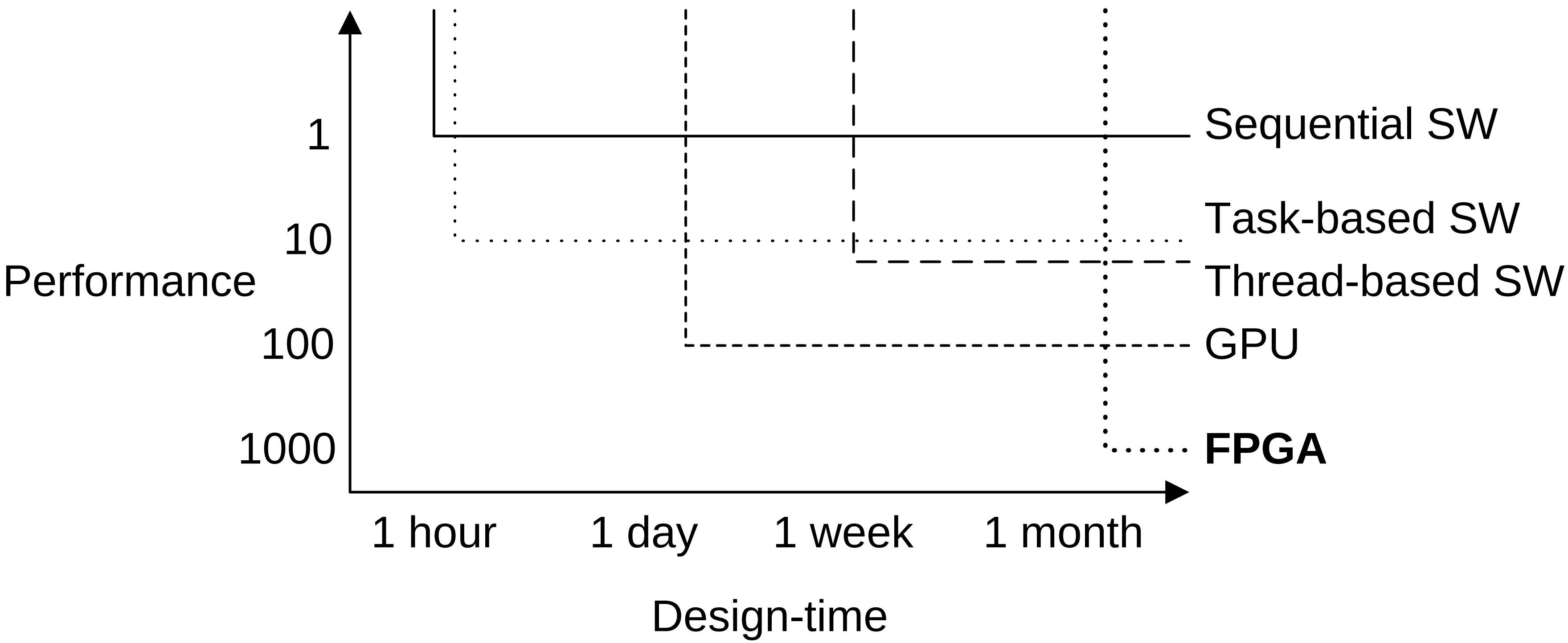

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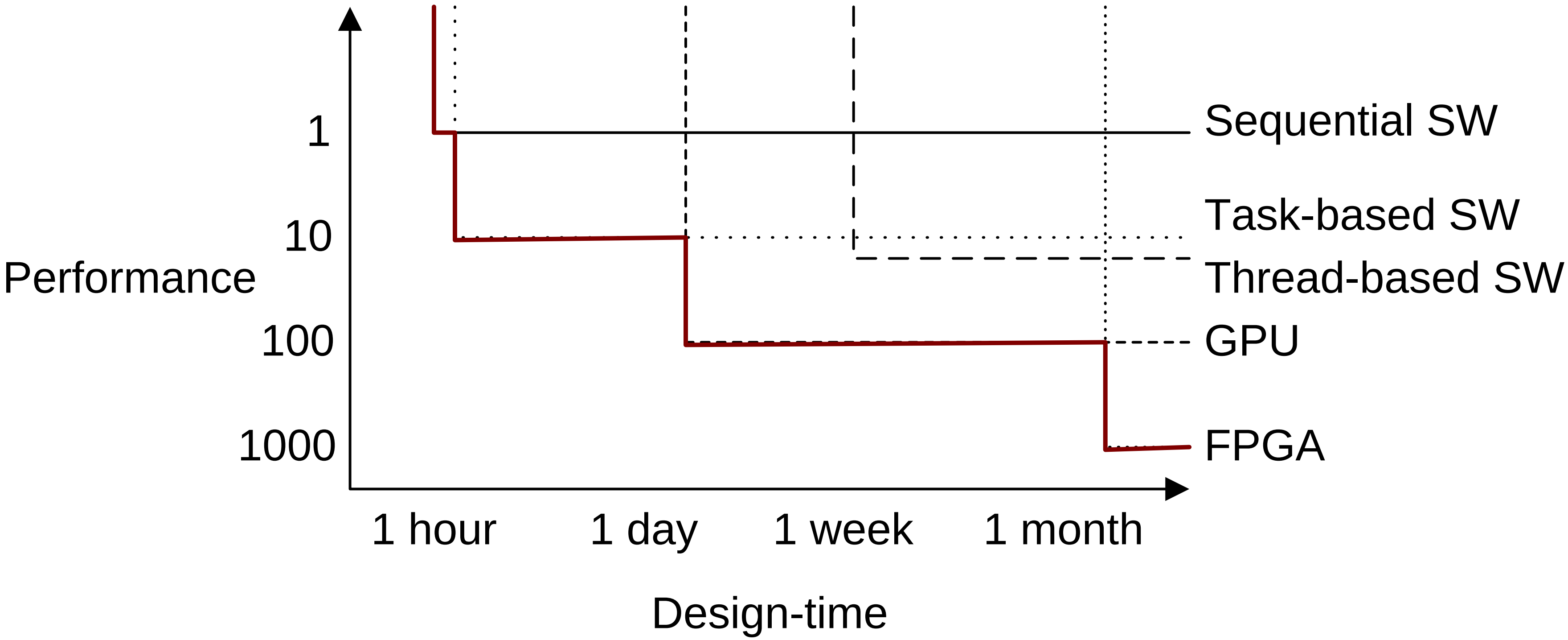
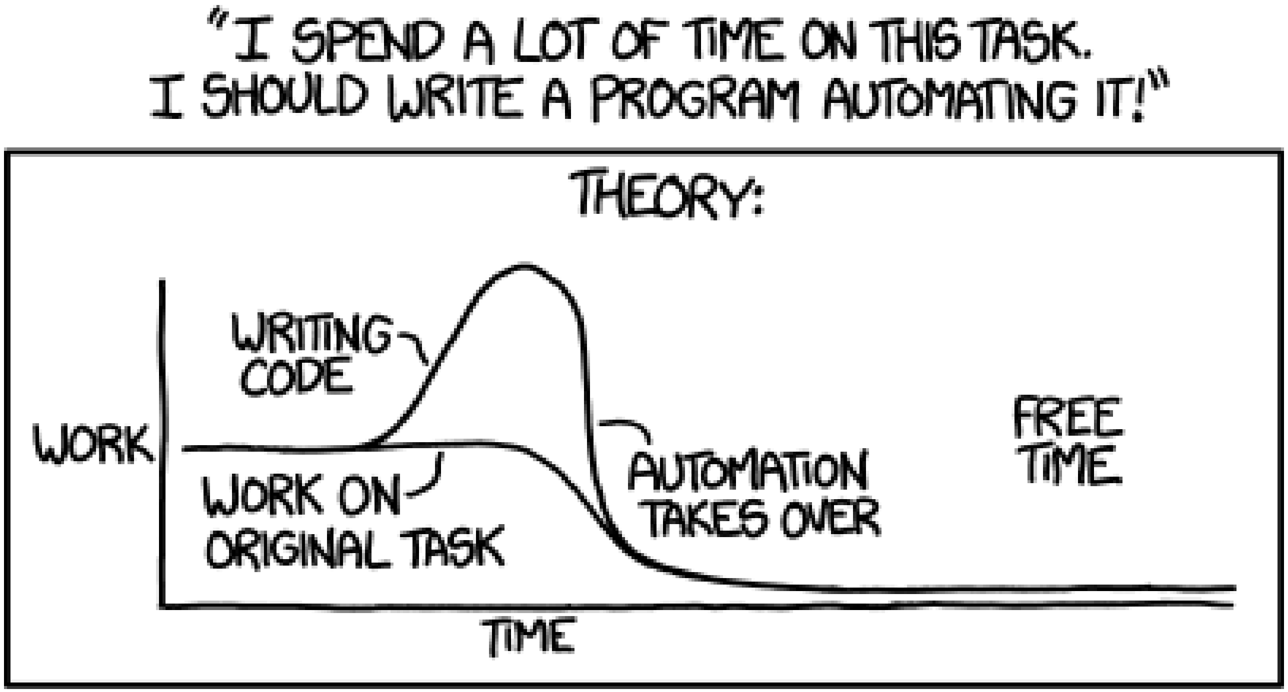


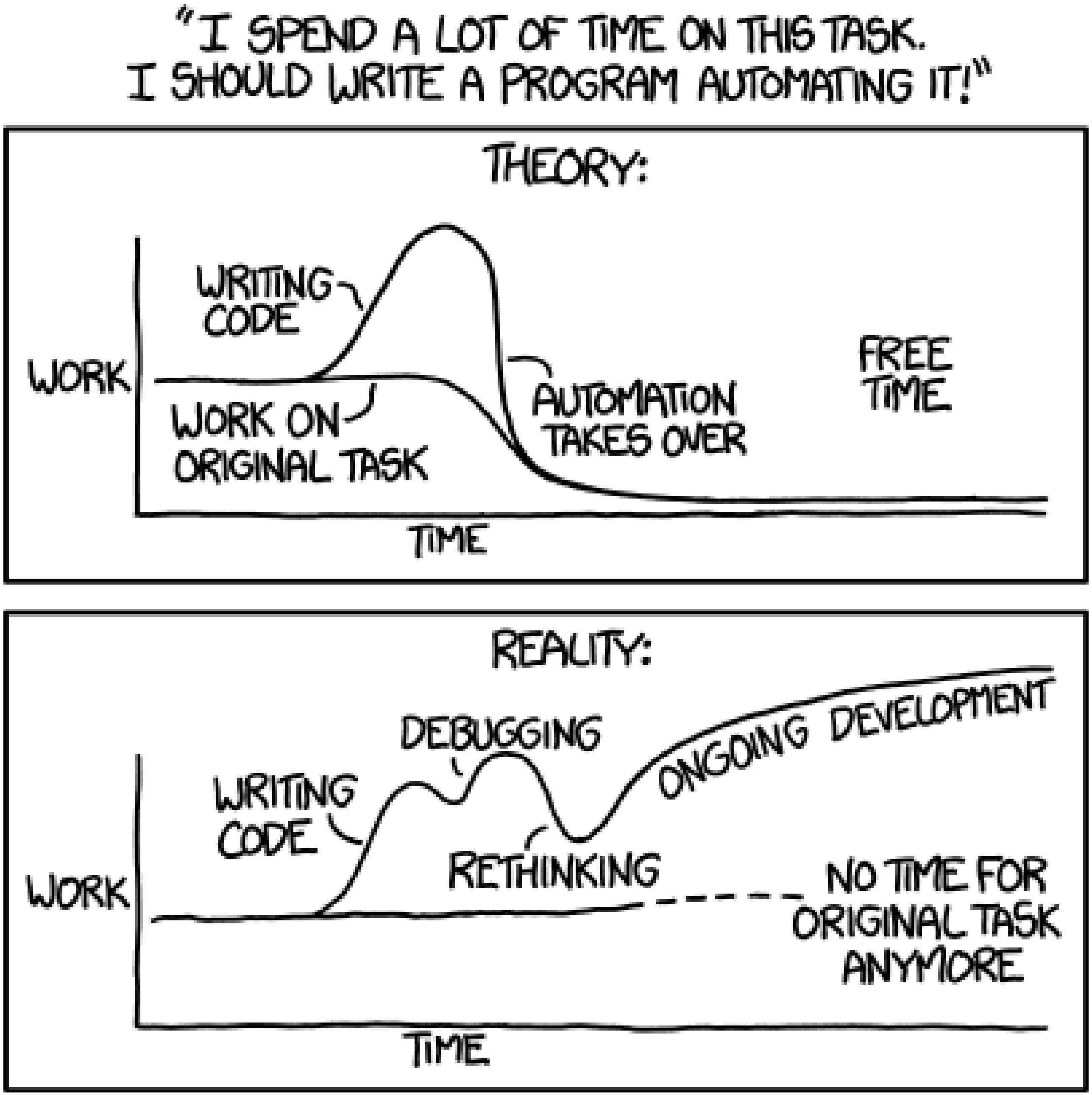
What you will learn

- **Systems**: what high-performance systems are available
- **Methods**: how these systems can be programmed
- **Practise**: concrete experience with multi-core and GPUs
- **Analysis**: knowing what to use and when
- **Tools**: making better use of your time



Developer productivity
is also part of performance

http://xkcd.com/1319/



http://xkcd.com/1319/

Re: XKCD - My Professional Context

- Undergraduate degree and PhD from Computing
  - If pushed, I self-identify as a “programmer”
- Research focuses on hardware acceleration
  - Both academic and industrial applications
- My motivation for this course
  - Supervising final year project students
  - Working with PhD students
  - Talking to industry people

Why are you here?

Course Assessment

- 40% : Four short exercises to build skills
  - Get familiar with environments and how to do common tasks
  - Structured and quite linear – should not be taxing
  - Force people to do work earlier in term

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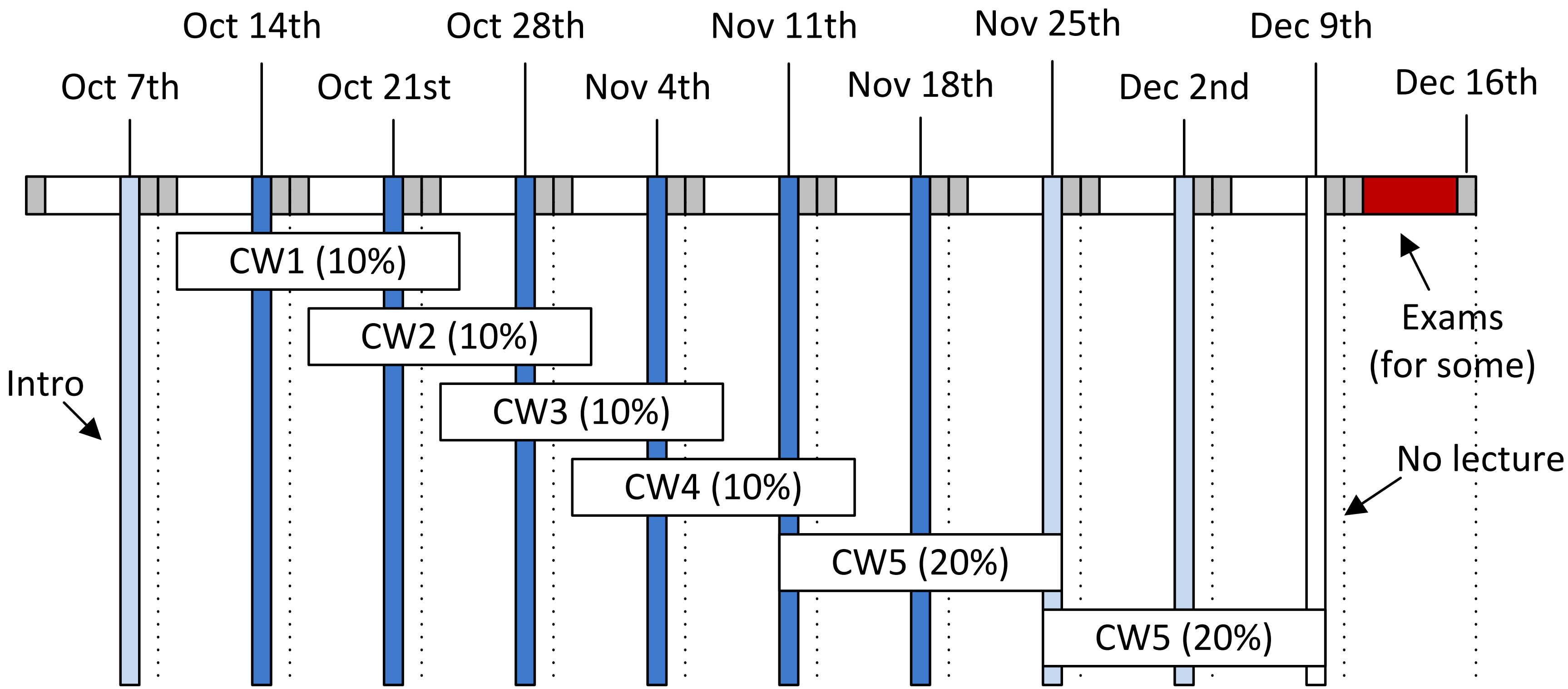
  - Unstructured; open-ended; competitive; hard
- 20% : Oral assessment; individual
  - 30 minutes each, will happen at the start of spring term
  - Test ability to communicate about your code and solutions
  - (Check that you did the work)

Timetable



- Moved to 2-hour blocks (Bleh. Makes the timetable easier)
- Try to place lectures *within* first four courseworks
- Avoid exams at the end of term

Feedback

- Feedback != grades
  - Feedback is formative : what worked, what is going well, ...
- 100% coursework isn't intended to give instant marks
  - But... it is supposed to have fast feedback
  - Should be fast enough to be useful during learning process

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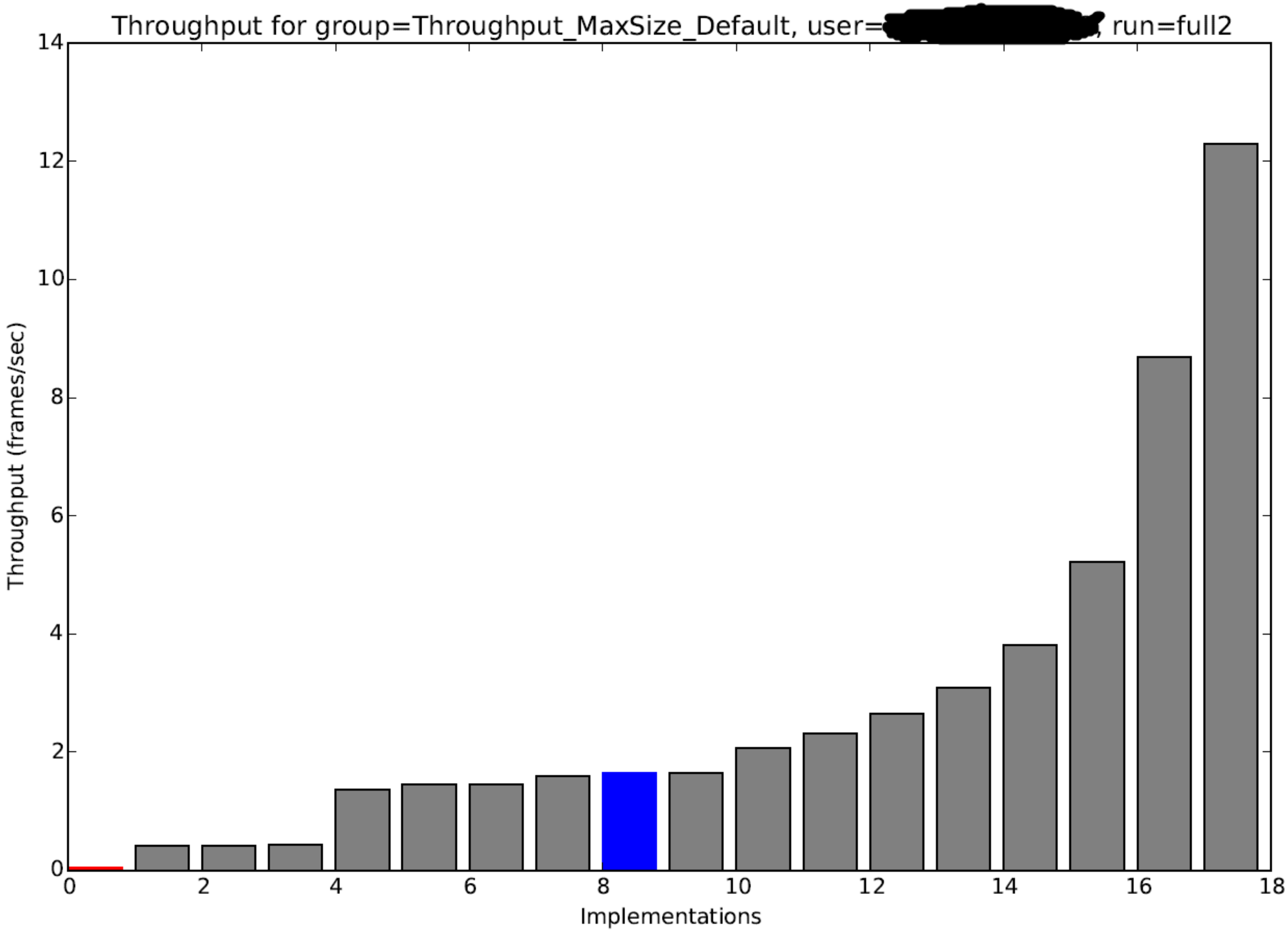
- Looking at previous years:
  - Success : discussions with me + students via github issues and PRs
  - Success : feedback during CW5 and CW6 via git
  - Success : orals are a good point for reflection (students say so!)
  - Failure : timing of CW1-CW4. Too variable, takes too long


Throughput for group=Throughput_MaxSize_Default, user=[redacted], run=full2
Throughput (frames/sec)
Implementations
0
2
4
6
8
10
12
14
16
18

Approach to CW1-CW4 feedback

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- Formative feedback is on demand
  - Ask a question about submission on github
  - Ask a question in class

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- Basic programming
  - If you can’t program in _any_ language then worry
- Intel TBB uses C++ rather than C
  - Some weird C++ stuff, but not scary: *explained in lectures*
  - Setup and basics covered in coursework
- GPU programming uses OpenCL (C-like)
  - Let’s you use whatever graphics card you happen to have
  - Working examples, explained in lectures
  - Language and compiler setup covered in coursework

- Not expected to become a guru, just make it faster

Key Focus: Engineering

- How does this apply to you?

- Examples from Elec. Eng. problems
  - Mathematical analysis
  - Simulation of digital circuits
  - VLSI circuit layout
  - Communication channel evaluation

- Tools and languages used in EE
  - C / C++
  - MATLAB

Course admin

- Slides on the course homepage
  - https://github.com/HPCE/hpce-2016
- Blackboard site is not used very much
  - (Why? Because I can automate git. No clicks)
- Other tools/sites we will be using
  - github : various forms of code distribution and submission
  - AWS (Amazon Web Services) for multi-core and GPUs later on
- Bring a device to lectures (laptop, tablet, charged phone)

The almighty git

- Git (and github) is used extensively in this course
  - As a method of distributing information + coursework
  - As a means of communication and clarification (issues)
  - As a way to provide online feedback (pushes during CW)
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- You ***do*** need a github account

Platforms

- I don't care what platform/OS you use, as long as:
  - You have access to a bash-like command line
  - You have a fairly modern C++ compiler
  - There is more than one CPU
- Reasonable choices are:
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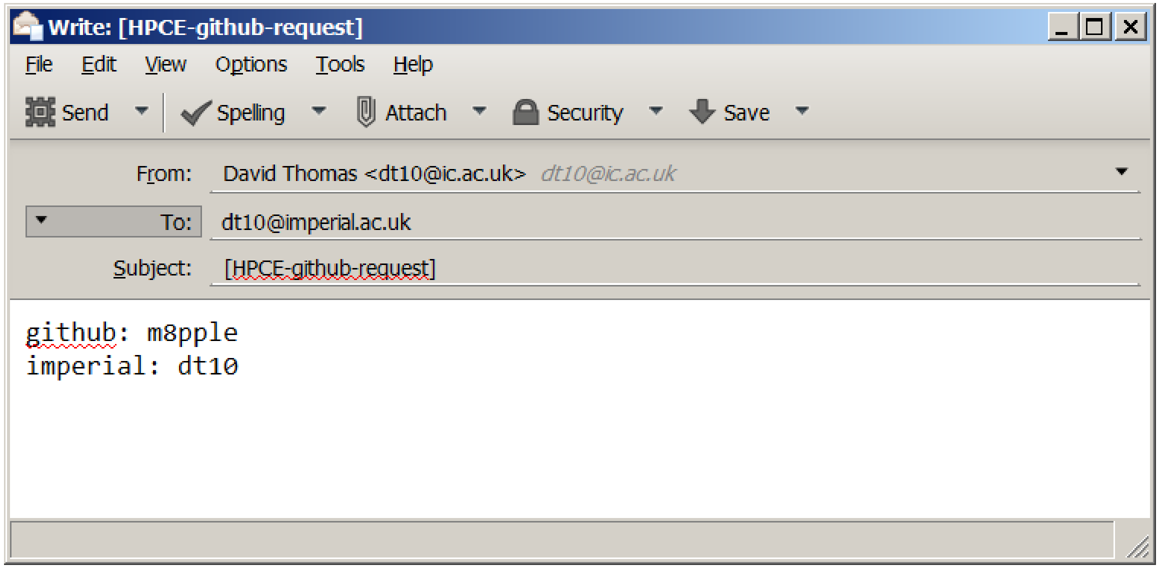
  - Note: you can do dev on one platform, eval on another
- Eventually you will use AWS GPU instances
  - No GUI. Not even on this continent.

Action

- If you want to take this course then:
  1. Get a github account
  2. Send me an email:
     - Subject: “[HPCE-github-request]”
     - Body: github id + your Imperial ***login*** (the short one)



How do you do well in this course?

Simple example : Totient function

- Eulers totient function: totient(n)
  - Number of integers in range 1..n which are relatively prime to n
  - Integers i and j are relatively prime if gcd(i,j)=1

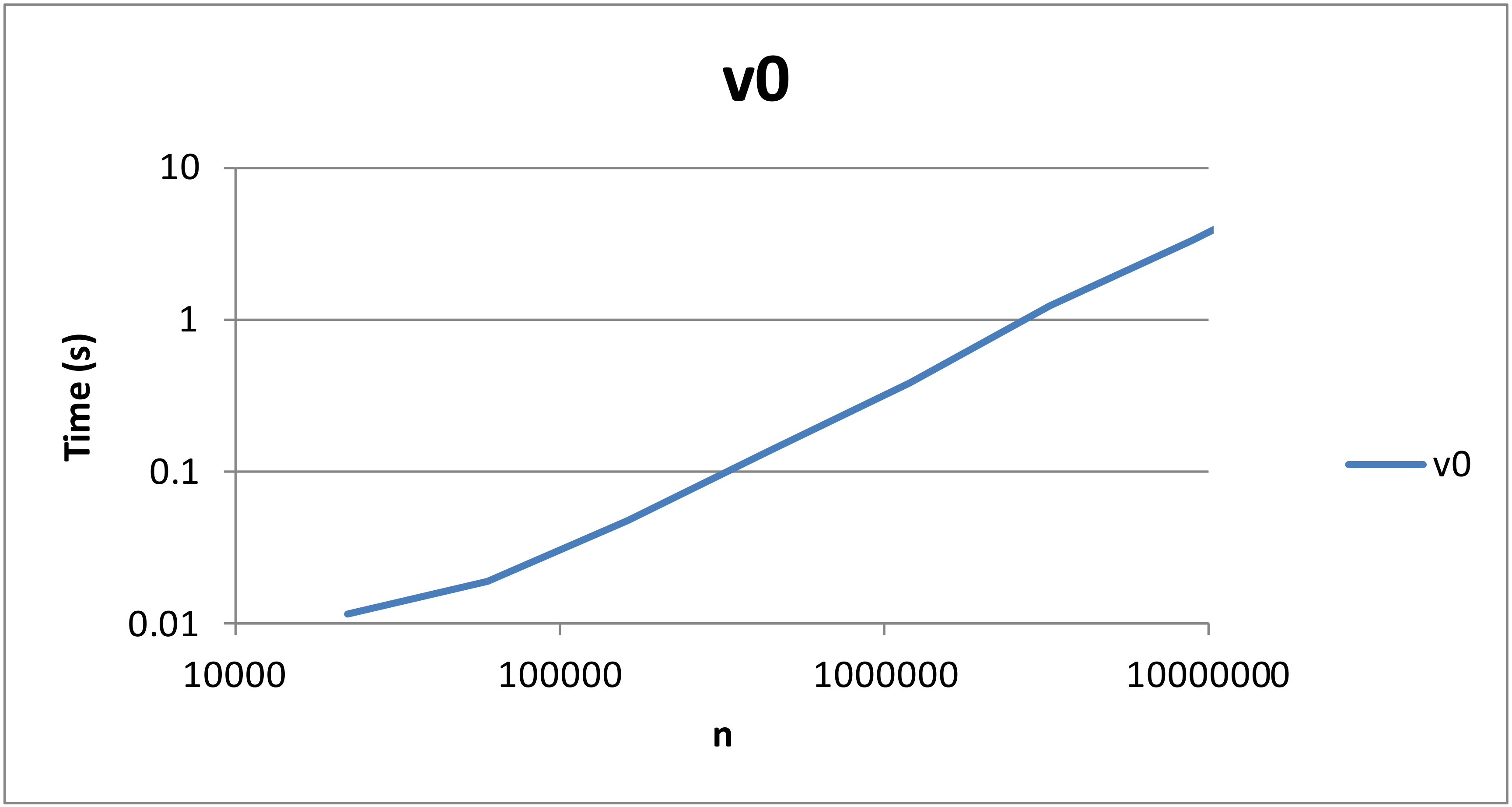
Version 0 : Simple loop

- Eulers totient function: totient(n)
  - Number of integers in range 1..n which are relatively prime to n
  - Integers i and j are relatively prime if gcd(i,j)=1

```
unsigned totient_v0(unsigned begin, unsigned end)
{
    unsigned count=0;

    for(unsigned i=begin; i<end; i++){
        count = count + gcd(i);
    }

    return count;
}
```

/vagrant/lec0

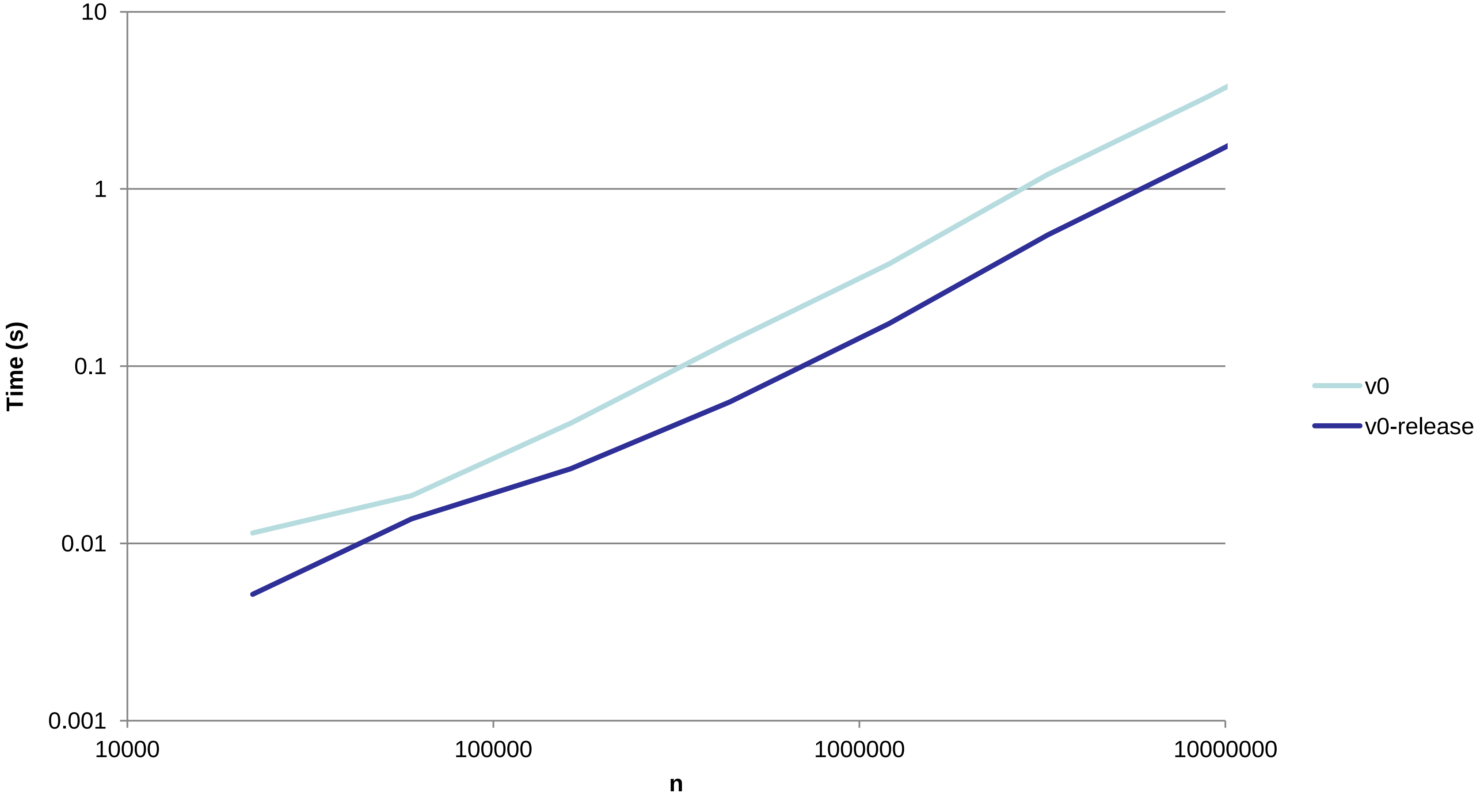
```
vagrant@debiancontrib-jessie /vagrant/lec0
$

vagrant@debiancontrib-jessie /vagrant/lec0
$ g++ -std=c++11 -o totient_v0 totient_v0.cpp

vagrant@debiancontrib-jessie /vagrant/lec0
$ ES=" 10 11 12 13 14 15 16 17 18";

vagrant@debiancontrib-jessie /vagrant/lec0
$ for e in $ES; do ./totient_v0 $e; done
e^10.000,      22026,       7340,  0.011545
e^11.000,      59874,      18752,  0.029131
e^12.000,     162754,      77076,  0.047173
e^13.000,     442413,     294936,  0.141477
e^14.000,    1202604,     369408,  0.384869
e^15.000,    3269017,    3264016,  1.241035
e^16.000,    8886110,    3367296,  3.366319
e^17.000,   24154952,   11599680,  9.706297
^C

vagrant@debiancontrib-jessie /vagrant/lec0
$ |
```


v0
10
1
0.1
0.01
Time (s)
10000
100000
1000000
10000000
n
v0

Turn on optimisation!

/vagrant/lec0

```
e^13.000,     442413,     294936,  0.141477
e^14.000,    1202604,     369408,  0.384869
e^15.000,    3269017,    3264016,  1.241035
e^16.000,    8886110,    3367296,  3.366319
e^17.000,   24154952,   11599680,  9.706297
^C

vagrant@debiancontrib-jessie /vagrant/lec0
$ g++ -O3 -std=c++11 -o totient_v0 totient_v0.cpp

vagrant@debiancontrib-jessie /vagrant/lec0
$ for e in $ES; do ./totient_v0 $e; done
e^10.000,      22026,       7340,  0.005334
e^11.000,      59874,      18752,  0.015950
e^12.000,     162754,      77076,  0.031679
e^13.000,     442413,     294936,  0.066495
e^14.000,    1202604,     369408,  0.180856
e^15.000,    3269017,    3264016,  0.574568
e^16.000,    8886110,    3367296,  1.570109
e^17.000,   24154952,   11599680,  4.524068
^C

vagrant@debiancontrib-jessie /vagrant/lec0
$
```


10
1
0.1
0.01
0.001
Time (s)
10000
100000
1000000
10000000
n
v0
v0-release

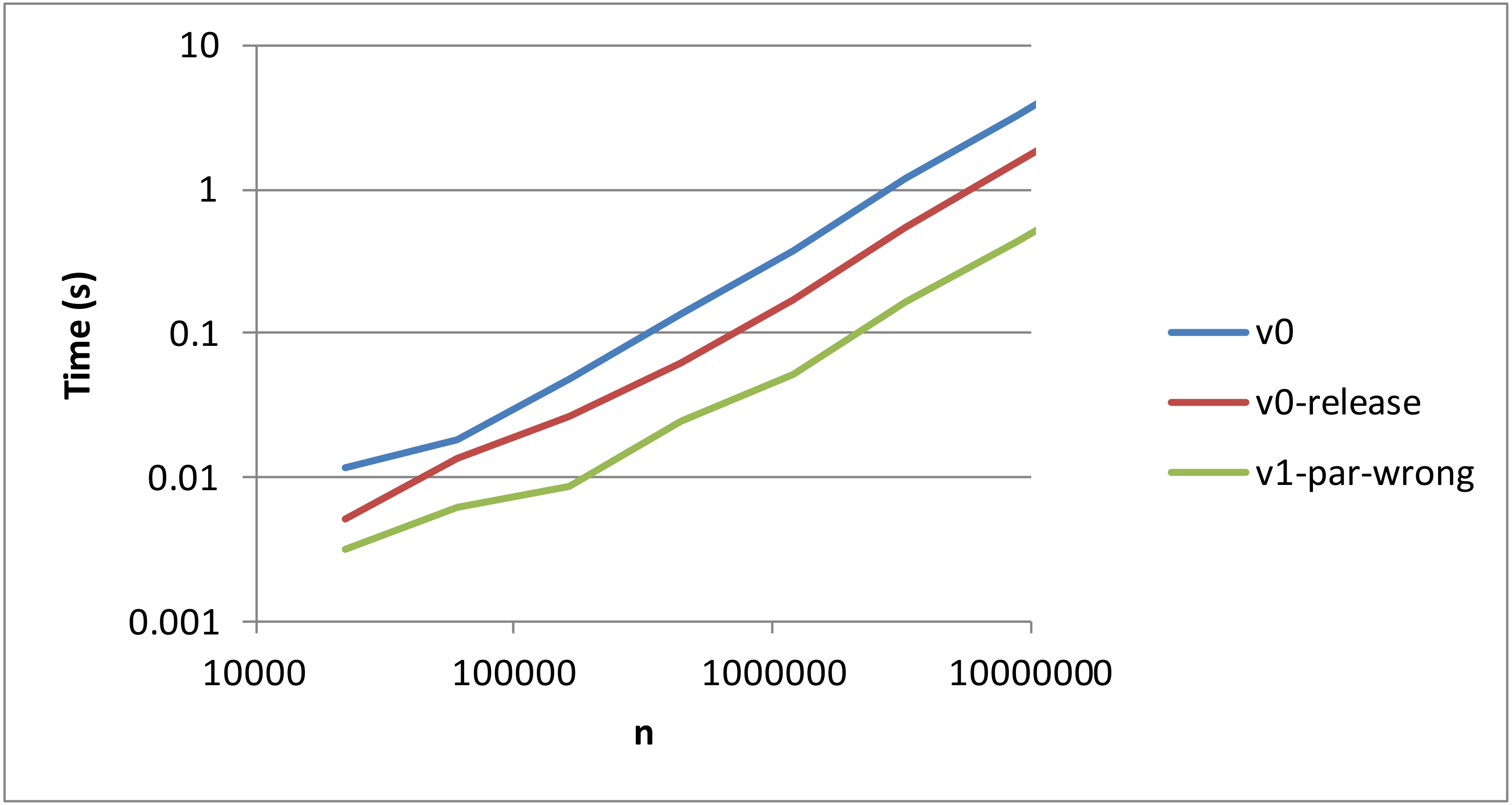
Convert the for loop to parallel loop

```
#include "tbb/parallel_for.h"

uint64_t totient_v1(uint64_t n)
{
    uint64_t count=0;

    //for(uint64_t i=1; i<=n; i++){
    tbb::parallel_for(uint64_t(1), (n+1), [&](uint64_t i){
        if(gcd(i,n)==1){
            count = count + 1;
        }
    });

    return count;
}
```

Compile with TBB

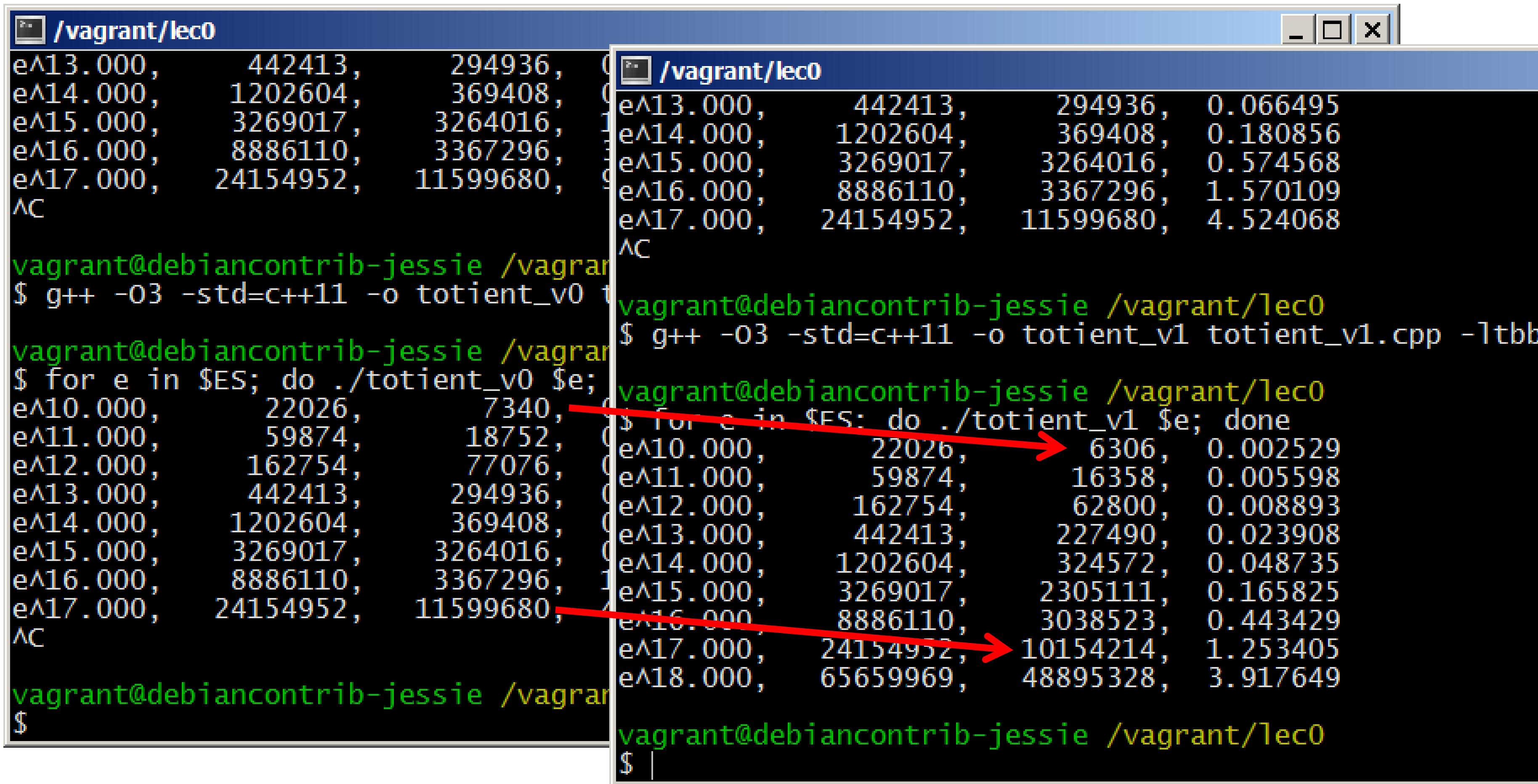
```
/vagrant/lec0
e^13.000,     442413,      294936,   0.066495
e^14.000,    1202604,      369408,   0.180856
e^15.000,    3269017,     3264016,   0.574568
e^16.000,    8886110,     3367296,   1.570109
e^17.000,   24154952,    11599680,   4.524068
^C

vagrant@debiancontrib-jessie /vagrant/lec0
$ g++ -O3 -std=c++11 -o totient_v1 totient_v1.cpp -ltbb

vagrant@debiancontrib-jessie /vagrant/lec0
$ for e in $ES; do ./totient_v1 $e; done
e^10.000,      22026,        6306,   0.002529
e^11.000,      59874,       16358,   0.005598
e^12.000,     162754,       62800,   0.008893
e^13.000,     442413,      227490,   0.023908
e^14.000,    1202604,      324572,   0.048735
e^15.000,    3269017,     2305111,   0.165825
e^16.000,    8886110,     3038523,   0.443429
e^17.000,   24154952,    10154214,   1.253405
e^18.000,   65659969,    48895328,   3.917649

vagrant@debiancontrib-jessie /vagrant/lec0
$ |
```

Faster, but...



10
1
0.1
0.01
0.001
Time (s)
10000
100000
1000000
10000000
n
v0
v0-release
v1-par-wrong

Faster but wrong ☹



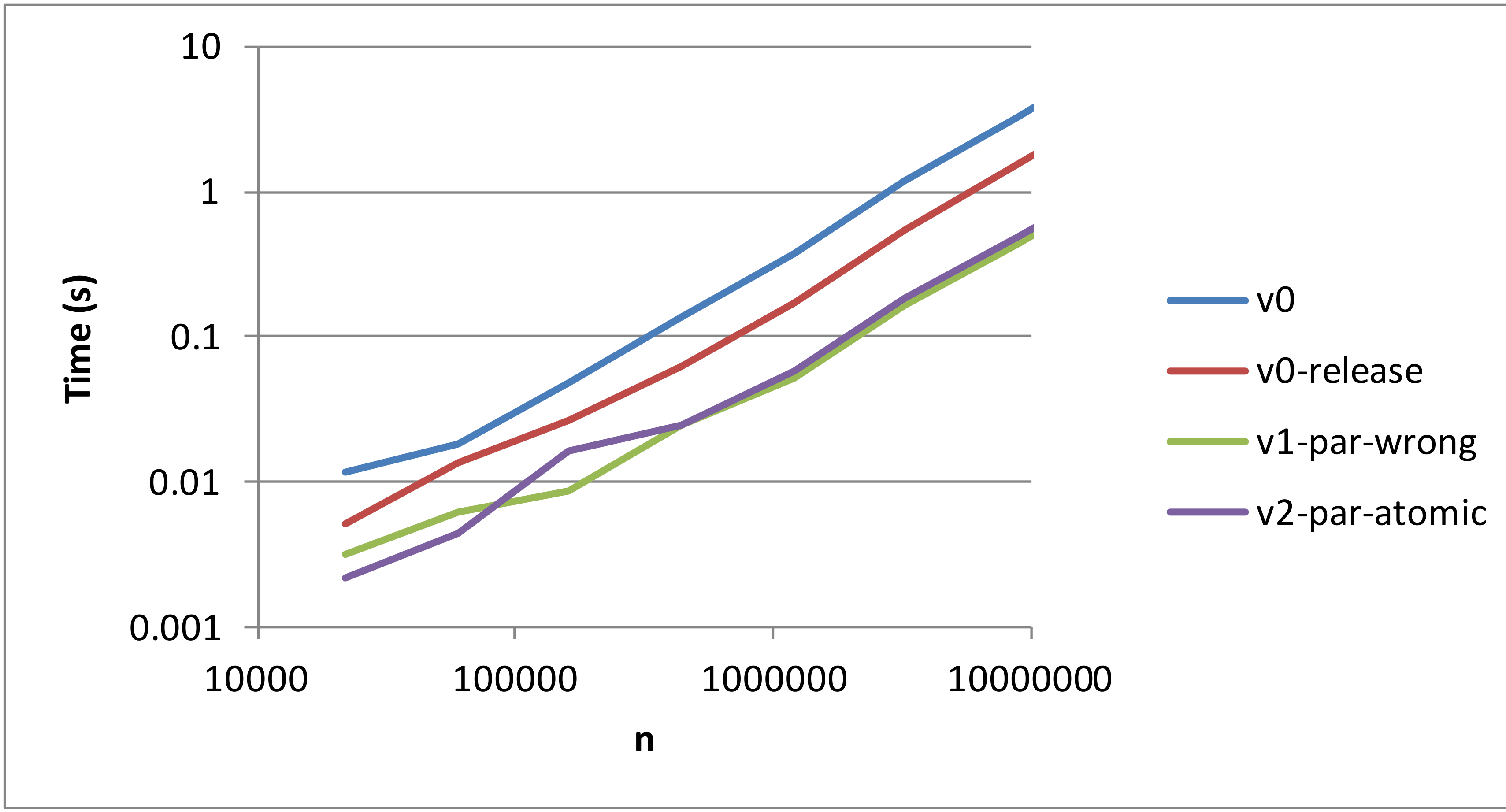
Unsafe use of shared variable

```
#include "tbb/parallel_for.h"

uint64_t totient_v1(uint64_t n)
{
    uint64_t count=0;

    //for(uint64_t i=1; i<=n; i++){
    tbb::parallel_for(uint64_t(1), (n+1), [&](uint64_t i){
        if(gcd(i,n)==1){
            count = count + 1;
        }
    });

    return count;
}
```

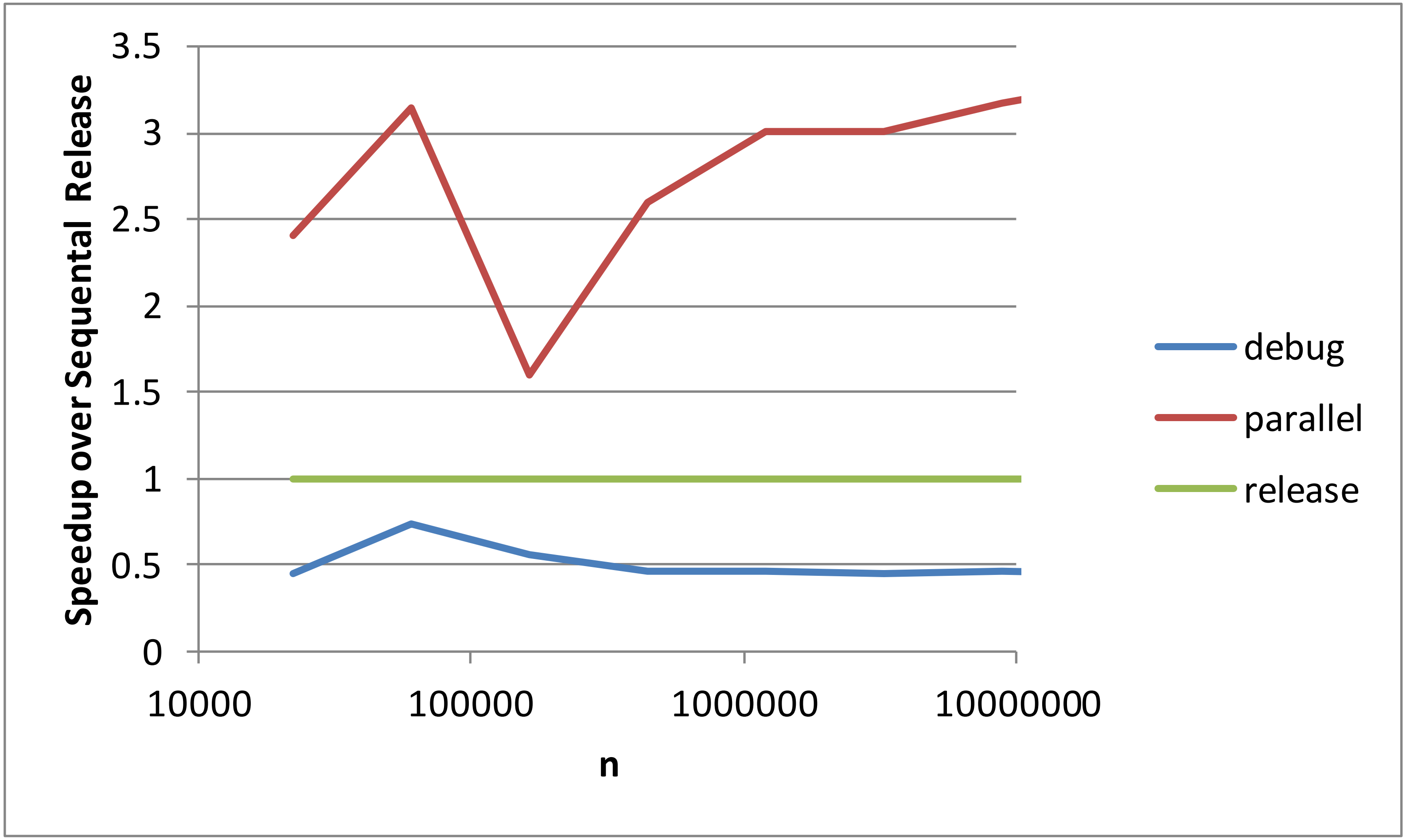
Make it atomic

```
uint64_t totient_v2(uint64_t n)
{
    std::atomic<uint64_t> count;

    //for(uint64_t i=1; i<=n; i++){
    tbb::parallel_for(uint64_t(1), (n+1), [&](uint64_t i){
        if(gcd(i,n)==1){
            count += 1;
        }
    });

    return count;
}
```

Fast and correct



Speedup (4 CPU machine)



Initial Lessons

- Speeding up loops *can* be easy
- Need to watch out for shared variables
- The speedup in P cores is less than P

Reminder Action

- If you want to take this course then:
  1. Get a github account
  2. Send me an email:
     - Subject: “[HPCE-github-request]”
     - Body: github id + your Imperial ***login*** (the short one)