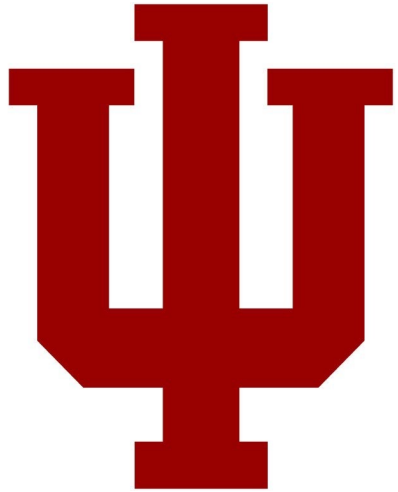
Introduction

Engr 315: Hardware / Software Codesign

Andrew Lukefahr
Indiana University

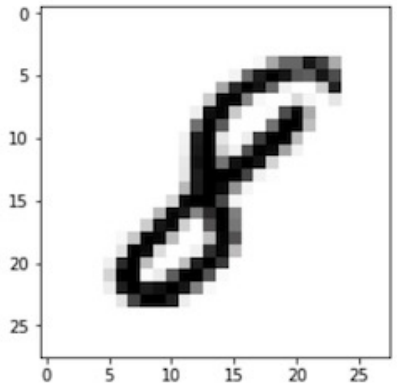


Course Website

engr315.github.io

Write that down!

The goal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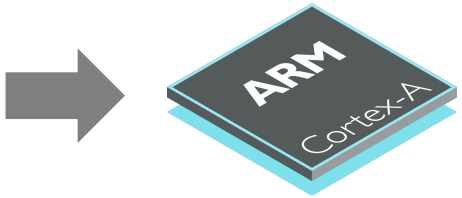
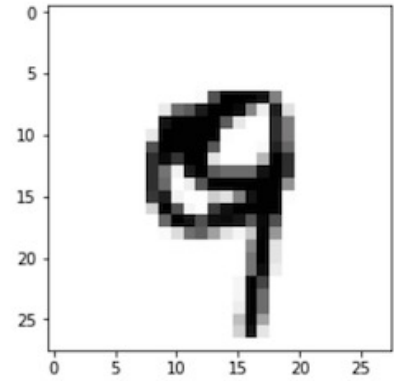

ARM
Cortex-A

8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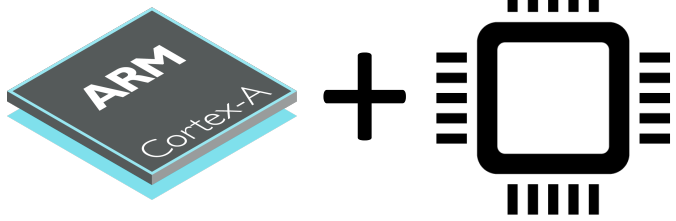
ARM
Cortex-A

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This class is ***NOT*** about computing.

It's about computing ***FAST***

How can we make our computation FAST?

How can we make our computation FAST?

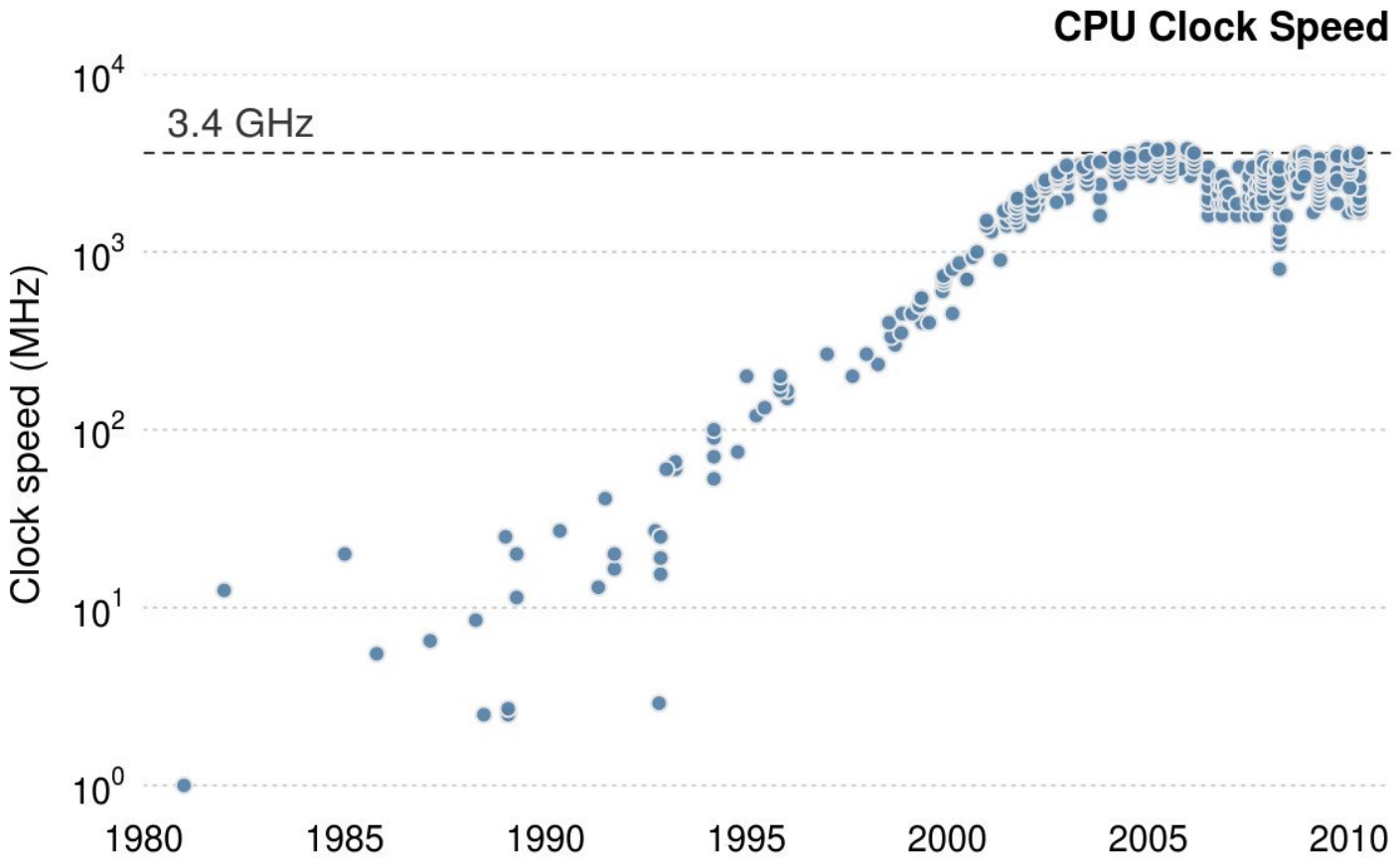
- Do less work.
- Do work faster.
- Do work in parallel.

Doing less work?

- Algorithmic complexity
- Languages:
  - Python vs. C++ vs. C/ASM
- Optimizing compiler
  - `gcc -O3`

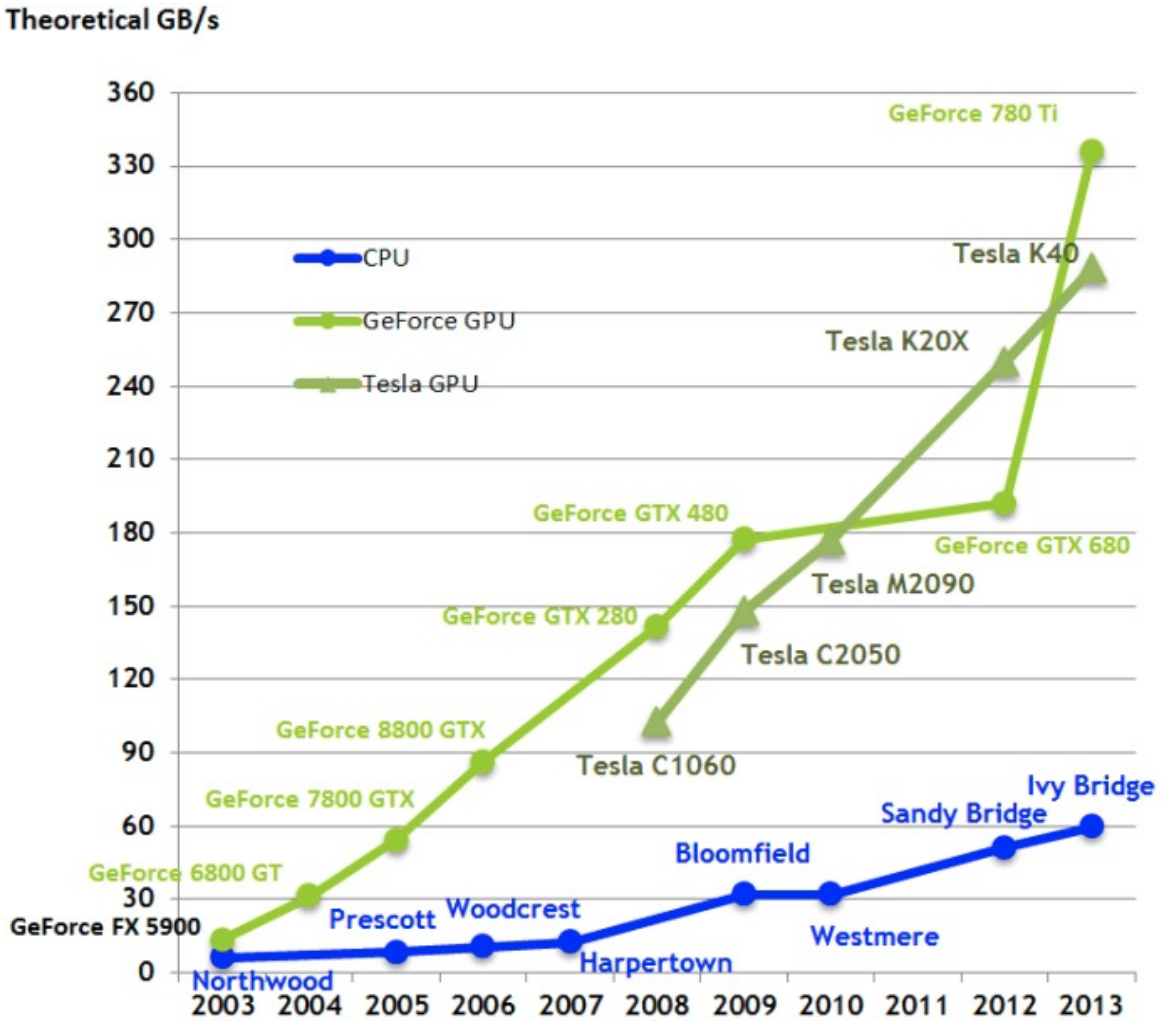
Yep. What else?

Do work faster?



Tried it. Next?

Do work in parallel?



When it works,
it really works!

How to do work in parallel?

The primary goal of this class is:

Learn methods to accelerate applications

Especially using hardware!

The secondary goals of this class are:

- Find performance bottlenecks in applications
- Accelerate applications using parallelization
- Learn computer systems architectures!

About Me

Andrew Lukefahr, Assistant Professor

Office: 2032 Luddy Hall

Email: *lukefahr@Indiana.edu*

Office Hours: M/W 3-4pm

Research work on security for FPGA-based systems.

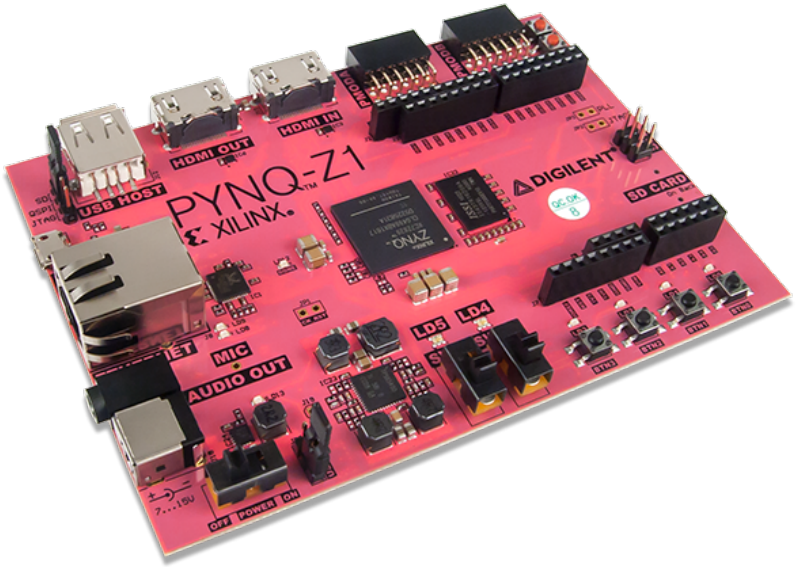
Email

- I treat email as “e”-mail, not instant massaging
- I bulk respond ~1 time / day. Sometimes ~1 time / 2 days.

Slack

- Can someone set this up? And add me?

We'll be using the Pynq-Z1



- System-on-Chip
  - SoC - "S-O-C" or "Sock"
- Contains both FPGA and CPU
- Runs Linux + Python
- http://www.pynq.io/

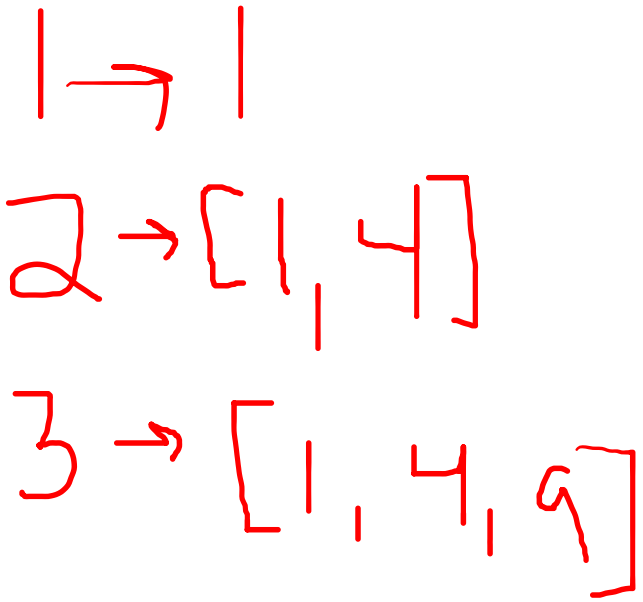
https://engr315.github.io/syllabus.html

Read it.

What does this code do?

```
1  for i in range(1,10):
2      print (squares(i))
```

```
1  def squares(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = squares(n-1)
6          seq.append(n*n)
7          return seq
```



Squared Values

```
1  def squares(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = squares(n-1)
6          seq.append(n*n)
7          return seq
```

```
1  for i in range(1,10):
2      print (squares(i))
```

```
[1]
[1, 4]
[1, 4, 9]
[1, 4, 9, 16]
[1, 4, 9, 16, 25]
[1, 4, 9, 16, 25, 36]
[1, 4, 9, 16, 25, 36, 49]
[1, 4, 9, 16, 25, 36, 49, 64]
[1, 4, 9, 16, 25, 36, 49, 64, 81]
```

Which version is faster?

```
1  def squares(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = squares(n-1)
6          seq.append(n*n)
7          return seq
```

```
1  def squares2(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = []
6          for i in range(1,n):
7              seq.append(i*i)
8          return seq
```

Performance Profiling

How long does your code take to run?

Measuring Execution Time

```
1  import time
2
3  start_time = time.time()
4  squares(10)
5  end_time = time.time()
6
7  # at the end of the program:
8  print("%f seconds" % (end_time - start_time))
```

```
0.000107 seconds
```

Measuring Execution Time

```
1  import time
2  import sys
3  sys.setrecursionlimit(21000)
4
5  start_time = time.time()
6  squares(20000)
7  end_time = time.time()
8
9  # at the end of the program:
10 print("%f seconds" % (end_time - start_time))
```

```
0.009825 seconds
```

How do we *reduce* that time?

```
1  def squares(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = squares(n-1)
6          seq.append(n*n)
7          return seq
```

How would we know *what* to optimize?

Profilers give us call-stack information about where the program is spending its time.

```
1 import cProfile
2 cProfile.run('squares(20000)')
```

```
         40002 function calls (20003 primitive calls) in 0.021 seconds

   Ordered by: standard name

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
  20000/1    0.019    0.000    0.021    0.021 <ipython-input-8-50d13c5dd8df>:1(squares)
        1    0.000    0.000    0.021    0.021 <string>:1(<module>)
        1    0.000    0.000    0.021    0.021 {built-in method builtins.exec}
    19999    0.002    0.000    0.002    0.000 {method 'append' of 'list' objects}
        1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler' objects}
```

```
ncalls  tottime  percall  cumtime  percall filename:lineno(function)
```

ncalls: the total number of calls made to a function

tottime: the total time taken by all calls to a function

percall: time per function call (tottime / ncalls)

cumtime: total time spend in this and sub-functions

percall: total cumulative time / total time

filename:lineno (function): The name of the python function

What does this tell us?

```
 ncalls  tottime  percall  cumtime  percall filename:lineno(function)
20000/1    0.019    0.000    0.021    0.021 <ipython-input-8-50d13c5dd8df>:1(squares)
      1    0.000    0.000    0.021    0.021 <string>:1(<module>)
      1    0.000    0.000    0.021    0.021 {built-in method builtins.exec}
  19999    0.002    0.000    0.002    0.000 {method 'append' of 'list' objects}
      1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler' objects}
```

Now, how do we *reduce* that time?

```
1  def squares(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = squares(n-1)
6          seq.append(n*n)
7          return seq
```

```
         40002 function calls (20003 primitive calls) in 0.021 seconds

   Ordered by: standard name

    ncalls  tottime  percall  cumtime  percall filename:lineno(function)
  20000/1    0.019    0.000    0.021    0.021 <ipython-input-8-50d13c5dd8df>:1(squares)
        1    0.000    0.000    0.021    0.021 <string>:1(<module>)
        1    0.000    0.000    0.021    0.021 {built-in method builtins.exec}
    19999    0.002    0.000    0.002    0.000 {method 'append' of 'list' objects}
        1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler' objects}
```

Can we cut the recursion?

```
1  def squares(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = squares(n-1)
6          seq.append(n*n)
7          return seq
```

```
1  def squares2(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = []
6          for i in range(1,n):
7              seq.append(i*i)
8          return seq
```

```python
import time
import sys
sys.setrecursionlimit(21000)

start_time = time.time()
squares(20000)
end_time = time.time()

# at the end of the program:
print("%f seconds" % (end_time - start_time))
```

```
0.009825 seconds
```

```python
import time

start_time = time.time()
squares2(20000)
end_time = time.time()

# at the end of the program:
print("%f seconds" % (end_time - start_time))
```

```
0.004209 seconds
```

0.009825/0.004209 = 2.33

2.33x Faster!

Why was it faster?

```
1  def squares2(n):
2      if n <= 1:
3          return [1]
4      else:
5          seq = []
6          for i in range(1,n):
7              seq.append(i*i)
8          return seq
```

```
1  import cProfile
2  cProfile.run('squares2(20000)')
```

```
         20003 function calls in 0.007 seconds

   Ordered by: standard name

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.005    0.005    0.006    0.006 <ipython-input-21-5c6731cb3b0c>:1(squares2)
        1    0.000    0.000    0.007    0.007 <string>:1(<module>)
        1    0.000    0.000    0.007    0.007 {built-in method builtins.exec}
    19999    0.002    0.000    0.002    0.000 {method 'append' of 'list' objects}
        1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler' objects}
```

What's missing?

Conclusion #1: Overheads to function calls!

Can we make it go even faster?

```
def squares2(n):
    if n <= 1:
        return [1]
    else:
        seq = []
        for i in range(1,n):
            seq.append(i*i)
        return seq
```

```
import time

start_time = time.time()
squares2(20000)
end_time = time.time()

# at the end of the program:
print("%f seconds" % (end_time - start_time))
```

```
0.004209 seconds
```

Is there a way to remove list.append()?

Can we make it go even faster?

```python
def squares2(n):
    if n <= 1:
        return [1]
    else:
        seq = []
        for i in range(1,n):
            seq.append(i*i)
        return seq
```

```python
import time

start_time = time.time()
squares2(20000)
end_time = time.time()

# at the end of the program:
print("%f seconds" % (end_time - start_time))
```

```
0.004209 seconds
```

```python
import numpy as np
def squares3(n):

    seq = np.zeros(n, dtype=np.int)
    for i in range(1, n+1):
        seq[i-1] = i * i
    return seq
```

```python
import time

start_time = time.time()
squares3(20000)
end_time = time.time()

# at the end of the program:
print("%f seconds" % (end_time - start_time))
```

```
0.003960 seconds
```

```
1 import cProfile
2 cProfile.run('squares3(20000)')
```

```
         5 function calls in 0.005 seconds

   Ordered by: standard name

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.005    0.005    0.005    0.005 <ipython-input-68-7272dceb0678>:2(squares3)
        1    0.000    0.000    0.005    0.005 <string>:1(<module>)
        1    0.000    0.000    0.005    0.005 {built-in method builtins.exec}
        1    0.000    0.000    0.000    0.000 {built-in method numpy.zeros}
        1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler' objects}
```

Next Time

- More on Profiling!

Introduction

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