Canvas link - rw

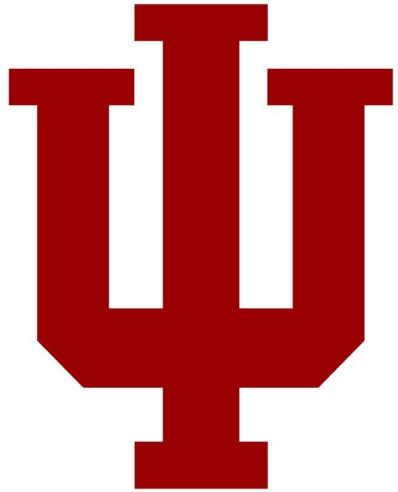
door code: 2-3-5

# Introduction

Engr 315: Hardware / Software Codesign

Andrew Lukefahr
*Indiana University*

waitlist: see me after class



# Course Website

engr315.github.io

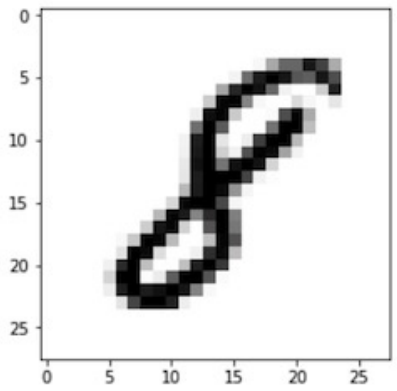
Write that down!

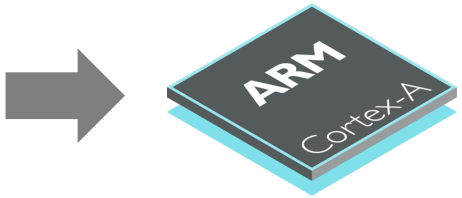
# WARNING: Know Thy Foo()

- Python – First few weeks
- C – 2nd week onward
- Verilog – 3nd week onward

If you are not familiar with these, see me after class!

# The goal



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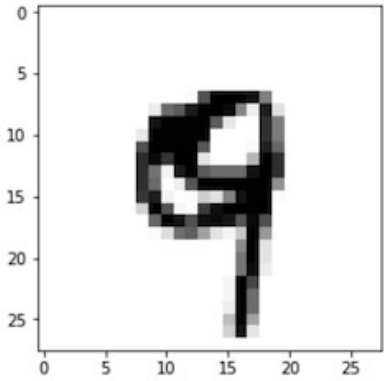

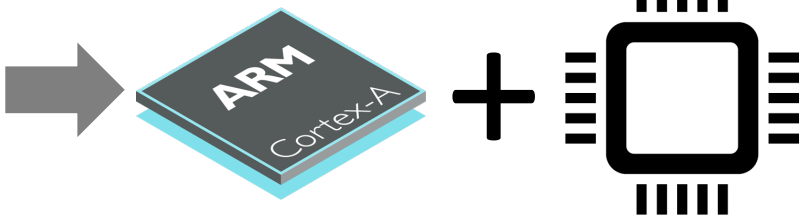


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This class is ***NOT*** about computing.

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

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

# How can we make our computation FAST?

- better/more data structures
  - caching - SW
- do less work
- "better" algorithm
- parallelism
  - different CPUs
    - FPGA parallelism
- memory placement
- memory cache (HW)
- make CPU faster
- pipelining / OoO

# How can we make our computation FAST?

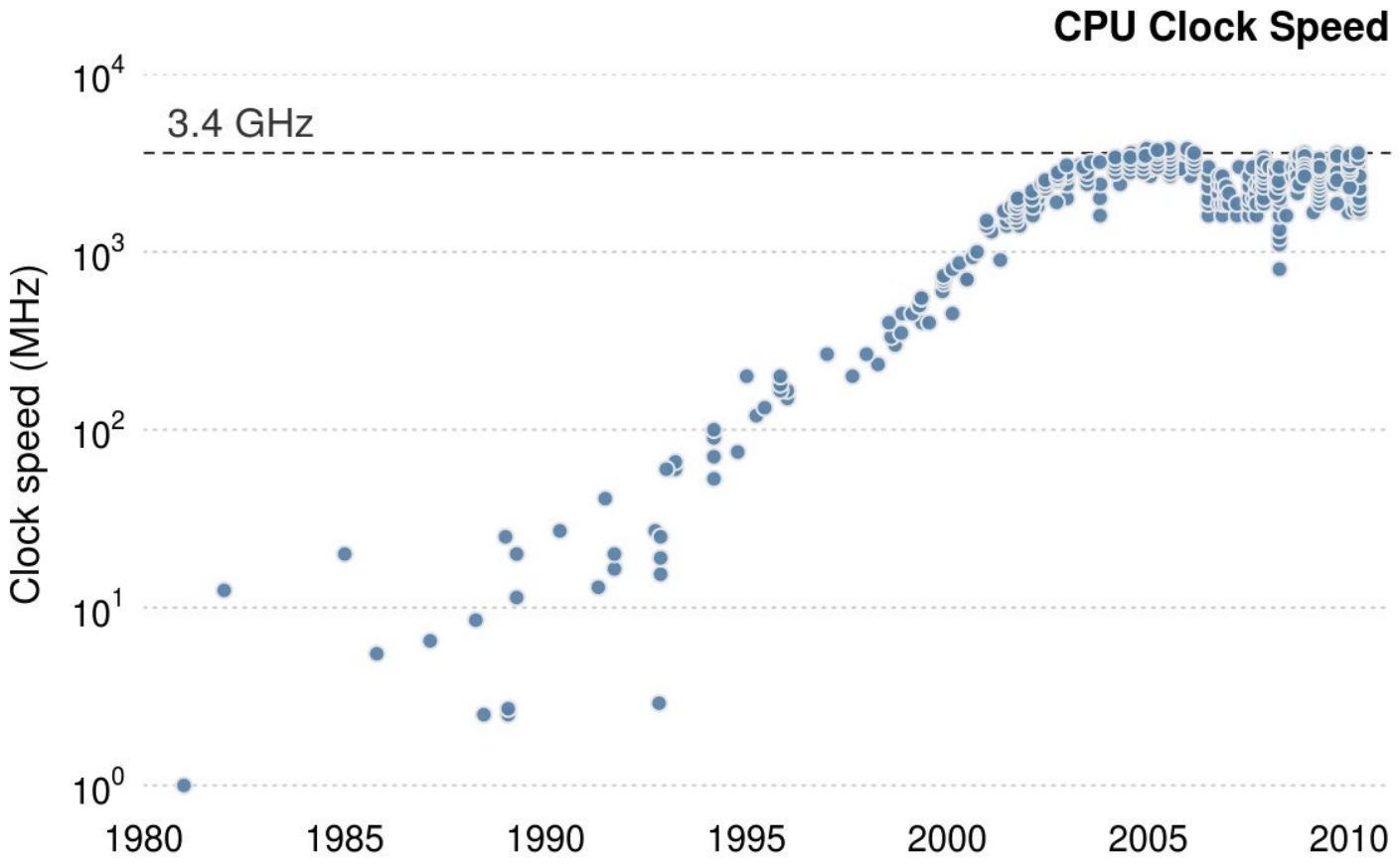
- Do less work.
- Do work faster.
- Do work in parallel.

# Doing less work?

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

Yep. What else?

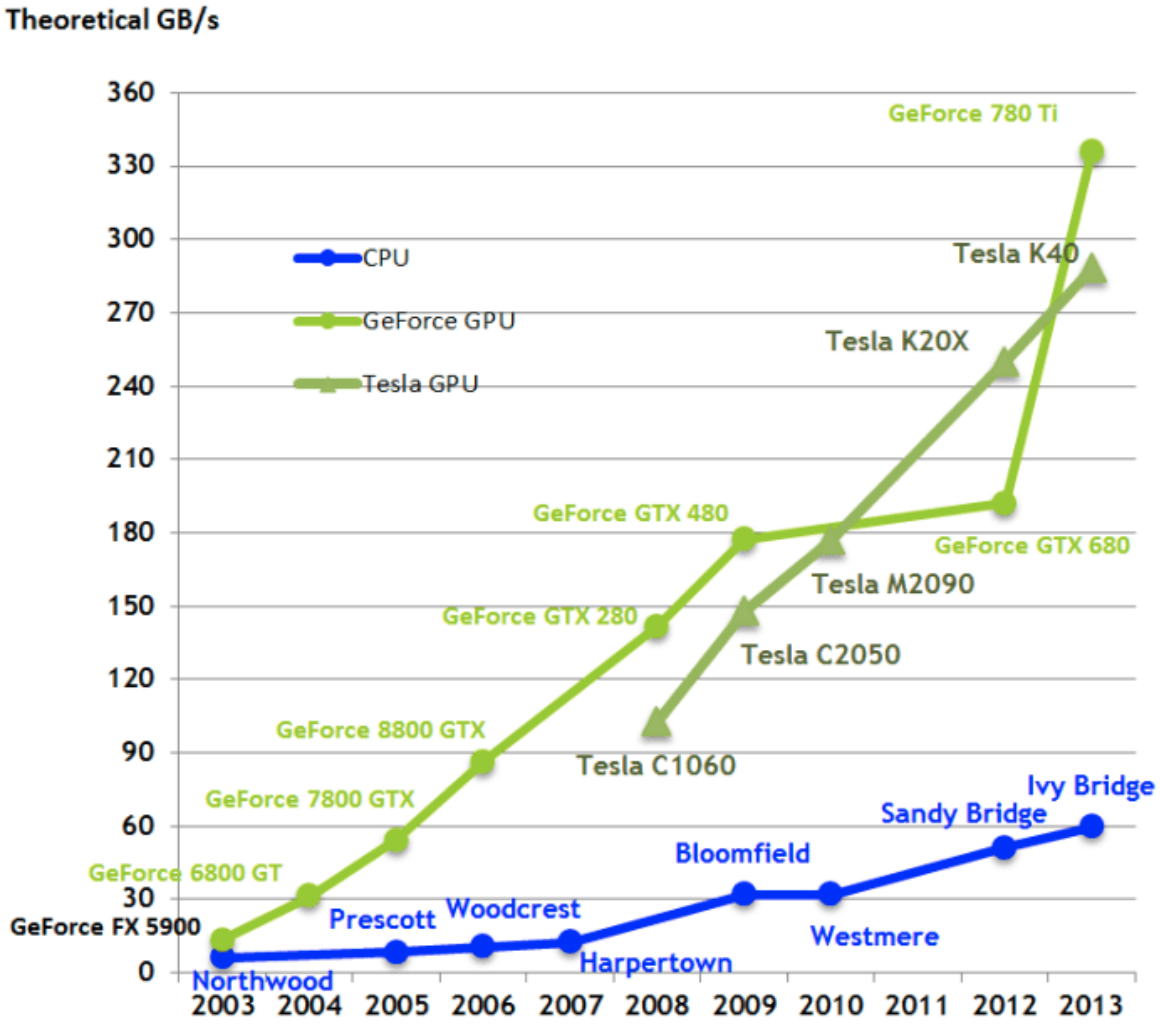
# Do work faster?





Tried it.  Next?

# Do work in parallel?





When it works,
it really works!

# How to do work in parallel?

1) Find pallelel work* * difficult

2) Parallelize

3) Profit!

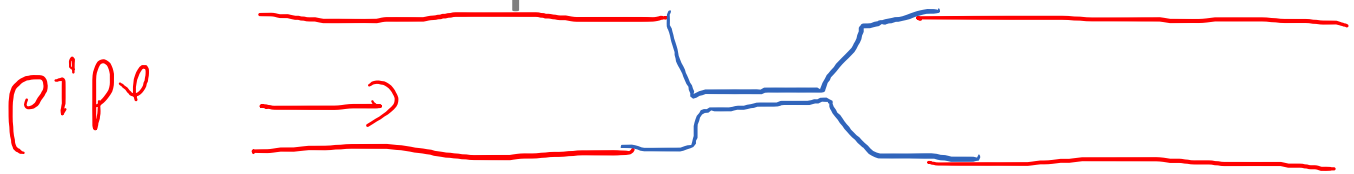
The primary goal of this class is:

Learn methods to accelerate applications

Especially using hardware!

# The secondary goals of this class are:

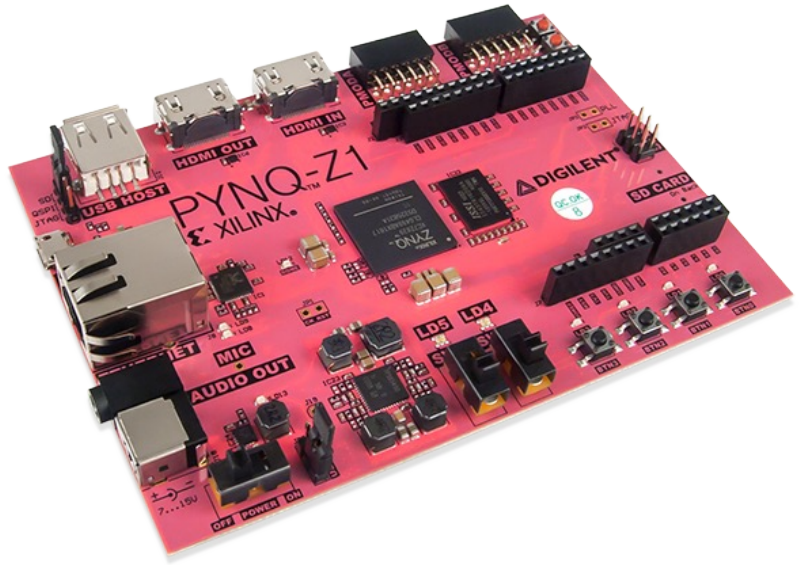
- Find performance bottlenecks in applications




- Accelerate applications using parallelization

- Learn computer systems architectures!

# We'll be using the Pynq-Z1




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

# E315 assignments are all “optimizations”

- I give you a working software version.

- You need to:
  a) Make it go faster
  b) Make it run on hardware
  c) (usually) both

# About Me

Andrew Lukefahr, Assistant Professor

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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?

TA's

# WARNING: Know Thy Foo()

- Python – First few weeks
- C – 2nd week onward.
- Verilog – 3nd week onward.

If you are not familiar with these, see me after class!

# Course Website

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Write that down!

# Performance Profiling

How long does your code take to run?

# 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]
```

# 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
```

107 μSec

# 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
```

~ 10 mSec

# 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?

# Code Profiling

- In software engineering, profiling ("program profiling", "software profiling") is a form of dynamic program analysis that measures, for example, the space (memory) or time complexity of a program, the usage of particular instructions, or the frequency and duration of function calls. Most commonly, profiling information serves to aid program optimization. [Wiki]

# **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

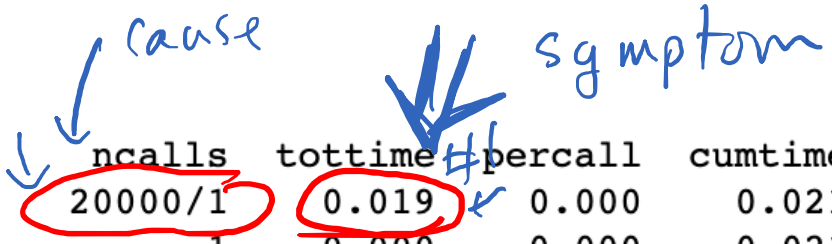
percall:  time per function call (tottime / ncalls)

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!

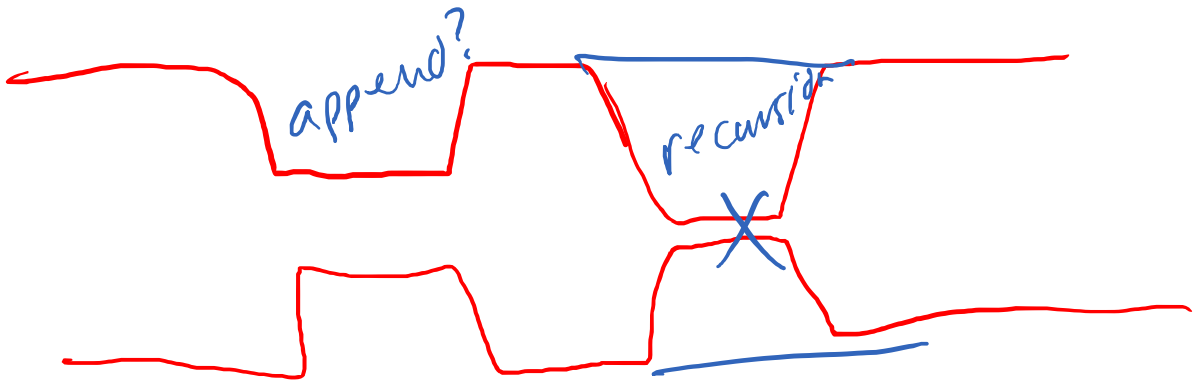
# Why was it faster?

```
1 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?

list comprehensions?

```
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 time
2
3  start_time = time.time()
4  squares2(20000)
5  end_time = time.time()
6
7  # at the end of the program:
8  print("%f seconds" % (end_time - start_time))
```

```
0.004209 seconds
```

```
1  import numpy as np
2  def squares3(n):
3
4      seq = np.zeros(n, dtype=np.int)
5      for i in range(1, n+1):
6          seq[i-1] = i * i
7      return seq
```

```
1  import time
2
3  start_time = time.time()
4  squares3(20000)
5  end_time = time.time()
6
7  # at the end of the program:
8  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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