Lecture 13 - Utilizing Compiled Code

DSE 512

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From Last Time

- Next time: wrapup with I/O
- New homework "soon"
- Won't be due before March 26
- Questions?

A Quick Comment

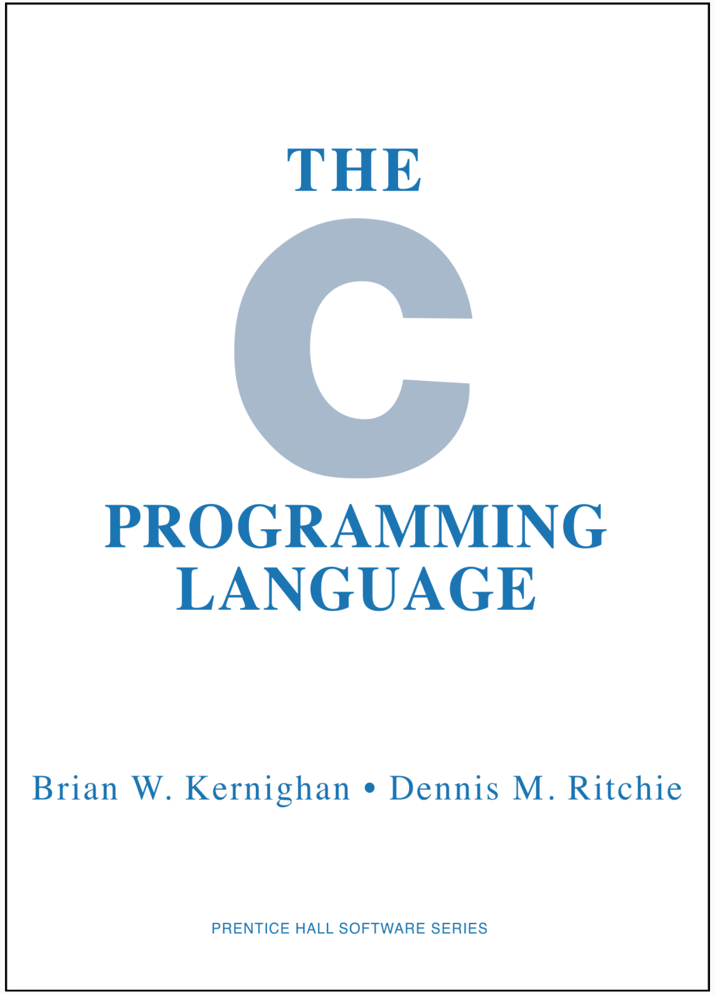
- I am not *ideological*
- But I am very *opinionated*
- I'm not always right
- You are free to disagree

Compiled Code

- Very specialized set of skills
- Could *easily* spend *all semester* on just this
- This is a single lecture
- We will focus on just a few principles and examples
- This is probably the least useful topic for most of you
- *But it's important that you see it and understand it*

Using Compiled Code in a HLL

- Pros
  - fast
  - memory-efficient
  - best of both worlds
- Cons
  - hard to write
  - hard to debug
  - multiple skillsets
- Julia???



Differences

HLL

- Memory managed *for* you
- Type (usually) implicit
- Interactive REPL

LLL

- Memory managed *by* you
- Type (usually) explicit
- Non-interactive

Memory

Python

```python
import numpy as np
np.array(range(0, n))
```

C

```c
double *x = malloc(n * sizeof(*x));
for (int i=0; i<n; i++)
  x[i] = i;
// ...
free(x);
```

Types

R

```r
x = 1
typeof(x)
```

```
## [1] "double"
```

```r
y = 2
typeof(x)
```

```
## [1] "double"
```

```r
z = 1:2
typeof(z)
```

```
## [1] "integer"
```

C

```c
double x = 1;
double y = 2;
int z = {1, 2};
```

Bringing Compiled Code to HLL

- C/C++/Fortran/etc. code must be:
  - compiled
  - linked
  - loaded
- Each HLL handles this differently
- So why is this hard?

Machine Code

```c
#include <stdio.h>

int main()
{
  printf("hi\n");
  return 0;
}
```

```
gcc -g -O2 hello.c -o hello
```

```
(gdb) disass main
Dump of assembler code for function main:
  0x0000000000001060 <+0>:    endbr64
  0x0000000000001064 <+4>:    sub    $0x8,%rsp
  0x0000000000001068 <+8>:    lea    0xf95(%rip),%rd
  0x000000000000106f <+15>:    callq  0x1050 <puts@p
  0x0000000000001074 <+20>:    xor    %eax,%eax
  0x0000000000001076 <+22>:    add    $0x8,%rsp
  0x000000000000107a <+26>:    retq
End of assembler dump.
```

Python Bytecode

```python
def hello():
  print('hi')

import dis
dis.dis(hello)
```

```
##   2           0 LOAD_GLOBAL              0 (print)
##               2 LOAD_CONST               1 ('hi')
##               4 CALL_FUNCTION            1
##               6 POP_TOP
##               8 LOAD_CONST               0 (None)
##              10 RETURN_VALUE
```

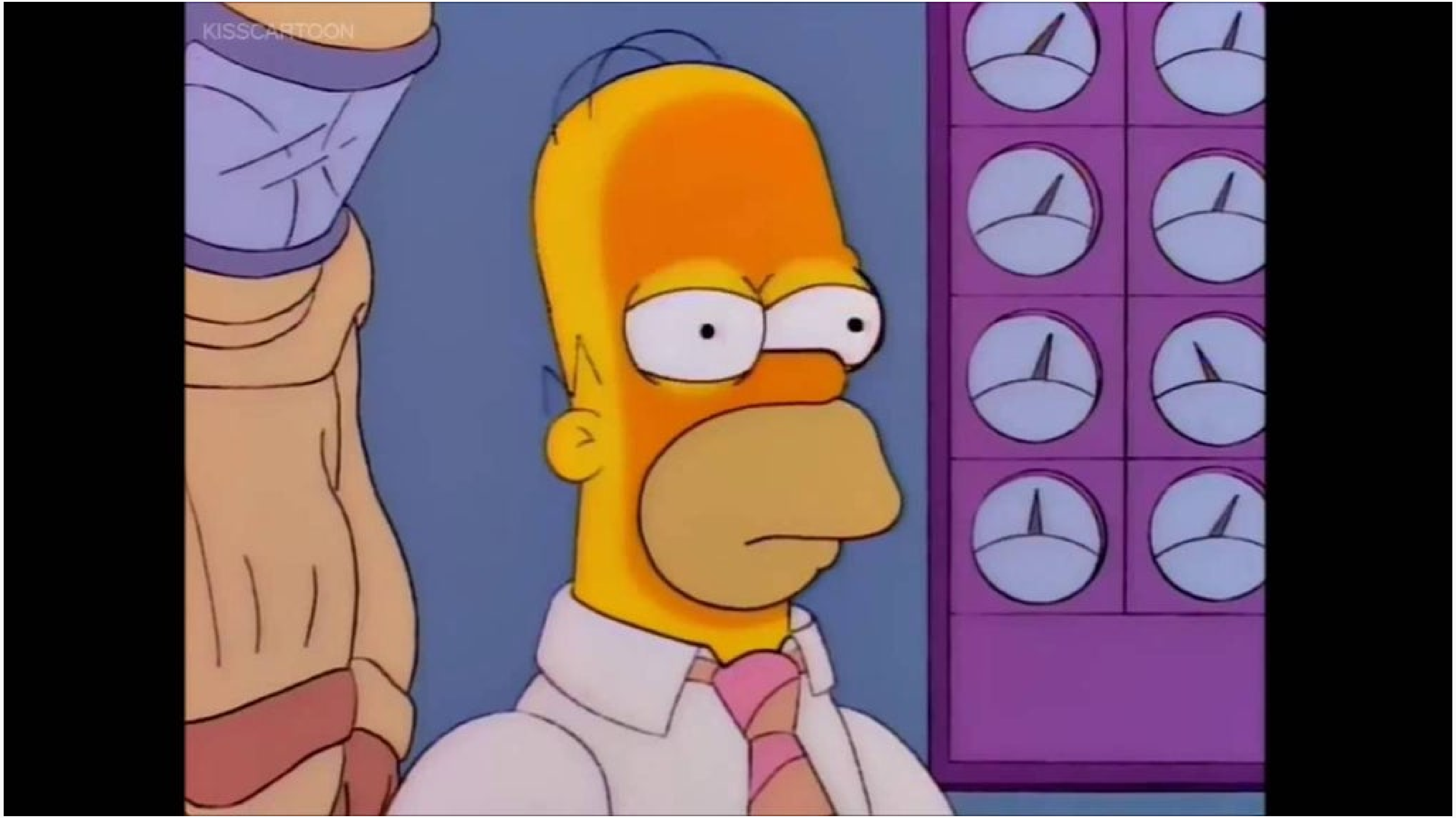
R Bytecode

```r
hello = function() print("hi")
hello = compiler::cmpfun(hello)
compiler::disassemble(hello)
```

```
## list(.Code, list(12L, GETFUN.OP, 1L, PUSHCONSTARG.OP, 3L, CALL.OP,
##     0L, RETURN.OP), list(print("hi"), print, structure(c(1L,
## 9L, 1L, 30L, 9L, 30L, 1L, 1L), srcfile = <environment>, class = "srcref"),
##     "hi", structure(c(NA, 0L, 0L, 0L, 0L, 0L, 0L, 0L), class = "expressionsIndex"),
##     structure(c(NA, 2L, 2L, 2L, 2L, 2L, 2L, 2L), class = "srcrefsIndex")))
```

Cython

I'm not going to be polite about this...



How I Feel About Cython

- Only really useful for package developers
- Can't decide if it wants to be C or Python
- The Cython docs are *terrible*
- If you want a different take, see last year's Lecture 18

Basic Structure

- `whatever.pyx` - Cython code
- `setup.py` - build script
- See the badly written docs for more information
  https://cython.readthedocs.io/en/latest/src/tutorial/cython_tutorial.html

Example

There is no *basic* example I can give you that wouldn't be

- easier
- cleaner
- better

in Numba.

Tutorial

An Introduction to Just Enough Cython to be Useful

https://www.peterbaumgartner.com/blog/intro-to-just-enough-cython-to-be-useful/

Rcpp

Bringing Compiled Code to R

- R is a C program
- It has a C interface
- Do you know C?

Rcpp

- C++ interface
- Builds on top of the native C interface
- Can run compiled kernels "inline" (don't do this in production)
- Can be used in an R package (do this in production)

Rcpp

What it is

- An R package
- A C++ interface for R extensions
- An R-like C++ interface
- One piece with many extensions
  - RcppArmadillo
  - RcppEigen
  - ...

What it is not

- The only way to use C++ with R
- Zero-overhead
- As easy to use as R

How I Think About Rcpp

Somewhere between Numba and Cython

Rcpp

If you know what you're doing

- You can often outperform Rcpp in runtime
- You can *always* outperform Rcpp in memory
- You can *massively* outperform Rcpp in compilation time

and if you don't

- Rcpp is probably your best bet

Idiomatic C

```c
void vec_vec_add(const int n, const double *a, const double *b, double *c){
  for (int i=0; i<n; i++)
    c[i] = a[i] + b[i];
}

void caller(const int n){
  double *a = malloc(n * sizeof(*a));
  double *b = malloc(n * sizeof(*b));
  set_values(n, a, b);

  double *c = malloc(n * sizeof(*c));
  vec_vec_add(n, a, b, c)
}
```

R Native C Interface

```c
#include <R.h>
#include <Rinternals.h>

SEXP vec_vec_add(SEXP a, SEXP b){
  R_xlen_t n = LENGTH(a);
  SEXP c;
  PROTECT(c = allocVector(REALSXP, n));
  for (int i=0; i<n; i++)
    REAL(c)[i] = REAL(a)[i] + REAL(b)[i];

  UNPROTECT(1);
  return c;
}
```

Rcpp

```
#include <Rcpp.h>

// [[Rcpp::export]]
Rcpp::NumericVector vec_vec_add(Rcpp::NumericVector a, Rcpp::NumericVector b){
  int n = a.length();
  Rcpp::NumericVector c(n);
  for (int i=0; i<n; i++)
    c[i] = a[i] + b[i];

  return c;
}
```

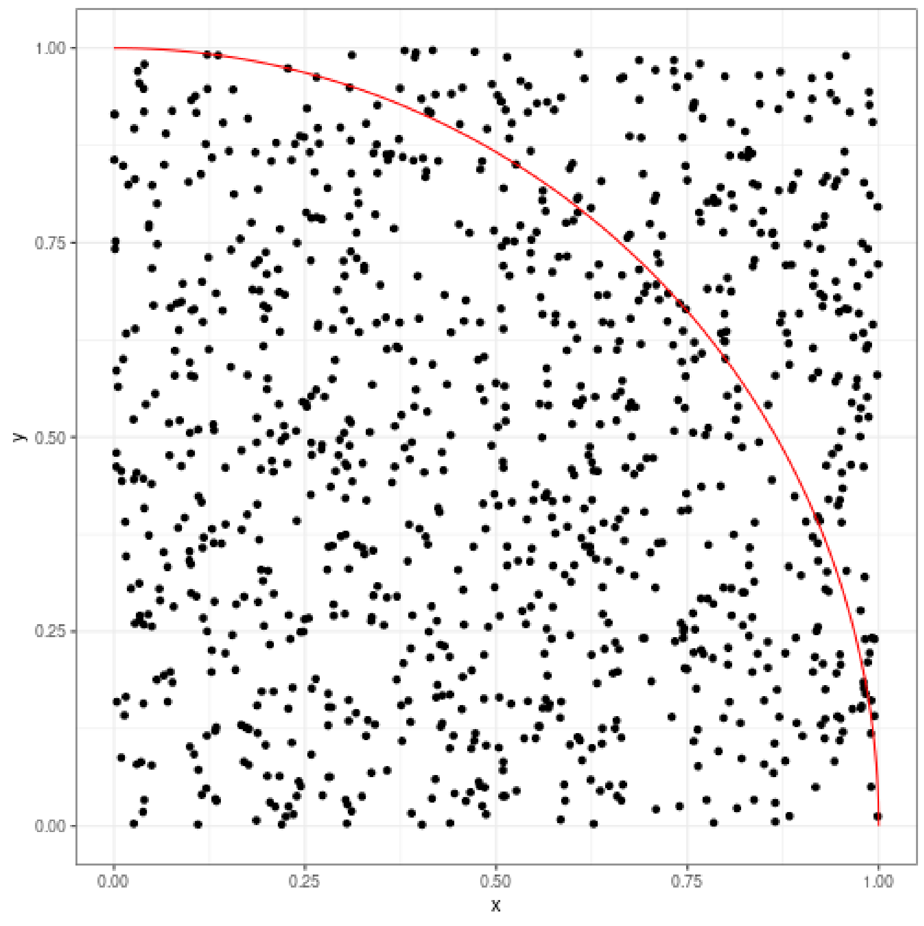
Rcpp

```
#include <Rcpp.h>
using namespace Rcpp;

// [[Rcpp::export]]
NumericVector vec_vec_add(NumericVector a, NumericVector b){
  int n = a.length();
  NumericVector c(n);
  for (int i=0; i<n; i++)
    c[i] = a[i] + b[i];

  return c;
}
```

Monte Carlo π Simulation

$\text{Area} = \pi r^2$

```
set.seed(1234)
n = 1000
x = runif(n)
y = runif(n)

circ_pts = seq(0, pi/2,length.out=100)
library(ggplot2)
g = ggplot(data.frame(x=x, y=y), aes(x, y
  theme_bw() +
  geom_point() +
  annotate("path",
   x = 0 + 1*cos(circ_pts),
   y = 0 + 1*sin(circ_pts),
   color="red"
  )
```



Estimating π: Naive Implementation

```r
pi_sim = function(n=1e6, seed=1234){
  set.seed(seed)

  s = 0
  for (i in 1:n)
  {
    x = runif(1)
    y = runif(1)
    if (x*x + y*y < 1)
      s = s + 1
  }

  4 * s / n
}
```

```r
system.time(pi_sim())
```

```
##   user  system elapsed
## 3.883   0.012   3.898
```

Estimating π: Vectorized

```
pi_sim_vec = function(n=1e6, seed=1234){
  set.seed(seed)
  x = runif(n)
  y = runif(n)
  4 * sum(x*x + y*y < 1) / n
}
```

```
system.time(pi_sim_vec())
```

```
##   user  system elapsed
## 0.035   0.004   0.039
```

Estimating π: Rcpp

```cpp
#include <Rcpp.h>

// [[Rcpp::export]]
double pi_sim_rcpp(int n){
  int s = 0;
  for (int i=0; i<n; i++){
    double x = R::runif(0, 1);
    double y = R::runif(0, 1);
    if (x*x + y*y < 1)
      s++;
  }

  return 4.0 * ((double) s / n);
}
```

```r
Rcpp::sourceCpp("pi_sim_rcpp.cpp")
system.time(pi_sim_rcpp())[3]
```

```
##   user  system elapsed
## 0.019   0.000   0.018
```

Summary

Method	Runtime	Relative Performance	Memory
Naive	3.898	216.556	~ 36 bytes
Vectorized	0.039	2.167	> 15 MB
Rcpp	0.018	1	36 bytes

Questions?