CSC2/452 Computer Organization Mixed Language Programming

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URCS

December 7, 2022

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Why Mixed Language Programming?

How to do Mixed Language Programming

Case study I: Assembly in C

Case study II: C in Python using FFI

Case study III: C in Python using C Modules and Cython

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A5 (final assignment) is out

- Due Dec 13, 2022 at 7PM
- One more interesting bug before whole class gets extra credit
- All homework grades and solutions available
 - Review them and ask questions on Blackboard
- Two review lectures next week
- Exam will be 90–120 minutes, one sheet of handwritten notes allowed

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Reason #1: Reuse

Reuse

- The best way to write bug free code is not write code at all
- The second best way is to reuse existing, well-tested, already available code

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Example: Numpy

- numpy: Numerical programming for Python
- Matrix manipulations, multiplication, etc.
- Much code reused from earlier projects like BLAS

Reason #2: Performance

Performance

- Many languages focus on productivity, not raw performance
- 80% of the code doesn't need performance (e.g. UI, File I/O)
- Find hotspots in your code and write them in language capable of delivering high performance
 - Using a tool called a 'profiler'
- Example: Numpy
 - when you multiply matrices in Numpy, it almost inevitably calls gemm in BLAS

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Reason #3: Accelerators/Machine capabilities

New instructions and extensions

- "Advanced Matrix Extension" (AMX) Intel's matrix multiply instruction
- "Advanced Vector Extensions" (AVX) for vector/SIMD processing
- "Multimedia Extensions" (MMX) for video processing
- New accelerators
 - GPUs require you to write code in CUDA or OpenCL
 - Shouldn't have to rewrite entire application in CUDA/OpenCL

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Native Code

 Languages that compile to native code (i.e. machine code/assembly language)

- C++ program calls C functions (or vice versa)
- Rust programs calls C functions
- C calls CUDA
- Mostly for reuse or to access machine capabilities
- Relatively easy:
 - The programs ultimately compile to assembly language
 - Just compile them individually and link them
- Interoperability must be ensured:
 - Each language must follow the ABI
 - Each language has its own rules (naming, calling conventions, etc.)
 - Each language has its own data formats

Example: C++ calling C

```
Contents of test.cpp file.
    #include <cstdio>
    int add2num(int a, int b);
    int main(int argc, char *argv[]) {
      int c, d;
      c = 3:
      d = 4:
      c = add2num(c, d);
    }
Contents of add2num.c file.
    int add2num(int a, int b) {
      return a + b;
    }
```

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Compiling and Linking

g++ -c test.cpp -o test.o
gcc -c add2num.c -o add2num.o
gcc test.o -o mlp_compiled
test.o: In function 'main':
test.cpp:(.text+0x28): undefined reference to 'add2num(int, int)'
collect2: error: ld returned 1 exit status
make: *** [mlp_compiled] Error 1

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Name Mangling in C++

 $C{++}\xspace$ supports polymorphism, so function names are mangled at the assembly level.

Here is the name the C++ program is looking for (generated by C++ compiler):

```
objdump -t test.o
[...]
```

Here is the name the C compiler generated:

```
objdump -t add2num.o
[...]
0000000000000000 g F .text 00000000000014 add2num
```

Handling name mangling

```
#include <cstdio>
    extern "C" int add2num(int a, int b);
    int main(int argc, char *argv[]) {
      int c, d;
      c = 3:
      d = 4:
      c = add2num(c, d);
    }
Now, recompilation works
    gcc -c add2num.c -o add2num.o
    g++ -c test2.cpp -o test2.o
    gcc add2num.o test2.o -o mlp_compiled_2
```

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Bytecode Languages: The easy cases

Usually, but not always, interpreted

- They don't compile to assembly
- Byte code programs calling each other
 - Usually all need to run on top of the same VM/interpreter
 - Examples: IronPython and C# (.NET)
 - Or: Jython and Java (JVM)
 - Logically similar to native languages, but more "natural" since all languages follow the VM rules

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 Interesting combination: JavaScript calling WebAssembly (both are bytecode)

Bytecode Languages: The hard cases

Byte code calling Native code

- Python calling C
- Java calling C

Native code calling byte code

- C calling Python functions
- These almost always need "marshalling"
 - Converting data types between VM and native representations
 - Transferring control between native and byte code/VM code correctly

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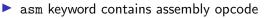
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Using asm in C

```
#include <stdio.h>
int add2num(int a, int b) {
    asm("addl %1, %0" : "+r" (a) : "r" (b));
    return a;
}
int main(void) {
    printf("%d\n", add2num(1, 3));
}
```



- Also contains argument references %0
- Also contains information on how to pass arguments to assembly instruction
 - Here r means register
 - The + indicates the register will be modified

Alternatives to writing asm

Use assembly-language intrinsics

- Basically assembly language dressed up to look like C functions
- Example: _mm256_mul_pd corresponds to the VMULPD instruction
- Most commonly for SIMD functionality
- Look exactly like C function calls, except they may use special data types

For _mm256 intrinsics, 256-bit values

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Using ctypes

- This assumes the C code you want to call is a shared object (or a DLL).
- The code doesn't have to be aware of Python's rules #!/usr/bin/env python3

```
import ctypes
```

```
libadd2num = ctypes.cdll.LoadLibrary("add2num.so")
```

```
libadd2num.add2num.argtypes = [ctypes.c_int, ctypes.c_int]
libadd2num.add2num.restype = ctypes.c_int
```

```
print(libadd2num.add2num(1, 3))
```

- ctypes does the hard work of translating types from Python to C and vice versa under the hood.
- Another alternative is to use c_ffi library

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Writing Modules in C

- Many modules (e.g. 'import x') are written in C
- They're much more closely integrated with Python
- Called "Extension Modules"

See the documentation here: https://docs.python.org/3/extending/extending.html

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Writing Modules in Cython

- Cython allows you to write native code modules in a Python-like language
- Cython compiles these to Python modules
- Very convenient if you want to speed up code with less effort than writing in C

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Recommended https://cython.readthedocs.io/en/ latest/src/tutorial/cython_tutorial.html

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Pure X programming is portable

"Pure Python Programs"

- Only need the Python interpreter to work
- CPython, PyPy, Jython, IronPython, etc.
- Python + C modules dramatically cuts portability

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tied to Cython and C

Mixed language programming can be brittle

- All languages need to coordinate
- Many languages provide "foreign function interfaces" to make this easier
- May need to understand all languages at a fairly low level
- Intellectually rewarding
 - Not very hard since ultimately everything is assembly

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