Calling Chapel Code: Interoperability Improvements

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@ChapelLanguage
Interoperability: Introduction

• Have had a draft capability to create libraries from Chapel source files
  • Compiling with '--library' flag generates library instead of executable
  • Historically designed for use from C
  • Given very little attention until recently

• Ideally, would allow integration of Chapel code into already large projects, e.g.
  • Enable easier distribution/parallelism for C or Fortran programs
  • Enable better performance for Python
    • Written in friendlier language than C, making it easier to debug
Interoperability: Introduction

• Accessible symbols specified via 'export' keyword
  
  // Declares a Chapel function for use from outside the library

  export proc foo(): int {...}

• Only supports functions with concrete signatures
  
  • Exporting module-level variables or type definitions is future work
Interoperability: MonteCarloPi

• For this talk, we'll define three MonteCarloPi implementations via exported procs
  • We will demonstrate calling these functions from Python, C, and Fortran

MonteCarloPi.chpl:

// Computes pi using a serial implementation of the Monte Carlo simulation
export proc serialVersion(n: int, seed: int) {...}

// Computes pi using a task parallel implementation
export proc taskParVersion(n: int, seed: int) {...}

// Computes pi using a data parallel implementation
export proc dataParVersion(n: int, seed: int) {...}
Python Interoperability
Interoperability: Python

• Some background: Python support was provided via Simon Lund's PyChapel
  • Chapel code usable via inline doc strings, source files, fn body files
    ```python
    from pych.extern import Chapel
    @Chapel()
    def serialVersion(n = int, seed = int):
        """ ... // Chapel code in Python comment """
        return None
    ```
  • Installed via pip, or by downloading and building the repository
    • Rather brittle: assumed Linux, virtual environment, Python 2 …
  • Didn't support most Chapel settings
Interoperability: Python

• We learned a lot, but decided to try a different tactic built using **Cython**
  • User doesn't have to write wrapper code themselves
    • Just compile library with '--library-python' and ensure on '$PYTHONPATH'

```python
import MonteCarloPi  # Treated like any other Python module!
```

• Can also take advantage of Python's argument default values

```python
// Both calls behave the same!
MonteCarloPi.taskParVersion(100000)
MonteCarloPi.taskParVersion(n=100000, seed=589494289)
```
C Interoperability
Interoperability: C

- C interoperability was a huge pain
  - Had to write header files/prototypes by hand, after inspecting generated C

MonteCarloPi.chpl:

```chpl
export proc serialVersion(n: int, seed: int) { … }
```

MonteCarloPi.h:

```chpl
#include "stdchpl.h"

void chpl__init_MonteCarloPi(int64_t _ln,
                            int32_t _fn);
void serialVersion(int64_t n, int64_t seed);
```
Interoperability: C

• Getting the '-I' includes and '-L'/-l' libraries right for compilation was tricky

• Had a shortcut to help, but didn't account for program-specific 'require's
Interoperability: C

• Most of that information could be determined by the compiler, so generate it
  
  chpl --library MonteCarloPi.chpl  # generates MonteCarloPi.h
  # also creates helper Makefile, which includes program-specific information
  chpl --library-makefile MonteCarloPi.chpl

• Compiling with the helper Makefile's variables is much easier
Fortran Interoperability
Interoperability: Fortran

- Chapel compiler generates Fortran interfaces to Chapel libraries
  - Compiling with '--library-fortran' flag generates a library and interface module
  - Interface module is 'use'd by Fortran code to access Chapel symbols

```fortran
program CallMonteCarloPi
  use MonteCarloPi ! use the generated library

  integer(8):: n, seed
  n = 100000
  seed = 589494289

  call chpl_library_init() ! initialize the library
  call taskParVersion(n, seed) ! call a Chapel procedure
  call chpl_library_finalize() ! tear down the library

end program CallMonteCarloPi
```
Interoperability: Fortran

• Steps to compile and use the library

```plaintext
% chpl --library=fortran MonteCarloPi.chpl  # build library and interface module
% gfortran -c lib/MonteCarloPi.f90              # create the module description file
% gfortran runMonte.f90  -Llib -lMonteCarloPi \  
 `$CHPL_HOME/util/config/compileline --libraries` \       # compile and link the code and library
  -o runMonte
```

User written code

- MonteCarloPi.chpl
- runMonte.f90

chpl generated code

- lib/MonteCarloPi.f90
- lib/MonteCarloPi.a

ftn generated code

- MonteCarloPi.mod
- runMonte
Interoperability Using Arrays
Interoperability: Arrays

- 1D arrays translate into native Chapel arrays from C, Fortran, and Python
- Support parallel operations, slicing, etc.

```chapel
export proc serialVersion(n: int, seed: int, p: [] real) { ... p[i] = rnd; ... }
```

**Python**

```python
import MonteCarloPi as mcp
A = [0.0]*200000
n = 100000; seed = 12345
...
mcp.serialVersion(n, seed, A)
```

**Fortran**

```fortran
include "MonteCarloPi.h"
double* A = malloc(...);
int n, seed;
...
chpl_external_array Aext =
   chpl_make_external_array_ptr(A, n*2);
serialVersion(n, seed, Aext);
```

**C**

```c
#include <MonteCarloPi.h>
double* A = malloc(...);
int n, seed;
...
call serialVersion(n, seed, A)
```
Interoperability: Arrays

• Chapel arrays without native representations handled opaquely in C or Python
  • e.g. Block or Cyclic Distributed arrays

```chapel
export proc serialVersion(n: int, seed: int) {
    var A = newBlockArr(1..2*n);
    ... A[i] = rnd; ...
    return A;
}
```

```python
import MonteCarloPi as mcp
n = 100000; seed = 12345
A = mcp.serialVersion(n, seed)
... mcp.otherFunction(A) ...
A.cleanup()
```

```c
#include "MonteCarloPi.h"
int n = 100000, seed = 12345;
chpl_opaque_array A;
A = serialVersion(n, seed);
... otherFunction(A); ...
cleanupOpaqueArray(&A);
```
What's Next?
Interoperability: Next Steps

- Multilocal libraries
  - Launch multilocal Chapel library on compute notes
  - Communicate with it from the main program to execute functions
- Multidimensional arrays
  - Currently only support 1D arrays
  - Desire capability to support Chapel's rich multidimensional arrays
- Support calling Chapel libraries from additional languages
  - C++
  - Chapel
  - More?
Multilocale Libraries
Multilocale Libraries: Background

• Not automatically supported
  • Chapel launcher did not adjust for wrapping a library file

• Chapel expected to control how the program is distributed
  • Trickier when Chapel doesn't own 'main()'

• Had mock-up of intended strategy
  • Users can and have implemented it themselves, but it's a lot of work
  • We've started adding automatic support but there are still some kinks
    • Should have a basic version in 1.20
Typical Multi-Locale Compilation + Execution

MonteCarloPi.chpl → chpl --comm=… → MonteCarlo Pi

Login node → MonteCarloPi_real

The user executes this Which launches this onto the various locales

Locale 0
Locale 1
Locale 2
Locale n

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Typical Multi-Locale Compilation + Execution

MonteCarloPi.chpl → chpl --comm=… → MonteCarlo Pi → Login node

Locale 0
MonteCarloPi_real

Locale 1
MonteCarloPi_real

Locale 2
MonteCarloPi_real

Locale n
MonteCarloPi_real
Multilocal Libraries: Background Motivation

• Make multilocal 'library' support feel natural
  • Like non-library multilocal, users shouldn't have to worry about launching
    • Should be agnostic to user program running on compute or login node

• Similar behavior for function calls, argument types, etc. to single-locale
  • Though we do expect a numlocales argument for library initialization

    chpl_setup(); // Call in Python to set up library in single-locale
    chpl_setup(numLocales); // New call
Multilocale Libraries: The Plan

• Will generate stand-alone binary to be launched
  • Its existence should be a black box to the user
    • Will be used by the library's interface
    • But the user won't be responsible for ensuring that happens
  • Library's interface will communicate to this binary using a socket
    • Binary's 'main()' will wait for function calls from socket, then execute them
    • Use ZeroMQ module for communication
      • Some extensions needed, currently on master
Multilocale Libraries: The Plan

• User code will link to a library that launches the binary on initialization
  • Library will have wrappers that communicate to the launched binary

    // definition in library file
    export proc serialVersion(n: int, seed: int) {
        socket.send(/* actual serialVersion's function number */);
        socket.send(n);
        socket.send(seed); // we hope to bundle these args together eventually
        socket.receive(/* type of indicator that the function is done */) ;
    }
Multilocale Libraries: The Plan

• Potentially implement a protobuf module for serialization
  • Instead of communicating arguments individually, can serialize into one

• Could allow users to sidestep temporary argument type restrictions
  • E.g. to send class instance (which can't be an exported function arg today)
    • Users would serialize the instance themselves, then send and unpack

• Protobuf is a well-known and widely used package
  • So having an implementation for Chapel is beneficial on its own merits
Multilocale Libraries: Next Steps

• Short-term: Finish implementing basic plan
  • Have split user source file into library and executable sub-components
  • Have implemented communication between both sides
  • Supports c_string arguments and most other primitives
    • Still need to support arrays
    • We're also looking into supporting Chapel strings

• Medium-term: Start work on serialization strategy
And that's it!
Interoperability: Additional Resources

• We have a technote describing the currently supported features
• We intend to create a primer or two to demonstrate using the generated libraries
• And of course, you can ask questions on our mailing lists, Gitter channel, StackOverflow, etc.
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