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

```
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'

```
import MonteCarloPi // Treated like any other Python module!
```

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

```
// 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:

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

MonteCarloPi.h:

```
#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

```
lydia@C02SY01RGTFM:exportArray (master)$ clang -fno-strict-overflow -I$CHPL_HOME/third-party/qthread/install/darwi
n-clang-native-flat-jemalloc-hwloc/include -I$CHPL_HOME/third-party/hwloc/install/darwin-clang-native-flat/include
 -DCHPL_JEMALLOC_PREFIX=chpl_je_ -DCHPL_HAS_GMP -fPIC -I$CHPL_HOME/modules/standard -I$CHPL_HOME/modules/packages
-Wno-unused -Wno-uninitialized -Wno-pointer-sign -Wno-tautological-compare -I$CHPL_HOME/third-party/qthread/instal
l/darwin-clang-native-flat-jemalloc-hwloc/include -I. -I$CHPL_HOME/runtime//include/localeModels/flat -I$CHPL_HOME
/runtime//include/localeModels -I$CHPL_HOME/runtime//include/comm/none -I$CHPL_HOME/runtime//include/comm -I$CHPL_
HOME/runtime//include/tasks/qthreads -I$CHPL_HOME/runtime//include/threads/none -I$CHPL_HOME/runtime//include -I$C
HPL_HOME/runtime//include/qio -I$CHPL_HOME/runtime//include/atomics/intrinsics -I$CHPL_HOME/runtime//include/mem/j
emalloc -I$CHPL_HOME/third-party/utf8-decoder -I$CHPL_HOME/runtime//../build/runtime/darwin/clang/arch-native/loc-
flat/comm-none/tasks-qthreads/tmr-generic/unwind-none/mem-jemalloc/atomics-intrinsics/hwloc/re2/fs-none/include -I
$CHPL_HOME/third-party/jemalloc/install/darwin-clang-native/include -I$CHPL_HOME/third-party/gmp/install/darwin-cl
ang-native/include -I$CHPL_HOME/third-party/hwloc/install/darwin-clang-native-flat/include -o callFuncReturnsArray
 callFuncReturnsArray.test.c -Llib/ -lreturnExternArray-L$CHPL_HOME/third-party/qthread/install/darwin-clang-nativ
e-flat-jemalloc-hwloc/lib -Wl,-rpath,$CHPL_HOME/third-party/qthread/install/darwin-clang-native-flat-jemalloc-hwlo
c/lib -L$CHPL_HOME/third-party/jemalloc/install/darwin-clang-native/lib -Wl,-rpath,$CHPL_HOME/third-party/jemalloc
/install/darwin-clang-native/lib -L$CHPL_HOME/third-party/gmp/install/darwin-clang-native/lib -Wl,-rpath,$CHPL_HOM
E/third-party/gmp/install/darwin-clang-native/lib -L$CHPL_HOME/third-party/hwloc/install/darwin-clang-native-flat/
lib -Wl,-rpath,$CHPL_HOME/third-party/hwloc/install/darwin-clang-native-flat/lib -L$CHPL_HOME/third-party/re2/inst
all/darwin-clang-native/lib -Wl,-rpath,$CHPL_HOME/third-party/re2/install/darwin-clang-native/lib -L$CHPL_HOME/lib
/darwin/clang/arch-native/loc-flat/comm-none/tasks-qthreads/tmr-generic/unwind-none/mem-jemalloc/atomics-intrinsic
s/hwloc/re2/fs-none -lchpl -lm -lgmp -ljemalloc -lchpl -lqthread -L$CHPL_HOME/third-party/hwloc/install/darwin-cla
ng-native-flat/lib -lhwloc -lm -lre2 -lpthread
```

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

```
[redacted]:exportArray (master)$ `$CHPL_HOME/util/config/compileline --compile` -o callFuncReturnsArray ca
llFuncReturnsArray.test.c -Llib/ -lreturnExternArray `$CHPL_HOME/util/config/compileline --libraries`
```

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

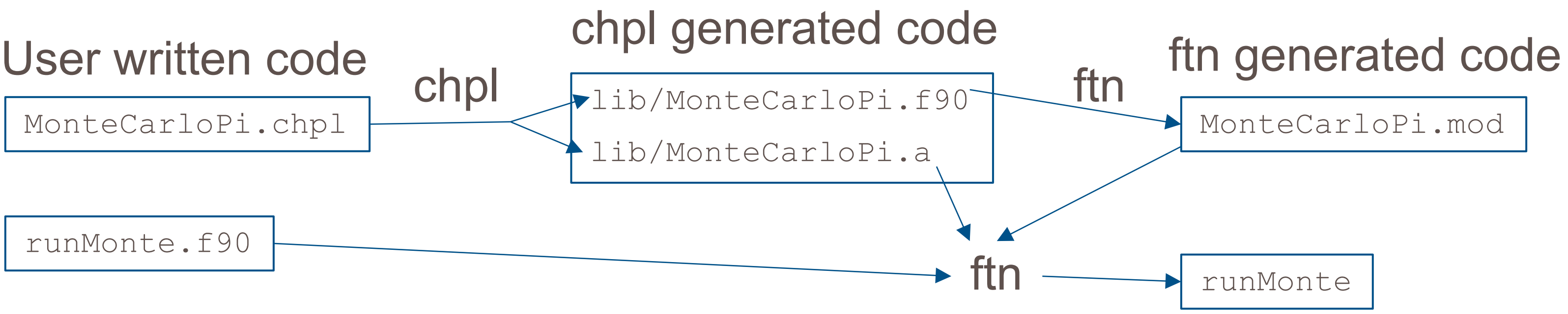
- Chapel compiler generates Fortran interfaces to Chapel libraries
  - Compiling with '--library-fortran' flag generates a library and interface module
  - Interface module is 'use'd by Fortran code to access Chapel symbols

```
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

```
% 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` \
    -o runMonte                             # compile and link the code and library
```



Interoperability Using Arrays

Interoperability: Arrays

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

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

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

Python

Fortran

```
use MonteCarloPi
real(8), dimension(200000) :: A
integer(8) :: n, seed
…
call serialVersion(n, seed, A)
```

```
#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

Interoperability: Arrays

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

```
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

CRAY

- Multilocale libraries
  - Launch multilocale 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

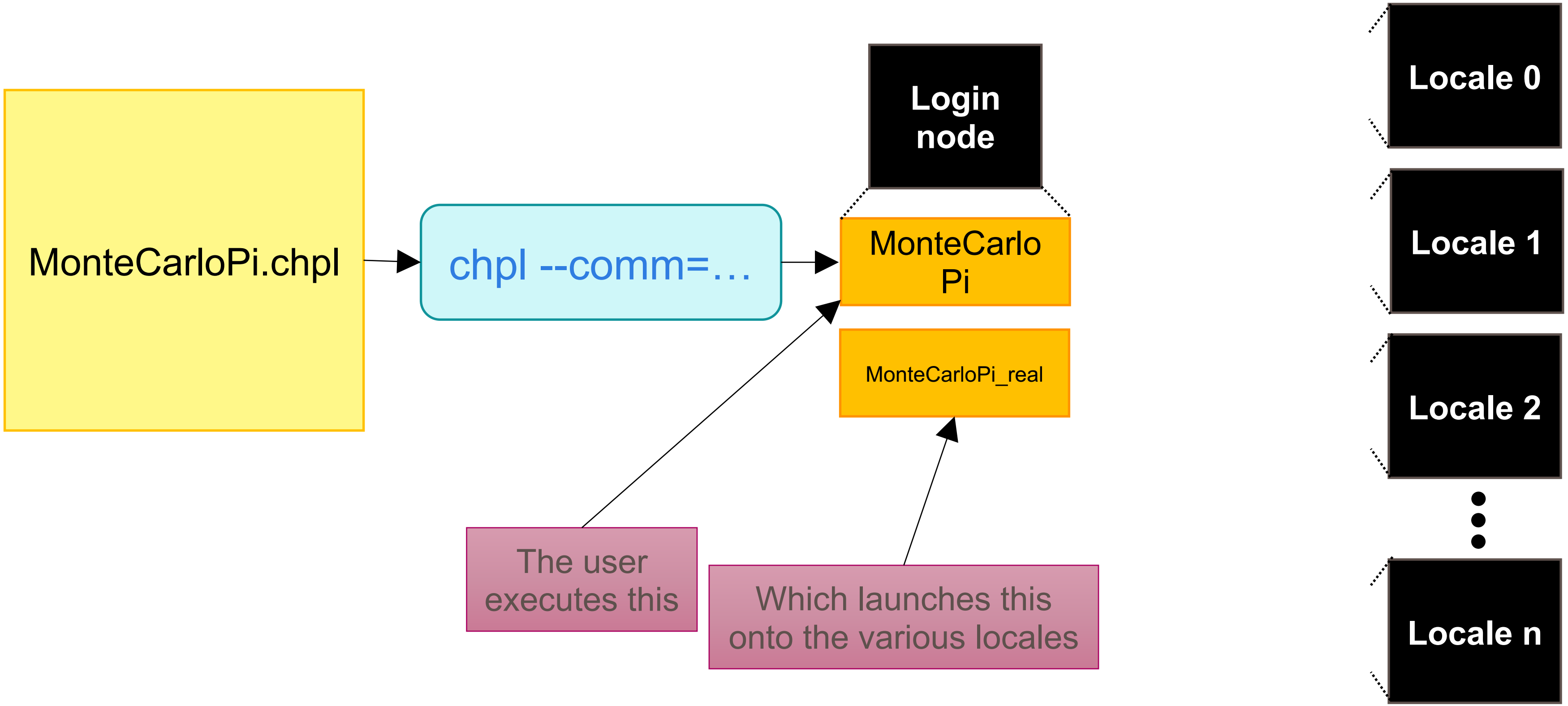
Multilocale Libraries: Background

- 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



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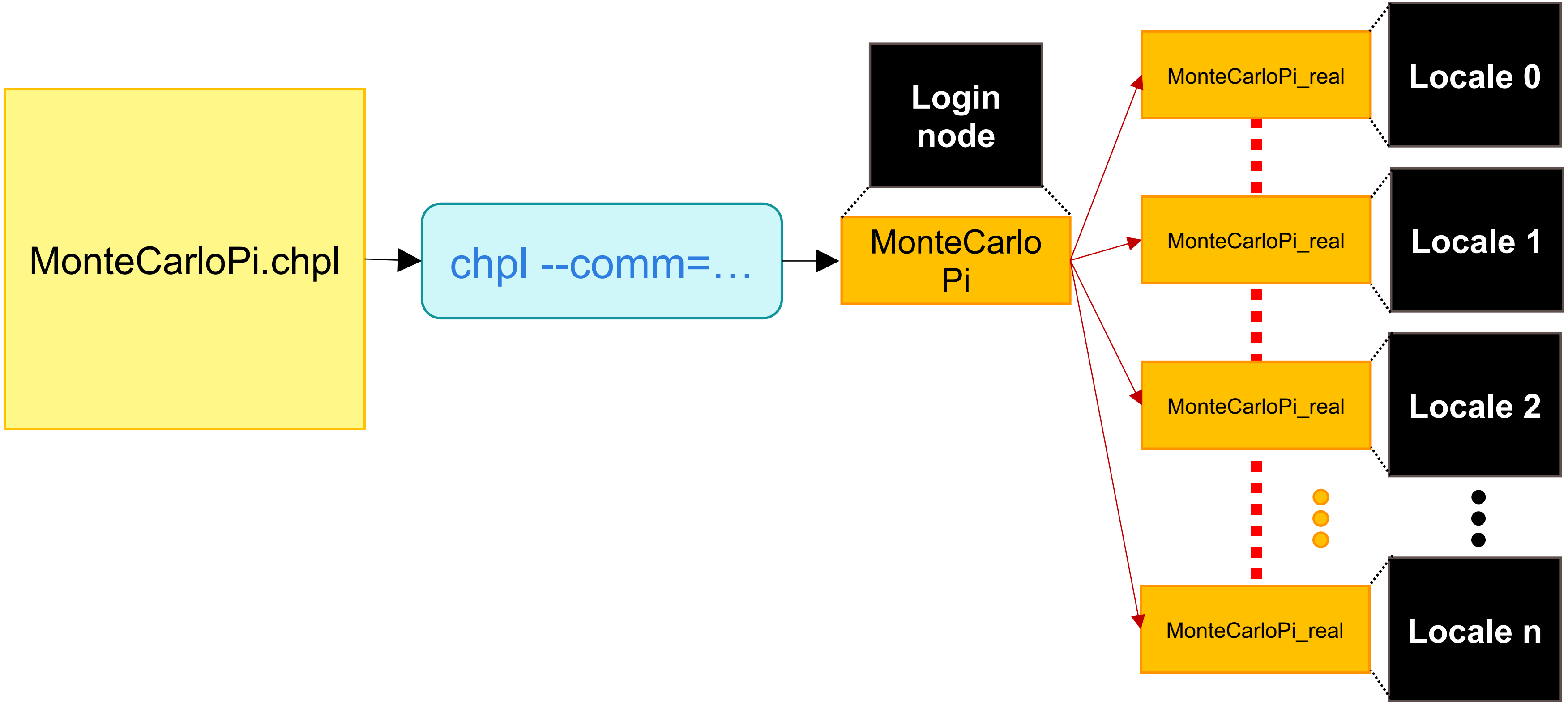


Multilocale Libraries: Background Motivation

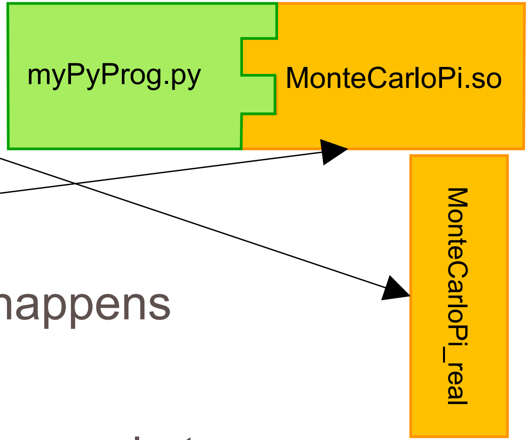
- Make multilocale '--library' support feel natural
  - Like non-library multilocale, users shouldn't have to worry about launching
    - Should be agnostic to user program running on compute or login node

  - 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.

Interoperability: Acknowledgements

- We would like to thank Ben Albrecht, Brad Chamberlain, Michael Ferguson, David Longnecker and the rest of the Chapel team, past and present, for their feedback, input and contributions.
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  - And various other users that have also provided their feedback

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