Portability and Interoperability Improvements

Chapel version 1.19

March 21, 2019

chapel_info@cray.com

chapel-lang.org

@ChapelLanguage

Outline

- 'ofi' Communication Layer
- Chapel Libraries
  - Exporting Arrays
  - Interoperating with Fortran
  - Chapel in Python Modules
  - LLVM For Libraries
  - PIC Library Code
  - Multilocale Libraries
  - Next Steps for Libraries
- Interoperating with C Arrays
- Renaming Extern Variables

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'ofi' Communication Layer

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ofi Comm Layer: Background and Progress

Aim: a single comm layer for HPC networks, with:

- minimal software overhead
- good day-1 performance for new networks

Last release: ofi “mock-up” standalone multi-node proxy for comm layer activities

This release: functional comm=ofi implementation

- Libfabric has *providers* for each network, similar to GASNet conduits
  - Provider capabilities may vary; user (comm layer) must adapt or avoid
- All but 2 tests pass with 'sockets' and 'verbs' providers on InfiniBand cluster
- All examples and most multilocale tests pass with 'gni' provider on Cray XC
  - Failures in multilocale were Cray XC-specific, not libfabric-specific

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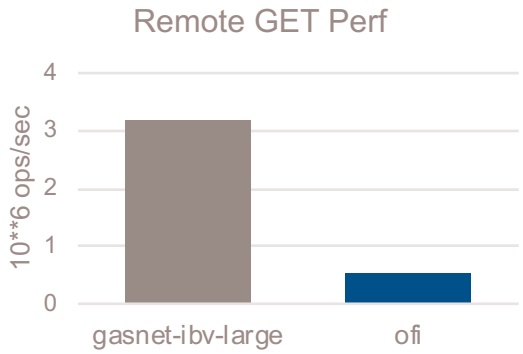
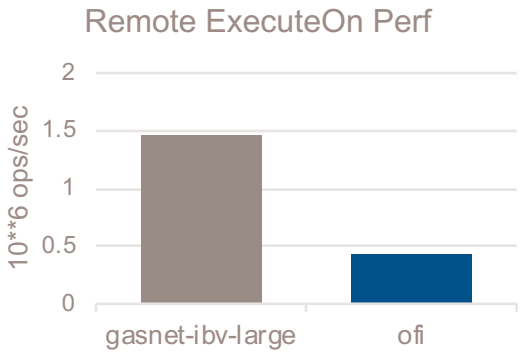
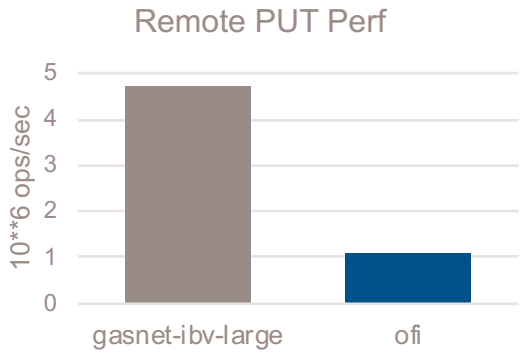
ofi Comm Layer: Status

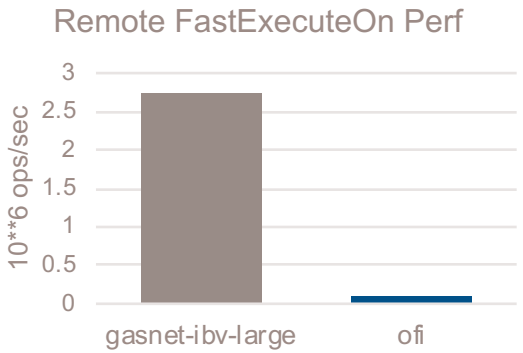
- InfiniBand results:





- Microbenchmark performance with default settings is not yet on par with comm=gasnet





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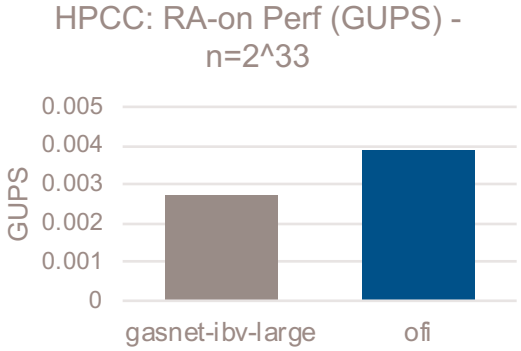
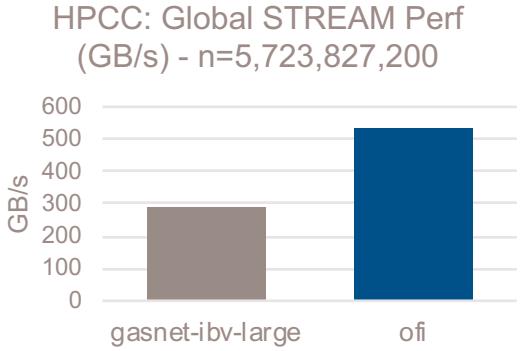
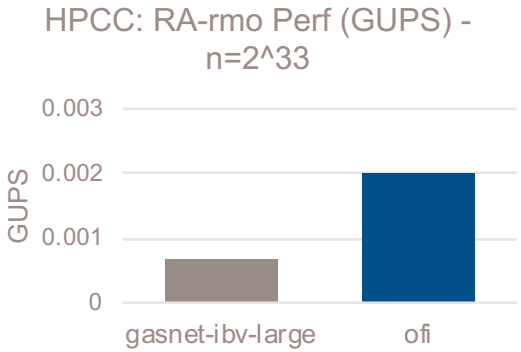
ofi Comm Layer: Status

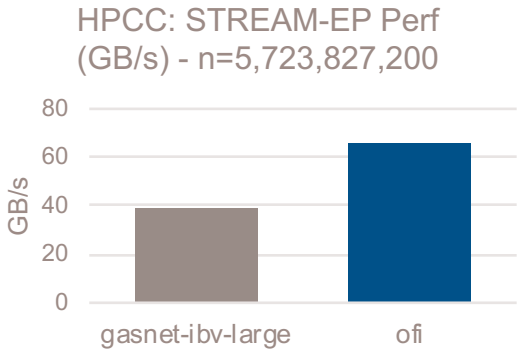
- InfiniBand results:

- Poor microbenchmark performance doesn't necessarily mean poor performance overall









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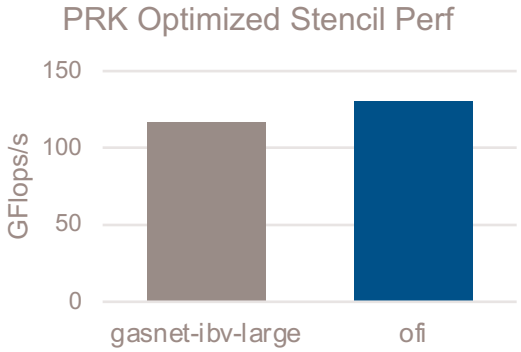
ofi Comm Layer: Status

- InfiniBand results:



- Poor microbenchmark performance doesn't necessarily mean poor performance overall

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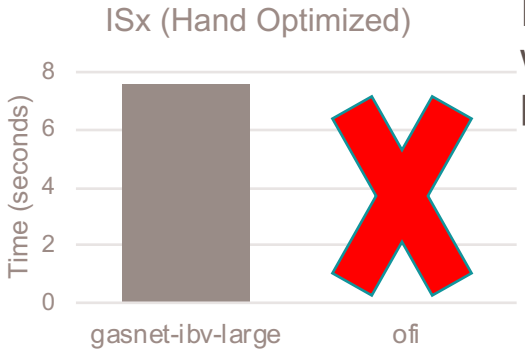
ofi Comm Layer: Status

- InfiniBand results:

- There are still some anomalies …



With comm=ofi, ISx got an InfiniBand-related error when sized for multilocale performance testing.

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ofi Comm Layer: Next Steps

- Complete functionality
  - Fix bugs (ISx, e.g.) revealed by preliminary performance testing
  - Add support for nonblocking GET/PUT and unordered atomics
  - Integrate better with Chapel launchers
- Begin nightly functional and performance testing
- Tune for performance
  - Libfabric interactions (examples: provider selection, progress threads)
  - Provider/platform optimizations (examples: 'verbs'-specific settings, Shasta)

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Creating and Using Chapel Libraries

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Chapel Libraries: Background

- Have had a draft capability to create Chapel libraries
  - '--library' flag generates library instead of executable
    - 'main()' function not valid in this compilation mode
  - The 1.18 release added:
    - Support for 1D rectangular array arguments and return types
    - Many helper flags, especially for use with C client programs
    - The ability to compile into a Python module
  - Much work remained

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Exporting Arrays

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Exporting Arrays: Background

- Last release added support for 1D rectangular array arguments and return types
  - Available for both Python and C interoperability
    - Translated to NumPy array in Python, 'chpl_external_array' struct in C

- Multidimensional rectangular arrays and other array types not supported

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Exporting Arrays: Background

- Motivation: want to tell Chapel to manipulate array that C/Python can't represent
  - Stop-gap solution until we can natively support them

ChapelLib.chpl:

```
const D = {1..n} dmapped Block(…);
export proc getArr(): [D] int {…}
export proc manipulate(x: [D] int) {…}
```

PythonProg.py:

```
import ChapelLib
x = ChapelLib.getArr() // details of x not representable just yet
ChapelLib.manipulate(x)
```

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Exporting Arrays: This Effort

- Added opaque representation of most other array types
  - 'chpl_opaque_array' struct for C, 'ChplOpaqueArray' class for Python
  - Allows us to pass unrepresentable arrays around
  - Can only be obtained from an exported Chapel function that returns an array
    - Unlike 'chpl_external_array', which can be created in C
    - Only array types unsupported by 'chpl_external_array' will generate it

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Exporting Arrays: This Effort

- Contents cannot be accessed in C/Python
  - Can only send as argument to Chapel functions

```
const D = {1..n} dmapped Block(…);
export proc foo(x: [D] int) {…}
// transforms into this declaration in C
void foo(x: chpl_opaque_array) {…}
```

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Exporting Arrays: Next Steps

- Support interoperation between multidimensional Chapel and NumPy arrays
  - Would support these arrays more natively than by using opaque arrays
  - Intend to take approach similar to Fortran array support (see next section)

- Interoperate on arrays in place
  - Currently performs a copy when crossing Python-Chapel function borders

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Interoperating with Fortran

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Fortran Interoperation: Background

- Fortran is popular in the HPC and scientific programming space
- Chapel and Fortran can both interoperate with C
- Seemed possible to use the C bindings of both languages to tie them together

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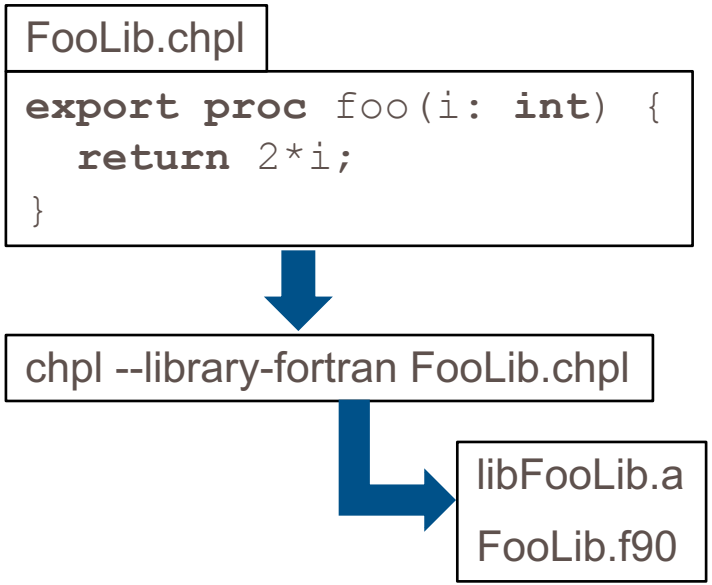
Fortran Interoperation: This Effort (Fortran→Chapel)

- Added support for calling Chapel functions from Fortran
  - Using the compiler flag '--library-fortran' builds a library with 'export' functions
    - Also generates a Fortran interface module for the 'export' functions



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Fortran Interoperation: This Effort (Fortran→Chapel)

- Fortran array arguments are handled specially by the Chapel compiler
  - Declare the 'export' function's argument with regular Chapel array syntax
  - Compiler translates from Fortran array to regular Chapel array
    - Uses ISO/IEC specified structures for Fortran/C interoperability
    - Can then be iterated over in parallel with 'forall', sliced, reduced, etc.

```
export proc foo(A: [] real) {
  forall i in A.domain do
    A[i] = i*10;
}
```

```
program PassArray
  use FooLib ! chpl-generated interface
  real(kind=8), dimension (9) :: arr
  call foo(arr)
end program PassArray
```

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Fortran Interoperation: This Effort (Chapel→Fortran)

- Added support for calling Fortran functions from Chapel
  - Separately compile the Fortran code with a Fortran compiler
  - Declare the interface using marked 'extern' functions in Chapel
  - Chapel compiler generates the signature of the marked 'extern' functions
    - Currently marked using 'pragma "generate signature"'
    - Fills the purpose of the header files used in C 'extern' support
  - Chapel compiler links the Fortran binary with the Chapel binary
    - Requires explicitly linking with the Fortran runtime library

```
$ chpl chplCode.chpl ftnCode.o -L$LIBGFORTRAN_PATH -lgfortran
```

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Fortran Interoperation: Impact, Next Steps

Impact: Chapel and Fortran functions can call each other

- Can use primitive types as arguments and return values
- Compiler automatically generates Fortran interface code
- 1D Fortran arrays automatically convert to regular Chapel arrays
  - Enables parallel iteration, slicing, reductions, etc.

Next Steps: Continue to improve support

- Support more complex arguments and return types
  - Multidimensional arrays, records, tuples
- Support multilocale Chapel as a library for Fortran

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Chapel in Python Modules

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Chapel Python Modules: Background

- Can compile Chapel libraries into a Python module
  - Imported in Python code like any other module

```
import ChapelLib; // for some ChapelLib.chpl
```

  - Supports primitive types and array arguments
    - Arrays are returned as NumPy arrays (but lists accepted as arguments)

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Chapel Python Modules: This Effort

- Added support for literal argument default values

```
// can call both 'foo' and 'bar' from Python w/ or w/o the 'x' arg
export proc foo(x: int = 4) {…}
export proc bar(x: c_string = "blah") {…}
```

  - Complicated default values will be dropped on the floor, with a warning
    - Must always provide that argument when calling the function from Python

```
export proc foo(x: int, y: int = x) {…}    // must call with ‘x’ and ‘y’
export proc bar(x: int = someGlobalVar) {…} // must call with 'x' arg
export proc baz(x: complex = 4 + 3i) {…}    // must call with 'x' arg
```

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Chapel Python Modules: This Effort

- 'c_ptr' Chapel arguments now supported in Python code
  - With NumPy arrays:

```
arr = numpy.empty(6, dtype=numpy.double)
ChapelLib.func(arr) // usually want to specify size of array as another arg
```

  - With ctypes pointers:

```
dub = ctypes.c_double()
doubPtr = ctypes.pointer(dub)
ChapelLib.func(doubPtr)
```

ChapelLib.chpl

```
export
proc func(x:c_ptr(real)) {…}
```

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Chapel Python Modules: This Effort

- Made Python module compilation use PrgEnv wrappers on Crays
  - It is better to use the Cray wrappers rather than the unwrapped compilers
    - E.g. 'PrgEnv-gnu' and 'cc' rather than just 'gcc'
  - Allowed builds with CHPL_REGEXP=re2, for instance
- Hid a warning with recent versions of Cython
  - Due to Python 2 deprecation — we require Python 3 anyways

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Chapel Python Modules: Next Steps

- Extend support to include calls to multilocale Chapel libraries
- Improve support for default argument values
- Performance improvements
  - Remove unnecessary copies for arrays and strings
- Support Anaconda distribution
  - Common among scientists/engineers/HPC users
- Error message improvements

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Chapel Python Modules: Next Steps

- Fix known bugs
  - Shutting down the Chapel runtime also ends Python execution
  - Python output lost when redirecting program output into a file

- Automatically set up and tear down runtime w/o user calls(?)
  - Remove need for 'chpl_setup()' and 'chpl_cleanup()' calls

- Remove fix for Python 2 deprecation warning when no longer needed

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LLVM for Libraries

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LLVM: Background and This Effort

Background: '--library' compilation did not work with the LLVM compiler backend

- Would still create an executable instead of a library

This Effort: fix basic compilation with '--library'

- Some issues remain:
  - Not all '--library-*' flags supported yet
  - Arrays encounter memory issues due to known ABI incompatibility

- Note: compiling C code w/ library built using LLVM requires listing it twice

```
… -Llib/ -lmyChplLib <chpl support libraries> -lmyChplLib
```

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LLVM: Next Steps

- Fix known issues:
  - Array memory issues
  - '--library-makefile'
  - '--library-python'
  - 'CHPL_LIB_PIC' not respected

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Position-Independent Code for Libraries

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PIC Library Code: Background

- Python requires linking against position independent code
  - So added 'CHPL_LIBMODE' for previous Python interoperability solution
    - Enabled use of '-fPIC' when building Chapel
    - Settings were "shared" or "none"
  - Runtime/third-party libraries wouldn't automatically rebuild for new settings
    - Had to fully rebuild whenever the setting was switched

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PIC Library Code: This Effort

- Replace with 'CHPL_LIB_PIC'
  - Settings are "none" or "pic”
    - "none" is the default
    - “pic” may impact performance, use sparingly
  - Runtime/third-party rebuilds when new setting is used
    - Old builds are kept around so don't have to rebuild every time

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Multilocale Libraries

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Multilocale Libraries: Background

- Not automatically supported today
  - Chapel launcher does not adjust for wrapping a library file
  - Chapel expects to control how the program is distributed
    - Trickier when Chapel doesn't own 'main()'
  - Have mock-up of intended strategy
    - Users can and have implemented it themselves, but it's a lot of work
    - We're hoping to start adding automatic support in the next release cycle

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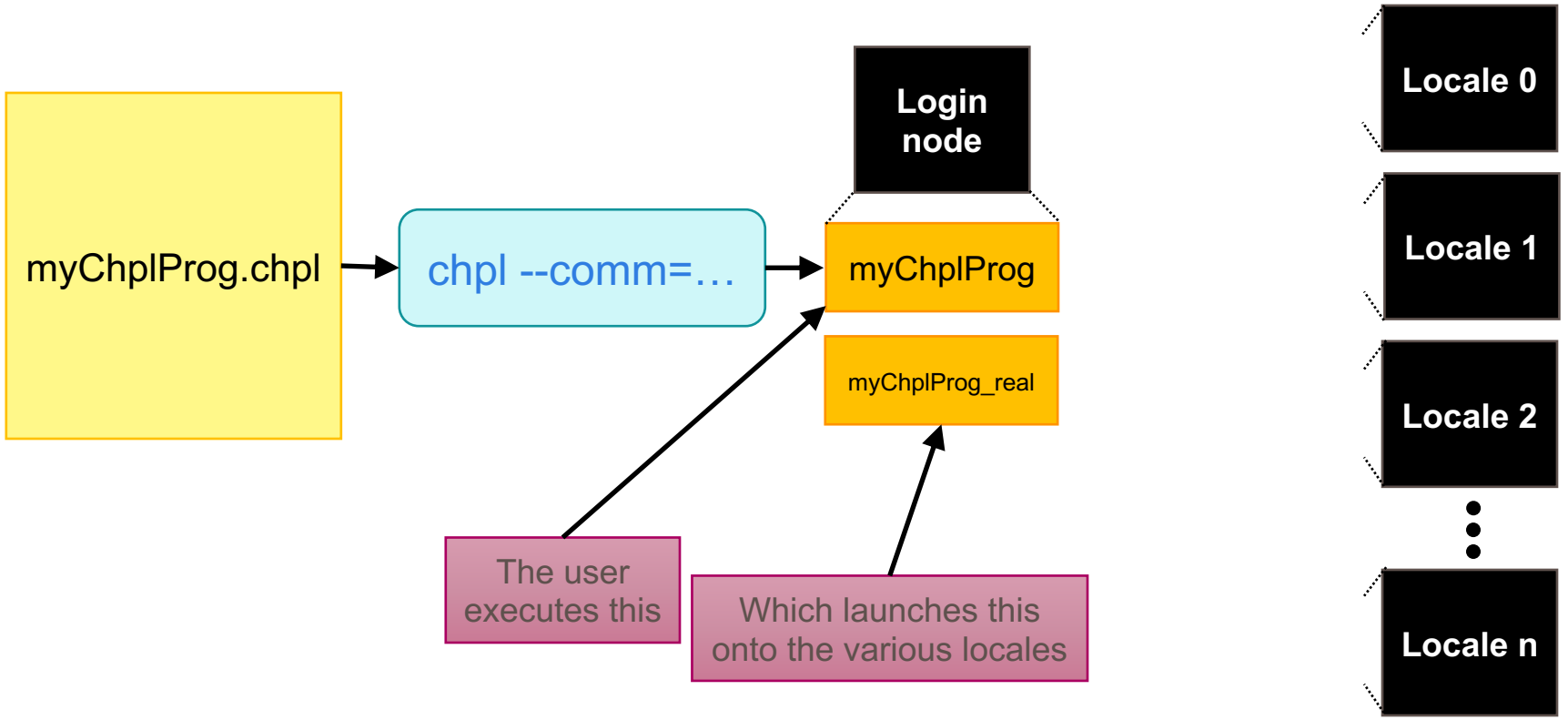
Typical Multi-Locale Compilation + Execution



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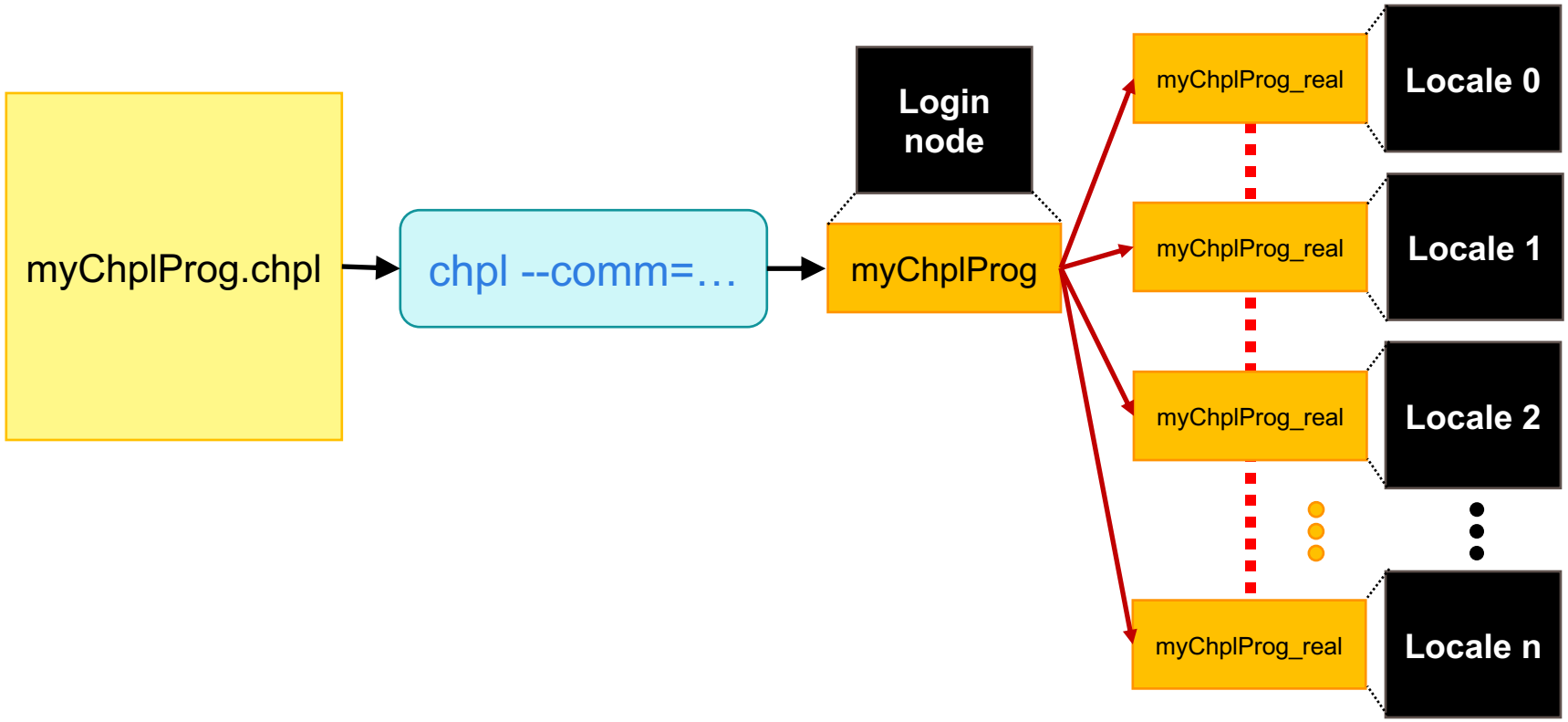
Typical Multi-Locale Compilation + Execution



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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 willing to change library initialization, e.g. for a numlocales arg

```
chpl_library_init(…); // Call to set up library in single-locale
chpl_multilocale_library_init(…, numLocs); // potential new call
```

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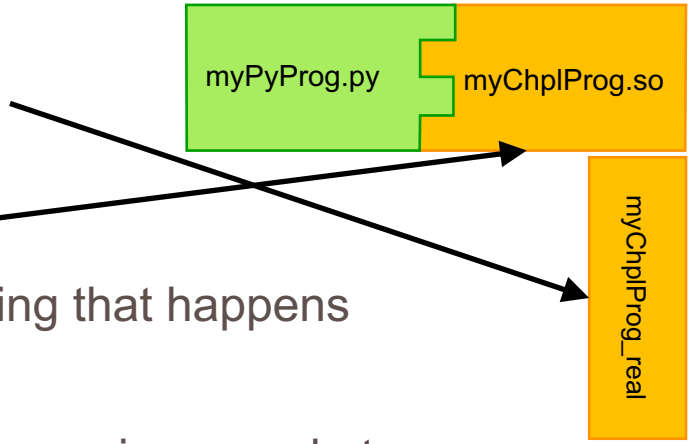
Multilocale Libraries: The Plan



- 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
    - Plan to use ZeroMQ module for communication
      - Some extensions needed, currently in progress

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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

```
export proc foo(arg: int): int {  // definition in library file
    socket.send(/* actual foo's function number */);
    socket.send(arg);
    return socket.receive(int);
}
```

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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

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Multilocale Libraries: Next Steps

- Short-term: Implement basic plan
  - Split user source file into library and executable sub-components
  - Implement communication between both sides
  - Only support string arguments for first draft

- Medium-term: Start work on serialization strategy
  - Extend argument types to all types single-locale interoperability supports

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Next Steps for Libraries

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Chapel Libraries: Next Steps

- Support multi-locale library builds natively
- Improve support for arrays
  - Multidimensional rectangular arrays
- Improve support for LLVM back-end
  - Expected to be the default soon
- Expand set of exportable features (e.g., additional types, variables, functions?)

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Interoperating with C Arrays

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c_array: Background

- Interoperability support had trouble with fixed-sized C arrays
- Compiler considered them as 'c_ptr', but this view is not quite accurate
  - A fixed-size C array field is allocated inside the structure
  - But a 'c_ptr' field is a pointer to some memory
- This approximation includes several drawbacks:
  - Missing opportunity for writeln of the fixed-size array to print elements
  - Setting a fixed-sized array field to a 'c_ptr' is invalid C code
    - Can occur within compiler-generated copy and default initializers

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c_array: This Effort

- 'c_array' is a new type in CPtr.chpl
- 'c_array'
  - Is a value type
  - Is always 1-dimensional
  - Stores the size as a 'param' compile-time constant
  - Indexing starts at 0
- Chapel compiler translates to a fixed-size array:

```
var x: c_array(c_int, 4)
// produces this C declaration
int x[4];
```

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c_array: Basic Usage

```
var arr: c_array(int, 4);
writeln(arr); // [0, 0, 0, 0]
for i in 0..3 do
  arr[i] = i;
writeln(arr); // [0, 1, 2, 3]
var copy = arr; // copy-initialize the elements
writeln(copy); // [0, 1, 2, 3]
copy[0] = 100; // modifies 'copy' but not 'arr'
writeln(copy); // [100, 1, 2, 3]
writeln(arr); // [0, 1, 2, 3]
```

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c_array: Interoperability

```
// header.h
typedef struct {
  double dat[2];
} mycomplex;

// test.chpl
extern record mycomplex {
  var dat: c_array(real(64), 2);
}
```

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c_array: Impact, Next Steps

Impact:

- Certain C interoperability scenarios are enabled
- Chapel includes a new useful low-level array type

Next Steps:

- Adjust compiler to use 'c_array' to implement homogeneous tuples
  - e.g. ‘4096*int’

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Renaming Extern Variables

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Rename Extern Vars: Background & This Effort

Background:

- Chapel's 'extern' declarations refer to external code (e.g., from C)
- Strings can be used to indicate that the external name differs from Chapel's

```
// This routine is called 'foo' in C, but 'c_foo' in Chapel
extern "foo" proc c_foo(x: c_int);
```

- This renaming has been supported for procedures and records

This Effort:

- Extend the renaming support to variables (including constants and fields)

```
extern "type" var c_type: c_int;
```

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Rename Extern Vars: Impact and Next Steps

Impact:

- Extends flexibility of renaming external symbols for use within Chapel
- Supports referring to external variables that conflict with Chapel keywords
- Helped with supporting Fortran array interoperability
  - Fortran's array descriptor has a field named 'type' (reserved in Chapel)

Next Steps:

- Extend renaming capability to support extern types
- Ensure all extern renamings work with general 'param' string expressions
  - Currently, only procedures do; others only support string literals

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For More Information

For a more complete list of related changes in the 1.19 release, refer to the 'Portability' and 'Interoperability' sections in the CHANGES.md file.

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