Ongoing Efforts

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Outline

- **Open Fabrics Interface (‘ofi’) Communication Layer**
- **Creating and Using Chapel Libraries**
Open Fabrics Interface (‘ofi’) Communication Layer
'ofi' Comm Layer: Background and This Effort

**Background:** Progress toward an OFI-based comm layer
- Goal (dream?): a single comm layer supporting all HPC networks, and with timely performance
- Previously: “Design work and stubbed implementation complete”
- Turned out to be premature
- Encountered problems expanding the stubbed implementation

**This Effort:** ofi “mock-up”
- Standalone multi-node proxy for comm layer activities
  - Registers memory, sends & handles Active Messages, does RDMA, etc.
  - Small: functional portion only 1/10 LOC of comm=ugni
- Avoided comm layer intricacies while prototyping network interactions
- Quicker exploration cycle (study ⇒ code ⇒ test)
- Completed in mid-September
‘ofi’ Comm Layer: Impact, Status, Next Steps

**Impact:** Path to comm=ofi is clear
- Have match between comm layer needs and provider capabilities
- Working code demonstrates basic comm layer functions (AM, RDMA)

**Status:** Functionality sufficient, performance adequate
- Mockup works with both sockets and gni providers
- Single-thread performance compared to comm=ugni:
  10% AM rate, 50% RDMA bandwidth; ok for now

**Next Steps:** Produce initial comm=ofi implementation
- Adapt code for network interactions (AM, RDMA) from ofi mockup
- Adapt code for runtime interactions (tasking, e.g.) from comm=ugni
Creating and Using Chapel Libraries
Chapel Libraries: Outline

- Background
- Chapel Code Changes
- Calling from C
- Python Modules
- Arrays
- Error Message Improvements
- Status and Next Steps
Chapel Libraries: Background

- **Have had a draft capability to create Chapel libraries**
  - Historically designed for use from C
  - Left much to be desired...

- **Accessible symbols specified via `export` keyword**
  ```
  export proc bar(): int { ... }
  ```

- Only supports exporting functions with concrete signatures
  - Couldn’t export functions involving array arguments (considered generic)
  - Can’t export module-level variables or type definitions
Chapel Libraries: Chapel Code Changes
**Background:**
- Module-level variables were not initialized in library mode
  - Could be referenced by exported functions
  - But, would not have been given initial value

**This Effort:**
- Automatically export module initialization functions
  - For a module ‘foo’, creates routine named `chpl__init_foo()`
  - Establishes initial values of module-level variables
    - `chpl_library_finalize()` call deinitializes such variables
Chapel Changes: Next Steps

- Allow multiple Chapel libraries to be used by one program
  - Currently, each library includes the Chapel runtime
    - Linking multiple libraries leads to duplicate symbols

- Create single entry-point to initialize modules and runtime
  - Similar to Python support described in subsequent slides
  - Or even zero calls to set things up?

- Support exporting module-level variables, types
Chapel Libraries: Calling From C
Calling From C: Background

- Client programs must call two runtime functions ...
  ... one to set up the Chapel runtime and third-party libraries ...
    ```c
    void chpl_library_init(int argc, char* argv[]);
    ```
  - Must be called prior to any calls in the generated library itself

  ... and one to clean up at the end of the program
    ```c
    void chpl_library_finalize(void);
    ```
Calling From C: Background

- **Generated library using `--library`**
  - For foo.chpl, `--dynamic` created `foo.so` and `--static` created `foo.a`
  - Default behavior determined by platform, back-end compiler

- Could change name using `-o`/`--output` flag
  
  ```bash
  chpl --library -o libfoo foo.chpl # libfoo.a or libfoo.so
  ```
Calling From C: Background

- Header files / prototypes had to be written by hand
  - Had to inspect generated C code for Chapel→C translation

```
myLib.chpl:

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

myLib.h:

#include "stdchpl.h"

#include myLib.h

void chpl__init_myLib(int64_t _Ln, int32_t _fn);
int64_t foo(int64_t x);
```
Calling From C: Background

- Compilation command to use libraries was very extensive
  - Needed to include runtime and third-party directories

- Even when using `compileline` shortcut, still longer than ideal
  - also, doesn’t account for `require` statements in the code
Calling From C: This Effort

● Improved the naming of the generated library
  ● Prepends “lib”, unless name already started with “lib”
    chpl --library foo.chpl # libfoo.a
    chpl --library libfoo.chpl # libfoo.a
    chpl --library -o bar foo.chpl # libbar.a

● Started generating a header file alongside the library
  ● Default name comes from base library name
  ● Can change using `--library-header`
    chpl --library foo.chpl # generates foo.h
    chpl --library -o bar foo.chpl # generates bar.h
    chpl --library --library-header bar foo.chpl # generates bar.h
    chpl --library-header bar foo.chpl # generates bar.h
Calling From C: This Effort

- Added `--library-makefile` to generate a Makefile stub
  - Named `Makefile.<base library name>`

- Defines Makefile variables for:
  - Compilation flags and include directories (`CHPL_CFLAGS`)
  - Library directories and `-l` libraries (`CHPL_LDFLAGS`)
  - The back-end C compiler used to create the library (`CHPL_COMPILER`)
  - Linker commands (`CHPL_LINKER` and `CHPL_LINKERSHARED`)

- Can be included by other Makefiles to simplify compilation
  - Sample Makefile for `foo.chpl` and client C code `myCProg.c`:

```makefile
include lib/Makefile.foo

myCProg: myCProg.c lib/libfoo.a
  
  $(CHPL_COMPILER) $(CHPL_CFLAGS) -o myCProg myCProg.c $(CHPL_LDFLAGS)
```
Calling From C: This Effort

- **Changed the default location of the generated files**
  - Was: same directory as compilation command
  - Now: defaults to “lib/” sub-directory (will create if it doesn’t exist)
  - Can change location via `--library-dir` flag
    - `chpl --library --static foo.chpl # lib/libfoo.a, lib/foo.h`
    - `chpl --library --static --library-dir bar foo.chpl # bar/libfoo.a ..`

- **All `--library-*` compilation flags implicitly throw `--library`**
  - `--library-header`
  - `--library-makefile`
  - `--library-dir`
  - And the Python library flags (see upcoming slides)
Calling From C: This Effort

- Reflect Chapel `require` statements in C and Makefiles
  - Headers result in a `#include` in generated .h files
    ```
    require "bar.h"
    #include "bar.h"
    ```
  - Libraries get added to the generated Makefile’s `CHPL_LDFLAGS`
    ```
    require "-lbar"
    CHPL_LDFLAGS = ... -lbar ...
    ```
Calling From C: Impact

● --library compilation is now easier to use
  ● Users have less repetitive code to write
  ● Generated Makefile makes compiling with generated libraries easier

● Library name is now more standard

● Functionality is expanded
  ● Module-level variables now have their declared initial values
Chapel Libraries: Python Modules
Python Modules: Background

- **Python interoperability was provided through PyChapel**
  - The implementation was prototypical
    - Contributed from the open-source community
  - Supported some primitive types and 1D arrays of reals
    - Multidimensional arrays and arrays of other types not supported

- Chapel code usable via inline doc strings, source files, fn body files
  - Inline example:
    ```python
    from pych.extern import Chapel
    @Chapel()
    def hello_world():
        """
        writeln("Hello, world");
        """
        return None
    ```
Python Modules: Background

- **PyChapel was hard to use and hard to maintain**
  - Installed via pip, or by downloading and building the repository
    - Installation process rather brittle: assumed Linux, virtual environment …
    - Also assumed a particular directory structure
  - Only worked for Python 2, not Python 3
  - Required quickstart settings for Chapel
    - No qthreads, no jemalloc …
Python Modules: This Effort

● **Added support for a new compiler flag `--library-python`**
  ● Generates and compiles Cython files under the hood

● **Accessible via normal Python `import` and function calls**
  ● Directory with generated files must be in `$PYTHONPATH`

● **Supports all Chapel primitives, C strings, 1D arrays**
  ● Primitives of different sizes (e.g. `int(8)`) supported via NumPy
  ● C strings correspond to Python `bytes` type
  ● 1D array arguments supported via anything iterable
  ● 1D array returns supported using NumPy arrays
Python Modules: This Effort

● **Supports Python 3**
  ● Decided not to support Python 2 for now
    ● Python 2 support expected to end after 2020

● **Works for any single-locale Chapel installation**
  ● Multi-locale support designed and prototyped, but not implemented

● **Name of generated module matches base name of library**
  ● foo.chpl can be used via `import foo` by default
  ● Can change module name (without changing the .a/.so name):
    ● `--library-python-name`
  ● Turns on creation of the Python module if not already specified
    chpl --library-python-name foo foobar.chpl  # Python module: foo
As in C, user must set up and tear down Chapel runtime

Unlike C, no need for a separate call to module initialization function

```python
import foo  # Import Chapel module

foo.chpl_setup()  # Set up Chapel runtime, third party libs, module-level vars
foo.baz(7)  # Call into a library function
foo.chpl_cleanup()  # Shut down the Chapel runtime and exit the program
```
Python Modules: Status

● PyChapel is now deprecated

● --library-python has more functionality than PyChapel
  ● Lives in Chapel repo rather than a distinct one

● Plenty of work remains
  ● Yet, desired features seem achievable
Python Modules: Next Steps

● **Improve support for arrays and C strings**
  ● Currently performs copies
  ● Would like to access arrays in-place

● **Explore supporting default values for arguments**
  ● C doesn’t support this
  ● But the Python code that calls it could …
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

- **Support Anaconda distribution**
  - Common among scientists/engineers/HPC users

- **Error message improvements**
Chapel Libraries: Arrays
Arrays: Background

● Couldn’t export functions involving arrays
  ● Array arguments were considered generic, even when fully specified
    \[
    \text{proc } \text{foo}(x: [0..5] \text{ int}) \{ \ldots \}
    \]
  ● In Chapel, this routine accepts a 1D array with any domain map
  ● But, generic routines can’t be exported…

● PyChapel supported 1D arrays of ‘real’ arguments
  ● Didn’t support:
    ● Returning arrays
    ● Multidimensional arrays
    ● Arrays of integers, bools, strings, …
Arrays: This Effort

- **Exported functions can take 1D dense array arguments**
  - Declared like normal Chapel functions
    
    ```chapel
default export proc foo(x: [0..3] int): [0..3] int { ... }
    ```

  - Domain must start at 0
  - Can omit domain declaration
    - C version of array will store size (see later slides on calling from C)

  - Cannot omit element type
    - No way to store without hard-coding it via C type
    - Argument would be generic (and can’t export generic functions)
Arrays: This Effort

- **Exported functions can return 1D dense arrays**
  - Cannot omit return type declaration when returning arrays
    - Return type will not be properly transformed

- Can omit the domain and/or element type, e.g.
  
  ```chapel
  export proc foo(...) : [] 
  { ... }
  ```

  - Chapel will error when client code is run if inferred domain is inappropriate
  - Element type won’t be visible in C, client will have to reason about it
Arrays: Calling from Python

- Python users can call functions that take or return arrays
  - Array arguments will accept any iterable Python object
    - Will copy contents at present
    - Have ideas about how to avoid this penalty
  - Returned arrays will be NumPy arrays

```python
import intArrays

intArrays.chpl_setup() # set up runtime, modules
x = [5, 4, 3, 2, 1] # list of int
intArrays.takesArray(x)
y = intArrays.returnsArray() # array of numpy.int64
intArrays.takesArray(y)
intArrays.chpl_cleanup() # shut down Chapel code
```
Arrays: Calling Functions

- **Calling from the C side:**
  - Requires use of a wrapper struct for appropriate translations:

    ```
    typedef struct {
        void* elts;  // pointer to C array
        uint64_t size;

        chpl_free_func freer;  // function to free the array memory, if applicable
    } chpl_external_array;
    ```

  - `chpl_external_array` will assume the correct element type is used
    - Like any C program, memory errors will occur if this is not true
Arrays: Calling from C

- **Two ways to create instances of `chpl_external_array`**
  - From a pointer and the size of the buffer it points to:
    ```c
    chpl_external_array chpl_make_external_array_ptr(void* elts, uint64_t size);
    ```
  - From the size and number of elements:
    ```c
    chpl_external_array chpl_make_external_array(uint64_t elt_size, uint64_t num_elts);
    ```

- **Its free function can be called via this helper:**
  ```c
  void chpl_free_external_array(chpl_external_array x);
  ```

- Workaround for issue with C function pointers in Chapel code
Arrays: Impact

- **Storing the free function allows it to be called anywhere**
  - Using different allocation/free strategy can cause problems
    
    ```
    void* alloc1 = chpl_mem_alloc(...);
    free(alloc1); // doesn't tell Chapel the memory is free, could cause problems
    void* alloc2 = malloc(...);
    chpl_mem_free(alloc2 ...); // tells Chapel to free memory it wasn't tracking!
    ```

- If stored, user doesn’t have to reason about which one was used
- `x.freer == NULL` means someplace else will clean it up
Arrays: Impact

- **Wrapper replacement keeps direct 1:1 translation for args**
  - Chapel array argument doesn’t turn into array + size
  - Chapel array return can communicate size with returned memory

- **This is a tradeoff between elegance in C vs. Chapel**
  - C must use `chpl_external_array` structure around native arrays
  - This design decision is still under active discussion in [this issue](#)
Arrays: Next Steps

- Eliminate unnecessary array copies to compute in-place

- Add support for arrays that are:
  - Multidimensional
  - Sparse
  - Distributed
  - Associative

- Revisit design of chpl_external_array structure
  - And its counterpart in Chapel module code
Chapel Libraries:
Error Message Improvements
Error Messages: Strings

Background:
- Functions involving strings were causing link-time issues
  
  ```chapel
  proc foo(x: string): string { ... }
  ```

- ‘string’ type defined entirely as Chapel code and not currently exportable
- Wouldn’t cause problems until library was linked
  - Could bite user without access to original code

- Can translate a C string into a Chapel string in Chapel code
  - Performing same operation at the C level has large potential for errors

This Effort:
- Temporary fix: generate compile-time error when using strings
  - Signals to library author to switch to `c_string` arguments / returns
Error Messages: Multiple Modules

Background:
● Generated error asking for ‘--main-module’ flag when multiple modules
  ● e.g., when two source files are included on the command line

● But main() has no meaning in library compilation
  ● It causes a warning when included

This Effort:
● Only require ‘-o’ / ‘--output’ flag for libraries with multiple modules
  ● Used to determine generated name (which would be difficult to determine)
    
    chpl --library -o foo A.chpl B.chpl
Chapel Libraries: Status and Next Steps
Chapel Libraries: Status & Next Steps

Status:
- The library technote has been updated to reflect the new features
- Expanding current support remains a priority

Next Steps:
- Expand set of features
- Improve handling of arrays and strings \textit{in situ}
- Add support for other languages:
  - Fortran
  - Chapel code using precompiled Chapel libraries
  - C++
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