Hewlett Packard Enterprise

CHAPEL 1.25 RELEASE NOTES: ONGOING EFFORTS

Chapel Team

September 23, 2021

OUTLINE

- Update on GPU Support
- Compiler Rework Update
- Attributes
- First-Class Functions and Closure Support
- User How-to Documentation
- Ongoing Library Efforts
- Chapel 2.0 / Standard Library Stabilization

UPDATE ON GPU SUPPORT

BACKGROUND
Overview

- We are developing support for GPU programming from Chapel
  - GPUs are very common, yet challenging to program
  - GPU support is frequently asked about at Chapel presentations
  - it would improve upon Chapel's "any parallel algorithm on any parallel hardware" theme

Collaborations / External Studies

- early work at UIUC
- partnership with AMD [1] [2] [3]
- recent work from Georgia Tech and ANU, featured at CHIUW 2019, CHIUW 2020 and CHIUW 2021
- meanwhile, user applications have run on GPUs via Chapel interoperability features (e.g., ChOp and CHAMPS)

Releases

- **1.23:** Design effort and discussions started
- **1.24:** Can use non-user-facing features to generate GPU binaries for Chapel functions and launch them
- ***1.25:*** *Can natively generate Chapel functions from order-independent loops and launch them*

BACKGROUND
Vision

Memory/Locality Management

- Chapel's locale model concept supports describing a compute node with a GPU naturally
  - The execution and memory allocations can be moved to GPU sublocales
- Arrays can be declared inside 'on' statements to allocate them on GPU memory
- Or distributed arrays that target GPU sublocales can be created

Execution

- Chapel's order-independent loops (i.e., 'forall' and 'foreach') can be transformed into GPU kernels
  - If such a loop is encountered while executing on a GPU sublocale, the corresponding kernel is launched
  - Kernels are generated for every call inside the loop body

BACKGROUND
Vision

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- Chapel's locale model concept supports describing a compute node with a GPU naturally
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- Arrays can be declared inside 'on' statements to allocate them on GPU memory

Done in 1.25

- Or distributed arrays that target GPU sublocales can be created **Next step**

Execution

- Chapel's order-independent loops (i.e., 'forall' and 'foreach') can be transformed into GPU kernels
  - If such a loop is encountered while executing on a GPU sublocale, the corresponding kernel is launched

Done in 1.25

  - Kernels are generated for every call inside the loop body **Next step**

BACKGROUND

Sample Computation: Our Goal

Our Goal:

```
on here.getGPU(0) {
  var a = [1, 2, 3, 4, 5];
  forall  aElem in a do
    aElem += 5;
}
```

BACKGROUND

Sample Computation: Our Goal

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```
on here.getGPU(0) {
  var a = [1, 2, 3, 4, 5];
  forall  aElem in a do
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```

This method name is notional—the precise locale model and method for referring to the GPU sublocale are still under discussion

BACKGROUND

Sample Computation: Status After 1.24

Chapel

```
pragma "codegen for GPU"
export proc add_nums(a: c_ptr(real(64))){
  a[0] = a[0]+5;
}

var funcPtr = createFunction();
var a = [1, 2, 3, 4, 5];
__primitive("gpu kernel launch", funcPtr,
            <grid and block size>,…,
            c_ptrTo(a), …);
writeln(a);
```

Manual CUDA Driver API Calls

```
extern {
  #define FATBIN_FILE "chpl__gpu.fatbin"
  double createFunction(){
    fatbinBuffer = <read FATBIN_FILE into buffer>
    cuModuleLoadData(&cudaModule, fatbinBuffer);
    cuModuleGetFunction(&function, cudaModule,
                                   "add_nums");}

}
```

Read fat binary and create a CUDA function

BACKGROUND

Sample Computation: Status After 1.24

Chapel

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pragma "codegen for GPU"
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Read fat binary and create a CUDA function

In 1.25: Kernel and launch is created from 'forall' by the compiler

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Read fat binary and create a CUDA function

In 1.25: Kernel and launch is created from 'forall' by the compiler

1.25: Function is loaded and launched by the runtime

BACKGROUND

Sample Computation: Status in 1.25

Our Goal:

```
on here.getGPU(0) {
  var a = [1, 2, 3, 4, 5];
  forall  aElem in a do
    aElem += 5;
}
```

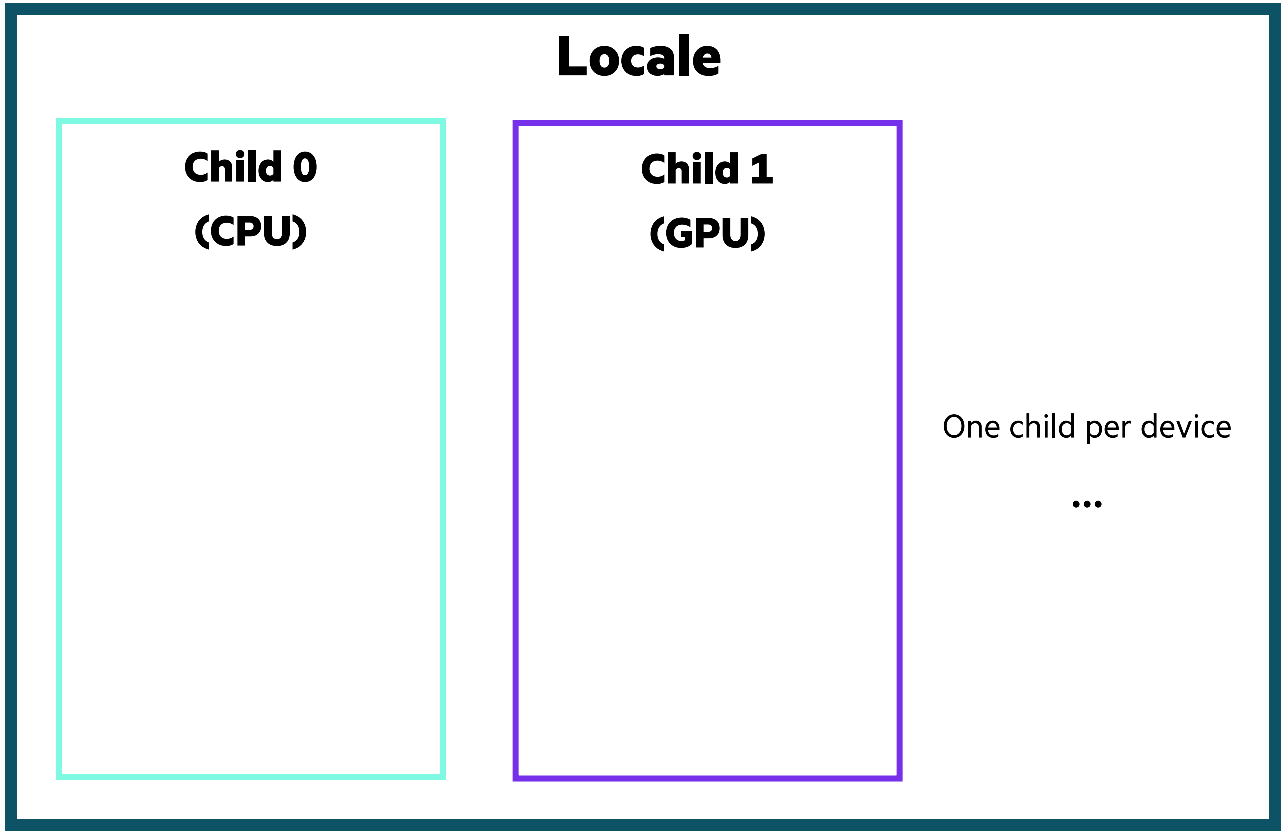
What works today (1.25):

```
on here.getChild(1) {
  var a = [1, 2, 3, 4, 5];
  forall  aElem in a do
    aElem += 5;
}
```

THIS EFFORT

The current GPU Locale Model

- The ‘gpu’ locale model is used



THIS EFFORT

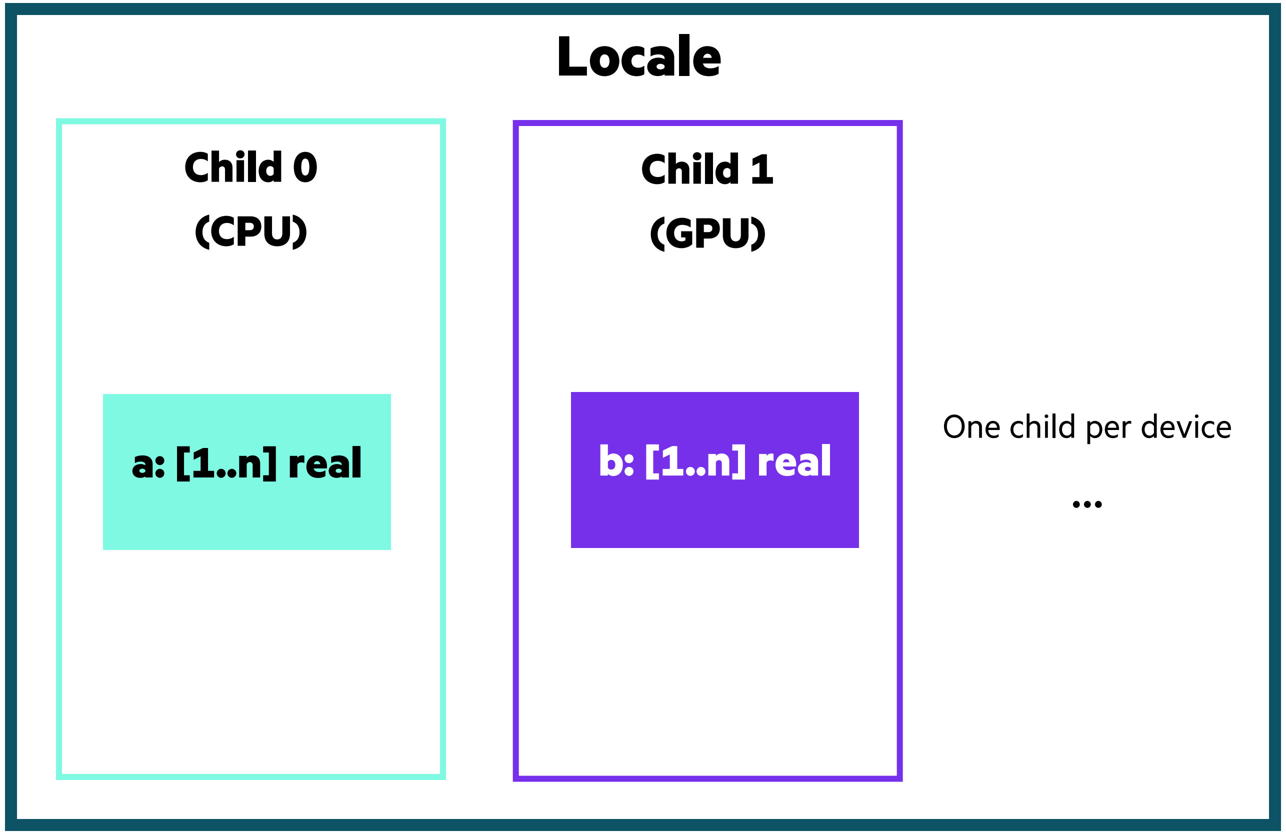
The current GPU Locale Model

- The ‘gpu’ locale model is used

```
var a: [1..n] real;

on here.getChild(1) {
  var b: [1..n] real;
  ...
}
```

- Allocations on GPU sublocales are done with unified memory
  - Accessible from both host and device
  - Allows initializing class instances allocated on device from host
- May have implications for array data
  - Potentially higher cost per access
  - Future releases will support both unified and device-exclusive memory

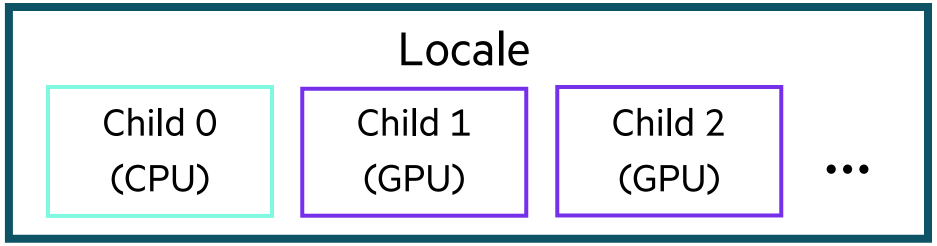


THIS EFFORT

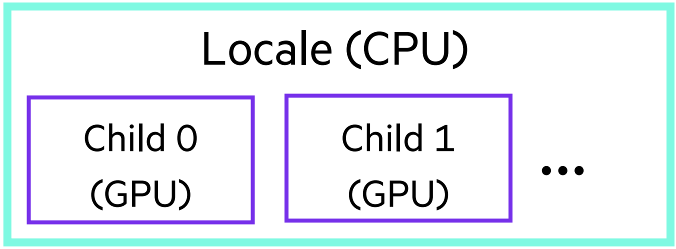
Potential future locale models

- Currently, there's no real difference between 'on Locale[i]' and 'on Locale[i].getChild[0]'
- The current approach was adopted from earlier work without much consideration
- So now, we're brainstorming alternate models

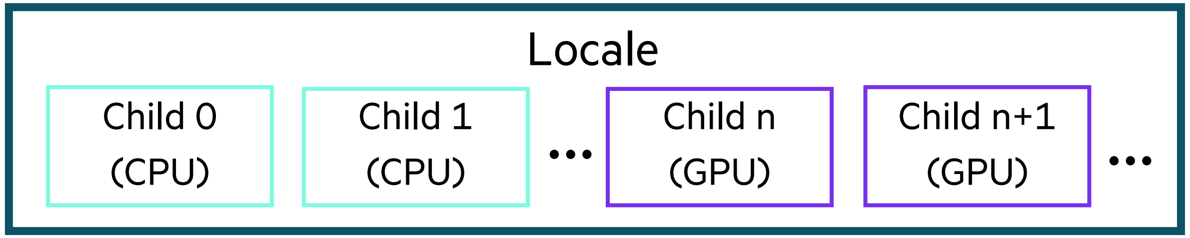
What we have now (sublocale 0 = CPU)



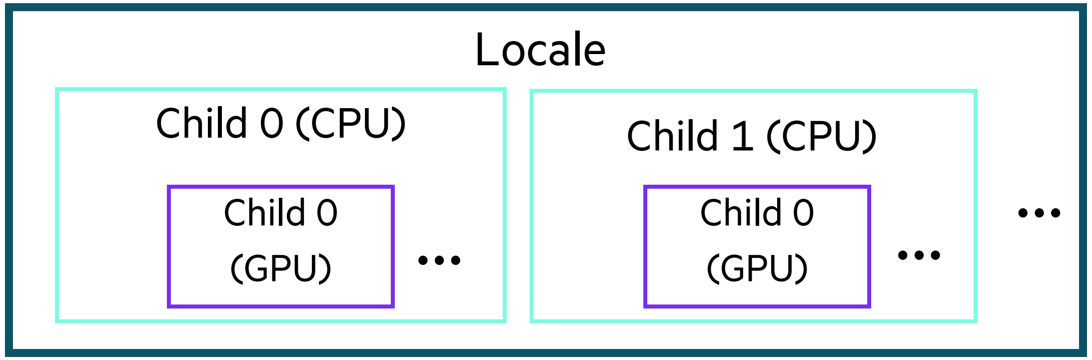
Locale for CPU; sublocales for GPUs



NUMA aware (flat)



NUMA aware (hierarchical)



THIS EFFORT

Creating GPU Kernels from Loops

User's loop

```
forall i in 1..n do arr[i] = i*mul
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Conceptual C loop

```
for (i=1 ; i<=n ; i++) {   // order-independent loop
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
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  *addrToChange = newVal;
}
```

Generated GPU Kernel

```
pragma "codegen for GPU"
proc kernel(                                   ) {



}
```

THIS EFFORT

Creating GPU Kernels from Loops

The loop's start and end indices are passed by value

User's loop

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forall i in 1..n do arr[i] = i*mul
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Generated GPU Kernel

```
pragma "codegen for GPU"
proc kernel(in startIdx, in endIdx                    ) {



}
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Creating GPU Kernels from Loops

The loop's start and end indices are passed by value

Outer variables are passed depending on their type

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forall i in 1..n do arr[i] = i*mul
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Generated GPU Kernel

```
pragma "codegen for GPU"
proc kernel(in startIdx, in endIdx, ref arrArg, in mulArg) {



}
```

THIS EFFORT

Creating GPU Kernels from Loops

The loop's start and end indices are passed by value

Outer variables are passed depending on their type

Loop body is copied

User's loop

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forall i in 1..n do arr[i] = i*mul
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THIS EFFORT

Creating GPU Kernels from Loops

The loop's start and end indices are passed by value

Outer variables are passed depending on their type

Loop body is copied

Variables declared inside remain untouched

User's loop

```
forall i in 1..n do arr[i] = i*mul
```

Conceptual C loop

```
for (i=1 ; i<=n ; i++) {   // order-independent loop
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
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Generated GPU Kernel

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proc kernel(in startIdx, in endIdx, ref arrArg, in mulArg) {

  var arrData = arrArg->data;
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Creating GPU Kernels from Loops

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forall i in 1..n do arr[i] = i*mul
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```
for (i=1 ; i<=n ; i++) {   // order-independent loop
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
```

Generated GPU Kernel

```
pragma "codegen for GPU"
proc kernel(in startIdx, in endIdx, ref arrArg, in mulArg) {
  var index = ...; // calculate and return if >length

  var arrData = arrArg->data;
  ref addrToChange = &arrData[index];
  var newVal = index*mulArg;
  *addrToChange = newVal;
}
```

The loop's start and end indices are passed by value

Outer variables are passed depending on their type

Loop body is copied

Variables declared inside remain untouched

Symbols are replaced appropriately

THIS EFFORT
Launching GPU Kernels

User's loop

```
forall i in 1..n do arr[i] = i*mul
```

Conceptual C loop

```
for (i=1 ; i<=n ; i++) {
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
```

Kernel signature

```
proc kernel(in startIdx, in length,
            ref arrArg, in mulArg);
```

THIS EFFORT

Launching GPU Kernels

User's loop

```
forall i in 1..n do arr[i] = i*mul
```

Kernel signature

```
proc kernel(in startIdx, in length,
            ref arrArg, in mulArg);
```

Conceptual C loop

```
for (i=1 ; i<=n ; i++) {
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
```

Generated Kernel Launch

```
launch_kernel(                                        );
```

THIS EFFORT
Launching GPU Kernels

User's loop

```
forall i in 1..n do arr[i] = i*mul
```

Conceptual C loop

```
for (i=1 ; i<=n ; i++) {
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
```

Kernel signature

```
proc kernel(in startIdx, in length,
            ref arrArg, in mulArg);
```

Function name

Generated Kernel Launch

```
launch_kernel("kernel",                                              );
```

THIS EFFORT

Launching GPU Kernels

User's loop

```
forall i in 1..n do arr[i] = i*mul
```

Conceptual C loop

```
for (i=1 ; i<=n ; i++) {
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
```

Generated Kernel Launch

```
launch_kernel("kernel", n-1, 512,                           );
```

Kernel signature

```
proc kernel(in startIdx, in length,
            ref arrArg, in mulArg);
```

Function name

Loop length and block size are used for dimension calculation

THIS EFFORT

Launching GPU Kernels

User's loop

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forall i in 1..n do arr[i] = i*mul
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for (i=1 ; i<=n ; i++) {
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Kernel signature

```
proc kernel(in startIdx, in length,
            ref arrArg, in mulArg);
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Function name

Loop length and block size are used for dimension calculation

Pass-by-value arguments have an accompanying 0

Generated Kernel Launch

```
launch_kernel("kernel", n-1, 512, 1, 0, n, 0,             , mul, 0);
```

THIS EFFORT

Launching GPU Kernels

User's loop

```
forall i in 1..n do arr[i] = i*mul
```

Conceptual C loop

```
for (i=1 ; i<=n ; i++) {
  var arrData = arr->data;
  ref addrToChange = &arrData[i];
  var newVal = i*mul;
  *addrToChange = newVal;
}
```

Generated Kernel Launch

```
launch_kernel("kernel", n-1, 512, 1, 0, n, 0, &arr, 32, mul, 0);
```

Kernel signature

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proc kernel(in startIdx, in endIdx,
            ref arrArg, in mulArg);
```

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Loop length and block size are used for dimension calculation

Pass-by-value arguments have an accompanying 0

Pass-by-offload arguments have an accompanying copy size

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Launching GPU Kernels

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for (i=1 ; i<=n ; i++) {
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}
```

Generated Kernel Launch

```
if executingOnGPUSublocale() then
  launch_kernel("kernel", n-1, 512, 1, 0, n, 0, &arr, 32, mul, 0);
else
  // loop with no change
```

Kernel signature

```
proc kernel(in startIdx, in length,
            ref arrArg, in mulArg);
```

Function name

Loop length and block size are used for dimension calculation

Pass-by-value arguments have an accompanying 0

Pass-by-offload arguments have an accompanying copy size

A dynamic check for GPU execution is added

THIS EFFORT

Translating Loop Indices Into Kernel Indices

Kernel function

```
proc kernel(in startIdx, in endIdx,
            ref arrArg, in mulArg) {

  var blockIdxX  = __primitive('gpu blockIdx x');
  var blockDimX  = __primitive('gpu blockDim x');
  var threadIdxX = __primitive('gpu threadIdx x');

  var t0 = blockIdxX * blockDimX;
  var t1 = t0 + threadIdxX;
  var index = t1 + startIdx;

  var chpl_is_oob = index > endIdx;
  if (chpl_is_oob) { return; }

  // copied loop body
}
```

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proc kernel(in startIdx, in endIdx,
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Primitives correspond to CUDA threadIdx, blockIdx, blockDim, and gridDim variables

Primitives lower to calls to corresponding llvm intrinsic functions (e.g. llvm.nvvm.read.ptx.sreg.ctaid.x)

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Currently we are only targeting 1-dimensional kernels

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Check that index is in bounds

Can occur if length is not evenly divisible by block size

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THIS EFFORT

Putting the Pieces Together

User's loop

```
forall i in 1..n do arr[i] = i*mul;
```

The loop is replaced with:

```
if executingOnGPUSublocale() then
  launch_kernel("kernel", n-1, 512, 1, 0,
                       n, 0, &arr, 32, mul, 0);
else
  for (i=1 ; i<=n ; i++) {
    var arrData = arr->data;
    ref addrToChange = &arrData[i];
    var newVal = i*mul;
    *addrToChange = newVal;
  }
```

Generated GPU kernel looks like:

```
pragma "codegen for GPU"
proc kernel(in startIdx, in endIdx,
                  ref arrArg, in mulArg) {
  var blockIdxX  = __primitive('gpu blockIdx x');
  var blockDimX  = __primitive('gpu blockDim x');
  var threadIdxX = __primitive('gpu threadIdx x');

  var t0 = blockIdxX * blockDimX;
  var t1 = t0 + threadIdxX;
  var index = t1 + startIdx;

  var chpl_is_oob = index > endIdx;
  if (chpl_is_oob) { return; }

  var arrData = arrArg->data;
  ref addrToChange = &arrData[index];
  var newVal = myIdx*mulArg;
  *addrToChange = newVal;
}
```

THIS EFFORT
Loop Eligibility

- An analysis marks loops as “GPU eligible”
  - We copy and outline eligible loops into a function that can be called on the GPU (i.e., a kernel)
  - Ineligible loops are always executed on the CPU
  - Eligible loops are executed on the GPU if called in a GPU locale
- To be eligible, a loop must be:
  - Order-independent (e.g., ‘forall’ or ‘foreach’)
  - In user code
  - Free of any function calls except those that have been inlined
  - Only use primitives that are “fast” and “local”
    - “fast” means “safe to run in an active message handler”
    - “local” means “doesn’t cause any network communication”

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- An analysis marks loops as "GPU eligible"
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- To be eligible, a loop must be:
  - Order-independent (e.g., 'forall' or 'foreach')
  - In user code
  - Free of any function calls except those that have been inlined
  - Only use primitives that are "fast" and "local"
    - "fast" means "safe to run in an active message handler"
    - "local" means "doesn't cause any network communication"

Ineligible:

```
for i in 1..10 { a[i] += 10; }
forall i in 1..10 { a[i] += foo(); }
```

Eligible:

```
forall  i in 1..n { a[i] += i+10; }
foreach  i in 1..n { a[i] += i+10; }
```

STATUS
Stream

```
on here.getChild(1) {
  var a, b, c: [1..n] real;
  const alpha = 2.0;



}
```

- Arrays are allocated in unified memory
- Scalars are allocated on the function stack
  - So, they are on host memory

STATUS
Stream

```
on here.getChild(1) {
  var a, b, c: [1..n] real;
  const alpha = 2.0;

  forall bElem in b do bElem = 1.0;
  forall cElem in c do cElem = 2.0;

}
```

- Arrays are allocated in unified memory
- Scalars are allocated on the function stack
  - So, they are on host memory

Promotion (e.g., ‘b = 1.0’) still executes on host

STATUS

Stream

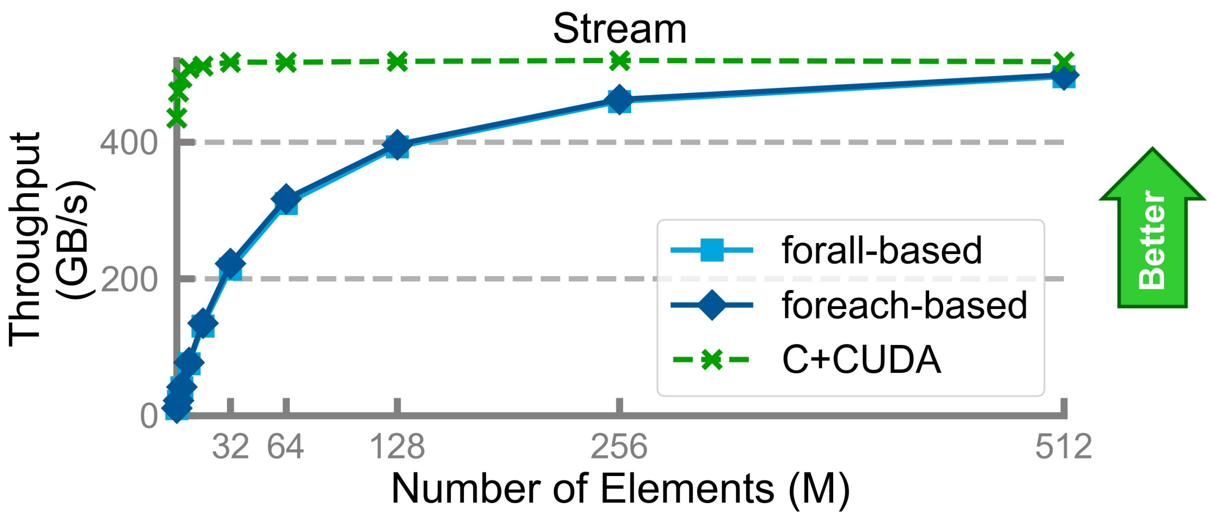
```
on here.getChild(1) {
  var a, b, c: [1..n] real;
  const alpha = 2.0;

  forall bElem in b do bElem = 1.0;
  forall cElem in c do cElem = 2.0;

  forall aElem, bElem, cElem in zip(a, b, c) do
    aElem = bElem + alpha * cElem;
  // or
  forall i in a.domain do
    a[i] = b[i] + alpha * c[i];

}
```

- Arrays are allocated in unified memory
- Scalars are allocated on the function stack
  - So, they are on host memory

Promotion (e.g., ‘b = 1.0’) still executes on host

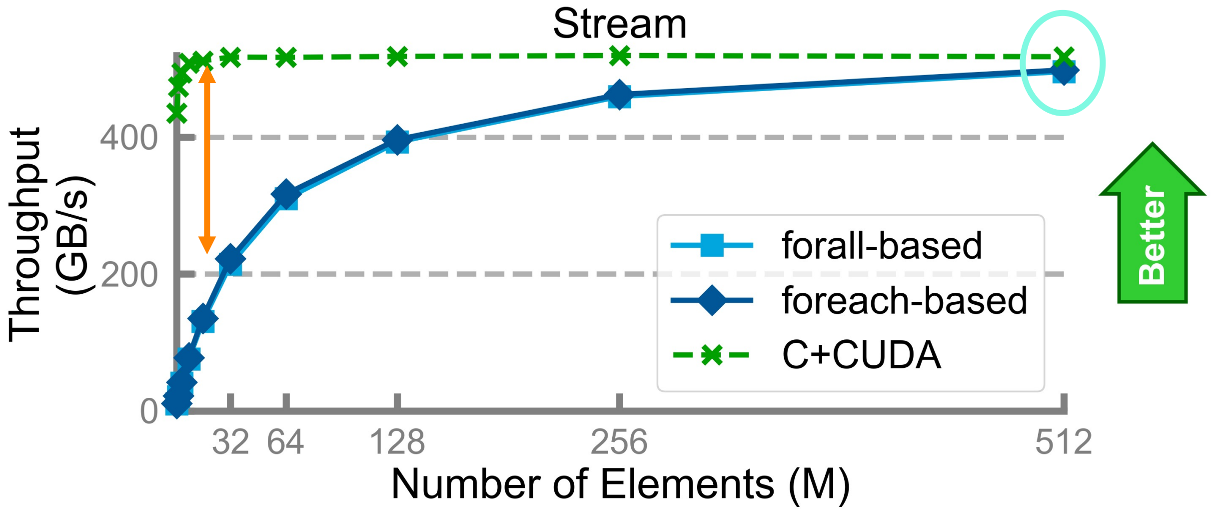
These foralls will execute on GPU

STATUS
An Early Performance Study



STATUS

An Early Performance Study

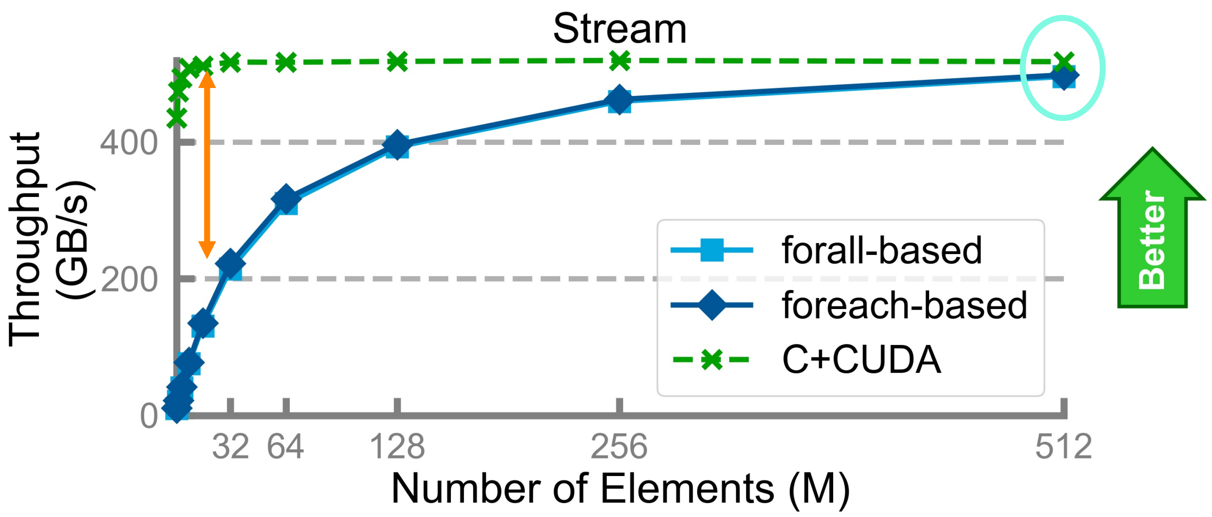


At smaller vector sizes throughput is low

At larger vector sizes efficiency reaches 96%

STATUS

An Early Performance Study



At smaller vector sizes throughput is low

At larger vector sizes efficiency reaches 96%

Takeaways

- No major performance-related issue in the prototype
- Gets close to 100% efficiency with large datasets
- ‘foreach’ is slightly faster than ‘forall’

Potential Sources of Overhead

- I/O for loading the GPU kernel for each launch
- Unified memory vs. device memory
- Kernel argument allocations

Prospects

- Generating single binary will remove the I/O cost
- Profile the remaining costs
- Implement other benchmarks

NEXT STEPS

Near-Term Goals: Implementation

- Generate single binary
  - We currently generate a GPU binary and dynamically load the GPU kernel from that binary
- Support reductions
- Allow non-inlined function calls inside loop bodies
  - We do not mark functions called from loops as a GPU kernel
  - Challenge: What if the function has a system call, or ‘halt’?
- Enable communication between device and host
  - The host can access device memory thanks to unified memory, but not vice versa
  - We want to use the existing wide pointers and comm interface to handle this
- Support multiple GPUs in one node
  - The ‘gpu’ locale model creates as many children as number of devices on the node
  - However, the runtime always uses device 0

NEXT STEPS

Near-Term Goals: Design Discussions

- What should the locale model be? (#18529)

- How do we enable block/grid size to be determined by the user?
  - Should there be a new feature for order-independent loops to support that? How can that be portable?

- How can we handle intra-block synchronization?

- Should tasks of a ’forall’ “know” their IDs?

- Should there be a way to write and launch a GPU kernel explicitly in Chapel?

NEXT STEPS
Long-Term Goals

- Support AMD and Intel GPUs
- Support inter-locale communication from GPUs
- Performance optimizations


COMPILER REWORK UPDATE

COMPILER REWORK OUTLINE

INTRODUCTION AND MOTIVATION

PROBLEMS WITH THE CURRENT CHAPEL COMPILER

Speed

- The current compiler is generally slow, and extremely so for large programs (~7s to 15 minutes)
- Large programs require complete recompilation whenever a change is made

Errors

- For incorrect programs, the compiler frequently displays only some of the errors at a time
- Compilation errors can be hard for users to understand and resolve

Structure and Program Representation

- The compiler is structured only for whole-program analysis, preventing separate/incremental compilation
- Unclear how to integrate an interpreter, provide IDE support, or ‘eval’ Chapel snippets
- Compilation passes are highly coupled

Development

- The modularity of the compiler implementation needs improvement
- There is a steep learning curve to become familiar with the compiler implementation

COMPILER REWORK DELIVERABLES

Incremental Compilation Frontend

- Only reparse and do type resolution on files that were edited
- Could result in reducing compilation time
- Will still have the whole-program optimization and code-generation back-end

Separate Compilation

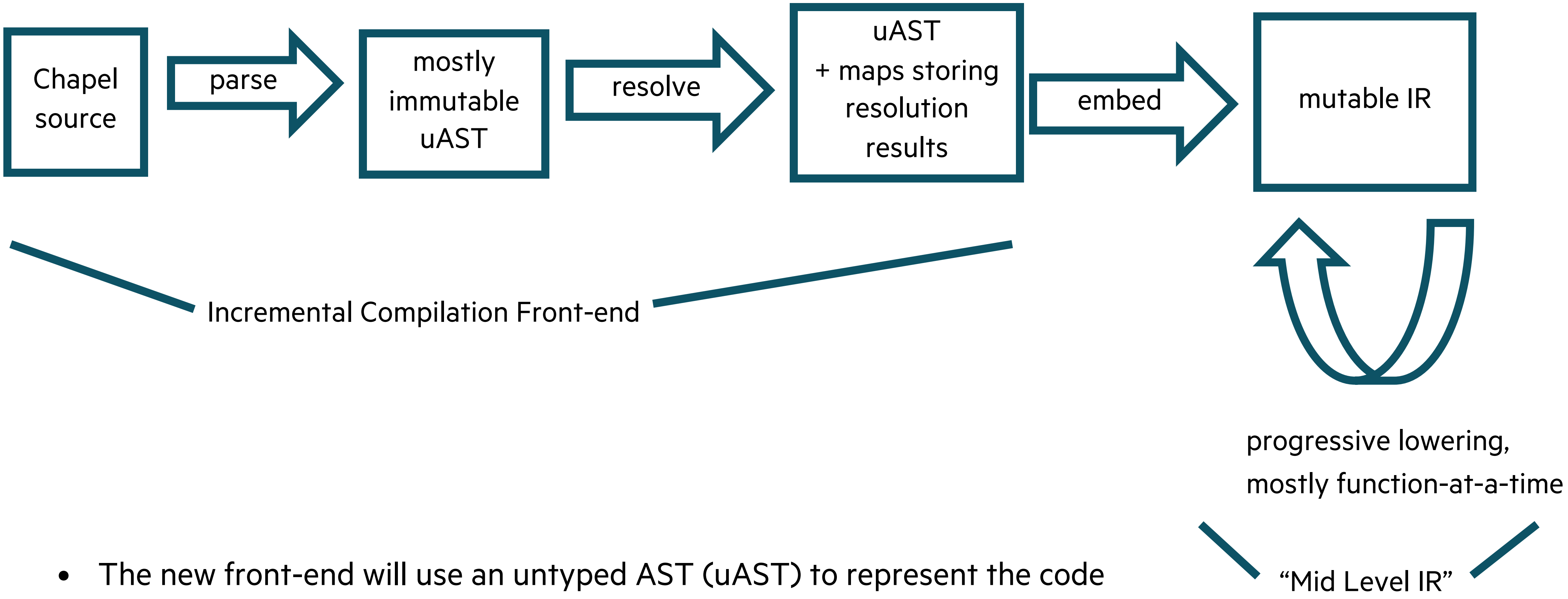
- Make most of the whole-program optimization happen per file
- Will need a linking step for optimizations like function inlining that span files
- Should result in significantly faster compilation times

Dynamic Compilation and Evaluation

- Enable Chapel code snippets to be written and run interactively
  - e.g., in Jupyter notebooks

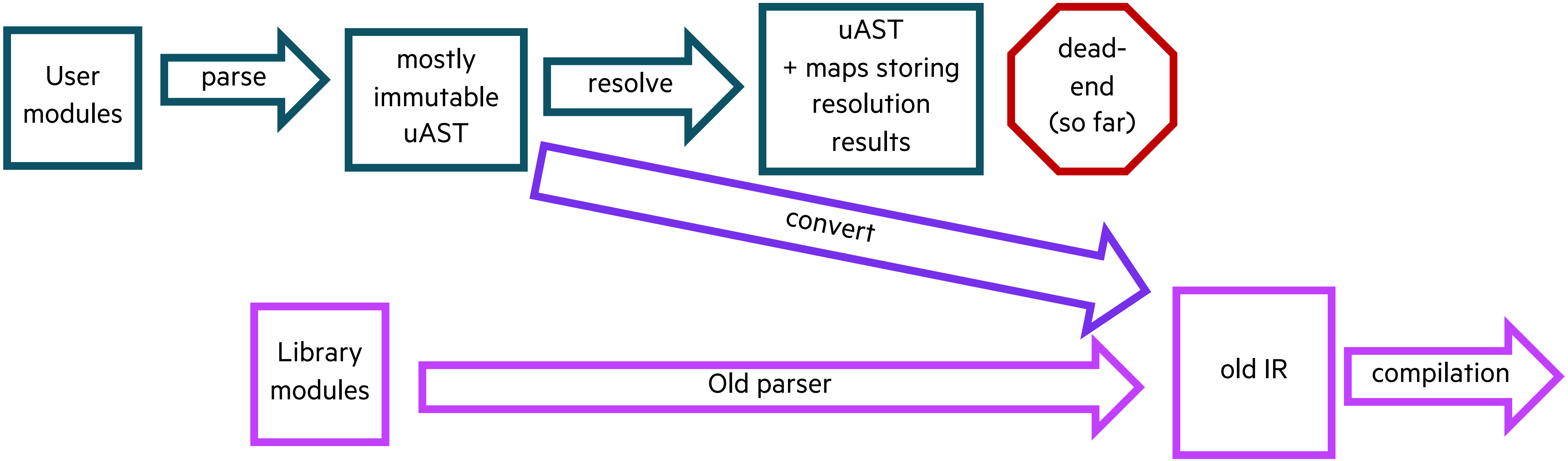
Throughout the effort, working towards improving the learning curve and error messages.

COMPILER REWORK PLAN



- The new front-end will use an untyped AST (uAST) to represent the code
- Began work implementing these changes after the 1.24 release

COMPILER REWORK STATUS



Current Status

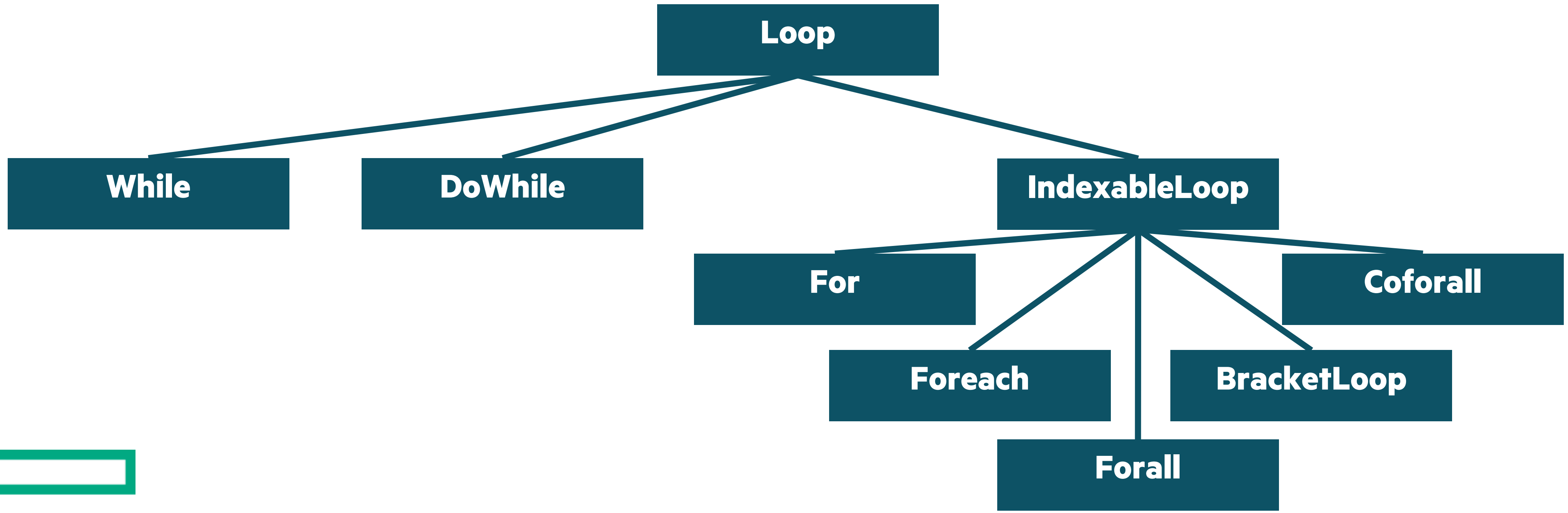
- Can parse and represent about ¾ of the Chapel language in uAST
- Can go from source code from one file to the production compiler AST to working generated code
  - Included library code is still being built with the production compiler
- Type resolution is well underway including some resolution of generics

PROGRESS ON UNTYPED AST

UNTYPED AST CLASS HIERARCHY

- Around 70 classes have been added to the untyped AST (uAST) class hierarchy
- Each uAST class includes comments that generate API documentation
- Unlike old AST, prefer one class per feature instead of overloading a single class
  - For example, old AST used CallExpr to represent primitives and function calls
  - In the uAST, these are represented by PrimCall and FnCall

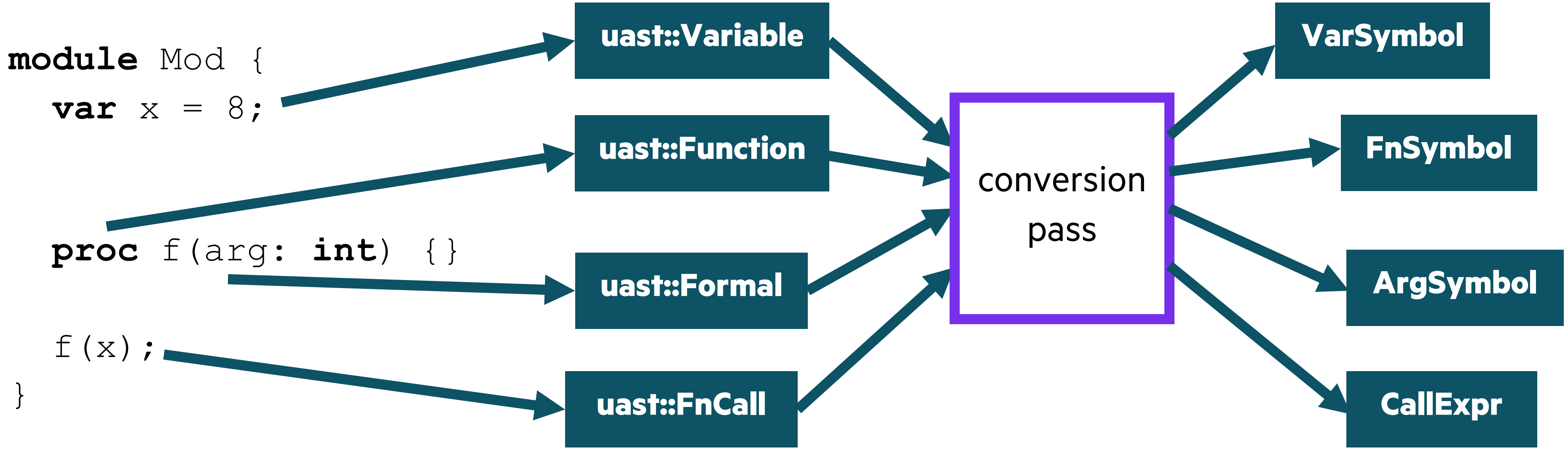
- Class hierarchy organizes different classes based on functionality, e.g...



TRANSLATION FROM UAST TO AST

- A new parser creates uAST from source code
  - '--compiler-library-parser' enables this parser for files named on the command line
  - All other modules are currently processed by the old parser

- A new pass in the old compiler can translate uAST to the old AST
  - Most translation is done using the same builders the production compiler's parser uses



PROGRESS ON UNTYPED UAST

- All of the “Hello Worlds” in ‘release/examples’ can be compiled with the new front-end
- 9 out of 41 primers in ‘release/examples/primers’ can be compiled with the new front-end
- At present, only the files named on the command line are parsed by the new front-end
- When more primers can pass, the next step is to try compiling internal modules as well
  - This will work out many remaining bugs and edge cases
- The new parser can replace the old one when all tests pass with the new front-end


PROGRESS ON RESOLUTION

PROGRESS ON RESOLUTION

- Resolution is the process of determining what each symbol refers to and its type

```
var x: int;        // what is the type of 'x'?
f(x);              // what does 'x' refer to? which 'f' function is called?
proc f(x) {
  writeln(x);      // which x does this refer to?
}
```

- Resolution can be divided into scope resolution and type resolution (see next slides)

- New resolution code is implemented as incremental queries
  - each query has the same output when given the same input
  - queries are memoized—repeated invocations will reuse the computed result
  - queries are recomputed when needed when the input changes
  - at present, these query results are only saved in memory in a running compiler process

SCOPE RESOLUTION

- Scope resolution is the process of determining which symbols a given name can refer to
- The result might be one or many symbols
- It handles details of inner and outer scopes, ‘use’ statements, and ‘import’ statements

- For example, the prototype can incrementally determine the information described below:

```
module Lib {
  var x;
  proc f(arg: int) { }     // #1
  proc f(arg: string) { } // #2
}
module Program {
  use Lib;

  x;

  f(…);
}
```

Scope includes ‘x’ and ‘f’ from ‘Lib’

Refers to ‘Lib.x’ above

Refers to ‘f’ #1 or #2 above

TYPE RESOLUTION

- Type resolution is the process of determining the types of all expressions + which functions are called
- Makes use of the result of scope resolution
- Includes instantiating generic functions
- Includes determining values of params

- For example, the prototype can incrementally determine the information below:

```
proc f(arg) {
  return arg;
}

param p = 1;

var x = f(p);
```

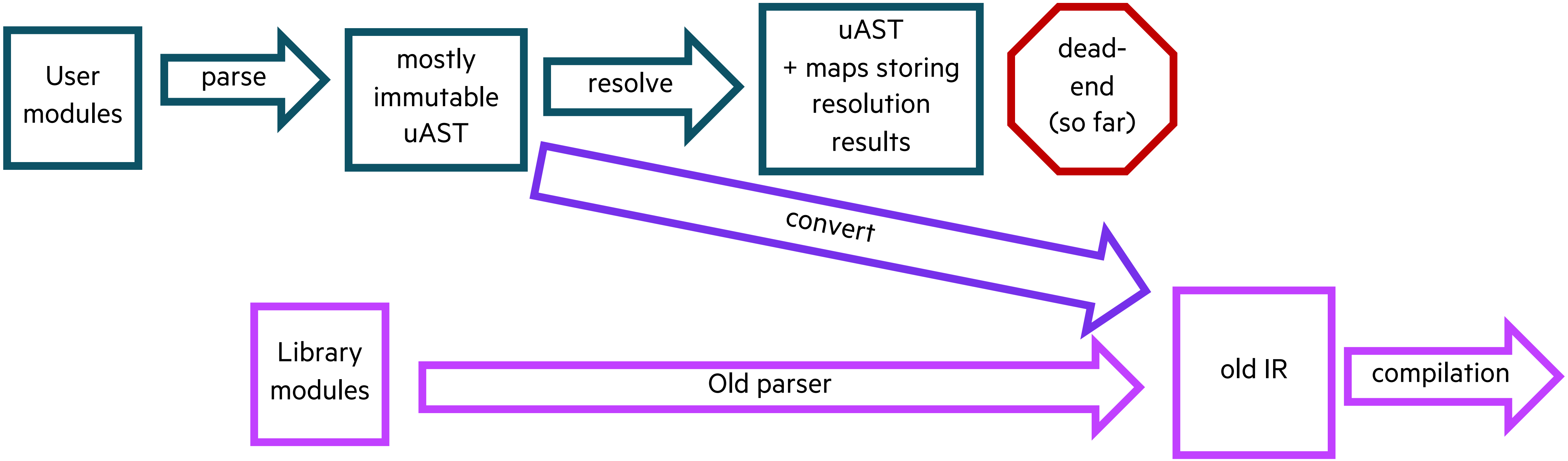
‘1’ is an ‘int’ and ‘p’ is ‘1’

the ‘f’ call invokes an instantiation of ‘f’ with an ‘int’ argument

the instantiation returns an ‘int’ and therefore ‘x’ has type ‘int’

SUMMARY

SUMMARY



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- Can parse and represent about ¾ of the Chapel language in uAST
- Can go from source code from one file to the production compiler AST to working generated code
  - Included library code is still being built with the production compiler
- Type resolution is well underway including some resolution of generics

SUMMARY

- The Chapel compiler has problems with
  - speed
  - error reporting
  - structure and program representation
  - its steep learning curve

- This rework effort is addressing the speed problems through architectural adjustments
  - to enable incremental compilation and separate compilation

- During development, this rework effort is taking steps to improve the learning curve
  - more modular design
  - generated API documentation

- Next steps are to complete parsing for the full language and then complete the incremental resolver


ATTRIBUTES

ATTRIBUTES
Background

- Attributes are metadata associated with a particular symbol
  - Attached using the same general syntax to enable easy support of less commonly used features

- Many languages have some form of support
  - Java has annotations

```
@Override          // Annotation that indicates this method overrides one on the parent type
void myOverrideMethod() { ... }
```

  - Rust has attributes

```
#[deprecated]      // Attribute that indicates function has been deprecated
pub fn myDepFunc() { … }
```

  - Python has decorators

```
@memorize          // Decorator to store result of previous call to this function to speed up computation (defined by user)
def fac():
```

ATTRIBUTES
Background

- Chapel's 'pragma' syntax has typically been used for similar purposes

```
pragma "no doc"   // Hide this symbol from documentation output
var x = 17;
```

- But pragmas are not intended for users
  - Users also can't define their own pragmas since adding one requires modifying the compiler

- Need a new feature
  - Some pragmas could be converted to this new feature
  - Others will need to remain pragmas

ATTRIBUTES
This Effort

- Investigated attribute/annotation syntax in other languages
- Conducted a survey among Chapel implementers about prospective attributes
  - Determined that there are sufficient prospective attribute candidates to warrant implementing this feature
  - Agreed on 14 potential attributes, including:
    - opting out of optimizations on a per-symbol basis
    - deprecating a symbol
    - indicating maturity level of code
    - indicating code is stable/unstable
    - controlling warnings within a block
    - turning on '--warn-unstable' for a particular module
    - controlling linter warning levels
    - marking a symbol as "no doc"
    - providing "version changed" info
    - marking a function as a test or a test function as ignored

ATTRIBUTES
Next Steps

- Determine syntax to use
  - Likely will involve '@' like other languages

- Determine extent of attribute features to support
  - Should attributes have attributes? Should attributes be macro-like? etc.

- Implement attribute syntax
  - Convert 'deprecated' keyword to attribute
  - Implement remaining attributes with broad support

- Continue discussing prospective attributes that were less clear-cut, such as…
  - Indicate if a loop is SIMD (single instruction, multiple data)
  - Indicate a type is/isn't compatible with copy elision
  - Indicate if type's deinit method must be called at the end of a block

FIRST-CLASS FUNCTIONS AND CLOSURE SUPPORT

FIRST-CLASS FUNCTIONS AND CLOSURE SUPPORT
Background

- Chapel has prototypical support for first-class functions, anonymous functions, and function types

```
proc foo(x: int) { writeln(x); }

// Capture a named function as a value
var fn1 = foo;
fn1(8);

// Capture an anonymous function as a value
var fn2 = lambda(x: int) { writeln(x); };
fn2(8);

// Construct the type of a function
type fnType = func(int, void);

// These three types are equal!
assert(fn1.type == fn2.type && fn2.type == fnType);
```

FIRST-CLASS FUNCTIONS AND CLOSURE SUPPORT
Closures

- A closure is a first-class function which refers to one or more outer (non-local) variables
  - Can be thought of as referring to a nested function by name

- Chapel does not currently offer support for creating closures
  - The following does not compile today:

```
proc call(fn) { fn(); }

proc main() {
  var x = 0;
  var fn = lambda() { x += 1; };
  call(fn);
  assert(x == 1);
}
```

FIRST CLASS FUNCTIONS AND CLOSURE SUPPORT

Status, Next Steps

Status:

- Recently started developing a prototype to add support for closures
  - not far enough along to make it into 1.25

Next Steps:

- Extend the existing FCF infrastructure to support closures that cannot escape
  - A closure escapes when it outlives its declaration point (e.g., is returned from a procedure)
- Explore extending a function's type to include its argument/return intents
- Consider adjustments to syntax for function types and anonymous functions
- Investigate optimizations to FCF infrastructure and ways to reduce cost of dynamic dispatch
  - Quietly optimizing to use a function pointer when possible?
  - Experiment with "lightweight" / "interface-backed closures"

USER HOW-TO DOCUMENTATION

USER HOW-TO DOCUMENTATION

Background:

- Have long wanted to create *how-to examples* illustrating common computational patterns
  - These would be complementary to the existing 'primers' examples that introduce specific language concepts

This Effort:

- Created a 'how-to' about reading in CSV files
  - In the 1.25 release, can be found in 'examples/patterns/readmecsv.chpl'
  - In Github, can be found in https://github.com/chapel-lang/chapel/blob/main/test/release/examples/patterns/readcsv.chpl

Next Steps:

- Create additional how-to examples, such as:
  - k-mer counting in Chapel (common bioinformatics computation)
  - Calling existing CUDA kernels from within Chapel
  - Using Chapel to orchestrate distributed instances of Python program executions (ensemble computation)
  - Using Chapel in an MPI program for on-node parallelism
- Render the examples as part of Chapel's online documentation, similar to the primer examples


ONGOING LIBRARY EFFORTS

OUTLINE

- Apache Arrow Support
- Apache Parquet Support
- Go-Style Channels
- Socket Library

APACHE ARROW SUPPORT

APACHE ARROW SUPPORT
Background

- “Apache Arrow is a language-agnostic software framework” [Wikipedia]
  - Supports columnar storage via “record batches” and tables
  - Inter-process communication and zero-copy memory sharing

- Production implementation is written in C++
  - Also supports a GLib C interface, though it is not feature complete

- Supported to varying degrees by many modern programming languages
  - Rust, Python, Julia, etc.

- Supporting Apache Arrow could…

  …provide a means for Chapel programs to share data with one another

  …enable additional interoperability capabilities in Chapel

  …allow greater in-memory analytics options to Chapel users

APACHE ARROW SUPPORT

This Effort

Goal: add Chapel module that enables the use of Arrow data structures

f0	*f1*	*f2*
1	‘foo’	true
2	‘bar’	-
3	‘baz’	false
4	-	true

- Add support using Arrow data structures
  - Use C-interoperability to call Apache Arrow GLib library
- Required ~100 lines of C code to create this simple Arrow table

```
GArrowRecordBatch* build_record_batch_for_me_please(){
// 2
// Record Batches
// Get right into into it
/*
GArrowRecordBatch *
garrow_record_batch_new (GArrowSchema *schema,
guint32 n_rows,
GList *columns, // basically GArrowArrays
GError **error);
*/
// Create a three arrays with the data we care about
/*
data = [
pa.array([1,2,3,4]),
pa.array(['foo', 'bar', 'baz', None]),
pa.array([True, None, False, True])
]
record_batch = pa.RecordBatch.from_arrays(data, ['f0','f1','f2'])
*/
GArrowArray *intArr, *strArr, *boolArr;
{
GArrowIntArrayBuilder *builder;
gboolean success = TRUE;
GError *error = NULL;
builder = garrow_int_array_builder_new();
if (success) {
gint64 intValArr[4] = {1,2,3,4};
gint64 intArrLen = 4;
gboolean intValidityArr[4] = {TRUE, TRUE, TRUE, TRUE};
gint64 intValidityArrLen = 4;
success = garrow_int_array_builder_append_values(
builder, intValArr, intArrLen, intValidityArr, intValidityArrLen, &error);
}
if (!success) {
g_print("failed to append values: %s\n", error->message);
g_error_free(error);
g_object_unref(builder);
exit(EXIT_FAILURE);
}
intArr = garrow_array_builder_finish(GARROW_ARRAY_BUILDER(builder), &error);
if (!intArr) {
g_print("failed to finish: %s\n", error->message);
g_error_free(error);
g_object_unref(builder);
exit(EXIT_FAILURE);
}
g_object_unref(builder);
}
// Now Making the string array (second column)
{
GArrowStringArrayBuilder *builder;
gboolean success = TRUE;
GError *error = NULL;
builder = garrow_string_array_builder_new();
if (success) {
const gchar* charValArr[4] = {"foo", "bar", "baz", "some_invalid_value"};
gint64 charArrLen = 4;
gboolean charValidityArr[4] = {TRUE, TRUE, TRUE, FALSE};
gint64 charValidityArrLen = 4;
success = garrow_string_array_builder_append_strings(
builder, charValArr, charArrLen, charValidityArr, charValidityArrLen, &error);
}
if (!success) {
g_print("failed to append values: %s\n", error->message);
g_error_free(error);
g_object_unref(builder);
exit(EXIT_FAILURE);
}
strArr = garrow_array_builder_finish(GARROW_ARRAY_BUILDER(builder), &error);
if (!strArr) {
g_print("failed to finish: %s\n", error->message);
g_error_free(error);
g_object_unref(builder);
exit(EXIT_FAILURE);
}
g_object_unref(builder);
}
```

```
// Now building the Boolean Array
{
GArrowBooleanArrayBuilder *builder;
gboolean success = TRUE;
GError *error = NULL;
builder = garrow_boolean_array_builder_new();
if (success) {
gboolean boolValArr[4] = {TRUE,FALSE,FALSE,TRUE}; // Second value is actually invalid as
// as is told by the boolValidityArr
gint64 boolArrLen = 4;
gboolean boolValidityArr[4] = {TRUE, FALSE, TRUE, TRUE};
gint64 boolValidityArrLen = 4;
success = garrow_boolean_array_builder_append_values(builder, boolValArr, boolArrLen, boolValidityArr, boolValidityArrLen, &error);
}
if (!success) {
g_print("failed to append values: %s\n", error->message);
g_error_free(error);
g_object_unref(builder);
exit(EXIT_FAILURE);
}
boolArr = garrow_array_builder_finish(GARROW_ARRAY_BUILDER(builder), &error);
if (!boolArr) {
g_print("failed to finish: %s\n", error->message);
g_error_free(error);
g_object_unref(builder);
exit(EXIT_FAILURE);
}
g_object_unref(builder);
}
// Whew
// That was MUCH harder than python, I don't like it...
// But we're not done yet
// Now we have to actually put these arrays in a Record batch
/*
GArrowRecordBatch *
garrow_record_batch_new (GArrowSchema *schema,
guint32 n_rows,
GList *columns,
GError **error);
*/

// Making a schema for the record batch.
// We have three fields as follows:
// ColA: gint64, ColB: gchar*, ColC: gboolean
GArrowField *ColA, *ColB , *ColC;
ColA = garrow_field_new("ColA", (GArrowDataType*) garrow_int8_data_type_new ());
ColB = garrow_field_new("ColB", (GArrowDataType*) garrow_string_data_type_new());
ColC = garrow_field_new("ColC", (GArrowDataType*) garrow_boolean_data_type_new ());
//GArrowField* fieldsSimple[3] = {ColA, ColB, ColC};
GList* fields = NULL;
fields = g_list_append(fields, ColA);
fields = g_list_append(fields, ColB);
fields = g_list_append(fields, ColC);
// Gotta build this list elsehow
GArrowSchema *schema;
//schema = garrow_schema_new(fieldsSimple);
schema = garrow_schema_new(fields);

gint64 n_rows = 4;
//GArrowArray* arraysSimple[3] = {intArr, strArr, boolArr};
GList *arrays = NULL;
arrays = g_list_append(arrays, intArr);
arrays = g_list_append(arrays, strArr);
arrays = g_list_append(arrays, boolArr);
// Gotta build the above list using GArrowListArray

GError *error = NULL;
GArrowRecordBatch *record_batch = garrow_record_batch_new(schema, n_rows, arrays, &error);
if(!record_batch){
g_print("%s\n", error->message);
}
// And after a lot of lines of code we have created the record batch.
// The last part can also be done using a record batch builder class.
//print_record_batch(record_batch);
return record_batch;
//return 0;
}
```

APACHE ARROW SUPPORT
Impact

The Chapel version is much simpler

```
use Arrow;

var arrowIntArray = new ArrowArray([1,2,3,4]);

var arrowStringArray = new ArrowArray(["foo", "bar", "baz", "bogus_value"],
                                      validIndices=[0,1,2]);

var arrowBoolArray = new ArrowArray([true, false, false, true],
                                    invalidIndices=[1]);
```

f0	*f1*	*f2*
1	‘foo’	true
2	‘bar’	-
3	‘baz’	false
4	-	true

Create Arrow Arrays in Chapel

APACHE ARROW SUPPORT
Impact

The Chapel version is much simpler

```
use Arrow;

var arrowIntArray = new ArrowArray([1,2,3,4]);

var arrowStringArray = new ArrowArray(["foo", "bar", "baz", "bogus_value"],
                                      validIndices=[0,1,2]);

var arrowBoolArray = new ArrowArray([true, false, false, true],
                                    invalidIndices=[1]);

var rcbatch = new ArrowRecordBatch("f0", arrowIntArray,
                                   "f1", arrowStringArray,
                                   "f2", arrowBoolArray);

var table = new ArrowTable(rcbatch, rcbatch);
```

f0	*f1*	*f2*
1	‘foo’	true
2	‘bar’	-
3	‘baz’	false
4	-	true

Create Arrow Arrays in Chapel

Create ArrowRecordBatch and Table

APACHE ARROW SUPPORT
Status and Next Steps

Status:

- Currently a draft PR while we finalize design decisions (#18472)
- Can now express those ~100 lines of C code in ~5 lines of Chapel code to create the same Arrow table
- The proposed interface is a superset of the C interface

Next Steps:

- Extend Chapel interface
- Explore how distributed Chapel arrays can be integrated with Arrow
  - Can the Chapel memory allocator be used to allocate Arrow memory?

APACHE PARQUET SUPPORT

APACHE PARQUET SUPPORT
Background and This Effort

Background:

Apache Parquet:

- Widely used columnar file format for data analytics supported by Apache Arrow
- Strengths are interoperability, space efficiency, and query efficiency

This Effort:

- Added a high-level interface to…
  …read Parquet file columns into distributed Chapel arrays
  …write distributed Chapel arrays to Parquet files
- Explored use-cases in Arkouda as an early-adopter of this functionality

APACHE PARQUET SUPPORT
Impact

Prototype Chapel Interface

```
use Arrow;
use BlockDist;

var filenames = ["file1.parquet", "file2.parquet"];
var datasetname = "first-int-col";
var (sizes, ty) = getArrSizeAndType(filenames,
                                    datasetname);
```

Get array size and type from file metadata

APACHE PARQUET SUPPORT
Impact

Prototype Chapel Interface

```
use Arrow;
use BlockDist;

var filenames = ["file1.parquet", "file2.parquet"];
var datasetname = "first-int-col";
var (sizes, ty) = getArrSizeAndType(filenames,
                                    datasetname);

var A = newBlockArr(0..#(+ reduce sizes), ty);

readParquetFiles(A, filenames, sizes, datasetname);
```

Get array size and type from file metadata

Read a Parquet column into a Chapel array

APACHE PARQUET SUPPORT
Impact

Prototype Chapel Interface

```
use Arrow;
use BlockDist;

var filenames = ["file1.parquet", "file2.parquet"];
var datasetname = "first-int-col";
var (sizes, ty) = getArrSizeAndType(filenames,
                                    datasetname);

var A = newBlockArr(0..#(+ reduce sizes), ty);

readParquetFiles(A, filenames, sizes, datasetname);

writeDistArrayToParquet(A, "dist-parquet");
```

Get array size and type from file metadata

Read a Parquet column into a Chapel array

Write a Chapel array to Parquet files (1 per locale)

APACHE PARQUET SUPPORT
Status and Next Steps

Status:

- Recently moved from the Arrow GLib C interface to the C++ interface
- This is currently a draft PR as we work on installing Apache Arrow onto our testing machines

I/O Type	Parquet	HDF5
Read	0.65 GiB/sec	2.15 GiB/sec
Write	0.11 GiB/sec	2.26 GiB/sec

Next Steps:

- Improve Parquet read performance
  - Explore parallelizing column reading, interacting with Parquet low level API for batch reading, etc.
- Explore compression and other available Parquet file features

GO-STYLE CHANNELS

GO-STYLE CHANNELS
Background and This Effort

Background: Chapel intends to support general parallel programming

- One missing idiom is a message queue like in Go and Rust (known as a ‘channel’ there)

This Effort: Implement Go-style channels in Chapel

- Implemented as a Google Summer of Code Project
  - Student: Divye Nayyar
  - Mentors: Michael Ferguson, Aniket Mathur (Chapel GSoC 2020 Alum)

Status: Design reviewed; Implementation PR #18168 under review

Next Steps:

- Merge the PR
- Add compiler support for blocking ‘select’ statements (see example on next slide)
- Investigate and improve performance
- Enable channels to communicate across locales

GO-STYLE CHANNELS
Examples

```
// simple send/recv
use Channel;

var chan1 = new channel(int, 5);

begin {
  chan1.send(4);
}
var recv1 : int;
chan1.recv(recv1);
writeln("Received ", recv1);
```

```
// proposed select statement syntax
select {
  when var x1 = channel1.recv() {
    writeln("Received: ", x1);
  }
  when channel2.send(x2) {
    writeln("Sent: ", x2);
  }
}

// module currently supports a lower level
// way of expressing this
```

SOCKET LIBRARY

SOCKET LIBRARY
Background, This Effort

Background: TCP and UDP socket programming have not been supported in Chapel

- Could only be done through C interoperability
- Blocking socket calls are a mismatch for qthreads-based user-level tasking

This Effort: Implemented a Socket module in Chapel

- Implemented as a Google Summer of Code Project
  - Student: Lakshya Singh
  - Mentors: Ankush Bhardwaj (Chapel GSoC 2020 Alum), Krishna Kumar Dey (Chapel GSoC 2019 Alum), Michael Ferguson

SOCKET LIBRARY
Example

```
use Socket;

var port:uint(16) = 8812;
var host = "127.0.0.1";
var addr = ipAddr.ipv4(IPv4Localhost, port);

proc server(srvSock: udpSocket) throws {
  writeln("Server recv'ing");
  var got = srvSock.recv(5);
  writeln("Server recv'd: ", got);
}
```

```
proc client() throws {
  var clientSock = new udpSocket();
  writeln("Client send'ing");
  var n = clientSock.send(b"hello", addr);
  writeln("Client sent ", n, " bytes");
}

proc main() throws {
  writeln("Creating server socket");
  var srvSock = new udpSocket();
  bind(srvSock, addr);

  cobegin {
    server(srvSock);
    client();
  }
}
```

SOCKET LIBRARY
Status, Next Steps

Status:

- Design has been reviewed and implementation PR #17960 is under review
- Uses ‘libevent’ to allow useful work in other Chapel tasks while waiting on network activity
- Implementation has some caveats at present:
  - only works with C back-end (e.g. CHPL_TARGET_COMPILER=gnu)
  - only works with CHPL_TASKS=qthreads
  - requires ‘libevent’ header to be installed in ‘/usr/include’

Next Steps:

- Complete PR review
- Address caveats listed above
- Use the I/O plugin facility to arrange socket I/O calls to work with libevent
- Study the performance of servers written in Chapel
- Add a helper class to make it easier to implement a server and demonstrate a simple HTTP server


CHAPEL 2.0

CHAPEL 2.0

Background and This Effort

Background:

- Over the past few years, we have been working toward a forthcoming Chapel 2.0 release
- Intent: stop making backward-breaking changes to core language and library features
  - thereafter, use semantic versioning to reflect if/when such changes are made

This Effort:

- Major language-related changes largely wound down as of 1.24
- Remaining efforts tackled for 1.25 (described in “Language” deck):
  - deprecating old ‘proc’-based operator declarations
  - improving support for resizable arrays and collections
  - addressing feature requests and bugs
- Stretch goals:
  - interfaces
  - first-class functions / closures
- Remaining efforts lie predominantly in stabilizing the standard libraries

STANDARD LIBRARY STABILIZATION

STANDARD LIBRARY STABILIZATION: BACKGROUND

- The effort to release Chapel 2.0 is currently focused on standard library stabilization
  - *Stabilization:* The interface is unlikely to change soon; and if so, backward-compatibility will be ensured

- For the Chapel 1.24 release, we started reviewing standard libraries
  - Bi-weekly meetings
  - One team member leads a review discussion on the module interface, scrutinizing…
    - the name of the module itself
    - names of public types, enums, global variables, constants, …
    - names of public procedures, arguments
    - behaviors / definitions of all public symbols

STANDARD LIBRARY STABILIZATION

This Effort: Our Procedure

- During the Chapel 1.25 release, we kept the same pace for reviews but also started follow-up meetings:
  - We meet every week
    - on even weeks, we review a new module as usual
    - on odd weeks, we follow up on a previously reviewed module
  - The team member who oversaw the initial review leads a follow-up discussion, to...
    - go over remaining open issues
    - find owners for making the changes that are decided but not implemented
  - We also created a sub-team to review the IO module
    - the IO interface is much bigger compared to other modules
    - it is also one of the key modules in the standard library
      - and it has a list of known issues
    - IO sub-team members meet regularly and call full-team meetings when parts of the interface are ready for discussion

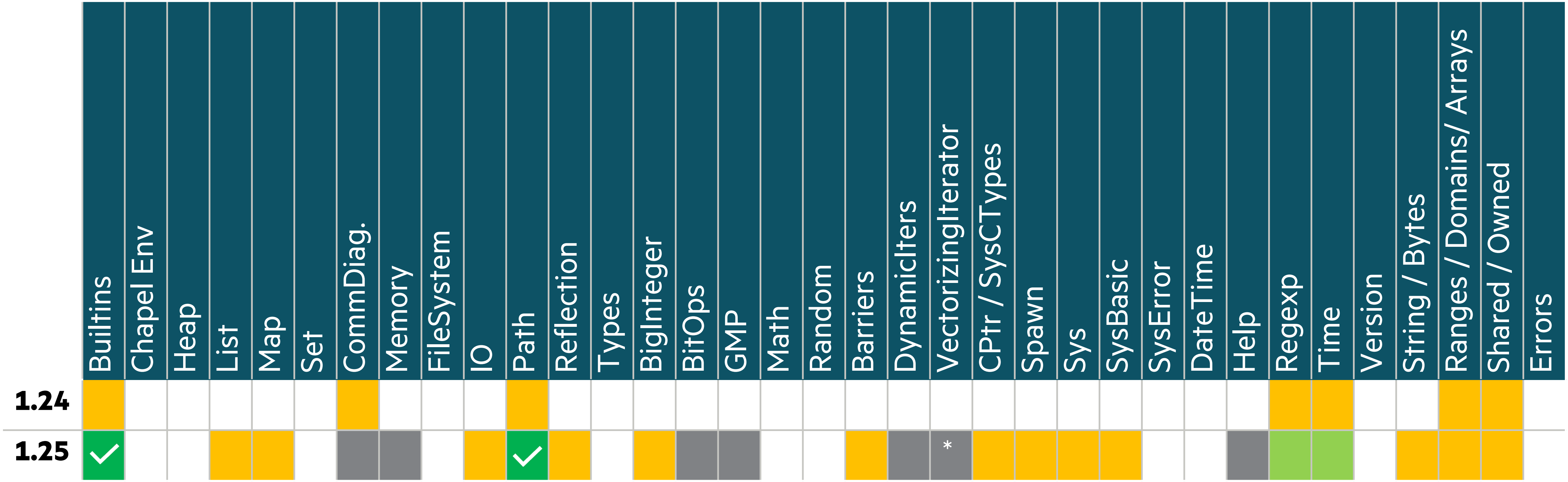
STANDARD LIBRARY STABILIZATION

This Effort: In Numbers

- As of the Chapel 1.24 release, we had:
  - Reviewed 7 standard libraries
- During this release cycle, we:
  - Reviewed 16 additional standard libraries
  - Re-reviewed 7 standard libraries
- As a result, our current status is:
  - 23 modules reviewed
  - 2 modules stabilized:
    - Path, Builtins
  - 5 modules that are close to being stabilized:
    - CPtr, SysCTypes, Sys, Regex, Time
  - 7 modules that we've decided not to stabilize before Chapel 2.0:
    - CommDiagnostics, Memory, BitOps, GMP, DynamicIters, VectorizingIterator, Help
  - 11 modules that still need review:
    - ChapelEnv, Types, Version, SysError, Errors, FileSystem, DateTime, Math, Set, Heap, Random

STANDARD LIBRARY STABILIZATION

This Effort: Overview



Stable **Progress** **Review Started** **Not 2.0**

* - VectorizingIterator is likely to be deprecated in 1.26—its functionality is superseded by 'foreach'

STANDARD LIBRARY STABILIZATION

- Path
- List
- Map
- Builtins
- Sys
- CPtr & SysCTypes & SysBasic
- Time
- Range
- Domain
- Array
- Shared & Owned
- String & Bytes
- Regex
- Reflection
- Barriers
- Spawn
- BigInteger
- IO

PATH MODULE

Background:

- The Path module contains mostly string-based operations on paths
- First reviewed during the 1.24 release cycle

Actions Taken:

- Overhauled interactions between this module and the ‘file’ type

1.24	1.25
file.getParentName()	N/A – Deprecated
file.relPath()	relPath(f: file)
file.realPath()	realPath(f: file)
file.absPath()	absPath(f: file)

Other Comments:

- As of 1.25, we consider the Path module to be stable

LIST MODULE

Background:

- The List module provides the 'list' type, a key data structure
  - Lightweight data structure that supports fast appends and iterations
  - Appending and indexing is O(1)
  - Insertions and removals from the front/middle are O(n)

Open Discussions:

- What are the expectations from this data structure? (#18095)
- How should we control parallel-safety for list? (#18097)
- Reduce the number of ways by which list elements can be modified (#18101)
- Should we deprecate 'list.sort'? (#18100)
- Retire 'list.extend' in favor of new list.append overloads (#18098) – generally supported
- Rename 'list.indexOf' as 'list.find' and make it not halt on empty lists (#18099) – generally supported

MAP MODULE

Background:

- Provides a 'map' data type, allowing for key/value data storage

Open Discussions:

- Design proposals for serial/parallel/distributed maps (#18494)
  - Separation would be useful as a simplification; the current version of Map puts both serial and parallel in a single type
  - Separate types would allow each to be cleaner and more complete
  - However, having a separate type for serial and parallel maps would detract from Chapel's scalability
  - Create mock proposal to get an idea of how this idea might work

- Deprecate operators (#18493)
  - Removing old operator methods (=, ==, !=, +, +=, |, |=, &, &=, -, -=, ^, ^=)
  - Added by default when the module was created
  - Unneeded and unused, will be removed unless requested by users

BUILTINS MODULE

Background:

- 'Builtins' was automatically included and contained these functions:
  - 'assert', 'compilerError', 'compilerWarning', 'compilerAssert', 'exit'
- It was initially added to close a memory leak
- The name is arguably confusing since it does not include all built-in features

Actions Taken:

- Resolved remaining questions about module structure and removed the 'Builtins' module
- Decided to move internal type docs to spec (#18027)
- Created a new automatically-included standard module 'Errors' containing:
  - the contents of 'Builtins' ; the contents of 'ChapelError' ; 'halt' and 'warning' from 'ChapelIO'
- Decided upon having two flavors of 'assert': one disabled with '--fast' and one that is always on

Open Discussions:

- How to select each flavor of assert (to be discussed in 'Errors' now that they live there—#18024)
  - Could use 'assert' and 'debugAssert', where 'debugAssert' does nothing with '--fast' (similar to Rust)
  - Could use 'assert' and 'releaseAssert', where 'assert' does nothing with '--fast' ('assert' similar to C)
  - Could use an additional argument, e.g. 'assert(permitOpt=true, …)'

SYS MODULE

Background:

- The Sys module defines the operating system interface: types, constants, and functions

Actions Taken:

- Agreed to a hierarchical organization for the module:

```
module OS              // parent module for all specific OS interfaces
  module POSIX         // what is currently in Sys, with some symbol renamings (see below)
  module Linux         // things in Linux but not POSIX
  module MacOS         // things in macOS but not POSIX
```

- Agreed that the module should follow the C interface as much as possible, as opposed to being Chapel-tastic
  – other modules may use this as a building block and provide Chapel-tastic interfaces to the same capabilities
- Agreed that the module will initially only define symbols that are currently used or will be soon
  – others will be added as they are needed

Open Discussions:

- None; we think we're done with the design of this one! (Implementation tasks remain)
- See #18448 for the detailed proposal

CPTR & SYSCTYPES & SYSBASIC MODULES

Background:

- These modules primarily provide access to C types, like ‘c_int’, ‘c_ptr(c_int)’, etc. for interoperability purposes

Decisions Made:

- Agreed to bring all such C types into a single module
- Agreed that ‘[s]size_t’ should become ‘c_[s]size_t’ (#18012)
- Generally agreed that the ‘c_’ prefix is an acceptable departure from typical Chapel style since it’s reflecting C
- Need to stop revealing ‘c_ptr’ to the user as a ‘class’ in the documentation

Open Discussions (others also exist):

- What should we name the module that holds these C types? (‘CTypes’, ‘CInterop’, ‘C’, …?) (#18013)
- Should ‘c_void_ptr’ become simply ‘c_ptr(void)’? Or does it deserve a special identifier? (#18011)
- Questions about ‘c_nil’, ‘is_c_nil’, ‘c_ptrTo()’, and allocation routines (#18014 , #18015, #18016, #18017)

Other Comments:

- Much of the work here feels like relatively low-hanging fruit

TIME MODULE

Background:

- This is a module from the project's early days that has felt stale and in need of refreshing

Actions Taken / Decisions Made:

- Added timeSinceEpoch() to 'DateTime', necessary to deprecate getCurrentTime() (#17395, #16773, #1442)
- Planning to deprecate 'Day', 'getCurrent*()' features in favor of 'DateTime' (#17922)
- Agreed to rename 'Timer' to 'stopwatch'
- Agreed to extend the interface for 'stopwatch' to include additional routines (#16395)

Open Discussions (others also exist):

- Where should 'sleep()' live? Or should we just retire 'sleep()' as a bad practice? (#18467)

Other Comments:

- This effort is largely waiting on a review of the 'DateTime' module to establish a unified plan
  - Specifically, we want to avoid deprecating a given symbol multiple times

RANGE MODULE

Background:

- This is a built-in module whose library-like features are being reviewed (methods, functions on ranges)

Actions Taken:

- Updated definition of '.size' and deprecated 'ident()' — see "Language Changes" deck for details
- Agreed that ranges should be immutable values (e.g., 'myRange.low = 10;' will continue to be illegal)
- Agreed to retain range slicing as intersection and '.contains' for subset queries

Open Discussions (others also exist):

- Redefine '.low' / '.high' for strided ranges to return the *aligned* low and high bounds? (#17130)
  - generally well-received, but we need to see how impactful it is
- Rename / redefine the 'enum' defining a range's boundedness and the 'bool' defining its stridability? (#17131)
  - current names are clunky, old-school, unpopular
- Make 'range' a generic type by default (e.g., no default stridability, boundedness, and/or 'idxType'?) (#18215)

Other Comments:

- This remains a high-priority module for action, due to its ties to the language and heavy use

DOMAIN MODULE

Background:

- This is another built-in module whose library-like features are being reviewed (methods, functions on domains)

Actions Taken:

- Redefining '.size' to return an 'int' — see "Language Changes" deck for details
- Agreed to continue disallowing '+' as translation on rectangular domains (e.g., '{0..5, 0..5} + (1, 1) == {1..6, 1..6}')
- Agreed to replace 'isSubset()', 'isSuperset()' with 'contains()' overloads that takes a domain
- Agreed to retain 'isEmpty' rather than requiring a '.size == 0' check

Open Discussions (others also exist):

- Are we happy with '.dim(d)' and '.dims()' as-is? (#17916, #17917)
- Rename '.dist' query? (which returns the domain map of a domain—its distribution or layout) (#17908)
- Should we drop the parenthesis from '.targetLocales()'? (#18470)

Other Comments:

- This remains a high-priority module for action, due to its ties to the language and heavy use

ARRAY MODULE

Background:

- This is another built-in module whose library-like features are being reviewed
  - For this release, we reviewed methods on arrays

```
A.isEmpty(); A.reverse(); ...
```

Actions Taken:

- Added 'dim()' and 'dims()' methods to arrays
  - Previously, these were only available on domains
  - Languages without domains would put these methods on the array directly
- Reading/writing a multi-dimensional array in Chapel syntax style now produces an error

```
var A:[1..2, 1..2] string = "hi"; writef("%ht\n", A);
```

  - Why: there is currently no syntax in Chapel for a multi-dimensional array literal

Open Discussions:

- Should we remove: 'sorted()', 'reverse()', 'find()', and 'count()' methods from the array type? (#18089)

SHARED & OWNED MODULES

Background:

- The Shared and Owned modules implement the ‘shared’ and ‘owned’ class memory management strategies

Actions Taken:

- Did initial review of Shared and Owned modules

Next Steps:

- Need clear descriptions for assignment between all combinations and the impact of nilable vs. non-nilable
- Plan to create documentation table(s) for conversions between differently-managed instances
- Discuss whether to make borrows explicit with a method call
- Considering what it would take to implement something like a C++ ‘weak_ptr’ in Chapel

STRING & BYTES MODULES

Background:

- Modules for manipulating ‘string’ and ‘bytes’ variables
  - ‘bytes’ is like ‘string’ but can store arbitrary data

Open Discussions:

- Align argument names in ‘find’, ‘rfind’, ‘count’, ‘startsWith’, ‘endsWith’ and ‘replace’ (#18264)
  - Rename ‘needle’ and ‘region’ arguments
- Should the type ‘codepointIndex’ be deprecated? (#18265)
  - Use ‘int’ in most cases or ‘byteIndex’ for maximum performance
- Deprecation of ‘c_str’ method in favor of a common ‘c_ptrTo’ or similar (#18266)
  - Extension of existing issue about C interoperability (#18016)

REGEX MODULE

Background:

- The Regexp module provides regular expressions based on Google's RE2 library

Actions Taken:

- Standard module Regexp renamed to Regex
- Replaced environment variable 'CHPL_REGEXP' with 'CHPL_RE2'
  - **In 1.24:** 'CHPL_REGEXP=re2' or 'CHPL_REGEXP=none'
  - **In 1.25:** 'CHPL_RE2=bundled' or 'CHPL_RE2=none'
  - Consistent with other environment variables that control third party builds: 'CHPL_LLVM', 'CHPL_HWLOC', 'CHPL_GMP' …

Open Discussions:

- Should tertiary methods on string/bytes be defined by the Regex module? (#17226)
  - Keep the existing 'search', 'match', 'split', and 'matches' methods for strings/bytes or remove them?
- Which method to use for compiling regular expressions? (#17187)
  - Today we use 'compile("/a/")', should we instead use 'new regex("/a/")' or 'regex.compile("/a/")'?
- Should Chapel support regex literals? (#17219)
  - Might look like r"a|b$" or 'qr/…/'

REFLECTION MODULE

Background: Reflection is a module that lets you:

- Query properties about an aggregate type, such as a field's name or ordinal position
- Get a reference to the field of an instance given a string or ordinal position
- Check if a function or method call could be resolved
- Query properties about the current module (line number, name of current function, etc.)

Open Discussions:

- Should most Reflection module functions be methods instead? (#17984)
- Allow variables as arguments to Reflection module functions (#7650)
- Should Reflection module functions prefixed with 'get' drop the 'get'? (#18006)
- Should the 'canResolve' family of functions be renamed? (#17986)
- Should 'getRoutineName' be renamed? (#17987)
- Support counting inherited fields with 'numFields' (#8736)

BARRIERS MODULE

Background:

- ‘Barriers’ module provides a general-purpose barrier
  - Initializer only accepts the number of tasks participating with no notion of locality, which limits scalability
- ‘AllLocalesBarriers’ module provides a global singleton barrier between all locales
  - Has good scalability, but only suitable for SPMD-style codes

Open Discussions:

- What is the right interface to create a scalable barrier between an arbitrary set of Locales?
  - Should there be different initializers for local and distributed barriers or distinct types?
- Should we move the barriers into a ‘Barrier’ or ‘Collectives’ module?
- Must the number of participants be known at barrier creation time, or can they be registered dynamically?

SPAWN MODULE

Background:

- Provides functionality to create and communicate with subprocesses
  - Send signals, communicate through pipes, wait for termination, etc.

```
use Spawn;

// start a process to run 'ls t*' in the $CWD
var sub = spawn(["ls", "t*"]);
sub.wait();
```

Actions Taken:

- Reviewed the Spawn module for changes needed to publicly visible interfaces
- Deprecated ‘sublocale.exit_status’ in favor of ‘sublocale.exitCode’
- Decided that:
  - All CAPS Posix constant names should be renamed with camelCase and moved to 'Posix' module
  - Want to rename the module from 'Spawn' to 'Subprocess'
  - Want to rename remaining publicly visible symbols that have underscores to use camelCase

BIGINTEGER MODULE

Background:

- Provides ‘bigint’ type for storing very large integers, and many methods and functions that use them

Actions Taken:

- Decided module interface should be more independent of its underlying GMP implementation
- Renamed division, ‘powm()’, ‘sizeinbase()’ methods and ‘Round’ enum to conform with other libraries
  - Also renamed some arguments when adjusting these methods
- Deprecated ‘size()’ method - returned “number of limbs”, a GMP implementation detail
- Added documentation for finalized methods and enum

Open Discussions:

- There are 27 small library stabilization issues remaining that are likely uncontentious
  - See the list of issues
  - And 9 non-breaking changes

IO MODULE
Background and Actions Taken

Background:

- The IO module handles reading and writing to files, as well as formatted IO
  – ‘write()’, ‘writeln()’ and ‘writef()’ are provided by default, all other IO functions are defined in the IO module
- Implements ‘file’ and ‘channel’ types
- This module is very large, ~7300 lines
- The IO module has quite a few known API design issues (#7954)

Actions Taken:

- Created a sub-team to work towards IO module stabilization
- Examined formatted IO submodule at length
- Developed 5 proposals for improvement (see next slide)

IO MODULE

Proposals

- Rename I/O ‘channel’ type to ‘reader’ and ‘writer’ (#18112)
  - because ‘reader’/’writer’ are more common terminology in other languages
  - and we’d like to have ‘channel’ free for the Go-style channels described earlier in this deck
- Deprecate the I/O style feature (#18501)
  - because it is little-used and has many design problems
- Deprecate binary format strings including endianness specifiers (#18503)
  - to make ‘readf’/‘writef’ more focused on text formatting
  - replace these with individual method calls—e.g., ‘writer.writeBigEndian(1)’
- Add an extensible Encoder/Decoder mechanism (#18499)
- Deprecate ‘j’ and ‘h’ format string specifiers in favor of Encoder/Decoder
  - ‘%jt’ today specifies to read or write a type in JSON format
  - ‘%ht’ today specifies to read or write a type in Chapel syntax

IO MODULE
Open Discussion and Status

Open Discussions:

- Should we prefer ‘read(type t)’ to ‘read(ref value)’? (#18496)
- What should the relationship be between ‘channel’ and Encoder/Decoder? (#18504)
- Should there be more consistency between use of ‘+’ and ‘-’ in format strings? (#18495)
- Meaning of ‘%.6’ varies depending on what type it is applied to (#18497)
- Format string numeric specifiers for complex numbers impact the number differently (#18498)

Next Steps:

- Reach a decision on proposals and on the open discussion items above
- Implement the Encoder/Decoder design
- Review ‘file’ and ‘channel’ interfaces
- Improve the formatted IO documentation

STANDARD LIBRARY STABILIZATION

Next Steps

- Continue with our current process:
  - Start reviewing the remaining 11 modules
  - Revisit modules that were first examined in previous releases
  - Continue resolving issues discussed in reviews, e.g.
    - Design proposal for serial/parallel/distributed maps (#18494)
    - Deprecation of ‘c_str’ method in favor of a common ‘c_ptrTo’ or similar (#18266)
- Determine whether any additional modules can be put into the “stabilize after Chapel 2.0” camp
  - e.g., does ‘Heap’ require stabilization for Chapel 2.0?
- Develop a means of documenting the stability of a module (or language feature)

CHAPEL 2.0
Status and Next Steps

Status:

- language stabilization continues to be in increasingly good shape
- module review process is proceeding apace

Next Steps:

- continue to focus predominantly on the module review process and follow-ups
- while also seeing remaining language-related efforts through to completion
  - and being responsive to new user issues around the language

THANK YOU

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