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# Interfacing Chapel with traditional HPC programming languages

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# Introducing CRAY CHAPEL

- new programming language developed by Cray Inc. as part of DARPA High Productivity Computing Systems program
- provides a parallel programming model for use in HPC systems
- supports “global-view” abstractions allowing operations on distributed data to be expressed naturally
  - no explicit communications like MPI programs

# Language Interoperability

- providing *new features* isn't enough to attract developers to adopt a new programming language
- should be easy to **integrate existing code** into new programs
- good support for interoperability lowers hurdle of accepting a new language

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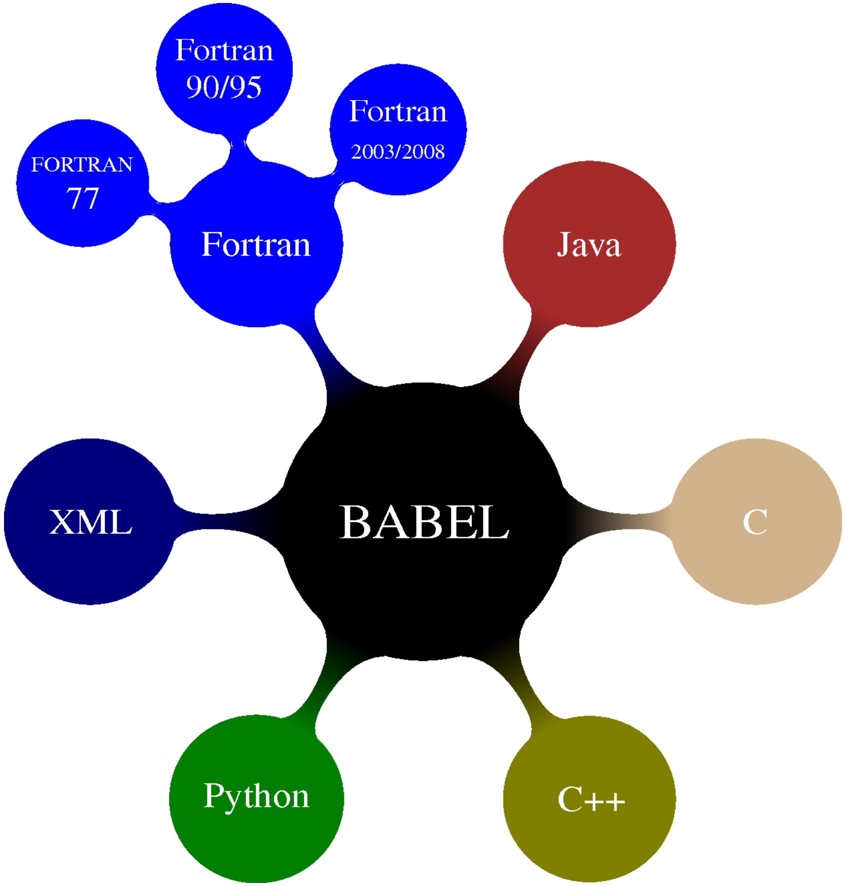
# Babel – language interoperability tool

- LLNL's language interoperability toolkit for high-performance computing
- designed for fast, in-process communication
- handles generation of all glue-code

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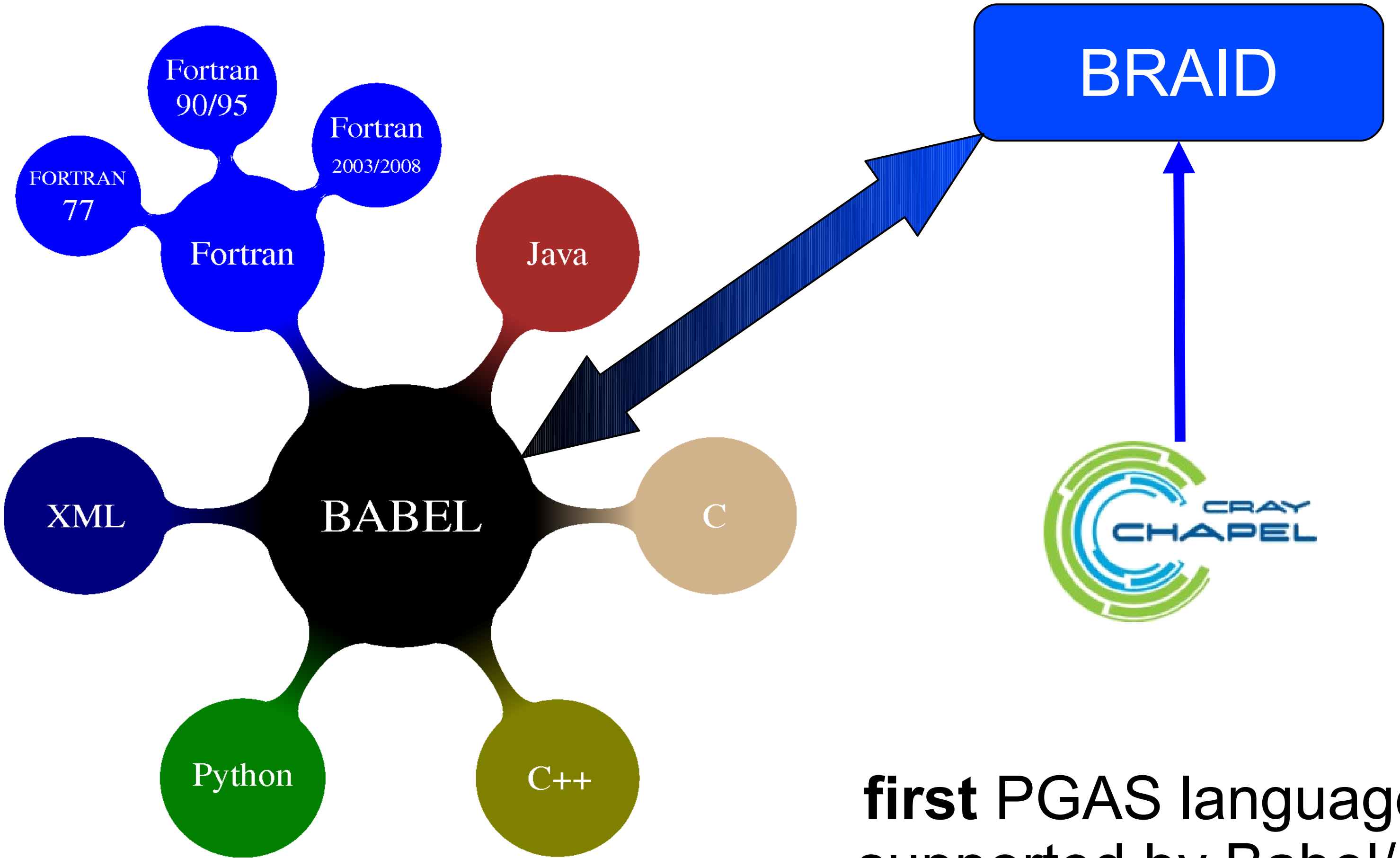
# Babel – relevant features

- programming language-neutral interface specification language – Scientific Interface Definition Language (SIDL)
- SIDL supports
  - fundamental data types
  - object-oriented programming (user-defined types)
  - interface inheritance
  - exception handling
  - dynamic multi-dimensional arrays

# Chapel: Language Interoperability




**first** PGAS language to be supported by Babel/BRAID

# Design goals

- be minimally invasive
  - minimal changes to the Chapel compiler
  - user shouldn't have to write 'special' code
- play well with the Chapel runtime
  - expected behavior of programs remains unchanged
  - support distributed data types
- achieve maximum performance
  - avoid copying of arguments (when possible)
  - introduce minimal overhead

# Using Chapel with BRAID - I

- first, define the interface in SIDL

```
import hplsupport;
package hpcc version 1.0 {
  class ParallelTranspose {
    // C[i,j] = A[j,i] + beta * C[i,j]
    static void ptransCompute(
        in hplsupport.Array2dDouble a,
        in hplsupport.Array2dDouble c,
        in double beta,
        in int i,
        in int j);
  }
}
```

  - no data members are defined in the SIDL file
  - all methods are public and virtual
  - methods can be defined to be final or static

# Using Chapel with BRAID - II

- next, use the Babel compiler to generate the server (callee) glue code:
  - `~/cxxLib> babel --server=cxx hpcc.sidl`
  - generates code for skeleton and Intermediate Object Representation (IOR)
  - generates empty blocks expecting user code
- user fills in empty blocks as implementation code
- user compiles code into shared libraries
  - Babel provides support for generating makefiles

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# Using Chapel with BRAID - III

- next, use the BRAID compiler to generate the client (caller) glue code:
  - `~/chplClient> braid --client=chapel hpcc.sidl`
  - generates code for stub and IOR
- user code uses the stub to make method calls
- user code unaware of implementation
- link to server code and SIDL runtime library during compilation and run the executable
  - Babel/BRAID bindings take care of interoperability!

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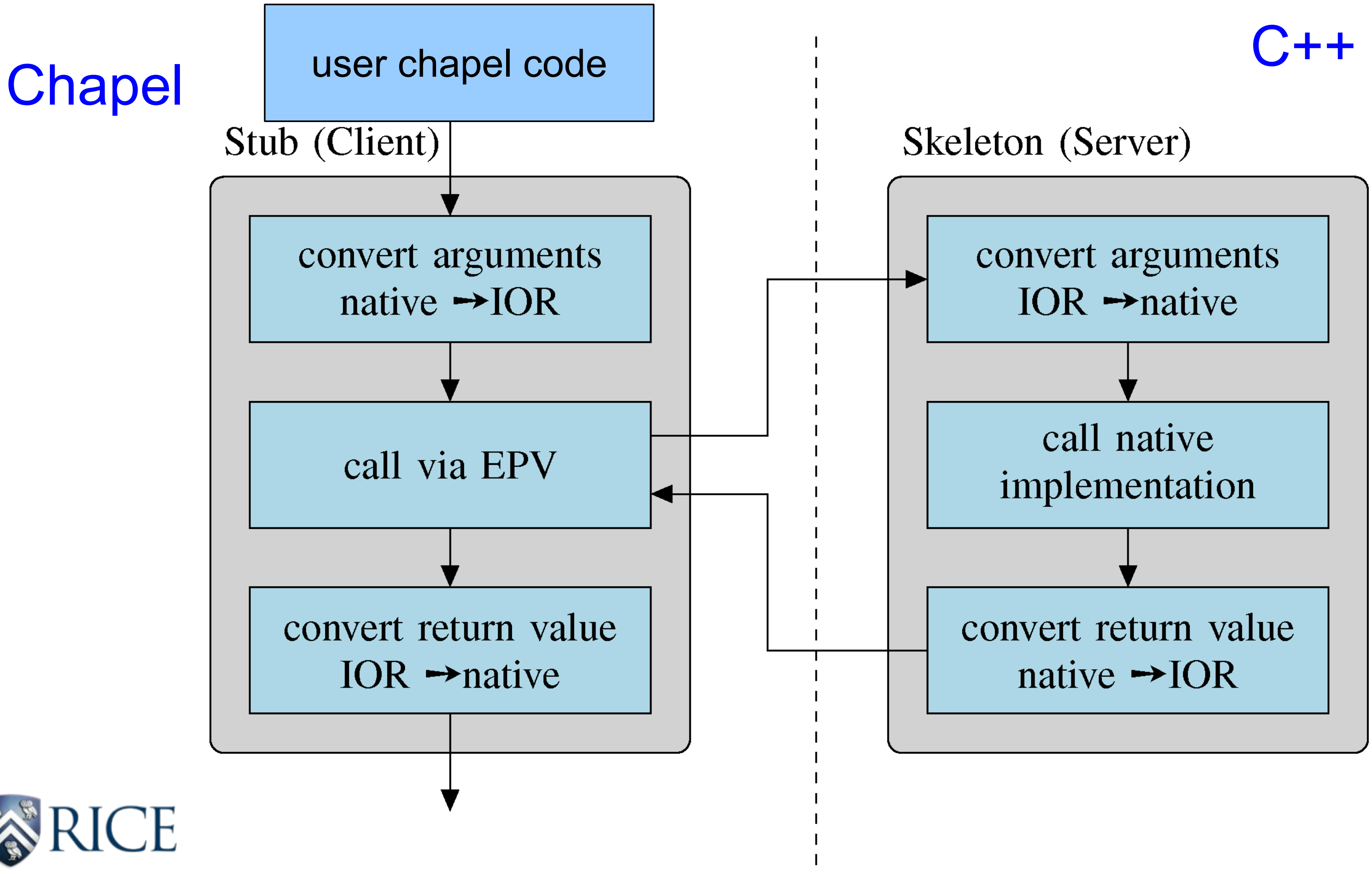
# Babel/Braid – method invocation scheme

- example flow while calling from Chapel into C++



# Chapel as client - challenges

- convert Chapel data types to the IOR
- add support for
  - fundamental (primitive) types
  - local arrays
  - distributed arrays
  - object-oriented programming
  - exception handling

# Supporting scalar data types

| SIDL Type | Size (in bits) | Corresponding Chapel Type |
|---|---|---|
| bool | 1 | bool |
| char | 8 | string (length=1) |
| int | 32 | int(32) |
| long | 64 | int(64) |
| float | 32 | real(32) |
| double | 64 | real(64) |
| fcomplex | 64 | complex(64) |
| dcomplex | 128 | complex(128) |
| opaque | 64 | int(64) |
| string | varies | string |
| enum | 32 | enum |

# Local Arrays

- SIDL arrays represent rectangular regions
- two flavors of SIDL arrays
  - normal SIDL arrays
    - general interface for arrays
    - can be used as parameters/return types
    - row-major or column-major order
  - raw arrays (r-arrays)
    - can be used only as parameters
    - must be contiguous in memory with column-major order

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# Local Arrays contd.

- user can use **any** Chapel rectangular array as raw array
  - includes support for distributed arrays
- BRAID client code automatically converts input arrays to required SIDL type
  - copying involved when input arrays are
    - not contiguous (e.g. distributed)
    - not in column-major order for raw-arrays
  - uses custom Chapel library extensions for column-major ordered arrays and borrowed-arrays to allow ease of using raw-arrays

# Local Arrays: Raw Array Example

## SIDL File:

```
class ArrayOps {
 static void matrixMultiply(in rarray<int,2> aArr(n,m),
   in rarray<int,2> bArr(m,o), inout rarray<int,2> res(n,o),
   in int n, in int m, in int o);
}
```

## User writes Chapel code:

```
var sidl_ex: BaseException = nil;
var n = 3, m = 3, o = 2;
var a: [0.. #n, 0.. #m] int(32); // a 2D Chapel local array
var b: [0.. #m, 0.. #o] int(32);
var x: [0.. #n, 0.. #o] int(32);
// initialize the input matrices
[(i) in [0..8]] a[i / m, i % m] = i;
[(i) in [0..5]] b[i / o, i % o] = i;
// call the implementation of matrix multiply
ArrayOps_static.matrixMultiply(a, b, x, n, m, o, sidl_ex);
```

# Local Arrays: SIDL Array Example

## SIDL File:

```
class ArrayOps {
 static bool reverseDouble(inout array<double,1> a);
}
```

## User writes Chapel code:

```
var sidl_ex: BaseException = nil;
// create a sidl array using SIDL runtime
var darray: sidl.Array(real(64), sidl_double__array) = ...;
...
// call the implementation method
ArrayOps_static.reverseDouble(darray, sidl_ex)
```

# Distributed Arrays

- one of the most challenging to support since Chapel allow user-defined data distributions
- Chapel runtime handles communication transparently, user uses these arrays just as local arrays
- BRAID requires users to distinguish between distributed arrays and SIDL arrays
  – BRAID provides library support for distributed arrays

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# Distributed Arrays: SIDL.DistributedArray

- copying/syncing of data is expensive
- SIDL arrays are not sufficient
  - meant for traditional langauges like C, C++, …
- create our custom type: SIDL.DistributedArray
  - no contiguous or ordering requirements
  - use Chapel runtime to access elements, server language (C, Java, etc.) unaware of communication
  - minimal overhead, no copying!

# Distributed Arrays: Example

## SIDL File:

```
class ParallelTranspose {
  static void ptransCompute(in hplsupport.Array2dDouble a,
    in hplsupport.Array2dDouble c, in double beta,
    in int i, in int j);
}
```

## User Chapel Code:

```
...
var A: [MatrixDom    ] real(64), // Chapel Distributed Array
    C: [TransposeDom] real(64);
forall (i,j) in TransposeDom do { // parallel loop
  var aWrapper = new hplsupport.BlockCyclicDistArray2dDouble();
   aWrapper.initData(GET_CHPL_REF(A));
  var cWrapper = new hplsupport.BlockCyclicDistArray2dDouble();
   cWrapper.initData(GET_CHPL_REF(C));
  // C[i,j] = beta * C[i,j]  +  A[j,i];
  ParallelTranspose_static.ptransCompute(
    aWrapper, cWrapper, beta, i, j, sidl_ex);
}
```

# Object-oriented programming

- SIDL supports packages, abstract classes, static and virtual methods
- Chapel doesn't yet fully support OOP, minimal support for classes
  - cannot inherit from classes with custom constructors
- support for packages and static methods:
  - packages mapped to Chapel modules
  - multiple Chapel classes can reside in a single module
  - static methods mapped to additional Chapel modules

# Object-oriented programming - II

- Chapel classes allocate IOR via calls to SIDL runtime
  - reference counting used to keep track of references to this newly allocated object
  - Chapel class destructors decrement reference count to the IOR object
- Chapel types delegate calls to IOR data structure which maintains virtual function table
- inheritance simulated via the IOR object, SIDL runtime manage the IOR representation
  - type-casting supported by explicit cast calls

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# Object-oriented programming: Example

## SIDL File:

```
interface A { string a(); };
interface B { int b(); };
class C { string c(); };
class D extends implements-all A, B { string d(); };
```

## User Chapel Code:

```
// var a: A = new A(); disallowed as A is an interface

var d: D = new D(sidl_ex);
var v1 = d.a(sidl_ex);
var v2 = d.c(sidl_ex);

var a: A = d.asA(); // Explicitly cast d as an instance of A
var v3 = a.a(sidl_ex);
assertEquals(v1, v3);

var c: C = d.asC(); // Explicitly cast d as an instance of C
var v4 = c.c(sidl_ex);
assertEquals(v2, v4);
```

# Exception Handling

- Chapel supports inout arguments
- SIDL exposed functions require an exception object as argument
- BRAID generated code fills in exception object to notify calling code of exceptions

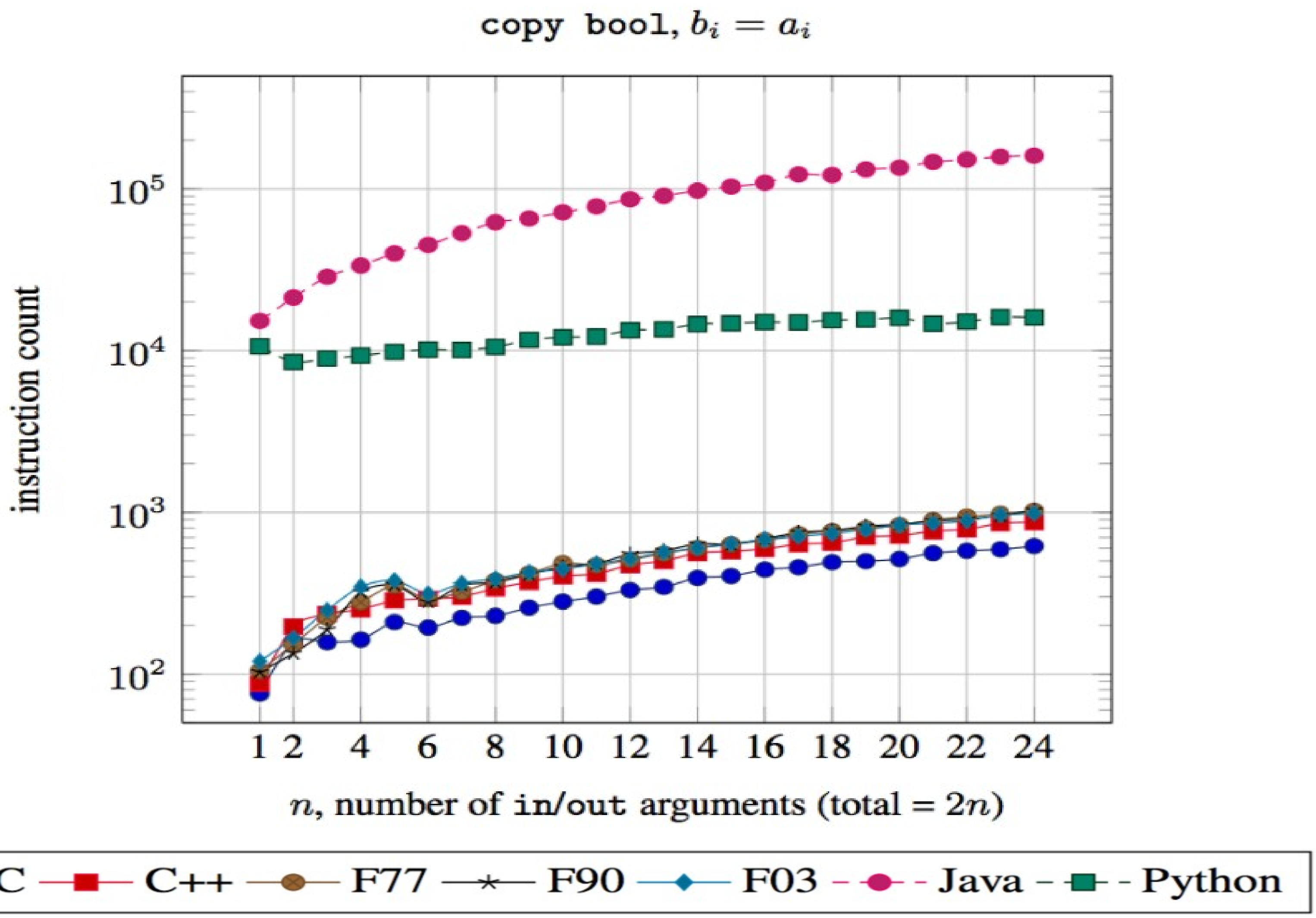
# Exception Handling: Example

- User Chapel code for handling exceptions

```
var sidl_ex: BaseException = nil;
  // create a sidl array using SIDL runtime
  var darray: sidl.Array(real(64), sidl_double__array) = ...;
  ...
  // call the implementation method
  ArrayOps_static.reverseDouble(darray, sidl_ex)

  if (sidl_ex != nil) {
    // exception occurred while invoking reverseDouble()
    // user handles exception how she wishes
 halt(sidl_ex.getMessage());
  }
```

# Performance results - I

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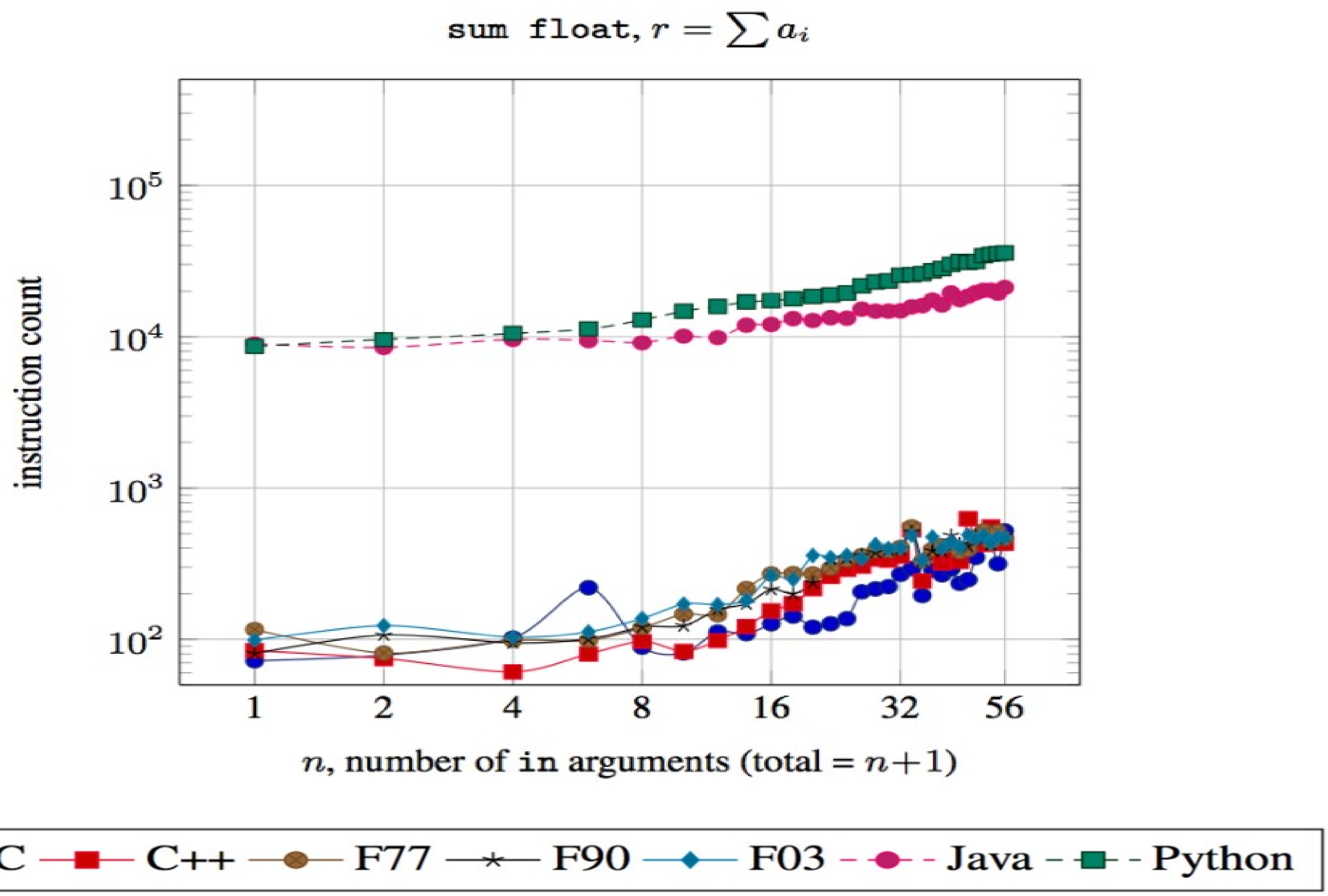
# Performance results - II

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# Performance results - III

| Nodes/locales | Pure execution time | Hybrid execution time | Overhead (in %) |
|---|---|---|---|
| 4 | 898.26 | 893.08 | −0.58 |
| 6 | 520.51 | 540.88 | 3.91 |
| 8 | 443.74 | 457.59 | 3.12 |
| 12 | 343.90 | 339.42 | −1.30 |
| 16 | 221.93 | 226.60 | 2.11 |
| 24 | 163.17 | 169.04 | 3.60 |
| 32 | 112.11 | 114.30 | 1.95 |
| 48 | 112.55 | 114.77 | 1.97 |
| 64 | 59.45 | 60.59 | 1.91 |

The ptrans Benchmark, hybrid and pure Chapel versions execution times (in seconds) compared, input matrix is of size 2048 × 2048 with a block size of 128 DistributedArray interface in SIDL, reusing our own infrastructure to make it completely portable

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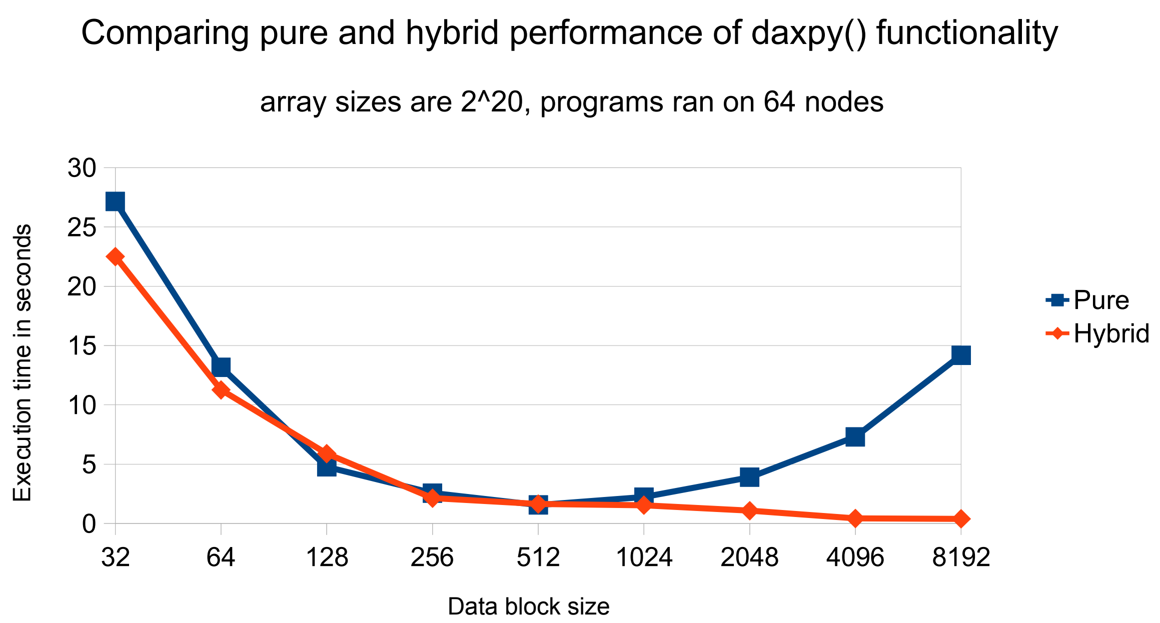
# Performance results - IV




pure: Chapel implementation of C = a * X + Y where X and Y are distributed arrays
hybrid: same example implemented by calling the blas daxpy() function using SIDL.DistributedArray

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# Summary and Future Work

- achieved interoperability between Chapel and traditional HPC languages
  - support all basic data types
  - support distributed arrays
- future work:
  - add support for Chapel as server language
  - use similar concepts to add support for UPC and X10

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# Questions