Interfacing Chapel with traditional HPC programming languages[1]

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Interoperability with other programming languages. . .

- is **not optional**
- essential for the acceptance of a new language

Realistically, nobody will rewrite their entire multi-million line codebase in the language *du jour*.

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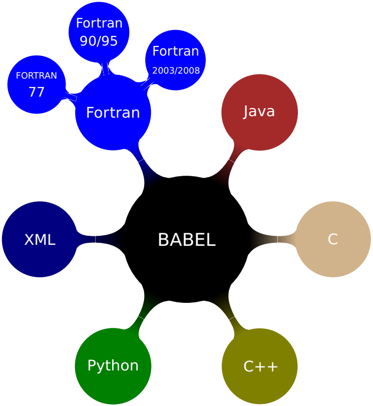
BRAID

a tool that provides interoperability for PGAS languages

➡Chapel first language to be supported

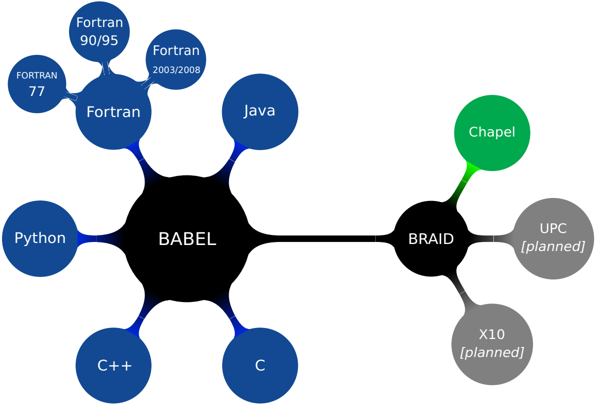
Related work



Babel

- LLNL's language interoperability toolkit for high-performance computing
- Designed for fast in-process communication
- Handles generation of all glue-code
- Features multi-dim. arrays, OOP, RMI, . . .

BRAID connects Babel with PGAS languages



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

How does it work

Programming-language-neutral **interface specification**

Scientific Interface Definition Language (SIDL)

SIDL supporting

- fundamental data types
- object-oriented programming (user-defined types)
- interface inheritance
- exception handling
- dynamic multi-dimensional arrays

Using Chapel with BRAID — I

first, define the interface in SIDL

Example

```
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

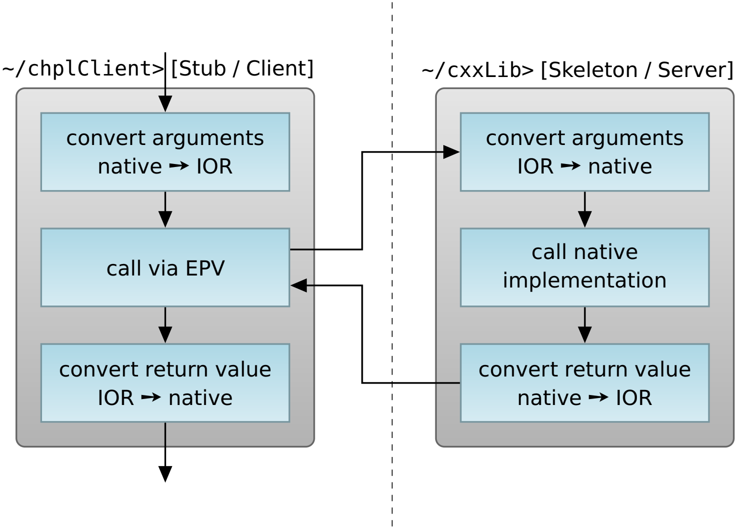
Using Chapel with BRAID — III

- 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!

Control flow for crossing the language boundary


~/chplClient> [Stub / Client]
convert arguments native ➙ IOR
call via EPV
convert return value IOR ➙ native
~/cxxLib> [Skeleton / Server]
convert arguments IOR ➙ native
call native implementation
convert return value native ➙ IOR

IOR ....intermediate object representation

EPV ....entry point vector (vtable)

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

Local Arrays

SIDL arrays represent rectangular regions

normal SIDL arrays

- general interface for arrays
- can be used as parameters/return types
- row-major or column-major order
- support arbitrary strides

➥ access via interface

raw arrays (r-arrays)

- not as return type or *out* args
- must be contiguous in memory with column-major order

➥ presented as *native* array type

Local Arrays: Raw Array Example

Example

SIDL File (interface of external function)

```
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 cont'd.

user can use *any* Chapel rectangular array as raw array

➥ includes support for distributed arrays!

Local Arrays cont'd.

user can use *any* Chapel rectangular array as raw array

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BRAID client code automatically

converts input arrays to required SIDL type

- copying involved when input arrays are
  1. not contiguous (e.g. distributed)
  2. not in column-major order for raw-arrays
- custom Chapel library extensions for column-major ordered arrays and **borrowed arrays** for extra speed

Distributed Arrays

Copying everything is too inefficient?

Distributed Arrays

Copying everything is too inefficient?

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, data transferred on access!

Object-oriented programming — I

SIDL supports packages, abstract classes, static and virtual methods

Chapel OOP support still in flux

- cannot inherit from classes with custom constructors

BRAID 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

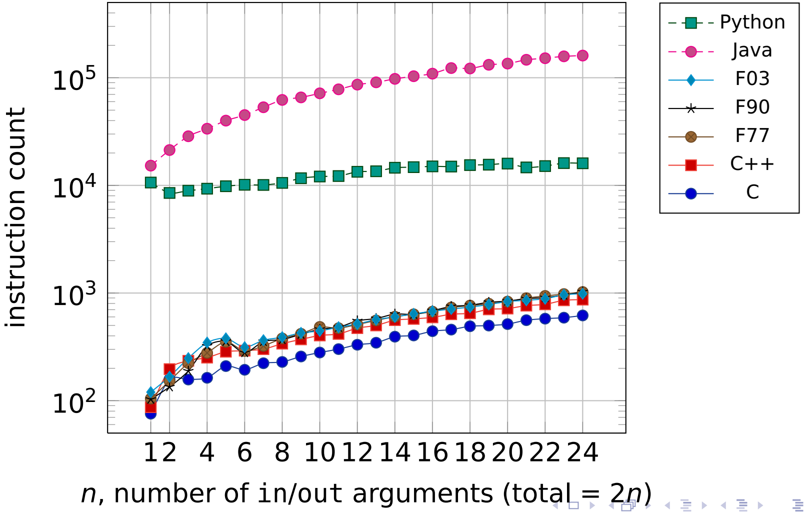
Chapel types delegate calls to IOR

- virtual function calls are handled by SIDL runtime
- type-casting supported by explicit cast calls

Benchmark

Calling a function that copies n arguments

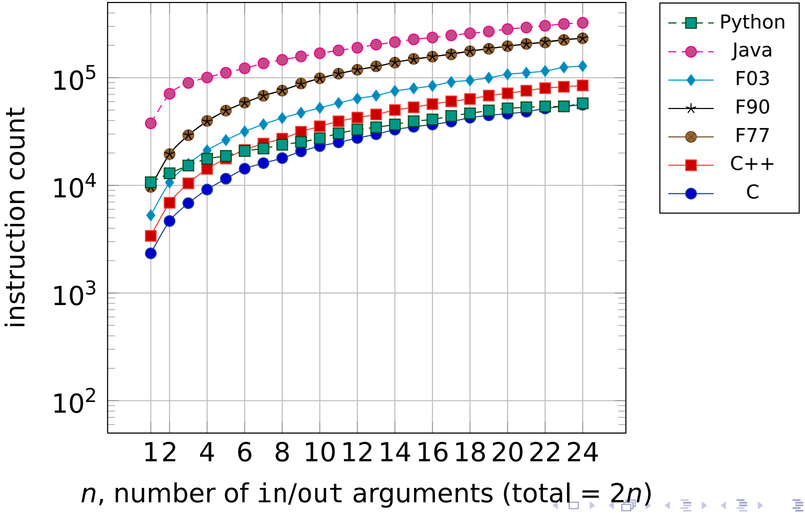
`copy bool`, $b_i = a_i$



Benchmark

Calling a function that copies *n* arguments

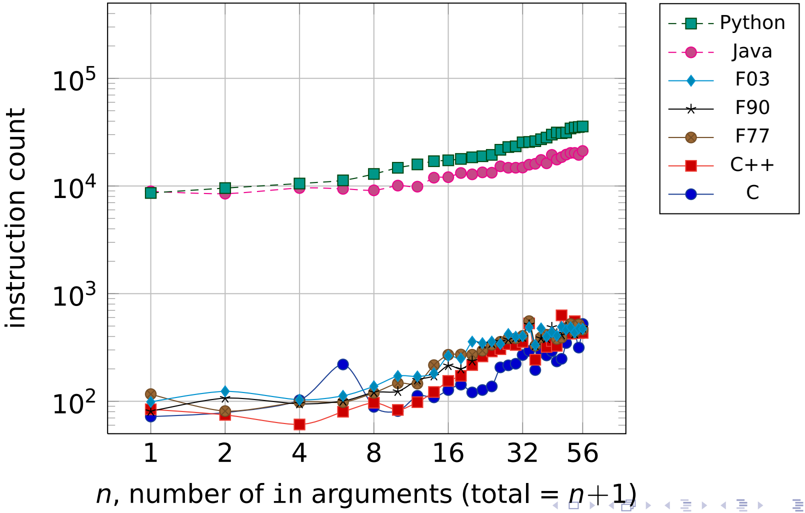
`copy string`, $b_i = a_i$



Benchmark

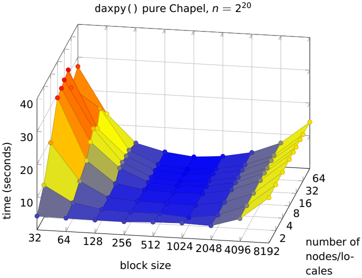
Calling a function that calculates the sum of *n* arguments

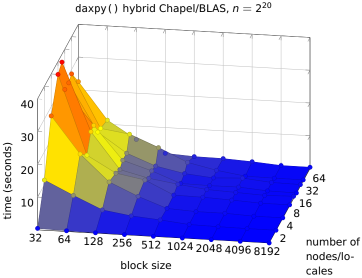
`sum float`, $r = \sum a_i$



Benchmark (distributed)

daxpy Benchmark





pure Chapel

hybrid Chapel/BLAS

Summary and Future Work

- Achieved interoperability between Chapel and
  1. C
  2. C++
  3. FORTRAN 77
  4. Fortran 90/95
  5. Fortran 2003/2008
  6. Java
  7. Python

➡including support distributed arrays

Future work

- add support for Chapel as server language
- use similar concepts to add support for UPC and X10

Thank you!

Thank you!

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Are there any Questions?