Tool Improvements

Chapel Team, Cray Inc.
Chapel version 1.11
April 2, 2015
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Tools Overview

- **Prototype Chapel Interactive Programming Environment**
- **chpltags: source code navigation aid**
- **chpldoc: source-to-documentation tool**
- **Tool Priorities and Next Steps**
Prototype Chapel IPE
(Interactive Programming Environment)
Executive Summary

- **Foundation for interpreter developed**
  - Taking a depth-first approach in implementing features
    - Initially support narrow feature set, sprinting toward parallelism/locality
    - Then broaden iteratively

- **Recent focus**
  - Managing scopes / environments
  - Scope/Function resolution
  - Incremental application development

- **Primary challenges**
  - Sequencing of transformations
    - Currently applied on a program-wide basis
    - IPE must operate on single statements
  - Current implementation of resolve is complex
    - Implemented in multiple passes
    - Interleaved with other passes esp. normalization
Status of Prototype
What Can It Do?

1> proc PowerOfTwo(n : int) : int
{
    var i   = 0;
    var res = 1;

    while (i < n)
    {
        i   = i   + 1;
        res = res * 2;
    }

    return res;
}

2> writeln('2**10 = ', PowerOfTwo(10));
   2**10 = 1024
Simple Operations

- **Arithmetic operations on int, real**
  - Unary +,-
  - Binary +, -, *, /

- **Equality comparison on int, real, bool**
  - ==, !=

- **Ordered comparison on int, real**
  - <, >, <=, >=

- **Misc**
  - abs
  - _cond_test: implicit conversion to bool for conditionals
  - primitive version of writeln

- **Expressed as module code in ChapelBase**
Simple Control Flow

- if-then and if-then-else statements
- while-do statement
  - no break or continue
- return statement
  - If present, must be final statement of procedure
User-defined Functions

- Fixed number of formals
  - Types must be specified

- Return type must be specified
  - Can be void

- At most 1 return statement
  - Must be last statement
Interactive Console

- **Enter statements interactively**
  - Variable definitions
  - Procedure definitions
  - If statements
  - While-Do statements
  - Function calls

- **Output using limited version of writeln()**

```plaintext
1> var x = 8;
2> writeln('x = ', x);
   x = 8
3> x = 12 + 4 * x;
4> writeln('x = ', x);
   x = 44
```
Development Strategy

- **Initially narrow and deep**
  - Manage modules
  - Simple expressions on default integers, reals, bools, cstring
  - Simple control flow and function calls
  - Simple interactive console
  - Tasks within a single locale e.g. implement `begin` statement
  - Multi-locale e.g. implement `on` statement

- **Then widen iteratively**
  - Remaining primitive types
  - Remaining sequential control flow
  - Generic functions
  - Iterators
  - Classes, records, enums, etc
  - Remaining parallel control flow
Compatibility with Static Chapel

- Static Chapel programs are valid interactive programs
  - Currently
    - Very small fraction of static Chapel supported
  - Nearer-term
    - Multi-tasking within a single locale
    - Increasing support for breadth of static Chapel
    - Investigation to support multi-locale programs
  - Longer-term
    - Full support for sequential static Chapel
    - Multi-locale programs
    - Scalable support for extern C procedures

- Strive to make interactive programs valid static programs
  - Some challenges exist due to nature of interactivity
    - e.g. incremental definition and redefinition of functions
Common Codebase
Mostly Positive for Compiler and Interpreter

● **Pros**
  - Compiler provides a mature infrastructure for Chapel
    - Existing parser, AST, transformations
  - Development for IPE benefits compiler
    - Improved abstraction in AST e.g. introduction of Loop statements
    - Interactive console => pure parser
  - Chapel language and implementation still maturing
    - Interpreter and compiler grow together
    - Additional changes to AST
    - Refinement of scope/function resolution

● **Cons**
  - Existing pipeline tailored to compiler
    - Limited abstraction
    - Largely fixed-order program-wide transformations
    - Refactoring reduces initial rate of progress for IPE
Refactoring Driven By IPE

- **Introduced new AST nodes derived from LoopStmt**
  - Conceived to simplify interpreter’s use of While stmts
    - These had been expanded as nested BlockStmts during parsing
    - Minor work remains for compiler
  - Reduced reliance on BlockStmt::blockInfo for loop management
    - Reported to have benefited vectorization effort
  - LoopStmt currently derives from BlockStmt
    - Should derive from Stmt

- **Parser is reentrant (almost)**
  - Bison/Flex updated to use pure, push API
    - No changes to grammar
  - Basis to develop a Chapel-rific source include feature
    - Will need to complete the removal of global state
Future Contributions to Compiler Front-end

- **Interpreter should drive enhancements to AST**
  - Interpreters should provide source-level error messages and tracing
    - Challenging with current AST
    - Compiler lowers many statements during parse pass

- **Interpreter should drive improvements to resolve**
  - Interpreter requires statement-oriented version of resolve
    - Efficiency argues for performing this once per program statement

- **Interpreter and Compiler should share a front-end**
  - Parser generates source-level untyped AST
    - Literals, identifiers, source-level statements, line numbers
    - Input for chpldoc and resolution
  - Resolution generates typed AST
    - Types, variables, fields, expressions, environments
    - Can be executed with acceptable efficiency by interpreter
    - Compiler can lower/transform as appropriate
What the Interpreter Wants

Read
- Literals, Identifiers, Comments, Punctuation
- Untyped expressions and statements
- File names and line numbers

Resolve
- Lexical scope explicit
- Typed literals, variables, fields, expressions
- Implies function calls selected

Optional Streamline
- Environment chains flattened
- Variable locations defined
- Function call dispatch streamlined

Eval
- Evaluate typed/resolved expressions

Print
- Print value

Source-level untyped AST

Typed AST

Typed AST

Eval

Param Eval
What the Interpreter Gets

- **Parse**: Untyped identifiers and symbols, Lowered statements and expressions
  - AST
  - **Pass**: 1

- **Scope Resolve**: Identifiers mapped to symbols
  - AST
  - **Pass**: 7

- **Normalize**: Additional lowering of untyped AST
  - AST
  - **Pass**: 9

- **Resolve**: Variables and expressions typed, Functions resolved
  - AST
  - **Pass**: 13

- **Call Destructors**: addr-of primitive inserted for ref args
  - AST
  - **Pass**: 19

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What the Compiler Wants

**Parse**
- Literals, Identifiers, Comments, Punctuation
- Untyped expressions and statements
- File names and line numbers

**Resolve**
- Lexical scopes explicit
- Typed literals, variables, fields, expressions
- Implied function calls selected

**Optimize**
- Scalar optimizations
- Loop optimizations
- Communication optimizations

**Codegen**
- Generate C and invoke platform compiler
A Shared Future

Parse
- Literals, Identifiers, Comments, Punctuation
- Untyped expressions and statements
- File names and line numbers
- Source-level typed AST
- Lexical scopes explicit
- Typed literals, variables, fields, expressions
- Implied function calls selected

Resolve
- Param Eval

Optimize
- Scalar optimizations
- Loop optimizations
- Communication optimizations
- Low Level AST

CodeGen
- Invoke platform compiler
- Typed AST
- Eval typed expressions
- Print value
- Streamline
- Eval
- Print

Compiler
- Invoke platform compiler
- Eval typed expressions
- Print value
- Streamline

Interpreter
- Eval typed expressions
- Print value
- Streamline
30,000’ View of Interpreter
Focus is on Expressions and Environments

● **Expressions**
  ● Literals
  ● Identifiers
  ● Definitions
  ● Control flow (if, while, for, ...)
  ● Calls

● **Environments**
  ● A sequence of frames
    ● A frame is a table of bindings from identifiers to types and values
  ● Frames are created by
    ● parsing a module declaration
    ● calling a function
    ● entering a block statement
  ● Frames related by lexical nesting and use statements
Syntactic Dispatch on Expression Type

- **Literals**
  - Self-evaluating

- **Identifiers**
  - Walk the environment chain to find the current binding

- **Definitions**
  - Extend the current environment frame

- **Control flow (if, while, for, ...)**
  - Handful of special cases to implement

- **Calls**
  - Determine the type of every actual and select required definition
  - Construct a new environment and bind formals to actuals
  - Evaluate body in new environment
  - Drive most of the effort
Efficiency

- Operating on source level statements is inefficient
  - walking static environment chains to find binding for an identifier
  - resolving functions
  - walking dynamic environment chains to find value for a binding

- Opportunities to streamline execution
  - Adopt scope resolve to map identifiers to symbols
  - Adopt function resolution to select function statically
    - Must be able to handle redefinition of functions
  - Flatten environments
    - Module level variables in common store at depth 0; respect lexical scoping
    - Flatten nested block-statement environments within a function
  - Inline calls to primitive operations

- Be lazy e.g. do not resolve functions until/unless called

- “Try not to be stupid about things” cuts both ways
Redefine a Function

1> proc square(x : int) : int return x + x;   // typo
2> proc sumOfSquares(x : int, y : int) : int
   return square(x) + square(y);
3> writeln(`sos(3, 4) => ` `, sumOfSquares(3, 4));
   sos(3, 4) => 14
4> proc square(x : int) : int return x * x;
5> writeln(`sos(3, 4) => ` `, sumOfSquares(3, 4));   // 14 or 25?

The call to sumOfSquares()
resolved the formals and body of sumOfSquares()

The execution of the body of sumOfSquares()
resolved the formals and body of square()

Natural representation of the first call to square() in sumOfSquares() is
  `<CallExpr `<SymExpr var: `<FnSymbol name: “square”>>
    `<SymExpr var: `<ArgSymbol name: “x”>>`>
How Do We Get 25?

- **Bookkeeping and back-patching call-sites**
  - Feels complex and error prone
  - Some code updates might result in an observable pause

- **Indirection**
  - Treat a function definition “as if” a variable definition i.e.
    - `var square = lambda(x : int) : int return x * x;`
  - Redefinition becomes a variable assignment
  - Sets stage for better support of first-class functions
  - At call-site resolve baseExpr to VarSymbol rather than FnSymbol
    - Calls fetch value of function variable and apply the value to the actuals
    - Indirection could be optimized away for sealed modules
Add an Override

1> proc square(x : real) : real return x * x;
2> proc sumOfSquares(x : int, y : int) : real
   return square(x) + square(y);
3> writeln('sos(3, 4) => ', sumOfSquares(3, 4));
   sos(3, 4) => 25.0
4> proc square(x : int) : int return x + x;  // Deliberate
5> writeln('sos(3, 4) => ', sumOfSquares(3, 4));

How do we get 14.0?

- Treat functions as collections of typed methods
  - Inspired by CLOS’s view of generic functions
- Functions are versioned
  - Version id updated if set of methods is altered
- Call sites encode the version id and method offset
  - Version id inspected for every call
  - Call-site updated if version-id obsolete
IPE Next Steps

● **Expand feature set:**
  ● Support for single-locale parallelism (e.g., `begin`)
  ● Support for multi-locale execution (e.g., locales and `on-clauses`)

● **Improve compiler/interpreter architecture:**
  ● Additional AST refactorings
  ● Investigate shared, revamped, early resolution pass---also desired for:
    ● concepts/constrained generics/interfaces work
    ● compiler optimization efforts
    ● reducing generated code size / compile time
    ● richer support for param computations
    ● developer community
chpltags: source code navigation aid
Background: Navigating the Chapel modules is challenging
- ~47,000 lines of Chapel source as of 1.11 release

This Effort: Create a new utility – chpltags
- Generates ‘tags’ files for Chapel source code
- Passes regular expressions off to ctags or etags

Impact: We now build ‘tags’ for all module code
- Try out the tag support in your favorite editor!

Next Steps: Write a parser-based chpltags
- Regular expressions alone cannot parse all valid Chapel source:
  ```chapel```
  ```var x, y, z = 5.0;  // Only the definition of x will be found```
- Not a priority – the current state gives us most of what we need
chpldoc: source-to-documentation tool
chpldoc: Background

- Modern users expect online library docs
- Ideally, generate docs from source code and comments
- chpldoc prototype present since Chapel 1.6
chpldoc: chpldoc prototype

chpldoc prototype...
...Parsed code and comments
...Generated text or HTML

myfile.chpl:

/* This is a documentation comment */
proc foo (x: int, y): bool {
    ...
}

// This is not documentation
proc bar (): int {
    ...
}

myfile.txt:

Module: myfile
    proc foo(x: int(64), y): bool
        This is a documentation comment
    proc bar(): int(64)

myfile.html:

myfile

Module: myfile
    proc foo(x: int(64), y): bool
        This is a documentation comment
    proc bar(): int(64)
chpldoc: chpldoc prototype (cont)

- **HTML output had minimal features**
  - Minimal UI
  - Missing search and cross references (links)

- **Limited language support**
  - Missing some language features
  - Bugs in output

- **Tightly coupled to compiler**
  - chpldoc and chpl shared same flags
  - chpldoc info hard to find in man page
  - Extra build step to get html
chpldoc: This Effort

- separate chpldoc from chpl
- Rich HTML output
- Support standard library
- New features
- Fix bugs in existing chpldoc
chpldoc: separate chpldoc from chpl

- Built separately: make chpldoc
- Separate flags
  - No longer need --doc prefixes
- Separate man pages
chpldoc: Rich HTML output

- Comments use **reStructuredText formatting**
- **Sphinx** used under the covers
  - reStructuredText parsing and formatting
  - Rich HTML UI
  - Provides cross references (links), search, etc.
  - Uses new Chapel domain for Sphinx
chpldoc: Support standard library

- Module docs online:
- See “Chapel Documentation” slides for more detail
chpldoc: New features

- Support for enums and globals
- `pragma “no doc”` to stifle symbols
- Source-based output ordering
- Hide inline/extern for procs
- “Module Index” listing all modules
- …and many incremental features!
chpldoc: Fixed bugs

- **Addressed several output bugs with:**
  - Function argument and return types
  - Class and record members
  - Missing default values in certain places
- **No-Paren procs output with parens**
- **type symbols output as var**
- **Secondary methods output twice**
  - E.g. proc MyClass.myProc() {}
- **…and many more!**
chpldoc: Impact

- Hardened standalone chpldoc program
- Used chpldoc to create online module documentation
- Added many new features
- And fixed existing bugs
chpldoc: Status and Next Steps

Status:

● chpldoc is first class citizen in project
● Usable by 3\textsuperscript{rd} party library developers

Next Steps:

● Continue fixing bugs
● Support inline tests in docs
  ● Similar to python doctests
chpldoc: Next steps (cont)

- Support documentation-only files, e.g. READMEs
  - And interaction with module docs
- Add class and record index
- Improve error handling for reStructuredText formatting
- Support class inheritance
- Additional output orderings
  - Like alphabetical and logical groupings
- Link to source code from docs
Tool Priorities and Next Steps
Tool Priorities and Next Steps

● **IPE:**
  ● support for dynamic execution
  ● support for multi-locale execution
  ● architect and implement shared resolution pass with compiler

● **chpldoc:**
  ● prioritize additional features based on developer/user needs
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