Generated Code Improvements

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Outline

- Incremental Compilation
- Denormalize Pass
- Vectorization Changes
- LLVM Debug Information
- Other Generated Code Improvements
Incremental Compilation
Incremental Compilation: Background

- Compiler analyzes whole program at one time
  - This includes recompilation of standard library code

- [Re]compilation is relatively slow
  - Even for minor changes to a small application

- Goal: provide a quick recompilation mode for users

![Average Total Compilation Time](chart)

Left: Average compilation time for all tests in our nightly testing suite.

Compilation time for hello.chpl on the same machine is ~3.4 seconds
Incremental Compilation: Background

- Majority of time spent in 2 passes:
  - makeBinary – compilation of generated C code
  - functionResolution – type resolution and resolving function calls

- Improvements here would benefit compilation significantly
  - makeBinary accounts for ~40% of the compilation time
Incremental Compilation: This Effort

- **Google Summer of Code project**
  - Work from Kushal Singh at IIIT Hyderabad
  - Description of current work and future plans available in **CHIP 15**

- **Preliminary design for functionResolution pass**

- **Implementation work on codegen/makeBinary passes**
Incremental Compilation: This Effort

● Preliminary design for functionResolution pass
  ● Including list of cases where a function would need recompilation:
    ● Changes to its body
    ● Changes to declaration of functions it depends on
    ● New potential matches when resolving calls within its body
  ● Lower implementation priority than makeBinary
Incremental Compilation: This Effort

- Implementation work on codegen/makeBinary
  - makeBinary compiles every generated .c file into one monolithic .o file
    - Any change to one file would trigger a complete rebuild of this .o
  - Moved to generating two .o files and linking them together
    - One for user code, one for library code
    - User changes hopefully would not modify library .o file, saving recomp time
  - Required “purifying” generated header file
    - Moved definitions into another file but left declarations in place
    - In incremental mode, removed “static” keyword from exported symbols
    - Allowed header to be #included by both .o files w/o link time errors
Incremental Compilation: This Effort

● How to reuse the unmodified parts of the generated code?
  ● Codegen always generated completely new copies of the .c files
    ● Even if some of the files would be identical to previous versions
  ● Need to maintain persistent state between compiles
    Compare new generated code against persistent copy…
    … and move the changed code into the persistent storage location, …
    … then rebuild only the touched parts of the persistent state
  ● Remove the persistent state if changes detected in:
    ● Compilation flags
    ● Environment variables
    ● Changes in library code effectively yield the same result
    ● Can be more selective later, but not a high priority
Incremental Compilation: This Effort

● Add flag to enter this compilation mode, --incremental
  ● Generates two .o’s instead of one
  ● During first run, saves persistent state and current compilation options
    ● Subsequent runs perform check, then overwrite persistent state as needed

● Challenge: generated .c must be stable, but currently isn’t
  ● i.e. An unmodified application should always yield the same .c files
    ● Today we see differences in the ordering of functions from run to run
    ● This means we must overwrite the persistent state too frequently
Incremental Compilation: Status

- **Known Issues**
  - Generated .c code not completely stable
  - No support for the LLVM back-end
  - Will differ in execution performance from a normal compile
    - Certain gcc optimizations thwarted by multiple .o’s, removing static keyword
Incremental Compilation: Next Steps

- Finish stabilizing generated C code
- Discuss next steps before function resolution changes
- Make our library .o file reusable across different programs
  - This would speed up compile time for all programs, not just recompiles
  - Challenge: library code is highly generic and varies with user code
- Add framework for recompilation to function resolution
  - Including persistent storage of AST dependencies for functions
- Other compilation time improvements
Denormalize
Denormalize: Background

- Generated C code includes a lot of temporary variables
- Consider this Chapel code:
  ```chapel
  var x = 123;
  writeln(x*x + x);
  ```
- It generates the C code:
  ```c
  int64_t call_tmp_chpl;
  int64_t call_tmp_chpl2;
  call_tmp_chpl = (INT64(123) * INT64(123));
  call_tmp_chpl2 = (call_tmp_chpl + INT64(123));
  writeln_chpl2(call_tmp_chpl2);
  ```
- The C compiler often optimizes these temps away, but
  - it has to work to do so
  - they increase the complexity for developers looking at the generated C
Denormalize: Background

- Most of the Chapel compiler works with *normalized* AST
- AST is *normalized* so there are no nested call expressions
  
  \[ x^2 + x \]
  
  becomes
  
  ```
  call_tmp = x^2
  call_tmp + x
  ```

- The *normalize* pass adds these `call_tmp` temporaries
- Later passes rely on call expressions not being nested
Denormalize: This Effort

● Add a pass to remove these call temporaries

● Pass runs just before generating C code
  ● only codegen needs to be able to work with a denormalized AST
Denormalize: Impact

- **Remember this Chapel code:**
  ```chapel
  var x = 123;
  writeln(x*x + x);
  ```

- **With --denormalize, it generates C code like**
  ```c
  writeln_chpl2((INT64(123) * INT64(123)) + INT64(123));
  ```

- **Results in a 25%-50% reduction in lines of C code**
Multi-slide topic: Status and Next Steps

**Status:**
- --denormalize available in 1.14 release
  - off by default due to insufficient testing prior to release

**Next Steps:**
- turn --denormalize on by default
- consider further improvements to code generation to clean up
  - useless casts
  - unnecessary parentheses
- improve --denormalize to cover more cases
  - e.g. function calls with a single argument
Changes to --vectorize
Chapel Vectorization: Background

● Chapel is well-suited for vectorization
  ● limited aliasing
  ● support for array programing
    \[ A = B + C; \]
  ● parallelism is a first class citizen
    \[ \text{forall } i \text{ in } 1..10 \text{ do } \ldots \]

● Need to convey Chapel semantics to back-end
  ● do not want to generate explicit vectorization
    ● rather, convey when vectorization is legal
    ● leverage back-end compilers’ sophisticated and refined cost models
Changes to --vectorize

Background:

- Added --vectorize in 1.11.0
- It finds and marks order-independent (data parallel) loops
- And attaches “#pragma ivdep” to the generated code
  - ivdep == ignore vector dependencies
- In 1.14.0, we saw data parallel loops that had vector dependencies
  - in particular with reductions, likely also any loop with “task-private” vars
  - realized order-independence is not sufficient for asserting ivdep

This Effort:

- Stopped enabling --vectorize with --fast
  - is now an opt-in (use at your own risk) flag

Next Steps:

- Determine what additional analysis is needed to safely use ivdep
- Continue exploring other vectorization strategies
LLVM Debug Information
LLVM Debug Information

**Background:** Chapel includes --llvm code generation option
- generates LLVM IR instead of C code
- initially added in 1.6.0
- supports several research projects
- but, did not generate debug information with -g

**This Effort:** Include debug information in generated LLVM IR
- contributed to by Matt Baker, Hui Zhang
- finished as part of Google Summer of Code

**Impact:** --llvm -g works to debug Chapel programs
- debugger can show Chapel source code lines
- debugger can show Chapel global variables

**Next Steps:** Further improve the debug experience
- make debug variable names match Chapel source code
- generate debug information for local variables
Other Generated Code Improvements
Other Generated Code Improvements

● Improved accuracy of #line directives for vars, procs
  ● Improves debugging of Chapel code through the generated C

● Improved quality of 'local' blocks in generated C code
  ● merged adjacent blocks to reduce curly braces
  ● added a "/* local block */" comment for developers
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