HERCULES/PL: The Pattern Language of HERCULES

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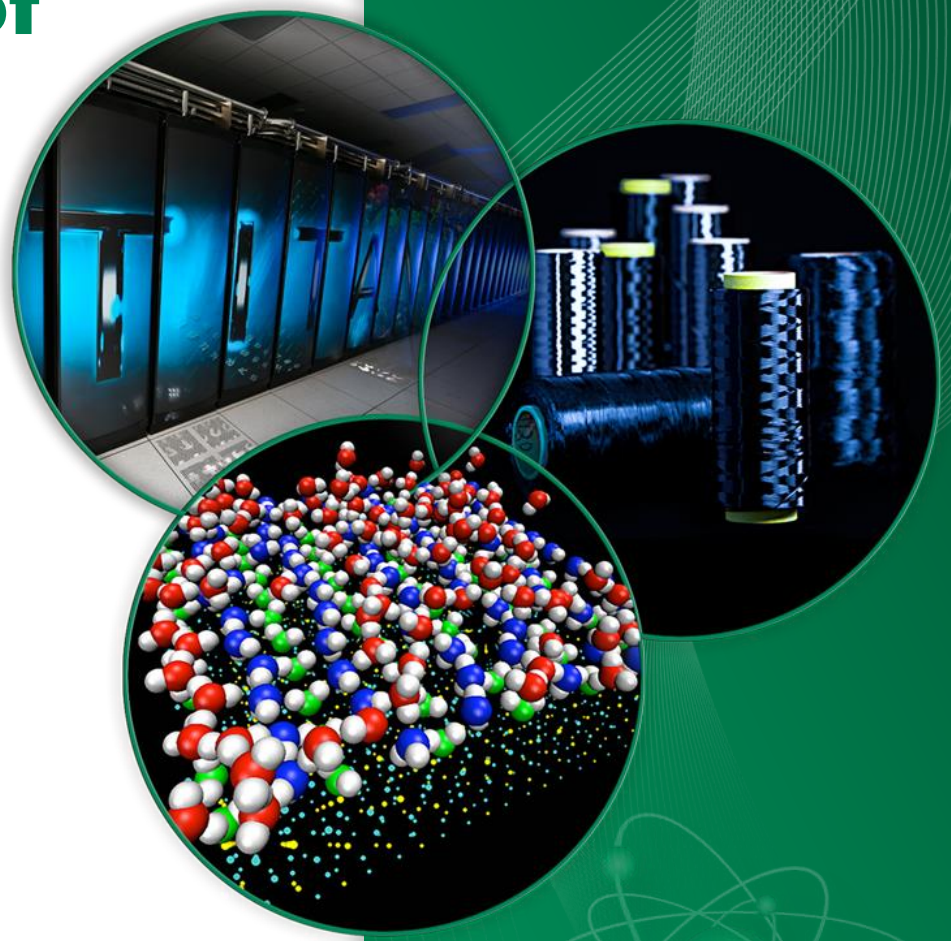

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Workshop on Programming Language Evolution 2014 (PLE14)

HERCULES Framework

- DoE application challenges in accelerator & exascale era
  - Large production-grade simulation codes need porting
  - Reengineering challenges going beyond parameterization
  - Little or no expectation for compiler readiness
- HERCULES: A user-extensible compiler infrastructure
  - Compiler-supported analysis/transformation tools
  - Help computational scientists with average optimization experience achieve reuse in this context
- Typical scenario: users search for codes similar to what they have optimized in the past
  - Good candidates for similar optimizations
  - How to do this?

User-Level Analysis

- Impractical for users to construct custom analysis by diving into a compiler's implementation
- Possibly easier to formulate analysis in terms of high-level primitives
  - User analysis as a set of properties that different parts of a program must have
- Mixed-type Compiler Intermediate Representation (IR) CPS
  - A constraint programming system (CPS)
  - Informally referred to as a "pattern"
  - Type of unknowns is drawn from the IR domain (symbols, cfg, …)
- The CPS solution tells you which components of a given program satisfy certain constraints

HERCULES/PL

- Language-level front-end for this compiler IR CPS
  - C/Fortran + Directives
- Incremental
  - User writes a sample program or uses an existing program that resembles what they are looking for
  - User uses HERCULES/PL directives to generalize/specialize or “steer” the pattern derivation process
- Directives
  - **#pragma NAMESPACE** in C, **!$NAMESPACE** in Fortran
  - HPC programmers accustomed to this level of programming (HPF, OpenMP, HMPP, OpenACC)
  - Decorate code with hints, transformation requests, etc.

Brief Fortran HERCULES/PL Example

```
subroutine driver(J,N,A)
  integer :: I,J,N,A(1:N)
!$hercules pattern declare loop_accesses(symbol A, statement L), statement
!$hercules symbol I,J promote(expression)

!$hercules statement bind L
  do I=1,N
!$hercules statement insert ...
! -- array write here or deeper
!$hercules statement bind ACCESS +nested() +affine(I)
    A(I)=J
!$hercules statement insert ...
  end do
!$hercules pattern declare end
end subroutine
```

- Find a DO LOOP that contains a *nested array write* with an index expression that is an *affine expression of* ***I*** and which may be assigned *anything*.
- HERCULES will tell you in a matching code which loop **L** (by line number) and which symbol **A** (by name).

Overview: Declarations

- Signifies which portion/region of the program will be used for constraint derivation (scoping)
- **!$hercules pattern declare NAME(TYPE ARG,...) [, MODE]**
  - **block** (default): all the non-declaring statements
  - **statement**: a single statement
  - **expression**: the right hand side of an assignment statement
  - {**statement**, **expression**}_**nested**: as before, but at any depth
- Declared patterns can be reused via the property mechanism (later)

Overview: Binding

- For the CPS everything you write generates unknowns
- Statement: **for (i=0 ; i<n ; i++) s[i]=0;**
  - 3 symbol unknowns: **i**, **n** & **s**
  - 4 statement unknowns: **for (..)**, **i=0**, **i++** & **s[i]**=0
  - Multiple expression unknowns: **i** & **0** in **i=0**, etc.
- Binding assigns ids/labels to these unknowns
  - Symbols default to their actual name
  - Statements can be tagged
  - Statement components can be "reached": e.g. index of **s[i]**
- **#pragma hercules symbol|statement|type bind**

Overview: Modifying (I)

- Often need to manipulate the syntax tree
- Symbol promotion to expression interprets all symbol "use sites" as expressions
  - A(I) = J in the example with both I & J promoted
  - Using a promoted symbol at multiple sites requires all sites to have identical ASTs
  - **#pragma hercules symbol NAME promote**
- Statement insertion allows additional statements to be present
  - Inserting "…" to give a floating effect to successors
  - **#pragma hercules statement insert EXPR**

Overview: Modifying (II)

- Often need to relate or limit elements
- Properties
  - *Constraining*: what must or must not hold
  - *Inspective*: find something that exhibits certain behavior
    - E.g. find an array access as opposed to "writing" one
  - **+PROPERTY(ARG, …)** mechanism & variants (aggregation, negation, etc.)
  - HERCULES/PL does not define who "proves" the property
- Combining with other modifiers for a "foreach" effect
  - To require all sites where a promoted symbol appears to have a property
  - To require all inserted statements to a have a property

Implementation

- Implemented in the Open64 compiler for both C & Fortran using PROLOG as the CPS back-end
  - At VHO time, but deferrable to later stages (e.g. LNO) also
  - Source + Directives compiled into a PROLOG predicate, standard patterns library (SPL) incorporated
  - Target program's IR "lowered" to PROLOG facts, extra analyses run and/or merged with the db
  - SWIPL invoked on db + predicate, solutions passed to hfe
- HERCULES front-end (hfe) gives choice of
  - Return-to-user: report to shell, e.g. hscan
  - Return-to-compiler: solution → real IR refs + callback

Experiences

- Amount of directives used subject to workflow
  - Plenty if starting from scratch, a lot less if building on existing sources, hardly any if targeting clone detection
- Implementation reveals many compiler challenges
  - Intercepting expression trees with directives
  - HERCULES/PL processing needs to happen before the compiler "lowers" the code
  - CPS back-end choice critical, HERCULES/PL performance
- Application
  - DoE CAM/SE & Sweep3D auto-opt (HIPS)
  - Predictive modeling & custom feature vectors (ICPP)

Current Work

- Insertion & ordering directives for types

```
struct list {
#pragma hercules type unordered
    struct list* next;
#pragma hercules type +extrafield(F1)
};
```

- **statement ignore** keyword
- **operator OP ungrouped** (no left/right associativity)
  - a+b+c: ((a+b)+c) if L/A; we may not care about order

Questions

Example

```
subroutine driver()
  integer :: I,J,N
!$hercules pattern declare test(statement FOR1, statement FOR2, list:symbol MSYMS)
!$hercules symbol E1,E2 promote(expression)
!$hercules statement insert …
!$hercules statement bind FOR1 +body(B1) +B1:reads_only_all_of(MSYMS)
  do I=E1,E2
!$hercules statement insert …
  end do

!$hercules statement insert [ANY] +[]:!writes(MSYMS)

!$hercules statement bind FOR2 +body(B2) +B2:writes_only_all_of(MSYMS)
  do I=E1,E2
!$hercules statement insert …
  end do

!$hercules statement insert …
!$hercules pattern declare end
end subroutine
```

```
do I=2,n-1
   b(i) = a(i-1) + a(i) + a(i+1)
end do
do I=2,n-1
   a(i) = b(i)
end do
```