Porting to Hybrid, Multi-core Systems

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When to Move to a Hybrid Programming Model

- When code is network bound
  - Look at collective time, excluding sync time: this goes up as network becomes a problem
  - Look at point-to-point wait times: if these go up, network may be a problem
- When MPI starts leveling off
  - Too much memory used, even if on-node shared communication is available
  - As the number of MPI ranks increases, more off-node communication can result, creating a network injection issue
- When contention of shared resources increases

Optimizations for multi-core systems

- Reduce number of MPI ranks per node
- Add parallelism to MPI ranks to take advantage of cores within a node while minimizing network injection contention
- Maximize on-node communication between MPI ranks
- Relieve on-node shared resource contention by pairing threads or processes that perform different work (for example computation with off-node communication) on the same node
- Accelerate work intensive parallel loops

Steps to Porting to Hybrid Multi-core Systems

- Determine where to add additional levels of parallelism
  - Assumes MPI application is functioning correctly on X86
  - Find top work-intensive loops (perftools + CCE loop work estimates)
- Split loop work among threads
  - Do parallel analysis and restructuring on targeted high level loops
  - Use CCE loopmark feedback, Reveal loopmark and source browsing
- Add parallel directives and acceleration extensions
  - Insert OpenMP directives (Reveal scoping assistance)
  - Run on X86 to verify application and check for performance improvements
  - Convert desired OpenMP directives to OpenACC

Steps to Porting to Hybrid Multi-core Systems (2)

- Run on X86 + GPU and get performance feedback
  - perftools profiling analysis
- Optimize for data locality and copies to the GPU
  - perftools accelerator statistics
- Optimize kernel on GPU
  - perftools GPU counter statistics
  - perftools Kernel statistics
- Optimize core performance on CPU
  - Automatic profiling analysis with CPU HW counter threshold feedback

Determine where to add additional levels of parallelism – loop work estimates

Loop Work Estimates

- Helps identify loops to optimize (parallelize serial loops):
  - Loop timings approximate how much work exists within a loop
  - Trip counts can be used to approximate work and help carve up loop on GPU
- Enabled with CCE –h profile_generate option
  - Should be done as separate experiment – compiler optimizations are restricted with this feature
- Loop statistics reported by default in pat_report table
- *Coming soon*: integrated loop information in profile
  - Get exclusive times and loops attributed to functions

Collecting Loop Statistics

- Access CCE and perftools software

```
module load PrgEnv-cray perftools
```

- Compile AND link with –h profile_generate

```
cc –h profile_generate –c my_program.c
cc –h profile_generate –o my_program my_program.o
```

- Instrument binary for tracing

```
pat_build –u my_program   OR
pat_build –w my_program
```

- Run application
- Create report with loop statistics

```
pat_report my_program+pat.xf > loops_report
```

Example Report – Loop Work Estimates

```
Table 1:  Profile by Function Group and Function

 Time%   |      Time    |     Imb.   |  Imb.   |  Calls   |Group
         |              |     Time   | Time%   |          | Function
         |              |            |         |          |  PE=HIDE
         |              |            |         |          |   Thread=HIDE

 100.0% | 176.687480 |        -- |      -- | 17108.0 |Total
|------------------------------------------------------------------------
|  85.3% | 150.789559 |        -- |      -- |     8.0 |USER
||-----------------------------------------------------------------------
|  85.0% | 150.215785 | 24.876709 |  14.4% |     2.0 | jacobi_.LOOPS
||=======================================================================
|  12.2% |  21.600616 |        -- |      -- | 16071.0 |MPI
||-----------------------------------------------------------------------
|  11.9% |  21.104488 | 41.016738 |  67.1% |  3009.0 | mpi_waitall
||=======================================================================
|   2.4% |   4.297301 |        -- |      -- |  1007.0 |MPI_SYNC
||-----------------------------------------------------------------------
|   2.4% |   4.166092 |  4.135016 |  99.3% |  1004.0 | mpi_allreduce_(sync)
|========================================================================
```

Example Report – Loop Work Estimates (2)

```
Table 3:  Inclusive Loop Time from -hprofile_generate

 Loop Incl  |     Loop  |  Loop  |  Loop  |Function=/.LOOP[.]
      Time  |      Hit  | Trips  | Trips  | PE=HIDE
     Total  |           |   Min  |   Max  |
|-----------------------------------------------------------------
…
| 175.676881 |         2 |       0 |   1003 |jacobi_.LOOP.07.li.267
|   0.917107 |      1003 |       0 |    260 |jacobi_.LOOP.08.li.276
|   0.907515 |    129888 |       0 |    260 |jacobi_.LOOP.09.li.277
|   0.446784 |      1003 |       0 |    260 |jacobi_.LOOP.10.li.288
|   0.425763 |    129888 |       0 |    516 |jacobi_.LOOP.11.li.289
|   0.395003 |      1003 |       0 |    260 |jacobi_.LOOP.12.li.300
|   0.374206 |    129888 |       0 |    516 |jacobi_.LOOP.13.li.301
| 126.250610 |      1003 |       0 |    256 |jacobi_.LOOP.14.li.312
| 126.223035 |    127882 |       0 |    256 |jacobi_.LOOP.15.li.313
| 124.298650 |  16305019 |       0 |    512 |jacobi_.LOOP.16.li.314
|  20.875086 |      1003 |       0 |    256 |jacobi_.LOOP.17.li.336
|  20.862715 |    127882 |       0 |    256 |jacobi_.LOOP.18.li.337
|  19.428085 |  16305019 |       0 |    512 |jacobi_.LOOP.19.li.338
|========================================================================
```

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Do parallel analysis and restructuring on targeted high level loops – Reveal

Compiler Feedback

- Generate compiler program library with whole program analysis for more in-depth inter-procedural analysis
  - `% cc –hwp –h pl=/path_to_my_program_library/`
- Generate loopmark information, view .lst files
  - `% cc –rm –c my_program.c`
- Use Reveal to view loopmark information, compiler messages, browse source

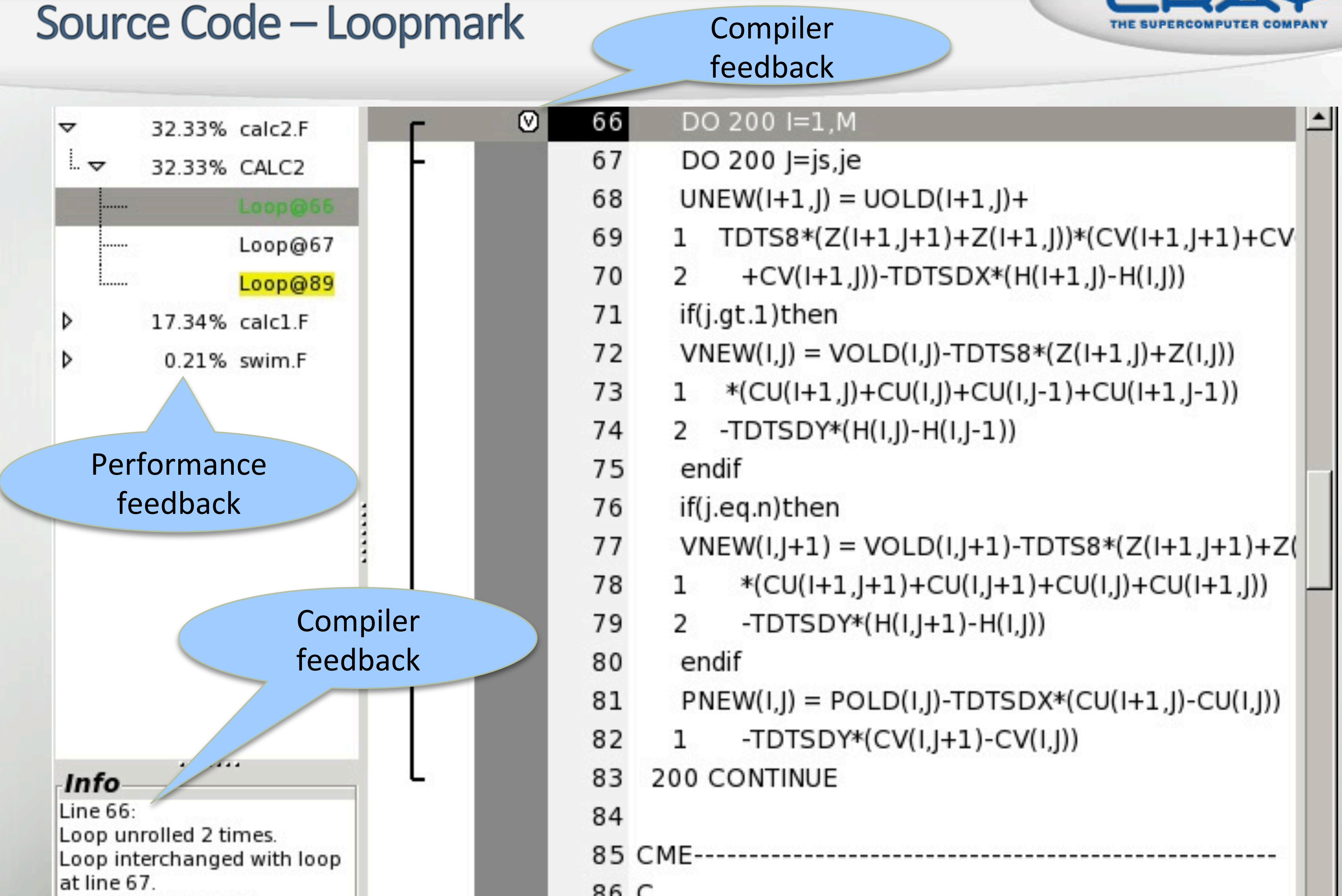
Reveal

New code restructuring and analysis assistant…

- Uses both the performance toolset and CCE's program library functionality to provide static and runtime analysis information
- Assists user with the code optimization phase by correlating source code with analysis to help identify which areas are key candidates for optimization

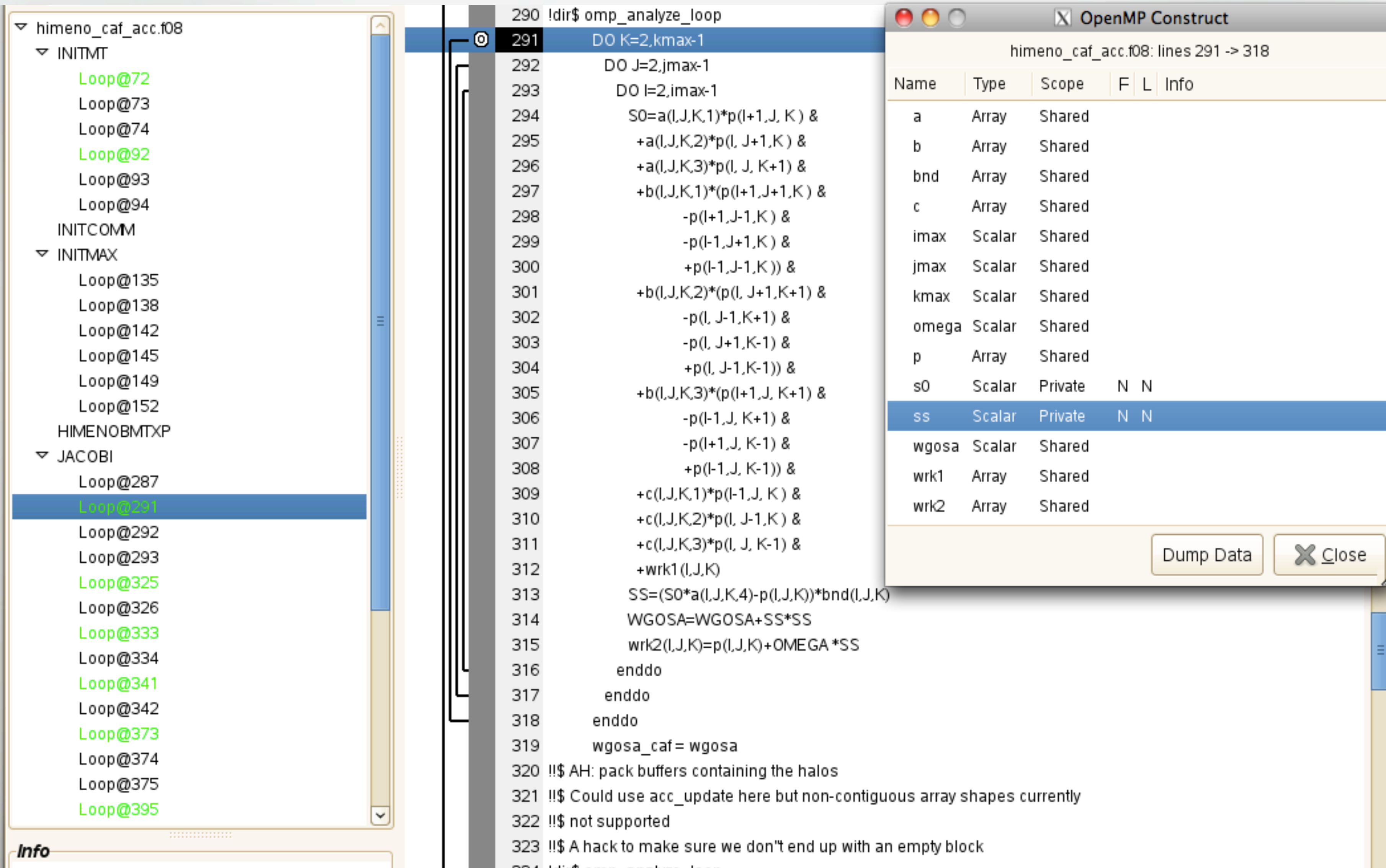
- Key Features
  - Annotated source code with compiler optimization information
    - Feedback on critical dependencies that prevent optimizations
  - Scoping analysis
    - Identify, shared, private and ambiguous arrays
      - Allow user to privatize ambiguous arrays
      - Allow user to override dependency analysis
  - Source code navigation based on performance data collected through CrayPat

Source Code – Loopmark



Add parallel directives and acceleration extensions - Reveal

Display Scoping Information for Selected Loop



Reveal Next Steps

- Navigate by profile call tree with loops
- Initiate scoping analysis from within Reveal (no omp_analyze directives or compiler command-line option)
- Directive generation and insertion into source
- Focus on loops with unknowns
- Create OpenMP or OpenAcc directives
- Highlight "interesting" compiler feedback
  - Was call site flattened or not?
  - Was loop flattened or not?
  - Was loop or region pattern-matched?

How to use Reveal 0.1 (early alpha version)

- Use cce 8.0.3 or later
- Start with clean build
- Collect loop statistics with cce and perftools to identify loops to parallelize
- Add !dir$ omp_analyze_loop directive before each loop to parallelize
  - This directive only works with serial loops. Add –x omp or –x acc to your cce compile options if loop is already parallel
- Compile application for scoping analysis
  - `% ftn -homp_analyze -hwp -hpl=/full_path/program.pl`
- Launch reveal:
  - `% reveal program.pl`

How to use Reveal 0.1 (early alpha version)

- Expand files and functions to look for loops with scoping information (highlighted green)
- Scope any unknowns
- Dump scoping information to stderr (where you launched reveal) to copy and past into a directive in your source by clicking “Dump Data”

Questions

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