A PORTABLE OPENMP RUNTIME LIBRARY BASED ON MCA APIs FOR MULTICORE EMBEDDED SYSTEMS

Sunita Chandrasekaran (sunita@cs.uh.edu)
Cheng Wang
Barbara Chapman
HPCTools Group, University of Houston, USA

IN COLLABORATION WITH FREESCALE SEMICONDUCTOR (FSL) AND SEMICONDUCTOR RESEARCH CORPORATION (SRC)
Multicore embedded systems are everywhere.

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cwang35@uh.edu
Multicore in Embedded Systems

TMDXEVM6678L EVM
- 8 core @ 1.25GHz
- 32 KB L1D and L1P cache.
- 512 KB L2 local cache.
- 4 MB shared L2 cache.
- 8 GB of shared external DDR3 memory at 12.8 GB/s.
Freescale’s Communication processor with data path

QorlQ P4080 processor
- 4-8 Power architecture e500mc cores
- Accelerators
  - Encryption (SEC)
  - Pattern Matching Engine (PME)
- Target applications:
  - Aerospace and Defense
  - Ethernet Switch, Router
  - Pre-crash detection
  - Forward Collision Warning

http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=P4080&tid=redP4040
Programmers’ requirements

- Rewriting applications from scratch requires considerable time and effort
  - Need easy way to parallelize existing codes
  - Incremental migration path essential for major application codes
  - May need to exploit multiple levels of parallelism
- …with familiar and/or commodity programming models
  - Not all programming models are created equal
  - None are perfect, but industry adoption is critical
Defacto and mature standard - OpenMP

- High-level API for shared memory programming
  - Widespread vendor support and a large user base
  - User makes strategic decisions; compiler figures out details
- OpenMP code is portable
  - Across compilers, runtimes
  - Mainstream compilers for Fortran, C and C++ support OpenMP

```c
#pragma omp parallel
#pragma omp for schedule(dynamic)
for (i=0;i<N;i++){
    NEAT_STUFF(i);
} /* implicit barrier here */
```
OpenMP for Embedded Systems

- Embedded programmers need portability too
  - Across diverse platforms; supported by multiple compilers and tools
  - Lets programmers focus on the algorithm and not the low-level details of concurrency (very important factor for embedded systems)

- OpenMP seen as very useful in this domain also, but:
  - OpenMP runtime relies on lower level components
    - OS and threading/hardware libraries
    - Memory allocation, synchronization e.g. Linux, Pthreads
      - But embedded systems typically lack some of these features
  - OpenMP has shared-memory cache-coherent memory model
    - However embedded platforms feature distributed, non-uniform memory, with no cache-coherency

- Vocabulary for heterogeneity is required in the embedded space
Portable OpenMP Implementation

- Translated OpenMP for MPSoCs
- Used Multicore Association (MCA) APIs as target for our OpenMP translation
- Developed MCA-based runtime:
  - Portable across MPSoCs
  - Light-weight
  - Supports non-cache-coherent systems
  - Performance comparable to customized vendor-specific implementations
Compilation Process

- OpenUH as our frontend source-to-source compiler
  - Translates C+OpenMP source into C with OpenMP runtime function calls
- PowerPC-GCC as our backend to generate the object file and libraries
- Final executable file is generated by linking the object file, our OpenMP runtime library and the MCA runtime library.
Dijkstra Kernel – Case Study

```c
me = omp_get_thread_num();
#pragma omp master
{
    nth = omp_get_num_threads();
    chunk = nv/nth;
}
startv = me * chunk;
endv = startv + chunk - 1;
for (step = 0; step < nv; step++){
    #pragma omp master
    {
        md = largeint; mv = 0;
    }
    findmymin(startv,endv,&mymd,&mymv);
    #pragma omp critical
    {
        if (mymd < md) {
            md = mymd; mv = mymv;
        }
    }
    #pragma omp barrier
    #pragma omp master
    {
        notdone[mv] = 0;
    }
```
extern void DijkstraKernel()
{
    register _INT32 _w2c__ompv_ok_to_fork;
    register _UINT64 _w2c_reg3;
    register _INT32 _w2c__comma;
    register _INT32 _w2c__comma0;
    _INT32 __ompv_gtid_s1;
    /*Begin_of_nested_PU*/
    _w2c__ompv_ok_to_fork = 1;
    if(_w2c__ompv_ok_to_fork)
    {
      _w2c__ompv_ok_to_fork = __ompc_can_fork();
    }
    if(_w2c__ompv_ok_to_fork)
    {
      __ompc_fork(num_threads, &__omprg_DijkstraKernel_1, _w2c_reg3);
    }
    else
    {
      //run the code sequentially
    }
    return;
} /* DijkstraKernel */
Calling MCA routines

```c
int __omp_c_init_rtl()
{
    mca_status_t mrap_status;
    mrapl_parameters_t parms = 0;
    mrapl_info_t version;
    mrapl_initialize(DOMAIN, NODE, parms, &version, &mrapl_status);
    /* get the number of hardware processors */
    __omp_num_cpus = __omp_get_num_cpu();
    if (__omp_num_cpus == 0){
        init_rtl = -2;
        return init_rtl;
    }
    /* number of MCA nodes */
    __omp_threads_var = __omp_num_cpus;
    /* parse OpenMP environment variables */
    __omp_parse_environment_variables();
    /* register the finalize function*/
    atexit(__omp_c_fini_rtl);
    /* setup MCA shared memory */
    /* ... */
    shmem_data = mrapl_shmem_create(OMP_SHMEM_DATA_KEY, __omp_shmem_size, NULL, 0, NULL, 0, &mrapl_status);
    /* ... */
    /* setup MCA nodes */
    /* ... */
    mrapl_initialize(0, node_id, parms, &version, &mrapl_status);
    shmem_data = mrapl_shmem_get(OMP_SHMEM_DATA_KEY, &mrapl_status);
    /* ... */
    return init_rtl;
}
```
void __omp_forke(const int _num_threads, omp_micro micro_task, frame_pointer_t frame_pointer)
{
    int num_threads = _num_threads;
    int i;
    omp_icv_t* icvs = (omp_icv_t*)addr_data_root;
    omp_mca_node_t* list_nodes = (omp_mca_node_t*)((unsigned long)addr_data_root + icvs->offset_list_nodes);

    mca_status_t mrapi_status;
    mrapi_node_t mrapi_node_id = mrapi_node_id_get(&mrapi_status);
    omp_mca_node_t* n = &list_nodes[mrapi_node_id];

    if(n->omp_exe_mode == OMP_EXE_MODE_SEQUENTIAL){
        // ...
        /* Master node wake up the child nodes and schedule tasks for the team*/
        // ...

        /* barrier */
        _omp_level_1_barrier(0);
        /* back to serial execution */
        n->omp_exe_mode = OMP_EXE_MODE_SEQUENTIAL;
    }
}
Make file and Compilation output

```bash
-o Dijkstra_kernel.w2c.o
c Dijkstra_kernel.w2c.c

linux-gnu-gcc
Dijkstra_kernel.w2c.c
-o Dijkstra_mca

Makefile

$(OBJ) $(C_INC) $(LDFLAGS) $(C_LIB) -o Dijkstra_mca

$(C_INC) -c Dijkstra.c
$(C_INC) -c Dijkstra_kernel.w2c.c

output *.w2c.c *.w2c.h

Output

$gcc -te500mc -O3 -std=c99 -w -I /home/cwang/opt/openuh-install/include/4.2 -c Dijkstra.o
$gcc -te500mc -O3 -std=c99 -w -I /home/cwang/opt/openuh-install/include/4.2 -c Dijkstra_kernel.w2c.o
$gcc -te500mc -O3 -std=c99 -w /home/cwang/opt/openuh-install/include/4.2 -lopenmp -lpthread -lm -lmrapi
/mca-build/lib -L /home/cwang/opt/openuh-install/lib/gcc-lib/x86_64-open64-linux/4.2 -o Dijkstra_mca
```
Results

#LibEomp with 1 thread
Success to initialize the mrapi
The parallel wall time is 10.461896 sec
deallocating mrapi memory
#LibEomp with 8 threads
Success to initialize the mrapi
The parallel wall time is 1.301495 sec
deallocating mrapi memory
Comparison of execution time of our libEOMP with native GCC libGOMP on a Freescale 8-core power processor board.

**DIJKSTRA**

**JACOBI**

**FFT**

**LU Decomposition**
Let’s make programming embedded devices EASY!!
Publications

Cheng Wang, Sunita Chandrasekaran, Barbara Chapman, and Jim Holt. 2013, "libEOMP: a portable OpenMP runtime library based on MCA APIs for embedded systems", in Proceedings of the 2013 International Workshop (PMAM), co-located with 18th ACM SIGPLAN Symposium on (PPoPP), Shenzhen, China, 2013