A Common Library Interface to Shared-Memory Multiprocessors

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Abstract

Programmers using a wide variety of shared-memory multiprocessors cannot yet rely on the availability of programming tools other than K&R C and Fortran 77. To overcome the sequential nature of these languages, vendors usually provide parallel programming primitives via user-callable libraries. Unfortunately, the vendor-provided libraries often differ substantially. In addition to providing differing mechanisms to create and synchronize processes; libraries often have different models of how the processes share and allocate memory within their address space.

This paper describes a common library interface to seven different shared-memory multiprocessors. Surprisingly, this library needs only two pages of implementation on each of the multiprocessors. However, the effect on the programming model is significant. Programmers must use the library's virtual machine model to obtain efficient programs on all the different physical machines.

1 Introduction

Despite recent parallel language standardization efforts (e.g. PCF [Parallel Computing Forum, 1991], ANSI Parallel C [Rudd (document editor), 1993], and HPF [Forum, 1993]), application programmers cannot yet expect that any given parallel programming language will be available on a wide variety of machines [Pancake, 1993]. Indeed, the K&R C and Fortran 77 are the only languages widely available on multiprocessors. To overcome the sequential nature of these languages, vendors usually provide parallel programming primitives via user-callable libraries. Unfortunately, the vendor-provided libraries often differ substantially. In addition to providing differing mechanisms to create and synchronize processes; libraries often have different models of how the processes share and allocate memory within their address space.

Programmers can overcome the differences in vendor-supplied libraries by accessing parallel primitives through their own program-specific library and then implementing that library in terms of the vendor-supplied library. However, this approach requires that the program-specific library not only be implementable on all vendor-supplied libraries, but also provide a programming model that permits efficient use of all machines. For example, a program-specific library with a model of uniform memory access times (UMA) would not permit writing programs that execute efficiently on machines with non-uniform memory access times (NUMA). In essence, a program-specific library must represent the union of difficult features and the intersection of helpful features among all vendor-supplied libraries.

This paper describes a parallel programming library for the C programming language that enables programs to run effectively on a wide range of architectures. We developed this library in conjunction with of a program to solve the subgraph isomorphism problem in parallel. This program executes efficiently on three UMA shared-memory multiprocessors and four NUMA shared-memory multiprocessors. While developed for a single program, we believe this library has general applicability. The library supports an address space model that is consistent with all seven multiprocessors, a mechanism to create parallelism, and a set of synchronization primitives. Surprisingly, this library needs only two pages of implementation on each of the seven multiprocessors. However, the effect on the programming model is significant.

The remainder of this section describes the multiprocessors our library supports. Section 2 develops the virtual model underlying the library. Section 3 describes the interface to the model. Section 4 discusses programming with the library and its performance implications. Section 5 presents our conclusions. Finally, appendix A provides the complete implementation of the library for three multiprocessors.

1.1 Multiprocessors Supported

Our library has implementations for seven shared-memory multiprocessor systems covering a range of operating system, processor, and interconnect technologies. In addition, the library has two uniprocessor implementations, which we discuss no further.

The BBN Butterfly uses the Motorola 68000 processor, each with its own local memory. Each processor may access another's memory through an FFT switching network. The access times to local memory and another processor's memory are in the ratio 1:5. There is no memory cache. The

Butterfly runs the Chrysalis operating system [BBN, 1985a]. Rather than use Chrysalis directly, we use the vendor-supplied Uniform System library [BBN, 1985b].

The BBN TC2000 uses the Motorola 88100 processor, each with its own local memory. Each processor may access another's memory through an FFT switching network. The 8 KB processor data caches are used for private data, but are not used for shared data because they are not kept consistent. The TC2000 runs a variant of the Mach operating system. Again, we use the vendor-supplied Uniform System library. This library is the same in intent as the Butterfly library, but differs in detail.

The IBM 8CE uses the ROMPC processor (as found in the IBM RT). In addition to a global shared memory, each processor has its own local memory. Access to non-local memory is through a shared bus, and the access times to local, global and another processor's local memory are in the ratio 1:2:5. There is no memory cache. The 8CE has an experimental variant of the Mach operating system [Bolosky *et al.*, 1989] that hides the presence of local memories by dynamically placing shared pages in the global shared memory and placing unshared pages in local memories. We use the Mach Cthreads library.

The Kendal Square Research KSR1 uses a custom 64-bit processor. All memory in the system is managed as a set of caches, with each processor containing a 32 MB cache and a 512 KB subcache. Access times to the subcache, the local cache, and a remote cache are in the ratio 1:9:88. Cache block movement is through a high-speed ring network.[1] The KSR1 uses the OSF/1 operating system, a variant of Mach. We use the vendor-supplied POSIX Pthreads library [POSIX, 1993].

The Sequent Balance uses the National Semiconductor 32032 processor. There is a single global shared memory, accessed through a shared bus. Each processor has an 8KB write-through cache. The Balance runs a variant of BSD Unix. We use the vendor-supplied parallel programming library [Sequent, 1987].

The Sequent Symmetry uses the Intel 80386 processor. There is a single global shared memory, accessed through a shared bus. Each processor has an 64KB write-back cache. The Symmetry runs a variant of System V Unix. Again, we use the vendor-supplied parallel programming library.

The SGI Iris uses the MIPS R3000 processor. There is a single global memory accessed through a shared bus. Each processor has 64 KB primary cache and a 1 MB secondary cache, which is large enough that the Iris is most effectively programmed as though it had local memories. The Iris runs a variant of System V Unix. We use the vendor-supplied parallel programming library [SGI, 1991].

2 Virtual Machine Model

Vendor-supplied parallel programming libraries generally export a *virtual* machine model that is very close to the *physical* machine. To construct a common parallel programming library, we must first define a common virtual machine model. If programs written using the common library are to be efficient, the corresponding virtual machine model must have an efficient mapping to each of the physical machines.

[1] The KSR1 has a multi-level ring architecture, but all our work was done on a single ring.

2.1 Memory Organization

The multiprocessors in this study differ substantially in their memory model. The Balance and Symmetry provide a single, global memory. The Butterfly and TC2000 provide one local memory per processor, but provide remote memory access from one processor to another. The Iris and KSR1 provide a global memory, but their local caches are so large that they can only be programmed efficiently as though there were a local memory for each processor. The 8CE is somewhat unusual in that it provides both local memories (with remote access) and a global memory.

The common view of these disparate memory models is the more complex one — one global memory, one local memory per processor, and remote access to other processor's local memories. This NUMA virtual machine model is both more complex and more accurate than UMA virtual machine model, such as Presto's model [Bershad *et al.*, 1988]. This common virtual model can be mapped relatively efficiently to each of the hardware models. In the case of global-memory-only multiprocessors, the virtual local memories simply get mapped to a region of the physical global memory. In the case of multiple-local-memory-only multiprocessors, the virtual global memory gets mapped to some physical local memory. Because this latter mapping could introduce a point of contention, the model require a certain style of programming if programs are to be efficient. We address this issue in section 4.

With the exception of the TC2000, each multiprocessors provides a sequentially-consistent view of memory. In the case of the TC2000, the memory view can be kept consistent by not caching data from shared memory. Because all multiprocessors support a sequentially-consistent view of memory, and because this view is easer to program than an inconsistent view, the common library provides a sequentially-consistent view of memory.

2.2 Processor Organization

Each of the multiprocessors provides at least eight processors, and may provide many more. Rather than assume any specific number of processors, we assume there will at least one processor but potentially many processors. On initialization, the program indicates the number of processors it wishes.

The vendor-libraries generally provide continuously executing processes with busy waiting. To support this view, our virtual machine model provides no more than one operating system process per processor.

Several multiprocessors provide memories local to a given processor. In order to ensure locality, programmers must be able to co-locate processing and data. To support this, our library indexes virtual processors and their corresponding local memories by a number in the range 0 to $n - 1$. Furthermore, for those systems that provide local memories, the processes will not migrate among processors.

2.3 Address Space Organization

Each process has an address space that defines it's view of memory. The multiprocessors' different views of which portions of the address space are shared has a significant impact on the virtual machine model and its implementation.

Like most vendor-libraries, we limit our scope to single-program-multiple-data computing. Each multiprocessor places all code in identical regions of the address space of each process, so the common library also does this. A consequence is that processes may pass function pointers across process boundaries. The model replicates code to local memories if the multiprocessors have local memories.

The multiprocessors differ in whether or not C global variables shared among all processes (the 8CE, KSR1 and Iris) or are private to a single process (the Butterfly, TC2000, Balance and Sequent). The Balance and Sequent compilers provide a mechanism to share certain explicitly declared global variables, while the Butterfly and TC2000 provide a mechanism to replicate the value of global variables among the processors. Thus, the common view for C global variables is somewhat complicated — programmers cannot rely on global variables being private, programmers must explicitly declare variables that are shared, and programmers must explicitly replicate shared variables.

The vendor systems also differ in whether or not dynamically allocated (`malloc`ed) memory is shared. In the 8CE, KSR1 and Iris, `malloc`ed memory is shared, but each `malloc` yields a distinct region of memory. On the other hand, `malloc` on the Butterfly, TC2000, Balance and Sequent yields process-private memory. The common view is that `malloc`ed memory is distinct among processes, but may not be shared and may not be assumed private.

The systems that provide private `malloc` memory also provide a mechanism to dynamically allocate shared memory. The common library also provides such a mechanism. As discussed in section 2.1, programmers may allocate from specific local memories or from the global memory.

Because many multiprocessors manage memory in pages, programmers should not place both process-private and shared variables within the same region of memory. That is, programmers should allocate memory for process-private variable separately from that for shared variables.

2.4 Synchronization

Not all multiprocessors provide atomic reads and writes for C scalar variables, so the common virtual machine model does not assume such reads and writes are atomic. For higher-level synchronization, Some multiprocessors provide locks, and some provide test-and-set or fetch-and-add primitives. Because efficient synchronization is important to many programs, the common view must provide transparent access to hardware-based synchronization primitives. To this end, the common view must support the union of synchronization mechanisms. Our library provides atomic locks, atomic signals, and atomic counters. Our library does not provide barriers because our application did not neeed barriers.

3 Common Library Interface

This section describes the common library interface. We reserve discussions of programming and usage to section 4. The interface is built with a combination of C preprocessor macros, typedefs, global variables, and functions. All macros appear in upper case and start with "`SHML_`", while all variables, typedefs, and functions appear in lower case and start with "`shml_`". Programmers

should not pass arguments with side effects to macros because the implementation may evaluate the argument more than once.

3.1 Processes

The preprocessor symbol `SHML_MAX_PROCS` is a integer constant specifying the maximum number of processors that may appear on a given machine. This symbol may be used to size array variables.

The library is initialized by a call to `shml_initialize`, with the desired number of processors as a parameter. Programmers must call this function before any other library function, and may not call the function more than once.

```
void shml_initialize( int number_of_processors ) ;
```

The processes are forked with a call to `shml_fork`. This function accepts two parameters, the number of processors desired[2] and a function to execute on each processor. The parameter function receives an argument specifying the virtual processor on which it executes.

```
void shml_fork( int number_of_processors,
                void (*fork_body_function)( int processor_number ) ) ;
```

3.2 Memory and Address Space

The common library provides a `SHML_SHARED` storage class for all C global variables that are to be shared among processes. These variables must be explicitly replicated with the `SHML_REPLICATE` operation, which accepts a pointer to the global variable and the size of the variable. The `SHML_REPLICATE` operation may only be called after `shml_initialize` and before `shml_fork`, which means that programmers cannot modify shared C global variables once parallel execution has begun. Typical uses of shared global variables are to store pointers to modifiable shared memory, and to contain read-only data.

```
void SHML_REPLICATE( any *variable_ptr, int size_in_bytes ) ;
```

Programmers may dynamicly allocate shared memory on a specific local memory with a call to `SHML_PALLOC`, which accepts a virtual processor number on which to allocate the memory and a size to allocate in bytes. Programmers may dynamicly allocate global shared memory with a call to `SHML_GALLOC`, which accepts a size to allocate in bytes. Programmers may continue to use `malloc` to allocate semi-private memory on local processors, though programmers should not expect such memory to be protected from other processes.

[2]The specification of the number of processors in `shml_fork` is potentially redundant with that for `shml_initialize`, but it simplifies the implementation.

```
void *SHML_PALLOC( int processor_number, unsigned size_in_bytes ) ;
void *SHML_GALLOC( unsigned size_in_bytes ) ;
```

The SHML_COPY operation copies memory from a given source address to a given target address for a given number of bytes. This operation may be significantly faster than normal C memory copies on some machines. The SHML_ZERO operation zeros memory at a given address for a given number of bytes.

```
void SHML_COPY( any *source_address, any *target_address, int size_in_bytes ) ;
void SHML_ZERO( any *address, int size_in_bytes ) ;
```

3.3 Synchronization

The library provides three synchronization primitives, locks, signals, and counters.

The type shml_lock represents atomic lock variables. SHML_LOCK_INIT initializes a lock. SHML_LOCK_WAIT busy waits to acquire a lock. SHML_LOCK_VISIT attempts to acquire a lock and returns true if successful and false otherwise. SHML_LOCK_RELEASE releases a lock.

```
void SHML_LOCK_INIT( shml_lock *lock_ptr ) ;
void SHML_LOCK_WAIT( shml_lock *lock_ptr ) ;
int SHML_LOCK_VISIT( shml_lock *lock_ptr ) ;
void SHML_LOCK_RELEASE( shml_lock *lock_ptr ) ;
```

The type shml_signal represents atomic boolean variables. SHML_SIGNAL_CLEAR clears a signal. SHML_SIGNAL_SET sets a signal. SHML_SIGNAL_TEST returns true if a signal is set. SHML_SIGNAL_WAIT busy waits for a signal to become set. This abstraction has very efficient implementations on all machines, so should be used where possible in preference to locks.

```
void SHML_SIGNAL_CLEAR( shml_signal *signal_ptr ) ;
void SHML_SIGNAL_SET( shml_signal *signal_ptr ) ;
int SHML_SIGNAL_TEST( shml_signal *signal_ptr ) ;
void SHML_SIGNAL_WAIT( shml_signal *signal_ptr ) ;
```

The type shml_counter represents atomic unsigned counter variables. SHML_ADD atomicly adds the increment to the counter. SHML_FETCH_AND_ADD atomicly adds the increment to the counter and returns the value of the counter before the increment. In addition, programmers may atomicly read and write atomic counters as they would other unsigned variables.

```
void SHML_ADD( shml_counter *counter_ptr, int increment ) ;
unsigned short SHML_FETCH_AND_ADD( shml_counter *counter_ptr, int increment ) ;
```

3.4 Timing

Many parallel programs keep track of their execution time. The `shml_time_now` function returns a `double` representing the current time in seconds, relative to some unspecified base. On multiprocessors, the time is wall-clock time. On uniprocessors, the time may be either wall-clock time or CPU time. Because the value provided by `shml_time_now` has no particular base, programmers must compute elapsed time by subtracting values returned by two successive calls to `shml_time_now`.

```
double shml_time_now( ) ;
```

4 Programming and Performance

Our library's virtual machine model encourages programmers to adopt a few techniques if they are to obtain reasonable performance over a wide range of architectures. We discuss these techniques and then describe the program organization they encourage. We also provide an example building a convenient parallel for loop out of raw processes.

4.1 Distribution and Replication

The virtual machine model consists of both local and global memories, and on some multiprocessors access to non-local memory is significantly more expensive than access to local memory. In addition, the virtual global memory may be mapped to a local memory on some multiprocessors, which could be a source of excessive contention. Given the higher cost of non-local memory access and the potential contention of global memory, programmers should use local memory wherever possible. Not only will this approach yield better performance on NUMA multiprocessors, but may also yield better performance on UMA systems with large caches.

The first technique for using local memory is to distribute data so that processors have the portion of the data that they process within their local memory. Distributing data often requires an additional level of pointers in the implementation of data structures, which could reduce performance by requiring processors to chase an additional pointer when accessing the data. Figure 1 shows the effect of distribution on two multiprocessors: the TC2000 which is a local-memory-only NUMA multiprocessor, and the Balance which is a global-memory-only UMA multiprocessor. The figure shows that failing to distribute introduced a factor of four performance penalty on the NUMA multiprocessor. On the other hand, distributing introduced only a three percent performance penalty on the UMA multiprocessor up until the point where its shared memory bus became saturated. (The relatively poor speedup of this graph is due to the nature of the subgraph isomorphism problem, and not a consequence of the library.)

The second technique for using local memory is to replicate read-only data to the local memories. This technique should introduce little performance penalty, provided sufficient memory is available. If programmers use the library's `SHML_SHARED` and `SHML_REPLICATE` mechanisms, then the data will not actually be replicated on systems without physical local memory, but will reside in physical global memory, thus conserving memory space.

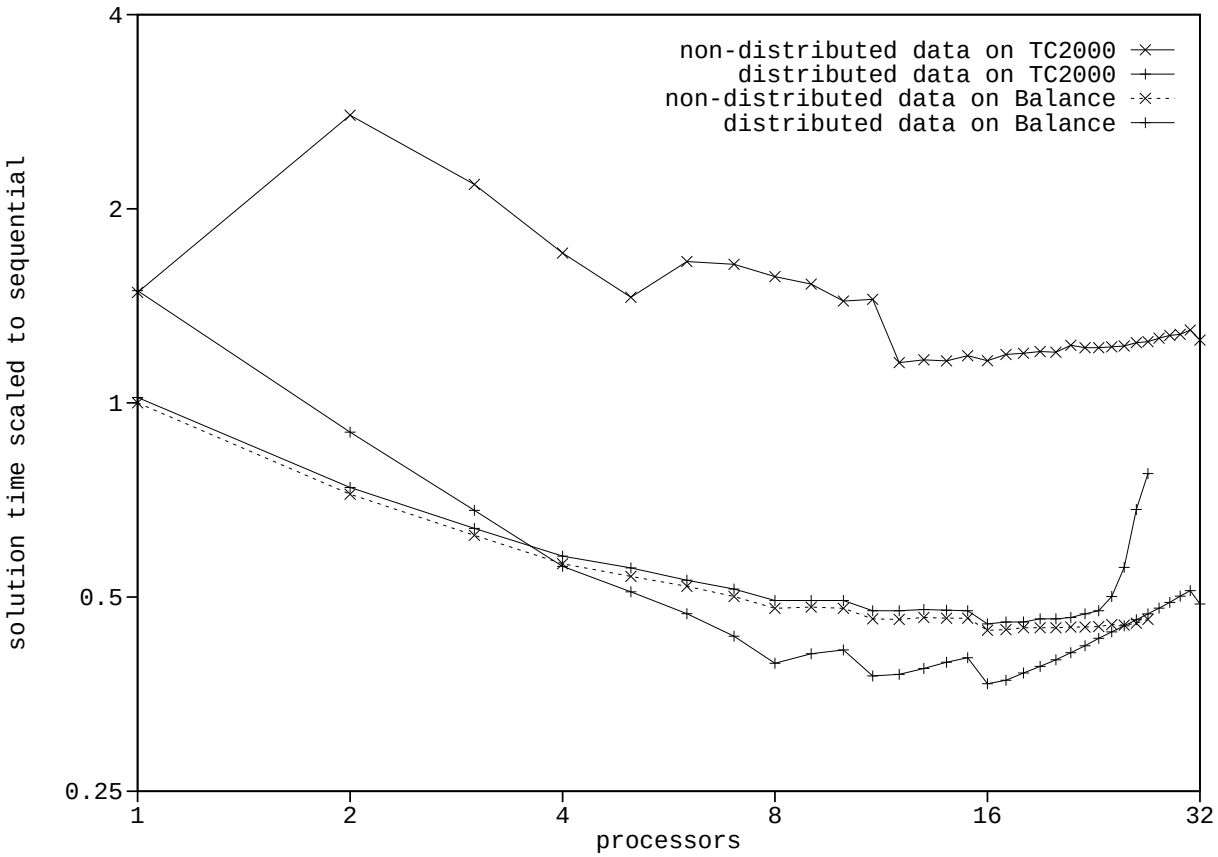

Figure 1: Effect of Distribution on Execution Time

The third technique is replicate read-write variables to local memories. This is possible for those variables for which there is a single writer and many readers. Each write to the original variable is replaced by a write to a copy on each processor. This technique is not applicable to atomic lock and counter variables, but can often be applied to atomic signal variables.

Because signal variables can be replicated, programmers should them in preference to locks or counters. Indeed, it may be better to rewrite synchronization using locks or counters into synchronization using signals. For example, many parallel programs maintain a counter of the number of processes that have completed initialization and are ready to begin execution. Processes then start when the counter reaches the expected value. Under our library, this counter would be placed in virtual global memory and may introduce a source of contention. Another approach, more appropriate to our model, is for each process to maintain its own signal indicating when it has completed initialization. Because each process has its own signal, there is only one writer, and signals may be replicated. To synchronize program initialization, each process writes all copies of its signal and then waits until all processes have set its copy of their signals.

Replicating signal variables has three effects on performance: it increases the cost of signals because of the multiple writes; it reduces the contention for signals because processes spin on their own copy; and it reduces the inter-processor communication because processes spin on local variables.

In summary, programmers should distribute or replicate data and synchronization where possible, and limit the use of virtual global memory to variables that cannot be replicated or distributed.

4.2 Program Organization

Our library encourages a program organization in which substantial work is devoted during initialization to setting up the shared memory regions.

The main program generally will follow the following sequence of events.

determine number of processors desired
call `shml_initialize` with the number of processors desired
allocate shared global memory with `SHML_GALLOC`
initialize both shared and unshared global variables
call `SHML_REPLICATE` on each shared global variable
fork processes with `shml_fork`

On starting up, each process will generally follow the following sequence of events.

allocate local private memory with `SHML_PALLOC`
allocate local shared memory with `SHML_PALLOC`
copy pointers to local memory into global memory
indicate process ready with `SHML_SIGNAL_SET` on a signal in global memory
wait for all other processes to signal ready
copy pointers to other processors' local memories into local memory

begin work

Alternatively, the main program may allocate the local memory for each process and set up the corresponding pointers before forking.

This organization is necessarily complex because it must handle a NUMA virtual machine model.

4.3 Programming Example — Forall

As an example of programming with our library, we outline how to implement a parallel for loop. This loop is implemented as a function which takes the loop bounds and a loop-body function as parameters. The implementation uses a master/slave process organization. The master executes the program's main and sequential code, and occasionally executes the `forall` function that requests parallel execution of a function. Each slave process executes a `forall_server` function that waits for work, executes it, and waits again. These functions synchronize through an 'idle' signal for each process. The master clears the idle signal when it has provided work; the slave waits for the signal to clear, does its work, and sets the signal when finished; and then the master waits until all processes have set their signal. The cycle may then repeat.

The outline of `forall` is:

```
divide loop iterations based on number of processors
for each other processor
    write loop sub-bounds, function pointer and parameters to processor
    clear other processor's idle with SHML_SIGNAL_CLEAR
do local iterations
for each other processor
    wait for idle with SHML_SIGNAL_WAIT
```

The outline of `forall_server` is

```
while program still running
    if still idle
        delay and repeat
    else
        read loop sub-bounds, function pointer and parameters
        execute loop iterations
        set idle with SHML_SIGNAL_SET
```

This example illustrates the concept of using distributed signals rather than single-point synchronization variables, and demonstrates that programmers can build more convenient programming abstractions than raw virtual processors in a machine-independent manner.

5 Conclusions

The library has efficient implementations on all seven multiprocessors, and programs can be written that are reasonably efficient on each multiprocessor, provide programmers adopt the virtual machine model and programming techniques outlined in this paper. However, optimal execution on each multiprocessor may require structural changes to the program which are beyond the scope of a library. For a discussion of these issues, see [Crowl *et al.*, 1992].

Our library is portable and reasonably efficient, but not particularly convenient. The need to explicitly manage replication and distribution places a significant burden on the programmer. This burden is not unique to our library, but is common to most NUMA multiprocessors. A more specific problem with our library is that programmers cannot rely on process-private global variables, and hence must pass pointers to the process-local memory regions as parameters to all functions that may access process-local variables by name. Given that the NUMA architecture is likely to persist in future multiprocessors, programming systems should provide convenient mechanisms to manage processor-local data. Our library can serve as a short-term solution for some programmers, but certainly will not substitute for current parallel programming standards efforts [Pancake, 1992].

Our experience developing our application and this library was a little difficult for the first three multiprocessors (the Butterfly, the Balance, and the Iris) because each new port highlighted additional incorrect assumptions embedded in the original application. Subsequent ports to the final four multiprocessors were relatively easy, with locating documentation as the most difficult task. The extremely short two-page implementations for this library make it easy for programmers to include the library directly within their programs and to implement the library for additional multiprocessors.

While parallel programming standards are still not widely accepted, programmers are not helpless in the face of diverse programming environments for shared-memory multiprocessors. We have described a shared-memory parallel programming library, its virtual machine model, and a set of techniques for programming with the library that enable programmers to write programs that execute effectively on seven different shared-memory multiprocessors.

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A Common Library Implementation

The library has implementations for the BBN Butterfly One and the Uniform System, the BBN Butterfly One as a uniprocessor, the BBN Butterfly TC2000 and the Uniform System, the IBM 8CE and Mach Cthreads, the Kendall Square Research One and POSIX Pthreads, the Sequent Balance and Sequent Parallel Programming Library, the Sequent Symmetry and SGI Parallel Programming Library, and a generic uniprocessor Unix. We provide the implementations for the Butterfly, 8CE, and Symmetry. the other multiprocessor implementations differ in detail, but similar to these three.

A.1 BBN Butterfly One and the Uniform System

```
#include <us.h>
#include <usgen.h>
#include <stdio.h>

#define SHML_SHARED
#define SHML_REPLICATE( variable_ptr, size ) \
    ShareBlk( (int *)(variable_ptr), (size) )

extern char *AllocateOnUsProc( /* int node, unsigned size */ ) ;
#define SHML_PALLOC( procr_num, size ) (AllocateOnUsProc( (procr_num), (size) ))
#define SHML_GALLOC( size ) (AllocateOnUsProc( 0, (size) ))

extern char *memcpy( /* char *target_addr, char *source_addr, int size */ ) ;
#define SHML_COPY( source_addr, target_addr, size ) \
    ((void)block_copy( (char *)(source_addr), (char *)(target_addr), (size) ))

#define SHML_ZERO( addr, size ) bzero( (char *)(addr), (size) )

void shml_delay( count )
    int count ;
    {
    while ( count-- > 0 ) ;
    }

typedef volatile short shml_signal ;
#define SHML_SIGNAL_CLEAR( signal_ptr ) (*(signal_ptr) = 0)
#define SHML_SIGNAL_SET( signal_ptr ) (*(signal_ptr) = 1)
#define SHML_SIGNAL_TEST( signal_ptr ) (*(signal_ptr))
#define SHML_SIGNAL_WAIT( signal_ptr ) (shml_signal_wait( signal_ptr ))

shml_signal_wait( signal_ptr )
    shml_signal *signal_ptr ;
    {
    while ( !SHML_SIGNAL_TEST( signal_ptr ) ) shml_delay( 10 ) ;
    }

typedef volatile short shml_lock ;
#define SHML_LOCK_INIT( lock_ptr ) (*(lock_ptr) = 0)
#define SHML_LOCK_WAIT( lock_ptr ) (shml_lock_wait( lock_ptr ))
#define SHML_LOCK_VISIT( lock_ptr ) (Atomic_ior( (lock_ptr), 1 ))
#define SHML_LOCK_RELEASE( lock_ptr ) (*(lock_ptr) = 0)
```

```
shml_lock_wait( lock_ptr )
    shml_signal *lock_ptr ;
    {
    while ( !SHML_SIGNAL_TEST( lock_ptr ) ) shml_delay( 10 ) ;
    }

typedef volatile unsigned short shml_counter ;
#define SHML_ADD( cntr_ptr, incr ) (Atomic_add( cntr_ptr, incr ))
#define SHML_FETCH_AND_ADD( cntr_ptr, incr ) (Atomic_add( cntr_ptr, incr ))

double shml_time_now( )
    {
    return (unsigned)GetRtc( ) / 16000.0 ;
    }

#define SHML_MAX_PROCS 128

void shml_initialize( num_procrs )
    int num_procrs ;
    {
    static int spec[ ] = { configProcs, 1, configSuppressInitMsgs, 1 } ;
    spec[ 1 ] = num_procrs ;
    ConfigureUs( spec, 2 ) ;
    InitializeUsForBenchMark( ) ;
    }

/*ARGSUSED*/
void shml_fork_helper( fork_body, dummy_index )
    void (*fork_body)( ) ;
    int dummy_index ;
    {
    fork_body( PhysProcToUsProc( pnn ) ) ;
    }

void shml_fork( num_procrs, fork_body )
    int num_procrs ;
    void (*fork_body)( ) ;
    {
    GenOnIndex( (int (*)())0, shml_fork_helper, fork_body, num_procrs ) ;
    }
```

A.2 IBM 8CE and Mach Cthreads

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/time.h>
#include <sys/times.h>
#include <mach.h>
#include <cthreads.h>

#define SHML_SHARED
#define SHML_REPLICATE( variable_ptr, size )

#define SHML_PALLOC( procr_num, size ) (shml_allocate( size ))
#define SHML_GALLOC( size ) (shml_allocate( size ))

char *shml_allocate( size )
    unsigned size ;
    {
    char *allocated ;
    vm_allocate( task_self( ), &allocated, size, TRUE ) ;
    return allocated ;
    }

extern char *memcpy( /* char *target_addr, char *source_addr, int size */ ) ;
#define SHML_COPY( source_addr, target_addr, size ) \
    ((void)memcpy( (char *)(target_addr), (char *)(source_addr), (size) ))

#define SHML_ZERO( addr, size ) bzero( (char *)(addr), (size) )

void shml_delay( count )
    int count ;
    {
    while ( count-- > 0 ) ;
    }

typedef volatile short shml_signal ;
#define SHML_SIGNAL_CLEAR( signal_ptr ) (*(signal_ptr) = FALSE)
#define SHML_SIGNAL_SET( signal_ptr ) (*(signal_ptr) = TRUE)
#define SHML_SIGNAL_TEST( signal_ptr ) (*(signal_ptr))
#define SHML_SIGNAL_WAIT( signal_ptr ) (shml_signal_wait( signal_ptr ))

shml_signal_wait( signal_ptr )
    shml_signal *signal_ptr ;
    {
    while ( !SHML_SIGNAL_TEST( signal_ptr ) ) shml_delay( 10 ) ;
    }

typedef volatile struct mutex shml_lock ;
#define SHML_LOCK_INIT( lock_ptr ) (mutex_init( lock_ptr ))
#define SHML_LOCK_WAIT( lock_ptr ) (mutex_lock( lock_ptr ))
#define SHML_LOCK_VISIT( lock_ptr ) (mutex_try( lock_ptr ))
#define SHML_LOCK_RELEASE( lock_ptr ) (mutex_unlock( lock_ptr ))
```

```
shml_lock shml_counter_lock ;
typedef volatile unsigned short shml_counter ;
#define SHML_ADD( cntr_ptr, increment ) \
    (mutex_lock( &shml_counter_lock ) \
     , *(cntr_ptr) += incr \
     , mutex_unlock( &shml_counter_lock ))
#define SHML_FETCH_AND_ADD( cntr_ptr, incr ) \
    (shml_fetch_and_add( cntr_ptr, incr ))

unsigned short shml_fetch_and_add( cntr_ptr, incr )
    shml_counter *cntr_ptr ;
    int incr ;
    {
    unsigned short old_value ;
    mutex_lock( &shml_counter_lock ) ;
    old_value = (*cntr_ptr += incr) - incr ;
    mutex_unlock( &shml_counter_lock ) ;
    return old_value ;
    }

double shml_time_now( )
    {
    struct timeval tv ;
    (void)gettimeofday( &tv, (struct timezone *)0 ) ;
    return tv.tv_sec + tv.tv_usec / 1000000.0 ;
    }

#define SHML_MAX_PROCS 8

/*ARGSUSED*/
void shml_initialize( num_procrs )
    int num_procrs ;
    {
    mutex_init( &shml_counter_lock ) ;
    }

void shml_fork( num_procrs, fork_body )
    int num_procrs ;
    void (*fork_body)() ;
    {
    int procr ;
    for ( procr = 1 ;  procr < num_procrs ;  procr++ )
        cthread_detach( cthread_fork( fork_body, procr ) ) ;
    fork_body( 0 ) ;
    }
```

A.3 Sequent Symmetry Parallel Library

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/time.h>
#include <sys/times.h>
#include <parallel/parallel.h>

extern void exit( ) ;

#define SHML_SHARED shared
#define SHML_REPLICATE( variable_ptr, size )

#define SHML_PALLOC( procr_num, size ) (shmalloc( size ))
#define SHML_GALLOC( size ) (shmalloc( size ))

extern char *memcpy( /* void *target_addr, void *source_addr, int size */ ) ;
#define SHML_COPY( source_addr, target_addr, size ) \
    ((void)memcpy( (void *)(target_addr), (void *)(source_addr), (size) ))

#define SHML_ZERO( addr, size ) shml_zero( (char *)(addr), (size) )

void shml_zero( addr, size )
    char *addr ;
    int  size ;
    {
    while ( size-- > 0 ) *addr++ = '\0' ;
    }

void shml_delay( count )
    int count ;
    {
    while ( count-- > 0 ) ;
    }

typedef volatile short shml_signal ;
#define SHML_SIGNAL_CLEAR( signal_ptr ) (*(signal_ptr) = FALSE)
#define SHML_SIGNAL_SET( signal_ptr ) (*(signal_ptr) = TRUE)
#define SHML_SIGNAL_TEST( signal_ptr ) (*(signal_ptr))
#define SHML_SIGNAL_WAIT( signal_ptr ) (shml_signal_wait( signal_ptr ))

shml_signal_wait( signal_ptr )
    shml_signal *signal_ptr ;
    {
    while ( !SHML_SIGNAL_TEST( signal_ptr ) ) shml_delay( 10 ) ;
    }

typedef volatile slock_t shml_lock ;
#define SHML_LOCK_INIT( lock_ptr ) (s_init_lock( lock_ptr ))
#define SHML_LOCK_WAIT( lock_ptr ) (s_lock( lock_ptr ))
#define SHML_LOCK_VISIT( lock_ptr ) (s_clock( lock_ptr ))
#define SHML_LOCK_RELEASE( lock_ptr ) (s_unlock( lock_ptr ))
```

```
typedef volatile unsigned short shml_counter ;
#define SHML_ADD( cntr_ptr, incr ) \
    ((void)m_lock( ) , *(cntr_ptr) += (incr) , (void)m_unlock( ))
#define SHML_FETCH_AND_ADD( cntr_ptr, incr ) \
    (shml_fetch_and_add( (cntr_ptr), (incr) ))

unsigned short shml_fetch_and_add( cntr_ptr, incr )
    shml_counter *cntr_ptr ;
    int incr ;
    {
    unsigned short old_value ;
    (void)m_lock( ) ;
    old_value = (*cntr_ptr += incr) - incr ;
    (void)m_unlock( ) ;
    return old_value ;
    }

double shml_time_now( )
    {
    struct timeval tv ;
    (void)gettimeofday( &tv, (struct timezone *)0 ) ;
    return tv.tv_sec + tv.tv_usec / 1000000.0 ;
    }

#define SHML_MAX_PROCS 32

/*ARGSUSED*/
void shml_initialize( num_procrs )
    int num_procrs ;
    {
    }

void shml_fork_helper( fork_body )
    void (*fork_body)( ) ;
    {
    fork_body( m_get_myid( ) ) ;
    }

void shml_fork( num_procrs, fork_body )
    int num_procrs ;
    void (*fork_body)( ) ;
    {
    if ( -1 == m_set_procs( num_procrs ) )
        {
        (void)fprintf( stderr, "m_set_procs( %d ) failed\n", num_procrs ) ;
        exit( -1 ) ;
        }

    (void)m_fork( shml_fork_helper, fork_body ) ;
    }
```