Privatization Techniques for Process Virtualization: AMPI (+ PiP)

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Background

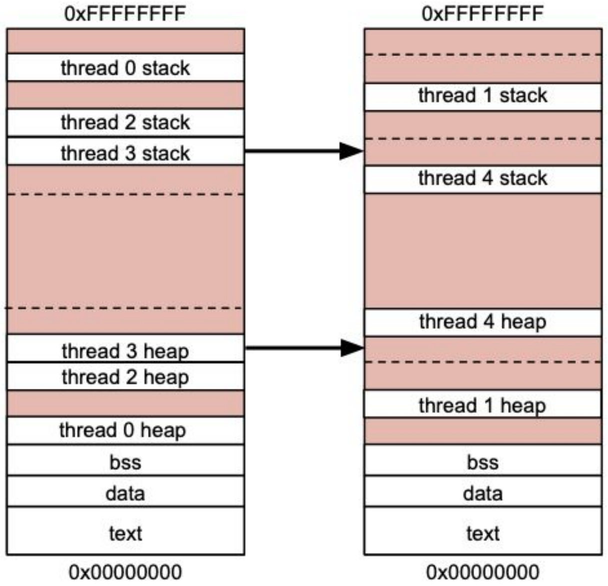
- AMPI virtualizes the ranks of MPI_COMM_WORLD
  - AMPI ranks are user-level threads (ULTs), not OS processes
  - Benefits:
    - Overdecomposition: run with more ranks than cores
    - Asynchrony: overlap one rank’s communication with another rank’s computation
    - Migratability: ULTs are migratable at runtime across address spaces
      - Enables dynamic load balancing and fault tolerance

AMPI Benefits

- Communication Optimizations
  - Overlap of computation and communication
  - Communication locality of virtual ranks in shared address space
- Dynamic Load Balancing
  - Many strategies available, balance by migrating AMPI virtual ranks
  - Isomalloc memory allocator serializes all of a rank’s state
- Fault Tolerance
  - Can restart online, within the same job

Migratability

- Isomalloc memory allocator *reserves* a globally unique slice of the virtual memory address space in each process for each virtual rank
- Benefit: no application-specific serialization code
    - Handles the user-level thread stack and all user heap allocations
    - Works everywhere except BGQ and Windows
    - Enables dynamic load balancing and fault tolerance
- Hurdle: Address-Space Layout Randomization
    - Can synchronize at startup and determine the lowest address space common among all processes



Privatization

Illustration of unsafe global/static variable accesses:

```c
int rank_global;

void func(void)
{
  MPI_Comm_rank(MPI_COMM_WORLD, &rank_global);

  MPI_Barrier(MPI_COMM_WORLD);

  printf("rank: %d\n", rank_global);
}
```

Privatization Goals

- Fully automatic privatization, or at least semi-automated
- Portable across OSes, compilers
- User-level: no changes to OS, compiler, or system libraries preferably
- Handling of both global and static variables
- Support for static and dynamic linking
- Ability to share read-only state across virtual ranks
- Support for runtime migration of virtual processes (achieved with Isomalloc)

Privatization Methods

- Existing Methods
  - Manual refactoring
    - Developer encapsulates mutable global state
    - Can take days/weeks of developer effort
  - Refactoring tools (Photran)
  - GOT (global offset table) swapping (Swapglobals)
    - Doesn’t handle statics, requires ELF and a patched linker
  - Thread-local storage segment pointer swapping (TLSglobals)
    - Only works with GCC and new Clang
    - Need to tag variable declarations (but not accesses)

Privatization Methods

- In-Development Methods
  - Process-in-Process (PiPglobals): user-level library by Atsushi Hori (RIKEN R-CCS)
  - File-system Globals (FSglobals)
  - Clang/Libtooling-based source-to-source transformation
- Proposed Methods
  - MPC (Multi-Processor Computing) `-fmpc-privatize`: requires compiler and linker support
  - ROSE tool for source-to-source transformation

AMPI + PiP: Implementation Details

1. Compile MPI user binary as PIE (Position Independent Executable)
2. For each rank's binary, call *dlmopen* with a unique namespace index (`lmid`)
    - `void *dlmopen (Lmid_t lmid, const char *filename, int flags);`
3. Use *dlsym* to look up and call the entry point for each rank
4. Global variables will be privatized with no modification to user program code
    - PIE binaries locate .data immediately following .text in memory
    - PIE global variables are accessed relative to the instruction pointer
    - *dlmopen* creates a separate copy of the binary in memory for each namespace

AMPI + PiP

Implementation Hurdles:

- *dlmopen* fails after 11 virtual ranks per process due to glibc limits
    - Requires patched glibc: PiP-glibc
- Runtime migration of virtual processes is difficult
    - Will require patched ld-linux.so to intercept mmap allocations of .data (and .text) segments
    - Allocations would be redirected through Isomalloc

AMPI + Filesystem Globals

Similar to PiPglobals, but <u>copies PIE binary on filesystem per-rank</u>, then *dlopen*

- \+ Does not depend on GNU/Linux-specific *dlmopen* extension
- \+ Does not have 11-rank per-process limit in the absence of patched glibc
- \+ Like PiPglobals, requires no modification of user program code
- − Wasteful, slow use of filesystem at startup
- − Same migration limitation as PiPglobals

Conclusion

- AMPI is valuable for a growing set of applications, though privatization remains a challenge for legacy MPI codes
    - Clang refactoring tool and PiPglobals are promising
    - Hurdle: migration support for AMPI + PiP

- Questions for you:
    - Use cases for process virtualization or for privatization?
    - Any JLESC applications interested in AMPI?
    - Ideas for other privatization techniques?

Questions?

AMPI + PiP Details

Implementation Hurdles:

- Cannot simply compile AMPI programs as PIE and call *dlmopen*
    - Depending on approach, would either
        - Privatize entire Charm++/AMPI runtime system
            - Runtime would not function
            - Waste of memory
        - Prevent *dlmopen*'ed binary from seeing launcher's AMPI symbols
    - Instead, restructure headers and link with a function pointer shim
    - Only user program needs to be PIE

ampi_functions.h:

```
AMPI_FUNC (int, MPI_Send, const void *msg, int count,
          MPI_Datatype type , int dest, int tag, MPI_Comm comm)
```

mpi.h:

```
#ifdef AMPI_USE_FUNCPTR
  #define AMPI_FUNC(return_type, function_name, ...) \
    extern return_type (* function_name)(__VA_ARGS__);
#else
  #define AMPI_FUNC(return_type, function_name, ...) \
    extern return_type function_name(__VA_ARGS__);
#endif
#include "ampi_functions.h"
```

ampi_funcptr.h:

```
struct AMPI_FuncPtr_Transport {
  #define AMPI_FUNC(return_type, function_name, ...) \
    return_type (* function_name)(__VA_ARGS__);
  #include "ampi_functions.h"
};
```

ampi_funcptr_loader.C (linked with AMPI runtime):

```
void AMPI_FuncPtr_Pack(struct AMPI_FuncPtr_Transport * x) {
  #define AMPI_FUNC(return_type, function_name, ...) \
    x->function_name = function_name;
  #include "ampi_functions.h"
}
```

ampi_funcptr_shim.C (linked with MPI user program):

```
void AMPI_FuncPtr_Unpack(struct AMPI_FuncPtr_Transport * x) {
  #define AMPI_FUNC(return_type, function_name, ...) \
    function_name = x->function_name;
  #include "ampi_functions.h"
}
```