A Scalable Framework for Offline Parallel Debugging

Karl Lindekugel, Anthony DiGirolamo, and Dan Stanzione
{klindeku, anthony.d, dstanzi}@asu.edu

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Arizona State University

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{klindeku, anthony.d, dstanzi}@asu.edu

High Performance Computing systems continue to grow in size and complexity

- The recent advent of multi- and many- core chips has only accelerated this trend
- Large scale applications require 10,000-100,000s of threads to achieve maximum performance

Debugging technology has remained fairly constant

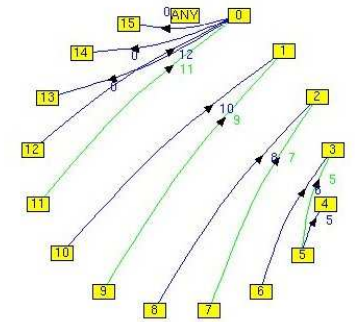
- Most effort is still focused on interactive debugging schemes
- It is not clear that large scale interactive debugging is compatible with the way large systems are operated

In this talk we will look at how debugging parallel applications in an offline manner solves these issues.

{klindeku, anthony.d, dstanzi}@asu.edu

Large Scale Debugging

- The volume of data generated by debugging and monitoring tools requires an efficient infrastructure for collection and organization.
- Visual representation of data may be untenable for applications and systems executing at very large scales.



Correctness and Performance Debugging

- Applications can be faulty without producing an error. Performance can be degraded by:
  - Calculation mistakes
  - Large amount of I/O
  - Poor communication patterns
- Inefficiency wastes expensive computational cycles
- Finding errors of this kind can be very difficult
- **Future debugging systems must combine application performance and correctness data, including data across multiple runs, to find application efficiency errors.**

{klindeku, anthony.d, dstanzi}@asu.edu

Reliability

- As systems grow, hardware failures occur more often
- As applications utilize more cores, hardware failures may be a part of many jobs.
- It will not be immediately clear if errors are software or hardware related
- **Future debugging systems must be able to monitor system performance across jobs in order to detect hardware related errors.**

{klindeku, anthony.d, dstanzi}@asu.edu

Production Environments

- Most sites use batch systems in order to maintain high utilization
- Interactive debugging complicates batch operation
- Sites often limit the scale at which interactive debuggers can run
- **Future debugging systems must be able to operate properly inside of existing batch queuing systems so they may run at the largest scales.**

Challenges

To summarize, future debugging systems must be able to:

- Operate within batch queue systems
- Detect hardware related errors
- Combine performance and correctness debugging information across multiple runs
- Provide different methods of presenting information
- Scale to next generation systems

GDBase

In response to these challenges we have built GDBase, a framework for offline parallel debugging.

GDBase Provides

- scalable offline debugging
- the functionality of GDB
- operation within batch queuing systems

GDBase Functionality

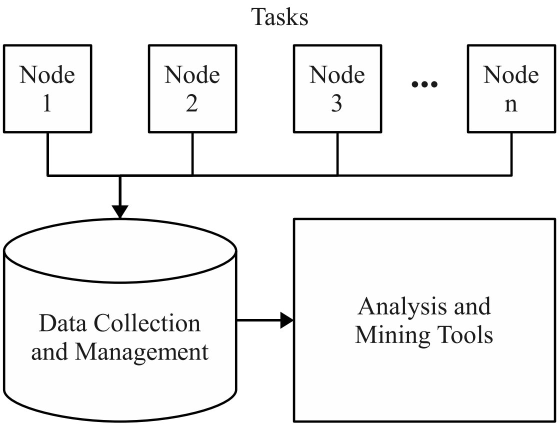
- GDBase gathers runtime information from a GDB instance
- Collects this information to a distributed event database
- Provides a mechanism for analysis of this data

Workflow

1. **Specify debugger behavior**
   - Multiple interfaces are available to users (or agents) for controlling debugger behavior
2. **Run your application under debugger control**
   - Debugging messages are collected local to each task or to shared storage
3. **Collect debugging messages**
   - After execution, events from debugging tasks are moved to a central location for analysis
4. **Use analysis agents on collected information**
   - Agents provide a simple way for users to detect common problems

{klindeku, anthony.d, dstanzi}@asu.edu

Design



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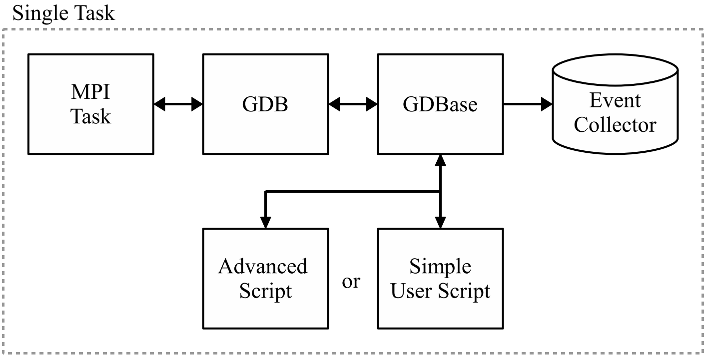
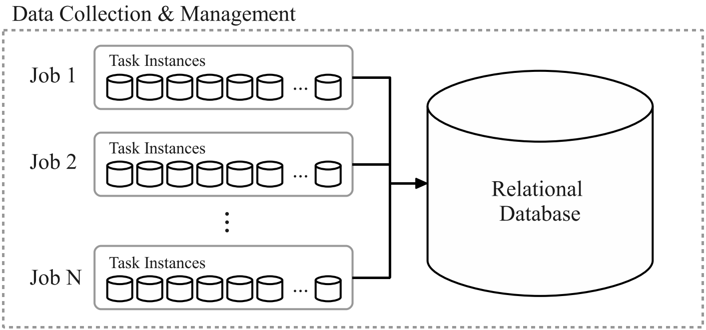
Runtime



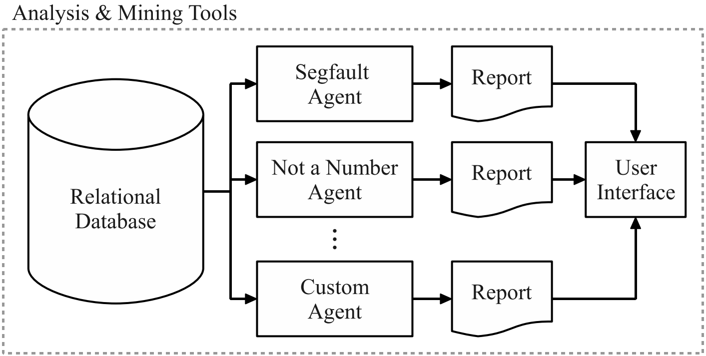
- MPI Application is launched under GDB control
- Events are logged to a local disk or shared storage
- Behavior may be controlled via interfaces

Data Collection



- Events from multiple jobs collected and stored in a relational database
- Analysis tools can compare data between runs

Offline Analysis



- Each analysis agent is designed to search for a specific type of error
- A few example agents are provided

Interface

Debugging Specification

- Multiple interfaces are available: simple and advanced
- Debugging specification files allow setting of breakpoints, watchpoints and variable logging
- Aids users in the transition from interactive to offline

```
@bp functionName
variable1
variable2

@bp myapp.c:231
variable3

@watch myapp.c:10 variable4
```

{klindeku, anthony.d, dstanzi}@asu.edu

Interface

Advanced Scripting

- If you need more control, use a debugging script
- Debugging scripts are written in TCL
- Provides fine grained control over GDB
- Intended for agent development

```
proc user_setup {} {
  gdb_setBreakpoint "main" "myMethod"
  db_logMessage "user.break" [gdb_lastOutput]
}
```

- Messages are stored in the database as a key-value pair using the db_logMessage command.

Interface

Advanced Scripting

```
proc myMethod {} {
  gdb_getStackFrames
  db_logMessage "stack" [gdb_lastOutput]

  gdb_listLocals
  db_logMessage "locals" [gdb_lastOutput]

  set \$result [gdb_evalExpr "var % 2"]
  if { \$result == "1" } {
    db_logMessage "var" "even"
  }

  gdb_continue
}
```

{klindeku, anthony.d, dstanzi}@asu.edu

Agents

Agents mine the collected event data to find and locate faults or problems in code. It's a simple way for users to detect common problems in their parallel applications. Agents can produce reports text or graphical.

Sample Agents Constructed

- Segmentation Fault
- Deadlock
- AllgatherV

Segmentation Fault Agent

Segmentation Fault Agent detects a Segmentation Fault in the event database and produces a report of:

- Task Affected
- Code Location
- Current Stack
- Local Variables

Job Exection

```
baseexec ./myprogram
```

Segmentation Fault Agent

Output

```
PBS JOBID: 198325.moab.local
DatabaseID: 206
        elapsed:        00:00:51
        ncpus:          64
        Messages:       964
Detector Results:
Job crashed on rank: 16
At:     main    in      fdtd.c:385
With stack:
0       main    in      fdtd.c:385
With locals:
int *   p       =       (int *) 0x4
int     i       =       132
int     t       =       4250209
int     n       =       68
```

{klindeku, anthony.d, dstanzi}@asu.edu

Deadlock Agent

The Deadlock Agent identifies tasks involved in a communication pattern that cannot continue. The tasks are then organized according to number of dependencies. A report is produced containing:

- Outstanding communications
- Location in code for each task
- Stack for each Task

This Agent was motivated by user problems in an asynchronously communicating code. A race condition existed causing the program to randomly deadlock during execution.

{klindeku, anthony.d, dstanzi}@asu.edu

Deadlock Agent Usage

Job Exection

```
baseexec --agent deadlock -t 600 ./myprogram
```

- Deadlock catches each Send and Recv from an application and logs their parameters, start, and end to the database.
- The -t option tells the program to time out if it has not received an event from the program in x seconds.

Deadlock Agent Usage

Analysis

```
gdbase --agent deadlock --jobid 1234.moab
```

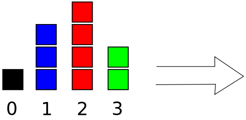
Example Output

```
Incomplete Communication
Send : 12 ---> 13
Send : 11 ---> 12
Send : 10 ---> 11
Send : 9 ---> 10
Send : 8 ---> 9
Final Stack for Rank 13
Stack:
Level   Function                 File:Line
  11    main              in    deadtest.c:37
  10    PMPI_Barrier      in    pbarrier.c:52
```

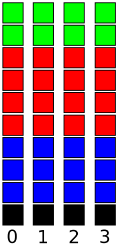
{klindeku, anthony.d, dstanzi}@asu.edu

AllgatherV Agent

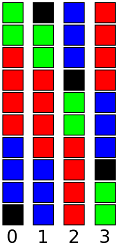
An AllgatherV collects variable amounts of data from each task and puts the resulting array on every task.



AllgatherV takes data of varied length from each task and distributes it to all tasks.



AllgatherV can also alter the order of data based on task.



The AllgatherV Agent analyzes each AllgatherV call across tasks to:

- Identify improper item counts
- Identify improper offset values

The Agent then produces a report with the affected Task, Location in Code, etc.

AllgatherV Agent Usage

Job Execution

```
baseexec --agent allgatherv ./myapp myargs
```

Analysis

```
gdbase --agent allgatherv --jobid 1234.moab
```

Example output

```
Error at element 4 in Recvcount array on
task 7 was 64 but should be 63
Stack:
Depth   Function            Location
0   main                in  mpi-nbody-allg.c:270
1   PMPI_Allgatherv     in  pallgatherv.c:39
```

{klindeku, anthony.d, dstanzi}@asu.edu

Agent Development

- Python API for accessing database (anything that can query a SQL database will work)
- Provides an abstraction for reading messages
- Provides helper methods for parsing gdb output

```
from gdbase import *

##connect to database
db = GDBase()
db.connect()

## obtains job id to read from environment
J = db.getJob()

## Look for messages starting with 'opd.SEGFAULT'
M = J.getMessages()
M.setKey('opd.SEGFAULT')
```

Results

GDBase

- Can launch with mpiexec or mpirun
- Tested with the Torque batch queue system
- Tested with OpenMPI and MVAPICH

Impact of GDBase on Application Run Time with -g

Execution Type	*Time (s)*	*Percent Extra*
No GDBase	39.00	-
Segfault Only	40.04	2.67%
Ten breakpoints	40.65	4.23%
40 breakpoints	45.50	16.66%

User Experience

GDBase was used to find several bugs in a user Finite Difference Time Domain (FDTD) code using the Segmentation Fault Agent and its generated report. Three bugs were found:

- Swapped loop indexes on nested loops
- Incorrect ghost row boundries on another loop
- Incorrect initialization on another loop

Each of these bugs caused the application to crash at sizes about 1024 tasks.

Test Environment

Clusters

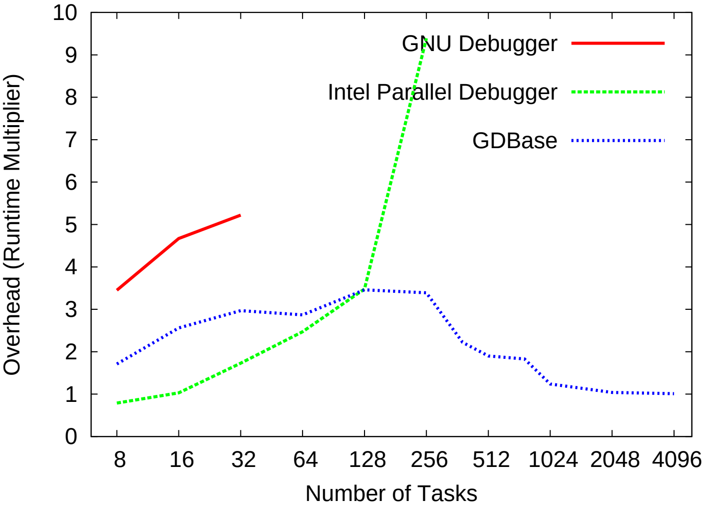
- Saguaro — ASU, 240 Dual socket, Quad Core Linux computers with Infiniband interconnect. Used for runs up to 1024 tasks.
- Ranger — TACC, 3,963 Quad socket, Quad Core Linux computers with Infiniband interconnect. Used for runs up to 4096 tasks.

Debuggers

- Gnu Debugger (GDB) — Freely available, launches a debugger instance for each task.
- Intel Debugger (IDB) — Commercial Product, uses a tree to manage communication with each task.

Segmentation Fault

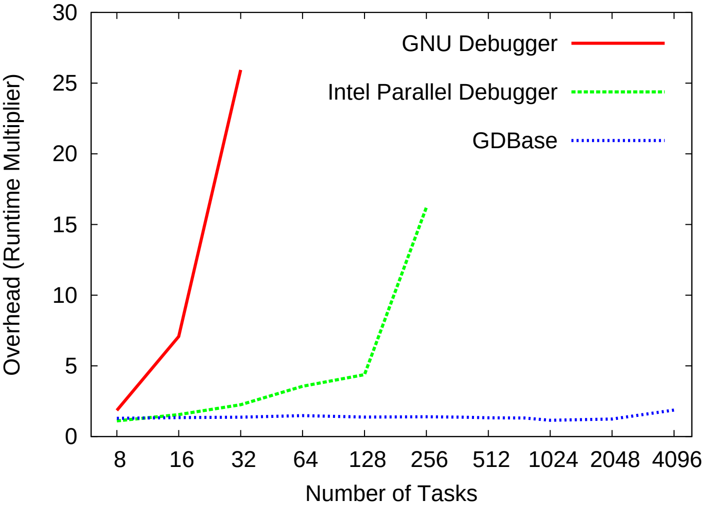
Segfault predictably after 89 iterations



{klindeku, anthony.d, dstanzi}@asu.edu

Break & Collect

Breakpoint set on each iteration, 10 iterations



Future Work

Continued development of the GDBase will focus on:

- Test scalability at 50,000 tasks
- Comprehensive user interface (web or graphical)
- Enhancing the facilities provided through the interfaces
- Developing additional analysis agents, including ones that compare data between runs
- Adding support for other tools besides GDB, such as performance and profiling tools (Tau, DPCL)

{klindeku, anthony.d, dstanzi}@asu.edu

Conclusions

- Offline debugging shows a lot of promise
- More scalable than interactive debugging
- The framework may provide a viable alternative for debugging at the petascale level

{klindeku, anthony.d, dstanzi}@asu.edu

Thank you!