Cray Debugging Support Tools

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Debugging on Cray Systems

- **Systems with thousands of threads of execution need a new debugging paradigm**
- **Cray's focus is to build tools around traditional debuggers with innovative techniques for productivity and scalability**
  - Support for traditional debugging mechanism
    - RogueWave TotalView and Allinea DDT
  - Scalable Solutions based on MRNet from University of Wisconsin
    - **STAT - Stack Trace Analysis Tool**
      - Scalable generation of a single, merged, stack backtrace tree
    - **ATP - Abnormal Termination Processing**
      - Scalable analysis of a sick application, delivering a STAT tree and a minimal, comprehensive, core file set.
  - lgdb 2.0
    - Ability to see data from multiple processors in the same instance of lgdb
      - without the need for multiple windows
    - **Comparative debugging**
      - A **data-centric paradigm** instead of the traditional control-centric paradigm
      - Collaboration with Monash University and University of Wisconsin for scalability
  - Fast Track Debugging
    - Debugging optimized applications
    - Added to Allinea's DDT 2.6 (June 2010)

MRNet - Multicast Reduction Network

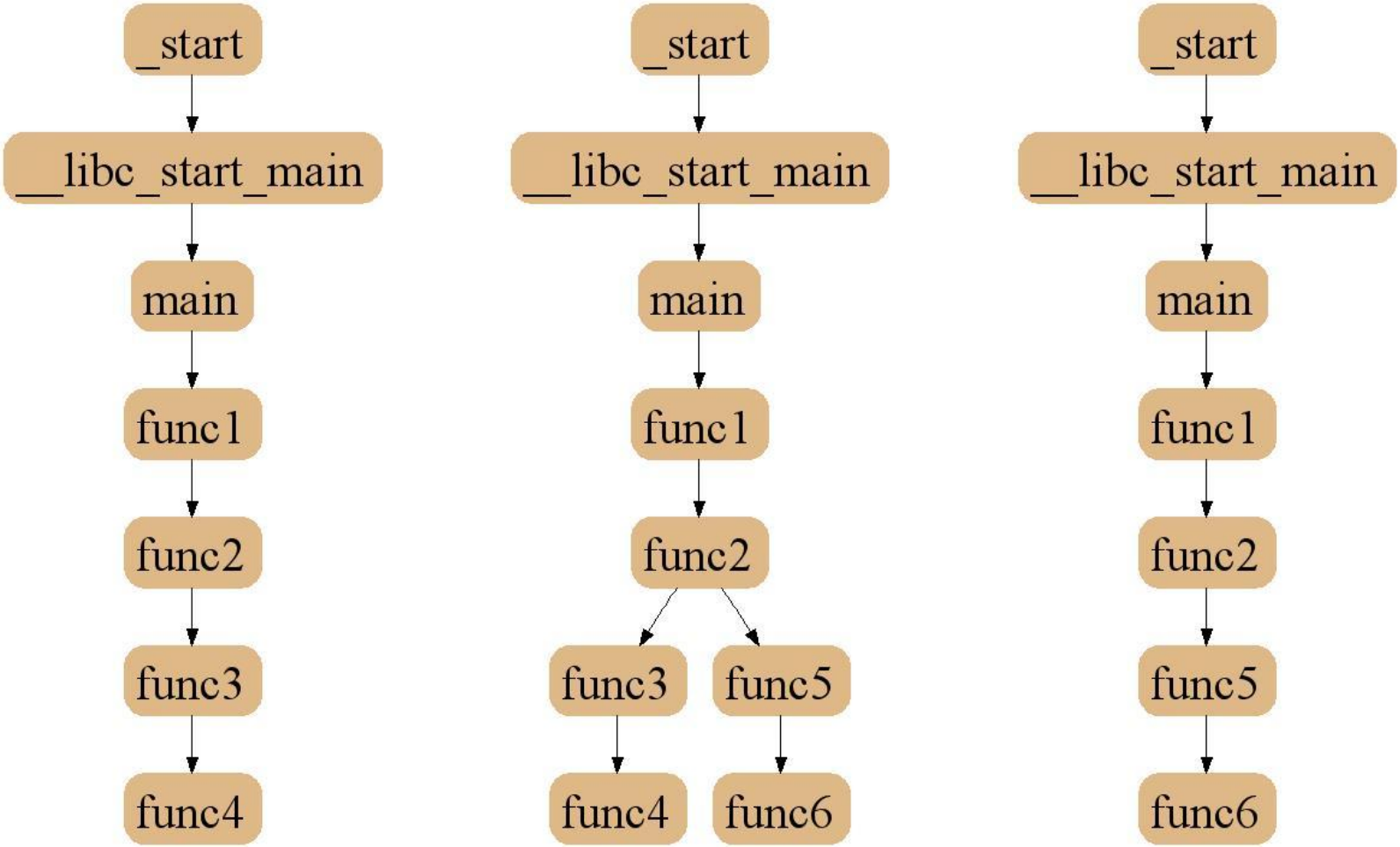
- **Tree based software overlay network**
- **Provides efficient multicast and reduction communications for parallel and distributed tools**
- **Uses a tree of processes between the tool's front-end and back-ends to improve group communication performance**
  - Internal processes are used to distribute important tool activities
    - Reduce data analysis time
    - Keep tool front-end loads manageable

Stack Trace Analysis Tool (STAT)

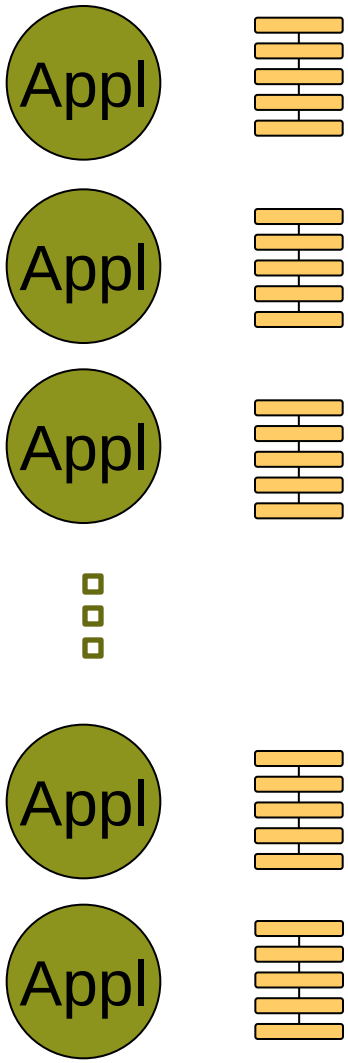
- **Stack trace sampling and analysis for large scale applications**
  - Sample application stack traces
  - Scalable generation of a single, merged, stack backtrace tree
    - A comprehensible view of the entire application
    - Discover equivalent process behavior
      - Group similar processes
      - Reduce number of tasks to debug
    - 128K processes analyzed in 2.7 seconds, using MRNet

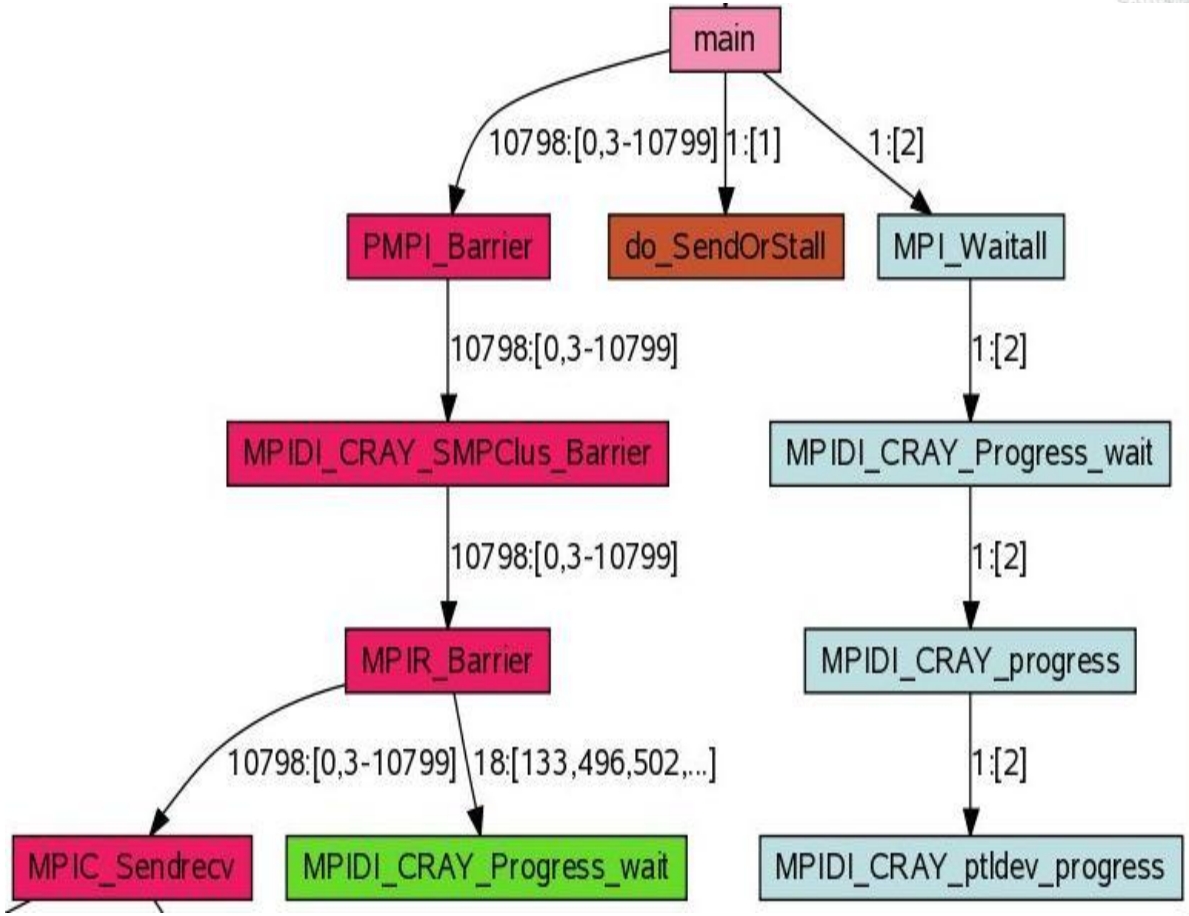
- **Merge/analyze traces:**
  - Facilitate scalable analysis/data presentation
  - Multiple traces over space or time
  - Create call graph prefix tree
    - Compressed representation
    - Scalable visualization
    - Scalable analysis

Stack Trace Merge Example



2D-Trace/Space Analysis





STATview & STATGUI

- **STATview is a GUI for viewing STAT outputted DOT files**
  - STATview provides easy navigation of the call prefix tree and also allows manipulation of the call tree to help focus on areas of interest
- **STATGUI is a GUI that drives STAT and allows you to interactively control the sampling of stack traces from your parallel application**
  - STATGUI is built on top of STATview and provides the same call tree manipulation operations
  - In addition to the operations provided by STATview, STATGUI provides a toolbar to control STAT's operations
- **STATGUI can also serve as an interface to attach a full-featured debugger such as DDT to a subset of the application tasks**

STAT 1.2.1.3

- **module load stat**
  - Not loaded by default
- **man STAT**
- **STAT <pid_of_aprun>**
  - Creates STAT_results/<app_name>/<merged_bt_file>
- **Scaling limited by number file descriptor**

ATP: The Problem Being Solved

- **When a large scale parallel application dies, one, many, or all processes might trap!**
  - It is next to impossible to examine all the core files and backtraces
    - No one wants that many stack backtraces
    - No one wants that many core files
      - They are too slow and too big
        - Sufficient storage for all core files is a problem
    - They are too much to comprehend
  - A single core file or stack backtrace is usually not enough to debug either!
    - A single backtrace produced might not be from the process that first failed

- **Requirements:**
  - Minimum jitter
  - Scalability
  - Robustness
  - Small footprint
  - Limited core file dumping

- **ATP 1.6.1 was released in January 2013**

ATP Description

- **System of light weight back-end monitor processes on compute nodes**
  - Coupled together with **MRNet**
  - Automatically launched by aprun in parallel with application launch
    - Enabled/disabled via ATP_ENABLED environment variable
- **Leap into action on any application process trapping**
  - stderr backtrace of first process to trap
    - dumps core file set (if limit/ulimit allows)
  - Uses **StackwalkerAPI** to collect individual stack backtraces, even for optimized code
- **STAT like analysis provides merged stack backtrace tree**
  - Leaf nodes of tree define a modest set of processes to core dump
    - or, a set of processes to attach to with a debugger

Abnormal Termination Processing

- **ATP produces a single merged stack trace**
  - or a **reduced set of core files**
    - ATP selects a single representative from each leaf node of the merged stack backtrace tree
      - Each core file is named core.atp.apid.rank
    - Users can control, to some degree, the set of core dumps created by ATP

- **The benefits:**
  - Minimal impact on application run
    - Can be used with production runs
  - Automated, transparent collection of data
  - Ability to hold failing application for close inspection
    - This is site dependent
  - Easy to navigate the merged stack trace
  - Manageable set of core files
  - Reduced amount of data saved
    - Especially true in the core file situation

ATP: How It Works

- **ATP is launched via an ALPS enhancement which includes the fork/exec of a login side ATP front-end daemon**
  - The ATP front-end uses MRNet and the ALPS tool helper library to launch ATP back-end servers on all compute nodes associated with the application
- **ATP signal handler runs within an application to catch fatal errors**
  - It handles the following signals:
    - SIGQUIT, SIGILL, SIGTRAP, SIGABRT, SIGFPE, SIGBUS, SIGSEGV, SIGSYS, SIGXCPU, SIGXFSZ
    - Setting the environment variables MPICH_ABORT_ON_ERROR and SHMEM_ABORT_ON_ERROR will cause a signal to be thrown and captured for MPI and SHMEM fatal errors
- **ATP daemon running on the compute node captures signals, starts termination processing**
  - Rest of the application processes are notified
  - Generates a stacktrace
  - Creates a single merged stack trace file
- **The stack trace file is viewed with the STATview tool**

ATP Hold Time

- **ATP is able to hold a dying application in stasis in order to allow the user to attach to it with a debugger**
  - To do so, set the **ATP_HOLD_TIME** environment variable to the number of minutes desired
- **Once attached, the debugging session can last as long as the batch system allows**
  - Which in turn depends on the compute node resources you requested when you began your session
  - So use ATP_HOLD_TIME to define the time you need to attach to the application, not the total time needed for the debugging session.
- **If ATP_HOLD_TIME is set, core dumping is disabled**

Comparative Debugger

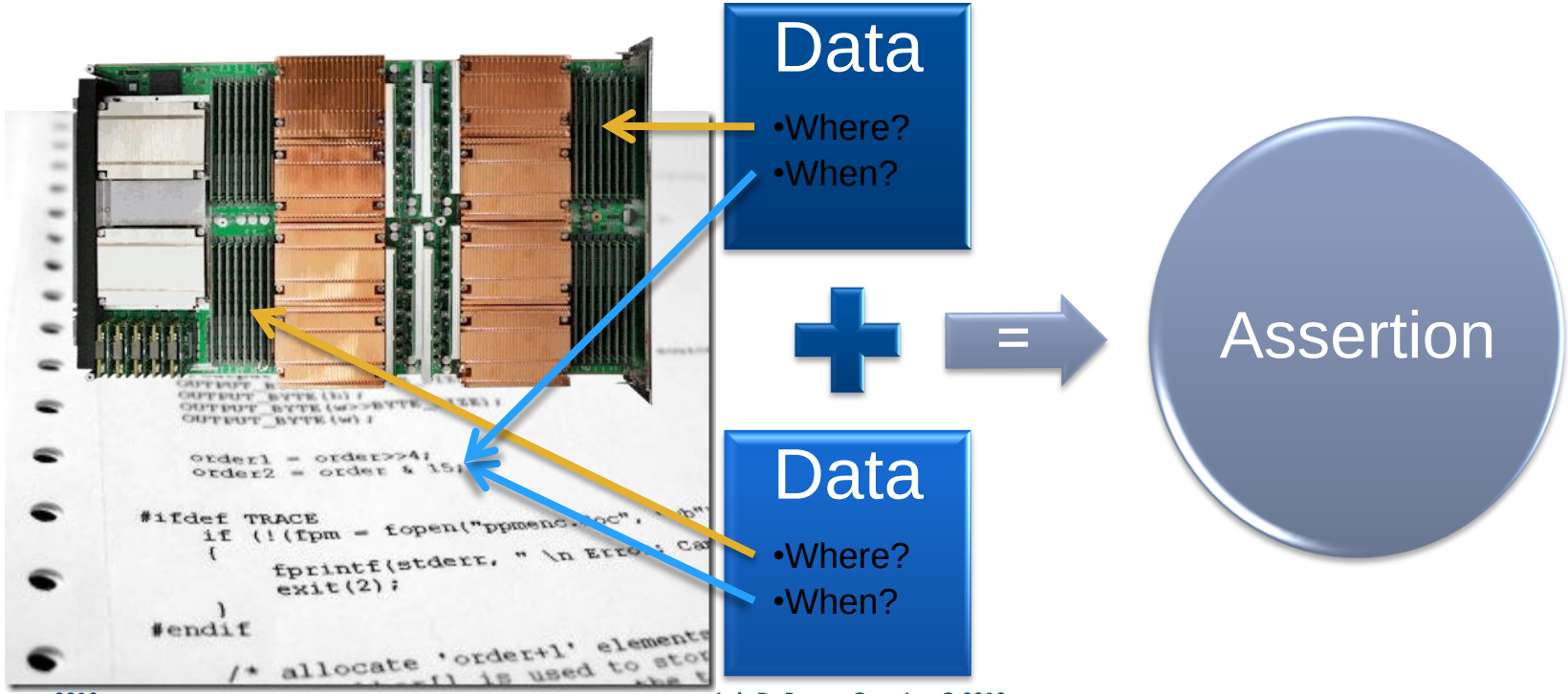
- **Collaboration with Monash University**
  - A **data-centric paradigm** instead of the traditional control-centric paradigm

- **Helps the programmer locate errors in the program by observing the divergence in key data structures as the programs are executing**
  - Allows comparison of a “suspect” program against a “reference” code using assertions
    - Simultaneous execution of both
    - Ability to assert the match of data at given points in execution
    - Focus on data – not state and internal operations
    - Narrow down problem without massive thread study
  - Data comparison
    - Tolerance control – nobody expect it to be perfect
    - Array subsets – correlate serial to parallel bits
    - Array index permutation – loops rearranged
    - Automated asserts – let it run until a problem is found
    - Forcing correct values – continue on with correct data

Assertions, Graphs and Blockmaps…

Oh my!

- **Need a way to declare that we expect two pieces of data are equivalent**
  - Backup: What is data?
  - Define specific variables in the source (where?)
  - Define a particular line number to observe the variables (when?)
- **Assertions provide this ability**
  - Assert that the two should be equivalent at that moment

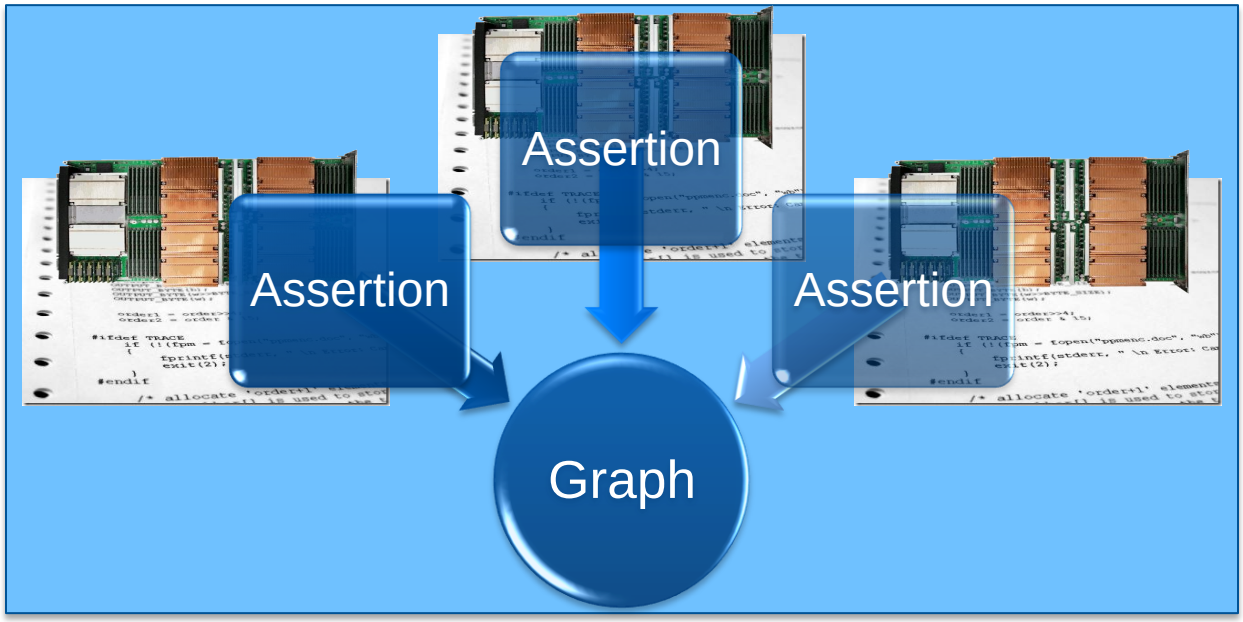


Assertions, Graphs and Blockmaps…

Oh my!

- **But wait, there's more**
  - Want to compare multiple variables at the same line number in the code
  - Want to compare a single variable at many different line numbers in the code.

- **There's a graph for that**
  - Execute many different assertions simultaneously

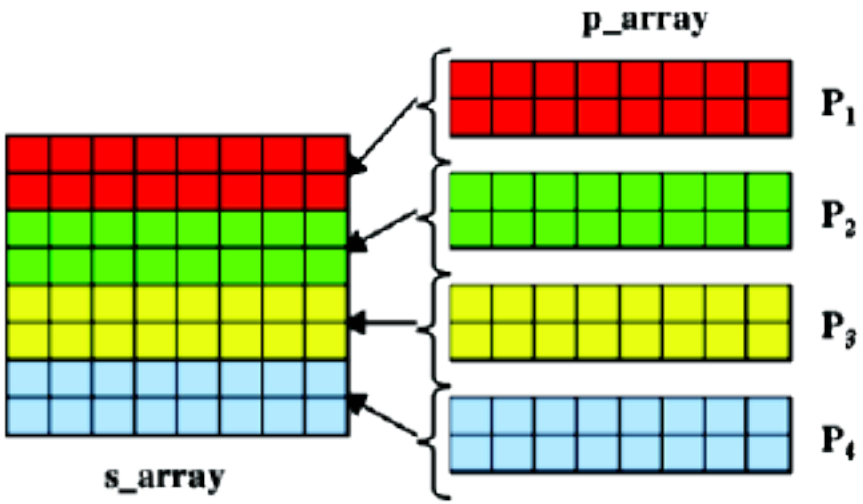


Assertions, Graphs and Blockmaps…

Oh my!

- **Sometimes assertions alone are not enough**
  - Serial data to distributed data
  - One-dimensional to multi-dimensional data.
  - Scalar to non-scalar data.

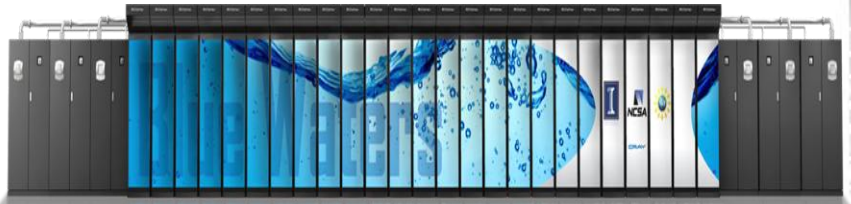
- **Blockmaps provide a simple mechanism to decompose data**
  - Based on HPF syntax
  - Allows for block, cyclic, and * (wildcard) decomposition definitions
  - Defines how the data is distributed across a set of parallel processes

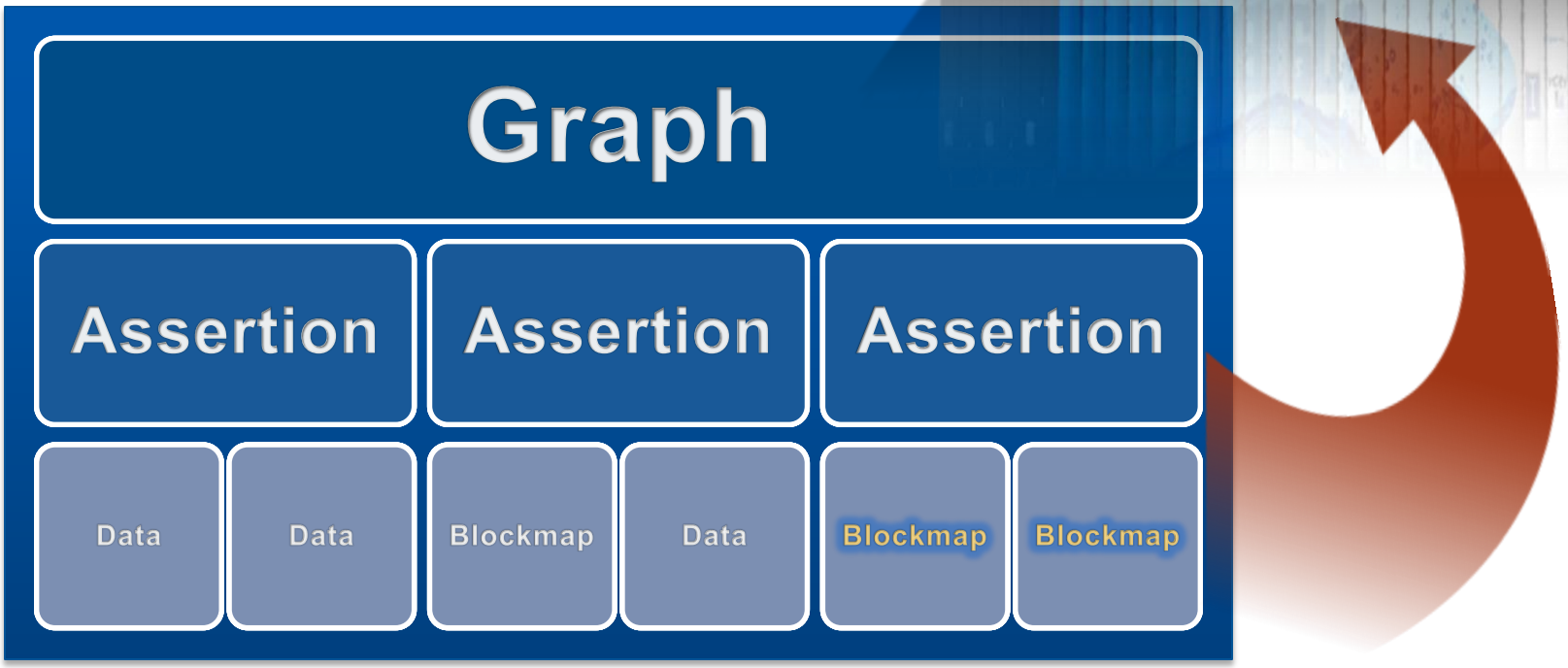


Example of a (block,*) decomposition.

Putting It Together

- A graph is made up of assertions which contains data definitions
  - Data versus data, blockmap versus data, blockmap versus blockmap.
- Once defined, a graph is executed





Comparative Debugger Status

- **Released with lgdb 2.0.0 (November 2012)**
  - module load cray-lgdb
    - On Blue Waters - cray-lgdb/2.0.1(default)
- **Supports applications compiled with CCE, PGI, and GNU Fortran, C, and C++ compilers.**
- **Basic operation is documented in the lgdb man page**
  - man lgdb(1)
- **A white paper on "Using the lgdb Comparative Debugging Feature" will be available soon**
- **We are working on a graphical user interface (GUI) for better ease of use**

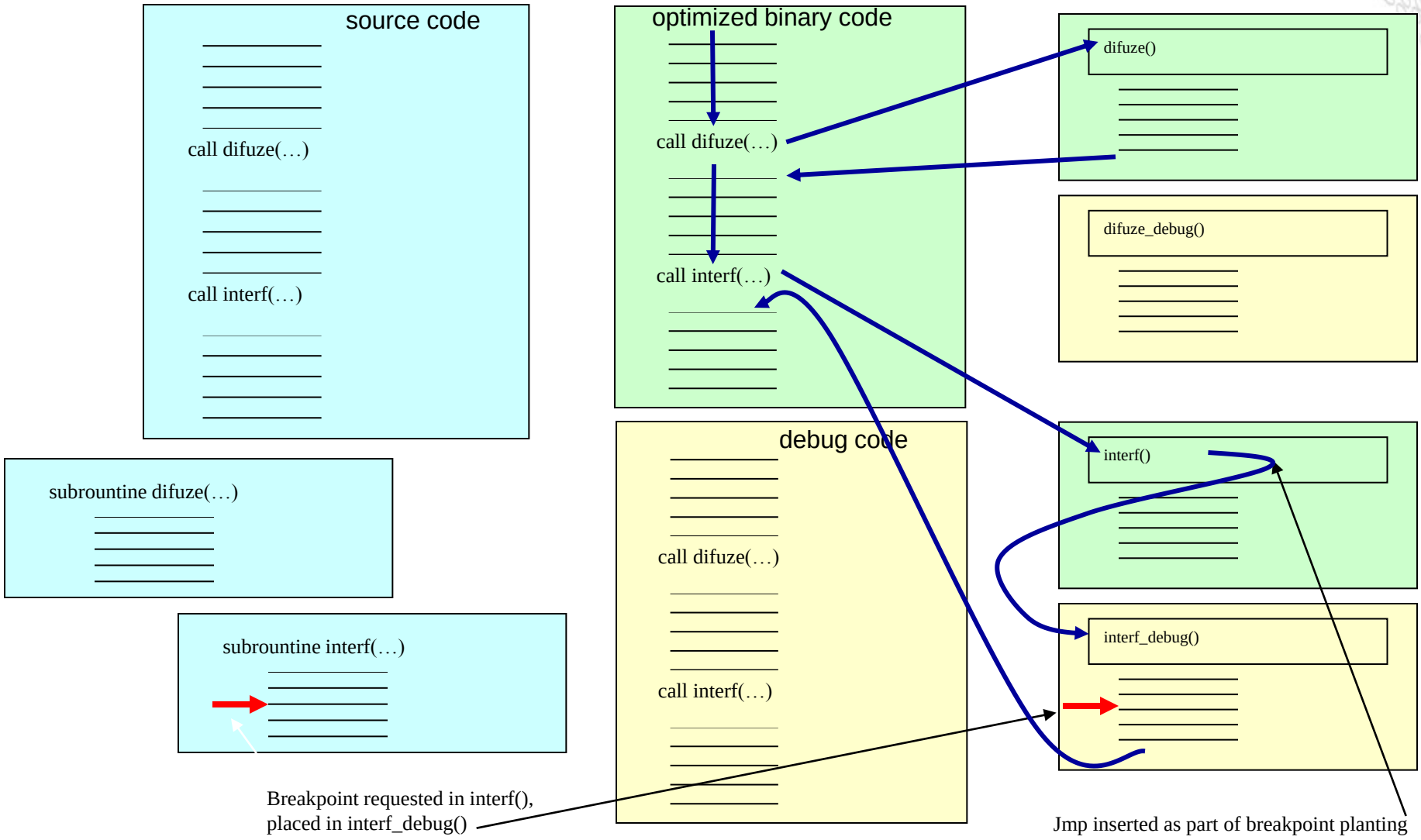
Fast Track Debugging: The Problem Being Solved

- How to debug parallel optimized codes
- Debug flags eliminate optimizations
  - Today's machines really need optimizations
  - Slows down execution
  - Problem might disappear
- Fast Track Debugging addresses this problem

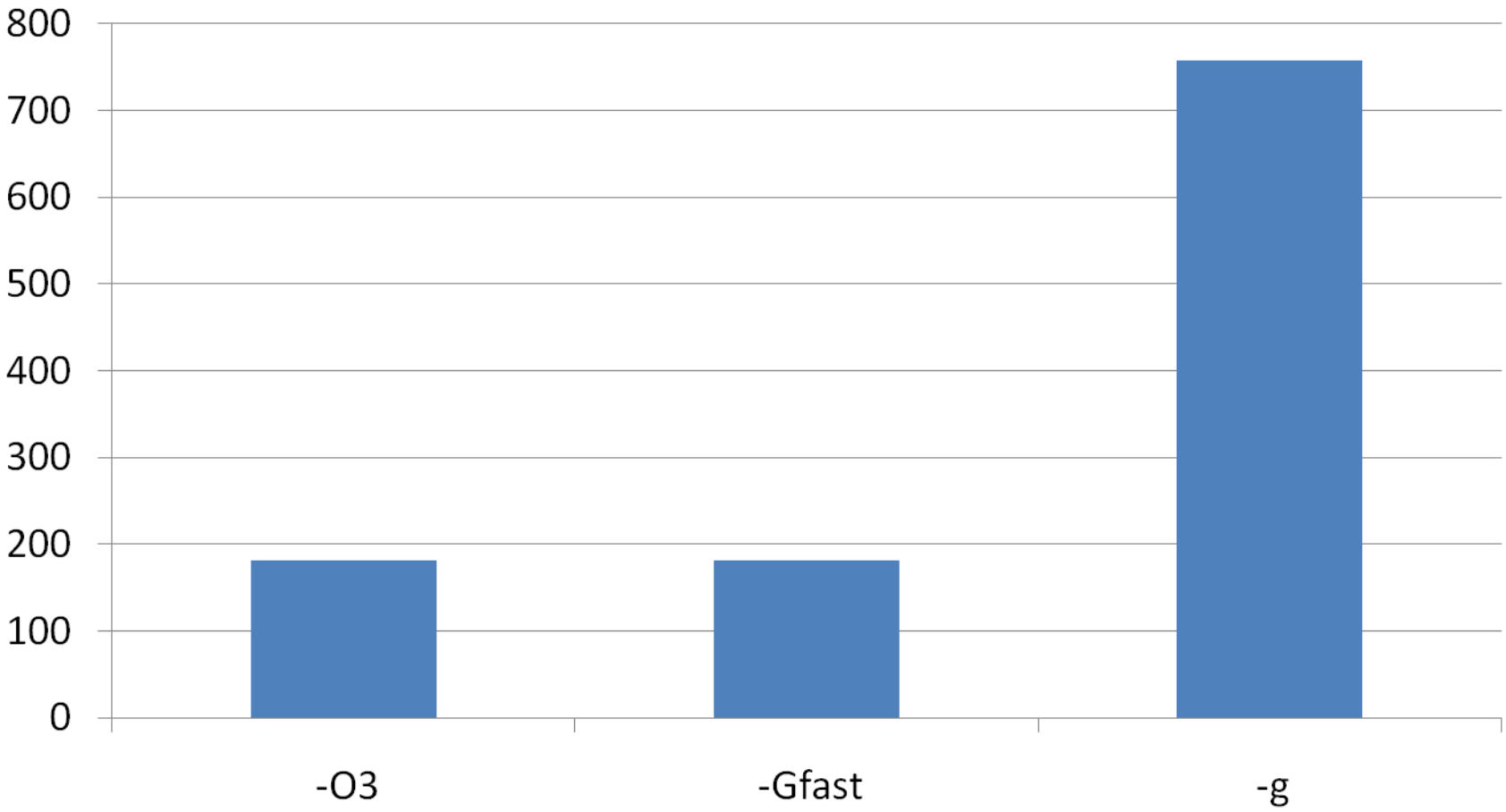
How to do "Fast Track Debugging"?

- **Compile such that both debug and non-debug (optimized) versions of each routine are created**
  - Debug and non-debug versions of each subroutine appear in the executable
- **Linkage such that optimized versions are used by default**
- **User sets breakpoints or other debug constructs**
  - Debugger overrides default linkage when setting breakpoints and stepping into functions
  - Routines automatically presented using the debug version of the routine
  - Rest of program executes using optimized versions of the routines

A Closer Look at How FTD Works



Tera TF Execution Time



Fast Track Debugger – Issues / Cost

- **Compiles are slower**
- **Executable uses more disk space**
- **Libraries probably don't have a debug version**
- **Inlining turned off**
  - 1.7% average slow down of all SPEC2007MPI tests
  - Range of slight speedup to 19.5% slow down
- **Uses more memory**
  - 4% larger at start up
  - 0.0001% larger after computation

Fast Track Debugger Status

- Support available in the Cray Compilation Environment (CCE)
- Prototype in gdb
  - Exercised through lgdb
- Added to Allinea's DDT 2.6 (June 2010)