Support for Debugging Automatically Parallelized Programs

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Background

- Computational Intensive Applications
- Fortran, C/C++
- Migration of codes to parallel computers
- Shared memory parallelization:
  - Multithreading
  - Compiler support via directives
- Distributed memory parallelization:
  - Requires explicit message passing, e.g. MPI
- Desire to generate message passing versions of existing sequential code
The CAPTools Parallelization Support Tool

- Developed at the University of Greenwich
- Transforms existing sequential Fortran code into parallel message passing code
  - Extensive dependence analysis across statements, loop iterations, and subroutine calls.
  - Partitioning of array data
  - Generation of necessary calls to communication routines

```
program Laplace
real u(100), v(100)
...
do 10 i = 2, 99
   u(i) = 0.5 * (v(i-1) + v(i+1))
end do
...
```

User guidance

```
program PARALLELlapse
real u(100), v(100)
...
CALL CAP_EXCHANGE(v, CAP_RIGHT...)
CALL CAP_EXCHANGE(v, CAP_LEFT,...)
do i = CAP_LOW, CAP_HIGH
   u(i) = 0.5*(v(i-1) + v(i+1))
end do
...
```

Possible sources for errors:
- Wrong user information
- Tool makes mistake
Relative Debugging

- P1: version of a program that produces correct results.
- P2: version of the same program that produces incorrect results.
- Relative Debugging:
  - Compare data between P1 and P2 to locate the error.
  - P1 and P2 can possibly run on different machines, e.g., a sequential and a parallel architecture.
    - Applies directly to our situation.
Questions

• What data values should be compared?
  – Variables that have been determined as being incorrect and variables that define them.

• When during execution should they be compared?
  – Places where suspicious variables are defined.

• Where should data residing in multiple address space be compared?
  – Suspicious values from both executables written to file.
  – Debugger collects data from both executables.
  – Executables establish communication and compare data.

• How do we decide whether the values are correct?
  – Array checksums, element-by-element comparison, etc.

• How do we handle distributed data?
  – Array distribution information is necessary.
Main Players in the Prototype:
The CAPTools Database

- The CAPTools Database:
  - Provides **variable definition information** across subroutines to determine which variables should be checked.
  - Provides **array distribution information** to determine how distributed data should be compared against undistributed data.

<table>
<thead>
<tr>
<th>Undistributed array</th>
<th>Replicated Memory</th>
<th>Reduced Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

Block wise distributions

CAPTools Information:

sub1: var1: CAP1_LOW:CAP1_HIGH, 1:N
sub2: var2: 1:M, CAP1_LOW: CAP2_HIGH
Main Players in the Prototype: The Comparison Routines

- The comparison routines: inserted at entry and exit of suspicious routines to bracket error location.
- compit1: Inserted in sequential program S
  - Receives data from each processor from parallel program P1, P2, ...
  - Compares data to its own:
    - checksum, partial checksums, element-by-element
  - Calls special routine if discrepancy detected.
- compit2: Inserted in parallel program.
  - Sends local data to sequential process.

```
S
  ... subroutine sub1(var1)
  call compit1(var1)
  ...
  call compit1(var1)
  end

P1
  ... subroutine sub1(var1)
  call compit2(var1)
  ...
  call compit2(var1)
  end

P2
  ... subroutine sub1(var1)
  call compit2(var1)
  ...
  call compit2(var1)
  end
```
Main Players in the Prototype: **Instrumentation Server and P2d2**

- **Instrumentation Server (IS):**
  - Based on dyninstAPI which was developed at the University of Maryland
    - C++ library that provides API for runtime code patching,
  - Permits insertion of calls to comparison routines into a running program

- **P2d2 debugger:**
  - Developed at NASA Ames Research Center
  - Portable, scalable, parallel debugger
  - Client-Server architecture based on gdb
  - P2d2 coordinates the actions of the other players and provides user interface
A Relative Debugging Session (1)

```fortran
40- subroutine output (phi3, nptsx, nptsy)
    implicit none
    integer nptsx, nptsy, i, j
    double precision phi3 (0:nptsx+1, 0:nptsy+1)
    double precision phi7 (0:nptsx+1, 0:nptsy+1)
45-    do j = 0, nptsx+1
        do i = 0, nptsy+1
            phi7 (i,j) = phi3 (i,j)
        end do
        end do
50-    do j = 0, nptsx+1
        write (8,*) (phi7 (i,j), i = 0, nptsx+1)
        end do
55-    return
end

60- subroutine update (phi4, oldphi4)
    implicit none
    integer nptsx, nptsy, i, j
    double precision phi4 (0:nptsx+1, 0:nptsy+1)
```

file: testnew2.f
Behind the Scenes

p2d2 → gdb

Instrumentation

executable name
process id
machine name
port number

Contact Info File
Behind the Scenes (2)

breakpoint trap if error is detected

p2d2 indicates difference was detected

p2d2 indicates to user that difference was detected

Run outside of debugger control

Communicate with $S_x$
A difference was detected in variable 'phi4' when exiting from function 'update'.
The variable had tested equal when entering function 'update'.

OK
Related Work

- GUARD
  - Relative Debugger for Parallel Programs
  - Developed at the Griffith University in Brisbane, Australia.
  - The debugger collects data from both executables and performs comparison.
  - Does not aim particularly at automatically parallelized programs.
  - Provides user commands like “assert” and “compare” for comparison.
  - Provides means for the user to describe array distribution.
Project Status and Future Work

- We have built a prototype of a relative debugging system for comparing serial codes and their tool produced counterparts.
  - Prototype runs on SGI Origin IRIX6.5
- We used dynamic instrumentation to minimize comparison overhead:
  - First timing experiments were inconclusive.
- We plan to modify the p2d2 user interface to support multiple computations executing simultaneously.
- Extend prototype to handle OpenMP programs.