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

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

program PARALLEL_laplace
  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>
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<tbody>
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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.
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
subroutine output (phi3, nptsx, nptsy)
  implicit none
  integer nptsx, nptsy, i, j
  double precision phi3 (:, nptsx+1, 0:nptsy+1)
  double precision phi7 (:, nptsx+1, 0:nptsy+1)
  do j = 0, nptsx+1
    do i = 0, nptsy+1
      phi7 (i, j) = phi3 (i, j)
    end do
  end do
  do j = 0, nptsx+1
    write (8,*) (phi7 (i, j), i = 0, nptsy)
  end do
  return
end

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

file: testnew2.f
Behind the Scenes

p2d2 → gdb → S

CAP Tools database

Contact Info file

copyphi:oldphi5
update:phi4
setupgrid:phi6

Instrumentation Server

P1

P2

P3

P4
Behind the Scenes (2)

- **p2d2** indicates to user that difference was detected.
- **gdb**
- **compit1**
- **S**

- breakpoint trap if error is detected

- Run outside of debugger control
- Communicate with \( S \)
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.