



Remember when  
the sky was the limit?

# Fortran Compiler Use of Temporaries

Improving  
Performance,  
Reducing Stack  
Utilization



# Problems and Concerns: Agenda

- Stack Application runs out of stack and aborts
- Application creating temporary copies of actual arguments before procedure call.
- Application creating temporary copies of arrays because of Fortran 95 statements or array syntax
- OpenMP Considerations



# General Stack Exhaustion and Increasing Stack Space



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# Intel Fortran Compiler Stack Usage

- **Driven by array temporaries**
- **OpenMP puts a heavy demand on stack (all thread PRIVATE data is put on stack)**
- **-heap-arrays option added, v9.1 Aug 06**
  - **Linux: 9.1.037 and later**
  - **Windows: 9.1.029 and later**
  - **Mac OS\* X: present in all ifort versions**



# Symptoms and Solutions to Stack Exhaustion

- Symptoms:
  - Linux: process aborts with SEGV (sigsegv), segmentation fault
  - Mac OS X: process aborts with “illegal instruction”
- Solutions/Workarounds
  - Use 9.1 or greater compiler option `-heap-arrays`
  - Linux: `unlimit` stack via C system call
  - Linux, Windows, Mac OS X: Use loader options to increase stack size and possibly stack starting address
  - System: Increase system wide user shell stack limit
    - Via default system `/etc/login /etc/csh.cshrc`
    - Via kernel params and custom kernel builds
  - User: Increase stack size in user shell
    - User login scripts
    - Setting stack size just before running (wrapper scripts)



# -heap-arrays

- -heap-arrays[:size]
- Default is **no** -heap-arrays
- Optional [:size] – arrays of size or smaller are stack allocated, larger arrays are heap allocated
- From Release\_Notes: “May have slight performance penalty”
  - Varies by application
  - Stack memory management is fast and simple (allocate/deallocate straightforward, fast)
  - Heap management: large amounts of allocations/frees of differing sizes can frag heap, impact performance.
  - Use [:size] to restrict to large allocations and avoiding fragmentation



# -heap-arrays

- -heap-arrays affects automatic arrays and temporaries only.  
For example:

```
RECURSIVE SUBROUTINE F( N )
```

```
INTEGER :: N
```

```
REAL :: X ( N ) ! an automatic array
```

```
REAL :: Y ( 1000 ) ! an explicit-shape  
local array on the stack
```

Array X in the example above is affected by the heap-array option. **Array Y is not.**



# Linux: unlimiting stack via C system call

```
#include <stdio.h>           // perror
#include <stdlib.h>          // exit
#include <sys/time.h>        // setrlimit
#include <sys/resource.h>    // setrlimit
#include <unistd.h>          // setrlimit

void unlimit_stack_(void) {
    struct rlimit rlim = { RLIM_INFINITY, RLIM_INFINITY };

    if ( setrlimit(RLIMIT_STACK, &rlim) == -1 ) {
        perror("setrlimit error");
        exit(1);
    }
}
```





# Linker/Loader Option for Stack Size

- Adds stack size change to executable image
- Loader will ignore shell limits and give process the requested, non-default, stack size

Example: Increase to 256MB on Mac OS X:

```
ld -stacksize 0x10000000 -o foo foo.o
```

ifort:

```
ifort -o foo -Wl,-stack_size,0x10000000,-stack_addr,0xc0000000 foo.f
```



# Temporary Creation on Procedure Call



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# Case: Local Variables

```
subroutine sub( a )  
  
real(8) :: a(1000,1000)  
  
real(8) :: temp(1000,1000), work(1000,1000)
```

- Local arrays **temp** and **work** allocated on stack (assuming default options)
- Work arounds:
  - SAVE attribute will cause allocation in heap
  - **-save** compiler option (same effect) but affects entire source file(s)
- Default: default of **-auto** (same as **-automatic**) default compiler option



# Case: Array Temporaries in Fortran

## Automatic Arrays

```
subroutine sub( f, x, y, z )  
integer :: x, y, z  
real(8) :: f(x,y,z) !...argument  
real(8) :: temp(x,y,z) !stack alloc'ed automatic array
```

- Replace with allocatable array – allocation occurs in heap

```
Subroutine sub( f, x, y, z )  
  
...  
real(8), allocatable :: temp(:, :, :)  
allocate ( temp(x,y,z) )
```



# Case: Array Temporaries in Fortran

## Passing Non-contiguous Array Sections

- If passing a noncontiguous array section to another routine, have the called routine accept it as a deferred-shape array
- an explicit INTERFACE is required
- Example: BEFORE (using explicit-shape dummy )

```
real(8) :: f(1800,3600,1)
```

```
external sub
```

```
subroutine sub( f )
```

```
call sub( f(1:900, :, :) )
```

```
real(8) :: f(900,3600,1)
```

Sub is expecting a contiguous array 900x3600x1  
a temp is created on entry (gather) and copied  
back on exit (scatter)



# Continued: Array Temporaries in Fortran Passing Non-contiguous Array Sections

- Explicit interface and assumed shape arrays avoid the temporary

```
real(8) :: f(1800,3600,1)
```

```
interface
```

```
  subroutine sub(f)
```

```
    real(8) :: f(:, :, :)
```

```
  end subroutine sub
```

```
end interface
```

```
call sub( f(1:900, :, :) )
```

```
subroutine sub( f )
```

```
real(8) :: f(:, :, :)
```

```
...
```

```
end subroutine sub
```

Downside: within 'sub',  
the optimizer must assume  
that 'f' might be non-  
contiguous



# Continued: Array Temporaries in Fortran Passing Non-contiguous Array Sections

- gen-interfaces option can be used to generate INTERFACE blocks for SUBROUTINES and FUNCTIONS in your source
- Creates 2 source files for each:
  - A <subroutine>\_mod.f90 file with the INTERFACE inside a MODULE
  - A <subroutine>\_mod.mod file (the MOD file for the above)
  - Placed in -module <dir>, or -I <dir>, or in current directory
- CHECK YOUR WORK: -check arg\_temp\_created
  - Runtime check to print warnings when temporaries are created at procedure calls.



# Temporaries Creation By Fortran Statements and Ininsics



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# Case: Array Temporaries in Fortran WHERE statement

- WHERE statement will always create an array temporary for the array expression:

```
real(8) :: f(1800,3600)
```

```
!...requires 8x1800x3600 = 51,840,000 byte temp array
```

```
where ( f .gt. 0 )
```

```
  f = log10(f)
```

```
else where
```

```
  f = -1.0
```

```
end where
```

- Only workaround is to avoid WHERE (explicitly write DO loop with conditional) – not advised



# Case: Array Temporaries Caused by Cray Pointers

- Cases vary: in general, anytime the compiler cannot determine if there is overlap in the RHS and LHS expressions
- Cray pointers – compiler errs on the side of safety

```
pointer (pb, b)
pb = getstorage()
do i = 1, n
b(i) = a(i) + 1    !...assumes b may overlap with a, makes
                  temporary of 'a'
enddo
```

- –safe-cray-pointers JUDICIOUSLY

```
pointer (pb, b)
pb = loc(a(2))
do i=1, n
b(i) = a(i) +1    !... –safe-cray-pointers will avoid temp.
                  but give wrong results
enddo
```



# Case: Array Temporaries Created by Fortran Pointers

```
real, pointer, dimension (:,:) :: xptr, yptr
```

```
real, target :: z(100,100)
```

```
allocate ( xptr(100,100) )
```

```
allocate ( yptr(100,100) )
```

```
...
```

```
xptr = yptr*2    !...the compiler must assume overlap
```

```
z = xptr * yptr !...X or Y or both could point to Z
```



# Continued: Array Temporaries Created by Fortran Pointers

When a pointer-based array appears in an assignment statement on the LHS of the assignment, and a TARGET or another POINTER appears on the RHS, the compiler will assume a possible overlap condition and will create array temporaries.

Similarly, when a TARGET appears on the LHS and a POINTER appears on the RHS expression, a temporary is created. Again, any time there is a possible overlap in the LHS and RHS expression, the compiler will choose the safest path and create an array temporary.

In general ONLY use POINTER-based arrays where absolutely necessary. If you can use ALLOCATABLE arrays instead, do so



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# Array Temporaries in Fortran Others (work in progress)

- Array-valued function procedures return values on the stack
  - Only work around is to convert to subroutine procedures and pass the array as an argument ( INTENT OUT or INOUT )
- Intrinsic often use array temporaries
- RESHAPE
- MERGE
- SUM
- (others (tbd))



# Array Syntax and Temporaries

- Does array syntax create temporaries?
- If the compiler is doing it's job, NO. (caveat: we have been finding and fixing such cases over the years)
- If you find such a case, please open a bug report



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# OpenMP Stack Considerations



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# -openmp Interaction with -heap-arrays

- -openmp will cause the compiler use slightly different behavior for -heap-arrays
- Procedure local data with -heap-arrays and -openmp are STACK allocated (therefore, thread-safe) – must explicitly override with SAVE attribute to get on heap
- Automatic arrays: descriptor allocated on stack, data allocated in heap (thus, also thread-safe).
- OpenMP puts a heavy load on stack, threadprivate variables need stack allocation
- Use stack-increasing methods – you will need much more stack than an non-OpenMP application





# Summary Recommendations

- Code to avoid temporaries on procedure calls, use `-check arg_temp_created` to verify
- `-heap-array:<size>` may be used for codes needing large array temporaries
  - Requires 9.1.x or greater compilers since August 2006
  - 9.0 and older compilers: Use either loader options and/or `setrlimit()` to bypass shell stack size limitations
- When passing array sections, use assumed shape arrays and explicit `INTERFACE`

