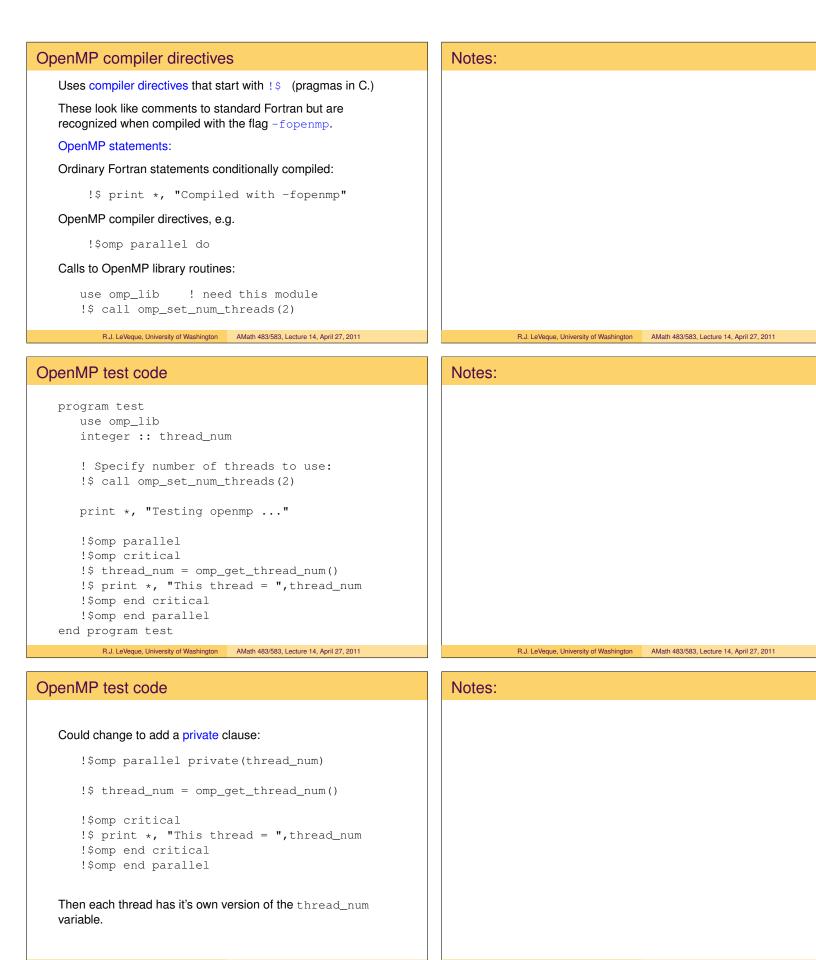
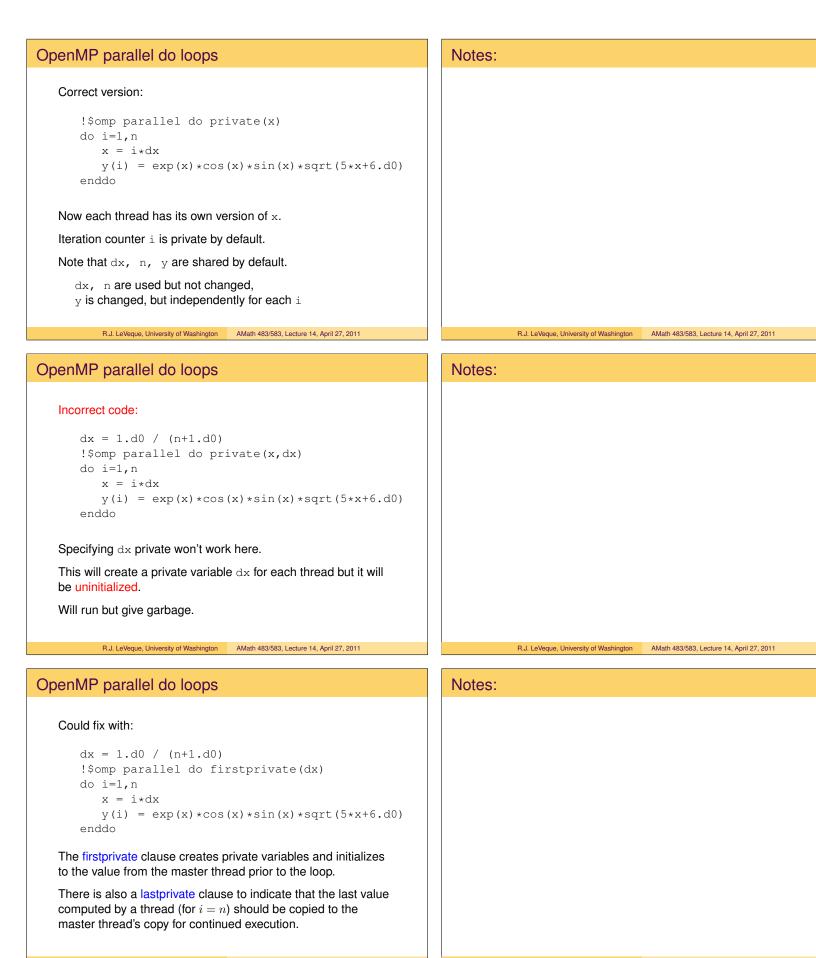
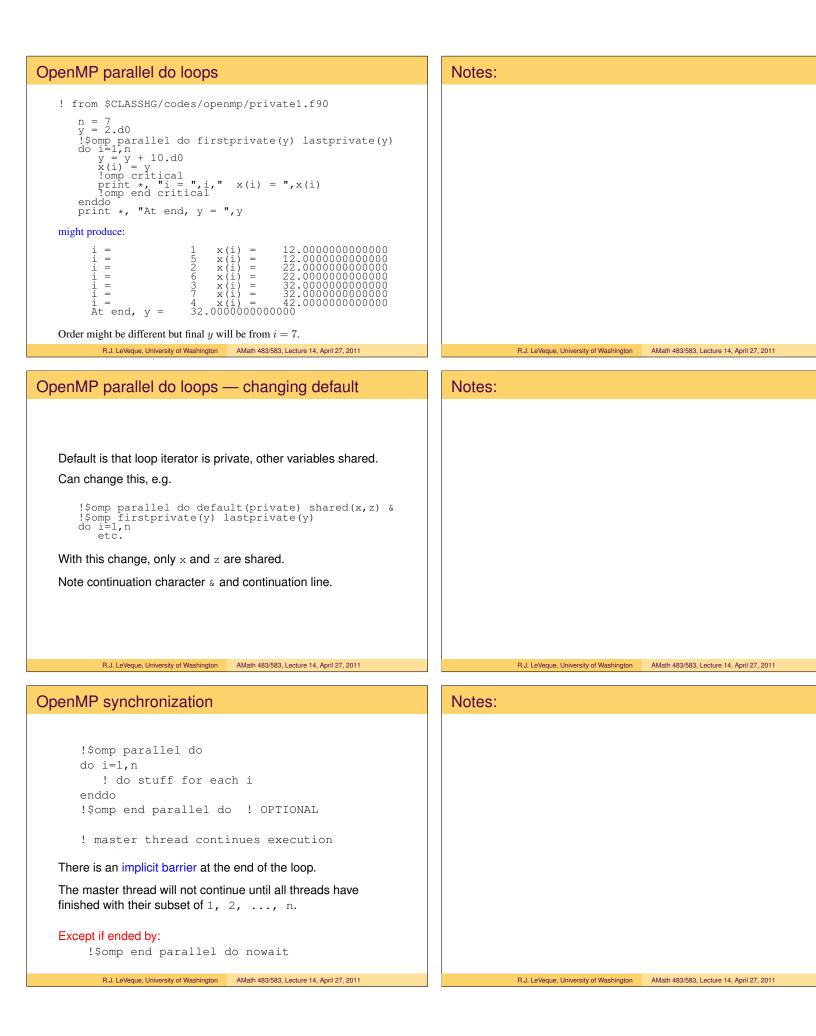
AMath 483/583 — Lecture 14 — April 27, 2011	Notes:		
Today: • OpenMP			
Friday: More OpenMP			
Read: Class notes and references			
Homework 4 is posted, due next Thursday.			
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Memory stack	Notes:		
Note: Parallel threads use stack and you may need to increase	110100.		
the limit (e.g. on the VM):			
\$ gfortran -fopenmp yeval.f90			
\$./a.out Segmentation fault			
\$ ulimit -s			
8192			
\$ ulimit -s unlimited			
\$./a.out			
Using OpenMP with 2 threads			
Filled vector y of length 10000000			
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Memory: Heap and Stack	Notes:		
Memory devoted to data for a program is generally split up:			
Heap: Dynamically allocated memory — memory allocator looks for free block of memory, keeps track of free list, does			
garbage collection, etc.			
Stack: Block of memory where space is allocated on "top" of			
the stack as needed and "popped" off the stack when no longer needed. Last in – first out (LIFO).			
Fast relative to heap allocation.			
Natural way to allocate storage for nested subroutine or function calls: If A calls B calls C, then when the variables used by C are popped off the stack, we're back to the variables of B.			
Private variables for threads also put on stack, popped off when			
parallel block ends.			
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OpenMP parallel do loops	Notes:
<pre>!\$omp parallel do do i=1,n ! do stuff for each i enddo !\$omp end parallel do ! OPTIONAL indicates that the do loop can be done in parallel. Requires: what's done for each value of <i>i</i> is independent of others Different values of <i>i</i> can be done in any order. The iteration variable i is private to the thread: each thread has its own version. By default, all other variables are shared between threads unless specified otherwise.</pre>	
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OpenMP parallel do loops	Notes:
This code fills a vector y with function values that take a bit of time to compute: ! fragment of $CLASSHG/codes/openmp/yeval.f90$ dx = 1.d0 / (n+1.d0) !\$omp parallel do private(x) do i=1, n x = i*dx y(i) = exp(x)*cos(x)*sin(x)*sqrt(5*x+6.d0) enddo Elapsed time for $n = 10^8$, without OpenMP: about 9.3 sec. Elapsed time using OpenMP on 2 processors: about 5.0 sec.	
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OpenMP parallel do loops This code is not correct: !\$omp parallel do do i=1,n	Notes:
<pre>x = i*dx y(i) = exp(x)*cos(x)*sin(x)*sqrt(5*x+6.d0) enddo By default, x is a shared variable. Might happen that: Processor 0 sets x properly for one value of i, Processor 1 sets x properly for another value of i, Processor 0 uses x but is now incorrect.</pre>	
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onditional clause	Notes:
Loop overhead may not be worthwhile for short loops.	
(Multi-thread version may run slower than sequential)	
Can use conditional clause:	
<pre>\$omp parallel do if (n > 1000)</pre>	
do i=1,n ! do stuff	
enddo	
If $n \le 1000$ then no threads are created, master thread executes loop sequentially.	
master thread executes loop sequentially.	
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ested loops	Notes:
!\$omp parallel do private(i) do j=1,m	
do $i=1, n$	
a(i,j) = 0.d0 enddo	
enddo	
The loop on j is split up between threads.	
The thread handling $j=1$ does the entire loop on i,	
sets a(1,1), a(2,1),, a(n,1).	
Note: The loop iterator i must be declared private!	
$_{\rm j}$ is private by default, ${\rm i}$ is shared by default.	
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ested loops	Notes:
Which is better? (assume $m \approx n$)	
<pre>!\$omp parallel do private(i)</pre>	
do $j=1, m$ do $i=1, n$	
a(i,j) = 0.d0	
enddo enddo	
or	
do j=1,m	
!\$omp parallel do	
do $i=1, n$	
a(i,j) = 0.d0 enddo	
enddo	
The first has less overhead: Threads created only once.	
The second has more overhead: Threads created <i>m</i> times.	

Nested loops	Notes:
But have to make sure loop can be parallelized!	
Incorrect code for replicating first column:	
!\$omp parallel do private(j)	
do i=2,n	
do $j=1,m$ a(i,j) = a(i-1,j)	
a(1, j) = a(1-1, j)enddo	
enddo	
Corrected: (j's can be done in any order, i's cannot)	
!\$omp parallel do private(i)	
do j=1,m	
do $i=2, n$ a(i, j) = a(i-1, j)	
enddo	
enddo	
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Reductions	Notes:
Incorrect code for computing $ x _1 = \sum_i x_i $:	
norm = 0.d0	
!\$omp parallel do	
do $i=1, n$ norm = norm + abs(x(i))	
enddo	
There is a race condition: each thread is updating same shared variable norm.	
Correct code:	
<pre>!\$omp parallel do reduction(+ : norm)</pre>	
do i=1,n	
<pre>norm = norm + abs(x(i)) enddo</pre>	
A reduction reduces an array of numbers to a single value. R.J. LeVeque, University of Washington AMath 483/583, Lecture 14, April 27, 2011	R.J. LeVeque, University of Washington AMath 483/583, Lecture 14, April 27, 2011
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Reductions	Notes:
A more complicated way to do this:	
norm = 0.d0	
<pre>!\$omp parallel private(mysum) shared(norm)</pre>	
mysum = 0 !\$omp do	
do i=1, n	
<pre>mysum = mysum + abs(x(i))</pre>	
enddo	
!\$omp critical	
norm = norm + mysum	
!\$omp end critical !\$omp end parallel	
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!\$omp end parallel

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ome other reductions	Notes:		
Can do reductions using $+,-,\ast,$ min, max, .and., .or., some others			
General form:			
<pre>!\$omp parallel do reduction(operator : list)</pre>			
Example with max:			
<pre>y = -1.d300 ! very negative value !\$omp parallel do reduction(max: y) do i=1,n y = max(y,x(i)) enddo print *, 'max of x = ',y</pre>			
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	Notes:	R.J. LeVeque, University of Washington	AMath 483/583, Lecture 14, April 27, 201
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Ome other reductions General form: !\$omp parallel do reduction(operator : list) Example with .or.:	Notes:	R.J. LeVeque, University of Washington	AMath 483/583, Lecture 14, April 27, 20
<pre>ome other reductions General form: !\$omp parallel do reduction(operator : list) Example with .or.: logical anyzero ! set x anyzero = .false. !\$omp parallel do reduction(.or.: anyzero) do i=1,n anyzero = anyzero .or. (x(i) == 0.d0)</pre>	Notes:	R.J. LeVeque, University of Washington	AMath 483/583, Lecture 14, April 27, 20
<pre>ome other reductions General form: !\$omp parallel do reduction(operator : list) Example with .or.: logical anyzero ! set x anyzero = .false. !\$omp parallel do reduction(.or.: anyzero) do i=1,n</pre>	Notes:	R.J. LeVeque, University of Washington	AMath 483/583, Lecture 14, April 27, 20
<pre>ome other reductions General form: !\$omp parallel do reduction(operator : list) Example with .or.: logical anyzero ! set x anyzero = .false. !\$omp parallel do reduction(.or.: anyzero) do i=1,n anyzero = anyzero .or. (x(i) == 0.d0) enddo</pre>	Notes:	R.J. LeVeque, University of Washington	AMath 483/583, Lecture 14, April 27