Programming OpenMP

Scoping

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Scoping Rules

- Managing the Data Environment is the challenge of OpenMP.

- *Scoping* in OpenMP: Dividing variables in *shared* and *private*:
  - *private*-list and *shared*-list on Parallel Region
  - *private*-list and *shared*-list on Worksharing constructs
  - General default is *shared* for Parallel Region, *firstprivate* for Tasks.
  - Loop control variables on *for*-constructs are *private*
  - Non-static variables local to Parallel Regions are *private*
  - *private*: A new uninitialized instance is created for the task or each thread executing the construct
    - *firstprivate*: Initialization with the value before encountering the construct
    - *lastprivate*: Value of last loop iteration is written back to Master
  - Static variables are *shared*

Tasks are introduced later

Privatization of Global/Static Variables

- Global / static variables can be privatized with the *threadprivate* directive
  - One instance is created for each thread
    - Before the first parallel region is encountered
    - Instance exists until the program ends
    - Does not work (well) with nested Parallel Region
  - Based on thread-local storage (TLS)
    - TlsAlloc (Win32-Threads), pthread_key_create (Posix-Threads), keyword `__thread` (GNU extension)

C/C++

```
static int i;
#pragma omp threadprivate(i)
```

Fortran

```
SAVE INTEGER :: i
!$omp threadprivate(i)
```

Privatization of Global/Static Variables

- Global / static variables can be privatized with the *threadprivate* directive
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C/C++

```
static int i;
#pragma omp threadprivate(i)
```

Fortran

```
SAVE INTEGER :: i
!$omp threadprivate(i)
```

Really: try to avoid the use of threadprivate and static variables!

Back to our example

C/C++

```
int i, s = 0;
#pragma omp parallel for
for (i = 0; i < 100; i++)
{
#pragma omp critical
   {  s = s + a[i];  }
}
```

It‘s your turn: Make It Scale!

```
#pragma omp parallel
{

#pragma omp for
   for (i = 0; i < 99; i++)
   {

        s = s + a[i];

   }

} // end parallel
```

```
do i = 0, 99
   s = s + a(i)
end do
```

→

```
do i = 0, 24
   s = s + a(i)
end do
```

```
do i = 25, 49
   s = s + a(i)
end do
```

```
do i = 50, 74
   s = s + a(i)
end do
```

```
do i = 75, 99
   s = s + a(i)
end do
```

(done)

```
#pragma omp parallel
{
    double ps = 0.0;    // private variable
#pragma omp for
   for (i = 0; i < 99; i++)
   {
          ps = ps + a[i];
   }
#pragma omp critical
{
    s += ps;
}
} // end parallel
```

do i = 0, 99
  s = s + a(i)
end do

→

do i = 0, 24
  $s_1 = s_1 + a(i)$
end do
$s = s + s_1$

do i = 25, 49
  $s_2 = s_2 + a(i)$
end do
$s = s + s_2$

do i = 50, 74
  $s_3 = s_3 + a(i)$
end do
$s = s + s_3$

do i = 75, 99
  $s_4 = s_4 + a(i)$
end do
$s = s + s_4$

The Reduction Clause

- In a *reduction*-operation the operator is applied to all variables in the list. The variables have to be *shared*.
  - `reduction(operator:list)`
  - The result is provided in the associated reduction variable

C/C++

```
int i, s = 0;

#pragma omp parallel for reduction(+:s)
for(i = 0; i < 99; i++)
{
   s = s + a[i];
}
```

  - Possible reduction operators with initialization value:
    `+ (0), * (1), - (0), & (~0), | (0), && (1), || (0), ^ (0), min (largest number), max (least number)`
  - Remark: OpenMP also supports user-defined reductions (not covered here)

Example

PI

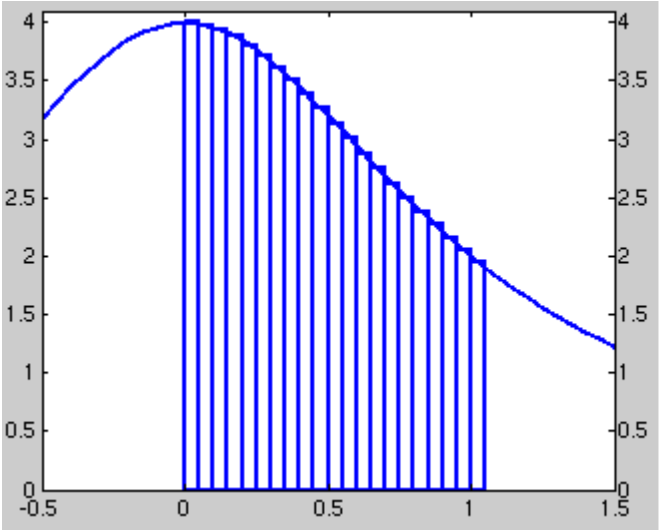
Example: Pi (1/2)

```
double f(double x)
{
   return (4.0 / (1.0 + x*x));
}

double CalcPi (int n)
{
   const double fH   = 1.0 / (double) n;
   double fSum = 0.0;
   double fX;
   int i;

#pragma omp parallel for
   for (i = 0; i < n; i++)
   {
      fX = fH * ((double)i + 0.5);
      fSum += f(fX);
   }
   return fH * fSum;
}
```

$$\pi = \int_0^1 \frac{4}{1+x^2}$$



Example: Pi (2/2)

$$\pi = \int_0^1 \frac{4}{1+x^2}$$

```
double f(double x)
{
   return (4.0 / (1.0 + x*x));
}

double CalcPi (int n)
{
   const double fH   = 1.0 / (double) n;
   double fSum = 0.0;
   double fX;
   int i;

#pragma omp parallel for private(fX,i) reduction(+:fSum)
   for (i = 0; i < n; i++)
   {
      fX = fH * ((double)i + 0.5);
      fSum += f(fX);
   }
   return fH * fSum;
}
```