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SUMMIT

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Introduction to OpenMP

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Before we start…

Clarify a few phrases:

- Process
  - Scheduled execution unit with its own address space
- Thread
  - Scheduled execution unit, sharing address space with other threads
- Future, (Task)
  - Description of work, not scheduled

Forms of Parallelism

Multi-process:

- Unix `fork()`
- Separate address space: sharing is explicit
  - Linux's `clone()` and `unshare()` provide finer granularity
- More robust:
  - No accidental memory corruption
  - No complete tear-down on crash
- Fast Linux Inter-Process Communication (IPC)
  - Pipes, message queues, shared memory
  - Robust mutexes for crash handling

Forms of Parallelism

Multi-process:

- Exploit multiple machines with few additional changes
- Not well suited for automatically generated parallelism
  - Exception: using of MPI

Forms of Parallelism

Multi-threaded:

- Widely available through pthread_create()
- Share everything except register content (implies stack pointer)
- Accidental corruptions felt by every thread
- Thread crash causes complete tear-down
- Communication costs minimal
  - Only synchronization cost
- Limited to single machine

Explicit Parallelism

Processes and threads require explicit handling

- Start explicitly
  - How many?
  - What to do?

→ Not scalable

  - Programmers cannot keep track of more than a handful of execution paths

- Parametrize explicitly
  - Where to run (affinity)?

→ Machine architecture changes and becomes more important

  - Programmers cannot adjust each program individually

Parallel Code

Parallel code looks like serial code to tools

- Programmer's responsibility to use synchronization
- Hard to check for all kinds of mistakes

Better model: tell tools about parallelism

- Requires integration into language
- Tools can
  - Warn about some incorrect uses
  - Use optimal mechanisms without hardcoding in sources
- After adjustment of tools for new machine architecture only recompilation needed

OpenMP

Language Extension

- C, C++, Fortran
- Compiler gets insight into parallelism
- Same program can work sequentially
  - Makes debugging easier
  - Allows using older tools on same code

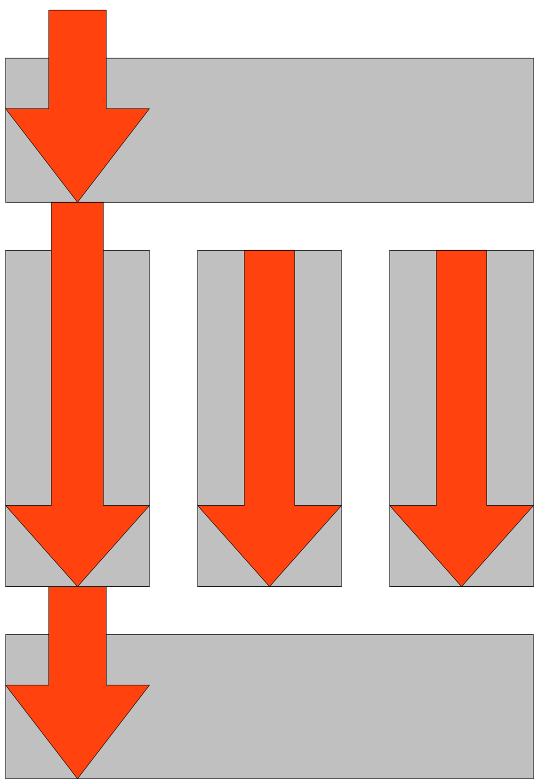
Openly developed specification

Central place for many optimizations

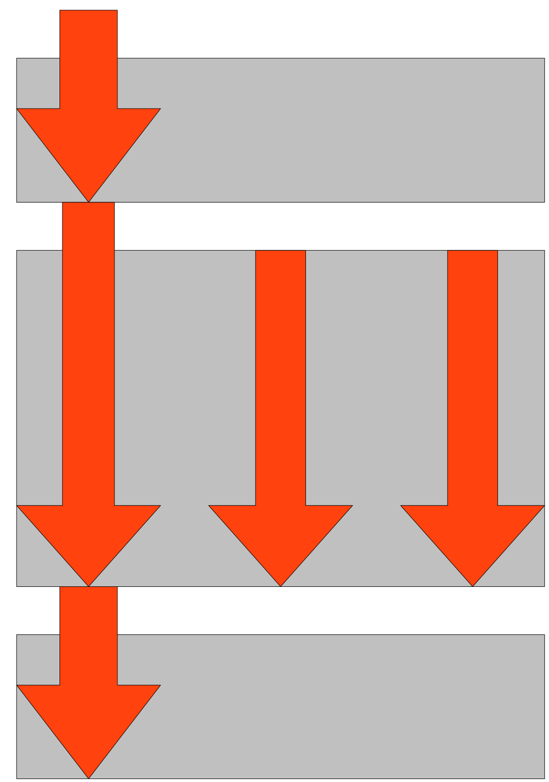
- OpenMP comes with runtime parts
- Specification allows runtime to make decisions about number and placement of threads

Forms of Structured Parallelism

Independent sections



Loops



Parallel Sections

```
sum = 0;



for (i = 0; i < N; ++i)
    sum += count_whatever(some_data1[i]);
for (i = 0; i < N; ++i)
    sum += count_whatever(some_data2[i]);
```

Parallel Sections

Available in OpenMP v2.5 (RHEL5):

```
    sum = 0;
#   pragma omp parallel sections
{

    for (i = 0; i < N; ++i)
#       pragma omp atomic
        sum += count_whatever(some_data1[i]);
#   pragma omp section
    for (i = 0; i < N; ++i)
#       pragma omp atomic
        sum += count_whatever(some_data2[i]);
}
```

Parallel Sections

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    sum = 0;
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    for (i = 0; i < N; ++i)
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        sum += count_whatever(some_data1[i]);
#   pragma omp section
    for (i = 0; i < N; ++i)
#       pragma omp atomic
        sum += count_whatever(some_data2[i]);
}
```

Runtime may start threads

Implicit barrier

Parallel Sections

Available in OpenMP v2.5 (RHEL5):

```
    sum = 0;
#   pragma omp parallel sections reduction(+:sum)
{

    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data1[i]);
#    pragma omp section
    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data2[i]);
}
```

Parallel Sections

Available in OpenMP v2.5 (RHEL5): **NEW!**

```
    sum = 0;
#   pragma omp parallel sections reduction(+:sum)
{

    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data1[i]);
#   pragma omp section
    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data2[i]);
}
```

No Atomic

Parallel Sections

Available in OpenMP v2.5 (RHEL5):

```
sum = 0;

#  pragma omp parallel for reduction(+:sum)
   for (i = 0; i < N; ++i)

       sum += count_whatever(some_data1[i]);
#  pragma omp parallel for reduction(+:sum)
   for (i = 0; i < N; ++i)

       sum += count_whatever(some_data2[i]);
```

Parallel Sections

Available in OpenMP v2.5 (RHEL5):

```
sum = 0;

#  pragma omp parallel for reduction(+:sum)
   for (i = 0; i < N; ++i)

       sum += count_whatever(some_data
#  pragma omp parallel for reducti
   for (i = 0; i < N; ++i)

       sum += count_whatever(some_data2[i]);
```

Implicit barrier

Implicit barrier

Parallel Sections

Available in OpenMP v2.5 (RHEL5):

```
    sum = 0;
#   pragma omp parallel
{
#   pragma omp for reduction(+:sum) nowait
    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data1[i]);
#    pragma omp for reduction(+:sum)
    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data2[i]);
}
```

Parallel Sections

Available in OpenMP v2.5 (RHEL5):

```
    sum = 0;
#   pragma omp parallel
{
#   pragma omp for reduction(+:sum) nowait
    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data1[i]);
#    pragma omp for reduction(+:sum)
    for (i = 0; i < N; ++i)

        sum += count_whatever(some_data2[i]);
}
```

No implicit barrier

Convenience

```
#pragma omp parallel for
for (...)
    ...
```

short for

```
#pragma omp parallel
{
#   pragma omp for
    for (...)
        ...
}
```

Similarly for parallel sections

Explicit Tasks

Available in OpenMP v3 (RHEL6):

```
     sum = 0;
#  pragma omp parallel
{
#  pragma omp for nowait
     for (i = 0; i < N; ++i)
#          pragma omp task untied
           {
#             pragma omp atomic
                sum += count_whatever(some_data1[i]);
           }
#  pragma omp for nowait
     for (i = 0; i < N; ++i)
#          pragma omp task untied
           {
#             pragma omp atomic
              sum += count_whatever(some_data2[i]);
           }
}
```

Explicit Tasks

Available in OpenMP v3 (RHEL6):

```
    sum = 0;
#  pragma omp parallel
{
#  pragma omp for nowait
    for (i = 0; i < N; ++i)
#         pragma omp task untied
          {
#            pragma omp atomic
               sum += count_whatever(some_data1[i]);
          }
#  pragma omp for nowait
    for (i = 0; i < N; ++i)
#         pragma omp task untied
          {
#            pragma omp atomic
             sum += count_whatever(some_data2[i
          }
}
```

Any thread can pick up task

Implicit barrier, incl all tasks

Exclusion

Producer

```
struct elem *newp
  = ...;
#pragma critical
  pclock
{
   newp->next = first;
   first = newp;
}
```

Consumer

```
#pragma critical pclock
{
   curp = first;
   if (curp != NULL)
      first = first-
       >next;
}
... use curp ...
```

Only One

Executed by one thread

```
#pragma omp parallel
{
  fct1();
# pragma omp single
  nowait
  fct2();
  fct3();
}
```

Executed by master thread

```
#pragma omp parallel
{
  fct1();
# pragma omp master
  fct2();
  fct3();
}
```

Only One

Executed by one thread

```
#pragma omp parallel
{
  fct1();
# pragma omp single
  nowait
  fct2();
  fct
}
```

No implied barrier

Executed by master thread

```
#pragma omp parallel
{
  fct1();
# pragma omp master
  fct2();
  fct3();
}
```

Also available for other constructs

Extending the Range

Nested loops are “natural”

```
for (i = 1; i < N - 1; ++i)
    for (j = 1; j < M - 1; ++j)
        b[i][j] = (a[i][j-1]+a[i-1][j]+a[i][j]
                   +a[i+1][j]+a[i][j+1]) / 5;
```

Extending the Range

Nested loops are “natural”

Available in OpenMP v3 (RHEL6):

```
#pragma omp parallel for collapse(2)
for (i = 1; i < N - 1; ++i)
    for (j = 1; j < M - 1; ++j)
        b[i][j] = (a[i][j-1]+a[i-1][j]+a[i][j]
                  +a[i+1][j]+a[i][j+1]) / 5;
```

Extending the Range

Nested loops are “natural”

Available in OpenMP v3 (RHEL6):

Both loops in one iteration range

```
#pragma omp parallel for collapse(2)
for (i = 1; i < N - 1; ++i)
    for (j = 1; j < M - 1; ++j)
        b[i][j] = (a[i][j-1]+a[i-1][j]+a[i][j]
                   +a[i+1][j]+a[i][j+1]) / 5;
```

Scheduling

Parallel section has rules for how many threads to create

- Programmer can request number
- User can control through environment variable
- Or: OpenMP runtime can be in complete control

Loop scheduling:

- Reliable assignment of iterations to threads
- Fair distribution
- Or: also under control of the runtime

Outlook

OpenMP compiler & runtime become more intelligent:

- Runtime knows about machine architecture
- Compiler tells runtime about cost and memory behavior of the code

→Runtime in good position to make decision

- No adjust of program for new machine needed

Example:

- Tightly coupled tasks, writing to same memory
  - Run on one socket or cache domain

Outlook

Example: Large Working Set

- Choose loop iterations to touch different pages, allocate pages on different NUMA nodes, set thread affinity

Coordination:

- Many uncoordinated OpenMP programs unnecessarily stress machine
- With coordination between all OpenMP processes runtime could ensure machine resources are not oversubscribed

Result:

If possible, let runtime decide!

Questions?

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