Overcoming Distributed Debugging Challenges in the MPI+OpenMP Programming Model

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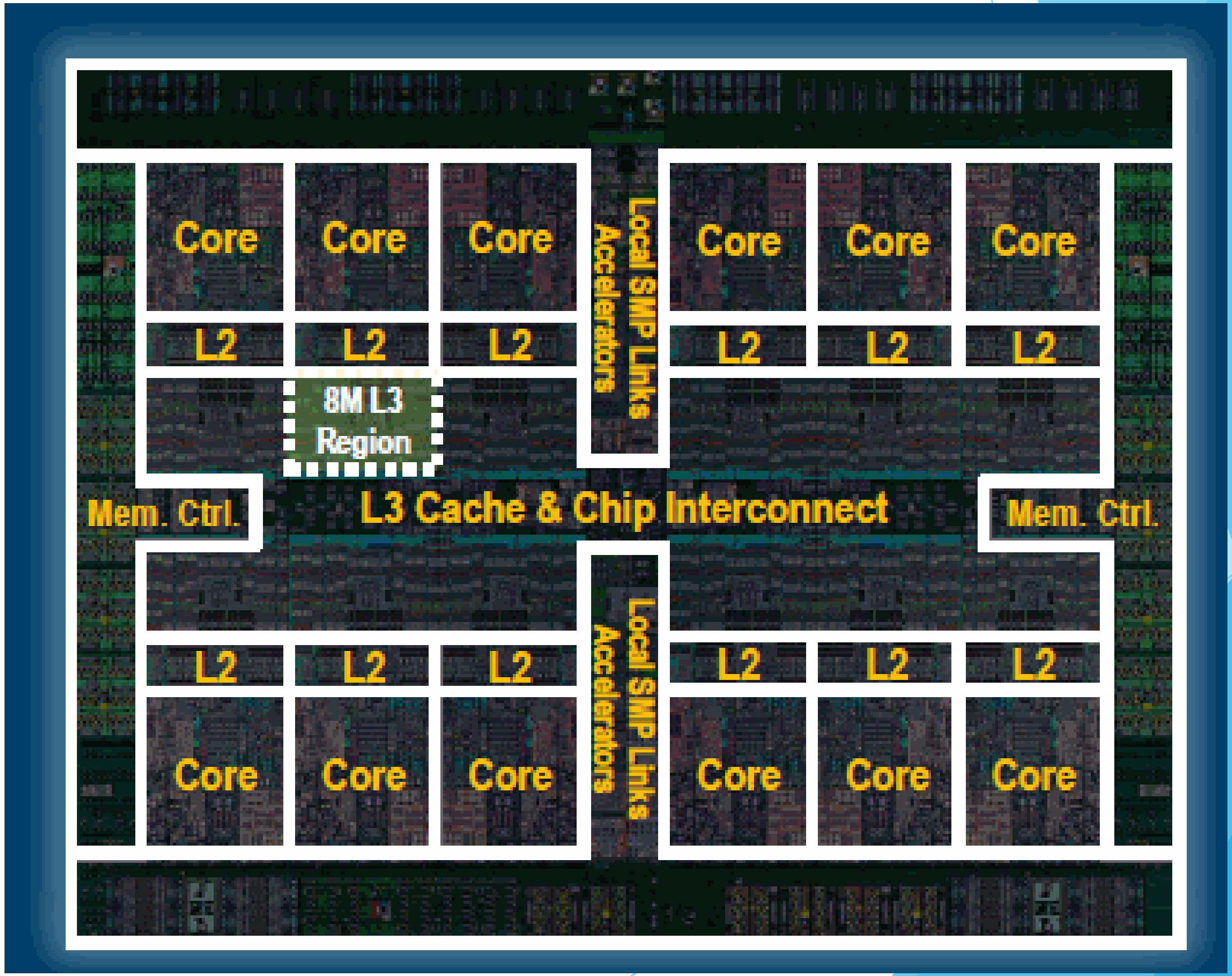
Growing computation power in supercomputers

- Supercomputers
  - Powerful compute nodes
  - Interconnection network & I/O subsystem

- Within each compute node
  - Multiple cores per chip, multiple threads per core
  - Acceleration devices: GPU, Intel MIC

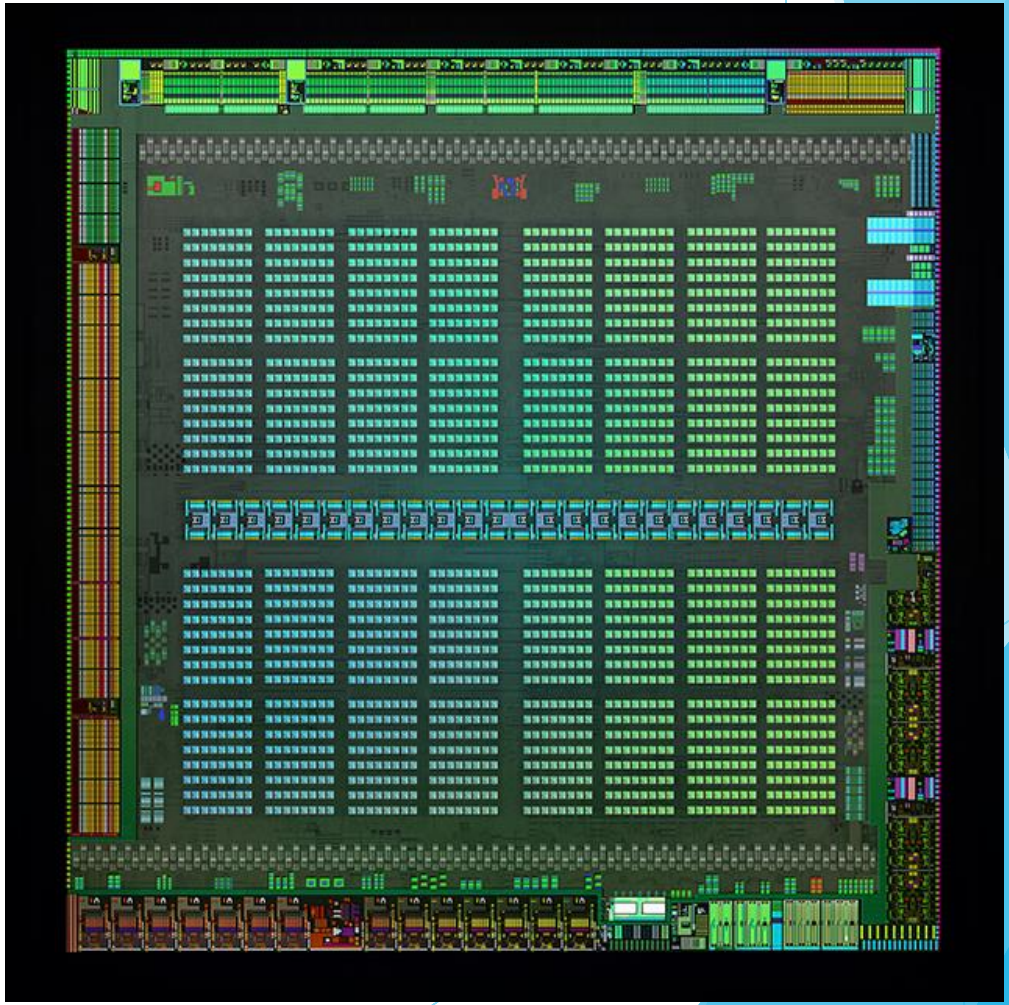
IBM POWER8

- 12 cores per chip
- 8 threads per core



NVIDIA GeForce GTX 980

- 2048 CUDA cores



SIERRA

- Next generation supercomputer coming to LLNL (2017)
  - ~150 petaflops
  - ~5x compared to top
  - IBM POWER9
  - NVIDIA GPU

Harnessing many levels of architectural parallelism

- Using a wide range of parallel programming models
  - Inter-node: MPI
  - Intra-node
    - Between CPUs: OpenMP, Cilk Plus
    - Host - Device: OpenMP 4, CUDA, OpenCL

MPI+OpenMP as a solution

- MPI dominates in message passing programming models
- OpenMP 4 supports both CPUs and devices

- MPI+OpenMP help exploit the SIERRA machine

- However, lack of debugging support

Outline

- OpenMP debugging support
  - Motivation -- what’s at hand
  - Background -- OMPD
  - Approach -- OpenMP stack builder
- MPI+OpenMP debugging support

An example of OpenMP debugging

```c
7   void bar()
8   {
9     #pragma omp parallel for num_threads(2)
10    for (int i = 0; i < 10; i++)
11      sleep(18);
12  }
13
14  void foo()
15  {
16    omp_set_nested(1);
17    #pragma omp parallel num_threads(2)
18    {
19      if (omp_get_thread_num() == 0)
20        sleep(90);
21      else
22        bar();
23    }
24  }
25
26  int main(int argc, char *argv[])
27  {
28    foo();
29    return 0;
30  }
```

Unnecessary frames from OpenMP runtime

Stack of main thread

__nanosleep_nocancel
__sleep
foo@example.c:20
__kmp_invoke_microtask
__kmp_invoke_task_func
__kmp_fork_call
__kmpc_fork_call
foo@example.c:17
main@example.c:28
__libc_start_main
_start

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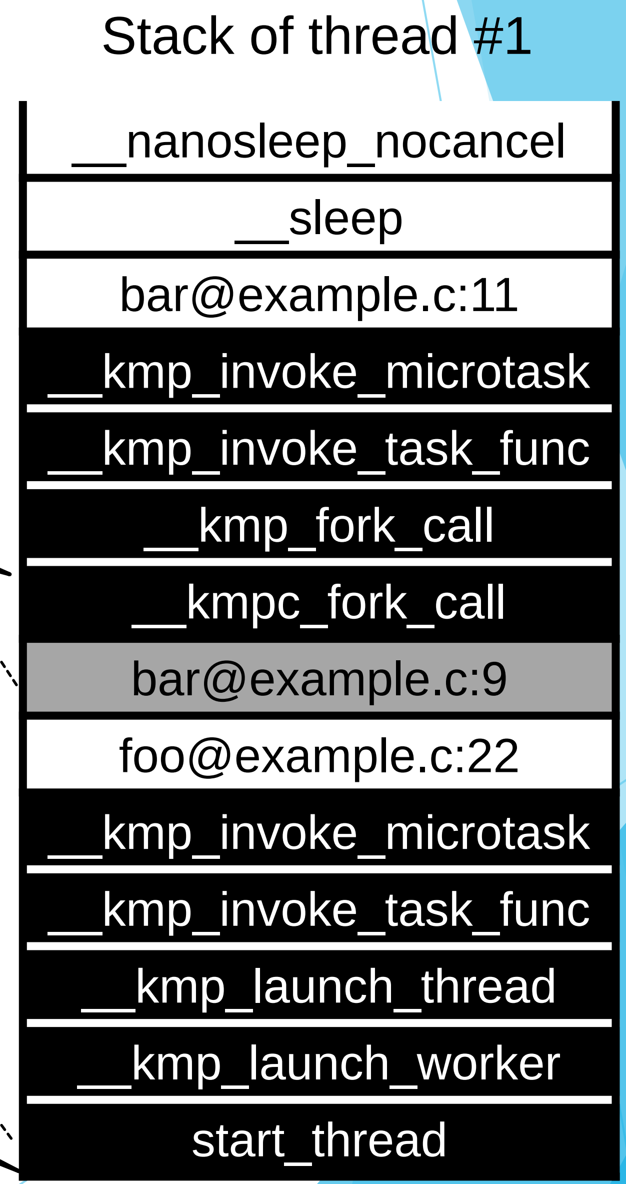

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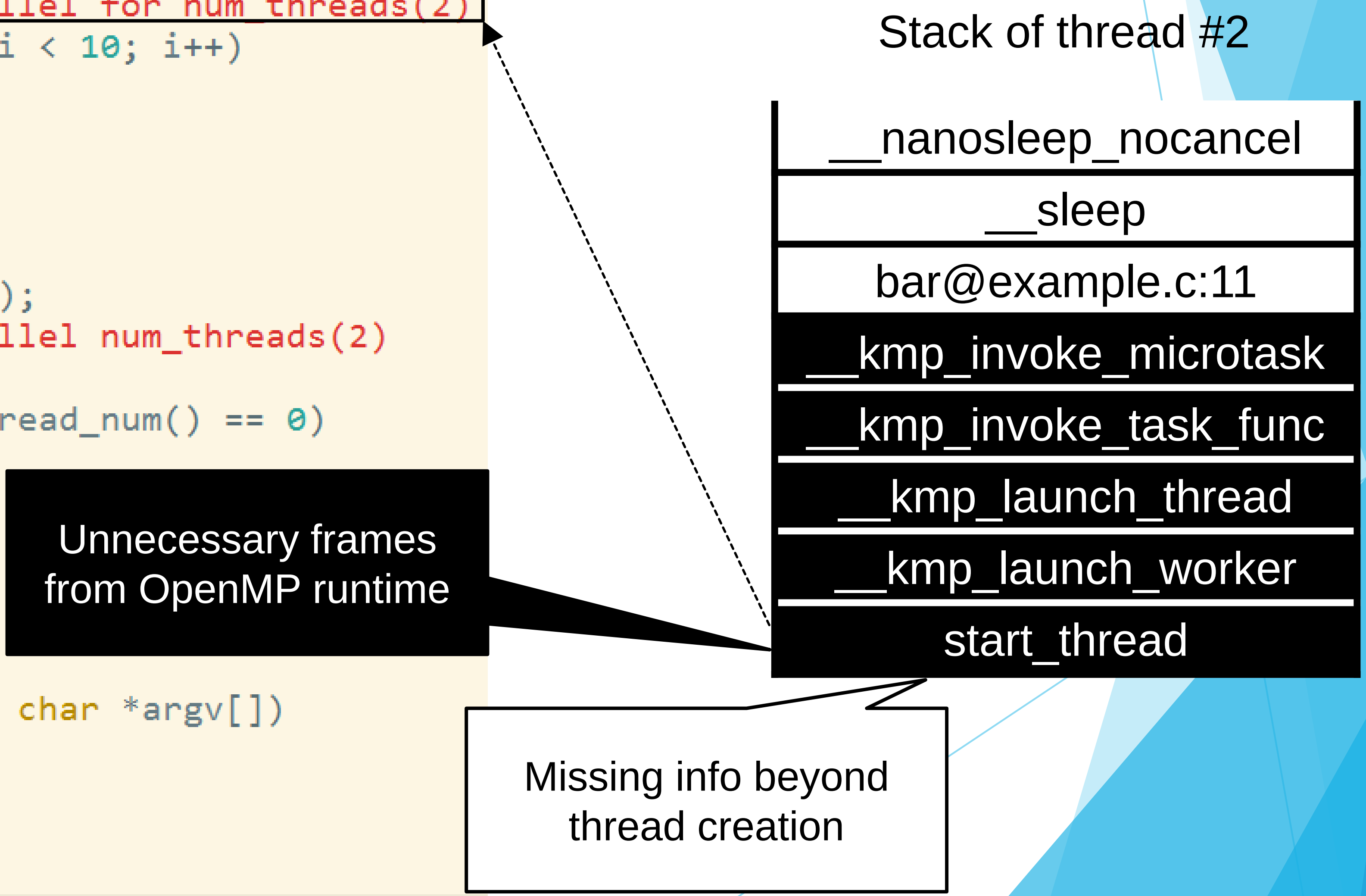
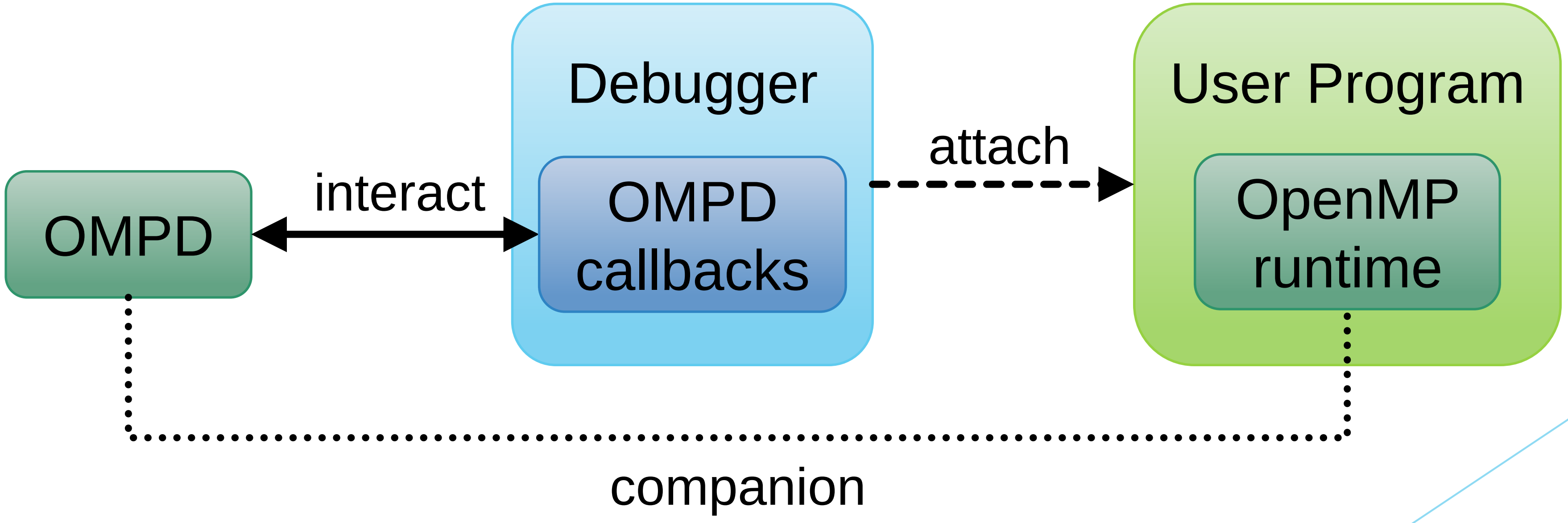


What’s at hand

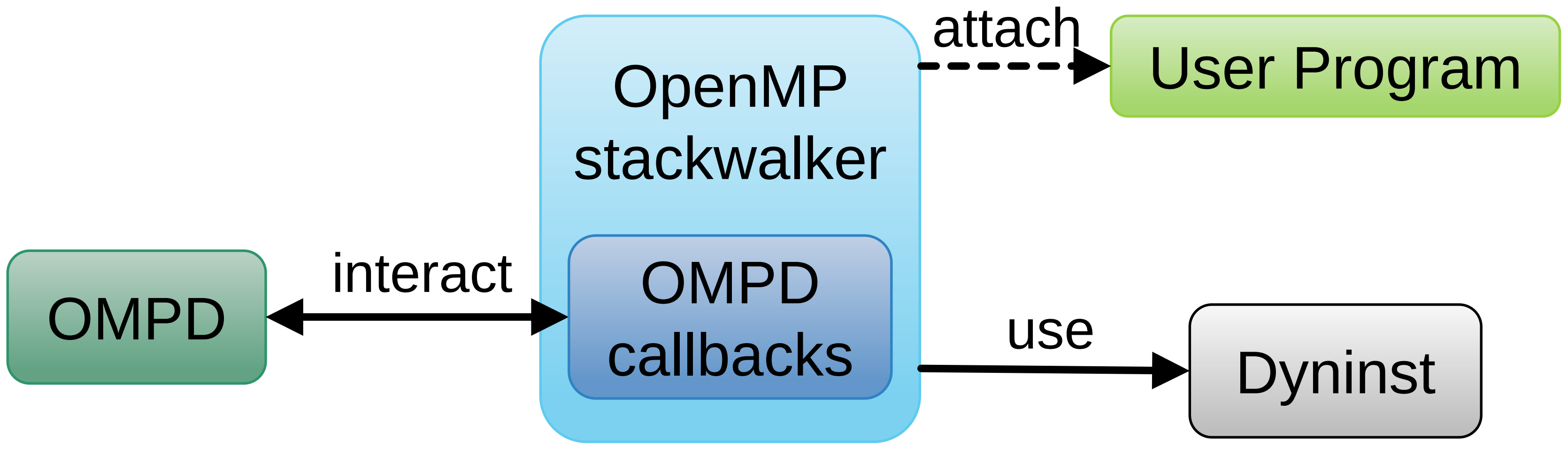
- Debugging OpenMP programs could be painful
  - Debugger users need intuitive stack info to reason about bugs
  - However, raw stacks of OpenMP threads don’t make sense
  - Need a way to reconstruct the stacks

Background -- OMPD

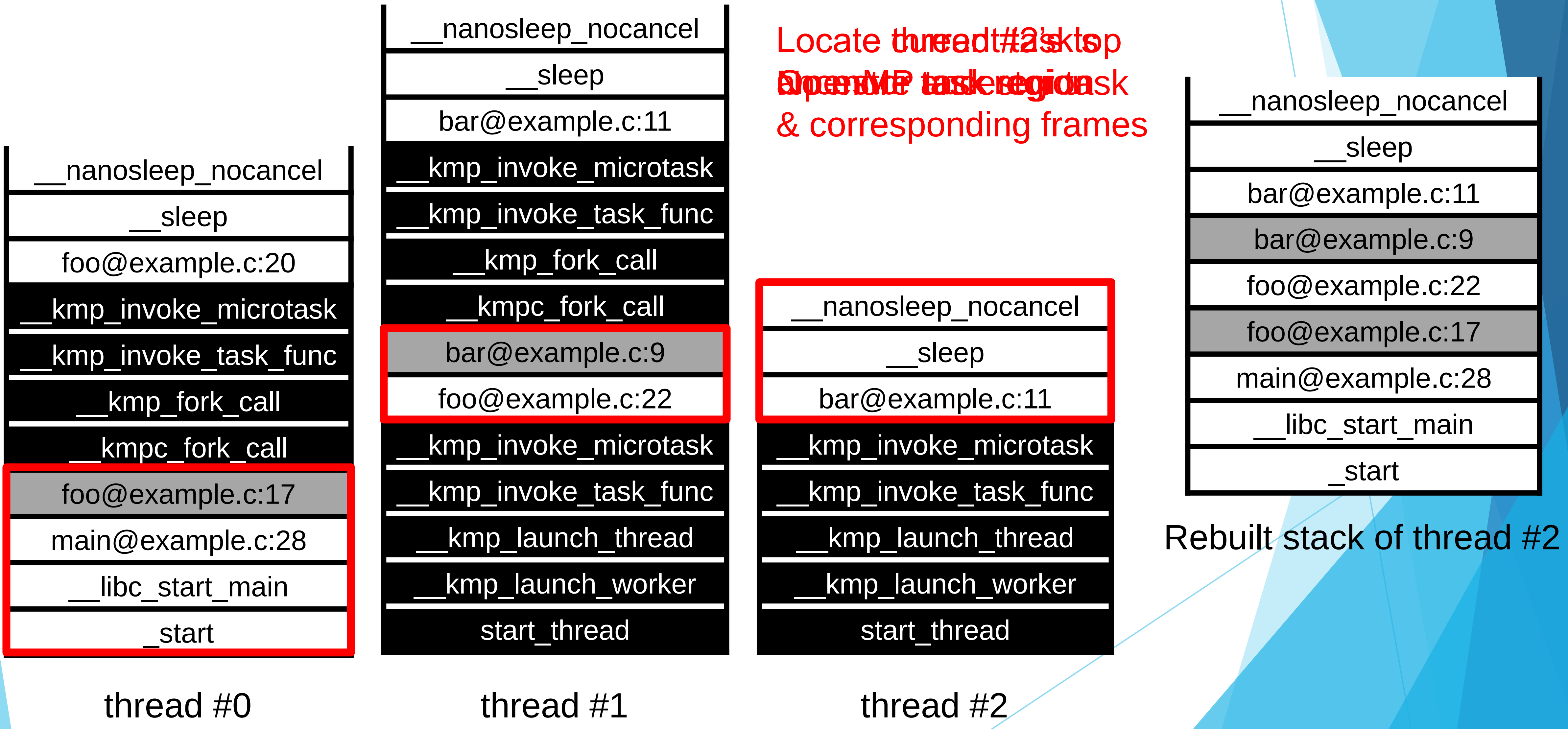
- A shared library companion to an OpenMP runtime system



OpenMP stackwalker



Rebuilding stacks for OpenMP threads



Results of OpenMP stackwalker

```
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Stack of main thread

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__sleep
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foo@example.c:17
main@example.c:28
__libc_start_main
_start

Results of OpenMP stackwalker

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19      if (omp_get_thread_num() == 0)
20        sleep(90);
21      else
22        bar();
23    }
24  }
25
26  int main(int argc, char *argv[])
27  {
28    foo();
29    return 0;
30  }
```

Stack of thread #1 & #2

__nanosleep_nocancel
__sleep
bar@example.c:11
bar@example.c:9
foo@example.c:22
foo@example.c:17
main@example.c:28
__libc_start_main
_start

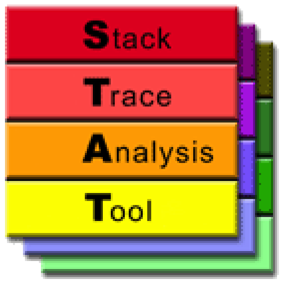
Summary of OpenMP Debugging

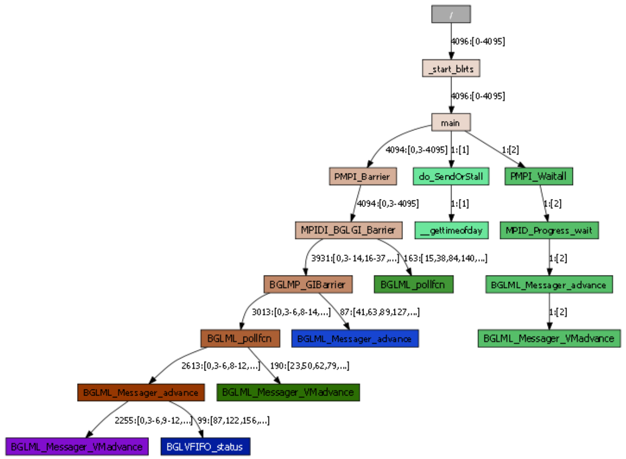
- Debugging OpenMP programs could be painful
  - Stacks of OpenMP threads are not intuitive
- People proposed OMPD to facilitate OpenMP debugging
- Our work: rebuild stacks of OpenMP threads
  - Eliminated unnecessary frames from OpenMP runtime
  - Rebuild the full calling context for OpenMP threads

Outline

- OpenMP debugging support
- MPI+OpenMP debugging support

Stack trace analysis tool (STAT)

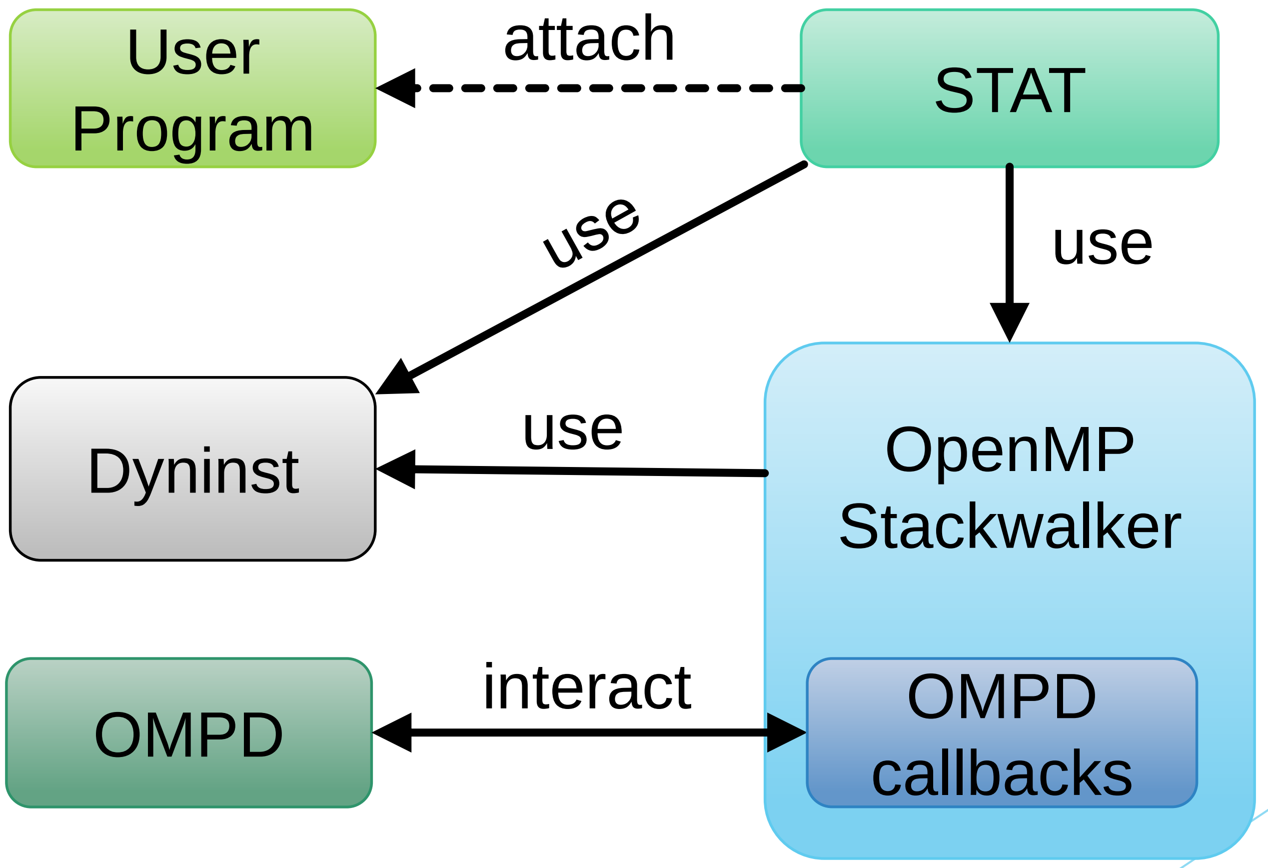




- Developed at LLNL
  - Highly-scalable, lightweight debugging tool for MPI applications
  - Various views to facilitate debugging on MPI

- We try to add OpenMP awareness into STAT so that it supports MPI+OpenMP debugging

STAT for MPI+OpenMP



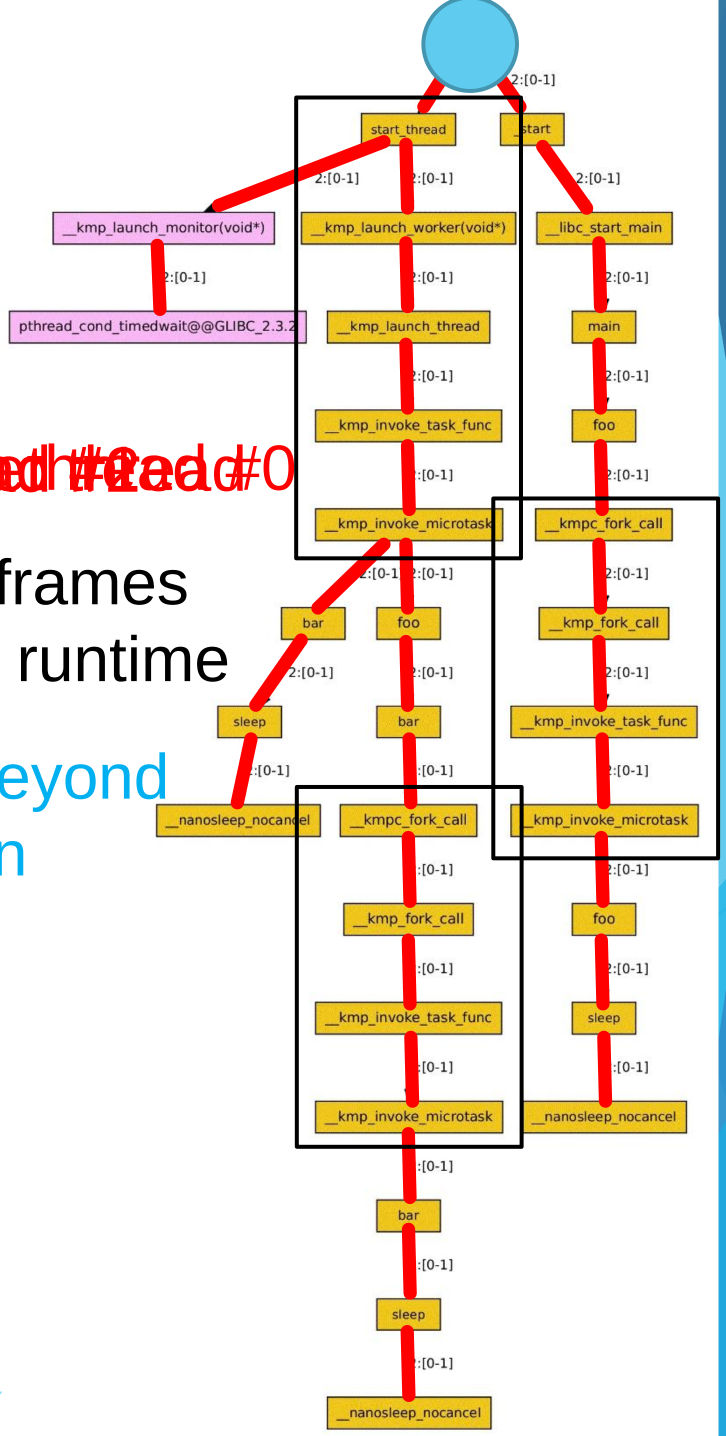
STAT without OpenMP awareness

```
void bar()
{
  #pragma omp parallel for num_threads(2)
  for (int i = 0; i < 10; i++)
    sleep(18);
}

void foo()
{
  omp_set_nested(1);
  #pragma omp parallel num_threads(2)
  {
    if (omp_get_thread_num() == 0)
      sleep(90);
    else
      bar();
  }
}

int main(int argc, char *argv[])
{
  MPI_Init(&argc, &argv);
  foo();
  MPI_Finalize();
  return 0;
}
```

OpenMP thread #0

Unnecessary frames from OpenMP runtime

Missing info beyond thread creation



STAT with OpenMP awareness

```c
void bar()
{
  #pragma omp parallel for num_threads(2)
  for (int i = 0; i < 10; i++)
    sleep(18);
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void foo()
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  omp_set_nested(1);
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  {
    if (omp_get_thread_num() == 0)
      sleep(90);
    else
      bar();
  }
}

int main(int argc, char *argv[])
{
  MPI_Init(&argc, &argv);
  foo();
  MPI_Finalize();
  return 0;
}
```

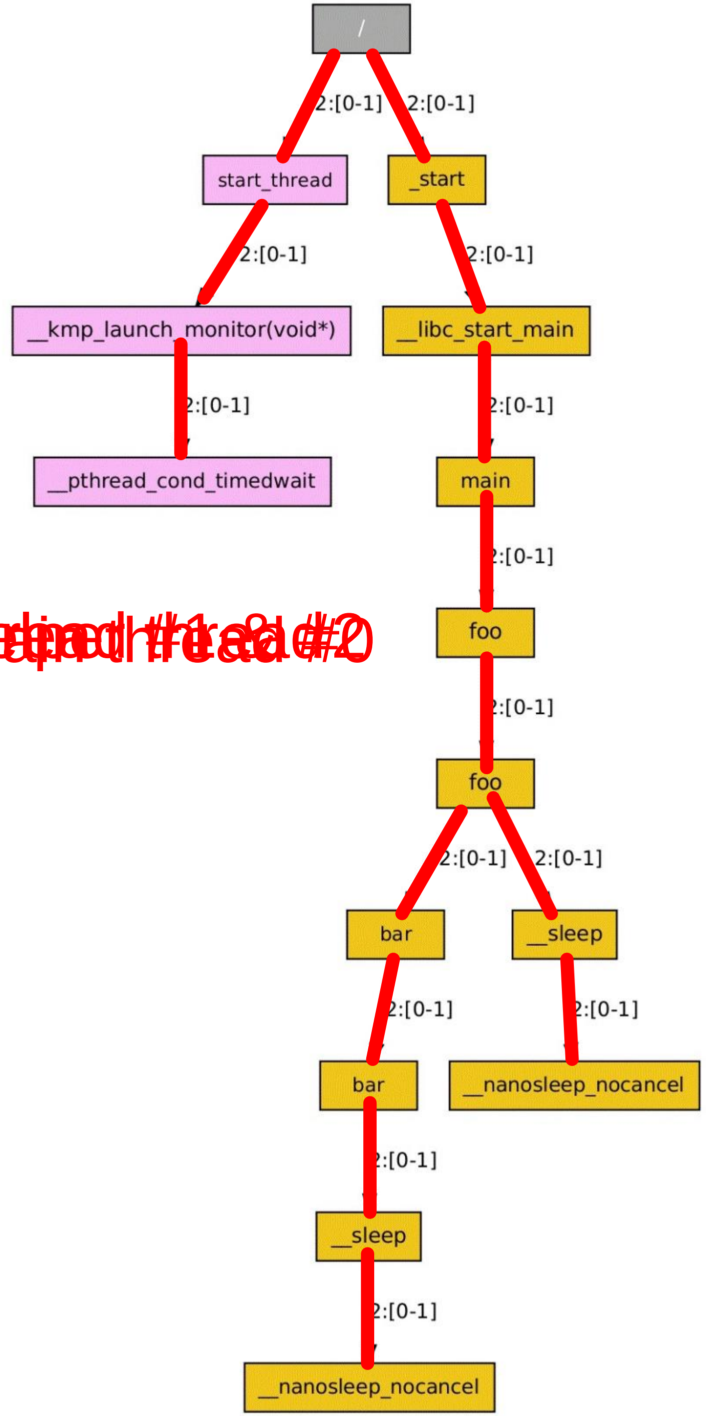

Conclusion

- Rebuild stacks of OpenMP threads using OMPD
- Provide intuitive stack trace view of MPI+OpenMP programs (prototype)

Future work

- Further improve generated stack trace view
- Evaluate STAT on large MPI+OpenMP applications

- Allowing debugging of OpenMP 4.0 programs (device support)
- Other views including OpenMP task view, parent/child view, etc.

References

- [1] D. Arnold, D. Ahn, B. de Supinski, G. Lee, B. Miller, and M. Schulz. Stack trace analysis for large scale debugging. In Parallel and Distributed Processing Symposium, 2007. IPDPS 2007. IEEE International, pages 1-10, March 2007.
- [2] A. Eichenberger, J. Mellor-Crummey, M. Schulz, N. Copty, J. Cownie, R. Dietrich, X. Liu, E. Loh, and D. Lorenz. OpenMP technical report 2 on the OMPT interface. Technical report, 2014.
- [3] A. Eichenberger, J. Mellor-Crummey, M. Schulz, N. Copty, J. Cownie, R. Dietrich, J. Signore, E. Loh, and D. Lorenz. OMPD: An application programming interface for a debugger support library for OpenMP. Technical report, 2014.
- [4] G. Ravipati, A. R. Bernat, N. Rosenblum, B. P. Miller, and J. K. Hollingsworth. Toward the deconstruction of dyninst. Technical report, 2007.