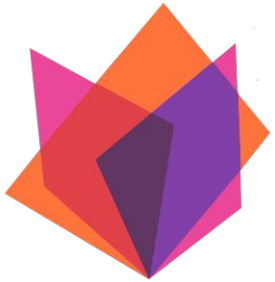
OpenMP

SC'20 Booth Talk Series



OpenMP compiler optimizations in LLVM

Johannes Doerfert, Argonne National Laboratory

OpenMP Compiler Optimizations in LLVM

Johannes Doerfert (Argonne National Laboratory)

Adapted from our LLVM-Developers Meeting 2020 talk

https://youtu.be/M0DrhQbjrro

OpenMP in LLVM

http://openmp.llvm.org/docs

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OpenMP in LLVM

http://openmp.llvm.org/docs

Clang

OpenMP Parser

OpenMP Sema

OpenMP CodeGen

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OpenMP runtimes

libomp.so (classic, host)

libomptarget + plugins (offloading, host)

libomptarget-nvptx (offloading, device)

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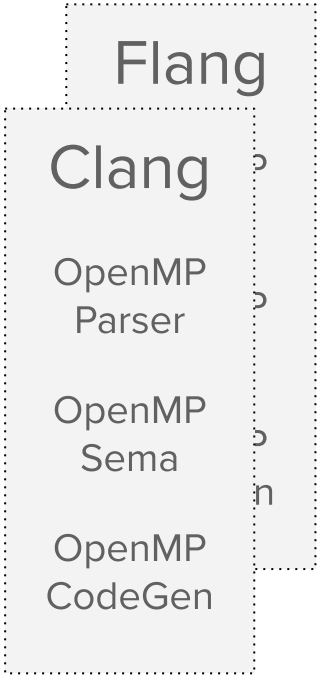

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OpenMPIRBuilder

frontend-independant OpenMP LLVM-IR generation

favor simple and expressive LLVM-IR

reusable for non-OpenMP parallelism

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OpenMPOpt

interprocedural optimization pass

contains host & device optimizations

run with -O2 and -O3 since LLVM 11

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Joseph Huber
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Design Goal

Report every successful and failed optimization

Optimization Remarks

Example: OpenMP runtime call deduplication

```
double *A = malloc(size * omp_get_thread_limit());
double *B = malloc(size * omp_get_thread_limit());

#pragma omp parallel
do_work(&A[omp_get_thread_num()*size]);
#pragma omp parallel
do_work(&B[omp_get_thread_num()*size]);
```

OpenMP runtime calls with same return values can be merged to a single call

Optimization Remarks

Example: OpenMP runtime call deduplication

```
double *A = malloc(size * omp_get_thread_limit());
double *B = malloc(size * omp_get_thread_limit());

#pragma omp parallel
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do_work(&B[omp_get_thread_num()*size]);
```

OpenMP runtime calls with same return values can be merged to a single call

$ clang -g -O2 deduplicate.c -fopenmp -Rpass=openmp-opt

```
deduplicate.c:12:29: remark: OpenMP runtime call omp_get_thread_limit moved to deduplicate.c:11:29: [-Rpass=openmp-opt]
   double *B = malloc(size*omp_get_thread_limit());
deduplicate.c:11:29: remark: OpenMP runtime call omp_get_thread_limit deduplicated [-Rpass=openmp-opt]
   double *A = malloc(size*omp_get_thread_limit());
```

Design Goal

Communicate and explain OpenMP implementation details to users

Optimization Remarks

Example: OpenMP Target Scheduling

```
clang -Rpass=openmp-opt ...
```

```
void bar(void) {
  #pragma omp parallel
  { }
}
void foo(void) {
 #pragma omp target teams
 {
  #pragma omp parallel
  {}
  bar();
  #pragma omp parallel
  {}
 }
}
```

```
remark: Found a parallel region that is called in a target region but not part of a combined target construct nor nested inside a target construct without intermediate code. This can lead to excessive register usage for unrelated target regions in the same translation unit due to spurious call edges assumed by ptxas.
remark: Parallel region is not known to be called from a unique single target region, maybe the surrounding function has external linkage?; will not attempt to rewrite the state machine use.
remark: Found a parallel region that is called in a target region but not part of a combined target construct nor nested inside a target construct without intermediate code. This can lead to excessive register usage for unrelated target regions in the same translation unit due to spurious call edges assumed by ptxas.
remark: Specialize parallel region that is only reached from a single target region to avoid spurious call edges and excessive register usage in other target regions. (parallel region ID: __omp_outlined__1_wrapper, kernel ID: __omp_offloading_35_a1e179_foo_l7)
remark: Target region containing the parallel region that is specialized. (parallel region ID: __omp_outlined__1_wrapper, kernel ID: __omp_offloading_35_a1e179_foo_l7)
remark: Found a parallel region that is called in a target region but not part of a combined target construct nor nested inside a target construct without intermediate code. This can lead to excessive register usage for unrelated target regions in the same translation unit due to spurious call edges assumed by ptxas.
remark: Specialize parallel region that is only reached from a single target region to avoid spurious call edges and excessive register usage in other target regions. (parallel region ID: __omp_outlined__3_wrapper, kernel ID: __omp_offloading_35_a1e179_foo_l7)
remark: Target region containing the parallel region that is specialized. (parallel region ID: __omp_outlined__3_wrapper, kernel ID: __omp_offloading_35_a1e179_foo_l7)
remark: OpenMP GPU kernel __omp_offloading_35_a1e179_foo_l7
```

OpenMP Advisor and Runtime Information

- Development of the `llvm-openmp-advisor` tool (LLVM 12, current git)
- Optimization remark explanations, examples, FAQs, … all gradually added to http://openmp.llvm.org/docs
- Environment variable LIBOMPTARGET_INFO for runtime library interactions

```
$ clang -O2 generic.c -fopenmp -fopenmp-targets=nvptx64-nvidia-cuda -o generic
$ env LIBOMPTARGET_INFO=1 ./generic
```

```
CUDA device 0 info: Device supports up to 65536 CUDA blocks and 1024 threads with a warp size of 32
CUDA device 0 info: Launching kernel __omp_offloading_fd02_c2a59832_main_l106 with 48 blocks and 128 threads in Generic mode
```

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Design Goal

Allow modular OpenMP code without performance penalty

no need for manual low-level optimizations

Tracking OpenMP Internal Control Variables

```
void foo() {
  #pragma omp parallel
  bar();
}

void bar() {
  if (omp_in_parallel()) {
    ...
  } else {
    ...
  }
}
```

Tracking OpenMP Internal Control Variables

```
void foo() {
  #pragma omp parallel
  bar();
}

void bar() {
  if (omp_in_parallel()) {
    ...
  } else {
    ...
  }
}
```


Can be deleted if `omp_in_parallel()` is known* to return true, e.g., after inlining into foo.

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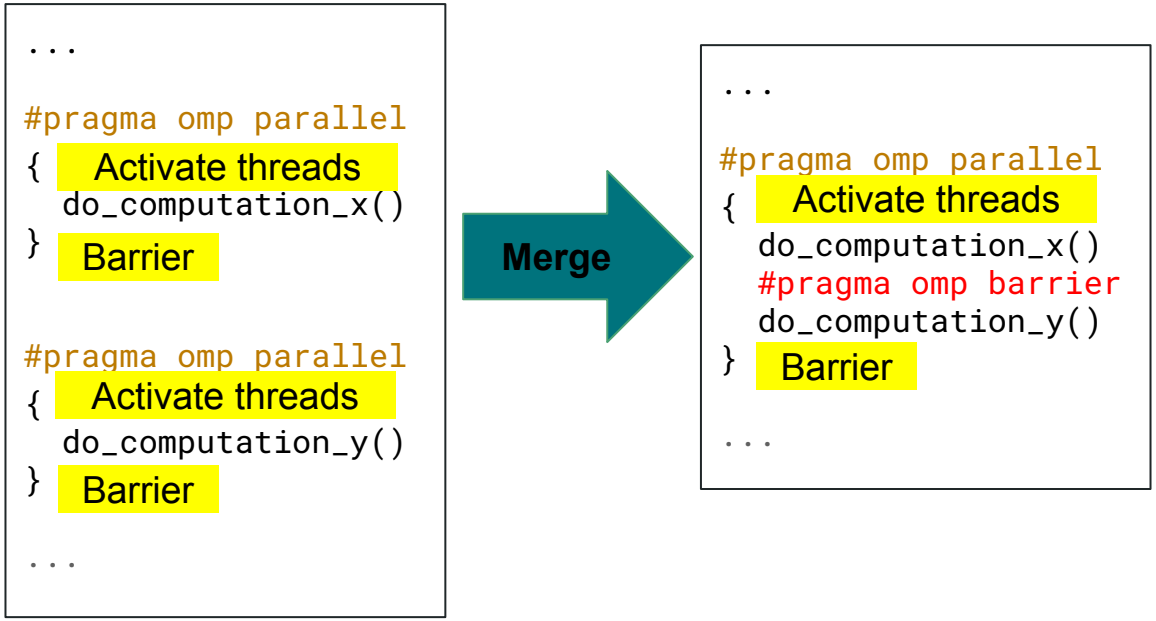
Design Goal

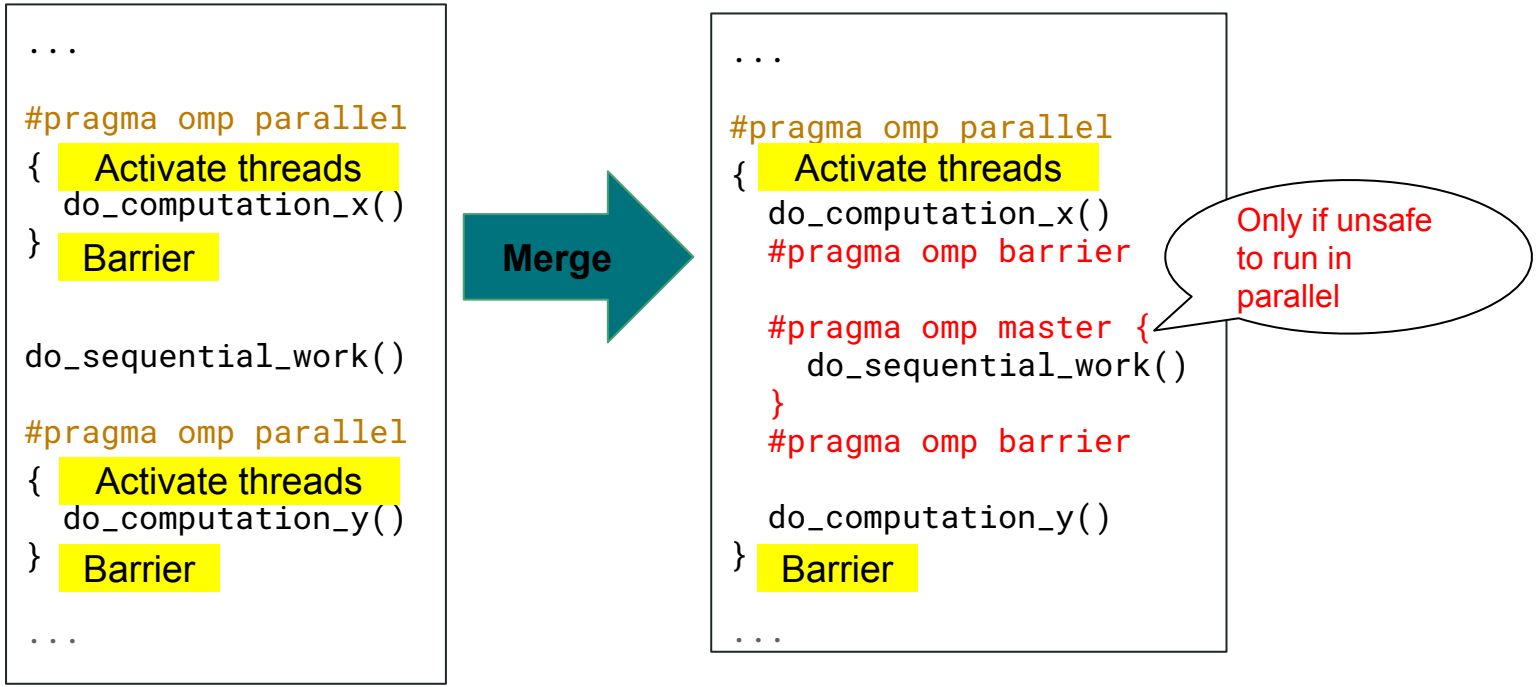
Allow modular OpenMP code without performance penalty

no need for manual high-level optimizations

Parallel Region Merging Optimization



Parallel Region Merging Optimization



Hamilton Tobon Mosquera
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EAFIT University

Design Goal

Allow modular OpenMP code without performance penalty

no need for manual high-level optimizations

Hide Latency from Host to Device Memory Transfers

```
void process_array(double * restrict a, unsigned size) {


    some_computation();


    #pragma omp target data map(a[0:size], size)
    #pragma omp target teams
    for (int i = 0; i < size; i++)
        compute(a[i]);
}
```

Hide Latency from Host to Device Memory Transfers

```
void process_array(double * restrict a, unsigned size) {

    #pragma omp target data map(a[0:size], size) depend(out:transfer) nowait
    some_computation(); // We ensure this computation does not modify *a nor size.

    #pragma omp taskwait depend(in:transfer)
    #pragma omp target data map(a[0:size], size)
    #pragma omp target teams
    for (int i = 0; i < size; i++)
        compute(a[i]);
}
```

Hide Latency from Host to Device Memory Transfers

```
void process_array(double * restrict a, unsigned size) {
    #pragma omp target data map(tofrom: a[0:size], size)
    #pragma omp target teams
    for (int i = 0; i < size; i++)
        first_transformation(a[i]);


    some_computation();


    #pragma omp target data map(tofrom: a[0:size], size)
    #pragma omp target teams
    for (int i = 0; i < size; i++)
        second_transformation(a[i]);
}
```

Hide Latency from Host to Device Memory Transfers

```
void process_array(double * restrict a, unsigned size) {
    #pragma omp target data map(to: a[0:size], size)  // no need to send `a` nor `size` back from the device.
    #pragma omp target teams
    for (int i = 0; i < size; i++)
        first_transformation(a[i]);


    some_computation(); // we make sure this does not modify `a` nor `size`.


    #pragma omp target data map(from: a[0:size], size) // no need to send `a` nor `size` to the device.
    #pragma omp target teams
    for (int i = 0; i < size; i++)
        second_transformation(a[i]);
}
```

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Stony Brook University

Design Goal

Optimize offloading code

perform host + accelerator optimizations

Heterogeneous LLVM-IR Module

user_code_1.c

```
void foo() {
  int N = 1024;

#pragma omp target
  *mem = N;
}
```

* RFC: https://bit.ly/3bJzAx3

Heterogeneous LLVM-IR Module

user_code_1.c

```
void foo() {
  int N = 1024;

#pragma omp target
  *mem = N;
}
```

host.c

```
extern void device_func7(int);

void foo() {
  int N = 1024;

  if (!offload(device_func7, N)) {
    // host fallback
    *mem = N;
  }
}
```

device.c

```
void device_func7(int N) {
  *mem = N;
}
```

* RFC: https://bit.ly/3bJzAx3

Heterogeneous LLVM-IR Module

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```
void foo() {
  int N = 1024;

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```
extern void device_func7(int);

void foo() {
  int N = 1024;

  if (!offload(device_func7, 1024)) {
    // host fallback
    *mem = 1024;
  }
}
```

device.c

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void device_func7(int N) {
  *mem = N;
}
```

* RFC: https://bit.ly/3bJzAx3

Heterogeneous LLVM-IR Module

user_code_1.c

```
void foo() {
  int N = 1024;

#pragma omp target
  *mem = N;
}
```

host.c

```
extern void device

void foo() {
  int N = 1024;

  if (!offload(device_func7, 1024)) {
    // host fallback
    *mem = 1024;
  }
}
```

The constant is part of the "host code".

device.c

```
void device_func7(int N) {
  *mem = N;
}
```

* RFC: https://bit.ly/3bJzAx3

Heterogeneous LLVM-IR Module

user_code_1.c

```
void foo() {
  int N = 1024;

#pragma omp target
  *mem = N;
}
```

heterogeneous.c

```
__attribute__((callback(Func, ...)))
int offload(void (*)(...) Func, ...);

target 0 void foo() {
  int N = 1024;

  if (!offload(device_func7, N)) {
    // host fallback
    *mem = N;
  }
}

target 1 void device_func7(int N) {
  *mem = N;
}
```

* RFC: https://bit.ly/3bJzAx3

* `callback` attribute: https://bit.ly/32l68ds

Heterogeneous LLVM-IR Module

user_code_1.c

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heterogeneous.c

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* RFC: https://bit.ly/3bJzAx3

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Acknowledgements

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OpenMP

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openmp.org OpenMP API specs, forum, reference guides, and more

link.openmp.org/sc20 Videos and PDFs of OpenMP SC'20 presentations