OpenMP and Vectorization in GCC

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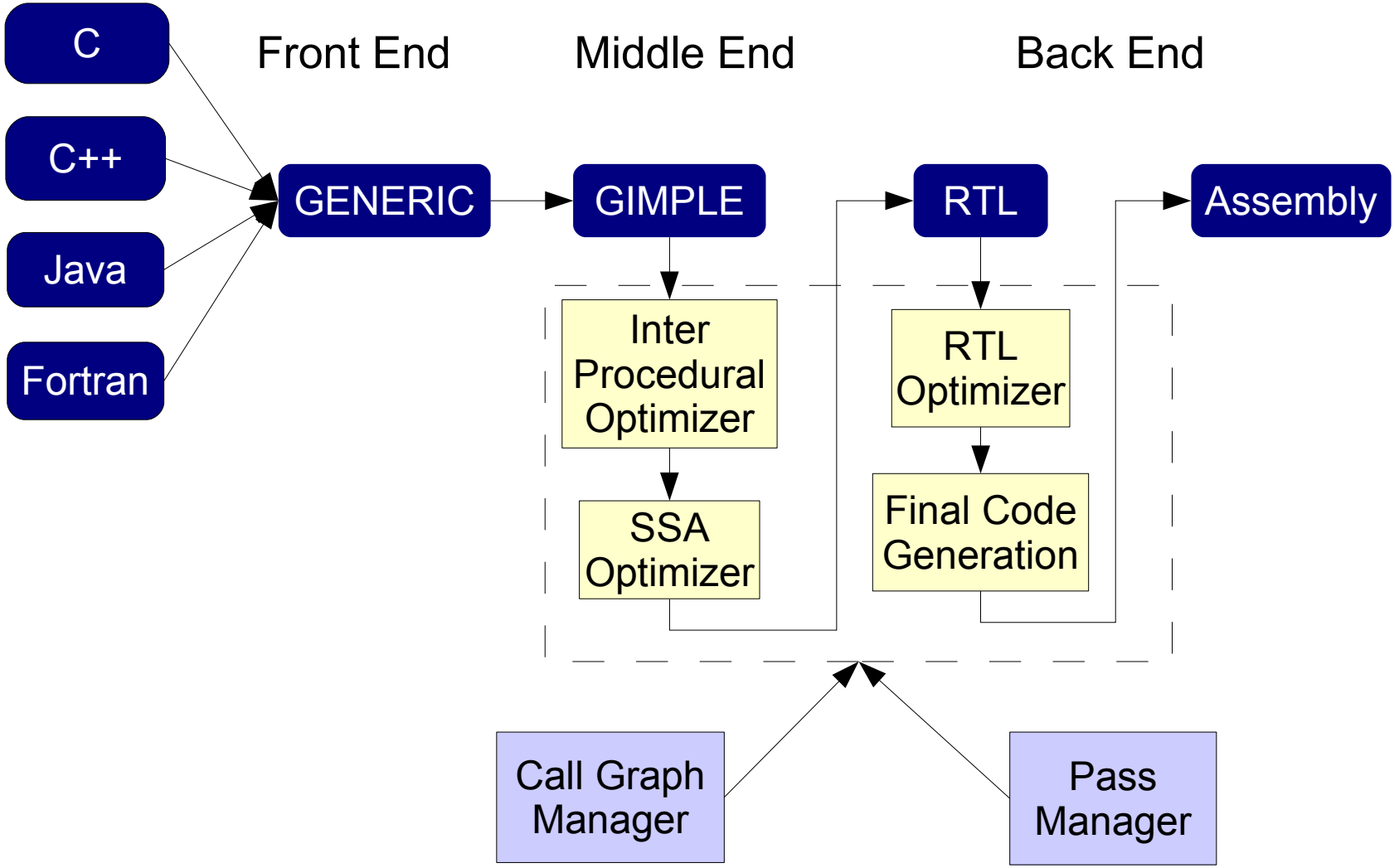
Introduction

- Overview of GCC
- OpenMP
- Automatic parallelization
- Vectorization
- Status and Future Work

GCC Overview



OpenMP

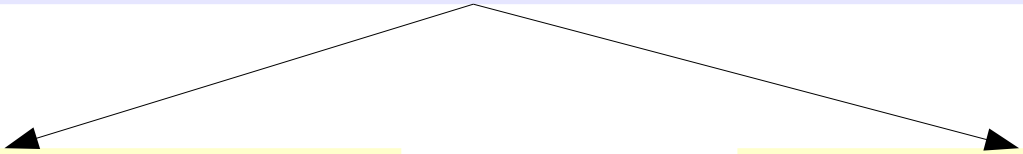
```
#include <omp.h>

main()

{

  #pragma omp parallel

  printf ("[%d] Hello\n", omp_get_thread_num());
}
```



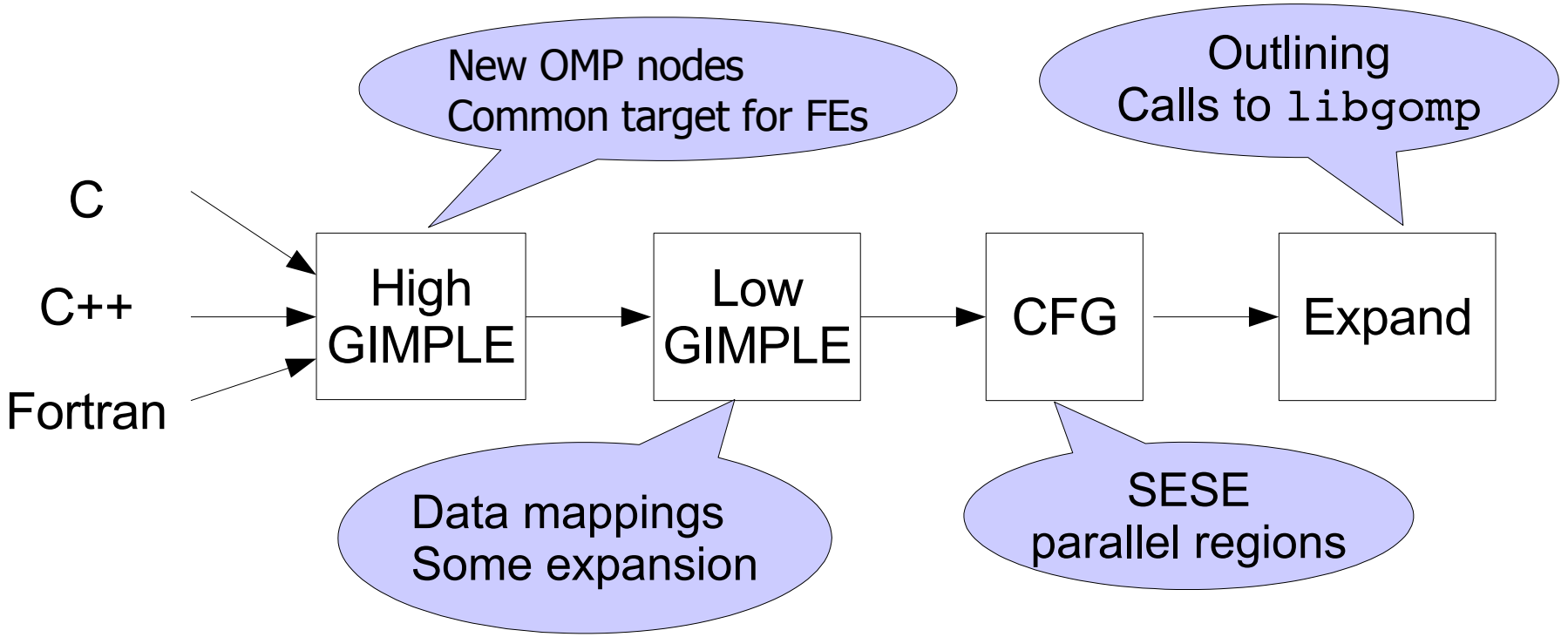
```
$ gcc -fopenmp -o hello hello.c
$ ./hello
[2] Hello
[3] Hello
[0] Hello        ← Master thread
[1] Hello
```

```
$ gcc -o hello hello.c
$ ./hello
[0] Hello
```

OpenMP Implementation

- GNU OpenMP (GOMP)
- Four components
  - Parsing
  - Intermediate Representation
  - Code Generation
  - Run time library (`libgomp`)

OpenMP Implementation



Original Program

```
main()
{
  int i, sum = 0;

  #pragma omp parallel for
  for (i = 0; i < 10; i++)
   {
      #pragma omp atomic
      sum += i;
   }
  printf ("sum = %d\n", sum);
}
```

High GIMPLE

```
main()
{
  int i, sum = 0;

  #pragma omp parallel shared(sum)
    {
      #pragma omp for nowait private(i)
      for (i = 0; i <= 9; i = i + 1)
        __sync_fetch_and_add_4 (&sum, i);
    }
  printf ("sum = %d\n", sum);
}
```

Low GIMPLE

```
main()
{
  int i, *D.1576, sum = 0;
  struct .omp_data_s .omp_data_o;

  .omp_data_o.sum = &sum;
  #pragma omp parallel shared(sum)
  .omp_data_i = &.omp_data_o;
  #pragma omp for nowait private(i)
  for (i = 0; i <= 9; i = i + 1)
  D.1576 = .omp_data_i->sum;
  __sync_fetch_and_add_4 (D.1576, i.0);
  OMP_RETURN
  OMP_RETURN
  printf (&"sum = %d\n"[0], sum.1);
}
```

To be Outlined

Final expansion (`main`)

```
main()
{
  int i, sum = 0;
  struct .omp_data_s .omp_data_o;

  .omp_data_o.sum = &sum;
  __builtin_GOMP_parallel_start (main.omp_fn.0,
                                 &.omp_data_o, 0);
  main.omp_fn.0 (&.omp_data_o);
  __builtin_GOMP_parallel_end ();
  printf ("sum = %d\n", sum);
}
```

Final Expansion (main.omp_fn.0)

```
main.omp_fn.0 (.omp_data_i)
{
 D.1581 = __builtin_omp_get_num_threads();
 D.1582 = (unsigned int) D.1581;
 D.1583 = __builtin_omp_get_thread_num();
 D.1584 = (unsigned int) D.1583;
 D.1585 = 10 / D.1582;
 D.1586 = D.1585 * D.1582;
 D.1587 = D.1586 != 10;
 D.1588 = D.1585 + D.1587;
 D.1589 = D.1588 * D.1584;
 D.1590 = D.1589 + D.1588;
 D.1591 = MIN_EXPR <D.1590, 10>;
 if (D.1589>=D.1591) goto <L2> else
   goto <L0>
<L2>:
 return;
```

Iteration space partitioning

```
<L0>:
  D.1592 = (int) D.1589;
  D.1593 = D.1592 * 1;
  i = D.1593 + 0;
  D.1594 = (int) D.1591;
  D.1595 = D.1594 * 1;
  D.1596 = D.1595 + 0;
<L1>:;
  D.1576 = .omp_data_i->sum;
  __sync_fetch_and_add_4 (D.1576, i);
  i = i + 1;
  D.1597 = i < D.1596;
  if (D.1597) goto <L1>; else goto <L2>;
}
```

Local min/max limits

Runtime library

- Wrapper around POSIX threads
  - Various system-specific performance tweaks
- Synchronization usually 1-1 mapping except
  - `omp master` → Blocks threads with ID != 0
  - `omp single` → `copyprivate` needs special expansion to handle broadcast.
- All scheduling variants of `omp for` implemented
  - Static schedules are open coded by compiler

Auto Parallelization

- OMP codes can be emitted internally as result of analysis
  - `OMP_SECTIONS` → task parallelism
  - `OMP_FOR` → loop parallelism
  - `OMP` sharing clauses → data sharing
  - Synchronization with appropriate directives
- Work in progress scheduled for GCC 4.3.

Vectorization

- Traditional pattern-based implementation
  - New patterns added with every release
- Multi-platform: x86, ppc64, ia64
- Two distinct phases
  - Analysis → high-level (GIMPLE)
  - Transformation → low-level (RTL)

Vectorization

- GIMPLE extended with vector abstractions
  - Concise expression of high-level idioms
  - Reductions, saturated ops, dot products, extractions, type conversions, etc.
- RTL and target API conveys
  - Available operations
  - Costs
- Designed to simplify portability to many platforms

Vectorization

```
int a[256], b[256], c[256];

foo ()
{
  for (i = 0; i < 256; i++)
   a[i] = b[i] + c[i];
}
```

$ gcc -O2 -ftree-vectorize

(~2x on P4)

```
.L2:
        movdqa  c(%eax), %xmm0
        paddd   b(%eax), %xmm0
        movdqa  %xmm0, a(%eax)
        addl    $16, %eax
        cmpl    $1024, %eax
        jne     .L2
```

$ gcc -O2

```
.L2:
        movl    c(,%edx,4), %eax
        addl    b(,%edx,4), %eax
        movl    %eax, a(,%edx,4)
        addl    $1, %edx
        cmpl    $256, %edx
        jne     .L2
```

Status and Future Work

- Vectorizer exists as of version 4.0
  - New patterns added with every release
  - Straight line code vectorization in progress
- OpenMP to be released with GCC 4.2
  - Full 2.5 spec implemented
  - Performance comparable to ICC (SPECOMP2001)
  - Automatic parallelization in progress
- Implementation available in Fedora Core 5