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Exploiting Heterogeneous Computing with Intel oneAPI Threading Building Blocks (oneTBB)

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Agenda

- oneTBB Introduction
- oneTBB Task Execution Model
- oneTBB Code Examples

Intel® oneAPI Threading Building Blocks (oneTBB) - Advanced Scaling for Fast Applications

- Flexible C++ Library for Parallelism
- Future Proof & Scale Application Performance
- Compatible with other Threading Packages
- Simplified & Enhanced Application Composability

Part of the Intel® oneAPI Base Toolkit

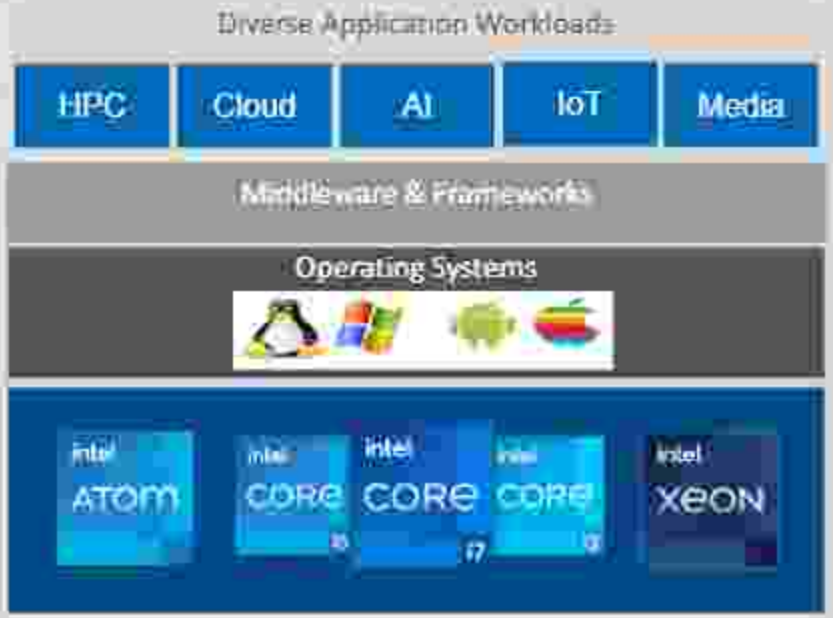
Multi-Threading & Heterogeneous Computing made easy with Intel® oneAPI Threading Building Blocks

What is oneTBB?

A highly templatized C++ library designed to simplify the task of adding CPU parallelism to your application and interoperate with accelerator offload code.

Why should you use oneTBB?

- High Performance
- Easy to use APIs
- Faster Time To Market
- Production Ready & Scalable



How to get oneTBB?

- Intel® oneAPI Base Toolkit
- As standalone component
- Open-source version

Key Applications

- Animation Rendering
- Numeric weather prediction
- Oceanography & Astrophysics
- Artificial intelligence & Automation
- Genetic Engineering
- Medical applications (image processing, MRI reconstruction)
- Remote sensing applications
- Socio Economics
- Financial sector (stock derivative pricing, statistics)
- Bulk updating data files
- Any Big Data problems

Find out more at: http://software.intel.com/intel-tbb
Contact us through our forum:
http://software.intel.com/en-us/forums/intel-threading-building-blocks

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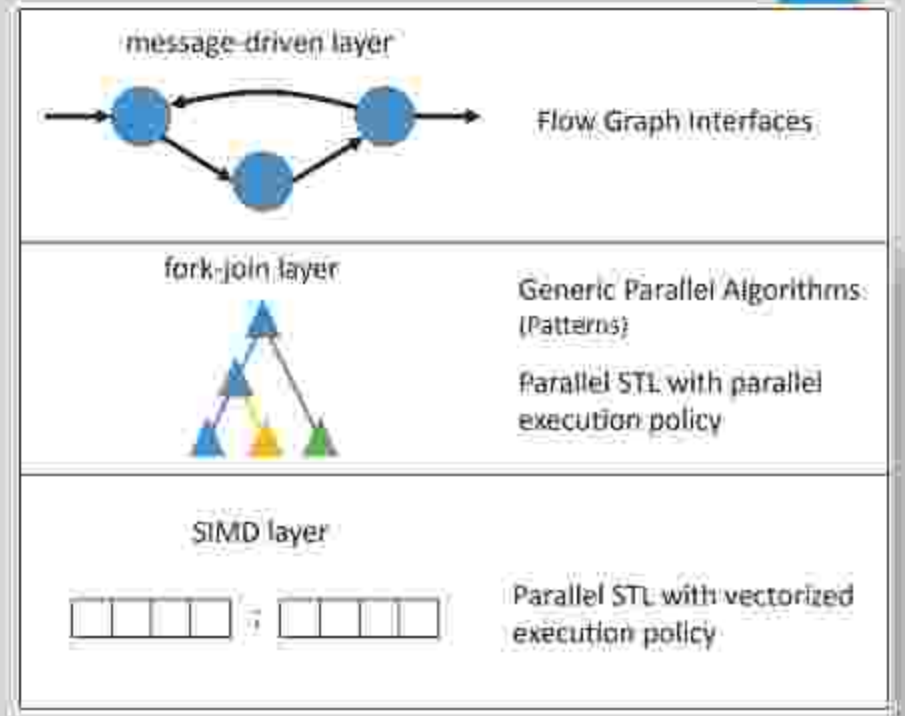
Advantages of Using Intel® oneAPI TBB over other Threading Models

- Specify tasks instead of manipulating threads.
- oneTBB uses proven , efficient parallel patterns.
- oneTBB uses work stealing to support load balancing.
- Flow graph feature in Intel oneTBB allows developers to easily express dependency and data flow graphs.
- Includes high level parallel algorithms and concurrent containers and low-level building blocks.

Three Parallelism Levels in oneTBB

- Message driven layer - (oneTBB Flow Graph)
- Fork-join layer - (oneTBB Tasks)
- Single Instruction Multiple Data (SIMD) layer

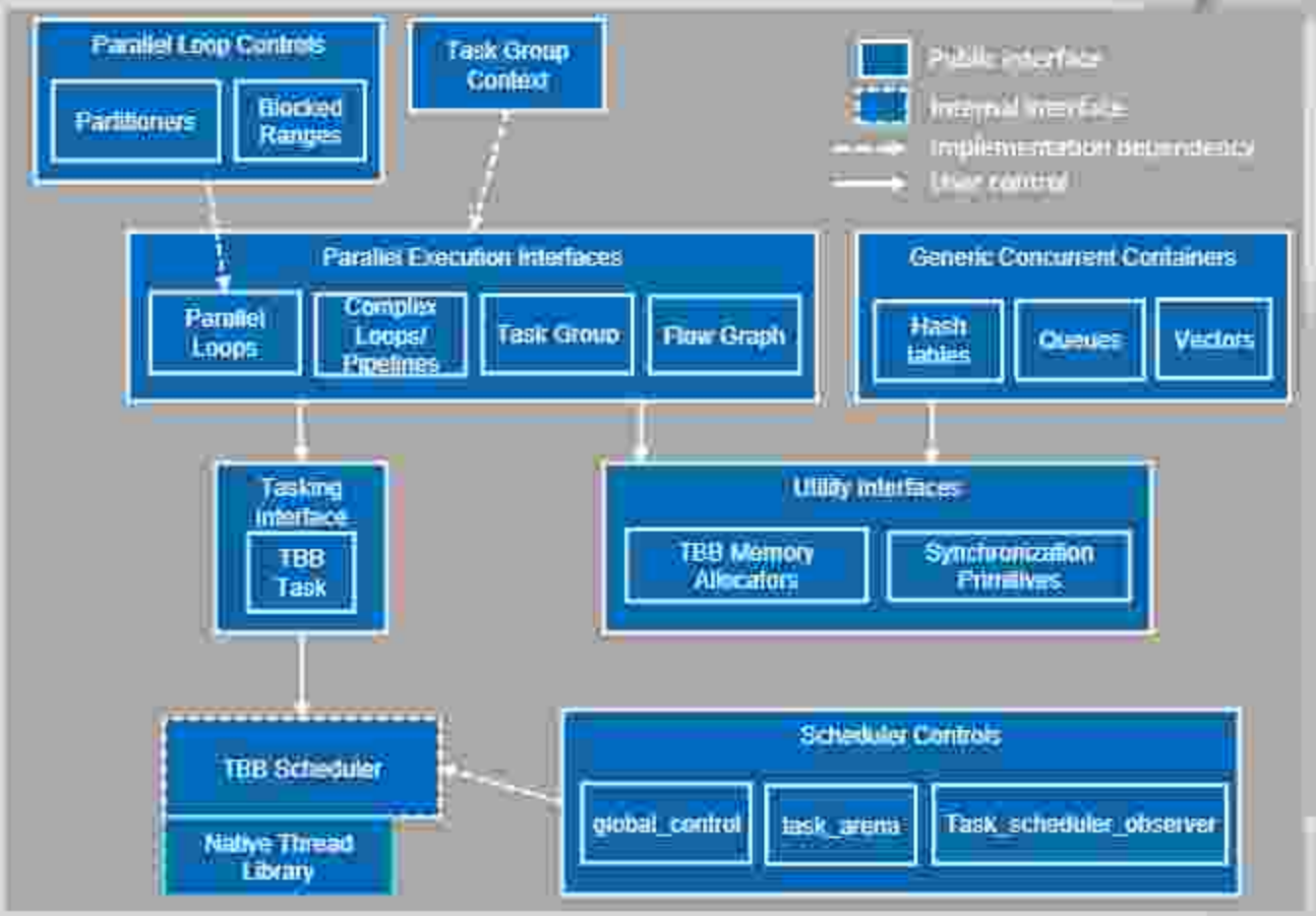


Source: Pro TBB

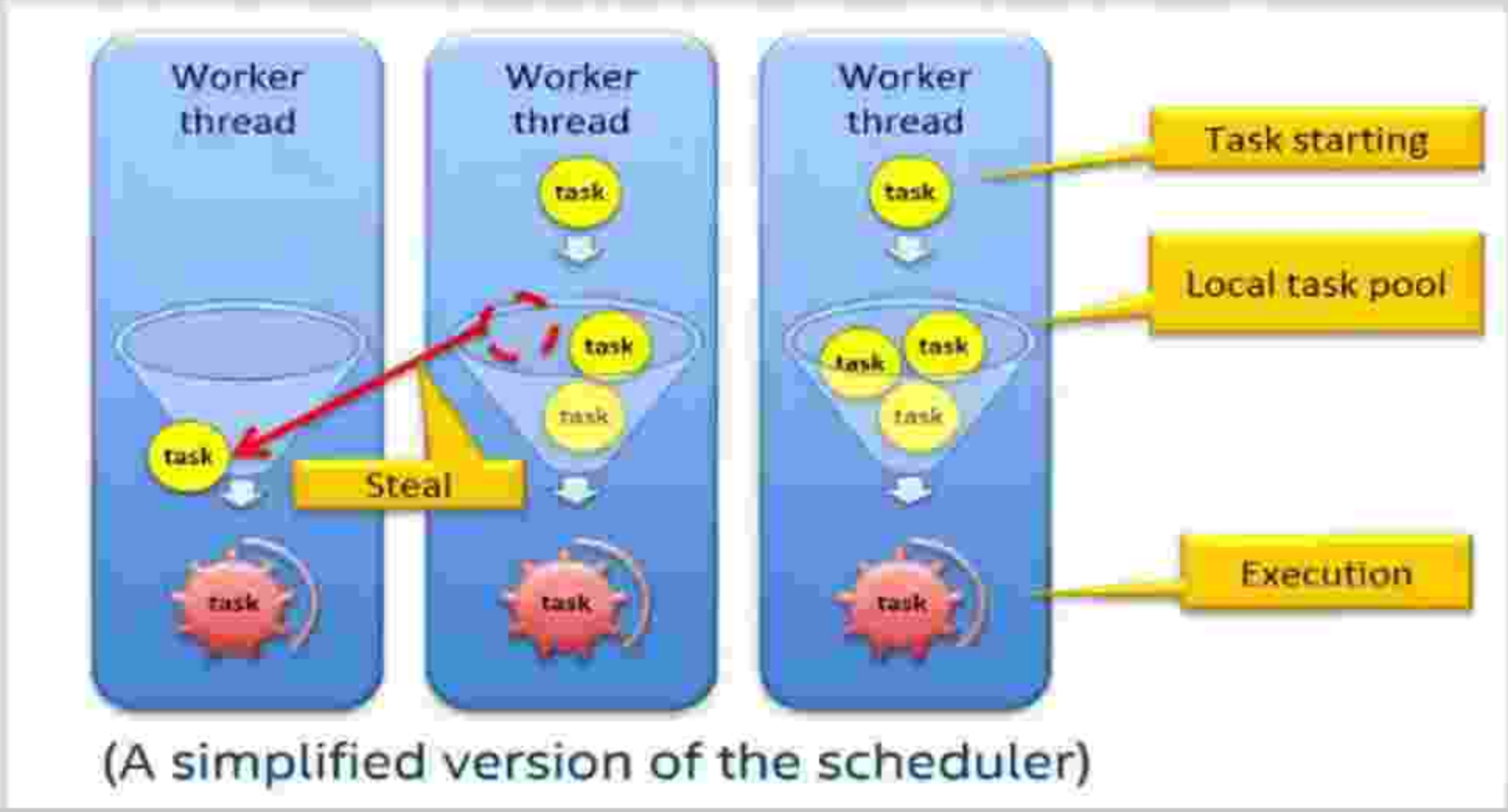
oneTBB Architecture Overview

oneTBB is a Collection of Building Blocks to Develop Highly-scalable Threaded Applications

- oneTBB includes high-level parallel execution interfaces
  - **Parallel Loops**: parallel_for, parallel_reduce, etc.
  - **Complex Algorithms**: pipelines, task groups
  - **Flow Graph**: Expressing data flow independent graphs
- Built on TBB tasks executed on TBB scheduler
- Controls for scheduler and parallel loops
- Concurrent Containers - Queues, Vectors, etc. are thread safe and thread friendly
- Scalable memory allocator, synchronization primitives



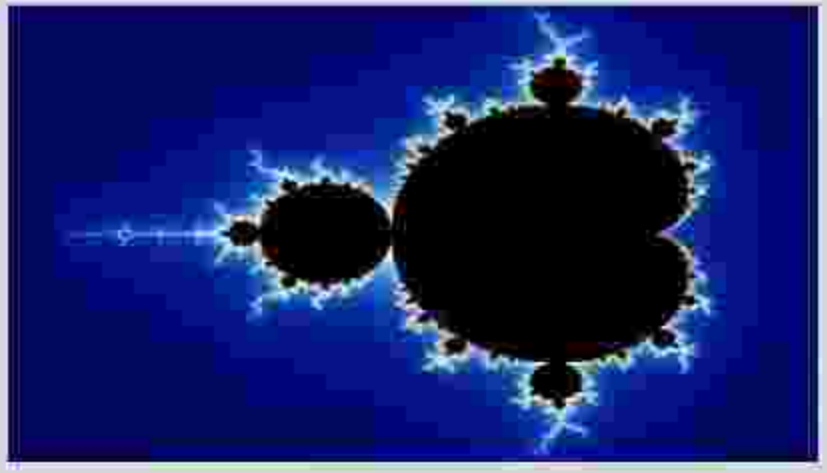
Task Execution In oneTBB



Generic Algorithms Allow Reuse of Proven Parallel Patterns

```
int mandel(Complex c, int max_count) {

 int count = 0; Complex z = 0;

 for (int i = 0; i < max_count; i++) {

   if (abs(z) >= 2.0) break;

   z = z*z + c; count++;
for (int i = 0; i < max_row; i++) {

 for (int j = 0; j < max_col; j++ ) {

   p[i][j] = mandel( Complex(scale(i), scale(j)), depth);

 }

}
```

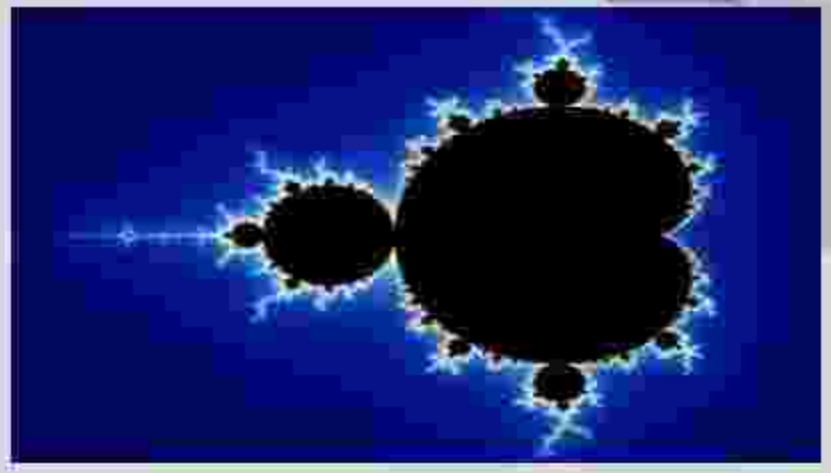
Sequential Version



For each point, is z = z*z + c bounded?

Mandelbrot Speedup

```
int mandel(Complex c, int max_count) {

 int count = 0; Complex z = 0;

 for (int i = 0; i < max_count; i++) {

  if (abs(z) >= 2.0) break;

 Parallel algorithm

 }

 return count;

}
```

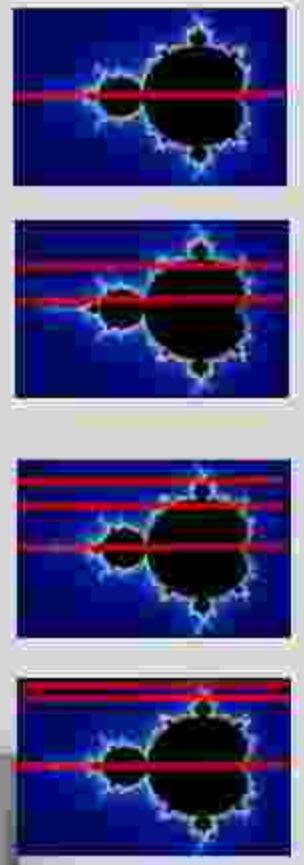


Task is a function object

Use C++ lambda functions to define function object in-line

```
 }

};
```

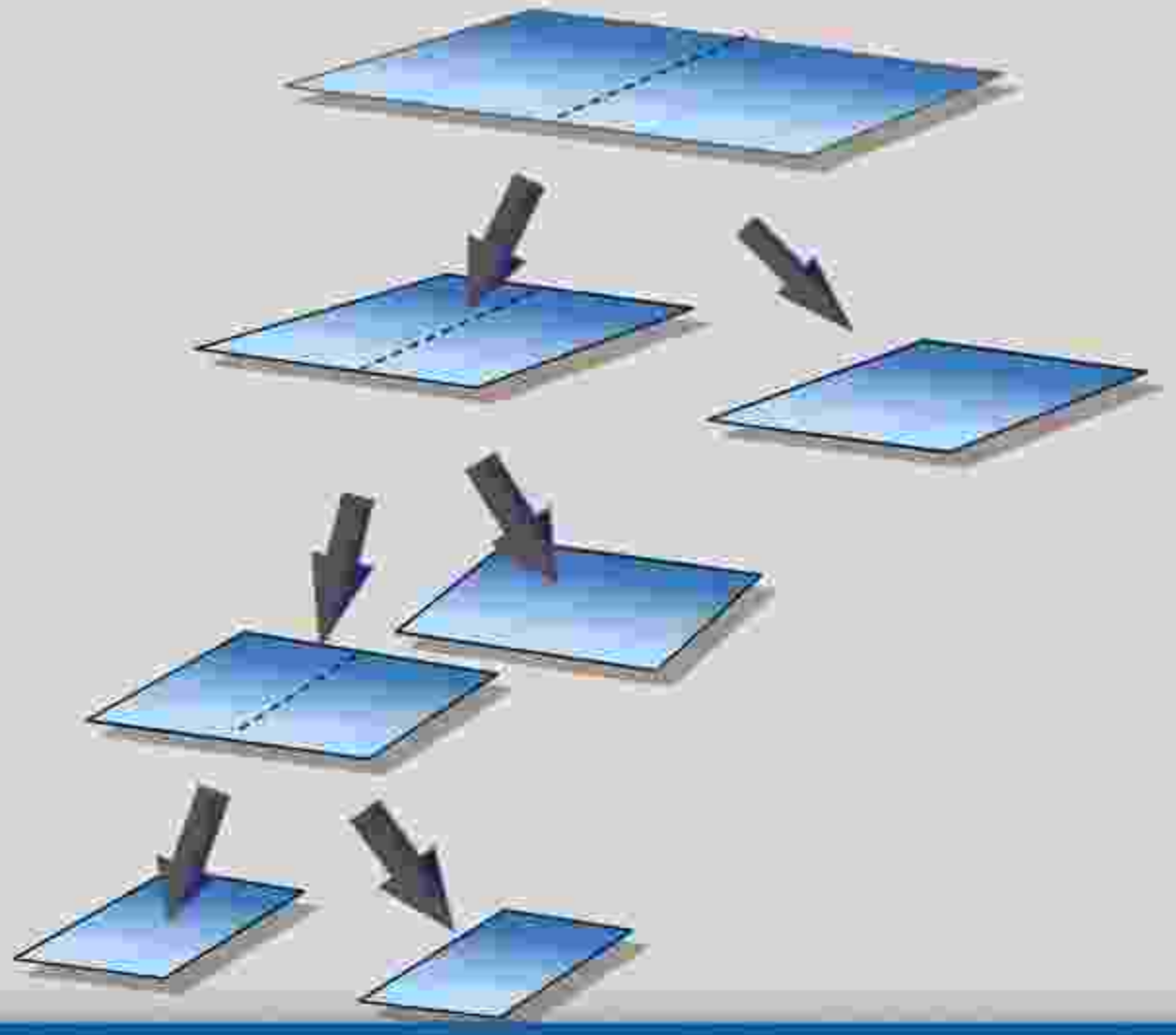
A parallel_for recursively divides the range into subranges that execute as tasks - Intel® oneAPI Threading Building Blocks (oneTBB)



Split range...

.. recursively...

...until ≤ grainsize.



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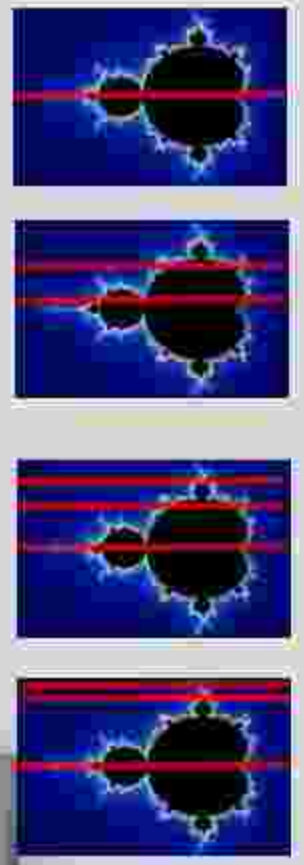

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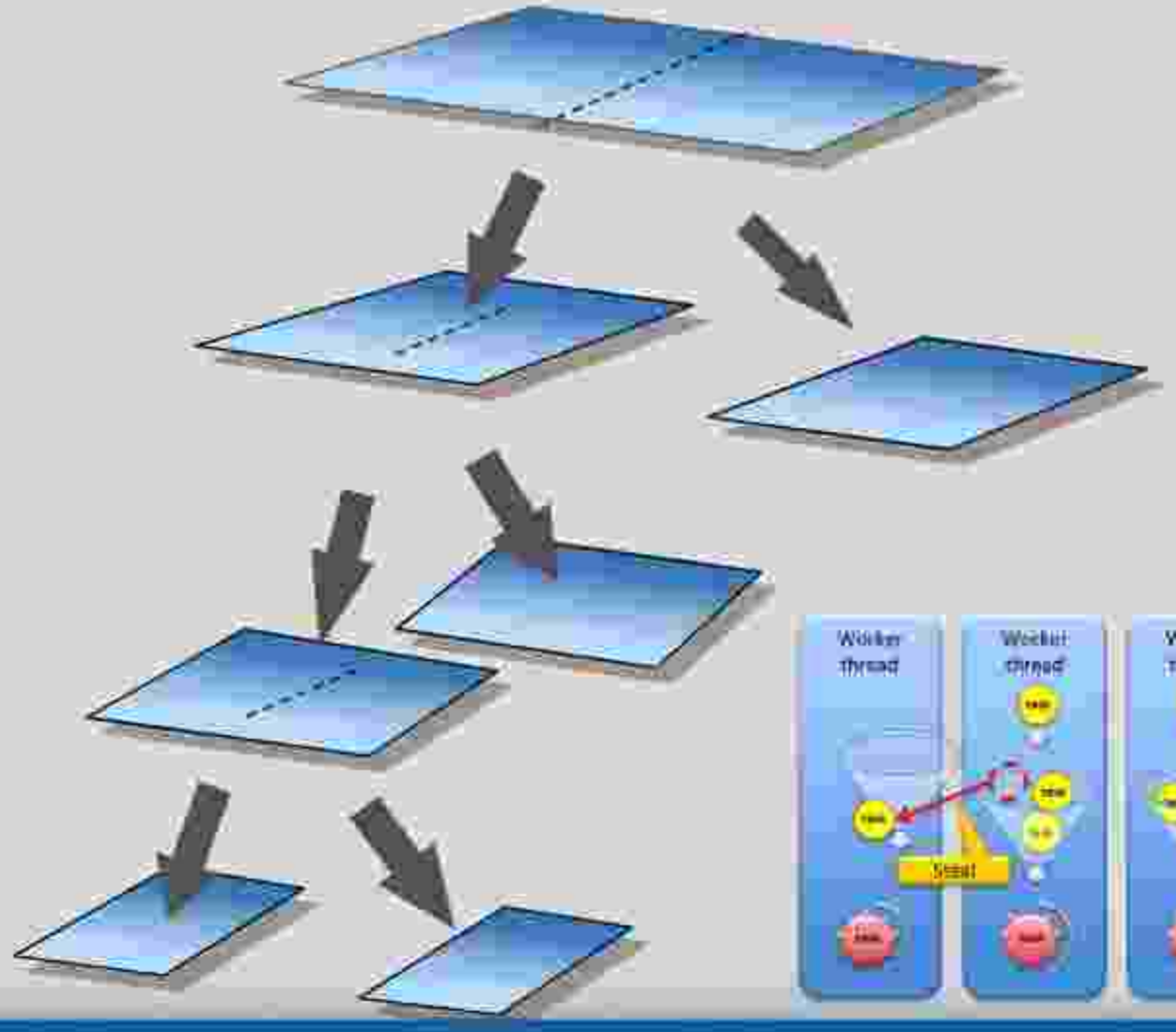
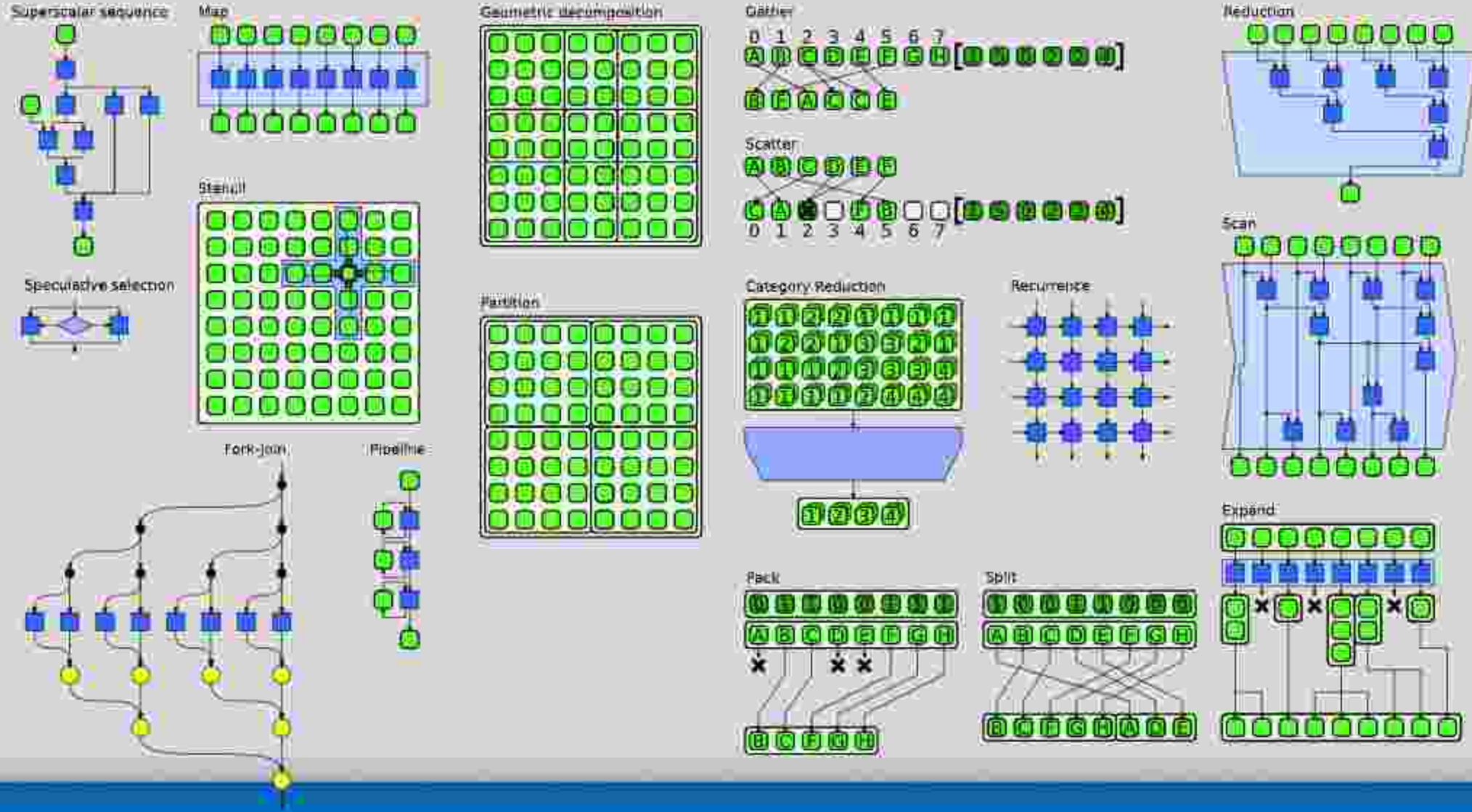


Examples of Parallel Algorithms



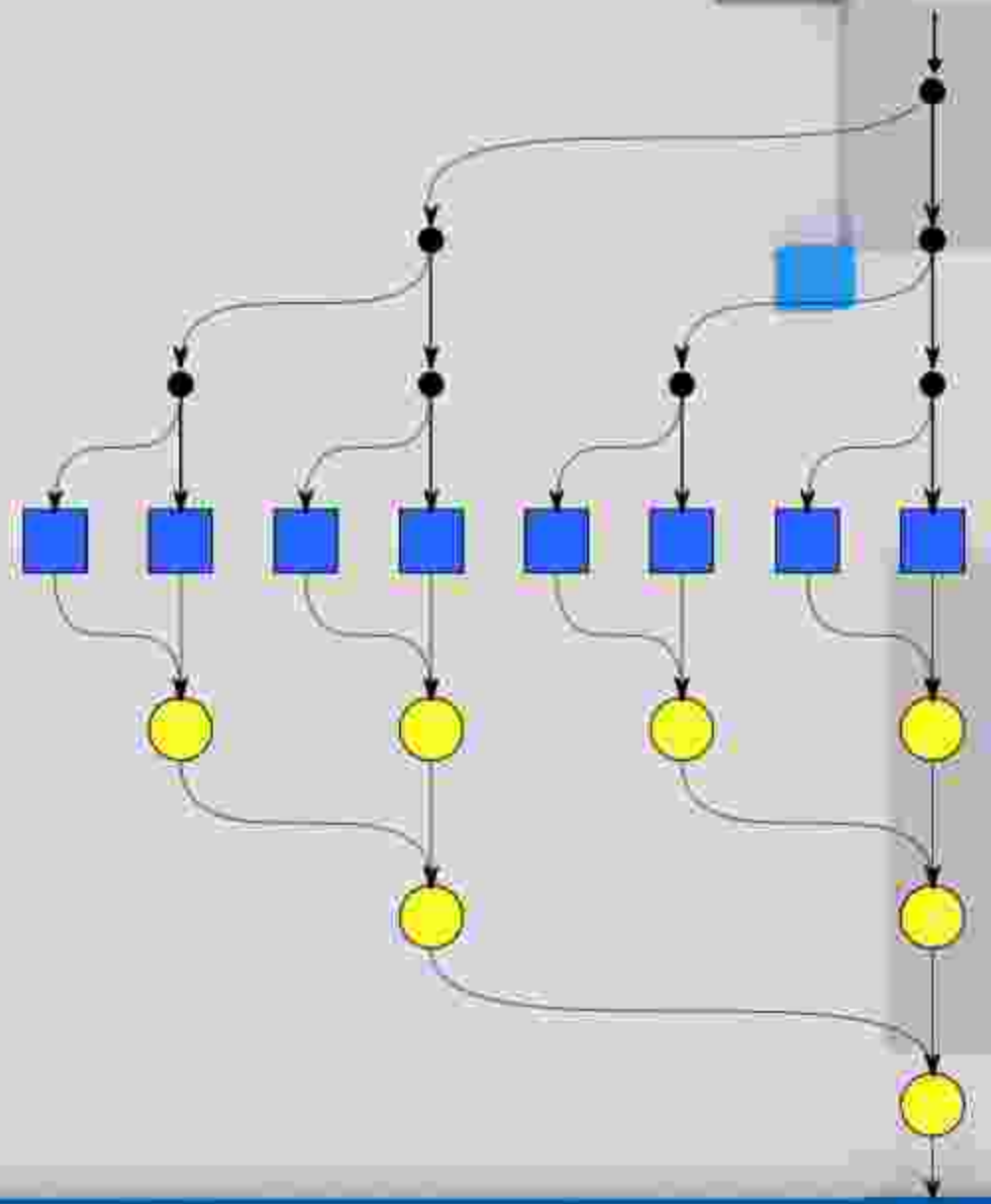
Fork-Join model

For small, known in advance number of tasks

```
parallel_invoke( func1, func2, ...);
```

For large or unknown in advance number of tasks

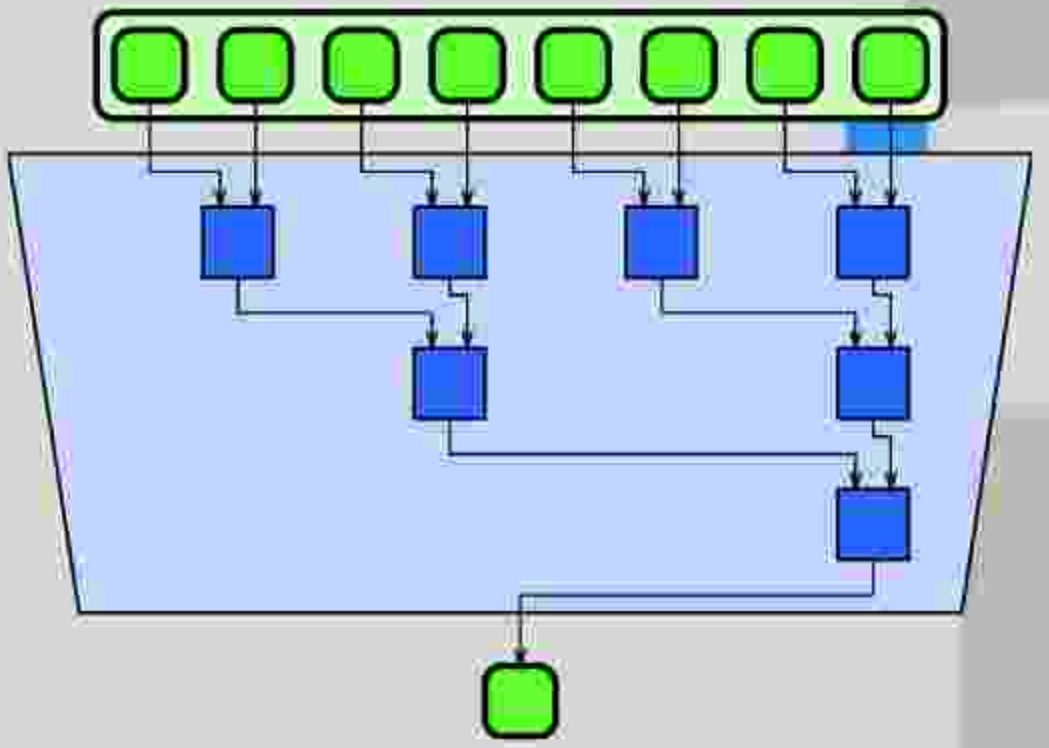
```
task_group g;
...
g.run( func1 );
...
g.run( func2 );
...
g.wait();
```



Reduce Pattern

With **parallel_reduce** function

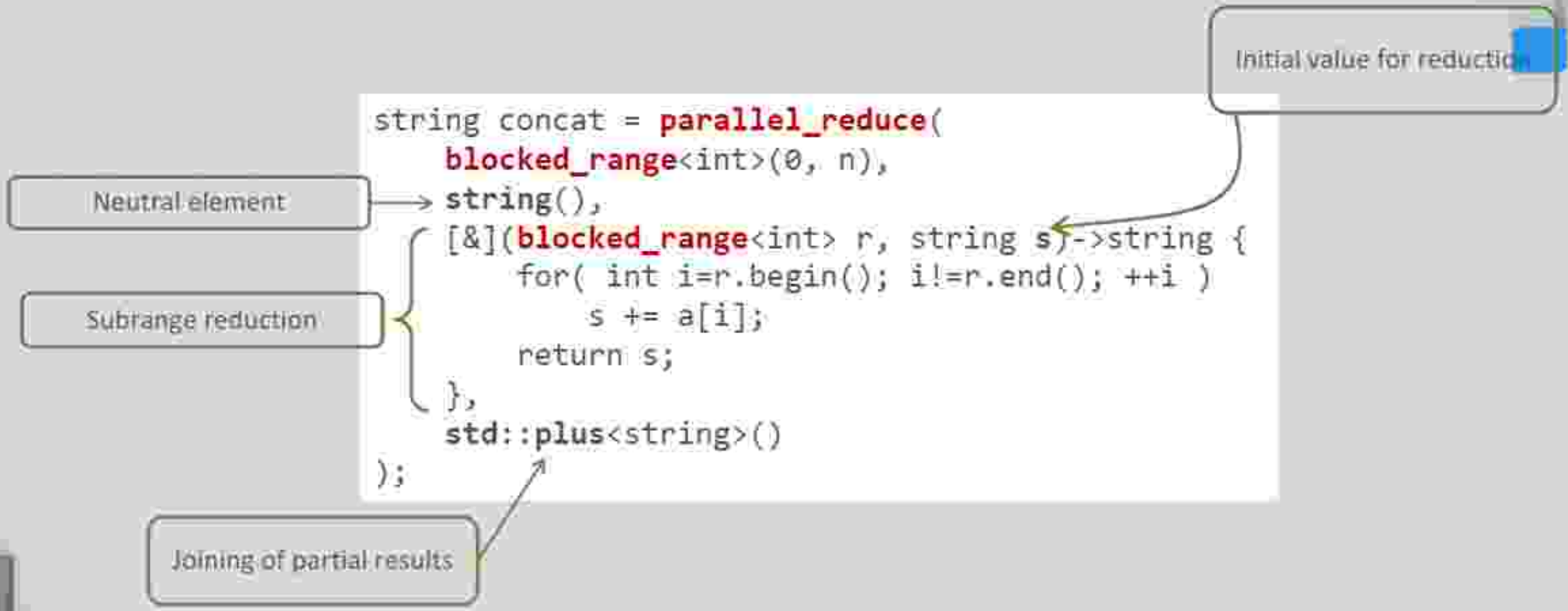
```
T sum = parallel_reduce(
    blocked_range<int>(0,n),
    0.f,
    [&](blocked_range<int> r, T s) -> T {
        for( int i=r.begin(); i!=r.end(); ++i )
            s += a[i];
        return s;
    },
    std::plus<T>()
);
```



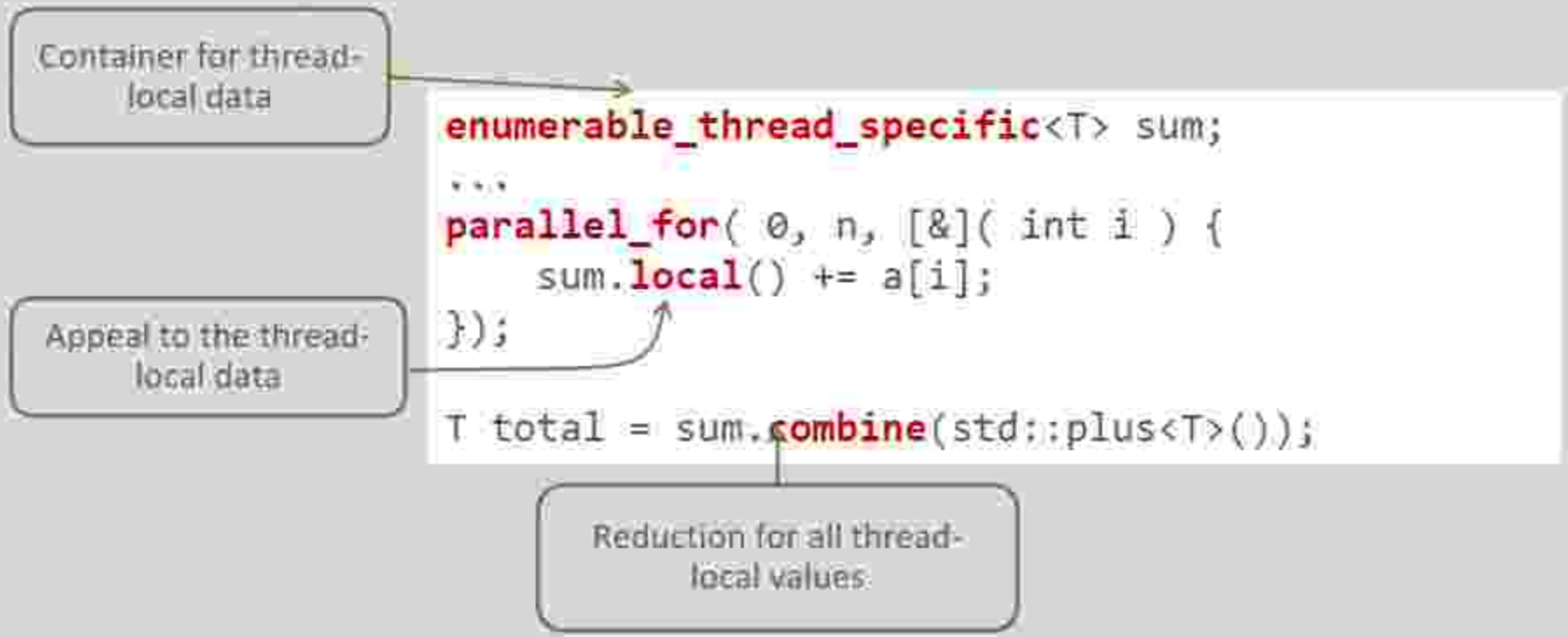
Using **enumerable_thread_specific** class

```
enumerable_thread_specific<T> sum;
parallel_for( 0, n, [&]( int i ) {
    sum.local() += a[i];
});
T total = sum.combine(std::plus<T>());
```

Reduction Using parallel_reduce Function



Reduction Using enumerable_thread_specific class



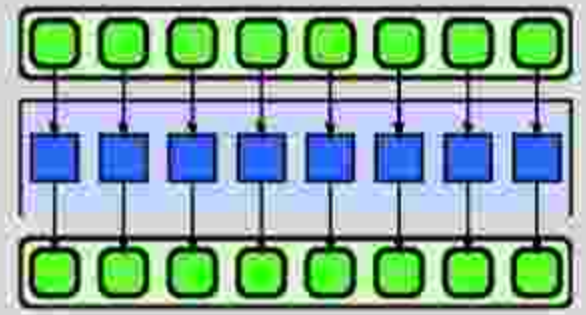
Intel® Threading Building Blocks. Map pattern

Apply *functor(i)* to all $i \in [lower, upper)$

```
parallel_for( lower, upper, func );
```

Apply *functor(i)*, changing *i* in a given step

```
parallel_for( lower, upper, stride, func );
```



Apply *functor(subrange)* to all *subranges* in the *range*

```
parallel_for( range, func );
```

Examples of parallel_for

```
void saxpy( float a, float x[], float (&y)[], size_t n ) {
    tbb::parallel_for( size_t(0), n, [&]( size_t i ) {
        y[i] += a * x[i];
    });
}
```

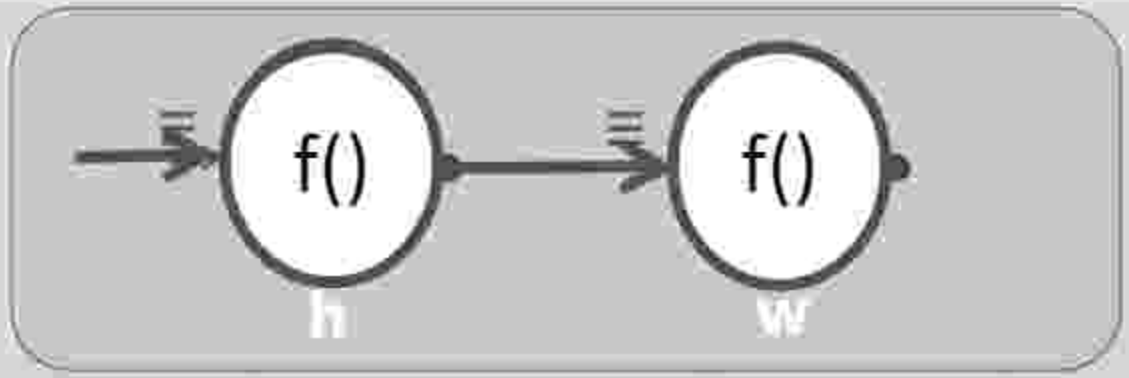
```
void saxpy( float a, float x[], float (&y)[], size_t n ) {
    size_t grain_size = 1000;
    tbb::parallel_for( tbb::blocked_range<size_t>(0, n, grain_size),
    [&]( tbb::blocked_range<size_t> r ) {
        for( size_t i = r.begin(); i != r.end(); ++i )
            y[i] += a * x[i];
    }
    );
}
```

Flow Graph Hello World Example (C++17+preview)

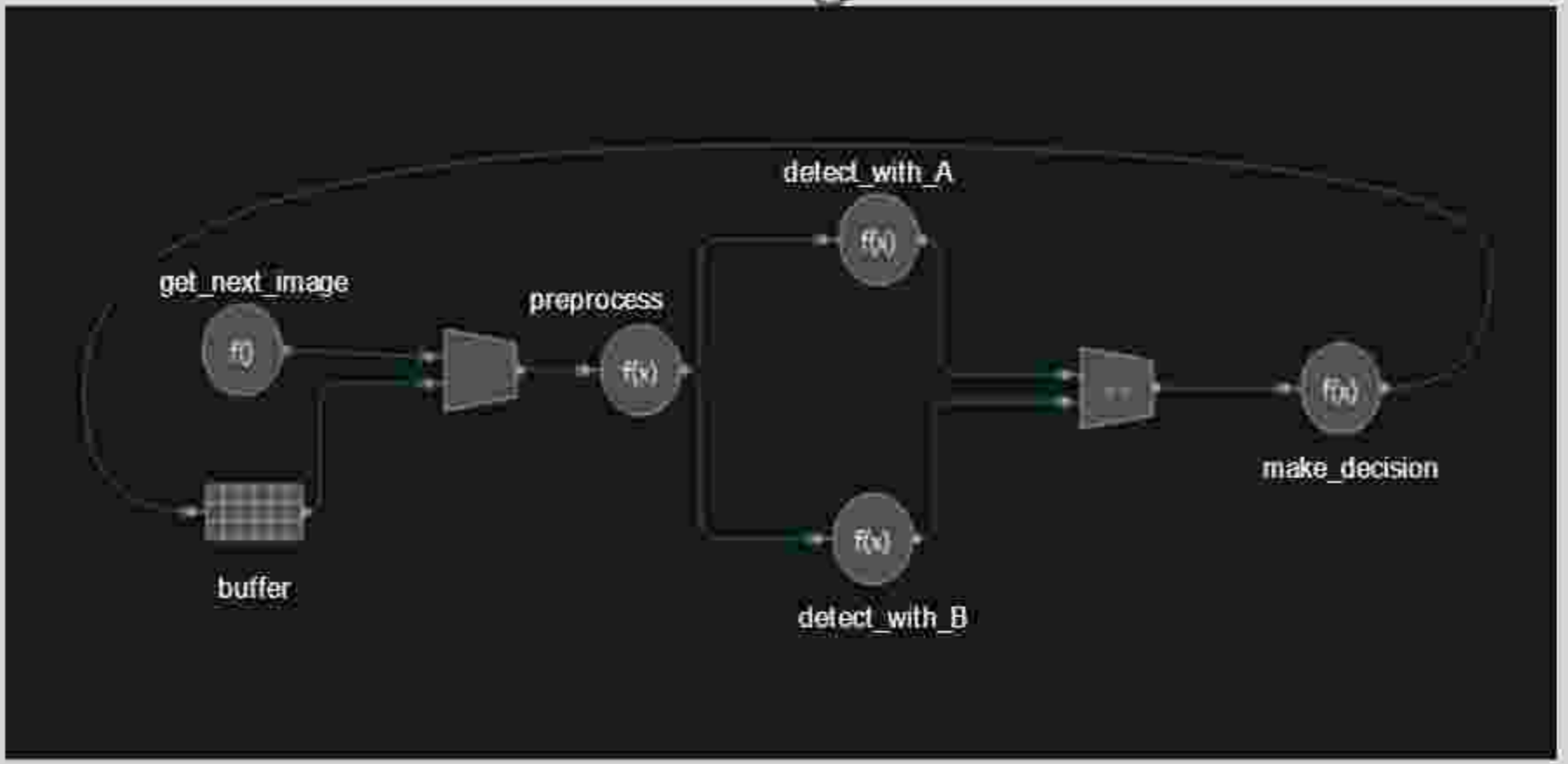
A user creates nodes and edges, interacts with the graph and waits for it to complete

```
tbb::flow::graph g;
tbb::flow::continue_node h( g,
    [](const continue_msg &) { std::cout << "Hello "; } );
tbb::flow::continue_node w( tbb::flow::follows(h),
    [](const continue_msg &) { std::cout << "World\n"; } );
```

```
h.try_put(continue_msg());
g.wait_for_all();
```

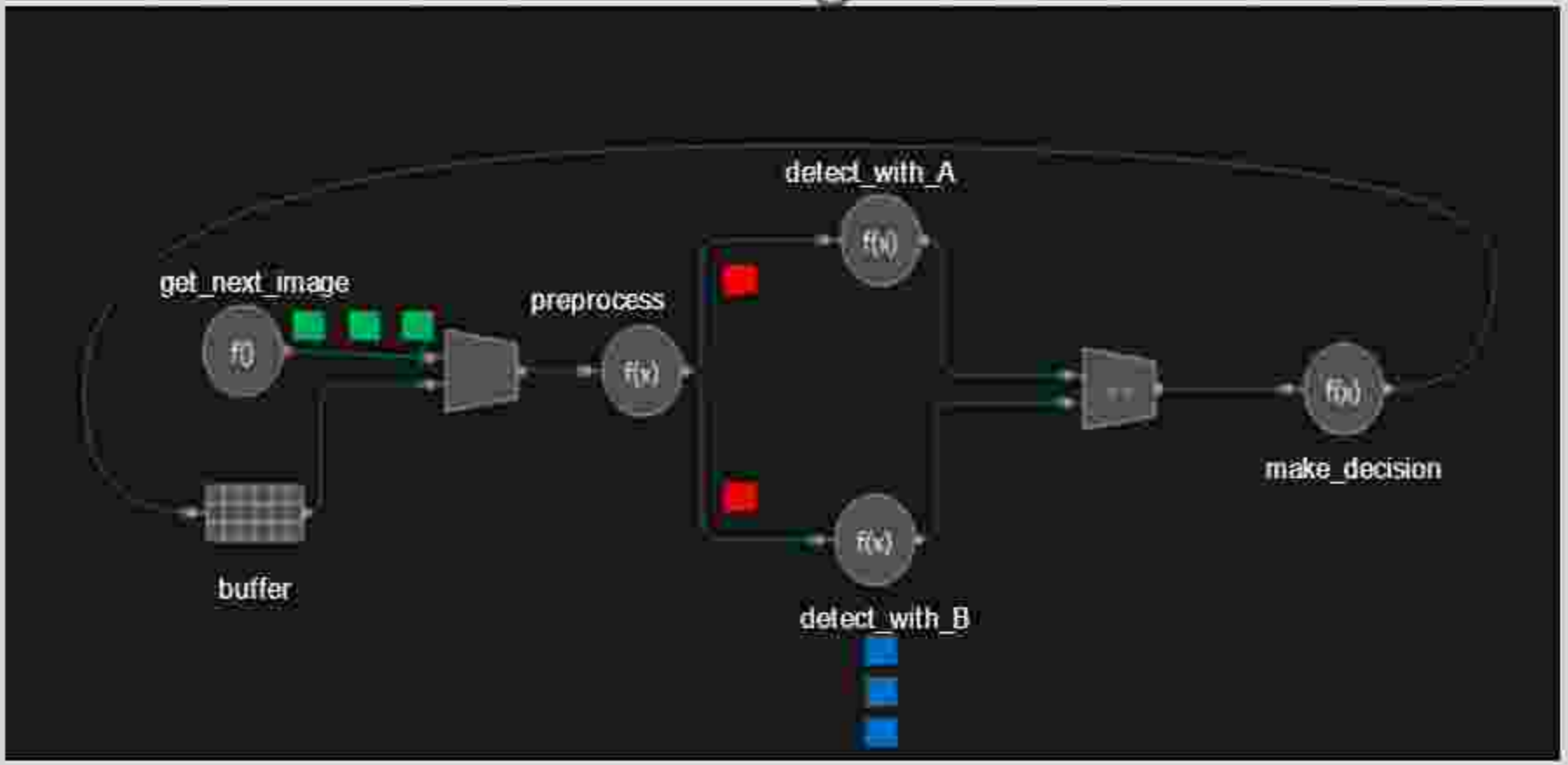


Example: Feature Detection Algorithm



Can express pipelining, task parallelism and data parallelism

Example: Feature Detection Algorithm



Can express pipelining, task parallelism and data parallelism

And supports nested parallelism with Intel® oneAPI Threading Building Blocks, OpenMP, Intel® oneAPI Math Kernel Library, etc.*

Resources

- Intel® oneAPI Base Toolkit
- As standalone component
- Open-source version

C++ Programming with oneTBB

Conclusion

- oneTBB provides flexible parallelism via C++ templates
- Parallelism is achieved by breaking work into tasks and assigning tasks to worker threads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