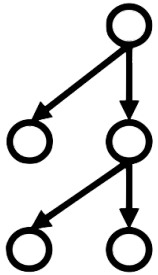
A Modern C++ Parallel Task Programming Library



GitHub: https://github.com/cpp-taskflow

Docs: https://cpp-taskflow.github.io/cpp-taskflow/

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Cpp-Taskflow's Project Mantra

*A programming library helps developers **quickly** write **efficient** parallel programs on a manycore architecture using **task-based** models in **modern C++***

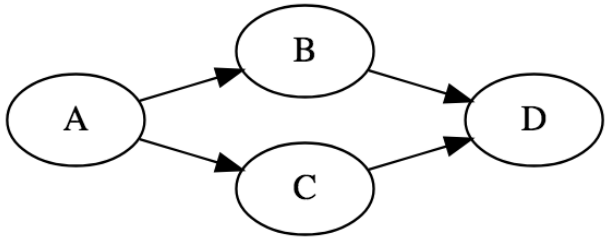
- **Parallel computing is important in modern software**
  - Multimedia, machine learning, scientific computing, etc.
- **Task-based approach scales best with manycore arch**
  - We should write *tasks* NOT *threads*
  - Not trivial due to dependencies (race, lock, bugs, etc.)
- **We want developers to write parallel code that is:**
  - *Simple*, *expressive*, and *transparent*
- **We don't want developers to manage:**
  - Threads, concurrency controls, scheduling

Hello-World in Cpp-Taskflow

```
#include <taskflow/taskflow.hpp>   // Cpp-Taskflow is header-only
int main(){
   tf::Taskflow tf;
   auto [A, B, C, D] = tf.emplace(
      [] () { std::cout << "TaskA\n"; }
      [] () { std::cout << "TaskB\n"; },
      [] () { std::cout << "TaskC\n"; },
      [] () { std::cout << "TaskD\n"; }
   );
   A.precede(B);              // A runs before B
   A.precede(C);              // A runs before C
   B.precede(D);              // B runs before D
   C.precede(D);              // C runs before D
   tf::Executor().run(tf);  // create an executor to run the taskflow
   return 0;
}
```

*Only **15 lines** of code to get a parallel task execution!*

- ✓ *No hardcode threads*
- ✓ *No concurrency controls*
- ✓ *No explicit task scheduling*
- ✓ *No extra library dependency*



Hello-World in OpenMP

```
#include <omp.h>  // OpenMP is a lang ext to describe parallelism in compiler directives
int main(){
   #omp parallel num_threads(std::thread::hardware_concurrency())
   {
      int A_B, A_C, B_D, C_D;
      #pragma omp task depend(out: A_B, A_C)
      {
         s t d : : c o u t << ”TaskA\n” ;
      }
      #pragma omp task depend(in: A_B; out: B_D)
      {
         s t d : : c o u t << ” TaskB\n” ;
      }
      #pragma omp task depend(in: A_C; out: C_D)
      {
         s t d : : c o u t << ” TaskC\n” ;
      }
      #pragma omp task depend(in: B_D, C_D)
      {
         s t d : : c o u t << ”TaskD\n” ;
      }
   }
   return 0;
}
```

Task dependency clauses

Task dependency clauses

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Task dependency clauses

OpenMP task clauses are static and explicit; Programmers are responsible a proper order of writing tasks consistent with sequential execution

Hello-World in Intel's TBB Library

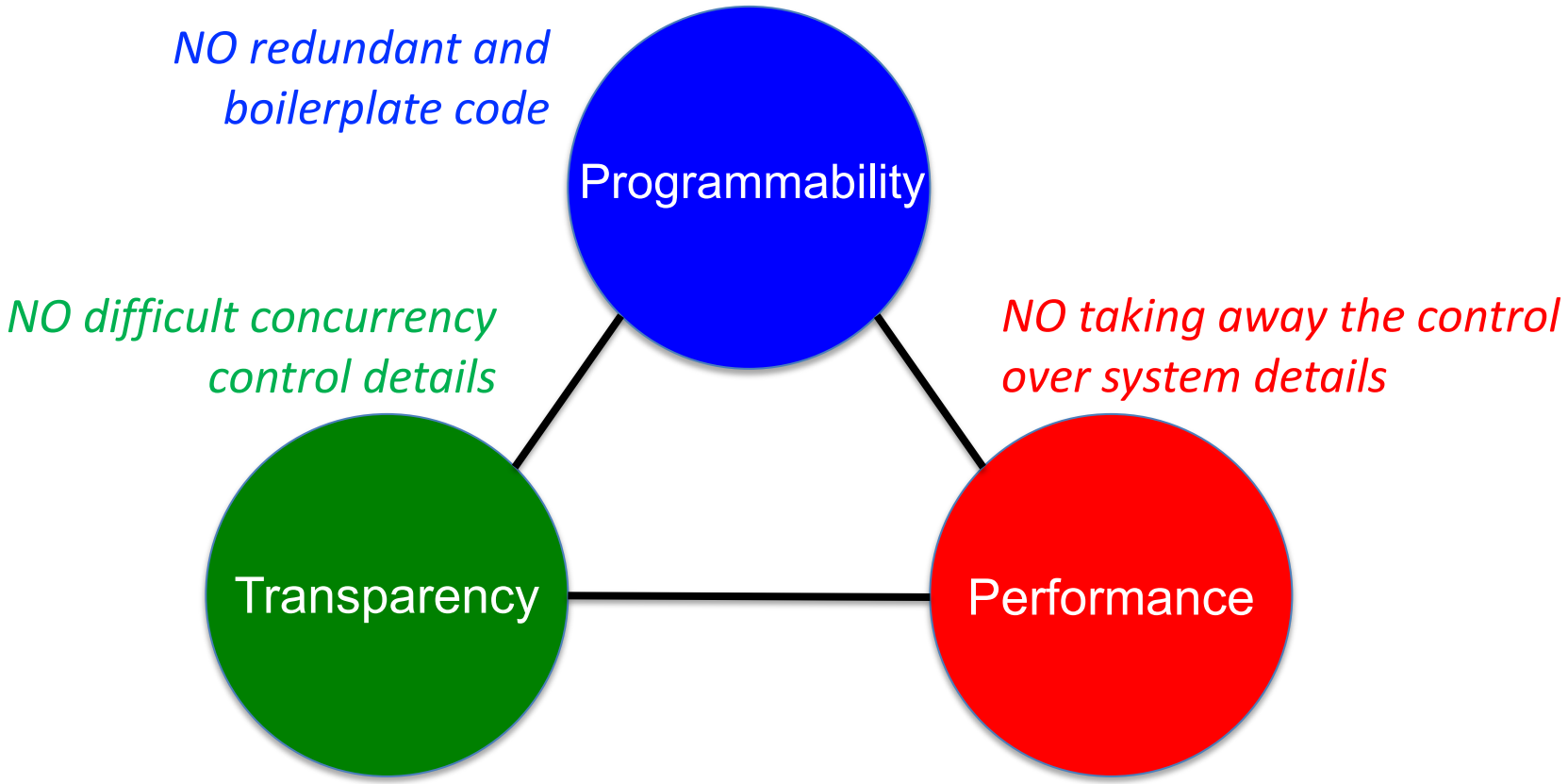
```
#include <tbb.h>  // Intel's TBB is a general-purpose parallel programming library in C++
int main(){
    using namespace tbb;
    using namespace tbb:flow;
    int n = task_scheduler init::default_num_threads () ;
    task scheduler_init init(n);
    graph g;
    continue_node<continue_msg> A(g, [] (const continue msg &) {
        s t d : : c o u t << "TaskA" ;
    }) ;
    continue_node<continue_msg> B(g, [] (const continue msg &) {
        s t d : : c o u t << "TaskB" ;
    }) ;
    continue_node<continue_msg> C(g, [] (const continue msg &) {
        s t d : : c o u t << "TaskC" ;
    }) ;
    continue_node<continue_msg> C(g, [] (const continue msg &) {
        s t d : : c o u t << "TaskD" ;
    }) ;
    make_edge(A, B);
    make_edge(A, C);
    make_edge(B, D);
    make_edge(C, D);
    A.try_put(continue_msg());
    g.wait_for_all();
}
```

Use TBB's FlowGraph for task parallelism

Declare a task as a continue_node

TBB has excellent performance in generic parallel computing. Its drawback is mostly in the ease-of-use standpoint (simplicity, expressivity, and programmability).

Our Goal of Parallel Task Programming



"We want to let users easily express their parallel computing workload without taking away the control over system details to achieve high performance, using our expressive API in modern C++"

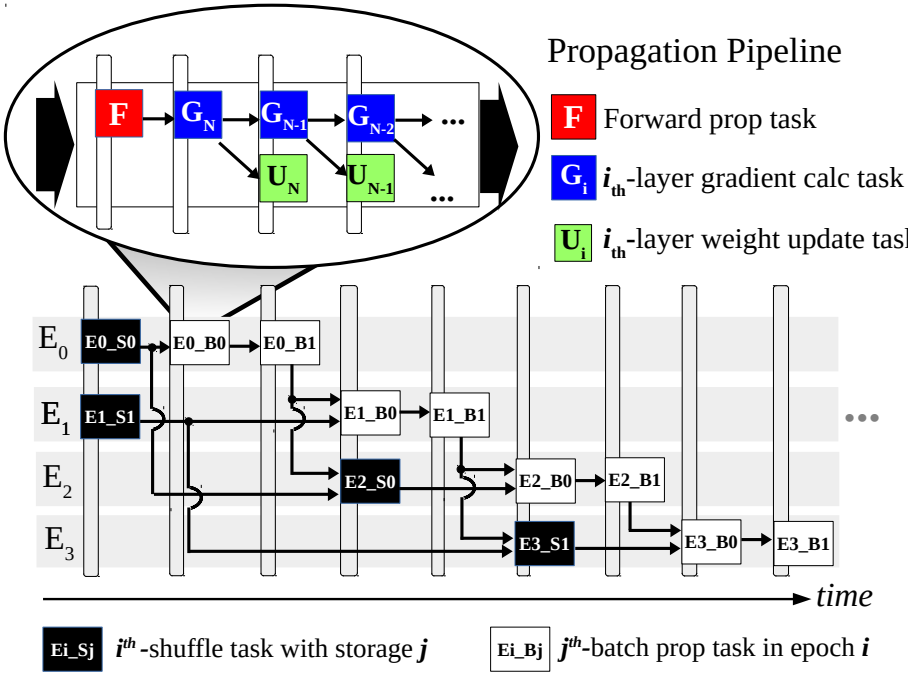
Accelerating DNN Training

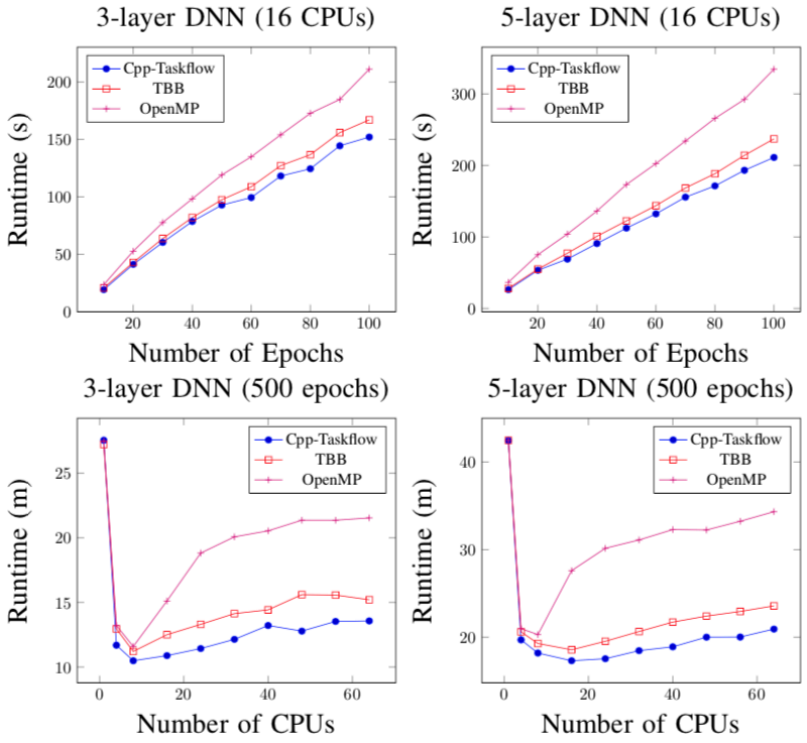
❑ 3-layer DNN and 5-layer DNN image classifier

Cpp-Taskflow			OpenMP			TBB			Sequential		
LOC	CC	T	LOC	CC	T	LOC	CC	T	LOC	CC	T
59	11	3	162	23	9	90	12	3	33	9	2

CC: cyclomatic complexity of the implementation
T: development time (in hours) by an experienced programmer

Dev time (hrs): 3 (Cpp-Taskflow) vs 9 (OpenMP)

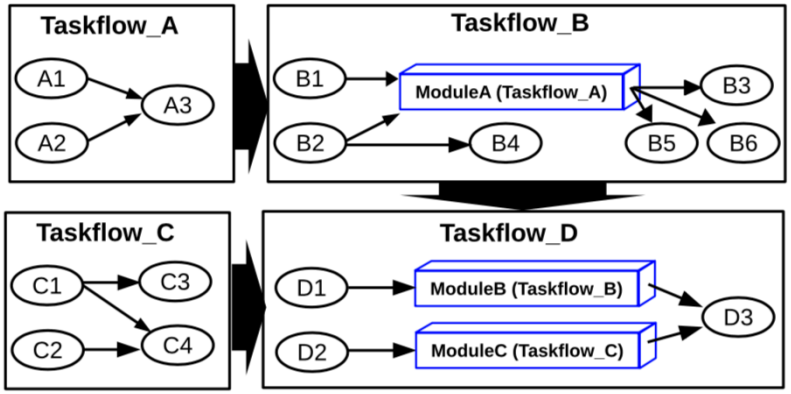


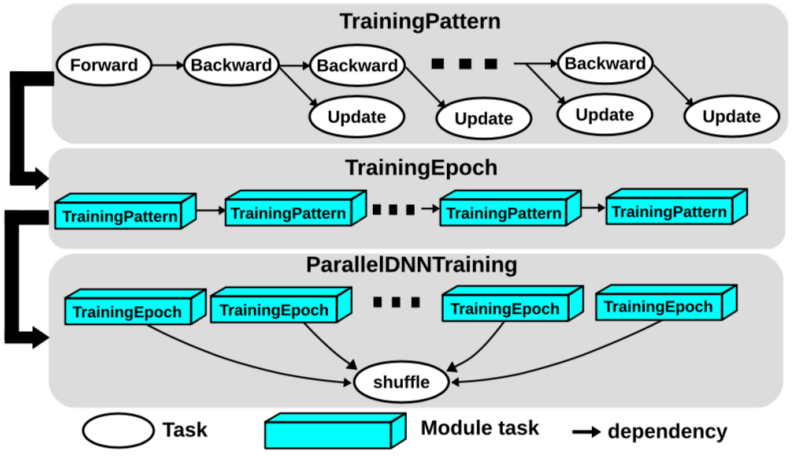


Cpp-Taskflow is about 10%-17% faster than OpenMP and Intel TBB in avg, using the least amount of source code

Cpp-Taskflow is Composable

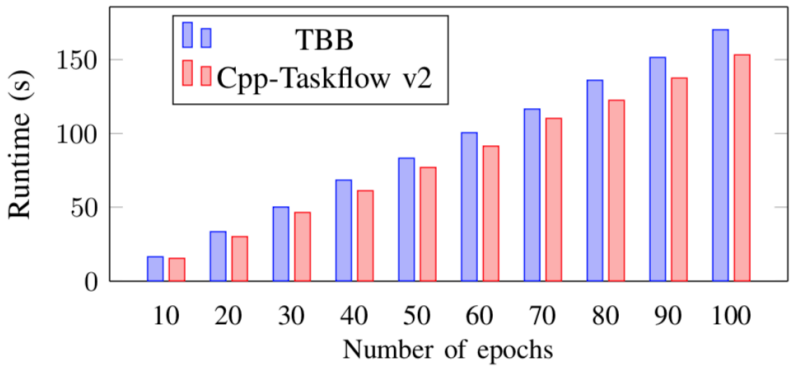
- **Large parallel graphs from small parallel patterns**
  - Key to improving programming productivity





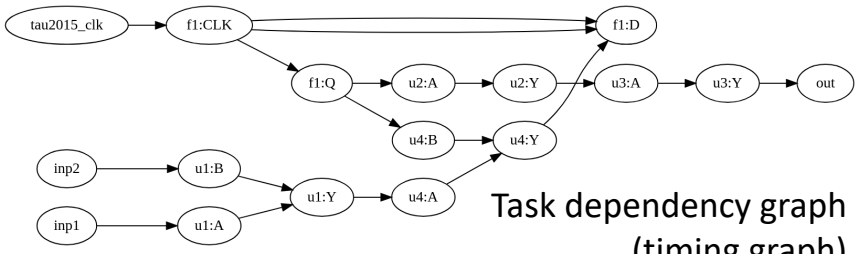
Describes end-to-end parallelisms both inside and outside a machine learning workflow -> less code, more powerful, and better runtime

22% less coding complexity and up to **40%** faster than Intel TBB in Neural Architecture Search (NAS) applications



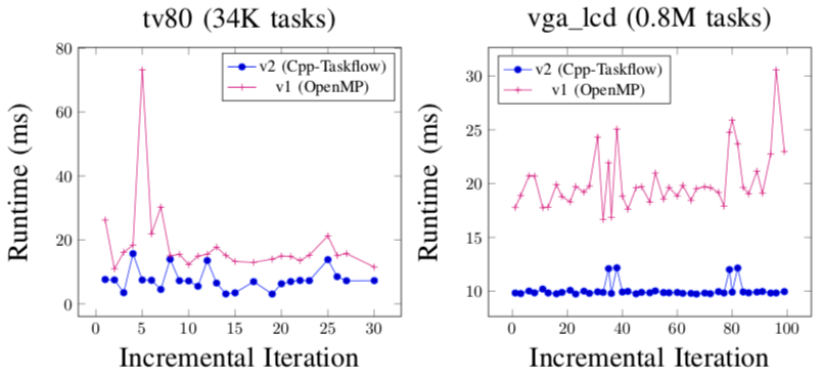
Large-Scale Graph Analytics

- **OpenTimer v1: A VLSI Static Timing Analysis Tool**
  - v1 first released in 2015 (open-source under GPL)
  - Loop-based parallelism using OpenMP 4.0
- **OpenTimer v2: A New Parallel Incremental Timer**
  - v2 first released in 2018 (open-source under MIT)
  - Task-based parallel decomposition using Cpp-Taskflow



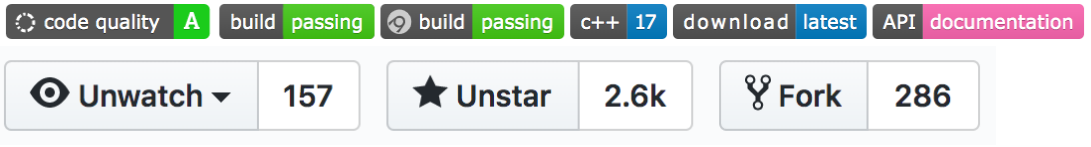
Task dependency graph (timing graph)

Cpp-Taskflow saved 4K+ lines of parallel code (https://dwheeler.com/sloccount/)

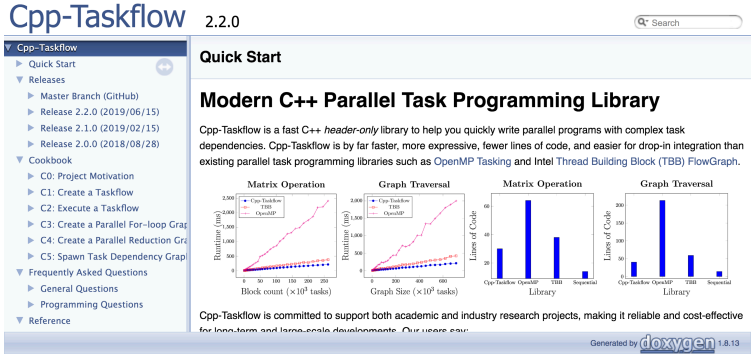


v2 (Cpp-Taskflow) is **1.4-2x** faster than v1 (OpenMP)

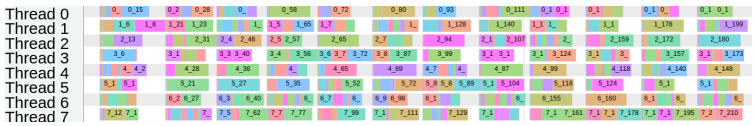
Community



- **GitHub: https://github.com/cpp-taskflow (MIT)**
  - README to start with Cpp-Taskflow in just a few mins
  - Doxygen-based C++ API and step-by-step tutorials
    - https://cpp-taskflow.github.io/cpp-taskflow/index.html
  - Showcase presentation: https://cpp-taskflow.github.io/



Cpp-Taskflow ***API documentation***



Cpp-Taskflow ***thread observer***
(profiling, debugging, testing)

"Cpp-Taskflow has the cleanest C++ Task API I have ever seen," *Damien Hocking*

"Best poster award for open-source parallel programming library," *2018 Cpp-Conference*
(voted by 1K+ professional developers)

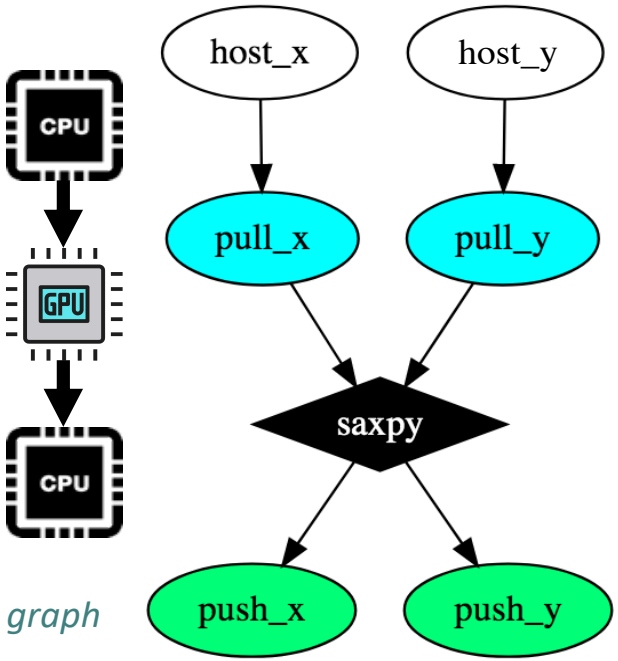
Beyond Cpp-Taskflow: Heteroflow

❑ Concurrent CPU-GPU task programming library

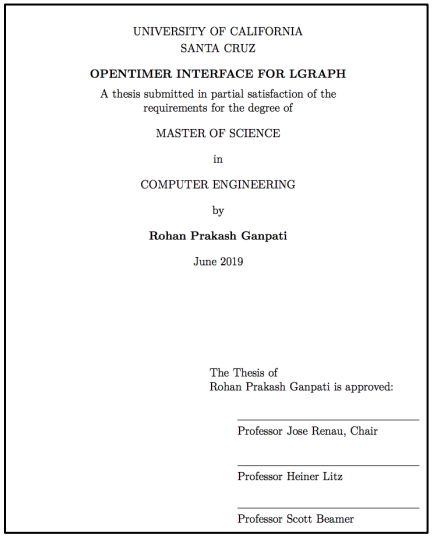
```
#include <heteroflow/heteroflow.hpp>
__global__ void saxpy(int n, float a, float *x, float *y) {
  int i = blockIdx.x*blockDim.x + threadIdx.x;
  if (i < n) y[i] = a*x[i] + y[i];
}
int main(void) {
  const int N = 1<<20;
  std::vector<float> x, y;
  hf::Heteroflow hf;              // create a heteroflow object
  auto host_x = hf.host([&](){ x.resize(N, 1.0f); });
  auto host_y = hf.host([&](){ y.resize(N, 2.0f); });
  auto pull_x  = hf.pull(x);
  auto pull_y  = hf.pull(y);
  auto kernel  = hf.kernel(saxpy, N, 2.0f, pull_x, pull_y)
                   .shape((N+255)/256, 256);
  auto push_x = hf.push(pull_x, x);
  auto push_y = hf.push(pull_y, y);
  host_x.precede(pull_x);    // host_x to run before pull_x
  host_y.precede(pull_y);    // host_y to run before pull_y
  kernel.precede(push_x, push_y).succeed(pull_x, pull_y);
  hf::Executor().run(hf).wait();  // create an executor to run the graph
}
```

*Only **20 lines** of code to enable parallel CPU-GPU task execution!*

- ✓ *No device memory controls*
- ✓ *No manual device offloading*
- ✓ *No explicit CPU-GPU synchronization*
- ✓ *No hardcoded scheduling*



Thank You All (Users + Sponsors) ☺



UNIVERSITY OF CALIFORNIA
SANTA CRUZ

OPENTIMER INTERFACE FOR LGRAPH

A thesis submitted in partial satisfaction of the
requirements for the degree of

MASTER OF SCIENCE

in

COMPUTER ENGINEERING

by

Rohan Prakash Ganpati

June 2019

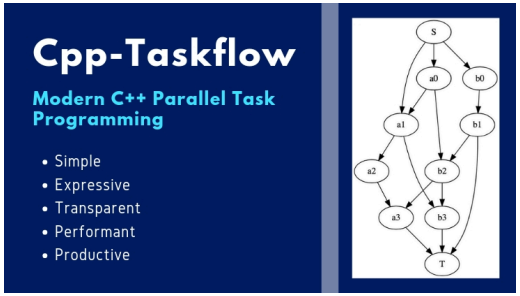
The Thesis of
Rohan Prakash Ganpati is approved:

Professor Jose Renau, Chair

Professor Heiner Litz

Professor Scott Beamer

Cpp-Taskflow integration with LGraph
(master thesis by R. Ganpati @ UCSC)

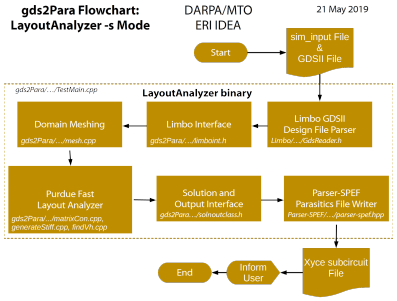


Cpp-learning's highlight
(written by Hayabusa)

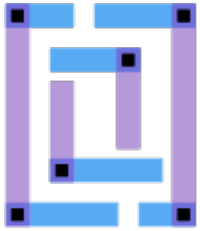
NovusCore's World of
Warcraft emulator

IDEA grant

Golden timer in ACM
TAU contests



Purdue's gds2Para



Qflow Placement &
Route

VSD open-source flow

Parallel Graph
Processing Systems

LSOracle