Lecture 10: Futures, Promises, and Data Driven Tasks

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Last Lecture (Object Based Isolation)

```
class Account {
  int id;
  double balance;
  void debit(double amount);
  void credit(double amount);
};
```

```
class Transfer {
  Account source, destination;
  double amount;
  void run() {
    isolated(&source, &destination, [&]() {
      source.debit(amount);
      destination.credit(amount);
    });
  }
};
```

```
class Bank {
  void fund_transfer() {
    Accounts numAccounts[N];
    Transfer pending[TOTAL];
    loop_domain_t loop = {0, TOTAL, 1,1};
    enable_isolation_n(numAccounts, N);
    finish([&]() {
      foasync1D([=](int i) {
        pending[i].run();
      }, FORASYNC_MODE_RECURSIVE);
    });
    disable_isolation_n(numAccounts, N);
  }
};
```

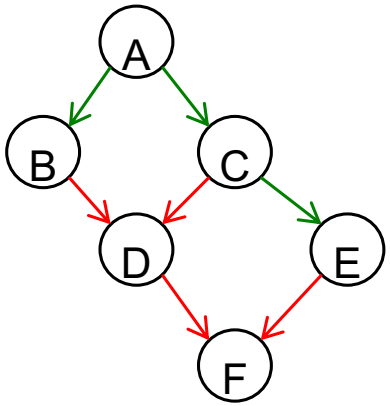
- Pros
  - Productivity: simpler approach than “locks”
  - Deadlock-freedom property is guaranteed
- Cons
  - Programmer needs to worry about getting the object list right
  - Objects in object list can only be specified at start of the isolated construct (new objects cannot be added later on)

Today's Lecture

- **Futures**
- Promises
- Data-driven tasks

Issues with async-finish

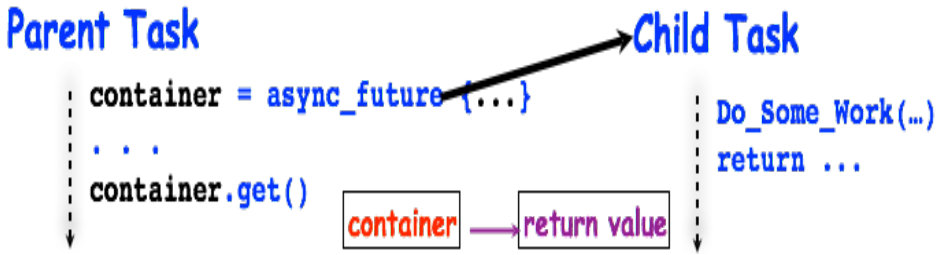
- We cannot return values from an async
- The finish synchronizes across all the async tasks created within its immediate scope
  - What if we want to synchronize across tasks selectively?
- Can we create the following CG using async-finish?



No, Finish cannot be used to ensure that D waits for both B & C, while E waits only for C

Functional Parallelism: Adding Return Values to Async Tasks

```
int main(int argc, char** argv) {
  launch([&]() {
    hclib::future_t<int> *part1 =
            hclib::async_future([=]() {          // Task-T1
        int res = DO_SOME_WORK();
        return res;
    });
    int part2 = DO_SOME_OTHER_WORK();            // Task-T2
    //get will block until result is ready
    int total = part1->get() + part2;
  });
}
```



- Two issues to be addressed:
  1) Distinction between container and value in container (future)
  2) Synchronization to avoid race condition in container accesses

async_future & get() vs. async & finish

future_t<T> *f = async_future { S }

- Creates a new child task that executes S, which must terminate with a return statement and return value
- Async expression returns a pointer to a container of type future_t

T result = f.get()

- get() evaluates f and blocks if f's value is unavailable
- Unlike finish which waits for all tasks in the finish scope, a get operation only waits for the specified async_future

Source:https://wiki.rice.edu/confluence/download/attachments/24426821/comp322-s16-lec5-slides.pdf?version=1&modificationDate=1483206145961&api=v2

Two-Way Parallel ArraySum

```
int main(int argc, char** argv) {
  launch([&]() {
    double array[SIZE]; // initialized with random numbers

    hclib::future_t<double> *sum1 = async_future([=]() {          // Task-T1
      double sum = 0;
      for(int i=0; i<SIZE/2; i++) sum += array[i];
      return sum;
    });

    hclib::future_t<double> *sum2 = async_future([=]() {          // Task-T2
      double sum=0;
      for(int i=SIZE/2; i<SIZE; i++) sum += array[i];
      return sum;
    });

    //get will block until result is ready
    double total = sum1->get() + sum2->get();
  });
}
```

Is there a data-race?

Code available on github: https://github.com/vivkumar/cse502/blob/master/hclib/test/lec13/

Comparison of Future Task and Regular Async Versions of Two-Way Parallel ArraySum

- Future task version initializes two pointers to future objects, sum1 and sum2
  - No finish construct needed in this example
  - Instead parent task waits for child tasks by performing sum1->get() and sum2->get()
- Easier to guarantee absence of race conditions in Future Task version
  - No race on sum because it is declared as a local variable in both tasks T1 and T2
  - No race on future variables, sum1 and sum2, because of blocking-read semantics

Source:https://wiki.rice.edu/confluence/download/attachments/24426821/comp322-s16-lec5-slides.pdf?version=1&modificationDate=1483206145961&api=v2

Fibonacci with Future Tasks

```
uint64_t fib(uint64_t n) {
  if(n<THRESHOLD) return fib_serial(n);
  else {
    hclib::future_t<uint64_t> *f1 = hclib::async_future([=](){ return fib(n-1); });
    hclib::future_t<uint64_t> *f2 = hclib::async_future([=](){ return fib(n-2); });
    //get will block until result is ready
    return f1->get() + f2->get();
  }
}
```

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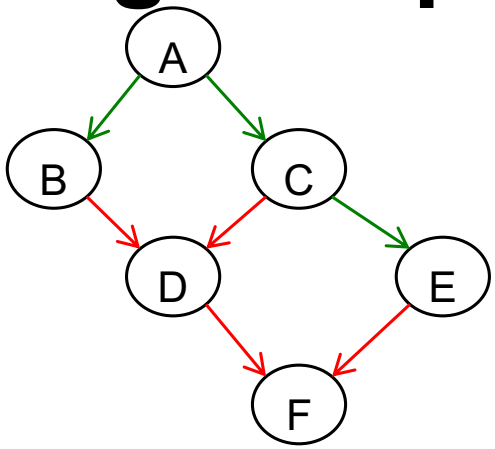
Task Parallel Code with Futures to Generate Following Computation Graph



Do you see any inefficiency in this implementation?

```
future_t<void> *A = async_future([=](){...; return;});
future_t<void> *B = async_future([=](){A->get(); ...; return;});
future_t<void> *C = async_future([=](){A->get(); ...; return;});
future_t<void> *D = async_future([=](){B->get(); C->get(); ...; return;});
future_t<void> *E = async_future([=](){C->get(); ...; return;});
future_t<void> *F = async_future([=](){D->get(); E->get(); ...; return;});
F->get();
```

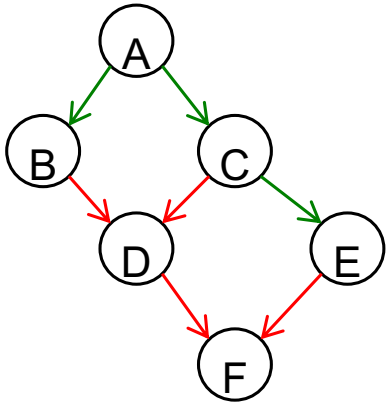
Code available on github: https://github.com/vivkumar/cse502/blob/master/hclib/test/lec13/

Today's Lecture

- Futures
- **Promises**
- Data-driven tasks

Issues with async-finish

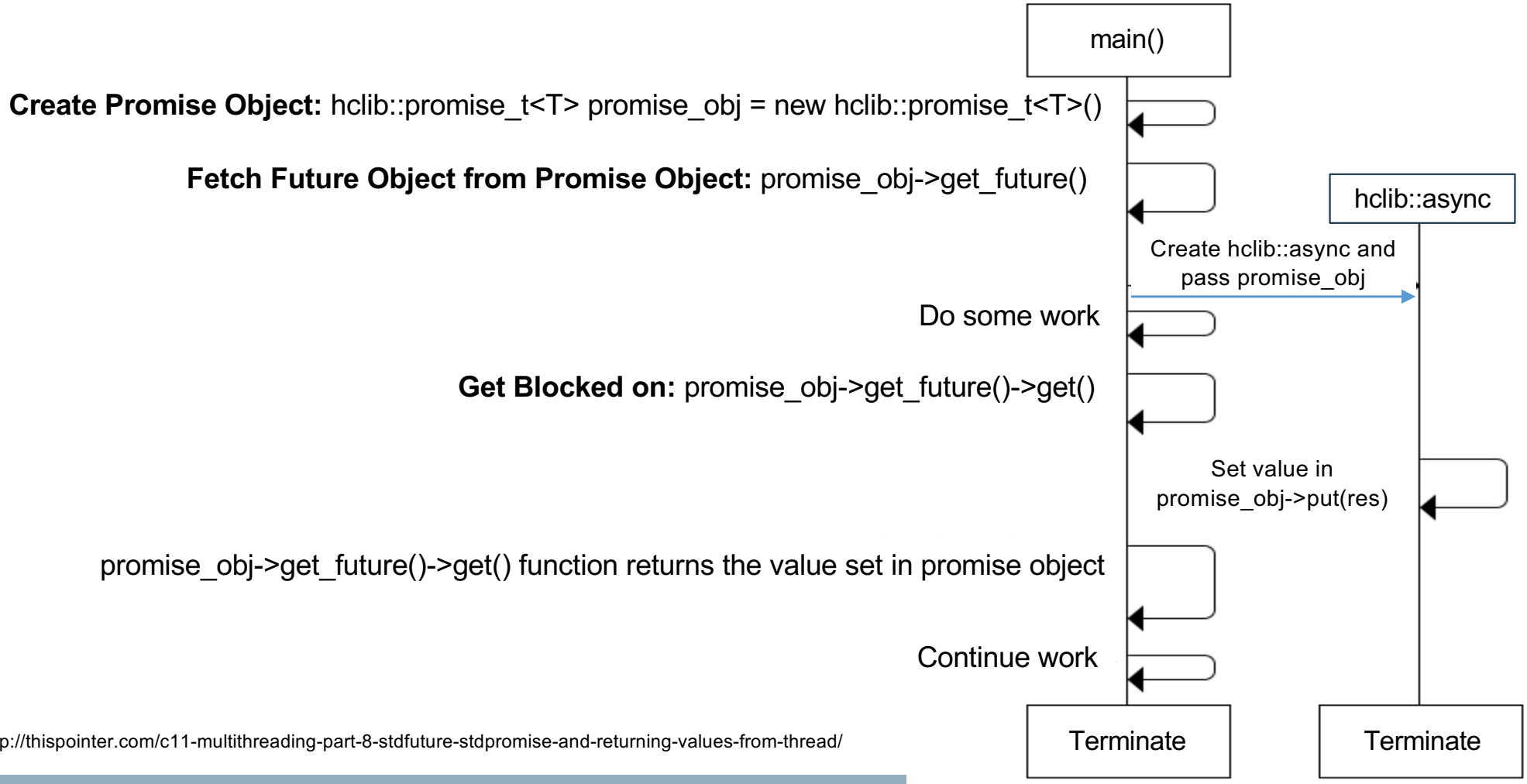
- We cannot return values from an async
- The finish synchronizes across all the async tasks created within its immediate scope
  - What if we want to synchronize across tasks selectively?
- Can we create the following CG using async-finish?
- async-finish does not allow point to point synchronization while the asyncs are in flight!



hclib::promise v/s hclib::future

- "*A promise is an object that can store a value of type T to be retrieved by a future object (possibly in another thread), offering a synchronization point*"
  - Writable end of an object
- "*A future is an object that can retrieve a value from some provider object or function, properly synchronizing this access if in different threads*"
  - Readable end of an object

hclib::promise_t & hclib::future_t workflow



Source: http://thispointer.com/c11-multithreading-part-8-stdfuture-stdpromise-and-returning-values-from-thread/

Code for the Workflow in Previous Slide

```
using namespace hclib;
int main(int argc, char** argv) {
  launch([&]() {
    hclib::promise_t<int> *promise_obj = new promise_t<int>();
    hclib::promise_t<int> *future_obj->get_future();
    async([=]() {                              // Task-T1
      int result = new int;
      promise_obj->put(result);
    });

    int my_part = DO_SOME_WORK();              // Task-T2
    // Wait for Task-1
    int other_part = future_obj->get();
    int total_result = my_part + other_part;
    delete(promise_obj);
  });
}
```

Code available on github: https://github.com/vivkumar/cse502/blob/master/hclib/test/lec13/

Rules for Read and Write

- put(…)
  - Only allowed on a promise_t object
  - Single-assignment only
  - Runtime assertions to guard against multiple put on same promise_t object
- get()
  - Only allowed on a future_t object
  - Can be called multiple times
    - Simply blocks unless put has been done
  - Never returns without a matching put performed by any **other** task

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Today's Lecture

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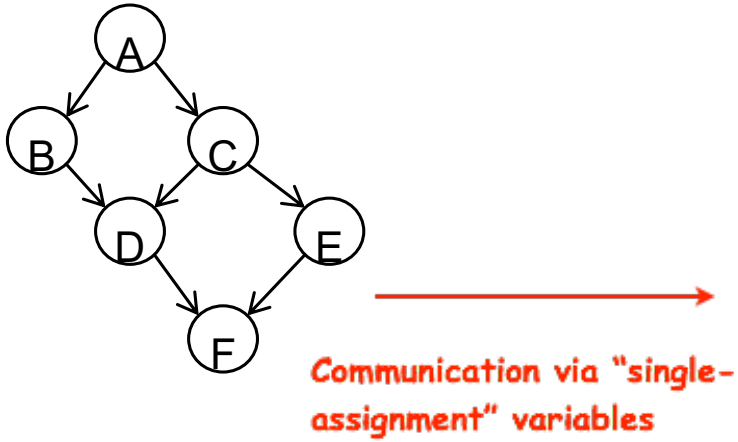
- **Data-driven tasks**

Dataflow Programming




```
future_t<void> *A = async_future([=](){...; return;});
future_t<void> *B = async_future([=](){A->get(); ...; return;});
future_t<void> *C = async_future([=](){A->get(); ...; return;});
future_t<void> *D = async_future([=](){B->get(); C->get(); ...; return;});
future_t<void> *E = async_future([=](){C->get(); ...; return;});
future_t<void> *F = async_future([=](){D->get(); E->get(); ...; return;});
F->get();
```

The above program will force workers executing an async to block until the future.get() is ready

- General idea: build an arbitrary task graph, but restrict all inter-task communications to single-assignment variables
- Semantic guarantees: race-freedom, determinism
- Deadlocks are possible due to unavailable inputs (but they are deterministic)

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Data-Driven Task (DDT) in HClib

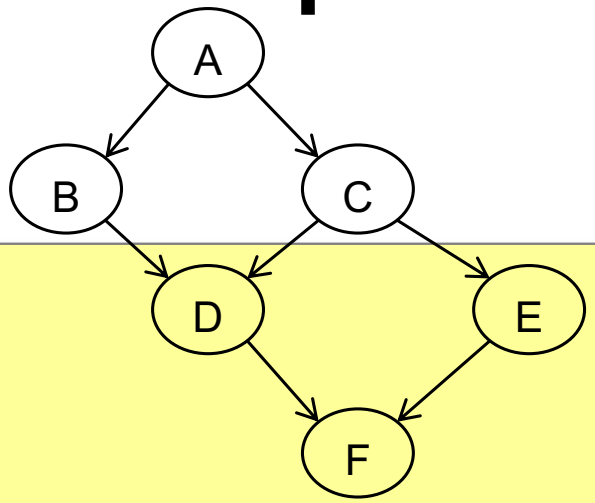
async_await(lambda, fObj_1, fObj_2,…..,fObj_n)

- Unlike any other async tasks that we have seen so far (async, asyncAtHpt, async_future), async_await task is **pushed to the deque ONLY after all the future objects in the parameter list are ready with values inside them**
  - i.e. the put has been performed on the promise end of each of the future objects

Source:https://wiki.rice.edu/confluence/download/attachments/24426821/comp322-s16-lec5-slides.pdf?version=1&modificationDate=1483206145961&api=v2

Converting Previous Future Example to DDTs

This implementation removes the inefficiency we discussed in async_future based implementation in Slide #9




```
promise_t<void>* prom_A = new promise_t<void>();
promise_t<void>* prom_B = new promise_t<void>();
promise_t<void>* prom_C = new promise_t<void>();
promise_t<void>* prom_D = new promise_t<void>();
promise_t<void>* prom_E = new promise_t<void>();
promise_t<void>* prom_F = new promise_t<void>();
finish([=]() {
  async([=]() { A(); prom_A->put(); });
  async_await([=]() { B(); prom_B->put(); }, prom_A->get_future());
  async_await([=]() { C(); prom_C->put(); }, prom_A->get_future());
  async_await([=]() { D(); prom_D->put(); }, prom_B->get_future(), prom_C->get_future());
  async_await([=]() { E(); prom_E->put(); }, prom_C->get_future());
  async_await([=]() { F(); prom_F->put(); }, prom_D->get_future(), prom_E->get_future());
});
```

Any possibility to remove this finish?

Code available on github: https://github.com/vivkumar/cse502/blob/master/hclib/test/lec13/

Fibonacci With DDTs

```
void fib(uint64_t n, hclib::promise_t<uint64_t> *prom) {
  if(n<THRESHOLD) {
    uint64_t res = fib_serial(n);
    prom->put(res);
  else {
    hclib::promise_t<uint64_t> *p1 = new hclib::promise_t<uint64_t>();
    hclib::async([=](){ fib(n-1, p1); }
    hclib::promise_t<uint64_t> *p2 = new hclib::promise_t<uint64_t>();
    hclib::async([=](){ fib(n-2, p2); }

    //wait for dependencies without using a blocking wait() operation
    hclib::async_await([=]() {
      uint64_t r = p1->get_future()->get() + p2->get_future()->get();
      prom->put(r);
      delete(p1); delete(p2);
    }, p1->get_future(), p2->get_future());
  }
}

main() {
  hclib::promise_t<uint64_t> *prom = new hclib::promise_t<uint64_t>();
  fib(n, prom); //NO finish
  uint64_t result = prom->get_future()->get();
  delete(prom);
}
```

Code available on github:
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Deadlock Example with DDT

```
promise_t<void>* left = new promise_t<void>();
promise_t<void>* right = new promise_t<void>();
finish([=]() {
  async_await([=]() { right->put(); }, left->get_future());
  async_await([=]() { left->put(); }, right->get_future());
});
```

Next Lecture

- Non Uniform Memory Access Architecture (NUMA)