Multithreading done right?

Overview

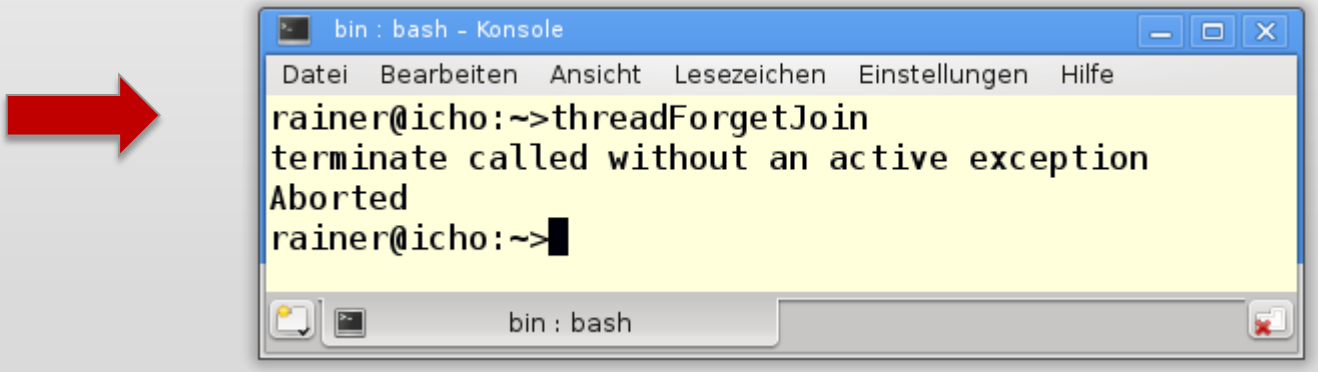
- Threads
- Shared Variables
- Thread local data
- Condition Variables
- Tasks
- Memory Model

Threads

- Needs a work package and run immediately
- The creator has to care of this child by
  - waiting for his child
  - detach from his child
- Accepts the data by copy or by reference

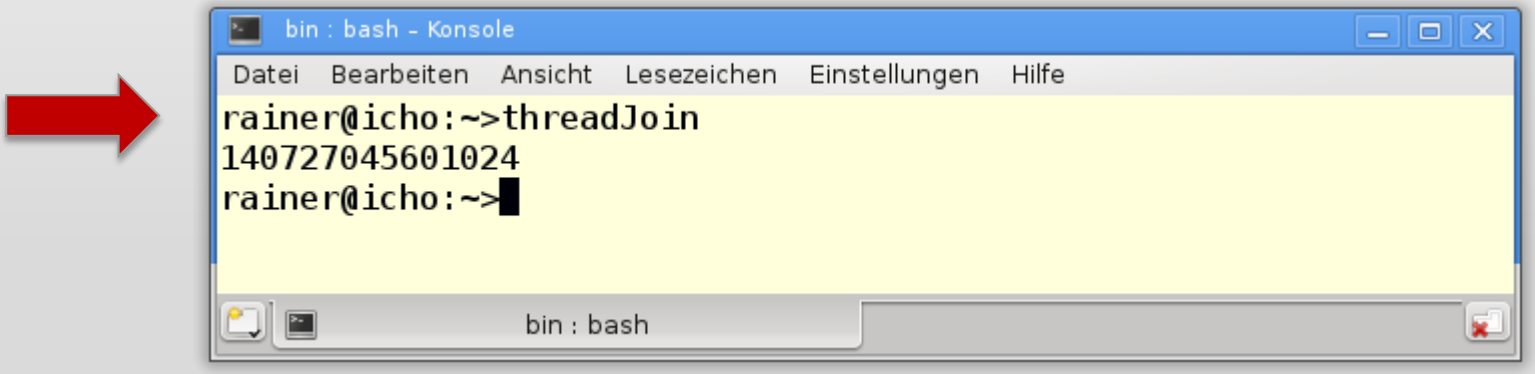
Problems?

```
#include <iostream>
#include <thread>

int main(){
  thread t( []{cout << this_thread::get_id();} );
}
```



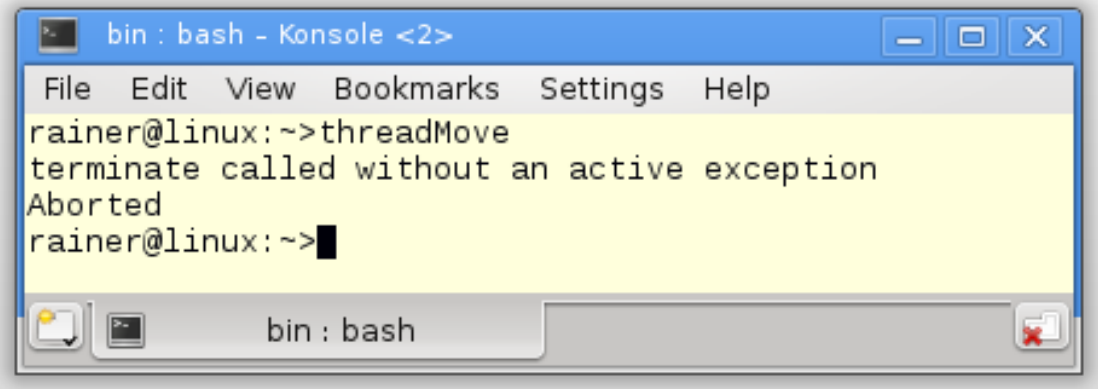
Solution: join or detach

```
#include <iostream>
#include <thread>

int main(){
  thread t( []{cout << this_thread::get_id();} );
  t.join();
  // t.detach();
}
```



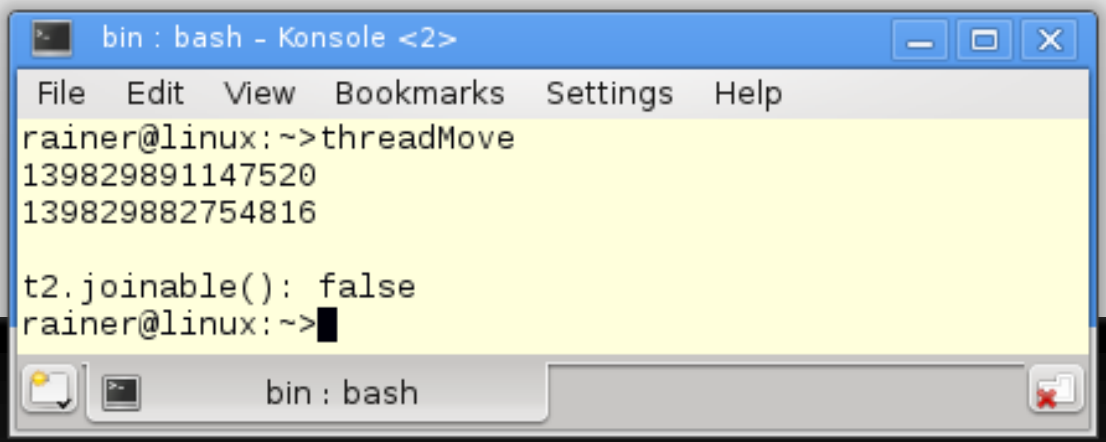
Problems?

```
#include <iostream>
#include <thread>

int main(){
  thread t( []{cout << this_thread::get_id();} );
  thread t2([]{cout << this_thread::get_id();});

  t= std::move(t2);

  t.join();
  t2.join();
}
```



Solution: join or detach

```
#include <iostream>
#include <thread>

int main(){
  thread t( []{cout << this_thread::get_id();} );
  thread t2([]{std::cout << this_thread::get_id();});

  t.join();
  t= std::move(t2);
  t.join();

  cout << "t2.joinable(): " << t2.joinable();
}
```



Solution: A. Williams "C++ Concurrency in Action"

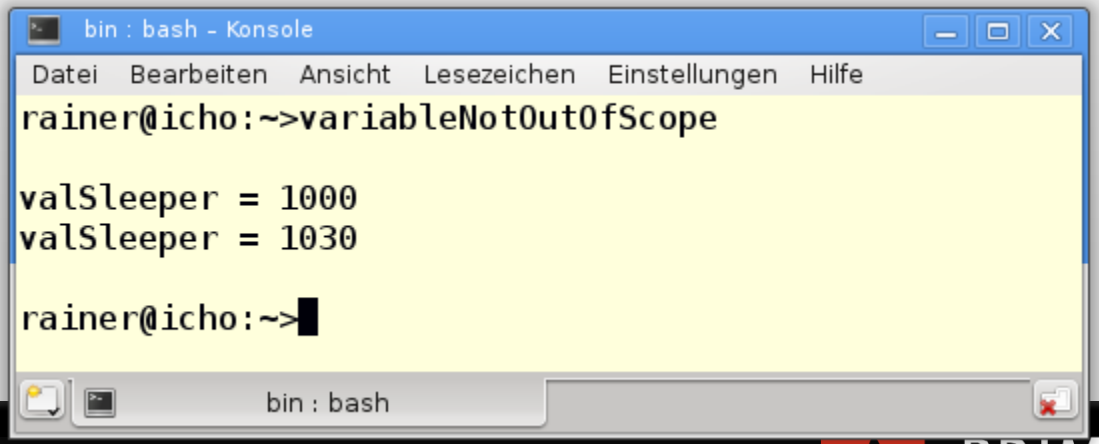
```
class scoped_thread{
  std::thread t;
public:
  explicit scoped_thread(std::thread t_):t(std::move(t_)){
    if ( !t.joinable() ) throw std::logic_error("No thread");
  }
  ~scoped_thread(){
    t.join();
  }
  scoped_thread(scoped_thread&)= delete;
  scoped_thread& operator=(scoped_thread const &)= delete;
};

int main(){
  scoped_thread t(std::thread(
                []{std::cout << std::this_thread::get_id();}
                           )
                  );
```

Problems?

```
struct Sleeper{
  Sleeper(int& i_):i{i_}{};
  void operator() (int k){
    for (unsigned int j= 0; j <= 5; ++j){
      this_thread::sleep_for(chrono::milliseconds(100));
      i += k;
    }
  }
private:
  int& i;
};
int main(){
  int valSleeper= 1000;
  cout << "valSleeper = " << valSleeper << endl;
  thread t(Sleeper(valSleeper),5);
  t.detach();
  cout << "valSleeper = " << valSleeper << endl;
}
```

Effect and Solution

```
thread t(Sleeper(valSleeper),5);
t.join(); // instead of t.detach()
```



Shared Variables

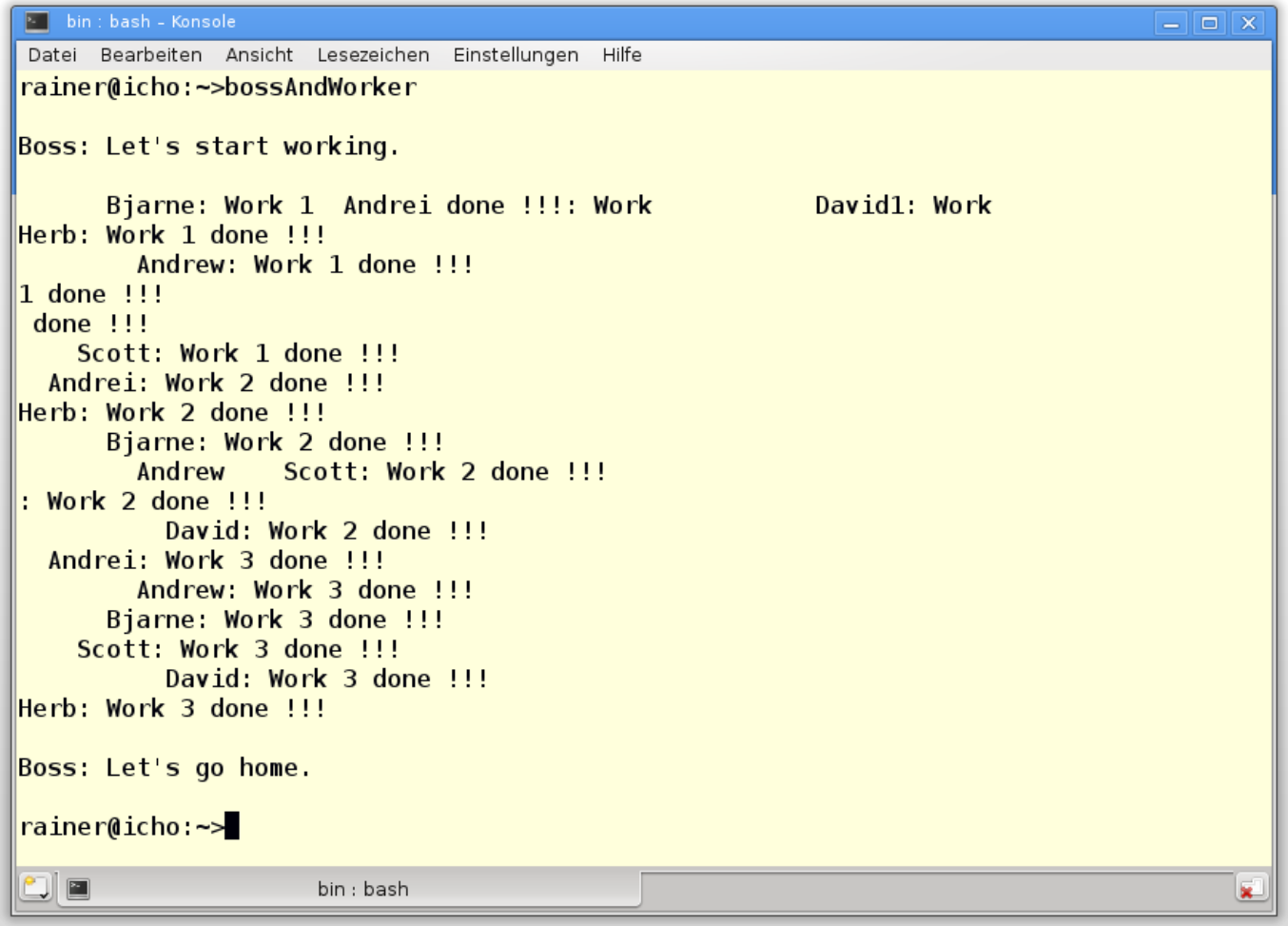
http://www.robinage.com/

- Has to be protected from shared access by
  - Atomic variables
  - Mutexe

Problems?

```
struct Worker{
  Worker(string n):name(n){};
  void operator() (){
    for (int i= 1; i <= 3; ++i){
      this_thread::sleep_for(chrono::milliseconds(200));
      cout << name << ": " << "Work " << i << " done !!!" << endl;
    }
  }
private:
  string name;
};
...
cout << "Boss: Let's start working.\n\n";
thread herb= thread(Worker("Herb"));
thread andrei= thread(Worker("  Andrei"));
thread scott= thread(Worker("    Scott"));
thread bjarne= thread(Worker("      Bjarne"));
thread andrew= thread(Worker("        Andrew"));
thread david= thread(Worker("          David"));
   // join all Worker
cout << "\n" << "Boss: Let's go home." << endl;
```

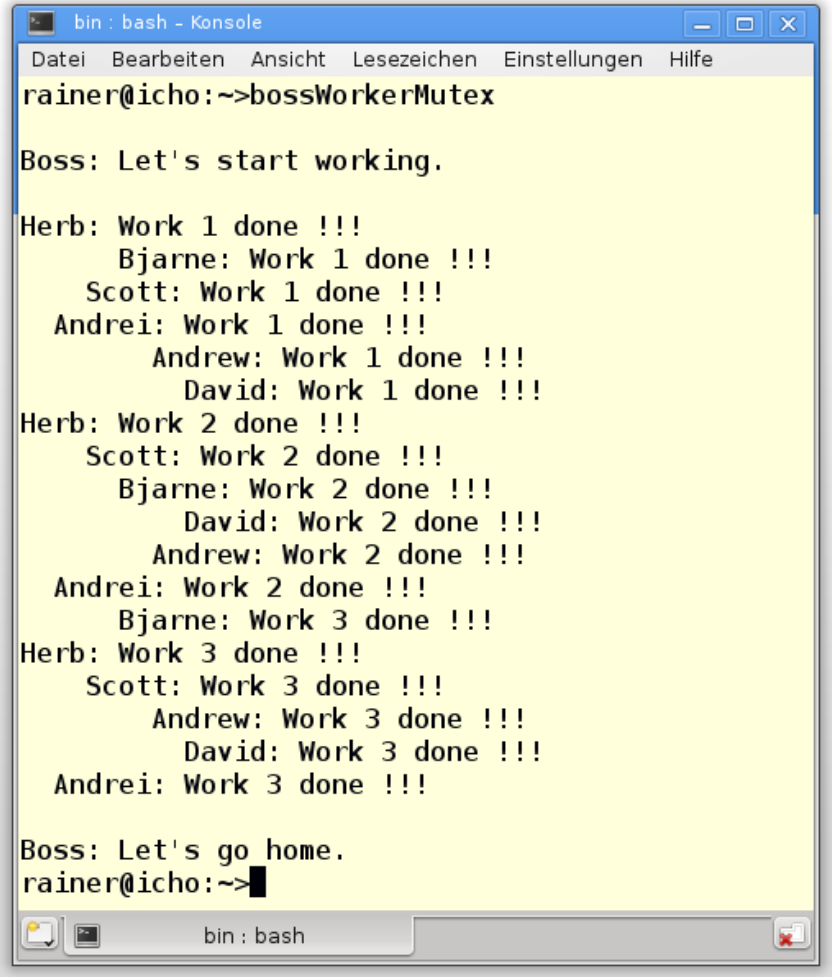
Effect



Solution: Mutex

```
mutex coutMutex;

struct Worker{
  Worker(string n):name(n){};
  void operator() (){
    for (int i= 1; i <= 3; ++i){
      sleep_for(milliseconds(200));
      coutMutex.lock();
      cout << name << ": " << "Work " <<
     i << " done !!!" << endl;
      coutMutex.unlock();
    }
  }
private:
  string name;
};
```

std::cout is thread-safe.



Still a problem?

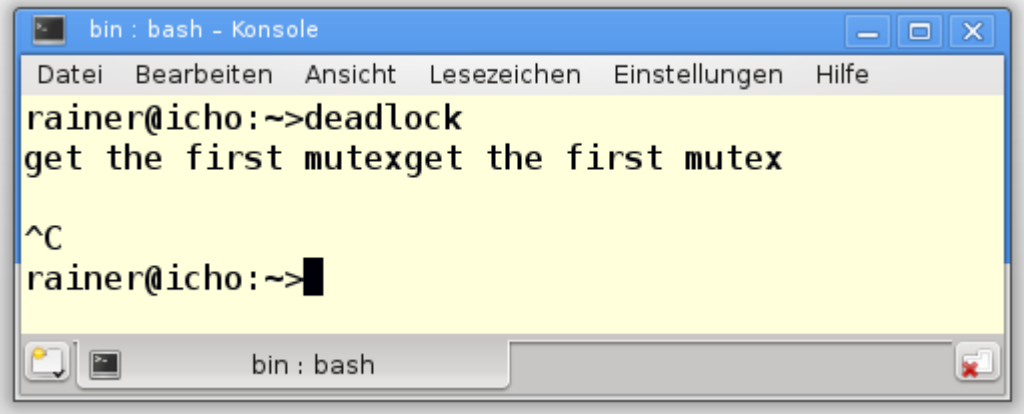
```
void operator() (){
  for (int i= 1; i <= 3; ++i){
    sleep_for(milliseconds(200));
    coutMutex.lock();
    cout << name << ": " << "Work "
    <<  i << " done !!!" << endl;
    coutMutex.unlock();
  }
}
```

~~Mutex~~ → Lock

```
void operator() (){
  for (int i= 1; i <= 3; ++i)
    sleep_for(milliseconds(200));
    lock_guard<mutex>coutGuard(coutMutex);
    cout << name << ": " << "Work " << i <<
    " done !!!" << endl;
  }
}
```

Problems? and Effect!

```
struct CriticalData{
  mutex mut;
};

void lock(CriticalData& a, CriticalData& b){
  lock_guard<mutex>guard1(a.mut);
  cout << "get the first mutex" << endl;
  this_thread::sleep_for(chrono::milliseconds(1));
  lock_guard<mutex>guard2(b.mut);
  cout << "get the second mutex" << endl;
  // do something with a and b
}

int main(){
  CriticalData c1;
  CriticalData c2;
  thread t1([&]{lock(c1,c2);});
  thread t2([&]{lock(c2,c1);});
  t1.join();
  t2.join();
}
```



Solution: unique_lock

```
void deadLock(CriticalData& a, CriticalData& b){

  unique_lock<mutex>guard1(a.mut,defer_lock);
  cout << "Thread: " << get_id() <<" first mutex"<< endl;

  this_thread::sleep_for(chrono::milliseconds(1));

  unique_lock<mutex>guard2(b.mut,defer_lock);
  cout <<"    Thread: " << get_id() <<" second mutex"<< endl;

  cout <<"        Thread: " << get_id() <<" get both mutex" << endl;

  lock(guard1,guard2);

}
```

Solution, but ...

```
mutex myMutex;

class MySingleton{
public:
  static MySingleton& getInstance(){
    lock_guard<mutex> myLock(myMutex);
    if( !instance ) instance= new MySingleton();
    return *instance;
  }
private:
  MySingleton();
  ~MySingleton();
  MySingleton(const MySingleton&)= delete;
  MySingleton& operator=(const MySingleton&)= delete;
  static MySingleton* instance;
};
MySingleton::MySingleton()= default;
MySingleton::~MySingleton()= default;
MySingleton* MySingleton::instance= nullptr;
...
MySingleton::getInstance();
```

Problems? Double-Checked Locking Pattern

```
class MySingleton{
  static mutex myMutex;
public:
  static MySingleton& getInstance(){
    if ( !instance ){
      lock_guard<mutex> myLock(myMutex);
      if( !instance ) instance= new MySingleton();
      return *instance;
    }
  }
```

`instance= new MySingleton();` is not atomic

1. Allocate memory for `MySingleton`
2. Create `MySingleton` object in the memory
3. Refer `instance` to `MySingleton` object

Possible execution order 1, 3 and 2

Solution: call_once, Meyers Singleton or Atomics

call_once and once_flag

```
class MySingleton{
public:
  static MySingleton& getInstance(){
    call_once(initInstanceFlag,
         &MySingleton::initSingleton);
    return *instance;
  }
private:
  ...
  static once_flag initInstanceFlag;
  static void initSingleton(){
    instance= new MySingleton;
  }
};
...
once_flag MySingleton::initInstanceFlag;
```

Meyers Singleton

```
class MySingleton{
public:
  static MySingleton& getInstance(){
    static MySingleton instance;
    return instance;
  }
private:
...
```

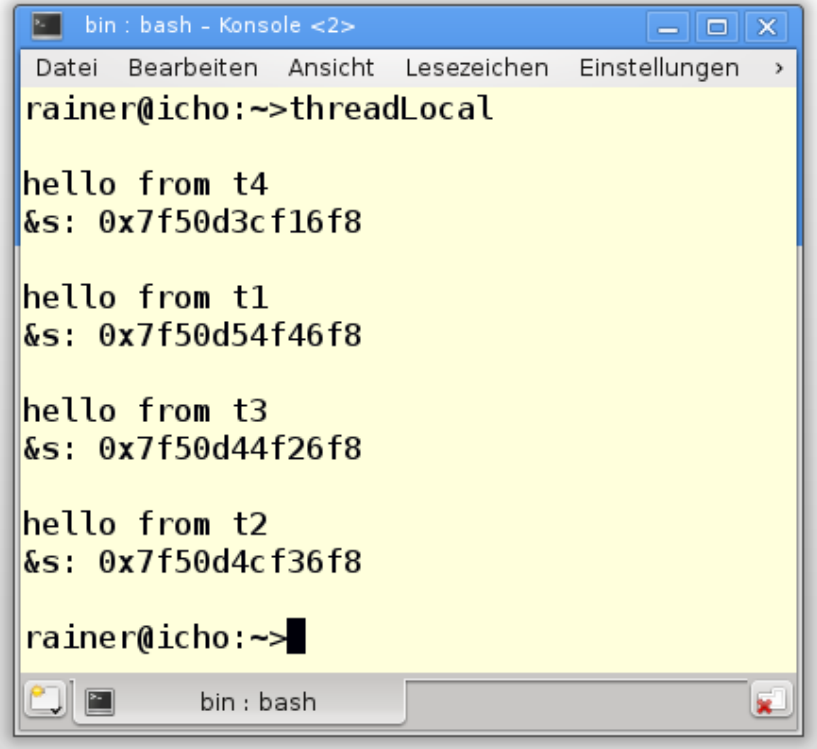
Atomic variables

Thread Local Data

- Are exclusively owned by a thread
- Each thread has his own copy of the data
- Behave like static data
  - will be created at the first usage
  - are bound to the lifetime of their thread

Problems?

```
mutex coutMutex;
thread_local string s("hello from ");

void addThreadLocal(string const& s2){
  s+=s2;
  lock_guard<mutex> guard(coutMutex);
  cout << s << endl;
  cout << "&s: " << &s << endl;
  cout << endl;
}

int main(){
  thread t1(addThreadLocal,"t1");
  thread t2(addThreadLocal,"t2");
  thread t3(addThreadLocal,"t3");
  thread t4(addThreadLocal,"t4");

  t1.join(), t2.join(), t3.join(),t4.join();
}
```



Condition Variables

- Empowers threads to synchronize via notifications
- One threads produces a result, a other thread is still waiting for
- The producer notifies one or more consumers

Problems?

```
mutex mutex_;
condition_variable condVar;

void waitingForWork(){
  unique_lock<mutex> lck(mutex_);
  condVar.wait(lck);
}

void setDataReady(){
  condVar.notify_one();
}

int main(){
  thread t1(waitingForWork);
  thread t2(setDataReady);
  t1.join(),
  t2.join();
}
```

Spurious Wakeup

```
bool dataReady= false;

void waitingForWork(){
  unique_lock<mutex> lck(mutex_);
  condVar.wait(lck,[]{return dataReady;});
}

void setDataReady(){
  {
    lock_guard<mutex> lck(mutex_);
    dataReady=true;
  }
  condVar.notify_one();
}
```

Problems?

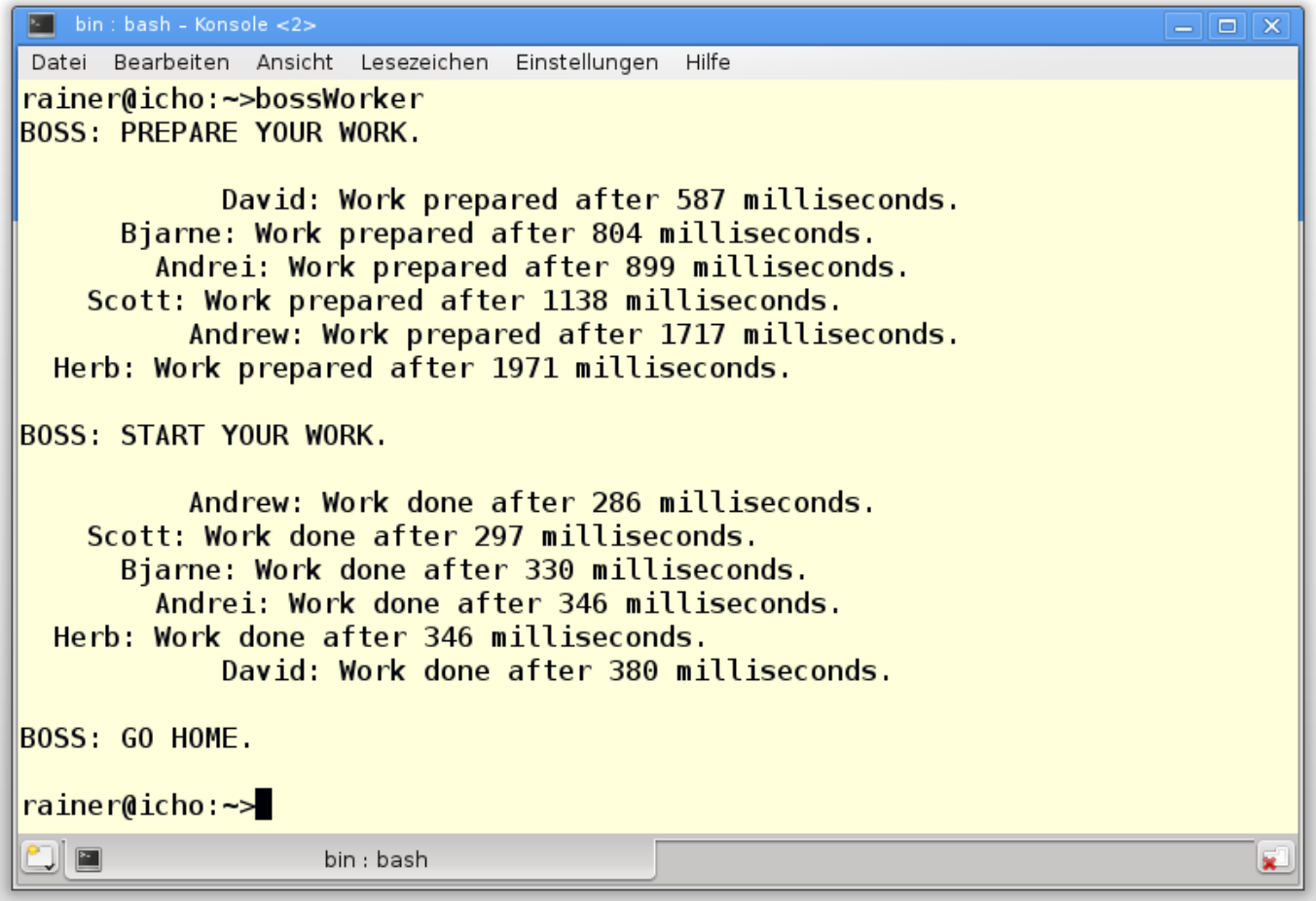
```
mutex mutex_;
condition_variable condVar;

void waitingForWork(){
  unique_lock<mutex> lck(mutex_);
  condVar.wait(lck,[]{return dataReady;});
}

void setDataReady(){
  {
    lock_guard<mutex> lck(mutex_);
    dataReady=true;
  }
  condVar.notify_one();
}
...
thread t1(setDataReady);
// short time delay
thread t2(waitingForWork);

t1.join(), t2.join();
```

Lost Wakeup

- The `condition_variable` class is a synchronization primitive that can be used to block a thread, or multiple threads at the same time, ...

http://en.cppreference.com/w/cpp/thread/condition_variable

Problem: A lot to do.



Solution: Boss

```
Worker herb("  Herb"), thread herbWork(herb);
...
Worker david("            David"), thread davidWork(david);

cout << "BOSS: PREPARE YOUR WORK.\n " << endl;

preparedCount.store(0);
unique_lock<mutex> preparedUniqueLock( preparedMutex );
worker2BossCondVariable.wait(preparedUniqueLock,[]{ return preparedCount == 6; });

startWork= true;  cout << "\nBOSS: START YOUR WORK. \n" << endl;
boss2WorkerCondVariable.notify_all();

doneCount.store(0);
unique_lock<mutex> doneUniqueLock( doneMutex );
worker2BossCondVariable.wait(doneUniqueLock,[]{ return doneCount == 6; });

goHome= true;  cout << "\nBOSS: GO HOME. \n" << endl;
boss2WorkerCondVariable.notify_all();

// join all Worker
```

Solution: Worker

```
struct Worker{
  Worker(string n):name(n){};
  void operator() (){
    int prepareTime= getRandomTime(500,2000);
    this_thread::sleep_for(milliseconds(prepareTime));
    preparedCount++;
    cout << name << ": " << "Work prepared after " << prepareTime << " milliseconds." << endl;
    worker2BossCondVariable.notify_one();
    { // wait for the boss
      unique_lock<mutex> startWorkLock( startWorkMutex );
      boss2WorkerCondVariable.wait( startWorkLock,[]{ return startWork;});
    }
    int workTime= getRandomTime(200,400);
    this_tread::sleep_for(milliseconds(workTime));
    doneCount++;
    cout << name << ": " << "Work done after " << workTime << " milliseconds." << endl;
    worker2BossCondVariable.notify_one();
    { // wait for the boss
      unique_lock<mutex> goHomeLock( goHomeMutex );
      boss2WorkerCondVariable.wait( goHomeLock,[]{ return goHome;});
    }
  }
....
```

Use Tasks.

Tasks

- Are channels between a Sender and a Receiver
- The Producer puts a value in the channel, the Consumer is waiting for
- The Sender is called Promise, the Receiver Future

Tasks: A little bit of background.

```
int a= 2000;
int b= 11;
```

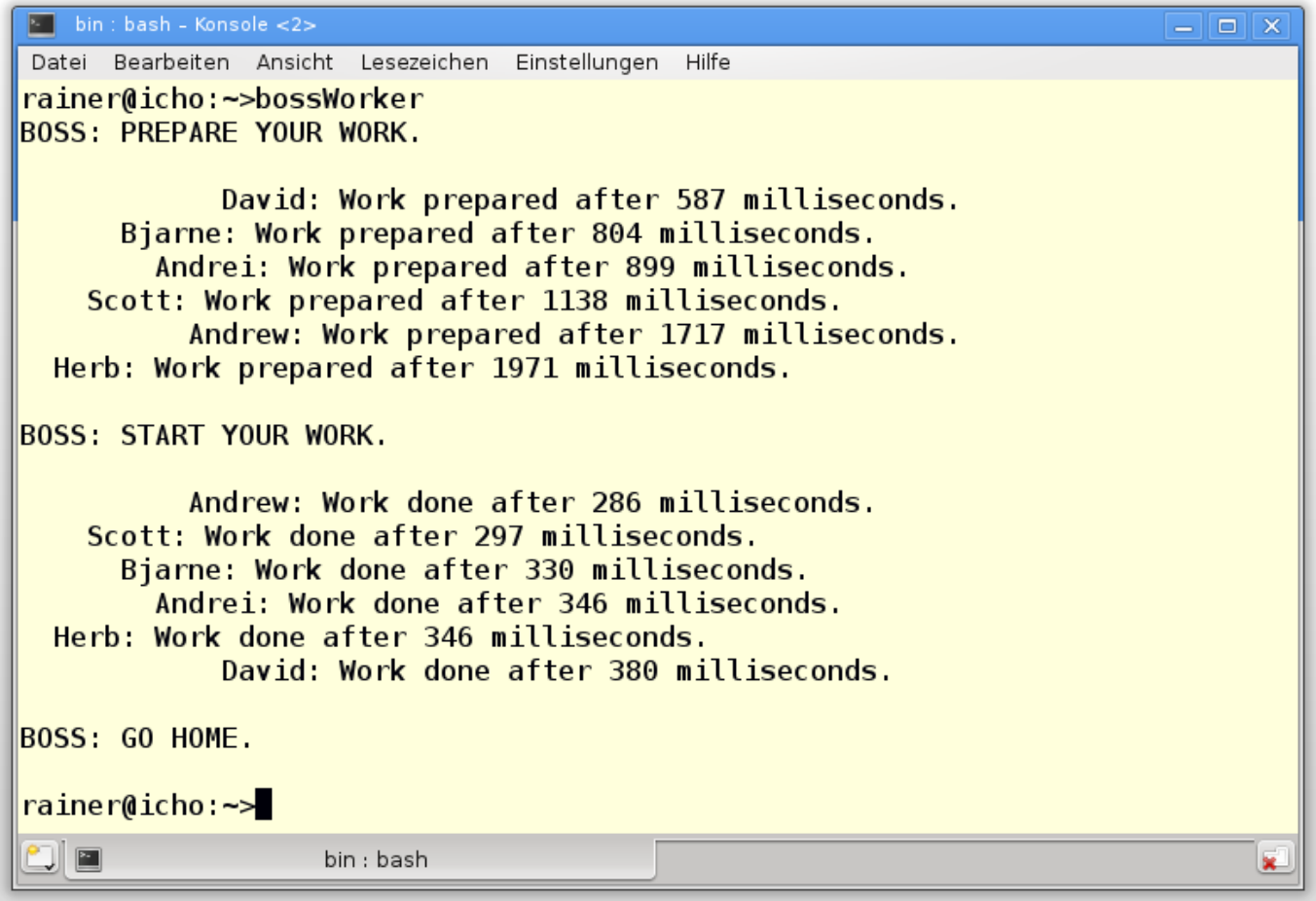
- implicit with `std::async`

```
future<int> sumFuture= async([=]{ return a+b; });
sumFuture.get();   // 2011
```

- explicit with `std::future` and `std::promise`

```
void sum(promise<int>&& intProm, int x, int y){
  intProm.set_value(x+y);
}
promise<int> sumPromise;
future<int> futRes= sumPromise.get_future();
thread sumThread(&sum, move(sumPromise),a,b);
futRes.get();      // 2011
```

Problem: A lot to do.



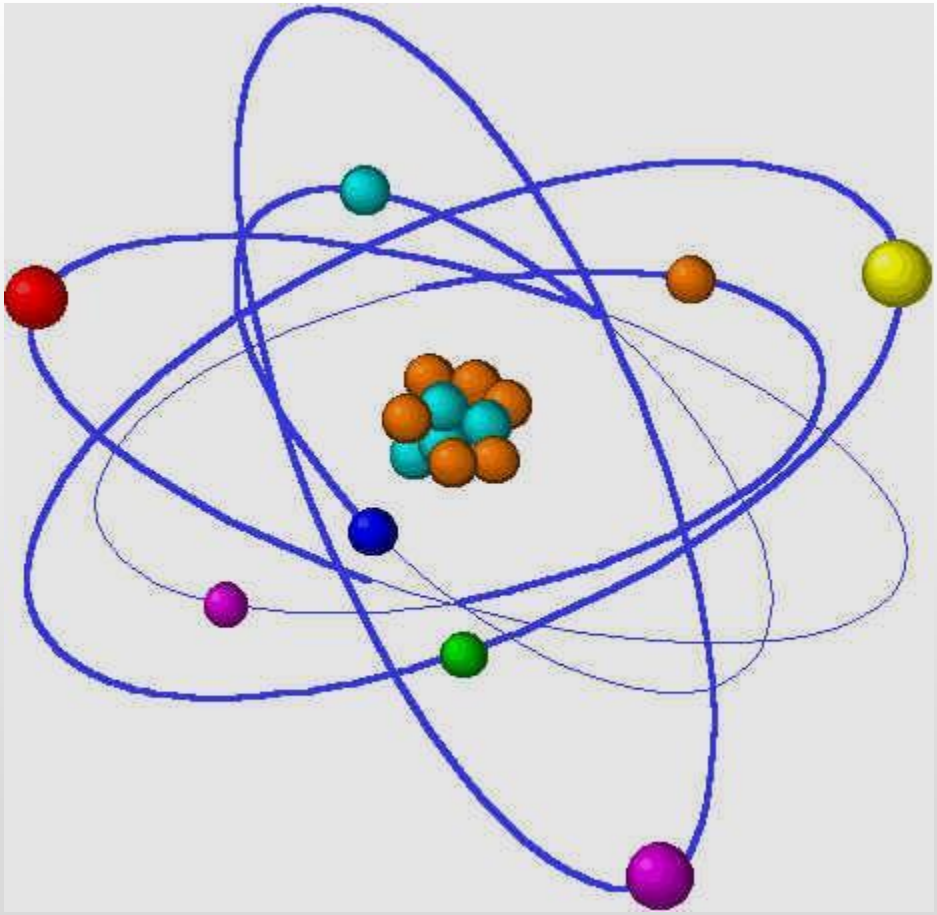
Solution: Boss

```
promise<void> startWorkProm;
promise<void> goHomeProm;

shared_future<void> startWorkFut= startWorkProm.get_future();
shared_future<void> goHomeFut= goHomeProm.get_future();

promise<void> herbPrepared;
future<void> waitForHerbPrepared= herbPrepared.get_future();
promise<void> herbDone;
future<void> waitForHerbDone= herbDone.get_future();
Worker herb("  Herb");
thread herbWork(herb,move(herbPrepared),startWorkFut,move(herbDone),goHomeFut);
...

cout << "BOSS: PREPARE YOUR WORK.\n " << endl;
waitForHerbPrepared.wait(), waitForScottPrepared.wait(), waitFor  ...
cout << "\nBOSS: START YOUR WORK. \n" << endl;
startWorkProm.set_value();
waitForHerbDone.wait(), waitForScottDone.wait(), waitFor ...
cout << "\nBOSS: GO HOME. \n" << endl;
goHomeProm.set_value();

// join all Worker
```

Solution: Worker

```
struct Worker{
  Worker(string n):name(n){};
  void operator() (promise<void>&& preparedWork, shared_future<void> boss2WorkerStartWork,
                   promise<void>&& doneWork, shared_future<void>boss2WorkerGoHome ){
    int prepareTime= getRandomTime(500,2000);
    this_thread::sleep_for(milliseconds(prepareTime));
    preparedWork.set_value();
    cout << name << ": " << "Work prepared after " << prepareTime << " milliseconds." << endl;

    boss2WorkerStartWork.wait();

    int workTime= getRandomTime(200,400);
    this_thread::sleep_for(milliseconds(workTime));
    doneWork.set_value();
    cout << name << ": " << "Work done after " << workTime << " milliseconds." << endl;

    boss2WorkerGoHome.wait();
  }
private:
  string name;
};
```

Memory Model



- The Memory Model deals with
  - atomic operations
  - partial ordering of operations
  - visible effect of operations

Problems?

```
int x= 0;
int y= 0;

void writing(){
  x= 2000;
  y= 11;
}

void reading(){
  cout << "y: " << y << " ";
  cout << "x: " << x << endl;
}

int main(){
  thread thread1(writing);
  thread thread2(reading);
  thread1.join();
  thread2.join();
};
```

y	x	Yes
0	0	☐
11	0	☐
0	2000	☐
11	2000	☐

Solution: Mutex

```
int x= 0;
int y= 0;
mutex mut;

void writing(){
  lock_guard<mutex> guard(mut);
  x= 2000;
  y= 11;
}

void reading(){
  lock_guard<mutex> guard(mut)
  cout << "y: " << y << " ";
  cout << "x: " << x << endl;
}
...

thread thread1(writing);
thread thread2(reading);
```

y	x	Yes
0	0	☐
11	0	☐
0	2000	☐
11	2000	☐

Solution: Atomic

```
atomic<int> x= 0;
atomic<int> y= 0;

void writing(){
  x.store(2000);
  y.store(11);
}

void reading(){
  cout << y.load() << " ";
  cout << x.load() << endl;
}

...

thread thread1(writing);
thread thread2(reading);
```

y	x	Yes
0	0	☐
11	0	☐
0	2000	☐
11	2000	☐

Solution: Atomic with acquire release semantic

```
atomic<int> x= 0;
atomic<int> y= 0;

void writing(){
  x.store(2000,memory_order_relaxed);
  y.store(11), memory_order_release);
}

void reading(){
  cout << y.load(memory_order_acquire) << " ";
  cout << x.load(memory_order_relaxed) << endl;
}

...

thread thread1(writing);
thread thread2(reading);
```

y	x	Yes
0	0	☐
11	0	☐
0	2000	☐
11	2000	☐

Solution: Atomic with sychronization of non atomics

```
int x= 0;
atomic<int> y= 0;

void writing(){
  x= 2000;
  y.store(11), memory_order_release);
}

void reading(){
  cout << y.load(memory_order_acquire) << " ";
  cout << x << endl;
}

...

thread thread1(writing);
thread thread2(reading);
```

y	x	Yes
0	0	☐
11	0	☐
0	2000	☐
11	2000	☐

Solution: Atomic with relaxed semantik

```
atomic<int> x= 0;
atomic<int> y= 0;

void writing(){
  x.store(2000,memory_order_relaxed);
  y.store(11), memory_order_relaxed);
}

void reading(){
  cout << y.load(memory_order_relaxed) << " ";
  cout << x.load(memory_order_relaxed) << endl;
}

...

thread thread1(writing);
thread thread2(reading);
```

y	x	Yes
0	0	☐
11	0	☐
0	2000	☐
11	2000	☐

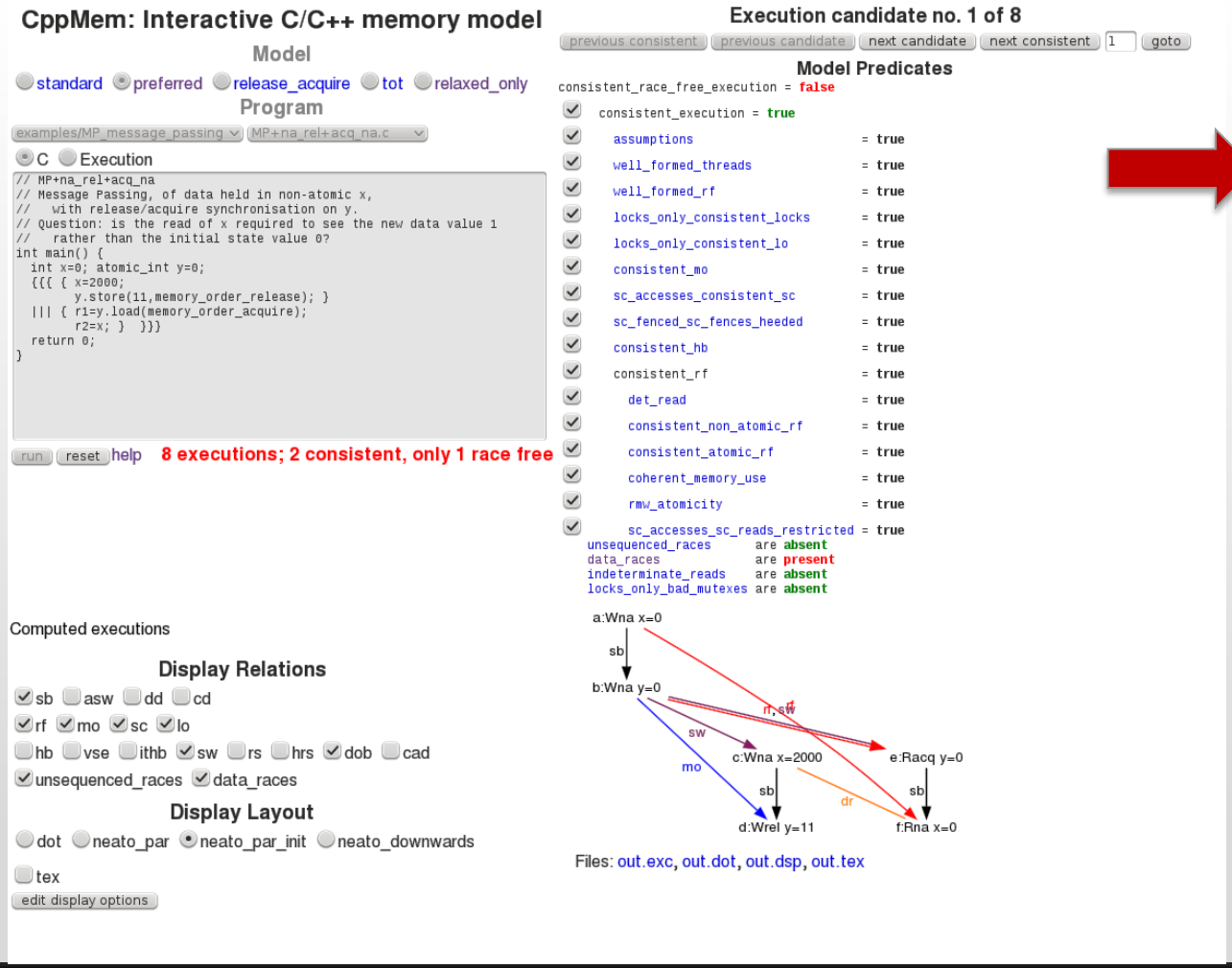
Solution: Singleton with Atomics

Sequentially Consistent

Acquire-Release

```
class MySingleton{
  static mutex myMutex;
  static atomic<MySingleton*> instance;
public:
  static MySingleton* getInstance(){
    MySingleton* sin= instance.load();          instance.load(memory_order_acquire);
    if ( !sin ){
      lock_guard<mutex> myLock(myMutex);
      if( !sin ){
        sin= new MySingleton();
        instance.store(sin);          instance.store(sin,memory_order_release);
      }
    }
    return sin;
  }
  ...
```

THE SOLUTION : CppMem



[CppMem]

Thank you for your attention

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