C++ Seasoning

Sean Parent | Principal Scientist

3 Goals for Better Code

No Raw Loops

What is a Raw Loop?

- A *raw loop* is any loop inside a function where the function serves purpose larger than the algorithm implemented by the loop

What is a Raw Loop?

```
void PanelBar::RepositionExpandedPanels(Panel* fixed_panel) {
  CHECK(fixed_panel);

  // First, find the index of the fixed panel.
  int fixed_index = GetPanelIndex(expanded_panels_, *fixed_panel);
  CHECK_LT(fixed_index, expanded_panels_.size());

  // Next, check if the panel has moved to the other side of another panel.
  const int center_x = fixed_panel->cur_panel_center();
  for (size_t i = 0; i < expanded_panels_.size(); ++i) {
    Panel* panel = expanded_panels_[i].get();
    if (center_x <= panel->cur_panel_center() ||
        i == expanded_panels_.size() - 1) {
      if (panel != fixed_panel) {
        // If it has, then we reorder the panels.
        ref_ptr<Panel> ref = expanded_panels_[fixed_index];
        expanded_panels_.erase(expanded_panels_.begin() + fixed_index);
        if (i < expanded_panels_.size()) {
          expanded_panels_.insert(expanded_panels_.begin() + i, ref);
        } else {
          expanded_panels_.push_back(ref);
        }
      }
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  int total_width = 0;
  fixed_index = -1;
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        expanded_panels_.push_back(ref);
      }
    }
    break;
  }
}

// Find the total width of the panels to the left of the fixed panel.
int total_width = 0;
fixed_index = -1;
for (int i = 0; i < static_cast<int>(expanded_panels_.size()); ++i) {
  Panel* panel = expanded_panels_[i].get();
  if (panel == fixed_panel) {
    fixed_index = i;
    break;
  }
  total_width += panel->panel_width();
}
CHECK_NE(fixed_index, -1);
int new_fixed_index = fixed_index;

// Move panels over to the right of the fixed panel until all of the ones
// on the left will fit.
int avail_width = max(fixed_panel->cur_panel_left() - kBarPadding, 0);
while (total_width > avail_width) {
  new_fixed_index--;
  CHECK_GE(new_fixed_index, 0);
  total_width -= expanded_panels_[new_fixed_index]->panel_width();
}
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for (int i = 0; i < static_cast<int>(expanded_panels_.size()); ++i) {
  Panel* panel = expanded_panels_[i].get();
  if (panel == fixed_panel) {
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    break;
  }
  total_width += panel->panel_width();
}
CHECK_NE(fixed_index, -1);
int new_fixed_index = fixed_index;

// Move panels over to the right of the fixed panel until all of the ones
// on the left will fit.
int avail_width = max(fixed_panel->cur_panel_left() - kBarPadding, 0);
while (total_width > avail_width) {
  new_fixed_index--;
  CHECK_GE(new_fixed_index, 0);
  total_width -= expanded_panels_[new_fixed_index]->panel_width();
}

// Reorder the fixed panel if its index changed.
if (new_fixed_index != fixed_index) {
  Panels::iterator it = expanded_panels_.begin() + fixed_index;
  ref_ptr<Panel> ref = *it;
  expanded_panels_.erase(it);
  expanded_panels_.insert(expanded_panels_.begin() + new_fixed_index, ref);
  fixed_index = new_fixed_index;
}

// Now find the width of the panels to the right, and move them to the
// left as needed.
total_width = 0;
for (Panels::iterator it = expanded_panels_.begin() + fixed_index + 1;
     it != expanded_panels_.end(); ++it) {
```

What is a Raw Loop?

```
    total_width -= expanded_panels_[new_fixed_index]->panel_width();
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  // Reorder the fixed panel if its index changed.
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    Panels::iterator it = expanded_panels_.begin() + fixed_index;
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    expanded_panels_.erase(it);
    expanded_panels_.insert(expanded_panels_.begin() + new_fixed_index, ref);
    fixed_index = new_fixed_index;
  }

  // Now find the width of the panels to the right, and move them to the
  // left as needed.
  total_width = 0;
  for (Panels::iterator it = expanded_panels_.begin() + fixed_index + 1;
       it != expanded_panels_.end(); ++it) {
    total_width += (*it)->panel_width();
  }

  avail_width = max(wm_->width() - (fixed_panel->cur_right() + kBarPadding),
                    0);
  while (total_width > avail_width) {
    new_fixed_index++;
    CHECK_LT(new_fixed_index, expanded_panels_.size());
    total_width -= expanded_panels_[new_fixed_index]->panel_width();
  }

  // Do the reordering again.
  if (new_fixed_index != fixed_index) {
    Panels::iterator it = expanded_panels_.begin() + fixed_index;
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    if (new_fixed_index != fixed_index) {
      Panels::iterator it = expanded_panels_.begin() + fixed_index;
      ref_ptr<Panel> ref = *it;
      expanded_panels_.erase(it);
      expanded_panels_.insert(expanded_panels_.begin() + new_fixed_index, ref);
      fixed_index = new_fixed_index;
    }

    // Finally, push panels to the left and the right so they don't overlap.
    int boundary = expanded_panels_[fixed_index]->cur_panel_left() - kBarPadding;
    for (Panels::reverse_iterator it =
           // Start at the panel to the left of 'new_fixed_index'.
           expanded_panels_.rbegin() +
           (expanded_panels_.size() - new_fixed_index);
         it != expanded_panels_.rend(); ++it) {
      Panel* panel = it->get();
      if (panel->cur_right() > boundary) {
        panel->Move(boundary, kAnimMs);
      } else if (panel->cur_panel_left() < 0) {
        panel->Move(min(boundary, panel->panel_width() + kBarPadding), kAnimMs);
      }
      boundary = panel->cur_panel_left() - kBarPadding;
    }

    boundary = expanded_panels_[fixed_index]->cur_right() + kBarPadding;
    for (Panels::iterator it = expanded_panels_.begin() + new_fixed_index + 1;
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Adobe

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    boundary = panel->cur_panel_left() - kBarPadding;
  }

  boundary = expanded_panels_[fixed_index]->cur_right() + kBarPadding;
  for (Panels::iterator it = expanded_panels_.begin() + new_fixed_index + 1;
       it != expanded_panels_.end(); ++it) {
    Panel* panel = it->get();
    if (panel->cur_panel_left() < boundary) {
      panel->Move(boundary + panel->panel_width(), kAnimMs);
    } else if (panel->cur_right() > wm_->width()) {
      panel->Move(max(boundary + panel->panel_width(),
                      wm_->width() - kBarPadding),
                  kAnimMs);
    }
    boundary = panel->cur_right() + kBarPadding;
  }
}
```

Why No Raw Loops?

- Difficult to reason about and difficult to prove post conditions
- Error prone and likely to fail under non-obvious conditions
- Introduce non-obvious performance problems
- Complicates reasoning about the surrounding code

Alternatives to Raw Loops

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∅ Patents

No Raw Loops

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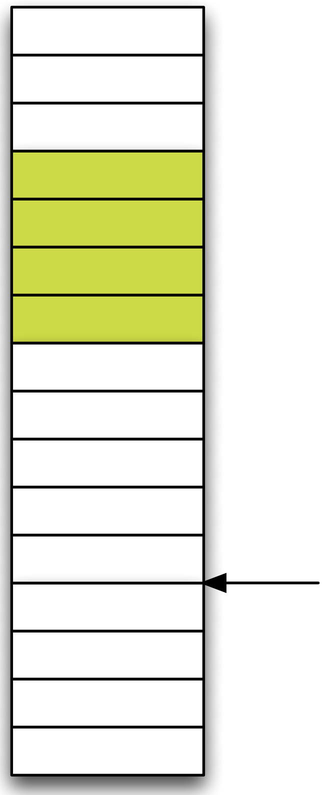
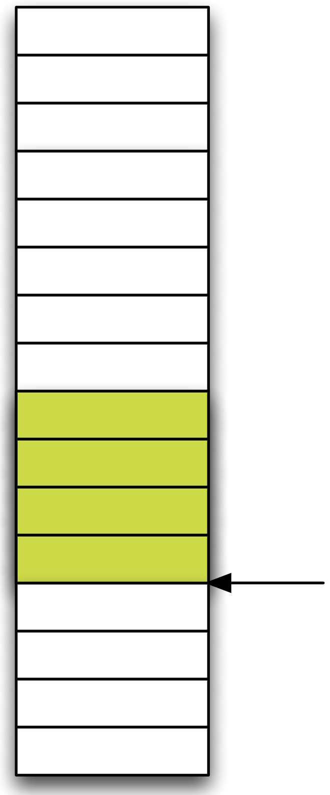
No Raw Loops

Two Beautiful Examples

No Raw Loops



No Raw Loops



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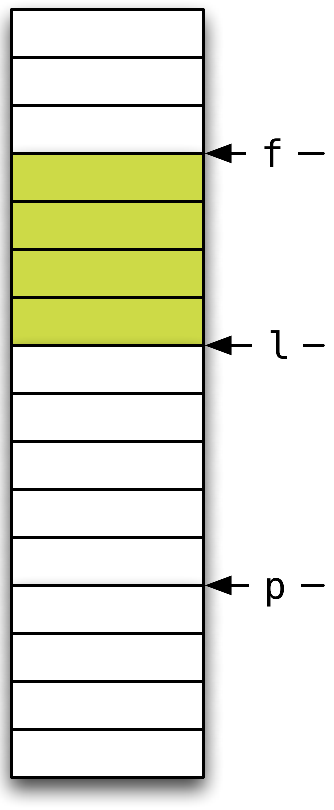


```
rotate(f, l, p);
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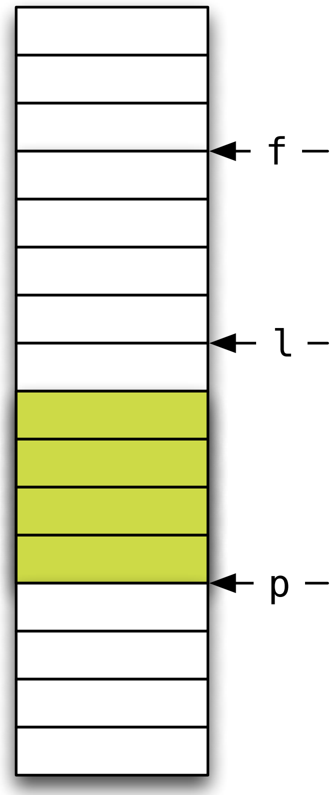
No Raw Loops

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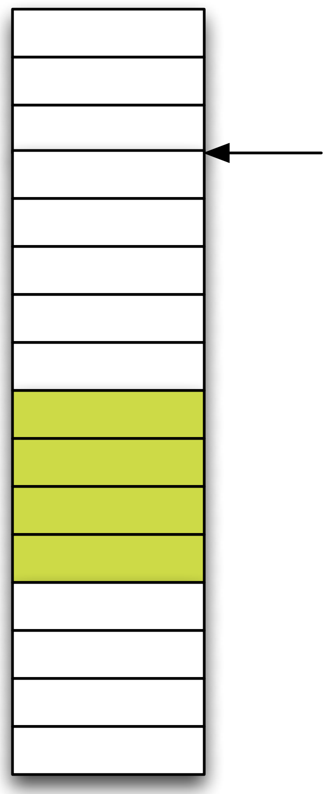

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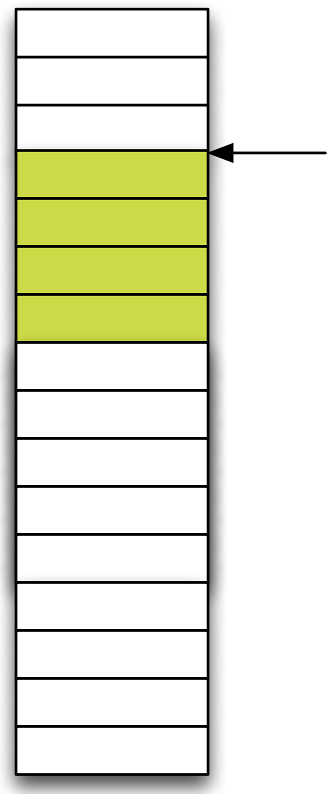

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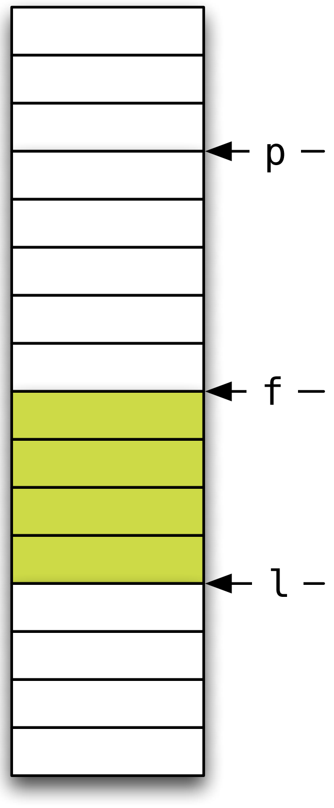


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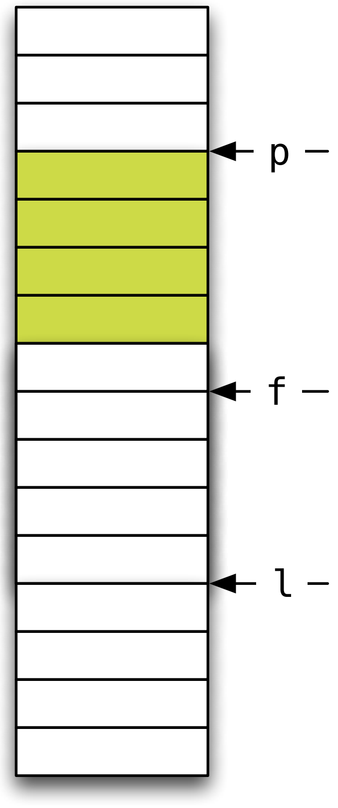


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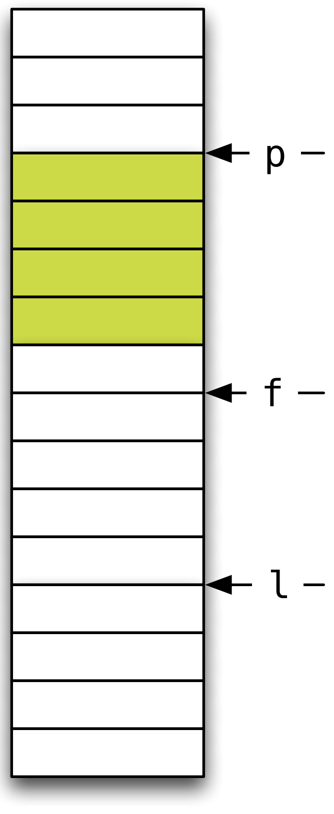


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if (p < f) rotate(p, f, l);
if (l < p) rotate(f, l, p);
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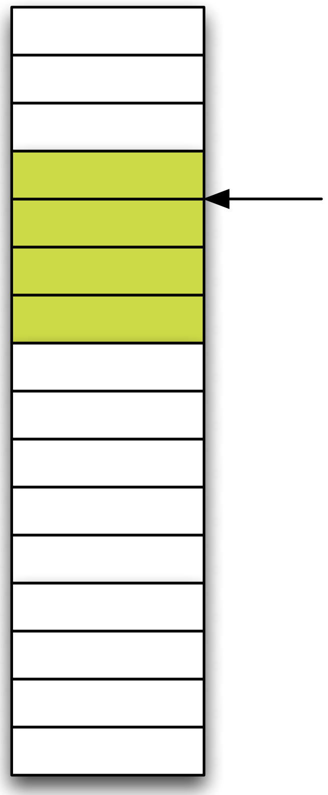
No Raw Loops



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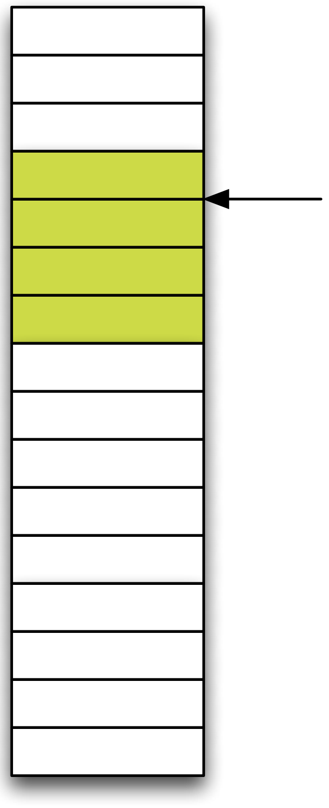

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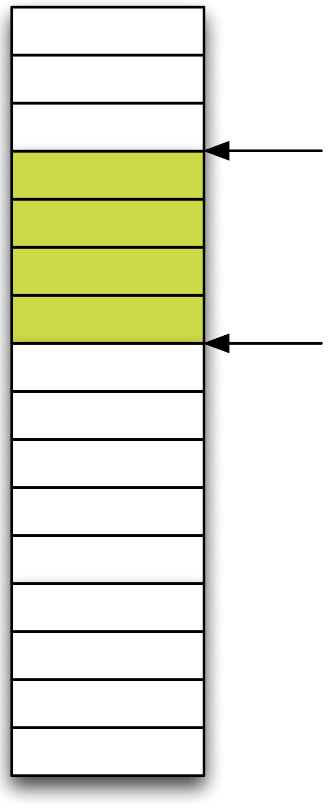

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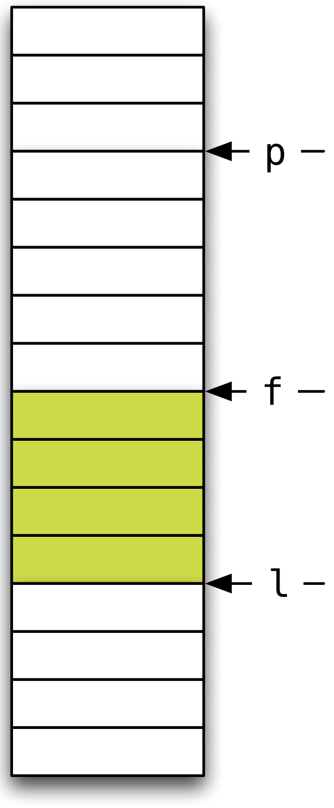


```
if (p < f) return { p, rotate(p, f, l) };
if (l < p) return { rotate(f, l, p), p };
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C++11

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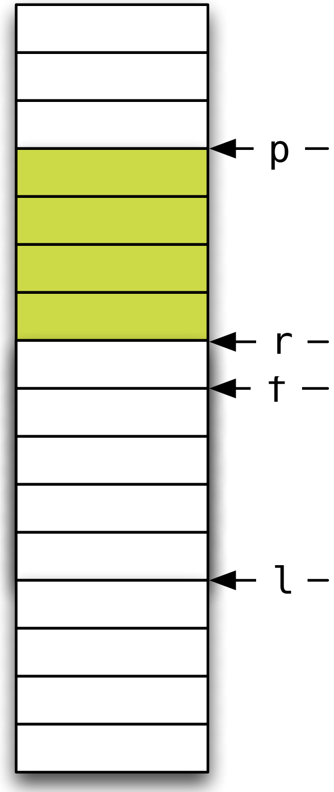


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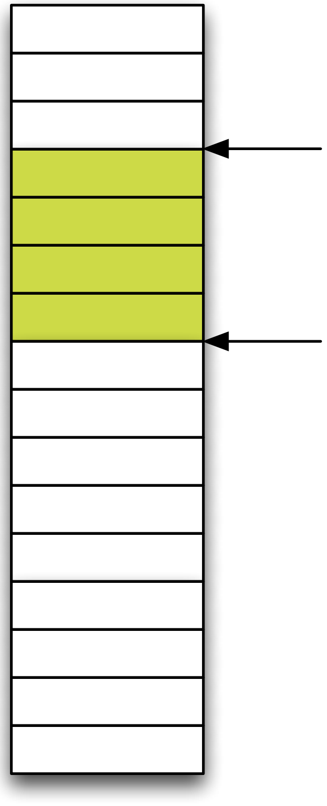

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return { f, l };
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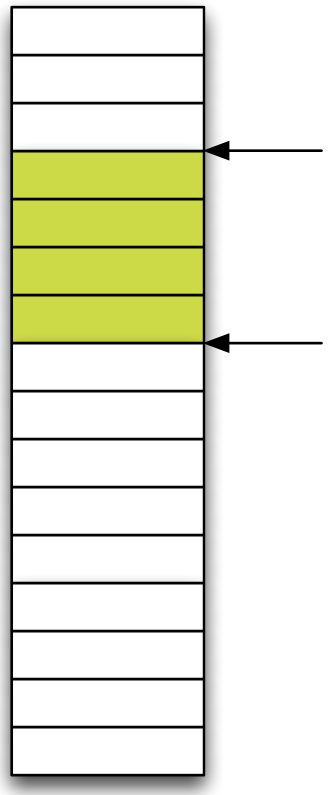

```
template <typename I> // I models RandomAccessIterator
auto slide(I f, I l, I p) -> pair<I, I>
{
    if (p < f) return { p, rotate(p, f, l) };
    if (l < p) return { rotate(f, l, p), p };
    return { f, l };
}
```

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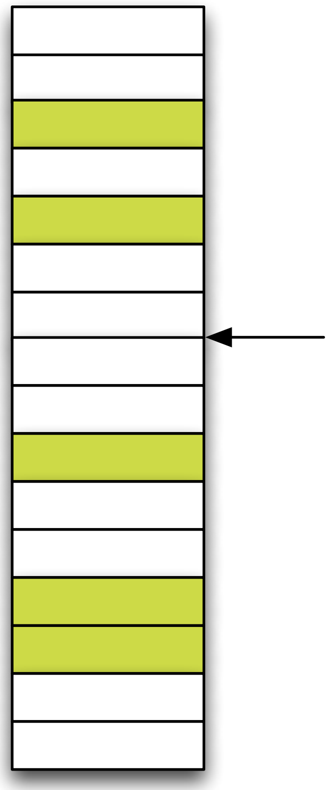

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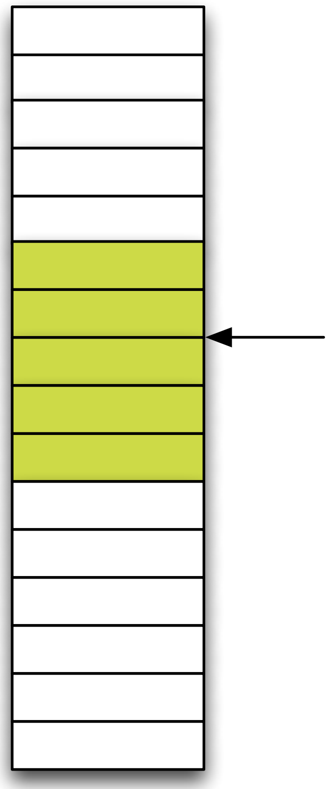

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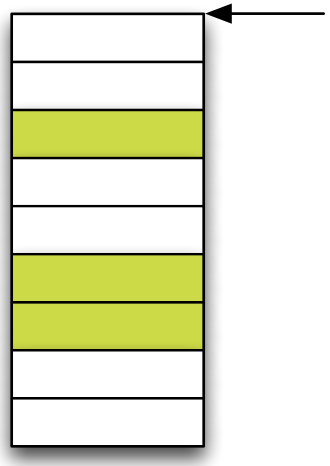

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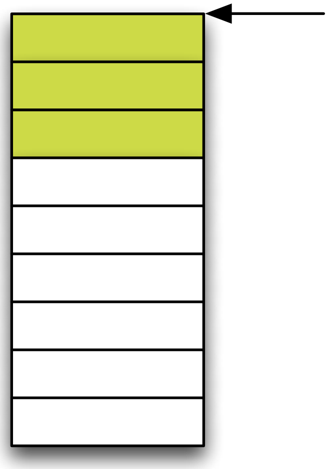
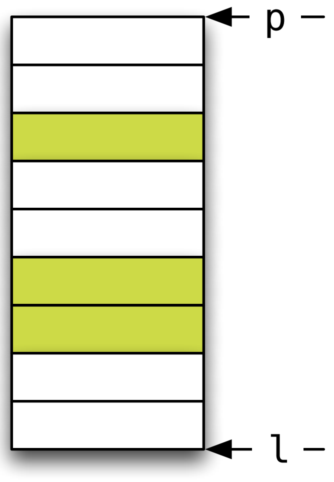


No Raw Loops

```
stable_partition(p, l, s)
```



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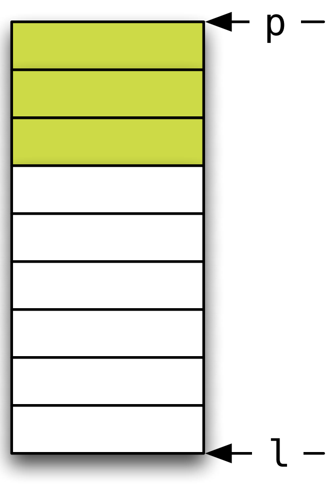

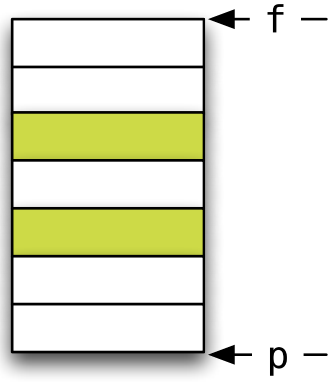


```
stable_partition(f, p, not1(s))
```

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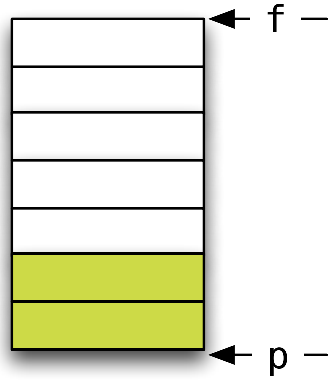


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stable_partition(f, p, not1(s))
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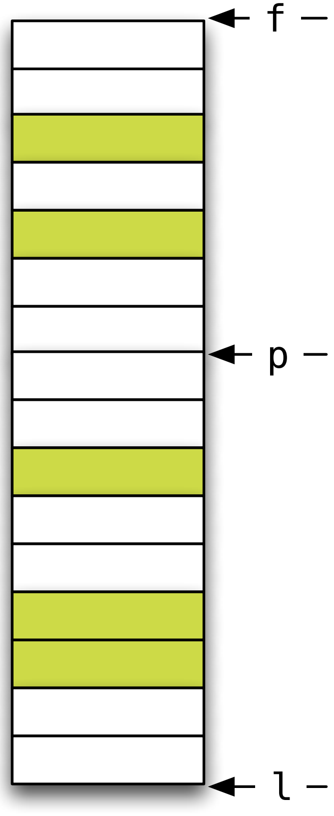
No Raw Loops

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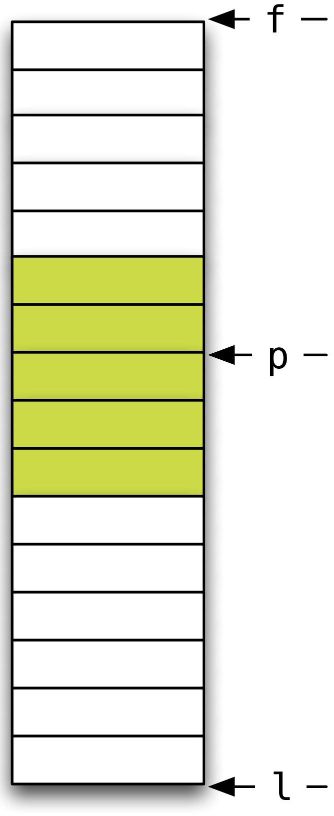


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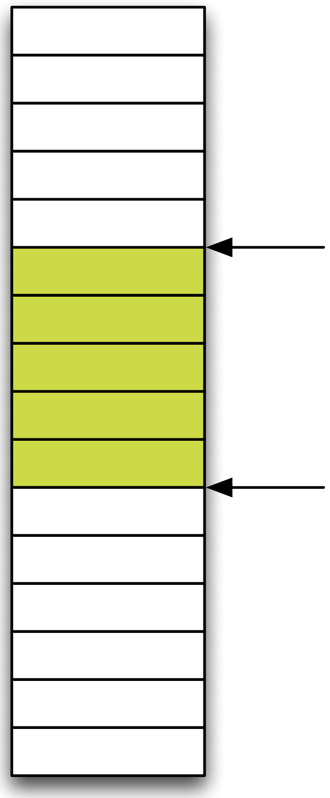

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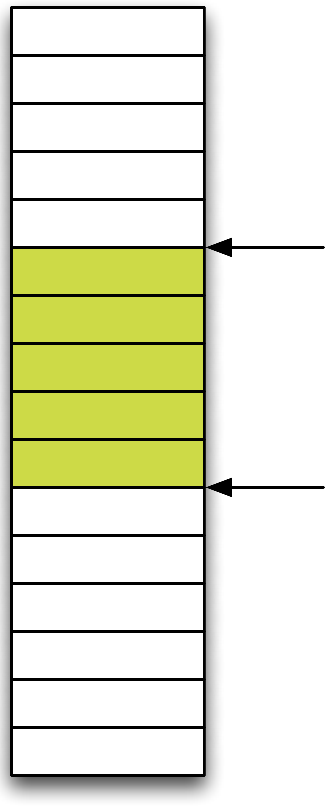

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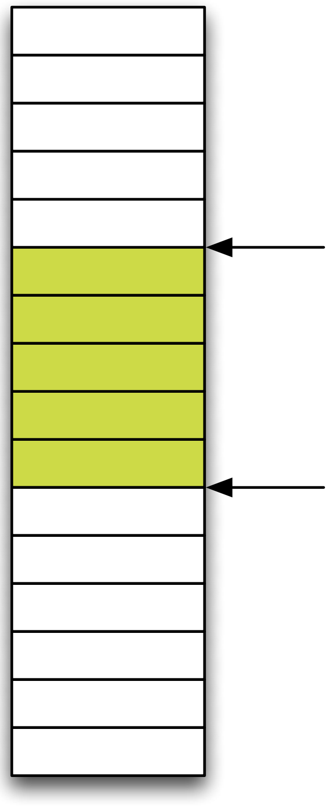

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template <typename I, // I models BidirectionalIterator
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auto gather(I f, I l, I p, S s) -> pair<I, I>
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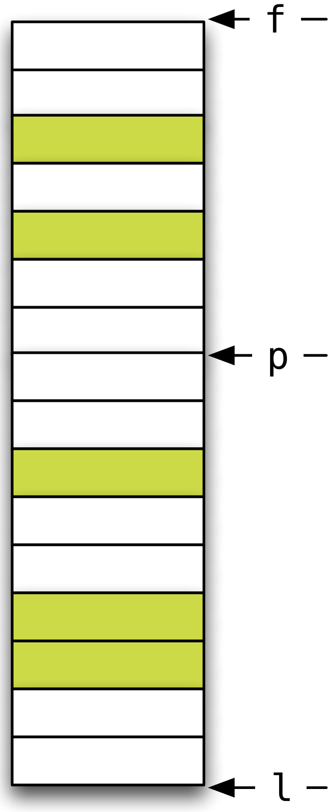


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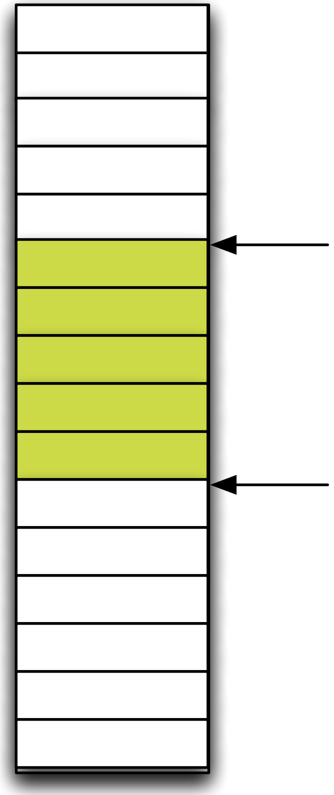

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What about that messy loop?

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// Next, check if the panel has moved to the other side of another panel.

for (size_t i = 0; i < expanded_panels_.size(); ++i) {
  Panel* panel = expanded_panels_[i].get();
  if (center_x <= panel->cur_panel_center() ||
      i == expanded_panels_.size() - 1) {
    if (panel != fixed_panel) {
      // If it has, then we reorder the panels.
      ref_ptr<Panel> ref = expanded_panels_[fixed_index];
      expanded_panels_.erase(expanded_panels_.begin() + fixed_index);
      if (i < expanded_panels_.size()) {
        expanded_panels_.insert(expanded_panels_.begin() + i, ref);
      } else {
        expanded_panels_.push_back(ref);
      }
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- None of the special cases were necessary
- This code is considerably more efficient
- Now we can have the conversation about supporting multiple selections and disjoint selections!

Seasoning

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- Use a range library (Boost or ASL)

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Adobe

Seasoning

Seasoning

- Range based for loops for for-each and simple transforms

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for (const auto& e: r) f(e);
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  - Use const auto& for for-each and auto& for transforms
  - Keep the body **short**
    - A general guideline is no longer than composition of two functions with an operator

```
for (const auto& e: r) f(g(e));
for (const auto& e: r) { f(e); g(e); };
for (auto& e: r) e = f(e) + g(e);
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  - If the body is longer, factor it out and give it a name

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- Use lambdas for predicates, comparisons, and projections, but keep them **short**

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- Use lambdas for predicates, comparisons, and projections, but keep them **short**

- Use function objects with template member function to simulate polymorphic lambda

```
struct last_name {
    using result_type = const string&;

    template <typename T>
    const string& operator()(const T& x) const { return x.last; }
};

// ...

auto p = lower_bound(a, "Parent", less(), last_name());
```

No Raw Synchronization Primitives

What are raw synchronization primitives?

- Synchronization primitives are basic constructs such as:
  - Mutex
  - Atomic
  - Semaphore
  - Memory Fence

You Will Likely Get It Wrong

Problems with Locks

```
template <typename T>
class bad_cow {
    struct object_t {
        explicit object_t(const T& x) : data_m(x) { ++count_m; }
        atomic<int> count_m;
        T           data_m; };
    object_t* object_m;
 public:
    explicit bad_cow(const T& x) : object_m(new object_t(x)) { }
    ~bad_cow() { if (0 == --object_m->count_m) delete object_m; }
    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            --object_m->count_m;
            object_m = tmp;
        }
        return *this;
    }
};
```

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    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            --object_m->count_m;
            object_m = tmp;
        }
        return *this;
    }
};
```

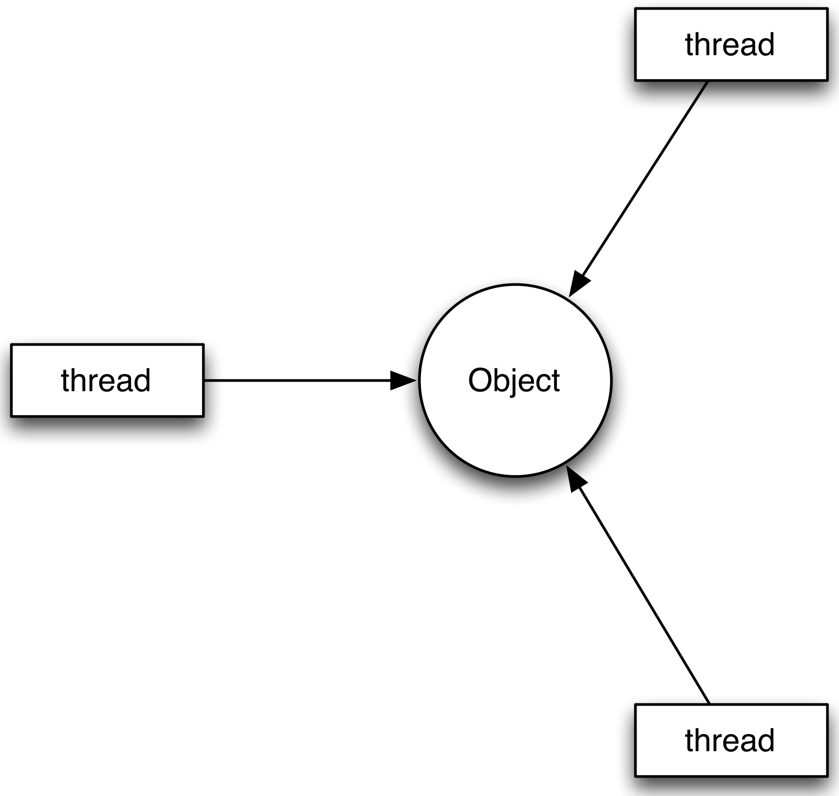
- There is a subtle race condition here:
  - if count != 1 then the bad_cow could also is owned by another thread(s)
  - if the other thread(s) releases the bad_cow between these two atomic operations
  - then our count will fall to zero and we will leak the object

Problems with Locks

```
template <typename T>
class bad_cow {
    struct object_t {
        explicit object_t(const T& x) : data_m(x) { ++count_m; }
        atomic<int> count_m;
        T           data_m; };
    object_t* object_m;
 public:
    explicit bad_cow(const T& x) : object_m(new object_t(x)) { }
    ~bad_cow() { if (0 == --object_m->count_m) delete object_m; }
    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            if (0 == --object_m->count_m) delete object_m;
            object_m = tmp;
        }
        return *this;
    }
};
```

Why No Raw Synchronization Primitives?



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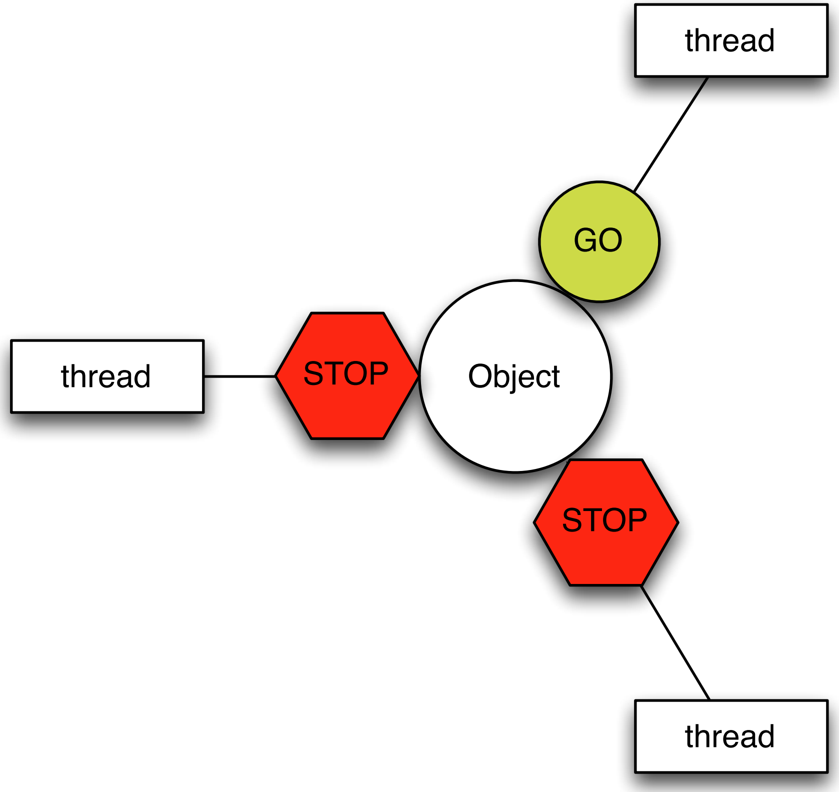

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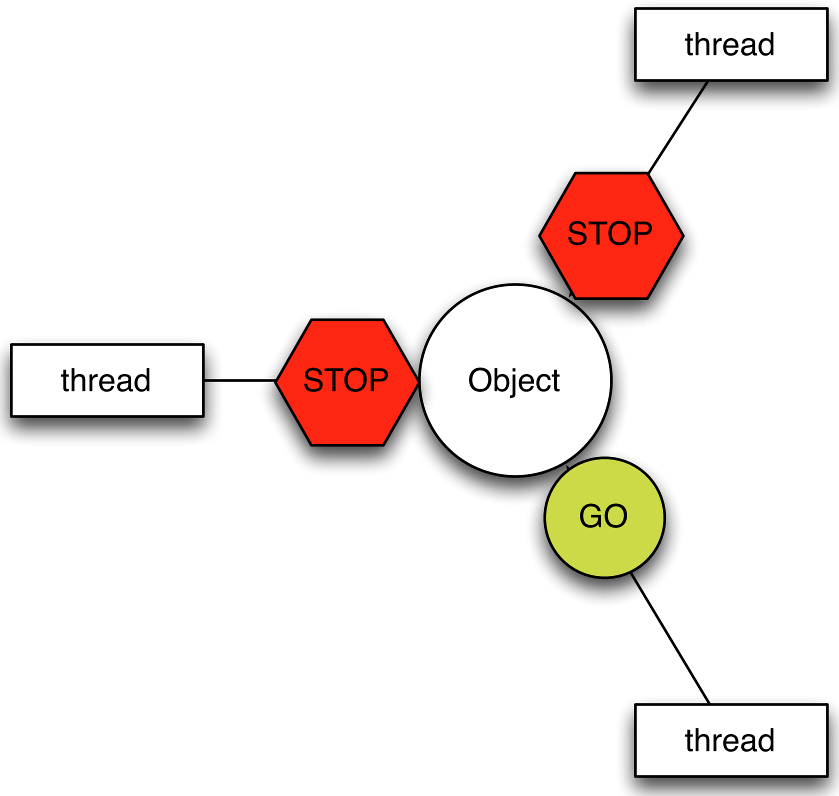

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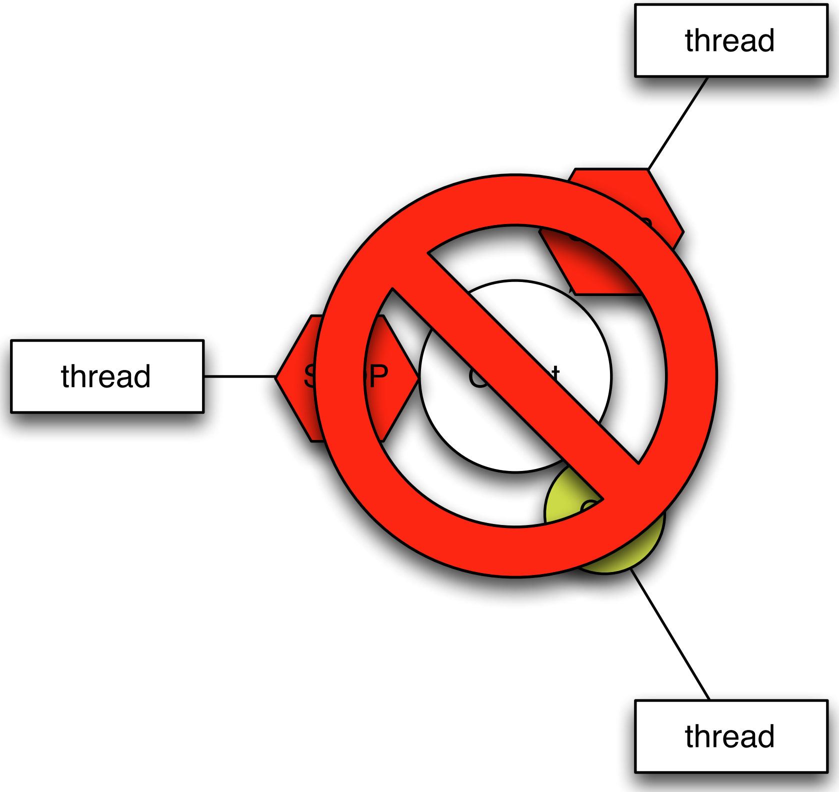
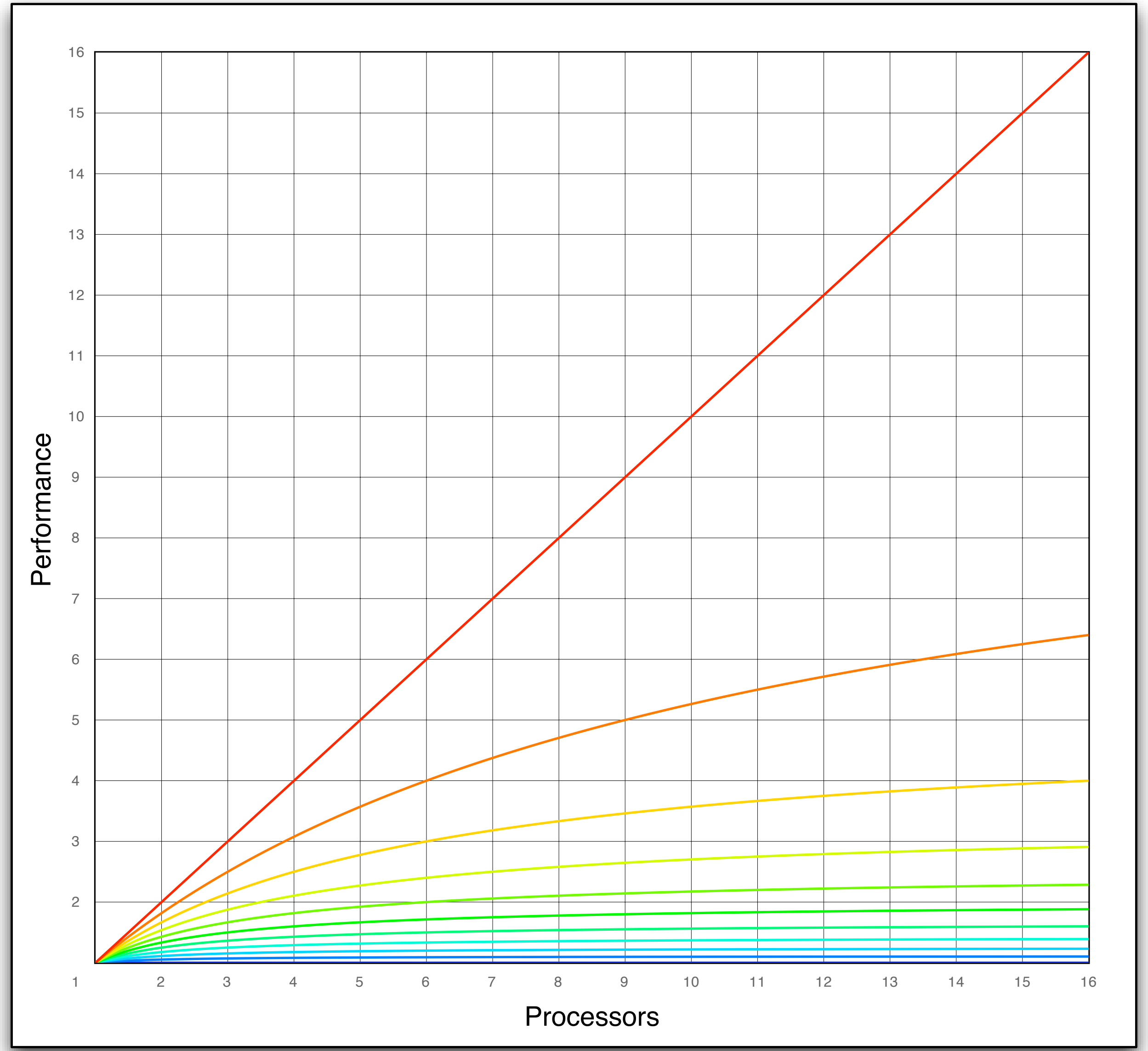


Amdahl's Law



Minimize Locks

Minimize Locks

No Raw Synchronization Primitives

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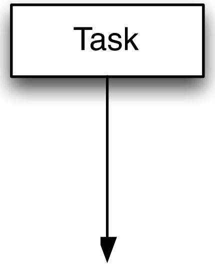

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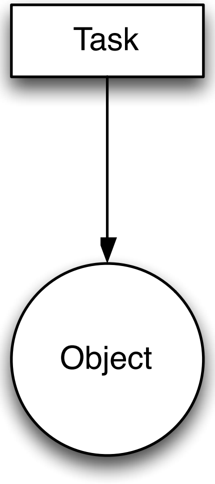

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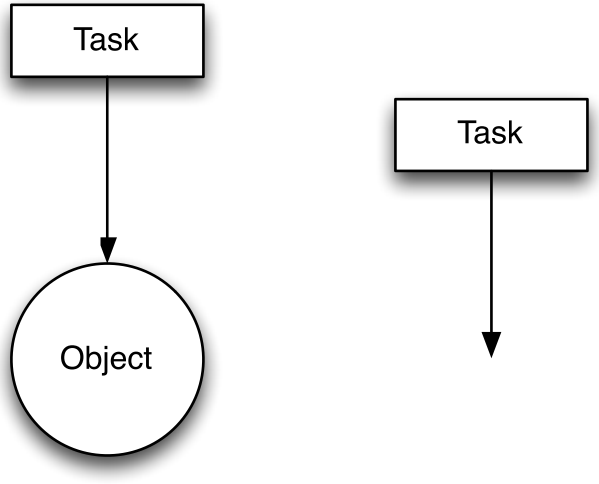

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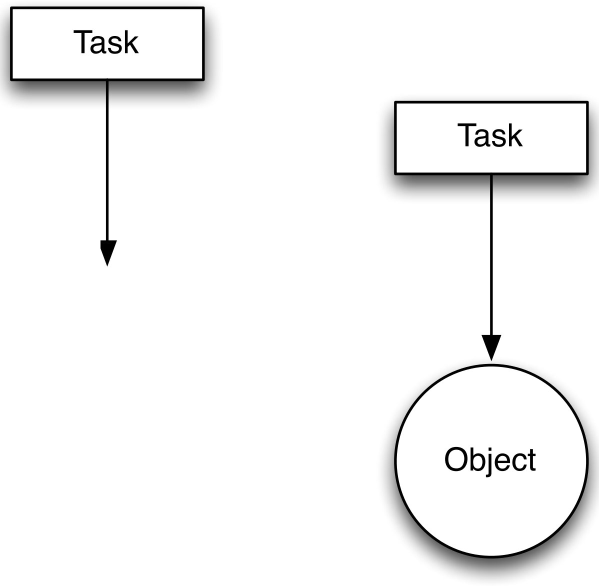

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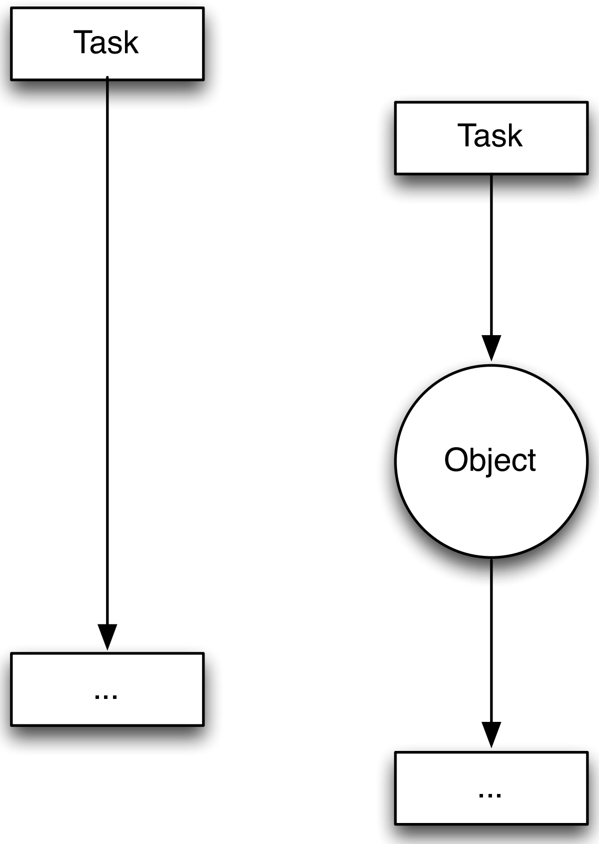

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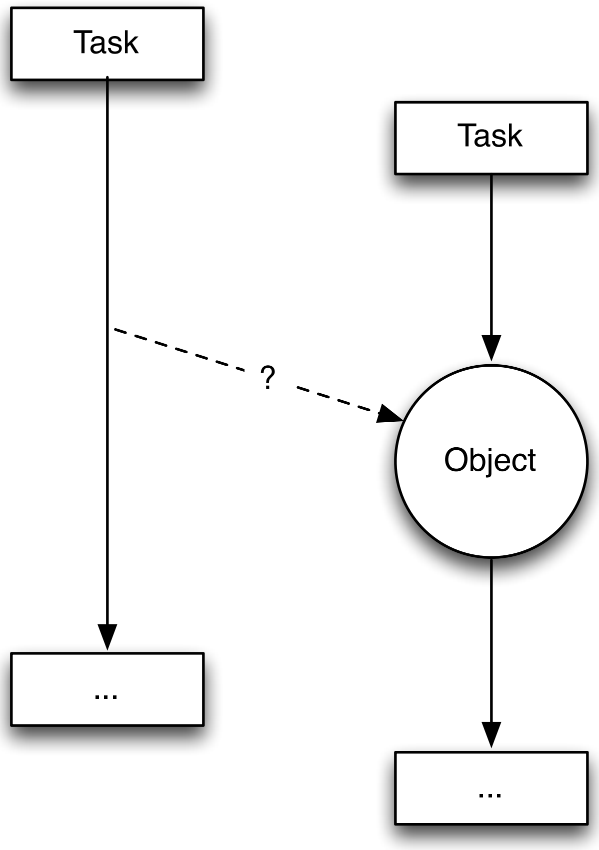


Tasks

- A task is a unit of work (a function) which is executed asynchronously
  - Tasks are scheduled on a thread pool to optimize machine utilization

- The arguments to the task and the task results are convenient places to communicate with other tasks
  - Any function can be "packaged" into such a task

Task Systems

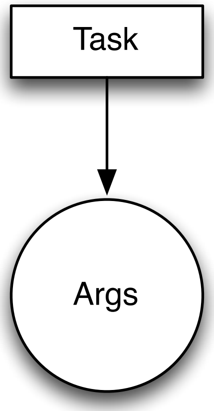
- Unfortunately, we don’t yet have a standard async task model
  - std::async() is currently defined to be based on threads
    - This may change in C++14 and Visual C++ 2012 already implements std::async() as a task model

- Windows - Window Thread Pool and PPL
- Apple - Grand Central Dispatch (libdispatch)
  - Open sourced, runs on Linux and Android
- Intel TBB - many platform

C++14 compatible async with libdispatch

```
namespace adobe {

template <typename F, typename ...Args>
auto async(F&& f, Args&&... args)
        -> std::future<typename std::result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = new packaged_type(std::forward<F>(f), std::forward<Args>(args)...);
    auto result = p->get_future();

    dispatch_async_f(dispatch_get_global_queue(DISPATCH_QUEUE_PRIORITY_DEFAULT, 0),
            p, [](void* f_) {
                packaged_type* f = static_cast<packaged_type*>(f_);
                (*f)();
                delete f;
            });

    return result;
}

} // namespace adobe
```

No Raw Synchronization Primitives



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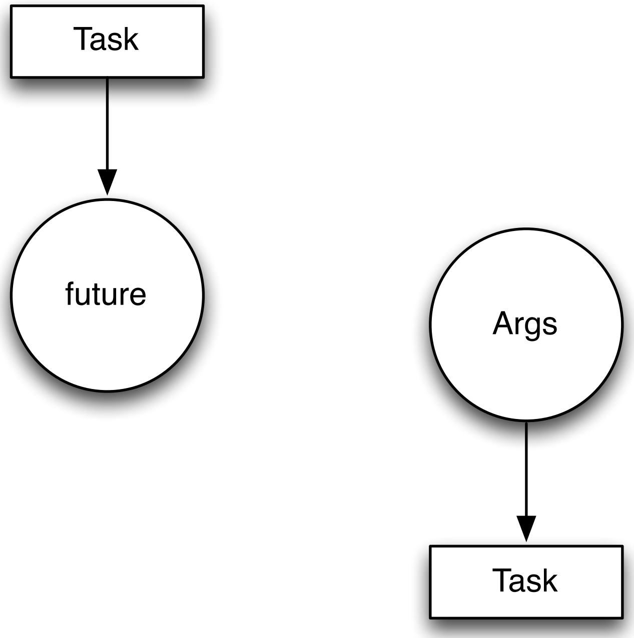

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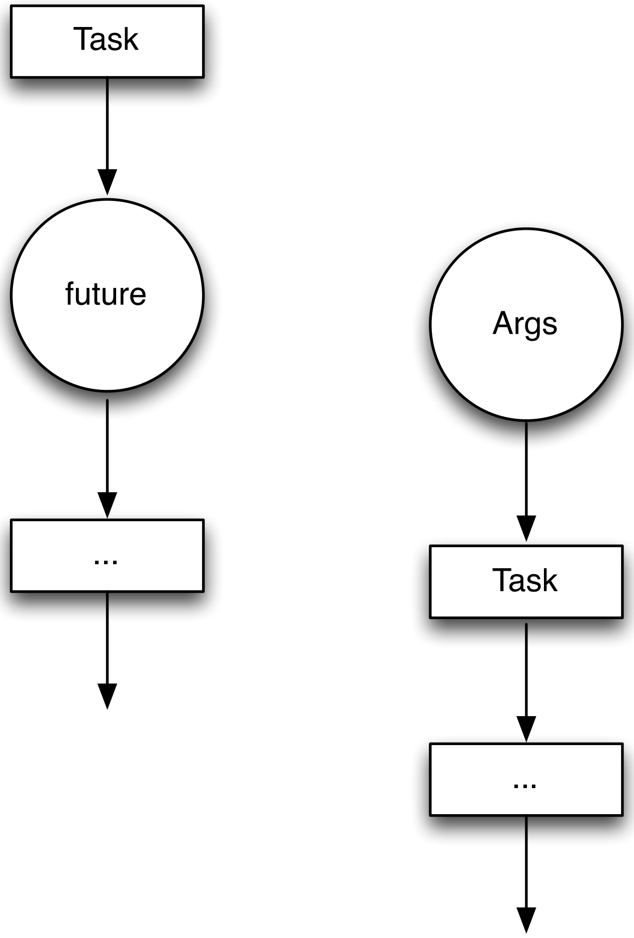

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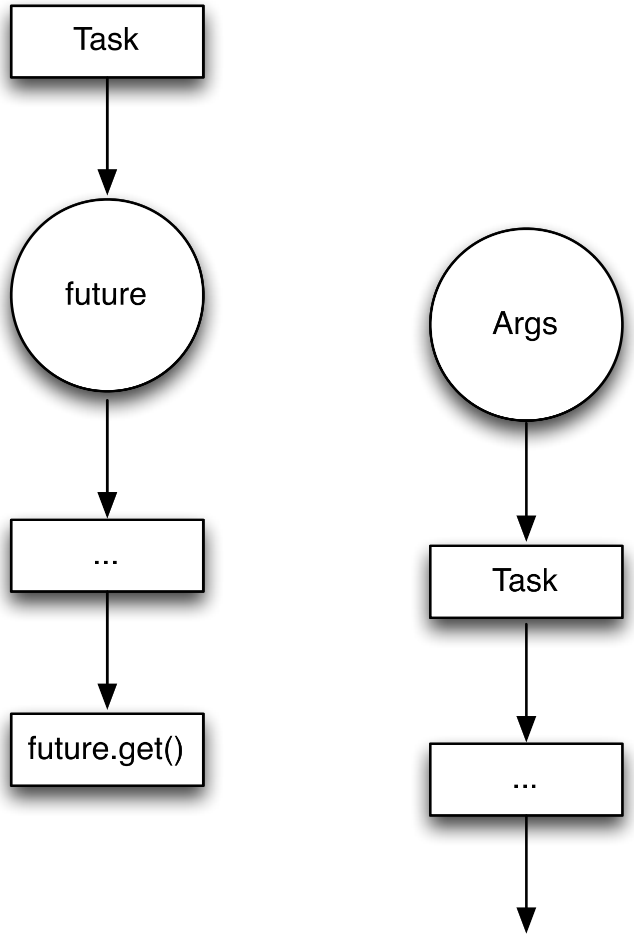

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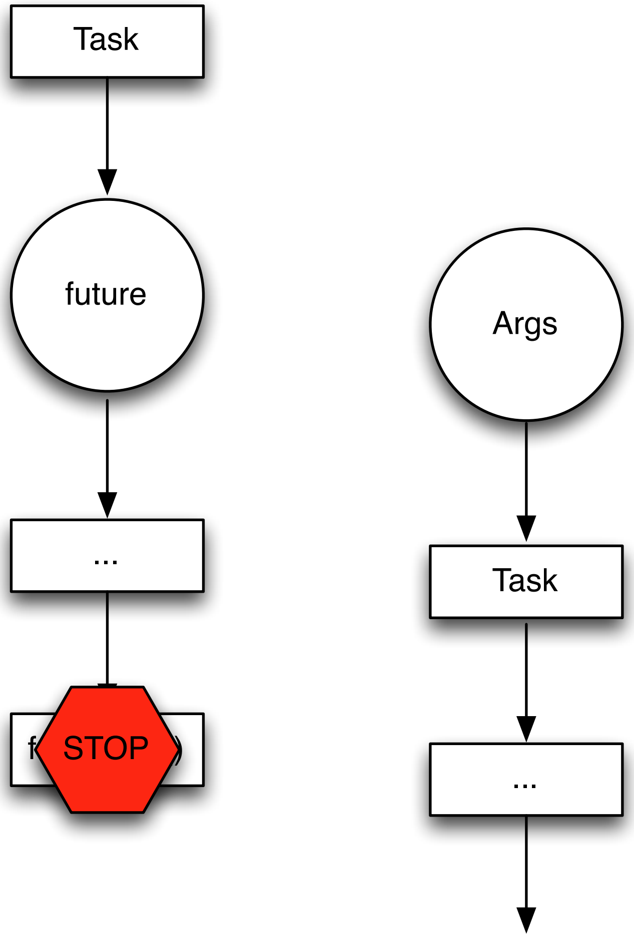

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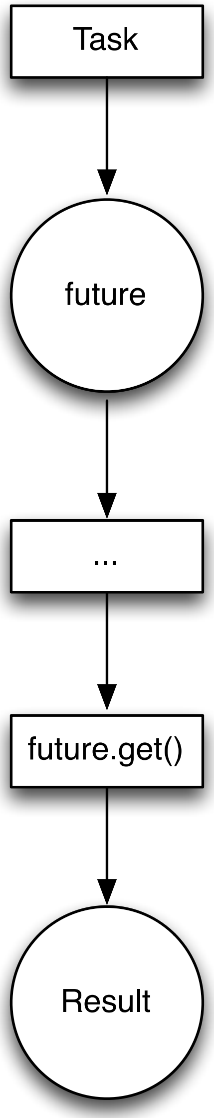
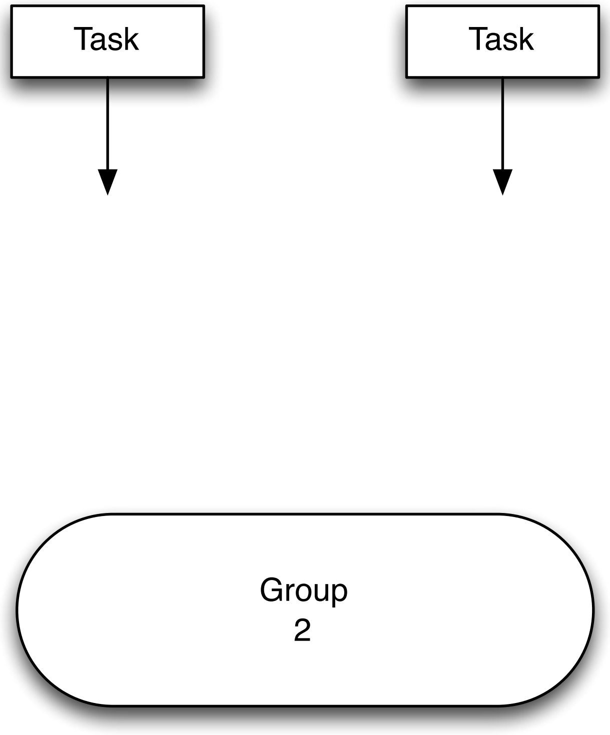


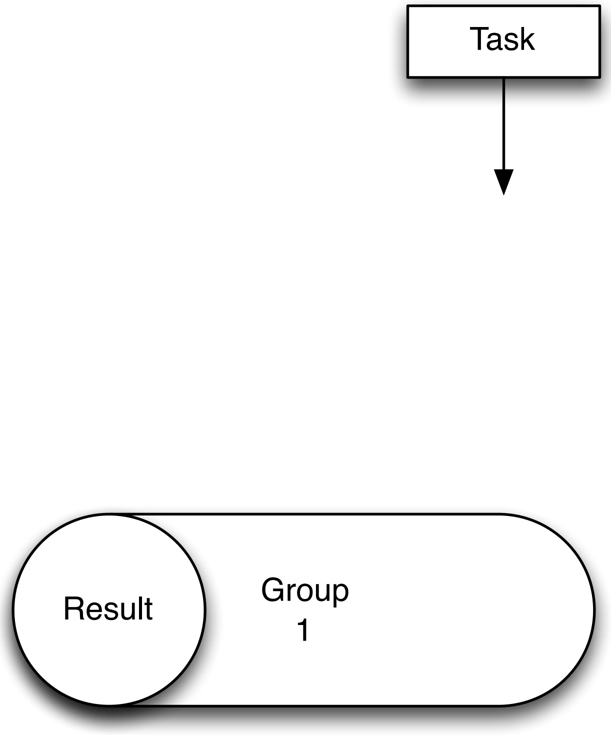
- Blocking on std::future.get() has two problems
  - One thread resource is consumed, increasing contention
  - Any subsequent non-dependent calculations on the task are also blocked

- Unfortunately, C++11 doesn't have dependent tasks
  - GCD has serialized queues and groups
  - PPL has chained tasks
  - TBB has flow graphs
- All are able to specify dependent tasks, including joins

Task Systems

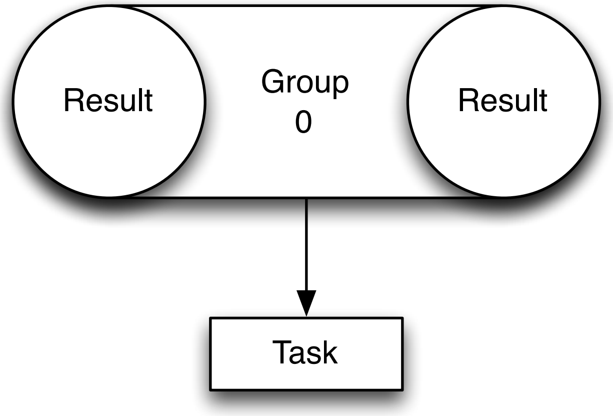


Task Systems



*
—

Task Systems



*
–

Seasoning

- std::list can be used in a pinch to create thread safe data structures with splice

```
template <typename T>
class concurrent_queue
{
    mutex   mutex_;
    list<T> q_;
  public:
    void enqueue(T x)
    {
        list<T> tmp;
        tmp.push_back(move(x));
        {
        lock_guard<mutex> lock(mutex);
        q_.splice(end(q_), tmp);
        }
    }

    // ...
};
```

Seasoning

- std::packaged_task can be used to marshall results, including exceptions, from tasks
  - std::packaged_task is also useful to safely bridge C++ code with exceptions to C code
  - see prior async() implementation for an example

No Raw Pointers

What is a Raw Pointer?

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- A pointer to an object with implied ownership and reference semantics
  - T* p = new T
  - unique_ptr<T>
  - shared_ptr<T>

Why pointers (heap allocations)?

- Runtime variable size
  - Runtime polymorphic
  - Container
- Satisfy complexity or stability requirements within a container (list vs. vector)
- Shared storage for asynchronous communication (future, message queue, …)
- Optimization to copy
  - Copy deferral (copy-on-write)
  - Immutable item
  - Transform Copy to Move [???]
- To separate implementation from interface (PIMPL)

Why Pointers

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  - Except for hierarchies - but containment hierarchies or non-intrusive hierarchies are both viable options
- PIMPL and copy optimizations are trivially wrapped
- See previous section regarding shared storage for asynchronous operations

- Runtime polymorphism

client | library

```
using object_t = int;

void draw(const object_t& x, ostream& out, size_t position)
{ out << string(position, ' ') << x << endl; }

using document_t = vector<object_t>;

void draw(const document_t& x, ostream& out, size_t position)
{
    out << string(position, ' ') << "<document>" << endl;
    for (const auto& e : x) draw(e, out, position + 2);
    out << string(position, ' ') << "</document>" << endl;
}
```

cout | guidelines | defects

client library

```
int main()
{
    document_t document;

    document.emplace_back(0);
    document.emplace_back(1);
    document.emplace_back(2);
    document.emplace_back(3);

    draw(document, cout, 0);
}
```

cout guidelines defects

client library

```
int main()
{
    document_t document;

    document.emplace_back(0);
    document.emplace_back(1);
    document.emplace_back(2);
    document.emplace_back(3);

    draw(document, cout, 0);
}
```

cout

<document>
0
1
2
3
</document>

Polymorphism

- What happens if we want the document to hold any drawable object?

client library

```
class object_t {
  public:
    virtual ~object_t() { }
    virtual void draw(ostream&, size_t) const = 0;
};

using document_t = vector<shared_ptr<object_t>>;

void draw(const document_t& x, ostream& out, size_t position)
{
    out << string(position, ' ') << "<document>" << endl;
    for (const auto& e : x) e->draw(out, position + 2);
    out << string(position, ' ') << "</document>" << endl;
}
```

cout guidelines defects

client library

```cpp
class my_class_t : public object_t
{
  public:
    void draw(ostream& out, size_t position) const
    { out << string(position, ' ') << "my_class_t" << endl; }
    /* ... */
};


int main()
{
    document_t document;

    document.emplace_back(new my_class_t());

    draw(document, cout, 0);
}
```

cout guidelines defects

client | library

```
class my_class_t : public object_t
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    void draw(ostream& out, size_t position) const
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int main()
{
    document_t document;

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    draw(document, cout, 0);
}
```

cout

<document>
my_class_t
</document>

client | library

```cpp
class my_class_t : public object_t
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    { out << string(position, ' ') << "my_class_t" << endl; }
    /* ... */
};


int main()
{
    document_t document;

    document.emplace_back(new my_class_t());

    draw(document, cout, 0);
}
```

defects

- An instance of my_class_t will be allocated first
- Then the document will grow to make room
- If growing the document throws an exception, the memory from my_class_t is leaked

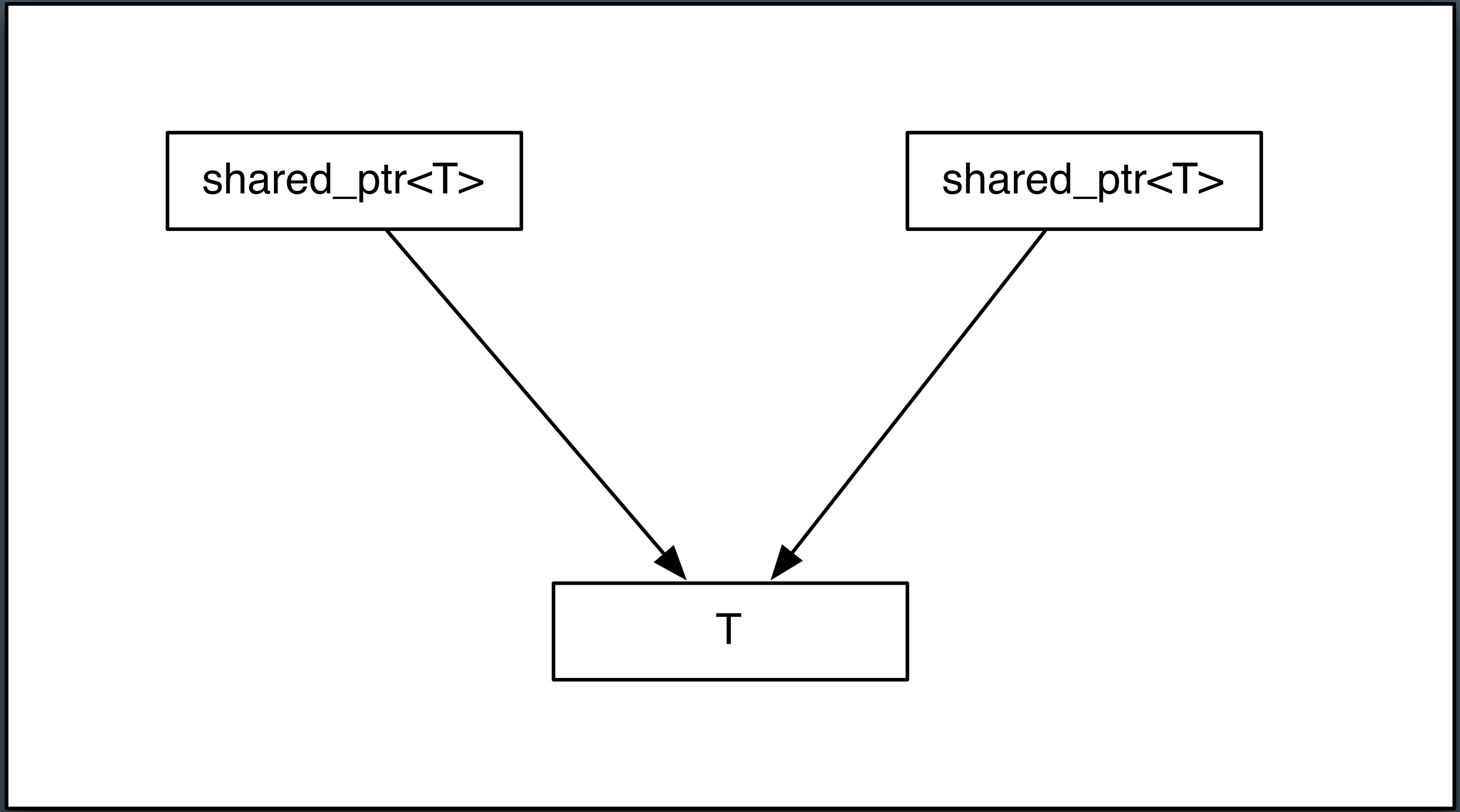
Deep problem

- Changed semantics of copy, assignment, and equality of my document
  - leads to incidental data structures
  - thread safety concerns

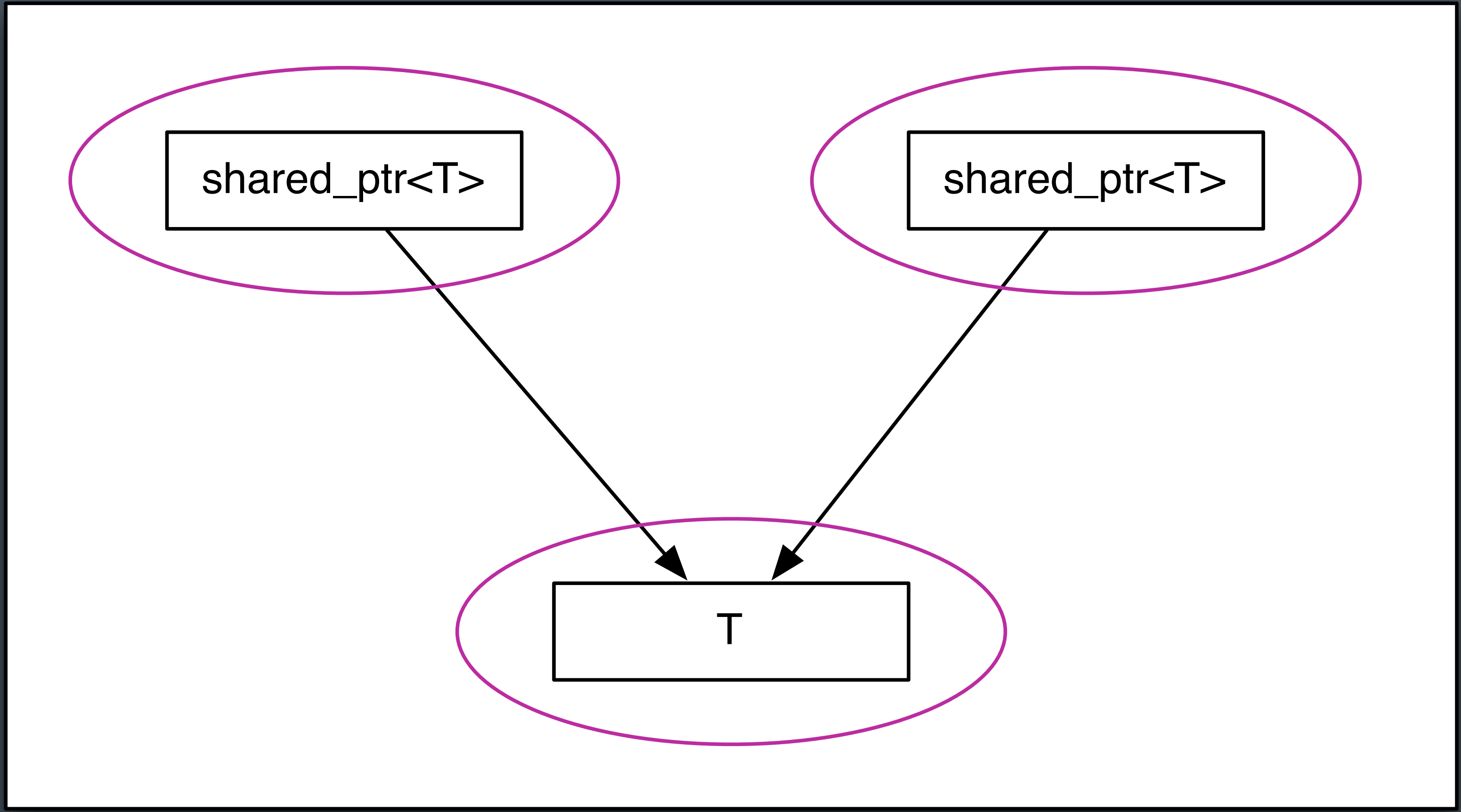
Semantics & Syntax

- We define an operation in terms of the operation's semantics:
  - "Assignment is a procedure taking two objects of the same type that makes the first object equal to the second without modifying the second."

Semantics & Syntax



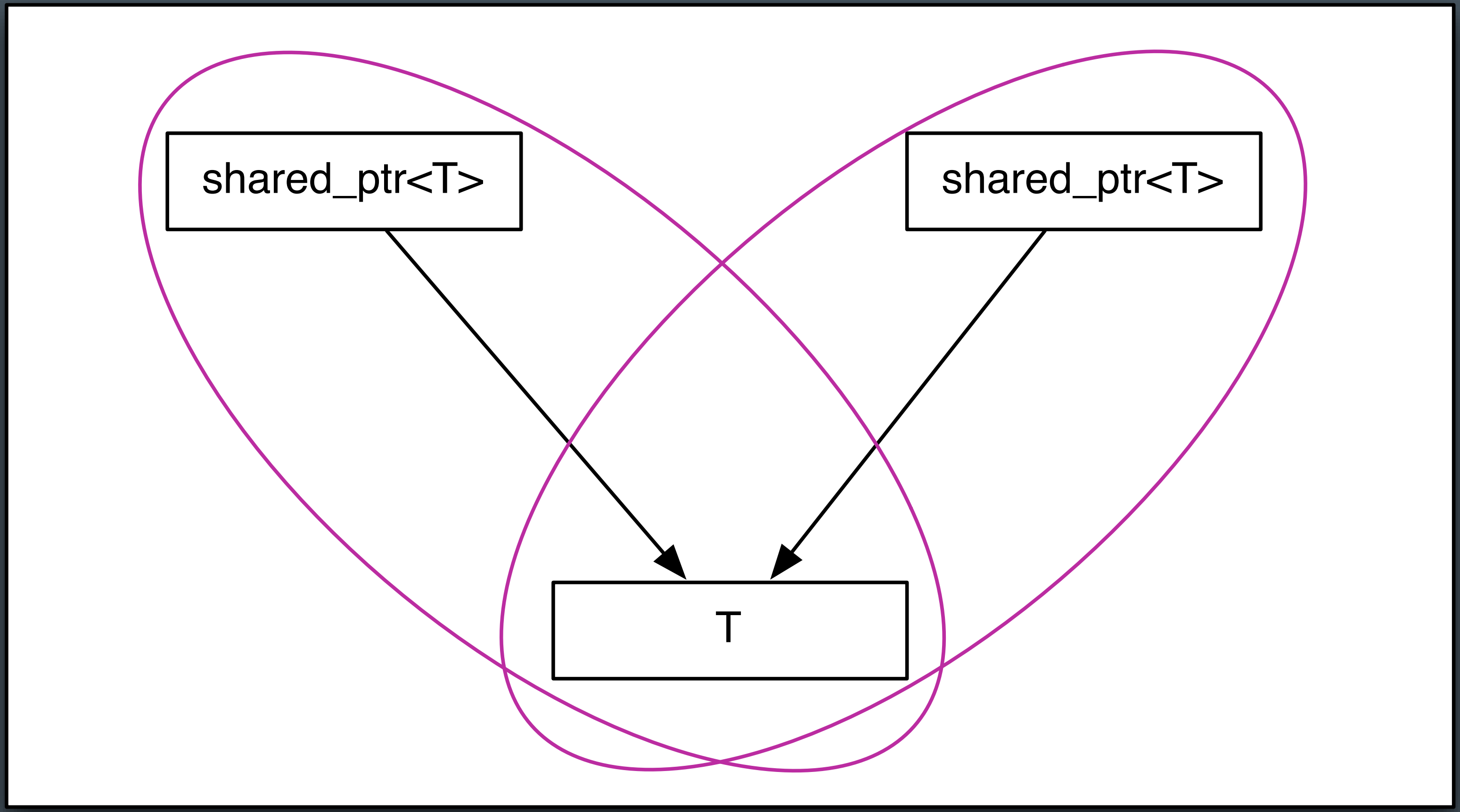
Semantics & Syntax



Semantics & Syntax

- Considered as individual types, assignment and copy hold their regular semantic meanings
  - However, this fails to account for the relationships (the arrows) which form an incidental data-structure. You cannot operate on T through one of the shared pointers without considering the effect on the other shared pointer

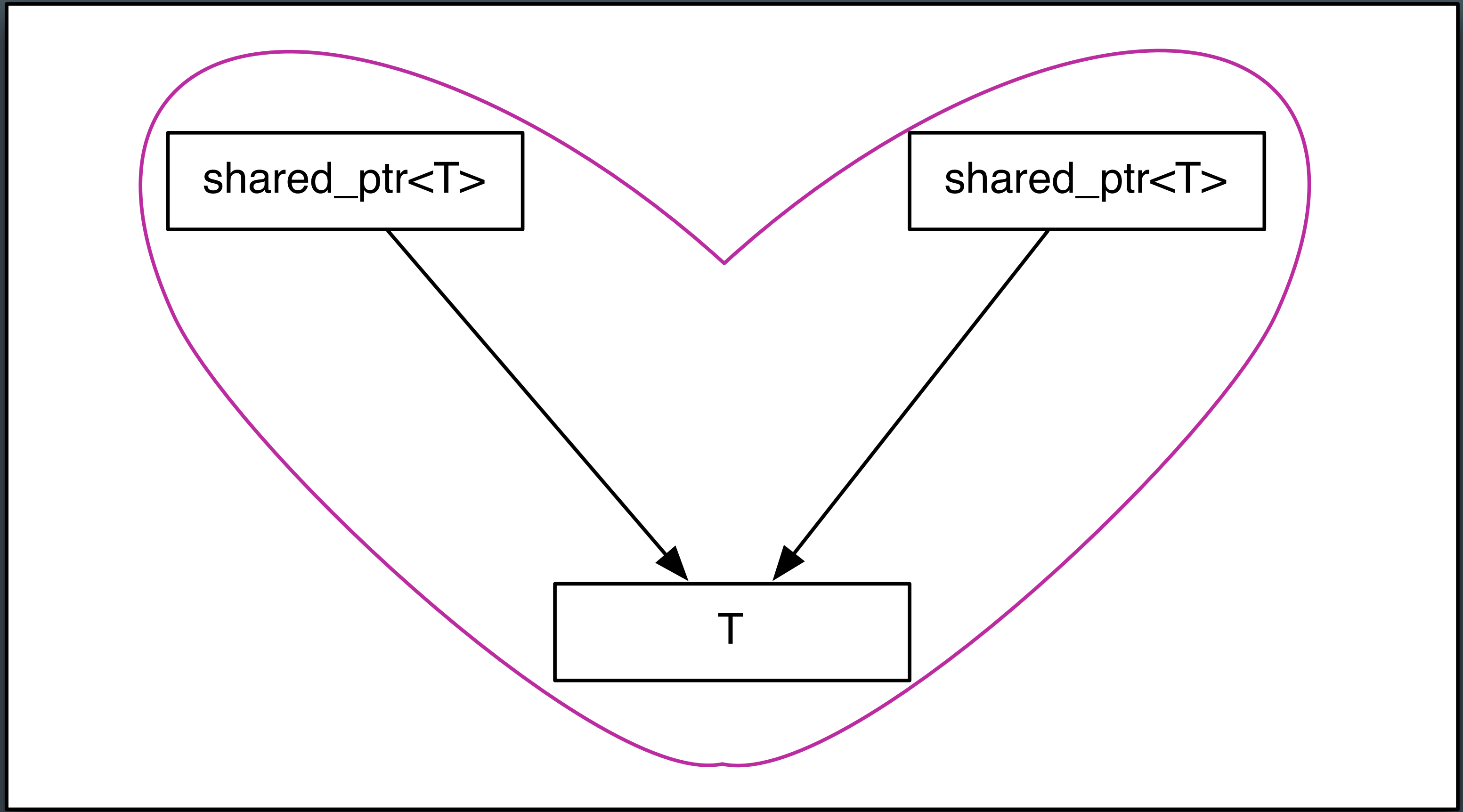
Semantics & Syntax



Semantics & Syntax

- If we extend our notion of object type to include the directly related part then we have intersecting objects which will interfere with each other

Semantics & Syntax



Semantics & Syntax

- When we consider the whole, the standard syntax for copy and assignment no longer have their regular semantics.
  - This structure is still copyable and assignable but these operations must be done through other means

- The shared structure also breaks our ability to reason locally about the code

Semantics & Syntax

- When we consider the whole, the standard syntax for copy and assignment no longer have their regular semantics.
  - This structure is still copyable and assignable but these operations must be done through other means

- The shared structure also breaks our ability to reason locally about the code

A shared pointer is as good as a global variable

client library

```
template <typename T>
void draw(const T& x, ostream& out, size_t position)
{ out << string(position, ' ') << x << endl; }
```

cout guidelines defects

client | library

```
template <typename T>
void draw(const T& x, ostream& out, size_t position)
{ out << string(position, ' ') << x << endl; }

class object_t {
  public:
    template <typename T>
    object_t(T x) : self_(make_shared<model<T>>(move(x))) { }

    friend void draw(const object_t& x, ostream& out, size_t position)
    { x.self_->draw_(out, position); }

  private:
    struct concept_t {
        virtual ~concept_t() = default;
        virtual void draw_(ostream&, size_t) const = 0;
    };
    template <typename T>
    struct model : concept_t {
        model(T x) : data_(move(x)) { }
        void draw_(ostream& out, size_t position) const
        { draw(data_, out, position); }

        T data_;
    };
```

cout | guidelines | defects

client | **library**

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cout | guidelines | defects

client | library

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   shared_ptr<const concept_t> self_;
```

cout | guidelines | defects

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cout guidelines defects

client | library

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cout | guidelines | defects

client | library

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cout | guidelines | defects

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        { draw(data_, out, position); }

        T data_;
    };

   shared_ptr<const concept_t> self_;
};

using document_t = vector<object_t>;
```

cout guidelines defects

client | library

```
    template <typename T>
    object_t(T x) : self_(make_shared<model<T>>(move(x))) { }

    friend void draw(const object_t& x, ostream& out, size_t position)
    { x.self_->draw_(out, position); }

  private:
    struct concept_t {
        virtual ~concept_t() = default;
        virtual void draw_(ostream&, size_t) const = 0;
    };
    template <typename T>
    struct model : concept_t {
        model(T x) : data_(move(x)) { }
        void draw_(ostream& out, size_t position) const
        { draw(data_, out, position); }

        T data_;
    };

   shared_ptr<const concept_t> self_;
};

using document_t = vector<object_t>;
```

cout | guidelines | defects

```
    friend void draw(const object_t& x, ostream& out, size_t position)
    { x.self_->draw_(out, position); }

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    struct concept_t {
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        void draw_(ostream& out, size_t position) const
        { draw(data_, out, position); }

        T data_;
    };

   shared_ptr<const concept_t> self_;
};

using document_t = vector<object_t>;

void draw(const document_t& x, ostream& out, size_t position)
{
```

client | library

```
    friend void draw(const object_t& x, ostream& out, size_t position)
    { x.self_->draw_(out, position); }

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    struct concept_t {
        virtual ~concept_t() = default;
        virtual void draw_(ostream&, size_t) const = 0;
    };
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    struct model : concept_t {
        model(T x) : data_(move(x)) { }
        void draw_(ostream& out, size_t position) const
        { draw(data_, out, position); }

        T data_;
    };

   shared_ptr<const concept_t> self_;
};

using document_t = vector<object_t>;

void draw(const document_t& x, ostream& out, size_t position)
{
    out << string(position, ' ') << "<document>" << endl;
```

cout | guidelines | defects

```
    { x.self_->draw_(out, position); }

  private:
    struct concept_t {
        virtual ~concept_t() = default;
        virtual void draw_(ostream&, size_t) const = 0;
    };
    template <typename T>
    struct model : concept_t {
        model(T x) : data_(move(x)) { }
        void draw_(ostream& out, size_t position) const
        { draw(data_, out, position); }

        T data_;
    };

   shared_ptr<const concept_t> self_;
};

using document_t = vector<object_t>;

void draw(const document_t& x, ostream& out, size_t position)
{
    out << string(position, ' ') << "<document>" << endl;
    for (auto& e : x) draw(e, out, position + 2);
```

```
  private:
    struct concept_t {
        virtual ~concept_t() = default;
        virtual void draw_(ostream&, size_t) const = 0;
    };
    template <typename T>
    struct model : concept_t {
        model(T x) : data_(move(x)) { }
        void draw_(ostream& out, size_t position) const
        { draw(data_, out, position); }

        T data_;
    };

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using document_t = vector<object_t>;

void draw(const document_t& x, ostream& out, size_t position)
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    out << string(position, ' ') << "<document>" << endl;
    for (auto& e : x) draw(e, out, position + 2);
    out << string(position, ' ') << "</document>" << endl;
```

client | library

```
private:
   struct concept_t {
       virtual ~concept_t() = default;
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   };
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   struct model : concept_t {
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       void draw_(ostream& out, size_t position) const
       { draw(data_, out, position); }

       T data_;
   };

    shared_ptr<const concept_t> self_;
};
```

```
using document_t = vector<object_t>;

void draw(const document_t& x, ostream& out, size_t position)
{
    out << string(position, ' ') << "<document>" << endl;
    for (auto& e : x) draw(e, out, position + 2);
    out << string(position, ' ') << "</document>" << endl;
}
```

cout | guidelines | defects

client library

cout guidelines defects

client library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());

    draw(document, cout, 0);
}
```

cout guidelines defects

client | library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());

    draw(document, cout, 0);
}
```

cout

```
<document>
 my_class_t
</document>
```

client library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());
    document.emplace_back(string("Hello World!"));

    draw(document, cout, 0);
}
```

cout guidelines defects

client

library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());
    document.emplace_back(string("Hello World!"));

    draw(document, cout, 0);
}
```

cout

```
<document>
 my_class_t
 Hello World!
</document>
```

client | library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());
    document.emplace_back(string("Hello World!"));
    document.emplace_back(document);

    draw(document, cout, 0);
}
```

cout | guidelines | defects

client | library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());
    document.emplace_back(string("Hello World!"));
    document.emplace_back(document);

    draw(document, cout, 0);
}
```

cout

```
<document>
 my_class_t
 Hello World!
 <document>
  my_class_t
  Hello World!
 </document>
</document>
```

client | library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.emplace_back(my_class_t());
    document.emplace_back(string("Hello World!"));

    auto saving = async([=]() {
        this_thread::sleep_for(chrono::seconds(3));
        cout << "-- save --" << endl;
        draw(document, cout, 0);
    });

    document.emplace_back(document);

    draw(document, cout, 0);
    saving.get();
}
```

cout | guidelines | defects

client library

```
class my_class_t {
    /* ... */
};

void draw(const my_class_t&, ostream& out, size_t position)
{ out << string(position, ' ') << "my_class_t" << endl; }

int main()
{
    document_t document;

ace_back(my_class_t());
ace_back(string("Hello World!"));
```

cout

```
<document>
 my_class_t
 Hello World!
 <document>
  my_class_t
  Hello World!
 </document>
</document>
-- save --
<document>
 my_class_t
 Hello World!
</document>
```

Seasoning

- Using make_shared<> to create shared_ptrs eliminates an extra heap allocation

```
template <typename T> // T models Drawable
object_t(T x) : self_(make_shared<model<T>>(move(x)))
{ }
```

- Pass *sink* arguments by value and move into place

Goals Recap

- No Raw Loops
- No Raw Syntonization Primitives
- No Raw Pointers

Locality of Reasoning

- Easier to reason about
- Composable
- General
- Correct
- Efficient

No Raw Loops

```
template <typename I, // I models BidirectionalIterator
          typename S> // S models UnaryPredicate
auto gather(I f, I l, I p, S s) -> pair<I, I>
{
    using value_type = typename iterator_traits<I>::value_type;

    return { stable_partition(f, p, [&](const value_type& x){ return !s(x); }),
             stable_partition(p, l, s) };
}
```

- `not1` is not lambda friendly because of the `argument_type` requirement
- With C++ 14 we should be able to express this with a `const auto&` argument
  - Perhaps with a fixed `not1` or `!bind`
- The `BidirectionalIterator` requirement should be weakened to `ForwardIterator`
  - See SGI STL for an implementation
- The `gather()` function was developed with Marshall Clow and is in Boost

Back

No Raw Loops

```
template <typename I, // I models BidirectionalIterator
          typename S> // S models UnaryPredicate
auto gather(I f, I l, I p, S s) -> pair<I, I>
{
    using value_type = typename iterator_traits<I>::value_type;

    return { stable_partition(f, p, [&](const value_type& x){ return !s(x); }),
             stable_partition(p, l, s) };
}
```

C++11

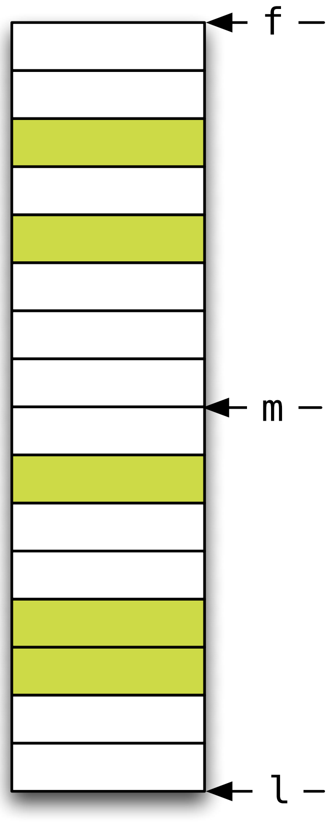
- `not1` is not lambda friendly because of the `argument_type` requirement
- With C++ 14 we should be able to express this with a `const auto&` argument
    - Perhaps with a fixed `not1` or `!bind`
- The `BidirectionalIterator` requirement should be weakened to `ForwardIterator`
    - See SGI STL for an implementation
- The `gather()` function was developed with Marshall Clow and is in Boost

Back

Adobe

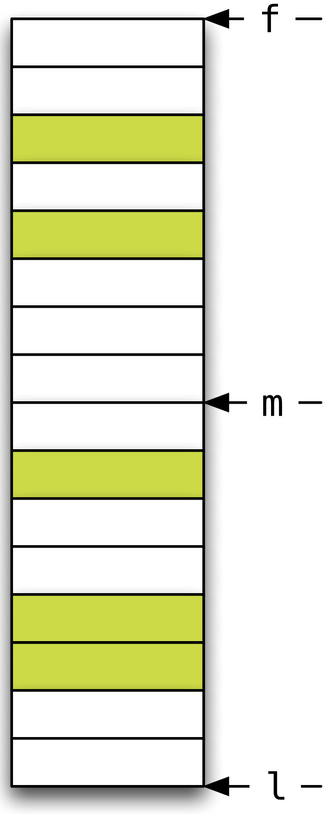
Stable Partition

Back



Back

Stable Partition



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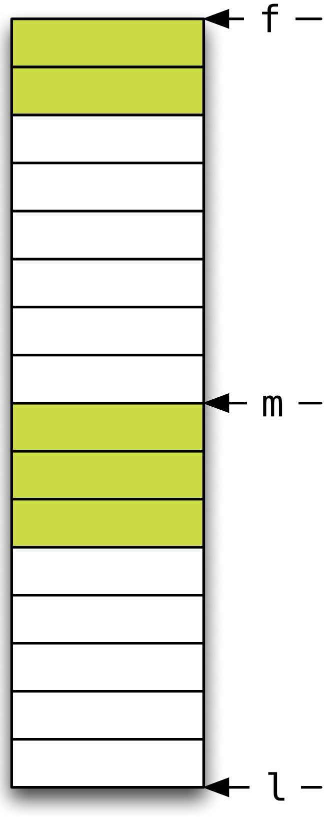
Stable Partition



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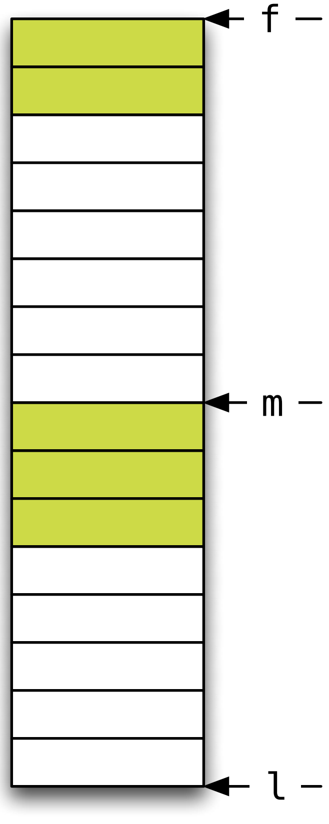
Stable Partition

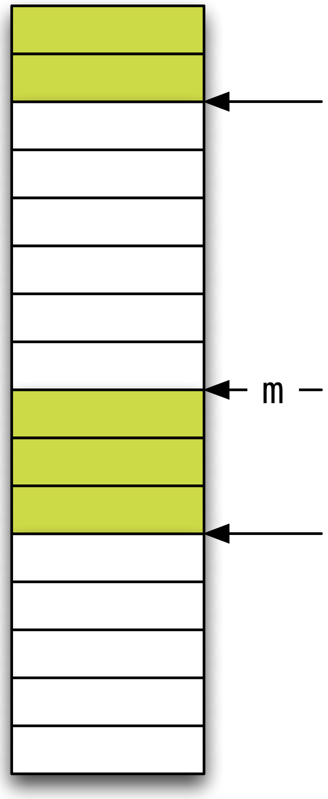



```
stable_partition(f, m, p)

stable_partition(m, l, p)
```

Back

Stable Partition

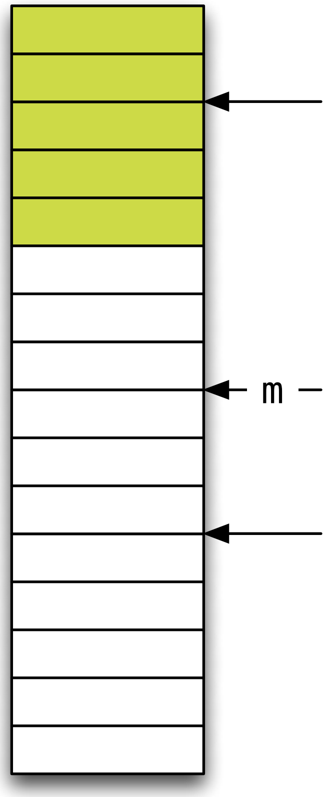



```
stable_partition(f, m, p)

stable_partition(m, l, p)
```

Back

Stable Partition

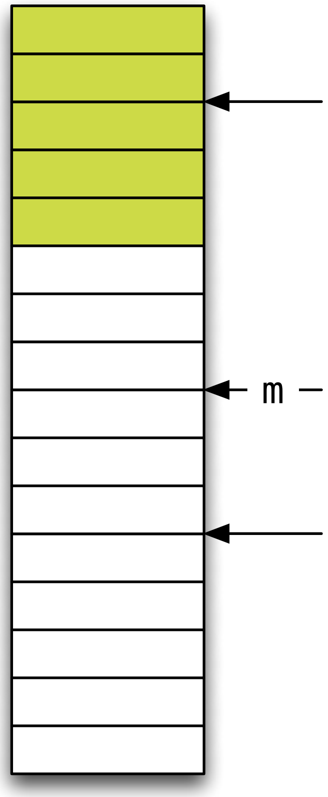



```
stable_partition(f, m, p)

stable_partition(m, l, p)
```

Back

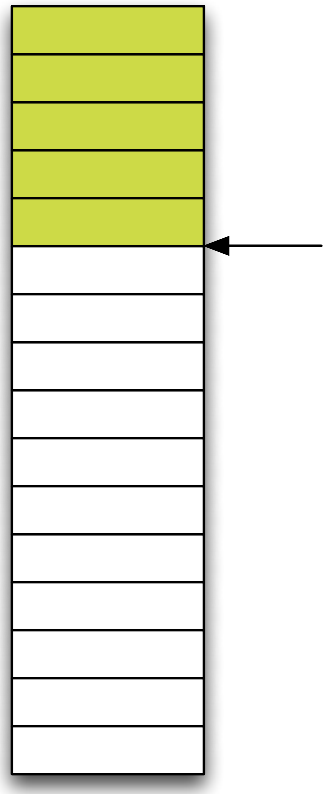
Stable Partition




```
rotate(stable_partition(f, m, p),
       m,
       stable_partition(m, l, p));
```

Back

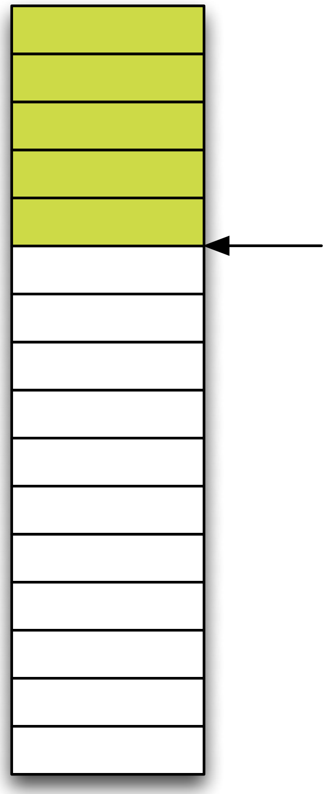
Stable Partition



```
rotate(stable_partition(f, m, p),
       m,
       stable_partition(m, l, p));
```

Back

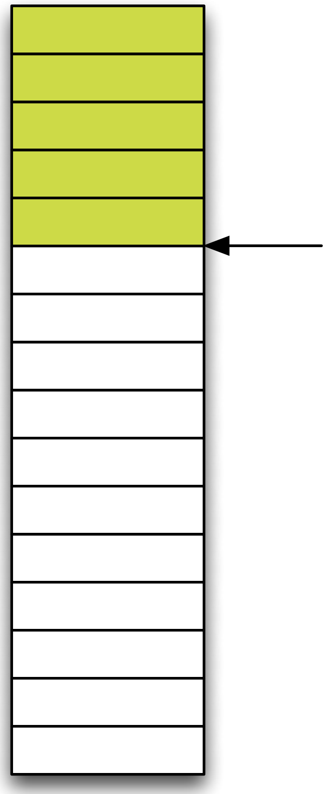
Stable Partition



```
return rotate(stable_partition(f, m, p),
              m,
              stable_partition(m, l, p));
```

Back

Stable Partition



```
template <typename I,
          typename P>
auto stable_partition(I f, I l, P p) -> I
{
    auto n = l - f;
    if (n == 0) return f;
    if (n == 1) return f + p(*f);

    auto m = f + (n / 2);

    return rotate(stable_partition(f, m, p),
                  m,
                  stable_partition(m, l, p));
}
```

Back

client | **library**

```cpp
// For illustration only
class group {
  public:
    template <typename F>
    void async(F&& f) {
        auto then = then_;
        thread(bind([then](F& f){ f(); }, std::forward<F>(f))).detach();
    }

    template <typename F>
    void then(F&& f) {
        then_->f_ = forward<F>(f);
        then_.reset();
    }

  private:
    struct packaged {
        ~packaged() { thread(bind(move(f_))).detach(); }
        function<void ()> f_;
    };

    shared_ptr<packaged> then_ = make_shared<packaged>();
};
```

client library

cout guidelines defects

client library

```
int main()
{
    group g;
    g.async([]() {
        this_thread::sleep_for(chrono::seconds(2));
        cout << "task 1" << endl;
    });

    g.async([]() {
        this_thread::sleep_for(chrono::seconds(1));
        cout << "task 2" << endl;
    });

    g.then([=](){
        cout << "done!" << endl;
    });

    this_thread::sleep_for(chrono::seconds(10));
}
```

cout guidelines defects

client library

```
int main()
{
    group g;
    g.async([]() {
        this_thread::sleep_for(chrono::seconds(2));
        cout << "task 1" << endl;
    });

    g.async([]() {
        this_thread::sleep_for(chrono::seconds(1));
        cout << "task 2" << endl;
    });

    g.then([=](){
        cout << "done!" << endl;
    });

    sleep_for(chrono::seconds(10));
}
```

cout

```
task 2
task 1
done!
```

```
// For illustration only
class group {
  public:
    template <typename F, typename ...Args>
    auto async(F&& f, Args&&... args)
        -> future<typename result_of<F (Args...)>::type>
    {
        using result_type = typename std::result_of<F (Args...)>::type;
        using packaged_type = std::packaged_task<result_type ()>;

        auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
        auto result = p.get_future();

        auto then = then_;
        thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

        return result;
    }

    template <typename F, typename ...Args>
    auto then(F&& f, Args&&... args)
        -> future<typename result_of<F (Args...)>::type>
    {
        using result_type = typename std::result_of<F (Args...)>::type;
        using packaged_type = std::packaged_task<result_type ()>;
```

```
class group {
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        using result_type = typename std::result_of<F (Args...)>::type;
        using packaged_type = std::packaged_task<result_type ()>;

        auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
        auto result = p.get_future();

        auto then = then_;
        thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

        return result;
    }

    template <typename F, typename ...Args>
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```

client | library

```
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  template <typename F, typename ...Args>
  auto then(F&& f, Args&&... args)
      -> future<typename result_of<F (Args...)>::type>
  {
      using result_type = typename std::result_of<F (Args...)>::type;
      using packaged_type = std::packaged_task<result_type ()>;

      auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
```

cout | guidelines | defects

client | library

```
template <typename F, typename ...Args>
auto async(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
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    using result_type = typename std::result_of<F (Args...)>::type;
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    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
auto then(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();
```

client library

```
auto async(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
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    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
auto then(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();
```

cout guidelines defects

```
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
auto then(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    then_->reset(new packaged<packaged_type>(move(p)));
```

```
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
auto then(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    then_->reset(new packaged<packaged_type>(move(p)));
    then_ = nullptr;
```

client | library

```
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
auto then(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
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    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    then_->reset(new packaged<packaged_type>(move(p)));
    then_ = nullptr;
```

cout | guidelines | defects

client library

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    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
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    then_ = nullptr;

    return result;
```

cout guidelines defects

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    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    auto then = then_;
    thread(bind([then](packaged_type& p){ p(); }, move(p))).detach();

    return result;
}

template <typename F, typename ...Args>
auto then(F&& f, Args&&... args)
    -> future<typename result_of<F (Args...)>::type>
{
    using result_type = typename std::result_of<F (Args...)>::type;
    using packaged_type = std::packaged_task<result_type ()>;

    auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
    auto result = p.get_future();

    then_->reset(new packaged<packaged_type>(move(p)));
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client | library

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client library

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    struct any_packaged {
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client | library

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    struct any_packaged {
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    struct packaged : any_packaged {
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client library

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client | library

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client | library

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client | library

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client | **library**

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        P f_;
    };

    shared_ptr<unique_ptr<any_packaged>> then_ = make_shared<unique_ptr<any_packaged>>();
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        auto p = packaged_type(forward<F>(f), forward<Args>(args)...);
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    shared_ptr<unique_ptr<any_packaged>> then_ = make_shared<unique_ptr<any_packaged>>();
};
```

client library

```
int main()
{
    group g;

    auto x = g.async([]() {
        this_thread::sleep_for(chrono::seconds(2));
        cout << "task 1" << endl;
        return 10;
    });

    auto y = g.async([]() {
        this_thread::sleep_for(chrono::seconds(1));
        cout << "task 2" << endl;
        return 5;
    });

    auto r = g.then(bind([](future<int>& x, future<int>& y) {
        cout << "done:" << (x.get() + y.get()) << endl;
    }, move(x), move(y)));

    r.get();
}
```

Back

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client library

```
int main()
{
    group g;

    auto x = g.async([]() {
        this_thread::sleep_for(chrono::seconds(2));
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                     ove(y)));
```

cout

```
task 2
task 1
done:15
```

Back