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Project: Programming Language C++, Library Working Group

Reply-to: Gary Powell <gwpowell at gmail dot com>

Tim Blechmann <tim at klingt dot org>

Priority Queue, Queue and Stack: Changes and Additions

Introduction

Priority Queues, Stacks and heaps are extremely useful data structures suitable for solving many common ordering problems. C++ 2011 provides only a couple of template adaptor classes; `priority_queue`, `stack` and `queue`, which provide limited functionality. To overcome the current limitations, this paper proposes that optional compile time configuration be added to the existing `std::priority_queue` adaptor. Additionally there are several alternative implementations of heaps having different performance characteristics which should be added to the standard library. Especially, the suggested options for these heaps deal with these additional aspects:

- **Iterators:** Heaps provide iterators to iterate all elements.
- **Mutability:** The priority of heap elements can be modified.
- **Mergeable:** While all heaps can be merged, some can be merged efficiently.
- **Stability:** Heaps can be configured to be stable sorted.
- **Comparison:** Heaps can be compared for equivalence.

Iterators allow a priority queue to be inspected without having to pop every element out of it. This of course is useful for programs which need to store their current state.

Mutability is required to achieve specific algorithmic complexity for some algorithms. The keys in fibonacci heaps can be changed in $O(1)$ which is better than removing and inserting, which is usually $O(\log(n))$. We propose two different interfaces for mutability: the first family of methods (`update`, `increase`, `decrease`) assigns a new key to a heap node which is referenced by a handle. The `increase/decrease` methods can be used, if the direction of the key change is known in advance. Apart from this, we propose a more advanced 'fixup' interface. This can be used to restore heap order, if the key of a heap node is modified from user code.

Mergability is helpful when efficiently combining two heaps. This is usually more efficient than creating a new heap based on the data from the original heaps. Fibonacci heaps for example can be merged in $O(1)$.

Stability gives the programmer control over the order in which elements which are otherwise equal, are popped from the heap.

Comparison is necessary both for debugging as well as one might wish to compare any other standard containers. Two heaps are equivalent, if their elements are in the same heap order (they do not necessarily have the same internal structure).

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The current `std::priority_queue` is a container adaptor. The authors propose that this interface remain the same for backwards compatibility and that these new containers reside in a separate namespace. The new heap implementations are all containers vs adaptors.

In addition, a `heap_merge` function is proposed to merge arbitrary heaps. There is also a corresponding `stack_merge` function which concatenates two stacks into one, and `queue_merge` which also concatenates two queues into one.

The paper uses the `boost::mpl` syntax to generate some types and instantiate some member functions based on compile time options. Obviously this interface will have to change but at the moment, its not clear to the authors what that interface should be. If the library committee accepts a MPL like library then that would be the interface of choice. It also uses a `std::parameter::void_` as a placeholder. However the authors do not want to depend on another library for the acceptance of this one. The full standard text is not provided in this paper, outlining all of the formal constraints on things like constructor complexity etc. If the library is accepted with that as a condition, the authors will be glad to provide the additional work.

The authors fully expect that the reviewing committee will have additional suggestions, and therefore look for guidance even if a full review is not possible due to time constraints. One consideration is whether the individual containers be separated out into unique proposals so that the committee can pick and chose which ones to move forward.

Changes from N3443=12-0133

- *) Leave existing adaptors alone
- *) Fully specify `priority_queue` container
- *) Add Queue and Stack Containers
- *) Add `stack_merge` and `queue_merge` functions
- *) Options, functions and containers are now in the namespace `std::heap`

Priority Queue

The template parameter `T` is the type to be managed by the container.

The container supports the following options:

- `std::heap::compare<>`, defaults to `compare<std::less<T> >`
- `std::heap::stable<>`, defaults to `stable<false>`
- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uintmax_t>`
- `std::heap::container<>`, defaults to `std::vector<T,heap::allocator<T> >`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`

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The interface is:

```
template <class T, class ...Options > class priority_queue {
public:
// types
typedef T          value_type;
typedef implementation_defined::size_type    size_type;
typedef implementation_defined::difference_type difference_type;
typedef implementation_defined::value_compare value_compare;

typedef implementation_defined::allocator_type allocator_type;
typedef implementation_defined::reference     reference;
typedef implementation_defined::const_reference const_reference;
typedef implementation_defined::pointer      pointer;
typedef implementation_defined::const_pointer const_pointer;
typedef implementation_defined::const_iterator const_iterator;

value_compare const & value_comp(void) const;
const_iterator cbegin(void) const;
const_iterator cend(void) const;

// construct/copy/destroy
explicit priority_queue(value_compare const & = value_compare());
priority_queue(priority_queue const &);
priority_queue& operator=(priority_queue const &);
priority_queue(priority_queue &&);           // move semantics
priority_queue& operator=(priority_queue &&); // move semantics

// public member functions
unspecified push(const_reference);           // push new element to heap
template<class... Args> void emplace(Args &&...); // push new element to heap
const_reference top() const;                 // return top element
void pop();                                  // remove top element
void clear();                                // clear heap
size_type size() const;                      // number of elements
bool empty() const;                          // priority queue is empty
allocator_type get_allocator(void) const;    // return allocator
size_type max_size(void) const;              // maximal possible size
void reserve(size_type);                      // reserve space, only available if (has_reserve == true)
```

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```
// heap equivalence
template<typename HeapType> bool operator==(HeapType const &) const;
template<typename HeapType> bool operator!=(HeapType const &) const;

// heap comparison
template<typename HeapType> bool operator<(HeapType const &) const;
template<typename HeapType> bool operator>(HeapType const &) const;
template<typename HeapType> bool operator>=(HeapType const &) const;
template<typename HeapType> bool operator<=(HeapType const &) const;

// public data members
static const bool constant_time_size;           // size() has constant complexity
static const bool has_ordered_iterators;       // priority queue has ordered iterators
static const bool is_mergable;                 // priority queue is efficiently mergable
static const bool is_stable;                   // priority queue has a stable heap order
static const bool has_reserve;                 // priority queue has a reserve() member
};
```

d_ary_heap

[D-ary heaps](#) are a generalization of binary heap with each non-leaf node having N children. For a low arity, the height of the heap is larger, but the number of comparisons to find the largest child node is bigger. The template parameter T is the type to be managed by the container.

The container supports the following options:

- `std::heap::arity<>`, required
- `std::heap::compare<>`, defaults to `compare<std::less<T> >`
- `std::heap::stable<>`, defaults to `stable<false>`
- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uintmax_t>`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`

```
template<class T, class... Options> class d_ary_heap {
public:
    // types
    typedef T value_type;
    typedef implementation_defined::size_type size_type;
    typedef implementation_defined::difference_type difference_type;
    typedef implementation_defined::value_compare value_compare;
    typedef implementation_defined::allocator_type allocator_type;
    typedef implementation_defined::reference reference;
    typedef implementation_defined::const_reference const_reference;
```

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```
typedef implementation_defined::pointer    pointer;
typedef implementation_defined::const_pointer  const_pointer;
typedef implementation_defined::const_iterator  const_iterator;
typedef implementation_defined::const_ordered_iterator const_ordered_iterator;
typedef implementation_defined::handle_type    handle_type;
```

```
// construct/copy/destroy
```

```
explicit d_ary_heap(value_compare const & = value_compare());
```

```
d_ary_heap(d_ary_heap const &);
```

```
d_ary_heap(d_ary_heap &&);
```

```
d_ary_heap& operator=(d_ary_heap &&);
```

```
d_ary_heap& operator=(d_ary_heap const &);
```

```
// public member functions
```

```
bool empty(void) const;
```

```
size_type size(void) const;
```

```
size_type max_size(void) const;
```

```
void clear(void);
```

```
allocator_type get_allocator(void) const;
```

```
value_type const & top(void) const;
```

```
mpl::if_c< is_mutable, handle_type, void >::type push(value_type const &);
```

```
template<class... Args>
```

```
    mpl::if_c< is_mutable, handle_type, void >::type emplace(Args &&...);
```

```
template<typename HeapType> bool operator<(HeapType const &) const;
```

```
template<typename HeapType> bool operator>(HeapType const &) const;
```

```
template<typename HeapType> bool operator>=(HeapType const &) const;
```

```
template<typename HeapType> bool operator<=(HeapType const &) const;
```

```
template<typename HeapType> bool operator==(HeapType const &) const;
```

```
template<typename HeapType> bool operator!=(HeapType const &) const;
```

```
void update(handle_type, const_reference);
```

```
void update(handle_type);
```

```
void increase(handle_type, const_reference);
```

```
void increase(handle_type);
```

```
void decrease(handle_type, const_reference);
```

```
void decrease(handle_type);
```

```
void erase(handle_type);
```

```
void pop(void);
```

```
void swap(d_ary_heap &);
```

```
const_iterator cbegin(void) const;
```

```
const_iterator cend(void) const;
```

```
ordered_iterator ordered_cbegin(void) const;
```

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```
ordered_iterator ordered_cend(void) const;
void reserve(size_type);
value_compare const & value_comp(void) const;

// public static functions
static handle_type s_handle_from_iterator(const_iterator const &);

// public data members
static const bool constant_time_size;
static const bool has_ordered_iterators;
static const bool is_mergable;
static const bool has_reserve;
static const bool is_stable;
};
```

binomial_heap

[Binomial heaps](#) are node-base heaps, that are implemented as a set of binomial trees of piecewise different order. The most important heap operations have a worst-case complexity of $O(\log n)$. In contrast to d-ary heaps, binomial heaps can also be merged in $O(\log n)$.

```
template<class T, class... Options> class binomial_heap{
public:
// types
typedef T value_type;
typedef implementation_defined::size_type size_type;
typedef implementation_defined::difference_type difference_type;
typedef implementation_defined::value_compare value_compare;
typedef implementation_defined::allocator_type allocator_type;
typedef implementation_defined::reference reference;
typedef implementation_defined::const_reference const_reference;
typedef implementation_defined::pointer pointer;
typedef implementation_defined::const_pointer const_pointer;
typedef implementation_defined::const_iterator const_iterator;
typedef implementation_defined::const_ordered_iterator const_ordered_iterator;
typedef implementation_defined::handle_type handle_type;

// member classes/structs/unions
template<typename T, typename A0 = std::parameter::void_,
        typename A1 = std::parameter::void_,
        typename A2 = std::parameter::void_,
        typename A3 = std::parameter::void_>
```

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```
struct force_inf {

    // public member functions
    template<typename X> bool operator()(X const &, X const &) const;
};
template<typename T, typename A0 = std::parameter::void_,
        typename A1 = std::parameter::void_,
        typename A2 = std::parameter::void_,
        typename A3 = std::parameter::void_>
struct implementation_defined {
    // types
    typedef T value_type;
    typedef unspecified size_type;
    typedef unspecified reference;
    typedef base_maker::compare_argument value_compare;
    typedef base_maker::allocator_type allocator_type;
    typedef base_maker::node_type node;
    typedef allocator_type::pointer node_pointer;
    typedef allocator_type::const_pointer const_node_pointer;
    typedef unspecified handle_type;
    typedef base_maker::node_type node_type;
    typedef unspecified node_list_type;
    typedef node_list_type::iterator node_list_iterator;
    typedef node_list_type::const_iterator node_list_const_iterator;
    typedef unspecified value_extractor;
    typedef const_iterator const_iterator;
    typedef unspecified ordered_iterator;
};

// construct/copy/destroy
explicit binomial_heap(value_compare const & = value_compare());
binomial_heap(binomial_heap const &);
binomial_heap(binomial_heap &&);
explicit binomial_heap(value_compare const &, node_list_type &, size_type);
binomial_heap& operator=(binomial_heap const &);
binomial_heap& operator=(binomial_heap &&);
~binomial_heap(void);

// public member functions
bool empty(void) const;
size_type size(void) const;
```

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```
    size_type max_size(void) const;
    void clear(void);
    allocator_type get_allocator(void) const;
    void swap(binomial_heap &);
    const_reference top(void) const;
    handle_type push(value_type const &);
    template<class... Args> handle_type emplace(Args &&...);
    void pop(void);
    void update(handle_type, const_reference);
    void update(handle_type);
    void increase(handle_type, const_reference);
    void increase(handle_type);
    void decrease(handle_type, const_reference);
    void decrease(handle_type);
    void merge(binomial_heap &);
    const_iterator cbegin(void) const;
    const_iterator cend(void) const;
    const_ordered_iterator ordered_cbegin(void) const;
    const_ordered_iterator ordered_cend(void) const;
    void erase(handle_type);
    value_compare const & value_comp(void) const;
    template<typename HeapType> bool operator<(HeapType const &) const;
    template<typename HeapType> bool operator>(HeapType const &) const;
    template<typename HeapType> bool operator==(HeapType const &) const;
    template<typename HeapType> bool operator<=(HeapType const &) const;
    template<typename HeapType> bool operator==(HeapType const &) const;
    template<typename HeapType> bool operator!=(HeapType const &) const;

    // public static functions
    static handle_type s_handle_from_iterator(iterator const &);

    // public data members
    static const bool constant_time_size;
    static const bool has_ordered_iterators;
    static const bool is_mergable;
    static const bool is_stable;
    static const bool has_reserve;
}
```

fibonacci_heap

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[Fibonacci heaps](#) are node-base heaps, that are implemented as a forest of heap-ordered trees. They provide better amortized performance than binomial heaps. Except `pop()` and `erase()`, the most important heap operations have constant amortized complexity.

The template parameter `T` is the type to be managed by the container.

The container supports the following options:

- `std::heap::stable<>`, defaults to `stable<false>`
- `std::heap::compare<>`, defaults to `compare<std::less<T> >`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`
- `std::heap::constant_time_size<>`, defaults to `constant_time_size<true>`
- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uimax_t>`

Fibonacci heaps have a notion of ‘lazy updates’, which updates the heap structure without forcing a consolidation of the heap. While still having an amortized complexity of $O(\log(n))$, it provides better performance in the average case.

```
template<class T,class... Options> class fibonacci_heap{
public:
    // types
    typedef T value_type;
    typedef implementation_defined::size_type size_type;
    typedef implementation_defined::difference_type difference_type;
    typedef implementation_defined::value_compare value_compare;
    typedef implementation_defined::allocator_type allocator_type;
    typedef implementation_defined::reference reference;
    typedef implementation_defined::const_reference const_reference;
    typedef implementation_defined::pointer pointer;
    typedef implementation_defined::const_pointer const_pointer;
    typedef implementation_defined::const_iterator const_iterator;
    typedef implementation_defined::const_ordered_iterator const_ordered_iterator;
    typedef implementation_defined::handle_type handle_type;

    // construct/copy/destroy
    explicit fibonacci_heap(value_compare const & = value_compare());
    fibonacci_heap(fibonacci_heap const &);
    fibonacci_heap(fibonacci_heap &&);
    fibonacci_heap(fibonacci_heap &);
    fibonacci_heap& operator=(fibonacci_heap &&);
    fibonacci_heap& operator=(fibonacci_heap const &);
    ~fibonacci_heap(void);
```

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```
// public member functions
bool empty(void) const;
size_type size(void) const;
size_type max_size(void) const;
void clear(void);
allocator_type get_allocator(void) const;
void swap(fibonacci_heap &);
value_type const & top(void) const;
handle_type push(value_type const &);
template<class... Args> handle_type emplace(Args &&...);
void pop(void);
void update(handle_type, const_reference);
void update_lazy(handle_type, const_reference);
void update(handle_type);
void update_lazy(handle_type);
void increase(handle_type, const_reference);
void increase(handle_type);
void decrease(handle_type, const_reference);
void decrease(handle_type);
void erase(handle_type const &);
const_iterator cbegin(void) const;
const_iterator cend(void) const;
const_ordered_iterator ordered_cbegin(void) const;
const_ordered_iterator ordered_cend(void) const;
void merge(fibonacci_heap &);
value_compare const & value_comp(void) const;
template<typename HeapType> bool operator<(HeapType const &) const;
template<typename HeapType> bool operator>(HeapType const &) const;
template<typename HeapType> bool operator>=(HeapType const &) const;
template<typename HeapType> bool operator<=(HeapType const &) const;
template<typename HeapType> bool operator==(HeapType const &) const;
template<typename HeapType> bool operator!=(HeapType const &) const;

// public static functions
static handle_type s_handle_from_iterator(iterator const &);

// public data members
static const bool constant_time_size;
static const bool has_ordered_iterators;
static const bool is_mergable;
```

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```
    static const bool is_stable;  
    static const bool has_reserve;  
};
```

pairing_heap

[Pairing heaps](#) are self-adjusting node-based heaps. Although design and implementation are rather simple, the complexity analysis is yet unsolved. For details, consult:

Pettie, Seth (2005), "Towards a final analysis of pairing heaps", Proc. 46th Annual IEEE Symposium on Foundations of Computer Science, pp. 174–183

The template parameter T is the type to be managed by the container.

The container supports the following options:

- `std::heap::compare<>`, defaults to `compare<std::less<T> >`
- `std::heap::stable<>`, defaults to `stable<false>`
- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uintmax_t>`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`
- `std::heap::constant_time_size<>`, defaults to `constant_time_size<true>`

```
template<class T, class... Options> class pairing_heap{  
public:  
    // types  
    typedef T value_type;  
    typedef implementation_defined::size_type size_type;  
    typedef implementation_defined::difference_type difference_type;  
    typedef implementation_defined::value_compare value_compare;  
    typedef implementation_defined::allocator_type allocator_type;  
    typedef implementation_defined::reference reference;  
    typedef implementation_defined::const_reference const_reference;  
    typedef implementation_defined::pointer pointer;  
    typedef implementation_defined::const_pointer const_pointer;  
    typedef implementation_defined::const_iterator const_iterator;  
    typedef implementation_defined::const_ordered_iterator const_ordered_iterator;  
    typedef implementation_defined::handle_type handle_type;  
  
    // construct/copy/destroy  
    explicit pairing_heap(value_compare const & = value_compare());  
    pairing_heap(pairing_heap const &);  
    pairing_heap(pairing_heap &&);  
    pairing_heap& operator=(pairing_heap &&);
```

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```
pairing_heap& operator=(pairing_heap const &);
~pairing_heap(void);

// public member functions
bool empty(void) const;
size_type size(void) const;
size_type max_size(void) const;
void clear(void);
allocator_type get_allocator(void) const;
void swap(pairing_heap &);
const_reference top(void) const;
handle_type push(value_type const &);
template<class... Args> handle_type emplace(Args &&...);
void pop(void);
void update(handle_type, const_reference);
void update(handle_type);
void increase(handle_type, const_reference);
void increase(handle_type);
void decrease(handle_type, const_reference);
void decrease(handle_type);
void erase(handle_type);
const_iterator cbegin(void) const;
const_iterator cend(void) const;
const_ordered_iterator ordered_cbegin(void) const;
const_ordered_iterator ordered_cend(void) const;
void merge(pairing_heap &);
value_compare const & value_comp(void) const;
template<typename HeapType> bool operator<(HeapType const &) const;
template<typename HeapType> bool operator>(HeapType const &) const;
template<typename HeapType> bool operator>=(HeapType const &) const;
template<typename HeapType> bool operator<=(HeapType const &) const;
template<typename HeapType> bool operator==(HeapType const &) const;
template<typename HeapType> bool operator!=(HeapType const &) const;

// public static functions
static handle_type s_handle_from_iterator(iterator const &);

// public data members
static const bool constant_time_size;
static const bool has_ordered_iterators;
static const bool is_mergable;
```

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```
static const bool is_stable;  
static const bool has_reserve;  
};
```

skew_heap

[Skew heaps](#) are self-adjusting node-based heaps. Although there are no constraints for the tree structure, all heap operations can be performed in $O(\log n)$.

The template parameter T is the type to be managed by the container.

The container supports the following options:

- `std::heap::compare<>`, defaults to `compare<std::less<T> >`
- `std::heap::stable<>`, defaults to `stable<false>`
- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uintmax_t>`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`
- `constant_time_size<>`, defaults to `constant_time_size<true>`
- `store_parent_pointer<>`, defaults to `store_parent_pointer<true>`. Maintaining a parent pointer adds some maintenance and size overhead, but iterating a heap is more efficient.
- `mutable<>`, defaults to `mutable<false>`.

```
template<class T, class... Options> class skew_heap{  
public:  
    // types  
    typedef T value_type;  
    typedef implementation_defined::size_type size_type;  
    typedef implementation_defined::difference_type difference_type;  
    typedef implementation_defined::value_compare value_compare;  
    typedef implementation_defined::allocator_type allocator_type;  
    typedef implementation_defined::reference reference;  
    typedef implementation_defined::const_reference const_reference;  
    typedef implementation_defined::pointer pointer;  
    typedef implementation_defined::const_pointer const_pointer;  
    typedef implementation_defined::const_iterator const_iterator;  
    typedef implementation_defined::const_ordered_iterator const_ordered_iterator;  
    typedef mpl::if_c< is_mutable, typename implementation_defined::handle_type, void * >::type  
    handle_type;
```

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```
// member classes/structs/unions
```

```
struct implementation_defined {  
    // types  
    typedef T                value_type;  
    typedef base_maker::compare_argument  value_compare;  
    typedef base_maker::allocator_type    allocator_type;  
    typedef base_maker::node_type        node;  
    typedef allocator_type::pointer      node_pointer;  
    typedef allocator_type::const_pointer const_node_pointer;  
    typedef unspecified                value_extractor;  
    typedef std::array< node_pointer, 2 > child_list_type;  
    typedef child_list_type::iterator    child_list_iterator;  
    typedef const_iterator                const_iterator;  
    typedef unspecified                const_ordered_iterator;  
    typedef unspecified                reference;  
    typedef unspecified                handle_type;  
};
```

```
// construct/copy/destroy
```

```
explicit skew_heap(value_compare const & = value_compare());  
skew_heap(skew_heap const &);  
skew_heap(skew_heap &&);  
skew_heap& operator=(skew_heap const &);  
skew_heap& operator=(skew_heap &&);  
~skew_heap(void);
```

```
// public member functions
```

```
mpl::if_c< is_mutable, handle_type, void >::type push(value_type const &);  
template<typename... Args>  
    mpl::if_c< is_mutable, handle_type, void >::type emplace(Args &&...);  
bool empty(void) const;  
size_type size(void) const;  
size_type max_size(void) const;  
void clear(void);  
allocator_type get_allocator(void) const;  
void swap(skew_heap &);  
const_reference top(void) const;  
void pop(void);  
const_iterator cbegin(void) const;  
const_iterator cend(void) const;
```

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Reply-to: Gary Powell <gwpowell at gmail dot com>

Tim Blechmann <tim at klingt dot org>

```
const_ordered_iterator ordered_begin(void) const;
const_ordered_iterator ordered_end(void) const;
void merge(skew_heap &);
value_compare const & value_comp(void) const;
template<typename HeapType> bool operator<(HeapType const &) const;
template<typename HeapType> bool operator>(HeapType const &) const;
template<typename HeapType> bool operator>=(HeapType const &) const;
template<typename HeapType> bool operator<=(HeapType const &) const;
template<typename HeapType> bool operator==(HeapType const &) const;
template<typename HeapType> bool operator!=(HeapType const &) const;
void erase(handle_type);
void update(handle_type, const_reference);
void update(handle_type);
void increase(handle_type, const_reference);
void increase(handle_type);
void decrease(handle_type, const_reference);
void decrease(handle_type);

// public static functions
static handle_type s_handle_from_iterator(iterator const &);

// public data members
static const bool constant_time_size;
static const bool has_ordered_iterators;
static const bool is_mergable;
static const bool is_stable;
static const bool has_reserve;
static const bool is_mutable;
};
```

Queue

The template parameter T is the type to be managed by the container.

The container supports the following options:

- `std::heap::stable<>`, defaults to `stable<true>`
- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uintmax_t>`
- `std::heap::container<>`, defaults to `std::deque<T,heap::allocator<T> >`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`

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The interface is:

```
template <class T,  
class ...Options > class queue {  
public:  
// types  
typedef T          value_type;  
typedef implementation_defined::size_type    size_type;  
typedef implementation_defined::difference_type difference_type;  
typedef implementation_defined::value_compare value_compare;  
  
typedef implementation_defined::allocator_type allocator_type;  
typedef implementation_defined::reference      reference;  
typedef implementation_defined::const_reference const_reference;  
typedef implementation_defined::pointer      pointer;  
typedef implementation_defined::const_pointer const_pointer;  
typedef implementation_defined::const_iterator const_iterator;  
  
const_iterator cbegin(void) const;  
const_iterator cend(void) const;  
  
// construct/copy/destroy  
explicit queue(value_compare const & = value_compare());  
queue(queue const &);  
queue& operator=(queue const &);  
queue(queue &&);          // move semantics  
queue& operator=(queue &&); // move semantics  
// public member functions  
unspecified push(const_reference);          // push new element to queue  
template<class... Args> void emplace(Args &&...); // push new element to queue  
reference front();          // return first element  
const_reference front() const; // return first element  
  
reference back()          // return last element  
const_reference back() const; // return last element  
  
void pop();          // remove top element  
void clear();       // clear queue  
size_type size() const; // number of elements  
bool empty() const; // queue is empty  
allocator_type get_allocator(void) const; // return allocator
```


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```
size_type max_size(void) const;           // maximal possible size
void reserve(size_type);                 // reserve space, only available if (has_reserve == true)

// queue equivalence
template<typename QueueType> bool operator==(QueueType const &) const;
template<typename QueueType> bool operator!=(QueueType const &) const;

// Queue comparison
template<typename QueueType> bool operator<(QueueType const &) const;
template<typename QueueType> bool operator>(QueueType const &) const;
template<typename QueueType> bool operator>=(QueueType const &) const;
template<typename QueueType> bool operator<=(QueueType const &) const;

// public data members
static const bool constant_time_size;    // size() has constant complexity
static const bool has_ordered_iterators; // queue has ordered iterators
static const bool is_mergable;           // queue is efficiently mergable
static const bool is_stable;             // queue has a stable order
static const bool has_reserve;           // queue has a reserve() member
};
```

Stack

The template parameter T is the type to be managed by the container.

The container supports the following options:

- `std::heap::stability_counter_type<>`, defaults to `stability_counter_type<std::uintmax_t>`
- `std::heap::container<>`, defaults to `std::deque<T,heap::allocator<T> >`
- `std::heap::allocator<>`, defaults to `allocator<std::allocator<T> >`

The interface is:

```
template <class T,
class ...Options > class queue {
public:
// types
typedef T          value_type;
typedef implementation_defined::size_type    size_type;
typedef implementation_defined::difference_type difference_type;
typedef implementation_defined::value_compare value_compare;
```

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```
typedef implementation_defined::allocator_type allocator_type;
typedef implementation_defined::reference reference;
typedef implementation_defined::const_reference const_reference;
typedef implementation_defined::pointer pointer;
typedef implementation_defined::const_pointer const_pointer;
typedef implementation_defined::const_iterator const_iterator;
```

```
const_iterator cbegin(void) const;
const_iterator cend(void) const;
```

```
// construct/copy/destruct
```

```
explicit stack(value_compare const & = value_compare());
```

```
stack(stack const &);
```

```
stack& operator=(stack const &);
```

```
stack(stack &&); // move semantics
```

```
stack& operator=(stack &&); // move semantics
```

```
// public member functions
```

```
unspecified push(const_reference); // push new element to queue
```

```
template<class... Args> void emplace(Args &&...); // push new element to queue
```

```
reference top(); // return first element
```

```
const_reference top() const; // return first element
```

```
void pop(); // remove top element
```

```
void clear(); // clear stack
```

```
size_type size() const; // number of elements
```

```
bool empty() const; // stack is empty
```

```
allocator_type get_allocator(void) const; // return allocator
```

```
size_type max_size(void) const; // maximal possible size
```

```
void reserve(size_type); // reserve space, only available if (has_reserve == true)
```

```
// queue equivalence
```

```
template<typename StackType> bool operator==(StackType const &) const;
```

```
template<typename StackType> bool operator!=(StackType const &) const;
```

```
// stack comparison
```

```
template<typename StackType> bool operator<(StackType const &) const;
```

```
template<typename StackType> bool operator>(StackType const &) const;
```

```
template<typename StackType> bool operator>=(StackType const &) const;
```

```
template<typename StackType> bool operator<=(StackType const &) const;
```

```
// public data members
```

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```
static const bool constant_time_size;           // size() has constant complexity
static const bool has_ordered_iterators;       // queue has ordered iterators
static const bool is_mergable;                 // queue is efficiently mergable
static const bool is_stable;                   // queue has a stable order
static const bool has_reserve;                 // queue has a reserve() member
};
```

Options

These are the current list of options for controlling the compile time aspects of the heaps.

```
template<typename T> struct compare;
```

Predicate for defining the heap order, optional (defaults to `compare<std::less<T> >`)

```
template<typename T> struct allocator;
```

Allocator for internal memory management, optional (defaults to `allocator<std::allocator<T> >`)

```
template<typename T> struct container;
```

Container for internal use by the heap container, optional (defaults to `std::deque<T, heap::allocator<T>` for queue and stack, `std::vector<T, heap::allocator>` for priority_queue)

```
template<bool T> struct stable;
```

Configures the heap to use a stable heap order, optional (defaults to `stable<false>`).

```
template<bool T> struct mutable_
```

Configures the heap to be mutable. `d_ary_heap` and `skew_heap` have to be configured with this policy to enable the mutability interface.

```
template<typename IntType> struct stability_counter_type;
```

Configures the integer type used for the stability counter, optional (defaults to `stability_counter_type<std::uintmax_t>`).

```
template<bool T> struct constant_time_size;
```

Specifies, whether `size()` should have linear or constant complexity. This argument is only available for node-based heap data structures and if available, it is optional (defaults to `constant_time_size<true>`)

```
template<bool T> struct store_parent_pointer;
```

Store the parent pointer in the heap nodes. This policy is only applicable to the `skew_heap`.

```
template<unsigned int T> struct arity;
```

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Specifies the arity of a d-ary heap. For details, consult the class reference of `d_ary_heap`

In order to provide the historical interface to `std::priority_queue` we may also want to provide:
`template<typename T, class Allocator> struct container;`

Iterators

```
class iterable_heap_interface
{
public:
    // types
    typedef unspecified      iterator;
    typedef unspecified      const_iterator;
    typedef unspecified      const_ordered_iterator;

    // public member functions
    const_iterator cbegin(void) const;
    const_iterator cend(void) const;

    const_ordered_iterator ordered_cbegin(void) const;
    const_ordered_iterator ordered_cend(void) const;
};
```

Priority queues, queues and stacks provide iterators, that can be used to traverse their elements. All heap, stack and queue iterators are `const_iterator`s, that means they cannot be used to modify the values, because changing the value of a heap node may corrupt the heap order.

Iterators do not visit heap elements in any specific order. Unless otherwise noted, all non-const heap member functions invalidate iterators, while all const member functions preserve the iterator validity.

Iterators for stacks and basic queues will visit the elements in container order.

Heap Merge

```
template<typename Heap1, typename Heap2> void heap_merge(Heap1 &rhs, Heap2 &lhs);
```

merge rhs into lhs

Effect: lhs contains all elements that have been part of rhs, rhs is empty.

Stack Merge

```
template<typename Stack1, typename Stack2> void stack_merge(Stack1 &rhs, Stack2 &lhs);
```

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merge rhs into lhs

Effect: lhs contains all elements that have been part of rhs, rhs is empty.

Queue Merge

```
template<typename Queue1, typename Queue2> void queu_merge(Queue1 &rhs, Queue2  
&lhs);
```

merge rhs into lhs

Effect: lhs contains all elements that have been part of rhs, rhs is empty.

Acknowledgements

The changes proposed here are based on work done at www.boost.org by Tim Blechmann's Heap library which can be found at http://www.boost.org/doc/libs/1_51_0/doc/html/heap.html

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