

CASC

1.0.5

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1 Colored Abstract Simplicial Complex (CASC) Library	1
1.1 Getting Started	1
1.1.1 Prerequisites	1
1.1.2 Installing	2
1.1.3 Documentation	2
1.2 Versioning & Contributing	2
1.3 Authors	2
1.4 License	2
1.5 Acknowledgments	3
2 CASC License	5
2.0.1 GNU LESSER GENERAL PUBLIC LICENSE	5
2.0.2 Preamble	5
2.0.3 TERMS AND CONDITIONS FOR COPYING, DISTRIBUTION AND MODIFICATION	7
2.0.4 END OF TERMS AND CONDITIONS	11
2.0.5 How to Apply These Terms to Your New Libraries	11
3 Building the documentation	13
3.0.1 Documentation for Developers	13
4 Frequently Asked Questions	15
5 Namespace Index	17
5.1 Namespace List	17
6 Data Structure Index	19
6.1 Data Structures	19
7 File Index	21
7.1 File List	21
8 Namespace Documentation	23
8.1 casc Namespace Reference	23
8.1.1 Typedef Documentation	26
8.1.1.1 AbstractSimplicialComplex	26
8.1.2 Function Documentation	26
8.1.2.1 check_orientation()	26
8.1.2.2 clear_orientation()	27
8.1.2.3 compute_orientation()	27
8.1.2.4 decimate()	27
8.1.2.5 decimateBackHalf()	28
8.1.2.6 decimateFirstHalf()	28
8.1.2.7 edge_up()	29
8.1.2.8 get() [1/3]	29
8.1.2.9 get() [2/3]	29

8.1.2.10	get() [3/3]	30
8.1.2.11	getClosure() [1/2]	30
8.1.2.12	getClosure() [2/2]	31
8.1.2.13	getLink() [1/2]	31
8.1.2.14	getLink() [2/2]	32
8.1.2.15	getStar() [1/2]	32
8.1.2.16	getStar() [2/2]	32
8.1.2.17	init_orientation()	33
8.1.2.18	kneighbors() [1/2]	33
8.1.2.19	kneighbors() [2/2]	34
8.1.2.20	kneighbors_up() [1/2]	34
8.1.2.21	kneighbors_up() [2/2]	35
8.1.2.22	neighbors() [1/2]	35
8.1.2.23	neighbors() [2/2]	36
8.1.2.24	neighbors_up() [1/2]	36
8.1.2.25	neighbors_up() [2/2]	37
8.1.2.26	operator!=(())	37
8.1.2.27	operator==(())	38
8.1.2.28	perform_insertion()	38
8.1.2.29	perform_removal()	39
8.1.2.30	run_user_callback()	39
8.1.2.31	set_difference()	39
8.1.2.32	set_intersection()	40
8.1.2.33	set_union()	40
8.1.2.34	to_string()	41
8.1.2.35	visit_BFS_down()	41
8.1.2.36	visit_BFS_up()	42
8.1.2.37	writeDOT()	42
8.2	index_tracker Namespace Reference	42
8.3	index_tracker::index_tracker_detail Namespace Reference	43
8.4	util Namespace Reference	44
8.4.1	Function Documentation	45
8.4.1.1	int_for_each()	45
8.4.1.2	make_range() [1/2]	46
8.4.1.3	make_range() [2/2]	46
9	Data Structure Documentation	49
9.1	index_tracker::index_tracker_detail::BTreeNode< _T, _d > Struct Template Reference	49
9.1.1	Detailed Description	49
9.2	casc::simplicial_complex< traits >::EdgeID< k > Struct Template Reference	50
9.2.1	Detailed Description	51
9.2.2	Constructor & Destructor Documentation	51

9.2.2.1 EdgeID() [1/2]	51
9.2.2.2 EdgeID() [2/2]	52
9.2.3 Member Function Documentation	52
9.2.3.1 down()	52
9.2.3.2 up()	52
9.3 index_tracker::index_tracker< _T, _d > Class Template Reference	53
9.3.1 Detailed Description	53
9.3.2 Constructor & Destructor Documentation	54
9.3.2.1 index_tracker()	54
9.4 util::int_type_map< IntegerType, OutHolder, IntegerSequence, F > Struct Template Reference	54
9.4.1 Detailed Description	54
9.5 index_tracker::index_tracker_detail::Interval< T > Struct Template Reference	55
9.5.1 Detailed Description	55
9.5.2 Member Function Documentation	55
9.5.2.1 operator=()	56
9.6 casc::Orientable Struct Reference	56
9.7 util::range< T > Struct Template Reference	56
9.7.1 Detailed Description	57
9.7.2 Constructor & Destructor Documentation	57
9.7.2.1 range() [1/2]	57
9.7.2.2 range() [2/2]	57
9.7.3 Member Function Documentation	58
9.7.3.1 begin()	58
9.7.3.2 end()	58
9.8 util::remove_first_val< Integer, IntegerSequence > Struct Template Reference	58
9.8.1 Detailed Description	58
9.9 util::remove_first_val< Integer, InHolder< Integer, I, Is... > > Struct Template Reference	59
9.9.1 Detailed Description	59
9.10 util::reverse_sequence< Integer, IntegerSequence > Struct Template Reference	59
9.10.1 Detailed Description	60
9.11 casc::simplicial_complex< traits >::SimplexID< k > Struct Template Reference	60
9.11.1 Detailed Description	62
9.11.2 Constructor & Destructor Documentation	62
9.11.2.1 SimplexID() [1/2]	62
9.11.2.2 SimplexID() [2/2]	62
9.11.3 Member Function Documentation	62
9.11.3.1 cover()	63
9.11.3.2 cover_insert()	63
9.11.3.3 get_simplex_up() [1/3]	63
9.11.3.4 get_simplex_up() [2/3]	64
9.11.3.5 get_simplex_up() [3/3]	64
9.11.3.6 indices()	65

9.11.4 Friends And Related Function Documentation	65
9.11.4.1 operator<<	65
9.12 casc::SimplexMap< Complex > Struct Template Reference	65
9.12.1 Detailed Description	66
9.12.2 Member Function Documentation	66
9.12.2.1 get() [1/2]	66
9.12.2.2 get() [2/2]	67
9.12.3 Friends And Related Function Documentation	67
9.12.3.1 operator<<	67
9.13 casc::SimplexSet< Complex > Struct Template Reference	68
9.13.1 Detailed Description	69
9.13.2 Member Function Documentation	69
9.13.2.1 begin()	70
9.13.2.2 cbegin()	70
9.13.2.3 cend()	70
9.13.2.4 empty()	71
9.13.2.5 end()	71
9.13.2.6 erase() [1/2]	71
9.13.2.7 erase() [2/2]	71
9.13.2.8 find() [1/2]	72
9.13.2.9 find() [2/2]	72
9.13.2.10 insert() [1/2]	73
9.13.2.11 insert() [2/2]	73
9.13.2.12 size()	73
9.13.3 Friends And Related Function Documentation	74
9.13.3.1 operator<<	74
9.14 casc::simplicial_complex< traits > Class Template Reference	74
9.14.1 Detailed Description	78
9.14.2 Member Typedef Documentation	78
9.14.2.1 EdgeData	79
9.14.2.2 NodeData	79
9.14.3 Constructor & Destructor Documentation	79
9.14.3.1 ~simplicial_complex()	79
9.14.4 Member Function Documentation	79
9.14.4.1 add_vertex() [1/2]	79
9.14.4.2 add_vertex() [2/2]	80
9.14.4.3 down() [1/3]	80
9.14.4.4 down() [2/3]	80
9.14.4.5 down() [3/3]	81
9.14.4.6 eq() [1/2]	81
9.14.4.7 eq() [2/2]	82
9.14.4.8 exists()	82

9.14.4.9 get_cover() [1/2]	82
9.14.4.10 get_cover() [2/2]	83
9.14.4.11 get_cover_insert()	83
9.14.4.12 get_edge_down() [1/2]	84
9.14.4.13 get_edge_down() [2/2]	84
9.14.4.14 get_edge_up() [1/2]	85
9.14.4.15 get_edge_up() [2/2]	85
9.14.4.16 get_level() [1/2]	86
9.14.4.17 get_level() [2/2]	86
9.14.4.18 get_level_id() [1/2]	86
9.14.4.19 get_level_id() [2/2]	87
9.14.4.20 get_name() [1/3]	87
9.14.4.21 get_name() [2/3]	87
9.14.4.22 get_name() [3/3]	88
9.14.4.23 get_simplex_down() [1/3]	88
9.14.4.24 get_simplex_down() [2/3]	89
9.14.4.25 get_simplex_down() [3/3]	89
9.14.4.26 get_simplex_up() [1/4]	90
9.14.4.27 get_simplex_up() [2/4]	90
9.14.4.28 get_simplex_up() [3/4]	90
9.14.4.29 get_simplex_up() [4/4]	91
9.14.4.30 insert() [1/4]	91
9.14.4.31 insert() [2/4]	92
9.14.4.32 insert() [3/4]	92
9.14.4.33 insert() [4/4]	92
9.14.4.34 leq()	93
9.14.4.35 lt()	93
9.14.4.36 nearBoundary()	94
9.14.4.37 onBoundary()	94
9.14.4.38 remove() [1/3]	95
9.14.4.39 remove() [2/3]	95
9.14.4.40 remove() [3/3]	96
9.14.4.41 size()	96
9.14.4.42 up() [1/3]	96
9.14.4.43 up() [2/3]	97
9.14.4.44 up() [3/3]	97
9.14.5 Friends And Related Function Documentation	98
9.14.5.1 EdgeID	98
9.14.5.2 SimplexID	98
9.15 util::type_get< k, T > Struct Template Reference	98
9.15.1 Detailed Description	98
9.16 util::type_get< 0, type_holder< Ts... > > Struct Template Reference	99

9.16.1 Detailed Description	99
9.17 util::type_get< k, type_holder< Ts... > > Struct Template Reference	99
9.17.1 Detailed Description	99
9.18 util::type_holder< Ts > Struct Template Reference	100
9.18.1 Detailed Description	100
9.19 util::type_holder< T, Ts... > Struct Template Reference	100
9.19.1 Detailed Description	101
9.20 util::type_map< C, V > Struct Template Reference	101
9.20.1 Detailed Description	101
9.21 util::type_swap< TUPLE, HOLDER_FULL > Struct Template Reference	102
9.21.1 Detailed Description	102
9.22 util::type_swap< TUPLE, HOLDER< Ts... > > Struct Template Reference	102
9.22.1 Detailed Description	102
10 File Documentation	105
10.1 include/casc/CASCFunctions.h File Reference	105
10.2 CASCFunctions.h	106
10.3 include/casc/CASCTraversals.h File Reference	111
10.4 CASCTraversals.h	113
10.5 include/casc/decimate.h File Reference	122
10.6 decimate.h	123
10.7 include/casc/index_tracker.h File Reference	130
10.8 index_tracker.h	132
10.9 include/casc/Orientable.h File Reference	143
10.10 Orientable.h	144
10.11 include/casc/SimplexMap.h File Reference	147
10.12 SimplexMap.h	148
10.13 include/casc/SimplexSet.h File Reference	150
10.14 SimplexSet.h	151
10.15 include/casc/SimplicialComplex.h File Reference	158
10.16 SimplicialComplex.h	160
10.17 include/casc/stringutil.h File Reference	192
10.18 stringutil.h	192
10.19 include/casc/typetraits.h File Reference	193
10.19.1 Detailed Description	193
10.19.2 Function Documentation	194
10.19.2.1 type_name()	194
10.20 typetraits.h	194
10.21 include/casc/util.h File Reference	195
10.22 util.h	196
Index	203

Chapter 1

Colored Abstract Simplicial Complex (CASC) Library

Master CI: Development CI:

CASC is a modern and header-only C++ library which provides a data structure to represent arbitrary dimension abstract simplicial complexes with user-defined classes stored directly on the simplices at each dimension. This is achieved by taking advantage of the combinatorial nature of simplicial complexes and new C++ code features such as: variadic templates and automatic function return type deduction. Essentially CASC stores the full topology of the complex according to a [Hasse diagram](#). The representation of the topology is decoupled from interactions of user data through the use of metatemplate programming.

1.1 Getting Started

These instructions will get you a copy of the project up and running on your local machine for development and testing purposes.

1.1.1 Prerequisites

CASC does not have any dependencies other than the C++ standard library. If you wish to use CASC, you can use the header files right away. There is no binary library to link to, and no configured header file. CASC is a pure template library defined in the headers.

We use the CMake build system (version 3+), but only to build the documentation and unit-tests, and to automate installation.

Doxygen and Graphviz is used to generate the documentation.

To use CASC in your software all you will need is a working C++ compiler with full C++14 support. This includes:

- GCC Versions 5+
- Clang Versions 3, 5+[†]
- XCode 8+[†]

[†] Note that there is a known issue with Clang 4.x.x versioned compilers (including XCode version 9.[0-2]), where the most specialized unique specialization is not selected leading to a compiler error. The current workaround to this problem is to either use GCC or to obtain Clang version 5+ (XCode version 9.3beta+).

1.1.2 Installing

CASC is header only meaning that there is nothing to compile out of the box. To use CASC, simply copy the desired headers into your project and included as necessary. If you wish to install CASC using CMake to your system, even though the library is header only, you must first create a new folder to prevent in-source "builds".

```
mkdir build
cd build
```

Subsequently run CMake specifying the installation prefix and the path to the root level CMakeLists.txt file.

```
cmake -DCMAKE_INSTALL_PREFIX=/usr/local/ ..
make install
```

Unit tests are also packaged along with CASC and are dependent upon [Googles C++ test framework](#). If you wish to build and run the tests, set the flag `-DBUILD_CASCTESTS=on` in your CMake command. CMake will then download and build `googletest` and link it with the CASC unit tests.

```
cmake -DBUILD_CASCTESTS=on ..
make
make tests          # Run tests through make
./bin/casctests     # Alternatively run the tests directly (more verbose)
```

Additional examples provided with CASC can be built in a similar fashion by passing the `-DBUILD_CASCEXAMPLES=on` flag to CMake.

1.1.3 Documentation

A current version of the documentation is available online via [github pages](#). You can also build the documentation locally if you have Doxygen and Graphviz on your system. CMake will automatically try to find a working Doxygen installation. If Doxygen is found then the documentation can be built using `make casc_doc`. Otherwise CMake will report that it could not find Doxygen.

1.2 Versioning & Contributing

We use [Github](#) for versioning. For the versions available, please see the [releases](#). If you find a bug or wish to request additional functionality please file an issue in the [CASC Github project](#).

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1.4 License

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1.5 Acknowledgments

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Chapter 2

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[This is the first released version of the Lesser GPL. It also counts as the successor of the GNU Library Public License, version 2, hence the version number 2.1.]

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If such an object file uses only numerical parameters, data structure layouts and accessors, and small macros and small inline functions (ten lines or less in length), then the use of the object file is unrestricted, regardless of whether it is legally a derivative work. (Executables containing this object code plus portions of the Library will still fall under Section 6.)

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```
one line to give the library's name and an idea of what it does.
Copyright (C) year  name of author
```

```
This library is free software; you can redistribute it and/or
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```

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```

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```
Yoyodyne, Inc., hereby disclaims all copyright interest in
the library 'Frob' (a library for tweaking knobs) written
by James Random Hacker.
```

```
signature of Ty Coon, 1 April 1990
Ty Coon, President of Vice
```

That's all there is to it!

Chapter 3

Building the documentation

The documentation for CASC can be generated locally using [Doxygen](#). You must have a working copy of doxygen installed on your machine in order to build the documentation.

If CMake is able to find your doxygen installation then the following sequence of commands will build the basic documentation.

```
cmake ..  
make casc_doc
```

3.0.1 Documentation for Developers

If you are contributing to or modifying the CASC library you may wish to document private class members or currently hidden metatemplate helper functions. Whether or not documentation for these items is generated can be controlled by modifying the default doxygen configuration: `doc/Doxyfile.in`.

To document private class functions and members toggle: `EXTRACT_PRIVATE = YES`

To enable metatemplate helper functions enable the conditional: `ENABLED_SECTIONS = detail`

Chapter 4

Frequently Asked Questions

1. Why is my simplex data not storing correctly?

If you are retrieving the data from the `SimplexID` using the dereference operator, you must retrieve the result as a reference in order to modify it. See the following example.

```
MeshType mesh = MeshType();
int key = mesh.insert({1}, 10);
auto data = *mesh.get_simplex_up({key});
data = 5;
std::cout << *mesh.get_simplex_up({key}); << std::endl // Prints 10

auto &dataRef = *mesh.get_simplex_up({key});
dataRef = 5;
std::cout << *mesh.get_simplex_up({key}) << std::endl // Prints 5
```


Chapter 5

Namespace Index

5.1 Namespace List

Here is a list of all documented namespaces with brief descriptions:

casc	Namespace for everything CASC	23
index_tracker	Index tracker namespace	42
index_tracker::index_tracker_detail	B-tree internal data structures	43
util	Metatemplate programming utilities namespace	44

Chapter 6

Data Structure Index

6.1 Data Structures

Here are the data structures with brief descriptions:

index_tracker::index_tracker_detail::BTreeNode< _T, _d >	
An array based BTree	49
casc::simplicial_complex< traits >::EdgeID< k >	
External reference to an edge or a connection within the complex	50
index_tracker::index_tracker< _T, _d >	
Tracker of available indices implemented as a B-tree of intervals	53
util::int_type_map< IntegerType, OutHolder, IntegerSequence, F >	
Maps an integer sequence and typename, F, into outholder	54
index_tracker::index_tracker_detail::Interval< T >	
Interval object represents a range	55
casc::Orientable	
Class representing the orientation	56
util::range< T >	
A range object to support range based for loops	56
util::remove_first_val< Integer, IntegerSequence >	
General template for removing the first value from a type holder	58
util::remove_first_val< Integer, InHolder< Integer, I, Is... > >	
Specialization for removing first integer from a sequence of compile time integers	59
util::reverse_sequence< Integer, IntegerSequence >	
Reverse an Integer Sequence	59
casc::simplicial_complex< traits >::SimplexID< k >	
A handle for a simplex object in the complex	60
casc::SimplexMap< Complex >	
A multimap to represent a map of simplex indices to a set of simplices	65
casc::SimplexSet< Complex >	
A multiset to store simplices in a simplicial_complex	68
casc::simplicial_complex< traits >	
The CASC data structure for representing simplicial complexes of arbitrary dimensionality with coloring	74
util::type_get< k, T >	
Helper to get the kth element from a type_holder	98
util::type_get< 0, type_holder< Ts... > >	
Specialization for terminal case	99
util::type_get< k, type_holder< Ts... > >	
Specialization to recursively pop types to get the kth type	99

util::type_holder< Ts >	
Queue based data structure to hold list of types	100
util::type_holder< T, Ts... >	
Partial specialization to allow FIFO access of typenames	100
util::type_map< C, V >	
Map the types in C into V<T>	101
util::type_swap< TUPLE, HOLDER_FULL >	
Move a list of types from one container to another	102
util::type_swap< TUPLE, HOLDER< Ts... > >	
Move a list of types from one container to another	102

Chapter 7

File Index

7.1 File List

Here is a list of all documented files with brief descriptions:

include/casc/CASCFunctions.h	
Contains various functions that operate on simplicial complexes	105
include/casc/CASCTraversals.h	
Implementations of various advanced traversals such as by neighborhood and breadth first search	111
include/casc/decimate.h	
Meta-data aware decimation functions	122
include/casc/index_tracker.h	
B-tree based interval tracker	130
include/casc/Orientable.h	
Data type for orientability	143
include/casc/SimplexMap.h	
SimplexMap data structure and associated convenience functions	147
include/casc/SimplexSet.h	
SimplexSet data structure and associated convenience functions	150
include/casc/SimplicialComplex.h	
This header contains the main CASC data structure and associated components	158
include/casc/stringutil.h	
String utilities for CASC	192
include/casc/typetraits.h	
Helper functions for debugging template types	193
include/casc/util.h	
Metatemplate pack expansion helpers	195

Chapter 8

Namespace Documentation

8.1 `casc` Namespace Reference

Namespace for everything CASC.

Data Structures

- struct [Orientable](#)
Class representing the orientation.
- struct [SimplexMap](#)
A multimap to represent a map of simplex indices to a set of simplices.
- struct [SimplexSet](#)
A multiset to store simplices in a [simplicial_complex](#).
- class [simplicial_complex](#)
The CASC data structure for representing simplicial complexes of arbitrary dimensionality with coloring.

Typedefs

- template<typename KeyType , typename ... Ts>
using [AbstractSimplicialComplex](#) = [simplicial_complex](#)< detail::simplicial_complex_traits_default< KeyType, Ts... > >
- template<typename T >
using **NodeSet** = std::unordered_set< T, simplex_set_detail::hashSimplexID< T > >
Helpful alias defining a `unordered_set` of simplices. See also `hashSimplexID`.

Functions

- template<typename Complex >
void [getStar](#) (Complex &F, [casc::SimplexSet](#)< Complex > &S, [casc::SimplexSet](#)< Complex > &dest)
Gets the star of a [SimplexSet](#).
- template<typename Complex , typename Simplex >
void [getStar](#) (Complex &F, Simplex &s, [casc::SimplexSet](#)< Complex > &dest)
Gets the star of a simplex.

- `template<typename Complex >`
`void getClosure (Complex &F, casc::SimplexSet< Complex > &S, casc::SimplexSet< Complex > &dest)`
Gets the closure of a simplex set.
- `template<typename Complex , typename Simplex >`
`void getClosure (Complex &F, Simplex &s, casc::SimplexSet< Complex > &dest)`
Compute the closure of a simplex.
- `template<typename Complex >`
`void getLink (Complex &F, casc::SimplexSet< Complex > &S, casc::SimplexSet< Complex > &dest)`
Gets the link of a [SimplexSet](#).
- `template<typename Complex , typename Simplex >`
`void getLink (Complex &F, Simplex &s, casc::SimplexSet< Complex > &dest)`
Gets the link of a simplex.
- `template<typename Complex >`
`void writeDOT (const std::string &filename, Complex &F)`
Writes out the topology of an ASC into the dot format.
- `template<typename Visitor , typename SimplexID >`
`void visit\_BFS\_up (Visitor &&v, typename SimplexID::complex &F, SimplexID s)`
Traverse BFS up the complex and apply a visitor function to each simplex visited.
- `template<typename Visitor , typename SimplexID >`
`void visit\_BFS\_down (Visitor &&v, typename SimplexID::complex &F, SimplexID s)`
Traverse BFS down the complex and apply a visitor function to each simplex visited.
- `template<typename Visitor , typename EdgeID >`
`void edge\_up (Visitor &&v, typename EdgeID::complex &F, EdgeID s)`
Traverse across edges BFS.
- `template<class Complex , std::size_t level, class InsertIter >`
`void neighbors (Complex &F, typename Complex::template SimplexID< level > nid, InsertIter iter)`
Push the immediate face neighbors into the provided iterator.
- `template<class Complex , class SimplexID , class InsertIter >`
`void neighbors (Complex &F, SimplexID nid, InsertIter iter)`
This is a helper function to assist neighbors to automatically deduce the integral level.
- `template<class Complex , std::size_t level, class InsertIter >`
`void neighbors\_up (Complex &F, typename Complex::template SimplexID< level > nid, InsertIter iter)`
Push the immediate coface neighbors into the provided iterator.
- `template<class Complex , class SimplexID , class InsertIter >`
`void neighbors\_up (Complex &F, SimplexID nid, InsertIter iter)`
This is a helper function to assist neighbors to automatically deduce the integral level.
- `template<class Complex , std::size_t level, typename Iterator >`
`void kneighbors\_up (Complex &F, int ring, std::set< typename Complex::template SimplexID< level > > &nbrs, Iterator begin, Iterator end)`
Code for returning a set of k-ring neighbors.
- `template<class Complex , class SimplexID >`
`void kneighbors\_up (Complex &F, SimplexID nid, int ring, std::set< SimplexID > &nbrs)`
Helper function to help [kneighbors_up](#) to deduce the integral level of SimplexID.
- `template<class Complex , std::size_t level, typename Iterator >`
`void kneighbors (Complex &F, int ring, std::set< typename Complex::template SimplexID< level > > &nbrs, Iterator begin, Iterator end)`
Code for returning a set of k-ring neighbors.
- `template<class Complex , class SimplexID >`
`void kneighbors (Complex &F, SimplexID nid, int ring, std::set< SimplexID > &nbrs)`
Helper function to help [kneighbors](#) to deduce the integral level of SimplexID.
- `template<typename Complex >`
`void perform\_removal (Complex &F, casc::SimplexSet< Complex > &S)`
Remove simplex in [SimplexSet](#) S from complex F.

- template<typename Complex >
void [perform_insertion](#) (Complex &F, typename decimation_detail::SimplexDataSet< Complex >::type &S)
Insert all simplices in [SimplexSet](#) S into complex F
- template<typename Complex , template< typename > class Callback>
void [run_user_callback](#) (Complex &F, [casc::SimplexMap](#)< Complex > &S, Callback< Complex > &&clbk, typename decimation_detail::SimplexDataSet< Complex >::type &rv)
Run the user specified callback function.
- template<typename Complex , typename Simplex , template< typename > class Callback>
void [decimate](#) (Complex &F, Simplex s, Callback< Complex > &&clbk)
Decimate a simplex of any dimension while considering any meta-data stores on decimated simplices.
- template<typename Complex , typename Simplex >
Complex::KeyType [decimateFirstHalf](#) (Complex &F, Simplex s, [SimplexMap](#)< Complex > &simplexMap)
Given a simplex to decimate generate a pre-post mapping.
- template<typename Complex >
void [decimateBackHalf](#) (Complex &F, [SimplexMap](#)< Complex > &simplexMap, typename decimation_detail::SimplexDataSet< Complex >::type &rv)
Given a simplexMap and mapped resulting data execute the decimation.
- template<typename Complex >
void [init_orientation](#) (Complex &F)
Initialize the partial ordering of the simplex edges.
- template<typename Complex >
void [clear_orientation](#) (Complex &F)
Clear the orientation of the facets.
- template<typename Complex >
std::tuple< int, bool, bool > [compute_orientation](#) (Complex &F)
Initializes and calculates the orientation of a [simplicial_complex](#).
- template<typename Complex >
std::tuple< int, bool, bool > [check_orientation](#) (Complex &F)
Checks for self consistent orientation and fill in missing orientations.
- template<std::size_t k, typename Complex >
static auto & [get](#) ([SimplexMap](#)< Complex > &S)
Get the map for a simplex dimension.
- template<std::size_t k, typename Complex >
static auto & [get](#) (const [SimplexMap](#)< Complex > &S)
This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.
- template<std::size_t k, typename Complex >
static auto & [get](#) ([SimplexSet](#)< Complex > &S)
Get the NodeSet for a simplex dimension from a [SimplexSet](#).
- template<std::size_t k, typename Complex >
static auto & [get](#) (const [SimplexSet](#)< Complex > &S)
- template<typename Complex >
bool [operator==](#) (const [SimplexSet](#)< Complex > &lhs, const [SimplexSet](#)< Complex > &rhs)
Compare if the sets are equivalent.
- template<typename Complex >
bool [operator!=](#) (const [SimplexSet](#)< Complex > &lhs, const [SimplexSet](#)< Complex > &rhs)
Compare if the sets are not equivalent.
- template<typename Complex >
static void [set_union](#) (const [SimplexSet](#)< Complex > &A, const [SimplexSet](#)< Complex > &B, [SimplexSet](#)< Complex > &dest)
Compute the set union.
- template<typename Complex >
static void [set_intersection](#) (const [SimplexSet](#)< Complex > &A, const [SimplexSet](#)< Complex > &B, [SimplexSet](#)< Complex > &dest)

Compute the set intersection.

- `template<typename Complex >`
`static void set_difference (const SimplexSet< Complex > &A, const SimplexSet< Complex > &B,`
`SimplexSet< Complex > &dest)`

Compute the set difference.

- `template<typename T, std::size_t k>`
`std::string to_string (const std::array< T, k > &A)`

Returns a string representation of the vertex subsimplicies of a given simplex.

8.1.1 Typedef Documentation

8.1.1.1 AbstractSimplicialComplex

```
template<typename KeyType, typename ... Ts>
using casc::AbstractSimplicialComplex = typedef simplicial_complex< detail::simplicial_↵
complex_traits_default<KeyType, Ts...> >
```

Alias to generate a CASC from a list of traits. See also `simplicial_complex_traits_default`. Example – To create a tetrahedral mesh with integer data on all simplices:

```
auto mesh = AbstractSimplicialComplex<
    int, // KEYTYPE
    int, // Root data
    int, // Vertex data
    int, // Edge data
    int, // Face data
    int  // Volume data
>();
```

8.1.2 Function Documentation

8.1.2.1 check_orientation()

```
template<typename Complex >
std::tuple< int, bool, bool > casc::check_orientation (
    Complex & F )
```

Parameters

<i>F</i>	Simplicial_complex
----------	--------------------

Template Parameters

<i>Complex</i>	Typename of the <code>simplicial_complex</code> .
----------------	---

Returns

A tuple of the number of connected components, where the complex is orientable, and if it is psuedo manifold.

8.1.2.2 clear_orientation()

```
template<typename Complex >
void casc::clear_orientation (
    Complex & F )
```

Parameters

<i>F</i>	Simplicial complex of interest
----------	--------------------------------

Template Parameters

<i>Complex</i>	Typename of the simplicial complex
----------------	------------------------------------

8.1.2.3 compute_orientation()

```
template<typename Complex >
std::tuple< int, bool, bool > casc::compute_orientation (
    Complex & F )
```

Parameters

<i>F</i>	Simplicial_complex
----------	--------------------

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

Returns

A tuple of the number of connected components, where the complex is orientable, and if it is psuedo manifold.

8.1.2.4 decimate()

```
template<typename Complex , typename Simplex , template< typename > class Callback>
void casc::decimate (
    Complex & F,
    Simplex s,
    Callback< Complex > && clbk )
```

Parameters

in	<i>F</i>	simplicial_complex to operate on.
in	<i>s</i>	Simplex to decimate.
in	<i>clbk</i>	Callback function to map meta-data

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex
<i>Simplex</i>	Typename of the simplex
<i>Callback</i>	Typename of the template template callback functor

Alias for [SimplexSet](#)

Alias for [SimplexMap](#)

8.1.2.5 `decimateBackHalf()`

```
template<typename Complex >
void casc::decimateBackHalf (
    Complex & F,
    SimplexMap< Complex > & simplexMap,
    typename decimation_detail::SimplexDataSet< Complex >::type & rv )
```

Parameters

<i>F</i>	Simplicial complex to operate on
<i>simplexMap</i>	SimplexMap mapping simplices before and after decimation
<i>rv</i>	Resulting data for each simplex

Template Parameters

<i>Complex</i>	Typename of the complex of interest
----------------	-------------------------------------

8.1.2.6 `decimateFirstHalf()`

```
template<typename Complex , typename Simplex >
Complex::KeyType casc::decimateFirstHalf (
    Complex & F,
    Simplex s,
    SimplexMap< Complex > & simplexMap )
```

Parameters

in	<i>F</i>	simplicial_complex to operate on.
in	<i>s</i>	Simplex to decimate.
	<i>simplexMap</i>	The simplex map to populate

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex
<i>Simplex</i>	Typename of the simplex

Alias for [SimplexSet](#)

8.1.2.7 edge_up()

```
template<typename Visitor , typename EdgeID >
void casc::edge_up (
    Visitor && v,
    typename EdgeID::complex & F,
    EdgeID s )
```

Parameters

in	<i>v</i>	Visitor functor to apply.
	<i>F</i>	The simplicial_complex to traverse.
in	<i>s</i>	The edge to start at.

Template Parameters

<i>Visitor</i>	Typename of the functor.
<i>EdgeID</i>	Typename of the edge.

8.1.2.8 get() [1/3]

```
template<std::size_t k, typename Complex >
static auto & casc::get (
    const SimplexSet< Complex > & S ) [inline], [static]
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

8.1.2.9 get() [2/3]

```
template<std::size_t k, typename Complex >
static auto & casc::get (
    SimplexMap< Complex > & S ) [inline], [static]
```

Parameters

S	SimplexMap to retrieve from.
---	--

Template Parameters

k	Simplex dimension.
<i>Complex</i>	Typename of the complex.

Returns

Returns a map of `std::Array<KeyType, k>` to [SimplexSet](#).

8.1.2.10 `get()` [3/3]

```
template<std::size_t k, typename Complex >
static auto & casc::get (
    SimplexSet< Complex > & S ) [inline], [static]
```

Parameters

S	SimplexSet of interest.
-----	---

Template Parameters

k	Simplex dimension desired.
<i>Complex</i>	Typename of the simplicial_complex .

Returns

A NodeSet which holds simplices of dimension 'k' and a member of [SimplexSet](#) 'S'.

8.1.2.11 `getClosure()` [1/2]

```
template<typename Complex >
void casc::getClosure (
    Complex & F,
    casc::SimplexSet< Complex > & S,
    casc::SimplexSet< Complex > & dest )
```

Parameters

in	F	Complex of interest.
in	S	SimplexSet to compute the closure of.
out	<i>dest</i>	Destination SimplexSet

Template Parameters

<i>Complex</i>	Typename of the complex.
----------------	--------------------------

8.1.2.12 `getClosure()` [2/2]

```
template<typename Complex , typename Simplex >
void casc::getClosure (
    Complex & F,
    Simplex & s,
    casc::SimplexSet< Complex > & dest )
```

Parameters

in	<i>F</i>	Complex of interest.
in	<i>s</i>	Simplex of interest.
out	<i>dest</i>	Destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the complex.
<i>Simplex</i>	Typename of the simplex.

8.1.2.13 `getLink()` [1/2]

```
template<typename Complex >
void casc::getLink (
    Complex & F,
    casc::SimplexSet< Complex > & S,
    casc::SimplexSet< Complex > & dest )
```

Parameters

in	<i>F</i>	Complex of interest.
in	<i>S</i>	SimplexSet to get the link of.
out	<i>dest</i>	Destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the complex.
----------------	--------------------------

8.1.2.14 getLink() [2/2]

```
template<typename Complex , typename Simplex >
void casc::getLink (
    Complex & F,
    Simplex & s,
    casc::SimplexSet< Complex > & dest )
```

Parameters

<i>F</i>	Complex of interest.
<i>s</i>	Simplex of interest.
<i>dest</i>	Destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the complex.
<i>Simplex</i>	Typename of the simplex.

8.1.2.15 getStar() [1/2]

```
template<typename Complex >
void casc::getStar (
    Complex & F,
    casc::SimplexSet< Complex > & S,
    casc::SimplexSet< Complex > & dest )
```

Parameters

in	<i>F</i>	Complex of interest.
in	<i>S</i>	SimplexSet to compute the star of.
out	<i>dest</i>	Destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the complex.
----------------	--------------------------

8.1.2.16 getStar() [2/2]

```
template<typename Complex , typename Simplex >
void casc::getStar (
    Complex & F,
    Simplex & s,
    casc::SimplexSet< Complex > & dest )
```

Parameters

in	<i>F</i>	Complex of interest.
	<i>s</i>	Simplex to get the star of.
out	<i>dest</i>	Destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the complex.
<i>Simplex</i>	Typename of the simplex.

8.1.2.17 init_orientation()

```
template<typename Complex >
void casc::init_orientation (
    Complex & F )
```

Parameters

<i>F</i>	Simplicial complex of interest
----------	--------------------------------

Template Parameters

<i>Complex</i>	Typename of the simplicial complex
----------------	------------------------------------

8.1.2.18 kneighbors() [1/2]

```
template<class Complex , std::size_t level, typename Iterator >
void casc::kneighbors (
    Complex & F,
    int ring,
    std::set< typename Complex::template SimplexID< level > > & nbors,
    Iterator begin,
    Iterator end )
```

Parameters

in	<i>F</i>	The simplicial_complex to traverse.
in	<i>ring</i>	The number of rings of neighbors to collect.
out	<i>nbors</i>	Set of previously seen simplices.
in	<i>begin</i>	The begin
in	<i>end</i>	The end

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
<i>level</i>	Simplex dimension of the simplex and neighbors.
<i>Iterator</i>	{ description }

8.1.2.19 `kneighbors()` [2/2]

```
template<class Complex , class SimplexID >
void casc::kneighbors (
    Complex & F,
    SimplexID nid,
    int ring,
    std::set< SimplexID > & nbors )
```

Parameters

in	<i>F</i>	The simplicial complex
in	<i>nid</i>	Simplex of interest to get the nieghbors of.
in	<i>ring</i>	The number of rings to include as a neighbor.
out	<i>nbors</i>	Set of neighbors to populate.

Template Parameters

<i>Complex</i>	Typename of the complex.
<i>SimplexID</i>	Typename of the SimplexID.

8.1.2.20 `kneighbors_up()` [1/2]

```
template<class Complex , std::size_t level, typename Iterator >
void casc::kneighbors_up (
    Complex & F,
    int ring,
    std::set< typename Complex::template SimplexID< level > > & nbors,
    Iterator begin,
    Iterator end )
```

Parameters

in	<i>F</i>	The simplicial_complex to traverse.
in	<i>ring</i>	The number of rings of neighbors to collect.
out	<i>nbors</i>	Set of previously seen simplices.
in	<i>begin</i>	The begin
in	<i>end</i>	The end

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
<i>level</i>	Simplex dimension of the simplex and neighbors.
<i>Iterator</i>	{ description }

8.1.2.21 kneighbors_up() [2/2]

```
template<class Complex , class SimplexID >
void casc::kneighbors_up (
    Complex & F,
    SimplexID nid,
    int ring,
    std::set< SimplexID > & nbors )
```

Parameters

in	<i>F</i>	The simplicial complex
in	<i>nid</i>	Simplex of interest to get the neighbors of.
in	<i>ring</i>	The number of rings to include as a neighbor.
out	<i>nbors</i>	Set of neighbors to populate.

Template Parameters

<i>Complex</i>	Typename of the complex.
<i>SimplexID</i>	Typename of the SimplexID.

8.1.2.22 neighbors() [1/2]

```
template<class Complex , class SimplexID , class InsertIter >
void casc::neighbors (
    Complex & F,
    SimplexID nid,
    InsertIter iter )
```

Parameters

	<i>F</i>	The simplicial complex.
in	<i>nid</i>	Simplex to get neighbors of.
in	<i>iter</i>	The iterator to push members into.

Template Parameters

<i>Complex</i>	Type of the simplicial complex
----------------	--------------------------------

Template Parameters

<i>level</i>	The integral level of the node
<i>InsertIter</i>	Typename of the iterator.

8.1.2.23 neighbors() [2/2]

```
template<class Complex , std::size_t level, class InsertIter >
void casc::neighbors (
    Complex & F,
    typename Complex::template SimplexID< level > nid,
    InsertIter iter )
```

This function gets the set of neighbors which share a common face. We compute this by traversing to all faces of the simplex of interest. Then we get all cofaces of this set. Depending on the type of iterator passed, duplicate simplices will be included or excluded. Note that this is the traditional definition of neighbor. For example, faces which share an edge are neighbors.

Parameters

	<i>F</i>	The simplicial complex
in	<i>nid</i>	Simplex to get neighbors of.
in	<i>iter</i>	The iterator to push members into.

Template Parameters

<i>Complex</i>	Type of the simplicial complex
<i>level</i>	The integral level of the node
<i>InsertIter</i>	Typename of the iterator.

8.1.2.24 neighbors_up() [1/2]

```
template<class Complex , class SimplexID , class InsertIter >
void casc::neighbors_up (
    Complex & F,
    SimplexID nid,
    InsertIter iter )
```

Parameters

	<i>F</i>	The simplicial complex.
in	<i>nid</i>	Simplex to get neighbors of.
in	<i>iter</i>	The iterator to push members into.

Template Parameters

<i>Complex</i>	Type of the simplicial complex
<i>level</i>	The integral level of the node
<i>InsertIter</i>	Typename of the iterator.

8.1.2.25 neighbors_up() [2/2]

```
template<class Complex , std::size_t level, class InsertIter >
void casc::neighbors_up (
    Complex & F,
    typename Complex::template SimplexID< level > nid,
    InsertIter iter )
```

Parameters

	<i>F</i>	The simplicial complex.
in	<i>nid</i>	Simplex to get neighbors of.
in	<i>iter</i>	The iterator to push members into.

Template Parameters

<i>Complex</i>	Type of the simplicial complex
<i>level</i>	The integral level of the node
<i>InsertIter</i>	Typename of the iterator.

8.1.2.26 operator"!="()

```
template<typename Complex >
bool casc::operator!= (
    const SimplexSet< Complex > & lhs,
    const SimplexSet< Complex > & rhs )
```

Parameters

in	<i>lhs</i>	The left hand side
in	<i>rhs</i>	The right hand side

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

Returns

True if the sets are inequal, false otherwise.

8.1.2.27 operator==()

```
template<typename Complex >
bool casc::operator== (
    const SimplexSet< Complex > & lhs,
    const SimplexSet< Complex > & rhs )
```

Parameters

in	<i>lhs</i>	The left hand side
in	<i>rhs</i>	The right hand side

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex
----------------	--

Returns

True if the sets are equal, false otherwise.

8.1.2.28 perform_insertion()

```
template<typename Complex >
void casc::perform_insertion (
    Complex & F,
    typename decimation_detail::SimplexDataSet< Complex >::type & S )
```

Parameters

<i>F</i>	The simplicial_complex to insert into.
<i>S</i>	SimplexSet of simplices to insert.

Template Parameters

<i>Complex</i>	Typename of complex
----------------	---------------------

8.1.2.29 perform_removal()

```
template<typename Complex >
void casc::perform_removal (
    Complex & F,
    casc::SimplexSet< Complex > & S )
```

Parameters

<i>F</i>	The simplicial_complex to remove from.
<i>S</i>	SimplexSet of simplices to remove.

Template Parameters

<i>Complex</i>	Typename of complex
----------------	---------------------

8.1.2.30 run_user_callback()

```
template<typename Complex , template< typename > class Callback>
void casc::run_user_callback (
    Complex & F,
    casc::SimplexMap< Complex > & S,
    Callback< Complex > && clbk,
    typename decimation_detail::SimplexDataSet< Complex >::type & rv )
```

Parameters

in	<i>F</i>	The simplicial_complex
in	<i>S</i>	SimplexMap of
in	<i>clbk</i>	User specified callback functor
out	<i>rv</i>	Multi-vector to place results.

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex
<i>Callback</i>	Typename of the template template callback functor

8.1.2.31 set_difference()

```
template<typename Complex >
static void casc::set_difference (
    const SimplexSet< Complex > & A,
    const SimplexSet< Complex > & B,
    SimplexSet< Complex > & dest ) [static]
```

Parameters

in	<i>A</i>	A SimplexSet
in	<i>B</i>	Another SimplexSet
out	<i>dest</i>	The destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

8.1.2.32 `set_intersection()`

```
template<typename Complex >
static void casc::set_intersection (
    const SimplexSet< Complex > & A,
    const SimplexSet< Complex > & B,
    SimplexSet< Complex > & dest ) [static]
```

Parameters

in	<i>A</i>	A SimplexSet
in	<i>B</i>	Another SimplexSet
out	<i>dest</i>	The destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

8.1.2.33 `set_union()`

```
template<typename Complex >
static void casc::set_union (
    const SimplexSet< Complex > & A,
    const SimplexSet< Complex > & B,
    SimplexSet< Complex > & dest ) [static]
```

Parameters

in	<i>A</i>	A SimplexSet
in	<i>B</i>	Another SimplexSet
out	<i>dest</i>	The destination SimplexSet .

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

8.1.2.34 to_string()

```
template<typename T , std::size_t k>
std::string casc::to_string (
    const std::array< T, k > & A )
```

Parameters

in	<i>A</i>	Array containing name of a simplex.
----	----------	-------------------------------------

Template Parameters

<i>T</i>	Typename KeyType.
<i>k</i>	Dimension of the simplex.

Returns

String representation of the object.

8.1.2.35 visit_BFS_down()

```
template<typename Visitor , typename SimplexID >
void casc::visit_BFS_down (
    Visitor && v,
    typename SimplexID::complex & F,
    SimplexID s )
```

Parameters

in	<i>v</i>	Visitor functor to apply.
	<i>F</i>	The simplicial_complex to traverse.
in	<i>s</i>	The simplex to start at.

Template Parameters

<i>Visitor</i>	Typename of the functor.
<i>SimplexID</i>	Typename of the simplex.

8.1.2.36 visit_BFS_up()

```
template<typename Visitor , typename SimplexID >
void casc::visit_BFS_up (
    Visitor && v,
    typename SimplexID::complex & F,
    SimplexID s )
```

Parameters

in	<i>v</i>	Visitor functor to apply.
	<i>F</i>	The simplicial_complex to traverse.
in	<i>s</i>	The simplex to start at.

Template Parameters

<i>Visitor</i>	Typename of the functor.
<i>SimplexID</i>	Typename of the simplex.

8.1.2.37 writeDOT()

```
template<typename Complex >
void casc::writeDOT (
    const std::string & filename,
    Complex & F )
```

The resulting dot file can be rendered into an image using tools such as GraphViz.

```
dot -Tpng input.dot > output.png
```

Parameters

in	<i>filename</i>	Filename to write out to.
in	<i>F</i>	Simplicial complex to generate the DOT of.

Template Parameters

<i>Complex</i>	Typename of the simplicial complex.
----------------	-------------------------------------

8.2 index_tracker Namespace Reference

Index tracker namespace.

Namespaces

- namespace [index_tracker_detail](#)
B-tree internal data structures.

Data Structures

- class [index_tracker](#)
Tracker of available indices implemented as a B-tree of intervals.

Functions

- template<typename T, std::size_t d>
std::ostream & **operator**<< (std::ostream &out, const [index_tracker_detail::BTreeNode](#)< T, d > *head)

8.3 index_tracker::index_tracker_detail Namespace Reference

B-tree internal data structures.

Data Structures

- struct [BTreeNode](#)
An array based BTree.
- struct [Interval](#)
Interval object represents a range.

Typedefs

- template<typename Node >
using **Pointer** = typename Node::Pointer
- template<typename Node >
using **Data** = typename Node::Data
- template<typename Node >
using **Scalar** = typename Node::Scalar

Functions

- template<typename T >
bool **operator**< (const [Interval](#)< T > &x, const [Interval](#)< T > &y)
- template<typename T >
bool **operator**> (const [Interval](#)< T > &x, const [Interval](#)< T > &y)
- template<typename T >
bool **operator**< (T x, const [Interval](#)< T > &y)
- template<typename T >
bool **operator**> (const [Interval](#)< T > &x, T y)
- template<typename T >
bool **operator**< (const [Interval](#)< T > &x, T y)
- template<typename T >
bool **operator**> (T x, const [Interval](#)< T > &y)
- template<typename T >
bool **operator**== (const [Interval](#)< T > &x, const [Interval](#)< T > &y)
- template<typename T >
std::ostream & **operator**<< (std::ostream &out, const [Interval](#)< T > &x)

- `template<typename T >`
`int merge (Interval< T > &A, T x)`
- `template<typename Node >`
`void rebalance (Pointer< Node > head, std::size_t i)`
- `template<typename Node >`
`void insert_H (Pointer< Node > head, const Data< Node > &data)`
- `template<typename Node >`
`Pointer< Node > insert (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`bool get (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`void get_replacement (Pointer< Node > head, Data< Node > &key)`
- `template<typename Node >`
`void remove_H (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`Pointer< Node > remove (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`void fill_left (Pointer< Node > head, Data< Node > &x)`
- `template<typename Node >`
`void fill_right (Pointer< Node > head, Data< Node > &x)`
- `template<typename Node >`
`void insert_scalar_H (Pointer< Node > head, Scalar< Node > data)`
- `template<typename Node >`
`Pointer< Node > insert_scalar (Pointer< Node > head, Scalar< Node > data)`
- `template<typename Node >`
`void insert_left (Pointer< Node > head, const Data< Node > &x)`
- `template<typename Node >`
`bool remove_scalar_H (Pointer< Node > head, Scalar< Node > x)`
- `template<typename Node >`
`bool remove_scalar (Pointer< Node > &head, Scalar< Node > data)`
- `template<typename Node >`
`Scalar< Node > pop_scalar (Pointer< Node > &head)`
- `template<typename Node >`
`void destruct (Pointer< Node > head)`
- `template<typename Node >`
`Data< Node > check_order (Pointer< Node > head, Data< Node > curr)`

8.4 util Namespace Reference

Metatemplate programming utilities namespace.

Data Structures

- struct [int_type_map](#)
Maps an integer sequence and typename, F, into outholder.
- struct [range](#)
A range object to support range based for loops.
- struct [remove_first_val](#)
General template for removing the first value from a type holder.
- struct [remove_first_val](#)< [Integer](#), [InHolder](#)< [Integer](#), I, Is... > >
Specialization for removing first integer from a sequence of compile time integers.
- struct [reverse_sequence](#)

- Reverse an Integer Sequence.*

 - struct [type_get](#)

Helper to get the kth element from a [type_holder](#).
- struct [type_get](#)< 0, [type_holder](#)< Ts... > >

Specialization for terminal case.
- struct [type_get](#)< k, [type_holder](#)< Ts... > >

Specialization to recursively pop types to get the kth type.
- struct [type_holder](#)

Queue based data structure to hold list of types.
- struct [type_holder](#)< T, Ts... >

Partial specialization to allow FIFO access of typenames.
- struct [type_map](#)

Map the types in C into $V<T>$.
- struct [type_swap](#)

Move a list of types from one container to another.
- struct [type_swap](#)< [TUPLE](#), [HOLDER](#)< Ts... > >

Move a list of types from one container to another.

Functions

- template<typename T >
[range](#)< T > [make_range](#) (T b, T e)

Make a range object.
- template<typename T >
[range](#)< T > [make_range](#) (std::pair< T, T > p)

Makes a range object.
- template<class Integer , typename IntegerSequence , typename Fn , typename ... Args>
void [int_for_each](#) (Fn &&f, Args &&... args)

Calls a function $f.apply<k>()$ for a sequence of integer k's.

8.4.1 Function Documentation

8.4.1.1 int_for_each()

```
template<class Integer , typename IntegerSequence , typename Fn , typename ... Args>
void util::int_for_each (
    Fn && f,
    Args &&... args )
```

Parameters

in	<i>args</i>	Arguments to f
in	<i>f</i>	Functor with <code>apply<k>()</code> method

Template Parameters

<i>Integer</i>	Integer type
<i>IntegerSequence</i>	Sequence of integers to iterate
<i>Fn</i>	Typename of functor f
<i>Args</i>	Typenames of the arguments

8.4.1.2 `make_range()` [1/2]

```
template<typename T >
range< T > util::make_range (
    std::pair< T, T > p )
```

Parameters

in	<i>p</i>	A pair containing begin and end iterators.
----	----------	--

Template Parameters

<i>T</i>	Typename of the iterator.
----------	---------------------------

Returns

Returns a range of the iterators.

8.4.1.3 `make_range()` [2/2]

```
template<typename T >
range< T > util::make_range (
    T b,
    T e )
```

Parameters

in	<i>b</i>	Iterator to the beginning.
in	<i>e</i>	Iterator to the end.

Template Parameters

<i>T</i>	Typename of the iterator.
----------	---------------------------

Returns

Returns a range of the iterators.

Chapter 9

Data Structure Documentation

9.1 `index_tracker::index_tracker_detail::BTreeNode<_T,_d>` Struct Template Reference

An array based BTree.

```
#include <index_tracker.h>
```

Public Types

- using **Scalar** = `_T`
- using **Data** = `Interval< Scalar >`
- using **Pointer** = `BTreeNode *`

Public Member Functions

- **BTreeNode** (const `Data` &t)
- `template<typename Iter >`
BTreeNode (Iter begin, Iter end)

Data Fields

- `std::size_t k`
- `std::array< Data, N > data`
- `std::array< Pointer, N+1 > next`

Static Public Attributes

- `static constexpr std::size_t d = _d`
- `static constexpr std::size_t N = 2*d+1`

9.1.1 Detailed Description

```
template<typename _T, std::size_t _d>
struct index_tracker::index_tracker_detail::BTreeNode<_T,_d>
```

Template Parameters

$\overleftarrow{\quad}$	{ description }
$\overleftarrow{\quad}$ $\overline{\quad}$ T	
$\overleftarrow{\quad}$	{ description }
$\overleftarrow{\quad}$ $\overline{\quad}$ d	

The documentation for this struct was generated from the following file:

- include/casc/[index_tracker.h](#)

9.2 `casc::simplicial_complex< traits >::EdgeID< k >` Struct Template Reference

External reference to an edge or a connection within the complex.

```
#include <SimplicialComplex.h>
```

Public Types

- using **complex** = [simplicial_complex](#)< traits >
Typename of the complex.

Public Member Functions

- **EdgeID** ()
Default constructor wraps a nullptr and dummy edge.
- **EdgeID** (NodePtr< k > p, [KeyType](#) e)
Constructor to wrap an Edge.
- **EdgeID** (const [EdgeID](#) &rhs)
Copy constructor.
- **EdgeID** & **operator=** (const [EdgeID](#) &rhs)
Assignment operator.
- auto const & **operator*** () const
Dereferencing an [EdgeID](#) gets the data on the edge.
- auto & **operator*** ()
Dereferencing an [EdgeID](#) gets the data on the edge.
- [KeyType](#) **key** () const
Get the key of the edge.
- auto const & **data** () const
Return the data stored on the edge.
- auto & **data** ()
Return the data stored on the edge.
- [SimplexID](#)< k > **up** () const
Get the coboundary simplex.
- [SimplexID](#)< k-1 > **down** () const
Get the simplex below.

Data Fields

- friend `simplicial_complex< traits >`
`EdgeID` is a friend of the complex.

Static Public Attributes

- static constexpr `std::size_t level` = `k`
The dimension of the simplex which the edge points to.

Friends

- bool `operator==` (`EdgeID` lhs, `EdgeID` rhs)
Equality of wrapped pointers and edges.
- bool `operator!=` (`EdgeID` lhs, `EdgeID` rhs)
Compare wrapped pointers and edges.
- bool `operator<=` (`EdgeID` lhs, `EdgeID` rhs)
Compare wrapped pointers and edges.
- bool `operator>=` (`EdgeID` lhs, `EdgeID` rhs)
Compare wrapped pointers and edges.
- bool `operator<` (`EdgeID` lhs, `EdgeID` rhs)
Less than defines an ordering of key types on the edges.
- bool `operator>` (`EdgeID` lhs, `EdgeID` rhs)
Greater than comparison.

9.2.1 Detailed Description

```
template<typename traits>
template<std::size_t k>
struct casc::simplicial_complex< traits >::EdgeID< k >
```

Template Parameters

<code>k</code>	The edge connects a simplex of size <code>k-1</code> to a simplex of size <code>k</code> .
----------------	--

9.2.2 Constructor & Destructor Documentation

9.2.2.1 `EdgeID()` [1/2]

```
template<typename traits >
template<std::size_t k>
casc::simplicial_complex< traits >::EdgeID< k >::EdgeID (
    NodePtr< k > p,
    KeyType e ) [inline]
```

Parameters

in	p	Pointer to the next Node.
in	e	Key of the edge

9.2.2.2 EdgelD() [2/2]

```
template<typename traits >
template<std::size_t k>
casc::simplicial_complex< traits >::EdgeID< k >::EdgeID (
    const EdgeID< k > & rhs ) [inline]
```

Parameters

in	rhs	The right hand side
----	-------	---------------------

9.2.3 Member Function Documentation**9.2.3.1 down()**

```
template<typename traits >
template<std::size_t k>
SimplexID< k-1 > casc::simplicial_complex< traits >::EdgeID< k >::down ( ) const [inline]
```

Returns

[SimplexID](#) of the simplex below the edge.

9.2.3.2 up()

```
template<typename traits >
template<std::size_t k>
SimplexID< k > casc::simplicial_complex< traits >::EdgeID< k >::up ( ) const [inline]
```

Returns

[SimplexID](#) of the simplex above the edge.

The documentation for this struct was generated from the following file:

- [include/casc/SimplicialComplex.h](#)

9.3 index_tracker::index_tracker< _T, _d > Class Template Reference

Tracker of available indices implemented as a B-tree of intervals.

```
#include <index_tracker.h>
```

Public Types

- using **Node** = [index_tracker_detail::BTreeNode](#)< _T, _d >
Typedef of BTree Node.
- using **T** = _T

Public Member Functions

- [index_tracker](#) ()
Number of bins.
- void **insert** (T x)
- [index_tracker_detail::Scalar](#)< [Node](#) > **pop** ()
- void **remove** ([index_tracker_detail::Scalar](#)< [Node](#) > x)
- bool **empty** () const

Static Public Attributes

- static constexpr std::size_t **d** = _d
Typename of the type to store.

Friends

- std::ostream & **operator**<< (std::ostream &out, const [index_tracker](#) &x)

9.3.1 Detailed Description

```
template<typename _T, std::size_t _d = 16>
class index_tracker::index_tracker< _T, _d >
```

Template Parameters

$\leftrightarrow$ — T	Typename of the indices
$\leftrightarrow$ — d	Max number of interval bins = 2*value+1

9.3.2 Constructor & Destructor Documentation

9.3.2.1 index_tracker()

```
template<typename _T , std::size_t _d = 16>
index_tracker::index_tracker< _T, _d >::index_tracker ( ) [inline]
```

Initialize with interval [0~max)

The documentation for this class was generated from the following file:

- include/casc/[index_tracker.h](#)

9.4 util::int_type_map< IntegerType, OutHolder, IntegerSequence, F > Struct Template Reference

Maps an integer sequence and typename, F, into outholder.

```
#include <util.h>
```

Public Types

- using **type** = typename detail::int_type_map_helper< IntegerType, OutHolder, IntegerSequence, F >::type
Tuple of Out<F<0>, F<1>, F<2>, ...>.

9.4.1 Detailed Description

```
template<class IntegerType, template< class ... > class OutHolder, class IntegerSequence, template< IntegerType > class F>
struct util::int_type_map< IntegerType, OutHolder, IntegerSequence, F >
```

Given an Integer Sequence $I<0, 1, 2, 3, \dots>$ and template template type $F<I>$, this function produces $Out<F<0>, F<1>, F<2>, \dots>$.

Template Parameters

<i>IntegerType</i>	Typename of an integer type
<i>OutHolder</i>	Typename of a holder for types
<i>IntegerSequence</i>	Integral sequence of types
<i>F</i>	Typename of class to be broadcast with integer

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.5 `index_tracker::index_tracker_detail::Interval< T >` Struct Template Reference

`Interval` object represents a range.

```
#include <index_tracker.h>
```

Public Member Functions

- **Interval** ()
Default constructor.
- **Interval** (T a)
Construct an interval from a to a+1.
- **Interval** (T a, T b)
Construct an interval from a to b.
- **Interval** (const `Interval< T >` &rhs)
Copy constructor.
- `Interval` & **operator=** (const `Interval` &rhs)
Assignment operator overload.
- `bool` **has** (T x)
Is x in the bounds of the interval.
- T **lower** () const
Get the lower inclusive bound of the interval.
- T **upper** () const
Get the upper exclusive bound of the interval.
- T & **lower** ()
Get the lower inclusive bound of the interval.
- T & **upper** ()
Get the upper exclusive bound of the interval.
- `std::size_t` **size** ()
Get the size of the interval.

9.5.1 Detailed Description

```
template<typename T>
struct index_tracker::index_tracker_detail::Interval< T >
```

Template Parameters

<i>T</i>	Typename of the interval data
----------	-------------------------------

9.5.2 Member Function Documentation

9.5.2.1 operator=()

```
template<typename T >
Interval & index_tracker::index_tracker_detail::Interval< T >::operator= (
    const Interval< T > & rhs ) [inline]
```

Parameters

in	rhs	The right hand side
----	-----	---------------------

Returns

Reference to this

The documentation for this struct was generated from the following file:

- include/casc/[index_tracker.h](#)

9.6 casc::Orientable Struct Reference

Class representing the orientation.

```
#include <Orientable.h>
```

Data Fields

- int **orientation**
Integer representing +/- 1 orientation.

The documentation for this struct was generated from the following file:

- include/casc/[Orientable.h](#)

9.7 util::range< T > Struct Template Reference

A range object to support range based for loops.

```
#include <util.h>
```

Public Member Functions

- template<class C >
[range](#) (C &&c)
Construct a range for a container class.
- [range](#) (T b, T e)
Construct a range from an iterator.
- T [begin](#) ()
Get the beginning iterator.
- T [end](#) ()
Get the end iterator.

9.7.1 Detailed Description

```
template<typename T>
struct util::range< T >
```

This is a basic data structure which implements a `begin()` and `end()` functions for range based for looping added in C++11. See also `range-for`.

Template Parameters

<i>T</i>	Typename of the iterator
----------	--------------------------

9.7.2 Constructor & Destructor Documentation

9.7.2.1 range() [1/2]

```
template<typename T >
template<class C >
util::range< T >::range (
    C && c ) [inline]
```

Parameters

in	<i>c</i>	Container class which implements <code>begin()</code> and <code>end()</code> .
----	----------	--

Template Parameters

<i>C</i>	Typename of the container.
----------	----------------------------

9.7.2.2 range() [2/2]

```
template<typename T >
util::range< T >::range (
    T b,
    T e ) [inline]
```

Parameters

in	<i>b</i>	Beginning iterator
in	<i>e</i>	End iterator.

9.7.3 Member Function Documentation

9.7.3.1 begin()

```
template<typename T >
T util::range< T >::begin ( ) [inline]
```

Returns

Returns an iterator to the beginning.

9.7.3.2 end()

```
template<typename T >
T util::range< T >::end ( ) [inline]
```

Returns

Returns an iterator to the end.

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.8 util::remove_first_val< Integer, IntegerSequence > Struct Template Reference

General template for removing the first value from a type holder.

```
#include <util.h>
```

9.8.1 Detailed Description

```
template<class Integer, class IntegerSequence>
struct util::remove_first_val< Integer, IntegerSequence >
```

Template Parameters

<i>Integer</i>	Typename of integer.
<i>IntegerSequence</i>	Sequence of compile time integers.

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.9 util::remove_first_val< Integer, InHolder< Integer, I, Is... > > Struct Template Reference

Specialization for removing first integer from a sequence of compile time integers.

```
#include <util.h>
```

Public Types

- using **type** = InHolder< Integer, Is... >
Type holder with first value removed.

9.9.1 Detailed Description

```
template<class Integer, template< class, Integer... > class InHolder, Integer I, Integer... Is>
struct util::remove_first_val< Integer, InHolder< Integer, I, Is... > >
```

Template Parameters

<i>Integer</i>	Typename of integer type.
<i>InHolder</i>	Type holder of integer sequence.
<i>I</i>	The first integer
<i>Is</i>	Remaining integers

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.10 util::reverse_sequence< Integer, IntegerSequence > Struct Template Reference

Reverse an Integer Sequence.

```
#include <util.h>
```

Public Types

- using **type** = typename detail::reverse_sequence_helper< Integer, IntegerSequence >::type
Reversed sequence of types.

9.10.1 Detailed Description

```
template<class Integer, class IntegerSequence>
struct util::reverse_sequence< Integer, IntegerSequence >
```

Template Parameters

<i>Integer</i>	Typename of an integer class.
<i>IntegerSequence</i>	Sequence of compile-time integers.

The documentation for this struct was generated from the following file:

- [include/casc/util.h](#)

9.11 `casc::simplicial_complex< traits >::SimplexID< k >` Struct Template Reference

A handle for a simplex object in the complex.

```
#include <SimplicialComplex.h>
```

Public Types

- using **complex** = [simplicial_complex](#)< traits >
Typename of the complex.

Public Member Functions

- **SimplexID** ()
Default constructor wraps a nullptr.
- **SimplexID** (NodePtr< k > p)
Constructor to wrap a NodePtr<k>.
- **SimplexID** (const **SimplexID** &rhs)
Copy constructor.
- **SimplexID** & **operator=** (const **SimplexID** &rhs)
Assignment operator.
- **operator std::uintptr_t** () const
Support casting to uintptr_t for hashing.
- **complex::NodeData**< k > const & **operator*** () const
Dereferencing a [SimplexID](#) returns the data stored.
- **complex::NodeData**< k > & **operator*** ()
Dereferencing a [SimplexID](#) returns the data stored.
- **complex::NodeData**< k > const & **data** () const
Get a handle to the stored data.
- **complex::NodeData**< k > & **data** ()
Get a handle to the stored data.

- `std::array< KeyType, k > indices () const`
Gets the name of a simplex as an std::Array.
- `template<class Inserter >`
`void cover_insert (Inserter pos) const`
Insert the coboundary keys of a simple into an inserter.
- `std::vector< KeyType > cover () const`
Get the coboundary keys of a simplex.
- `template<std::size_t j>`
`SimplexID< k+j > get_simplex_up (const KeyType(&s)[j]) const`
Get a coboundary simplex.
- `template<std::size_t j>`
`SimplexID< k+j > get_simplex_up (const std::array< KeyType, j > &arr) const`
Get a coboundary simplex.
- `SimplexID< k+1 > get_simplex_up (const KeyType s) const`
Convenience version of get_simplex_up when the name 's' consists of a single character.
- `template<std::size_t j>`
`SimplexID< k-j > get_simplex_down (const KeyType(&s)[j]) const`
Gets the simplex down.
- `template<std::size_t j>`
`SimplexID< k-j > get_simplex_down (const std::array< KeyType, j > &arr) const`
Gets the simplex down.
- `SimplexID< k-1 > get_simplex_down (const KeyType s) const`
Gets the simplex down.

Data Fields

- friend `simplicial_complex< traits >`
SimplexID is a friend of the complex.

Static Public Attributes

- static constexpr `std::size_t level = k`
The dimension of the simplex.

Friends

- `bool operator== (SimplexID lhs, SimplexID rhs)`
Equality of wrapped pointers.
- `bool operator!= (SimplexID lhs, SimplexID rhs)`
Inequality of wrapped pointers.
- `bool operator<= (SimplexID lhs, SimplexID rhs)`
Compare wrapped pointers.
- `bool operator>= (SimplexID lhs, SimplexID rhs)`
Compare wrapped pointers.
- `bool operator< (SimplexID lhs, SimplexID rhs)`
Compare wrapped pointers.
- `bool operator> (SimplexID lhs, SimplexID rhs)`
Compare wrapped pointers.
- `std::ostream & operator<< (std::ostream &out, const SimplexID &nid)`
Print the simplex as its name.

9.11.1 Detailed Description

```
template<typename traits>
template<std::size_t k>
struct casc::simplicial_complex< traits >::SimplexID< k >
```

[SimplexID](#) wraps a `Node*` for external handling. This way the end users are never exposed to a raw pointer. For all general purposes algorithms should use and pass `SimplexIDs` over raw pointers.

Template Parameters

<code>k</code>	The Simplex dimension.
----------------	------------------------

9.11.2 Constructor & Destructor Documentation

9.11.2.1 SimplexID() [1/2]

```
template<typename traits >
template<std::size_t k>
casc::simplicial_complex< traits >::SimplexID< k >::SimplexID (
    NodePtr< k > p ) [inline]
```

Parameters

in	<code>p</code>	The <code>NodePtr</code> to wrap
----	----------------	----------------------------------

9.11.2.2 SimplexID() [2/2]

```
template<typename traits >
template<std::size_t k>
casc::simplicial_complex< traits >::SimplexID< k >::SimplexID (
    const SimplexID< k > & rhs ) [inline]
```

Parameters

in	<code>rhs</code>	Another SimplexID to copy.
----	------------------	--

9.11.3 Member Function Documentation

9.11.3.1 `cover()`

```
template<typename traits >
template<std::size_t k>
std::vector< KeyType > casc::simplicial_complex< traits >::SimplexID< k >::cover ( ) const
[inline]
```

Returns

A vector of coboundary indices.

9.11.3.2 `cover_insert()`

```
template<typename traits >
template<std::size_t k>
template<class Inserter >
void casc::simplicial_complex< traits >::SimplexID< k >::cover_insert (
    Inserter pos ) const [inline]
```

Parameters

in	<i>pos</i>	Iterator inserter
----	------------	-------------------

Template Parameters

<i>Inserter</i>	Typename of the inserter.
-----------------	---------------------------

9.11.3.3 `get_simplex_up()` [1/3]

```
template<typename traits >
template<std::size_t k>
SimplexID< k+1 > casc::simplicial_complex< traits >::SimplexID< k >::get_simplex_up (
    const KeyType s ) const [inline]
```

Parameters

in	<i>id</i>	The identifier of a simplex.
in	<i>s</i>	The relative single character name of the desired simplex.

Template Parameters

<i>i</i>	The size of simplex 'id'.
----------	---------------------------

Returns

[SimplexID](#) of node corresponding to $id \cup s$.

9.11.3.4 `get_simplex_up()` [2/3]

```
template<typename traits >
template<std::size_t k>
template<std::size_t j>
SimplexID< k+j > casc::simplicial\_complex< traits >::SimplexID< k >::get_simplex_up (
    const KeyType (&) s[j] ) const [inline]
```

Parameters

in	s	Array of keys to follow
----	---	-------------------------

Template Parameters

j	Number of keys
---	----------------

Returns

The simplex up

9.11.3.5 `get_simplex_up()` [3/3]

```
template<typename traits >
template<std::size_t k>
template<std::size_t j>
SimplexID< k+j > casc::simplicial\_complex< traits >::SimplexID< k >::get_simplex_up (
    const std::array< KeyType, j > & arr ) const [inline]
```

Parameters

in	arr	Array of keys to follow
----	-----	-------------------------

Template Parameters

j	Number of keys
---	----------------

Returns

The simplex up

9.11.3.6 `indices()`

```
template<typename traits >
template<std::size_t k>
std::array< KeyType, k > casc::simplicial_complex< traits >::SimplexID< k >::indices ( )
const [inline]
```

Parameters

in	<i>id</i>	SimplexID of the simplex of interest.
----	-----------	---

Returns

Array containing the name of 'id'.

9.11.4 Friends And Related Function Documentation

9.11.4.1 `operator<<`

```
template<typename traits >
template<std::size_t k>
std::ostream & operator<< (
    std::ostream & out,
    const SimplexID< k > & nid ) [friend]
```

Parameters

	<i>out</i>	Handle to the stream
in	<i>nid</i>	SimplexID of interest

Returns

Handle to the stream

Example

```
{ (.c) }
mesh.insert<3>({0,1,2});
std::cout << s << std::endl;
s{0,1,2}"
```

The documentation for this struct was generated from the following file:

- `include/casc/SimplicialComplex.h`

9.12 `casc::SimplexMap< Complex >` Struct Template Reference

A multimap to represent a map of simplex indices to a set of simplices.

```
#include <SimplexMap.h>
```

Public Types

- `template<std::size_t j>`
using **SimplexID** = typename Complex::template [SimplexID](#)< j >
Alias for SimplexID.
- using **LevelIndex** = typename Complex::LevelIndex
Index sequence of types from the [simplicial_complex](#).
- using **cLevelIndex** = typename [util::remove_first_val](#)< std::size_t, [LevelIndex](#) >::type
Index sequence starting at 1.
- using **RevIndex** = typename [util::reverse_sequence](#)< std::size_t, [LevelIndex](#) >::type
Reversed Index sequence.
- using **cRevIndex** = typename [util::reverse_sequence](#)< std::size_t, [cLevelIndex](#) >::type
Reversed index sequence stops at 1.
- using **type_this** = [SimplexMap](#)< Complex >
Typename of this object.

Public Member Functions

- **SimplexMap** ()
Default constructor.
- `template<std::size_t k>`
`auto & get ()`
Get the map for a particular simplex dimension.
- `template<std::size_t k>`
`auto & get () const`

Friends

- `std::ostream & operator<< (std::ostream &output, const SimplexMap< Complex > &S)`
Print the [SimplexMap](#).

9.12.1 Detailed Description

```
template<typename Complex>
struct casc::SimplexMap< Complex >
```

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

9.12.2 Member Function Documentation

9.12.2.1 `get()` [1/2]

```
template<typename Complex >
template<std::size_t k>
```

```
auto & casc::SimplexMap< Complex >::get ( ) [inline]
```

Template Parameters

<i>k</i>	Simplex dimension to retrieve.
----------	--------------------------------

Returns

A map of `SimplexID<k>` to [SimplexSet](#).

9.12.2.2 `get()` [2/2]

```
template<typename Complex >
template<std::size_t k>
auto & casc::SimplexMap< Complex >::get ( ) const [inline]
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

9.12.3 Friends And Related Function Documentation

9.12.3.1 `operator<<`

```
template<typename Complex >
std::ostream & operator<< (
    std::ostream & output,
    const SimplexMap< Complex > & S ) [friend]
```

Parameters

	<i>output</i>	Handle to the stream to print to.
<i>in</i>	<i>S</i>	SimplexMap to print.

Returns

Handle to the stream.

The documentation for this struct was generated from the following file:

- `include/casc/SimplexMap.h`

9.13 `casc::SimplexSet< Complex >` Struct Template Reference

A multiset to store simplices in a [simplicial_complex](#).

```
#include <SimplexSet.h>
```

Public Types

- `template<std::size_t j>`
using **SimplexID** = typename `Complex::template SimplexID< j >`
Alias for SimplexID.
- using **LevelIndex** = typename `Complex::LevelIndex`
Index sequence of types from the [simplicial_complex](#).
- using **cLevelIndex** = typename `util::remove_first_val< std::size_t, LevelIndex >::type`
Index sequence starting at 1.
- using **RevIndex** = typename `util::reverse_sequence< std::size_t, LevelIndex >::type`
Reversed index sequence.
- using **cRevIndex** = typename `util::reverse_sequence< std::size_t, cLevelIndex >::type`
Reversed index sequence stops at 1.
- using **type_this** = `SimplexSet< Complex >`
Typename of this.
- using **SimplexIDLevel** = typename `util::int_type_map< std::size_t, std::tuple, LevelIndex, SimplexID >::type`
Tuple of SimplexIDs wrt an integral level.

Public Member Functions

- **SimplexSet** ()
Default constructor.
- **~SimplexSet** ()
Default destructor.
- `template<std::size_t k>`
`auto empty () const noexcept`
Checks if a level has no elements.
- `template<std::size_t k>`
`auto size () const noexcept`
Return the number of elements in a level.
- `void clear ()`
Clear the contents.
- `template<std::size_t k>`
`void insert (SimplexID< k > s)`
Insert a simplex into the set.
- `void insert (const SimplexSet< Complex > &s)`
Insert a [SimplexSet](#) into this.
- `template<std::size_t k>`
`void erase (SimplexID< k > s)`
Remove a simplex from the set.
- `void erase (const SimplexSet< Complex > &s)`
Remove a set of simplices.
- `template<std::size_t k>`
`auto find (const SimplexID< k > s)`

Get the simplex of interest.

- `template<std::size_t k>`
`auto find (const SimplexID< k > s) const`

Get the simplex of interest.

- `template<std::size_t k>`
`auto end ()`

Get the past-the-end iterator.

- `template<std::size_t k>`
`auto cend () const`

Get the past-the-end iterator.

- `template<std::size_t k>`
`auto begin ()`

Get an iterator to the first element of the container.

- `template<std::size_t k>`
`auto cbegin () const`

Get an iterator to the first element of the container.

- `template<std::size_t k>`
`auto & get ()`
- `template<std::size_t k>`
`auto & get () const`

Data Fields

- `util::type_map< SimplexIDLevel, NodeSet >::type tupleSet`
Tuple of NodeSets per level.

Friends

- `std::ostream & operator<< (std::ostream &output, const SimplexSet< Complex > &S)`
Print the SimplexSet.

9.13.1 Detailed Description

```
template<typename Complex>
struct casc::SimplexSet< Complex >
```

This is really a tuple of sets where each set corresponds to a simplex dimension. Many convenience functions are wrapped so this behaves much like a `std::set`.

Template Parameters

<i>Complex</i>	Typename of the simplicial_complex .
----------------	--

9.13.2 Member Function Documentation

9.13.2.1 begin()

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::begin ( ) [inline]
```

Template Parameters

<i>k</i>	The simplex dimension to get iterator of.
----------	---

Returns

Returns an iterator to the first element.

9.13.2.2 cbegin()

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::cbegin ( ) const [inline]
```

Template Parameters

<i>k</i>	The simplex dimension to get iterator of.
----------	---

Returns

Returns an iterator to the first element.

9.13.2.3 cend()

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::cend ( ) const [inline]
```

Template Parameters

<i>k</i>	The simplex dimension to get iterator of.
----------	---

Returns

Returns an iterator to the element following the last element of the set for the specified simplex dimension.

9.13.2.4 `empty()`

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::empty ( ) const [inline], [noexcept]
```

Template Parameters

<code>k</code>	Level to check.
----------------	-----------------

Returns

True if the container is empty, false otherwise.

9.13.2.5 `end()`

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::end ( ) [inline]
```

Template Parameters

<code>k</code>	The simplex dimension to get iterator of.
----------------	---

Returns

Returns an iterator to the element following the last element of the set for the specified simplex dimension.

9.13.2.6 `erase()` [1/2]

```
template<typename Complex >
void casc::SimplexSet< Complex >::erase (
    const SimplexSet< Complex > & s ) [inline]
```

Parameters

in	<code>s</code>	<code>SimplexSet</code> to remove.
----	----------------	------------------------------------

9.13.2.7 `erase()` [2/2]

```
template<typename Complex >
template<std::size_t k>
```

```
void casc::SimplexSet< Complex >::erase (
    SimplexID< k > s ) [inline]
```

Parameters

in	s	Simplex to remove.
----	---	--------------------

Template Parameters

k	Simplex dimension of 's'.
---	---------------------------

9.13.2.8 find() [1/2]

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::find (
    const SimplexID< k > s ) [inline]
```

Parameters

in	s	The simplex to search for.
----	---	----------------------------

Template Parameters

k	Simplex dimension of 's'.
---	---------------------------

Returns

Iterator to an element with key equivalent to s. If no such element is found, past-the-end iterator (see [end\(\)](#)) is returned.

9.13.2.9 find() [2/2]

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::find (
    const SimplexID< k > s ) const [inline]
```

Parameters

in	s	The simplex to search for.
----	---	----------------------------

Template Parameters

<code>k</code>	Simplex dimension of 's'.
----------------	---------------------------

Returns

Iterator to an element with key equivalent to `s`. If no such element is found, past-the-end iterator (see [end\(\)](#)) is returned.

9.13.2.10 `insert()` [1/2]

```
template<typename Complex >
void casc::SimplexSet< Complex >::insert (
    const SimplexSet< Complex > & s ) [inline]
```

Parameters

<code>in</code>	<code>s</code>	The SimplexSet to insert.
-----------------	----------------	---

9.13.2.11 `insert()` [2/2]

```
template<typename Complex >
template<std::size_t k>
void casc::SimplexSet< Complex >::insert (
    SimplexID< k > s ) [inline]
```

Parameters

<code>in</code>	<code>s</code>	Simplex to insert.
-----------------	----------------	--------------------

Template Parameters

<code>k</code>	Simplex dimension of 's'.
----------------	---------------------------

9.13.2.12 `size()`

```
template<typename Complex >
template<std::size_t k>
auto casc::SimplexSet< Complex >::size ( ) const [inline], [noexcept]
```

Template Parameters

k	Simplex dimension to query
-----	----------------------------

Returns

Returns the number of simplices of dimension k are in the set.

9.13.3 Friends And Related Function Documentation

9.13.3.1 operator<<

```
template<typename Complex >
std::ostream & operator<< (
    std::ostream & output,
    const SimplexSet< Complex > & S ) [friend]
```

See also `casc::simplicial_complex::SimplexID::operator<<`.

Parameters

	<i>output</i>	Handle to the stream to print to.
<i>in</i>	<i>S</i>	SimplexSet to print.

Returns

Handle to the stream.

The documentation for this struct was generated from the following file:

- `include/casc/SimplexSet.h`

9.14 `casc::simplicial_complex< traits >` Class Template Reference

The CASC data structure for representing simplicial complexes of arbitrary dimensionality with coloring.

```
#include <SimplicialComplex.h>
```

Data Structures

- struct [EdgeID](#)
External reference to an edge or a connection within the complex.
- struct [SimplexID](#)
A handle for a simplex object in the complex.

Public Types

- using **KeyType** = typename traits::KeyType
Typename of simplex keys.
- using **NodeDataTypes** = typename traits::NodeTypes
Typenames of the data stored on simplices.
- using **EdgeDataTypes** = typename traits::EdgeTypes
Typenames of the data stored on edges.
- using **type_this** = `simplicial_complex< traits >`
Type of this.
- using **LevelIndex** = typename std::make_index_sequence< `numLevels` >
Index of all simplex dimensions in the complex.
- template<std::size_t k>
using **NodeData** = typename `util::type_get< k, NodeDataTypes >::type`
- template<std::size_t k>
using **EdgeData** = typename `util::type_get< k, EdgeDataTypes >::type`

Public Member Functions

- **simplicial_complex** ()
Default constructor.
- **~simplicial_complex** ()
Destruct the simplicial complex.
- template<std::size_t n>
SimplexID< n > insert (const KeyType(&s)[n])
Insert a simplex and all sub-simplices into the complex.
- template<std::size_t n>
SimplexID< n > insert (const KeyType(&s)[n], const NodeData< n > &data)
Insert a simplex and all sub-simplices into the complex along with data.
- template<std::size_t n>
SimplexID< n > insert (const std::array< KeyType, n > &s)
Insert a simplex named and all sub-simplices into the complex.
- template<std::size_t n>
SimplexID< n > insert (const std::array< KeyType, n > &s, const NodeData< n > &data)
Insert a simplex and all sub-simplices into the complex along with data.
- **KeyType add_vertex** ()
Add a new vertex to the complex.
- **KeyType add_vertex** (const NodeData< 1 > &data)
Add a new vertex to the complex with data.
- template<std::size_t n, typename Lambda >
void **get_name** (SimplexID< n > id, Lambda fn) const
Apply a lambda function the name of a simplex.
- template<std::size_t n>
std::array< KeyType, n > **get_name** (SimplexID< n > id) const
Gets the name of a simplex as an std::Array.
- std::array< KeyType, 0 > **get_name** (SimplexID< 0 >) const
Gets the name of a simplex.
- template<std::size_t n>
SimplexID< n > get_simplex_up (const KeyType(&s)[n]) const
Gets the simplex with name 's'.
- template<std::size_t n>
SimplexID< n > get_simplex_up (const std::array< KeyType, n > &arr) const

- `template<std::size_t i, std::size_t j>`
`SimplexID< i+j > get_simplex_up (const SimplexID< i > id, const KeyType(&s)[j]) const`
Get the simplex identifier which has the name 's' relative to the simplex 'id'.
- `template<std::size_t i, std::size_t j>`
`SimplexID< i+j > get_simplex_up (const SimplexID< i > id, const std::array< KeyType, j > &arr) const`
- `template<std::size_t i>`
`SimplexID< i+1 > get_simplex_up (const SimplexID< i > id, const KeyType s) const`
Convenience version of get_simplex_up when the name 's' consists of a single character.
- `SimplexID< 0 > get_simplex_up () const`
Get the root simplex.
- `template<std::size_t i, std::size_t j>`
`SimplexID< i-j > get_simplex_down (const SimplexID< i > id, const KeyType(&s)[j]) const`
Get the sub-simplex of the simplex 'id' which does not have 's' in the name.
- `template<std::size_t i, std::size_t j>`
`SimplexID< i-j > get_simplex_down (const SimplexID< i > id, const std::array< KeyType, j > &arr) const`
- `template<std::size_t i>`
`SimplexID< i-1 > get_simplex_down (const SimplexID< i > id, const KeyType s) const`
Convenience version of get_simplex_down when the name 's' consists of a single character.
- `SimplexID< 0 > get_simplex_down () const`
Get the root simplex.
- `template<std::size_t k, class Inserter >`
`void get_cover_insert (const SimplexID< k > id, Inserter pos) const`
Insert the coboundary keys of a simple into an inserter.
- `template<std::size_t k, class Lambda >`
`void get_cover (const SimplexID< k > id, Lambda fn) const`
Apply a lambda function to the coboundary keys.
- `template<std::size_t k>`
`std::vector< KeyType > get_cover (const SimplexID< k > id) const`
Get the coboundary keys of a simplex.
- `template<std::size_t k>`
`std::set< SimplexID< k+1 > > up (const std::set< SimplexID< k > > &&simplices) const`
Get the coboundary of a set of simplices.
- `template<std::size_t k>`
`std::set< SimplexID< k+1 > > up (const std::set< SimplexID< k > > &simplices) const`
Get the coboundary of a set of simplices.
- `template<std::size_t k>`
`std::set< SimplexID< k+1 > > up (const SimplexID< k > nid) const`
Get the coboundary of a simplex.
- `template<std::size_t k, class InsertIter >`
`void up (const std::set< SimplexID< k > > &&simplices, InsertIter iter) const`
- `template<std::size_t k, class InsertIter >`
`void up (const std::set< SimplexID< k > > &simplices, InsertIter iter) const`
- `template<std::size_t k, class InsertIter >`
`void up (const SimplexID< k > simplex, InsertIter iter) const`
- `template<std::size_t k>`
`std::set< SimplexID< k-1 > > down (const std::set< SimplexID< k > > &&simplices) const`
Get the boundary of a set of simplices.
- `template<std::size_t k>`
`std::set< SimplexID< k-1 > > down (const std::set< SimplexID< k > > &simplices) const`
Get the boundary of a set of simplices.
- `template<std::size_t k>`
`std::set< SimplexID< k-1 > > down (const SimplexID< k > simplex) const`
Get the boundary of a simplex.

- `template<std::size_t k, class InsertIter >`
`void down (const std::set< SimplexID< k > > &&simplices, InsertIter iter) const`
- `template<std::size_t k, class InsertIter >`
`void down (const std::set< SimplexID< k > > &simplices, InsertIter iter) const`
- `template<std::size_t k, class InsertIter >`
`void down (const SimplexID< k > simplex, InsertIter iter) const`
- `template<std::size_t k>`
`EdgeID< k+1 > get_edge_up (SimplexID< k > simplex, KeyType a)`
Gets the edge up from a simplex.
- `template<std::size_t k>`
`EdgeID< k > get_edge_down (SimplexID< k > simplex, KeyType a)`
Gets the edge down from a simplex.
- `template<std::size_t k>`
`EdgeID< k+1 > get_edge_up (SimplexID< k > simplex, KeyType a) const`
Gets the edge up from a simplex.
- `template<std::size_t k>`
`EdgeID< k > get_edge_down (SimplexID< k > simplex, KeyType a) const`
Gets the edge down from a simplex.
- `template<std::size_t k>`
`bool exists (const KeyType(&s)[k]) const`
Check whether a simplex with some name exists.
- `template<std::size_t k>`
`std::size_t size () const`
Get the number of simplices of dimension 'k'.
- `template<std::size_t k>`
`auto get_level_id ()`
Create an iterator to traverse the SimplexIDs of a dimension.
- `template<std::size_t k>`
`auto get_level_id () const`
Create an iterator to traverse the SimplexIDs of a dimension.
- `template<std::size_t k>`
`auto get_level ()`
Create an iterator to traverse the simplex data of a dimension.
- `template<std::size_t k>`
`auto get_level () const`
Create an iterator to traverse the simplex data of a dimension.
- `template<std::size_t k>`
`std::size_t remove (const KeyType(&s)[k])`
Remove a simplex and all dependent simplices by name.
- `template<std::size_t k>`
`std::size_t remove (const std::array< KeyType, k > &s)`
Remove a simplex and all dependent simplices by name.
- `template<std::size_t k>`
`std::size_t remove (SimplexID< k > s)`
Remove a simplex and all dependent simplices by SimplexID.
- `template<std::size_t k>`
`bool onBoundary (const SimplexID< k > s) const`
Checks whether a simplex is on a boundary.
- `template<std::size_t level>`
`bool nearBoundary (const SimplexID< level > s) const`
Checks whether a simplex is near a boundary.
- `template<std::size_t L, std::size_t R>`
`bool leq (SimplexID< L > lhs, SimplexID< R > rhs) const`

Less than or equal to comparison operator of two SimplexIDs.

- `template<std::size_t L, std::size_t R>`
`bool eq (SimplexID< L >, SimplexID< R >) const`

Equality comparison of two simplices.

- `template<std::size_t k>`
`bool eq (SimplexID< k > lhs, SimplexID< k > rhs) const`

Equality comparison of two simplices.

- `template<std::size_t L, std::size_t R>`
`bool lt (SimplexID< L > lhs, SimplexID< R > rhs) const`

Less than comparison of simplices.

Static Public Attributes

- `static constexpr std::size_t numLevels = NodeDataTypes::size`

Total number of levels in the complex.

- `static constexpr std::size_t topLevel = numLevels-1`

Dimension of the simplicial complex.

- `static constexpr std::size_t bdryLevel = numLevels-2`

Dimension of boundaries.

Friends

- struct [SimplexID](#)
- struct [EdgeID](#)

9.14.1 Detailed Description

```
template<typename traits>
class casc::simplicial_complex< traits >
```

You can create a CASC object by defining a struct containing the traits of the complex. For example:

```
struct complex_traits{
    using KeyType = int;
    using NodeTypes = util::type_holder<int,int,int,int>;
    using EdgeTypes = util::type_holder<int,int,int>;
};

using SurfaceMesh = simplicial_complex<complex_traits>;
```

This is the preferred method for creating a new CASC type. Alternatively you can use the [AbstractSimplicialComplex](#) alias to build a struct for you.

Template Parameters

<i>traits</i>	A struct defining the dimension of the complex and data to be stored on each node and edge.
---------------	---

9.14.2 Member Typedef Documentation

9.14.2.1 EdgeData

```
template<typename traits >
template<std::size_t k>
using casc::simplicial_complex< traits >::EdgeData = typename util::type_get<k, EdgeDataTypes>↔
::type
```

Convenience alias for the user specified `EdgeData<k>` typename

9.14.2.2 NodeData

```
template<typename traits >
template<std::size_t k>
using casc::simplicial_complex< traits >::NodeData = typename util::type_get<k, NodeDataTypes>↔
::type
```

Convenience alias for the user specified `NodeData<k>` typename

9.14.3 Constructor & Destructor Documentation

9.14.3.1 `~simplicial_complex()`

```
template<typename traits >
casc::simplicial_complex< traits >::~~simplicial_complex ( ) [inline]
```

Recursively go over the simplices and remove them prior to destructing the CASC object itself.

9.14.4 Member Function Documentation

9.14.4.1 `add_vertex()` [1/2]

```
template<typename traits >
KeyType casc::simplicial_complex< traits >::add_vertex ( ) [inline]
```

A list of currently unused indices are tracked using a B-tree. This function retrieves a currently unused index and creates a new vertex while returning the new key.

Returns

The key of the new vertex.

9.14.4.2 add_vertex() [2/2]

```
template<typename traits >
KeyType casc::simplicial_complex< traits >::add_vertex (
    const NodeData< 1 > & data ) [inline]
```

Returns

The key of the new vertex.

9.14.4.3 down() [1/3]

```
template<typename traits >
template<std::size_t k>
std::set< SimplexID< k-1 > > casc::simplicial_complex< traits >::down (
    const SimplexID< k > simplex ) const [inline]
```

Parameters

<i>simplex</i>	The simplex of interest.
----------------	--------------------------

Template Parameters

<i>k</i>	The dimension of the simplex.
----------	-------------------------------

Returns

Set of (k-1)-simplices of which 'simplex' is a coface of.

9.14.4.4 down() [2/3]

```
template<typename traits >
template<std::size_t k>
std::set< SimplexID< k-1 > > casc::simplicial_complex< traits >::down (
    const std::set< SimplexID< k > > && simplices ) const [inline]
```

Parameters

<i>simplices</i>	The set of simplicies.
------------------	------------------------

Template Parameters

<i>k</i>	The dimension of the simplices.
----------	---------------------------------

Returns

The set of boundary simplices.

9.14.4.5 `down()` [3/3]

```
template<typename traits >
template<std::size_t k>
std::set< SimplexID< k-1 > > casc::simplicial_complex< traits >::down (
    const std::set< SimplexID< k > > & simplices ) const [inline]
```

Parameters

<i>simplices</i>	The set of simplices.
------------------	-----------------------

Template Parameters

<i>k</i>	The dimension of the simplices.
----------	---------------------------------

Returns

The set of boundary simplices.

9.14.4.6 `eq()` [1/2]

```
template<typename traits >
template<std::size_t k>
bool casc::simplicial_complex< traits >::eq (
    SimplexID< k > lhs,
    SimplexID< k > rhs ) const [inline]
```

Parameters

in	<i>lhs</i>	The left hand side
in	<i>rhs</i>	The right hand side

Template Parameters

<i>k</i>	Dimension of the simplices.
----------	-----------------------------

Returns

True if the names are the same.

9.14.4.7 eq() [2/2]

```
template<typename traits >
template<std::size_t L, std::size_t R>
bool casc::simplicial_complex< traits >::eq (
    SimplexID< L > ,
    SimplexID< R > ) const [inline]
```

Parameters

in	<i>lhs</i>	The left hand side
in	<i>rhs</i>	The right hand side

Template Parameters

<i>L</i>	Dimension of lhs simplex.
<i>R</i>	Dimension of rhs simplex.

Returns

Always false as $L \neq R$. The $L=R$ case is overloaded by partial specialization.

9.14.4.8 exists()

```
template<typename traits >
template<std::size_t k>
bool casc::simplicial_complex< traits >::exists (
    const KeyType (&) s[k] ) const [inline]
```

Parameters

in	<i>s</i>	C-style array of the name
----	----------	---------------------------

Template Parameters

<i>k</i>	The dimension of the simplex.
----------	-------------------------------

Returns

True if the simplex is in the complex.

9.14.4.9 get_cover() [1/2]

```
template<typename traits >
template<std::size_t k>
```

```
std::vector< KeyType > casc::simplicial_complex< traits >::get_cover (
    const SimplexID< k > id ) const [inline]
```

Parameters

in	<i>id</i>	The identifier of a simplex.
----	-----------	------------------------------

Template Parameters

<i>k</i>	The dimension of the simplex.
----------	-------------------------------

Returns

A vector of coboundary indices.

9.14.4.10 `get_cover()` [2/2]

```
template<typename traits >
template<std::size_t k, class Lambda >
void casc::simplicial_complex< traits >::get_cover (
    const SimplexID< k > id,
    Lambda fn ) const [inline]
```

Parameters

in	<i>id</i>	The identifier
in	<i>fn</i>	The function

Template Parameters

<i>k</i>	The dimension of the simplex.
<i>Lambda</i>	Typename of a functor which supports operator(KeyType).

9.14.4.11 `get_cover_insert()`

```
template<typename traits >
template<std::size_t k, class Inserter >
void casc::simplicial_complex< traits >::get_cover_insert (
    const SimplexID< k > id,
    Inserter pos ) const [inline]
```

Parameters

in	<i>id</i>	The identifier of a simplex.
in	<i>pos</i>	Iterator inserter

Template Parameters

<i>k</i>	The dimension of the simplex.
<i>Insertter</i>	Typename of the inserter.

9.14.4.12 `get_edge_down()` [1/2]

```
template<typename traits >
template<std::size_t k>
EdgeID< k > casc::simplicial_complex< traits >::get_edge_down (
    SimplexID< k > simplex,
    KeyType a ) [inline]
```

Parameters

in	<i>simplex</i>	The simplex of interest.
in	<i>a</i>	Key of the edge to get.

Template Parameters

<i>k</i>	The level of the simplex of interest
----------	--------------------------------------

Returns

The edge down.

9.14.4.13 `get_edge_down()` [2/2]

```
template<typename traits >
template<std::size_t k>
EdgeID< k > casc::simplicial_complex< traits >::get_edge_down (
    SimplexID< k > simplex,
    KeyType a ) const [inline]
```

Parameters

in	<i>simplex</i>	The simplex of interest.
in	<i>a</i>	Key of the edge to get.

Template Parameters

<i>k</i>	The level of the simplex of interest
----------	--------------------------------------

Returns

The edge down.

9.14.4.14 `get_edge_up()` [1/2]

```
template<typename traits >
template<std::size_t k>
EdgeID< k+1 > casc::simplicial_complex< traits >::get_edge_up (
    SimplexID< k > simplex,
    KeyType a ) [inline]
```

Parameters

in	<i>simplex</i>	The simplex of interest.
in	<i>a</i>	Key of the edge to get.

Template Parameters

<i>k</i>	The level of the simplex of interest
----------	--------------------------------------

Returns

The edge up.

9.14.4.15 `get_edge_up()` [2/2]

```
template<typename traits >
template<std::size_t k>
EdgeID< k+1 > casc::simplicial_complex< traits >::get_edge_up (
    SimplexID< k > simplex,
    KeyType a ) const [inline]
```

Parameters

in	<i>simplex</i>	The simplex of interest.
in	<i>a</i>	Key of the edge to get.

Template Parameters

<i>k</i>	The level of the simplex of interest
----------	--------------------------------------

Returns

The edge up.

9.14.4.16 get_level() [1/2]

```
template<typename traits >
template<std::size_t k>
auto casc::simplicial_complex< traits >::get_level ( ) [inline]
```

Template Parameters

<i>k</i>	The simplex dimension to traverse.
----------	------------------------------------

Returns

An iterator across the data of all k-simplices in the complex.

9.14.4.17 get_level() [2/2]

```
template<typename traits >
template<std::size_t k>
auto casc::simplicial_complex< traits >::get_level ( ) const [inline]
```

Template Parameters

<i>k</i>	The simplex dimension to traverse.
----------	------------------------------------

Returns

An iterator across the data of all k-simplices in the complex.

9.14.4.18 get_level_id() [1/2]

```
template<typename traits >
template<std::size_t k>
auto casc::simplicial_complex< traits >::get_level_id ( ) [inline]
```

Template Parameters

<i>k</i>	The simplex dimension to traverse.
----------	------------------------------------

Returns

An iterator across all k-simplices of the complex.

9.14.4.19 `get_level_id()` [2/2]

```
template<typename traits >
template<std::size_t k>
auto casc::simplicial_complex< traits >::get_level_id ( ) const [inline]
```

Template Parameters

<code>k</code>	The simplex dimension to traverse.
----------------	------------------------------------

Returns

An iterator across all k-simplices of the complex.

9.14.4.20 `get_name()` [1/3]

```
template<typename traits >
std::array< KeyType, 0 > casc::simplicial_complex< traits >::get_name (
    SimplexID< 0 > ) const [inline]
```

This is the explicit specialization which handles the empty set simplex.

Parameters

<code>in</code>	<code>id</code>	<code>SimplexID</code> of the simplex of interest.
-----------------	-----------------	--

Returns

Array containing the name of 'id'.

9.14.4.21 `get_name()` [2/3]

```
template<typename traits >
template<std::size_t n>
std::array< KeyType, n > casc::simplicial_complex< traits >::get_name (
    SimplexID< n > id ) const [inline]
```

Parameters

in	<i>id</i>	SimplexID of the simplex of interest.
----	-----------	---

Template Parameters

<i>n</i>	Size of the simplex referenced by 'id'.
----------	---

Returns

Array containing the name of 'id'.

9.14.4.22 `get_name()` [3/3]

```
template<typename traits >
template<std::size_t n, typename Lambda >
void casc::simplicial\_complex< traits >::get_name (
    SimplexID< n > id,
    Lambda fn ) const [inline]
```

Parameters

in	<i>id</i>	SimplexID of the simplex of interest.
in	<i>fn</i>	Lambda function to apply to the name of 'id'.

Template Parameters

<i>n</i>	Dimension of simplex 'id'.
<i>Lambda</i>	Functor which supports operator(KeyType).

9.14.4.23 `get_simplex_down()` [1/3]

```
template<typename traits >
SimplexID< 0 > casc::simplicial\_complex< traits >::get_simplex_down ( ) const [inline]
```

Returns

The root simplex.

9.14.4.24 `get_simplex_down()` [2/3]

```
template<typename traits >
template<std::size_t i>
SimplexID< i-1 > casc::simplicial_complex< traits >::get_simplex_down (
    const SimplexID< i > id,
    const KeyType s ) const [inline]
```

Parameters

in	<i>id</i>	The identifier of a simplex.
in	<i>s</i>	The relative single character name of the desired simplex.

Template Parameters

<i>i</i>	The size of simplex 'id'.
----------	---------------------------

Returns

The node down.

9.14.4.25 `get_simplex_down()` [3/3]

```
template<typename traits >
template<std::size_t i, std::size_t j>
SimplexID< i-j > casc::simplicial_complex< traits >::get_simplex_down (
    const SimplexID< i > id,
    const KeyType(&) s[j] ) const [inline]
```

Parameters

in	<i>id</i>	The identifier of a simplex.
in	<i>s</i>	The relative name of the desired simplex.

Template Parameters

<i>i</i>	The size of simplex 'id'.
<i>j</i>	The length of the name 's'

Returns

The node down.

9.14.4.26 get_simplex_up() [1/4]

```
template<typename traits >
SimplexID< 0 > casc::simplicial_complex< traits >::get_simplex_up ( ) const [inline]
```

Returns

The root simplex.

9.14.4.27 get_simplex_up() [2/4]

```
template<typename traits >
template<std::size_t n>
SimplexID< n > casc::simplicial_complex< traits >::get_simplex_up (
    const KeyType(&) s[n] ) const [inline]
```

Parameters

in	s	Name of the simplex to find.
----	---	------------------------------

Template Parameters

n	Dimension of simplex s.
---	-------------------------

Returns

SimplexID of node corresponding to 's'.

9.14.4.28 get_simplex_up() [3/4]

```
template<typename traits >
template<std::size_t i>
SimplexID< i+1 > casc::simplicial_complex< traits >::get_simplex_up (
    const SimplexID< i > id,
    const KeyType s ) const [inline]
```

Parameters

in	id	The identifier of a simplex.
in	s	The relative single character name of the desired simplex.

Template Parameters

i	The size of simplex 'id'.
---	---------------------------

Returns

`SimplexID` of node corresponding to $id \cup s$.

9.14.4.29 `get_simplex_up()` [4/4]

```
template<typename traits >
template<std::size_t i, std::size_t j>
SimplexID< i+j > casc::simplicial_complex< traits >::get_simplex_up (
    const SimplexID< i > id,
    const KeyType (&) s[j] ) const [inline]
```

Parameters

in	<i>id</i>	The identifier of a simplex.
in	<i>s</i>	The relative name of the desired simplex.

Template Parameters

<i>i</i>	The size of simplex 'id'.
<i>j</i>	The length of the name 's'.

Returns

`SimplexID` of node corresponding to $id \cup s$.

9.14.4.30 `insert()` [1/4]

```
template<typename traits >
template<std::size_t n>
SimplexID< n > casc::simplicial_complex< traits >::insert (
    const KeyType (&) s[n] ) [inline]
```

Example – insert the simplex {1,2,3}:

```
mesh.insert<3>({1,2,3});
```

Parameters

in	<i>s</i>	A C style array of vertices of simplex 's'.
----	----------	---

Template Parameters

<i>n</i>	Dimension of simplex 's'.
----------	---------------------------

9.14.4.31 insert() [2/4]

```
template<typename traits >
template<std::size_t n>
SimplexID< n > casc::simplicial_complex< traits >::insert (
    const KeyType (&) s[n],
    const NodeData< n > & data ) [inline]
```

Example – insert the simplex {1,2,3} with data:

```
mesh.insert<3>({1,2,3}, 5);
```

Parameters

in	<i>s</i>	A C style array of vertices of simplex 's'.
in	<i>data</i>	The data to be stored at the simplex 's'.

Template Parameters

<i>n</i>	Dimension of simplex 's'.
----------	---------------------------

9.14.4.32 insert() [3/4]

```
template<typename traits >
template<std::size_t n>
SimplexID< n > casc::simplicial_complex< traits >::insert (
    const std::array< KeyType, n > & s ) [inline]
```

Parameters

in	<i>s</i>	Array of vertices comprising 's'.
----	----------	-----------------------------------

Template Parameters

<i>n</i>	Dimension of simplex 's'.
----------	---------------------------

9.14.4.33 insert() [4/4]

```
template<typename traits >
template<std::size_t n>
SimplexID< n > casc::simplicial_complex< traits >::insert (
    const std::array< KeyType, n > & s,
    const NodeData< n > & data ) [inline]
```

Parameters

in	<i>s</i>	Array of vertices comprising 's'.
in	<i>data</i>	The data to be stored at the simplex 's'.

Template Parameters

<i>n</i>	Dimension of simplex 's'.
----------	---------------------------

9.14.4.34 `leq()`

```
template<typename traits >
template<std::size_t L, std::size_t R>
bool casc::simplicial_complex< traits >::leq (
    SimplexID< L > lhs,
    SimplexID< R > rhs ) const [inline]
```

Parameters

in	<i>lhs</i>	The left hand side
in	<i>rhs</i>	The right hand side

Template Parameters

<i>L</i>	Dimension of lhs simplex.
<i>R</i>	Dimension of rhs simplex.

Returns

True if lhs is rhs or a proper face of rhs.

9.14.4.35 `lt()`

```
template<typename traits >
template<std::size_t L, std::size_t R>
bool casc::simplicial_complex< traits >::lt (
    SimplexID< L > lhs,
    SimplexID< R > rhs ) const [inline]
```

Parameters

in	<i>lhs</i>	The left hand side
in	<i>rhs</i>	The right hand side

Template Parameters

<i>L</i>	Dimension of lhs simplex.
<i>R</i>	Dimension of rhs simplex.

Returns

True if lhs is a proper subface of rhs.

9.14.4.36 nearBoundary()

```
template<typename traits >
template<std::size_t level>
bool casc::simplicial_complex< traits >::nearBoundary (
    const SimplexID< level > s ) const [inline]
```

Parameters

in	<i>s</i>	SimplexID of interest
----	----------	-----------------------

Template Parameters

<i>level</i>	Dimension of the simplex
--------------	--------------------------

Returns

True if the simplex or any subsimplices are onBoundary.

9.14.4.37 onBoundary()

```
template<typename traits >
template<std::size_t k>
bool casc::simplicial_complex< traits >::onBoundary (
    const SimplexID< k > s ) const [inline]
```

Parameters

in	<i>s</i>	SimplexID of interest
----	----------	-----------------------

Template Parameters

<i>k</i>	Dimension of the simplex
----------	--------------------------

Returns

True if the simplex is a member of a topLevel-1 simplex on the boundary or if the simplex is on a boundary or if the simplex is a coboundary of a boundary topLevel-1 simplex.

9.14.4.38 `remove()` [1/3]

```
template<typename traits >
template<std::size_t k>
std::size_t casc::simplicial_complex< traits >::remove (
    const KeyType (&) s[k] ) [inline]
```

Parameters

<code>in</code>	<code>s</code>	C-style array with the name of the simplex to remove.
-----------------	----------------	---

Template Parameters

<code>k</code>	The dimension of the simplex.
----------------	-------------------------------

Returns

Integer corresponding to the number of simplices removed.

9.14.4.39 `remove()` [2/3]

```
template<typename traits >
template<std::size_t k>
std::size_t casc::simplicial_complex< traits >::remove (
    const std::array< KeyType, k > & s ) [inline]
```

Parameters

<code>in</code>	<code>s</code>	<code>std::array</code> with the name of the simplex to remove.
-----------------	----------------	---

Template Parameters

<code>k</code>	The dimension of the simplex.
----------------	-------------------------------

Returns

Integer corresponding to the number of simplices removed.

9.14.4.40 remove() [3/3]

```
template<typename traits >
template<std::size_t k>
std::size_t casc::simplicial\_complex< traits >::remove (
    SimplexID< k > s ) [inline]
```

Parameters

<i>in</i>	<i>s</i>	SimplexID of the simplex to remove.
-----------	----------	---

Template Parameters

<i>k</i>	The dimension of the simplex.
----------	-------------------------------

Returns

Integer corresponding to the number of simplices removed.

9.14.4.41 size()

```
template<typename traits >
template<std::size_t k>
std::size_t casc::simplicial\_complex< traits >::size ( ) const [inline]
```

Template Parameters

<i>k</i>	The dimension of interest.
----------	----------------------------

Returns

Integer number of k-simplices in the complex.

9.14.4.42 up() [1/3]

```
template<typename traits >
template<std::size_t k>
std::set< SimplexID< k+1 > > casc::simplicial\_complex< traits >::up (
    const SimplexID< k > nid ) const [inline]
```

Parameters

<i>nid</i>	The simplex of interest
------------	-------------------------

Template Parameters

<i>k</i>	The dimension of the simplex.
----------	-------------------------------

Returns

Set of (k+1)-simplices of which 'nid' is a face of.

9.14.4.43 `up()` [2/3]

```
template<typename traits >
template<std::size_t k>
std::set< SimplexID< k+1 > > casc::simplicial_complex< traits >::up (
    const std::set< SimplexID< k > > && simplices ) const [inline]
```

Parameters

<i>simplices</i>	The set of simplices
------------------	----------------------

Template Parameters

<i>k</i>	The dimension of the simplices.
----------	---------------------------------

Returns

The set of coboundary simplices.

9.14.4.44 `up()` [3/3]

```
template<typename traits >
template<std::size_t k>
std::set< SimplexID< k+1 > > casc::simplicial_complex< traits >::up (
    const std::set< SimplexID< k > > & simplices ) const [inline]
```

Parameters

<i>simplices</i>	The set of simplices
------------------	----------------------

Template Parameters

<i>k</i>	The dimension of the simplices.
----------	---------------------------------

Returns

The set of coboundary simplices.

9.14.5 Friends And Related Function Documentation**9.14.5.1 EdgeID**

```
template<typename traits >
friend struct EdgeID [friend]
```

EdgeID is a friend to [simplicial_complex](#)

9.14.5.2 SimplexID

```
template<typename traits >
friend struct SimplexID [friend]
```

SimplexID is a friend of [simplicial_complex](#)

The documentation for this class was generated from the following file:

- include/casc/[SimplicialComplex.h](#)

9.15 util::type_get< k, T > Struct Template Reference

Helper to get the kth element from a [type_holder](#).

```
#include <util.h>
```

9.15.1 Detailed Description

```
template<std::size_t k, typename T>
struct util::type_get< k, T >
```

This is the empty general template which will be later specialized.

Template Parameters

<i>k</i>	Integer index of the type to retrieve
<i>T</i>	A type_holder queue of typenames

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.16 util::type_get< 0, type_holder< Ts... > > Struct Template Reference

Specialization for terminal case.

```
#include <util.h>
```

Public Types

- using **type** = typename [type_holder](#)< Ts... >::head
The first type of the [type_holder](#).

9.16.1 Detailed Description

```
template<typename ... Ts>
struct util::type_get< 0, type_holder< Ts... > >
```

Template Parameters

<i>Ts</i>	Following typenames
-----------	---------------------

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.17 util::type_get< k, type_holder< Ts... > > Struct Template Reference

Specialization to recursively pop types to get the kth type.

```
#include <util.h>
```

Public Types

- using **type** = typename [type_get](#)< k-1, typename [type_holder](#)< Ts... >::tail >::type
Recurse after popping the first type off.

9.17.1 Detailed Description

```
template<std::size_t k, typename ... Ts>
struct util::type_get< k, type_holder< Ts... > >
```

Template Parameters

<i>k</i>	Integral constant of the type to get
<i>Ts</i>	List of typenames

The documentation for this struct was generated from the following file:

- `include/casc/`[util.h](#)

9.18 `util::type_holder< Ts >` Struct Template Reference

Queue based data structure to hold list of types.

```
#include <util.h>
```

Static Public Attributes

- static const std::size_t **size** = sizeof ... (Ts)
Length of the list of types.

9.18.1 Detailed Description

```
template<typename ... Ts>
struct util::type_holder< Ts >
```

Types in the [type_holder](#) can be accessed by accessing the `head` type. Subsequent types are in the `tail`. See also [type_get](#).

Template Parameters

<i>Ts</i>	List of typenames
-----------	-------------------

The documentation for this struct was generated from the following file:

- `include/casc/`[util.h](#)

9.19 `util::type_holder< T, Ts... >` Struct Template Reference

Partial specialization to allow FIFO access of typenames.

```
#include <util.h>
```

Public Types

- using **head** = T
The first type.
- using **tail** = [type_holder](#)< Ts... >
The following types.

Static Public Attributes

- static const std::size_t **size** = 1 + [type_holder](#)<Ts...>::size
Length of the list of types.

9.19.1 Detailed Description

```
template<typename T, typename ... Ts>
struct util::type_holder< T, Ts... >
```

Template Parameters

<i>T</i>	The first typename
<i>Ts</i>	The following typenames

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.20 util::type_map< C, V > Struct Template Reference

Map the types in C into V<T>.

```
#include <util.h>
```

Public Types

- using **type** = typename detail::type_map_helper< C, V >::type
Tuple of C<V<T1>, V<T2>, V<T3>, ...>

9.20.1 Detailed Description

```
template<class C, template< typename > class V>
struct util::type_map< C, V >
```

Given a container of types C<T1, T2, T3, ...> and template type V<T>, this function will apply the types in C to V<T>. This produces C<V<T1>, V<T2>, V<T3>, ...>.

Template Parameters

<i>C</i>	Container of compile time types.
<i>V</i>	Template template class $\mathbb{V}<\mathbb{T}>$ to map into.

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.21 `util::type_swap< TUPLE, HOLDER_FULL >` Struct Template Reference

Move a list of types from one container to another.

```
#include <util.h>
```

9.21.1 Detailed Description

```
template<template< class ... > class TUPLE, typename HOLDER_FULL>
struct util::type_swap< TUPLE, HOLDER_FULL >
```

Template Parameters

<i>TUPLE</i>	Empty container
<i>HOLDER_FULL</i>	Full container

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

9.22 `util::type_swap< TUPLE, HOLDER< Ts... > >` Struct Template Reference

Move a list of types from one container to another.

```
#include <util.h>
```

Public Types

- using **type** = `TUPLE< Ts... >`
Empty container filled with typenames from full container.

9.22.1 Detailed Description

```
template<template< class ... > class TUPLE, template< class ... > class HOLDER, typename ... Ts>
struct util::type_swap< TUPLE, HOLDER< Ts... > >
```

Template Parameters

<i>TUPLE</i>	Empty container
<i>HOLDER</i>	Full container
<i>Ts</i>	Typenames in full container

The documentation for this struct was generated from the following file:

- include/casc/[util.h](#)

Chapter 10

File Documentation

10.1 include/casc/CASCFunctions.h File Reference

Contains various functions that operate on simplicial complexes.

```
#include <iostream>
#include <fstream>
#include "SimplicialComplex.h"
#include "CASCTraversals.h"
#include "SimplexSet.h"
#include "stringutil.h"
```

Namespaces

- namespace `casc`
Namespace for everything CASC.

Functions

- template<typename Complex >
void `casc::getStar` (Complex &F, `casc::SimplexSet`< Complex > &S, `casc::SimplexSet`< Complex > &dest)
Gets the star of a `SimplexSet`.
- template<typename Complex , typename Simplex >
void `casc::getStar` (Complex &F, Simplex &s, `casc::SimplexSet`< Complex > &dest)
Gets the star of a simplex.
- template<typename Complex >
void `casc::getClosure` (Complex &F, `casc::SimplexSet`< Complex > &S, `casc::SimplexSet`< Complex > &dest)
Gets the closure of a simplex set.
- template<typename Complex , typename Simplex >
void `casc::getClosure` (Complex &F, Simplex &s, `casc::SimplexSet`< Complex > &dest)
Compute the closure of a simplex.
- template<typename Complex >
void `casc::getLink` (Complex &F, `casc::SimplexSet`< Complex > &S, `casc::SimplexSet`< Complex > &dest)
Gets the link of a `SimplexSet`.
- template<typename Complex , typename Simplex >
void `casc::getLink` (Complex &F, Simplex &s, `casc::SimplexSet`< Complex > &dest)
Gets the link of a simplex.
- template<typename Complex >
void `casc::writeDOT` (const std::string &filename, Complex &F)
Writes out the topology of an ASC into the dot format.

10.2 CASCFunctions.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *
00008  * This library is free software; you can redistribute it and/or
00009  * modify it under the terms of the GNU Lesser General Public
00010  * License as published by the Free Software Foundation; either
00011  * version 2.1 of the License, or (at your option) any later version.
00012  *
00013  * This library is distributed in the hope that it will be useful,
00014  * but WITHOUT ANY WARRANTY; without even the implied warranty of
00015  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
00016  * Lesser General Public License for more details.
00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file CASCFunctions.h
00027  * @brief Contains various functions that operate on simplicial complexes
00028  */
00029
00030 #pragma once
00031
00032 #include <iostream>
00033 #include <fstream>
00034 #include "SimplicialComplex.h"
00035 #include "CASCTraversals.h"
00036 #include "SimplexSet.h"
00037 #include "stringutil.h"
00038
00039 namespace casc
00040 {
00041     /// @cond detail
00042     /// Namespace for templated helpers of convenience functions
00043     namespace func_detail
00044     {
00045
00046         /**
00047          * @brief Visitor for grabbing simplices in a BFS traversal. See also
00048          * visit_BFS_up and visit_BFS_down.
00049          *
00050          * @tparam Complex Typename of the complex.
00051          */
00052         template <typename Complex>
00053         struct SimplexAggregator
00054         {
00055             /// Alias for a typed SimplexSet
00056             using SimplexSet = typename casc::SimplexSet<Complex>;
00057
00058             /**
00059              * @brief Constructor of the aggregator.
00060              *
00061              * @param p Pointer to SimplexSet to fill.
00062              */
00063             SimplexAggregator(SimplexSet* p) : pLevels(p) {}
00064
00065             /**
00066              * @brief Overloaded visit function to append different dimensioned
00067              * SimplexIDs into the SimplexSet.
00068              *
00069              * @param F The complex of interest
00070              * @param[in] s SimplexID to visit.
00071              *
00072              * @tparam k Dimension of the simplex.
00073              *
00074              * @return True if the traversal should continue.
00075              */
00076             template <std::size_t k>
00077             bool visit(Complex &, typename Complex::template SimplexID<k> s)
00078             {
00079                 // If the simplex isn't there, insert it.
00080                 if (pLevels->find(s) == pLevels->template end<k>())
00081                 {
00082                     pLevels->insert(s);
00083                 }
00084             }
00085         };
00086     }
00087 }

```

```

00083         return true;
00084     }
00085     else
00086     {
00087         // Everything after has been found already
00088         return false;
00089     }
00090 }
00091 private:
00092     SimplexSet* pLevels;
00093 };
00094
00095 /**
00096  * @brief      Helper for computing the star of a set of simplices.
00097  *
00098  * @tparam      Complex  Typename of the simplicial complex.
00099  */
00100 template <typename Complex>
00101 struct StarHelper
00102 {
00103     /**
00104      * @brief      Iterate over the SimplexSet and compute the star.
00105      *
00106      * @param      F      Complex of interest.
00107      * @param      S      SimplexSet of simplices to compute the star of.
00108      * @param      dest    SimplexSet where the star should go.
00109      *
00110      * @tparam      k      Dimension of the current simplex dimension to traverse.
00111      */
00112     template <std::size_t k>
00113     static void apply(Complex &F,
00114                      casc::SimplexSet<Complex> &S,
00115                      casc::SimplexSet<Complex> &dest)
00116     {
00117         auto s = casc::get<k>(S);
00118         for (auto simplex : s)
00119         {
00120             visit_BFS_up(SimplexAggregator<Complex>(&dest), F, simplex);
00121         }
00122     }
00123 };
00124
00125 /**
00126  * @brief      Helper for computing the closure of a set of simplices.
00127  *
00128  * @tparam      Complex  Typename of the simplicial complex.
00129  */
00130 template <typename Complex>
00131 struct ClosureHelper
00132 {
00133     /**
00134      * @brief      Iterate over the SimplexSet and compute the closure
00135      *
00136      * @param      F      Complex of interest.
00137      * @param      S      SimplexSet of simplices to compute the closure of.
00138      * @param      dest    SimplexSet where the closure should go.
00139      *
00140      * @tparam      k      Dimension of the current simplex dimension to traverse.
00141      */
00142     template <std::size_t k>
00143     static void apply(Complex &F,
00144                      casc::SimplexSet<Complex> &S,
00145                      casc::SimplexSet<Complex> &dest)
00146     {
00147         auto s = casc::get<k>(S);
00148         for (auto simplex : s)
00149         {
00150             visit_BFS_down(SimplexAggregator<Complex>(&dest), F, simplex);
00151         }
00152     }
00153 };
00154
00155 /**
00156  * @brief      Visitor for printing connectivity of the simplicial complex.
00157  *
00158  * @tparam      Complex  Typename of the simplicial complex.
00159  */
00160 template <typename Complex>
00161 struct GraphVisitor
00162 {
00163     /// ostream to write out to.
00164     std::ostream &fout;
00165
00166     /**
00167      * @brief      Constructor
00168      *
00169      * @param      os      Ostream to print to.

```

```

00170     */
00171     GraphVisitor(std::ostream &os) : fout(os) {}
00172
00173     /**
00174     * @brief      Generic visitor prints the simplices and edge connectivity.
00175     *
00176     * @param[in]  F          Complex of interest.
00177     * @param[in]  s          Simplex to visit.
00178     *
00179     * @tparam     level      Dimension of the simplex.
00180     *
00181     * @return     True
00182     */
00183     template <std::size_t level>
00184     bool visit(const Complex &F, typename Complex::template SimplexID<level> s)
00185     {
00186         auto name = to_string(F.get_name(s));
00187
00188         auto covers = F.get_cover(s);
00189         for (auto cover : covers)
00190         {
00191             auto edge = F.get_edge_up(s, cover);
00192             auto nextName = to_string(F.get_name(edge.up()));
00193             if ((*edge).orientation == 1)
00194             {
00195                 fout << "  \"\" < name < \"\" -> \"\"
00196                     << nextName < \"\" < std::endl;
00197             }
00198             else
00199             {
00200                 fout << "  \"\" < nextName < \"\" -> \"\"
00201                     << name < \"\" < std::endl;
00202             }
00203         }
00204         return true;
00205     }
00206
00207     /**
00208     * @brief      Explicit specialization for visiting the second to top level
00209     *              simplices.
00210     *
00211     * @param[in]  F          Complex of interest
00212     * @param[in]  s          Simplex to visit.
00213     *
00214     * @return     True;
00215     */
00216     bool visit(const Complex &F, typename Complex::template SimplexID<Complex::topLevel-1> s)
00217     {
00218
00219         auto name = to_string(F.get_name(s));
00220         auto covers = F.get_cover(s);
00221         for (auto cover : covers)
00222         {
00223             auto edge = F.get_edge_up(s, cover);
00224             auto nextName = to_string(F.get_name(edge.up()));
00225             auto orient = (*edge.up()).orientation;
00226             if (orient == 1)
00227             {
00228                 nextName = "+" + nextName;
00229             }
00230             else
00231             {
00232                 nextName = "-" + nextName;
00233             }
00234             if ((*edge).orientation == 1)
00235             {
00236                 fout << "  \"\" < name < \"\" -> \"\"
00237                     << nextName < \"\" < std::endl;
00238             }
00239             else
00240             {
00241                 fout << "  \"\" < nextName < \"\" -> \"\"
00242                     << name < \"\" < std::endl;
00243             }
00244         }
00245         return true;
00246     }
00247
00248     /**
00249     * @brief      Explicit specialization for visiting the facets of the
00250     *              *complex.
00251     *
00252     * @param[in]  F          Complex of interest.
00253     * @param[in]  s          Simplex to visit.
00254     */
00255     void visit(const Complex &, typename Complex::template SimplexID<Complex::topLevel>) {}
00256 };

```

```

00257
00258 /**
00259  * @brief      Generic template for printing out DOT meta info.
00260  *
00261  * @tparam      Complex  Typename of the complex.
00262  * @tparam      K        Dimension to go through.
00263  */
00264 template <typename Complex, typename K>
00265 struct DotHelper {};
00266
00267 /**
00268  * @brief      Partial specialization for listing names of simplices.
00269  *
00270  * @tparam      Complex  Typename of the complex.
00271  * @tparam      k        Simplex dimension to traverse.
00272  */
00273 template <typename Complex, std::size_t k>
00274 struct DotHelper<Complex, std::integral_constant<std::size_t, k> >
00275 {
00276     /**
00277      * @brief      Print out a list of simplices in a simplex dimension.
00278      *
00279      * @param      fout    Stream to print to.
00280      * @param[in]  F        Complex of interest.
00281      */
00282     static void printlevel(std::ofstream &fout, const Complex &F)
00283     {
00284         auto nodes = F.template get_level_id<k>();
00285         fout << "subgraph cluster_" << k << " {\n"
00286             << "label=\"Level " << k << "\"\n";
00287         for (auto node : nodes)
00288         {
00289             fout << "\" " << to_string(F.get_name(node)) << " ";
00290         }
00291         fout << "\n}\n";
00292         DotHelper<Complex, std::integral_constant<std::size_t, k+1> >::printlevel(fout, F);
00293     }
00294 };
00295
00296 /**
00297  * @brief      List the names of simplices at the top level
00298  *
00299  * @tparam      Complex  Typename of the complex.
00300  */
00301 template <typename Complex>
00302 struct DotHelper<Complex, std::integral_constant<std::size_t, Complex::topLevel> >
00303 {
00304     /**
00305      * @brief      Print out a list of facets of the complex.
00306      *
00307      * @param      fout    Stream to print to.
00308      * @param[in]  F        Complex of interest.
00309      */
00310     static void printlevel(std::ofstream &fout, const Complex &F)
00311     {
00312         auto nodes = F.template get_level_id<Complex::topLevel>();
00313         fout << "subgraph cluster_" << Complex::topLevel << " {\n"
00314             << "label=\"Level " << Complex::topLevel << "\"\n";
00315         for (auto node : nodes)
00316         {
00317             auto orient = (*node).orientation;
00318             if (orient == 1)
00319             {
00320                 fout << "\"+ ";
00321             }
00322             else
00323             {
00324                 fout << "\"- ";
00325             }
00326             fout << to_string(F.get_name(node)) << " ";
00327         }
00328         fout << "\n}\n";
00329     }
00330 };
00331 } // end namespace func_detail
00332 /// @endcond
00333
00334 /**
00335  * @brief      Gets the star of a SimplexSet.
00336  *
00337  * @param[in]  F        Complex of interest.
00338  * @param[in]  S        SimplexSet to compute the star of.
00339  * @param[out] dest      Destination SimplexSet.
00340  *
00341  * @tparam      Complex  Typename of the complex.
00342  */
00343 template <typename Complex>

```

```

00344 void getStar(Complex &F, casc::SimplexSet<Complex> &S,
00345               casc::SimplexSet<Complex> &dest)
00346 {
00347     using SimplexSet = typename casc::SimplexSet<Complex>;
00348     using RevIndex   = typename SimplexSet::cRevIndex;
00349
00350     // Start at the top and work up. We can assume that if we've seen it then
00351     // everything after has been added.
00352     util::int_for_each<std::size_t, RevIndex>(
00353         func_detail::StarHelper<Complex>(), F, S, dest);
00354 }
00355
00356 /**
00357  * @brief      Gets the star of a simplex.
00358  *
00359  * @param[in]  F      Complex of interest.
00360  * @param      s      Simplex to get the star of.
00361  * @param[out] dest   Destination SimplexSet.
00362  *
00363  * @tparam     Complex Typename of the complex.
00364  * @tparam     Simplex Typename of the simplex.
00365  */
00366 template <typename Complex, typename Simplex>
00367 void getStar(Complex &F, Simplex &s, casc::SimplexSet<Complex> &dest)
00368 {
00369     visit_BFS_up(func_detail::SimplexAggregator<Complex>(&dest), F, s);
00370 }
00371
00372 /**
00373  * @brief      Gets the closure of a simplex set.
00374  *
00375  * @param[in]  F      Complex of interest.
00376  * @param[in]  S      SimplexSet to compute the closure of.
00377  * @param[out] dest   Destination SimplexSet
00378  *
00379  * @tparam     Complex Typename of the complex.
00380  */
00381 template <typename Complex>
00382 void getClosure(Complex &F, casc::SimplexSet<Complex> &S,
00383                casc::SimplexSet<Complex> &dest)
00384 {
00385     using SimplexSet = typename casc::SimplexSet<Complex>;
00386     using LevelIndex = typename SimplexSet::cLevelIndex;
00387     // Start at the bottom and work down.
00388     // We can assume that everything below has been looked at.
00389     util::int_for_each<std::size_t, LevelIndex>(
00390         func_detail::ClosureHelper<Complex>(), F, S, dest);
00391 }
00392
00393 /**
00394  * @brief      Compute the closure of a simplex.
00395  *
00396  * @param[in]  F      Complex of interest.
00397  * @param[in]  s      Simplex of interest.
00398  * @param[out] dest   Destination SimplexSet.
00399  *
00400  * @tparam     Complex Typename of the complex.
00401  * @tparam     Simplex Typename of the simplex.
00402  */
00403 template <typename Complex, typename Simplex>
00404 void getClosure(Complex &F, Simplex &s, casc::SimplexSet<Complex> &dest)
00405 {
00406     visit_BFS_down(func_detail::SimplexAggregator<Complex>(&dest), F, s);
00407 }
00408
00409 /**
00410  * @brief      Gets the link of a SimplexSet.
00411  *
00412  * @param[in]  F      Complex of interest.
00413  * @param[in]  S      SimplexSet to get the link of.
00414  * @param[out] dest   Destination SimplexSet.
00415  *
00416  * @tparam     Complex Typename of the complex.
00417  */
00418 template <typename Complex>
00419 void getLink(Complex &F, casc::SimplexSet<Complex> &S,
00420             casc::SimplexSet<Complex> &dest)
00421 {
00422     using SimplexSet = typename casc::SimplexSet<Complex>;
00423
00424     SimplexSet star;
00425     SimplexSet closure;
00426     SimplexSet closeStar;
00427     SimplexSet starClose;
00428     getStar(F, S, star);
00429     getClosure(F, star, closeStar);
00430 }

```

```

00431     getClosure(F, S, closure);
00432     getStar(F, closure, starClose);
00433     casc::set_difference(closeStar, starClose, dest);
00434 }
00435
00436 /**
00437  * @brief      Gets the link of a simplex
00438  *
00439  * @param      F      Complex of interest.
00440  * @param      s      Simplex of interest.
00441  * @param      dest    Destination SimplexSet.
00442  *
00443  * @tparam     Complex Typename of the complex.
00444  * @tparam     Simplex Typename of the simplex.
00445  */
00446 template <typename Complex, typename Simplex>
00447 void getLink(Complex &F, Simplex &s, casc::SimplexSet<Complex> &dest)
00448 {
00449     using SimplexSet = typename casc::SimplexSet<Complex>;
00450     SimplexSet star;
00451     SimplexSet closure;
00452     SimplexSet closeStar;
00453     SimplexSet starClose;
00454     getStar(F, s, star);
00455     getClosure(F, star, closeStar);
00456
00457     getClosure(F, s, closure);
00458     getStar(F, closure, starClose);
00459     casc::set_difference(closeStar, starClose, dest);
00460 }
00461
00462 /**
00463  * @brief      Writes out the topology of an ASC into the dot format.
00464  *
00465  * The resulting dot file can be rendered into an image using tools such as
00466  * GraphViz.
00467  * ~~~~~{.sh}
00468  * dot -Tpng input.dot > output.png
00469  * ~~~~~
00470  *
00471  * @param[in]  filename  Filename to write out to.
00472  * @param[in]  F          Simplicial complex to generate the DOT of.
00473  *
00474  * @tparam     Complex   Typename of the simplicial complex.
00475  */
00476 template <typename Complex>
00477 void writeDOT(const std::string &filename, Complex &F)
00478 {
00479     // TODO: Put back the const F (0)
00480     std::ofstream fout(filename);
00481     if (!fout.is_open())
00482     {
00483         std::cerr << "File '" << filename
00484                 << "' could not be written to." << std::endl;
00485         fout.close();
00486         exit(1);
00487     }
00488
00489     fout << "digraph {\n"
00490         << "node [shape = record,height = .1]"
00491         << "splines=line;\n"
00492         << "dpi=300;\n";
00493     auto v = func_detail::GraphVisitor<Complex>(fout);
00494     visit_BFS_up(v, F, F.get_simplex_up());
00495
00496     // List the simplices
00497     func_detail::DotHelper<Complex,
00498         std::integral_constant<std::size_t, 0> >::printlevel(fout, F);
00499     fout << "}"<< "\n";
00500     fout.close();
00501 }
00502 } // end namespace casc

```

10.3 include/casc/CASCTraversals.h File Reference

Implementations of various advanced traversals such as by neighborhood and breadth first search.

```

#include <set>
#include <vector>

```

```
#include <iostream>
#include <string>
#include <type_traits>
#include <utility>
#include <casc/casc>
```

Namespaces

- namespace [casc](#)
Namespace for everything CASC.

Functions

- template<typename Visitor , typename SimplexID >
void [casc::visit_BFS_up](#) (Visitor &&v, typename SimplexID::complex &F, SimplexID s)
Traverse BFS up the complex and apply a visitor function to each simplex visited.
- template<typename Visitor , typename SimplexID >
void [casc::visit_BFS_down](#) (Visitor &&v, typename SimplexID::complex &F, SimplexID s)
Traverse BFS down the complex and apply a visitor function to each simplex visited.
- template<typename Visitor , typename EdgeID >
void [casc::edge_up](#) (Visitor &&v, typename EdgeID::complex &F, EdgeID s)
Traverse across edges BFS.
- template<class Complex , std::size_t level, class InsertIter >
void [casc::neighbors](#) (Complex &F, typename Complex::template SimplexID< level > nid, InsertIter iter)
Push the immediate face neighbors into the provided iterator.
- template<class Complex , class SimplexID , class InsertIter >
void [casc::neighbors](#) (Complex &F, SimplexID nid, InsertIter iter)
This is a helper function to assist neighbors to automatically deduce the integral level.
- template<class Complex , std::size_t level, class InsertIter >
void [casc::neighbors_up](#) (Complex &F, typename Complex::template SimplexID< level > nid, InsertIter iter)
Push the immediate coface neighbors into the provided iterator.
- template<class Complex , class SimplexID , class InsertIter >
void [casc::neighbors_up](#) (Complex &F, SimplexID nid, InsertIter iter)
This is a helper function to assist neighbors to automatically deduce the integral level.
- template<class Complex , std::size_t level, typename Iterator >
void [casc::kneighbors_up](#) (Complex &F, int ring, std::set< typename Complex::template SimplexID< level >
> &nbors, Iterator begin, Iterator end)
Code for returning a set of k-ring neighbors.
- template<class Complex , class SimplexID >
void [casc::kneighbors_up](#) (Complex &F, SimplexID nid, int ring, std::set< SimplexID > &nbors)
Helper function to help kneighbors_up to deduce the integral level of SimplexID.
- template<class Complex , std::size_t level, typename Iterator >
void [casc::kneighbors](#) (Complex &F, int ring, std::set< typename Complex::template SimplexID< level > >
&nbors, Iterator begin, Iterator end)
Code for returning a set of k-ring neighbors.
- template<class Complex , class SimplexID >
void [casc::kneighbors](#) (Complex &F, SimplexID nid, int ring, std::set< SimplexID > &nbors)
Helper function to help kneighbors to deduce the integral level of SimplexID.

10.4 CASCTraversals.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *
00008  * This library is free software; you can redistribute it and/or
00009  * modify it under the terms of the GNU Lesser General Public
00010  * License as published by the Free Software Foundation; either
00011  * version 2.1 of the License, or (at your option) any later version.
00012  *
00013  * This library is distributed in the hope that it will be useful,
00014  * but WITHOUT ANY WARRANTY; without even the implied warranty of
00015  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
00016  * Lesser General Public License for more details.
00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file CASCTraversals.h
00027  * @brief Implementations of various advanced traversals such as by neighborhood
00028  * and breadth first search.
00029  */
00030
00031 #pragma once
00032
00033 #include <set>
00034 #include <vector>
00035 #include <iostream>
00036 #include <string>
00037 #include <type_traits>
00038 #include <utility>
00039 #include <casc/casc>
00040
00041 namespace casc
00042 {
00043     /// @cond detail
00044     /// Visitor design pattern helper templates
00045     namespace visitor_detail
00046     {
00047
00048     /**
00049      * @brief General template for BFS up helper.
00050      *
00051      * @tparam Visitor Type of visitor functor.
00052      * @tparam Traits Traits of the BFS traversal.
00053      * @tparam Complex Typename of the simplicial_complex.
00054      * @tparam K Current simplex dimension to traverse.
00055      */
00056     template <typename Visitor, typename Traits, typename Complex, typename K>
00057     struct BFS_Up_Node {};
00058
00059     /**
00060      * @brief Partial specialization for BFS up helper for non facet
00061      * dimensions.
00062      *
00063      * @tparam Visitor Type of visitor functor.
00064      * @tparam Traits Traits of the BFS traversal.
00065      * @tparam Complex Typename of the simplicial_complex.
00066      * @tparam k Current simplex dimension to traverse.
00067      */
00068     template <typename Visitor, typename Traits, typename Complex, std::size_t k>
00069     struct BFS_Up_Node<Visitor, Traits, Complex, std::integral_constant<std::size_t, k> >
00070     {
00071         /// Simplex dimension currently traversed
00072         static constexpr auto level = k;
00073         /// Typename of the current simplex
00074         using CurrSimplexID = typename Complex::template SimplexID<level>;
00075         /// Typename of coboundary simplices
00076         using NextSimplexID = typename Complex::template SimplexID<level+1>;
00077         /// Container to use to hold coboundary simplices for next recursion.
00078         template <typename T> using Container = typename Traits::template Container<T>;
00079
00080         /// Alias for the recursive call
00081         using BFS_Up_Node_Next = BFS_Up_Node<Visitor, Traits, Complex, std::integral_constant<std::size_t,
00082         level+1> >;

```

```

00082
00083 /**
00084  * @brief Visit simplices in the current dimension and continue.
00085  *
00086  * @param[in] v Visitor functor.
00087  * @param[in] F The simplicial_complex to traverse.
00088  * @param[in] begin Iterator to simplices to traverse.
00089  * @param[in] end Iterator to end of simplices to traverse.
00090  *
00091  * @tparam Iterator Typename of the iterator.
00092  */
00093 template <typename Iterator>
00094 static void apply(Visitor &&v, Complex &F, Iterator begin, Iterator end)
00095 {
00096     Container<NextSimplexID> next;
00097
00098     for (auto curr = begin; curr != end; ++curr)
00099     {
00100         if (v.visit(F, *curr))
00101         {
00102             F.get_cover(*curr, [&](typename Complex::KeyType a)
00103             {
00104                 auto id = F.get_simplex_up(*curr, a);
00105                 next.insert(id);
00106             });
00107         }
00108     }
00109
00110     BFS_Up_Node_Next::apply(std::forward<Visitor>(v), F, next.begin(), next.end());
00111 }
00112 };
00113
00114 /**
00115  * @brief Partial specialization for BFS up helper for facets.
00116  *
00117  * @tparam Visitor Type of visitor functor.
00118  * @tparam Traits Traits of the BFS traversal.
00119  * @tparam Complex Typename of the simplicial_complex.
00120  */
00121 template <typename Visitor, typename Traits, typename Complex>
00122 struct BFS_Up_Node<Visitor, Traits, Complex, std::integral_constant<std::size_t, Complex::topLevel> >
00123 {
00124     /// Simplex dimension of facets
00125     static constexpr auto level = Complex::topLevel;
00126     /// Typename of the current simplices
00127     using CurrSimplexID = typename Complex::template SimplexID<level>;
00128
00129     /**
00130      * @brief Visit simplices in the current dimension and continue.
00131      *
00132      * @param[in] v Visitor functor.
00133      * @param[in] F The simplicial_complex to traverse.
00134      * @param[in] begin Iterator to simplices to traverse.
00135      * @param[in] end Iterator to end of simplices to traverse.
00136      *
00137      * @tparam Iterator Typename of the iterator.
00138      */
00139     template <typename Iterator>
00140     static void apply(Visitor &&v, Complex &F, Iterator begin, Iterator end)
00141     {
00142         for (auto curr = begin; curr != end; ++curr)
00143         {
00144             v.visit(F, *curr);
00145         }
00146     }
00147 };
00148
00149
00150 /**
00151  * @brief General template for BFS down helper.
00152  *
00153  * @tparam Visitor Type of visitor functor.
00154  * @tparam Traits Traits of the BFS traversal.
00155  * @tparam Complex Typename of the simplicial_complex.
00156  * @tparam K Current simplex dimension to traverse.
00157  */
00158 template <typename Visitor, typename Traits, typename Complex, typename K>
00159 struct BFS_Down_Node {};
00160
00161 /**
00162  * @brief Partial specialization for BFS down helper for non facet
00163  * dimensions.
00164  *
00165  * @tparam Visitor Type of visitor functor.
00166  * @tparam Traits Traits of the BFS traversal.
00167  * @tparam Complex Typename of the simplicial_complex.
00168  * @tparam k Current simplex dimension to traverse.

```

```

00169 */
00170 template <typename Visitor, typename Traits, typename Complex, std::size_t k>
00171 struct BFS_Down_Node<Visitor, Traits, Complex, std::integral_constant<std::size_t, k> >
00172 {
00173     /// Simplex dimension current traversed
00174     static constexpr auto level = k;
00175     /// Typename of the current simplices
00176     using CurrSimplexID = typename Complex::template SimplexID<level>;
00177     /// Typename of boundary simplices
00178     using NextSimplexID = typename Complex::template SimplexID<level-1>;
00179     /// Container to use to hold boundary simplices for next recursion
00180     template <typename T> using Container = typename Traits::template Container<T>;
00181
00182     /// Alias for the recursive call
00183     using BFS_Down_Node_Next = BFS_Down_Node<Visitor, Traits, Complex,
std::integral_constant<std::size_t, level-1> >;
00184
00185     /**
00186      * @brief      Visit simplices in the current dimension and continue.
00187      *
00188      * @param[in]  v      Visitor functor.
00189      * @param[in]  F      The simplicial_complex to traverse.
00190      * @param[in]  begin  Iterator to simplices to traverse.
00191      * @param[in]  end    Iterator to end of simplices to traverse.
00192      *
00193      * @tparam     Iterator  Typename of the iterator.
00194      */
00195     template <typename Iterator>
00196     static void apply(Visitor &&v, Complex &F, Iterator begin, Iterator end)
00197     {
00198         Container<NextSimplexID> next;
00199
00200         for (auto curr = begin; curr != end; ++curr)
00201         {
00202             if (v.visit(F, *curr))
00203             {
00204                 F.get_name(*curr, [&](typename Complex::KeyType a)
00205                 {
00206                     auto id = F.get_simplex_down(*curr, a);
00207                     next.insert(id);
00208                 });
00209             }
00210         }
00211
00212         BFS_Down_Node_Next::apply(std::forward<Visitor>(v), F, next.begin(), next.end());
00213     }
00214 };
00215
00216 /**
00217  * @brief      Partial specialization for BFS down helper for vertices
00218  *
00219  * @tparam     Visitor  Type of visitor functor.
00220  * @tparam     Traits   Traits of the BFS traversal.
00221  * @tparam     Complex  Typename of the simplicial_complex.
00222  */
00223 template <typename Visitor, typename Traits, typename Complex>
00224 struct BFS_Down_Node<Visitor, Traits, Complex, std::integral_constant<std::size_t, 1> >
00225 {
00226     /**
00227      * @brief      Visit simplices in the current dimension and continue.
00228      *
00229      * @param[in]  v      Visitor functor.
00230      * @param[in]  F      The simplicial_complex to traverse.
00231      * @param[in]  begin  Iterator to simplices to traverse.
00232      * @param[in]  end    Iterator to end of simplices to traverse.
00233      *
00234      * @tparam     Iterator  Typename of the iterator.
00235      */
00236     template <typename Iterator>
00237     static void apply(Visitor &&v, Complex &F, Iterator begin, Iterator end)
00238     {
00239         for (auto curr = begin; curr != end; ++curr)
00240         {
00241             v.visit(F, *curr);
00242         }
00243     }
00244 };
00245
00246 /**
00247  * @deprecated
00248  * @brief      Case to catch accidents... calling down on root is bad.
00249  *
00250  * @tparam     Visitor  { description }
00251  * @tparam     Traits   { description }
00252  * @tparam     Complex  { description }
00253  */
00254 // template <typename Visitor, typename Traits, typename Complex>

```

```

00255 // struct BFS_Down_Node<Visitor, Traits, Complex,
00256 // std::integral_constant<std::size_t,0>
00257 // {
00258 //     template <typename Iterator>
00259 //         static void apply(Visitor&& v, Complex& F, Iterator begin, Iterator end)
00260 //         {}
00261 // };
00262
00263
00264 /**
00265  * @brief      General tempalte for BFS traversal across edges.
00266  *
00267  * @tparam      Visitor    Type of visitor functor.
00268  * @tparam      Traits      Traits of the BFS traversal.
00269  * @tparam      Complex     Typename of the simplicial_complex.
00270  * @tparam      K          Current simplex dimension to traverse.
00271  */
00272 template <typename Visitor, typename Traits, typename Complex, typename K>
00273 struct BFS_Edge {};
00274
00275
00276 /**
00277  * @brief      Partial specialization for BFS Edge for non facets.
00278  *
00279  * @tparam      Visitor    Type of visitor functor.
00280  * @tparam      Traits      Traits of the BFS traversal.
00281  * @tparam      Complex     Typename of the simplicial_complex.
00282  * @tparam      k          Current simplex dimension to traverse.
00283  */
00284 template <typename Visitor, typename Traits, typename Complex, std::size_t k>
00285 struct BFS_Edge<Visitor, Traits, Complex, std::integral_constant<std::size_t, k> >
00286 {
00287     /// Current simplex dimension to traverse
00288     static constexpr auto level = k;
00289     /// Typename of the current EdgeID
00290     using CurrEdgeID = typename Complex::template EdgeID<level>;
00291     /// Typename of the next EdgeID
00292     using NextEdgeID = typename Complex::template EdgeID<level+1>;
00293     /// Typename of the current SimplexID
00294     using CurrSimplexID = typename Complex::template SimplexID<level>;
00295     /// Container to use to hold coboundary edges for next recursion.
00296     template <typename T> using Container = typename Traits::template Container<T>;
00297     /// Alias for the recursive call
00298     using BFS_Edge_Next = BFS_Edge<Visitor, Traits, Complex, std::integral_constant<std::size_t,
00299 level+1> >;
00300
00301 /**
00302  * @brief      Visit simplices in the current dimension and continue.
00303  *
00304  * @param[in]   v          Visitor functor.
00305  * @param[in]   F          The simplicial_complex to traverse.
00306  * @param[in]   begin      Iterator to edges to traverse.
00307  * @param[in]   end        Iterator to end of edges to traverse.
00308  *
00309  * @tparam      Iterator    Typename of the iterator.
00310  */
00311 template <typename Iterator>
00312 static void apply(Visitor &&v, Complex &F, Iterator begin, Iterator end)
00313 {
00314     Container<NextEdgeID> next;
00315     std::vector<typename Complex::KeyType> cover;
00316
00317     for (auto curr = begin; curr != end; ++curr)
00318     {
00319         v.visit(F, *curr);
00320
00321         CurrSimplexID n = curr->up();
00322         F.get_cover(n, std::back_inserter(cover));
00323         for (auto a : cover)
00324         {
00325             NextEdgeID id = F.get_edge_up(n, a);
00326             next.insert(next.end(), id);
00327         }
00328         cover.clear();
00329     }
00330     BFS_Edge_Next::apply(std::forward<Visitor>(v), F, next.begin(), next.end());
00331 }
00332 };
00333
00334
00335 /**
00336  * @brief      Partial specialization for BFS Edge for facets.
00337  *
00338  * @tparam      Visitor    Type of visitor functor.
00339  * @tparam      Traits      Traits of the BFS traversal.
00340  * @tparam      Complex     Typename of the simplicial_complex.

```

```

00341 */
00342 template <typename Visitor, typename Traits, typename Complex>
00343 struct BFS_Edge<Visitor, Traits, Complex, std::integral_constant<std::size_t, Complex::topLevel> >
00344 {
00345     /// Simplex dimension current traversed
00346     static constexpr auto level = Complex::topLevel;
00347     /// Typename of the current edge
00348     using CurrEdgeID = typename Complex::template EdgeID<level>;
00349
00350     /**
00351     * @brief Visit the edges to facets.
00352     *
00353     * @param[in] v Visitor functor.
00354     * @param[in] F The simplicial_complex to traverse.
00355     * @param[in] begin Iterator to edges to traverse.
00356     * @param[in] end Iterator to end of edges to traverse.
00357     *
00358     * @tparam Iterator Typename of the iterator.
00359     */
00360     template <typename Iterator>
00361     static void apply(Visitor &&v, Complex &F, Iterator begin, Iterator end)
00362     {
00363         for (auto curr = begin; curr != end; ++curr)
00364         {
00365             v.visit(F, *curr);
00366         }
00367     }
00368 };
00369
00370 /// Allow repeat visits of simplices for BFS visits.
00371 struct BFS_Repeat_Node_traits
00372 {
00373     /// Use a vector to allow duplicates
00374     template <typename T> using Container = std::vector<T>;
00375 };
00376
00377 /// No repeat traits for BFS simplex visitor.
00378 struct BFS_NoRepeat_Node_Traits
00379 {
00380     /// Use a NodeSet to avoid duplicates
00381     template <typename T> using Container = NodeSet<T>;
00382 };
00383
00384 /// No repeat traits for BFS edge visitor.
00385 struct BFS_NoRepeat_Edge_Traits
00386 {
00387     /// Use a NodeSet to avoid duplicates.
00388     template <typename T> using Container = NodeSet<T>;
00389     // template <typename Complex, typename SimplexID> auto node_next(Complex F,
00390     // SimplexID s);
00391 };
00392 } // End namespace visitor_detail
00393 /// @endcond
00394
00395 /**
00396 * @brief Traverse BFS up the complex and apply a visitor function to each
00397 * simplex visited.
00398 *
00399 * @param[in] v Visitor functor to apply.
00400 * @param[in] F The simplicial_complex to traverse.
00401 * @param[in] s The simplex to start at.
00402 *
00403 * @tparam Visitor Typename of the functor.
00404 * @tparam SimplexID Typename of the simplex.
00405 */
00406 template <typename Visitor, typename SimplexID>
00407 void visit_BFS_up(Visitor &&v, typename SimplexID::complex &F, SimplexID s)
00408 {
00409     namespace cvd = visitor_detail;
00410     cvd::BFS_Up_Node<Visitor, cvd::BFS_NoRepeat_Node_Traits, typename SimplexID::complex,
00411         std::integral_constant<std::size_t, SimplexID::level> >::apply(
00412         std::forward<Visitor>(v), F, &s, &s+1);
00413 }
00414
00415 /**
00416 * @brief Traverse BFS down the complex and apply a visitor function to
00417 * each
00418 * simplex visited.
00419 *
00420 * @param[in] v Visitor functor to apply.
00421 * @param[in] F The simplicial_complex to traverse.
00422 * @param[in] s The simplex to start at.
00423 *
00424 * @tparam Visitor Typename of the functor.
00425 * @tparam SimplexID Typename of the simplex.
00426 */
00427 template <typename Visitor, typename SimplexID>

```

```

00428 void visit_BFS_down(Visitor &&v, typename SimplexID::complex &F, SimplexID s)
00429 {
00430     namespace cvd = visitor_detail;
00431     cvd::BFS_Down_Node<Visitor, cvd::BFS_NoRepeat_Node_Traits, typename SimplexID::complex,
00432         std::integral_constant<std::size_t, SimplexID::level> >::apply(
00433         std::forward<Visitor>(v), F, &s, &s+1);
00434 }
00435
00436 /**
00437  * @brief      Traverse across edges BFS.
00438  *
00439  * @param[in]  v          Visitor functor to apply.
00440  * @param      F          The simplicial_complex to traverse.
00441  * @param[in]  s          The edge to start at.
00442  *
00443  * @tparam     Visitor    Typename of the functor.
00444  * @tparam     EdgeID     Typename of the edge.
00445  */
00446 template <typename Visitor, typename EdgeID>
00447 void edge_up(Visitor &&v, typename EdgeID::complex &F, EdgeID s)
00448 {
00449     namespace cvd = visitor_detail;
00450     cvd::BFS_Edge<Visitor, cvd::BFS_NoRepeat_Edge_Traits, typename EdgeID::complex,
00451         std::integral_constant<std::size_t, EdgeID::level> >::apply(
00452         std::forward<Visitor>(v), F, &s, &s+1);
00453 }
00454
00455
00456 /**
00457  * @brief      Push the immediate face neighbors into the provided iterator.
00458  *
00459  * This function gets the set of neighbors which share a common face. We
00460  * compute this by traversing to all faces of the simplex of interest. Then we
00461  * get all cofaces of this set. Depending on the type of iterator passed,
00462  * duplicate simplices will be included or excluded. Note that this is the
00463  * traditional definition of neighbor. For example, faces which share an edge
00464  * are neighbors.
00465  *
00466  * @param      F          The simplicial complex
00467  * @param[in]  nid        Simplex to get neighbors of.
00468  * @param[in]  iter       The iterator to push members into.
00469  *
00470  * @tparam     Complex    Type of the simplicial complex
00471  * @tparam     level      The integral level of the node
00472  * @tparam     InsertIter Typename of the iterator.
00473  */
00474 template <class Complex, std::size_t level, class InsertIter>
00475 void neighbors(Complex &F, typename Complex::template SimplexID<level> nid, InsertIter iter)
00476 {
00477     for (auto a : F.get_name(nid))
00478     {
00479         auto id = F.get_simplex_down(nid, a);
00480         for (auto b : F.get_cover(id))
00481         {
00482             auto nbor = F.get_simplex_up(id, b);
00483             if (nbor != nid)
00484             {
00485                 *iter++ = nbor;
00486             }
00487         }
00488     }
00489 }
00490
00491 /**
00492  * @brief      This is a helper function to assist neighbors to automatically
00493  * deduce the integral level.
00494  *
00495  * @param      F          The simplicial complex.
00496  * @param[in]  nid        Simplex to get neighbors of.
00497  * @param[in]  iter       The iterator to push members into.
00498  *
00499  * @tparam     Complex    Type of the simplicial complex
00500  * @tparam     level      The integral level of the node
00501  * @tparam     InsertIter Typename of the iterator.
00502  */
00503 template <class Complex, class SimplexID, class InsertIter>
00504 void neighbors(Complex &F, SimplexID nid, InsertIter iter)
00505 {
00506     neighbors<Complex, SimplexID::level, InsertIter>(F, nid, iter);
00507 }
00508
00509 /**
00510  * @brief      Push the immediate coface neighbors into the provided iterator.
00511  *
00512  * @param      F          The simplicial complex.
00513  * @param[in]  nid        Simplex to get neighbors of.
00514  * @param[in]  iter       The iterator to push members into.

```

```

00515 *
00516 * @tparam Complex      Type of the simplicial complex
00517 * @tparam level        The integral level of the node
00518 * @tparam InsertIter   Typename of the iterator.
00519 */
00520 template <class Complex, std::size_t level, class InsertIter>
00521 void neighbors_up(Complex &F, typename Complex::template SimplexID<level> nid, InsertIter iter)
00522 {
00523     for (auto a : F.get_cover(nid))
00524     {
00525         auto id = F.get_simplex_up(nid, a);
00526         for (auto b : F.get_name(id))
00527         {
00528             auto nbor = F.get_simplex_down(id, b);
00529             if (nbor != nid)
00530             {
00531                 *iter++ = nbor;
00532             }
00533         }
00534     }
00535 }
00536
00537 /**
00538 * @brief          This is a helper function to assist neighbors to automatically
00539 *                  deduce the integral level.
00540 *
00541 * @tparam F        The simplicial complex.
00542 * @tparam[in] nid   Simplex to get neighbors of.
00543 * @tparam[in] iter   The iterator to push members into.
00544 *
00545 * @tparam Complex  Type of the simplicial complex
00546 * @tparam level    The integral level of the node
00547 * @tparam InsertIter Typename of the iterator.
00548 */
00549 template <class Complex, class SimplexID, class InsertIter>
00550 void neighbors_up(Complex &F, SimplexID nid, InsertIter iter)
00551 {
00552     neighbors_up<Complex, SimplexID::level, InsertIter>(F, nid, iter);
00553 }
00554
00555
00556
00557 /**
00558 * @brief          Code for returning a set of k-ring neighbors.
00559 *
00560 * @tparam[in] F    The simplicial_complex to traverse.
00561 * @tparam[in] ring  The number of rings of neighbors to collect.
00562 * @tparam[out] nbors Set of previously seen simplices.
00563 * @tparam[in] begin The begin
00564 * @tparam[in] end   The end
00565 *
00566 * @tparam Complex  Typename of the simplicial_complex.
00567 * @tparam level    Simplex dimension of the simplex and neighbors.
00568 * @tparam Iterator Iterator { description }
00569 */
00570 template <class Complex, std::size_t level, typename Iterator>
00571 void kneighbors_up(Complex &F, int ring, std::set<typename Complex::template SimplexID<level> > &nbors,
00572                  Iterator begin, Iterator end)
00573 {
00574     if (ring == 0)
00575     {
00576         return;
00577     }
00578     std::set<typename Complex::template SimplexID<level> > next;
00579     for (auto nid = begin; nid != end; ++nid)
00580     {
00581         for (auto a : F.get_cover(*nid))
00582         {
00583             auto id = F.get_simplex_up(*nid, a);
00584             for (auto b : F.get_name(id))
00585             {
00586                 auto nbor = F.get_simplex_down(id, b);
00587                 if (nbors.insert(nbor).second)
00588                 {
00589                     next.insert(nbor);
00590                 }
00591             }
00592         }
00593     }
00594     return kneighbors_up<Complex, level>(F, ring-1, nbors, next.begin(), next.end());
00595 }
00596
00597
00598
00599
00600 /**
00601 * @brief          Helper function to help kneighbors_up to deduce the integral

```

```

00602 *           level of SimplexID.
00603 *
00604 * @param[in] F           The simplicial complex
00605 * @param[in] nid         Simplex of interest to get the nieghbors of.
00606 * @param[in] ring        The number of rings to include as a neighbor.
00607 * @param[out] nbors      Set of neighbors to populate.
00608 *
00609 * @tparam      Complex    Typename of the complex.
00610 * @tparam      SimplexID  Typename of the SimplexID.
00611 */
00612 template <class Complex, class SimplexID>
00613 void kneighbors_up(Complex &F, SimplexID nid, int ring, std::set<SimplexID> &nbors)
00614 {
00615     nbors.insert(nid);
00616     std::set<SimplexID> next {
00617         nid
00618     };
00619     kneighbors_up<Complex, SimplexID::level>(F, ring, nbors, next.begin(), next.end());
00620     nbors.erase(nid);
00621 }
00622
00623
00624 /**
00625 * @brief      Code for returning a set of k-ring neighbors.
00626 *
00627 * @param[in] F           The simplicial_complex to traverse.
00628 * @param[in] ring        The number of rings of neighbors to collect.
00629 * @param[out] nbors      Set of previously seen simplices.
00630 * @param[in] begin       The begin
00631 * @param[in] end         The end
00632 *
00633 * @tparam      Complex    Typename of the simplicial_complex.
00634 * @tparam      level      Simplex dimension of the simplex and neighbors.
00635 * @tparam      Iterator   { description }
00636 */
00637 template <class Complex, std::size_t level, typename Iterator>
00638 void kneighbors(Complex &F,
00639                int ring,
00640                std::set<typename Complex::template SimplexID<level> > &nbors,
00641                Iterator begin,
00642                Iterator end)
00643 {
00644     if (ring == 0)
00645     {
00646         return;
00647     }
00648     std::set<typename Complex::template SimplexID<level> > next;
00649     for (auto nid = begin; nid != end; ++nid)
00650     {
00651         for (auto a : F.get_name(*nid))
00652         {
00653             auto id = F.get_simplex_down(*nid, a);
00654             for (auto b : F.get_cover(id))
00655             {
00656                 auto nbor = F.get_simplex_up(id, b);
00657                 if (nbors.insert(nbor).second)
00658                 {
00659                     next.insert(nbor);
00660                 }
00661             }
00662         }
00663     }
00664     return kneighbors_up<Complex, level>(F, ring-1, nbors, next.begin(), next.end());
00665 }
00666
00667 /**
00668 * @brief      Helper function to help kneighbors to deduce the integral
00669 *             level of SimplexID.
00670 *
00671 * @param[in] F           The simplicial complex
00672 * @param[in] nid         Simplex of interest to get the nieghbors of.
00673 * @param[in] ring        The number of rings to include as a neighbor.
00674 * @param[out] nbors      Set of neighbors to populate.
00675 *
00676 * @tparam      Complex    Typename of the complex.
00677 * @tparam      SimplexID  Typename of the SimplexID.
00678 */
00679 template <class Complex, class SimplexID>
00680 void kneighbors(Complex &F, SimplexID nid, int ring, std::set<SimplexID> &nbors)
00681 {
00682     nbors.insert(nid);
00683     std::set<SimplexID> next {
00684         nid
00685     };
00686     kneighbors<Complex, SimplexID::level>(F, ring, nbors, next.begin(), next.end());
00687     nbors.erase(nid);
00688 }

```

```

00689
00690 } // End namespace casc
00691
00692
00693 // namespace visitor_detail
00694 // {
00695 // template <typename Visitor, typename Complex, std::size_t k, std::size_t
00696 // ring>
00697 // struct Neighbors_Up_Node
00698 // {
00699 //     static constexpr auto level = k;
00700 //     using SimplexID = typename Complex::template SimplexID<level>;
00701
00702 //     using Neighbors_Up_Node_Next =
00703 // Neighbors_Up_Node<Visitor,Complex,level,ring-1>;
00704
00705 //     template <typename Iterator>
00706 //     static void apply(Visitor&& v, Complex& F, NodeSet<SimplexID>& nodes,
00707 // Iterator begin, Iterator end)
00708 //     {
00709 //         NodeSet<SimplexID> next;
00710
00711 //         for(auto curr = begin; curr != end; ++curr)
00712 //         {
00713 //             if(v.visit(F, *curr))
00714 //             {
00715 //                 for(auto a : F.get_cover(*curr))
00716 //                 {
00717 //                     auto id = F.get_simplex_up(*curr,a);
00718 //                     for(auto b : F.get_name(id))
00719 //                     {
00720 //                         auto nbor = F.get_simplex_down(id,b);
00721 //                         if(nodes.insert(nbor).second)
00722 //                         {
00723 //                             next.insert(nbor);
00724 //                         }
00725 //                     }
00726 //                 }
00727 //             }
00728 //         }
00729
00730 //         Neighbors_Up_Node_Next::apply(std::forward<Visitor>(v), F, nodes,
00731 // next.begin(), next.end());
00732 //     }
00733 // };
00734
00735 // template <typename Visitor, typename Complex, std::size_t k>
00736 // struct Neighbors_Up_Node<Visitor, Complex, k, 0>
00737 // {
00738 //     static constexpr auto level = k;
00739 //     using SimplexID = typename Complex::template SimplexID<level>;
00740
00741 //     template <typename Iterator>
00742 //     static void apply(Visitor&& v, Complex& F, NodeSet<SimplexID>& nodes,
00743 // Iterator begin, Iterator end)
00744 //     {
00745 //         for(auto curr = begin; curr != end; ++curr)
00746 //         {
00747 //             v.visit(F, *curr);
00748 //         }
00749 //     }
00750 // };
00751
00752 // template <typename Visitor, typename Complex, std::size_t k, std::size_t
00753 // ring>
00754 // struct Neighbors_Down_Node
00755 // {
00756 //     static constexpr auto level = k;
00757 //     using SimplexID = typename Complex::template SimplexID<level>;
00758
00759 //     using Neighbors_Down_Node_Next = Neighbors_Down_Node<Visitor,Complex,
00760 // level,ring-1>;
00761
00762 //     template <typename Iterator>
00763 //     static void apply(Visitor&& v, Complex& F, NodeSet<SimplexID>& nodes,
00764 // Iterator begin, Iterator end)
00765 //     {
00766 //         NodeSet<SimplexID> next;
00767
00768 //         for(auto curr = begin; curr != end; ++curr)
00769 //         {
00770 //             if(v.visit(F, *curr))
00771 //             {
00772 //                 for(auto a : F.get_name(*curr))
00773 //                 {
00774 //                     auto id = F.get_simplex_down(*curr,a);
00775 //                     for(auto b : F.get_cover(id))

```

```

00776 //             {
00777 //                 auto nbor = F.get_simplex_up(id,b);
00778 //                 if(nodes.insert(nbor).second)
00779 //                     {
00780 //                         next.insert(nbor);
00781 //                     }
00782 //             }
00783 //         }
00784 //     }
00785 // }
00786
00787 //         Neighbors_Down_Node_Next::apply(std::forward<Visitor>(v), F, nodes,
00788 // next.begin(), next.end());
00789 //     }
00790 // };
00791
00792 // template <typename Visitor, typename Complex, std::size_t k>
00793 // struct Neighbors_Down_Node<Visitor, Complex, k, 0>
00794 // {
00795 //     static constexpr auto level = k;
00796 //     using SimplexID = typename Complex::template SimplexID<level>;
00797
00798 //     template <typename Iterator>
00799 //     static void apply(Visitor&& v, Complex& F, NodeSet<SimplexID>& nodes,
00800 // Iterator begin, Iterator end)
00801 //     {
00802 //         for(auto curr = begin; curr != end; ++curr)
00803 //         {
00804 //             v.visit(F, *curr);
00805 //         }
00806 //     }
00807 // };
00808 // }
00809
00810
00811 // template <std::size_t rings, typename Visitor, typename SimplexID>
00812 // void visit_neighbors_up(Visitor&& v, typename SimplexID::complex& F,
00813 // SimplexID s)
00814 // {
00815 //     NodeSet<SimplexID> nodes{s};
00816 //     namespace cvd = visitor_detail;
00817 //     cvd::Neighbors_Up_Node<Visitor,typename
00818 // SimplexID::complex,SimplexID::level,rings>::apply(
00819 //         std::forward<Visitor>(v),F,nodes,&s,&s+1);
00820 // }
00821
00822 // template <std::size_t rings, typename Visitor, typename SimplexID>
00823 // void visit_neighbors_down(Visitor&& v, typename SimplexID::complex& F,
00824 // SimplexID s)
00825 // {
00826 //     NodeSet<SimplexID> nodes{s};
00827 //     namespace cvd = visitor_detail;
00828 //     cvd::Neighbors_Down_Node<Visitor,typename
00829 // SimplexID::complex,SimplexID::level,rings>::apply(
00830 //         std::forward<Visitor>(v),F,nodes,&s,&s+1);
00831 // }

```

10.5 include/casc/decimate.h File Reference

Meta-data aware decimation functions.

```

#include <typeinfo>
#include "SimplexSet.h"
#include "SimplexMap.h"
#include "CASCTraversals.h"
#include "CASCFunctions.h"

```

Namespaces

- namespace [casc](#)

Namespace for everything CASC.

Functions

- `template<typename Complex >`
`void casc::perform_removal (Complex &F, casc::SimplexSet< Complex > &S)`
Remove simplex in SimplexSet S from complex F.
- `template<typename Complex >`
`void casc::perform_insertion (Complex &F, typename decimation_detail::SimplexDataSet< Complex >::type &S)`
Insert all simplices in SimplexSet S into complex F
- `template<typename Complex , template< typename > class Callback>`
`void casc::run_user_callback (Complex &F, casc::SimplexMap< Complex > &S, Callback< Complex > &&clbk, typename decimation_detail::SimplexDataSet< Complex >::type &rv)`
Run the user specified callback function.
- `template<typename Complex , typename Simplex , template< typename > class Callback>`
`void casc::decimate (Complex &F, Simplex s, Callback< Complex > &&clbk)`
Decimate a simplex of any dimension while considering any meta-data stores on decimated simplices.
- `template<typename Complex , typename Simplex >`
`Complex::KeyType casc::decimateFirstHalf (Complex &F, Simplex s, SimplexMap< Complex > &simplexMap)`
Given a simplex to decimate generate a pre-post mapping.
- `template<typename Complex >`
`void casc::decimateBackHalf (Complex &F, SimplexMap< Complex > &simplexMap, typename decimation_detail::SimplexDataSet< Complex >::type &rv)`
Given a simplexMap and mapped resulting data execute the decimation.

10.6 decimate.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *
00008  * This library is free software; you can redistribute it and/or
00009  * modify it under the terms of the GNU Lesser General Public
00010  * License as published by the Free Software Foundation; either
00011  * version 2.1 of the License, or (at your option) any later version.
00012  *
00013  * This library is distributed in the hope that it will be useful,
00014  * but WITHOUT ANY WARRANTY; without even the implied warranty of
00015  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
00016  * Lesser General Public License for more details.
00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file decimate.h
00027  * @brief Meta-data aware decimation functions.
00028  */
00029
00030 #pragma once
00031
00032 #include <typeinfo>
00033
00034 #include "SimplexSet.h"
00035 #include "SimplexMap.h"
00036 #include "CASCTraversals.h"
00037 #include "CASCFunctions.h"
00038
00039 #if __has_cpp_attribute(maybe_unused)

```

```

00040 #define MAYBE_UNUSED [[maybe_unused]]
00041 #else
00042 #define MAYBE_UNUSED
00043 #endif
00044
00045 namespace casc
00046 {
00047     /// @cond detail
00048     /// Namespace for decimation related helpers
00049     namespace decimation_detail
00050     {
00051         /**
00052          * @brief      A multi-vector of simplex, data pairs.
00053          *
00054          * @tparam      Complex  Typename of the simplicial_complex.
00055          */
00056         template <typename Complex>
00057         struct SimplexDataSet
00058         {
00059             /// Typename of vertices
00060             using KeyType = typename Complex::KeyType;
00061
00062             /**
00063              * @brief      Data type makes a pair of array of keys to data type.
00064              *
00065              * @tparam      k      Dimension of simplex.
00066              * @tparam      T      Typename of the data.
00067              */
00068             template <std::size_t k, typename T>
00069             struct DataType
00070             {
00071                 /// Pair of array to type
00072                 using type = std::pair<std::array<KeyType, k>, T>;
00073             };
00074
00075             /**
00076              * @brief      DataType for simplices with no data.
00077              *
00078              * @tparam      k      Dimension of the simplex.
00079              */
00080             template <std::size_t k>
00081             struct DataType<k, void>
00082             {
00083                 /// Array of keys
00084                 using type = std::array<KeyType, k>;
00085             };
00086
00087             /// Template to resolve NodeData types for DataType.
00088             template <std::size_t j>
00089             using DataSet = typename DataType<j, typename Complex::template NodeData<j> >::type;
00090             /// Sequence of compile time integers.
00091             using LevelIndex = typename std::make_index_sequence<Complex::numLevels>;
00092             /// Tuple of DataSets corresponding to an integral level.
00093             using SimplexIDLevel = typename util::int_type_map<std::size_t,
00094                                                         std::tuple, LevelIndex, DataSet>::type;
00095
00096             /// Helper vector definition for util.
00097             template <class T> using vector = std::vector<T>;
00098             /// Vector of DataTypes for each integral level.
00099             using type = typename util::type_map<SimplexIDLevel, vector>::type;
00100         };
00101
00102         /**
00103          * @brief      Struct functional to get the complete neighborhood around a
00104          *              simplex.
00105          *
00106          * @tparam      Complex  Type of simplicial complex
00107          */
00108         template <typename Complex>
00109         struct GetCompleteNeighborhood
00110         {
00111             /// Alias for SimplexSet
00112             using SimplexSet = typename casc::SimplexSet<Complex>;
00113
00114             /**
00115              * @brief      Constructor
00116              *
00117              * @param      p      SimplexSet to use to pass results back
00118              */
00119             GetCompleteNeighborhood(SimplexSet* p) : pLevels(p) {}
00120
00121             /**
00122              * @brief      Continue traversing, to the next level
00123              *
00124              * @return      True, continue the BFS
00125              */
00126             template <std::size_t level>
00127             bool visit(Complex &, typename Complex::template SimplexID<level>)

```

```

00127     {
00128         return true;
00129     }
00130
00131     /**
00132     * @brief      Terminal case, go back up (visit_node_up).
00133     *
00134     * @param      F          Simplicial Complex
00135     * @param[in]   s          Simplex of interest
00136     *
00137     * @return      False, stop the BFS traversal
00138     */
00139     bool visit(Complex &F, typename Complex::template SimplexID<1> s)
00140     {
00141         visit_BFS_up(
00142             func_detail::SimplexAggregator<Complex>(pLevels), F, s);
00143         return false;
00144     }
00145
00146     private:
00147         /// Pointer to SimplexSet to store the complete neighborhood.
00148         SimplexSet* pLevels;
00149 };
00150
00151 /**
00152 * @brief      Move found simplices from pLevels to pGrab.
00153 *
00154 * @tparam      Complex      Typename of Simplicial Complex
00155 */
00156 template <typename Complex>
00157 struct GrabVisitor
00158 {
00159     /// Alias for SimplexSet
00160     using SimplexSet = typename csc::SimplexSet<Complex>;
00161
00162     /**
00163     * @brief      Constructor
00164     *
00165     * @param      p          SimplexSet with complete neighborhood.
00166     * @param      grab       SimplexSet to store grabbed simplices.
00167     */
00168     GrabVisitor(SimplexSet* p, SimplexSet* grab) : pLevels(p), pGrab(grab) {}
00169
00170     template <std::size_t level>
00171     bool visit(Complex &, typename Complex::template SimplexID<level> s)
00172     {
00173         if (pLevels->find(s) != pLevels->template end<level>())
00174         {
00175             //std::cout << "GrabVisitor (found): " << s << std::endl;
00176             pLevels->erase(s);
00177             pGrab->insert(s);
00178             return true;
00179         }
00180         else
00181         {
00182             return false;
00183         }
00184     }
00185
00186     private:
00187         /// SimplexSet with the complete neighborhood
00188         SimplexSet* pLevels;
00189         /// SimplexSet with grabbed simplices
00190         SimplexSet* pGrab;
00191 };
00192
00193 template <typename Complex, std::size_t BaseLevel>
00194 struct InnerVisitor
00195 {
00196     using SimplexSet = typename csc::SimplexSet<Complex>;
00197     using SimplexMap = typename csc::SimplexMap<Complex>;
00198     using Simplex = typename Complex::template SimplexID<BaseLevel>;
00199     using KeyType = typename Complex::KeyType;
00200
00201     InnerVisitor(SimplexSet* p, Simplex s, KeyType np, SimplexMap* rv)
00202         : pLevels(p), simplex(s), new_point(np), data(rv) {}
00203
00204     /**
00205     * @brief      Overloaded visit function
00206     *
00207     * @param      F          { parameter_description }
00208     * @param[in]   <unnamed> { parameter_description }
00209     *
00210     * @tparam      OldLevel   { description }
00211     *
00212     * @return      { description_of_the_return_value }
00213     */

```

```

00214     template <std::size_t OldLevel>
00215     bool visit(Complex &F, typename Complex::template SimplexID<OldLevel> s)
00216     {
00217         constexpr std::size_t NewLevel = OldLevel - BaseLevel + 1;
00218
00219         if (pLevels->find(s) != pLevels->template end<OldLevel>())
00220         {
00221             //std::cout << "InnerVisitor (found): " << s << std::endl;
00222             std::array<KeyType, OldLevel> old_name = F.get_name(s);
00223             std::array<KeyType, BaseLevel> base_name = F.get_name(simplex);
00224             using NewArrayType = std::array<KeyType, NewLevel>;
00225             NewArrayType new_name;
00226
00227             std::size_t i = 0;    // new_name
00228             std::size_t j = 0;    // old_name
00229             std::size_t k = 0;    // base_name
00230
00231             new_name[i++] = new_point;
00232
00233             // Remove base_name from old_name and append to new_name
00234             while (i < NewLevel)
00235             {
00236                 if (k >= BaseLevel) {
00237                     // append to new_name and increment
00238                     new_name[i++] = old_name[j++];
00239                     continue;
00240                 }
00241                 if (base_name[k] == old_name[j])
00242                 {
00243                     // if equivalent than skip the value
00244                     ++j; ++k;
00245                 }
00246                 else
00247                 {
00248                     // append to new_name and increment
00249                     new_name[i++] = old_name[j++];
00250                 }
00251             }
00252
00253             SimplexSet grab;
00254             visit_BFS_down(GrabVisitor<Complex>(pLevels, &grab), F, s);
00255
00256             auto &levelMap = casc::get<NewLevel>(*data);
00257             auto it = levelMap.find(new_name);
00258             if (it != levelMap.end())
00259             {
00260                 it->second.insert(grab);
00261             }
00262             else
00263             {
00264                 MAYBE_UNUSED auto ret = levelMap.insert(
00265                     std::pair<NewArrayType, SimplexSet>(new_name, grab));
00266                 assert(ret.second);
00267             }
00268         }
00269         return true;
00270     }
00271
00272 private:
00273     SimplexSet* pLevels;
00274     Simplex simplex;
00275     KeyType new_point;
00276     SimplexMap* data;
00277 };
00278
00279
00280 template <typename Complex>
00281 struct MainVisitor
00282 {
00283     using SimplexSet = typename casc::SimplexSet<Complex>;
00284     using SimplexMap = typename casc::SimplexMap<Complex>;
00285     using KeyType = typename Complex::KeyType;
00286
00287     MainVisitor(SimplexSet* p, KeyType np, SimplexMap* rv)
00288         : pLevels(p), new_point(np), data(rv) {}
00289
00290     template <std::size_t level>
00291     bool visit(Complex &F, typename Complex::template SimplexID<level> s)
00292     {
00293         //std::cout << "MainVisitor: " << s << std::endl;
00294         visit_BFS_up(
00295             InnerVisitor<Complex, level>(
00296                 pLevels, s, new_point, data),
00297                 F, s);
00298         return true;
00299     }
00300

```

```

00301     private:
00302         SimplexSet* pLevels;
00303         KeyType      new_point;
00304         SimplexMap* data;
00305 };
00306
00307 template <typename Complex, template<typename> class Callback>
00308 struct RunCallback
00309 {
00310     using SimplexMap = typename casc::SimplexMap<Complex>;
00311     using SimplexSet = typename casc::SimplexSet<Complex>;
00312     using SimplexDataSet = typename SimplexDataSet<Complex>::type;
00313     using KeyType = typename Complex::KeyType;
00314     template <std::size_t level>
00315     using DataType = typename Complex::template NodeData<level>;
00316
00317     template <std::size_t k, typename ReturnType>
00318     struct PerformCallback
00319     {
00320     {
00321         static void apply(Complex &F, Callback<Complex> &&clbk,
00322                         SimplexDataSet &rv,
00323                         const std::array<KeyType, k> &new_name,
00324                         const SimplexSet &merged)
00325         {
00326             ReturnType rval = clbk(F, new_name, merged);
00327             std::get<k>(rv).push_back(std::make_pair(new_name, rval));
00328         }
00329     };
00330
00331     template <std::size_t k>
00332     struct PerformCallback<k, void>
00333     {
00334         static void apply(Complex &F, Callback<Complex> &&clbk,
00335                         SimplexDataSet &rv,
00336                         const std::array<KeyType, k> &new_name,
00337                         const SimplexSet &merged)
00338         {
00339             clbk(F, new_name, merged);
00340             std::get<k>(rv).push_back(new_name);
00341         }
00342     };
00343
00344     template <std::size_t k>
00345     static void apply(Complex &F, SimplexMap &S,
00346                     Callback<Complex> &&clbk, SimplexDataSet &rv)
00347     {
00348     {
00349         auto &levelMap = casc::get<k>(S);
00350         for (auto s : levelMap)
00351         {
00352             PerformCallback<k, DataType<k> >::apply(F, std::forward<Callback<Complex> >(clbk),
00353             rv, s.first, s.second);
00354         }
00355     }
00356 };
00357
00358 template <typename Complex>
00359 struct PerformRemoval
00360 {
00361     template <std::size_t k>
00362     static void apply(Complex &F, casc::SimplexSet<Complex> &S)
00363     {
00364         for (auto curr : casc::get<k>(S))
00365             F.remove(curr);
00366     }
00367 };
00368
00369 template <typename Complex>
00370 struct PerformInsertion {
00371     using KeyType = typename Complex::KeyType;
00372
00373     template <std::size_t k, class T>
00374     static void insert(Complex &F, std::pair<std::array<KeyType, k>, T> P)
00375     {
00376     {
00377         F.insert(P.first, P.second);
00378     }
00379
00380     template <std::size_t k>
00381     static void insert(Complex &F, std::array<KeyType, k> A)
00382     {
00383         F.insert(A);
00384     }
00385
00386     template <std::size_t k>
00387     static void apply(Complex
                                &F,

```

```

00388             typename SimplexDataSet<Complex>::type &data)
00389     {
00390         for (auto curr : std::get<k>(data))
00391         {
00392             insert(F, curr);
00393         }
00394     }
00395 };
00396
00397 template <typename Complex>
00398 struct DoomedHelper
00399 {
00400     template <std::size_t k>
00401     static void apply(SimplexSet<Complex> &doomed, SimplexMap<Complex> &simplexMap){
00402         auto s = casc::get<k>(simplexMap);
00403         for (auto map : s){
00404             doomed.insert(map.second);
00405         }
00406     }
00407 };
00408 } // end namespace decimation_detail
00409 /// @endcond
00410
00411 /**
00412  * @brief      Remove simplex in SimplexSet S from complex F
00413  *
00414  * @param      F      The simplicial_complex to remove from.
00415  * @param      S      SimplexSet of simplices to remove.
00416  * @tparam     Complex Typename of complex
00417  */
00418 template <typename Complex>
00419 void perform_removal(Complex &F, casc::SimplexSet<Complex> &S)
00420 {
00421     using SimplexSet = typename casc::SimplexSet<Complex>;
00422     using LevelIndex = typename SimplexSet::cRevIndex;
00423     util::int_for_each<std::size_t, LevelIndex>(
00424         decimation_detail::PerformRemoval<Complex>(), F, S);
00425 }
00426
00427 /**
00428  * @brief      Insert all simplices in SimplexSet 'S' into complex 'F'
00429  *
00430  * @param      F      The simplicial_complex to insert into.
00431  * @param      S      SimplexSet of simplices to insert.
00432  * @tparam     Complex Typename of complex
00433  */
00434 template <typename Complex>
00435 void perform_insertion(Complex &F,
00436     typename decimation_detail::SimplexDataSet<Complex>::type &S)
00437 {
00438     using SimplexSet = typename casc::SimplexSet<Complex>;
00439     using LevelIndex = typename SimplexSet::cLevelIndex;
00440     util::int_for_each<std::size_t, LevelIndex>(
00441         decimation_detail::PerformInsertion<Complex>(), F, S);
00442 }
00443
00444 /**
00445  * @brief      Run the user specified callback function
00446  *
00447  * @param[in]  F      The simplicial_complex
00448  * @param[in]  S      SimplexMap of
00449  * @param[in]  clbk   User specified callback functor
00450  * @param[out] rv     Multi-vector to place results.
00451  * @tparam     Complex Typename of the simplicial_complex
00452  * @tparam     Callback Typename of the template callback functor
00453  */
00454 template <typename Complex, template<typename> class Callback>
00455 void run_user_callback(Complex &F,
00456     casc::SimplexMap<Complex> &S,
00457     Callback<Complex> &&clbk,
00458     typename decimation_detail::SimplexDataSet<Complex>::type &rv)
00459 {
00460     using SimplexMap = typename casc::SimplexMap<Complex>;
00461     using LevelIndex = typename SimplexMap::cLevelIndex;
00462     util::int_for_each<std::size_t, LevelIndex>(
00463         decimation_detail::RunCallback<Complex, Callback>(),
00464         F, S, std::forward<Callback<Complex>>(clbk), rv);
00465 }
00466
00467 /**
00468  * @brief      Decimate a simplex of any dimension while considering any

```

```

00475 *          meta-data stores on decimated simplices.
00476 *
00477 * @param[in] F          simplicial_complex to operate on.
00478 * @param[in] s          Simplex to decimate.
00479 * @param[in] clbk       Callback function to map meta-data
00480 *
00481 * @tparam Complex       Typename of the simplicial_complex
00482 * @tparam Simplex       Typename of the simplex
00483 * @tparam Callback      Typename of the template template callback functor
00484 */
00485 template <typename Complex, typename Simplex, template<typename> class Callback>
00486 void decimate(Complex &F, Simplex s, Callback<Complex> &&clbk)
00487 {
00488     /// Alias for SimplexSet
00489     using SimplexSet = typename csc::SimplexSet<Complex>;
00490     /// Alias for SimplexMap
00491     using SimplexMap = typename csc::SimplexMap<Complex>;
00492
00493     // Create the vertex to replace 's'
00494     typename Complex::KeyType np = F.add_vertex();
00495     SimplexSet nbhd;
00496     SimplexMap simplexMap;
00497
00498     // Get the complete neighborhood
00499     visit_BFS_down(
00500         decimation_detail::GetCompleteNeighborhood<Complex>(&nbhd),
00501         F, s);
00502
00503     SimplexSet doomed = nbhd; // Backup the neighborhood
00504     // Call MainVisitor -> InnerVisitor -> GrabVisitor sequence
00505     visit_BFS_down(
00506         decimation_detail::MainVisitor<Complex>(&nbhd, np, &simplexMap),
00507         F, s);
00508
00509     // Run the user specified callback
00510     typename decimation_detail::SimplexDataSet<Complex>::type rv;
00511     run_user_callback(F, simplexMap, std::forward<Callback<Complex>>(>(clbk), rv);
00512     perform_removal(F, doomed); // Remove simplices in the neighborhood
00513     perform_insertion(F, rv); // Insert new simplices
00514 }
00515
00516 /**
00517 * @brief      Given a simplex to decimate generate a pre-post mapping
00518 *
00519 * @param[in] F          simplicial_complex to operate on.
00520 * @param[in] s          Simplex to decimate.
00521 * @param      simplexMap The simplex map to populate
00522 *
00523 * @tparam Complex       Typename of the simplicial_complex
00524 * @tparam Simplex       Typename of the simplex
00525 */
00526 template <typename Complex, typename Simplex>
00527 typename Complex::KeyType decimateFirstHalf(Complex &F, Simplex s, SimplexMap<Complex> &simplexMap)
00528 {
00529     /// Alias for SimplexSet
00530     using SimplexSet = typename csc::SimplexSet<Complex>;
00531
00532     // Create the vertex to replace 's'
00533     typename Complex::KeyType np = F.add_vertex();
00534     SimplexSet nbhd;
00535
00536     // Get the complete neighborhood
00537     visit_BFS_down(
00538         decimation_detail::GetCompleteNeighborhood<Complex>(&nbhd),
00539         F, s);
00540
00541     // Call MainVisitor -> InnerVisitor -> GrabVisitor sequence
00542     visit_BFS_down(
00543         decimation_detail::MainVisitor<Complex>(&nbhd, np, &simplexMap),
00544         F, s);
00545     return np;
00546 }
00547
00548 /**
00549 * @brief      Given a simplexMap and mapped resulting data execute the
00550 *              decimation.
00551 *
00552 * @param      F          Simplicial complex to operate on
00553 * @param      simplexMap SimplexMap mapping simplices before and after decimation
00554 * @param      rv          Resulting data for each simplex
00555 *
00556 * @tparam Complex       Typename of the complex of interest
00557 */
00558 template <typename Complex>
00559 void decimateBackHalf(Complex &F, SimplexMap<Complex> &simplexMap, typename
00560     decimation_detail::SimplexDataSet<Complex>::type &rv){

```

```

00561
00562     SimplexSet<Complex> doomed;
00563     util::int_for_each<std::size_t, typename
SimplexMap<Complex>::cLevelIndex>(decimation_detail::DoomedHelper<Complex>(), doomed, simplexMap);
00564
00565     perform_removal(F, doomed); // Remove simplices in the neighborhood
00566     perform_insertion(F, rv); // Insert new simplices
00567 }
00568
00569 } // end namespace casc

```

10.7 include/casc/index_tracker.h File Reference

B-tree based interval tracker.

```

#include <iostream>
#include <assert.h>
#include <array>
#include <vector>
#include <cstdlib>
#include <limits>

```

Data Structures

- struct [index_tracker::index_tracker_detail::Interval< T >](#)
Interval object represents a range.
- struct [index_tracker::index_tracker_detail::BTreeNode< _T, _d >](#)
An array based BTree.
- class [index_tracker::index_tracker< _T, _d >](#)
Tracker of available indices implemented as a B-tree of intervals.

Namespaces

- namespace [index_tracker](#)
Index tracker namespace.
- namespace [index_tracker::index_tracker_detail](#)
B-tree internal data structures.

Typedefs

- template<typename Node >
using [index_tracker::index_tracker_detail::Pointer](#) = typename Node::Pointer
- template<typename Node >
using [index_tracker::index_tracker_detail::Data](#) = typename Node::Data
- template<typename Node >
using [index_tracker::index_tracker_detail::Scalar](#) = typename Node::Scalar

Functions

- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator< (const Interval< T > &x, const Interval< T > &y)`
- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator> (const Interval< T > &x, const Interval< T > &y)`
- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator< (T x, const Interval< T > &y)`
- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator> (const Interval< T > &x, T y)`
- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator< (const Interval< T > &x, T y)`
- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator> (T x, const Interval< T > &y)`
- `template<typename T >`
`bool index_tracker::index_tracker_detail::operator== (const Interval< T > &x, const Interval< T > &y)`
- `template<typename T >`
`std::ostream & index_tracker::index_tracker_detail::operator<< (std::ostream &out, const Interval< T > &x)`
- `template<typename T >`
`int index_tracker::index_tracker_detail::merge (Interval< T > &A, T x)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::rebalance (Pointer< Node > head, std::size_t i)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::insert_H (Pointer< Node > head, const Data< Node > &data)`
- `template<typename Node >`
`Pointer< Node > index_tracker::index_tracker_detail::insert (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`bool index_tracker::index_tracker_detail::get (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::get_replacement (Pointer< Node > head, Data< Node > &key)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::remove_H (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`Pointer< Node > index_tracker::index_tracker_detail::remove (Pointer< Node > head, Data< Node > data)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::fill_left (Pointer< Node > head, Data< Node > &x)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::fill_right (Pointer< Node > head, Data< Node > &x)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::insert_scalar_H (Pointer< Node > head, Scalar< Node > data)`
- `template<typename Node >`
`Pointer< Node > index_tracker::index_tracker_detail::insert_scalar (Pointer< Node > head, Scalar< Node > data)`
- `template<typename Node >`
`void index_tracker::index_tracker_detail::insert_left (Pointer< Node > head, const Data< Node > &x)`
- `template<typename Node >`
`bool index_tracker::index_tracker_detail::remove_scalar_H (Pointer< Node > head, Scalar< Node > x)`
- `template<typename Node >`
`bool index_tracker::index_tracker_detail::remove_scalar (Pointer< Node > &head, Scalar< Node > data)`
- `template<typename Node >`
`Scalar< Node > index_tracker::index_tracker_detail::pop_scalar (Pointer< Node > &head)`

- `template<typename Node >`
`void index_tracker::index_tracker_detail::destruct (Pointer< Node > head)`
- `template<typename Node >`
`Data< Node > index_tracker::index_tracker_detail::check_order (Pointer< Node > head, Data< Node > curr)`
- `template<typename T, std::size_t d>`
`std::ostream & index_tracker::operator<< (std::ostream &out, const index_tracker_detail::BTreeNode< T, d > *head)`

10.8 index_tracker.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *
00008  * This library is free software; you can redistribute it and/or
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00011  * version 2.1 of the License, or (at your option) any later version.
00012  *
00013  * This library is distributed in the hope that it will be useful,
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00015  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
00016  * Lesser General Public License for more details.
00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file index_tracker.h
00027  * @brief B-tree based interval tracker.
00028  */
00029
00030 #pragma once
00031
00032 #include <iostream>
00033 #include <assert.h>
00034 #include <array>
00035 #include <vector>
00036 #include <cstdlib>
00037 #include <limits>
00038
00039
00040 /// Index tracker namespace
00041 namespace index_tracker
00042 {
00043     /// B-tree internal data structures
00044     namespace index_tracker_detail {
00045
00046
00047         /**
00048          * @brief Interval object represents a range.
00049          *
00050          * @tparam T Typename of the interval data
00051          */
00052         template <typename T>
00053         struct Interval
00054         {
00055             /// Default constructor
00056             Interval() : _a(0), _b(0) {}
00057             /// Construct an interval from a to a+1
00058             Interval(T a) : _a(a), _b(a+1) {}
00059             /// Construct an interval from a to b
00060             Interval(T a, T b) : _a(a), _b(b) { assert(a <= b); }
00061             /// Copy constructor
00062             Interval(const Interval<T>& rhs) : _a(rhs._a), _b(rhs._b) {}
00063
00064             /**
00065              * @brief Assignment operator overload.

```

```

00066      *
00067      * @param[in] rhs The right hand side
00068      *
00069      * @return Reference to this
00070      */
00071      Interval& operator=(const Interval& rhs)
00072      {
00073          _a = rhs._a;
00074          _b = rhs._b;
00075          return *this;
00076      }
00077
00078      /// Is x in the bounds of the interval
00079      bool has(T x) { return _a <= x && x < _b; }
00080
00081      /// Get the lower inclusive bound of the interval
00082      T lower() const { return _a; }
00083      /// Get the upper exclusive bound of the interval
00084      T upper() const { return _b; }
00085
00086      /// Get the lower inclusive bound of the interval
00087      T& lower() { return _a; }
00088      /// Get the upper exclusive bound of the interval
00089      T& upper() { return _b; }
00090
00091      /// Get the size of the interval
00092      std::size_t size() { return _b - _a; }
00093
00094      private:
00095          T _a;    /// Inclusive lower bound
00096          T _b;    /// Exclusive upper bound
00097      };
00098
00099      template <typename T>
00100      bool operator<(const Interval<T>& x, const Interval<T>& y)
00101      {
00102          return x.upper() <= y.lower();
00103      }
00104
00105      template <typename T>
00106      bool operator>(const Interval<T>& x, const Interval<T>& y)
00107      {
00108          return x.lower() >= y.upper();
00109      }
00110
00111      template <typename T>
00112      bool operator<(T x, const Interval<T>& y)
00113      {
00114          return x < y.lower();
00115      }
00116
00117      template <typename T>
00118      bool operator>(const Interval<T>& x, T y)
00119      {
00120          return x.lower() > y;
00121      }
00122
00123      template <typename T>
00124      bool operator<(const Interval<T>& x, T y)
00125      {
00126          return x.upper() <= y;
00127      }
00128
00129      template <typename T>
00130      bool operator>(T x, const Interval<T>& y)
00131      {
00132          return x >= y.upper();
00133      }
00134
00135      template <typename T>
00136      bool operator==(const Interval<T>& x, const Interval<T>& y)
00137      {
00138          return (x.lower() == y.lower()) && (x.upper() && y.upper());
00139      }
00140
00141      template <typename T>
00142      std::ostream& operator<<(std::ostream& out, const Interval<T>& x)
00143      {
00144          out << "[" << x.lower() << "~" << x.upper() << ")";
00145          return out;
00146      }
00147
00148      template <typename T>
00149      int merge(Interval<T>& A, T x)
00150      {
00151          // If x isn't the next lower value return 0
00152          if(x + 1 < A.lower())

```

```

00153         return 0;
00154     else if(x + 1 == A.lower())
00155     {
00156         // if x is the next lowest value assign to lower
00157         A.lower() = x;
00158         return 1;
00159     }
00160     else if(A.lower() <= x && x < A.upper()) // x is in range already
00161         return 2;
00162     else if(A.upper() == x)
00163     {
00164         // x is the next higher assign upper
00165         A.upper() = x + 1;
00166         return 3;
00167     }
00168     else if(A.upper() < x)
00169         // x isn't next after this range return 4
00170         return 4;
00171     else
00172         return 5; // Something undefined happened.
00173 }
00174
00175 /**
00176  * @brief      An array based BTree
00177  *
00178  * @tparam     _T      { description }
00179  * @tparam     _d      { description }
00180  */
00181 template <typename _T, std::size_t _d>
00182 struct BTreeNode
00183 {
00184     static constexpr std::size_t d = _d;
00185     static constexpr std::size_t N = 2*d+1;
00186     using Scalar = _T;
00187     using Data = Interval<Scalar>;
00188     using Pointer = BTreeNode*;
00189
00190     BTreeNode() {}
00191     BTreeNode(const Data& t)
00192         : k(1), next{nullptr, nullptr}
00193     {
00194         data[0] = t;
00195     }
00196
00197     template <typename Iter>
00198     BTreeNode(Iter begin, Iter end)
00199     {
00200         k = 0;
00201         while(begin != end)
00202         {
00203             next[k] = nullptr;
00204             data[k++] = *begin++;
00205         }
00206         next[k] = nullptr;
00207     }
00208
00209     std::size_t k;
00210     std::array<Data, N> data;
00211     std::array<Pointer, N+1> next;
00212 };
00213
00214 template <typename Node> using Pointer = typename Node::Pointer;
00215 template <typename Node> using Data = typename Node::Data;
00216 template <typename Node> using Scalar = typename Node::Scalar;
00217
00218
00219
00220
00221 template <typename Node>
00222 void rebalance(Pointer<Node> head, std::size_t i)
00223 {
00224     Pointer<Node> curr = head->next[i];
00225
00226     if(curr->k == Node::N)
00227     {
00228         // Pointer<Node> left = curr; // UNUSED
00229         Pointer<Node> right = new Node(curr->data.begin() + Node::d + 1, curr->data.end());
00230         curr->k = Node::d;
00231
00232         if(curr->next[0] == nullptr)
00233         {
00234             right->next[0] = nullptr;
00235         }
00236         else
00237         {
00238             for(std::size_t i = 0; i <= Node::d; ++i)
00239             {

```

```

00240         right->next[i] = curr->next[Node::d + i + 1];
00241     }
00242 }
00243
00244 Data<Node> up = curr->data[Node::d];
00245
00246 for(std::size_t j = head->k; j > i; --j)
00247 {
00248     head->data[j] = head->data[j-1];
00249     head->next[j+1] = head->next[j];
00250 }
00251 head->data[i] = up;
00252 head->next[i+1] = right;
00253 ++(head->k);
00254 }
00255 else if(curr->k < Node::d)
00256 {
00257     if(i > 0 && head->next[i-1]->k > Node::d)
00258     {
00259         Pointer<Node> left = head->next[i-1];
00260         Pointer<Node> right = head->next[i];
00261
00262         if(right->next[0] != nullptr)
00263             right->next[right->k + 1] = right->next[right->k];
00264         for(std::size_t j = right->k; j > 0; --j)
00265         {
00266             right->data[j] = right->data[j-1];
00267             if(left->next[0] != nullptr)
00268                 right->next[j] = right->next[j-1];
00269         }
00270         right->data[0] = head->data[i-1];
00271         if(left->next[0] != nullptr)
00272             right->next[0] = left->next[left->k];
00273         ++(right->k);
00274
00275         head->data[i-1] = left->data[left->k-1];
00276
00277         --(left->k);
00278
00279         // std::cout << "Rotate Right" << std::endl;
00280     }
00281     else if(i < head->k && head->next[i+1]->k > Node::d)
00282     {
00283         Pointer<Node> left = head->next[i];
00284         Pointer<Node> right = head->next[i+1];
00285
00286         left->data[left->k] = head->data[i];
00287         ++(left->k);
00288         if(left->next[0] != nullptr)
00289             left->next[left->k] = right->next[0];
00290
00291         head->data[i] = right->data[0];
00292         for(std::size_t j = 0; j < right->k - 1; ++j)
00293         {
00294             right->data[j] = right->data[j+1];
00295             if(right->next[0] != nullptr)
00296                 right->next[j] = right->next[j+1];
00297         }
00298         --(right->k);
00299         if(right->next[0] != nullptr)
00300             right->next[right->k] = right->next[right->k + 1];
00301
00302         // std::cout << "Rotate Left" << std::endl;
00303     }
00304     else
00305     {
00306         if(i < head->k)
00307         {
00308             Pointer<Node> left = head->next[i];
00309             Pointer<Node> right = head->next[i+1];
00310
00311             left->data[(left->k)++] = head->data[i];
00312             for(std::size_t j = 0; j < right->k; ++j)
00313             {
00314                 left->data[left->k] = right->data[j];
00315                 if(left->next[0] != nullptr)
00316                     left->next[left->k] = right->next[j];
00317                 ++(left->k);
00318             }
00319             if(left->next[0] != nullptr)
00320                 left->next[left->k] = right->next[right->k];
00321
00322             delete right;
00323
00324             --(head->k);
00325             for(std::size_t j = i; j < head->k; ++j)
00326                 {

```

```

00327         head->data[j] = head->data[j+1];
00328         head->next[j+1] = head->next[j+2];
00329     }
00330 }
00331 else
00332 {
00333     Pointer<Node> left = head->next[i-1];
00334     Pointer<Node> right = head->next[i];
00335
00336     left->data[left->k] = head->data[i-1];
00337     ++(left->k);
00338     for(std::size_t j = 0; j < right->k; ++j)
00339     {
00340         left->data[left->k] = right->data[j];
00341         if(left->next[0] != nullptr)
00342             left->next[left->k] = right->next[j];
00343         ++(left->k);
00344     }
00345     if(left->next[0] != nullptr)
00346         left->next[left->k] = right->next[right->k];
00347
00348     delete right;
00349     --(head->k);
00350 }
00351 }
00352 }
00353 }
00354
00355 template <typename Node>
00356 void insert_H(Pointer<Node> head, const Data<Node>& data)
00357 {
00358     if(head->next[0] == nullptr)
00359     {
00360         const auto k = head->k;
00361
00362         std::size_t i = 0;
00363         while(i < k && head->data[i] < data)
00364         {
00365             ++i;
00366         }
00367         for(std::size_t j = k; j > i; --j)
00368         {
00369             head->data[j] = head->data[j-1];
00370         }
00371         head->data[i] = data;
00372         head->k = k+1;
00373     }
00374     else
00375     {
00376         const auto k = head->k;
00377
00378         std::size_t i = 0;
00379         while(i < k && head->data[i] < data)
00380             ++i;
00381
00382         insert_H<Node>(head->next[i], data);
00383         rebalance<Node>(head, i);
00384     }
00385 }
00386
00387 template <typename Node>
00388 Pointer<Node> insert(Pointer<Node> head, Data<Node> data)
00389 {
00390     if(head == nullptr)
00391     {
00392         return new Node(data);
00393     }
00394     else
00395     {
00396         insert_H<Node>(head, data);
00397         if(head->k == Node::N)
00398         {
00399             Pointer<Node> nn = new Node();
00400             nn->k = 0;
00401             nn->next[0] = head;
00402             rebalance<Node>(nn, 0);
00403             return nn;
00404         }
00405         else
00406         {
00407             return head;
00408         }
00409     }
00410 }
00411
00412 template <typename Node>
00413 bool get(Pointer<Node> head, Data<Node> data)

```

```

00414     {
00415         if(head->next[0] == nullptr)
00416         {
00417             for(std::size_t i = 0; i < head->k; ++i)
00418             {
00419                 if(data == head->data[i])
00420                 {
00421                     return true;
00422                 }
00423             }
00424             return false;
00425         }
00426         else
00427         {
00428             for(std::size_t i = 0; i < head->k; ++i)
00429             {
00430                 if(data < head->data[i])
00431                 {
00432                     return get<Node>(head->next[i], data);
00433                 }
00434                 else if(data == head->data[i])
00435                 {
00436                     return true;
00437                 }
00438             }
00439             return get<Node>(head->next[head->k], data);
00440         }
00441     }
00442
00443
00444
00445 template <typename Node>
00446 void get_replacement(Pointer<Node> head, Data<Node>& key)
00447 {
00448     if(head->next[0] == nullptr)
00449     {
00450         key = head->data[head->k-1];
00451         --(head->k);
00452     }
00453     else
00454     {
00455         get_replacement<Node>(head->next[head->k], key);
00456         rebalance<Node>(head, head->k);
00457     }
00458 }
00459
00460 template <typename Node>
00461 void remove_H(Pointer<Node> head, Data<Node> data)
00462 {
00463     if(head->next[0] == nullptr)
00464     {
00465         for(std::size_t i = 0; i < head->k; ++i)
00466         {
00467             if(data == head->data[i])
00468             {
00469                 for(std::size_t j = i+1; j < head->k; ++j)
00470                 {
00471                     head->data[j-1] = head->data[j];
00472                 }
00473                 --(head->k);
00474                 break;
00475             }
00476         }
00477     }
00478     else
00479     {
00480         for(std::size_t i = 0; i < head->k; ++i)
00481         {
00482             if(data < head->data[i])
00483             {
00484                 remove_H<Node>(head->next[i], data);
00485                 rebalance<Node>(head, i);
00486                 return;
00487             }
00488             else if(data == head->data[i])
00489             {
00490                 get_replacement<Node>(head->next[i], head->data[i]);
00491                 rebalance<Node>(head, i);
00492                 return;
00493             }
00494         }
00495         remove_H<Node>(head->next[head->k], data);
00496         rebalance<Node>(head, head->k);
00497     }
00498 }
00499
00500 template <typename Node>

```

```

00501     Pointer<Node> remove(Pointer<Node> head, Data<Node> data)
00502     {
00503         remove_H<Node>(head, data);
00504
00505         if(head->k == 0)
00506         {
00507             Pointer<Node> rval = head->next[0];
00508             delete head;
00509             return rval;
00510         }
00511         else
00512         {
00513             return head;
00514         }
00515     }
00516
00517
00518     template <typename Node>
00519     void fill_left(Pointer<Node> head, Data<Node>& x)
00520     {
00521         if(head->next[0] == nullptr)
00522         {
00523             Data<Node>& left = head->data[head->k-1];
00524             if(left.upper() == x.lower())
00525             {
00526                 x.lower() = left.lower();
00527                 --(head->k);
00528             }
00529         }
00530         else
00531         {
00532             fill_left<Node>(head->next[head->k], x);
00533             rebalance<Node>(head, head->k);
00534         }
00535     }
00536
00537
00538     template <typename Node>
00539     void fill_right(Pointer<Node> head, Data<Node>& x)
00540     {
00541         if(head->next[0] == nullptr)
00542         {
00543             Data<Node>& right = head->data[0];
00544             if(right.lower() == x.upper())
00545             {
00546                 x.upper() = right.upper();
00547                 --(head->k);
00548                 for(std::size_t i = 0; i < head->k; ++i)
00549                 {
00550                     head->data[i] = head->data[i+1];
00551                 }
00552             }
00553         }
00554         else
00555         {
00556             fill_right<Node>(head->next[0], x);
00557             rebalance<Node>(head, 0);
00558         }
00559     }
00560
00561
00562     template <typename Node>
00563     void insert_scalar_H(Pointer<Node> head, Scalar<Node> data)
00564     {
00565         // If the
00566         if(head->next[0] == nullptr)
00567         {
00568             const auto k = head->k;
00569
00570             std::size_t i;
00571             for(i = 0; i < k; ++i)
00572             {
00573                 Data<Node>& A = head->data[i];
00574                 Scalar<Node> x = data;
00575
00576                 if(x + 1 < A.lower())
00577                 {
00578                     for(std::size_t j = k; j > i; --j)
00579                     {
00580                         head->data[j] = head->data[j-1];
00581                     }
00582                     head->data[i] = data;
00583                     ++(head->k);
00584                     return;
00585                 }
00586                 else if(x + 1 == A.lower())
00587                 {

```

```

00588         A.lower() = x;
00589         return;
00590     }
00591     else if(A.lower() <= x && x < A.upper())
00592     {
00593         return;
00594     }
00595     else if(A.upper() == x)
00596     {
00597         if(i + 1 < k)
00598         {
00599             Data<Node>& B = head->data[i+1];
00600             if(x + 1 == B.lower())
00601             {
00602                 A.upper() = B.upper();
00603                 for(std::size_t j = i+1; j < k-1; ++j)
00604                 {
00605                     head->data[j] = head->data[j+1];
00606                 }
00607                 --(head->k);
00608             }
00609             else
00610             {
00611                 A.upper() = x + 1;
00612             }
00613         }
00614         else
00615         {
00616             A.upper() = x + 1;
00617         }
00618         return;
00619     }
00620 }
00621 head->data[i] = data;
00622 ++(head->k);
00623 }
00624 else
00625 {
00626     const auto k = head->k;
00627
00628     std::size_t i;
00629     for(i = 0; i < k; ++i)
00630     {
00631         Data<Node>& A = head->data[i];
00632         Scalar<Node> x = data;
00633
00634         if(x + 1 < A.lower())
00635         {
00636             insert_scalar_H<Node>(head->next[i], data);
00637             rebalance<Node>(head, i);
00638             return;
00639         }
00640         else if(x + 1 == A.lower())
00641         {
00642             A.lower() = x;
00643             fill_left<Node>(head->next[i], A);
00644             rebalance<Node>(head, i);
00645             return;
00646         }
00647         else if(A.lower() <= x && x < A.upper())
00648         {
00649             return;
00650         }
00651         else if(A.upper() == x)
00652         {
00653             A.upper() = x + 1;
00654             fill_right<Node>(head->next[i+1], A);
00655             rebalance<Node>(head, i+1);
00656             return;
00657         }
00658     }
00659     insert_scalar_H<Node>(head->next[i], data);
00660     rebalance<Node>(head, i);
00661 }
00662 }
00663
00664 template <typename Node>
00665 Pointer<Node> insert_scalar(Pointer<Node> head, Scalar<Node> data)
00666 {
00667     if(head == nullptr)
00668     {
00669         return new Node(data);
00670     }
00671     else
00672     {
00673         insert_scalar_H<Node>(head, data);
00674         if(head->k == Node::N)

```

```

00675         {
00676             Pointer<Node> nn = new Node();
00677             nn->k = 0;
00678             nn->next[0] = head;
00679             rebalance<Node>(nn, 0);
00680             return nn;
00681         }
00682         else if(head->k == 0)
00683         {
00684             Pointer<Node> rval = head->next[0];
00685             delete head;
00686             return rval;
00687         }
00688         else
00689         {
00690             return head;
00691         }
00692     }
00693 }
00694
00695 template <typename Node>
00696 void insert_left(Pointer<Node> head, const Data<Node>& x)
00697 {
00698     if(head->next[0] == nullptr)
00699     {
00700         head->data[head->k] = x;
00701         ++(head->k);
00702     }
00703     else
00704     {
00705         insert_left<Node>(head->next[head->k], x);
00706         rebalance<Node>(head, head->k);
00707     }
00708 }
00709
00710
00711 template <typename Node>
00712 bool remove_scalar_H(Pointer<Node> head, Scalar<Node> x)
00713 {
00714     if(head->next[0] == nullptr)
00715     {
00716         const auto k = head->k;
00717
00718         std::size_t i;
00719         for(i = 0; i < k; ++i)
00720         {
00721             Data<Node>& A = head->data[i];
00722
00723             if(x < A.lower())
00724             {
00725                 std::cout << "if(x < A.lower())" << std::endl;
00726                 return false;
00727             }
00728             else if(x == A.lower())
00729             {
00730                 std::cout << "if(x == A.lower())" << std::endl;
00731                 if(x + 1 == A.upper())
00732                 {
00733                     std::cout << "if(x + 1 == A.upper())" << std::endl;
00734                     --(head->k);
00735                     for(std::size_t j = i; j < head->k; ++j)
00736                     {
00737                         head->data[j] = head->data[j+1];
00738                     }
00739                     return true;
00740                 }
00741                 A.lower() = x + 1;
00742                 return true;
00743             }
00744             else if(*A.lower() < x &&* / x + 1 < A.upper())
00745             {
00746                 std::cout << "x + 1 < A.upper()" << std::endl;
00747                 for(std::size_t j = head->k; j > i; --j)
00748                 {
00749                     head->data[j] = head->data[j-1];
00750                 }
00751                 ++(head->k);
00752                 A.upper() = x;
00753                 head->data[i+1].lower() = x + 1;
00754                 return true;
00755             }
00756             else if(x + 1 == A.upper())
00757             {
00758                 std::cout << "x + 1 < A.upper()" << std::endl;
00759                 A.upper() = x;
00760                 return true;
00761             }

```

```

00762         }
00763         return false;
00764     }
00765     else
00766     {
00767         const auto k = head->k;
00768
00769         std::size_t i;
00770         for(i = 0; i < k; ++i)
00771         {
00772             Data<Node>& A = head->data[i];
00773
00774             if(x < A.lower())
00775             {
00776                 bool rval = remove_scalar_H<Node>(head->next[i], x);
00777                 rebalance<Node>(head, i);
00778                 return rval;
00779             }
00780             else if(x == A.lower())
00781             {
00782                 if(x + 1 == A.upper())
00783                 {
00784                     get_replacement<Node>(head->next[i], A);
00785                     rebalance<Node>(head, i);
00786                     return true;
00787                 }
00788                 A.lower() = x + 1;
00789                 return true;
00790             }
00791             else if(/*A.lower() < x &&*/ x + 1 < A.upper())
00792             {
00793                 Data<Node> B(A.lower(), x);
00794                 A.lower() = x + 1;
00795                 insert_left<Node>(head->next[i], B);
00796                 rebalance<Node>(head, i);
00797                 return true;
00798             }
00799             else if(x + 1 == A.upper())
00800             {
00801                 A.upper() = x;
00802                 return true;
00803             }
00804         }
00805         bool rval = remove_scalar_H<Node>(head->next[i], x);
00806         rebalance<Node>(head, i);
00807         return rval;
00808     }
00809 }
00810
00811 template <typename Node>
00812 bool remove_scalar(Pointer<Node>& head, Scalar<Node> data)
00813 {
00814     if(head == nullptr)
00815     {
00816         return false;
00817     }
00818
00819     bool rval = remove_scalar_H<Node>(head, data);
00820
00821     if(head->k == Node::N)
00822     {
00823         Pointer<Node> nn = new Node();
00824         nn->k = 0;
00825         nn->next[0] = head;
00826         rebalance<Node>(nn, 0);
00827         head = nn;
00828     }
00829     else if(head->k == 0)
00830     {
00831         Pointer<Node> tmp = head;
00832         head = head->next[0];
00833         delete tmp;
00834     }
00835
00836     return rval;
00837 }
00838
00839 template <typename Node>
00840 Scalar<Node> pop_scalar(Pointer<Node>& head)
00841 {
00842     if(head)
00843     {
00844         Scalar<Node> x = head->data[0].lower();
00845         remove_scalar<Node>(head, x);
00846         return x;
00847     }
00848     exit(-1);

```

```

00849     }
00850
00851     template <typename Node>
00852     void destruct(Pointer<Node> head)
00853     {
00854         if(head == nullptr)
00855         {
00856             return;
00857         }
00858         else
00859         {
00860             if(head->next[0] != nullptr)
00861             {
00862                 for(std::size_t i = 0; i < head->k; ++i)
00863                 {
00864                     destruct<Node>(head->next[i]);
00865                 }
00866             }
00867             delete head;
00868         }
00869     }
00870
00871
00872     template <typename Node>
00873     Data<Node> check_order(Pointer<Node> head, Data<Node> curr)
00874     {
00875         if(head != nullptr)
00876         {
00877             if(head->next[0] == nullptr)
00878             {
00879                 for(std::size_t i = 0; i < head->k; ++i)
00880                 {
00881                     if(curr > head->data[i])
00882                     {
00883                         std::cout << "ORDER WRONG!!!  --  " << curr << " > " << head->data[i] <<
00884                         std::endl;
00885                         exit(1);
00886                     }
00887                     curr = head->data[i];
00888                 }
00889             }
00890             else
00891             {
00892                 for(std::size_t i = 0; i < head->k; ++i)
00893                 {
00894                     curr = check_order<Node>(head->next[i], curr);
00895                     if(curr > head->data[i])
00896                     {
00897                         std::cout << "ORDER WRONG!!!  --  " << curr << " > " << head->data[i] <<
00898                         std::endl;
00899                         exit(1);
00900                     }
00901                     curr = head->data[i];
00902                 }
00903             }
00904             curr = check_order<Node>(head->next[head->k], curr);
00905         }
00906         return curr;
00907     }
00908 } // End namespace index_tracker_detail
00909
00910 template <typename T, std::size_t d>
00911 std::ostream& operator<<(std::ostream& out, const index_tracker_detail::BTreeNode<T,d>* head)
00912 {
00913     if(head == nullptr)
00914     {
00915         out << "[nil]";
00916     }
00917     else
00918     {
00919         out << "[";
00920         for(std::size_t i = 0; i < head->k; ++i)
00921         {
00922             if(head->next[0] != nullptr)
00923             {
00924                 out << head->next[i] << " ";
00925             }
00926             out << head->data[i] << " ";
00927         }
00928         if(head->next[0] != nullptr)
00929         {
00930             out << head->next[head->k];
00931         }
00932         out << "]";
00933     }
00934     return out;
00935 }
00936
00937 /**
00938  * @brief      Tracker of available indices implemented as a B-tree of intervals.
00939  */

```

```

00934 * @tparam    _T    Typename of the indices
00935 * @tparam    _d    Max number of interval bins = 2*value+1
00936 */
00937 template <typename _T, std::size_t _d = 16>
00938 class index_tracker
00939 {
00940 public:
00941     /// Typedef of BTree Node
00942     using Node = index_tracker_detail::BTreeNode<_T, _d>;
00943     using T = _T; /// Typename of the type to store
00944     constexpr static std::size_t d = _d; /// Number of bins
00945
00946     /**
00947      * @brief      Initialize with interval [0~max)
00948      */
00949     index_tracker()
00950         : head(new Node(index_tracker_detail::Interval<T>(0, std::numeric_limits<T>::max())))
00951     {}
00952     ~index_tracker()
00953     {
00954         index_tracker_detail::destruct<Node>(head);
00955     }
00956
00957     void insert(T x)
00958     {
00959         head = index_tracker_detail::insert_scalar<Node>(head, x);
00960     }
00961
00962     index_tracker_detail::Scalar<Node> pop()
00963     {
00964         auto x = index_tracker_detail::pop_scalar<Node>(head);
00965         return x;
00966     }
00967
00968     void remove(index_tracker_detail::Scalar<Node> x)
00969     {
00970         index_tracker_detail::remove_scalar<Node>(head, x);
00971     }
00972
00973     bool empty() const
00974     {
00975         return head == nullptr;
00976     }
00977
00978     friend std::ostream& operator<<(std::ostream& out, const index_tracker& x)
00979     {
00980         out << x.head;
00981         return out;
00982     }
00983
00984 private:
00985     index_tracker_detail::Pointer<Node> head;
00986 };
00987 } // end namespace index_tracker

```

10.9 include/casc/Orientable.h File Reference

Data type for orientability.

```

#include <iostream>
#include <queue>
#include <set>

```

Data Structures

- struct [casc::Orientable](#)
Class representing the orientation.

Namespaces

- namespace [casc](#)
Namespace for everything CASC.

Functions

- `template<typename Complex >`
`void casc::init\_orientation (Complex &F)`
Initialize the partial ordering of the simplex edges.
- `template<typename Complex >`
`void casc::clear\_orientation (Complex &F)`
Clear the orientation of the facets.
- `template<typename Complex >`
`std::tuple< int, bool, bool > casc::compute\_orientation (Complex &F)`
Initializes and calculates the orientation of a [simplicial_complex](#).
- `template<typename Complex >`
`std::tuple< int, bool, bool > casc::check\_orientation (Complex &F)`
Checks for self consistent orientation and fill in missing orientations.

10.10 Orientable.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
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00012  *
00013  * This library is distributed in the hope that it will be useful,
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00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file Orientable.h
00027  * @brief Data type for orientability
00028  */
00029
00030
00031 #pragma once
00032
00033 #include <iostream>
00034 #include <queue>
00035 #include <set>
00036
00037 namespace casc{
00038 /**
00039  * @brief Class representing the orientation.
00040  */
00041 struct Orientable {
00042     /// Integer representing +/- 1 orientation.
00043     int orientation;
00044 };
00045
00046 /// @cond detail
00047 /// Namespace for orientation helpers
00048 namespace orientation_detail{
00049
00050 template <class Complex, class SizeT >
00051 struct init_orientation_helper {};
00052
00053 template <class Complex, std::size_t k >
00054 struct init_orientation_helper<Complex, std::integral_constant<std::size_t, k>

```

```

00056 {
00057     static void f(Complex& F)
00058     {
00059         for(auto curr : F.template get_level_id<k>())
00060         {
00061             for(auto a : F.get_cover(curr))
00062             {
00063                 int orient = 1;
00064                 for(auto b : F.get_name(curr))
00065                 {
00066                     // Count the number of indices > name
00067                     if(a > b)
00068                     {
00069                         orient *= -1;
00070                     }
00071                     else
00072                     {
00073                         break;
00074                     }
00075                 }
00076                 (*F.get_edge_up(curr,a)).orientation = orient;
00077             }
00078         }
00079         init_orientation_helper<Complex, std::integral_constant<std::size_t, k+1>::f(F);
00080     }
00081 };
00082
00083
00084 /**
00085  * @brief      Terminating case for initializing orientation
00086  *
00087  * @tparam      Complex  Typename of the simplicial complex
00088  */
00089 template <typename Complex>
00090 struct init_orientation_helper<Complex, std::integral_constant<std::size_t, Complex::topLevel>
00091 {
00092     static void f(Complex&) {}
00093 };
00094 } // end namespace orientation_detail
00095 /// @endcond
00096
00097 /**
00098  * @brief      Initialize the partial ordering of the simplex edges
00099  *
00100  * @param      F          Simplicial complex of interest
00101  *
00102  * @tparam      Complex  Typename of the simplicial complex
00103  */
00104 template <typename Complex>
00105 void init_orientation(Complex& F)
00106 {
00107     orientation_detail::init_orientation_helper<Complex, std::integral_constant<std::size_t, 0>::f(F);
00108 }
00109
00110 /**
00111  * @brief      Clear the orientation of the facets
00112  *
00113  * @param      F          Simplicial complex of interest
00114  *
00115  * @tparam      Complex  Typename of the simplicial complex
00116  */
00117 template <typename Complex>
00118 void clear_orientation(Complex& F)
00119 {
00120     // clear orientation
00121     for(auto& curr : F.template get_level<Complex::topLevel>())
00122     {
00123         curr.orientation = 0;
00124     }
00125 }
00126
00127 // TODO: Implement this as a disjoint set operation during insertion (2)
00128 /**
00129  * @brief      Initializes and calculates the orientation of a
00130  *              simplicial_complex.
00131  *
00132  * @param      F          Simplicial_complex
00133  *
00134  * @tparam      Complex  Typename of the simplicial_complex.
00135  *
00136  * @return      A tuple of the number of connected components, where the complex
00137  *              is orientable, and if it is psuedo manifold.
00138  */
00139 template <typename Complex>
00140 std::tuple<int, bool, bool> compute_orientation(Complex& F)
00141 {
00142     init_orientation(F);

```

```

00143     clear_orientation(F);
00144     return check_orientation(F);
00145 }
00146
00147
00148 /**
00149  * @brief      Checks for self consistent orientation and fill in missing
00150  *              orientations
00151  *
00152  * @param      F      Simplicial_complex
00153  *
00154  * @tparam     Complex Typename of the simplicial_complex.
00155  *
00156  * @return     A tuple of the number of connected components, where the complex
00157  *              is orientable, and if it is psuedo manifold.
00158  */
00159 template <typename Complex>
00160 std::tuple<int, bool, bool> check_orientation(Complex& F)
00161 {
00162     // compute orientation
00163     constexpr std::size_t k = Complex::topLevel - 1;
00164
00165     std::deque<typename Complex::template SimplexID<k> > frontier;
00166     std::set<typename Complex::template SimplexID<k> > visited;
00167     int connected_components = 0;
00168     bool orientable = true;
00169     bool psuedo_manifold = true;
00170     for(auto outer : F.template get_level_id<k>())
00171     {
00172         if(visited.find(outer) == visited.end())
00173         {
00174             ++connected_components;
00175             frontier.push_back(outer);
00176
00177             while(!frontier.empty())
00178             {
00179                 typename Complex::template SimplexID<k> curr = frontier.front();
00180                 if(visited.find(curr) == visited.end())
00181                 {
00182                     visited.insert(curr);
00183
00184                     auto w = F.get_cover(curr);
00185
00186                     if(w.size() == 1)
00187                     {
00188                         // w is a boundary
00189                         //std::cout << curr << ":" << w[0] << " ~ Boundary" << std::endl;
00190                     }
00191                     else if(w.size() == 2)
00192                     {
00193                         auto& edge0 = *F.get_edge_up(curr, w[0]);
00194                         auto& edge1 = *F.get_edge_up(curr, w[1]);
00195
00196                         auto& node0 = *F.get_simplex_up(curr, w[0]);
00197                         auto& node1 = *F.get_simplex_up(curr, w[1]);
00198
00199                         // If node0 doesn't have an orientation yet... Assign one
00200                         if(node0.orientation == 0)
00201                         {
00202                             if(node1.orientation == 0)
00203                             {
00204                                 node0.orientation = -1;
00205                                 node1.orientation = -edge1.orientation * edge0.orientation *
00206                                     node0.orientation;
00207                             }
00208                             else
00209                             {
00210                                 node0.orientation = -edge0.orientation * edge1.orientation *
00211                                     node1.orientation;
00212                             }
00213                         }
00214                         else
00215                         {
00216                             // if node1 doesn't have an orientation...
00217                             if(node1.orientation == 0)
00218                             {
00219                                 node1.orientation = -edge1.orientation * edge0.orientation *
00220                                     node0.orientation;
00221                             }
00222                             else
00223                             {
00224                                 // Check if the orientations are consistent
00225                                 if(edge0.orientation*node0.orientation +

```

```

00226                                     // std::cout << edge0.orientation << " : " << node0.orientation <<
std::endl;
00227                                     // std::cout << edge1.orientation << " : " << node1.orientation <<
std::endl;
00228
00229                                     // std::cout << " : "
00230                                     // << edge0.orientation*node0.orientation +
edge1.orientation*node1.orientation // << std::endl;
00231                                     // std::cout << "-----"
00232                                     // std::cout << std::endl;
00233                                     // std::cout << "Non-Orientable: "
00234                                     // << edge0.orientation*node0.orientation +
edge1.orientation*node1.orientation // << std::endl;
00236                                     // << std::endl;
00237                                     }
00238                                     }
00239                                     }
00240                                     neighbors_up(F, curr, std::back_inserter(frontier));
00241                                     }
00242                                     else
00243                                     {
00244                                         // W.size() != 1 or 2
00245                                         psuedo_manifold = false;
00246                                     }
00247                                     }
00248                                     frontier.pop_front();
00249                                     }
00250                                     }
00251                                     }
00252                                     return std::make_tuple(connected_components, orientable, psuedo_manifold);
00253                                     }
00254                                     } // end namespace casc

```

10.11 include/casc/SimplexMap.h File Reference

SimplexMap data structure and associated convenience functions.

```

#include <array>
#include <map>
#include "util.h"
#include "stringutil.h"

```

Data Structures

- struct [casc::SimplexMap< Complex >](#)
A multimap to represent a map of simplex indices to a set of simplices.

Namespaces

- namespace [casc](#)
Namespace for everything CASC.

Functions

- template<std::size_t k, typename Complex >
static auto & [casc::get](#) (SimplexMap< Complex > &S)
Get the map for a simplex dimension.
- template<std::size_t k, typename Complex >
static auto & [casc::get](#) (const SimplexMap< Complex > &S)
This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

10.12 SimplexMap.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
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00013  * This library is distributed in the hope that it will be useful,
00014  * but WITHOUT ANY WARRANTY; without even the implied warranty of
00015  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
00016  * Lesser General Public License for more details.
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00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file SimplexMap.h
00027  * @brief SimplexMap data structure and associated convenience functions.
00028  */
00029
00030 #pragma once
00031
00032 #include <array>
00033 #include <map>
00034 #include "util.h"
00035 #include "stringutil.h"
00036
00037 namespace casc
00038 {
00039
00040 /**
00041  * @brief A multimap to represent a map of simplex indices to a set of
00042  * simplices.
00043  *
00044  * @tparam Complex Typename of the simplicial_complex.
00045  */
00046 template <typename Complex>
00047 struct SimplexMap
00048 {
00049     /// Alias for SimplexID
00050     template <std::size_t j>
00051     using SimplexID = typename Complex::template SimplexID<j>;
00052     /// Index sequence of types from the simplicial_complex
00053     using LevelIndex = typename Complex::LevelIndex;
00054     /// Index sequence starting at 1
00055     using cLevelIndex = typename util::remove_first_val<std::size_t,
00056                                                         LevelIndex>::type;
00057     /// Reversed Index sequence
00058     using RevIndex = typename util::reverse_sequence<std::size_t,
00059                                                         LevelIndex>::type;
00060     /// Reversed index sequence stops at 1
00061     using cRevIndex = typename util::reverse_sequence<std::size_t,
00062                                                         cLevelIndex>::type;
00063     /// Typename of this object
00064     using type_this = SimplexMap<Complex>;
00065
00066     /**
00067      * @brief Default constructor.
00068      */
00069     SimplexMap() {};
00070
00071     // TODO: Put in convenience functions for easy accession etc... (0)
00072     /**
00073      * @brief Get the map for a particular simplex dimension.
00074      *
00075      * @tparam k Simplex dimension to retrieve.
00076      *
00077      * @return A map of SimplexID<k> to SimplexSet.
00078      */
00079     template <std::size_t k>
00080     inline auto &get()
00081     {
00082         return std::get<k>(tupleMap);
00083     }
00084
00085 private:
00086     std::array<SimplexSet, LevelIndex::value> tupleMap;
00087 };

```

```

00083     }
00084
00085     /**
00086      * @overload
00087      */
00088     template <std::size_t k>
00089     inline auto &get() const
00090     {
00091         return std::get<k>(tupleMap);
00092     }
00093
00094     /**
00095      * @brief      Print the SimplexMap.
00096      *
00097      * @param      output  Handle to the stream to print to.
00098      * @param[in]   S      SimplexMap to print.
00099      *
00100      * @return      Handle to the stream.
00101      */
00102     friend std::ostream &operator<<(std::ostream &output, const SimplexMap<Complex> &S)
00103     {
00104         output << "SimplexMap(";
00105         util::int_for_each<std::size_t, LevelIndex>(PrintHelper(),
00106                                                     output, S);
00107         output << ")";
00108         return output;
00109     }
00110
00111     private:
00112         /**
00113          * @brief      Helper struct to print the SimplexMap.
00114          */
00115         struct PrintHelper
00116         {
00117             /**
00118              * @brief      Print the SimplexMap.
00119              *
00120              * @param      output  Handle to the stream to print to.
00121              * @param[in]   S      SimplexMap to print.
00122              *
00123              * @tparam      k      The simplex dimension to print.
00124              */
00125             template <std::size_t k>
00126             static void apply(std::ostream &output, const SimplexMap<Complex> &S)
00127             {
00128                 output << "[l=" << k;
00129                 auto s = std::get<k>(S.tupleMap);
00130                 for (auto simplex : s)
00131                 {
00132                     output << ", " << to_string(simplex.first) << ":" << simplex.second;
00133                 }
00134                 output << "]";
00135             }
00136         };
00137
00138         /// Alias to create an Array of size k to store keys.
00139         template <std::size_t k> using array = std::array<typename Complex::KeyType, k>;
00140         /// A tuple of arrays of increasing size.
00141         using ArrayLevel = typename util::int_type_map<std::size_t, std::tuple, LevelIndex,
array>::type;
00142         /// Alias for a Map of type T to a SimplexSet.
00143         template <class T> using map = std::map<T, SimplexSet<Complex> >;
00144         /// The full tuple of maps of an Array of keys to SimplexSet.
00145         typename util::type_map<ArrayLevel, map>::type tupleMap;
00146     };
00147
00148     /**
00149      * @brief      Get the map for a simplex dimension.
00150      *
00151      * @param      S      SimplexMap to retrieve from.
00152      *
00153      * @tparam      k      Simplex dimension.
00154      * @tparam      Complex  Typename of the complex.
00155      *
00156      * @return      Returns a map of std::Array<KeyType, k> to SimplexSet.
00157      */
00158     template <std::size_t k, typename Complex>
00159     static inline auto &get(SimplexMap<Complex> &S)
00160     {
00161         return S.template get<k>();
00162     }
00163
00164     /// @overload
00165     template <std::size_t k, typename Complex>
00166     static inline auto &get(const SimplexMap<Complex> &S)
00167     {
00168         return S.template get<k>();

```

```
00169 }
00170 } // end namespace casc
```

10.13 include/casc/SimplexSet.h File Reference

SimplexSet data structure and associated convenience functions.

```
#include <algorithm>
#include <unordered_set>
#include "util.h"
```

Data Structures

- struct `casc::SimplexSet< Complex >`
A multiset to store simplices in a [simplicial_complex](#).

Namespaces

- namespace `casc`
Namespace for everything CASC.

Functions

- template<std::size_t k, typename Complex >
static auto & `casc::get` (SimplexSet< Complex > &S)
Get the NodeSet for a simplex dimension from a [SimplexSet](#).
- template<std::size_t k, typename Complex >
static auto & `casc::get` (const SimplexSet< Complex > &S)
- template<typename Complex >
bool `casc::operator==` (const SimplexSet< Complex > &lhs, const SimplexSet< Complex > &rhs)
Compare if the sets are equivalent.
- template<typename Complex >
bool `casc::operator!=` (const SimplexSet< Complex > &lhs, const SimplexSet< Complex > &rhs)
Compare if the sets are not equivalent.
- template<typename Complex >
static void `casc::set_union` (const SimplexSet< Complex > &A, const SimplexSet< Complex > &B, SimplexSet< Complex > &dest)
Compute the set union.
- template<typename Complex >
static void `casc::set_intersection` (const SimplexSet< Complex > &A, const SimplexSet< Complex > &B, SimplexSet< Complex > &dest)
Compute the set intersection.
- template<typename Complex >
static void `casc::set_difference` (const SimplexSet< Complex > &A, const SimplexSet< Complex > &B, SimplexSet< Complex > &dest)
Compute the set difference.

10.14 SimplexSet.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
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00012  *
00013  * This library is distributed in the hope that it will be useful,
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00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file SimplexSet.h
00027  * @brief SimplexSet data structure and associated convenience functions.
00028  */
00029
00030 #pragma once
00031
00032 #include <algorithm>
00033 #include <unordered_set>
00034 #include "util.h"
00035
00036 namespace casc
00037 {
00038
00039 /**
00040  * @brief A multiset to store simplices in a simplicial_complex.
00041  *
00042  * This is really a tuple of sets where each set corresponds to a simplex
00043  * dimension. Many convenience functions are wrapped so this behaves much like
00044  * a std::set.
00045  *
00046  * @tparam Complex Typename of the simplicial_complex.
00047  */
00048 template <typename Complex>
00049 struct SimplexSet
00050 {
00051     /// Alias for SimplexID
00052     template <std::size_t j>
00053     using SimplexID = typename Complex::template SimplexID<j>;
00054     /// Index sequence of types from the simplicial_complex
00055     using LevelIndex = typename Complex::LevelIndex;
00056     /// Index sequence starting at 1
00057     using cLevelIndex = typename util::remove_first_val<std::size_t,
00058                                                         LevelIndex>::type;
00059     /// Reversed index sequence
00060     using RevIndex = typename util::reverse_sequence<std::size_t,
00061                                                         LevelIndex>::type;
00062     /// Reversed index sequence stops at 1
00063     using cRevIndex = typename util::reverse_sequence<std::size_t,
00064                                                         cLevelIndex>::type;
00065     /// Typename of this
00066     using type_this = SimplexSet<Complex>;
00067
00068     /// Tuple of SimplexIDs wrt an integral level.
00069     using SimplexIDLevel = typename util::int_type_map<std::size_t,
00070                                                         std::tuple, LevelIndex, SimplexID>::type;
00071     // No real sense to hide this tuple of sets from the end users.
00072     // Making it private, we'd have to introduce lots of friend structs.
00073     /// Tuple of NodeSets per level.
00074     typename util::type_map<SimplexIDLevel, NodeSet>::type tupleSet;
00075
00076     /// Default constructor
00077     SimplexSet() {};
00078     /// Default destructor
00079     ~SimplexSet() {};
00080
00081     // type_this& operator=(const type_this& other){
00082     //     util::int_for_each<std::size_t, LevelIndex>(CopyHelper(), this, other);

```

```

00083 // }
00084
00085 // type_this& operator=(type_this&& other){
00086 //     util::int_for_each<std::size_t, LevelIndex>(CopyHelper(), this, other);
00087 // }
00088
00089 /**
00090  * @brief Checks if a level has no elements.
00091  *
00092  * @tparam k Level to check.
00093  *
00094  * @return True if the container is empty, false otherwise.
00095  */
00096 template <std::size_t k>
00097 inline auto empty() const noexcept{
00098     return std::get<k>(tupleSet).empty();
00099 }
00100
00101 /**
00102  * @brief Return the number of elements in a level.
00103  *
00104  * @tparam k Simplex dimension to query
00105  *
00106  * @return Returns the number of simplices of dimension 'k' are in the
00107  *         set.
00108  */
00109 template <std::size_t k>
00110 inline auto size() const noexcept{
00111     return std::get<k>(tupleSet).size();
00112 }
00113
00114 /**
00115  * @brief Clear the contents.
00116  */
00117 void clear()
00118 {
00119     util::int_for_each<std::size_t, LevelIndex>(ClearHelper(), this);
00120 }
00121
00122 /**
00123  * @brief Insert a simplex into the set.
00124  *
00125  * @param[in] s Simplex to insert.
00126  *
00127  * @tparam k Simplex dimension of 's'.
00128  */
00129 template <std::size_t k>
00130 inline void insert(SimplexID<k> s)
00131 {
00132     std::get<k>(tupleSet).insert(s);
00133 }
00134
00135 /**
00136  * @brief Insert a SimplexSet into this.
00137  *
00138  * @param[in] s The SimplexSet to insert.
00139  */
00140 void insert(const SimplexSet<Complex> &s)
00141 {
00142     util::int_for_each<std::size_t, LevelIndex>(
00143         InsertHelper(), this, s);
00144 }
00145
00146 /**
00147  * @brief Remove a simplex from the set.
00148  *
00149  * @param[in] s Simplex to remove.
00150  *
00151  * @tparam k Simplex dimension of 's'.
00152  */
00153 template <std::size_t k>
00154 inline void erase(SimplexID<k> s)
00155 {
00156     std::get<k>(tupleSet).erase(s);
00157 }
00158
00159 /**
00160  * @brief Remove a set of simplices.
00161  *
00162  * @param[in] s SimplexSet to remove.
00163  */
00164 void erase(const SimplexSet<Complex> &s)
00165 {
00166     util::int_for_each<std::size_t, LevelIndex>(
00167         EraseHelper(), this, s);
00168 }
00169

```

```

00170  /**
00171   * @brief      Get the simplex of interest.
00172   *
00173   * @param[in]  s      The simplex to search for.
00174   *
00175   * @tparam     k      Simplex dimension of 's'.
00176   *
00177   * @return     Iterator to an element with key equivalent to s. If no such
00178   *              element is found, past-the-end iterator (see end()) is
00179   *              returned.
00180   */
00181  template <std::size_t k>
00182  inline auto find(const SimplexID<k> s)
00183  {
00184      return std::get<k>(tupleSet).find(s);
00185  }
00186
00187  /**
00188   * @brief      Get the simplex of interest.
00189   *
00190   * @param[in]  s      The simplex to search for.
00191   *
00192   * @tparam     k      Simplex dimension of 's'.
00193   *
00194   * @return     Iterator to an element with key equivalent to s. If no such
00195   *              element is found, past-the-end iterator (see end()) is
00196   *              returned.
00197   */
00198  template <std::size_t k>
00199  inline auto find(const SimplexID<k> s) const
00200  {
00201      return std::get<k>(tupleSet).find(s);
00202  }
00203
00204  /**
00205   * @brief      Get the past-the-end iterator.
00206   *
00207   * @tparam     k      The simplex dimension to get iterator of.
00208   *
00209   * @return     Returns an iterator to the element following the last element
00210   *              of the set for the specified simplex dimension.
00211   */
00212  template <std::size_t k>
00213  inline auto end()
00214  {
00215      return std::get<k>(tupleSet).end();
00216  }
00217
00218  /**
00219   * @brief      Get the past-the-end iterator.
00220   *
00221   * @tparam     k      The simplex dimension to get iterator of.
00222   *
00223   * @return     Returns an iterator to the element following the last element
00224   *              of the set for the specified simplex dimension.
00225   */
00226  template <std::size_t k>
00227  inline auto cend() const
00228  {
00229      return std::get<k>(tupleSet).cend();
00230  }
00231
00232  /**
00233   * @brief      Get an iterator to the first element of the container.
00234   *
00235   * @tparam     k      The simplex dimension to get iterator of.
00236   *
00237   * @return     Returns an iterator to the first element.
00238   */
00239  template <std::size_t k>
00240  inline auto begin()
00241  {
00242      return std::get<k>(tupleSet).begin();
00243  }
00244
00245  /**
00246   * @brief      Get an iterator to the first element of the container.
00247   *
00248   * @tparam     k      The simplex dimension to get iterator of.
00249   *
00250   * @return     Returns an iterator to the first element.
00251   */
00252  template <std::size_t k>
00253  inline auto cbegin() const
00254  {
00255      return std::get<k>(tupleSet).cbegin();
00256  }

```

```

00257
00258 // /**
00259 // * @brief      Get the NodeSet for a particular simplex dimension.
00260 // *
00261 // * @tparam      k      Simplex dimension to get.
00262 // *
00263 // * @return      Returns the NodeSet corresponding to the requested dimension.
00264 // */
00265 template <std::size_t k>
00266 inline auto &get()
00267 {
00268     return std::get<k>(tupleSet);
00269 }
00270
00271 // /**
00272 // * @brief      Get the NodeSet for a particular simplex dimension.
00273 // *
00274 // * @tparam      k      Simplex dimension to get.
00275 // *
00276 // * @return      Returns the NodeSet corresponding to the requested dimension.
00277 // */
00278 template <std::size_t k>
00279 inline auto &get() const
00280 {
00281     return std::get<k>(tupleSet);
00282 }
00283
00284 /**
00285 * @brief      Print the SimplexSet.
00286 *
00287 * See also casc::simplicial_complex::SimplexID::operator«.
00288 *
00289 * @param      output      Handle to the stream to print to.
00290 * @param[in]   S           SimplexSet to print.
00291 *
00292 * @return      Handle to the stream.
00293 */
00294 friend std::ostream &operator<<(std::ostream &output, const SimplexSet<Complex> &S)
00295 {
00296     output << "SimplexSet(";
00297     util::int_for_each<std::size_t, LevelIndex>(PrintHelper(),
00298                                                output, S);
00299     output << ")";
00300     return output;
00301 }
00302
00303 private:
00304 /**
00305 * @brief      Helper struct to insert a SimplexSet.
00306 */
00307 struct InsertHelper
00308 {
00309     /**
00310     * @brief      Perform the insertion for a dimension.
00311     *
00312     * @param      that      Typename of this SimplexSet.
00313     * @param[in]   S         SimplexSet to insert
00314     *
00315     * @tparam      k         Simplex dimension to insert.
00316     */
00317     template <std::size_t k>
00318     static void apply(type_this* that, const SimplexSet<Complex> &S)
00319     {
00320         {
00321             auto s = std::get<k>(S.tupleSet);
00322             for (auto simplex : s)
00323             {
00324                 that->insert(simplex);
00325             }
00326         }
00327     };
00328
00329 /**
00330 * @brief      Helper struct to compute a set difference.
00331 */
00332 struct EraseHelper
00333 {
00334     /**
00335     * @brief      Perform the set difference for a dimension.
00336     *
00337     * @param      that      Typename of this SimplexSet.
00338     * @param[in]   S         SimplexSet to remove from this.
00339     *
00340     * @tparam      k         Simplex dimension to erase.
00341     */
00342     template <std::size_t k>
00343     static void apply(type_this* that, const SimplexSet<Complex> &S)

```

```

00344         {
00345             auto s = std::get<k>(S.tupleSet);
00346             for (auto simplex : s)
00347             {
00348                 that->erase(simplex);
00349             }
00350         }
00351     };
00352
00353     /**
00354      * @brief      Helper struct to print the SimplexSet
00355      */
00356     struct PrintHelper
00357     {
00358         /**
00359          * @brief      Print the simplices in the level.
00360          *
00361          * @param      output    Handle to the stream to output to.
00362          * @param[in]   S        SimplexSet to print.
00363          *
00364          * @tparam      k        Simplex dimension to print.
00365          */
00366         template <std::size_t k>
00367         static void apply(std::ostream &output, const SimplexSet<Complex> &S)
00368         {
00369             output << "[l=" << k;
00370             auto s = std::get<k>(S.tupleSet);
00371             for (auto simplex : s)
00372             {
00373                 output << ", " << simplex;
00374             }
00375             output << "];";
00376         }
00377     };
00378
00379     /**
00380      * @brief      Helper struct to clear the SimplexSet.
00381      */
00382     struct ClearHelper
00383     {
00384         /**
00385          * @brief      Clear a dimension.
00386          *
00387          * @param      that      Typename of this SimplexSet.
00388          *
00389          * @tparam      k        Simplex dimension to clear.
00390          */
00391         template <std::size_t k>
00392         void apply(type_this* that)
00393         {
00394             auto &s = std::get<k>(that->tupleSet);
00395             s.clear();
00396         }
00397     };
00398
00399     // struct CopyHelper
00400     // {
00401     //     template <std::size_t k>
00402     //     void apply(type_this& that, type_this& other){
00403     //         auto &s = that.get<k>();
00404     //         s = other.get<k>();
00405     //     }
00406     //
00407     //     template <std::size_t k>
00408     //     void apply(type_this& that, type_this&& other){
00409     //         auto &s = that.get<k>();
00410     //         s = other.get<k>();
00411     //     }
00412     // };
00413 };
00414
00415 /**
00416 * @brief      Get the NodeSet for a simplex dimension from a SimplexSet.
00417 *
00418 * @param      S        SimplexSet of interest.
00419 *
00420 * @tparam      k        Simplex dimension desired.
00421 * @tparam      Complex  Typename of the simplicial_complex.
00422 *
00423 * @return     A NodeSet which holds simplices of dimension 'k' and a member of
00424 *             SimplexSet 'S'.
00425 */
00426 template <std::size_t k, typename Complex>
00427 static inline auto &get(SimplexSet<Complex> &S)
00428 {
00429     return S.template get<k>();
00430 }

```

```

00431
00432 /**
00433  * @overload
00434  */
00435 template <std::size_t k, typename Complex>
00436 static inline auto &get(const SimplexSet<Complex> &S)
00437 {
00438     return S.template get<k>();
00439 }
00440
00441 /// @cond detail
00442 /// Namespace for simplex container related helpers
00443 namespace simplex_set_detail
00444 {
00445
00446 /**
00447  * @brief      Helper struct to compute the union of two SimplexSets.
00448  *
00449  * @tparam      Complex  Typename of the simplicial_complex.
00450  */
00451 template <typename Complex>
00452 struct UnionH
00453 {
00454     /**
00455      * @brief      Compute the union of two SimplexSets.
00456      *
00457      * \f$A \cup B \f$
00458      *
00459      * @param[in]   A      A SimplexSet
00460      * @param[in]   B      Another SimplexSet
00461      * @param[out]  dest   The destination SimplexSet
00462      *
00463      * @tparam      k      The current simplex dimension to merge.
00464      */
00465     template <std::size_t k>
00466     static void apply(const SimplexSet<Complex> &A,
00467                     const SimplexSet<Complex> &B,
00468                     SimplexSet<Complex> &dest)
00469     {
00470         auto a = std::get<k>(A.tupleSet);
00471         auto b = std::get<k>(B.tupleSet);
00472         auto &d = std::get<k>(dest.tupleSet);
00473         d.insert(a.begin(), a.end());
00474         d.insert(b.begin(), b.end());
00475     }
00476 };
00477
00478 /**
00479  * @brief      Helper struct to compute the intersection of two SimplexSets.
00480  *
00481  * @tparam      Complex  Typename of the simplicial_complex.
00482  */
00483 template <typename Complex>
00484 struct IntersectH
00485 {
00486     /**
00487      * @brief      Compute the intersection of two SimplexSets.
00488      *
00489      * \f$A \cap B \f$
00490      *
00491      * @param[in]   A      A SimplexSet
00492      * @param[in]   B      Another SimplexSet
00493      * @param       dest   The destination SimplexSet.
00494      *
00495      * @tparam      k      The current simplex dimension to merge.
00496      */
00497     template <std::size_t k>
00498     static void apply(const SimplexSet<Complex> &A,
00499                     const SimplexSet<Complex> &B,
00500                     SimplexSet<Complex> &dest)
00501     {
00502         auto a = casc::get<k>(A);
00503         auto b = casc::get<k>(B);
00504         auto &d = casc::get<k>(dest);
00505
00506         if (a.size() < b.size())
00507         {
00508             for (auto item : a)
00509             {
00510                 if (b.find(item) != b.end())
00511                     d.insert(item);
00512             }
00513         }
00514         else
00515         {
00516             for (auto item : b)
00517             {

```

```

00518             if (a.find(item) != a.end())
00519                 d.insert(item);
00520         }
00521     }
00522 }
00523 };
00524
00525 /**
00526  * @brief      Helper struct to compute the set intersection.
00527  *
00528  * @tparam      Complex Typename of the simplicial_complex.
00529  */
00530 template <typename Complex>
00531 struct DifferenceH
00532 {
00533     /**
00534      * @brief      Compute the set difference for a simplex dimension.
00535      *
00536      * \f$ dest = A \setminus B \f$
00537      *
00538      * @param[in]  A      A SimplexSet.
00539      * @param[in]  B      Remove this SimplexSet from A.
00540      * @param      dest   The destination SimplexSet.
00541      *
00542      * @tparam      k      The simplex dimension to compute the difference of.
00543      */
00544     template<std::size_t k>
00545     static void apply(const SimplexSet<Complex> &A,
00546                     const SimplexSet<Complex> &B,
00547                     SimplexSet<Complex> &dest)
00548     {
00549         auto a = casc::get<k>(A);
00550         auto b = casc::get<k>(B);
00551         auto &d = casc::get<k>(dest);
00552
00553         for (auto item : a)
00554         {
00555             if (b.find(item) == b.end())
00556                 d.insert(item);
00557         }
00558     }
00559 };
00560
00561 /**
00562  * @brief      Helper struct to compute set equivalence.
00563  *
00564  * @tparam      Complex Typename of the simplicial_complex.
00565  */
00566 template <typename Complex>
00567 struct OperatorEQH
00568 {
00569     /// Result of the comparison
00570     bool result;
00571
00572     /// Default constructor
00573     OperatorEQH(): result(true) {}
00574
00575     /**
00576      * @brief      Compare the two sets by level.
00577      *
00578      * @param[in]  lhs   The left hand side
00579      * @param[in]  rhs   The right hand side
00580      *
00581      * @tparam      k      Level to compare.
00582      */
00583     template <std::size_t k>
00584     void apply(const SimplexSet<Complex> &lhs,
00585              const SimplexSet<Complex> &rhs){
00586         auto a = casc::get<k>(lhs);
00587         auto b = casc::get<k>(rhs);
00588         result &= a==b;
00589     }
00590 };
00591 } // end namespace simplex_set_detail
00592 /// @endcond
00593
00594 /**
00595  * @brief      Compare if the sets are equivalent
00596  *
00597  * @param[in]  lhs   The left hand side
00598  * @param[in]  rhs   The right hand side
00599  *
00600  * @tparam      Complex Typename of the simplicial_complex
00601  *
00602  * @return      True if the sets are equal, false otherwise.
00603  */
00604 template <typename Complex>

```

```

00605 bool operator==(const SimplexSet<Complex> &lhs, const SimplexSet<Complex> &rhs){
00606     auto func = simplex_set_detail::OperatorEQH<Complex>();
00607     util::int_for_each<std::size_t, typename Complex::LevelIndex>(
00608         func, lhs, rhs);
00609     return func.result;
00610 }
00611
00612 /**
00613  * @brief      Compare if the sets are not equivalent.
00614  *
00615  * @param[in]  lhs      The left hand side
00616  * @param[in]  rhs      The right hand side
00617  *
00618  * @tparam     Complex  Typename of the simplicial_complex.
00619  *
00620  * @return     True if the sets are inequal, false otherwise.
00621  */
00622 template <typename Complex>
00623 bool operator!=(const SimplexSet<Complex> &lhs, const SimplexSet<Complex> &rhs){
00624     return !(lhs == rhs);
00625 }
00626
00627 /**
00628  * @brief      Compute the set union.
00629  *
00630  * @param[in]  A          A SimplexSet
00631  * @param[in]  B          Another SimplexSet
00632  * @param[out] dest       The destination SimplexSet.
00633  *
00634  * @tparam     Complex    Typename of the simplicial_complex.
00635  */
00636 template <typename Complex>
00637 static void set_union(const SimplexSet<Complex> &A,
00638                     const SimplexSet<Complex> &B,
00639                     SimplexSet<Complex> &dest)
00640 {
00641     util::int_for_each<std::size_t,
00642                     typename Complex::LevelIndex>(
00643         simplex_set_detail::UnionH<Complex>(), A, B, dest);
00644 }
00645
00646 /**
00647  * @brief      Compute the set intersection.
00648  *
00649  * @param[in]  A          A SimplexSet
00650  * @param[in]  B          Another SimplexSet
00651  * @param[out] dest       The destination SimplexSet.
00652  *
00653  * @tparam     Complex    Typename of the simplicial_complex.
00654  */
00655 template <typename Complex>
00656 static void set_intersection(const SimplexSet<Complex> &A,
00657                             const SimplexSet<Complex> &B,
00658                             SimplexSet<Complex> &dest)
00659 {
00660     util::int_for_each<std::size_t,
00661                     typename Complex::LevelIndex>(
00662         simplex_set_detail::IntersectH<Complex>(), A, B, dest);
00663 }
00664
00665 /**
00666  * @brief      Compute the set difference.
00667  *
00668  * @param[in]  A          A SimplexSet
00669  * @param[in]  B          Another SimplexSet
00670  * @param[out] dest       The destination SimplexSet.
00671  *
00672  * @tparam     Complex    Typename of the simplicial_complex.
00673  */
00674 template <typename Complex>
00675 static void set_difference(const SimplexSet<Complex> &A,
00676                           const SimplexSet<Complex> &B,
00677                           SimplexSet<Complex> &dest)
00678 {
00679     util::int_for_each<std::size_t,
00680                     typename Complex::LevelIndex>(
00681         simplex_set_detail::DifferenceH<Complex>(), A, B, dest);
00682 }
00683 } // end namespace casc

```

10.15 include/casc/SimplicialComplex.h File Reference

This header contains the main CASC data structure and associated components.

```

#include <algorithm>
#include <assert.h>
#include <stdint>
#include <map>
#include <set>
#include <iterator>
#include <array>
#include <vector>
#include <iostream>
#include <fstream>
#include <functional>
#include <type_traits>
#include <ostream>
#include <unordered_set>
#include <unordered_map>
#include <utility>
#include <stdexcept>
#include "index_tracker.h"
#include "util.h"

```

Data Structures

- class [casc::simplicial_complex< traits >](#)
The CASC data structure for representing simplicial complexes of arbitrary dimensionality with coloring.
- struct [casc::simplicial_complex< traits >::SimplexID< k >](#)
A handle for a simplex object in the complex.
- struct [casc::simplicial_complex< traits >::EdgeID< k >](#)
External reference to an edge or a connection within the complex.

Namespaces

- namespace [casc](#)
Namespace for everything CASC.

Typedefs

- template<typename KeyType, typename ... Ts>
using [casc::AbstractSimplicialComplex](#) = simplicial_complex< detail::simplicial_complex_traits_default< KeyType, Ts... > >
- template<typename T>
using [casc::NodeSet](#) = std::unordered_set< T, simplex_set_detail::hashSimplexID< T > >
Helpful alias defining an unordered_set of simplices. See also hashSimplexID.

10.16 SimplicialComplex.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *
00008  * This library is free software; you can redistribute it and/or
00009  * modify it under the terms of the GNU Lesser General Public
00010  * License as published by the Free Software Foundation; either
00011  * version 2.1 of the License, or (at your option) any later version.
00012  *
00013  * This library is distributed in the hope that it will be useful,
00014  * but WITHOUT ANY WARRANTY; without even the implied warranty of
00015  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
00016  * Lesser General Public License for more details.
00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file SimplicialComplex.h
00027  * @brief This header contains the main CASC data structure and associated
00028  * components.
00029  */
00030
00031 #pragma once
00032
00033 #include <algorithm>
00034 #include <assert.h>
00035 #include <stdint_t>
00036 #include <map>
00037 #include <set>
00038 #include <iterator>
00039 #include <array>
00040 #include <vector>
00041 #include <iostream>
00042 #include <fstream>
00043 #include <functional>
00044 #include <type_traits>
00045 #include <ostream>
00046 #include <unordered_set>
00047 #include <unordered_map>
00048 #include <utility>
00049 #include <stdexcept>
00050
00051 #include "index_tracker.h"
00052 #include "util.h"
00053
00054 #if __has_cpp_attribute(maybe_unused)
00055 #define MAYBE_UNUSED [[maybe_unused]]
00056 #else
00057 #define MAYBE_UNUSED
00058 #endif
00059
00060 /// Namespace for everything CASC
00061 namespace casc
00062 {
00063     /// @cond detail
00064     /// Namespace for CASC internal data structures
00065     namespace detail
00066     {
00067         /// Data structure to store simplices by level.
00068         template <class T> using map = std::map<std::size_t, T>;
00069
00070         /**
00071          * @brief A generic pair type representing Key to Value associations.
00072          *
00073          * @tparam T1 Typename of the Key
00074          * @tparam T2 Typename of the Value
00075          */
00076         template <typename T1, typename T2>
00077         struct asc_pair {
00078             using this_t = asc_pair<T1, T2>;
00079             asc_pair() {}
00080             asc_pair(const T1& first, const T2& second) : _pair(first, second) {}
00081             asc_pair(T1&& first, T2&& second) : _pair(std::forward<T1>(first), std::forward<T2>(second)) {}
00082             asc_pair(const this_t& other) : _pair(other._pair) {}

```

```

00083     asc_pair(this_t&& other) : _pair(std::forward<std::pair<T1,T2>>(other._pair)) {}
00084
00085     operator T1() const {
00086         return _pair.first;
00087     }
00088
00089     this_t& operator=(const this_t& other){
00090         _pair = other._pair;
00091         return *this;
00092     }
00093
00094     this_t& operator=(this_t&& other){
00095         _pair = std::move(other._pair);
00096         return *this;
00097     }
00098
00099     friend bool operator==(const this_t& lhs, const this_t& rhs) {return lhs.first == rhs.first;}
00100     friend bool operator!=(const this_t& lhs, const this_t& rhs) {return lhs.first != rhs.first;}
00101     friend bool operator<=(const this_t& lhs, const this_t& rhs) {return lhs.first <= rhs.first;}
00102     friend bool operator>=(const this_t& lhs, const this_t& rhs) {return lhs.first >= rhs.first;}
00103     friend bool operator<(const this_t& lhs, const this_t& rhs) {return lhs.first < rhs.first;}
00104     friend bool operator>(const this_t& lhs, const this_t& rhs) {return lhs.first > rhs.first;}
00105
00106     T1& first = _pair.first;
00107     T2& second = _pair.second;
00108 private:
00109     std::pair<T1,T2> _pair;
00110 };
00111
00112 /**
00113  * @brief      Array of asc_pairs sorted by Key for boundary adjacency storage.
00114  *
00115  * @tparam      KEY_T      Typename of Key
00116  * @tparam      VAL_T      Typename of Value
00117  * @tparam      k          Size of the array
00118  */
00119 template <typename KEY_T, typename VAL_T, std::size_t k>
00120 struct asc_arraymap {
00121     using pair_t = asc_pair<KEY_T, VAL_T>;
00122     using array_t = std::array<pair_t, k>;
00123     using iterator = typename array_t::iterator;
00124     using const_iterator = typename array_t::const_iterator;
00125
00126     asc_arraymap(){
00127         _begin = _array.begin();
00128         _end = _array.begin();
00129     }
00130
00131     void insert(pair_t& p){
00132         if (_end == _array.end())
00133             throw std::out_of_range("insert&: Adding element beyond the end of array.");
00134         *_end = p;
00135         ++_end;
00136         std::sort(_begin, _end);
00137     }
00138
00139     void insert(pair_t&& p){
00140         if (_end == _array.end())
00141             throw std::out_of_range("insert&&: Adding element beyond the end of array.");
00142         *_end = std::forward<pair_t>(p);
00143         ++_end;
00144         std::sort(_begin, _end);
00145     }
00146
00147     iterator find(const KEY_T& key){
00148         return std::find(_begin, _end, key);
00149     }
00150
00151     void erase(const KEY_T& key){
00152         auto it = std::find(_begin, _end, key);
00153         if(it != _end){
00154             std::copy(it+1, _end, it);
00155             --_end;
00156         }
00157     }
00158
00159     std::size_t size() const{
00160         return std::distance(_end, _begin);
00161     }
00162
00163     VAL_T& operator[](const KEY_T& key){
00164         auto it = std::find(_begin, _end, key);
00165         if(it != _end){
00166             return it->second;
00167         }
00168         else{
00169             if (_end == _array.end())

```

```

00170         throw std::out_of_range("operator[]: Adding element beyond the end of array.");
00171         _end->first = key;
00172         ++_end;
00173         std::sort(_begin, _end);
00174         return std::find(_begin, _end, key)->second;
00175     }
00176 }
00177
00178 iterator begin(){ return _begin; }
00179 iterator end(){ return _end; }
00180 const_iterator cbegin() const {return _begin;}
00181 const_iterator cend() const {return _end;}
00182
00183 private:
00184     array_t _array;
00185     iterator _begin;
00186     iterator _end;
00187 };
00188
00189
00190 /**
00191  * @brief      Sorted vector of asc_pairs for coboundary relation storage.
00192  *
00193  * @tparam     KEY_T  Typename of Key
00194  * @tparam     VAL_T  Typename of Values
00195  */
00196 template <typename KEY_T, typename VAL_T>
00197 struct asc_vectormap {
00198     using pair_t = asc_pair<KEY_T, VAL_T>;
00199     using vector_t = std::vector<pair_t>;
00200     using iterator = typename vector_t::iterator;
00201     using const_iterator = typename vector_t::const_iterator;
00202
00203     asc_vectormap() {}
00204
00205     void insert(pair_t& p){
00206         iterator first = std::lower_bound(_vector.begin(), _vector.end(), p);
00207         if ((first == _vector.end()) || (*first != p)){
00208             _vector.insert(first, p);
00209         }
00210         else{
00211             std::cout << "Item already exists...";
00212         }
00213     }
00214
00215     void insert(pair_t&& p){
00216         iterator first = std::lower_bound(_vector.begin(), _vector.end(), p);
00217         if ((first == _vector.end()) || (*first != p)){
00218             _vector.insert(first, std::forward<pair_t>(p));
00219         }
00220         else{
00221             std::cout << "Item already exists...";
00222         }
00223     }
00224
00225     iterator find(const KEY_T& key){
00226         iterator first = std::lower_bound(_vector.begin(), _vector.end(), key);
00227         if (first != _vector.end()){
00228             if (*first != key){
00229                 return _vector.end();
00230             }
00231             else{
00232                 return first;
00233             }
00234         }
00235         else{
00236             return first;
00237         }
00238     }
00239
00240     void erase(const KEY_T& key){
00241         iterator it = this->find(key);
00242         if (it != _vector.end()){
00243             _vector.erase(it);
00244         }
00245     }
00246
00247     std::size_t size() const{
00248         return _vector.size();
00249     }
00250
00251     VAL_T& at(const KEY_T& key){
00252         iterator first = std::lower_bound(_vector.begin(), _vector.end(), key);
00253         if ((first == _vector.end()) || (first->first != key)){
00254             throw std::out_of_range("Could not find element in asc_vectormap.");
00255         }
00256         else {

```

```

00257         return first->second;
00258     }
00259 }
00260
00261 VAL_T& operator[](const KEY_T& key){
00262     iterator first = std::lower_bound(_vector.begin(), _vector.end(), key);
00263     if ((first == _vector.end()) || (first->first != key)){
00264         first = _vector.emplace(first, pair_t());
00265         first->first = key;
00266         return first->second;
00267     }
00268     else {
00269         return first->second;
00270     }
00271 }
00272
00273 iterator begin(){ return _vector.begin(); }
00274 iterator end(){ return _vector.end(); }
00275 const_iterator cbegin() const {return _vector.cbegin();}
00276 const_iterator cend() const {return _vector.cend();}
00277 private:
00278     vector_t _vector;
00279 };
00280
00281
00282 /**
00283  * @brief Template prototype for Nodes in CASC.
00284  *
00285  * asc_Node must be defined outside of simplicial_complex because C++ does
00286  * not allow internal templates to be partially specialized. This template
00287  * prototype is later specialized to represent various Node roles.
00288  */
00289 template <class KeyType, std::size_t k, std::size_t N, typename DataTypes, class> struct asc_Node;
00290
00291 /// This is the base Node class.
00292 struct asc_NodeBase {
00293     /**
00294      * @brief Construct a Node
00295      *
00296      * @param[in] id An internal integer identifier of the Node.
00297      */
00298     asc_NodeBase(std::size_t id) : _node(id) {}
00299     virtual ~asc_NodeBase() {}; /**< Destructor */
00300     std::size_t _node; /**< Internal Node ID*/
00301 };
00302
00303 /**
00304  * @brief Base class for Node with some data.
00305  *
00306  * @tparam DataType Typename of the data to be stored.
00307  */
00308 template <class DataType>
00309 struct asc_NodeData {
00310     DataType _data; /**< stored data with type DataType */
00311 };
00312
00313 /**
00314  * @brief Explicit specialization for Nodes without data.
00315  *
00316  * This exists so that the compiler knows to not allocate any memory to
00317  * store data when void is specified.
00318  */
00319 template <>
00320 struct asc_NodeData<void> {};
00321
00322 /**
00323  * @brief Base class for Nodes with edge data.
00324  *
00325  * @tparam KeyType Typename of index for indexing Nodes.
00326  * @tparam DataType Typename of the data stored on the edge.
00327  */
00328 template <class KeyType, class DataType>
00329 struct asc_EdgeData {
00330     /** The map of SimplexIDs to stored edge data. */
00331     std::unordered_map<KeyType, DataType> _edge_data;
00332 };
00333
00334 /**
00335  * @brief Explicit specialization for Nodes with no edge data.
00336  *
00337  * @tparam KeyType Typename of index for indexing Nodes.
00338  */
00339 template <class KeyType>
00340 struct asc_EdgeData<KeyType, void> {};
00341
00342 /**
00343  * @brief Base class for Node with parent nodes

```

```

00344 *
00345 * @tparam KeyType      Typename of the Node index
00346 * @tparam k            The Simplex dimension
00347 * @tparam N            Dimension of the Complex
00348 * @tparam NodeDataTypes A util::type_holder array of Node types
00349 * @tparam EdgeDataTypes A util::type_holder array of Edge types
00350 */
00351 template < class KeyType,
00352            std::size_t k,
00353            std::size_t N,
00354            class NodeDataTypes,
00355            class EdgeDataTypes>
00356 struct asc_NodeDown :
00357     public asc_EdgeData<KeyType,
00358         typename util::type_get<k-1, EdgeDataTypes>::type> {
00359     /** Alias the typename of the parent Node */
00360     using DownNodeT = asc_Node<KeyType, k-1, N, NodeDataTypes, EdgeDataTypes>;
00361
00362     /** Map of indices to parent Node pointers*/
00363     asc_arraymap<KeyType, DownNodeT*, k> _down;
00364     // std::map<KeyType, DownNodeT*> _down;
00365 };
00366
00367 /**
00368 * @brief      Base class for Node with children Nodes
00369 *
00370 * @tparam KeyType      Typename of the Node index
00371 * @tparam k            The Simplex dimension
00372 * @tparam N            Dimension of the Complex
00373 * @tparam NodeDataTypes A util::type_holder array of Node types
00374 * @tparam EdgeDataTypes A util::type_holder array of Edge types
00375 */
00376 template < class KeyType,
00377            std::size_t k,
00378            std::size_t N,
00379            class NodeDataTypes,
00380            class EdgeDataTypes>
00381 struct asc_NodeUp {
00382     /// Typename of the nodes up.
00383     using UpNodeT = asc_Node<KeyType, k+1, N, NodeDataTypes, EdgeDataTypes>;
00384     asc_vectormap<KeyType, UpNodeT*> _up;
00385     // std::unordered_map<KeyType, UpNodeT*> _up;      /**< @brief Map of pointers to children */
00386 };
00387
00388 /**
00389 * @brief      Node with both parents and children
00390 *
00391 * @tparam KeyType      Typename of the Node index
00392 * @tparam k            The Simplex dimension
00393 * @tparam N            Dimension of the Complex
00394 * @tparam NodeDataTypes A util::type_holder of Node types
00395 * @tparam EdgeDataTypes A util::type_holder of Edge types
00396 */
00397 template <class KeyType, std::size_t k, std::size_t N, class NodeDataTypes, class EdgeDataTypes>
00398 struct asc_Node : public asc_NodeBase,
00399     public asc_NodeData<typename util::type_get<k, NodeDataTypes>::type>,
00400     public asc_NodeDown<KeyType, k, N, NodeDataTypes, EdgeDataTypes>,
00401     public asc_NodeUp<KeyType, k, N, NodeDataTypes, EdgeDataTypes>
00402 {
00403     /// Dimension of the simplex.
00404     static constexpr std::size_t level = k;
00405
00406     /**
00407     * @brief      Default constructor
00408     *
00409     * @param[in] id The internal integer identifier.
00410     */
00411     asc_Node(std::size_t id) : asc_NodeBase(id) {}
00412
00413     /**
00414     * @brief      Print the Node out for debugging only
00415     *
00416     * @param      output The output stream.
00417     * @param[in] node The Node of interest to print.
00418     *
00419     * @return     A handle to the output stream.
00420     */
00421     friend std::ostream &operator<<(std::ostream &output, const asc_Node &node)
00422     {
00423         output << "Node(level=" << k << ", " << "id=" << node._node;
00424         if (node._down.size() > 0)
00425         {
00426             for (auto it = node._down.cbegin(); it != node._down.cend(); ++it)
00427             {
00428                 output << ", NodeDownID={'"
00429                     << it->first << "', "
00430                     << it->second->_node << "}'";

```

```

00431     }
00432     }
00433     if (node._up.size() > 0)
00434     {
00435         for (auto it = node._up.cbegin(); it != node._up.cend(); ++it)
00436         {
00437             output << " , NodeUpID={'"
00438                 << it->first << " , "
00439                 << it->second->_node << " }";
00440         }
00441     }
00442     output << ")";
00443     return output;
00444 }
00445 };
00446
00447 /**
00448  * @brief      Node with only children i.e., the root.
00449  *
00450  * @tparam      KeyType          Typename of the Node index
00451  * @tparam      N                The Simplex dimension
00452  * @tparam      NodeDataTypes    A util::type_holder of Node types
00453  * @tparam      EdgeDataTypes    A util::type_holder of Edge types
00454  */
00455 template <class KeyType, std::size_t N, class NodeDataTypes, class EdgeDataTypes>
00456 struct asc_Node<KeyType, 0, N, NodeDataTypes, EdgeDataTypes> :
00457     public asc_NodeBase,
00458     public asc_NodeData<typename util::type_get<0, NodeDataTypes>::type>,
00459     public asc_NodeUp<KeyType, 0, N, NodeDataTypes, EdgeDataTypes>
00460 {
00461     /// Dimension of the simplex.
00462     static constexpr std::size_t level = 0;
00463
00464     /**
00465      * @brief      Default constructor
00466      *
00467      * @param[in]   id          The internal integer identifier.
00468      */
00469     asc_Node(std::size_t id) : asc_NodeBase(id) {}
00470
00471     /**
00472      * @brief      Print the Node out for debugging only
00473      *
00474      * @param       output      The output stream.
00475      * @param[in]   node        The Node of interest to print.
00476      *
00477      * @return      A handle to the output stream.
00478      */
00479     friend std::ostream &operator<<(std::ostream &output, const asc_Node &node)
00480     {
00481         output << "Node(level=" << 0
00482             << " , id=" << node._node;
00483         if (node._up.size() > 0)
00484         {
00485             for (auto it = node._up.cbegin(); it != node._up.cend(); ++it)
00486             {
00487                 output << " , NodeUpID={'"
00488                     << it->first << " , "
00489                     << it->second->_node << " }";
00490             }
00491         }
00492         output << ")";
00493         return output;
00494     }
00495 };
00496
00497 /**
00498  * @brief      Top level node with only parents
00499  *
00500  * @tparam      KeyType          Typename of the Node index
00501  * @tparam      N                The Simplex dimension
00502  * @tparam      NodeDataTypes    A util::type_holder of Node types
00503  * @tparam      EdgeDataTypes    A util::type_holder of Edge types
00504  */
00505 template <class KeyType, std::size_t N, class NodeDataTypes, class EdgeDataTypes>
00506 struct asc_Node<KeyType, N, N, NodeDataTypes, EdgeDataTypes> :
00507     public asc_NodeBase,
00508     public asc_NodeData<typename util::type_get<N, NodeDataTypes>::type>,
00509     public asc_NodeDown<KeyType, N, N, NodeDataTypes, EdgeDataTypes>
00510 {
00511     /// Dimension of the simplex.
00512     static constexpr std::size_t level = N;
00513
00514     /**
00515      * @brief      Default constructor
00516      *
00517      * @param[in]   id          The internal integer identifier.

```

```

00518     */
00519     asc_Node(std::size_t id) : asc_NodeBase(id) {}
00520
00521     /**
00522     * @brief      Print the Node out for debugging only
00523     *
00524     * @param      output  The output stream.
00525     * @param[in]   node    The Node of interest to print.
00526     *
00527     * @return      A handle to the output stream.
00528     */
00529     friend std::ostream &operator<<(std::ostream &output, const asc_Node &node)
00530     {
00531         output << "Node(level=" << N
00532             << ", id=" << node._node;
00533         if (node._down.size() > 0)
00534         {
00535             for (auto it = node._down.cbegin(); it != node._down.cend(); ++it)
00536             {
00537                 output << ", NodeDownID={'"
00538                     << it->first << "', "
00539                     << it->second->_node << "}'";
00540             }
00541         }
00542         output << ")";
00543         return output;
00544     }
00545 };
00546
00547 /**
00548 * @brief      An iterator adapter to iterate over NodeIDs.
00549 *
00550 * @tparam      Iter  Typename of the iterator
00551 * @tparam      Data  Typename of the data
00552 */
00553 template <typename Iter, typename Data>
00554 struct node_id_iterator : public std::bidirectional_iterator_tag, Data> {
00555     public:
00556         /// Inherit from a bidirectional std::iterator.
00557         using super = std::iterator<std::bidirectional_iterator_tag, Data>;
00558         /// Empty constructor
00559         node_id_iterator() {}
00560         /// Instantiate with an iterator to wrap
00561         node_id_iterator(Iter j) : i(j) {}
00562         /// Increment the iterator
00563         node_id_iterator &operator++() { ++i; return *this; }
00564         /// Increment the iterator
00565         node_id_iterator operator++(int) { auto tmp = *this; ++(*this); return tmp; }
00566         /// Decrement the iterator
00567         node_id_iterator &operator--() { --i; return *this; }
00568         /// Decrement the iterator
00569         node_id_iterator operator--(int) { auto tmp = *this; --(*this); return tmp; }
00570         /// Iterator equality comparison
00571         bool operator==(node_id_iterator j) const { return i == j.i; }
00572         /// Iterator inequality comparison
00573         bool operator!=(node_id_iterator j) const { return !(*this == j); }
00574         /// Dereferencing the iterator produces a SimplexID.
00575         Data operator*() { return Data(i->second); }
00576         /// Const version
00577         const Data operator*() const { return Data(i->second); }
00578         /// Dereferencing the iterator produces a SimplexID.
00579         typename super::pointer operator->() { return Data(i->second); }
00580     protected:
00581         /// The iterator to wrap.
00582         Iter i;
00583 };
00584
00585 /**
00586 * @brief      Convert an iterator into a node_id_iterator.
00587 *
00588 * @param[in]   j        The iterator to wrap
00589 *
00590 * @tparam      Iter  Typename of the iterator
00591 * @tparam      Data  Typename of the data
00592 *
00593 * @return      An iterator over NodeIDs.
00594 */
00595 template <typename Iter, typename Data>
00596 inline node_id_iterator<Iter, Data> make_node_id_iterator(Iter j)
00597 {
00598     return node_id_iterator<Iter, Data>(j);
00599 }
00600
00601 /**
00602 * @brief      An iterator adapter to iterate over Node data.
00603 *
00604 * @tparam      Iter  Typename of the iterator

```

```

00605 * @tparam      Data  Typename of the data
00606 */
00607 template <typename Iter, typename Data>
00608 struct node_data_iterator : public std::iterator<std::bidirectional_iterator_tag, Data> {
00609     public:
00610         /// Inherit from a bidirectional std::iterator.
00611         using super = std::iterator<std::bidirectional_iterator_tag, Data>;
00612         /// Empty constructor.
00613         node_data_iterator() {}
00614         /// Instantiate with an iterator to wrap.
00615         node_data_iterator(Iter j) : i(j) {}
00616         /// Increment the iterator
00617         node_data_iterator &operator++() { ++i; return *this; }
00618         /// Increment the iterator
00619         node_data_iterator operator++(int) { auto tmp = *this; ++(*this); return tmp; }
00620         /// Decrement the iterator
00621         node_data_iterator &operator--() { --i; return *this; }
00622         /// Decrement the iterator
00623         node_data_iterator operator--(int) { auto tmp = *this; --(*this); return tmp; }
00624         /// Iterator comparison
00625         bool operator==(node_data_iterator j) const { return i == j.i; }
00626         /// Iterator inequality comparison
00627         bool operator!=(node_data_iterator j) const { return !(*this == j); }
00628         /// Dereferencing the iterator produces the data.
00629         typename super::reference operator*() { return i->second->_data; }
00630         /// Dereferencing the iterator produces the data.
00631         typename super::pointer operator->() { return i->second->_data; }
00632     protected:
00633         /// The wrapped iterator.
00634         Iter i;
00635 };
00636
00637 /**
00638 * @brief      Convert an iterator into a node_data_iterator.
00639 *
00640 * @param[in]  j      The iterator to wrap
00641 *
00642 * @tparam     Iter    Typename of the iterator
00643 * @tparam     Data    Typename of the data
00644 *
00645 * @return     An iterator over Node data.
00646 */
00647 template <typename Iter, typename Data>
00648 inline node_data_iterator<Iter, Data> make_node_data_iterator(Iter j)
00649 {
00650     return node_data_iterator<Iter, Data>(j);
00651 }
00652
00653 /**
00654 * @brief      Helper to build a traits struct via expanding explicitly
00655 * @specified
00656 *
00657 * traits from AbstractSimplicialComplex.
00658 *
00659 * @tparam     K      Typename for the KeyType
00660 * @tparam     Ts      Types of data to be stored on simplices.
00661 */
00662 template <typename K, typename ... Ts>
00663 struct simplicial_complex_traits_default
00664 {
00665     /// Template to assign ints for all levels.
00666     template <std::size_t k> using all_int = int;
00667     /// Alias for KeyType
00668     using KeyType = K;
00669     /// The typenames of the data to be stored on simplices.
00670     using NodeTypes = util::type_holder<Ts...>;
00671     /// Assign all_int type to all edges
00672     using EdgeTypes = typename util::int_type_map<std::size_t,
00673                                                 util::type_holder,
00674                                                 typename std::make_index_sequence<sizeof ...
00675                                                 (Ts)-1>,
00676                                                 all_int>::type;
00677 };
00678
00679 /**
00680 * @class      simplicial_complex
00681 *
00682 * @brief      The CASC data structure for representing simplicial complexes of
00683 *             arbitrary dimensionality with coloring.
00684 *
00685 * You can create a CASC object by defining a struct containing the
00686 * traits of the complex. For example:
00687 * ~~~~~{.cpp}
00688 * struct complex_traits{
00689 *     using KeyType = int;
00690 *     using NodeTypes = util::type_holder<int,int,int,int>;
00691 * };
00692 * simplicial_complex c(complex_traits{});
00693 *
00694 * ~~~~~
00695 */

```

```

00691 *      using EdgeTypes = util::type_holder<int,int,int>;
00692 * };
00693 *
00694 * using SurfaceMesh = simplicial_complex<complex_traits>;
00695 * ~~~~~
00696 * This is the preferred method for creating a new CASC type. Alternatively you
00697 * can use the ::AbstractSimplicialComplex alias to build a struct for you.
00698 *
00699 * @tparam      traits  A struct defining the dimension of the complex and data
00700 *                      to be stored on each node and edge.
00701 */
00702 template <typename traits>
00703 class simplicial_complex
00704 {
00705     public:
00706         /// Typename of simplex keys.
00707         using KeyType = typename traits::KeyType;
00708         /// Typenames of the data stored on simplices.
00709         using NodeDataTypes = typename traits::NodeTypes;
00710         /// Typenames of the data stored on edges.
00711         using EdgeDataTypes = typename traits::EdgeTypes;
00712         /// Type of this
00713         using type_this = simplicial_complex<traits>;
00714         /// Total number of levels in the complex.
00715         static constexpr std::size_t numLevels = NodeDataTypes::size;
00716         /// Dimension of the simplicial complex.
00717         static constexpr std::size_t topLevel = numLevels-1;
00718         /// Dimension of boundaries.
00719         static constexpr std::size_t bdryLevel = numLevels-2;
00720         /// Index of all simplex dimensions in the complex.
00721         using LevelIndex = typename std::make_index_sequence<numLevels>;
00722     private:
00723         /// Alias templated asc_node<...> as Node<k>
00724         template <std::size_t k> using Node = detail::asc_Node<KeyType, k, topLevel, NodeDataTypes,
EdgeDataTypes>;
00725         /// Alias Node<k>* as NodePtr<k>
00726         template <std::size_t k> using NodePtr = Node<k>*;
00727     public:
00728         /** Convenience alias for the user specified NodeData<k> typename */
00729         template <std::size_t k> using NodeData = typename util::type_get<k, NodeDataTypes>::type;
00730         /** Convenience alias for the user specified EdgeData<k> typename */
00731         template <std::size_t k> using EdgeData = typename util::type_get<k, EdgeDataTypes>::type;
00732         friend struct SimplexID; /**< SimplexID is a friend of
                                simplicial_complex */
00733
00734     /**
00735      * @brief      A handle for a simplex object in the complex.
00736      *
00737      * SimplexID wraps a Node* for external handling. This way
00738      * the end users are never exposed to a raw pointer. For all general
00739      * purposes algorithms should use and pass SimplexIDs over raw pointers.
00740      *
00741      * @tparam      k      The Simplex dimension.
00742      */
00743     template <std::size_t k>
00744     struct SimplexID {
00745         /// Typename of the complex
00746         using complex = simplicial_complex<traits>;
00747         /// SimplexID is a friend of the complex
00748         friend simplicial_complex<traits>;
00749         /// The dimension of the simplex.
00750         static constexpr std::size_t level = k;
00751
00752         /**
00753          * @brief      Default constructor wraps a nullptr.
00754          */
00755         SimplexID() : ptr(nullptr) {}
00756
00757         /**
00758          * @brief      Constructor to wrap a NodePtr<k>.
00759          *
00760          * @param[in]  p      The NodePtr to wrap
00761          */
00762         SimplexID(NodePtr<k> p) : ptr(p) {}
00763
00764         /**
00765          * @brief      Copy constructor.
00766          *
00767          * @param[in]  rhs      Another SimplexID to copy.
00768          */
00769         SimplexID(const SimplexID &rhs) : ptr(rhs.ptr) {}
00770
00771         /// Assignment operator
00772         SimplexID &operator=(const SimplexID &rhs) { ptr = rhs.ptr; return *this;}
00773
00774     };
00775
00776

```

```

00777     /// Equality of wrapped pointers
00778     friend bool operator==(SimplexID lhs, SimplexID rhs) { return lhs.ptr == rhs.ptr; }
00779     /// Inequality of wrapped pointers
00780     friend bool operator!=(SimplexID lhs, SimplexID rhs) { return lhs.ptr != rhs.ptr; }
00781     /// Compare wrapped pointers
00782     friend bool operator<=(SimplexID lhs, SimplexID rhs) { return lhs.ptr <= rhs.ptr; }
00783     /// Compare wrapped pointers
00784     friend bool operator>=(SimplexID lhs, SimplexID rhs) { return lhs.ptr >= rhs.ptr; }
00785     /// Compare wrapped pointers
00786     friend bool operator<(SimplexID lhs, SimplexID rhs) { return lhs.ptr < rhs.ptr; }
00787     /// Compare wrapped pointers
00788     friend bool operator>(SimplexID lhs, SimplexID rhs) { return lhs.ptr > rhs.ptr; }
00789
00790     /// Support casting to uintptr_t for hashing.
00791     explicit operator std::uintptr_t () const { return reinterpret_cast<std::uintptr_t>(ptr); }
00792 }
00793
00794     /// Dereferencing a SimplexID returns the data stored.
00795     complex::NodeData<k> const &operator*() const { return ptr->_data; }
00796     /// Dereferencing a SimplexID returns the data stored.
00797     complex::NodeData<k> &operator*() { return ptr->_data; }
00798
00799     /// Get a handle to the stored data.
00800     complex::NodeData<k> const &data() const { return ptr->_data; }
00801     /// Get a handle to the stored data.
00802     complex::NodeData<k> &data() { return ptr->_data; }
00803
00804     /**
00805      * @brief      Gets the name of a simplex as an std::Array.
00806      *
00807      * @param[in]  id      SimplexID of the simplex of interest.
00808      *
00809      * @return      Array containing the name of 'id'.
00810      */
00811     std::array<KeyType, k> indices() const
00812     {
00813         std::array<KeyType, k> s;
00814         std::size_t i = 0;
00815         for (auto curr : ptr->_down)
00816         {
00817             s[i++] = curr.first;
00818         }
00819         return std::move(s);
00820     }
00821
00822     // Valid in C++17
00823     // TODO: (0) expose this to modern compilers
00824     // if constexpr (k < complex::topLevel){
00825     /**
00826      * @brief      Insert the coboundary keys of a simple into an inserter.
00827      *
00828      * @param[in]  pos      Iterator inserter
00829      *
00830      * @tparam      Inserter Typename of the inserter.
00831      */
00832     template <class Inserter>
00833     void cover_insert(Inserter pos) const
00834     {
00835         for (auto curr : ptr->_up)
00836         {
00837             *pos++ = curr.first;
00838         }
00839     }
00840
00841     /**
00842      * @brief      Get the coboundary keys of a simplex.
00843      *
00844      * @return      A vector of coboundary indices.
00845      */
00846     std::vector<KeyType> cover() const
00847     {
00848         std::vector<KeyType> rval;
00849         cover_insert(std::back_inserter(rval));
00850         return rval;
00851     }
00852 // }
00853
00854     /**
00855      * @brief      Get a coboundary simplex
00856      *
00857      * @param[in]  s      Array of keys to follow
00858      *
00859      * @tparam      j      Number of keys
00860      *
00861      * @return      The simplex up
00862      */

```

```

00863     template <std::size_t j>
00864     SimplexID<k+j> get_simplex_up(const KeyType (&s)[j]) const
00865     {
00866         static_assert(k+j <= complex::topLevel, "Cannot get simplex greater than the facets");
00867         return complex::get_recurse<k, j>::apply(s, this->ptr);
00868     }
00869
00870     /**
00871     * @brief      Get a coboundary simplex
00872     * @param[in]  arr    Array of keys to follow
00873     * @param      j      Number of keys
00874     * @return     The simplex up
00875     */
00876     template <std::size_t j>
00877     SimplexID<k+j> get_simplex_up(const std::array<KeyType, j> &arr) const
00878     {
00879         static_assert(k+j <= complex::topLevel, "Cannot get simplex greater than the facets");
00880         return get_recurse<k, j>::apply(arr.data(), this->ptr);
00881     }
00882
00883     /**
00884     * @brief      Convenience version of get_simplex_up when the name 's'
00885     *             consists of a single character.
00886     * @param[in]  id      The identifier of a simplex.
00887     * @param[in]  s        The relative single character name of the desired
00888     *             simplex.
00889     * @tparam     i        The size of simplex 'id'.
00890     * @return     SimplexID of node corresponding to \f$id\cup s\f$.
00891     */
00892     SimplexID<k+1> get_simplex_up(const KeyType s) const
00893     {
00894         return get_recurse<k, 1>::apply(&s, this->ptr);
00895     }
00896
00897     /**
00898     * @brief      Gets the simplex down.
00899     */
00900     template <std::size_t j>
00901     SimplexID<k-j> get_simplex_down(const KeyType (&s)[j]) const
00902     {
00903         return get_down_recurse<k, j>::apply(s, this->ptr);
00904     }
00905
00906     /**
00907     * @brief      Gets the simplex down.
00908     */
00909     template <std::size_t j>
00910     SimplexID<k-j> get_simplex_down(const std::array<KeyType, j> &arr) const
00911     {
00912         return get_down_recurse<k, j>::apply(arr.data(), this->ptr);
00913     }
00914
00915     /**
00916     * @brief      Gets the simplex down.
00917     */
00918     SimplexID<k-1> get_simplex_down(const KeyType s) const
00919     {
00920         return get_down_recurse<k, 1>::apply(&s, this->ptr);
00921     }
00922
00923     /**
00924     * @brief      Print the simplex as its name.
00925     * @param      out    Handle to the stream
00926     * @param[in]  nid    SimplexID of interest
00927     * @return     Handle to the stream
00928     *
00929     * Example
00930     * ~~~~~~(.c)
00931     * mesh.insert<3>({0,1,2});
00932     * std::cout << s << std::endl;
00933     * s{0,1,2}"
00934     * ~~~~~~
00935     */
00936     friend std::ostream &operator<<(std::ostream &out,
00937                                     const SimplexID &nid)
00938     {
00939         // currently no such thing as static_if in c++ so we use a
00940         // template
00941         // helper

```

```

00950         out << "s{";
00951         print_helper<k, 0>::apply(out, nid);
00952         out << "}";
00953         return out;
00954     }
00955
00956
00957     // NOTE: Manually swap out these print functions for debugging if
00958     // desired.
00959     // /**
00960     //  * @brief      A full debug printout of of the node itself
00961     //  *
00962     //  * @param      out      Handle to the stream
00963     //  * @param[in]   nid      SimplexID of interest
00964     //  *
00965     //  * @return      Handle to the stream
00966     //  */
00967     // friend std::ostream& operator<<(std::ostream& out, const
00968     // SimplexID& nid){ out << *nid.ptr; return out; }
00969
00970     // /**
00971     //  * @brief      Print the SimplexID as an ID.
00972     //  *
00973     //  * Example "0x7fd502402f10"
00974     //  *
00975     //  * @param      out      Handle to the stream
00976     //  * @param[in]   nid      Node of interest
00977     //  *
00978     //  * @return      Handle to the stream
00979     //  */
00980     // friend std::ostream &operator<<(std::ostream &out, const
00981     // SimplexID &nid) { out << nid.ptr; return out; }
00982
00983 private:
00984     /**
00985     * @brief      Base Case helper for printing SimplexIDs.
00986     *
00987     * @tparam      l          The Simplex dimension
00988     * @tparam      foo        Dummy argument to avoid explicit
00989     * specialization
00990     *
00991     * in class scope
00992     */
00992     template <std::size_t l, std::size_t foo>
00993     struct print_helper
00994     {
00995         /**
00996         * @brief      Print out the name of the simplex.
00997         *
00998         * @param      out      Stream to pipe to.
00999         * @param[in]   nid      The simplex to print.
01000         *
01001         * @return      Handle to the output stream.
01002         */
01003         static std::ostream &apply(std::ostream &out,
01004                                     const SimplexID<l> &nid)
01005         {
01006             auto down = (*nid.ptr)._down;
01007             for (auto it = down.cbegin(); it != down.cend()-1; ++it)
01008             {
01009                 out << it->first << ", ";
01010             }
01011             out << (down.cend()-1)->first;
01012             return out;
01013         }
01014     };
01015
01016     /**
01017     * @brief      Explicit specialization to print 0-Simplices
01018     *
01019     * @tparam      foo        Dummy argument to avoid explicit
01020     * specialization
01021     *
01022     * in class scope
01023     */
01023     template <std::size_t foo>
01024     struct print_helper<0, foo>
01025     {
01026         /**
01027         * @brief      Print the root simplex
01028         *
01029         * @param      out      Stream to print to.
01030         * @param[in]   nid      The simplex to print.
01031         *
01032         * @return      Handle to the output stream.
01033         */
01034         static std::ostream &apply(std::ostream &out,
01035                                     const SimplexID &nid)
01036         {

```

```

01037         out << "root " << nid;
01038         return out;
01039     }
01040 };
01041 /// The wrapped pointer.
01042 NodePtr<k> ptr;
01043 };
01044
01045 friend struct EdgeID; /**< EdgeID is a friend to simplicial_complex */
01046
01047 /**
01048  * @brief      External reference to an edge or a connection within the
01049  *              complex.
01050  *
01051  * @tparam      k      The edge connects a simplex of size k-1 to a
01052  *                      simplex of size k.
01053  */
01054 template <std::size_t k>
01055 struct EdgeID {
01056     /// Typename of the complex
01057     using complex = simplicial_complex<traits>;
01058     /// EdgeID is a friend of the complex
01059     friend simplicial_complex<traits>;
01060     /// The dimension of the simplex which the edge points to.
01061     static constexpr std::size_t level = k;
01062
01063     /**
01064      * @brief      Default constructor wraps a nullptr and dummy edge.
01065      */
01066     EdgeID() : ptr(nullptr), edge(0) {}
01067
01068     /**
01069      * @brief      Constructor to wrap an Edge.
01070      *
01071      * @param[in]   p      Pointer to the next Node.
01072      * @param[in]   e      Key of the edge
01073      */
01074     EdgeID(NodePtr<k> p, KeyType e) : ptr(p), edge(e) {}
01075
01076     /**
01077      * @brief      Copy constructor
01078      *
01079      * @param[in]   rhs     The right hand side
01080      */
01081     EdgeID(const EdgeID &rhs) : ptr(rhs.ptr), edge(rhs.edge) {}
01082
01083     /// Assignment operator
01084     EdgeID &operator=(const EdgeID &rhs) { ptr = rhs.ptr; edge = rhs.edge; return *this; }
01085
01086     /// Equality of wrapped pointers and edges
01087     friend bool operator==(EdgeID lhs, EdgeID rhs) { return lhs.ptr == rhs.ptr && lhs.edge ==
rhs.edge; }
01088     /// Compare wrapped pointers and edges.
01089     friend bool operator!=(EdgeID lhs, EdgeID rhs) { return !(lhs == rhs); }
01090     /// Compare wrapped pointers and edges.
01091     friend bool operator<=(EdgeID lhs, EdgeID rhs) { return lhs < rhs || lhs == rhs; }
01092     /// Compare wrapped pointers and edges.
01093     friend bool operator>=(EdgeID lhs, EdgeID rhs) { return lhs > rhs || lhs == rhs; }
01094     /// Less than defines an ordering of key types on the edges.
01095     friend bool operator<(EdgeID lhs, EdgeID rhs)
01096     {
01097         return (lhs.ptr < rhs.ptr) || (lhs.ptr == rhs.ptr && lhs.edge < rhs.edge);
01098     }
01099     /// Greater than comparison
01100     friend bool operator>(EdgeID lhs, EdgeID rhs) { return rhs < lhs; }
01101
01102     // explicit operator std::size_t () const { return
01103     // static_cast<std::size_t>(ptr);
01104
01105     /// Dereferencing an EdgeID gets the data on the edge.
01106     auto const &operator*() const { return data(); }
01107     /// Dereferencing an EdgeID gets the data on the edge.
01108     auto &operator*() { return data(); }
01109
01110     /// Get the key of the edge.
01111     KeyType key() const { return edge; }
01112
01113     /// Return the data stored on the edge.
01114     auto const &data() const { return ptr->_edge_data[edge]; }
01115     /// Return the data stored on the edge.
01116     auto &data() { return ptr->_edge_data[edge]; }
01117
01118     /**
01119      * @brief      Get the coboundary simplex.
01120      *
01121      * @return      SimplexID of the simplex above the edge.
01122      */

```

```

01123         SimplexID<k> up() const { return ptr; }
01124
01125     /**
01126      * @brief      Get the simplex below.
01127      *
01128      * @return     SimplexID of the simplex below the edge.
01129      */
01130     SimplexID<k-1> down() const { return SimplexID<k-1>(ptr->_down[edge]); }
01131
01132     private:
01133         /// Pointer to the next node.
01134         NodePtr<k> ptr;
01135         /// The Key of the edge.
01136         KeyType edge;
01137 };
01138
01139 /**
01140  * @brief      Default constructor
01141  */
01142 simplicial_complex()
01143 : node_count(0)
01144 {
01145     for (auto &x : level_count) // Initialize level_count to 0 for all
01146         // levels
01147     {
01148         x = 0;
01149     }
01150     // Create a root node
01151     _root = create_node<0>();
01152 }
01153
01154 /**
01155  * @brief      Destruct the simplicial complex.
01156  *
01157  * Recursively go over the simplices and remove them prior to
01158  * destructing
01159  * the CASC object itself.
01160  */
01161 ~simplicial_complex()
01162 {
01163     std::size_t count;
01164     remove_recurse<0, 0>::apply(this, &_root, &_root + 1, count);
01165 }
01166
01167 /**
01168  * @brief      Insert a simplex and all sub-simplices into the complex.
01169  *
01170  * Example -- insert the simplex {1,2,3}:
01171  * ~~~~~~{.cpp}
01172  * mesh.insert<3>({1,2,3});
01173  * ~~~~~~
01174  *
01175  * @param[in]  s      A C style array of vertices of simplex 's'.
01176  *
01177  * @tparam     n      Dimension of simplex 's'.
01178  */
01179 template <std::size_t n>
01180 SimplexID<n> insert(const KeyType (&s)[n])
01181 {
01182     for (const KeyType* p = s; p < s + n; ++p)
01183     {
01184         unused_vertices.remove(*p);
01185     }
01186     return insert_full<0, n>::apply(this, _root, s);
01187 }
01188
01189 /**
01190  * @brief      Insert a simplex and all sub-simplices into the complex
01191  *              along with data.
01192  *
01193  * Example -- insert the simplex {1,2,3} with data:
01194  * ~~~~~~{.cpp}
01195  * mesh.insert<3>({1,2,3}, 5);
01196  * ~~~~~~
01197  *
01198  * @param[in]  s      A C style array of vertices of simplex 's'.
01199  * @param[in]  data    The data to be stored at the simplex 's'.
01200  *
01201  * @tparam     n      Dimension of simplex 's'.
01202  */
01203 template <std::size_t n>
01204 SimplexID<n> insert(const KeyType (&s)[n], const NodeData<n> &data)
01205 {
01206     for (const KeyType* p = s; p < s + n; ++p)
01207     {
01208         unused_vertices.remove(*p);
01209     }

```

```

01210         Node<n>* rval = insert_full<0, n>::apply(this, _root, s);
01211         rval->_data = data;
01212         return rval;
01213     }
01214
01215     /**
01216     * @brief      Insert a simplex named and all sub-simplices into the
01217     * complex.
01218     *
01219     * @param[in]  s      Array of vertices comprising 's'.
01220     *
01221     * @tparam     n      Dimension of simplex 's'.
01222     */
01223     template <std::size_t n>
01224     SimplexID<n> insert(const std::array<KeyType, n> &s)
01225     {
01226         for (KeyType x : s)
01227         {
01228             unused_vertices.remove(x);
01229         }
01230         return insert_full<0, n>::apply(this, _root, s.data());
01231     }
01232
01233     /**
01234     * @brief      Insert a simplex and all sub-simplices into the complex
01235     * along with data.
01236     *
01237     * @param[in]  s      Array of vertices comprising 's'.
01238     * @param[in]  data    The data to be stored at the simplex 's'.
01239     *
01240     * @tparam     n      Dimension of simplex 's'.
01241     */
01242     template <std::size_t n>
01243     SimplexID<n> insert(const std::array<KeyType, n> &s, const NodeData<n> &data)
01244     {
01245         for (KeyType x : s)
01246         {
01247             unused_vertices.remove(x);
01248         }
01249         Node<n>* rval = insert_full<0, n>::apply(this, _root, s.data());
01250         rval->_data = data;
01251         return rval;
01252     }
01253
01254     /**
01255     * @brief      Add a new vertex to the complex.
01256     *
01257     * A list of currently unused indices are tracked using a B-tree. This
01258     * function retrieves a currently unused index and creates a new vertex
01259     * while returning the new key.
01260     *
01261     * @return     The key of the new vertex.
01262     */
01263     KeyType add_vertex()
01264     {
01265         KeyType v[1] = {unused_vertices.pop()};
01266         insert<1>(v);
01267         return v[0];
01268     }
01269
01270     /**
01271     * @brief      Add a new vertex to the complex with data.
01272     *
01273     * @return     The key of the new vertex.
01274     */
01275     KeyType add_vertex(const NodeData<1> &data)
01276     {
01277         KeyType v[1] = {unused_vertices.pop()};
01278         insert<1>(v, data);
01279         return v[0];
01280     }
01281
01282     /**
01283     * @brief      Apply a lambda function the name of a simplex.
01284     *
01285     *
01286     * @param[in]  id      SimplexID of the simplex of interest.
01287     * @param[in]  fn      Lambda function to apply to the name of 'id'.
01288     *
01289     * @tparam     n      Dimension of simplex 'id'.
01290     * @tparam     Lambda  Functor which supports operator(KeyType).
01291     */
01292     template <std::size_t n, typename Lambda>
01293     void get_name(SimplexID<n> id, Lambda fn) const
01294     {
01295         for (auto curr : id.ptr->_down)
01296         {

```

```

01297         fn(curr.first);
01298     }
01299 }
01300
01301 /**
01302  * @brief      Gets the name of a simplex as an std::Array.
01303  *
01304  * @param[in]   id      SimplexID of the simplex of interest.
01305  *
01306  * @tparam      n        Size of the simplex referenced by 'id'.
01307  *
01308  * @return      Array containing the name of 'id'.
01309  */
01310 template <std::size_t n>
01311 std::array<KeyType, n> get_name(SimplexID<n> id) const
01312 {
01313     std::array<KeyType, n> s;
01314     std::size_t i = 0;
01315     for (auto curr : id.ptr->_down)
01316     {
01317         s[i++] = curr.first;
01318     }
01319     assert(i == n);
01320     return s;
01321 }
01322
01323 /**
01324  * @brief      Gets the name of a simplex.
01325  *
01326  * This is the explicit specialization which handles the empty set
01327  * simplex.
01328  *
01329  * @param[in]   id      SimplexID of the simplex of interest.
01330  *
01331  * @return      Array containing the name of 'id'.
01332  */
01333 std::array<KeyType, 0> get_name(SimplexID<0>) const
01334 {
01335     std::array<KeyType, 0> name{};
01336     return name;
01337 }
01338
01339 /**
01340  * @brief      Gets the simplex with name 's'.
01341  *
01342  * @param[in]   s        Name of the simplex to find.
01343  *
01344  * @tparam      n        Dimension of simplex s.
01345  *
01346  * @return      SimplexID of node corresponding to 's'.
01347  */
01348 template <std::size_t n>
01349 SimplexID<n> get_simplex_up(const KeyType (&s)[n]) const
01350 {
01351     return get_recurse<0, n>::apply(s, _root);
01352 }
01353
01354 template <std::size_t n>
01355 SimplexID<n> get_simplex_up(const std::array<KeyType, n> &arr) const
01356 {
01357     return get_recurse<0, n>::apply(arr.data(), _root);
01358 }
01359
01360 /**
01361  * @brief      Get the simplex identifier which has the name 's'
01362  *              relative to the simplex 'id'.
01363  *
01364  * @param[in]   id      The identifier of a simplex.
01365  * @param[in]   s        The relative name of the desired simplex.
01366  *
01367  * @tparam      i        The size of simplex 'id'.
01368  * @tparam      j        The length of the name 's'.
01369  *
01370  * @return      SimplexID of node corresponding to  $f_{id} \cup s$ .
01371  */
01372 template <std::size_t i, std::size_t j>
01373 SimplexID<i+j> get_simplex_up(const SimplexID<i> id, const KeyType (&s)[j]) const
01374 {
01375     return get_recurse<i, j>::apply(s, id);
01376 }
01377
01378 template <std::size_t i, std::size_t j>
01379 SimplexID<i+j> get_simplex_up(const SimplexID<i> id, const std::array<KeyType, j> &arr) const
01380 {
01381     return get_recurse<i, j>::apply(arr.data(), id);
01382 }
01383

```

```

01384
01385
01386     /**
01387      * @brief      Convenience version of get_simplex_up when the name 's'
01388      *              consists of a single character.
01389      *
01390      * @param[in]  id      The identifier of a simplex.
01391      * @param[in]  s        The relative single character name of the desired
01392      *                      simplex.
01393      *
01394      * @tparam     i        The size of simplex 'id'.
01395      *
01396      * @return     SimplexID of node corresponding to \f$id\cup s\f$.
01397      */
01398     template <std::size_t i>
01399     SimplexID<i+1> get_simplex_up(const SimplexID<i> id, const KeyType s) const
01400     {
01401         return get_recurse<i, 1>::apply(&s, id.ptr);
01402     }
01403
01404     /**
01405      * @brief      Get the root simplex.
01406      *
01407      * @return     The root simplex.
01408      */
01409     SimplexID<0> get_simplex_up() const
01410     {
01411         return _root;
01412     }
01413
01414
01415     /**
01416      * @brief      Get the sub-simplex of the simplex 'id' which does not
01417      *              have 's' in the name.
01418      *
01419      * @param[in]  id      The identifier of a simplex.
01420      * @param[in]  s        The relative name of the desired simplex.
01421      *
01422      * @tparam     i        The size of simplex 'id'.
01423      * @tparam     j        The length of the name 's'
01424      *
01425      * @return     The node down.
01426      */
01427     template <std::size_t i, std::size_t j>
01428     SimplexID<i-j> get_simplex_down(const SimplexID<i> id, const KeyType (&s)[j]) const
01429     {
01430         return get_down_recurse<i, j>::apply(s, id.ptr);
01431     }
01432
01433     template <std::size_t i, std::size_t j>
01434     SimplexID<i-j> get_simplex_down(const SimplexID<i> id, const std::array<KeyType, j> &arr)
01435     const
01436     {
01437         return get_down_recurse<i, j>::apply(arr.data(), id.ptr);
01438     }
01439
01440     /**
01441      * @brief      Convenience version of get_simplex_down when the name 's'
01442      *              consists of a single character.
01443      *
01444      * @param[in]  id      The identifier of a simplex.
01445      * @param[in]  s        The relative single character name of the desired
01446      *                      simplex.
01447      *
01448      * @tparam     i        The size of simplex 'id'.
01449      *
01450      * @return     The node down.
01451      */
01452     template <std::size_t i>
01453     SimplexID<i-1> get_simplex_down(const SimplexID<i> id, const KeyType s) const
01454     {
01455         return get_down_recurse<i, 1>::apply(&s, id.ptr);
01456     }
01457
01458     /**
01459      * @brief      Get the root simplex.
01460      *
01461      * @return     The root simplex.
01462      */
01463     SimplexID<0> get_simplex_down() const
01464     {
01465         return _root;
01466     }
01467
01468     /**
01469      * @brief      Insert the coboundary keys of a simple into an inserter.

```

```

01470     * @param[in] id      The identifier of a simplex.
01471     * @param[in] pos      Iterator inserter
01472     *
01473     * @tparam      k      The dimension of the simplex.
01474     * @tparam      Inserter Typename of the inserter.
01475     */
01476     template <std::size_t k, class Inserter>
01477     void get_cover_insert(const SimplexID<k> id, Inserter pos) const
01478     {
01479         for (auto curr : id.ptr->_up)
01480         {
01481             *pos++ = curr.first;
01482         }
01483     }
01484
01485     /**
01486     * @brief      Apply a lambda function to the coboundary keys.
01487     *
01488     * @param[in] id      The identifier
01489     * @param[in] fn      The function
01490     *
01491     * @tparam      k      The dimension of the simplex.
01492     * @tparam      Lambda Typename of a functor which supports
01493     * @operator(KeyType).
01494     */
01495     template <std::size_t k, class Lambda>
01496     void get_cover(const SimplexID<k> id, Lambda fn) const
01497     {
01498         for (auto curr : id.ptr->_up)
01499         {
01500             fn(curr.first);
01501         }
01502     }
01503
01504     /**
01505     * @brief      Get the coboundary keys of a simplex.
01506     *
01507     * @param[in] id      The identifier of a simplex.
01508     *
01509     * @tparam      k      The dimension of the simplex.
01510     *
01511     * @return      A vector of coboundary indices.
01512     */
01513     template <std::size_t k>
01514     std::vector<KeyType> get_cover(const SimplexID<k> id) const
01515     {
01516         std::vector<KeyType> rval;
01517         get_cover_insert(id, std::back_inserter(rval));
01518         return rval;
01519     }
01520
01521     /**
01522     * @brief      Get the coboundary of a set of simplices.
01523     *
01524     * @param      simplices The set of simplices
01525     *
01526     * @tparam      k      The dimension of the simplices.
01527     *
01528     * @return      The set of coboundary simplices.
01529     */
01530     template <std::size_t k>
01531     std::set<SimplexID<k+1> > up(const std::set<SimplexID<k> > &&simplices) const
01532     {
01533         std::set<SimplexID<k+1> > rval;
01534         for (auto simplex : simplices)
01535         {
01536             for (auto p : simplex.ptr->_up)
01537             {
01538                 rval.insert(SimplexID<k+1>(p.second));
01539             }
01540         }
01541         return rval;
01542     }
01543
01544     /**
01545     * @brief      Get the coboundary of a set of simplices.
01546     *
01547     * @param      simplices The set of simplices
01548     *
01549     * @tparam      k      The dimension of the simplices.
01550     *
01551     * @return      The set of coboundary simplices.
01552     */
01553     template <std::size_t k>
01554     std::set<SimplexID<k+1> > up(const std::set<SimplexID<k> > &&simplices) const
01555     {
01556         std::set<SimplexID<k+1> > rval;

```

```

01557         for (auto simplex : simplices)
01558         {
01559             for (auto p : simplex.ptr->_up)
01560             {
01561                 rval.insert(SimplexID<k+1>(p.second));
01562             }
01563         }
01564         return rval;
01565     }
01566
01567     /**
01568     * @brief      Get the coboundary of a simplex.
01569     *
01570     * @param      nid    The simplex of interest
01571     *
01572     * @tparam     k      The dimension of the simplex.
01573     *
01574     * @return     Set of (k+1)-simplices of which 'nid' is a face of.
01575     */
01576     template <std::size_t k>
01577     std::set<SimplexID<k+1> > up(const SimplexID<k> nid) const
01578     {
01579         std::set<SimplexID<k+1> > rval;
01580         for (auto p : nid.ptr->_up)
01581         {
01582             rval.insert(SimplexID<k+1>(p.second));
01583         }
01584         return rval;
01585     }
01586
01587     template <std::size_t k, class InsertIter>
01588     void up(const std::set<SimplexID<k>&& simplices, InsertIter iter) const
01589     {
01590         for (auto simplex : simplices)
01591         {
01592             for (auto p : simplex.ptr->_up)
01593             {
01594                 *iter++ = SimplexID<k+1>(p.second);
01595             }
01596         }
01597     }
01598
01599     template <std::size_t k, class InsertIter>
01600     void up(const std::set<SimplexID<k>&& simplices, InsertIter iter) const
01601     {
01602         for (auto simplex : simplices)
01603         {
01604             for (auto p : simplex.ptr->_up)
01605             {
01606                 *iter++ = SimplexID<k+1>(p.second);
01607             }
01608         }
01609     }
01610
01611     template <std::size_t k, class InsertIter>
01612     void up(const SimplexID<k> simplex, InsertIter iter) const
01613     {
01614         for (auto p : simplex.ptr->_up)
01615         {
01616             *iter++ = SimplexID<k+1>(p.second);
01617         }
01618     }
01619
01620     /**
01621     * @brief      Get the boundary of a set of simplices.
01622     *
01623     * @param      simplices  The set of simplicies.
01624     *
01625     * @tparam     k          The dimension of the simplices.
01626     *
01627     * @return     The set of boundary simplices.
01628     */
01629     template <std::size_t k>
01630     std::set<SimplexID<k-1> > down(const std::set<SimplexID<k> > &&simplices) const
01631     {
01632         std::set<SimplexID<k-1> > rval;
01633         for (auto nid : simplices)
01634         {
01635             for (auto p : nid.ptr->_down)
01636             {
01637                 rval.insert(SimplexID<k-1>(p.second));
01638             }
01639         }
01640         return rval;
01641     }
01642
01643     /**

```

```

01644     * @brief      Get the boundary of a set of simplices.
01645     *
01646     * @param      simplices  The set of simplicies.
01647     *
01648     * @tparam     k          The dimension of the simplices.
01649     *
01650     * @return     The set of boundary simplices.
01651     */
01652 template <std::size_t k>
01653 std::set<SimplexID<k-1> > down(const std::set<SimplexID<k> > &simplices) const
01654 {
01655     std::set<SimplexID<k-1> > rval;
01656     for (auto simplex : simplices)
01657     {
01658         for (auto p : simplex.ptr->_down)
01659         {
01660             rval.insert(SimplexID<k-1>(p.second));
01661         }
01662     }
01663     return rval;
01664 }
01665
01666 /**
01667  * @brief      Get the boundary of a simplex.
01668  *
01669  * @param      simplex  The simplex of interest.
01670  *
01671  * @tparam     k          The dimension of the simplex.
01672  *
01673  * @return     Set of (k-1)-simplices of which 'simplex' is a coface of.
01674  */
01675 template <std::size_t k>
01676 std::set<SimplexID<k-1> > down(const SimplexID<k> simplex) const
01677 {
01678     std::set<SimplexID<k-1> > rval;
01679     for (auto p : simplex.ptr->_down)
01680     {
01681         rval.insert(SimplexID<k-1>(p.second));
01682     }
01683     return rval;
01684 }
01685
01686 template <std::size_t k, class InsertIter>
01687 void down(const std::set<SimplexID<k>&& simplices, InsertIter iter) const{
01688     for (auto simplex : simplices)
01689     {
01690         for (auto p : simplex.ptr->_down)
01691         {
01692             *iter++ = SimplexID<k-1>(p.second);
01693         }
01694     }
01695 }
01696
01697 template <std::size_t k, class InsertIter>
01698 void down(const std::set<SimplexID<k>& simplices, InsertIter iter) const{
01699     for (auto simplex : simplices)
01700     {
01701         for (auto p : simplex.ptr->_down)
01702         {
01703             *iter++ = SimplexID<k-1>(p.second);
01704         }
01705     }
01706 }
01707
01708 template <std::size_t k, class InsertIter>
01709 void down(const SimplexID<k> simplex, InsertIter iter) const{
01710     for (auto p : simplex.ptr->_down)
01711     {
01712         *iter++ = SimplexID<k-1>(p.second);
01713     }
01714 }
01715
01716 /**
01717  * @brief      Gets the edge up from a simplex.
01718  *
01719  * @param[in]  simplex  The simplex of interest.
01720  * @param[in]  a        Key of the edge to get.
01721  *
01722  * @tparam     k          The level of the simplex of interest
01723  *
01724  * @return     The edge up.
01725  */
01726 template <std::size_t k>
01727 EdgeID<k+1> get_edge_up(SimplexID<k> simplex, KeyType a)
01728 {
01729     return EdgeID<k+1>(simplex.ptr->_up.at(a), a);
01730 }

```

```

01731
01732     /**
01733      * @brief      Gets the edge down from a simplex.
01734      *
01735      * @param[in]   simplex    The simplex of interest.
01736      * @param[in]   a          Key of the edge to get.
01737      *
01738      * @tparam      k          The level of the simplex of interest
01739      *
01740      * @return      The edge down.
01741      */
01742     template <std::size_t k>
01743     EdgeID<k> get_edge_down(SimplexID<k> simplex, KeyType a)
01744     {
01745         return EdgeID<k>(simplex.ptr, a);
01746     }
01747
01748     /**
01749      * @brief      Gets the edge up from a simplex.
01750      *
01751      * @param[in]   simplex    The simplex of interest.
01752      * @param[in]   a          Key of the edge to get.
01753      *
01754      * @tparam      k          The level of the simplex of interest
01755      *
01756      * @return      The edge up.
01757      */
01758     template <std::size_t k>
01759     EdgeID<k+1> get_edge_up(SimplexID<k> simplex, KeyType a) const
01760     {
01761         return EdgeID<k+1>(simplex.ptr->_up.at(a), a);
01762     }
01763
01764     /**
01765      * @brief      Gets the edge down from a simplex.
01766      *
01767      * @param[in]   simplex    The simplex of interest.
01768      * @param[in]   a          Key of the edge to get.
01769      *
01770      * @tparam      k          The level of the simplex of interest
01771      *
01772      * @return      The edge down.
01773      */
01774     template <std::size_t k>
01775     EdgeID<k> get_edge_down(SimplexID<k> simplex, KeyType a) const
01776     {
01777         return EdgeID<k>(simplex.ptr, a);
01778     }
01779
01780     /**
01781      * @brief      Check whether a simplex with some name exists.
01782      *
01783      * @param[in]   s          C-style array of the name
01784      *
01785      * @tparam      k          The dimension of the simplex.
01786      *
01787      * @return      True if the simplex is in the complex.
01788      */
01789     template <std::size_t k>
01790     bool exists(const KeyType (&s)[k]) const
01791     {
01792         return get_recurse<0, k>::apply(s, _root) != nullptr;
01793     }
01794
01795     /**
01796      * @brief      Get the number of simplices of dimension 'k'.
01797      *
01798      * @tparam      k          The dimension of interest.
01799      *
01800      * @return      Integer number of k-simplices in the complex.
01801      */
01802     template <std::size_t k>
01803     std::size_t size() const
01804     {
01805         return std::get<k>(levels).size();
01806     }
01807
01808     // template <std::size_t k> using SimplexIDIterator = detail::node_id_iterator<typename
01809     detail::map<NodePtr<k>::iterator, SimplexID<k>;
01810
01811     /**
01812      * @brief      Create an iterator to traverse the SimplexIDs of a
01813      *              dimension.
01814      *
01815      * @tparam      k          The simplex dimension to traverse.
01816      *

```

```

01817     * @return      An iterator across all k-simplices of the complex.
01818     */
01819     template <std::size_t k>
01820     auto get_level_id()
01821     {
01822         auto begin = std::get<k>(levels).begin();
01823         auto end = std::get<k>(levels).end();
01824         auto data_begin = detail::make_node_id_iterator<decltype(begin), SimplexID<k> >(begin);
01825         auto data_end = detail::make_node_id_iterator<decltype(end), SimplexID<k> >(end);
01826         return util::make_range(data_begin, data_end);
01827     }
01828
01829     /**
01830     * @brief        Create an iterator to traverse the SimplexIDs of a
01831     *               dimension.
01832     *
01833     * @tparam      k      The simplex dimension to traverse.
01834     *
01835     * @return      An iterator across all k-simplices of the complex.
01836     */
01837     template <std::size_t k>
01838     auto get_level_id() const
01839     {
01840         auto begin = std::get<k>(levels).cbegin();
01841         auto end = std::get<k>(levels).cend();
01842         auto data_begin = detail::make_node_id_iterator<decltype(begin), const SimplexID<k>
01843         >(begin);
01844         auto data_end = detail::make_node_id_iterator<decltype(end), const SimplexID<k> >(end);
01845         return util::make_range(data_begin, data_end);
01846     }
01847
01848     // template <std::size_t k> using DataIterator = detail::node_data_iterator<typename
01849     std::map<std::size_t, NodePtr<k>>::iterator, NodeData<k>;
01850     /**
01851     * @brief        Create an iterator to traverse the simplex data of a
01852     *               dimension.
01853     *
01854     * @tparam      k      The simplex dimension to traverse.
01855     *
01856     * @return      An iterator across the data of all k-simplices in the
01857     *               complex.
01858     */
01859     template <std::size_t k>
01860     auto get_level()
01861     {
01862         auto begin = std::get<k>(levels).begin();
01863         auto end = std::get<k>(levels).end();
01864         auto data_begin = detail::make_node_data_iterator<decltype(begin), NodeData<k> >(begin);
01865         auto data_end = detail::make_node_data_iterator<decltype(end), NodeData<k> >(end);
01866         return util::make_range(data_begin, data_end);
01867     }
01868
01869     /**
01870     * @brief        Create an iterator to traverse the simplex data of a
01871     *               dimension.
01872     *
01873     * @tparam      k      The simplex dimension to traverse.
01874     *
01875     * @return      An iterator across the data of all k-simplices in the
01876     *               complex.
01877     */
01878     template <std::size_t k>
01879     auto get_level() const
01880     {
01881         auto begin = std::get<k>(levels).cbegin();
01882         auto end = std::get<k>(levels).cend();
01883         auto data_begin = detail::make_node_data_iterator<decltype(begin), const NodeData<k>
01884         >(begin);
01885         auto data_end = detail::make_node_data_iterator<decltype(end), const NodeData<k> >(end);
01886         return util::make_range(data_begin, data_end);
01887     }
01888
01889     /**
01890     * @brief        Remove a simplex and all dependent simplices by name.
01891     *
01892     * @param[in]    s      C-style array with the name of the simplex to
01893     *                       remove.
01894     *
01895     * @tparam      k      The dimension of the simplex.
01896     *
01897     * @return      Integer corresponding to the number of simplices removed.
01898     */
01899     template <std::size_t k>
01900     std::size_t remove(const KeyType (&s)[k])
01901     {
01902         Node<k>* root = get_recurse<0, k>::apply(s, _root);
01903     }

```

```

01901         std::size_t count = 0;
01902         return remove_recurse<k, 0>::apply(this, &root, &root + 1, count);
01903     }
01904
01905     /**
01906      * @brief      Remove a simplex and all dependent simplices by name.
01907      *
01908      * @param[in]   s      std::array with the name of the simplex to remove.
01909      *
01910      * @tparam      k      The dimension of the simplex.
01911      *
01912      * @return      Integer corresponding to the number of simplices removed.
01913      */
01914     template <std::size_t k>
01915     std::size_t remove(const std::array<KeyType, k> &s)
01916     {
01917         Node<k>* root = get_recurse<0, k>::apply(s.data(), _root);
01918         std::size_t count = 0;
01919         return remove_recurse<k, 0>::apply(this, &root, &root + 1, count);
01920     }
01921
01922     /**
01923      * @brief      Remove a simplex and all dependent simplices by
01924      *              SimplexID.
01925      *
01926      * @param[in]   s      SimplexID of the simplex to remove.
01927      *
01928      * @tparam      k      The dimension of the simplex.
01929      *
01930      * @return      Integer corresponding to the number of simplices removed.
01931      */
01932     template <std::size_t k>
01933     std::size_t remove(SimplexID<k> s)
01934     {
01935         std::size_t count = 0;
01936         return remove_recurse<k, 0>::apply(this, &s.ptr, &s.ptr + 1, count);
01937     }
01938
01939     /**
01940      * @brief      Checks whether a simplex is on a boundary.
01941      *
01942      * @param[in]   s      SimplexID of interest
01943      *
01944      * @tparam      k      Dimension of the simplex
01945      *
01946      * @return      True if the simplex is a member of a topLevel-1 simplex
01947      *              on the boundary or if the simplex is on a boundary or if
01948      *              the simplex is a coboundary of a boundary topLevel-1
01949      *              simplex.
01950      */
01951     template <std::size_t k>
01952     bool onBoundary(const SimplexID<k> s) const
01953     {
01954         return onBoundaryH<k, 0>::apply(s);
01955     }
01956
01957     /**
01958      * @brief      Checks whether a simplex is near a boundary.
01959      *
01960      * @param[in]   s      SimplexID of interest
01961      *
01962      * @tparam      level   Dimension of the simplex
01963      *
01964      * @return      True if the simplex or any subsimplices are onBoundary.
01965      */
01966     template <std::size_t level>
01967     bool nearBoundary(const SimplexID<level> s) const
01968     {
01969         return nearBoundaryH<level, 0>::apply(s);
01970     }
01971
01972     /**
01973      * Reintroduce this code block when this is resolved
01974      * // http://www.open-std.org/jtc1/sc22/wg21/docs/cwg\_defects.html#727
01975      */
01976     // /**
01977     //  * @brief      Checks whether a simplex is on a boundary.
01978     //  *
01979     //  * @param[in]   s      SimplexID of interest
01980     //  *
01981     //  * @tparam      k      Dimension of the simplex
01982     //  *
01983     //  * @return      True if the simplex interacts with a
01984     //  *              topLevel-1 simplex which is on a boundary.
01985     //  */
01986     // template <std::size_t k>
01987     // bool onBoundary(const SimplexID<k> s) const

```

```

01988     // {
01989     //     for(auto p : s.ptr->_up)
01990     //     {
01991         //         if(onBoundary(SimplexID<k+1>(p.second)))
01992             //             return true;
01993         //     }
01994     //     return false;
01995     // }
01996
01997     // /**
01998     //  * @brief      Specialization of the facets
01999     //  *
02000     //  * @param[in]  s      SimplexID of interest
02001     //  *
02002     //  * @tparam      k      Dimension of the simplex
02003     //  *
02004     //  * @return      True if s is on a boundary
02005     //  */
02006     // template<>
02007     // bool onBoundary(const SimplexID<topLevel> s) const
02008     // {
02009     //     for(auto p : s.ptr->_down){
02010         //         if(onBoundary(SimplexID<topLevel-1>(p.second)))
02011             //             return true;
02012         //     }
02013     //     return false;
02014     // }
02015
02016     // /**
02017     //  * @brief      Specialization of the topLevel-1 simplices
02018     //  *
02019     //  * @param[in]  s      SimplexID of interest
02020     //  *
02021     //  * @tparam      k      Dimension of the simplex
02022     //  *
02023     //  * @return      True if s is on a boundary
02024     //  */
02025     // template<>
02026     // bool onBoundary(const SimplexID<topLevel-1> s) const
02027     // {
02028     //     return s.ptr->_up.size() != 2;
02029     // }
02030
02031
02032     /**
02033     * @brief      Less than or equal to comparison operator of two
02034     *              SimplexIDs.
02035     *
02036     * @param[in]  lhs    The left hand side
02037     * @param[in]  rhs    The right hand side
02038     *
02039     * @tparam      L      Dimension of lhs simplex.
02040     * @tparam      R      Dimension of rhs simplex.
02041     *
02042     * @return      True if lhs is rhs or a proper face of rhs.
02043     */
02044     template <std::size_t L, std::size_t R>
02045     bool leq(SimplexID<L> lhs, SimplexID<R> rhs) const
02046     {
02047         auto name_lhs = get_name(lhs);
02048         auto name_rhs = get_name(rhs);
02049
02050         std::size_t i = 0;
02051         for (std::size_t j = 0; i < L && j < R; ++j)
02052         {
02053             if (name_lhs[i] == name_rhs[j])
02054             {
02055                 ++i;
02056             }
02057         }
02058         return (i == L);
02059     }
02060
02061     /**
02062     * @brief      Equality comparison of two simplices.
02063     *
02064     * @param[in]  lhs    The left hand side
02065     * @param[in]  rhs    The right hand side
02066     *
02067     * @tparam      L      Dimension of lhs simplex.
02068     * @tparam      R      Dimension of rhs simplex.
02069     *
02070     * @return      Always false as L != R. The L==R case is overloaded by
02071     *              partial specialization.
02072     */
02073     template <std::size_t L, std::size_t R>
02074     bool eq(SimplexID<L>, SimplexID<R>) const

```

```

02075     {
02076         return false;
02077     }
02078
02079     /**
02080     * @brief      Equality comparison of two simplices.
02081     * @param[in]  lhs    The left hand side
02082     * @param[in]  rhs    The right hand side
02083     * @tparam     k      Dimension of the simplices.
02084     * @return     True if the names are the same.
02085     */
02086     template <std::size_t k>
02087     bool eq(SimplexID<k> lhs, SimplexID<k> rhs) const
02088     {
02089         auto name_lhs = get_name(lhs);
02090         auto name_rhs = get_name(rhs);
02091
02092         for (std::size_t i = 0; i < k; ++i)
02093         {
02094             if (name_lhs[i] != name_rhs[i])
02095             {
02096                 return false;
02097             }
02098         }
02099         return true;
02100     }
02101
02102     /**
02103     * @brief      Less than comparison of simplices.
02104     * @param[in]  lhs    The left hand side
02105     * @param[in]  rhs    The right hand side
02106     * @tparam     L      Dimension of lhs simplex.
02107     * @tparam     R      Dimension of rhs simplex.
02108     * @return     True if lhs is a proper subface of rhs.
02109     */
02110     template <std::size_t L, std::size_t R>
02111     bool lt(SimplexID<L> lhs, SimplexID<R> rhs) const
02112     {
02113         return L < R && leq(lhs, rhs);
02114     }
02115
02116 private:
02117     /**
02118     * @brief      Base case for checking if simplex is near a boundary
02119     * @tparam     level  Dimension of the simplex
02120     * @tparam     foo    Dummy argument to avoid explicit specialization in
02121     *                    class scope
02122     */
02123     template <std::size_t level, std::size_t foo>
02124     struct nearBoundaryH
02125     {
02126         static bool apply(const SimplexID<level> s){
02127             auto name = s.indices();
02128             KeyType down[level-1];
02129
02130             for(std::size_t i = 0; i < level; ++i){
02131                 std::size_t k = 0;
02132                 for(std::size_t j = 0; j < level; ++j){
02133                     if (i != j){
02134                         down[k++] = name[j];
02135                     }
02136                 }
02137                 if(onBoundaryH<1, 0>::apply(
02138                     get_down_recurse<level, level-1>::apply(down, s.ptr)
02139                 ))
02140                     return true;
02141             }
02142             return false;
02143         }
02144     };
02145
02146     /**
02147     * @brief      Specialization of vertices
02148     * @tparam     foo    Dummy argument to avoid explicit specialization in
02149     *                    class scope
02150     */
02151     template <std::size_t foo>
02152     struct nearBoundaryH<1, foo>
02153     {
02154

```

```

02162         static bool apply(const SimplexID<1> s){
02163             if(onBoundaryH<1, 0>::apply(s))
02164                 return true;
02165             return false;
02166         }
02167     };
02168
02169     /**
02170     * @brief      Base case for checking if simplex is on a boundary
02171     *
02172     * @tparam      level  Dimension of the simplex
02173     * @tparam      foo    Dummy argument to avoid explicit specialization in
02174     *                     class scope
02175     */
02176     template <std::size_t level, std::size_t foo>
02177     struct onBoundaryH
02178     {
02179         /**
02180         * @brief      Recurse up complex to find boundary.
02181         *
02182         * @param[in]  s      Simplex of interest
02183         *
02184         * @return      True if on boundary
02185         */
02186         static bool apply(const SimplexID<level> s)
02187         {
02188             for(auto p : s.ptr->_up)
02189             {
02190                 if(onBoundaryH<level+1, foo>::apply(SimplexID<level+1>(p.second)))
02191                     return true;
02192             }
02193             return false;
02194         }
02195     };
02196
02197     /**
02198     * @brief      Specialization for if facets are on boundary.
02199     *
02200     * @tparam      foo    Dummy argument to avoid explicit specialization in
02201     *                     class scope}
02202     */
02203     template <std::size_t foo>
02204     struct onBoundaryH<topLevel, foo>
02205     {
02206         /**
02207         * @brief      Check if a face is on a boundary
02208         *
02209         * @param[in]  s      SimplexID<topLevel> of interest
02210         *
02211         * @return      True if a member SimplexID<topLevel-1> is a boundary.
02212         */
02213         static bool apply(const SimplexID<topLevel> s)
02214         {
02215             for(auto p : s.ptr->_down){
02216                 if(onBoundaryH<topLevel-1, foo>::apply(SimplexID<topLevel-1>(p.second)))
02217                     return true;
02218             }
02219             return false;
02220         }
02221     };
02222
02223     /**
02224     * @brief      Specialization for topLevel-1 simplices
02225     *
02226     * @tparam      foo    Dummy argument to avoid explicit specialization in
02227     *                     class scope}
02228     */
02229     template <std::size_t foo>
02230     struct onBoundaryH<bdryLevel, foo>
02231     {
02232         /**
02233         * @brief      Check if SimplexID<topLevel-1> is on a boundary
02234         *
02235         * @param[in]  s      SimplexID of interest
02236         *
02237         * @return      True if simplex has less than 2 coboundary faces.
02238         */
02239         static bool apply(const SimplexID<bdryLevel> s)
02240         {
02241             return s.ptr->_up.size() < 2;
02242         }
02243     };
02244
02245     /**
02246     * @brief      Base case for recursively deleting simplices.
02247     *
02248     * @tparam      level  Simplex dimension to operate at.

```

```

02249     * @tparam    foo    Dummy argument to avoid explicit specialization in
02250     *                class scope
02251     */
02252     template <std::size_t level, std::size_t foo>
02253     struct remove_recurse
02254     {
02255         /**
02256          * @brief      Recursively remove simplices.
02257          *
02258          * @param      that    The CASC object
02259          * @param[in]   begin    Iterator to beginning of the set of simplices
02260          *                to remove.
02261          * @param[in]   end      Iterator to the end of the set.
02262          * @param      count    Number of simplices removed already.
02263          *
02264          * @tparam      T        Typename of the iterator.
02265          *
02266          * @return      Recurse to the next level and remove coboundary
02267          *                simplices.
02268          */
02269         template <typename T>
02270         static std::size_t apply(type_this* that, T begin, T end, std::size_t &count)
02271         {
02272             std::set<Node<level+1*>> next;
02273             // for each node of interest...
02274             for (auto i = begin; i != end; ++i)
02275             {
02276                 auto up = (*i)->_up;
02277                 for (auto j = up.begin(); j != up.end(); ++j)
02278                 {
02279                     next.insert(j->second);
02280                 }
02281                 that->remove_node(*i);
02282                 ++count;
02283             }
02284             return remove_recurse<level+1, foo>::apply(that, next.begin(), next.end(), count);
02285         }
02286     };
02287
02288     /**
02289     * @brief      Terminal condition for remove_recurse.
02290     *
02291     * @tparam      foo    Dummy argument to avoid explicit specialization in
02292     *                class scope
02293     */
02294     template <std::size_t foo>
02295     struct remove_recurse<topLevel, foo>
02296     {
02297         /**
02298          * @brief      Remove the facets of the complex.
02299          *
02300          * @param      that    The CASC object
02301          * @param[in]   begin    Iterator to beginning of the set of simplices
02302          *                to remove.
02303          * @param[in]   end      Iterator to the end of the set.
02304          * @param      count    Number of simplices removed already.
02305          *
02306          * @tparam      T        Typename of the iterator.
02307          *
02308          * @return      The number of simplices removed
02309          */
02310         template <typename T>
02311         static std::size_t apply(type_this* that, T begin, T end, std::size_t &count)
02312         {
02313             for (auto i = begin; i != end; ++i)
02314             {
02315                 that->remove_node(*i);
02316                 ++count;
02317             }
02318             return count;
02319         }
02320     };
02321
02322     /**
02323     * @brief      Recursively retrieve a simplex of interest.
02324     *
02325     * @tparam      level    The current simplex dimension.
02326     * @tparam      n        Number of remaining times to recurse.
02327     */
02328     template <std::size_t level, std::size_t n>
02329     struct get_recurse
02330     {
02331         /**
02332          * @brief      Get the simplex of interest.
02333          *
02334          * @param[in]   that    The simplicial complex to search.
02335          * @param[in]   s        Pointer to an array of Keys.

```

```

02336         * @param      root  The current simplex
02337         *
02338         * @return      Returns a pointer to the node.
02339         */
02340     static Node<level+n>* apply(const KeyType* s, Node<level>* root)
02341     {
02342         // TODO: We probably don't need to check if root is a valid
02343         // simplex (10)
02344         if (root)
02345         {
02346             auto p = root->_up.find(*s);
02347             if (p != root->_up.end())
02348             {
02349                 return get_recurse<level+1, n-1>::apply(s+1, root->_up.at(*s));
02350             }
02351             else
02352             {
02353                 return nullptr;
02354             }
02355         }
02356         else
02357         {
02358             return nullptr;
02359         }
02360     }
02361 };
02362 /**
02363  * @brief      Recursively retrieve a simplex of interest.
02364  *
02365  * @tparam      level  The current simplex dimension.
02366  */
02367 template <std::size_t level>
02368 struct get_recurse<level, 0>
02369 {
02370     /**
02371     * @brief      Get the simplex of interest.
02372     *
02373     * @param[in]  that  The simplicial complex to search.
02374     * @param[in]  s      Pointer to an array of Keys.
02375     * @param      root  The current simplex
02376     *
02377     * @return      Returns a pointer to the node.
02378     */
02379     static Node<level>* apply(const KeyType*, Node<level>* root)
02380     {
02381         return root;
02382     }
02383 };
02384
02385 /**
02386  * @brief      Recursively retrieve a simplex of interest going down.
02387  *
02388  * @tparam      level  The current simplex dimension.
02389  * @tparam      n      Number of remaining times to recurse.
02390  */
02391 template <std::size_t level, std::size_t n>
02392 struct get_down_recurse
02393 {
02394     /**
02395     * @brief      Get the simplex of interest.
02396     *
02397     * @param[in]  that  The simplicial complex to search.
02398     * @param[in]  s      Pointer to an array of Keys.
02399     * @param      root  The current simplex
02400     *
02401     * @return      Returns a pointer to the node.
02402     */
02403     static Node<level-n>* apply(const KeyType* s, Node<level>* root)
02404     {
02405         if (root)
02406         {
02407             auto p = root->_down.find(*s);
02408             if (p != root->_down.end())
02409             {
02410                 return get_down_recurse<level-1, n-1>::apply(s+1, root->_down[*s]);
02411             }
02412             else
02413             {
02414                 return nullptr;
02415             }
02416         }
02417         else
02418         {
02419             return nullptr;
02420         }
02421     }
02422 };

```

```

02423
02424     /**
02425      * @brief      Recursively retrieve a simplex of interest going down.
02426      *
02427      * @tparam      level  The current simplex dimension.
02428      */
02429     template <std::size_t level>
02430     struct get_down_recurse<level, 0>
02431     {
02432         /**
02433          * @brief      Get the simplex of interest.
02434          *
02435          * @param[in]   this  The simplicial complex to search.
02436          * @param[in]   s     Pointer to an array of Keys.
02437          * @param       root  The current simplex
02438          *
02439          * @return      Returns a pointer to the node.
02440          */
02441         static Node<level>* apply(const KeyType*, Node<level>* root)
02442         {
02443             return root;
02444         }
02445     };
02446
02447     /**
02448      * @brief      Insert a simplex and all dependent simplices into the
02449      *              complex.
02450      *
02451      * @tparam      level  Dimension of the current root simplex
02452      * @tparam      n       The number of times to recurse.
02453      */
02454     template <std::size_t level, std::size_t n>
02455     struct insert_full
02456     {
02457         /**
02458          * @brief      Kick off a for loop to insert all cofaces.
02459          *
02460          * @param       that  The simplicial complex
02461          * @param       root  The current simplex to insert at.
02462          * @param[in]   begin  Pointer to an array of Keys.
02463          *
02464          * @return      Returns the node to insert.
02465          */
02466         static Node<level+n>* apply(type_this* that, Node<level>* root, const KeyType* begin)
02467         {
02468             return insert_for<level, n, n>::apply(that, root, begin);
02469         }
02470     };
02471
02472     /**
02473      * @brief      Insert a simplex and all dependent simplices into the
02474      *              complex.
02475      *
02476      * @tparam      level  Dimension of the current root simplex
02477      */
02478     template <std::size_t level>
02479     struct insert_full<level, 0>
02480     {
02481         /**
02482          * @brief      Terminal case.
02483          *
02484          * @param       that  The simplicial complex
02485          * @param       root  The current simplex to insert at.
02486          * @param[in]   begin  Pointer to an array of Keys.
02487          *
02488          * @return      Returns the node to insert.
02489          */
02490         static Node<level>* apply(type_this*, Node<level>* root, const KeyType*)
02491         {
02492             return root;
02493         }
02494     };
02495
02496     /**
02497      * @brief      Iterate over antistep
02498      *
02499      * @tparam      level  Dimension of the current root simplex
02500      * @tparam      antistep  Antistep to track which indices to append to root.
02501      * @tparam      n       Original antistep.
02502      */
02503     template <std::size_t level, std::size_t antistep, std::size_t n>
02504     struct insert_for
02505     {
02506         /**
02507          * @brief      Call insert_raw and continue for loop
02508          *
02509          */

```

```

02510         * @param      that      The simplicial complex
02511         * @param      root      The current simplex to insert at.
02512         * @param[in]   begin     Pointer to an array of Keys.
02513         *
02514         * @return      Returns the node to insert.
02515         */
02516         static Node<level+n>* apply(type_this* that, Node<level>* root, const KeyType* begin)
02517         {
02518             insert_raw<level, n-antistep>::apply(that, root, begin);
02519             return insert_for<level, antistep-1, n>::apply(that, root, begin);
02520         }
02521     };
02522
02523     /**
02524     * @brief          Terminal case.
02525     *
02526     * @tparam         level      Dimension of the current root simplex.
02527     * @tparam         n          Original antistep.
02528     */
02529     template <std::size_t level, std::size_t n>
02530     struct insert_for<level, 1, n>
02531     {
02532         /**
02533         * @brief          Call insert_raw and stop loop
02534         *
02535         * @param         that      The simplicial complex
02536         * @param         root      The current simplex to insert at.
02537         * @param[in]     begin     Pointer to an array of Keys.
02538         *
02539         * @return        Returns the node to insert.
02540         */
02541         static Node<level+n>* apply(type_this* that, Node<level>* root, const KeyType* begin)
02542         {
02543             return insert_raw<level, n-1>::apply(that, root, begin);
02544         }
02545     };
02546
02547     /**
02548     * @brief          Actually insert the node and connect up and down.
02549     *
02550     * @tparam         level      Dimension of the current root simplex.
02551     * @tparam         n          The index to append to root.
02552     */
02553     template <std::size_t level, std::size_t n>
02554     struct insert_raw
02555     {
02556         /**
02557         * @brief          Create the node and connect up and down.
02558         *
02559         * @param         that      The simplicial complex
02560         * @param         root      The current simplex to insert at.
02561         * @param[in]     begin     Pointer to an array of Keys.
02562         *
02563         * @return        Returns the node to insert.
02564         */
02565         static Node<level+n+1>* apply(type_this* that, Node<level>* root, const KeyType* begin)
02566         {
02567             KeyType      v = *(begin+n);
02568             Node<level+1>* nn;
02569             // if root->v doesn't exist then create it
02570             auto         iter = root->_up.find(v);
02571             if (iter == root->_up.end())
02572             {
02573                 nn = that->create_node<level+1>();
02574
02575                 nn->_down[v] = root;
02576                 root->_up[v] = nn;
02577                 that->backfill(root, nn, v);
02578             }
02579             else
02580             {
02581                 nn = iter->second; // otherwise get it
02582             }
02583             return insert_full<level+1, n>::apply(that, nn, begin);
02584         }
02585     };
02586
02587     /**
02588     * @brief          Backfill in the pointers from prior nodes to the new node
02589     *
02590     * @param         root      is a parent node
02591     * @param         nn        is the new child node
02592     * @param         value     is the exposed id of nn
02593     * @return        void
02594     *
02595     * @tparam         level      Dimension of the current root simplex.

```

```

02597     */
02598     template <std::size_t level>
02599     void backfill(Node<level>* root, Node<level+1>* nn, KeyType value)
02600     {
02601         for (auto curr = root->_down.begin(); curr != root->_down.end(); ++curr)
02602         {
02603             int v = curr->first;
02604
02605             Node<level-1>* parent = curr->second;
02606             Node<level> * child = parent->_up[value];
02607
02608             nn->_down[v] = child;
02609             child->_up[v] = nn;
02610         }
02611     }
02612
02613     /**
02614     * @brief Fill in the pointers from level 1 to 0.
02615     *
02616     * @param root is a level 0 node
02617     * @param nn is a level 1 node
02618     * @param value is the exposed id of nn
02619     * @return void
02620     */
02621     void backfill(Node<0>*, Node<1>*, int)
02622     {
02623         return;
02624     }
02625
02626     /**
02627     * @brief Creates a new node of some dimension.
02628     *
02629     * @param[in] x Argument to help deduce the new node dimension
02630     *
02631     * @tparam level Simplex dimension
02632     *
02633     * @return A pointer to the new node.
02634     */
02635     template <std::size_t level>
02636     Node<level>* create_node()
02637     {
02638         // Create the new node
02639         auto p = new Node<level>(node_count++);
02640         ++(level_count[level]); // Increment the count in the level
02641
02642         // node_count-1 to match the internal IDs correctly.
02643         MAYBE_UNUSED bool ret = std::get<level>(levels).insert(
02644             std::pair<std::size_t, NodePtr<level> >(node_count-1, p)).second;
02645         assert(ret);
02646         /*
02647         // sanity check to make sure there aren't duplicate keys...
02648         if (ret==false) {
02649             std::cout << "Error: Node '" << node_count << "' already existed
02650                 with value " << *p << std::endl;
02651         }
02652         */
02653         return p;
02654     }
02655
02656     /**
02657     * @brief Removes a node.
02658     *
02659     * @param p Simplex to remove
02660     *
02661     * @tparam level Dimension of the simplex
02662     */
02663     template <std::size_t level>
02664     void remove_node(Node<level>* p)
02665     {
02666         for (auto curr = p->_down.begin(); curr != p->_down.end(); ++curr)
02667         {
02668             curr->second->_up.erase(curr->first);
02669         }
02670         for (auto curr = p->_up.begin(); curr != p->_up.end(); ++curr)
02671         {
02672             curr->second->_down.erase(curr->first);
02673         }
02674         --(level_count[level]);
02675         std::get<level>(levels).erase(p->_node);
02676         delete p;
02677     }
02678
02679     /**
02680     * @brief Removes a node.
02681     *
02682     * @param p Simplex to remove
02683     */

```

```

02684 void remove_node(Node<1>* p)
02685 {
02686     // This for loop should only have a single iteration.
02687     for (auto curr = p->_down.begin(); curr != p->_down.end(); ++curr)
02688     {
02689         unused_vertices.insert(curr->first);
02690         curr->second->_up.erase(curr->first);
02691     }
02692     for (auto curr = p->_up.begin(); curr != p->_up.end(); ++curr)
02693     {
02694         curr->second->_down.erase(curr->first);
02695     }
02696     --(level_count[1]);
02697     std::get<1>(levels).erase(p->_node);
02698     delete p;
02699 }
02700
02701 /**
02702  * @brief      Removes a node.
02703  *
02704  * @param      p      Simplex to remove
02705  */
02706 void remove_node(Node<0>* p)
02707 {
02708     for (auto curr = p->_up.begin(); curr != p->_up.end(); ++curr)
02709     {
02710
02711         curr->second->_down.erase(curr->first);
02712     }
02713     --(level_count[0]);
02714     std::get<0>(levels).erase(p->_node);
02715     delete p;
02716 }
02717
02718 /**
02719  * @brief      Removes a node.
02720  *
02721  * @param      p      Simplex to remove
02722  */
02723 void remove_node(Node<topLevel>* p)
02724 {
02725     for (auto curr = p->_down.begin(); curr != p->_down.end(); ++curr)
02726     {
02727         curr->second->_up.erase(curr->first);
02728     }
02729     --(level_count[topLevel]);
02730     std::get<topLevel>(levels).erase(p->_node);
02731     delete p;
02732 }
02733
02734 /// The root node
02735 NodePtr<0> _root;
02736 /// A counter of the total number of nodes.
02737 std::size_t node_count;
02738 /// A counter of the number of simplices per level.
02739 std::array<std::size_t, numLevels> level_count;
02740 /// Typename of a tuple of LevelIndex broadcasted with NodePtr<k>.
02741 using NodePtrLevel = typename util::int_type_map<std::size_t, std::tuple, LevelIndex,
NodePtr>::type;
02742 /// Typename of a map of levels to NodePtr<k>'s.
02743 typename util::type_map<NodePtrLevel, detail::map::type levels;
02744 /// B-tree of unused vertex indices.
02745 index_tracker::index_tracker<KeyType> unused_vertices;
02746 };
02747
02748 /**
02749  * Alias to generate a CASC from a list of traits.
02750  * See also simplicial_complex_traits_default. Example -- To create a
02751  * tetrahedral mesh with integer data on all simplices:
02752  * ~~~~~{.cpp}
02753  * auto mesh = AbstractSimplicialComplex<
02754  *     int, // KEYTYPE
02755  *     int, // Root data
02756  *     int, // Vertex data
02757  *     int, // Edge data
02758  *     int, // Face data
02759  *     int // Volume data
02760  * >();
02761  * ~~~~~
02762  */
02763 template <typename KeyType, typename ... Ts>
02764 using AbstractSimplicialComplex = simplicial_complex<
    detail::simplicial_complex_traits_default<KeyType, Ts...> >;
02765
02766 /// @cond detail
02767 namespace simplex_set_detail{

```

```

02770 /**
02771  * @brief      Template to compute a hash for a SimplexID.
02772  *
02773  * Since SimplexID is actually a wrapper around a Node* we have to hash it
02774  * accordingly. The static_cast calls the defined explicit operator which
02775  * reinterprets the stored Node* pointer as a uintptr_t which we can hash
02776  * directly.
02777  *
02778  * @tparam      SimplexID  Typename of the SimplexID.
02779  */
02780 template <typename SimplexID>
02781 struct hashSimplexID{
02782     /**
02783      * @brief      Compute the hash.
02784      *
02785      * ~~~~~(.cpp)
02786      * std::cout << hashSimplexID<decltype(nid)>{}(nid) << std::endl;
02787      * ~~~~~
02788      *
02789      * @param[in]  nid      The simplex of interest.
02790      * @return      Resultant hash.
02791      */
02792     std::size_t operator()(const SimplexID nid) const
02793     {
02794         return std::hash<std::uintptr_t>() (static_cast<uintptr_t>(nid));
02795     }
02796 };
02797 } // end namespace simplex_set_detail
02798 /// @endcond
02799
02800 /// Helpful alias defining a unordered_set of simplices. See also hashSimplexID.
02801 template <typename T> using NodeSet =
02802     std::unordered_set<T, simplex_set_detail::hashSimplexID<T> >;
02803 } // end namespace casc

```

10.17 include/casc/stringutil.h File Reference

String utilities for CASC.

```
#include <string>
```

Namespaces

- namespace `casc`
Namespace for everything CASC.

Functions

- template<typename T, std::size_t k>
std::string `casc::to_string` (const std::array< T, k > &A)
Returns a string representation of the vertex subsimplices of a given simplex.

10.18 stringutil.h

[Go to the documentation of this file.](#)

```

00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *

```

```

00008  * This library is free software; you can redistribute it and/or
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00012  *
00013  * This library is distributed in the hope that it will be useful,
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00017  *
00018  * You should have received a copy of the GNU Lesser General Public
00019  * License along with this library; if not, write to the Free Software
00020  * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021  *
00022  * *****
00023  */
00024
00025 /**
00026  * @file stringutil.h
00027  * @brief String utilities for CASC.
00028  */
00029
00030 #pragma once
00031
00032 #include <string>
00033
00034 namespace casc
00035 {
00036 /**
00037  * @brief      Returns a string representation of the vertex subsimplicies
00038  *             of a given simplex
00039  *
00040  * @param[in]  A      Array containing name of a simplex.
00041  *
00042  * @tparam    T      Typename KeyType.
00043  * @tparam    k      Dimension of the simplex.
00044  *
00045  * @return     String representation of the object.
00046  */
00047 template <typename T, std::size_t k>
00048 std::string to_string(const std::array<T,k>& A)
00049 {
00050     if (k==0){
00051         return "{root}";
00052     }
00053     std::string out;
00054     out += "{";
00055     for(int i = 0; i + 1 < k; ++i)
00056     {
00057         out += std::to_string(A[i]) + ",";
00058     }
00059     if(k > 0)
00060     {
00061         out += std::to_string(A[k-1]);
00062     }
00063     out += "}";
00064     return out;
00065 }
00066 } // end namespace casc

```

10.19 include/casc/typetraits.h File Reference

Helper functions for debugging template types.

Functions

- `template<class T >`
`CONSTEXPR14_TN static_string type_name ()`
Print the typename of an object at compile time.

10.19.1 Detailed Description

This is copied directly from this very helpful post from [Stackoverflow](#).

10.19.2 Function Documentation

10.19.2.1 type_name()

```
template<class T >
CONSTEXPR14_TN static_string type_name ( )
```

Example usage:

```
std::cout << "decltype(i) is " << type_name<decltype(i)>() << '\n';
```

10.20 typetraits.h

[Go to the documentation of this file.](#)

```
00001 /**
00002  * @file typetraits.h
00003  * @brief Helper functions for debugging template types.
00004  *
00005  * This is copied directly from this very helpful post from
00006  * <a
00007  href="https://stackoverflow.com/questions/81870/is-it-possible-to-print-a-variables-type-in-standard-c/20170989#20170989"
00008  */
00009 /// @cond hidden
00010 #pragma once
00011
00012 #include <cstdint>
00013 #include <stdexcept>
00014 #include <cstring>
00015 #include <ostream>
00016
00017 #ifndef _MSC_VER
00018 #   if __cplusplus < 201103
00019 #       define CONSTEXPR11_TN
00020 #       define CONSTEXPR14_TN
00021 #       define NOEXCEPT_TN
00022 #   elif __cplusplus < 201402
00023 #       define CONSTEXPR11_TN constexpr
00024 #       define CONSTEXPR14_TN
00025 #       define NOEXCEPT_TN noexcept
00026 #   else
00027 #       define CONSTEXPR11_TN constexpr
00028 #       define CONSTEXPR14_TN constexpr
00029 #       define NOEXCEPT_TN noexcept
00030 #   endif
00031 #else // _MSC_VER
00032 #   if _MSC_VER < 1900
00033 #       define CONSTEXPR11_TN
00034 #       define CONSTEXPR14_TN
00035 #       define NOEXCEPT_TN
00036 #   elif _MSC_VER < 2000
00037 #       define CONSTEXPR11_TN constexpr
00038 #       define CONSTEXPR14_TN
00039 #       define NOEXCEPT_TN noexcept
00040 #   else
00041 #       define CONSTEXPR11_TN constexpr
00042 #       define CONSTEXPR14_TN constexpr
00043 #       define NOEXCEPT_TN noexcept
00044 #   endif
00045 #endif // _MSC_VER
00046
00047 class static_string
00048 {
00049     const char* const p_;
00050     const std::size_t sz_;
00051
00052 public:
00053     typedef const char* const_iterator;
00054
00055     template <std::size_t N>
00056     CONSTEXPR11_TN static_string(const char(&a) [N]) NOEXCEPT_TN
00057         : p_(a)
```

```

00058         , sz_(N-1)
00059     {}
00060
00061     CONSTEXPR11_TN static_string(const char* p, std::size_t N) NOEXCEPT_TN
00062     : p_(p)
00063     , sz_(N)
00064     {}
00065
00066     CONSTEXPR11_TN const char* data() const NOEXCEPT_TN {return p_;}
00067     CONSTEXPR11_TN std::size_t size() const NOEXCEPT_TN {return sz_;}
00068
00069     CONSTEXPR11_TN const_iterator begin() const NOEXCEPT_TN {return p_;}
00070     CONSTEXPR11_TN const_iterator end() const NOEXCEPT_TN {return p_ + sz_;}
00071
00072     CONSTEXPR11_TN char operator[](std::size_t n) const
00073     {
00074         return n < sz_ ? p_[n] : throw std::out_of_range("static_string");
00075     }
00076 };
00077
00078 inline
00079 std::ostream&
00080 operator<<(std::ostream& os, static_string const& s)
00081 {
00082     return os.write(s.data(), s.size());
00083 }
00084 /// @endcond
00085
00086 /**
00087  * @brief      Print the typename of an object at compile time.
00088  *
00089  * Example usage:
00090  * ~~~~~{.cpp}
00091  * std::cout << "decltype(i) is " << type_name<decltype(i)>() << '\n';
00092  * ~~~~~
00093  */
00094 template <class T>
00095 CONSTEXPR14_TN
00096 static_string
00097 type_name()
00098 {
00099     #ifdef __clang__
00100         static_string p = __PRETTY_FUNCTION__;
00101         return static_string(p.data() + 31, p.size() - 31 - 1);
00102     #elif defined(__GNUC__)
00103         static_string p = __PRETTY_FUNCTION__;
00104         # if __cplusplus < 201402
00105             return static_string(p.data() + 36, p.size() - 36 - 1);
00106         # else
00107             return static_string(p.data() + 46, p.size() - 46 - 1);
00108         # endif
00109     #elif defined(_MSC_VER)
00110         static_string p = __FUNCSIG__;
00111         return static_string(p.data() + 38, p.size() - 38 - 7);
00112     #endif
00113 }

```

10.21 include/casc/util.h File Reference

Metatemplate pack expansion helpers.

```

#include <utility>
#include <array>

```

Data Structures

- struct [util::range< T >](#)
A range object to support range based for loops.
- struct [util::type_holder< Ts >](#)
Queue based data structure to hold list of types.
- struct [util::type_holder< T, Ts... >](#)

- Partial specialization to allow FIFO access of typenames.*
 - struct `util::type_get< k, T >`
 - Helper to get the kth element from a `type_holder`.*
 - struct `util::type_get< 0, type_holder< Ts... > >`
 - Specialization for terminal case.*
 - struct `util::type_get< k, type_holder< Ts... > >`
 - Specialization to recursively pop types to get the kth type.*
 - struct `util::type_map< C, V >`
 - Map the types in C into $V<T>$.*
 - struct `util::int_type_map< IntegerType, OutHolder, IntegerSequence, F >`
 - Maps an integer sequence and typename, F , into outholder.*
 - struct `util::type_swap< TUPLE, HOLDER_FULL >`
 - Move a list of types from one container to another.*
 - struct `util::type_swap< TUPLE, HOLDER< Ts... > >`
 - Move a list of types from one container to another.*
 - struct `util::reverse_sequence< Integer, IntegerSequence >`
 - Reverse an Integer Sequence.*
 - struct `util::remove_first_val< Integer, IntegerSequence >`
 - General template for removing the first value from a type holder.*
 - struct `util::remove_first_val< Integer, InHolder< Integer, I, Is... > >`
 - Specialization for removing first integer from a sequence of compile time integers.*

Namespaces

- namespace `util`
- Metatemplate programming utilities namespace.*

Functions

- template<typename T >
`range< T > util::make_range (T b, T e)`
Make a range object.
- template<typename T >
`range< T > util::make_range (std::pair< T, T > p)`
Makes a range object.
- template<class Integer, typename IntegerSequence, typename Fn, typename ... Args>
`void util::int_for_each (Fn &&f, Args &&... args)`
Calls a function $f.apply<k>()$ for a sequence of integer k 's.

10.22 util.h

[Go to the documentation of this file.](#)

```
00001 /*
00002  * *****
00003  * This file is part of the Colored Abstract Simplicial Complex library.
00004  * Copyright (C) 2016-2017
00005  * by Christopher Lee, John Moody, Rommie Amaro, J. Andrew McCammon,
00006  * and Michael Holst
00007  *
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```

```

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00012 *
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00016 * Lesser General Public License for more details.
00017 *
00018 * You should have received a copy of the GNU Lesser General Public
00019 * License along with this library; if not, write to the Free Software
00020 * Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA
00021 *
00022 * *****
00023 */
00024
00025 /**
00026 * @file util.h
00027 * @brief Metatemplate pack expansion helpers
00028 */
00029
00030 #pragma once
00031
00032 #include <utility>
00033 #include <array>
00034
00035 /// Metatemplate programming utilities namespace
00036 namespace util
00037 {
00038 /**
00039 * @brief A range object to support range based for loops.
00040 *
00041 * This is a basic data structure which implements a 'begin()' and 'end()'
00042 * functions for range based for lopping added in C++11.
00043 * See also
00044 * <a href="http://en.cppreference.com/w/cpp/language/range-for">range-for</a>.
00045 *
00046 * @tparam T Typename of the iterator
00047 */
00048 template<typename T> struct range
00049 {
00050
00051 /**
00052 * @brief Construct a range for a container class.
00053 *
00054 * @param[in] c Container class which implements begin() and end().
00055 *
00056 * @tparam C Typename of the container.
00057 */
00058 template <class C>
00059 range(C &c) : _begin(c.begin()), _end(c.end()) {}
00060
00061 /**
00062 * @brief Construct a range from an iterator.
00063 *
00064 * @param[in] b Beginning iterator
00065 * @param[in] e End iterator.
00066 */
00067 range(T b, T e) : _begin(b), _end(e) {}
00068
00069 /**
00070 * @brief Get the beginning iterator.
00071 *
00072 * @return Returns an iterator to the beginning.
00073 */
00074 T begin() { return _begin; }
00075
00076 /**
00077 * @brief Get the end iterator.
00078 *
00079 * @return Returns an iterator to the end.
00080 */
00081 T end() { return _end; }
00082
00083 private:
00084 /// Iterator to the beginning.
00085 T _begin;
00086 /// Iterator to the end.
00087 T _end;
00088 };
00089
00090 /**
00091 * @brief Make a range object.
00092 *
00093 * @param[in] b Iterator to the beginning.
00094 * @param[in] e Iterator to the end.
00095 *
00096 * @tparam T Typename of the iterator.
00097 */

```

```

00098 * @return      Returns a range of the iterators.
00099 */
00100 template<typename T> range<T> make_range(T b, T e)
00101 {
00102     return range<T>(std::move(b), std::move(e));
00103 }
00104
00105 /**
00106 * @brief      Makes a range object.
00107 *
00108 * @param[in]  p      A pair containing begin and end iterators.
00109 *
00110 * @tparam     T      Typename of the iterator.
00111 *
00112 * @return     Returns a range of the iterators.
00113 */
00114 template<typename T> range<T> make_range(std::pair<T, T> p)
00115 {
00116     return range<T>(std::move(p.first), std::move(p.second));
00117 }
00118
00119 /**
00120 * @brief      Queue based data structure to hold list of types.
00121 *
00122 * Types in the type_holder can be accessed by accessing the 'head' type.
00123 * Subsequent types are in the 'tail'. See also type_get.
00124 *
00125 * @tparam     Ts      List of typenames
00126 */
00127 template <typename ... Ts>
00128 struct type_holder
00129 {
00130     /// Length of the list of types
00131     static const std::size_t size = sizeof ... (Ts);
00132 };
00133
00134 /**
00135 * @brief      Partial specialization to allow FIFO access of typenames.
00136 *
00137 * @tparam     T      The first typename
00138 * @tparam     Ts      The following typenames
00139 */
00140 template <typename T, typename ... Ts>
00141 struct type_holder<T, Ts...>
00142 {
00143     /// The first type
00144     using head = T;
00145     /// The following types
00146     using tail = type_holder<Ts...>;
00147     /// Length of the list of types
00148     static const std::size_t size = 1 + type_holder<Ts...>::size;
00149 };
00150
00151 /**
00152 * @brief      Helper to get the kth element from a type_holder.
00153 *
00154 * This is the empty general template which will be later specialized.
00155 *
00156 * @tparam     k      Integer index of the type to retrieve
00157 * @tparam     T      A type_holder queue of typenames
00158 */
00159 template <std::size_t k, typename T>
00160 struct type_get {};
00161
00162 /**
00163 * @brief      Specialization for terminal case.
00164 *
00165 * @tparam     Ts      Following typenames
00166 */
00167 template <typename ... Ts>
00168 struct type_get<0, type_holder<Ts...> >
00169 {
00170     /// The first type of the type_holder
00171     using type = typename type_holder<Ts...>::head;
00172 };
00173
00174 /**
00175 * @brief      Specialization to recursively pop types to get the kth type.
00176 *
00177 * @tparam     k      Integral constant of the type to get
00178 * @tparam     Ts      List of typenames
00179 */
00180 template <std::size_t k, typename ... Ts>
00181 struct type_get<k, type_holder<Ts...> >
00182 {
00183     /// Recurse after popping the first type off
00184     using type = typename type_get<k-1, typename type_holder<Ts...>::tail::type;

```

```

00185 };
00186
00187 /// @cond detail
00188 /// Namespace for utility helper functions
00189 namespace detail
00190 {
00191 /**
00192  * @brief      Helper to broadcast a list of types into a class.
00193  *
00194  * @tparam     C      Class to old a list of types
00195  * @tparam     V      Class to broadcast the types into
00196  * @tparam     Rs     List of resulting types
00197  */
00198 template <class C, template <typename> class V, typename ... Rs>
00199 struct type_map_helper {};
00200
00201 /**
00202  * @brief      Terminal condition: place the mapped types into a tuple
00203  *
00204  * @tparam     G      Empty tuple
00205  * @tparam     V      Type template <class T> class to map into
00206  * @tparam     Rs     List of already mapped types
00207  */
00208 template <template <class ...> class G, template <typename> class V, typename ... Rs>
00209 struct type_map_helper<G<>, V, Rs...>
00210 {
00211     using type = G<Rs...>;
00212 };
00213
00214 /**
00215  * @brief      Map types into
00216  *
00217  * @tparam     G      Tuple of types
00218  * @tparam     T      Current type
00219  * @tparam     Ts     List of remaining types
00220  * @tparam     V      Type template <class T> class to map into
00221  * @tparam     Rs     List of already mapped types
00222  */
00223 template <template < class ...> class G, typename T, typename ... Ts, template <typename> class V,
00224         typename ... Rs>
00225 struct type_map_helper<G<T, Ts...>, V, Rs...>
00226 {
00227     using type = typename type_map_helper<G<Ts...>, V, Rs..., V<T> >::type;
00228 };
00229 // end of namespace detail
00230 /// @endcond
00231
00232 /**
00233  * @brief      Map the types in C into 'V<T>'.
00234  *
00235  * Given a container of types 'C<T1,T2,T3,...>' and template template type
00236  * 'V<T>', this function will apply the types in C to 'V<T>'. This produces
00237  * 'C<V<T1>, V<T2>, V<T3>, ...>'.
00238  *
00239  * @tparam     C      Container of compile time types.
00240  * @tparam     V      Template template class 'V<T>' to map into.
00241  */
00242 template <class C, template <typename> class V>
00243 struct type_map
00244 {
00245     /// Tuple of 'C<V<T1>, V<T2>, V<T3>, ...>'
00246     using type = typename detail::type_map_helper<C, V>::type;
00247 };
00248 /// @cond detail
00249 namespace detail
00250 {
00251 /**
00252  * @brief      Template for future specialization
00253  */
00254 template <class IntegerType, template <class ...> class OutHolder, class IntegerSequence, template
00255         <IntegerType> class F, typename ... Accumulators>
00256 struct int_type_map_helper {};
00257
00258 /**
00259  * @brief      Apply the typenames to the OutHolder
00260  *
00261  * @tparam     Integer      Integral type
00262  * @tparam     OutHolder    Type to ultimately hold the accumulated
00263  * @tparam     InHolder     Class of index sequence
00264  * @tparam     F            Type to apply index to
00265  * @tparam     Accumulator  List of mapped typenames F<I>
00266  */
00267 template <class Integer, template <class ...> class OutHolder, template <class, Integer...> class
00268         InHolder, template <Integer> class F, class ... Accumulator>
00269 struct int_type_map_helper<Integer, OutHolder, InHolder<Integer>, F, Accumulator...>
00270 {

```

```

00269     using type = OutHolder<Accumulator...>;
00270 };
00271
00272 /**
00273  * @brief      Iterates across integers and fills accumulator with F<I>
00274  *
00275  * @tparam      Integer      Integral type
00276  * @tparam      OutHolder    Type to ultimately hold the accumulated
00277  * @tparam      InHolder     Class of index sequence
00278  * @tparam      I            Current integer
00279  * @tparam      Is          Next integer(s)
00280  * @tparam      F            Type to apply index to
00281  * @tparam      Accumulator  List of previously mapped typenames F<I>
00282  */
00283 template <class Integer, template <class ...> class OutHolder, template <class, Integer...> class
InHolder, Integer I, Integer... Is, template <Integer> class F, class ... Accumulator>
00284 struct int_type_map_helper<Integer, OutHolder, InHolder<Integer, I, Is...>, F, Accumulator...>
00285 {
00286     using type = typename int_type_map_helper<Integer, OutHolder, InHolder<Integer, Is...>, F,
Accumulator..., F<I> >::type;
00287 };
00288 } // end namespace detail
00289 /// @endcond
00290
00291 /**
00292  * @brief      Maps an integer sequence and typename, F, into outholder.
00293  *
00294  * Given an Integer Sequence 'I<0,1,2,3,...>' and template type 'F<I>',
00295  * this function produces 'Out<F<0>, F<1>, F<2>, ...>'.
00296  *
00297  * @tparam      IntegerType  Typename of an integer type
00298  * @tparam      OutHolder    Typename of a holder for types
00299  * @tparam      IntegerSequence Integral sequence of types
00300  * @tparam      F            Typename of class to be broadcast with integer
00301  */
00302 template <class IntegerType, template <class ...> class OutHolder, class IntegerSequence, template
<IntegerType> class F>
00303 struct int_type_map
00304 {
00305     /// Tuple of 'Out<F<0>, F<1>, F<2>, ...>'.
00306     using type = typename detail::int_type_map_helper<IntegerType, OutHolder, IntegerSequence,
F>::type;
00307 };
00308
00309 /**
00310  * @brief      Move a list of types from one container to another.
00311  *
00312  * @tparam      TUPLE        Empty container
00313  * @tparam      HOLDER_FULL  Full container
00314  */
00315 template <template <class ...> class TUPLE, typename HOLDER_FULL>
00316 struct type_swap
00317 {};
00318
00319 /**
00320  * @brief      Move a list of types from one container to another.
00321  *
00322  * @tparam      TUPLE        Empty container
00323  * @tparam      HOLDER       Full container
00324  * @tparam      Ts          Typenames in full container
00325  */
00326 template <template <class ...> class TUPLE, template <class ...> class HOLDER, typename ... Ts>
00327 struct type_swap<TUPLE, HOLDER<Ts...> >
00328 {
00329     /// Empty container filled with typenames from full container
00330     using type = TUPLE<Ts...>;
00331 };
00332
00333 /// @cond detail
00334 namespace detail
00335 {
00336 /**
00337  * @brief      Helper struct to reverse a typed sequence.
00338  *
00339  * @tparam      Integer      Typename of integer class.
00340  * @tparam      IntegerSequence Sequence of integral types.
00341  * @tparam      Accumulator  Bucket ot hold types.
00342  */
00343 template <class Integer, class IntegerSequence, Integer... Accumulator>
00344 struct reverse_sequence_helper {};
00345
00346 /**
00347  * @brief      Terminal case of typed sequence reversal.
00348  *
00349  * @tparam      Integer      Typename of an integer class
00350  * @tparam      InHolder     Template template type holder
00351  * @tparam      Accumulator  List of reverse ordered typenames.

```

```

00352 */
00353 template <class Integer,
00354           template<class, Integer...> class InHolder,
00355           Integer... Accumulator>
00356 struct reverse_sequence_helper<Integer, InHolder<Integer>, Accumulator...>
00357 {
00358     /// Reversed sequence of types.
00359     using type = InHolder<Integer, Accumulator...>;
00360 };
00361
00362 /**
00363  * @brief      Helper struct to reverse a typed sequence.
00364  *
00365  * @tparam     Integer      Typename of integer class.
00366  * @tparam     InHolder     Type holder.
00367  * @tparam     I            First type in InHolder.
00368  * @tparam     Is           The following types in InHolder.
00369  * @tparam     Accumulator  List of reversed typenames.
00370  */
00371 template <class Integer,
00372           template<class, Integer...> class InHolder,
00373           Integer I, Integer... Is,
00374           Integer... Accumulator>
00375 struct reverse_sequence_helper<Integer, InHolder<Integer, I, Is...>, Accumulator...>
00376 {
00377     // Push the first type into the Accumulator and recurse.
00378     /// Reversed sequence of types.
00379     using type = typename reverse_sequence_helper<Integer,
00380                                                    InHolder<Integer, Is...>, I, Accumulator...>::type;
00381 };
00382 } // end namespace detail
00383 /// @endcond
00384
00385 /**
00386  * @brief      Reverse an Integer Sequence
00387  *
00388  * @tparam     Integer      Typename of an integer class.
00389  * @tparam     IntegerSequence  Sequence of compile-time integers.
00390  */
00391 template <class Integer, class IntegerSequence>
00392 struct reverse_sequence
00393 {
00394     /// Reversed sequence of types.
00395     using type = typename detail::reverse_sequence_helper<Integer, IntegerSequence>::type;
00396 };
00397
00398
00399 /**
00400  * @brief      General template for removing the first value from a type holder.
00401  *
00402  * @tparam     Integer      Typename of integer.
00403  * @tparam     IntegerSequence  Sequence of compile time integers.
00404  */
00405 template <class Integer, class IntegerSequence>
00406 struct remove_first_val {};
00407
00408 /**
00409  * @brief      Specialization for removing first integer from a sequence of
00410  *              compile time integers.
00411  *
00412  * @tparam     Integer      Typename of integer type.
00413  * @tparam     InHolder     Type holder of integer sequence.
00414  * @tparam     I            The first integer
00415  * @tparam     Is           Remaining integers
00416  */
00417 template <class Integer,
00418           template<class, Integer...> class InHolder,
00419           Integer I, Integer... Is>
00420 struct remove_first_val<Integer, InHolder<Integer, I, Is...> >
00421 {
00422     /// Type holder with first value removed.
00423     using type = InHolder<Integer, Is...>;
00424 };
00425
00426 /// @cond detail
00427 namespace detail
00428 {
00429     /**
00430      * @brief      Template type for future specialization
00431      */
00432     template <typename Integer, typename IntegerSequence, typename Fn, typename ... Args>
00433     struct int_for_each_helper {};
00434
00435     /**
00436      * @brief      Terminal Case
00437      */

```

```

00439 * @tparam Integer { description }
00440 * @tparam InHolder { description }
00441 * @tparam I { description }
00442 * @tparam Fn { description }
00443 * @tparam Args { description }
00444 */
00445 template <class Integer, template <class, Integer...> class InHolder,
00446 Integer I, typename Fn, typename ... Args>
00447 struct int_for_each_helper<Integer, InHolder<Integer, I>, Fn, Args...>
00448 {
00449     static void apply(Fn &&f, Args && ... args)
00450     {
00451         f.template apply<I>(std::forward<Args>(args) ...);
00452     }
00453 };
00454
00455 /**
00456 * @brief Recurse through the integer series
00457 *
00458 * @tparam Integer { description }
00459 * @tparam InHolder { description }
00460 * @tparam I { description }
00461 * @tparam Is { description }
00462 * @tparam Fn { description }
00463 * @tparam Args { description }
00464 */
00465 template <class Integer, template <class, Integer...> class InHolder,
00466 Integer I, Integer... Is, typename Fn, typename ... Args>
00467 struct int_for_each_helper<Integer, InHolder<Integer, I, Is...>, Fn, Args...>
00468 {
00469     static void apply(Fn &&f, Args && ... args)
00470     {
00471         f.template apply<I>(std::forward<Args>(args) ...);
00472         int_for_each_helper<Integer, InHolder<Integer, Is...>, Fn, Args...>::apply(
00473             std::forward<Fn>(f),
00474             std::forward<Args>(args) ...);
00475     }
00476 };
00477 } // end namespace detail
00478 /// @endcond
00479
00480 /**
00481 * @brief Calls a function 'f.apply<k>()' for a sequence of integer k's
00482 *
00483 * @param[in] args Arguments to f
00484 * @param[in] f Functor with 'apply<k>()' method
00485 *
00486 * @tparam Integer Integer type
00487 * @tparam IntegerSequence Sequence of integers to iterate
00488 * @tparam Fn Typename of functor f
00489 * @tparam Args Typenames of the arguments
00490 */
00491 template <class Integer, typename IntegerSequence, typename Fn, typename ... Args>
00492 void int_for_each(Fn &&f, Args && ... args)
00493 {
00494     detail::int_for_each_helper<Integer, IntegerSequence, Fn, Args...>::apply(std::forward<Fn>(f),
00495                                     std::forward<Args>(args) ...);
00496 }
00497 } // End of namespace util

```

Index

- `~simplicial_complex`
 - `casc::simplicial_complex< traits >`, 79
- `AbstractSimplicialComplex`
 - `casc`, 26
- `add_vertex`
 - `casc::simplicial_complex< traits >`, 79
- `begin`
 - `casc::SimplexSet< Complex >`, 69
 - `util::range< T >`, 58
- `casc`, 23
 - `AbstractSimplicialComplex`, 26
 - `check_orientation`, 26
 - `clear_orientation`, 27
 - `compute_orientation`, 27
 - `decimate`, 27
 - `decimateBackHalf`, 28
 - `decimateFirstHalf`, 28
 - `edge_up`, 29
 - `get`, 29, 30
 - `getClosure`, 30, 31
 - `getLink`, 31
 - `getStar`, 32
 - `init_orientation`, 33
 - `kneighbors`, 33, 34
 - `kneighbors_up`, 34, 35
 - `neighbors`, 35, 36
 - `neighbors_up`, 36, 37
 - `operator!=`, 37
 - `operator==`, 38
 - `perform_insertion`, 38
 - `perform_removal`, 38
 - `run_user_callback`, 39
 - `set_difference`, 39
 - `set_intersection`, 40
 - `set_union`, 40
 - `to_string`, 41
 - `visit_BFS_down`, 41
 - `visit_BFS_up`, 41
 - `writeDOT`, 42
- `casc::Orientable`, 56
- `casc::SimplexMap< Complex >`, 65
 - `get`, 66, 67
 - `operator<<`, 67
- `casc::SimplexSet< Complex >`, 68
 - `begin`, 69
 - `cbegin`, 70
 - `cend`, 70
 - `empty`, 70
 - `end`, 71
 - `erase`, 71
 - `find`, 72
 - `insert`, 73
 - `operator<<`, 74
 - `size`, 73
- `casc::simplicial_complex< traits >`, 74
 - `~simplicial_complex`, 79
 - `add_vertex`, 79
 - `down`, 80, 81
 - `EdgeData`, 78
 - `EdgeID`, 98
 - `eq`, 81
 - `exists`, 82
 - `get_cover`, 82, 83
 - `get_cover_insert`, 83
 - `get_edge_down`, 84
 - `get_edge_up`, 85
 - `get_level`, 86
 - `get_level_id`, 86, 87
 - `get_name`, 87, 88
 - `get_simplex_down`, 88, 89
 - `get_simplex_up`, 89–91
 - `insert`, 91, 92
 - `leq`, 93
 - `lt`, 93
 - `nearBoundary`, 94
 - `NodeData`, 79
 - `onBoundary`, 94
 - `remove`, 95
 - `SimplexID`, 98
 - `size`, 96
 - `up`, 96, 97
- `casc::simplicial_complex< traits >::EdgeID< k >`, 50
 - `down`, 52
 - `EdgeID`, 51, 52
 - `up`, 52
- `casc::simplicial_complex< traits >::SimplexID< k >`, 60
 - `cover`, 62
 - `cover_insert`, 63
 - `get_simplex_up`, 63, 64
 - `indices`, 64
 - `operator<<`, 65
 - `SimplexID`, 62
- `cbegin`
 - `casc::SimplexSet< Complex >`, 70
- `cend`
 - `casc::SimplexSet< Complex >`, 70

check_orientation
 casc, 26
 clear_orientation
 casc, 27
 compute_orientation
 casc, 27
 cover
 casc::simplicial_complex< traits >::SimplexID< k
 >, 62
 cover_insert
 casc::simplicial_complex< traits >::SimplexID< k
 >, 63
 decimate
 casc, 27
 decimateBackHalf
 casc, 28
 decimateFirstHalf
 casc, 28
 down
 casc::simplicial_complex< traits >, 80, 81
 casc::simplicial_complex< traits >::EdgeID< k >,
 52
 edge_up
 casc, 29
 EdgeData
 casc::simplicial_complex< traits >, 78
 EdgeID
 casc::simplicial_complex< traits >, 98
 casc::simplicial_complex< traits >::EdgeID< k >,
 51, 52
 empty
 casc::SimplexSet< Complex >, 70
 end
 casc::SimplexSet< Complex >, 71
 util::range< T >, 58
 eq
 casc::simplicial_complex< traits >, 81
 erase
 casc::SimplexSet< Complex >, 71
 exists
 casc::simplicial_complex< traits >, 82
 find
 casc::SimplexSet< Complex >, 72
 get
 casc, 29, 30
 casc::SimplexMap< Complex >, 66, 67
 get_cover
 casc::simplicial_complex< traits >, 82, 83
 get_cover_insert
 casc::simplicial_complex< traits >, 83
 get_edge_down
 casc::simplicial_complex< traits >, 84
 get_edge_up
 casc::simplicial_complex< traits >, 85
 get_level
 casc::simplicial_complex< traits >, 86
 get_level_id
 casc::simplicial_complex< traits >, 86, 87
 get_name
 casc::simplicial_complex< traits >, 87, 88
 get_simplex_down
 casc::simplicial_complex< traits >, 88, 89
 get_simplex_up
 casc::simplicial_complex< traits >, 89–91
 casc::simplicial_complex< traits >::SimplexID< k
 >, 63, 64
 getClosure
 casc, 30, 31
 getLink
 casc, 31
 getStar
 casc, 32
 include/casc/CASCFunctions.h, 105, 106
 include/casc/CASCTraversals.h, 111, 113
 include/casc/decimate.h, 122, 123
 include/casc/index_tracker.h, 130, 132
 include/casc/Orientable.h, 143, 144
 include/casc/SimplexMap.h, 147, 148
 include/casc/SimplexSet.h, 150, 151
 include/casc/SimplicialComplex.h, 158, 160
 include/casc/stringutil.h, 192
 include/casc/typetraits.h, 193, 194
 include/casc/util.h, 195, 196
 index_tracker, 42
 index_tracker::index_tracker< _T, _d >, 54
 index_tracker::index_tracker< _T, _d >, 53
 index_tracker, 54
 index_tracker::index_tracker_detail, 43
 index_tracker::index_tracker_detail::BTreeNode< _T, _d
 >, 49
 index_tracker::index_tracker_detail::Interval< T >, 55
 operator=, 55
 indices
 casc::simplicial_complex< traits >::SimplexID< k
 >, 64
 init_orientation
 casc, 33
 insert
 casc::SimplexSet< Complex >, 73
 casc::simplicial_complex< traits >, 91, 92
 int_for_each
 util, 45
 neighbors
 casc, 33, 34
 neighbors_up
 casc, 34, 35
 leq
 casc::simplicial_complex< traits >, 93
 lt
 casc::simplicial_complex< traits >, 93

- make_range
 - util, [46](#)
- nearBoundary
 - casc::simplicial_complex< traits >, [94](#)
- neighbors
 - casc, [35](#), [36](#)
- neighbors_up
 - casc, [36](#), [37](#)
- NodeData
 - casc::simplicial_complex< traits >, [79](#)
- onBoundary
 - casc::simplicial_complex< traits >, [94](#)
- operator!=
 - casc, [37](#)
- operator<<
 - casc::SimplexMap< Complex >, [67](#)
 - casc::SimplexSet< Complex >, [74](#)
 - casc::simplicial_complex< traits >::SimplexID< k >, [65](#)
- operator=
 - index_tracker::index_tracker_detail::Interval< T >, [55](#)
- operator==
 - casc, [38](#)
- perform_insertion
 - casc, [38](#)
- perform_removal
 - casc, [38](#)
- range
 - util::range< T >, [57](#)
- remove
 - casc::simplicial_complex< traits >, [95](#)
- run_user_callback
 - casc, [39](#)
- set_difference
 - casc, [39](#)
- set_intersection
 - casc, [40](#)
- set_union
 - casc, [40](#)
- SimplexID
 - casc::simplicial_complex< traits >, [98](#)
 - casc::simplicial_complex< traits >::SimplexID< k >, [62](#)
- size
 - casc::SimplexSet< Complex >, [73](#)
 - casc::simplicial_complex< traits >, [96](#)
- to_string
 - casc, [41](#)
- type_name
 - typetraits.h, [194](#)
- typetraits.h
 - type_name, [194](#)
- up
 - casc::simplicial_complex< traits >, [96](#), [97](#)
 - casc::simplicial_complex< traits >::EdgeID< k >, [52](#)
- util, [44](#)
 - int_for_each, [45](#)
 - make_range, [46](#)
- util::int_type_map< IntegerType, OutHolder, IntegerSequence, F >, [54](#)
- util::range< T >, [56](#)
 - begin, [58](#)
 - end, [58](#)
 - range, [57](#)
- util::remove_first_val< Integer, InHolder< Integer, I, Is... > >, [59](#)
- util::remove_first_val< Integer, IntegerSequence >, [58](#)
- util::reverse_sequence< Integer, IntegerSequence >, [59](#)
- util::type_get< 0, type_holder< Ts... > >, [99](#)
- util::type_get< k, T >, [98](#)
- util::type_get< k, type_holder< Ts... > >, [99](#)
- util::type_holder< T, Ts... >, [100](#)
- util::type_holder< Ts >, [100](#)
- util::type_map< C, V >, [101](#)
- util::type_swap< TUPLE, HOLDER< Ts... > >, [102](#)
- util::type_swap< TUPLE, HOLDER_FULL >, [102](#)

- visit_BFS_down
 - casc, [41](#)
- visit_BFS_up
 - casc, [41](#)
- writeDOT
 - casc, [42](#)