sdsl Cheat Sheet

Data structures

The library code is in the sdsl namespace. Either import the namespace in your program (using namespace sdsl;) or qualify all identifieres by a sdsl::-prefix.
Each section corresponds to a header file. The file is hyperlinked as part of the section heading.
We have two types of data structures in **sdsl**. *Self-contained* and *support* structures. A support object s can extend a self-contained object o (e.g. add functionality), but requires access to o. Support structures contain the substring support in their class names.

Integer Vectors (IV)

The core of the library is the class int_vector<w>.
Parameter w corresponds to the fixed length of each element in bits. For $w = 8, 16, 32, 64, 1$ the length is fixed during compile time and the vectors correspond to std::vector<uint$w$_t> resp. std::vector<bool>. If $w = 0$ (default) the length can be set during runtime. *Constructor:* int_vector<>(n,x,ℓ), with n equals size, x default integer value, ℓ width of integer (has no effect for $w > 0$).
Public methods: operator[i], size(), width(), data().

Manipulating int_vector<w> v

Method	*Description*
v[i]=x	Set entry v[i] to x.
v.width(ℓ)	Set width to ℓ, if $w = 0$.
v.resize(n)	Resize v to n elements.

Useful methods in namespace sdsl::util:

set_to_value(v,k)	Set v[i]=k for each i.
set_to_id(v)	Set v[i]=i for each i.
set_random_bits(v)	Set elements to random bits.
mod(v,m)	Set v[i]=v[i] $\bmod m$ for each i.
bit_compress(v)	Gets $x = \max_i$ v[i] and $\ell = \lceil\log(x-1)\rceil+1$ and packs the entries in ℓ-bit integers.
expand_width(v,ℓ)	Expands the width of each integer to ℓ bits, if $\ell \geq$ v.width().

Compressed Integer Vectors (CIV)

For a vector v, enc_vector stores the self-delimiting coded deltas (v[i+1]−v[i]). Fast random access is achieved by sampling values of v at rate t_dens. Available coder are coder::elias_delta and coder::fibonacci.
Class vlc_vector stores each v[i] as self-delimiting codeword. Samples at rate t_dens are inserted for fast random access.

Bitvectors (BV)

Representations for a bitvector of length n with m set bits.

Class	*Description*	*Space*
bit_vector	plain bitvector	$64\lceil n/64{+}1\rceil$
bit_vector_il	interleaved bitvector	$\approx n(1 + K/64)$
rrr_vector	H_0-compressed bitvector	$\approx \lceil\log\binom{m}{n}\rceil$
sd_vector	sparse bitvector	$\approx 2m \cdot \log\frac{n}{m}$

bit_vector equals int_vector<1> and is therefore dynamic.
Public Methods: operator[i], size(), begin(), end()
Public Types: rank_1_type, select_1_type, select_0_type[1].
Each bitvector can be constructed out of a bit_vector object.

Rank Supports (RS)

RSs add rank functionality to BV. Methods rank(i) and operator(i) return the number of set bits[2] in the prefix $[0..i)$ of the supported BV for $i \in [0, n]$.

Class	*Compatible BV*	*+Bits*	*Time*
rank_support_v	bit_vector	$0.25n$	$\mathcal{O}(1)$
rank_support_v5	bit_vector	$0.0625n$	$\mathcal{O}(1)$
rank_support_scan	bit_vector	64	$\mathcal{O}(n)$
rank_support_il	bit_vector_il	128	$\mathcal{O}(1)$
rank_support_rrr	rrr_vector	80	$\mathcal{O}(k)$
rank_support_sd	sd_vector	64	$\mathcal{O}(1)$

Call util::init_support(rs,bv) to initialize rank structure rs to bitvector bv. Call rs(i) to get rank(i) $= \sum_{k=0}^{k<i}$ bv[k]

Select Supports (SLS)

SLSs add select functionality to BV. Let m be the number of set bits in BV. Methods select(i) and operator(i) return the position of the i-th set bit[3] in BV for $i \in [1..m]$.

Class	*Compatible BV*	*+Bits*	*Time*
select_support_mcl	bit_vector	$\leq 0.2n$	$\mathcal{O}(1)$
select_support_scan	bit_vector	64	$\mathcal{O}(n)$
select_support_il	bit_vector_il	64	$\mathcal{O}(\log n)$
select_support_rrr	rrr_vector	64	$\mathcal{O}(\log n)$
select_support_sd	sd_vector	64	$\mathcal{O}(1)$

Call util::init_support(sls,bv) to initialize sls to bitvector bv. Call sls(i) to get select(i) $= \min\{j \mid$ rank$(j{+}1) = i\}$.

Wavelet Trees (WT=BV+RS+SLS)

Wavelet trees represent sequences over byte or integer alphabets of size σ and consist of a tree of BVs. Rank and select on the sequences is reduced to rank and select on BVs, and the runtime is multiplied by a factor in $[H_0, \log\sigma]$.

Class	*Shape*	lex_ordered	*Default alphabet*
wt_blcd	Balanced	✓	byte
wt_huff	Huffman	×	byte
wt_hutu	Hu-Tucker	✓	integer
wt_int	Balanced	✓	byte
wt_rlmn	underlying WT dependent		

Public methods: operator[i], rank(i,c), select(i,c), inverse_select(i,c), size(), begin(), end()
Order preserving WTs (lex_ordered) provide more methods: lex_count and lex_smaller_count. In addition wt_int provides: range_search_2d, quantil_freq, topk_greedy, topk_qprobing, intersect.

Suffix Arrays (CSA=IV+WT)

Compressed suffix arrays use CIVs or WTs to represent the suffix arrays (SA), its inverse (ISA), BWT, Ψ, and LF. CSAs can be built over byte and integer alphabets.

Class	*Description*
csa_bitcompressed	Based on SA and ISA stored in a IV.
csa_sada	Based on Ψ stored in a CIV.
csa_wt	Based on the BWT stored in a WT.

Public methods: operator[i], size(), begin(), end().
Public members: isa, bwt, lf, psi, text, C, char2comp, comp2char, sigma.
Policy classes: alphabet strategy (e.g. byte_alphabet, succinct_byte_alphabet, int_alphabet) and SA sampling strategy (e.g. sa_order_sa_sampling, text_order_sa_sampling)

Longest Common Prefix (LCP) Arrays

Class	*Description*
lcp_bitcompressed	Values in a int_vector<>.
lcp_dac	Direct accessible codes used.
lcp_byte	Small values in a byte; 2 words per large.
lcp_wt	Small values in a WT; 1 word per large.
lcp_vlc	Values in a vlc_vector.
lcp_support_sada	Values stored permuted. CSA needed.
lcp_support_tree	Only depths of CST inner nodes stored.
lcp_support_tree2	+ large values are sampled using LF.

Public methods: operator[i], size(), begin(), end()

Balanced Parentheses Supports (BPS)

We represent a sequence of parentheses as a bit_vector. An opening/closing parenthesis corresponds to 1/0.

Class	*Description*
bp_support_g	Two-level pioneer structure.
bp_support_gg	Multi-level pioneer structure.
bp_support_sada	Min-max-tree over excess sequence.

Public methods: find_open(i), find_close(i), enclode(i), double_enclose(i,j), excess(i), rr_enclose(i,j), rank(i)[4], select(i).
Call util::init_support(bps,bv) to initialize a BPS bps to bit_vector bv.

Suffix Trees (CST=CSA+LCP+BPS)

A CST can be parametrized by any combination of CSA ,LCP, and BPS. The operation of each part can still be accessed through member varaibles. The additional operations are listed below. CSTs can be built for byte or integer alphabets.

Class	*Description*
cst_sada	Represents a node as position in BPS. Navigational operations are fast (they are directly translated in BPS operations on the DFS-BPS). Space: $4n{+}o(n){+}\lvert CSA\rvert{+}\lvert LCP\rvert$ bits.
cst_sct3	Represents nodes as intervals. Fast construction, but slower navigational operations. Space: $3n + o(n){+}\lvert CSA\rvert{+}\lvert LCP\rvert$

Public types: node_type. In the following let v and w be nodes and i, d, lb, rb integers.
Public methods: nodes(), root(), begin(), end(), begin_bottom_up(), end_bottom_up, size(v), is_leaf(v), degree(v), depth(v), node_depth(v), edge(v, d), lb(v), rb(v), id(v), inv_id(i), sn(v), select_leaf(i), node(lb, rb), parent(v), sibling(v), lca(v, w), select_child(v, i), child(v, c), sl(v), wl(v, c), leftmost_leaf(v), rightmost_leaf(v)
Public members: csa, lcp.
The traversal example shows how to use the DFS-iterator.

Range Min/Max Query (RMQ)

A RMQ `rmq` can be used to determine the position of the miniumum value[5] in an arbitrary subrange $[i, j]$ of an preprocessed vector `v`. Operator `operator(`i`,`j`)` returns $x = \min\{r | r \in [i,j] \wedge \texttt{v}[r] \leq \texttt{v}[k]\ \forall k \in [i,j]\}$

Class	*Space*	*Time*
`rmq_support_sparse_table`	$n \log^2 n$	$\mathcal{O}(1)$
`rmq_succint_sada`	$4n + o(n)$	$\mathcal{O}(1)$
`rmq_succint_sct`	$2n + o(n)$	$\mathcal{O}(1)$

Constructing data structures

Let `o` be a WT-, CSA-, or CST-object. Object `o` is built with `construct(o,file,num_bytes=0)` from a sequence stored in `file`. File is interpreted dependent on the value of `num_bytes`:

Value	*File interpreted as*
`num_bytes=0`	serialized `int_vector<>`.
`num_bytes=1`	byte sequence of length `util::file_size(file)`.
`num_bytes=2`	16-bit word sequence.
`num_bytes=4`	32-bit word sequence.
`num_bytes=8`	64-bit word sequence.
`num_bytes=d`	Parse decimal numbers.

Note: `construct` writes/reads data to/from disk during construction. Accessing disk for small instances is a considerable overhead. `construct_im(o,data,num_bytes=0)` will build `o` using only main memory. Have a look at this handy tool for an example.

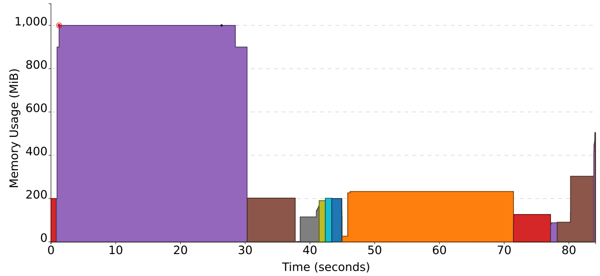
Configuring construction

The locations and names of the intermediate files can be configured by a `cache_config` object. It is constructed by `cache_config(del,tmp_dir,id, map)` where `del` is a boolean variable which specifies if the intermediate files should be deleted after construction, `tmp_dir` is a path to the directory where the intermediate files should be stored, `id` is used as part of the file names, and `map` contains a mapping of keys (e.g. `conf::KEY_BWT`, `conf::KEY_SA`,...) to file paths.
The `cache_config` parameter extends the construction method to: `construct(o,file,config,num_bytes)`.
The following methods (`key` is a key string, `config` represenet a `cache_config` object, and `o` a **sdsl** object) should be handy in customized construction processes:

```
cache_file_name(key,config)
cache_file_exists(key,config)
register_cache_file(key,config)
load_from_cache(o,key,config)
store_to_cache(o,key,config)
```

Resource requirements

Memory: The memory peak of CSA and CST construction occurs during the SA construction, which is 5 times the texts size for byte-alphabets and inputs < 2 GiB (see Phase #2 in the Figure below for a 200 MB text) and 9 times for larger inputs. For integer alphabets the construction takes about twice the space of the resulting output.
Time: A CST construction processes at about 2 MB/s. The Figure below shows the resource consumption during the construction of a `cst_sct3<>` CST for 200 MB English text.
Phases description: #1=copy TEXT, #2=SA, #3=BWT, #4=`wt_huff<>`, #7=LCP, #8=BP, #9=`bp_support_sada<>`, #10=`lcp_dac<>`.



This diagram was generated from the output of this example program, which print the memory log to `stdout`.

Reading and writing data

Importing data into sdsl structures

`load_vector_from_file(v, file, num_bytes)`
Load `file` into an `int_vector v`. Interpretation of `file` depends on `num_bytes`; see method `construct`.

Store sdsl structures

Use `store_to_file(o, file)` to store an **sdsl** object `o` to `file`. Object `o` can also be serialized into a `std::ostream`-object `out` by the call `o.serialize(out)`.

Load sdsl structures

Use `load_from_file(o, file)` to load an **sdsl** object `o`, which is stored in `file`. Call `o.load(in)` reads `o` from `std::istream`-object `in`.

Utility methods

More useful methods in the `sdsl::util` namespace:

Method	*Description*
`pid()`	Id of current process.
`id()`	Get unique id inside the process.
`basename(p)`	Get filename part of a path `p`.
`dirname(p)`	Get directory part of a path `p`.
`demangle(o)`	Demangles output of `typeid(o).name()`.
`demangle2(o)`	Simplifies output of `demangle`. E.g. removes `sdsl::`-prefixes, ...
`to_string(o)`	Transform object `o` to a string.
`assign(o1,o2)`	Assign `o1` to `o2`, or swap `o1` and `o2` if the objects are of the same type.
`clear(o)`	Set `o` to the empty object.

Measuring and Visualizing Space

`size_in_bytes(o)` returns the space used by an **sdsl** object `o`. Call `write_structure<JSON_FORMAT>(o,out)` to get a detailed space breakdown written in JSON format to stream `out`. `<HTML_FORMAT>` will write a html page (like this), which includes an interactive svg-figure.

Methods on words

Class `bits` contains various fast methods on a 64-bit word x. Here the most important ones.

Method	*Description*
`bits::cnt(`x`)`	Number of set bits in x.
`bits::sel(`x`,`i`)`	Position of i-th set bit, $i \in [0, \texttt{cnt}(x)-1)$.
`bits::lo(`x`)`	Position of least significant set bit.
`bits::hi(`x`)`	Position of most significant set bit.

Note: Positions in x start at 0. `lo` and `hi` return 0 for $x = 0$.

Tests

A `make test` call in the test directory, downloads test inputs, compiles tests, and executes them.

Benchmarks

Directory benchmark contains configurable benchmarks for various data structure, like CSAs/FM-indexes (measuring time and space for operations count, locate, and extract).

Debugging

You get the gdb command `pv <int_vector> <idx1> <idx2>`, which displays the elements of an `int_vector` in the range $[\texttt{idx1}, \texttt{idx2}]$ by appending the file sdsl.gdb to your `.gdbinit`.

Notes

1 `select_0_type` not defined for `sd_vector`.

2 It is also possible to rank `0` or the patterns `10` and `01`.

3 It is also possible to select `0` or the patterns `10` and `01`.

4 For PBS the bits are counted in the prefix $[0..i]$.

5 Or maximum value; can be set by a template parameter.