Report of experiments

O. Denas

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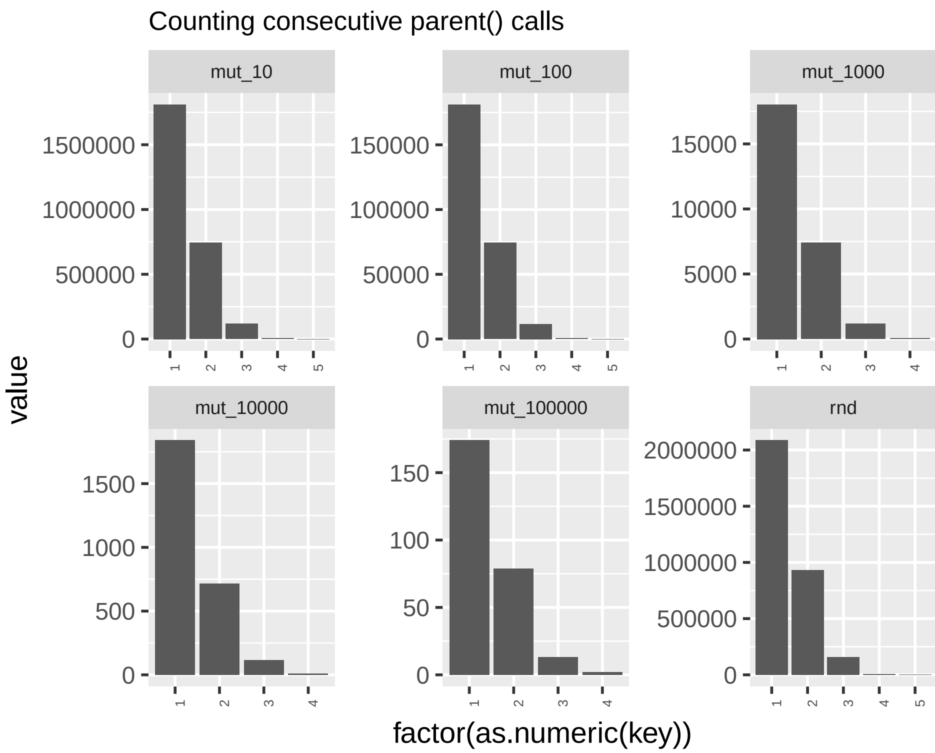
Contents

1 Input properties

For various types of inputs ("mut_XMs_YMt_Z" means `s` and `t` are random identical strings of length X, and Y million respectively with mutations inserted every Z characters. "rnd_XMs_YMt" means `s` and `t` are random strings of length X, and Y million respectively) run the MS algorithm and count the number of

- consecutive `parent()` calls during the `runs` construction.
- consecutive `wl()` calls during the `ms` construction.
- the number of 1s in the `runs` bit vector
- double rank calls that fail (i.e the search down the WT is interrupted prior to reaching a leaf)
- the number of maximal repeats



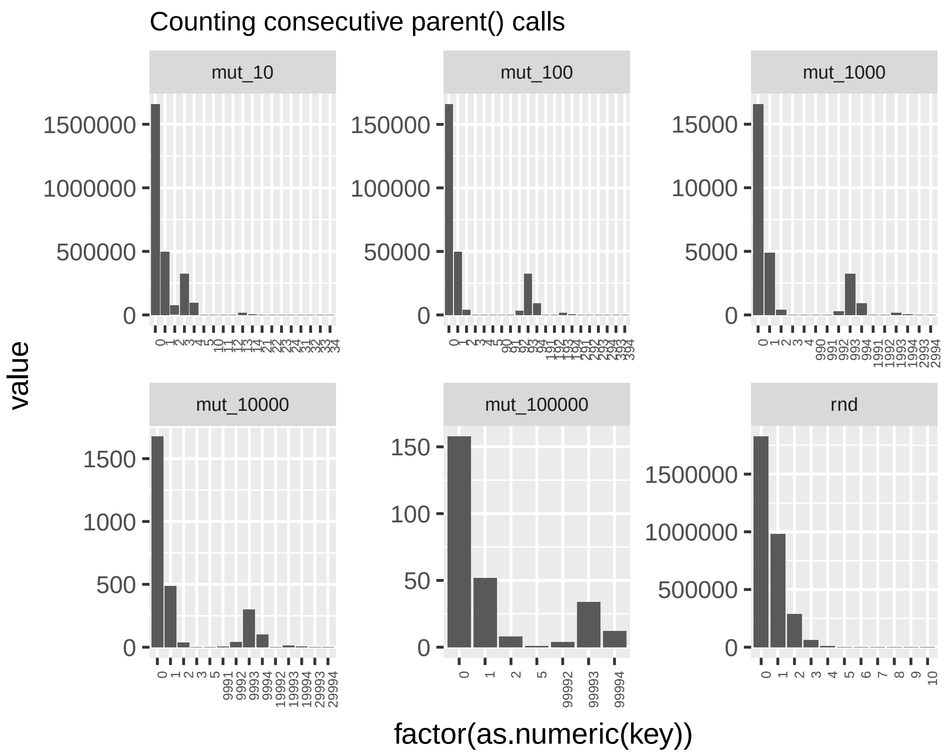


Table 1: Double rank iterations that fail for various input types.

b_path	fail	nofail	perc
rnd_100Ms_5Mt	690911	1818974	37.98
mut_100Ms_5Mt_10	1494544	2323907	64.31
mut_100Ms_5Mt_100	4649474	4732340	98.25
mut_100Ms_5Mt_1000	4965082	4973326	99.83
mut_100Ms_5Mt_10000	4996520	4997320	99.98
mut_100Ms_5Mt_100000	4999634	4999731	100.00

Table 2: Composition of the `runs` vector for various input types.

inp_type	one	zero	zero_perc
mut_10	2323907	2676093	115.15
mut_100	4732340	267660	5.66
mut_1000	4973326	26674	0.54
mut_10000	4997320	2680	0.05
mut_100000	4999731	269	0.01
rnd	1818974	3181026	174.88

Table 3: Composition of the `B` vector (containing ends of maximal repeats) for various input types.

inp_type	maximal	non_maximal	non_maximal_perc
mut_10	34894073	982212	2.81
mut_100	34893276	981720	2.81

inp_type	maximal	non_maximal	non_maximal_perc
mut_1000	34891214	980977	2.81
mut_10000	34894098	982309	2.82
mut_100000	34897894	980817	2.81
rnd	50053548	5525912	11.04

2 Current performance

Table 4: Run time in seconds, on random input with |s| = 1MB, |t| = 5MB

lazy	fail	maxrep	total_s	maxrep_s	tot_minus_maxrep_s
0	1	0	90.351	NA	90.351
1	1	0	90.817	NA	90.817
1	1	1	92.478	2.024	90.454
1	0	0	92.844	NA	92.844
0	0	0	92.850	NA	92.850
0	1	1	93.020	2.020	91.000
0	0	1	94.044	1.987	92.057
1	0	1	94.092	1.992	92.100

3 Double vs. single rank

3.1 Rank support optimization

The optimization occurs first at `rank_support_v.hpp` where we avoid recomputing a major block for intervals that are going to fall on the same major block anyways.

The condition that checks whether endpoints (i, j) of an interval end up in the same major block is

`bool((i>>8) == (j>>8))`

3.1.1 Code

The single rank and double rank implementations in sdsl: rank_support_v.hpp link

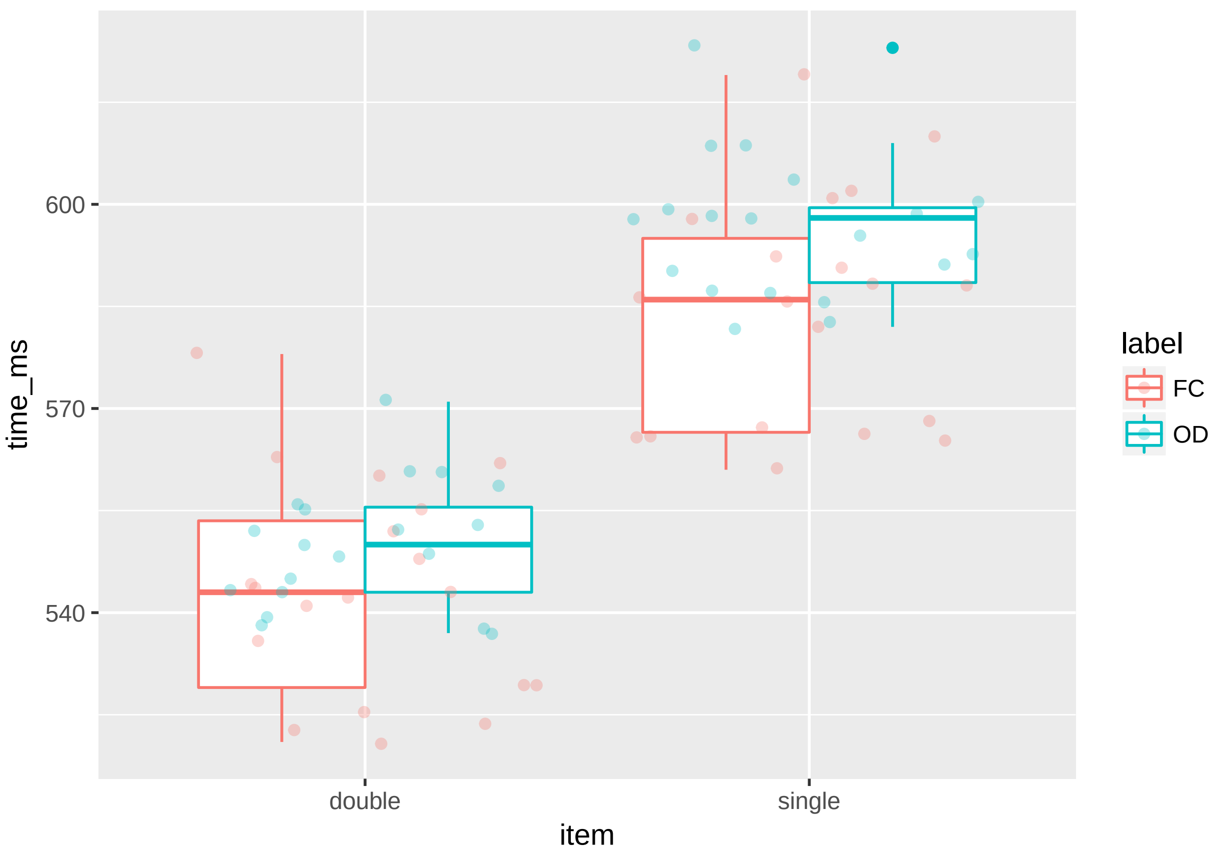
```
// RANK(idx)
const uint64_t* p = m_basic_block.data() + ((idx>>8)&0xFFFFFFFFFFFFFFFEULL);
return *p + ((*(p+1)>>(63 - 9*((idx&0x1FF)>>6)))&0x1FF) +
      (idx&0x3F ? trait_type::word_rank(m_v->data(), idx) : 0);

// DOUBLE RANK OD(i, j)
if((i>>8) == (j>>8)){
  const uint64_t* p = m_basic_block.data() + ((i>>8)&0xFFFFFFFFFFFFFFFEULL);
  res.first  = *p + ((*(p+1)>>(63 - 9*((i&0x1FF)>>6)))&0x1FF) +
            (i&0x3F ? trait_type::word_rank(m_v->data(), i) : 0);
  res.second = *p + ((*(p+1)>>(63 - 9*((j&0x1FF)>>6)))&0x1FF) +
            (j&0x3F ? trait_type::word_rank(m_v->data(), j) : 0);
} else {
  const uint64_t* p = m_basic_block.data() + ((i>>8)&0xFFFFFFFFFFFFFFFEULL);
  res.first  = *p + ((*(p+1)>>(63 - 9*((i&0x1FF)>>6)))&0x1FF) +
            (i&0x3F ? trait_type::word_rank(m_v->data(), i) : 0);
  p -= (((i>>8)&0xFFFFFFFFFFFFFFFEULL) - ((j>>8)&0xFFFFFFFFFFFFFFFEULL));
  res.second = *p + ((*(p+1)>>(63 - 9*((j&0x1FF)>>6)))&0x1FF) +
            (j&0x3F ? trait_type::word_rank(m_v->data(), j) : 0);
}
return res

// DOUBLE RANK FC(i, j)
const uint64_t* b = m_basic_block.data();
const uint64_t* pi = b + ((i>>8)&0xFFFFFFFFFFFFFFFEULL);
const uint64_t* pj = b + ((j>>8)&0xFFFFFFFFFFFFFFFEULL);

return (*pi + ((*(pi+1)>>(63 - 9*((i&0x1FF)>>6)))&0x1FF) +
              (i&0x3F ? trait_type::word_rank(m_v->data(), i) : 0),
      *pj + ((*(pj+1)>>(63 - 9*((j&0x1FF)>>6)))&0x1FF) +
              (j&0x3F ? trait_type::word_rank(m_v->data(), j) : 0));
```

3.1.2 Performance

The FC implementation seems to work better and will be adopted from now on.

Table 5: Time (in ms) of 500K calls to `wl()` based on `single_rank()` or `double_rank()` methods on 100MB random DNA input; Mean/sd over 20 repetitions.

item	label	avg_time	sd_time
double	FC	543.11	15.88
double	OD	550.00	9.27
single	FC	584.32	17.11
single	OD	596.37	10.20



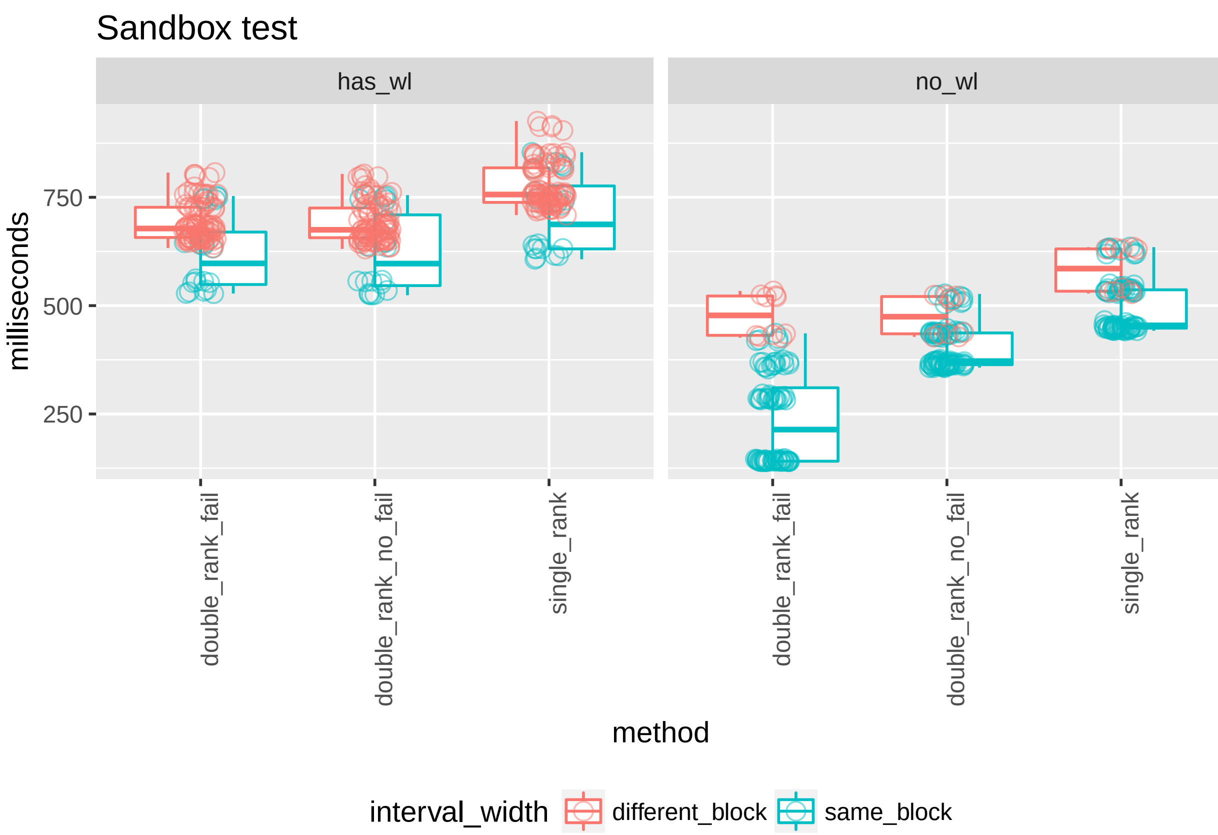
3.2 Weiner Link optimization

3.2.1 Sandbox performance

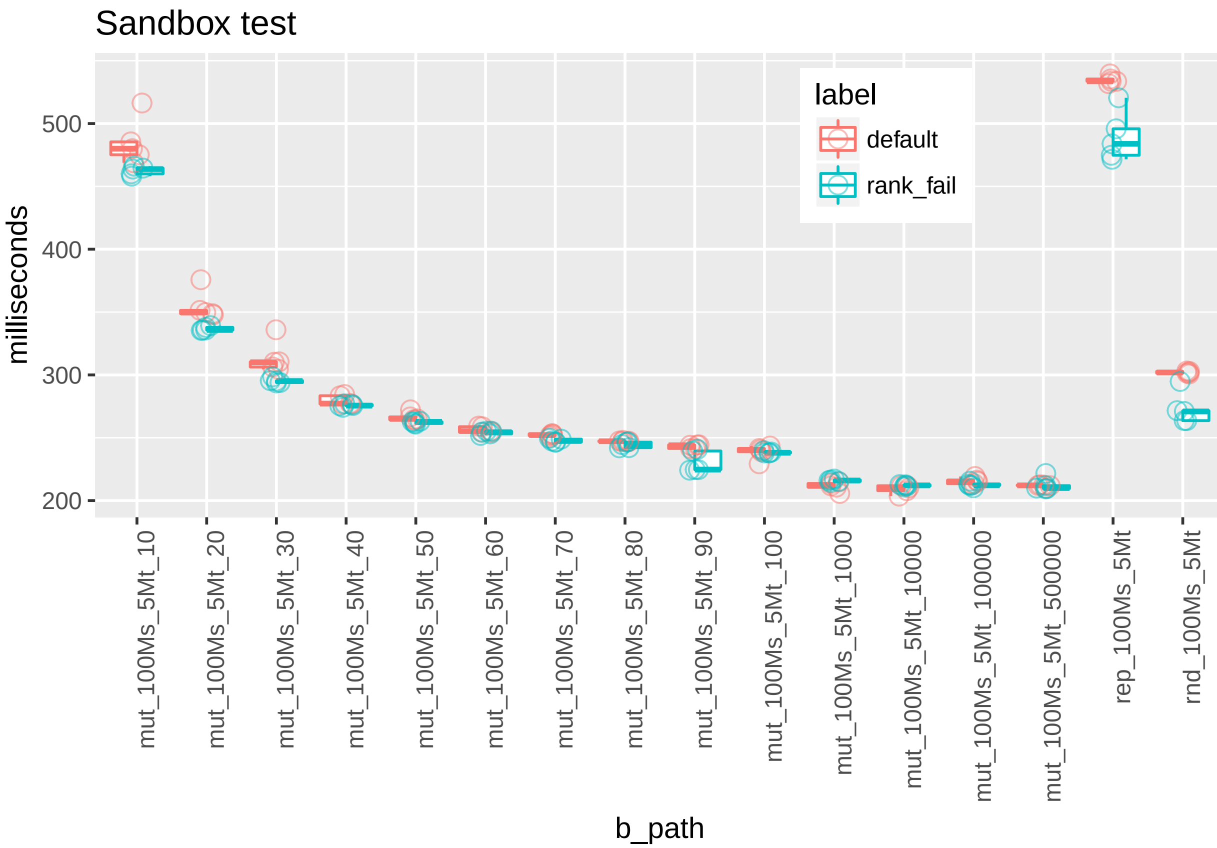
TODO: describe dataset and tests

Table 6: Sandbox performance of the two tricks

interval_width	wl_presence	double_rank_fail	double_rank_no_fail	single_rank
different_block	has_wl	694.03	692.11	777.76
different_block	no_wl	477.60	476.30	582.80
same_block	has_wl	618.90	621.30	706.35
same_block	no_wl	237.47	406.01	498.62



3.2.2 Full algorithm performance



b_path	default	rank_fail
mut_100Ms_5Mt_10	485.152	462.508
mut_100Ms_5Mt_20	354.672	336.752
mut_100Ms_5Mt_30	313.440	295.308
mut_100Ms_5Mt_40	279.716	275.728
mut_100Ms_5Mt_50	266.412	262.132
mut_100Ms_5Mt_60	256.404	253.964
mut_100Ms_5Mt_70	252.088	247.784
mut_100Ms_5Mt_80	247.248	244.396
mut_100Ms_5Mt_90	243.100	230.744
mut_100Ms_5Mt_100	238.664	238.448
mut_100Ms_5Mt_1000	211.312	215.856
mut_100Ms_5Mt_10000	209.040	211.968
mut_100Ms_5Mt_100000	215.316	212.564
mut_100Ms_5Mt_500000	211.780	212.464
rep_100Ms_5Mt	534.788	489.308
rnd_100Ms_5Mt	301.992	272.912

4 Maxrep

4.1 Maxrep construction

Applying the first optimization we get 8% improvement on a (ran of a 1MB input string).

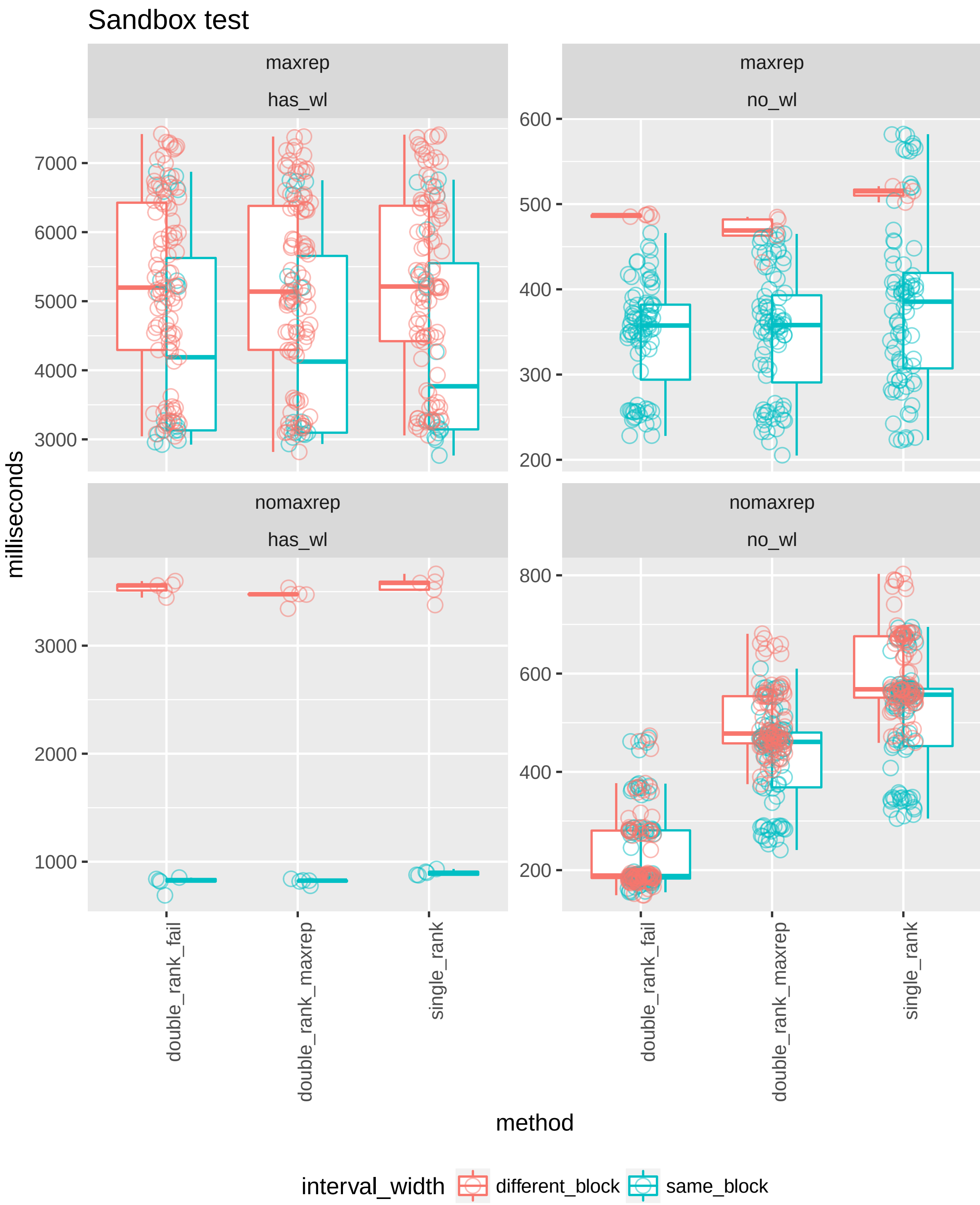
```
# EXISTING CODE
denas@denas-osx:$ for i in 1 2 3 4 5; \
do compute_maxrep -answer 0 -load_cst 0 -s_path datasets/synthetic/rnd_1Ms_5Mt.s; \
done  2>&1 | grep mill
 * computing MAXREP DONE ( 1098 milliseconds)
 * computing MAXREP DONE ( 1116 milliseconds)
 * computing MAXREP DONE ( 1120 milliseconds)
 * computing MAXREP DONE ( 1094 milliseconds)
 * computing MAXREP DONE ( 1100 milliseconds)
denas@denas-osx:$

# OPTIMIZED CODE
denas@denas-osx:$ for i in 1 2 3 4 5; \
do compute_maxrep -answer 0 -load_cst 0 -s_path datasets/synthetic/rnd_1Ms_5Mt.s; \
done  2>&1 | grep mill
 * computing MAXREP DONE ( 1020 milliseconds)
 * computing MAXREP DONE ( 1023 milliseconds)
 * computing MAXREP DONE ( 999 milliseconds)
 * computing MAXREP DONE ( 1020 milliseconds)
 * computing MAXREP DONE ( 1015 milliseconds)
```

4.2 Sandbox performance

TODO: describe dataset and tests

Table 8: Sandbox performance of the two tricks

interval_width	wl_presence	maximality	double_rank_fail	double_rank_maxrep	single_rank
different_block	has_wl	maxrep	5222.87	5206.71	5265.93
different_block	has_wl	nomaxrep	3535.20	3461.00	3546.40
different_block	no_wl	maxrep	486.60	466.20	513.00
different_block	no_wl	nomaxrep	233.53	502.60	604.16
same_block	has_wl	maxrep	4538.40	4530.50	4460.80
same_block	has_wl	nomaxrep	805.00	817.60	898.20
same_block	no_wl	maxrep	344.12	348.48	381.56
same_block	no_wl	nomaxrep	235.72	427.87	515.77


Sandbox test
maxrep
has_wl
maxrep
no_wl
nomaxrep
has_wl
nomaxrep
no_wl
7000
6000
5000
4000
3000
600
500
400
300
200
3000
2000
1000
800
600
400
200
milliseconds
double_rank_fail
double_rank_maxrep
single_rank
double_rank_fail
double_rank_maxrep
single_rank
method
interval_width
different_block
same_block

4.3 Full Algorithm Performance

The figure below shows 8 runs of the program with and without the use of the `maxrep` (or `B`) vector. The plot shows times (in seconds) for the construction of the `ms` bitvector. The table below that, shows the time (in seconds) to construct the `maxrep` vector. The input data is random and has |s|=100MB and |t|=5MB.

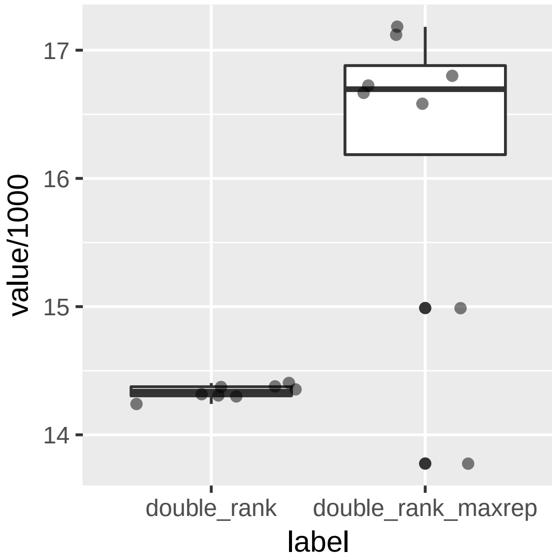


Table 9: Time to build the maxrep bit vector

label	avg_time_sec	se
double_rank_maxrep	131	71

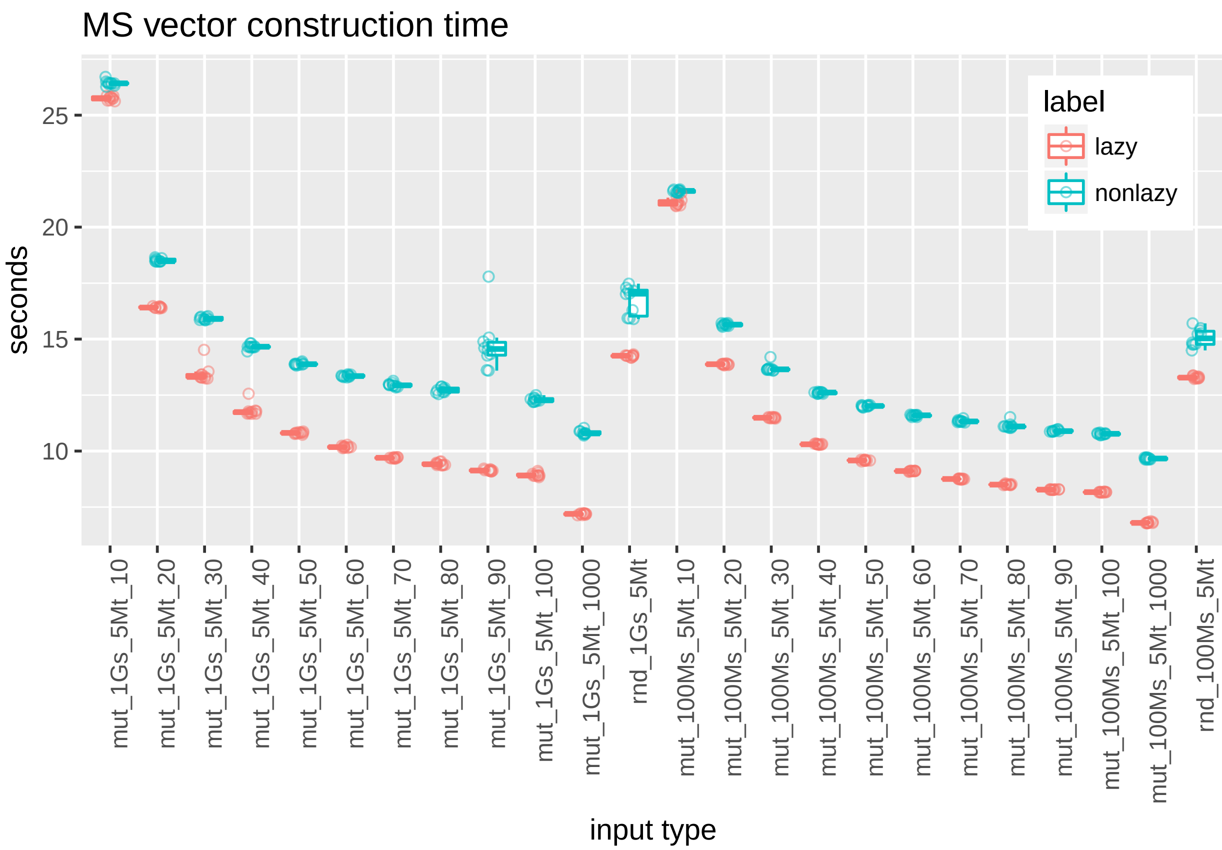
5 Lazy vs non-lazy

5.1 Code

The lazy and non-lazy versions differ in a couple of lines of code as follows

```
if(flags.lazy){
    for(; I.first <= I.second && h_star < ms_size; ){
        c = t[h_star];
        I = bstep_interval(st, I, c); //I.bstep(c);
        if(I.first <= I.second){
            v = st.lazy_wl(v, c);
            h_star++;
        }
    }
    if(h_star > h_star_prev) // // we must have called lazy_wl(). complete the node
        st.lazy_wl_followup(v);
} else { // non-lazy weiner links
    for(; I.first <= I.second && h_star < ms_size; ){
        c = t[h_star];
        I = bstep_interval(st, I, c); //I.bstep(c);
        if(I.first <= I.second){
            v = st.wl(v, c);
            h_star++;
        }
    }
}
```

5.2 Performance



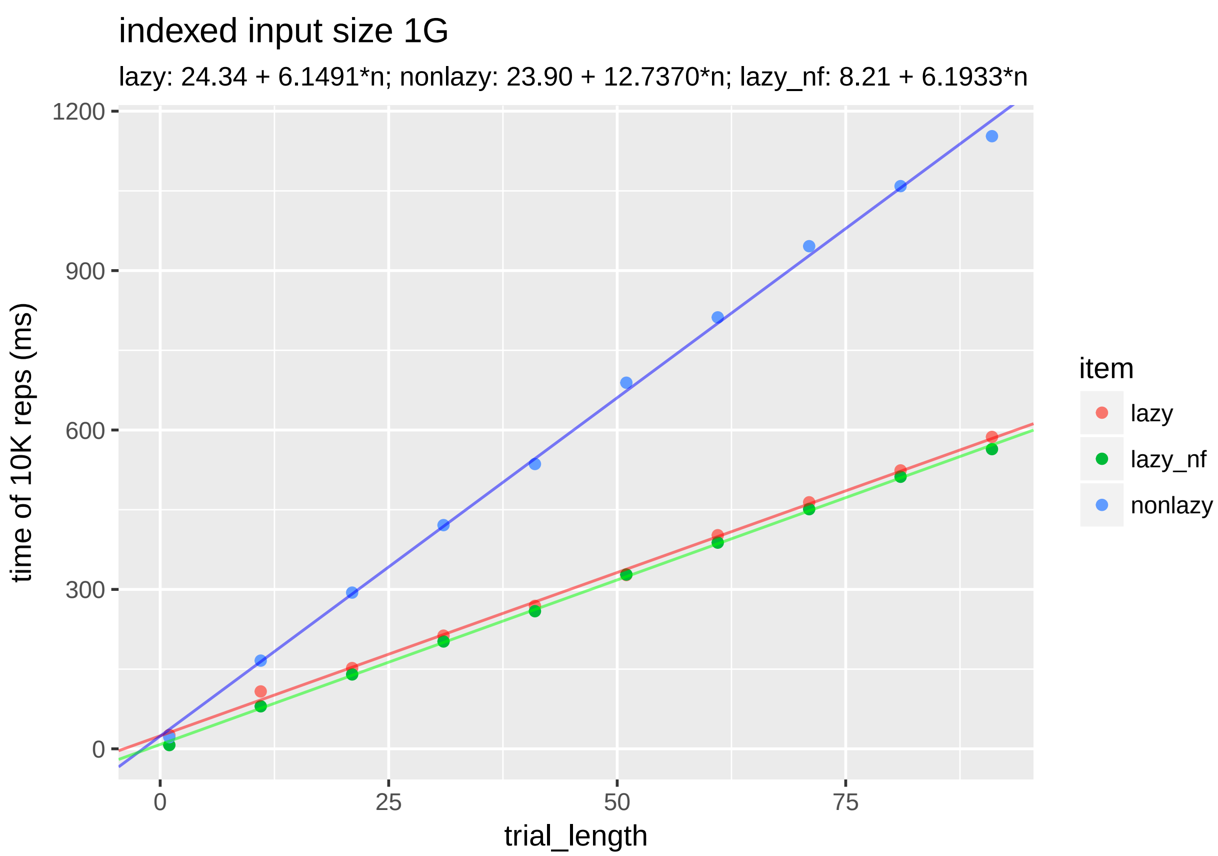
The right panel shows the time to construct the `runs` vector. This stage is the same for both versions and is shown as a control. On the left panel it can be seen that speedup correlates positively with both the size of the indexed string and the mutation period.

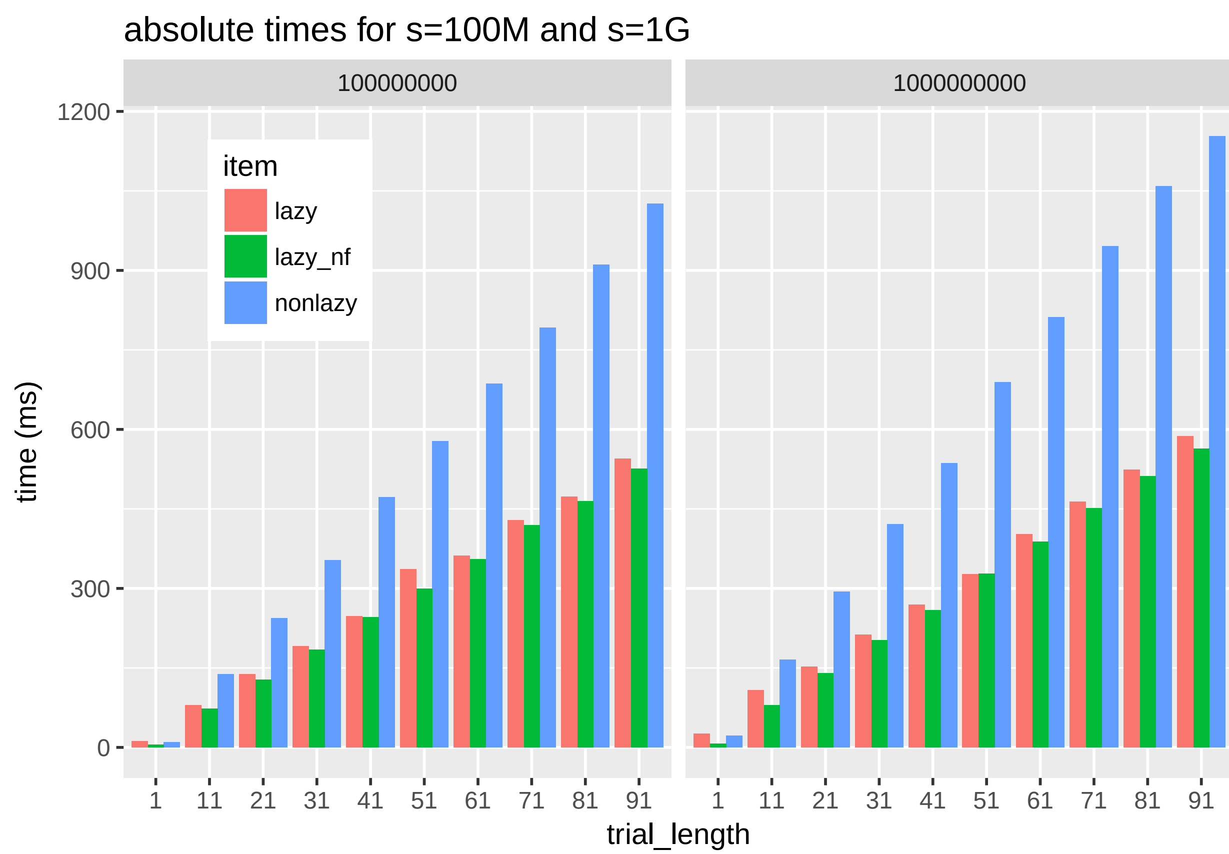
5.3 Sandbox timing

Measure the time of 10k repetitions of

- (lazy) n consecutive `lazy_wl()` calls followed by a `lazy_wl_followup()`
- (nonlazy) n consecutive `wl()` calls
- (lazy_nf) n consecutive `lazy_wl()` calls

```
// lazy
for(size_type i = 0; i < trial_length; i++)
    v = st.lazy_wl(v, s_rev[k--]);
if(h_star > h_star_prev) // // we must have called lazy_wl(). complete the node
    st.lazy_wl_followup(v);
...
// non-lazy
for(size_type i = 0; i < trial_length; i++)
    v = st.wl(v, s_rev[k--]);
...
// lazy_nf
for(size_type i = 0; i < trial_length; i++)
    v = st.lazy_wl(v, s_rev[k--]);
```





5.4 Check

In the experiments above we ran the program with the "lazy" or "non-lazy" flag and measured. The total time of each experiment can be written as $t_l = l_l + a$ and $t_n = l_n + a$ for the two versions respectively; only the ts being known. Furthermore, we have $\hat{l}_l$ and $\hat{l}_n$ estimations – computed by combining the time / wl call with the number of with the count of wl calls in each input (Section "Input Properties"). Hence we should expect

$$\delta t = t_l - t_n = l_l + a - l_n - a = l_l - l_n \approx \delta\hat{l} = \hat{l}_l - \hat{l}_n$$

b_path	t_l	t_n	l_l	l_n	delta_t	delta_l_hat
mut_100Ms_5Mt_10	21.12	21.61	8.56	6.16	-0.49	2.39
mut_100Ms_5Mt_100	8.16	10.77	3.36	4.33	-2.60	-0.97
mut_100Ms_5Mt_1000	6.80	9.67	2.84	4.15	-2.86	-1.31
mut_100Ms_5Mt_20	13.87	15.64	5.66	5.14	-1.77	0.52
mut_100Ms_5Mt_30	11.49	13.70	4.71	4.81	-2.21	-0.10
mut_100Ms_5Mt_40	10.31	12.60	4.22	4.64	-2.30	-0.41
mut_100Ms_5Mt_50	9.58	12.01	3.93	4.53	-2.43	-0.60
mut_100Ms_5Mt_60	9.11	11.58	3.74	4.47	-2.48	-0.72
mut_100Ms_5Mt_70	8.75	11.34	3.60	4.42	-2.59	-0.81
mut_100Ms_5Mt_80	8.51	11.13	3.50	4.38	-2.63	-0.88
mut_100Ms_5Mt_90	8.28	10.90	3.42	4.35	-2.62	-0.93
mut_1Gs_5Mt_10	25.75	26.43	7.57	6.65	-0.68	0.92
mut_1Gs_5Mt_100	8.94	12.29	3.49	4.90	-3.35	-1.41

b_path	t_l	t_n	l_l	l_n	delta_t	delta_l_hat
mut_1Gs_5Mt_1000	7.19	10.82	3.08	4.72	-3.63	-1.64
mut_1Gs_5Mt_20	16.42	18.52	5.30	5.68	-2.10	-0.37
mut_1Gs_5Mt_30	13.46	15.92	4.55	5.36	-2.46	-0.81
mut_1Gs_5Mt_40	11.81	14.66	4.17	5.20	-2.85	-1.02
mut_1Gs_5Mt_50	10.81	13.89	3.95	5.10	-3.08	-1.15
mut_1Gs_5Mt_60	10.19	13.36	3.80	5.03	-3.17	-1.24
mut_1Gs_5Mt_70	9.70	12.95	3.69	4.99	-3.26	-1.30
mut_1Gs_5Mt_80	9.43	12.72	3.61	4.95	-3.29	-1.35
mut_1Gs_5Mt_90	9.14	14.74	3.55	4.93	-5.60	-1.38
rnd_100Ms_5Mt	13.29	15.07	9.65	6.55	-1.78	3.10
rnd_1Gs_5Mt	14.25	16.72	8.20	6.92	-2.48	1.28

The numbers are not identical (process dependent factors might influence the running time of function calls), but they are correlated ($corr(\delta t, \delta \hat{l}) = 0.71$).

6 Double rank and fail

6.1 Code

```
// Given subtree_double_rank(v, i, j) -> (a.first, a.second) -- to simplify code

// DOUBLE RANK: int i, int j, char c
p = bit_path(c)
result_i, result_j = i, j;
node_type v = m_tree.root();
for (l = 0; l < path_len; ++l, p >>= 1) {
  a = subtree_double_rank(v, m_tree.bv_pos(v) + result_i, m_tree.bv_pos(v) + result_j);

  if(p&1){ // left child
      if(result_i > 0) result_i = a.first;
      if(result_j > 0) result_j = a.second;
  } else { // right child
      if(result_i > 0) result_i -= a.first;
      if(result_j > 0) result_j -= a.second;
  }
  v = m_tree.child(v, p&1); // goto child
}
return(result_i, result_j)

// DOUBLE RANK AND FAIL
p = bit_path(c)
result_i, result_j = i, j;
node_type v = m_tree.root();
for (l = 0; l < path_len; ++l, p >>= 1) {
  a = subtree_double_rank(v, m_tree.bv_pos(v) + result_i, m_tree.bv_pos(v) + result_j);

  if(p&1){ // left child
      if(result_i > 0) result_i = a.first;
      if(result_j > 0) result_j = a.second;
  } else { // right child
      if(result_i > 0) result_i -= a.first;
      if(result_j > 0) result_j -= a.second;
  }
  if(result_i == result_j) // Weiner Link call will fail
    return(0, 0)
  v = m_tree.child(v, p&1); // goto child
}
return(result_i, result_j)
```

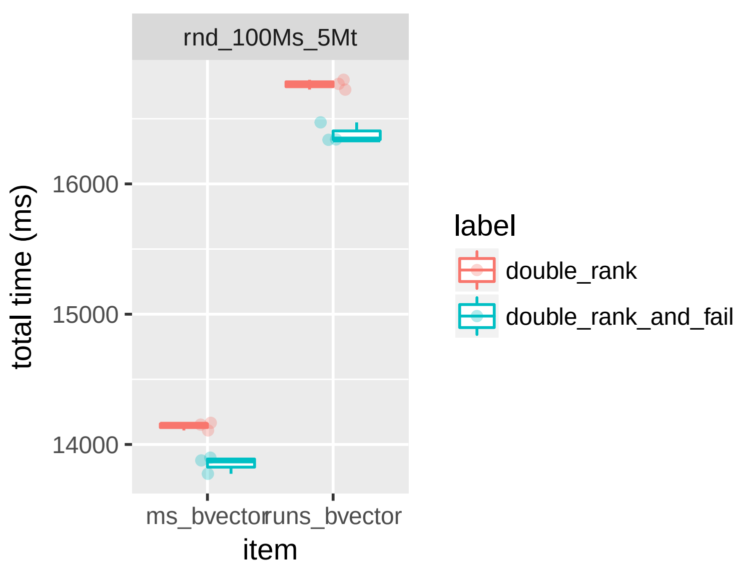
6.2 Performance

Table 11: Time (in ms) of 500K calls to `wl()` based on `single_rank()` or `double_rank()` methods on 100MB random DNA input; Mean/sd over 20 repetitions.

item	label	b_path	avg_time	sd_time
ms_bvector	double_rank	rnd_100Ms_5Mt	14142.00	30.27
ms_bvector	double_rank_and_fail	rnd_100Ms_5Mt	13850.33	66.16
runs_bvector	double_rank	rnd_100Ms_5Mt	16763.67	37.69
runs_bvector	double_rank_and_fail	rnd_100Ms_5Mt	16384.00	76.22

Table 12: Single vs. double rank. Absolute (double / single) and relative (100 * |double - single| / single) ratios of average times.

item	double_rank	double_rank_and_fail	abs_ratio	rel_ratio
ms_bvector	14142.00	13850.33	0.98	2.06
runs_bvector	16763.67	16384.00	0.98	2.26



7 Parallelization

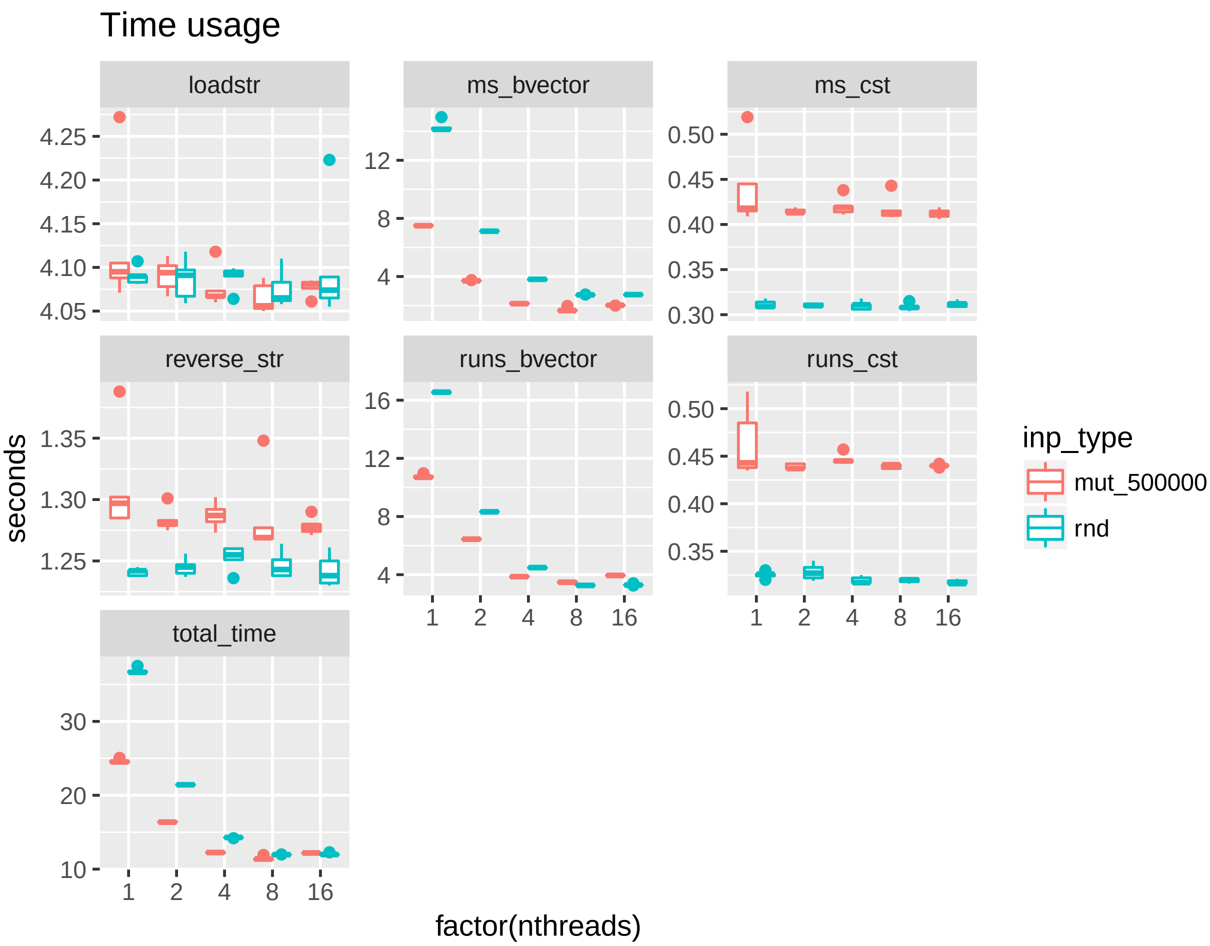
7.1 Code

See the pseudo-code in the repo (link)

7.2 Performance

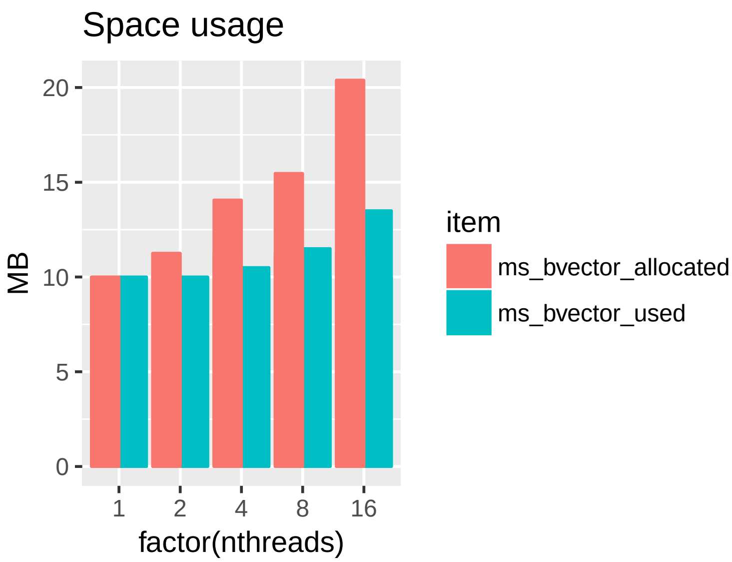
Run the MS construction program on the same input (random strings s of length 100M and t of length 5M) with varying parallelzation degree (nthreads = number of threads).

The time is reported over 5 runs for each fixed number of threads.



Space in MB for the same settings as above.

Each thread allocates its own ms vector with initial size $|t|/nthreads$ then it resizes by a factor of 1.5 each time it needs to. Resizing will always result in a vector smaller than $2|t|$ elements.


Space usage
20
15
10
5
0
MB
1
2
4
8
16
factor(nthreads)
item
ms_bvector_allocated
ms_bvector_used