cuckoohashing

Build and Run

Make sure that nvcc is avilable or set `nvcc` path in `Makefile`

```
make clean && make &&./bench
```

and the result will be saved as `task1_cuda.csv`,`task1_serial.csv` ...

cuckoohashing introduction

Cuckoo hashing is a simple hash table where

1. Lookups are worst-case $O(1)$.
2. Deletions are worst-case $O(1)$.
3. Insertions are amortized $O(1)$ with reasonably high probability.

This lab is a implication of CuckooHashing on `CUDA`. The parallelization processing will meet several challenges:

1. Seeing that hash look up or insert will access to uniformly distributed memory, this will introduce a large cache miss.
2. Cuckoo hashing is a variation of the open addressing hashing algorithm, in which the addressing iteration can cause a lot of divergence across threads in a warp.
3. The quality of the hash function have a large impact on the rehash times and hash function calculation efficiency.

cuckoohashing gpu imply

I follow the following pseudo code to deploy the cuckoohashing on CUDA.

```
procedure Cuckoo-Hashing-Insert(H, T, k)
    for i 0 to k-1 do
        T[i] = empty
    end for
    for all t in T do
        Push-Back(T[h(t)], t)
    end for
    parallel for i 0 to k-1 do
        parallel for j 1 to T[i] do
            call Insert(H[i], T[i][j]) on block i
        end for
    end for
end procedure

procedure Insert(H, t) // kernel funtion
    z = -1
    while true do
        for i 0 to d - 1 do
            if H[h_i(t)] is empty then
                H[h_i(t)] = t
                z = i
```

```
                break
            end if
        end for
        if z != -1 and H[h_z(t)] = t then
            return
        end if
        r = (z + 1) % d
        ATOMIC_SWAP(H[h_r(t)], t)
    end while
end procedure
```

Choice of Hash Function

So as to reduce the rehash times, we need a good hash function to decrease the probability of cillision.

I have tried some of the hash functions like `MUM`, or the original hash function mentioned in the paper: `[(c0 + c1 * k) mod 1900813]`. I choose `xxhash` at last, because an experiment has shown that `xxhash` is the fastest hash function with least collision, which result in nearly no rehash.

```
#define PRIME1 2654435761U
#define PRIME2 2246822519U
#define PRIME3 3266489917U
#define PRIME4 668265263U
#define PRIME5 374761393U

inline uint32_t rotate_left(uint32_t v, uint32_t n) {
  return (v << n) | (v >> (32 - n));
}

inline uint32_t xxhash(uint32_t seed, uint32_t v) {
  uint32_t acc = seed + PRIME5;

  acc = acc + v * PRIME3;
  acc = rotate_left(acc, 17) * PRIME4;

  uint8_t *byte = (uint8_t *)(&v);
  for (uint32_t i = 0; i < 4; i += 1) {
    acc = acc + byte[i] * PRIME5;
    acc = rotate_left(acc, 11) * PRIME1;
  }

  acc ^= acc >> 15;
  acc *= PRIME2;
  acc ^= acc >> 13;
  acc *= PRIME3;
  acc ^= acc >> 16;

  return acc;
}
```

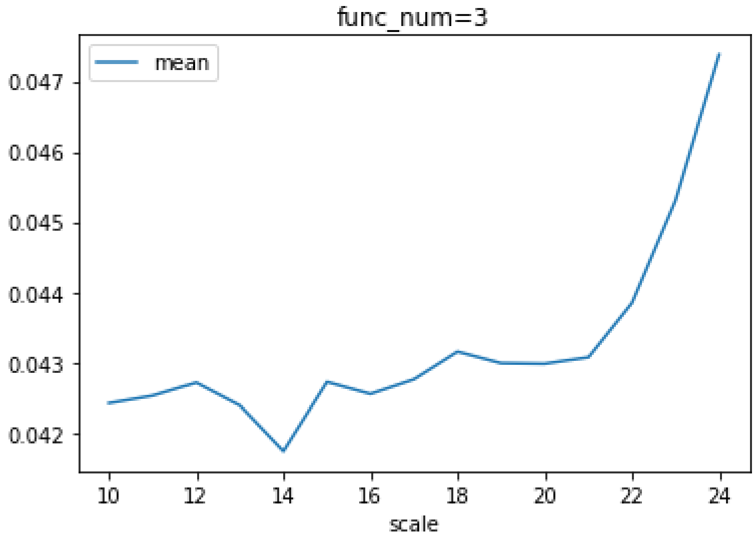
test env

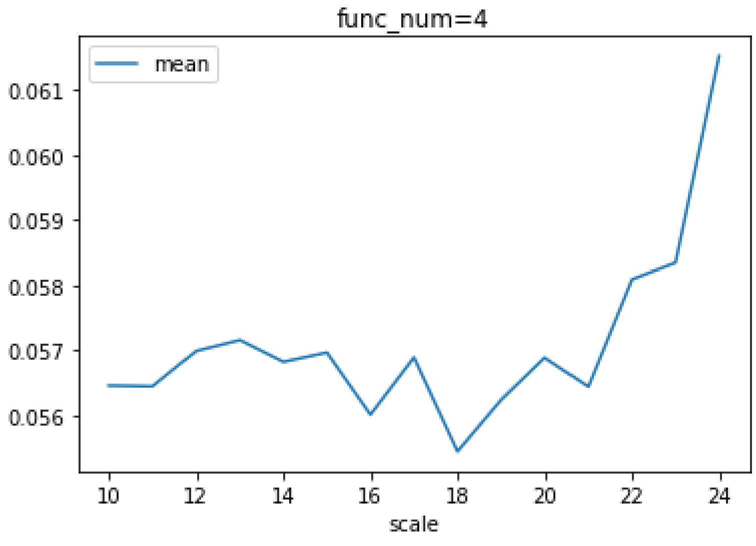
```
machine: Tesla V100-PCIE NVIDIA-SMI 470.42.01    Driver Version: 470.42.01
CUDA Version: 11.4

compiler:
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2019 NVIDIA Corporation
Built on Sun_Jul_28_19:07:16_PDT_2019
Cuda compilation tools, release 10.1, V10.1.243
```

result

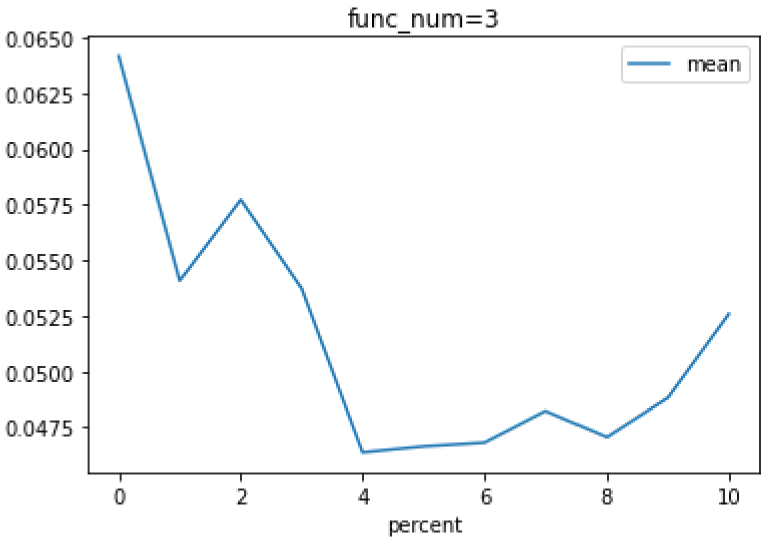
task 1

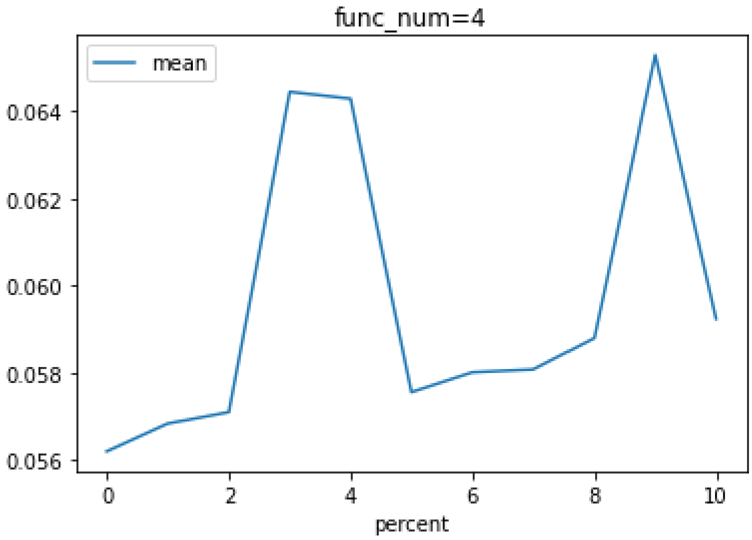




As expected, when the insert scale increase the insertion time is increasing because the collision times is increasing.

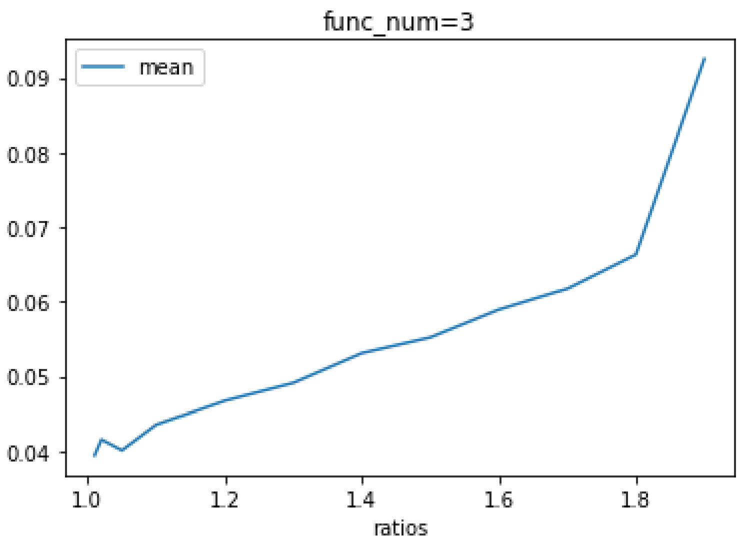
task 2

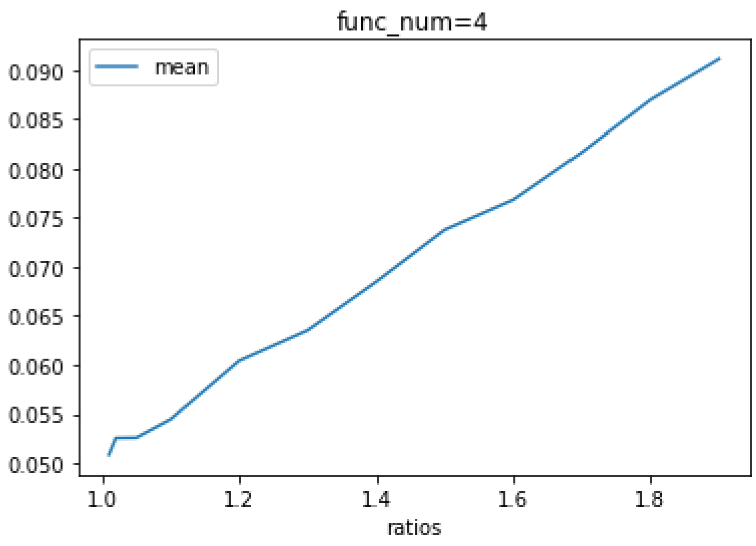




Seeing that the lookup procedure is nearly $O(1)$ and the CUDA version only affected by creating thread blocks, so the time is almost stable as long as the cuda device have enough threads.

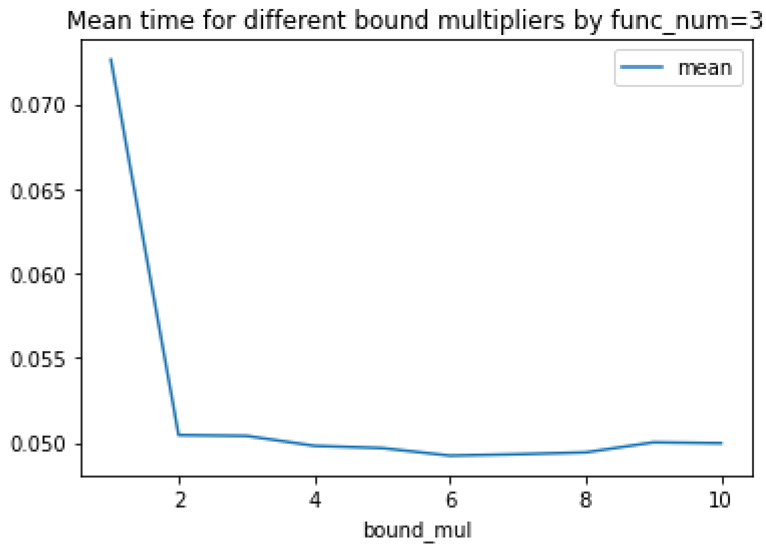
task 3

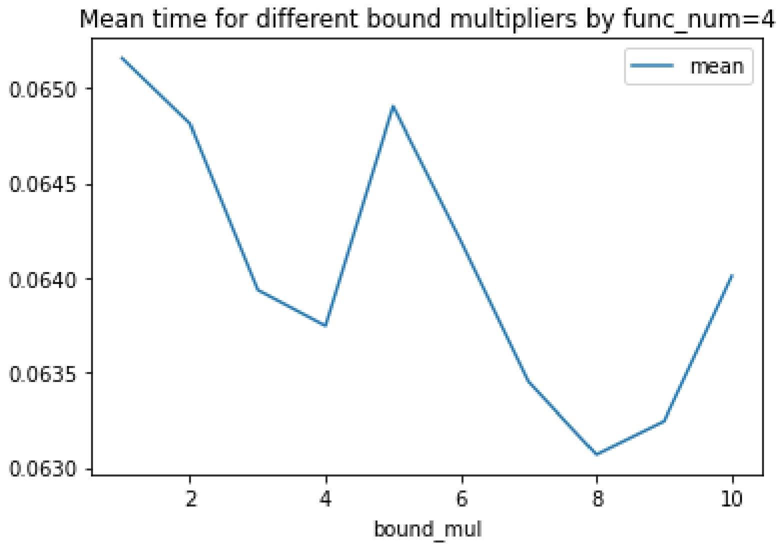




The results of the experiment indicate the hashing efficiency rules: a low load factor leads to greater performance.

task 4





the result shows that when the bound multiplier is around `4` we will get an efficient insertion. And this is relied on the `hash table size`, `insertion size` and the `hash funciton number` . A research from `cudpp` have discovered a special math function to calculate the evict bound

```
int cal_evict_bound(uint32_t n, uint32_t table_size)
{
    float lg_input_size = log2(n);
    float load_factor = float(n) / table_size;
    float ln_load_factor = (float)(log(load_factor) / log(2.71828183));

    unsigned max_iterations = (unsigned)(4 * ceil(-1.0 / (0.028255 +
1.1594772 * ln_load_factor) * lg_input_size));
    return max_iterations;
}
```

But it doesn't have a good result with my code, So we can study this in the future.

ref

https://github.com/cudpp/cudpp/blob/master/src/cudpp_hash/hash_table.cpp

https://github.com/cudpp/cudpp

https://arxiv.org/pdf/1712.09494.pdf

https://github.com/Cyan4973/xxHash

https://github.com/Cyan4973/xxHash/wiki/Collision-ratio-comparison#collision-study

https://hal.inria.fr/inria-00624777/document

https://mdsoar.org/bitstream/handle/11603/20126/paper.pdf?sequence=6&isAllowed=y

raw data

task 1

serial

t	scale	mean	stddev
2	10	0.00294358	0.00117434
2	11	0.00453888	2.50499e-05
2	12	0.00929965	0.000977017
2	13	0.0188897	0.00260624
2	14	0.0311063	0.00196453
2	15	0.048496	0.000189106
2	16	0.0691273	0.00129734
2	17	0.0836684	0.000473563
2	18	0.0991308	0.000285876
2	19	0.130948	0.0050953
2	20	0.193696	0.00665161
2	21	0.312579	0.00654705
2	22	0.579419	0.0129313
2	23	1.20794	0.00717695
2	24	6.31342	2.57052
3	10	0.00242764	4.84352e-05
3	11	0.00462542	4.73939e-05
3	12	0.00884682	7.31999e-05
3	13	0.0165434	5.152e-05
3	14	0.0294167	0.000107872
3	15	0.0476152	0.000395084
3	16	0.0667526	0.000277471
3	17	0.0820039	0.000516152
3	18	0.0982705	0.000424502
3	19	0.128771	0.00131435
3	20	0.185879	0.000716197
3	21	0.307996	0.00141848
3	22	0.575608	0.0106
3	23	1.17707	0.00836132
3	24	2.17964	0.0107465

t	scale	mean	stddev
4	10	0.00243318	2.03671e-05
4	11	0.00468536	8.1657e-05
4	12	0.0089843	8.31572e-05
4	13	0.0167891	8.05382e-05
4	14	0.0297521	0.000109064
4	15	0.0477755	0.000342193
4	16	0.0675574	0.000561497
4	17	0.0823062	0.000275971
4	18	0.0980929	0.00081326
4	19	0.12705	0.000958727
4	20	0.187746	0.00206568
4	21	0.307825	0.000470541
4	22	0.570981	0.00454909
4	23	1.16951	0.0114623
4	24	2.13056	0.00607601

cuda

t	scale	mean(s)	stddev
2	10	0.0439475	0.031358
2	11	0.028437	0.000538266
2	12	0.029533	0.00149321
2	13	0.029754	0.0014734
2	14	0.0304956	0.00255695
2	15	0.0287444	0.00074101
2	16	0.0288483	0.000477728
2	17	0.0288742	0.000659089
2	18	0.0287951	0.000542492
2	19	0.0297718	0.0010092
2	20	0.0294233	0.00063985
2	21	0.0292366	0.000466167
2	22	0.0298903	0.000506495
2	23	0.0308985	0.000410042
2	24	0.0339043	0.00127225
3	10	0.0424197	0.000729002
3	11	0.0425257	0.000471147
3	12	0.0427115	0.00092511
3	13	0.042387	0.00075543
3	14	0.041738	0.000511761
3	15	0.0427216	0.000867726
3	16	0.0425506	0.00127709
3	17	0.0427581	0.000675577
3	18	0.0431516	0.00134628
3	19	0.0429878	0.000797801
3	20	0.0429794	0.000995563
3	21	0.0430716	0.000920747
3	22	0.0438478	0.000834177
3	23	0.0453104	0.0011289
3	24	0.0473812	0.00133997

t	scale	mean(s)	stddev
4	10	0.0564562	0.000283378
4	11	0.0564457	6.24392e-05
4	12	0.0569901	0.00179263
4	13	0.0571567	0.00136263
4	14	0.0568225	0.00153941
4	15	0.0569652	0.0014114
4	16	0.0560084	0.00047187
4	17	0.0568908	0.00094533
4	18	0.0554421	0.000156175
4	19	0.0562346	0.000510276
4	20	0.0568849	0.00120743
4	21	0.0564395	0.000591619
4	22	0.0580903	0.00159833
4	23	0.0583454	0.00131948
4	24	0.0615281	0.00180113

task 2

serial

func_num	percent	mean	stddev
3	0	1.34678	0.0587823
3	1	1.41286	0.0877683
3	2	1.37728	0.00966961
3	3	1.40732	0.00638956
3	4	1.43947	0.00867214
3	5	1.456	0.0197337
3	6	1.49219	0.00751178
3	7	1.54796	0.0736653
3	8	1.53773	0.0125593
3	9	1.56582	0.00917863
3	10	1.60554	0.021908
4	0	1.43469	0.0177649
4	1	1.48251	0.0227062
4	2	1.52871	0.0226731
4	3	1.57684	0.0142959
4	4	1.63308	0.0164356
4	5	1.67967	0.0238586
4	6	1.70774	0.0231868
4	7	1.75888	0.0233812
4	8	1.81261	0.0148471
4	9	1.81874	0.00303701
4	10	1.88467	0.0165726

cuda

func_num	percent	mean	stddev
3	0	0.0641776	0.0154878
3	1	0.0540872	0.013985
3	2	0.057729	0.0148768
3	3	0.053734	0.0140887
3	4	0.0463816	8.02272e-05
3	5	0.0466504	0.000302077
3	6	0.0468175	0.000140561
3	7	0.0482275	0.00258002
3	8	0.0470635	3.9098e-05
3	9	0.0488269	0.00133298
3	10	0.0525858	0.00708853
4	0	0.056194	0.000200821
4	1	0.0568326	0.000866486
4	2	0.0570963	0.000747452
4	3	0.0644422	0.0135237
4	4	0.0642838	0.0132718
4	5	0.0575442	6.62837e-05
4	6	0.0580009	0.000212051
4	7	0.0580671	6.12257e-05
4	8	0.0587873	0.000668385
4	9	0.0652892	0.0133975
4	10	0.0592308	0.000674014

task 3

serial

func_num	ratios	mean	stddev
3	1.9	2.3893	0.249726
3	1.8	2.31445	0.0172794
3	1.7	2.40922	0.0549364
3	1.6	2.53768	0.036038
3	1.5	2.70946	0.0239621
3	1.4	2.8919	0.0256617
3	1.3	3.21708	0.0125243
3	1.2	6.33848	1.89421
3	1.1	12.0994	3.75464
3	1.05	8.24154	1.64733
3	1.02	10.2252	3.61084
3	1.01	9.26819	2.64024
4	1.9	2.20334	0.00657852
4	1.8	2.24865	0.00849129
4	1.7	2.32576	0.00664565
4	1.6	2.41653	0.012299
4	1.5	2.56341	0.0206585
4	1.4	2.67255	0.00898152
4	1.3	2.9339	0.0177339
4	1.2	3.39156	0.0188618
4	1.1	8.2102	3.26455
4	1.05	9.86271	1.67544
4	1.02	15.7333	2.37041
4	1.01	10.9119	2.16711

cuda

func_num	ratios	mean	stddev
3	1.9	0.0924973	0.0395274
3	1.8	0.0663222	0.00146865
3	1.7	0.0617394	0.000625437
3	1.6	0.0589297	0.00164882
3	1.5	0.055202	0.00120727
3	1.4	0.0530938	0.0010728
3	1.3	0.0491142	0.000880428
3	1.2	0.0467326	0.00058291
3	1.1	0.0435251	0.0015199
3	1.05	0.0400999	0.000109168
3	1.02	0.0415416	0.00143584
3	1.01	0.0394398	0.000970893
4	1.9	0.0911189	0.00193572
4	1.8	0.0869779	0.00164433
4	1.7	0.0816485	0.00193868
4	1.6	0.0768154	0.00127531
4	1.5	0.0737705	0.00305763
4	1.4	0.0684717	0.00120234
4	1.3	0.0635253	0.00137649
4	1.2	0.0604276	0.00139355
4	1.1	0.0544544	0.000986151
4	1.05	0.052581	0.00138648
4	1.02	0.0525545	0.000971579
4	1.01	0.0508431	0.000653479

task 4

serial

func_num	bound_mul	mean	stddev
3	1	6.67216	1.8861
3	2	2.9423	0.0529595
3	3	2.89136	0.00846956
3	4	2.89256	0.00984937
3	5	2.90935	0.035254
3	6	2.86938	0.0100022
3	7	2.878	0.019243
3	8	2.88295	0.0103433
3	9	2.88911	0.0175928
3	10	2.87754	0.00822457
4	1	2.68566	0.0162709
4	2	2.68867	0.0135275
4	3	2.67755	0.00633684
4	4	2.67851	0.00671768
4	5	2.67755	0.00890246
4	6	2.6794	0.00797972
4	7	2.68103	0.0145091
4	8	2.67792	0.00583736
4	9	2.6827	0.00952223
4	10	2.69846	0.0346252

cuda

func_num	bound_mul	mean	stddev
3	1	0.0726327	0.0402696
3	2	0.050474	0.00153943
3	3	0.0504257	0.0018765
3	4	0.0498386	0.00025331
3	5	0.0497058	0.000148922
3	6	0.0492598	0.00140374
3	7	0.0493404	0.00112154
3	8	0.0494495	0.000546652
3	9	0.0500446	0.00111553
3	10	0.0499941	0.00189854
4	1	0.0651577	0.000844501
4	2	0.0648131	0.000587351
4	3	0.0639362	0.00140711
4	4	0.0637468	0.00120811
4	5	0.0649046	0.0013293
4	6	0.0641954	0.00133467
4	7	0.0634533	0.00158846
4	8	0.0630698	0.00117277
4	9	0.0632451	0.00168766
4	10	0.06401	0.000882801