环境配置

1. 在windows下，即使用mingw32-make编译项目，wordvec2.c中的关键字CLOCKS_PER_SEC等关键字也没有定义；

- 把source.archive.zip放到Linux远程服务器，unzip

2. cd trunk; make; 完成项目编译

训练vector

1. CBOW+negative sample(=25)

参数设置

```
time ./word2vec -train text8 -output vectors.bin -cbow 1 -size 200 -window 8 -negative 25 -hs 0 -sample 1e-4 -threads 20 -binary 1 -iter 15
```

例子

```
Enter word or sentence (EXIT to break): cat

Word: cat  Position in vocabulary: 2601

                                               Word       Cosine distance
------------------------------------------------------------------------
                                               meow              0.591654
                                               cats              0.583658
                                             feline              0.558486
                                                dog              0.525981
                                             bobcat              0.506454
                                           purebred              0.503816
                                              felis              0.501500
                                            caracal              0.497818
                                             kitten              0.492816
                                           leopardus              0.490604
                                            rabbits              0.485997
                                              tabby              0.470818
                                              tapir              0.466516
                                                paw              0.463601
                                           squirrel              0.457647
                                                 ox              0.456307
                                           oncifelis              0.456119
                                             lynxes              0.455391
                                          proboscis              0.454971
                                             marten              0.452994
                                                pet              0.451990
                                            leopard              0.451740
                                                kat              0.447755
                                             nermal              0.447228
                                              eared              0.445608
                                               dogs              0.444447
                                            bobtail              0.442211
                                             possum              0.440880
                                             lemurs              0.436056
                                              hyena              0.435941
                                             bitten              0.434021
                                             albino              0.432281
                                               paws              0.431515
                                          silvestris              0.431369
                                             poodle              0.430292
                                          retriever              0.428684
                                            beagles              0.428403
                                          shorthair              0.425302
                                             catnip              0.424763
                                               cute              0.423778
```

单词准确率

- ./demo-word.sh

```
[root@hcss-ecs-4b66 trunk]# ./demo-word-accuracy.sh
make: Nothing to be done for 'all'.
Starting training using file text8
Vocab size: 71291
Words in train file: 16718843
Alpha: 0.000005  Progress: 100.10%  Words/thread/sec: 61.90k
real    34m32.214s
user    67m35.743s
sys     0m3.512s
capital-common-countries:
ACCURACY TOP1: 83.00 %  (420 / 506)
Total accuracy: 83.00 %   Semantic accuracy: 83.00 %   Syntactic accuracy: -nan %
capital-world:
ACCURACY TOP1: 63.57 %  (923 / 1452)
Total accuracy: 68.59 %   Semantic accuracy: 68.59 %   Syntactic accuracy: -nan %
currency:
ACCURACY TOP1: 25.37 %  (68 / 268)
Total accuracy: 63.39 %   Semantic accuracy: 63.39 %   Syntactic accuracy: -nan %
city-in-state:
ACCURACY TOP1: 47.61 %  (748 / 1571)
Total accuracy: 56.86 %   Semantic accuracy: 56.86 %   Syntactic accuracy: -nan %
family:
ACCURACY TOP1: 79.41 %  (243 / 306)
Total accuracy: 58.54 %   Semantic accuracy: 58.54 %   Syntactic accuracy: -nan %
gram1-adjective-to-adverb:
ACCURACY TOP1: 16.67 %  (126 / 756)
Total accuracy: 52.03 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 16.67 %
gram2-opposite:
ACCURACY TOP1: 19.93 %  (61 / 306)
Total accuracy: 50.13 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 17.61 %
gram3-comparative:
ACCURACY TOP1: 62.30 %  (785 / 1260)
Total accuracy: 52.51 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 41.86 %
gram4-superlative:
ACCURACY TOP1: 39.92 %  (202 / 506)
Total accuracy: 51.59 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 41.51 %
gram5-present-participle:
ACCURACY TOP1: 39.21 %  (389 / 992)
Total accuracy: 50.04 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 40.92 %
gram6-nationality-adjective:
ACCURACY TOP1: 86.43 %  (1185 / 1371)
Total accuracy: 55.41 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 52.94 %
gram7-past-tense:
ACCURACY TOP1: 38.51 %  (513 / 1332)
Total accuracy: 53.29 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 49.99 %
gram8-plural:
ACCURACY TOP1: 68.04 %  (675 / 992)
Total accuracy: 54.55 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 52.38 %
gram9-plural-verbs:
ACCURACY TOP1: 34.62 %  (225 / 650)
Total accuracy: 53.50 %   Semantic accuracy: 58.54 %   Syntactic accuracy: 50.96 %
Questions seen / total: 12268 19544   62.77 %
```

2. CBOW+hs

参数设置

```
time ./word2vec -train text8 -output vectors.bin -cbow 1 -size 200 -window 8 -negative 0 -hs 1 -sample 1e-4 -threads 20 -binary 1 -iter 15
```

例子

```
Enter word or sentence (EXIT to break): mouse

Word: mouse  Position in vocabulary: 2800

                                      Word       Cosine distance
------------------------------------------------------------------
                                 incentive              1.000000
                                      trim              1.000000
                             unsatisfactory              1.000000
                                 dancehall              1.000000
                                  entropic              1.000000
                                       gdf              1.000000
                                      casc              1.000000
                                   baddeley              1.000000
                                    yankees              0.282316
                                   memetics              0.282316
                                      posse              0.282316
                                    bateson              0.282316
                                    vitally              0.282316
                                    managua              0.282316
                                   pakenham              0.282316
                                   disbands              0.282316
                                 morphogens              0.282316
                                 commentary              0.270460
                                     napier              0.270460
                                    spouses              0.270460
                                    leaping              0.270460
                                  livermore              0.270460
                                hypergeometric              0.270460
                                    railcar              0.270460
                                   aquarist              0.270460
                                maimonidean              0.270460
                                       silk              0.264187
                                   cherokee              0.264187
                                   polybius              0.264187
                                      jonny              0.264187
                                    scarred              0.264187
                                        neu              0.264187
                                   pervaded              0.264187
                                     ducats              0.264187
                                  developing              0.249379
                                      hydro              0.249379
                                        mai              0.249379
                                    tiffany              0.249379
                                     jervis              0.249379
                                        alc              0.249379
```

- 将老鼠与刺激性、苗条的相关联

单词准确率

```
[root@hcss-ecs-4b66 trunk]# ./demo-word-accuracy.sh
gcc word2vec.c -o word2vec -lm -pthread -O3 -march=native -Wall -funroll-loops -Wno-unused-result
Starting training using file text8
Vocab size: 71291
Words in train file: 16718843
Alpha: 0.000005  Progress: 100.10%  Words/thread/sec: 134.62k
real    16m1.981s
user    31m4.835s
sys     0m3.005s
capital-common-countries:
ACCURACY TOP1: 63.24 %  (320 / 506)
Total accuracy: 63.24 %   Semantic accuracy: 63.24 %   Syntactic accuracy: -nan %
capital-world:
ACCURACY TOP1: 36.85 %  (535 / 1452)
Total accuracy: 43.67 %   Semantic accuracy: 43.67 %   Syntactic accuracy: -nan %
currency:
ACCURACY TOP1: 7.46 %  (20 / 268)
Total accuracy: 39.31 %   Semantic accuracy: 39.31 %   Syntactic accuracy: -nan %
city-in-state:
ACCURACY TOP1: 29.73 %  (467 / 1571)
Total accuracy: 35.34 %   Semantic accuracy: 35.34 %   Syntactic accuracy: -nan %
family:
ACCURACY TOP1: 51.63 %  (158 / 306)
Total accuracy: 36.56 %   Semantic accuracy: 36.56 %   Syntactic accuracy: -nan %
gram1-adjective-to-adverb:
ACCURACY TOP1: 5.03 %  (38 / 756)
Total accuracy: 31.65 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 5.03 %
gram2-opposite:
ACCURACY TOP1: 16.34 %  (50 / 306)
Total accuracy: 30.75 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 8.29 %
gram3-comparative:
ACCURACY TOP1: 36.75 %  (463 / 1260)
Total accuracy: 31.92 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 23.73 %
gram4-superlative:
ACCURACY TOP1: 14.03 %  (71 / 506)
Total accuracy: 30.62 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 21.99 %
gram5-present-participle:
ACCURACY TOP1: 20.67 %  (205 / 992)
Total accuracy: 29.37 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 21.65 %
gram6-nationality-adjective:
ACCURACY TOP1: 67.25 %  (922 / 1371)
Total accuracy: 34.96 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 33.69 %
gram7-past-tense:
ACCURACY TOP1: 31.16 %  (415 / 1332)
Total accuracy: 34.48 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 33.17 %
gram8-plural:
ACCURACY TOP1: 54.33 %  (539 / 992)
Total accuracy: 36.18 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 35.97 %
gram9-plural-verbs:
ACCURACY TOP1: 19.38 %  (126 / 650)
Total accuracy: 35.29 %   Semantic accuracy: 36.56 %   Syntactic accuracy: 34.65 %
Questions seen / total: 12268 19544   62.77 %
[root@hcss-ecs-4b66 trunk]# un
```

3. SG+negetive sample(=25)

- 用时：2024年4月23日19:03:56——2024年4月23日21:30:06
- 参数设置：

```
time ./word2vec -train text8 -output vectors.bin -cbow 0 -size 200 -window 8 -negative 25 -hs 0 -sample 1e-4 -threads 20 -binary 1 -iter 15
```

例子

```
Enter word or sentence (EXIT to break): huge

Word: huge  Position in vocabulary: 2119

                                              Word       Cosine distance
------------------------------------------------------------------------
                                             large              0.726111
                                           enormous             0.670705
                                           massive              0.653836
                                              vast              0.611748
                                             small              0.562903
                                       considerable             0.530114
                                       substantial              0.522347
                                           biggest              0.519985
                                         tremendous             0.519068
                                        frequenting             0.516090
                                             great              0.512095
                                          dizzying              0.503829
                                           immense              0.503750
                                            larger              0.502757
                                        staggering              0.500402
                                       unrivalled               0.497331
                                          hundreds              0.493835
                                          millions              0.489075
                                          bragging              0.488197
                                         stateside              0.485257
                                            around              0.479409
                                              well              0.477978
                                       significant              0.477726
                                     invincibility              0.476544
                                         spiraling              0.471656
                                                up              0.469751
                                          churning              0.469282
                                           quickly              0.468757
                                        largescale              0.465958
                                           largest              0.465698
                                       underfunded              0.465094
                                         expanses               0.464807
                                        impressive              0.464257
                                       blackening               0.461805
                                              rims              0.461214
                                       batholiths               0.460515
                                          meteora               0.460240
                                             wide               0.459095
                                             very               0.457122
                                         gigantic               0.456762
Enter word or sentence (EXIT to break):
```

```
                                        windows              0.548528
Enter word or sentence (EXIT to break): beef

Word: beef  Position in vocabulary: 7400

                                           Word       Cosine distance
------------------------------------------------------------------------
                                           pork              0.713921
                                           meat              0.707025
                                      sauerkraut             0.667158
                                      vegetables             0.658155
                                           veal              0.652703
                                       sausages              0.646866
                                        corned               0.643433
                                       potatoes              0.642969
                                        mutton               0.632715
                                      marinated              0.632120
                                         manioc              0.625835
                                          dairy              0.625682
                                          meats              0.621858
                                         salami              0.619041
                                          broth              0.617450
                                      plantains              0.612799
                                        bulgogi              0.610778
                                      arrowroot              0.605774
                                          beets              0.605187
                                        poultry              0.600733
                                          offal              0.599281
                                         mashed              0.598347
                                          steak              0.595782
                                       cabbages              0.593867
                                       soybeans              0.592297
                                       beancurd              0.591437
                                        chicken              0.589604
                                           tzle              0.588646
                                        walnuts              0.585221
                                      sweetcorn              0.584532
                                       dumpling              0.582411
                                         cattle              0.579450
                                      gochujang              0.578734
                                       apricots              0.577773
                                           okra              0.577109
                                        stewed               0.576042
                                        raisins              0.575148
                                          pecans             0.574777
                                         mangoes             0.574112
                                        zucchini             0.573858
Enter word or sentence (EXIT to break):
```

准确率

```
[root@hcss-ecs-4b66 trunk]# ./demo-word-accuracy.sh
gcc word2vec.c -o word2vec -lm -pthread -O3 -march=native -Wall -funroll-loops -Wno-unused-result
capital-common-countries:
ACCURACY TOP1: 89.33 %  (452 / 506)
Total accuracy: 89.33 %   Semantic accuracy: 89.33 %   Syntactic accuracy: -nan %
capital-world:
ACCURACY TOP1: 74.17 %  (1077 / 1452)
Total accuracy: 78.09 %   Semantic accuracy: 78.09 %   Syntactic accuracy: -nan %
currency:
ACCURACY TOP1: 15.30 %  (41 / 268)
Total accuracy: 70.53 %   Semantic accuracy: 70.53 %   Syntactic accuracy: -nan %
city-in-state:
ACCURACY TOP1: 58.18 %  (914 / 1571)
Total accuracy: 65.42 %   Semantic accuracy: 65.42 %   Syntactic accuracy: -nan %
family:
ACCURACY TOP1: 68.63 %  (210 / 306)
Total accuracy: 65.66 %   Semantic accuracy: 65.66 %   Syntactic accuracy: -nan %
gram1-adjective-to-adverb:
ACCURACY TOP1: 16.14 %  (122 / 756)
Total accuracy: 57.95 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 16.14 %
gram2-opposite:
ACCURACY TOP1: 17.32 %  (53 / 306)
Total accuracy: 55.55 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 16.48 %
gram3-comparative:
ACCURACY TOP1: 48.65 %  (613 / 1260)
Total accuracy: 54.19 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 33.94 %
gram4-superlative:
ACCURACY TOP1: 26.88 %  (136 / 506)
Total accuracy: 52.20 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 32.67 %
gram5-present-participle:
ACCURACY TOP1: 21.47 %  (213 / 992)
Total accuracy: 48.35 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 29.76 %
gram6-nationality-adjective:
ACCURACY TOP1: 91.10 %  (1249 / 1371)
Total accuracy: 54.66 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 45.96 %
gram7-past-tense:
ACCURACY TOP1: 32.66 %  (435 / 1332)
Total accuracy: 51.90 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 43.25 %
gram8-plural:
ACCURACY TOP1: 66.43 %  (659 / 992)
Total accuracy: 53.14 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 46.31 %
gram9-plural-verbs:
ACCURACY TOP1: 28.31 %  (184 / 650)
Total accuracy: 51.83 %   Semantic accuracy: 65.66 %   Syntactic accuracy: 44.87 %
Questions seen / total: 12268 19544   62.77 %
[root@hcss-ecs-4b66 trunk]#
```

4. SG+hs

用时：1h

参数设置

```
time ./word2vec -train text8 -output vectors.bin -cbow 0 -size 200 -window 8 -negative 0 -hs 1 -sample 1e-4 -threads 20 -binary 1 -iter 15
```

例子

- cat

```
[root@hcss-ecs-4b66 trunk]# ./demo-word.sh
make: Nothing to be done for 'all'.
Starting training using file text8
Vocab size: 71291
Words in train file: 16718843
Alpha: 0.000002  Progress: 100.11%  Words/thread/sec: 42.91k
real    49m38.492s
user    97m30.121s
sys     0m3.491s
Enter word or sentence (EXIT to break): cat

Word: cat  Position in vocabulary: 2601

                                              Word       Cosine distance
------------------------------------------------------------------------
                                              cats              0.746241
                                        prionailurus            0.621905
                                            kitten              0.616952
                                              dogs              0.605825
                                               dog              0.604699
                                             felis              0.592556
                                          leopardus             0.564313
                                            feline              0.556172
                                           felines              0.554351
                                          purebred              0.548890
                                              meow              0.538865
                                         silvestris             0.537084
                                            bobcat              0.536469
                                            lynxes              0.530785
                                           rabbits              0.519341
                                         sighthound             0.518568
                                             feral              0.514675
                                             tapir              0.513849
                                            coyote              0.505888
                                          hedgehogs             0.505031
                                            canine              0.501296
                                          hairless              0.498968
                                           leopard              0.497164
                                         oncifelis              0.497153
                                           marbled              0.496125
                                             breed              0.494114
                                            skunks              0.492557
                                          foxhound              0.491812
                                            mammal              0.491592
                                              bird              0.491533
                                           felidae              0.491337
                                           caracal              0.491154
                                             hares              0.490531
                                           weasels              0.490414
                                              purr              0.489356
                                             skink              0.488084
                                           purring              0.485832
                                             foxes              0.485814
                                              pets              0.485402
                                          squirrels             0.484346
Enter word or sentence (EXIT to break):
```

```
Enter word or sentence (EXIT to break):
```

- beef

```
Enter word or sentence (EXIT to break): beef

Word: beef  Position in vocabulary: 7400

                                      Word       Cosine distance
------------------------------------------------------------------
                                      pork              0.837427
                                    potatoes            0.822953
                                  vegetables            0.820009
                                      meat              0.805175
                                     dairy              0.788018
                                  sauerkraut            0.775371
                                     corned             0.759614
                                   poultry              0.756916
                                   lentils              0.742032
                                      stew              0.740848
                                       soy              0.737750
                                    mutton              0.736008
                                  marinated             0.734211
                                 cauliflower            0.731798
                                    onions              0.730454
                                    mashed              0.728839
                                   seafood              0.725203
                                     meats              0.719754
                                     offal              0.716346
                                     fried              0.715697
                                     beets              0.714562
                                   sausages             0.713819
                                    grilled             0.709343
                                    oilseed             0.708957
                                      rice              0.708570
                                    diced               0.707306
                                  vegetable             0.706809
                                   soybeans             0.700331
                                    sliced              0.699291
                                    shrimp              0.697173
                                    cheese              0.695822
                                    cooked              0.693799
                                  tomatoes              0.693536
                                     sauce              0.688957
                                     beans              0.684833
                                  zucchini              0.683065
                                    stewed              0.681175
                                    salami              0.679339
                                    manioc              0.678979
                                      tofu              0.678386
Enter word or sentence (EXIT to break):
```

准确率

```
[root@hcss-ecs-4b66 trunk]# ./demo-word-accuracy.sh
make: Nothing to be done for 'all'.
capital-common-countries:
ACCURACY TOP1: 85.18 %  (431 / 506)
Total accuracy: 85.18 %   Semantic accuracy: 85.18 %   Syntactic accuracy: -nan %
capital-world:
ACCURACY TOP1: 74.10 %  (1076 / 1452)
Total accuracy: 76.97 %   Semantic accuracy: 76.97 %   Syntactic accuracy: -nan %
currency:
ACCURACY TOP1: 16.42 %  (44 / 268)
Total accuracy: 69.68 %   Semantic accuracy: 69.68 %   Syntactic accuracy: -nan %
city-in-state:
ACCURACY TOP1: 47.04 %  (739 / 1571)
Total accuracy: 60.31 %   Semantic accuracy: 60.31 %   Syntactic accuracy: -nan %
family:
ACCURACY TOP1: 57.52 %  (176 / 306)
Total accuracy: 60.10 %   Semantic accuracy: 60.10 %   Syntactic accuracy: -nan %
gram1-adjective-to-adverb:
ACCURACY TOP1: 15.21 %  (115 / 756)
Total accuracy: 53.12 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 15.21 %
gram2-opposite:
ACCURACY TOP1: 18.95 %  (58 / 306)
Total accuracy: 51.09 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 16.29 %
gram3-comparative:
ACCURACY TOP1: 35.32 %  (445 / 1260)
Total accuracy: 48.00 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 26.61 %
gram4-superlative:
ACCURACY TOP1: 18.18 %  (92 / 506)
Total accuracy: 45.82 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 25.11 %
gram5-present-participle:
ACCURACY TOP1: 27.22 %  (270 / 992)
Total accuracy: 43.49 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 25.65 %
gram6-nationality-adjective:
ACCURACY TOP1: 81.18 %  (1113 / 1371)
Total accuracy: 49.05 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 40.32 %
gram7-past-tense:
ACCURACY TOP1: 31.38 %  (418 / 1332)
Total accuracy: 46.84 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 38.49 %
gram8-plural:
ACCURACY TOP1: 64.72 %  (642 / 992)
Total accuracy: 48.36 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 41.96 %
gram9-plural-verbs:
ACCURACY TOP1: 25.08 %  (163 / 650)
Total accuracy: 47.13 %   Semantic accuracy: 60.10 %   Syntactic accuracy: 40.61 %
Questions seen / total: 12268 19544   62.77 %
[root@hcss-ecs-4b66 trunk]#
```

比较与总结

配置	用时	TOTAL(ACCU)	SEMATIC(语义)	SYNTATIC(句法)
CBOW+negative	45min	53.50	58.54	50.96
CBOW+hs	15min	35.29	36.56	34.65
SG+negative	2h	51.83	65.66	44.87
SG+hs	1h	47.13	60.10	40.61

1. 负采样的准确率明显比继承Softmax要高，可能是因为采用了更多的训练样本
2. 在负采样下，CBOW的句法准确率比SG高，但语义准确率比SG低；
3. 在hs下，SG的语义与句法准确率均较高；
   这可能因为SG比CBOW有更多的输出，更多的反向传播过程。
4. 实验中，SG的用时明显CBOW要长，因为训练样本更多；
5. negative sampled的单个训练用时理应比hs要短，因为只要做一次内积，

   但实验中负采样规模较大(negative=25)，使得用时要长于 hs(假设训练时远程服务器主机的工作效率一致，因为只开了这一个进程和一个tomcat网站)

代码阅读

- demo-word.sh

全局变量

1. MAX_STRING: 单词的最大长度。
2. vocab_size: 词汇表的大小。
3. code: 二进制编码数组，用于存储词汇表中每个单词的哈夫曼编码。
4. point: 哈夫曼树中每个单词的路径，用于快速查询。
5. b_max_size: 未提供足够信息，无法确定其功能。
6. layer1_size: 神经网络隐藏层的大小。
7. train_words: 训练文本中的单词总数。
8. word_count_actual: 实际处理的单词数量。
9. iter: 迭代次数。
10. file_size: 文件大小。
11. classes: 未提供足够信息，无法确定其功能。

12. alpha、starting_alpha为学习率，sample为采样
13. syn0和neu1e为隐藏层，syn1=输出层，syn1neg为负采样的输出层，expTable为softmax函数表。

函数功能

1. InitUnigramTable()：构建一个根据词频分布进行负采样的表，以便在训练过程中高效地选择负样本。
2. ReadWord()：从文件中读取一个单词，放在word中国，如果a超过了最大字符数限制MAX_STRING-1，就将a减1，以截断过长的单词。
3. GetWordHash()：返回单词的Hash值
4. SearchVocab()：返回一个单词在词汇表中的作用
5. ReadWordIndex()：读一个单词，并返回在词汇表中的索引
6. AddWordToVocab()：往词汇表数组添加一个单词，内存越界重新分配内存；计算单词的hash值，线性探测法存储在vocab_hash中
7. VocabCompare()：比较a和b的频度
8. SortVocab()：按词频排序词汇表
9. ReduceVocab()：移除不常见的编码来降低词汇
10. CreateBinaryTree()：通过词频来构建二叉Huffman树
11. LearnVocabFromTrainFile()：从训练文件来学习词汇表
12. SaveVocab()：保存词汇表到save_vocab_file文件
13. ReadVocab()：阅读词汇表
14. InitNet()：初始化网络
15. *TrainModelThread()：

    读取当前单词序号，分别在CBOW框架中或Skip-gram框架中，使用

    hs或negative sample来更新网络
16. TrainModel()：多线程训练网络
17. main()：设置参数、训练

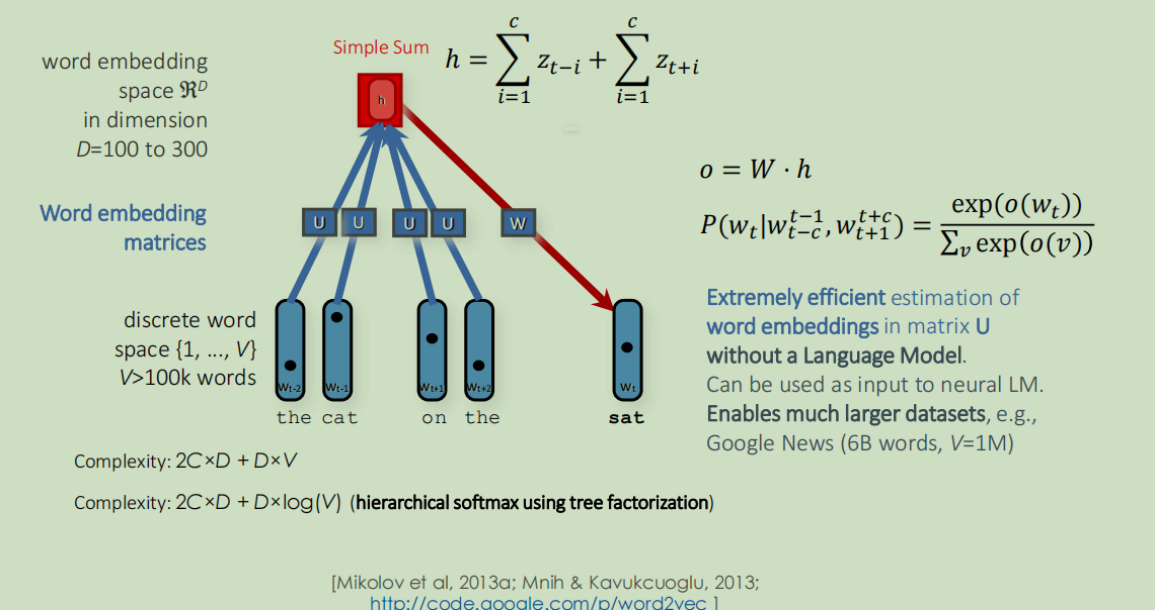
*TrainModelThread()阅读

CBOW

- 获取单词的嵌入式表示，并加入到neu1中，

```
    if (cbow) {  //train the cbow architecture
      // in -> hidden
      cw = 0;
      for (a = b; a < window * 2 + 1 - b; a++) if (a != window)
{
        c = sentence_position - window + a;
        if (c < 0) continue;
        if (c >= sentence_length) continue;
        last_word = sen[c];
        if (last_word == -1) continue;
        for (c = 0; c < layer1_size; c++) neu1[c] += syn0[c +
last_word * layer1_size];
        cw++;
      }
```

- 正向传播，反向更新，按如下公式：




```
      if (cw) {
        for (c = 0; c < layer1_size; c++) neu1[c] /= cw;
        if (hs) for (d = 0; d < vocab[word].codelen; d++) {
          f = 0;
          l2 = vocab[word].point[d] * layer1_size;
```

```
          // Propagate hidden -> output
          for (c = 0; c < layer1_size; c++) f += neu1[c] *
syn1[c + l2];
          if (f <= -MAX_EXP) continue;
          else if (f >= MAX_EXP) continue;
          else f = expTable[(int)((f + MAX_EXP) *
(EXP_TABLE_SIZE / MAX_EXP / 2))];
          // 'g' is the gradient multiplied by the learning rate
          g = (1 - vocab[word].code[d] - f) * alpha;
          // Propagate errors output -> hidden
          for (c = 0; c < layer1_size; c++) neu1e[c] += g *
syn1[c + l2];
          // Learn weights hidden -> output
          for (c = 0; c < layer1_size; c++) syn1[c + l2] += g *
neu1[c];
        }
```

负采样

```
        // NEGATIVE SAMPLING
        if (negative > 0) for (d = 0; d < negative + 1; d++) {
          if (d == 0) {
            target = word;
            label = 1;
          } else {
            next_random = next_random * (unsigned long
long)25214903917 + 11;
            target = table[(next_random >> 16) % table_size];
            if (target == 0) target = next_random % (vocab_size
- 1) + 1;
            if (target == word) continue;
            label = 0;
          }
          l2 = target * layer1_size;
```

- 其更新公式：

```
          l2 = target * layer1_size;
          f = 0;
          for (c = 0; c < layer1_size; c++) f += neu1[c] *
syn1neg[c + l2];
          if (f > MAX_EXP) g = (label - 1) * alpha;
          else if (f < -MAX_EXP) g = (label - 0) * alpha;
          else g = (label - expTable[(int)((f + MAX_EXP) *
(EXP_TABLE_SIZE / MAX_EXP / 2))]) * alpha;
          for (c = 0; c < layer1_size; c++) neu1e[c] += g *
syn1neg[c + l2];
          for (c = 0; c < layer1_size; c++) syn1neg[c + l2] += g
* neu1[c];
        }
```

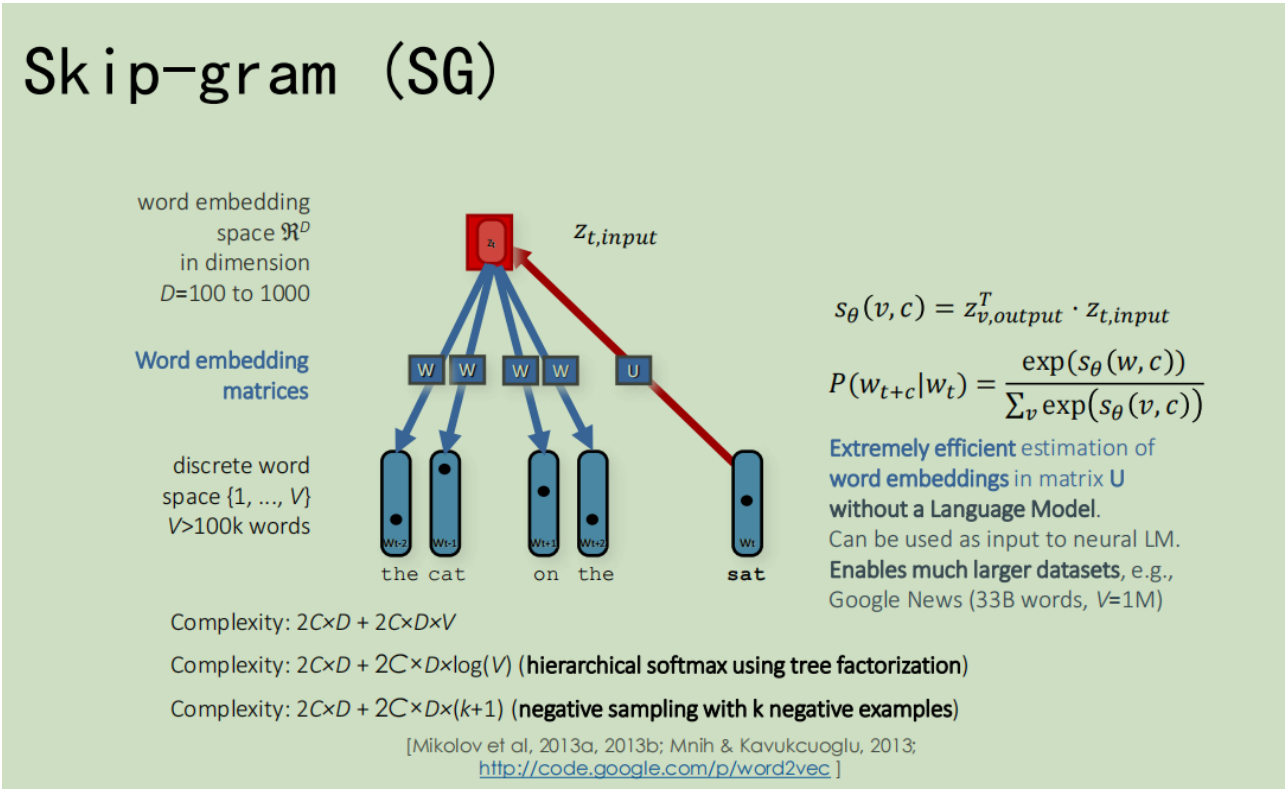
3. 隐藏层到输入层的更新

```
        // hidden -> in
        for (a = b; a < window * 2 + 1 - b; a++) if (a != window)
{
          c = sentence_position - window + a;
          if (c < 0) continue;
          if (c >= sentence_length) continue;
          last_word = sen[c];
          if (last_word == -1) continue;
          for (c = 0; c < layer1_size; c++) syn0[c + last_word *
layer1_size] += neu1e[c];
        }
```

SG

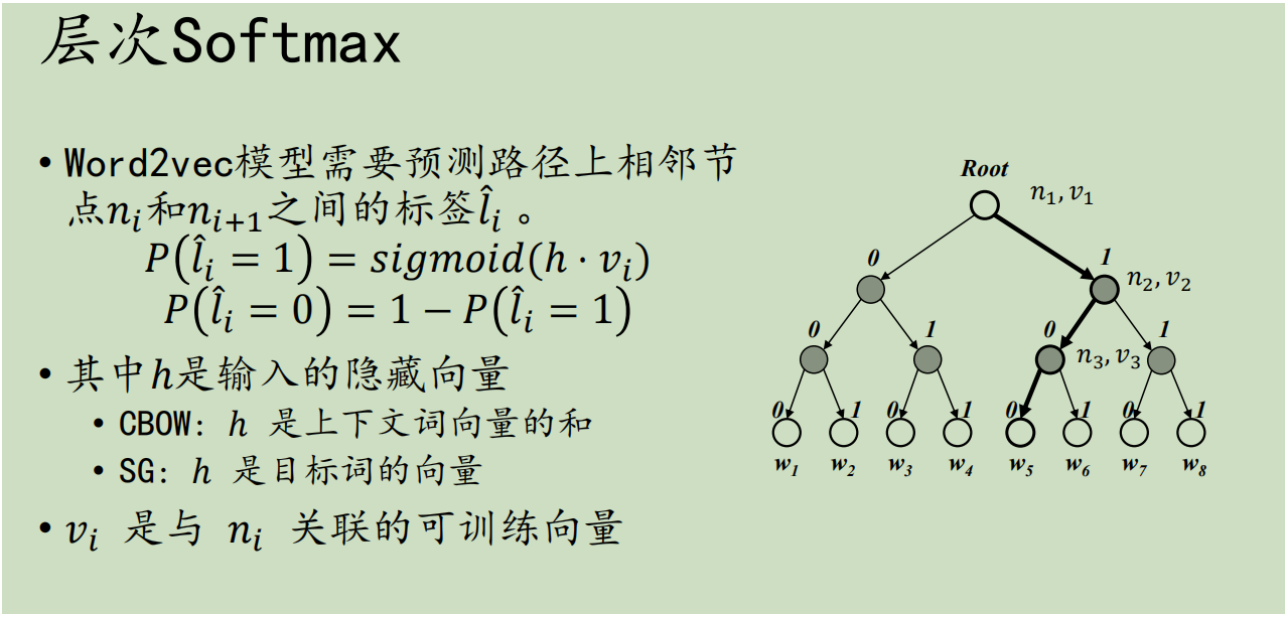
- 对[b,window*2-b]中不等于window的位置，找到syn0对应的输入的首地址，和syn1作内积

```
      for (a = b; a < window * 2 + 1 - b; a++) if (a != window) {
        c = sentence_position - window + a;
        if (c < 0) continue;
        if (c >= sentence_length) continue;
        last_word = sen[c];
        if (last_word == -1) continue;
        l1 = last_word * layer1_size;
```



层次Softmax

- 按层次Softmax，判别当前输入与输出的内积，



- 如果在[-MAX_EXP,MAX_EXP]内，更新nn、输入、输出层；否则继续

```
        // HIERARCHICAL SOFTMAX
        if (hs) for (d = 0; d < vocab[word].codelen; d++) {
          f = 0;
          l2 = vocab[word].point[d] * layer1_size;
          // Propagate hidden -> output
```

```
6           for (c = 0; c < layer1_size; c++) f += syn0[c + l1] *
    syn1[c + l2];
7           if (f <= -MAX_EXP) continue;
8           else if (f >= MAX_EXP) continue;
9           else f = expTable[(int)((f + MAX_EXP) *
    (EXP_TABLE_SIZE / MAX_EXP / 2))];
10          // 'g' is the gradient multiplied by the learning rate
11          g = (1 - vocab[word].code[d] - f) * alpha;
12          // Propagate errors output -> hidden
13          for (c = 0; c < layer1_size; c++) neu1e[c] += g *
    syn1[c + l2];
14          // Learn weights hidden -> output
15          for (c = 0; c < layer1_size; c++) syn1[c + l2] += g *
    syn0[c + l1];
16        }
```