A Technical Report about SAG,SAGA,SVRG

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Notice: this is a course project for <Algorithms for Big Data Analysis> conducted by Zaiwen Wen at Peking University; and <Deep Learning> conducted by Zhihua Zhang at Peking University.

- **for <ALgorithms for Big Data Analysis>, I completed the SAG, SAGA, SVRG algorithm programming.**
- **for <Deep Learning>, I completed different gradient method ablation study.**

I just write it as a entirety for for completeness and continuity!

Abstract

The project report mainly includes the ablation study about the regularization term, stochastic gradient method, etc. the source code is provided: https://github.com/dongzhuoyao/gd.git.

1 Overview

There exists many gradient method, Full Gradient(FG) is proposed first. as more and more data generate, a light-weight method named Stochastic Gradient(SG) appears. Based on the SG method, there emerges several Stochastic Method: Stochastic Gradient Method(SGD)[1], Momemtum[6], AdaDelta[10], RmsProp[9], SDCA[8]. Recently, NL Roux[7] proposed a Variation Method Stochastic Average Gradient (SAG) that realizes linear convergence. lots of variety based on Variance Method such as SVRG[3] SAGA[2], appears. In this project report I will compare several aspects about some of these methods.

Let x $\in \mathbb{R}^n$, y $\in$ -1,1, logistic regression model[5] is given by:

$$P(y/x) = \frac{1}{1+exp(-yw^T x)}$$

The problem I experiment on is regularized average logistic regression loss(through maximum likelihood expectation).

$$min_w \quad P(w) = \frac{1}{n}\sum_{i=1}^{n} ln(1 + exp(-w^T x_i y_i)) + \lambda L(w)$$

where w is weight, L(w) means regression item which can be Ridge Regression or Lasso Regression.

as we use gradient method, we have the gradient formula:

$$\nabla P(w) = \frac{1}{n}\sum_{i=1}^{n} \frac{exp(-y_i w^T x_i)}{1+exp(-y_i w^T x_i)}(-y_i x_i) + \lambda L^{'}(w)$$

if I use *l1*-regularized logistic regression, the L1-norm is not differentiable and has no gradient, thus l1-norm regulation is much more challenging than l2-norm. despite of computing challenge, there also exists several method to tackle the l1-norm regulation. the first strategy is very simple, which is just treating it as a non-smooth optimization problem. thus we can apply some sub-gradient based algorithm to solve it. the second strategy is to apply some smooth approximation to the l1-norm regulation. which can be further solved by some smooth optimization method.

in this paper, I use sub-gradient $L^{'}(w) = sign(w)$ for convenience if I choose l1-norm regulation.

if I use *l2*-regularized logistic regression, The whole formula is differentiable so that the gradient can be easily acquired. I will choose *l2*-regularized logistic regression which $L^{'}(w) = 2w$.

the dataset we use is mnist[4], so the x_i I use above is a 785-by-1 vector, y_i is a scalar, w is 1-by-785 vector. the mnist data size is 28-28, adding a bias totally is 785. for each mnist image, I have normalized it to 1 for convenience of training. as the logistic regression is a binary classification problem, hence I just divide the mnist data into even and odd for later study.

the final binary digit classfier is:

$$y = sign(w^T x)$$

y=1 means odd, otherwise means even.

2 Experiment

because the SVRG requires the data cannot be shuffled. so after each epoch is done, I will not shuffle the data. therefore in some of the following figures, you will observe some curve keep the same tendency as time goes.

2.1 How to obtain the optimal

In the following Experiment, I will use a parameter named " Objective minus Optimum" which we need the optimum, I will choose the optimal value by SGD with a exponential decay learning rate:

$$\mu_t = \eta_0 a^{\lfloor \frac{t}{step} \rfloor}$$

η_0, a are the grid search parameter,here we choose the step = 3, which means to decay the learning rate exponentially for every 3 epochs. 100 epochs were processed finally. the grid search result is in Table 1.

as the result shows, the minimal is 0.3707, we keep the same grid search parameter where $\eta_0 = 1, a = 0.9$ and increase the final epochs to 200, then further achieve minimal value 0.3638/0.9018, we choose the optimum 0.3638 in the following experiment.

Table 1: Optimum Grid Search Table

a | η_0	10	1	0.1	0.01	0.001
0.9	0.4200/0.9013	**0.3707/0.9018**	0.4173/0.8955	0.5830/0.8457	1.0758/0.7315
0.7	0.4118/0.9037	0.3826/0.9	0.4764/0.8705	0.5966/0.8097	1.8617/0.6378
0.5	0.4616/0.8997	0.3887/0.8975	0.4878/0.8615	0.8215/0.7896	3.113/0.5356

the element in every grid means "loss/test accuracy", the result is selected by the highest test accuracy in 100 epochs. best optimal achieves when a=0.9,$\eta_0 = 1$

2.2 Ablation Study

2.2.1 Regulation

There exists different regulation items including L1 norm, L2 norm. here I will compare different regression factor λ in Figure 1. different regulation type influence on test accuracy is also compared in Figure 2.

in those Figures, I choose 25 epochs(effective passes[1]) to run all the methods.

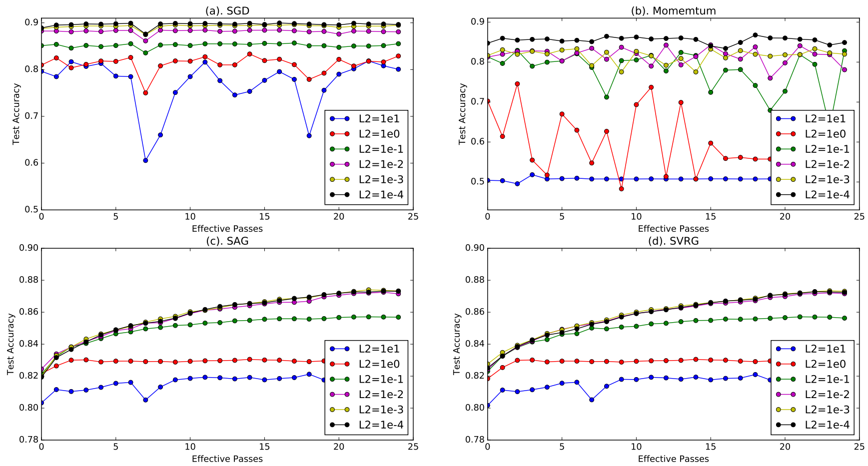

Figure 1: Regulation Value Experiment.all experiment use *l2*-regularized logistic regression as default. (a) Test Accuracy between different regulation λ with *SGD*. (b) Test Accuracy between different regulation λ with *SGD with Momentum*. (c) Test Accuracy between different regulation λ with *SAG*. (d) Test Accuracy between different regulation λ with *SVRG*.This figure is best viewed in colour.

in Figure 1, I compare different regulation value range from 1e1 to 1e-4. for simplicity L2 regulation is tested. for all four SG method, we can find $\lambda = 1e-3$ or 1e-4 is best. when $\lambda = 1e1$ the Test Accuracy is very slow and stop rising up as time passed. as λ becomes smaller and smaller, the Test Accuracy is boosting. until λ =1e-3 or 1e-4, the accuracy no longer fluctuated dramatically.

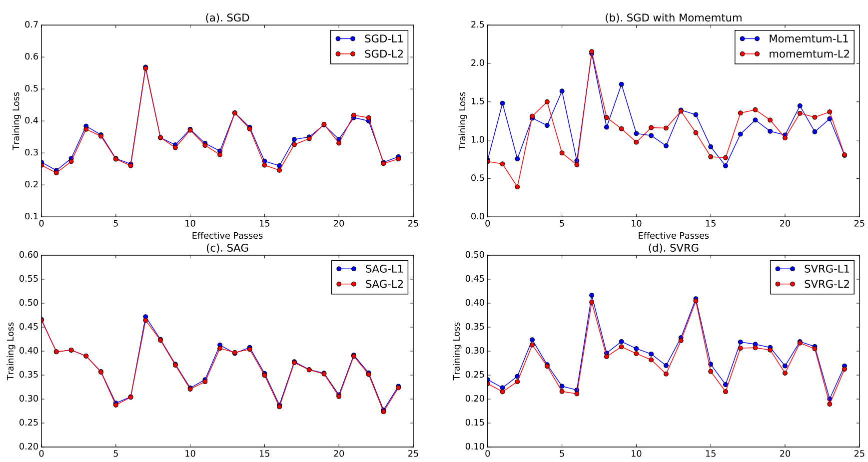

Figure 2: Regulation Type Experiment (a) Test Accuracy between *l1* and *l2* regularized logistic regression with *SGD*. (b) Test Accuracy between *l1* and *l2* regularized logistic regression *SGD with Momentum*. (c) Test Accuracy *l1* and *l2* regularized logistic regression with *SAG*. (d) Test Accuracy between *l1* and *l2* regularized logistic regression with *SVRG*.This figure is best viewed in colour.

[1] one effective pass means an interval that goes through all the finite data.

I also compared diverse regulation type(Figure 2) includes lasso and ridge regulation. However, they show no significant different in Training Loss. Furthermore, I also compared the weight visualization in Figure 3, here the y-axis is the absolute value of weight. if your observe carefully, you will find out the L1 regulation tends to cause more sparse solution.

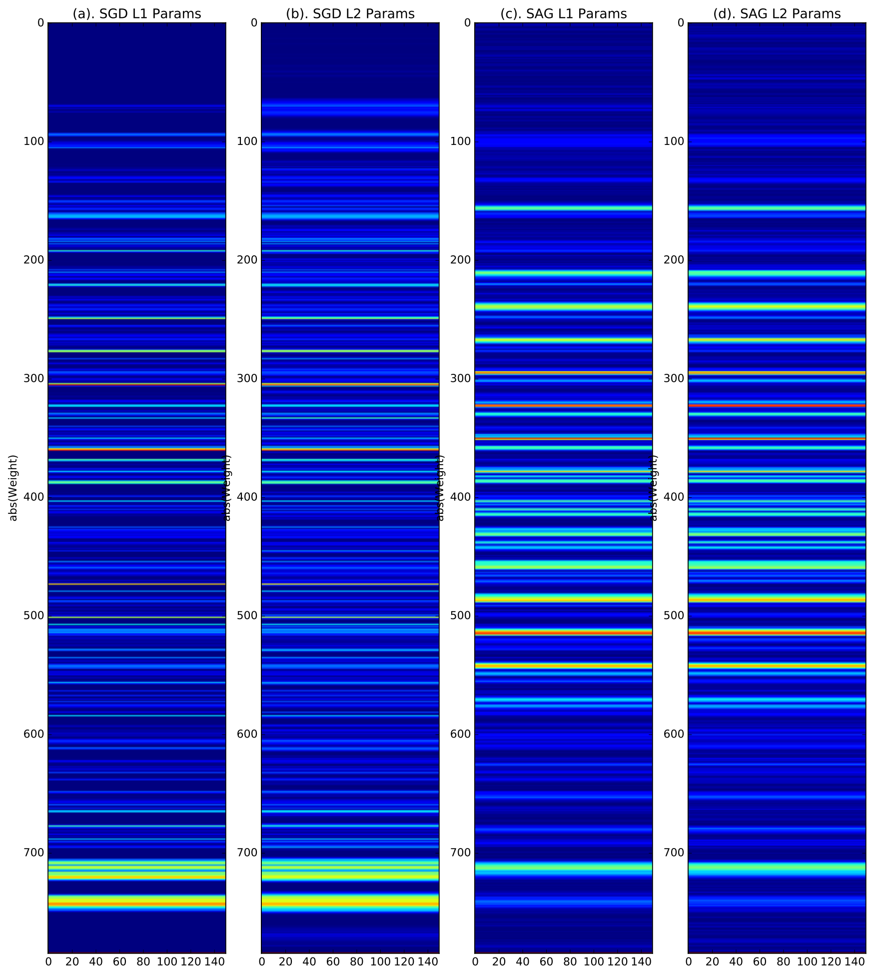

Figure 3: Weight Sparsity Experiment.all experiment use regularization=1e-3 as default. (a) *l1-SGD* weight distribution. (b) *l2-SGD* weight distribution. (c) *l1-SAG* weight distribution. (d) *l2-SAG* weight distribution.This figure is best viewed in colour.

2.2.2 Step Size Strategy

I mainly compared these step size strategy: fixed, exponential decay(step_size=3), backtracking. the training loss and test accuracy influenced by the step size strategy is displayed in Figure 4. 100 epochs are processed for every method.

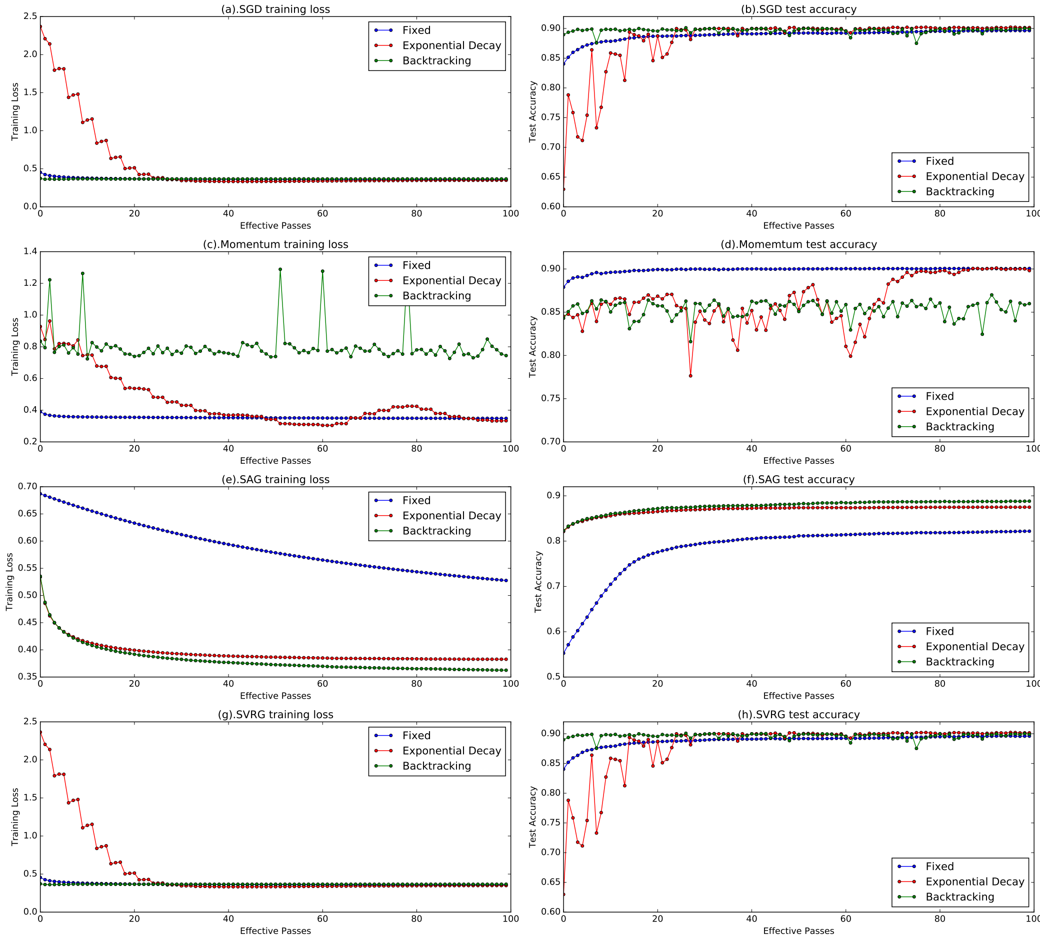

Figure 4: Step Size Strategy Experiment (a,b) training loss and test accuracy with three step size strategy with *SGD*. (c,d) training loss and test accuracy with three step size strategy *SGD with Momentum*. (e,f) training loss and test accuracy with three step size strategy with *SAG*. (g,h) training loss and test accuracy with three step size strategy with *SVRG*.This figure is best viewed in colour.

2.2.3 Different Method

Finally, different method including Stochastic Gradient Descend(SGD), SGD with Momentum, accelerated SGD with Momentum, SAG, SAGA, SVRG are compared in Figure 5. Training Loss, Validation Loss, Test Accuracy tendencies are listed.

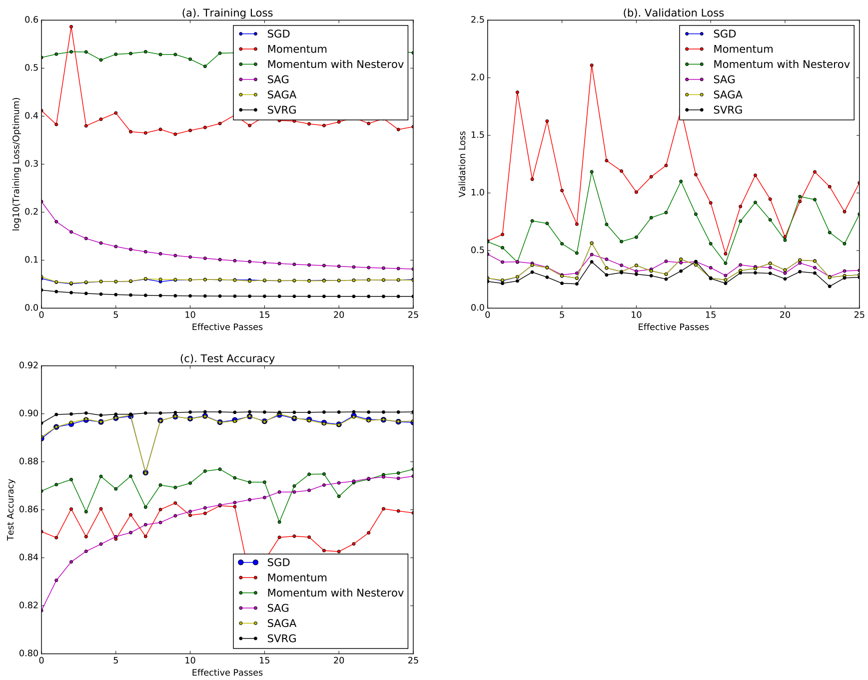

Figure 5: SG Method Experiment (a). training loss of different method. (b). validation loss of different method. (c). test accuracy of different method. This figure is best viewed in colour.

The time consuming is nearly the same except the SVRG. the SVRG is very slowly because it iteratively calculate the best gradient descent .

2.2.4 Vectorization Programming

vectorization programming is very important in numerical calculation. it's a bad habit using "for loop" too frequently. here I will list two different writing style concerning the "non-vectorization" and "vectorization" programming.

vectorization is necessary especially in algorithm like SAG, SVRG, because the gradient computing is very frequently.

Algorithm 1 Non-vectorization

Require: initial value w,x,y
  for i in 1:n **do**
    calculate gradient:$\nabla P(w) = \frac{1}{n}\sum_{i=1}^{n}\frac{exp(-y_i w^T x_i)}{1+exp(-y_i w^T x_i)}(-y_i x_i) + \lambda L^{'}(w)$
  end for
  Output $\nabla(w)$

Algorithm 2 vectorization

Require: initial value w:d-1,x:n-d,y:n-1
  $tmp = \frac{exp(-y\odot(xw))}{1+exp(-y\odot(xw)}$
  $\nabla P(w) = x^T(tmp \odot (-y))$
  Output $\nabla(w)$

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3 Conclusion

This technical report mainly compare the regulation type, regulation value, step-size strategy, different gradient method in table form. if time is enough, more detailed comparison can be presented.

Acknowledgments

some algorithm implement details are borrowed from `https://github.com/hiroyuki-kasai/SGDLibrary`. This is only a technical report, I will be glad it helps you.

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