

Distributed Machine Learning Systems



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Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 40,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 100 figures.

Christopher Hopkins

October 2020

Declaration

This is where you write your abstract ...

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1 Introduction

1.1 Motivation and Context

Machine Learning algorithms have become ubiquitous in modern life. Powering social media feeds, email spam filters, advertising personalisation and even identifying breast cancer more accurately and earlier than doctors. [1] To train these Machine Learning algorithms large datasets are needed. The more nuanced and complex the problem being solved the more data is necessary. As the scale of problems we are trying to solve dramatically increase, the scale of datasets are becoming truly gargantuan. Since 2008 Google has been processing more 20PB of data a day using their MapReduce algorithm. [2] While services like the Internet Archive as of 2020 contain over 70PB in its database. We now have labeled datasets such as AViD have 467k videos and 887 action classes, which is in the order of terabytes. [3] Whilst the data grows the as does the Machine Learning models in order to to obtain ever more accurate results. The cutting edge GTP-3 Natural Language Processing model contains 175 Billion parameters. [4] And efforts are being made to create models with trillions of parameters. [5]

Deriving meaning from these vast quantities of data to obtaining nuanced insights from them is a difficult task. Not only because deeper insights into data require a larger Machine Learning models. But because more data is needed to populate the parameters of these models. Both of these factors contribute to the need to distribute the computation of the model across multiple nodes otherwise known as Distributed Machine Learning. Distributed Machine Learning is often a pre-requisite for training models now datasets and models are becoming so large. [6]

Scalability is another challenge a Distributed Machine Learning system must face. As more machines are added, to a system the communication overhead increases. This is a limited resource which can produce bottlenecks when too many machines are added.

Now that machines are

The popular current solution is to have multiple machines compute the model together, communicating the improvements that they've made to each other. The model goes from operating on a single machine possessing all the data and needing to do all the computation, to a worker and parameter server paradigm. In which the parameter server contains the

model and the workers perform operations on it using test data segmented between them. [6]

There are two main variations with respect to the operation of the workers in parameter server model: 1) The parameter server has to wait for the last worker to be finished before it can calculate the new global parameters. much like the MapReduce algorithm. [2] 2) The workers operate asynchronously constantly updating the parameter server, the parameter server calculating new global parameters periodically. [7] Whilst this method is the most common method of machine learning with many benefits, there are 3 key drawbacks:

- The model sacrifices efficiency in either time or computation. Either it must wait for all workers to be done each round, or redundant computations must be made. [8]
- when the parameter server is calculating the new global parameters the workers are idle or otherwise computing on stale data. [9]
- Each time the parameter server calculates a new global parameters, these parameters must be broadcast to each worker simultaneously, consuming vast network bandwidth. [6]

As has already been addressed frequently models can get so large that they can no longer feasibly be held within one worker. Therefore there are also variations with respect to how much of the model each worker operates on: 1) The model is segmented and split between worker. This is known as *Model Parallelism* 2) The data is split between the workers which have their own full local models, but are synced with each other at periodic intervals. This is known as *Data Parallelism* [10] Though model parallelism shows promise it has its own set of drawbacks:

- Often in model parallelism nodes do not communicate with each other, this makes it performing algorithms such as Stochastic Gradient Decent difficult as clusters of nodes are isolated.
- some model parameters take more algorithmic iterations to converge than others, so that they converges at the same rate, this means that some nodes may be idle, not spreading the load equally or efficiently. [11]
- Because some parameters converge at different rates, a scheduler is needed. However this in turn require more computational overhead and communication and reduces iteration throughput. [12]

1.2 Aims

My solution to address these issues raised above is to introduce a new model for Distributed Machine Learning: *RingTMP*. RingTMP (Ring Topological Model Parallel) is a Ring Topological Model Parallel Distributed Machine Learning framework focusing on optimising Distributed Stochastic Gradient Descent.

Each of the limitations I have described before I aim to address with the RingTMP Framework:

- RingTMP aims to reduce the time workers are idle to lower than the parameter server model. This will manifest itself by distributing the work between workers more proportionally, This means each computers resource is used more efficiently and training should be faster per iteration.
- The system will also not have a global parameter store, meaning there will be no need for communication of weights across the network
- As the node network has a ring topology not a star topology due the lack of a need of a parameter server prevents one node getting flooded with data each iteration. This isn't scalable, as when the workers increase so does the data flooding the parameter server leading to bottlenecks. In contrast the ring topology allows data to flow in lockstep, with no bottlenecking
- There will be no isolated nodes as can be an issue in many model parallel designs, but they can communicate with each other by design.
- The convergence rate will be consistent across all nodes, and they are all sharing a global problem rather than working on their own subproblems.
- Because the convergence rate is the same across all nodes no scheduler is necessary. Instead scheduling is managed in a decentralised manner via communication with adjacent nodes.

As I have already alluded to this will take the form of a framework that will operate on multiple machines which henceforth I will describe as nodes. Each nodes contains a series of adjacent of Deep Neural Network (DNN) layers. The nodes (as before described) are

arranged in a ring. In the clockwise direction matrix multiplication is performed and in the anticlockwise direction gradient descent through backpropagation is performed. There are two kinds of nodes master nodes and worker nodes. Master nodes have direct access to the training data being input into the Neural Network, whilst also performing operations on the data flowing through the neural network. There is only one master node per network and as many worker nodes as desired.

Each node has a 3 part structure.

- The Parameter Store. This contains the parameters for this section of the model. For the majority of the time its only accessed by elements within the node.
- The Multiplication Module. Reads the parameter server weights and multiplies them with the matrix given by the previous node.
- The Backpropagation Module. Takes the last layer of the previous node and the parameters in the store. It uses them to calculate the new parameters they are then placed in the Parameter Store.

The master node has the addition of being connected to the training dataset. A master node takes an single training example and its solution. It then send the example around the ring until it arrives back at the master node at which point the master node evaluates the decision the Neural Network has come to and begins the backpropagation progress along the way it came, in order to improve the model.

1.3 Problem

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1.4 Overview

This document is split up into the following sections:

- **Section 1** Current section. Introduce the project and its aims.
- **Section 2** Presents related research material and similar applications and areas.
- **Section 3** Gives an overview on the technological choices that will be used.
- **Section 4** Project plan and time management.
- **Section 5** Summary of previous sections.

2 Background Research

Hello there

3 Technological Choices

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4 Project Plan and Time Management

example of reference is [13]

5 Design

5.1 subsection1

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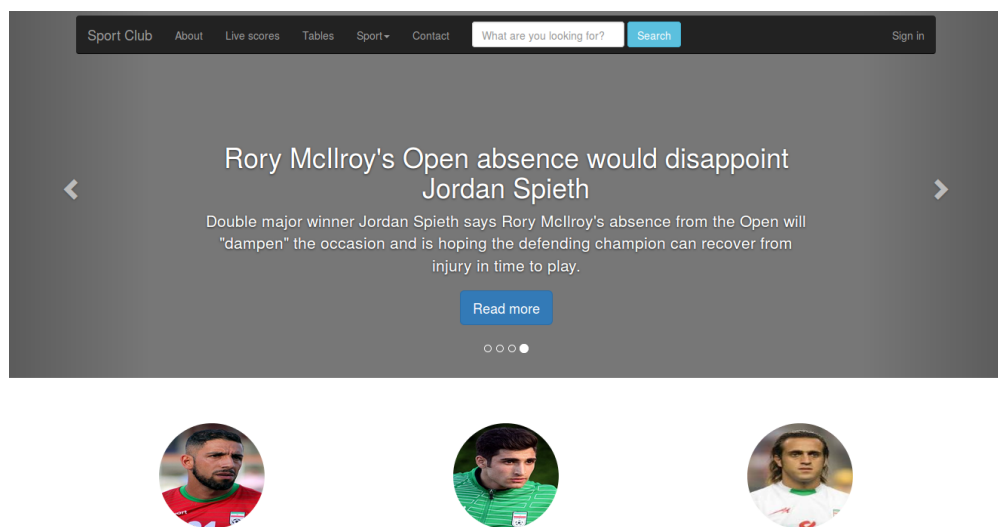


Figure 1: Project Homepage

6 Requirement and Specification

6.1 Keywords

Keyword	Definition
Completed	The requirement is implemented or fulfilled
Partial	The requirement is partially implemented or fulfilled
Not Completed	The requirement is not implemented or fulfilled
FR	Functional Requirement
NFR	Non Functional Requirement
FS	Functional Specification
NFS	Non Functional Specification

Table 1: Keywords

6.2 Requirements

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6.3 Specification

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6.4 Cross-References

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7 Implementation

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8 Reflection

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9 Future Work

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10 Conclusion

my conclusion

References

- [1] S. M. McKinney, M. Sieniek, V. Godbole, J. Godwin, N. Antropova, H. Ashraffian, T. Back, M. Chesus, G. S. Corrado, A. Darzi, M. Etemadi, F. Garcia-Vicente, F. J. Gilbert, M. Halling-Brown, D. Hassabis, S. Jansen, A. Karthikesalingam, C. J. Kelly, D. King, J. R. Ledsam, D. Melnick, H. Mostofi, L. Peng, J. J. Reicher, B. Romera-Paredes, R. Sidebottom, M. Suleyman, D. Tse, K. C. Young, J. De Fauw, and S. Shetty, “International evaluation of an ai system for breast cancer screening,” *Nature*, vol. 577, pp. 89–94, Jan 2020.
- [2] J. Dean and S. Ghemawat, “Mapreduce: Simplified data processing on large clusters,” *Commun. ACM*, vol. 51, p. 107–113, Jan. 2008.
- [3] A. Piergiovanni and M. S. Ryoo, “Avid dataset: Anonymized videos from diverse countries,” 2020.
- [4] T. B. Brown, B. Mann, N. Ryder, M. Subbiah, J. Kaplan, P. Dhariwal, A. Nee-lakantan, P. Shyam, G. Sastry, A. Askell, S. Agarwal, A. Herbert-Voss, G. Krueger, T. Henighan, R. Child, A. Ramesh, D. M. Ziegler, J. Wu, C. Winter, C. Hesse, M. Chen, E. Sigler, M. Litwin, S. Gray, B. Chess, J. Clark, C. Berner, S. McCandlish, A. Radford, I. Sutskever, and D. Amodei, “Language models are few-shot learners,” 2020.
- [5] S. Rajbhandari, J. Rasley, O. Ruwase, and Y. He, “Zero: Memory optimizations toward training trillion parameter models,” 2020.
- [6] M. Li, D. G. Andersen, J. W. Park, A. J. Smola, A. Ahmed, V. Josifovski, J. Long, E. J. Shekita, and B.-Y. Su, “Scaling distributed machine learning with the parameter server,” in *11th USENIX Symposium on Operating Systems Design and Implementation (OSDI 14)*, (Broomfield, CO), pp. 583–598, USENIX Association, Oct. 2014.
- [7] Q. Ho, J. Cipar, H. Cui, S. Lee, J. K. Kim, P. B. Gibbons, G. A. Gibson, G. Ganger, and E. P. Xing, “More effective distributed ml via a stale synchronous parallel parameter server,” in *Advances in Neural Information Processing Systems 26* (C. J. C. Burges, L. Bottou, M. Welling, Z. Ghahramani, and K. Q. Weinberger, eds.), pp. 1223–1231, Curran Associates, Inc., 2013.
- [8] T. Chilimbi, Y. Suzue, J. Apacible, and K. Kalyanaraman, “Project adam: Building an efficient and scalable deep learning training system,” in *11th USENIX Symposium on*

- Operating Systems Design and Implementation (OSDI 14)*, (Broomfield, CO), pp. 571–582, USENIX Association, Oct. 2014.
- [9] J. Verbraeken, M. Wolting, J. Katzy, J. Kloppenburg, T. Verbelen, and J. S. Rellermeyer, “A survey on distributed machine learning,” *ACM Comput. Surv.*, vol. 53, Mar. 2020.
 - [10] E. P. Xing, Q. Ho, W. Dai, J. K. Kim, J. Wei, S. Lee, X. Zheng, P. Xie, A. Kumar, and Y. Yu, “Petuum: A new platform for distributed machine learning on big data,” *IEEE Transactions on Big Data*, vol. 1, no. 2, pp. 49–67, 2015.
 - [11] J. Dean, G. Corrado, R. Monga, K. Chen, M. Devin, M. Mao, M. aurelio Ranzato, A. Senior, P. Tucker, K. Yang, Q. V. Le, and A. Y. Ng, “Large scale distributed deep networks,” in *Advances in Neural Information Processing Systems 25* (F. Pereira, C. J. C. Burges, L. Bottou, and K. Q. Weinberger, eds.), pp. 1223–1231, Curran Associates, Inc., 2012.
 - [12] J. K. Kim, Q. Ho, S. Lee, X. Zheng, W. Dai, G. A. Gibson, and E. P. Xing, “Strads: A distributed framework for scheduled model parallel machine learning,” in *Proceedings of the Eleventh European Conference on Computer Systems, EuroSys ’16*, (New York, NY, USA), Association for Computing Machinery, 2016.
 - [13] S. K. Patel, V. Rathod, and S. Parikh, “Joomla, drupal and wordpress-a statistical comparison of open source cms,” in *Trendz in Information Sciences and Computing (TISC), 2011 3rd International Conference on*, pp. 182–187, IEEE, 2011.

Appendices

A one

B two