

RWTH Aachen University
Software Engineering Group

Comparison of Deep Learning Architectures on Simulated Environments

Seminar Paper

presented by

Bergerbusch, Timo

1st Examiner: Prof. Dr. B. Rumpe

2nd Examiner:

Advisor: Evgeny Kusmenko

The present work was submitted to the Chair of Software Engineering

Aachen, May 16, 2018

The present translation is for your convenience only.
Only the German version is legally binding.

Statutory Declaration in Lieu of an Oath

Last Name, First Name

Matriculation No. (optional)

I hereby declare in lieu of an oath that I have completed the present Bachelor's
thesis/Master's thesis* entitled

independently and without illegitimate assistance from third parties. I have use no other than
the specified sources and aids. In case that the thesis is additionally submitted in an
electronic format, I declare that the written and electronic versions are fully identical. The
thesis has not been submitted to any examination body in this, or similar, form.

Location/City, Date

The German version has to be signed.

Signature

*Please delete as appropriate

Official Notification:

Para. 156 StGB (German Criminal Code): False Statutory Declarations

Whosoever before a public authority competent to administer statutory declarations falsely makes such a
declaration or falsely testifies while referring to such a declaration shall be liable to imprisonment not exceeding
three years or a fine.

Para. 161 StGB (German Criminal Code): False Statutory Declarations Due to Negligence

(1) If a person commits one of the offences listed in sections 154 to 156 negligently the penalty shall be
imprisonment not exceeding one year or a fine.

(2) The offender shall be exempt from liability if he or she corrects their false testimony in time. The provisions of
section 158 (2) and (3) shall apply accordingly.

I have read and understood the above official notification:

City, Date

The German version has to be signed.

Signature

Abstract

The topic of autonomous driving using artificial intelligence increases in importance with the overwhelming amount of software usage within vehicles. For that *Convolutional Neural Networks* (CNNs), which try to figure out the importance of special areas of a single picture, have been shown to be promising.

In this paper we will give a general introduction to the topic of CNNs. We distinguish between the three main *deep learning languages* (DLLs) currently used and researched for autonomous driving agents: mediated perception, behaviour reflex and direct perception. Further we will compare different languages, which can be used to implement the different DLLs, based on the factors of usability, scope of functionality and the integration on a subject.

As a proof of concept we will train a CNN using the language *CNNArch* on the famous KITTI dataset in order to create a trained model. This model will then be tested on a test set created using either the simulation tool *MontiSim* or the open source racing game *TORCS*, containing multiple different challenging scenarios the agent has to manage.

Finally we evaluate the trained model on it's performance and try to reason, why it performed particularly good/bad, and give an overview based on the implemented test in order to state the similarities and differences of the languages.

Contents

1	Introduction	1
1.1	Convolutional Neural Network (CNN)	1
1.1.1	AlexNet	2
1.2	Available Deep Learning Approaches	3
1.2.1	Mediated Perception	3
1.2.2	Behavior Reflex	3
1.2.3	Direct Perception	6
1.3	Deep Learning Languages	6
1.3.1	CNNArch	6
1.3.2	MxNet	6
2	Running Example	7
2.1	Implementation	7
2.2	Training	7
3	Evaluation	9
3.1	MontiSim	9
3.2	Results	9
4	Conclusion	11
	Literaturverzeichnis	11

Chapter 1

Introduction

The field of autonomous driving agents has rapidly increased in modern car manufacturing. Current research topic rises the agents from parking or lane keeping assistant fully autonomous driving agents obeying the traffic rules and having the ability to react to the volatile environment in a reasonable way.

For that machine learning techniques have proven themselves as an essential part. But in order to fulfil the security standards and create a sophisticated agent it has to be trained on hundred-thousands of scenarios each having a large set of data attached, for example sensor and camera data. The approach of *Convolutional Neural Networks* (CNNs) have been proven to be powerful enough to handle such many training iterations with a huge number of input variables, while maintaining the large learning capacity. [KSH12]

A CNN, as explained in Section 1.1, has a general structure, but can be altered to fit into the approach in various ways influencing the result. Therefore we introduce in Section 1.2 the three main approaches of using a CNN.

Further in Section 1.3 we see that there is the need of specific languages for the design and implementation of such agents. Two languages will be discussed and compared based on their suitability regarding the AlexNet, stated in Section 1.1.1.

1.1 Convolutional Neural Network (CNN)

A CNN is a special class of deep feed-forward neural networks. One of the main design goals of a CNN is that they require a minimal amount of preprocessing. This is an important aspect, because they are often fed with images. Preprocessing high resolution images is very costly in terms of computational time. In the context of autonomous driving the time is even more crucial, since the driving agent needs to be able to react to spontaneous events.

Like most parts of neural networks, also the CNNs are inspired by biological processes. It is mainly based on the connectivity pattern of an animal's visual cortex, where special neurons respond only to stimuli of their receptive field. Partially overlapping guarantees a complete coverage of the field of view. [Wik18]

Further CNNs make strong and mostly correct assumptions about the nature of images, like stationarity of statistics and locality of pixel dependencies. This leads to fewer connections and parameters, compared to a normal feed-forward neural net with similar sized

layers, and therefore reduces the time it takes to be trained, while being only slightly worse in their best-performance. [KSH12]

TODO:

1. how detailed?
 2. where starting?
-

1.1.1 AlexNet

The *AlexNet* is one of the best performing CNN architectures currently known. It is trained on the ImageNet subsets of ILSVRC-2010 and ILSVRC-2012¹ and became famous because of its result being way ahead of all other competitors.

A highly optimized GPU implementation of this architecture combined with innovative features is publicly available. Those features lead to improve performance and reduce training time. An important note is that the original test is dated back to 2012 and therefore was used with an overall GPU memory of 6GB, with which training took about six days. With modern hardware the training can be done faster, or the model can be trained much more. [KSH12]

TODO: maybe calc the possible speed up based on “Hardware for Machine Learning”

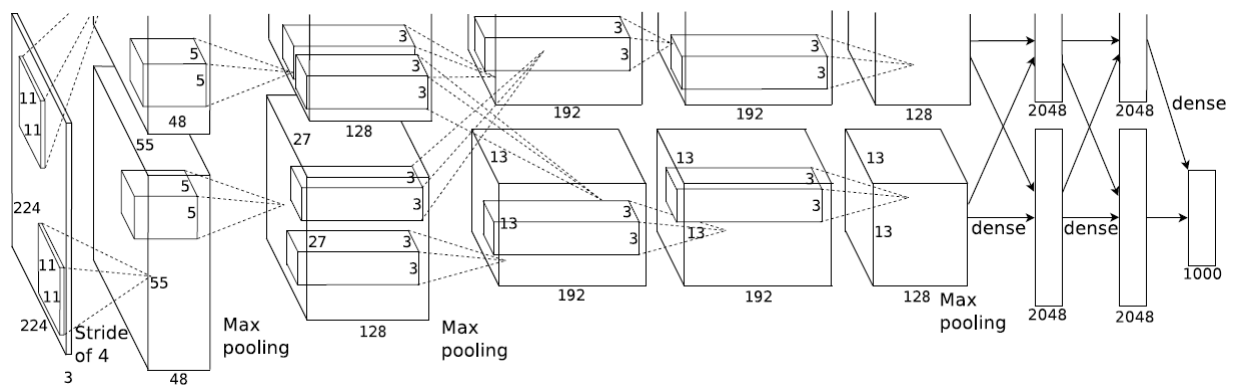


Figure 1.1: The AlexNet-architecture for two GPUs. It consists of 5 convolutional layers (at the beginning) and three fully-connected layers (at the end). The GPUs only communicate between two layers, but never within a layer.[KSH12]

TODO: Vereinfachen der Zeichnung

¹Further information: <http://www.image-net.org/challenges/LSVRC/>

1.2 Available Deep Learning Approaches

There are various approaches of autonomous driving agents making a variety of assumptions and differ in numerous options. But they can be mostly categorized into two major groups of approaches: mediated perception approaches and behavior reflex approaches. [CSKX15]

In this paper we further analyze a suggested third group, called direct perception, which can traced to [Gib79] in the mid 50's, but was sharply criticized by researchers of the other two groups, i.e. in [Ull80].

All these three groups differ in the way of interpreting the given sensor data and whether or not to create a some what bigger picture based on consequent data.

1.2.1 Mediated Perception

The mediated perception approach is a multi-component continuous process. Every component recognizes specific aspects for driving. For example traffic signs, lanes, other cars. Those components are then combined into one single world state representing the cars surrounding based on the sensor data. [GLSU13]

These world states are 3D models of the current world. Cars are identified using a classifier and then often surrounded by a 3D bounding box. An example can be seen in Figure 1.2. By comparing different frames generated one can estimate the speed and distance to those objects and derive an A.I. based precedence behavior. [GLSU13][CSKX15]

The often stated problems with such approaches are, that computing such a scene is costly in terms of computation time. Some information is irrelevant, redundant or even misleading due to inaccuracy of sensors. To perform a right turn the sensor information of the distance to a car left behind me is irrelevant, but becomes very important when taking a left turn.

Additionally many of the subtasks are still open research topics themselves. For example a reliable lane detection throughout various weather conditions or even a new road not having any drawn lines yet. [Aly08]

Also mediated perception approaches require very detailed information up front, like up-to-date maps.

The approach of mediated perception is a reasonable and very sturdy way of handling such a complex task, but has its drawbacks regarding computational time and additional knowledge.

1.2.2 Behavior Reflex

The behavior reflex approach of constructing a reliable autonomous driving agent can be dated back to 1989 , where researchers tried to directly map a single frame to a decision of a steering angle. For such approaches a quite simple neural network were created.

The network ALVINN, shown in Figure 1.4, consisted of a single hidden layer, used back-propagation and is fed by two cameras: a 30×32 pixel video and a 8×32 pixel range finder retina. The input neurons fired depending on the blue color band of its pixel, because it is believed to infer the highest contrast between road and non-road. The difference

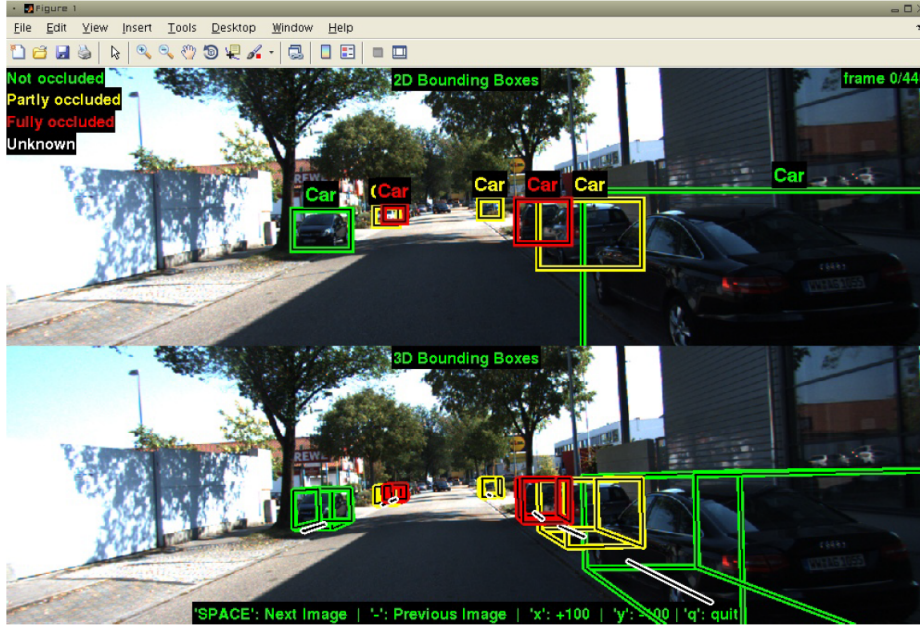


Figure 1.2: An example of a scene using 3D bounding boxes. This image is taken from the MATLAB development kit of [GLSU13]

in color of road and non-road was fed back to the network. The bias (activation level) is proportional to the proximity of the corresponding area, based on the likelihood and importance of having road in particular fields of the image.[Pom89]

For example having recognized that the road abruptly ends right in front of the car is more important than recognizing that there is a road in the top left corner.

Such systems, even though they are simple compared to the in Section 1.2.1 mentioned mediated perception approaches, have been proven to have the capability to perform simple tasks. It can elegantly be trained by having a human drive a car with the cameras equipped and forward the images to the neural network and adding the current steering angles as a label.[CSKX15]

The problem with behavior reflex approaches is, that they reach their limits very early when adding more complex scenarios. Having simple alternations to the trained scenarios, which enforce a different behavior, is very hard to train to such a neural network.

For example comparing a simple straight 3 lane road with the car in the middle, as sketched in Figure 1.3. The system is confidently able to hold the angle and make small adjustments to stay in the lane (Figure 1.3a). But what if on the same road there is an other car in the middle lane in front of the agent, which is slower? Having quite the same input the system would have to overtake the car left or right (considering an american highway) (Figure 1.3b). Now also considering a car in front, which has the same speed. One can simple stay in the lane (Figure 1.3c). This maneuver is very hard to train to a simple neural network like ALVINN.

TODO: noch mehr?

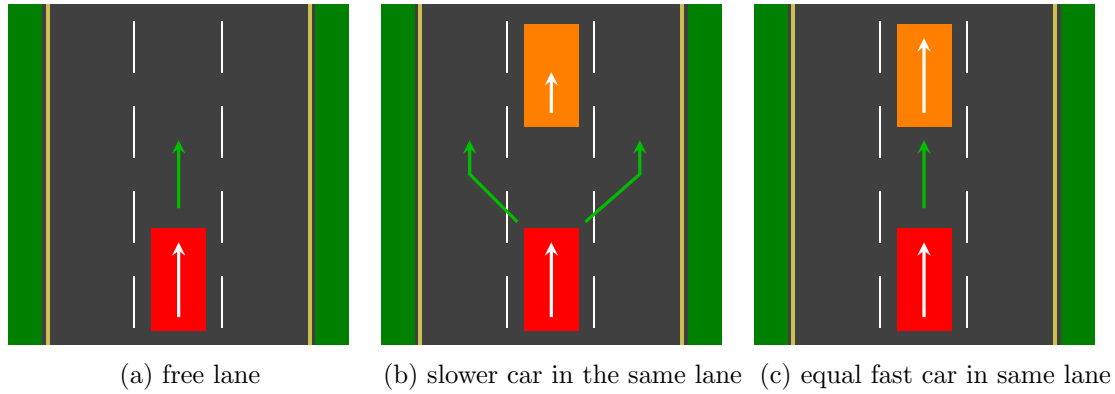


Figure 1.3: The 3 scenarios causing problems with behavior reflex approaches. The red block is the agent, the orange block the other car, the white arrows indicate the velocity and the green arrows the logically deduced behaviors.

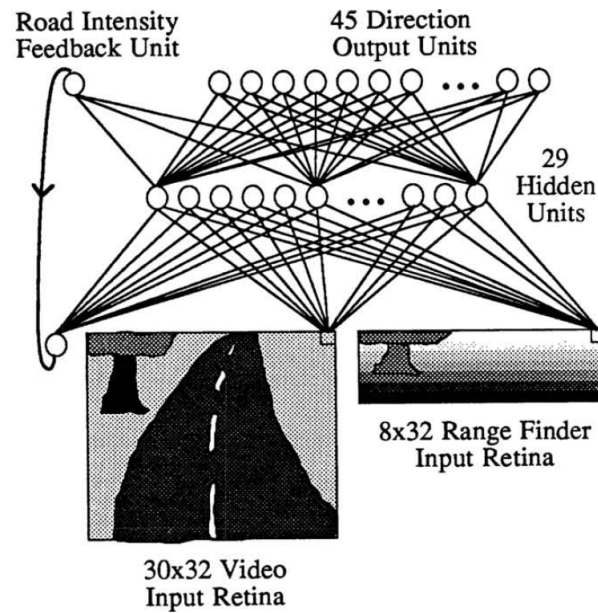


Figure 1.4: The neural network called ALVINN and used as a behavior reflex based autonomous agent. [Pom89]

1.2.3 Direct Perception

The direct perception is the third group of approaches, which can be dated back to the 1954 and was mainly researched by James J. Gibson. [Gib54] The approach is based on analyzing a picture not simply deducing a steering angle, or velocity change, like the behavior reflex approaches (cf. Section 1.2.2), but also performing further computation without parsing it into a 3D world state model like the mediated perception approaches (cf. Section 1.2.1). [CSKX15]

So it is a third paradigm, which can be interpreted as a hybrid of the two other paradigms. The approach tries to identify only the meaningful affordance indicators and make a decision based on those parameters.

We further consider a design based on [CSKX15] and their way of training.

TODO:

1. how to learn the affordance
2. how to conclude affordance to action

1.3 Deep Learning Languages

TODO:

1. why need a language
2. what should it in general do?
3. state that different languages ex.

1.3.1 CNNArch

general and some more in depth information about CNNArch based on [TvWH17]

1.3.2 MxNet

general information from [CLL⁺15]

Chapter 2

Running Example

The example net, AlexNet [KSH12] implemented as a Direct Perception approach

2.1 Implementation

Implementation of the net using CNNArch or MxNet (maybe discuss already implemented approaches to cover more details)

2.2 Training

The training of the implemented net based on the KITTI dataset [?]

Chapter 3

Evaluation

Test the trained set in a simulation environment

3.1 MontiSim

Short introduction of the tool used to evaluate the net in [Rea17]

3.2 Results

Evaluating the results of the test of the net in MontiSim

Chapter 4

Conclusion

Conclusion of differences and similarities between the frameworks

Also a general conclusion based on results and [Grz17]

Bibliography

- [Aly08] Mohamed Aly. Real time detection of lane markers in urban streets. In *Intelligent Vehicles Symposium, 2008 IEEE*, pages 7–12. IEEE, 2008.
- [CLL⁺15] Tianqi Chen, Mu Li, Yutian Li, Min Lin, Naiyan Wang, Minjie Wang, Tianjun Xiao, Bing Xu, Chiyuan Zhang, and Zheng Zhang. Mxnet: A flexible and efficient machine learning library for heterogeneous distributed systems. *arXiv preprint arXiv:1512.01274*, 2015.
- [CSKX15] Chenyi Chen, Ari Seff, Alain Kornhauser, and Jianxiong Xiao. Deepdriving: Learning affordance for direct perception in autonomous driving. In *Computer Vision (ICCV), 2015 IEEE International Conference on*, pages 2722–2730. IEEE, 2015.
- [Gib54] James J Gibson. A theory of pictorial perception. *Audiovisual communication review*, 2(1):3–23, 1954.
- [Gib79] James J Gibson. *The ecological approach to visual perception*. Psychology Press, 1979.
- [GLSU13] Andreas Geiger, Philip Lenz, Christoph Stiller, and Raquel Urtasun. Vision meets robotics: The kitti dataset. *The International Journal of Robotics Research*, 32(11):1231–1237, 2013.
- [Grz17] Adam Grzywaczewski. Training ai for self-driving vehicles: the challenge of scale. Technical report, Tech. rep., NVIDIA Corporation. URL <https://devblogs.nvidia.com/parallelforall/training-self-driving-vehicles-challenge-scale>, 2017.
- [KSH12] Alex Krizhevsky, Ilya Sutskever, and Geoffrey E Hinton. Imagenet classification with deep convolutional neural networks. In *Advances in neural information processing systems*, pages 1097–1105, 2012.
- [Pom89] Dean A Pomerleau. Alvin: An autonomous land vehicle in a neural network. In *Advances in neural information processing systems*, pages 305–313, 1989.
- [Rea17] Bernhard Rumpe and et. al. Montisim. <https://github.com/MontiSim>, 2017.
- [TvWH17] Thomas Timmermann, Michael von Wenckstern, and Malte Heithoff. Cnnarchlang. <https://github.com/EmbeddedMontiArc/CNNArchLang>, 2017.
- [Ull80] Shimon Ullman. Against direct perception. *Behavioral and Brain Sciences*, 3(3):373–381, 1980.

[Wik18] Wikipedia contributors. Convolutional neural networks — Wikipedia, the free encyclopedia, 2018. [Online; accessed 11-May-2018].