Deep Neural Networks for Safety-Critical Applications: Vision and Open Problems

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Motivations

1

Currently, many car manufacturers are tackling the race towards autonomous cars

2

Huge improvements in DNN accuracy for many tasks (e.g. image classification)

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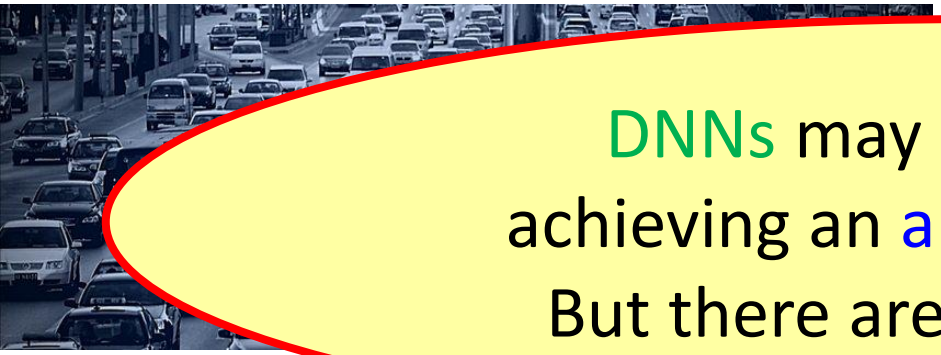


DNNs may be useful for achieving an autonomous car!
But there are many issues…

2

Huge improvements in DNN accuracy for many tasks (e.g. image classification)

Motivations

But not only autonomous driving…

- DNNs can be also adopted for other types of autonomous systems (e.g., robotics, industrial control)

Neural Networks

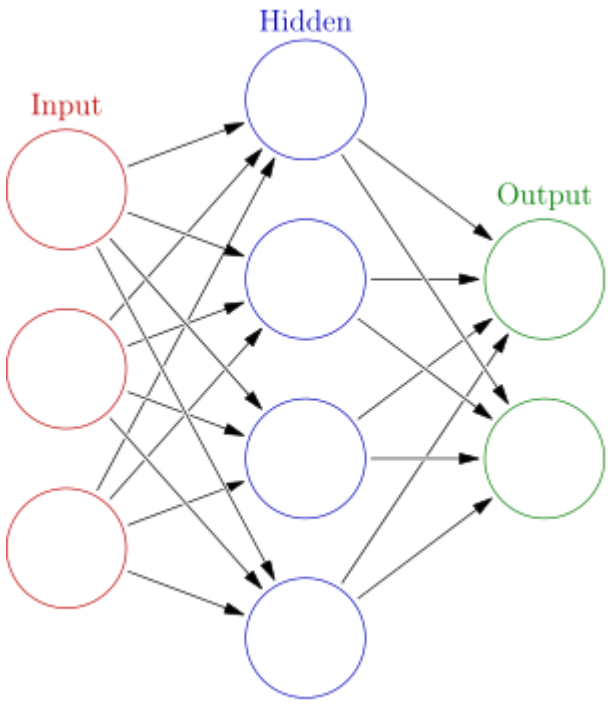
- Used to solve problems that are difficult to formalize by a set of rules.

Problems that depend on too many details are learned by direct experience

- Neural Networks imitate the way our brain works

Neural Networks

- Neural Networks consist of a set of neurons, often organized into layers
- Neurons are connected to each other by synaptic weights
- They are used for many different purposes, as speech recognition, image processing, wheather forecast, etc.



Supervised Learning

- They can learn "by examples" to associate input-output pairs

- Example: Before training

Input	Desired Output	Actual Output
	Red Semaphore	Car

Incorrect Classification!

Supervised Learning

- The training algorithm regulates the internal parameters (i.e., weights) of the network for producing the expected output

- Example: After training

Input	Desired Output	Actual Output
	Red Semaphore	Red Semaphore

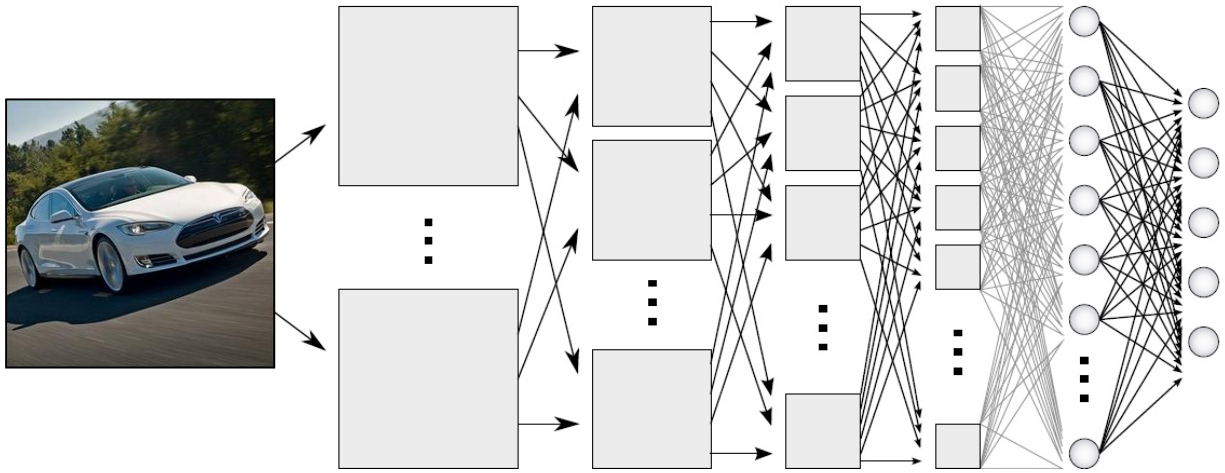
Correct!

Image Recognition

- The ILSVRC Challenge is a competition held from 2010 in which networks compete in classifying objects from images to labels, with 1000 possible categories

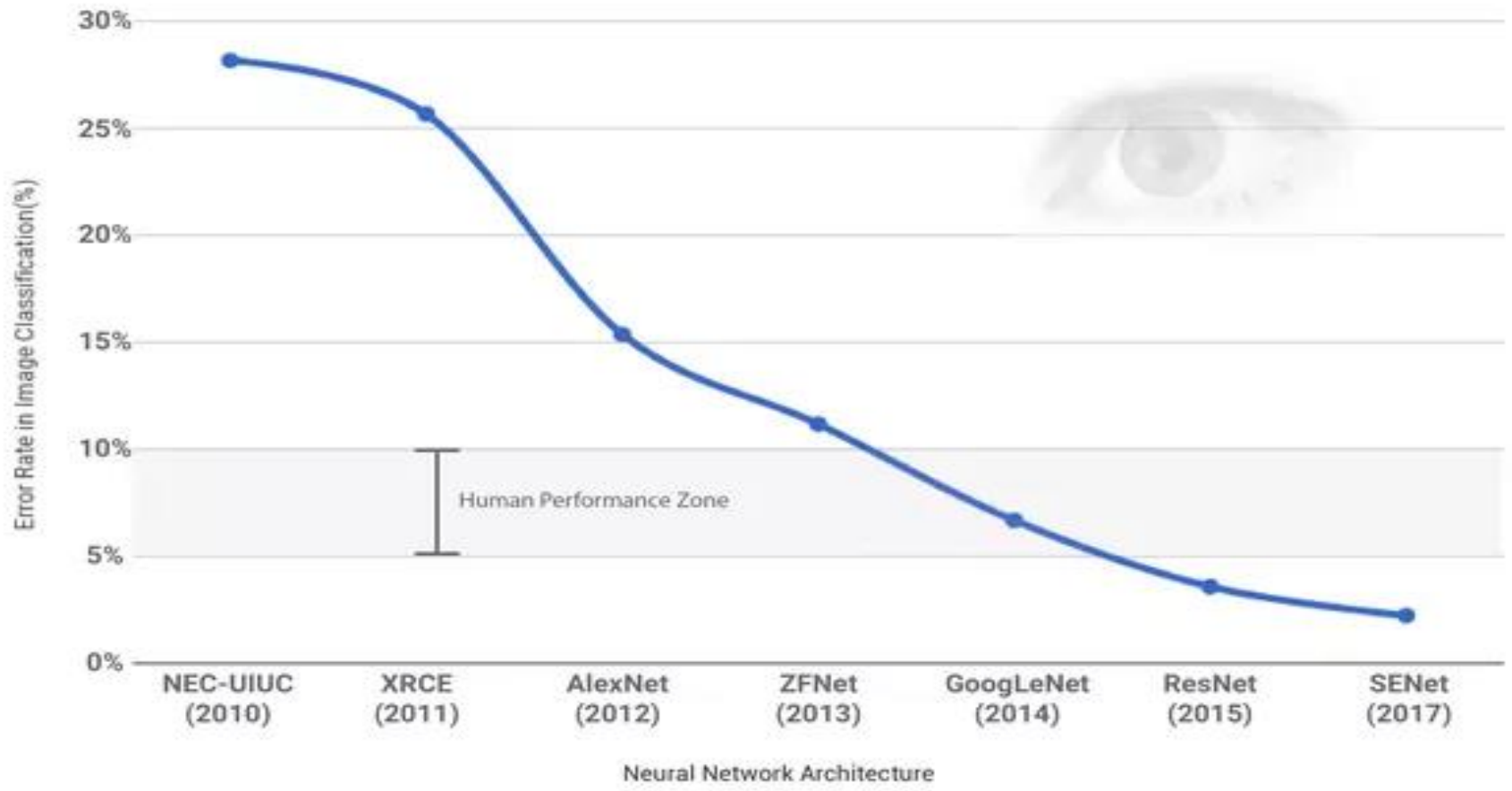
Training set: 1.2 million images (1,000 categories)

Test set: 150,000 images



Are DNNs good enough?

The winning network of 2017 (SENet), achieved an accuracy of 97.74%



Source: http://blog.paralleldots.com/data-science/must-read-path-breaking-papers-about-image-classification/

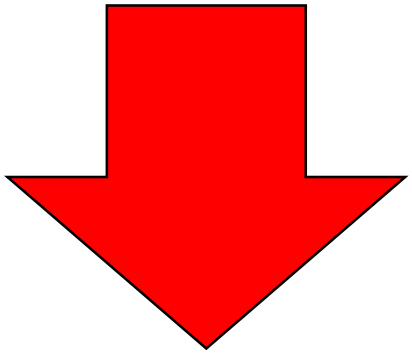
Deep Neural Networks in Safety Critical Scenarios:

1. Certification Issues

Certification Issues

- Deep Neural Networks do not have a well-defined behavior

- Their results are difficult to be replicated (e.g., changing few pixels of an image may lead to different results)



Huge problem for certification!

Certification Issues

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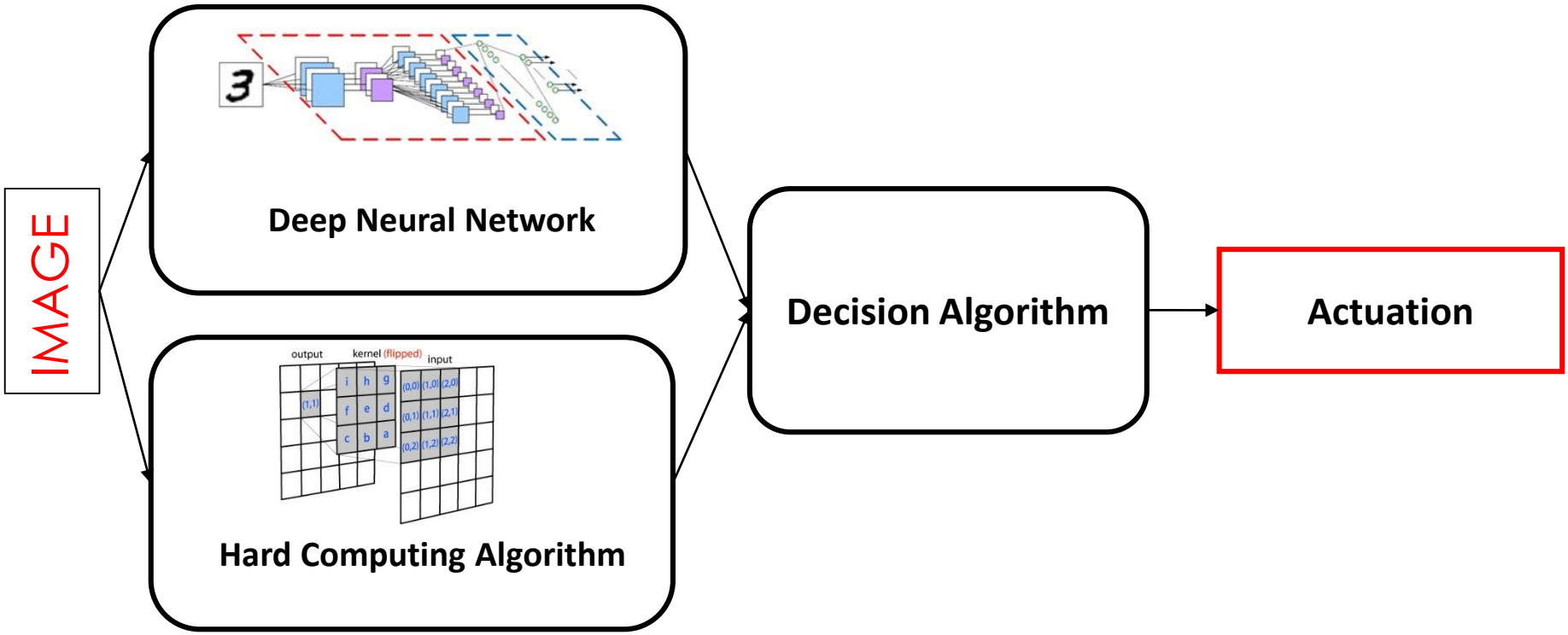
How to support DNNs in a safety-critical context to build a system that can be certified?

Huge problem for certification!

Hint of Solution

IDEA: Match each DNN with a corresponding algorithm based on hard computing (e.g., a convolution filter) to monitor their behavior and redirect the actuation to safe actions in case of detected misbehavior



Example of safe action

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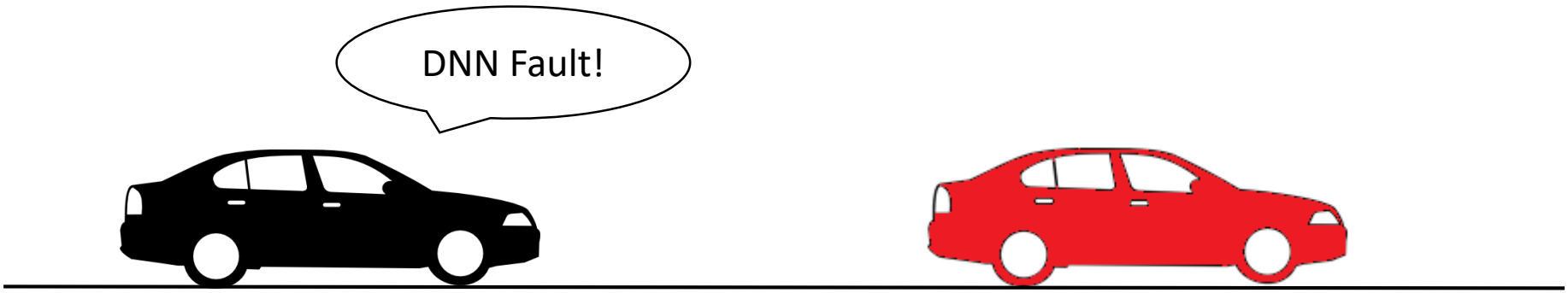

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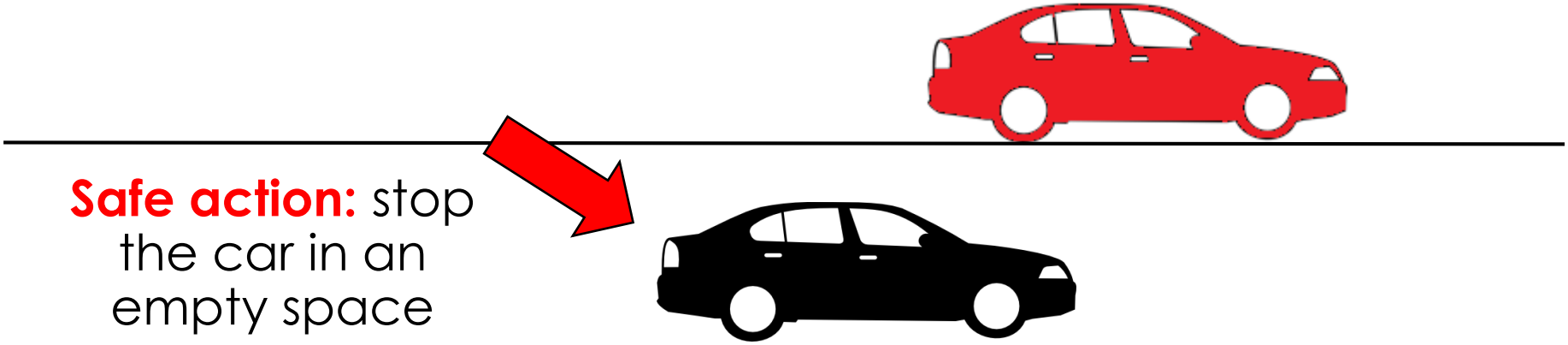
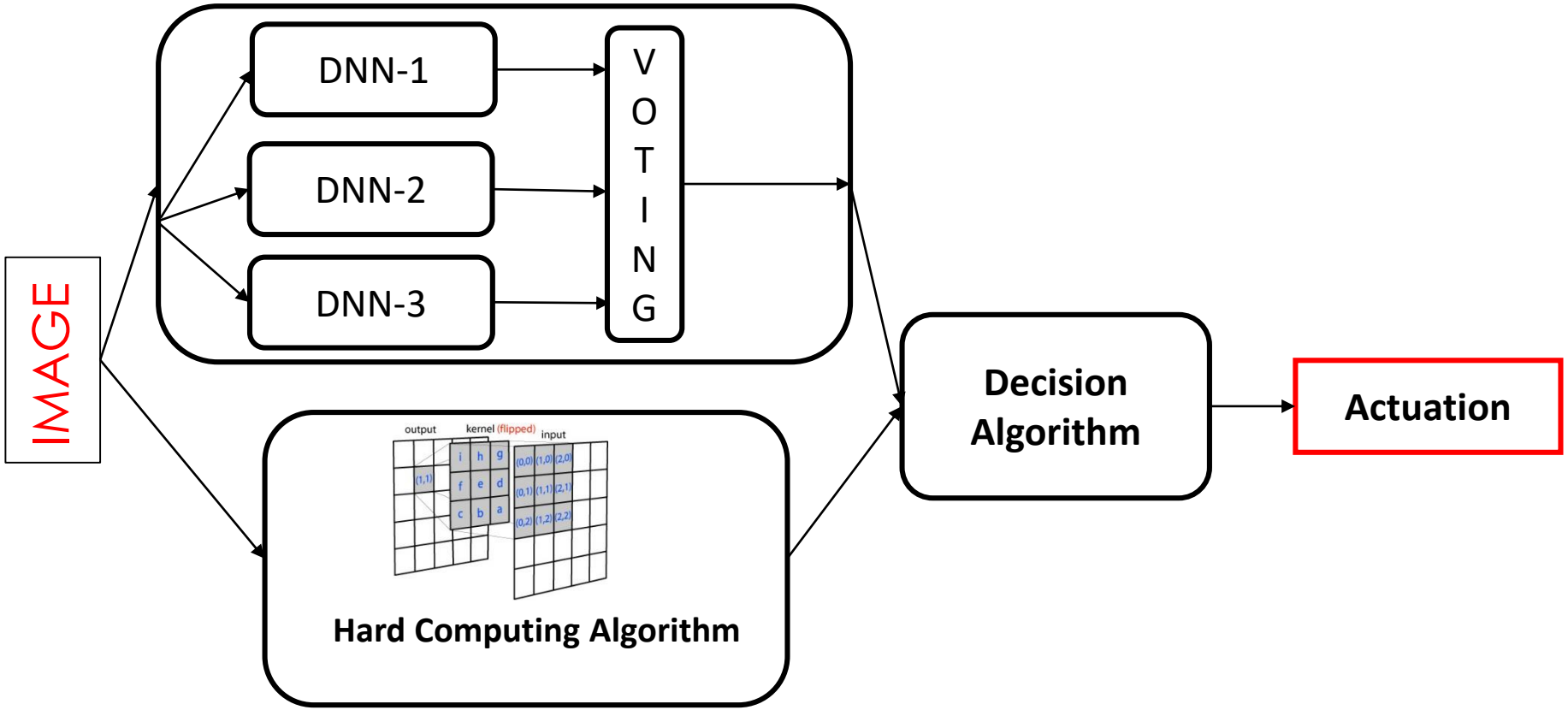


Safe action: stop the car in an empty space

Redundant Neural Networks

The average-case behavior can be improved by inserting redundant neural networks, based on different models or trained with a different algorithm.



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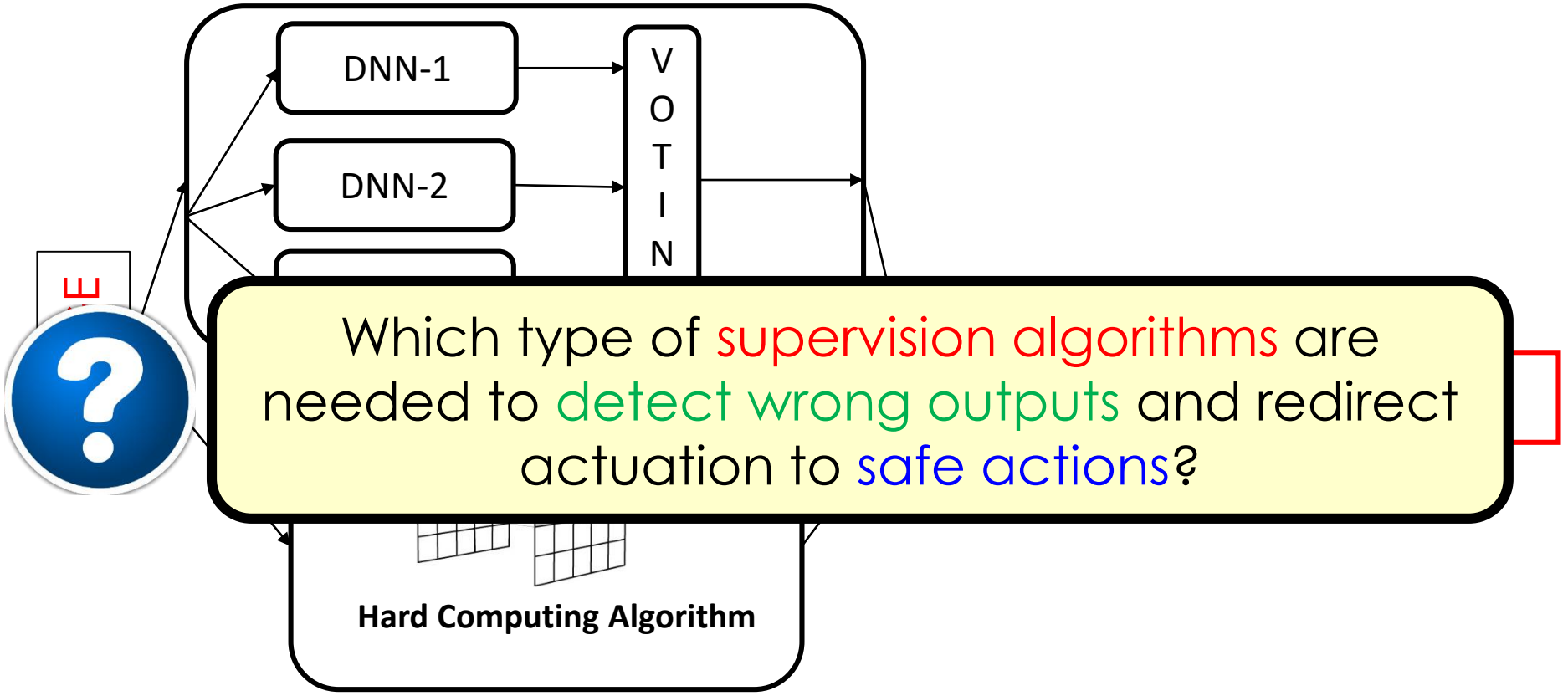


Which type of supervision algorithms are needed to detect wrong outputs and redirect actuation to safe actions?

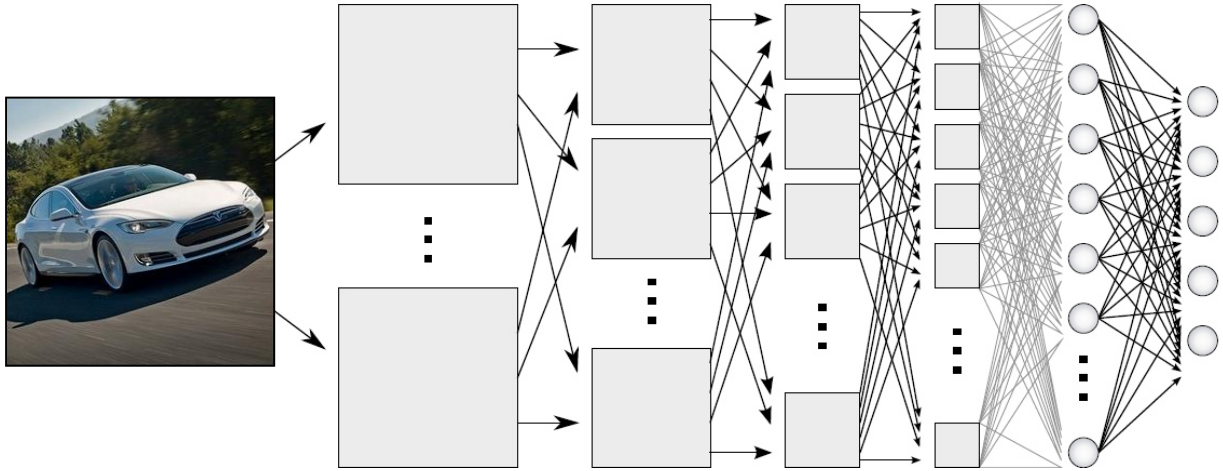
Deep Neural Networks in Safety Critical Scenarios:

2. Security and Isolation

Security and Isolation

- A DNN is a complex software, exposed to security threats

- What if an attacker exploits the weakness of a DNN to take control of the steering system?



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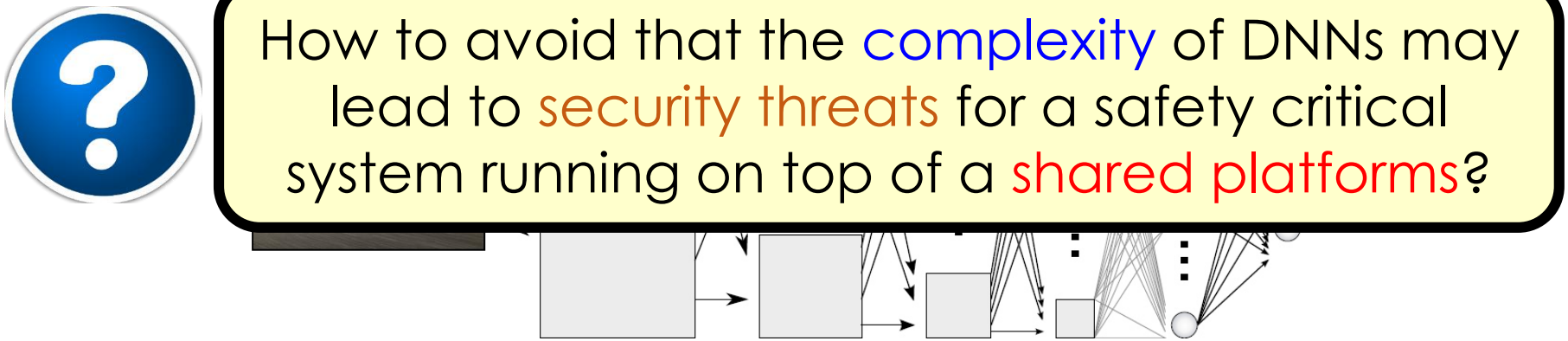


How to avoid that the complexity of DNNs may lead to security threats for a safety critical system running on top of a shared platforms?

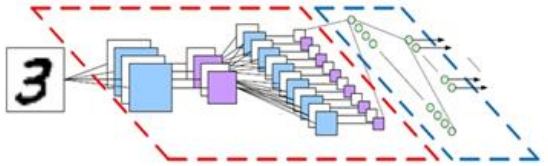
A hypervisor-based solution

IDEA: Divide a multicore heterogeneous platform in two domains

Safety-critical

AUTOSAR

Prone to attacks and malfunctioning



Deep Neural Networks

TensorFlow™ Caffe

Hypervisor

Multicore Heterogeneous Platform

A hypervisor-based solution

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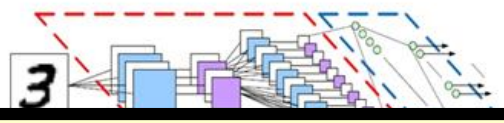


Which mechanisms have to be provided to allow them interacting while running on different OSes?

Hypervisor

Multicore Heterogeneous Platform

Deep Neural Networks in Safety Critical Scenarios:

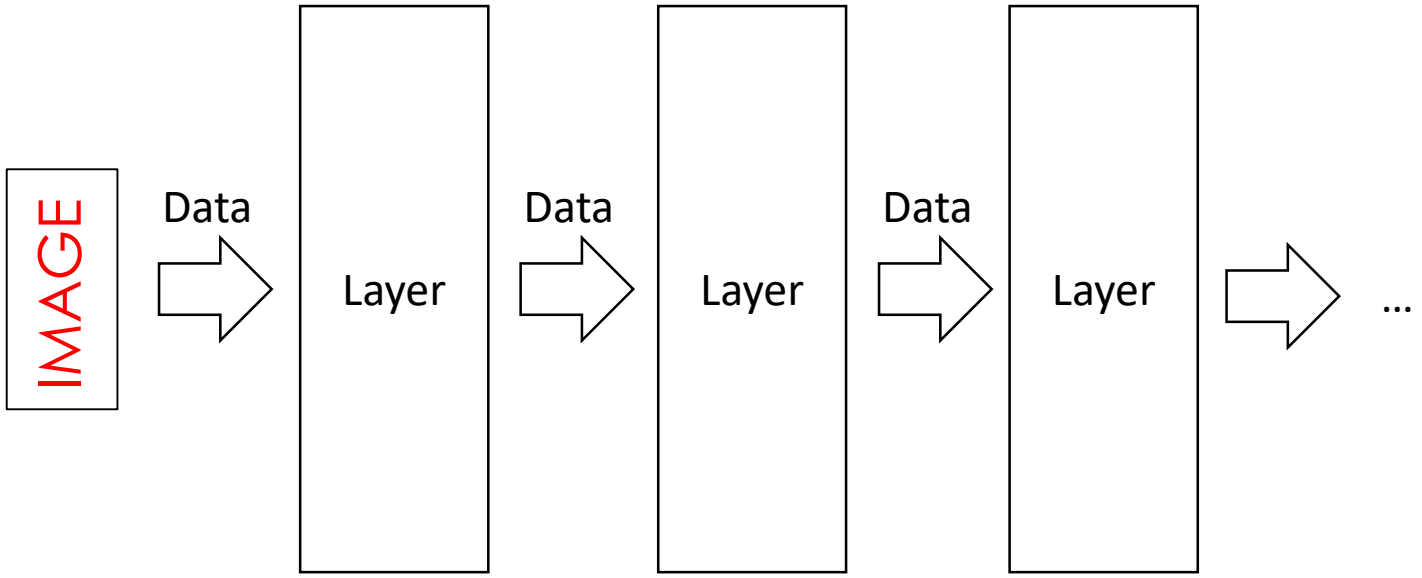
3. Predictability

Predictability

KEY ISSUE: Guaranteeing that a real-time workload composed of DNNs is schedulable

- Focus on the inference phase only

- A DNN is composed of a pipeline of layers, where each one implements an operation

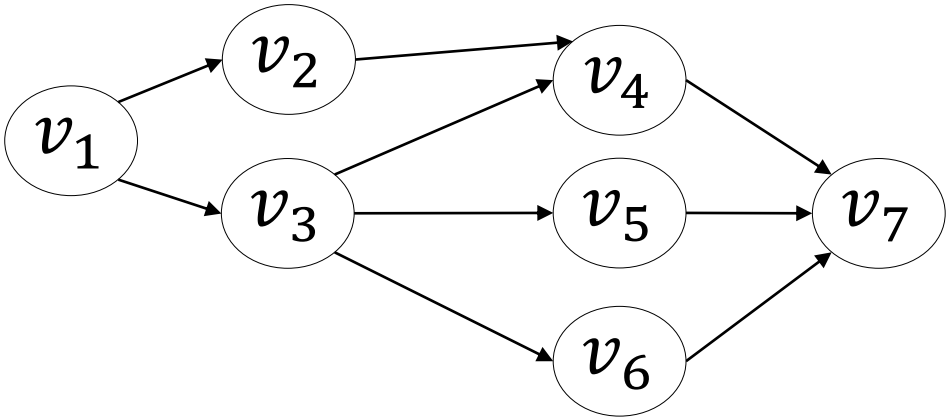


Predictability

- Many inference frameworks furtherly parallelize each layer

- The resulting computational activity can be represented by a Direct Acyclic Graph (DAG)

- A properly defined task model should also account for tensors (i.e., memory) exchanged among nodes



Predictability

- Many inference frameworks furtherly parallelize each layer
- The resulting computational activity can be represented by a Direct Acyclic Graph (DAG)
- A properly defined
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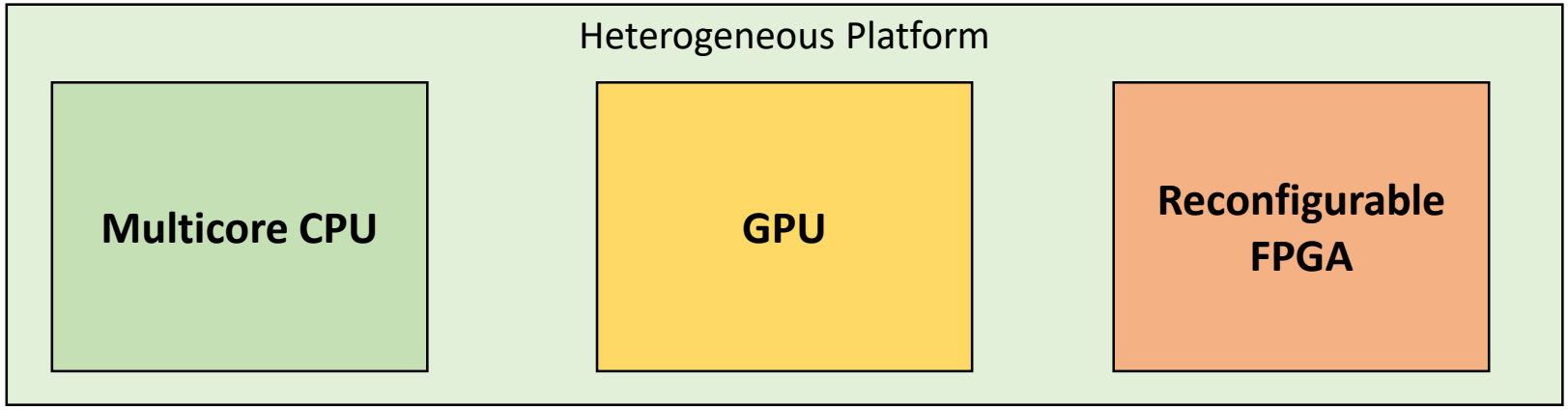
Which is a suitable task model to describe and analyze the temporal behavior of DNNs?

Heterogeneous Platforms

- Timing analysis should also account for the heterogeneity of the underlying hardware platform
- DNN execution on FPGA is not yet fully supported by inference engines

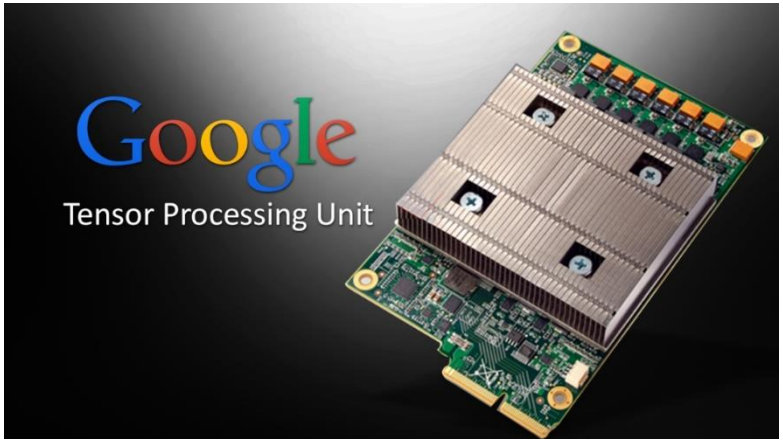
  Dynamic partial reconfiguration can be exploited for accelerating complex layers



Heterogeneous Platforms

- Recently, ad hoc application specific integrated circuits have been recently produced (e.g., the Tensor Processing Unit by Google)

- They can be included in commercial heterogeneous platforms soon



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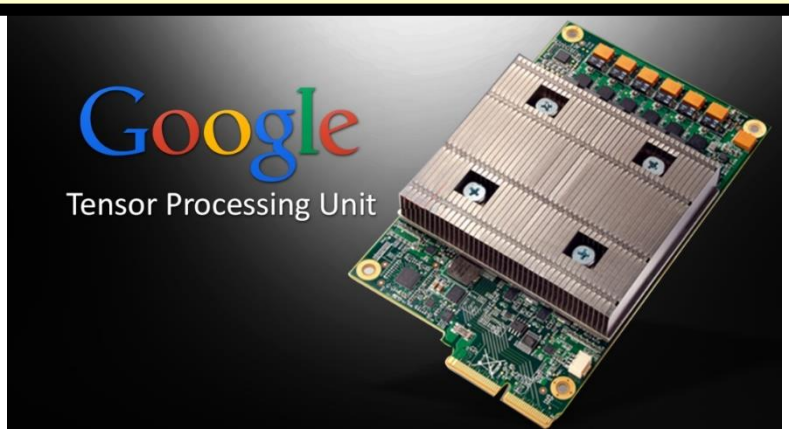
How to account for novel (highly heterogenous) computing platforms?



Inference Engines

- DNNs are typically executed by means of inference engines
  - Inference engines can affect the execution of DNNs

Caffe

TensorFlow™

Google

theano

torch

Inference Engines

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  - Inference engines can affect the execution of DNNs

How to account for inference engines that affect the DNN's execution?

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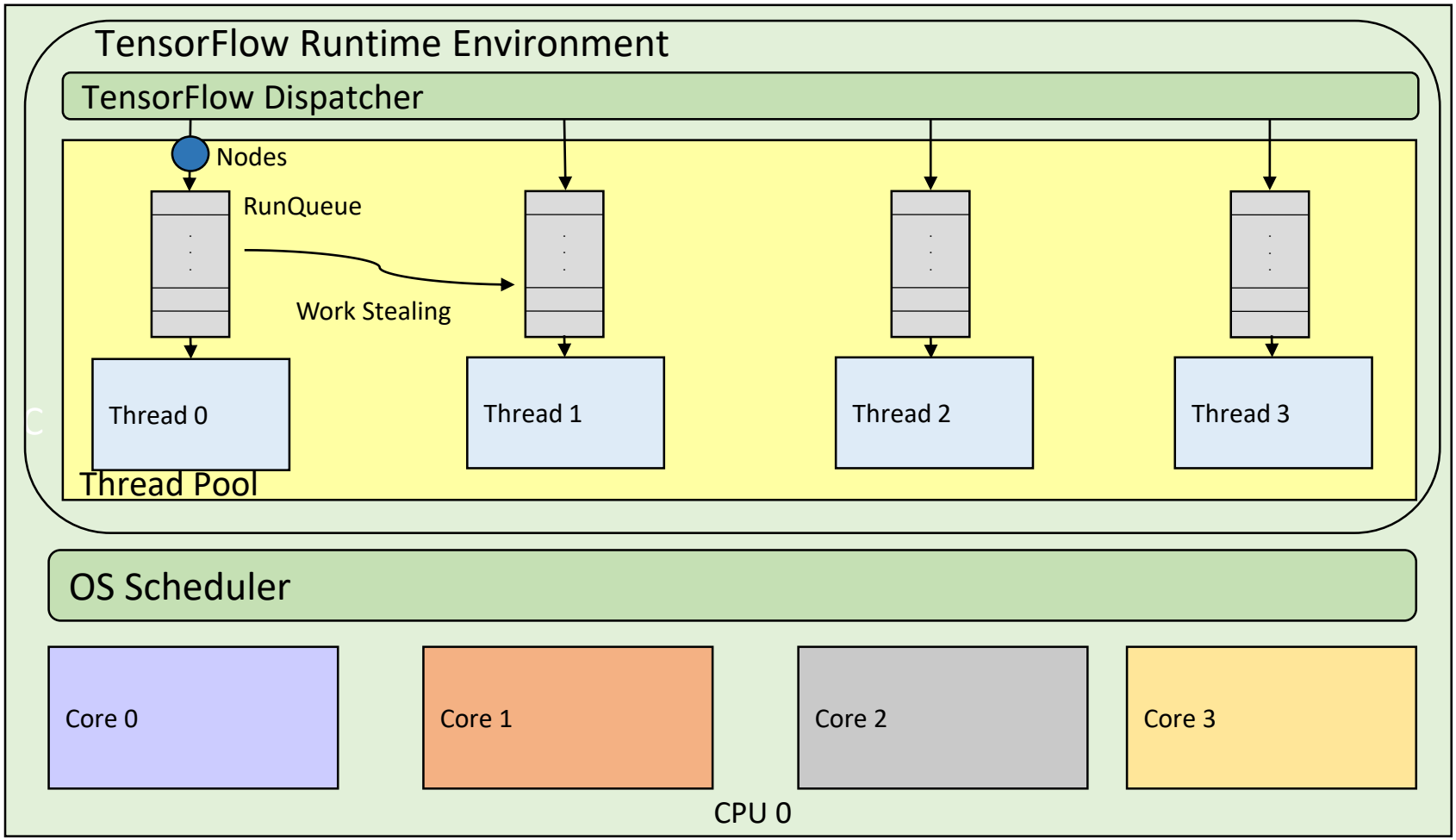
How Tensorflow works on CPUs?

- TensorFlow assigns ready nodes to threads of a thread pool (of globally-scheduled threads)



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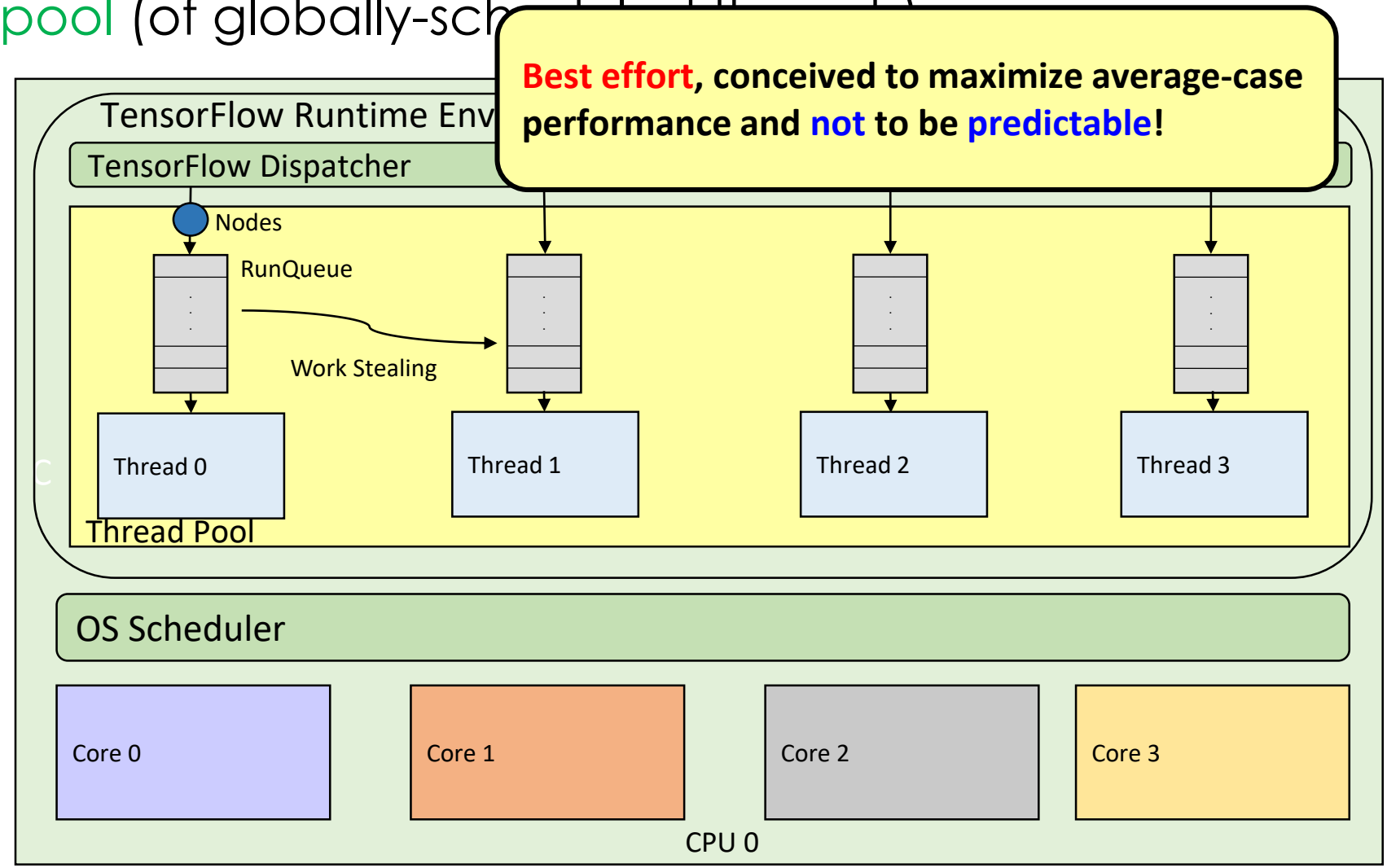

What we are doing?

Adding a layer for predictability in **TensorFlow**

- Extracting a computation model from DNNs, deriving precedence constraints, computation time of each node, memory exchanged, etc.
- Providing a **predictable** scheduling layer of nodes also aware of memory accesses
- Designing a partitioning scheme that considers producer-consumer relationships among nodes, for improving cache coherency
- Development of analysis techniques to assess schedulability of neural networks

Summary and conclusions

- Deep Neural Networks represent a promising technique for enacting autonomous driving, but…
  - their adoption in safety-critical scenarios presents many issues
- We focused on:
  - Certificability
  - Security and Isolation
  - Predictability

Summary and conclusions

- Deep Neural Networks represent a promising technique for enacting autonomous driving, but…

There is still a lot of work to do…

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- We focused on:
  - Certificability
  - Security an
  - Predictabili

Let's start!

Thank you!

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