Meta-Modeling and Self-Aware Networks

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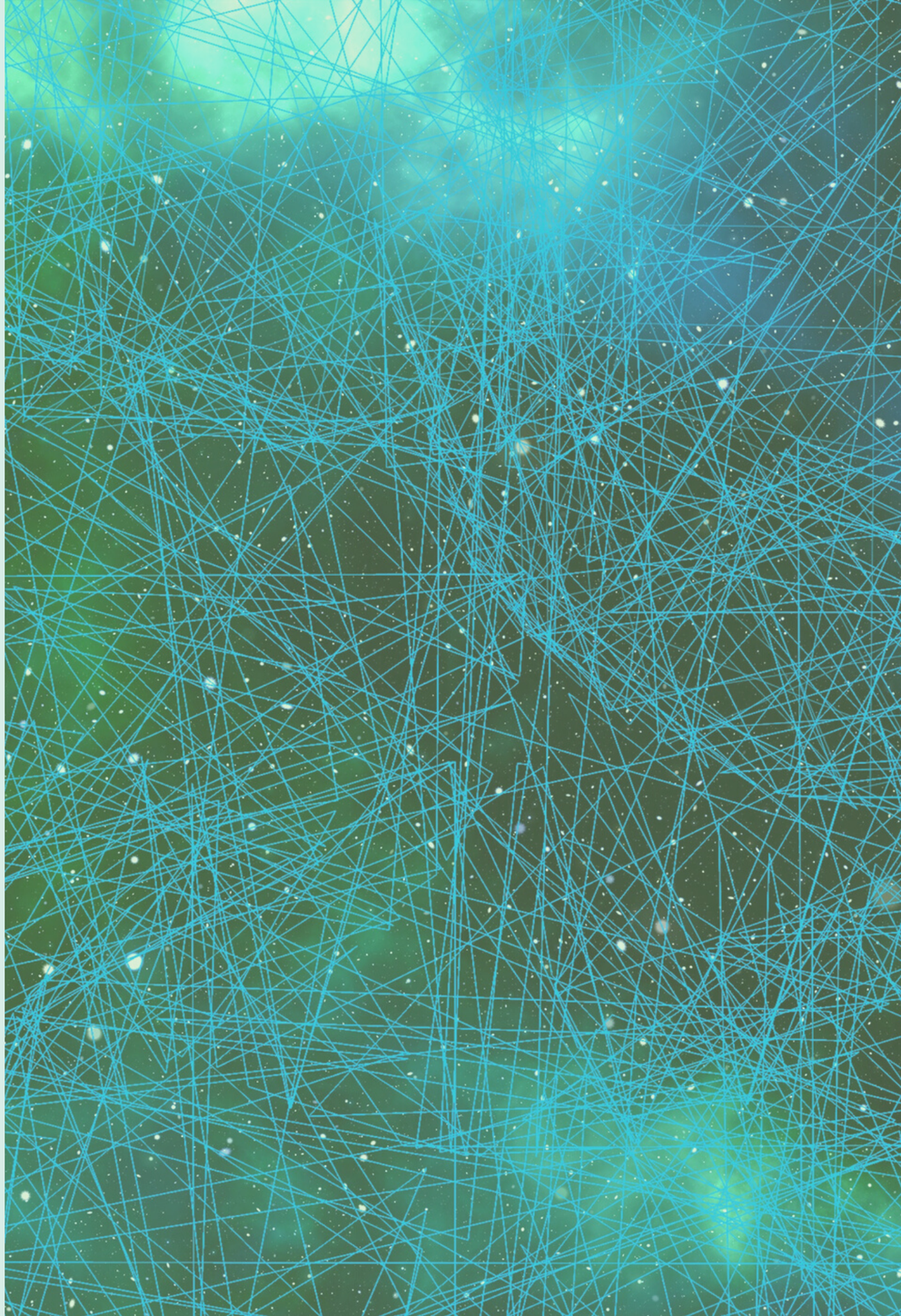


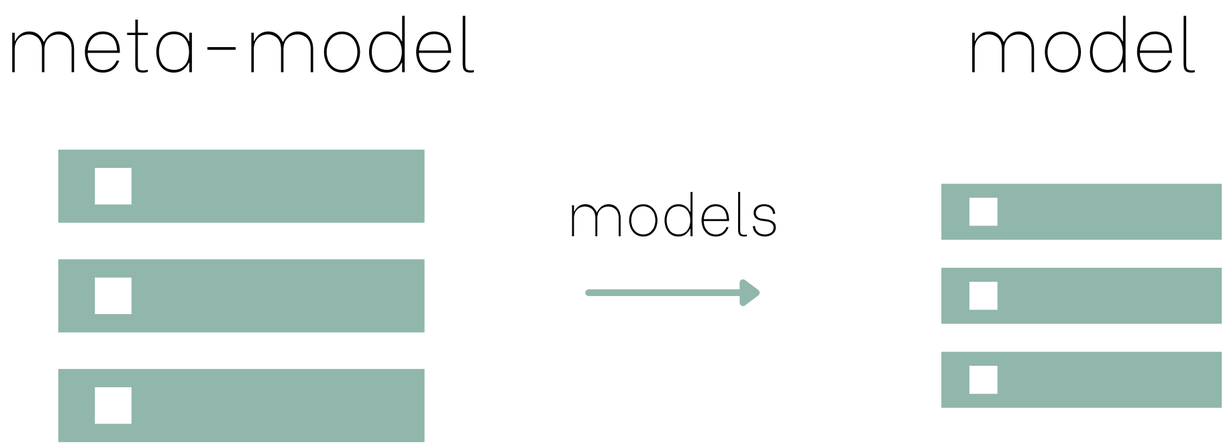
A representation of a phenomena learned from collected data.

Modeling (ML)

A representation of a set of models learned from observed behavior and state.

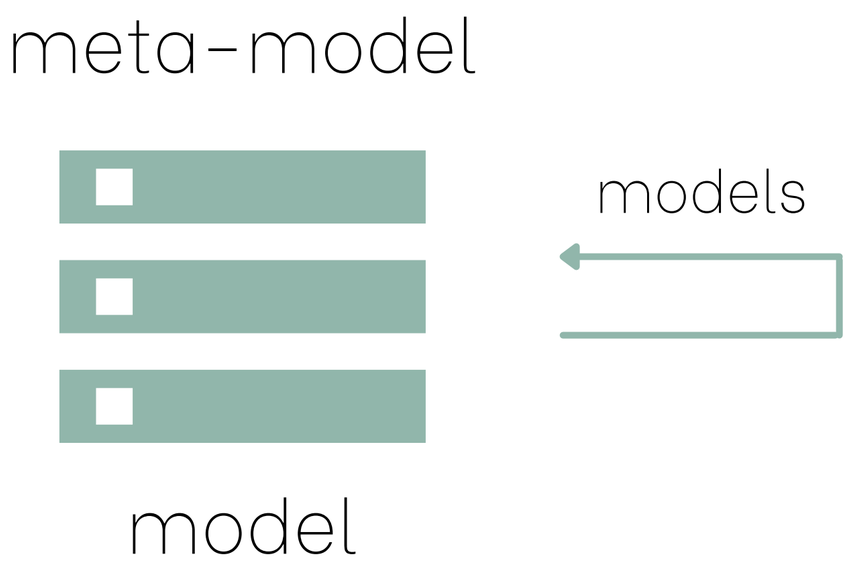
Meta-Modeling

2 Meta-Models



External Meta-Modeling

2 Meta-Models

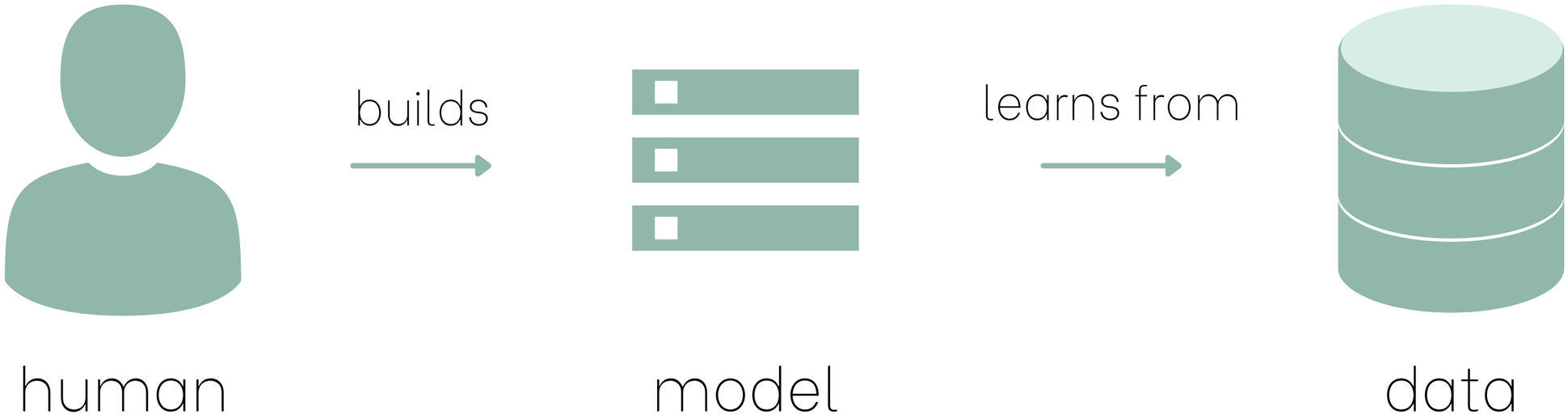


Internal Meta-Modeling
Self-Awareness

Humans can perform and integrate internal and external meta-modeling, e.g. teaching ourselves vs. teaching others.

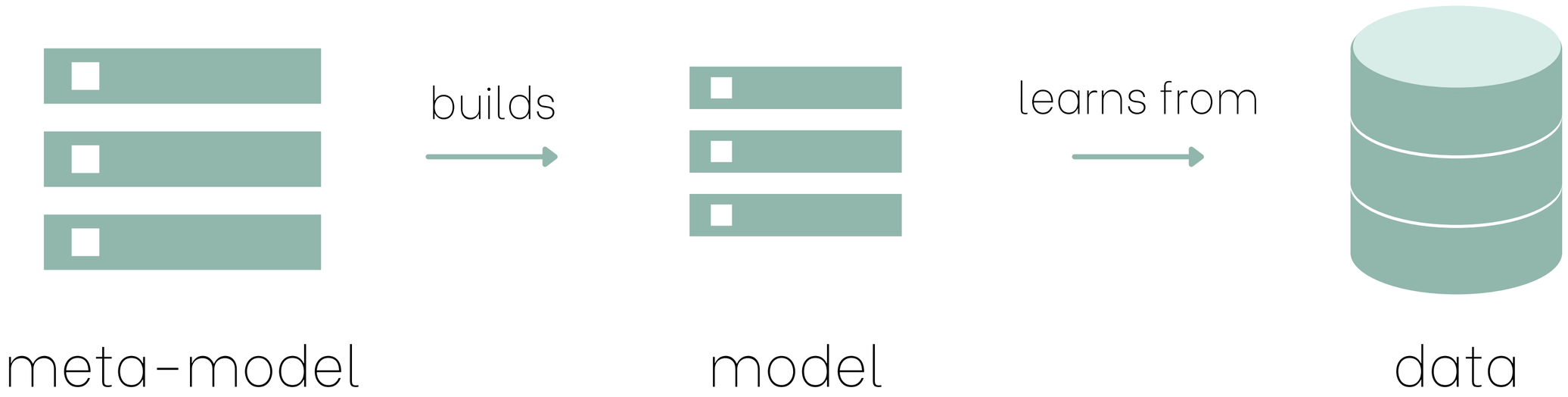
External Meta-modeling

Hyperparameter Optimization



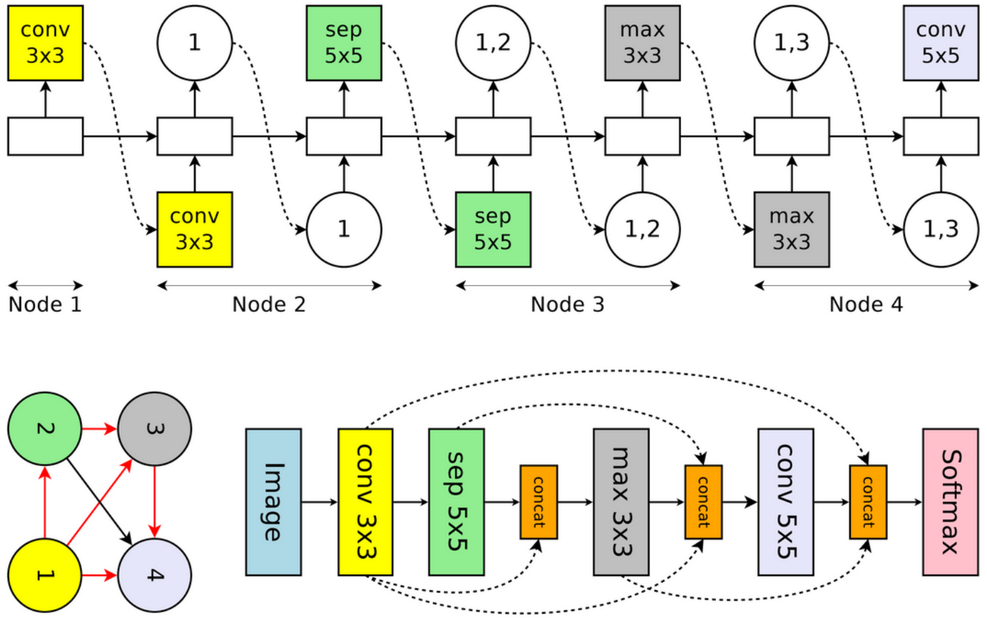
Traditional Modeling Process

Hyperparameter Optimization



Optimizing the Traditional Modeling Process

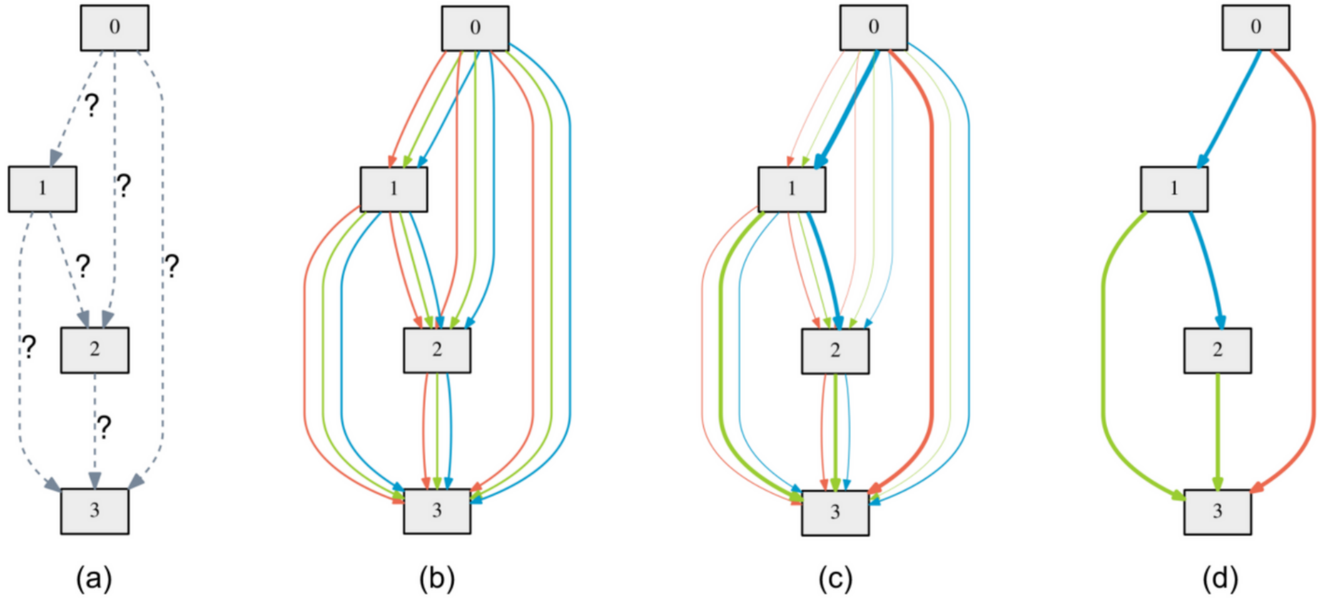
Neural Architecture Search



Efficient Neural Architecture Search (ENAS)

(Pham et al., 2018)

Neural Architecture Search



Differentiable Architecture Search (DARTS)

(Liu et al, 2019)

Neural Architecture Search

NAS is a **very difficult field** to research.

- Extraordinarily high computing costs
- Tremendous effort into designing meta-model and model search representation
- Limited applications in current state.

Internal Meta-modeling

Where’s the research?

Internal meta-modeling has a less direct value proposition. Therefore, it is **significantly less researched.**

Research on self-aware networks tends to…

- …incorporate biological or neurological perspectives
- …involve older/classic techniques and concepts
- …focus on robotics & RL-type problems

A note on the *self*

The concept of the *self* has many different definitions.

- The neural network itself
- The robot itself
- The software system itself

Literature Definitions of SA

Kounev's definition.

- *Self-reflection.* System should be aware of its environment, operational goals, quality of service reqs., and changes.
- *Self-prediction*. System should be able to predict effects of a dynamic environment and goals.
- *Self-adaptation*. System should be able to adapt to changes to ensure its goals are satisfied.

Jantsch's definition.

Learning from the history and dynamic goal management

"Self-Aware Neural Network Systems: A Survey and New Perspective" (Du, Guo, Zhao, Zhi, Chen, Xu)

Continuous Self-Modeling (2006)

- Aims to simulate biological healing through repairing itself
- “A robot is able to indirectly infer its own morphology through self-directed exploration and then use the resulting self-models to synthesize new behaviors. If the robot’s topology unexpectedly changes, the same process restructures its internal self-models, leading to the generation of qualitatively different, compensatory behavior“

“Resilient Machines Through Continuous Self-Modeling“ (Bongard)

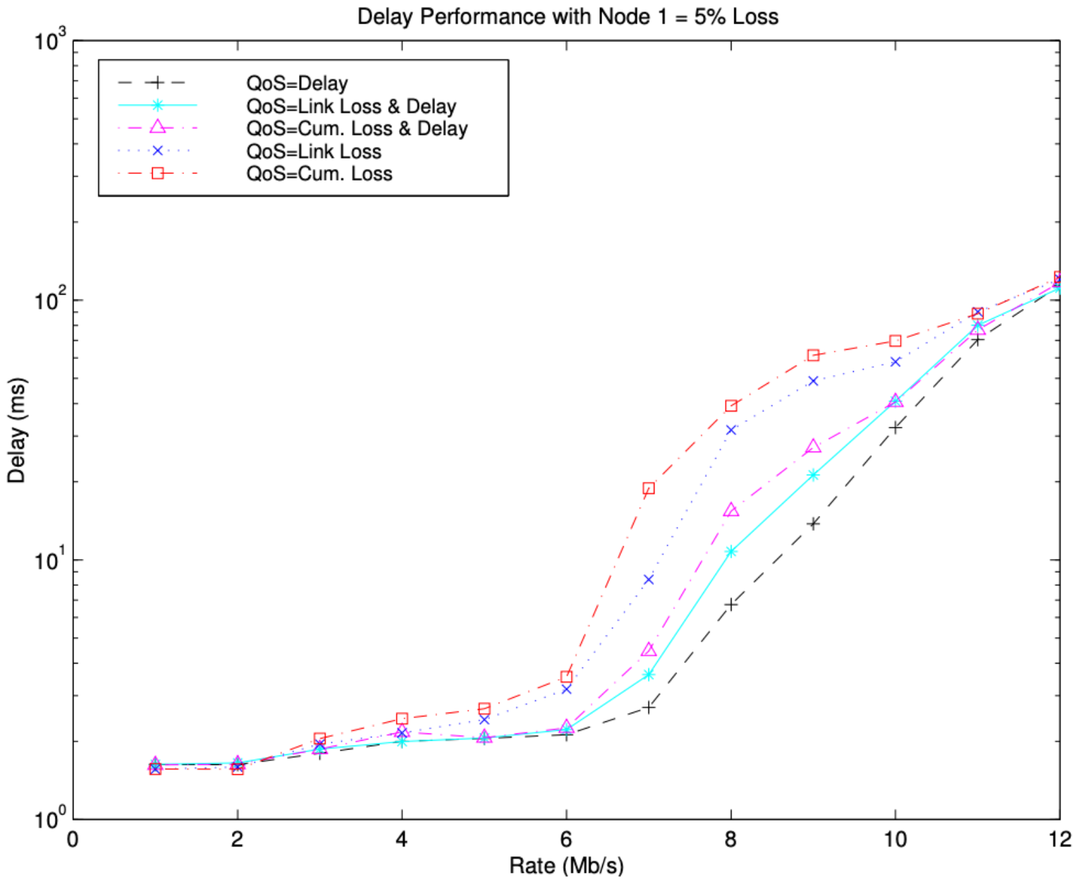
CPN Approach (2011)

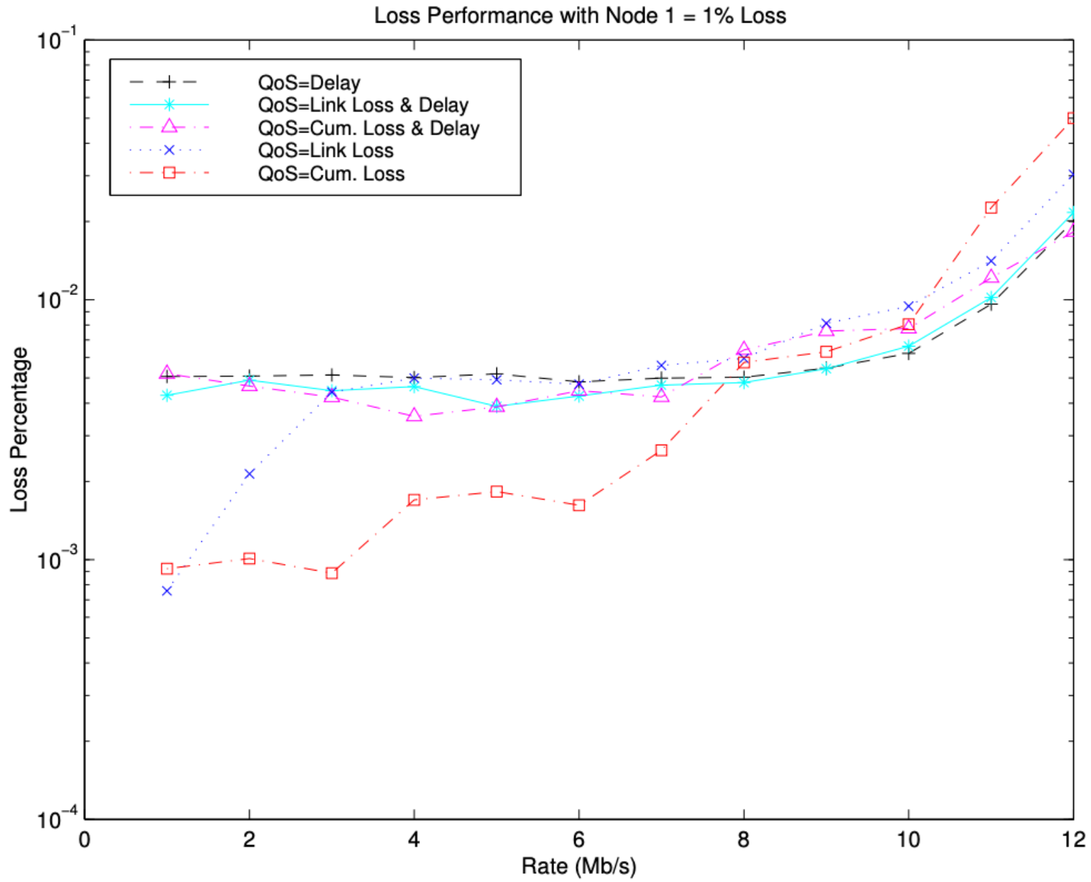
Cognitive Packet Network: A self-aware Quality of Service (QoS)-driven routing protocol

- Payload packets – carry information to be routed
- *Smart packets (SPs)* – explore network and obtain routing decisions based on…
  - …local measured QoS metrics
  - …local reinforcement learning algorithm using measurements collected by previous SPs
- *Acknowledgement packets (ACKs)* – when an SP reaches the destination, an ACK is sent back to the source with QoS information at each node along the path
  - ACKs are stored in the CPN's "memory" for future use in routing payload packets

"Self-Aware Networks". Gelenbe, 2011 Fifth IEEE Conference on Self-Adaptive and Self-Organizing Systems.

CPN Approach (2011)





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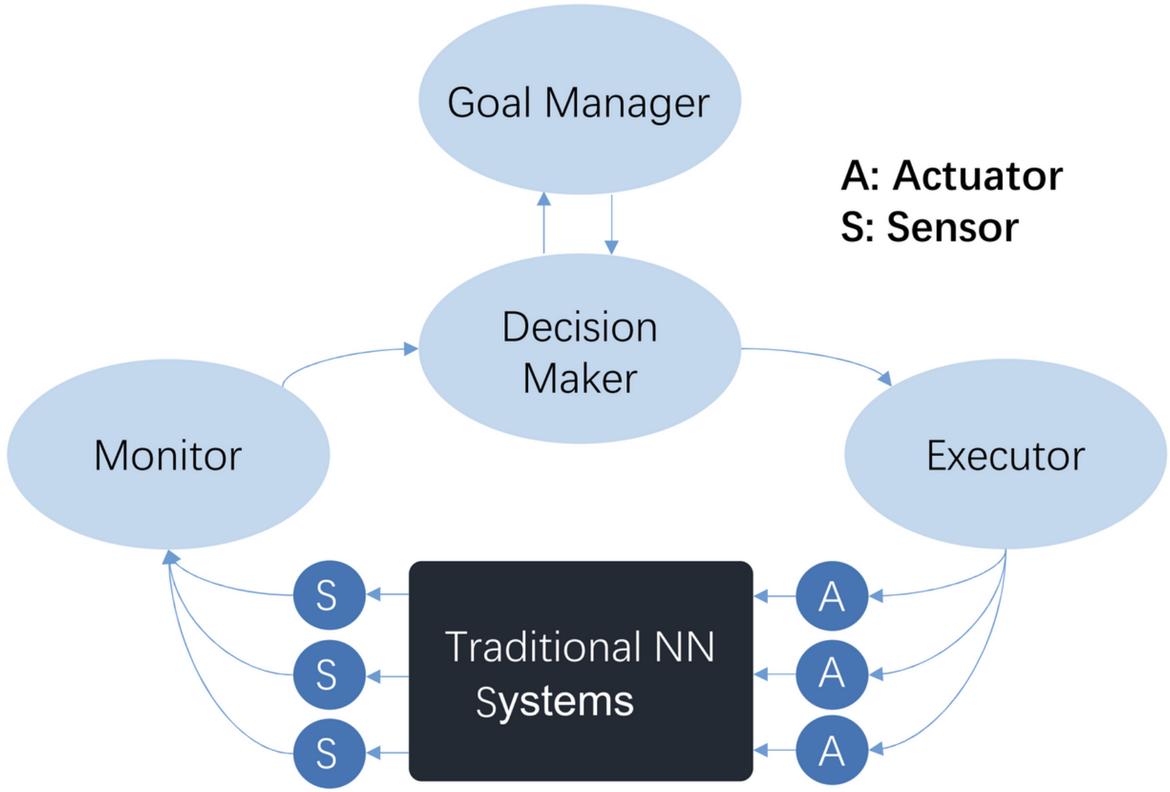
MinMaxNNs (2020)

MinMaxNNs dynamically switch between processing components in response to stimuli to optimize for the overarching goal.

It *understands* which of its faculties are most appropriate for certain problems.



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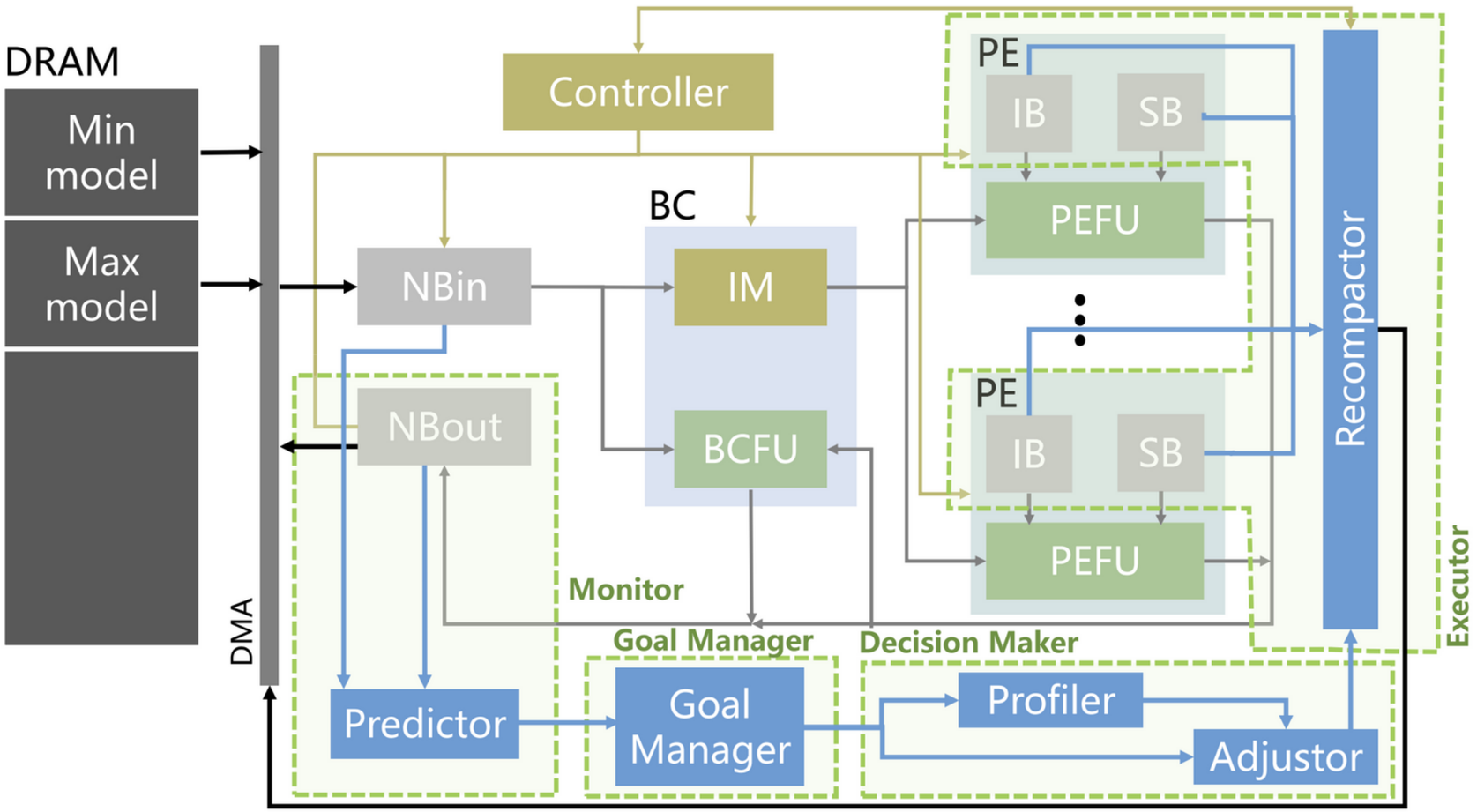

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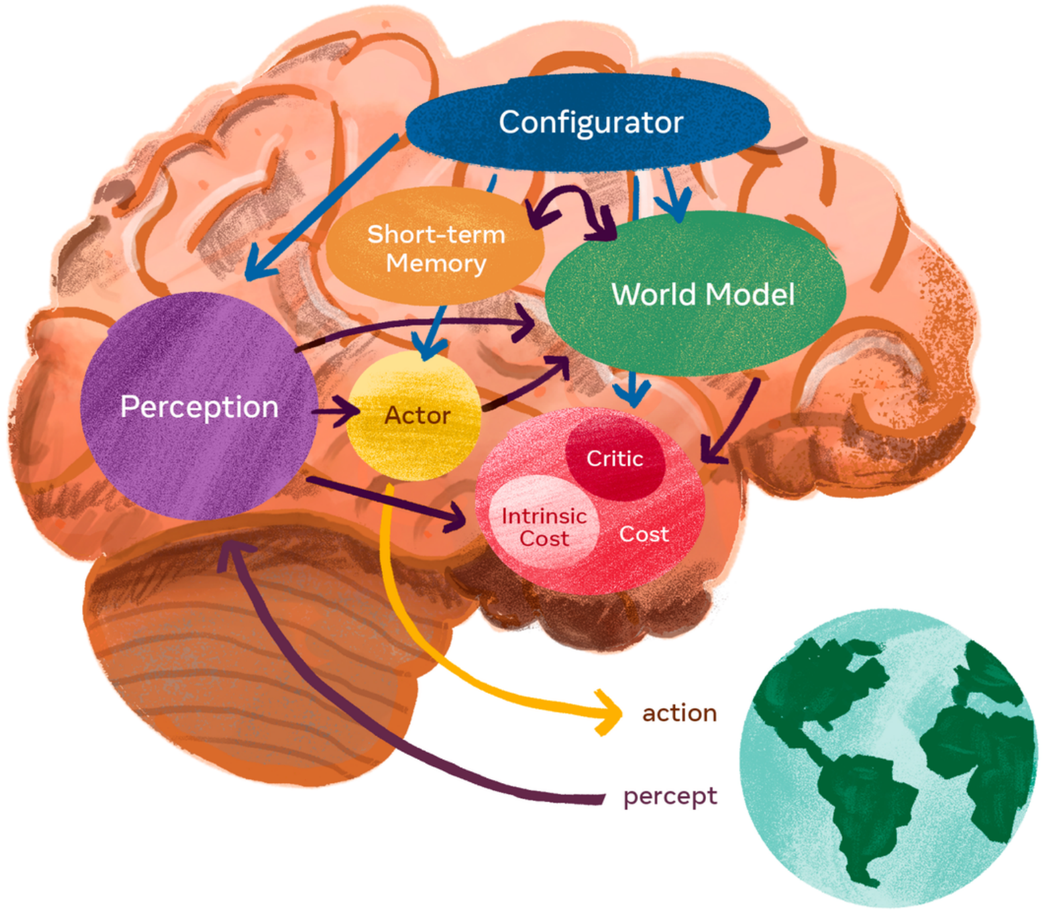
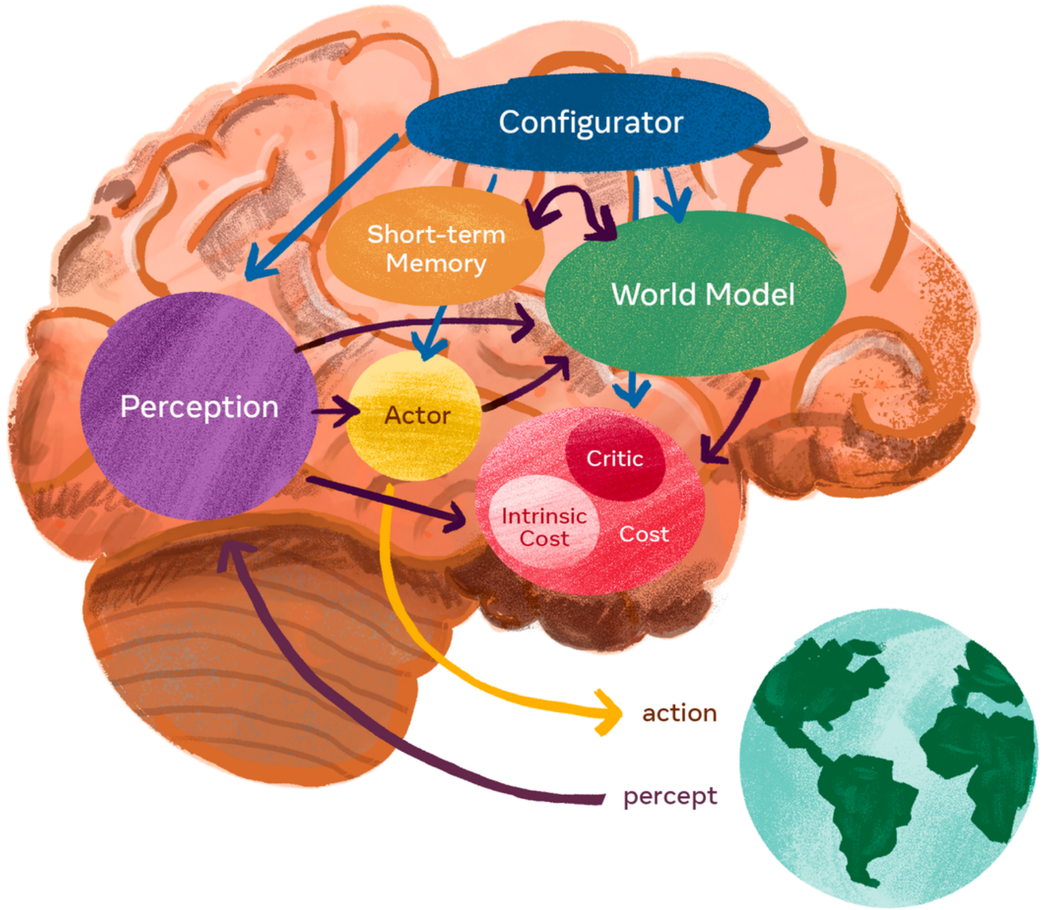
LeCun's World Model (2022)



- Configurator: executive control. Changes & directs meta-parameters of other modules.
- Perception: extracts relevant sensory information.
- World Model: estimate missing world state information, predict plausible future world states.

LeCun's World Model (2022)



- Cost: computes scalar discomfort value. Intrinsic cost + immediate discomfort.
- Actor: proposes future actions. Pursues actions that minimize the estimated future cost.
- ST Memory: keeps track of current & future world states

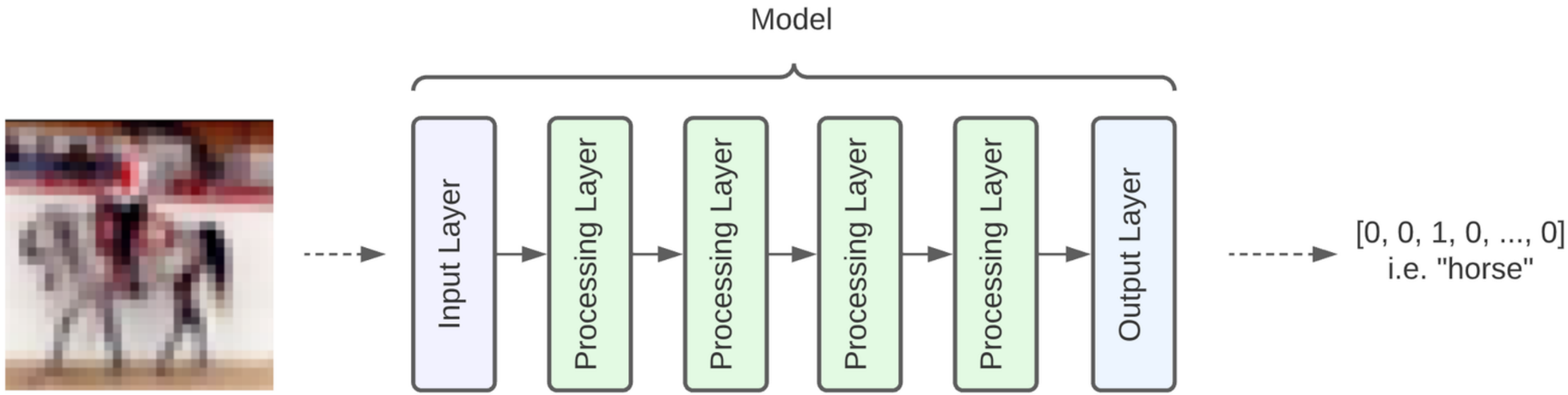
Project Ideas

Central Question

How can we force neural networks to develop representations of themselves?

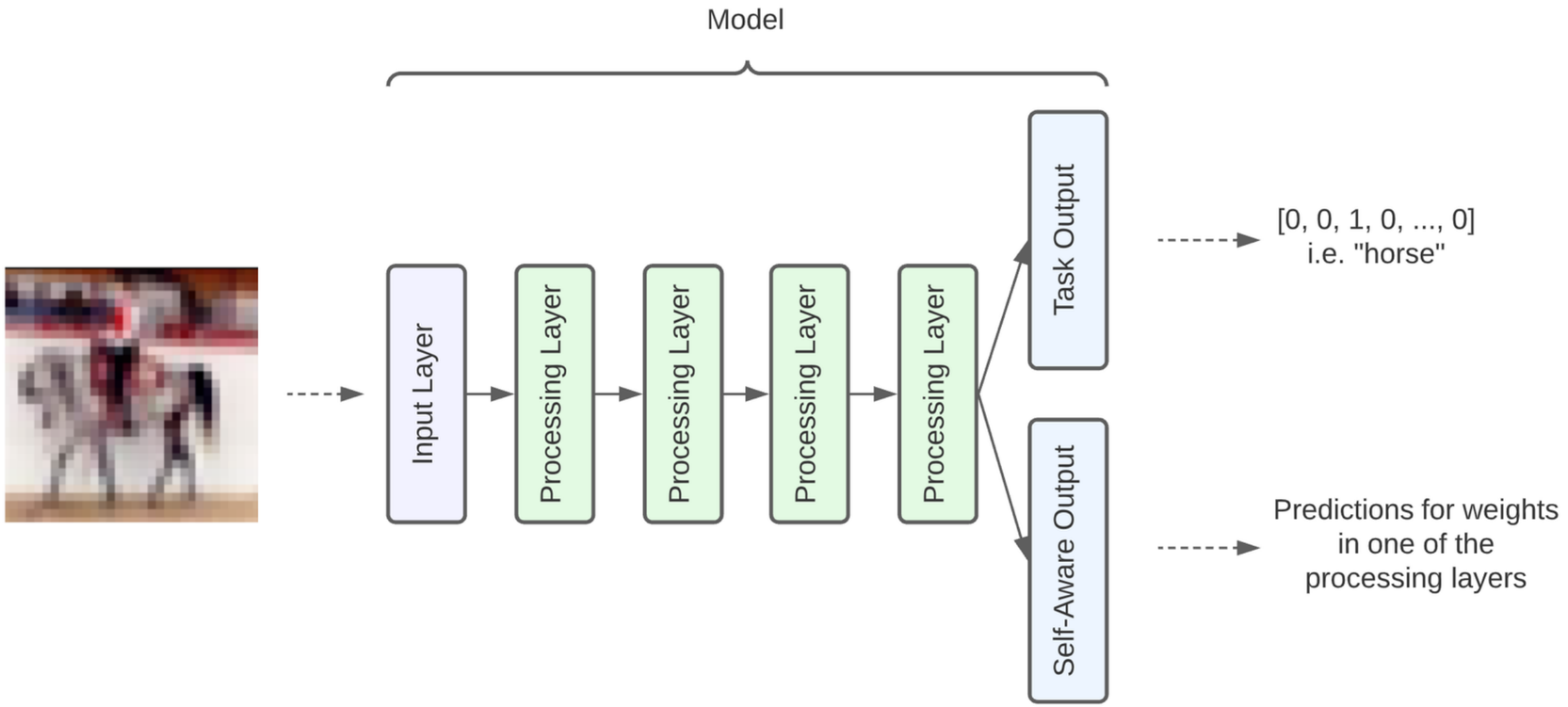
Self: architecture, weight values, knowledge, etc.

Self-Representing Networks



Standard Neural Network Task

Self-Representing Networks



$$\text{loss} = \alpha \cdot \text{BCE}\left(y_{\text{task pred}}, y_{\text{task true}}\right) + (1 - \alpha) \cdot \text{CosSim}\left(y_{\text{param pred}}, y_{\text{true params}}\right)$$

Additional Ideas

- Generating pictures/graphs of one's own architecture
- Generate natural language descriptions of how it is being trained and/or the model architecture
- Predicting which optimizer/loss the network is being trained on
- A discrete autoencoder but the inputs and outputs are graph/sequence representations of neural networks
- Meta-model that 'communicates' to a model in order to build it into a model that functions like the meta-model (meta-evolution!)

Thank you!