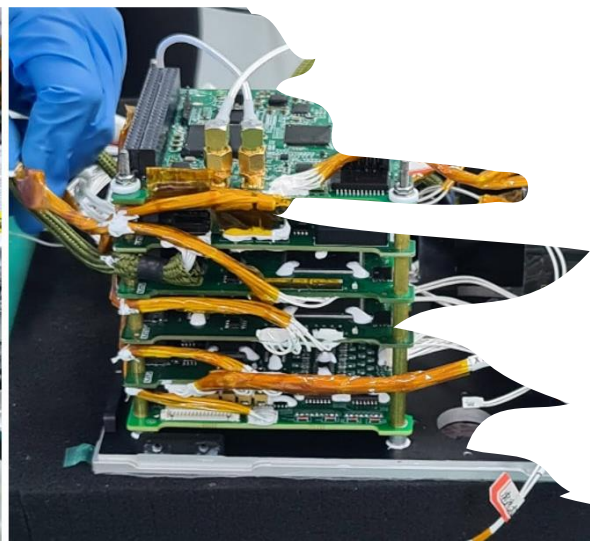




Enhancing Artificial Intelligence by Using Physics Informed Neural Networks

Dr. Syed Ali Irtaza

Assistant Professor
Electrical Engineering Department
Institute of Space Technology



[Institute of Space Technology, Islamabad. \(ist.edu.pk\)](http://ist.edu.pk) is a degree awarding entity and offers various graduate/undergraduate programs

Research Life

- Wireless Communications
- Autonomous Navigation for Air and Ground Vehicles
- Bio Signal Processing



TECHOTILS

- RnD based Startup
- Working on utilizing the benefits of AI and IoT to solve the problems of daily life

What is AI?

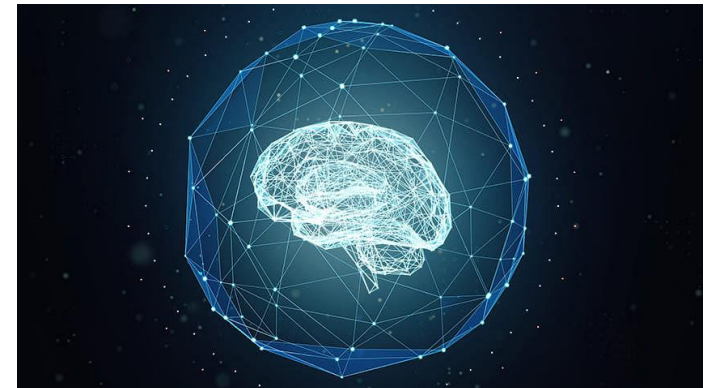
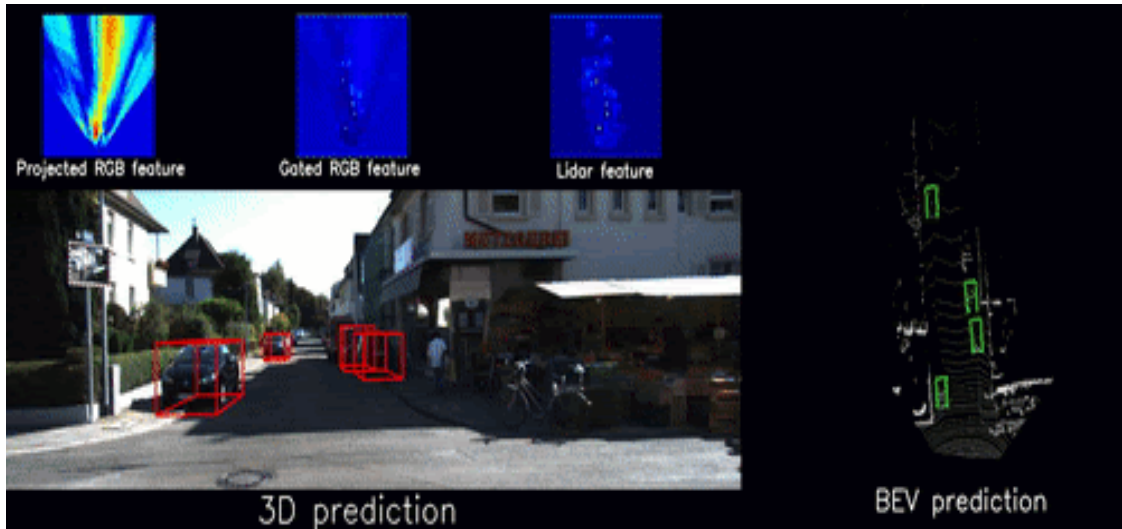
There are many definitions worked by different groups

- US
- European Union
- Others

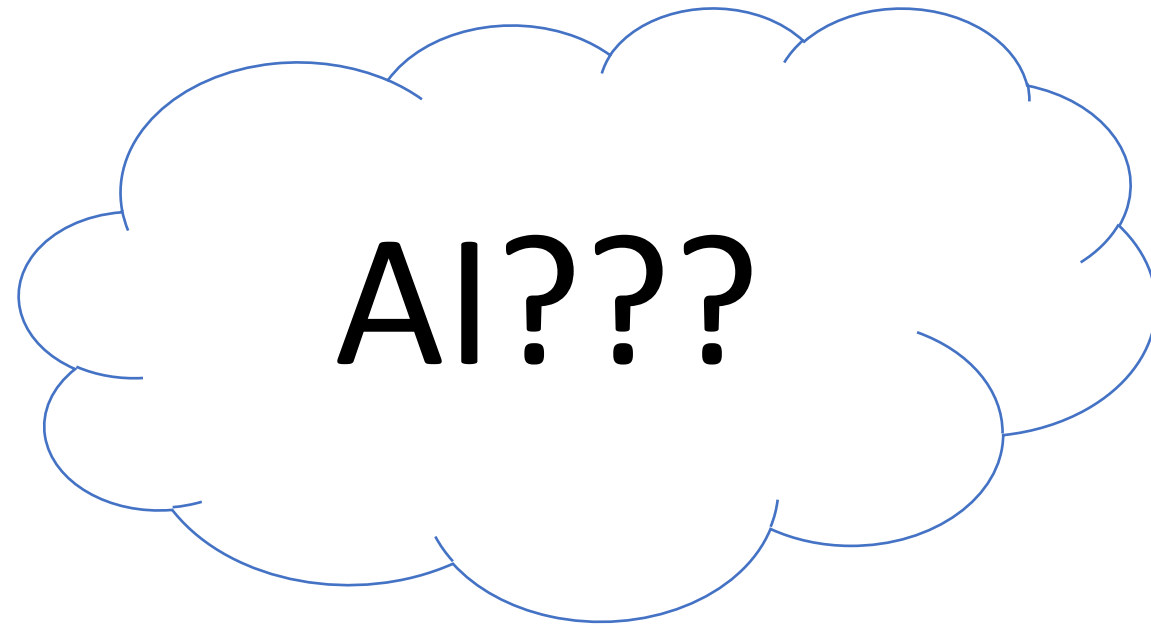
“A system that learns by solving a lot of examples”



AI: What can be Achieved?



AI: How it works?



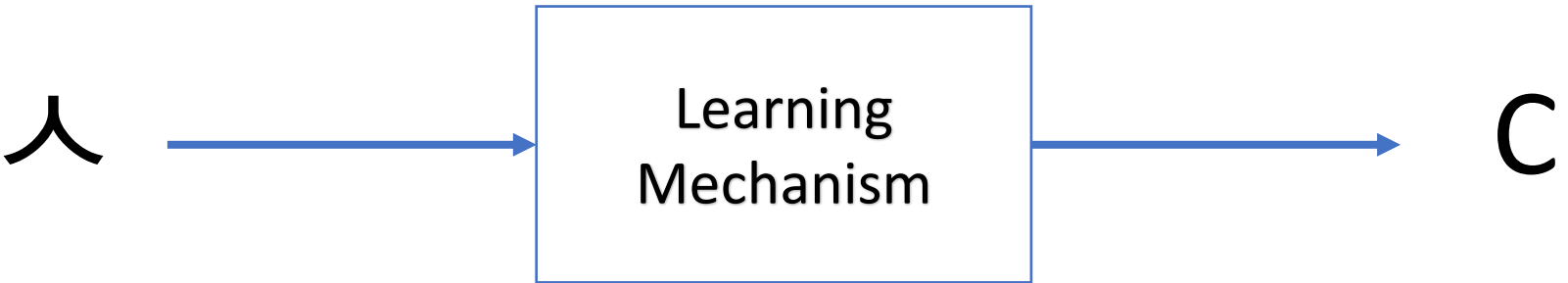
AI for Language Translation



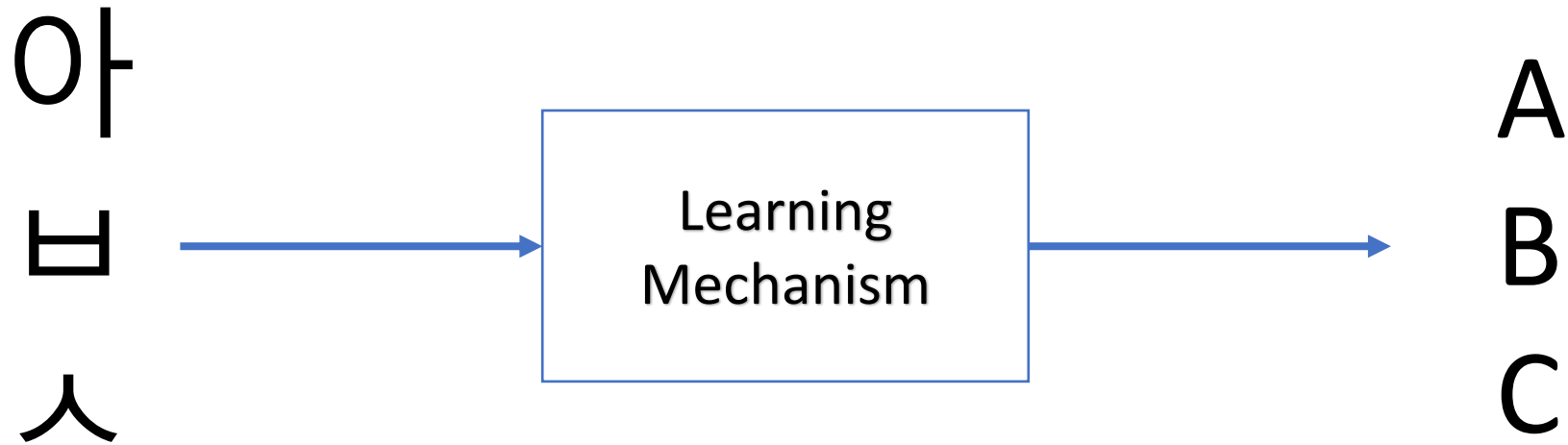
AI for Language Translation



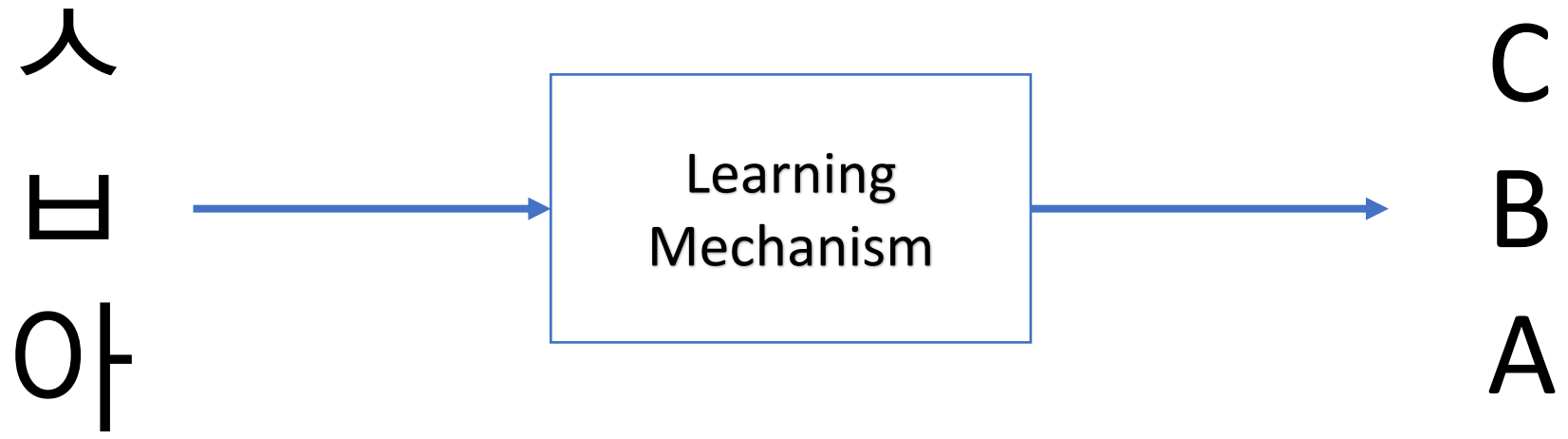
AI for Language Translation



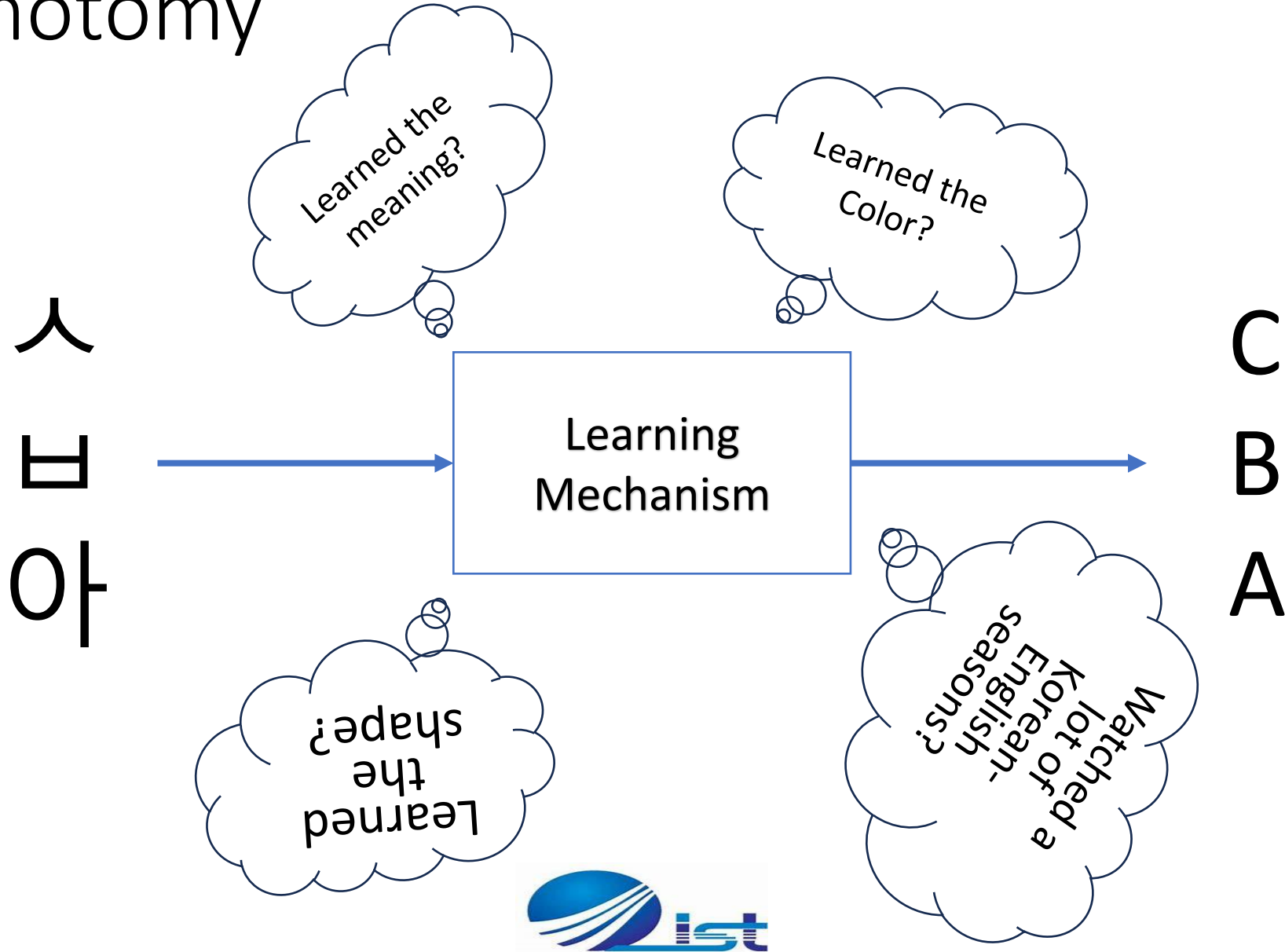
AI for Language Translation



AI for Language Translation



A Dichotomy



A Dilemma

Trust???



12:31 AM
5/27/2024

ChatGPT 3.5 ▾



You

Can you count down from 40 to 60?



ChatGPT

Sure, here you go:

40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12,
11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0. And then:

41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60.



Copilot

Certainly! Let's count down from 40 to 60:

40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26,
25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11,
10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0, -1, -2, -3, -4, -5, -6, -7, -8,
-9, -10, -11, -12, -13, -14, -15, -16, -17, -18, -19, -20,
-21, -22, -23, -24, -25, -26, -27, -28, -29, -30, -31, -32,
-33, -34, -35, -36, -37, -38, -39, -40, -41, -42, -43, -44,
-45, -46, -47, -48, -49, -50, -51, -52, -53, -54, -55, -56,
-57, -58, -59, -60.

There you go! If you need anything else, feel free to ask! 😊 🗣️



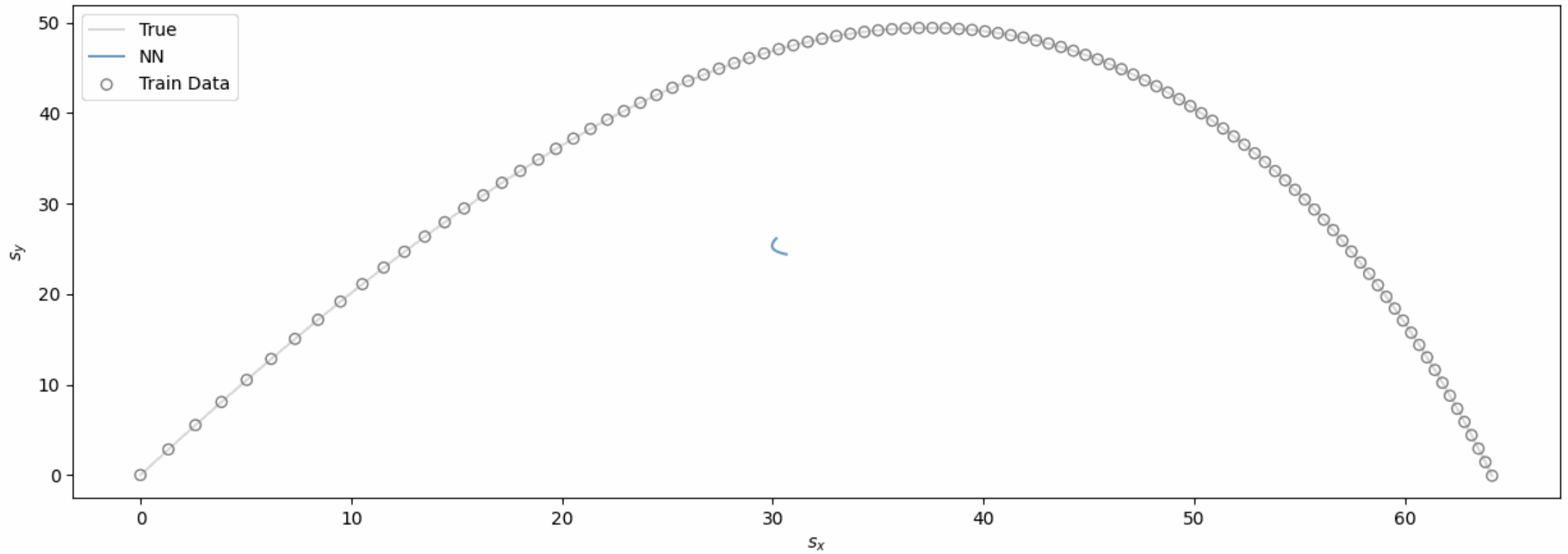
Physics Informed Neural Networks

PINNs: Claim

- Provide solutions to partial differential equations
- Uses Neural Networks
- Enforces Physical Laws governing the system dynamics
- Use much less data as compared to the standard Neural Networks
- Much faster and accurate than the existing classical algorithms

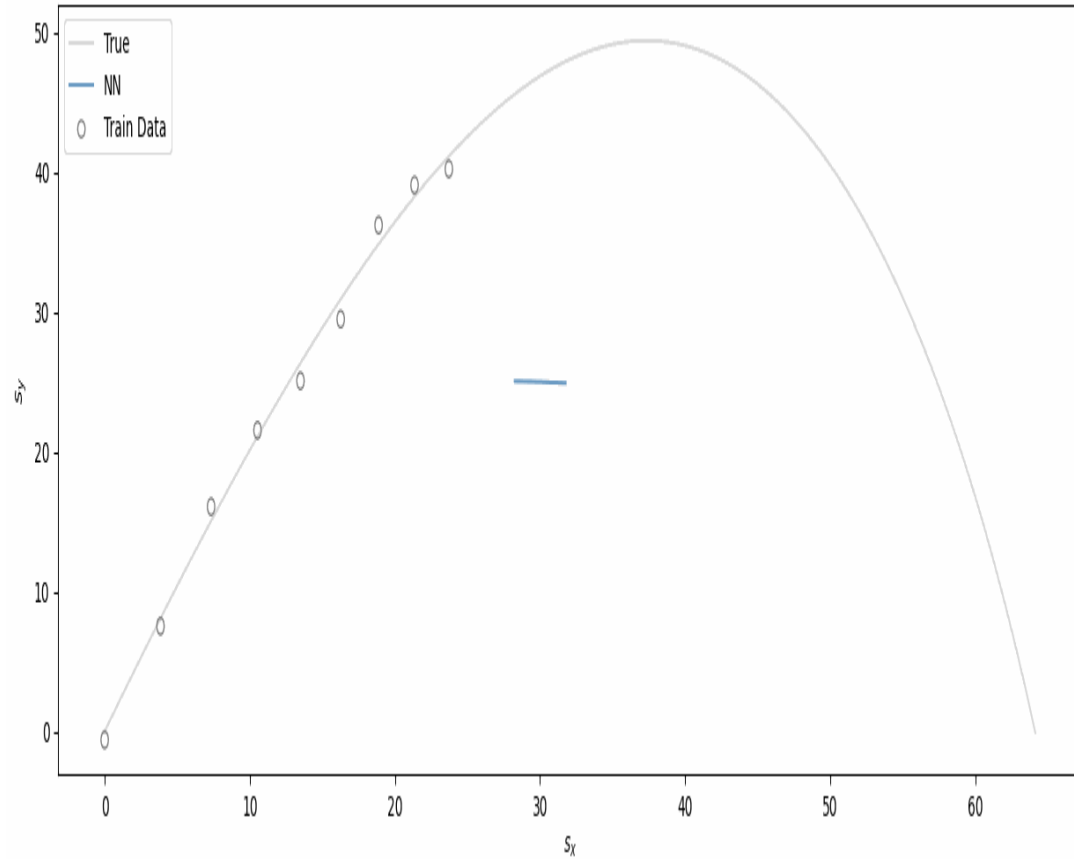


Neural Networks (Ideal Scenario)

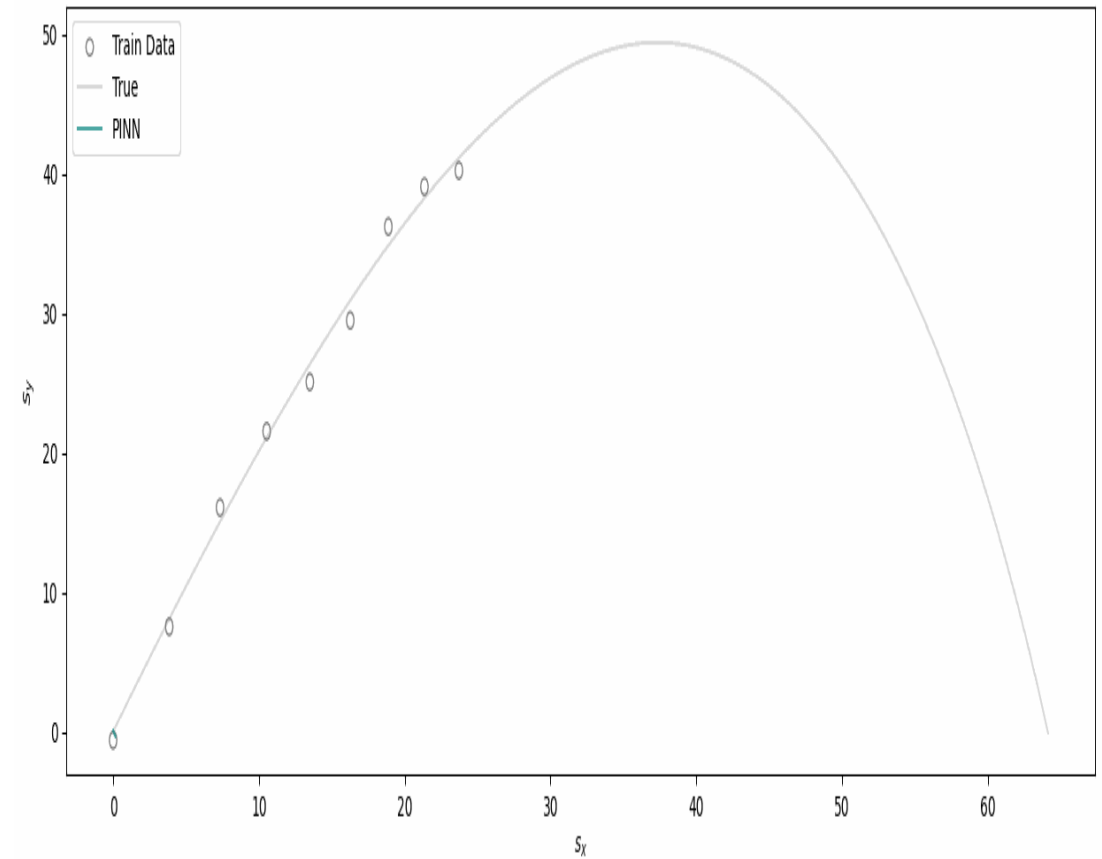


PINNs VS Neural Nets

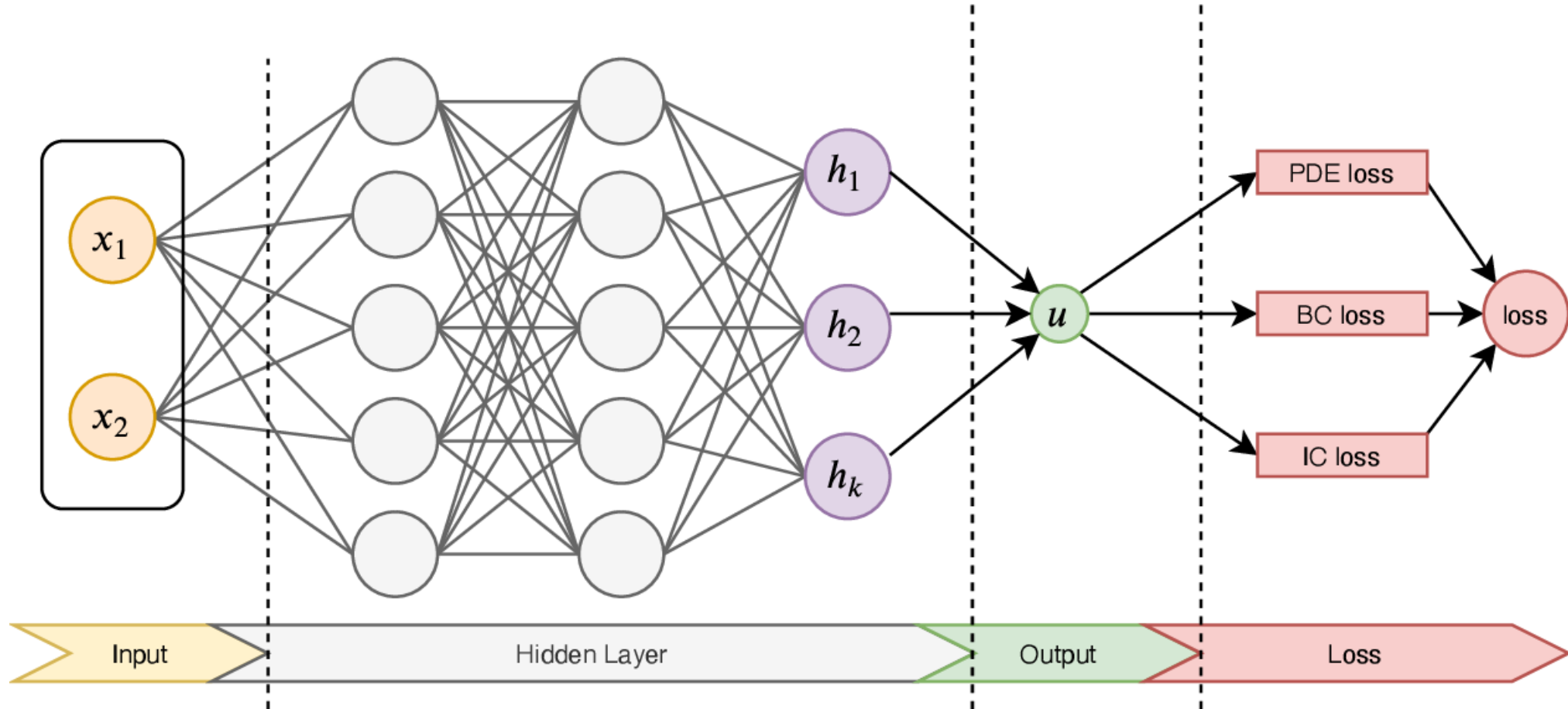
Noisy NN



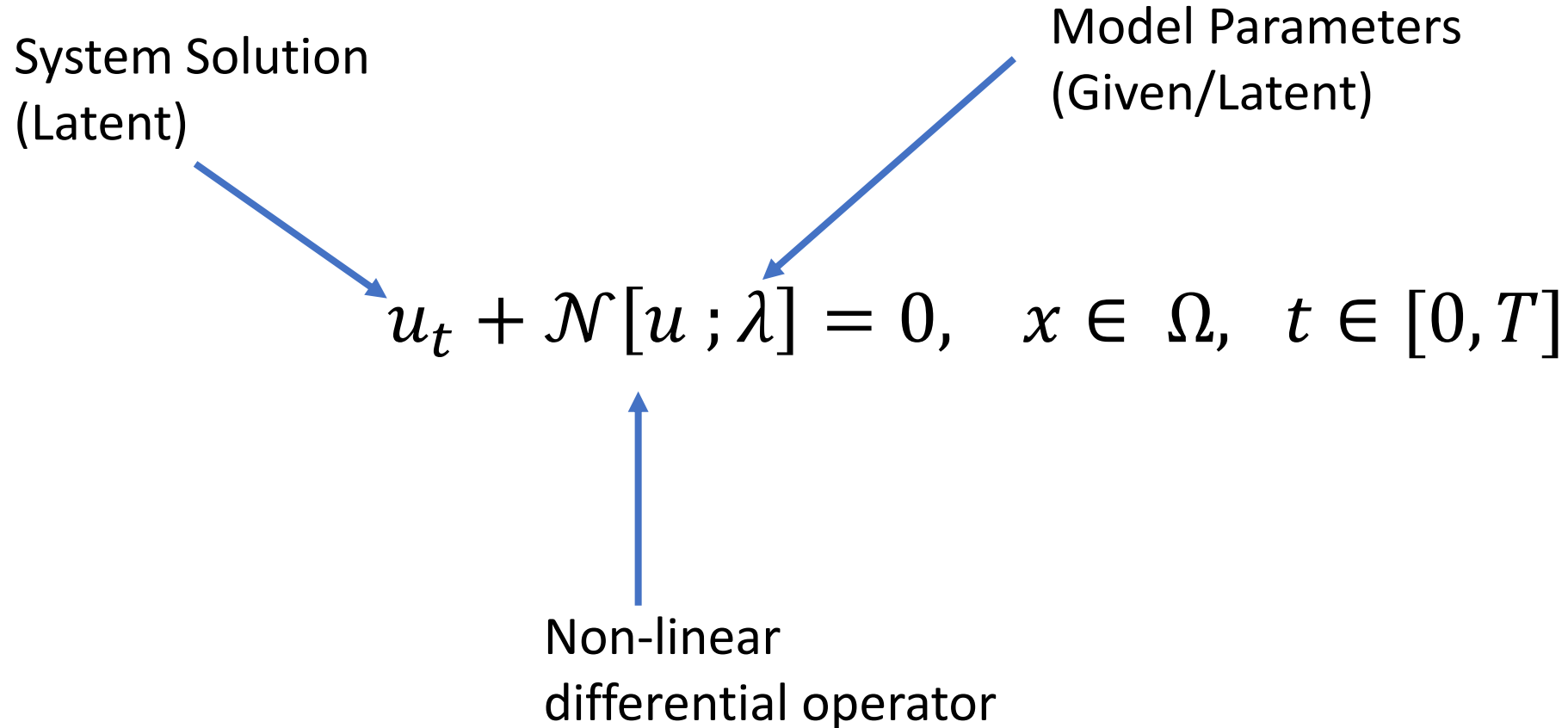
Noisy PINN



PINNs: Generic Architecture



PINNs: System Setup



PINNs: Type of Models

- Continuous Time
- Discrete Time



PINNs: Type of Solutions

Inference, Filtering, and Smoothing

Given system parameters λ , what can be said about the unknown hidden state $u(t, x)$ of the system

$$u_t + \mathcal{N}[u; \lambda] = 0, \quad x \in \Omega, \quad t \in [0, T]$$

To be discovered

Given



PINNs: Type of Solutions

System Identification

What are the parameters λ that best describes the observed data?

$$u_t + \mathcal{N}[u; \lambda] = 0, \quad x \in \Omega, \quad t \in [0, T]$$

To be discovered

To be discovered



PINNs: How the Physical Laws are Enforced?

- In an ordinary NN the final loss function can be given as

$$MSE_u = \frac{1}{N_u} \sum_{i=1}^{N_u} |u(t_u^i, x_u^i) - u^i|^2$$

- PINNs loss function can be given as

$$MSE = MSE_u + MSE_f$$

$$MSE_f = \frac{1}{N_f} \sum_{i=1}^{N_f} |f(t_f^i, x_f^i)|^2$$

$f := u_t + \mathcal{N}[u]$



PINNs: How the Physical Laws are Enforced?

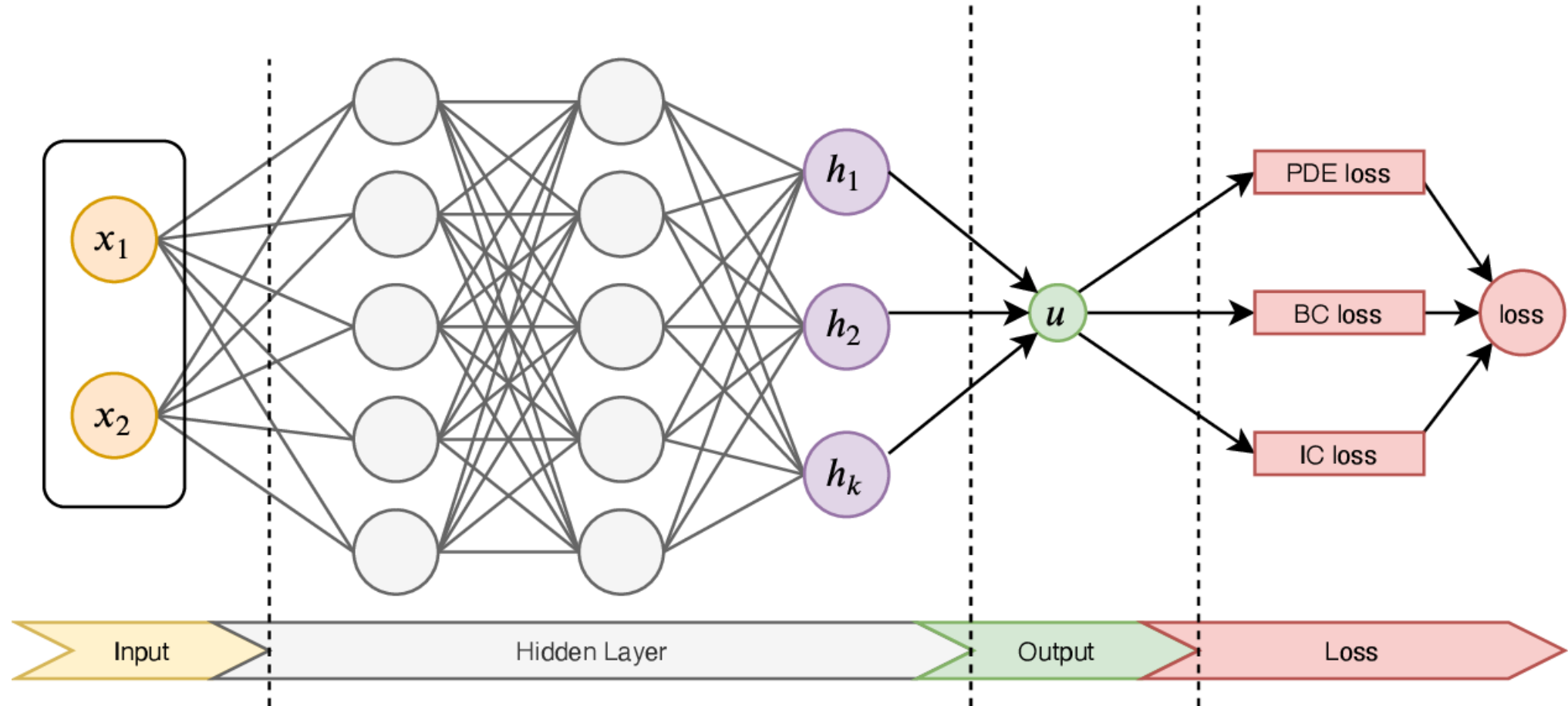
$$MSE = \frac{1}{N_u} \sum_{i=1}^{N_u} |u(t_u^i, x_u^i) - u^i|^2 + \frac{1}{N_f} \sum_{i=1}^{N_f} |f(t_f^i, x_f^i)|^2$$

$$MSE = \frac{1}{N_u} \sum_{i=1}^{N_u} |u(t_u^i, x_u^i) - u^i|^2 + \frac{1}{N_f} \sum_{i=1}^{N_f} |u_t + \mathcal{N}[u]|^2$$

Physical Laws Governing the System Parameters



PINNs: How the Physical Laws are Enforced?



Example: Embedding the Physical Laws

Burger's Equation

$$u_t + uu_x - (0.01/\pi)u_{xx} = 0, \quad x \in [-1, 1], \quad t \in [0, 1],$$

$$u(0, x) = -\sin(\pi x),$$

$$u(t, -1) = u(t, 1) = 0.$$

Let us define $f(t, x)$ to be given by

$$f := u_t + uu_x - (0.01/\pi)u_{xx},$$

Dirichlet Boundary Condition



PINNs: Tensor Flow Implementation

Conventional Neural Net

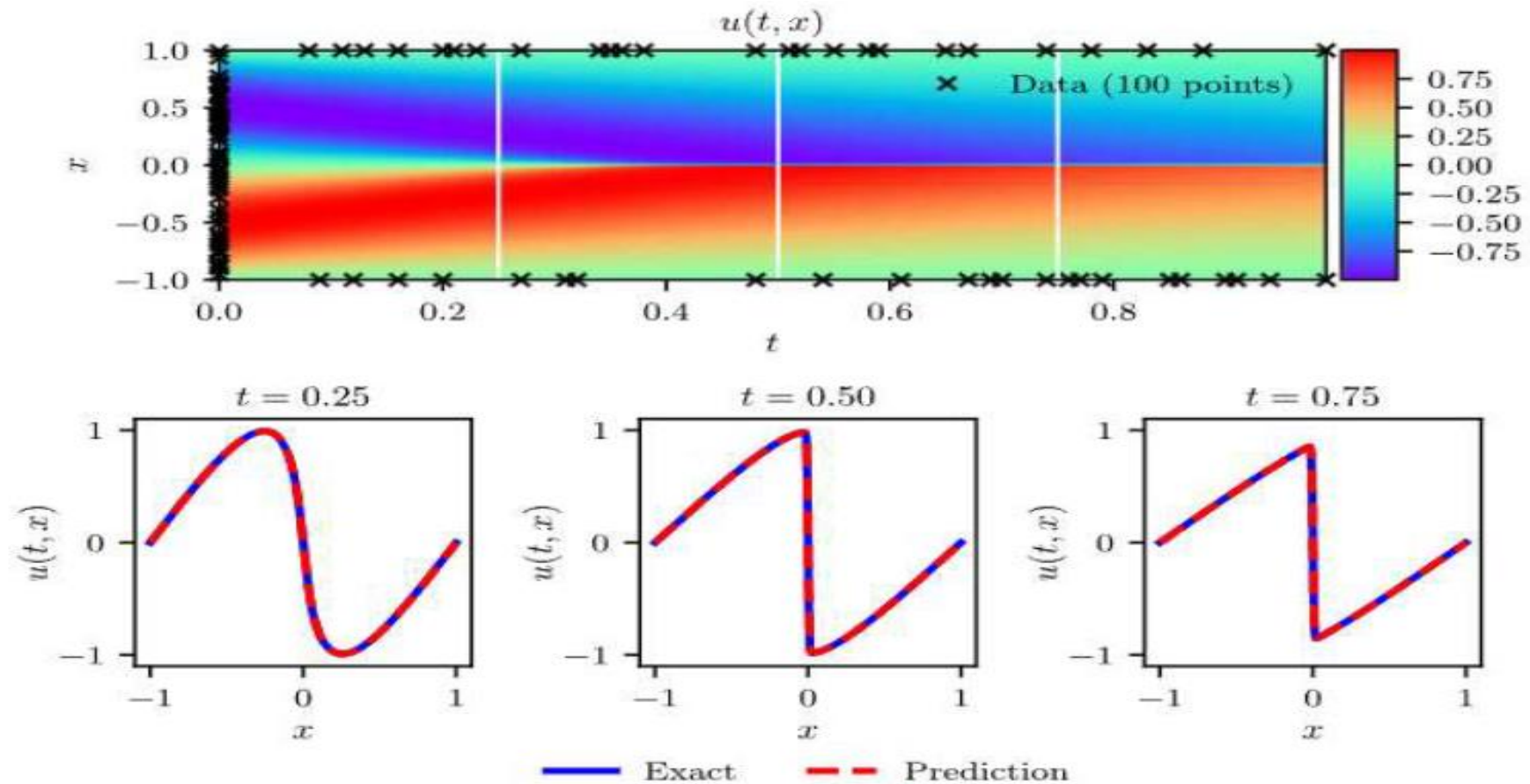
```
def u(t, x):  
    u = neural_net(tf.concat([t,x],1), weights, biases)  
    return u
```

```
def f(t, x):  
    u = u(t, x)  
    u_t = tf.gradients(u, t)[0]  
    u_x = tf.gradients(u, x)[0]  
    u_xx = tf.gradients(u_x, x)[0]  
    f = u_t + u*u_x - (0.01/tf.pi)*u_xx  
    return f
```

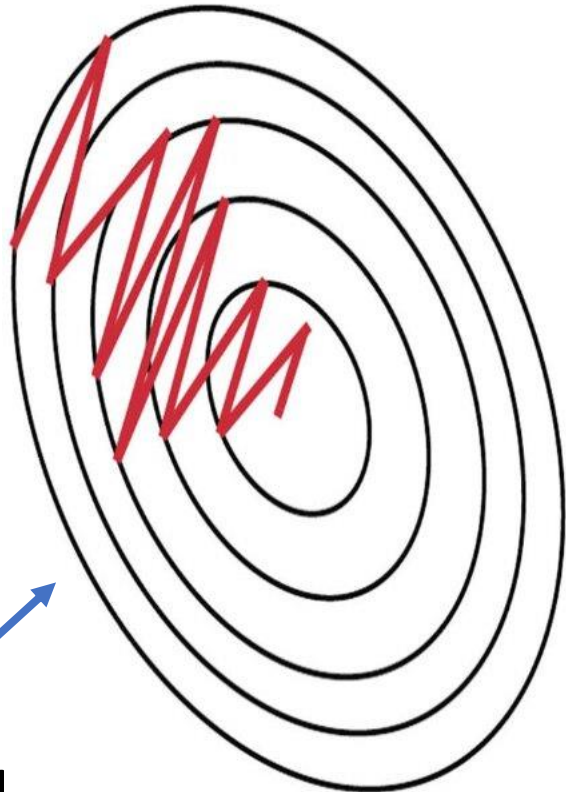
Physics Embedded Neural Net



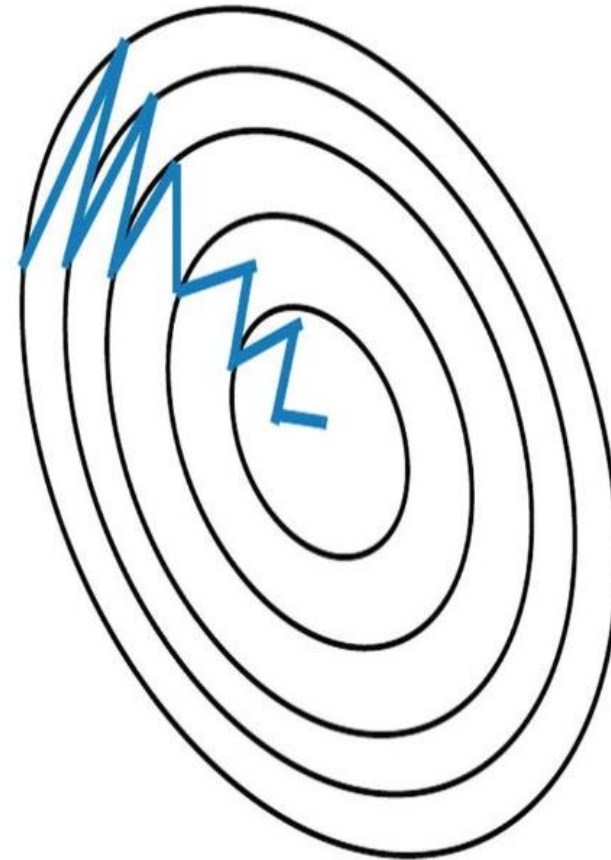
PINNs: Evaluation of Burger's Equation



PINNs: Learning Landscape



Conventional
NN



PINN

PINNs: The End?

Limitations

Hard to Train?

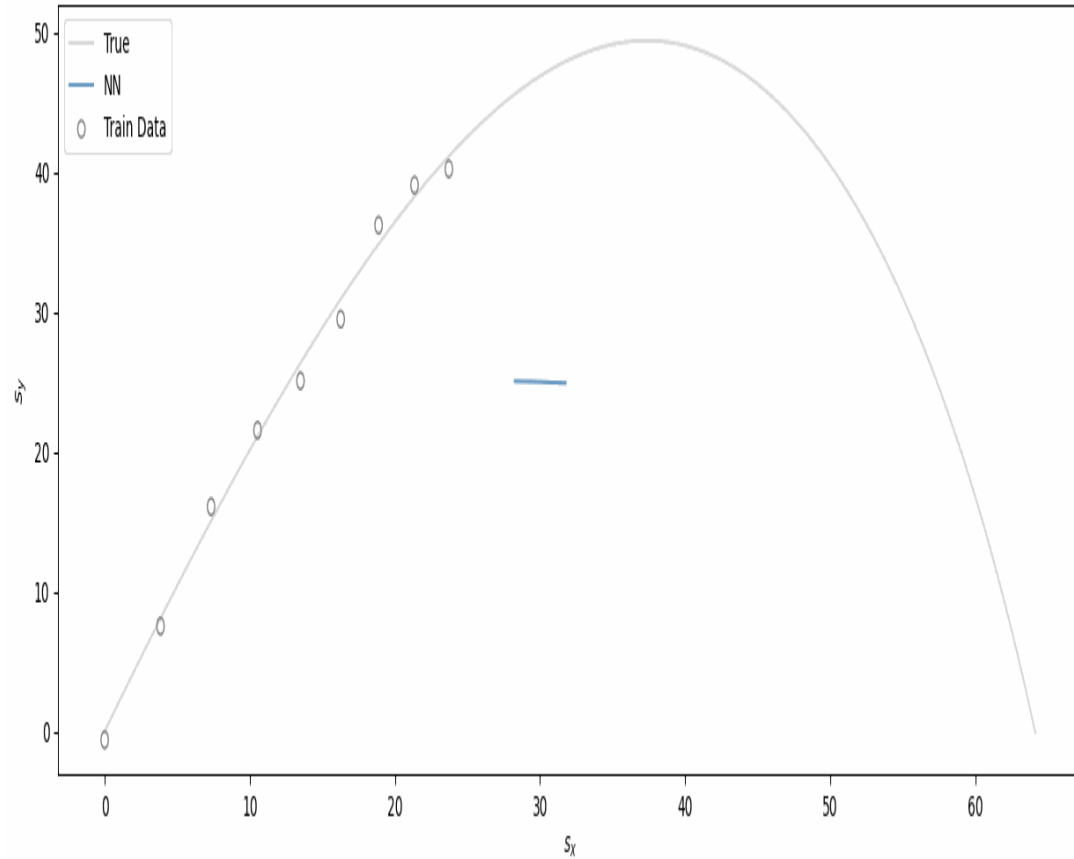
Availability of the Data?

What if an accurate system model doesn't exist?

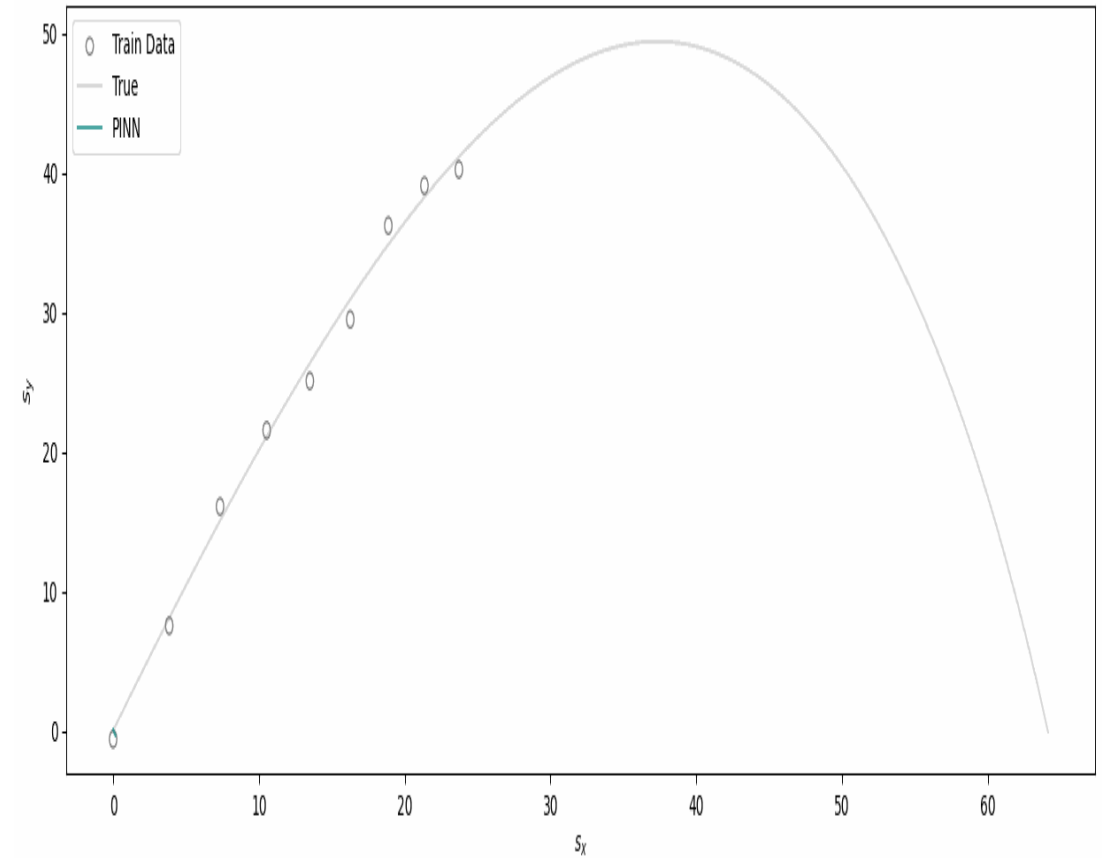


An Intuitive Conclusion: NN vs PINN

Noisy NN



Noisy PINN





THANKYOU

Dr. Syed Ali Irtaza
Assistant Professor
Electrical Engineering Department
Institute of Space Technology