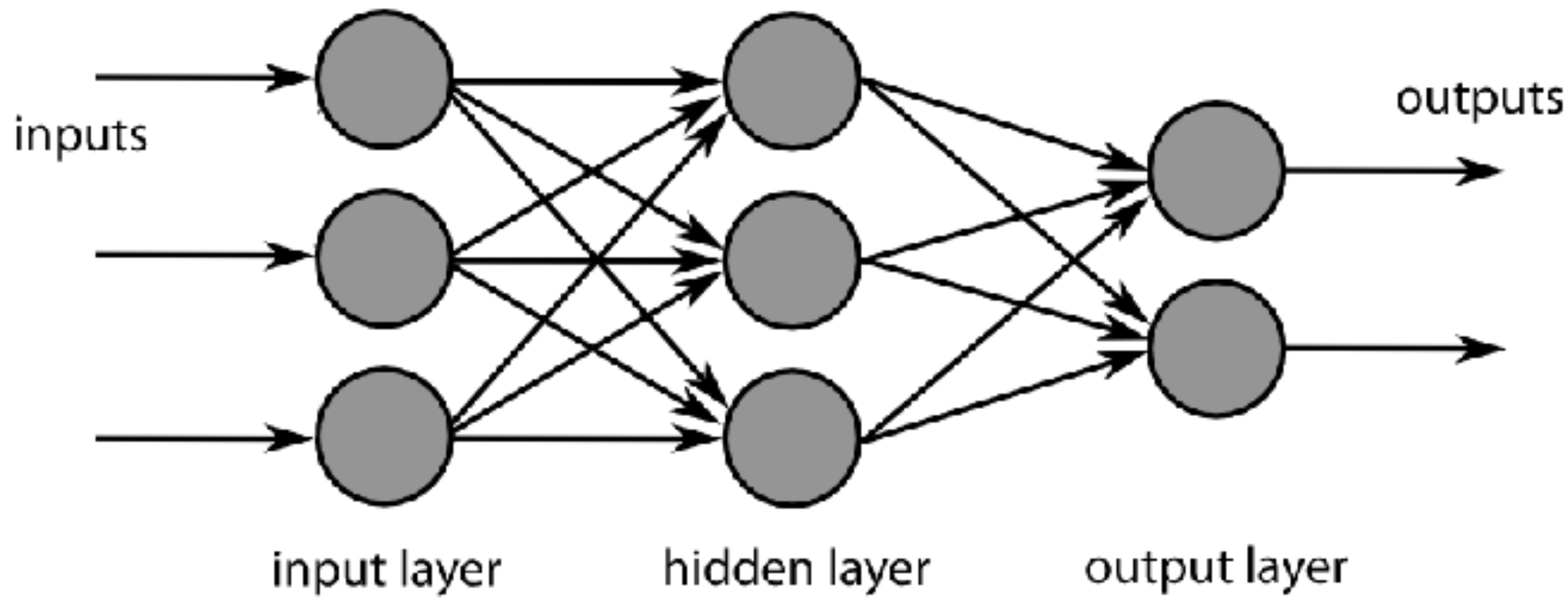
Forecasting Chaos with Machine Learning

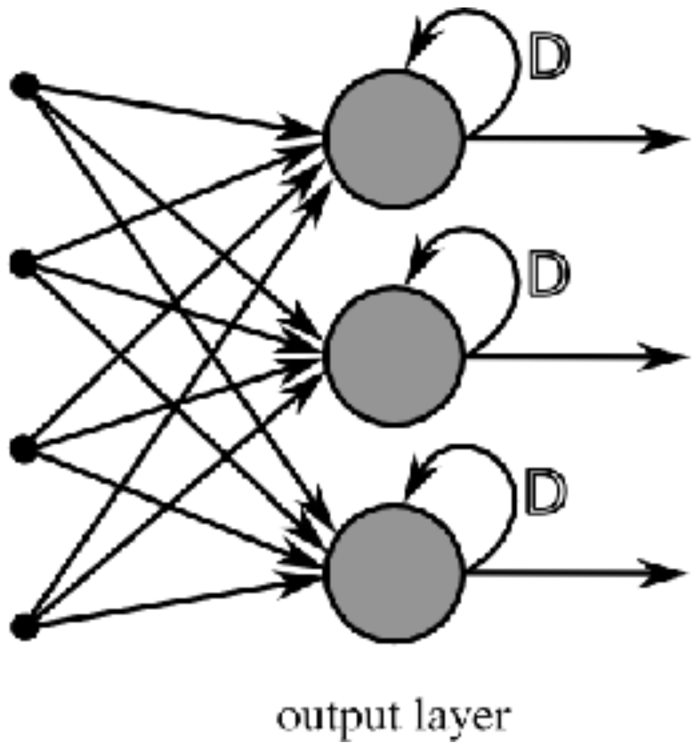
Ryan Abernathey

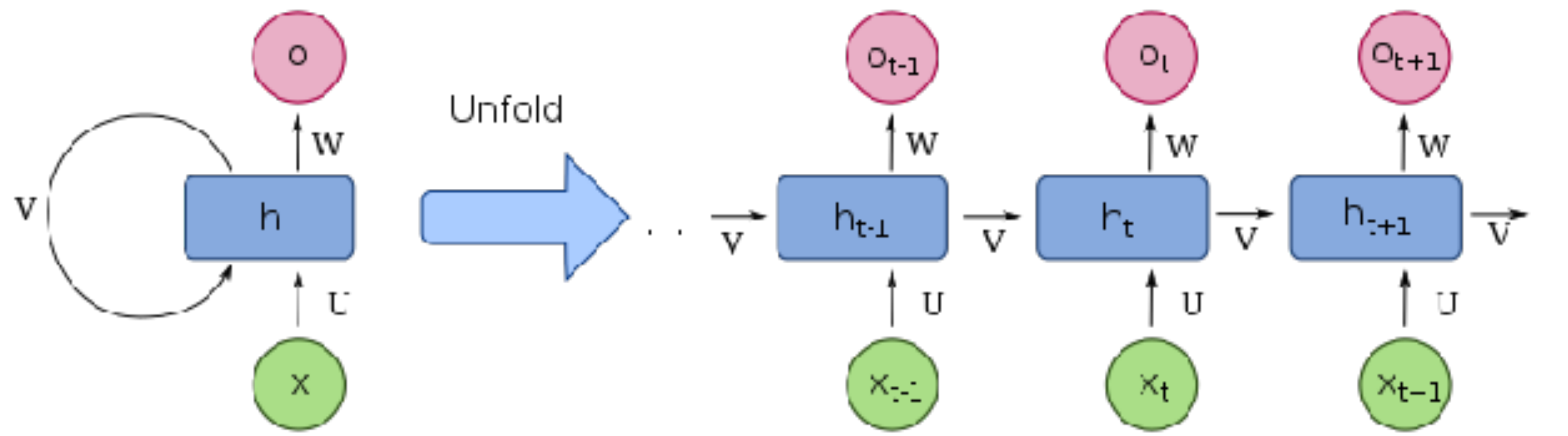
Feed Forward Network



- Connections between neurons point only in one direction (directed acyclic graph)
- Used for standard machine learning algorithms
- Network has no “state” (other than weights): activation determined completely by input vector

Recurrent Network



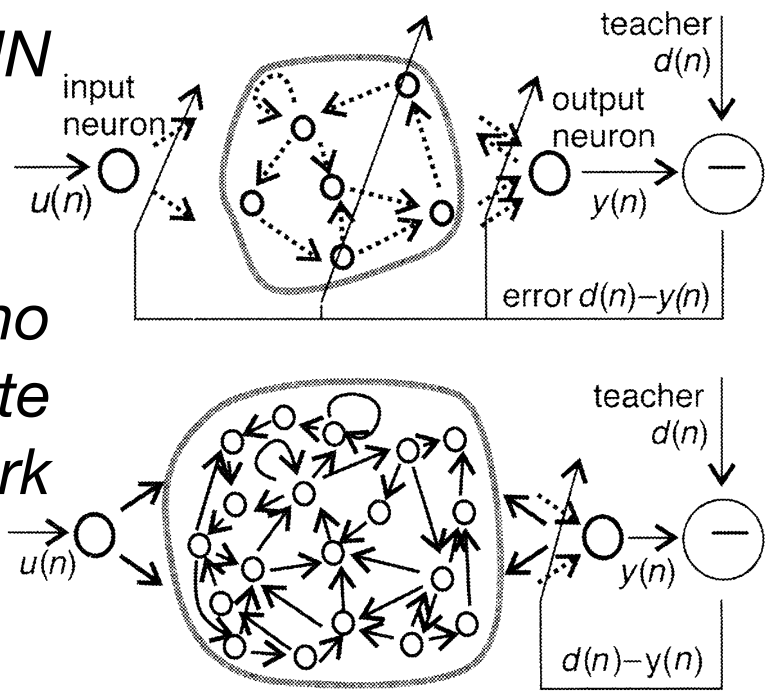


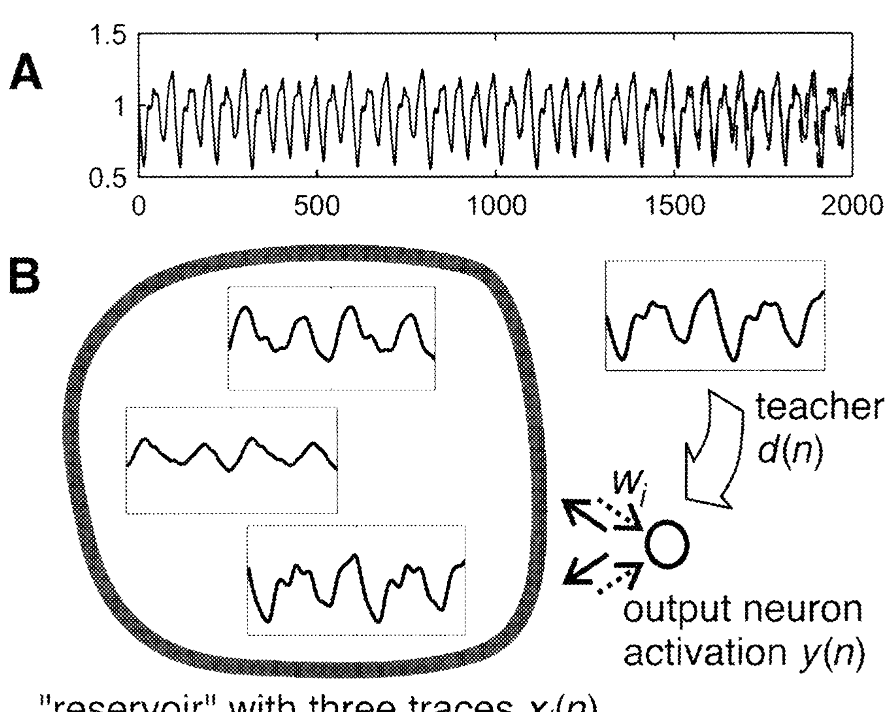
- Internal state of network persists and is fed back to input layers (along with the actual inputs)
- Allows network to have memory
- Used in time-dependent problems (speech recognition, games, etc.)

Reservoir Computing

Traditional RNN

Echo State Network





Harnessing Nonlinearity: Predicting Chaotic Systems and Saving Energy in Wireless Communication

BY HERBERT JAEGER, HARALD HAAS

SCIENCE APR 2004 : 78-80

- Large RNNs (> 30 neurons) are very expensive and unstable to train
- “Reservoir” is a large RNN (1000s of neurons) with feedback loops in connections (often a randomly generated network)
- Reservoir maintains activation even without inputs
- Only the input and output weights are learned; the internal network is fixed
- Skilled at forecasting low-D chaotic systems

Spatio-temporal chaos: Kuramoto-Sivashinsky equation

$$y_t = -yy_x - y_{xx} - y_{xxxx} + \mu \cos\left(\frac{2\pi x}{\lambda}\right)$$

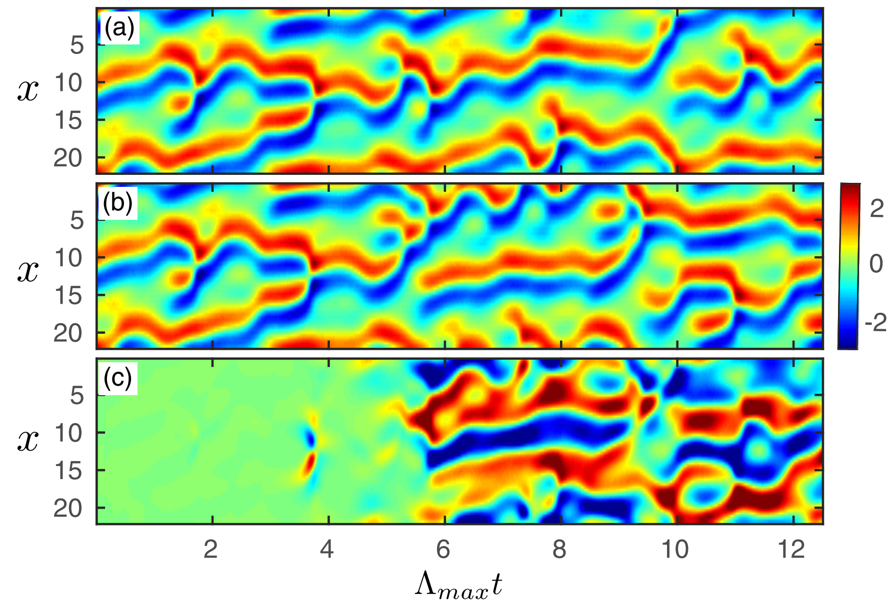
- Nonlinear 1D dynamical system
- Commonly used model
- https://www.youtube.com/watch?v=MdHk52m-5BY

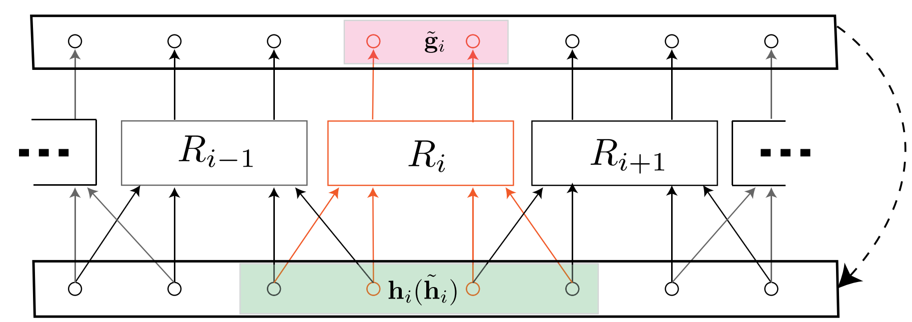
Model-Free Prediction of Large Spatiotemporally Chaotic Systems from Data: A Reservoir Computing Approach

Jaideep Pathak,[1,2,*] Brian Hunt,[3,4] Michelle Girvan,[1,3,2] Zhixin Lu,[1,3] and Edward Ott[1,2,5]

- Single reservoir approach doesn't scale to large domain sizes *L*

- Analogy to CNN: use multiple reservoirs spread over the spatial domain





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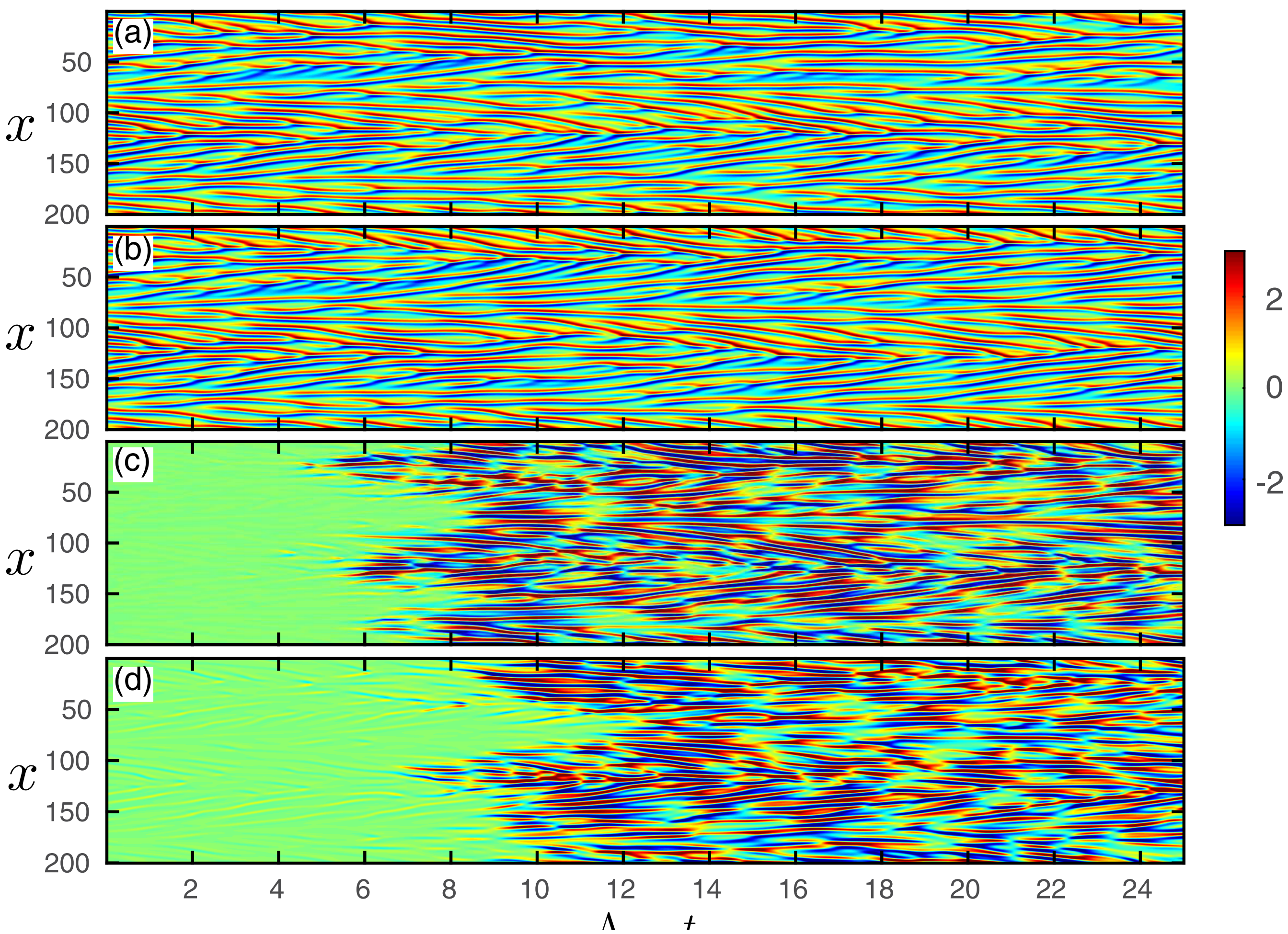
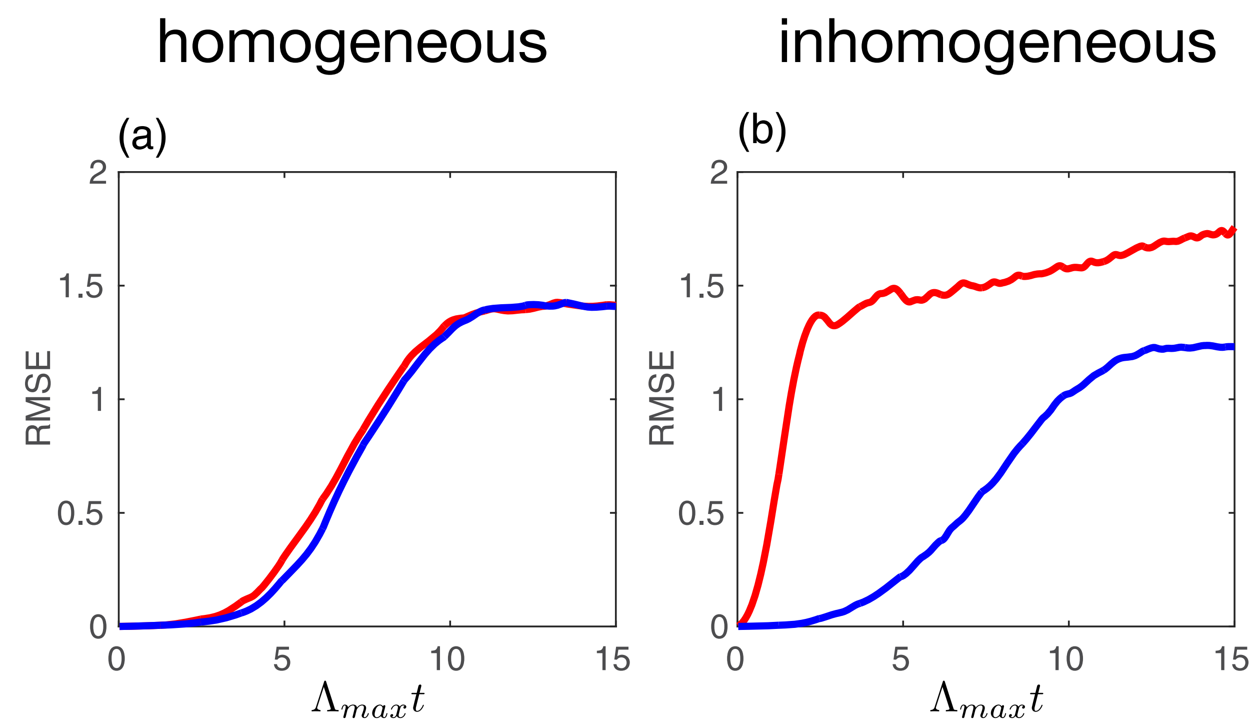
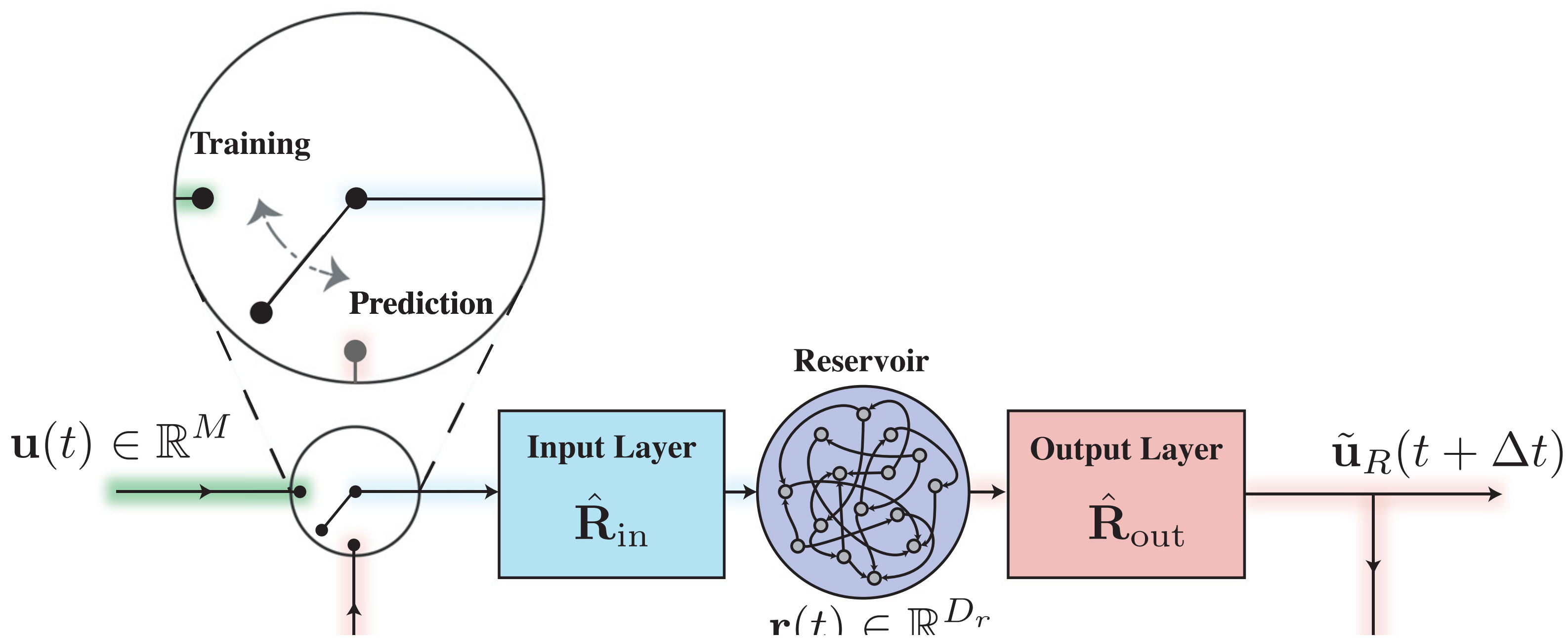




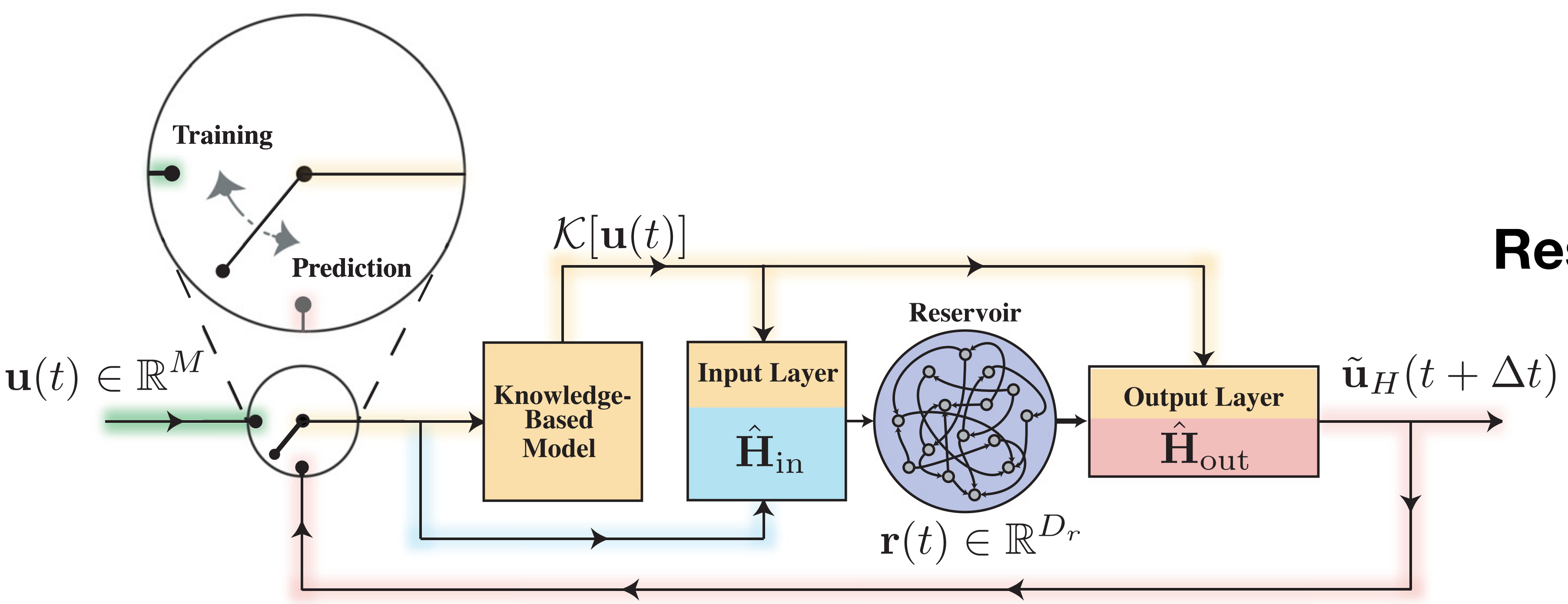
CHAOS **28**, 041101 (2018)

Hybrid forecasting of chaotic processes: Using machine learning in conjunction with a knowledge-based model

Jaideep Pathak,[1] Alexander Wikner,[2] Rebeckah Fussell,[3] Sarthak Chandra,[1] Brian R. Hunt,[1] Michelle Girvan,[1] and Edward Ott[1]



Reservoir only



Reservoir + model

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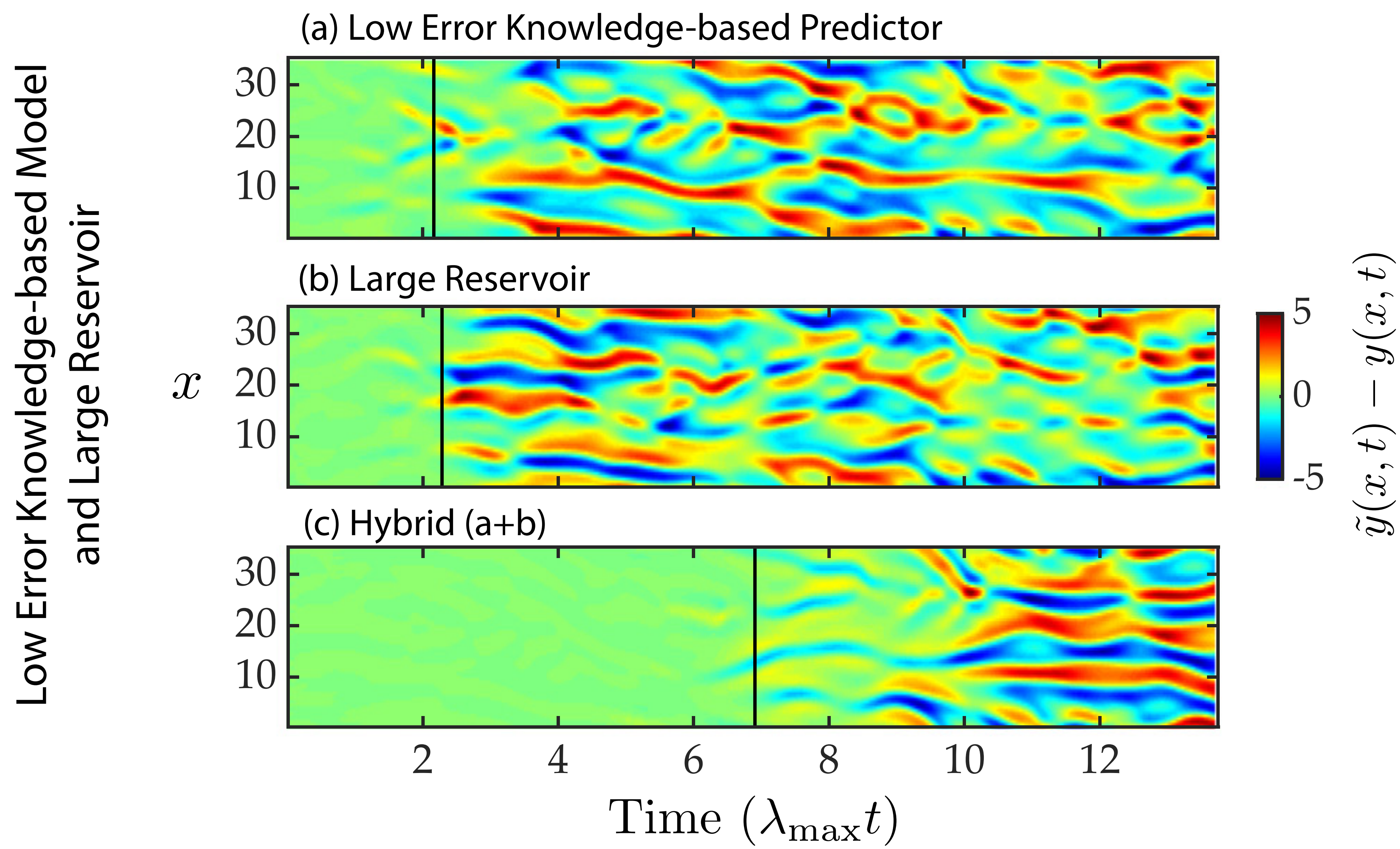

$$y_t = -yy_x - (1+\epsilon)y_{xx} - y_{xxxx}$$

Imperfect model