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# Diffusion models for time-series applications: a survey

**Key words:** Diffusion models; Time-series forecasting; Time-series imputation; Denoising diffusion probabilistic models; Score-based generative models; Stochastic differential equations

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# Motivation

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- ❑ In recent years, diffusion models, a family of deep learning based generative models, have been extended to time-series applications, and many powerful models have been developed.
- ❑ Considering the deficiency of a methodical summary and discourse on these models, we provide this survey as an elementary resource for new researchers in this area and to provide inspiration to motivate future research.
- ❑ The survey primarily focuses on diffusion models for time-series forecasting, imputation, and generation. It also compares existing methods with in-depth discussion, while presenting their real-world applications, relevant data resources, and future research directions.

# Summary of literature

- The survey reviews on diffusion models for time-series forecasting, imputation, and generation, and presents them, separately, in three individual sections. A summary of literature is listed as follows.

Application	Data type	Method	Source
Time-series forecasting	Multivariate time series	TimeGrad	Rasul et al., 2021
		ScoreGrad	Yan et al., 2021
		D <sup>3</sup> VAE	Li Y et al., 2022
		DSPD/CSPD	Biloš et al., 2023
	Spatio-temporal graphs	TimeDiff	Shen and Kwok, 2023
Time-series imputation	Multivariate time series	DiffSTG	Wen et al., 2023
		GCRDD	Li RK et al., 2023
	Spatio-temporal graphs	CSDI	Tashiro et al., 2021
		DSPD/CSPD	Biloš et al., 2023
		SSSD	Alcaraz and Strodthoff, 2023
Time-series generation	Multivariate time series	PriSTI	Liu MZ et al., 2023
		TSGM	Lim et al., 2023
		DiffTime	Coletta et al., 2023
		Loss-DiffTime	Coletta et al., 2023
		Guided-DiffTime	Coletta et al., 2023

# Model comparison

- The comparison of methods includes an assessment of their capabilities in handling various tasks and data types, along with an examination of their diffusion and sampling processes.

Method	Forecasting	Imputation	Generation	Data	Diffusion	Sampling
TimeGrad	✓			MTS/STG	Discrete	Autoregressive
ScoreGrad	✓			MTS/STG	Continuous	Autoregressive
D <sup>3</sup> VAE	✓			MTS/STG	Discrete	One-shot
DSPD	✓	✓		MTS/STG	Discrete	One-shot
CSPD	✓	✓		MTS/STG	Continuous	One-shot
TimeDiff	✓			MTS/STG	Discrete	One-shot
DiffSTG	✓			STG	Discrete	One-shot
GCRDD	✓			STG	Discrete	Autoregressive
CSDI	✓	✓		MTS/STG	Discrete	One-shot
SSSD	✓	✓		MTS/STG	Discrete	One-shot
PriSTI	✓	✓		STG	Discrete	One-shot
TSGM			✓	MTS/STG	Continuous	Autoregressive
DiffTime			✓	MTS/STG	Discrete	One-shot
Loss-DiffTime			✓	MTS/STG	Discrete	One-shot
Guided-DiffTime			✓	MTS/STG	Discrete	One-shot

# Applications and datasets

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- The survey showcases relevant application in real-world domains such as energy control and transportation.
- Additionally, we share valuable resources of frequently used public datasets to support researchers and practitioners in testing and understanding diffusion models for time series. Below is a fraction of resources presented in the survey.

Domain	Dataset	Source
Energy	SOLAR	<a href="https://github.com/laiguokun/multivariate-time-series-data">https://github.com/laiguokun/multivariate-time-series-data</a>
	ELECTRICITY	<a href="https://archive.ics.uci.edu/ml/datasets/ElectricityLoadDiagrams20112014">https://archive.ics.uci.edu/ml/datasets/ElectricityLoadDiagrams20112014</a>
	NORPOOL	<a href="https://www.nordpoolgroup.com/Market-data1/Power-system-data">https://www.nordpoolgroup.com/Market-data1/Power-system-data</a>
	CAISO	<a href="http://www.energyonline.com/Data">http://www.energyonline.com/Data</a>
	ETTm1	<a href="https://github.com/zhouhaoyi/ETDataset">https://github.com/zhouhaoyi/ETDataset</a>
	ETTh1	<a href="https://github.com/zhouhaoyi/ETDataset">https://github.com/zhouhaoyi/ETDataset</a>
Traffic	TRAFFIC	<a href="http://pems.dot.ca.gov">http://pems.dot.ca.gov</a>
	TAXI	<a href="https://www1.nyc.gov/site/tlc/about/tlc-trip-record-data.page">https://www1.nyc.gov/site/tlc/about/tlc-trip-record-data.page</a>
Climate	WEATHER	<a href="https://www.bgc-jena.mpg.de/wetter/">https://www.bgc-jena.mpg.de/wetter/</a>
Finance	EXCHANGE	<a href="https://github.com/laiguokun/multivariate-time-series-data">https://github.com/laiguokun/multivariate-time-series-data</a>
Website	WIKIPEDIA	<a href="https://github.com/mbohlkeschneider/gluon-ts/tree/mv_release/datasets">https://github.com/mbohlkeschneider/gluon-ts/tree/mv_release/datasets</a>

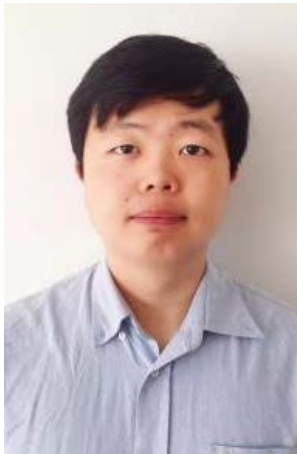
# Future research and conclusion

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- ❑ Three future research directions of diffusion models for time series have been proposed in the end of the survey, including heavy model selection, insufficient research on noise injection, and unsatisfactory performance with spatio-temporal graphs.
- ❑ Although existing methods have shown good performance with empirical evidence, the survey concludes by emphasizing that they are usually associated with very high computational costs.
- ❑ Moreover, because most diffusion models are constructed with a high level of theoretical background, there is still a lack of deeper discussion and exploration of the rationale behind these models, i.e., why they could work and when they may not work.



Lequan LIN received her Bachelor of Commerce degree (Hons) in business analytics at the University of Sydney Business School, the University of Sydney, Australia, in 2022. She is currently a PhD student in the Discipline of Business Analytics, at the University of Sydney Business School. Her recent research interest involves machine learning, especially graph neural networks and generative models.



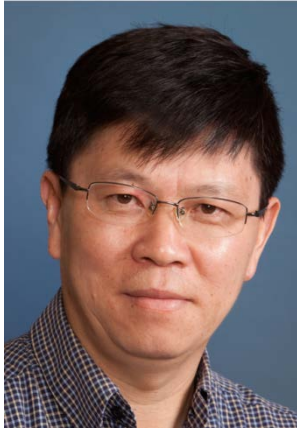
Zhengkun LI received his Bachelor of Commerce degree in finance and business analytics (with first-class honor) and his PhD degree in business analytics from the University of Sydney, Sydney, Australia, in 2018 and 2023, respectively. He is currently a postdoctoral researcher at the Postdoctoral Programme of Zhongtai Securities Co., Ltd, Jinan, China and the Postdoctoral Programme of PBC School of Finance, Tsinghua University, Beijing, China. His research interests include machine learning, financial econometrics, and factor investing.



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