

OO

Copula 熵

Jian Ma and Zengqi Sun. "Mutual Information Is Copula Entropy". In: *Tsinghua Science & Technology* 16.1 (2011). See also arXiv preprint arXiv:0808.0845 (2008), pp. 51–54

$$H_c(\mathbf{x}) = - \int_{\mathbf{u}} c(\mathbf{u}) \log c(\mathbf{u}) d\mathbf{u} \quad (1)$$

- 测光红移
 - 测光红移准确度提升¹
 - 斯隆类星体巡天观测数据

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- 相关粒子系统
 - 平衡态相关粒子系统中熵的推导和计算²

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- 变构效应研究
 - 变构效应配位点和激活点热力学耦合模型³
 - 丙氨酸二肽的 C 端和 N 端

³Michel A. Cuendet, Harel Weinstein, and Michael V. LeVine. "The Allosteric Landscape: Quantifying Thermodynamic Couplings in Biomolecular Systems". In: *Journal of Chemical Theory and Computation* 12.12 (2016), pp. 5758–5767. DOI: 10.1021/acs.jctc.6b00841.

- 分子设计
 - 设计具有特定属性的分子结构⁴
 - 有机分子属性 QM9 数据库

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- 洪水预报
 - 金沙江流域洪水预报⁶
- 河流相关性
 - 长江上游河段（金沙江、岷江、沱江、嘉陵江）相关性⁷
 - 长江上游河段复合洪水事件分析⁸
- 水沙关系分析
 - 黄河西柳沟河流域径流量和输沙量数据分析⁹

⁶ Lu Chen, Vijay P. Singh, and Shenglian Guo. "Measure of Correlation between River Flows Using the Copula-Entropy Method". In: *Journal of Hydrologic Engineering* 18.12 (2013), pp. 1591-1606, Lu Chen et al. "Copula entropy coupled with artificial neural network for rainfall-runoff simulation". In: *Stochastic Environmental Research and Risk Assessment* 28.7 (2014), pp. 1755-1767, 陈佳雷 et al. "一种基于多要素注意力时空图卷积网络的径流预报方法". Pat. CN117151285A. 2023.

⁷Lu Chen and Shenglian Guo. *Copulas and its application in hydrology and water resources*. Springer, 2019.

⁸Xu Wang and Yong-Ming Shen. "A Framework of Dependence Modeling and Evaluation System for Compound Flood Events". In: *Water Resources Research* 59.8 (2023), e2023WR034718. DOI: 10.1029/2023WR034718.

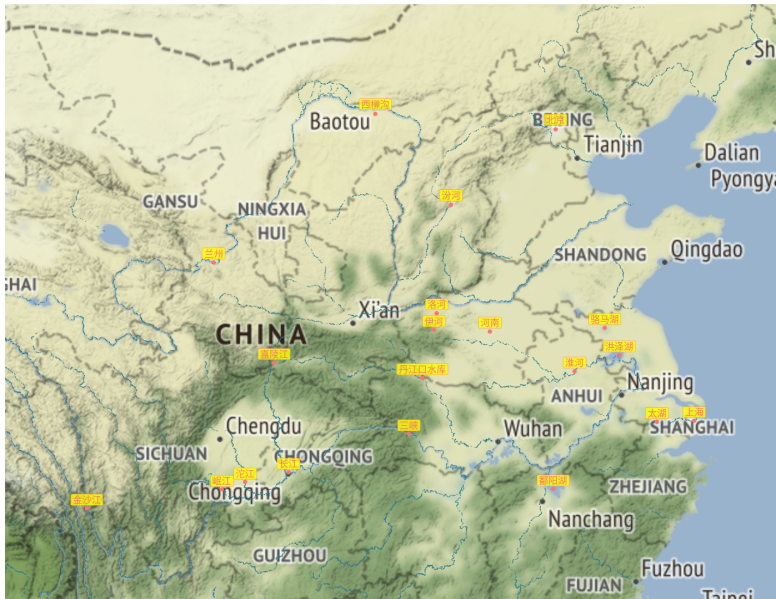
⁹ Longxia Qian et al. "A New Estimation Method for Copula Parameters for Multivariate Hydrological Frequency Analysis With Small Sample Sizes". In: *Water Resources Management* 36.4 (2022), pp. 1141–1157. DOI: 10.1007/s11269-021-03016-w.

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[illegible]

- ²⁴ 蒋佩东. “基于 Bayesian 模型的长江流域年径流对变化环境响应的空间效应”. 硕士学位论文. 武汉大学, 2023.

水文学-国内应用地图



气候学

- 气候变化对水文气象变量相关性的影响
 - 美国德州达拉斯地区降水和气温相关性关系分析²⁵
 - 达拉斯市沃斯堡 (Fort Worth) 地区降水和气温观测数据
- 气候评估
 - 欧洲城市气候分类²⁶
 - 欧洲 25 座城市气温和降水数据

²⁵ Zengchao Hao and Vijay P. Singh. "Integrating Entropy and Copula Theories for Hydrologic Modeling and Analysis". In: *Entropy* 17.4 (2015), pp. 2253–2280. DOI: 10.3390/e17042253.

²⁶Francesca Condino. "La divergenza di Jensen-Shannon nell'algoritmo di clustering dinamico per dati descritti da distribuzioni multivariate". PhD thesis. Università degli Studi di Napoli Federico II, 2009.

气象学

- 大气污染气象成因分析
 - 北京地区气象因素对 PM2.5 浓度的因果关系分析²⁷
 - 北京地区 PM2.5 和气象观测数据
 - PM2.5 浓度预测²⁸
 - 北京地区 PM2.5 和气象观测数据
 - 上海和广州大气污染预测预警²⁹
 - 上海和广州 PM2.5 和气象观测数据
- 气象灾害预测
 - 广西地区台风灾情预测类³⁰
 - 广西地区台风灾害数据

²⁷ Jian Ma. "Estimating Transfer Entropy via Copula Entropy". In: *arXiv preprint arXiv:1910.04375* (2019).

²⁸ Xiaoxuan Wu et al. "Research on PM2.5 Concentration Prediction Based on the CE-AGA-LSTM Model". In: *Applied Sciences* 12.14 (2022), p. 7009. DOI: 10.3390/app12147009, Jieyin Chen. "Short-Term Prediction of PM2.5 Concentration based on Self-Attention Mechanism Improved Temporal Convolution Network". In: *2023 International Seminar on Computer Science and Engineering Technology (SCSET)*. 2023, pp. 528–534. DOI: 10.1109/SCSET58950.2023.00121.

²⁹ Jujie Wang et al. "A novel air quality prediction and early warning system based on combined model of optimal feature extraction and intelligent optimization". In: *Chaos, Solitons & Fractals* 158 (2022), p. 112098. DOI: 10.1016/j.chaos.2022.112098.

³⁰ 陈燕璇, 刘合香, and 倪增华. "基于 Copula 熵因子选取的 PSO-ELM 台风灾情预测模型". In: *气象研究与应用* 40.2 (2019), pp. 7–11.

生态学

- 动物运动轨迹分析
 - Cylcop 算法包³³

³³Florian H. Hodel and John R. Fieberg. "Cylcop: An R Package for Circular-Linear Copulae with Angular Symmetry". In: *bioRxiv* (2021), p. 2021.07.14.452253, Florian Hodel. *cylcop: Circular-Linear Copulas with Angular Symmetry for Movement Data*. CRAN. R package version 0.2.0. 2022. URL: <https://cran.r-project.org/package=cylcop>.

- 动物形态学
 - 鱼类形态相似度研究³⁴
 - GatorBait 海洋鱼类外形数据库
 - 鲍鱼生长过程的形态学研究³⁵
 - UCI 鲍鱼数据集

³⁴Francisco Escolano et al. "The mutual information between graphs". In: *Pattern Recognition Letters* 87 (2017), pp. 12–19. DOI: 10.1016/j.patrec.2016.07.012.

³⁵ Soumik Purkayastha and Peter X.K. Song. "Asymmetric predictability in causal discovery: an information theoretic approach". In: *arXiv preprint arXiv:2210.14455* (2022).

- 作物产量预测
 - 气候变化对我国南方两季稻产量的影响及对策³⁶
 - 南方（江南和华南）54 个地点未来气候变化数据和作物数据

³⁶ **Ziya Zhang et al.** "Impact of climate change and planting date shifts on growth and yields of double cropping rice in southeastern China in future". In: *Agricultural Systems* 205 (2023), p. 103581. DOI: 10.1016/j.agsy.2022.103581, **张子雅**. "气候变化对中国水稻物候和产量的影响及播期优化". 硕士学位论文. 西北农林科技大学, 2023.

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- 生物心理学

- 情绪刺激下心跳诱发脑电位的时间交互现象⁴³
 - 用于情绪分析的生理信号 DEAP 数据集

⁴³ Liesa Ravijts. "Revealing temporal interactions around the heartbeat-evoked potential modulated by emotional perception".

生物学

● 系统生物学

- 生物信号调控和传导⁴⁴
 - 癌症分子机制数据
- 生物现象动态网络结构和功能⁴⁵
 - 酵母细胞周期数据

● 生物信息学

- 分析基因数据，研究生命和疾病机理⁴⁶
 - 肝炎病毒感染治疗基因表达谱数据
- 筛选与癌症有关的变异基因⁴⁷
 - cBioPortal 癌症基因组数据
 - 美国亚利桑那州立大学癌症基因组数据
- 单细胞测序基因调控网络构建⁴⁸
 - DREAM3 的 Ecoli 数据和小鼠胚胎早期血液发育的单细胞测序数据

⁴⁴Agata Charzyńska and Anna Gambin. "Improvement of the k-NN Entropy Estimator with Applications in Systems Biology". In: *Entropy* 18.1 (2015), p. 13.

⁴⁵Farzaneh Farhangmehr et al. "An information-theoretic algorithm to data-driven genetic pathway interaction network reconstruction of dynamic systems". In: *2013 IEEE International Conference on Bioinformatics and Biomedicine*. 2013, pp. 214–217.

⁴⁶Mario Wieser et al. "Inverse Learning of Symmetries". In: *Advances in Neural Information Processing Systems*. Vol. 33. 2020, pp. 18004–18015.

⁴⁷Qiang Wu and Dongxi Li. "CRISA: An Interactive Gene Selection Algorithm for Cancers Prediction Based on Copy Number Variations". In: *Frontiers in Plant Science* 13 (2022), p. 839044. DOI: 10.3389/fpls.2022.839044.

⁴⁸竺政彤. "基于单细胞测序数据构建基因调控网络的方法研究". 硕士学位论文. 内蒙古农业大学, 2023.

医学 I

- 临床医学

- 心脏病诊断⁴⁹

- UCI 心脏病数据

- 糖尿病病情管理⁵⁰

- 美国 Health Facts 糖尿病救治网络数据

- 癌症预后⁵¹

- UCI 肺癌数据

- SEER 数据库乳腺癌临床数据

⁴⁹ Jian Ma. "Variable Selection with Copula Entropy". In: *Chinese Journal of Applied Probability and Statistics* 37.4 (2021). See also arXiv preprint arXiv:1910.12389 (2019), pp. 405–420.

⁵⁰ Radko Mesiar and Ayyub Sheikh. "Nonlinear Random Forest Classification, a Copula-Based Approach". In: *Applied Sciences* 11.15 (2021), p. 15. DOI: 10.3390/app11157140.

⁵¹ Jian Ma. "Copula Entropy based Variable Selection for Survival Analysis". In: *arXiv preprint arXiv:2209.01561* (2022), 付金露. "基于特征选择的乳腺癌患者预后模型研究". 硕士学位论文. 江西财经大学, 2023.

医学 II

● 临床医学

- 白内障术后角膜水肿风险预测⁵²
 - 临床白内障超声乳化手术患者数据
- 主动脉瓣置换手术射血分数分析⁵³
 - 临床主动脉瓣置换手术前后射血分数数据
- 脑肿瘤医学影像组学诊断模型构建⁵⁴
 - 重庆医科大学附属第一医院、西南医院和四川省肿瘤医院脑肿瘤患者数据
- 基于脉搏波的高血压和糖尿病健康状态分类⁵⁵
 - 高血压和糖尿病患者脉搏波数据

⁵²Yu Luo et al. "Research on Establishing Corneal Edema after Phacoemulsification Prediction Model Based on Variable Selection with Copula Entropy". In: *Journal of Clinical Medicine* 12.4 (2023), p. 1290. DOI: 10.3390/jcm12041290.

⁵³S.M. Sunoj and N. Unnikrishnan Nair. "Survival Copula Entropy and Dependence in Bivariate Distributions". In: *REVSTAT-Statistical Journal* (2023). URL: <https://revstat.ine.pt/index.php/REVSTAT/article/view/560>.

⁵⁴潘红宇. "基于影像组学与深度学习的脑肿瘤图像分类研究". 硕士学位论文. 西南大学, 2023.

⁵⁵汤宇飞. "基于脉搏波的糖尿病和高血压诊断算法研究". 硕士学位论文. 中国矿业大学, 2023.

医学 III

- 认知医学

- 认知能力评估 / 痴呆症筛查⁵⁶
 - 北京和天津痴呆症老年人数据

- 运动医学

- 运动能力评估 / 跌倒风险预测⁵⁷
 - 天津和成都跌倒人群老年人数据
- 重复经颅磁刺激对帕金森病改善神经机制分析⁵⁸
 - 帕金森患者经颅磁刺激前后 EEG 数据

- 精神病学

- 抑郁症患者识别⁵⁹
 - 江苏常州抑郁症青少年患者 EEG 数据

⁵⁶ Jian Ma. "Predicting MMSE Score from Finger-Tapping Measurement". In: *Proceedings of 2021 Chinese Intelligent Automation Conference*. See also bioRxiv 817338 (2019). 2022, pp. 294–304.

⁵⁷ Jian Ma. "Predicting TUG score from gait characteristics based on video analysis and machine learning". In: *Proceedings of 2023 Chinese Intelligent Automation Conference*. See also bioRxiv 963686 (2020). 2023, pp. 1–12, Jian Ma. "Associations between finger tapping, gait and fall risk with application to fall risk assessment". In: *arXiv preprint arXiv:2006.16648* (2020).

⁵⁸ 李润泽 et al. "重复经颅磁刺激改善帕金森病运动症状的脑功能网络分析". In: *生物化学与生物物理进展* 50.1 (2023), pp. 126–134.

⁵⁹ 张婷婷 et al. "基于 Couple 熵的抑郁症相干性反馈指标提取". In: *电子测量技术* 45.9 (2022), pp. 160–167.

公共卫生学

- 新冠肺炎流行病 (COVID19)
 - 发热症状疑似病人筛查诊断⁶⁰
 - 新冠临床数据
- 高血压
 - 高血压关联基因研究⁶¹
 - ELEMENT 数据集

⁶⁰Radko Mesiar and Ayyub Sheikhi. "Nonlinear Random Forest Classification, a Copula-Based Approach". In: *Applied Sciences* 11.15 (2021), p. 15. DOI: 10.3390/app11157140.

⁶¹Soumik Purkayastha and Peter X.K. Song. "Asymmetric predictability in causal discovery: an information theoretic approach". In: *arXiv preprint arXiv:2210.14455* (2022).

社会科学 I

● 经济学

- 扶贫政策效果评估，用于政策目标人口鉴别⁶²
 - 2018 年政府贫困家庭状况普查数据（四川省和河南省）
- 议价机制中的互惠行为和时间效应⁶³
 - eBay 的 Best Offer 平台数据
- 产业链内部相关性分析⁶⁴
 - 国内畜禽养殖产业链主要上市企业股票价格数据
- 投资者情绪分析⁶⁵
 - 中国新能源汽车上市公司的百度搜索数据

⁶²Qingsong Shan and Qianning Liu. "Binary Trees for Dependence Structure". In: *IEEE Access* 8 (2020), pp. 150989–150998. DOI: 10.1109/ACCESS.2020.3017529, 罗良清 et al. "中国贫困治理经验总结：扶贫政策能够实现有效增收吗？". In: *管理世界* 38.2 (2022), pp. 70–83, Haonan Zhang, Jiapeng Dai, and Yousaf Ali Khan. "Poverty improvement policies and household income: Evidence from China". In: *Heliyon* (2023), E21442. DOI: 10.1016/j.heliyon.2023.e21442.

⁶³Leonie Bossemeyer. "Machine Learning for Causal Discovery with Applications in Economics". MA thesis. Ludwig-Maximilians-Universität München, 2021.

⁶⁴韦颖璐. "基于 pair-copula 熵的相关性度量". 硕士学位论文. 苏州大学, 2021.

⁶⁵Muye Han and Jinsheng Zhou. "Multi-Scale Characteristics of Investor Sentiment Transmission Based on Wavelet, Transfer Entropy and Network Analysis". In: *Entropy* 24.12 (2022), p. 1786. DOI: 10.3390/e24121786.

社会科学 II

● 管理学

● 商品期货价格预测⁶⁶

- 国家统计局猪肉价格数据和大连商品交易所大豆期货价格数据

● 单周期库存管理⁶⁷

- 大众朗逸汽车销售数据

● 中国企业海外并购影响因素分析⁶⁸

- Wind 数据库经济数据

● 社会学

● 分析教育、职业和收入上的性别不平等问题⁶⁹

- 美国国家成年人收入调查数据（1994 年）

⁶⁶ Wuyue An, Lin Wang, and Dongfeng Zhang. "Comprehensive commodity price forecasting framework using text mining methods". In: *Journal of Forecasting* 42.7 (2023), pp. 1865–1888. DOI: 10.1002/for.2985.

⁶⁷ Yu-Xin Tian and Chuan Zhang. "An end-to-end deep learning model for solving data-driven newsvendor problem with accessibility to textual review data". In: *International Journal of Production Economics* (2023), p. 109016. DOI: 10.1016/j.ijpe.2023.109016.

⁶⁸ 王琳君. "中国企业海外并购的影响因素和绩效评价研究". 博士学位论文. 中国科学院大学, 2022.

⁶⁹ Jian Ma. "Causal Domain Adaptation with Copula Entropy based Conditional Independence Test". In: *arXiv preprint arXiv:2202.13482* (2022).

社会科学 III

● 教育学

● 高中数学成绩与其他学科成绩相关性分析⁷⁰

- 某市 2013 级理科学生高一、高二期末成绩和高三两次模考成绩

● 计算语言学

● 城市热线派单系统知识图谱构建⁷¹

- 济南市民热线数据

● 新闻传播学

● 上海新冠疫情下的公众情绪变化⁷²

- 微博平台“上海疫情”主题数据

● 法学

● 社区属性与社区犯罪关系分析⁷³

- 美国社区与犯罪数据集

⁷⁰ 柳琼. “基于 Copula 和 MI 理论的相关性度量及其应用研究”. 硕士学位论文. 三峡大学, 2018.

⁷¹ 陈作海, 钱恒, and 高永超. “一种基于知识图谱的城市热线派单方法及系统”. Pat. CN115860436A. 2023.

⁷² Bowen Zhang et al. “Changes in Public Sentiment under the Background of Major Emergencies – Taking the Shanghai Epidemic as an Example”. In: *International Journal of Environmental Research and Public Health* 19.19 (2022), p. 12594. DOI: 10.3390/ijerph191912594.

⁷³ Mario Wieser. “Learning Invariant Representations for Deep Latent Variable Models”. PhD thesis. University of Basel, 2020.

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工程学 I

● 能源工程

- 能源网络管理，研究天气因素与能源网络的耦合⁷⁷
 - 北方某地区能源系统运行数据
- 光伏发电功率预测⁷⁸
 - 澳大利亚 Yulara 地区光伏电站数据
- 风电机组工况划分⁷⁹
 - 广东某海上风电场 SCADA 数据
- 电力负荷预测⁸⁰
 - 摩洛哥缔头万 (Tétouan) 城电力消费数据
 - 美国亚利桑那居民建筑综合能源负荷 2018 年数据
- 风光储协同规划⁸¹
 - 某工业园区风光火储联合发电系统

⁷⁷ Xueqian Fu et al. "Uncertainty analysis of an integrated energy system based on information theory". In: *Energy* 122.122 (2017), pp. 649–662.

⁷⁸ 朱正林 和 张冕. "基于 AO 优化 VMD-CE-BiGRU 的光伏发电功率预测". In: *国外电子测量技术* 41.10 (2022), pp. 56–61.

⁷⁹ 崔双双 和 孙单勋. "分工况下风电机组各变量相关性研究". In: *综合智慧能源* 44.12 (2022), pp. 49–55.

⁸⁰ Jian Ma. "Identifying Time Lag in Dynamical Systems with Copula Entropy based Transfer Entropy". In: *arXiv preprint arXiv:2301.06037* (2023), Qin Yan et al. "Short-term prediction of integrated energy load aggregation using a bi-directional simple recurrent unit network with feature-temporal attention mechanism ensemble learning model". In: *Applied Energy* 355 (2024), p. 122159. DOI: 10.1016/j.apenergy.2023.122159.

⁸¹ 董海艳 et al. "一种含源荷时序相似度约束的源储协同规划配置方法". Pat. CN114421538A. 2022.

工程学 II

● 能源工程

- 电网频率稳定性预测⁸²
 - 贵州电网数据
- 用户线损贡献分析⁸³
 - 辽宁电网数据
- 配电网拓扑辨识⁸⁴
 - 接入风机和光伏的家庭负荷配电网仿真数据
- 电价预测⁸⁵
 - 2017 年美国 PJM 电力市场电价数据
- 电力系统宽频振荡影响因素和传播路径分析⁸⁶
 - 直驱风机并网系统和含风电场的四机两区系统仿真数据

⁸²Peili Liu et al. "Frequency Stability Prediction of Power Systems Using Vision Transformer and Copula Entropy". In: *Entropy* 24.8 (2022), p. 1165. DOI: 10.3390/e24081165.

⁸³Wei Hu et al. "Research on User Loss Contribution Calculation of High-Loss Distribution Area Based on Transfer Entropy". In: *2022 China International Conference on Electricity Distribution (CICED)*. 2022, pp. 499–502. DOI: 10.1109/CICED56215.2022.9929052.

⁸⁴秦超 and 潘毓笙. "一种基于时空特征的配电网拓扑辨识方法". Pat. CN117154679A. 2023.

⁸⁵Xiaoping Xiong and Guohua Qing. "A hybrid day-ahead electricity price forecasting framework based on time series". In: *Energy* (2022), p. 126099. DOI: 10.1016/j.energy.2022.126099.

⁸⁶冯双 et al. "一种电力系统宽频振荡影响因素和传播路径分析方法". Pat. CN114977222A. 2022, 冯双 et al. "基于 Copula 传递熵的设备级和网络级宽频振荡传播路径分析及振荡源定位方法". In: *电工技术学报* (2023). DOI: 10.19595/j.cnki.1000-6753.tces.230873.

- 能源工程
 - 锂电池容量估计⁸⁷
 - NASA 锂电池退化数据
 - 能效异常原因诊断⁸⁸
 - 空压机系统运行数据

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⁸⁸ [Jian Ma](#). "Root Cause Analysis on Energy Efficiency with Transfer Entropy Flow". In: *arXiv preprint arXiv:2401.05664* (2024).

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- 交通运输
 - 大件货物运输方案制定⁹²
 - 大件货物运输案例数据
 - 航空和高铁票价影响因素分析⁹³
 - 京沪高铁和航空票价数据
 - 城市轨道交通客流分析和预测⁹⁴
 - 苏州市轨道交通系统客流时序数据

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- 可靠性工程

- 系统退化过程建模¹⁰⁰
 - 微波电子组件数据
- 风电机组健康状态评估¹⁰¹
 - 内蒙古某风场的风机 SCADA 数据
- 砂轮剩余寿命预测¹⁰²
 - 威孚高科 CPM2.2 生产线上磨床 SCADA 数据

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- 化学工程

- 化学过程故障监测和诊断¹⁰³
 - Tennessee Eastman 过程数据
- 化工过程因果网络构建¹⁰⁴
 - 连续搅拌槽式反应器数据和 Tennessee Eastman 过程数据
- 化工过程缺失数据补全¹⁰⁵
 - 脱丁烷塔过程数据和聚丙烯生产过程数据

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工程学 IX

● 航空航天

- 飞行器总体参数分析和优化¹⁰⁶
 - 美国喷气战斗机总体设计参数数据
- 卫星在轨健康状态监测¹⁰⁷
 - 真实卫星遥测数据
 - NASA 公开的 SMAP 和 MSL 数据集
- 涡扇发动机健康状态监测¹⁰⁸
 - NASA 格林中心引擎性能退化模拟数据
- 机场间航班延误因果关系分析¹⁰⁹

● 车辆工程

- CAN 总线入侵检测¹¹⁰
 - 现代汽车 YF 索纳塔 CAN 数据

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- 量化金融工具箱 MLFinLab¹²¹
- 金融系统性风险
 - 行业风险溢出效应分析¹²²
 - 我国股票市场 11 个行业交易数据
 - 金融脆弱性度量¹²³
 - 沪深 300 指数股票数据
- 信用风险评价
 - 信用风险卡模型建立¹²⁴
 - 信用卡客户数据
- 金融产品价格预测
 - 基于因果关系的迁移学习价格预测模型构建¹²⁵
 - 国际主要金融指数、能源期货价格和农产品价格数据

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