Time Series Continuous Modeling for Imputation and Forecasting with Implicit Neural Representations

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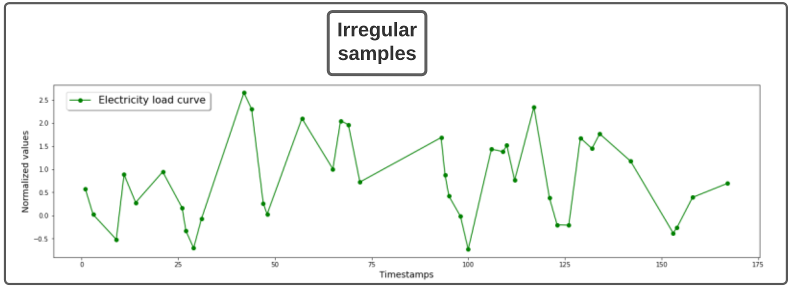
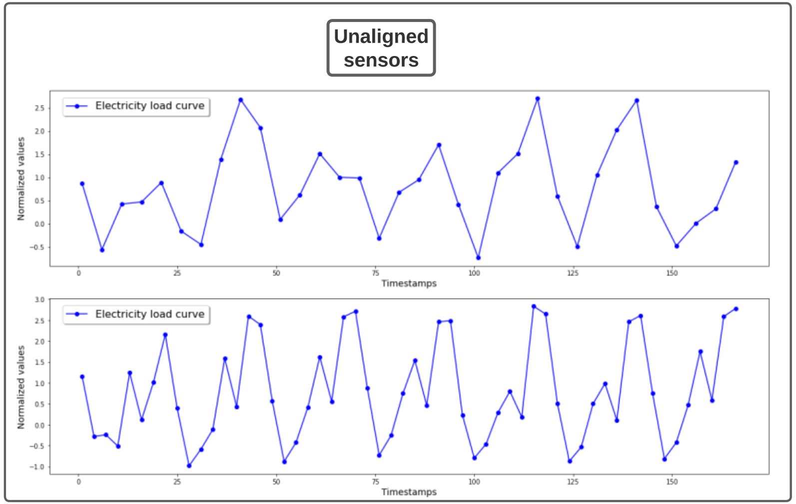
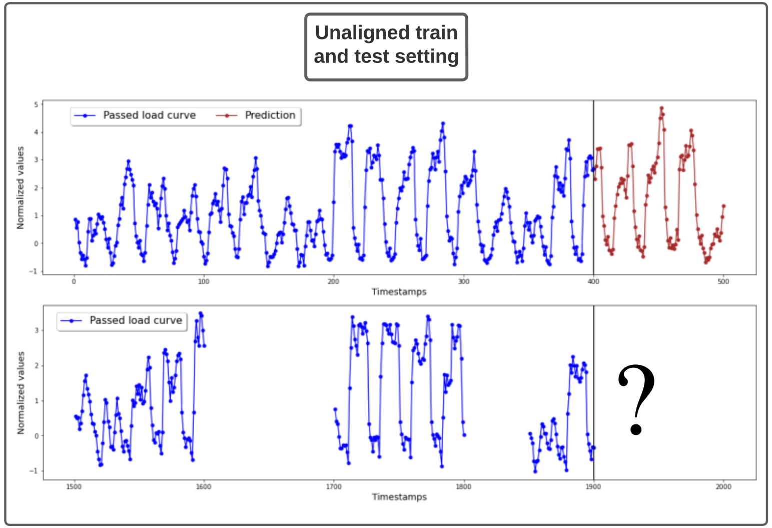
Time Series : continuous phenomena / observed partially

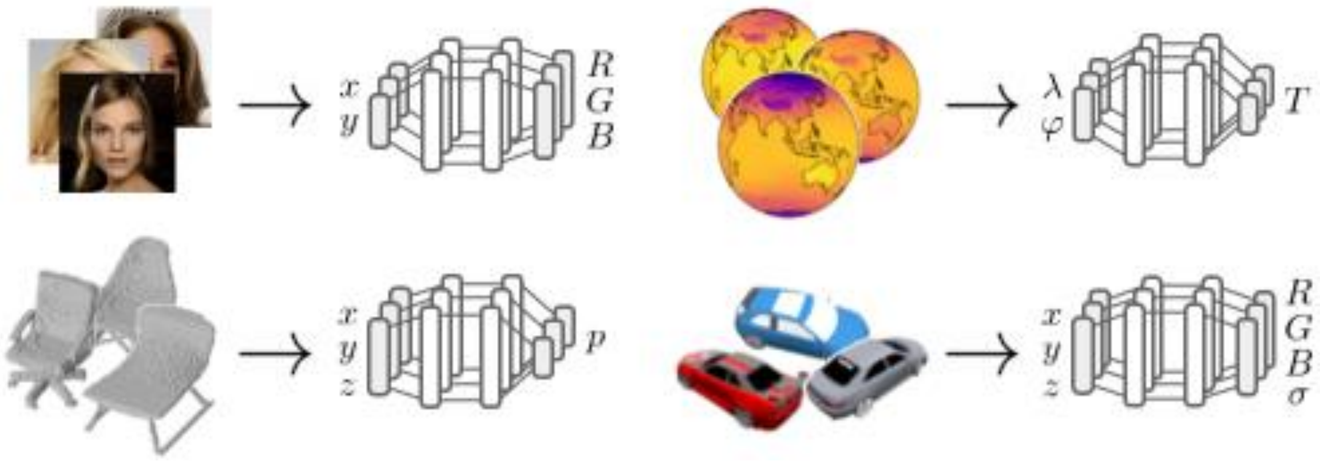






Technical options for continuous modeling

- Gaussian Processes [Williams & Rasmussen, 2006] / Neural Processes [Kim et al. 2019]
- Diffusion Model [Ho et al. 2020]
- Implicit Neural Representation (INR) [Dupont et al. 2022]



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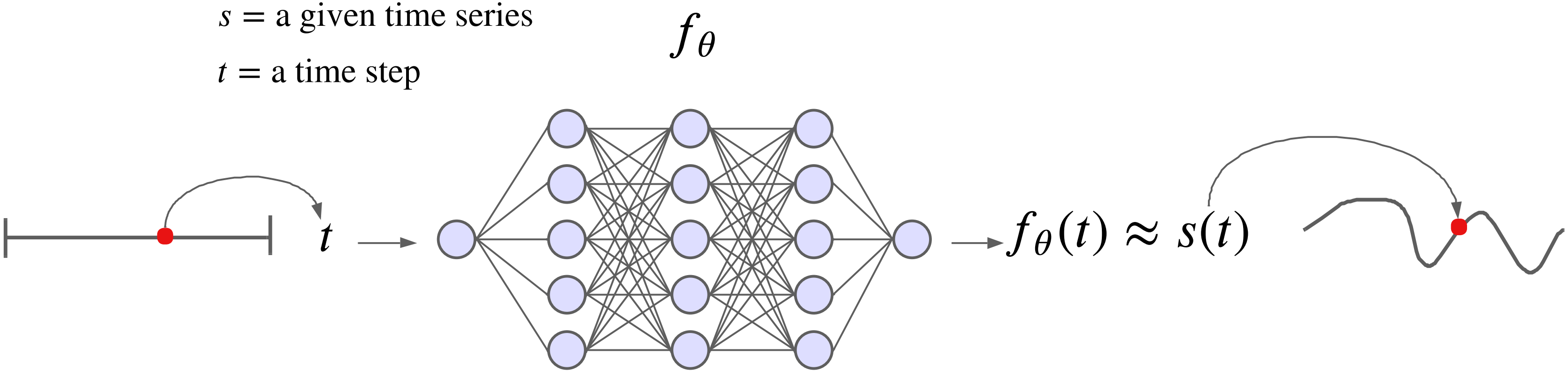
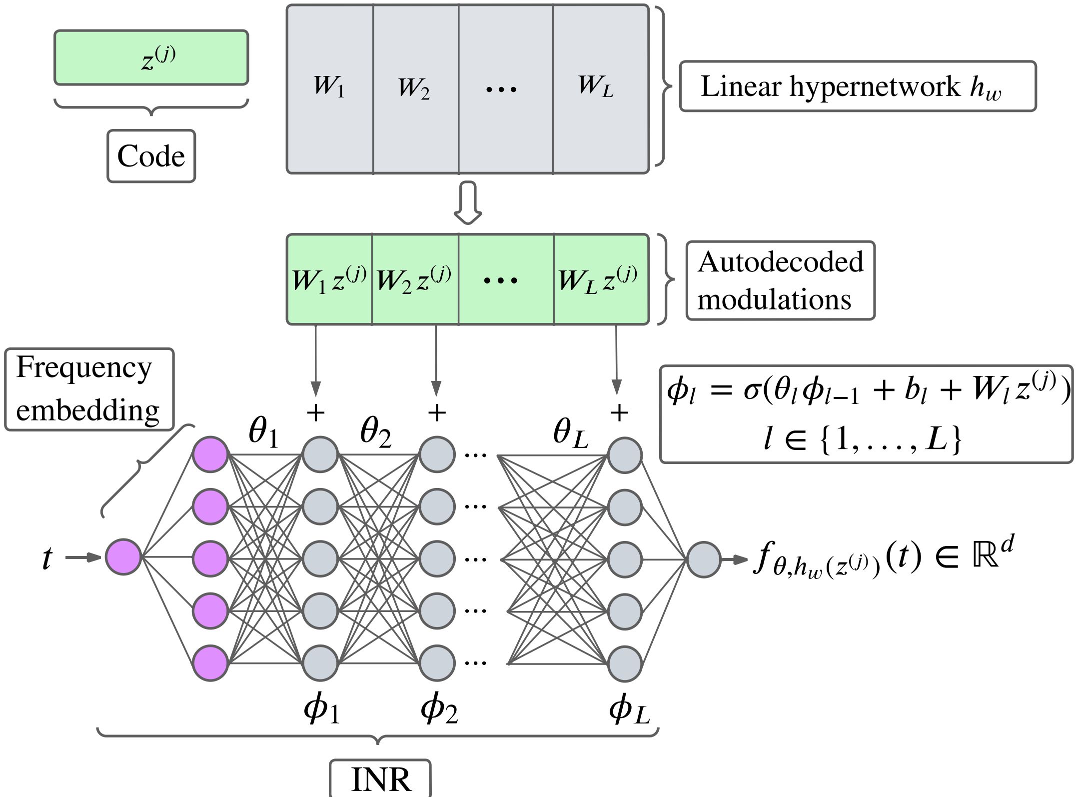
s = a given time series

t = a time step



Dealing with Multiple Time Series : HyperNetwork architecture



HyperNet

- 1 TS = 1 code z
- Linear mapping
- Generate specific b

INR = 1 time series

- Fixed 1st layer (Fourier)
- MLP : shared θ / specific *b*

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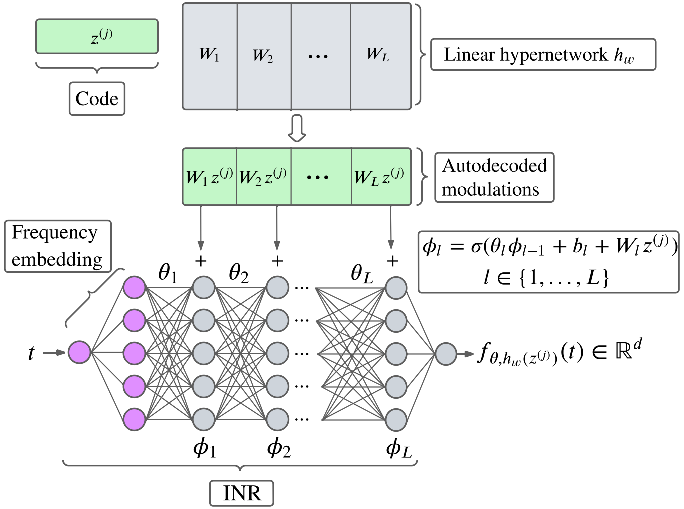
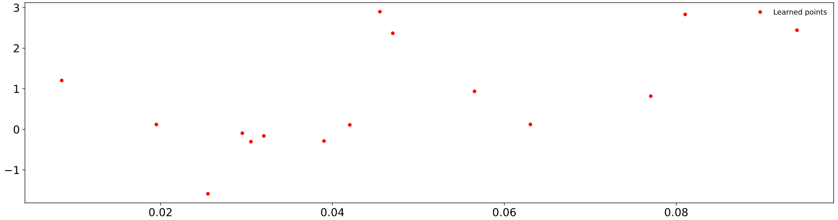


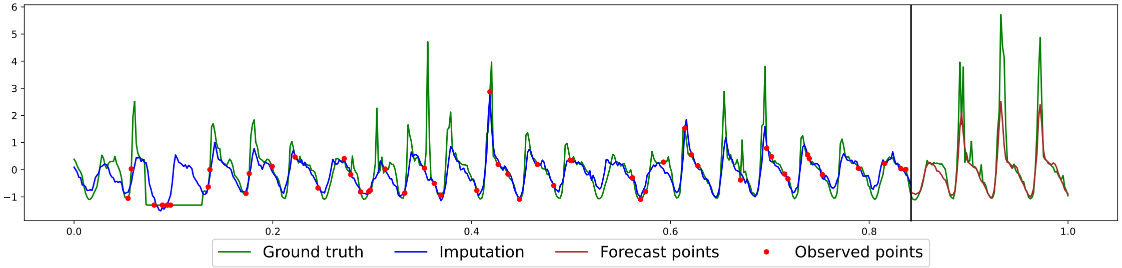
Inference:

1. Observations



2. Determining code z

3. Inputation + Forcasting



Results: it works in a very diverse range of situations

- Imputation
- Long range forecasting
- Forecasting from incomplete data

		Continuous methods				Discrete methods			
	τ	TimeFlow	DeepTime	mTAN	Neural Process	CSDI	SAITS	BRITS	TIDER
Electricity	0.05	0.324 ± 0.013	0.379 ± 0.037	0.575 ± 0.039	0.357 ± 0.015	0.462 ± 0.021	0.384 ± 0.019	0.329 ± 0.015	0.427 ± 0.010
	0.10	0.250 ± 0.010	0.333 ± 0.034	0.412 ± 0.047	0.417 ± 0.057	0.398 ± 0.072	0.308 ± 0.011	0.287 ± 0.015	0.399 ± 0.009
	0.20	0.225 ± 0.008	0.244 ± 0.013	0.342 ± 0.014	0.320 ± 0.017	0.341 ± 0.068	0.261 ± 0.008	0.245 ± 0.011	0.391 ± 0.010
	0.30	0.212 ± 0.007	0.240 ± 0.014	0.335 ± 0.015	0.300 ± 0.022	0.277 ± 0.059	0.236 ± 0.008	0.221 ± 0.008	0.384 ± 0.009
	0.50	0.194 ± 0.007	0.227 ± 0.012	0.340 ± 0.022	0.297 ± 0.016	0.168 ± 0.003	0.209 ± 0.008	0.193 ± 0.008	0.386 ± 0.009
Solar	0.05	0.095 ± 0.015	0.190 ± 0.020	0.241 ± 0.102	0.115 ± 0.015	0.374 ± 0.033	0.142 ± 0.016	0.165 ± 0.014	0.291 ± 0.009
	0.10	0.083 ± 0.015	0.159 ± 0.013	0.251 ± 0.081	0.114 ± 0.014	0.375 ± 0.038	0.124 ± 0.018	0.132 ± 0.015	0.276 ± 0.010
	0.20	0.072 ± 0.015	0.149 ± 0.020	0.314 ± 0.035	0.109 ± 0.016	0.217 ± 0.023	0.108 ± 0.014	0.109 ± 0.012	0.270 ± 0.010
			014	0.338 ± 0.05	0.108 ± 0.016	0.156 ± 0.002	0.100 ± 0.015	0.098 ± 0.012	0.266 ± 0.010
			013	0.315 ± 0.080	0.107 ± 0.015	0.079 ± 0.011	0.094 ± 0.013	0.088 ± 0.013	0.262 ± 0.009
			010	0.406 ± 0.074	0.318 ± 0.014	0.337 ± 0.045	0.293 ± 0.007	0.281 ± 0.010	0.363 ± 0.007
			007	0.319 ± 0.025	0.288 ± 0.018	0.288 ± 0.017	0.237 ± 0.006	0.245 ± 0.009	0.362 ± 0.006
			006	0.270 ± 0.012	0.271 ± 0.011	0.289 ± 0.017	0.197 ± 0.005	0.224 ± 0.008	0.361 ± 0.006
								± 0.007	0.355 ± 0.006
								± 0.060	0.354 ± 0.007
								80 %	53.40 %

	H	τ	TimeFlow		DeepTime		Neural Process	
			Imputation error	Forecast error	Imputation error	Forecast error	Imputation error	Forecast error
Electricity	96	0.5	0.151 ± 0.003	0.239 ± 0.013	0.209 ± 0.004	0.270 ± 0.019	0.460 ± 0.048	0.486 ± 0.078
		0.2	0.208 ± 0.006	0.260 ± 0.015	0.249 ± 0.006	0.296 ± 0.023	0.644 ± 0.079	0.650 ± 0.095
		0.1	0.272 ± 0.006	0.295 ± 0.016	0.284 ± 0.007	0.324 ± 0.026	0.740 ± 0.083	0.737 ± 0.106
	192	0.5	0.149 ± 0.004	0.235 ± 0.011	0.204 ± 0.004	0.265 ± 0.018	0.461 ± 0.045	0.498 ± 0.070
		0.2	0.209 ± 0.006	0.257 ± 0.013	0.244 ± 0.007	0.290 ± 0.023	0.601 ± 0.075	0.626 ± 0.101
		0.1	0.274 ± 0.010	0.289 ± 0.016	0.282 ± 0.007	0.315 ± 0.025	0.461 ± 0.045	0.724 ± 0.090
Traffic	96	0.5	0.180 ± 0.016	0.219 ± 0.026	0.272 ± 0.028	0.243 ± 0.030	0.436 ± 0.025	0.444 ± 0.047
		0.2	0.239 ± 0.019	0.243 ± 0.027	0.335 ± 0.026	0.293 ± 0.027	0.596 ± 0.049	0.597 ± 0.075
		0.1	0.312 ± 0.020	0.290 ± 0.027	0.385 ± 0.025	0.344 ± 0.027	0.734 ± 0.102	0.731 ± 0.132
	192	0.5	0.176 ± 0.014	0.217 ± 0.017	0.241 ± 0.027	0.234 ± 0.021	0.477 ± 0.042	0.476 ± 0.043
		0.2	0.233 ± 0.017	0.236 ± 0.021	0.286 ± 0.027	0.276 ± 0.020	0.685 ± 0.109	0.678 ± 0.108
		0.1	0.304 ± 0.019	0.277 ± 0.021	0.331 ± 0.025	0.324 ± 0.021	0.888 ± 0.178	0.877 ± 0.174
TimeFlow improvement			/	/	18.97 %	11.87 %	61.88 %	58.41 %

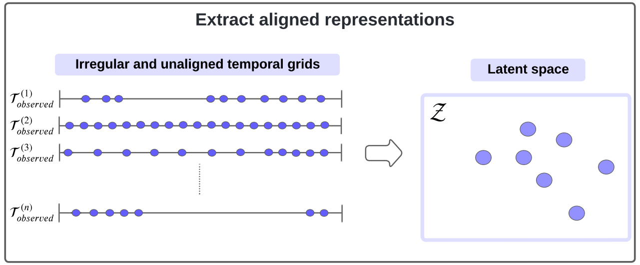
	H				Discrete methods			
		TimeFlow	DeepTime	Neural Process	Patch-TST	DLinear	AutoFormer	Informer
				± 0.045	0.214 ± 0.020	0.236 ± 0.035	0.310 ± 0.031	0.293 ± 0.0184
				± 0.046	0.225 ± 0.017	0.248 ± 0.032	0.322 ± 0.046	0.336 ± 0.032
				± 0.075	0.242 ± 0.024	0.284 ± 0.043	0.330 ± 0.019	0.405 ± 0.044
				± 0.149	0.291 ± 0.040	0.370 ± 0.036	0.456 ± 0.062	0.489 ± 0.072
				± 0.048	0.232 ± 0.008	0.204 ± 0.002	0.261 ± 0.053	0.273 ± 0.023
				± 0.046	0.231 ± 0.027	0.211 ± 0.012	0.312 ± 0.085	0.256 ± 0.026
				± 0.005	0.254 ± 0.046	0.212 ± 0.019	0.341 ± 0.107	0.287 ± 0.006
				± 0.147	0.271 ± 0.036	0.246 ± 0.015	0.368 ± 0.006	0.341 ± 0.049
				± 0.028	0.201 ± 0.031	0.225 ± 0.034	0.299 ± 0.080	0.324 ± 0.113
				± 0.023	0.195 ± 0.024	0.215 ± 0.022	0.320 ± 0.036	0.321 ± 0.052
	336	0.237 ± 0.040	0.247 ± 0.033	0.306 ± 0.039	0.220 ± 0.038	0.244 ± 0.035	0.450 ± 0.127	0.394 ± 0.086
	720	0.288 ± 0.048	0.290 ± 0.046	0.339 ± 0.037	0.288 ± 0.060	0.290 ± 0.047	0.630 ± 0.043	0.441 ± 0.056
TimeFlow improvement		/	6.56 %	30.79 %	2.64 %	7.30 %	35.43 %	33.07 %

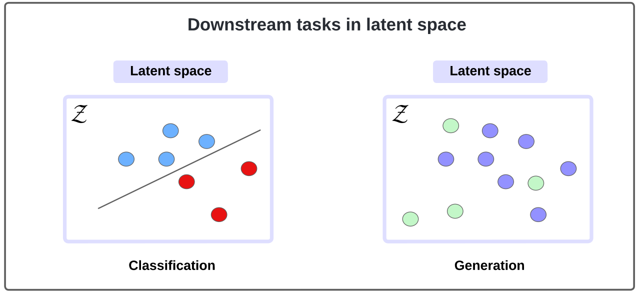
Conclusion: A path towards foundation models for time series

A way to learn semantic representations

Connections with diffusion models

Data generation/augmentation





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