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Multi-population mortality modeling with economic trends: A hybrid neural network approach

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Motivation

1. Want to **predict mortality for multiple populations**

- Human longevity continues to increase
- Mortality improvements in different populations are correlated

2. Want to account for the **complex links between mortality and GDP** (e.g., Hanewald, 2011, Boonen & Li, 2017)

- Links between GDP and mortality over time
- Links between GDP and mortality across countries
- Short-term and long-term links between GDP and mortality

Applications:

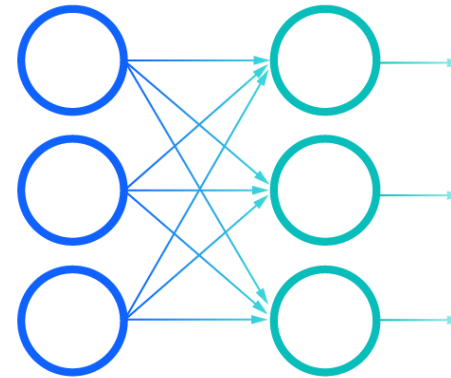
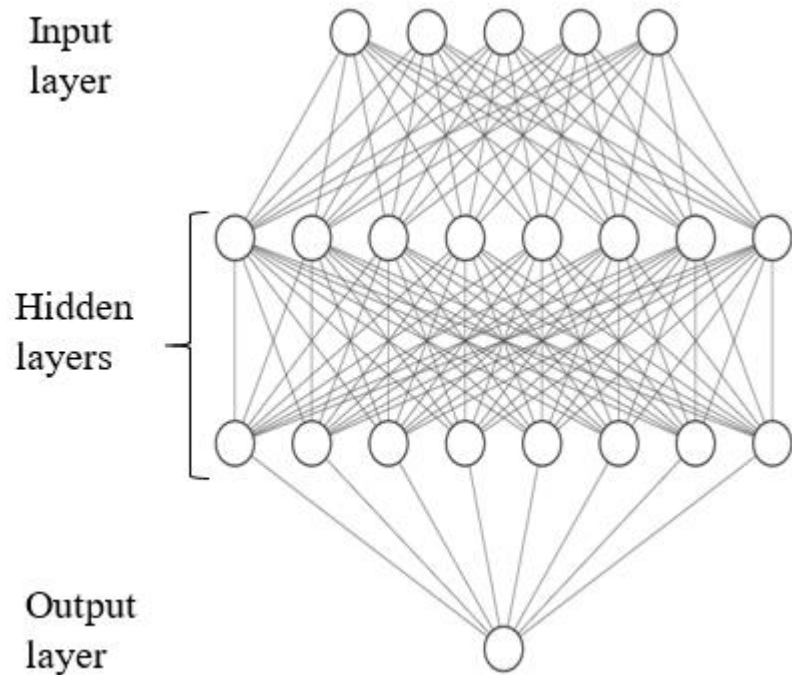
- More accurate mortality predictions (esp. for small populations)
- Predictions of mortality scenarios and economic scenarios
- Longevity risk hedging

Summary

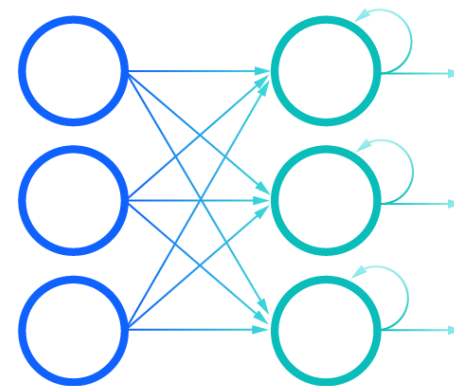
→ Propose a **new hybrid neural network approach** for estimating and predicting the mortality rates of multiple populations

- Uses a hybrid neural network structure: CNN-LSTM
 - Convolutional neural network (CNN) – powerful in identifying patterns
 - Long short-term memory (LSTM) – good at time-series predictions
- Finds linear and non-linear relationships between mortality and GDP per capita
- Predicts mortality rates and GDP per capita simultaneously for multiple populations

Neural network structures



Feedforward neural network:
Connections between nodes do not form a cycle



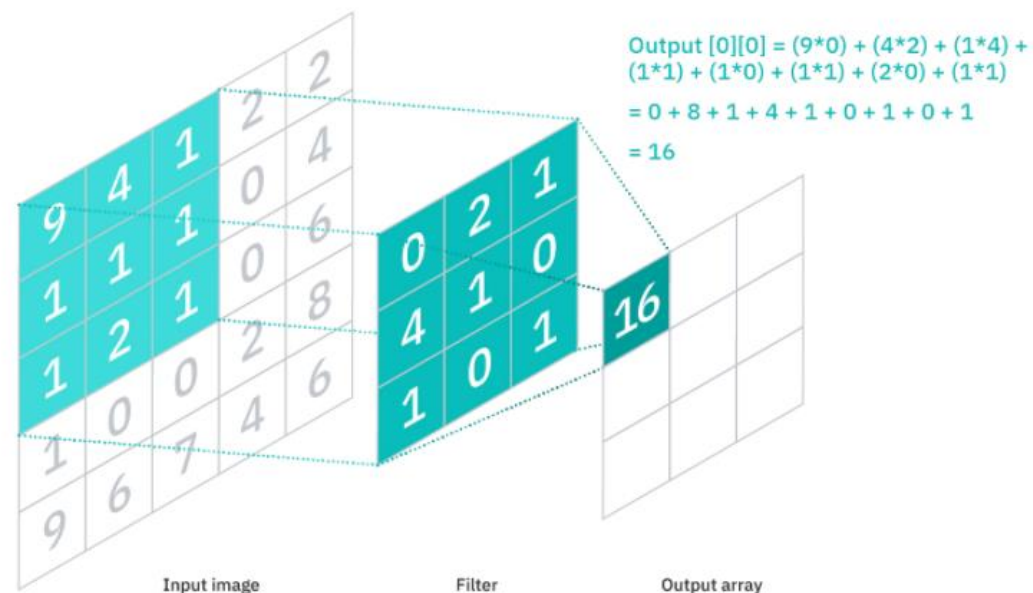
Recurrent neural network:
Uses feedback connections to learn long-term dependencies

Source: <https://www.ibm.com/cloud/learn/recurrent-neural-networks>

Neural network structures

Convolutional neural network

- Inspired by the organization of the visual cortex
- Three types of layers: convolutional layer, pooling layer, fully-connected (FC) layer
- Time series prediction (Wang et al., 2019); mortality rates (Perla et al., 2021)

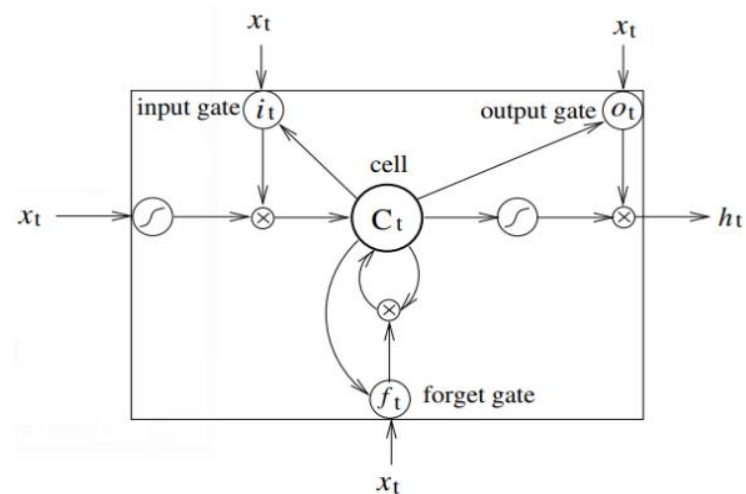


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Neural network structures

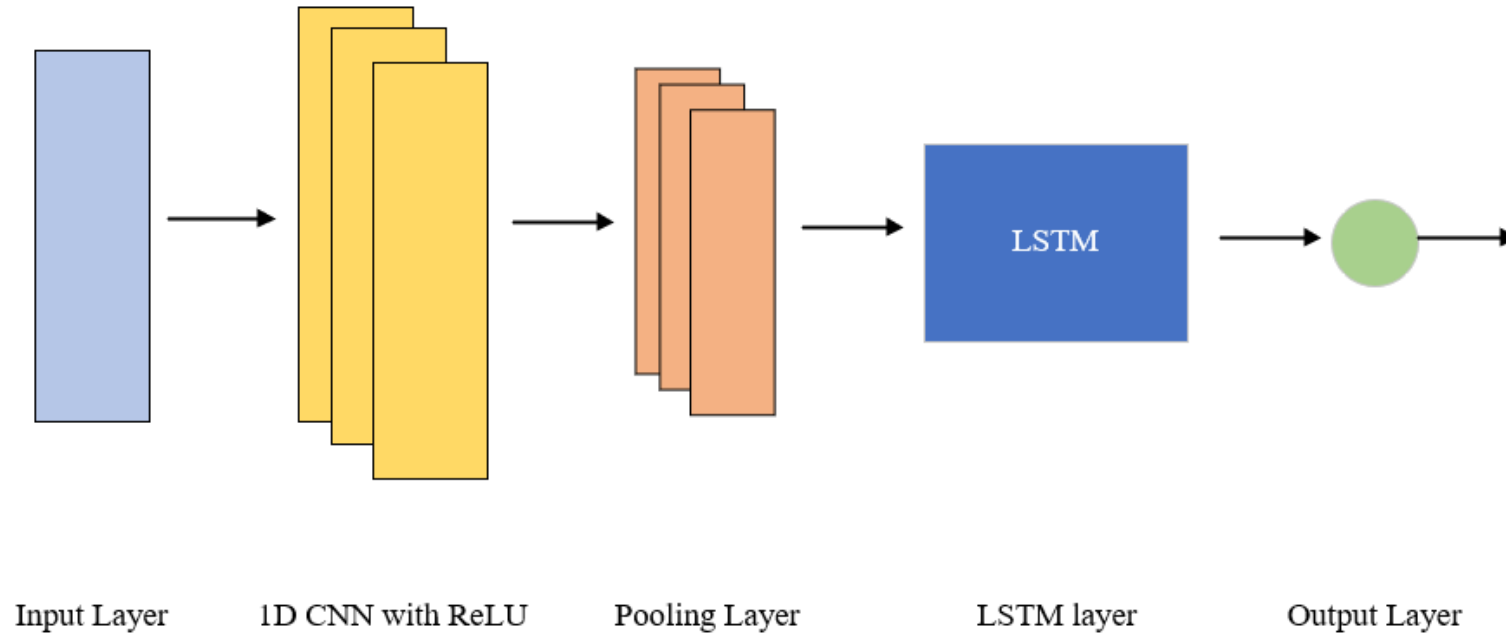
Long short-term memory (LSTM)

- A type of **recurrent** neural network
- Can learn long-term dependency
 - Input gate, forget gate: control the new information stored in the cell
 - Output gate: decides the next hidden state
- Has become popular in actuarial science (Nigri et al., 2019; Richman & Wüthrich, 2019, Perla et al., 2021; Lindholm and Palmborg, 2021)



Source: Graves et al. (2005)

Our proposed model



Convolutional layer: produces new feature values by convolution operation between the raw input data

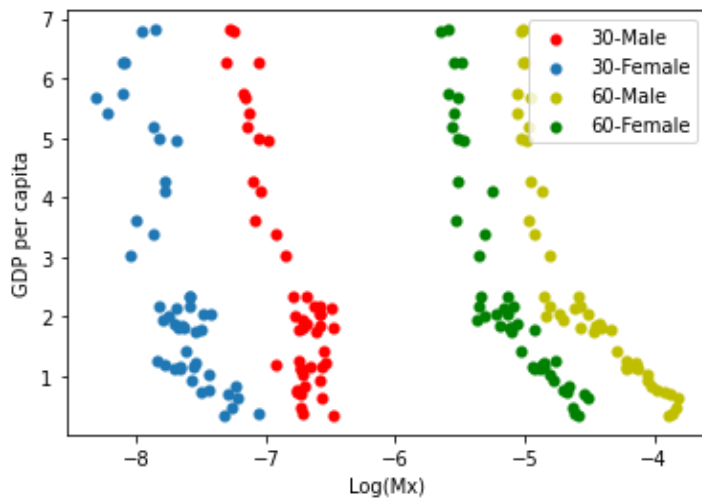
Pooling layer: produces a lower dimension matrix

LSTM: learns long-term dependencies

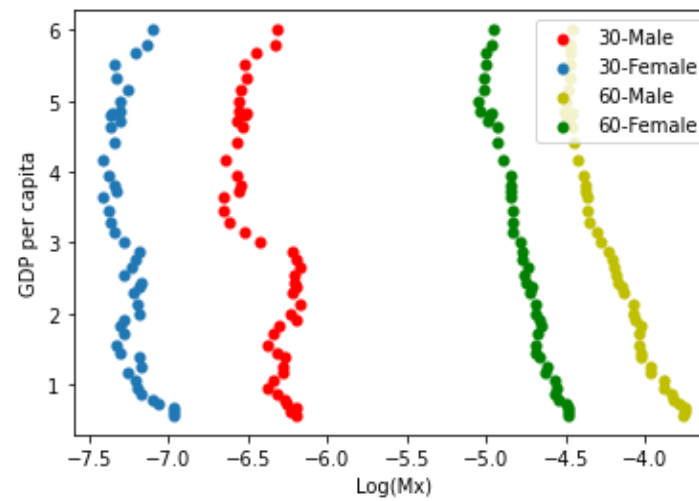
Data

- Male and female **mortality data** from the Human Mortality Database (HMD)
- **Real GDP per capita** data from the World Bank
- Sample: 30 countries with at least ten years of mortality and GDP data before the year 2000
- Training data: 1970-1999, test data: 2000-2018

Correlations between GDP and mortality over time

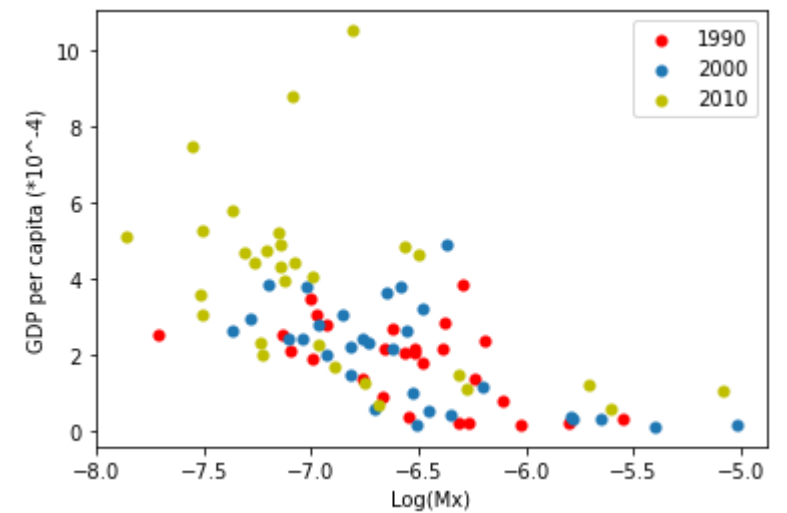


AUS



USA

Correlations between GDP and mortality across countries (30-Male)



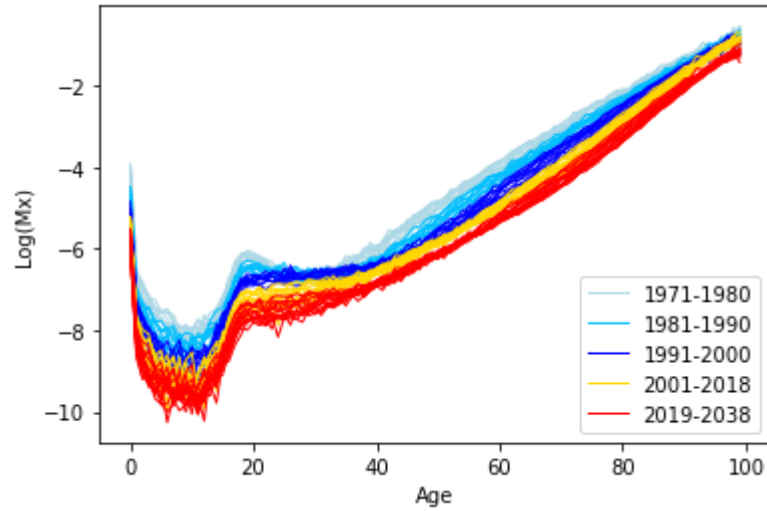
Model comparison

Compare models with and without GDP based on their mean square error (MSE):

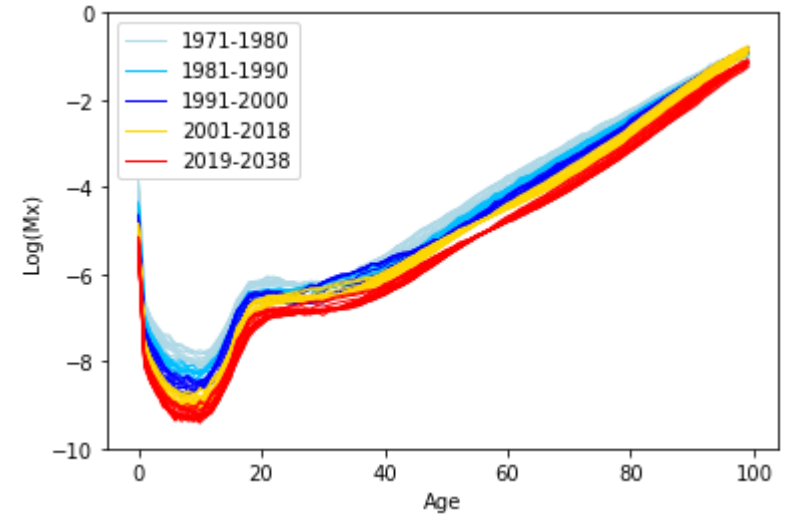
| Models | In sample loss ($\times 10^{-4}$) | Out-of-sample loss ($\times 10^{-4}$) |
|-----------|-------------------------------------|---|
| NN0 | 7.01 | 5.65 |
| LSTM0 | 5.44 | 4.78 |
| CNN0 | 5.25 | 4.29 |
| CNN-LSTM0 | 5.36 | 4.22 |
| LSTM | 5.49 | 4.34 |
| CNN | 5.20 | 4.15 |
| CNN-LSTM | 5.09 | 3.98 |

Mortality rates estimation and prediction

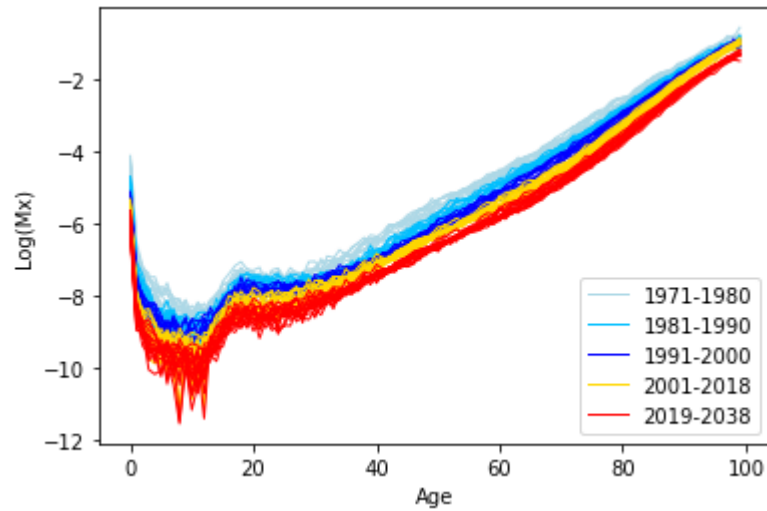
AUS Male



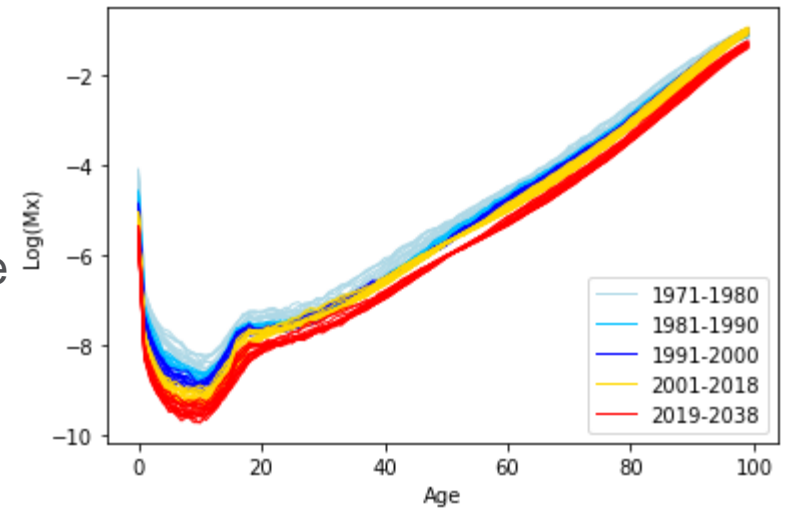
USA Male



AUS Female



USA Female



Conclusion

We propose a **hybrid neural network model for multi-population mortality prediction**

- Uses a hybrid neural network structure: CNN + LSTM
- Makes better prediction of mortality by finding linear and non-linear relationships between mortality and GDP
 - Links between GDP and mortality over time, and across countries
 - Links between past GDP and mortality (currently: 5 years)
- Predicts gross domestic product (GDP) per capita and mortality rates simultaneously for multiple populations
- Next steps:
 - Visualise & interpret links between GDP and mortality
 - Add comparisons with Li-Lee and Boonen-Li models
 - Analyse the impact of COVID-19 on mortality and GDP



Thank you!

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