Genetic Improvement of Shoreline Equilibrium Models

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Genetic Improvement of Shoreline Equilibrium Models

Context

- Need to anticipate changes in coastal topography/bathymetry in response to different natural processes
- Waves are a main driver in coastal zone evolution
- Goal: forecasting wave-driven shoreline change

Figure: “Schematic representation of the coastal zone, hazards, and metocean variables that are relevant for coastal marine hazards and their monitoring”. Source: [1]

Genetic Improvement of Shoreline Equilibrium Models

Outline

1) Context and Dataset
2) Cartesian Genetic Programming / Genetic Improvement
3) ShoreFor in CGP
4) Ablation study
5) Current study & future directions
Dataset
Dataset

- “Shoreshop” competition [8]
- Tairua, New Zealand
- ~15 years of data:
  - Daily video-derived shorelines
  - Hourly in-situ wave forcing (Hs, Tp, Dir)

Methods
Methods

Cartesian Genetic Programming

- GP: population-based stochastic optimization
- GP has different variants (Tree-based, Stack-based, Cartesian)
- “White-box” approach
Methods

Genetic Improvement of ShoreFor

• GI: Optimization of existing software/models using GA’s

• ShoreFor: shoreline equilibrium model [4,5]

\[
\frac{dx}{dt} = c(F^+ + rF^-) + b
\]

\[
\Omega_{eq} = \frac{\sum_{i=1}^{2\phi} \Omega_i 10^{-i/\phi}}{\sum_{i=1}^{2\phi} 10^{-i/\phi}}
\]


Methods
ShoreFor as a (sequential) CGP individual

\[ \Omega_{eq} = \frac{\sum_{i=1}^{2\phi} \Omega_i 10^{-i/\phi}}{\sum_{i=1}^{2\phi} 10^{-i/\phi}} \]

Figure: example sub-graph showing the encoding of the \( \Omega_{eq} \) equation

Table: ShoreFor system of equations

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Omega )</td>
<td>P</td>
</tr>
<tr>
<td>( \phi )</td>
<td>Current time</td>
</tr>
<tr>
<td>0.5</td>
<td>( \Delta t ) waves</td>
</tr>
<tr>
<td>( \text{coeff}_\text{time} )</td>
<td></td>
</tr>
<tr>
<td>( c )</td>
<td>( \Delta t ) ( \text{mult} )</td>
</tr>
<tr>
<td>( r )</td>
<td>( \text{div} ) ( \text{sum} )</td>
</tr>
</tbody>
</table>

Input window size = 2\( \phi \)

Table, Figure: sequential ShoreFor graph
Methods

Mutations & Constraints

Figure: General structure of an evolutionary algorithm

Level | Constraint
--- | ---
Evaluation | \( \text{std}(\hat{y}) > \alpha_1 \)
Mutation | model length > \( \alpha_2 \)
Mutation | \( \text{model}(\text{rand}_1) \neq \text{model}(\text{rand}_2) \)
Mutation | no input-output connections

Ablation Study
Ablation Study

Aggregate results

Fitness: Mielke skill

\[ \lambda = 1 - \frac{N^{-1} \sum_{i=1}^{N} (o_i - m_i)^2}{\sigma_o^2 + \sigma_m^2 + (\hat{o} - \hat{m})^2} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation series length</td>
<td>11 years</td>
</tr>
<tr>
<td>Number of columns</td>
<td>300</td>
</tr>
<tr>
<td>Constraints</td>
<td>all</td>
</tr>
<tr>
<td>Population size</td>
<td>30</td>
</tr>
<tr>
<td>Mutation rate</td>
<td>0.1</td>
</tr>
<tr>
<td>Output mutation rate</td>
<td>0.3</td>
</tr>
<tr>
<td>Recurrent connection rate</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Figure: Ablation study results comparing the sensitivity of CGP to the graph size (top left), evaluation series length (top right), constraint regime applied (bottom left) and initialization scheme (bottom right). Taken from [7]

Ablation Study

Best individuals

Calibration

Forecast
Ablation Study - Evolved variants of ShoreFor

CGP Inputs

- \( \Omega \)
- \( P \)
- \( \phi \)
- 0.5
- dt_waves
- current_time
- coeff1
- coeff2
- \( r \)
Ablation Study

Conclusions

• Full calibration series (~11 years in Tairua)
• Mutation-level constraints
• Smaller graph sizes
• Predicting $dx/dt$ instead of $X$:
  - More direct interpretability of the evolved graphs
  - Model-free parameter calibration during fitness evaluation
Current Study
Current Study

Modelling complete and sequential CGP-ShoreFor-dx/dt

Implementation of complete variant:

- Prediction of full target series in one model step
- ‘r’ can be calculated within the model
- Equilibrium omega passed as input (sequential calculation not modelled)
Current Study

Complete CGP-ShoreFor-dxdt results
## Current Study

**Complete CGP-ShoreFor-dxdt results**

<table>
<thead>
<tr>
<th>Model</th>
<th>Calibration</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correlation</td>
<td>RMSE</td>
</tr>
<tr>
<td>ShoreFor</td>
<td>0.68</td>
<td>4.11</td>
</tr>
<tr>
<td>CGP-ShoreFor-dxdt</td>
<td>0.74 ± 0.01</td>
<td>3.77 ± 0.31</td>
</tr>
<tr>
<td>CGP-RandomInit</td>
<td>0.75 ± 0.04</td>
<td>3.72 ± 0.33</td>
</tr>
</tbody>
</table>
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Future directions

• Sequential dx/dt variant
• Separate phenotypes ($\Omega_{eq}, dx/dt$)
• Mutation operators and selection methods
• Improved evaluation:
  - Multi-objective fitness (graphs, time-scales)
  - Wider variety of sites
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Thank you

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